Health effects in EU from cooking on gas

Phase II Field study

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Summary

Background
The EU is currently updating the Ecodesign legislation with regard to cooking appliances. It concerns Ecodesign Regulation EC No 66/2014 on domestic ovens, hobs and range hoods and the Energy Label Regulation EC No 65/2014 on domestic ovens and range hoods. In parallel, the United Kingdom (UK) government is conducting a review of these same two regulations, as they are also applicable under UK law. These regulatory reviews present an opportunity to include requirements in both the EU and UK law that will work to prevent exposure of households to harmful levels of indoor air pollution. CLASP has asked TNO to assist them with a study towards health effects from gas stove pollution. This study towards the health impacts of gas cooking appliances consists of two phases. The first phase consisted of a literature study and a simulation study in which air pollution in homes has been studied including solutions to improve the indoor air quality[1]. The simulation study indicated that in households cooking on gas in kitchens WHO and EU NO_2 limit concentrations can be exceeded. In the second phase, a field-measurement study was conducted in 276 dwellings in 7 European countries to show the current situation with regard to indoor air quality and gas hob usage. This report concerns results and findings for phase 2 and uses the results from phase 1 for comparison.

Research questions phase 2 field study
The research questions to be answered in this report are:
1. What are the concentrations of air pollutants – specifically, nitrogen dioxide (NO_2), carbon monoxide (CO) and fine particulate matter ($PM_{2.5}$) – released when cooking on gas compared to electric cooking in households across several European countries?
2. Do European households cooking on gas exceed the relevant WHO and EU limit concentrations of air pollutants more often than households cooking electric?
3. Which parameters have a statistical significant effect on the (indoor-attributed) NO_2, (highest 1-h) CO and $PM_{2.5}$ concentration?

Approach
Households were recruited from seven European countries by Opinium, a market research company. Participants were recruited based on the frequency of their at home cooking. During recruitment they all cooked meals at home at least 3 days out of 7. Other exclusion criteria were only non-smoking households and not living near a busy main road or an industrial complex. Further the households were selected in such a way that about 80% cooked with gas (either gas hob and/or gas oven) and for reference 20% had electric cooking. Measurements were conducted by sending a package of passive and active sensors to the participants' homes. Air pollutant concentrations were measured and with temperature sensors on the hob and the oven door the cooking periods were determined. The participants had to place the sensors by themselves in the kitchen, in the living room, and in one of the bedrooms, preferably one where children sleep, as well as outside their home. Outside the kitchen only passive NO_2 samplers were placed. Measurements were carried out over 13 days in each home. The first measurement period started in the Netherlands on January 27th 2023. The last measurement period in the UK and Romania started on May 12th 2023. An instructional video and supportive materials (including written instructions and a FAQs document) were shared with participants to improve consistency

and accuracy in equipment set up. In each country market support persons, trained on the same materials, also provided timely in-person assistance.
During the measurement period the participants were instructed to cook and behave as they would normally do. As part of the onboarding process, participants filled in an online questionnaire with details about their home, kitchen volume, installations, and ventilation system. During the test period participants completed an app based diary recording their cooking and ventilation behaviour. After the measurement period the participants returned the sensors to TNO for data retrieval and analysis. All data were checked with regard to sensor deviations. Households that did not deliver any concentration data at all were excluded. Starting with sending out 276 measurement boxes, this resulted in 247 households that met all the inclusion criteria.

Results

1. *What are the concentrations of air pollutants – specifically, nitrogen dioxide (NO_2), carbon monoxide (CO) and fine particulate matter ($PM_{2.5}$) – released when cooking on gas compared to electric cooking in households across several European countries?*

Nitrogen dioxide (NO_2):

Table 1.1 lists per country and per cooking method the average NO_2 concentration in the kitchen, living room, bedroom and outside. For six out of seven countries (all except Romania) a significant ($p < 0.05$) higher nitrogen dioxide (NO_2) concentration has been found in the kitchen for households cooking on gas compared to cooking on electric. Correcting for the outdoor concentration, also for the measured households in Romania a significant higher concentration in the kitchen, living room and bedroom has been found for those cooking on gas compared to cooking on electric.

The highest average NO_2 concentrations in houses cooking on gas were found in the kitchen, these concentrations were even higher than outside. In contrast, in houses cooking on electric the indoor NO_2 concentrations were below the outside concentration.
Higher NO_2 concentrations in the living room in houses cooking on gas can be explained by the fact that many houses are equipped with an open kitchen. Pollutants emitted in the kitchen will then mix up in this open space. Bedrooms have the lowest concentration as they are usually furthest away from the kitchen and their doors are more likely to be closed. Furthermore, a ventilation system or an open window can supply outside air to the bedroom.

Carbon monoxide (CO):

Table 1.2 lists per country and per cooking method the average CO concentration in the kitchen. In three out of seven countries a significant difference with regard to the mean and/or the highest 1 hour concentration between houses cooking on gas and cooking on electric could be distinguished with the Cairsens CO sensor. When taking all countries together a small but significant difference has been found for the mean CO concentrations between those cooking on gas and those cooking on electric. However no statistical significant effect has been found for the CO highest 1-h value. This result deviates from results obtained in a field study in the US where a significant difference has been found for the CO highest 1-hour value between homes cooking on gas and homes cooking on electric hobs. A confounding factor in the current study is that the applied Cairsens CO sensor from ENVEA is sensible for ethanol and maybe also for other volatile organic compounds. During normal use of cleaning agents and by alcohol consumption this interference for ethanol can be significant. We assume that this interference is similar for households cooking on gas or on electric hobs, thus still making a comparison of average concentrations meaningful.

Table 1.1: average NO_2 concentrations per country and per cooking method in different rooms.

Passive sensor	average NO_2 concentration in µg/m³													
	The Netherlands		Italy		Spain		France		Slovakia		UK		Romania	
	electric	gas	electric	gas	electric	gas	electric	gas	electric	gas	electric	gas	electric	gas
Kitchen	11.7	**22.3***	10.0	**32.8***	18.5	**31.7***	11.2	**20.3***	4.8	**21.3***	11.3	**26,6***	25.5	32.9
Living room	12.3	**20.7***	9.5	**27.5***	17.8	**32.9***	11.1	**18.7***	4.7	**16.4***	12.2	**23,4***	21.4	22.8
Sleeping room	11.2	15.2	13.1	21.3	15.8	**28.5***	10.3	**15.4***	4.3	**13.4***	10.5	**18,7***	20.9	19.0
Outdoor	21.3	22.0	17.2	21.2	26.7	22.9	13.3	13.3	6.7	**11.8***	12.5	13,5	28.5	18.5

**Significant difference, p-value < 0.05*

Table 1.2: kitchen average CO and highest 1-hour concentration measured with ENVEA Cairsens, per country and per cooking method.

CO sensor	CO concentration in mg/m³													
	The Netherlands		Italy		Spain		France		Slovakia		UK		Romania	
	electric	gas	electric	gas	electric	gas	electric	gas	electric	gas	electric	gas	Electric	gas
Mean value	0.54	0.53	0.95	**1.63***	0.60	0.90	0.64	0.73	0.75	**1.58***	0.30	0.29	0.21	**0.32***
Highest 1h value	3.34	4.17	7.52	7.64	5.90	6.30	4.78	5.02	2.45	**5.72***	1.42	1.43	0.86	**1.58***

**Significant difference, p-value < 0.05*

Table 1.3: kitchen average $PM_{2.5}$ concentration per country and per cooking method.

$PM_{2.5}$ sensor in	Average $PM_{2.5}$ concentration in µg/m³													
	The Netherlands		Italy		Spain		France		Slovakia		UK		Romania	
	electric	gas	electric	gas	Electric	gas	electric	gas	electric	gas	electric	gas	electric	gas
Kitchen	13.6	13.1	8.7	**27.5***	16.4	27.0	17.9	24.3	24.5	20.2	16.6	17.4	38.1	26.2

**Significant difference, p-value < 0.05*

Fine particulate matter ($PM_{2.5}$):

Table 1.3 lists per country the average kitchen fine particulate matter ($PM_{2.5}$) concentration. It ranges between 8.7 and 38 µg/m^3. Taking all country data together with regard to $PM_{2.5}$ no significant difference between houses cooking on gas and cooking electric could be distinguished. This is consistent with the fact that gas burners emit a negligible amount of $PM_{2.5}$ compared to the emissions from the cooking ingredients. During cooking $PM_{2.5}$ is mainly formed due to evaporation of the oil and ingredients in the pan. Thus if the same pan temperature and cooking practice is used, cooking food with a gas hob or with an electric hob is expected to emit a similar amount of $PM_{2.5}$. The significant higher $PM_{2.5}$ concentration in Italy for households cooking on gas can be explained with a longer cooking duration for these households compared to the households cooking on electric hobs.
Also here the outdoor concentration may have an effect, however this concentration has not been measured. We assume that this interference is similar for households cooking on gas or on electric hobs, thus still making a comparison of average concentrations meaningful. Furthermore, aside cooking also other indoor sources of $PM_{2.5}$ may contribute to the $PM_{2.5}$ concentration.

2. *Do European households cooking on gas exceed the relevant WHO and EU limit concentrations of air pollutants more often than households cooking electric?*

Nitrogen dioxide (NO_2):

Table 1.4 lists per country and per cooking method the percentage of households above limit values. In none of the kitchens of households cooking on electric the WHO hourly guideline value or the EU 1 h limit value of 200 µg/m^3 has been exceeded. In contrast, in all seven countries the WHO hourly guideline value for NO_2 of 200 µg/m^3 was exceeded in kitchens of households cooking on gas. The exceedance of the EU 1h limit value is lower than the WHO exceedance as it is based on the average concentration during clock hours[1], whereas the WHO guideline value is interpreted as a 1- hour moving average concentration. In all seven countries the majority of the households cooking on gas do exceed the WHO daily guideline value of 25 µg/m^3, while in 5 countries households cooking electric do not have any exceedance at all. The exceedances of the daily guideline value in the Netherlands and Spain for houses cooking with electric hobs may partly be caused by opening windows and the relatively high outdoor concentrations during the measurement period in these two countries, with mean ambient concentrations of 21 and 27 µg/m^3, respectively.

Carbon monoxide (CO):

Table 1.5 lists per country and per cooking method the percentage of households with a kitchen above limit values. No exceedances of the 8-h WHO/EU and 1-h WHO CO guideline value (10 and 35 mg/m^3, respectively) have been recorded in household cooking on gas or electric hobs. None of the households cooking electric exceeded the daily WHO CO guideline value of 4 mg/m^3. Whereas four of all the households cooking on gas did exceed this guideline value. However, as mentioned earlier the applied Cairsens CO sensor from ENVEA is sensible for ethanol and maybe also for other volatile organic compounds. During normal use of cleaning agents and by alcohol consumption this interference for ethanol can be significant. The reported values may therefore include the presence of ethanol. As a consequence the real CO value might be lower than the measured value and maybe stay under the daily guideline value.

[1] E.g. the average concentration between 18.00 and 19.00 hour.

Fine particulate matter ($PM_{2.5}$):
Table 1.6 lists per country and per cooking method the percentage of households with a kitchen above limit values. In all countries the majority (68% -100%) of the investigated households exceeds the daily WHO guideline value of 15 µg/m^3, independently of households cooking on gas or electric hobs. The outdoor concentration may have contributed to the exceedance, however this concentration has not been measured. Part of the exceedance can be explained by $PM_{2.5}$ emission during cooking. These exceedances confirm the need for providing effective cooking exhaust above cooking areas.

Table 1.4: exceedance of NO_2 limit and guideline values in the kitchen.

NO_2 limit/guideline value	% of households above limit value (el = electric)													
	The Netherlands		Italy		Spain		France		Slovakia		UK		Romania	
	El	Gas	El	Gas	El	Gas	El	Gas	El	Gas	El	Gas	El	Gas
WHO daily 25 µg/m^3	17	54	0	72	50	85	0	53	0	44	0	55	0	52
WHO hourly 200 µg/m^3	0	31	0	28	0	77	0	29	0	22	0	25	0	24
EU hourly limit 200 µg/m^3	0	27*	0	24*	0	69*	0	29*	0	15*	0	25	0	19*

**Extrapolation of 13 days of measurement data to yearly exceedance*

Table 1.5: exceedance of WHO CO guideline values measured in the kitchen with ENVEA Cairsens. Between brackets the number of exceeding households.

CO limit/guideline value	% of households above limit value (el = electric)													
	The Netherlands		Italy		Spain		France		Slovakia		UK		Romania	
	El	Gas	El	Gas	El	Gas	El	Gas	El	Gas	El	Gas	El	Gas
WHO daily 4 mg/m^3	0	4 (1)	0	11 (2)	0	9 (1)	0	0	0	0	0	0	0	0
WHO/EU 8 h 10 mg/m^3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WHO 1-h 35 mg/m^3	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 1.6: exceedance of the WHO daily $PM_{2.5}$ guideline value in the kitchen.

$PM_{2.5}$ sensor in	% of households above limit value (El = electric)													
	The Netherlands		Italy		Spain		France		Slovakia		UK		Romania	
	El	Gas	El	Gas	El	Gas	El	Gas	El	Gas	El	Gas	El	Gas
WHO daily 15 µg/m^3	100	81	100	96	69	92	89	83	100	76	86	68	100	96

3. *Which parameters have a statistical significant effect on the (indoor-attributed) NO_2, (highest 1-h) CO and $PM_{2.5}$ concentration?*

Cooking method
There is a significant ($p<0.001$) difference in the kitchen NO_2 concentration between households cooking on gas and cooking electric. The NO_2 concentration in kitchens cooking on gas hobs is almost 13 µg/m^3 higher than those cooking on electric hobs.
A small but significant difference has been found for the mean CO concentrations between those participants cooking on gas and those on electric. However, no statistical significant difference has been found for the CO highest 1-h value. The CO sensor sensitivity for alcohol might have affected the highest 1-h value.
With regard to $PM_{2.5}$ no significant difference between houses cooking on gas and cooking electric could be distinguished.

Cooking time
In households cooking on gas the indoor-attributed NO_2 concentration increased with longer daily average burner cooking time on the hob and /or gas oven. This increase was not visible for cooking on electric hobs. The indoor-attributed NO_2 concentration is the indoor concentration corrected for the outdoor NO_2 concentration.

Presence of a gas oven
There is an almost significant ($p=0.078$) difference in NO_2 concentration in houses with and without a gas oven. In houses with a gas oven the indoor-attributed NO_2 concentration in the kitchen was 4 µg/m^3 higher.

Presence and type of cooker hood
Although theoretically expected, participants cooking on gas and reporting the use of a cooker hood ducted to outside did not have a significant lower indoor-attributed NO_2 or a lower $PM_{2.5}$ concentration. Participants mentioning using a recirculation hood had even a non-significant higher concentration for these two pollutants compared to those reporting not using a cooker hood.

Kitchen volume & ventilation flow
Although theoretically expected, kitchen volume and estimated kitchen ventilation flow did not have a clear effect on the kitchen indoor-attributed NO_2 concentration.

Contents

1 Introduction

The EU is currently updating the Ecodesign legislation with regard to cooking appliances. It concerns Ecodesign Regulation EC No 66/2014 on domestic ovens, gas hobs and range hoods and the Energy Label Regulation EC No 65/2014 on domestic ovens and range hoods. In parallel, the United Kingdom (UK) government is conducting a review of these same two regulations, as they are also applicable under UK law. These regulatory reviews present an opportunity to include requirements in both the EU and UK law that will work to prevent exposure of households to harmful levels of indoor air pollution. To support these regulatory reviews, evidence concerning the health impacts of gas cooking appliances was compiled in this report.

The overall study of the health impacts of gas cooking appliances consists of two phases. The first phase consisted, among other, of a literature review and a simulation study in which indoor air pollution was studied including solutions to improve the indoor air quality[1]. In the second phase, a field-measurement study was conducted in 7 EU countries. The goal of this study is to show the current situation with regard to indoor air quality and gas hob usage. In total 276 sensor boxes have been sent out to 276 participants. This report concerns results and findings for phase 2.

The research questions to be answered in this report are:

1. What are the concentrations of air pollutants – specifically, nitrogen dioxide, carbon monoxide and fine particulate matter ($PM_{2.5}$) – released when cooking on gas in households across several European countries?

2. Do European households cooking on gas exceed the relevant WHO and EU limit concentrations of air pollutants more often than households cooking electric?

3. Which parameters have a statistical significant effect on the (indoor-attributed) NO_2, (highest 1-h) CO and $PM_{2.5}$ concentration?

In chapter 2 the recruitment, the research set up, data analysis and relevant WHO guideline values and EU limit values are described. Chapter 3 lists the characteristics of the participants that met the inclusion criteria. In chapter 4 five typical example households are presented as case study and illustrated with time series data. In chapter 5 the results per country are presented. Chapter 6 presents statistical analysis carried out on the total data set to investigate the influence of several variables. Chapter 7 discusses the research questions. Chapter 8 lists the conclusions and recommendations. And Chapter 9 gives a list of limitations for this research. In Appendix A per country a summary of the measurement data is given.

2 Approach

2.1 Research set up

2.1.1 Approach

The research set up was based on an earlier US study by Mullen et al.[2] in 352 Californian homes. Measurements were conducted by sending a package of passive and active air quality sensors to the participants' homes. The participants were given instructions to autonomously place the sensors and samplers in and around their home. CLASP, TNO and Opinium created a video, translated in all languages, to walk participating households through correct setup up and break down of the equipment: https://vimeo.com/789418035 (password: CLASP). Written instructions and a return label were also included in each box, and "help desks" as well as an online community were setup for in-country support in each national language. These help desks were trained and provided with a series of Frequently Asked Questions, which were continuously updated with each round of testing. Participants were tasked with uploading a picture of the sensor set up in their home, to ensure equipment was set up correctly. The study setup, the recruitment material and the materials to communicate with the participants were reviewed and approved by the TNO ethical commission.

2.1.2 Country choice

The choice of the 7 countries was based on the number of households in each country cooking on gas and the exposed population. Italy, Slovakia, the Netherlands and Romania have the highest percentage households cooking on gas within the EU, above 60%[3]. France and Spain have about 30% of the households cooking on gas, but due to their large populations the population exposed in these two countries is relative large. UK has been added as the UK is outside the EU and in the UK more than 50% of the families are cooking on gas.

2.1.3 Selected pollutants

The pollutants to be measured are based on the literature review carried out by TNO in phase 1[1]: nitrogen dioxide and $PM_{2.5}$. Further carbon monoxide has been added as pollutant because in a US field study[2] the highest 1-h CO concentrations were higher in homes that cooked on gas.

The literature review has also advised to measure in a limited number of houses ultra-fine particles. However, these measurements require specialised personnel and are therefore quite costly. Further currently no limit values exist for ultra-fine particles. Based on these reasons ultra-fine particles have not been included in the study. For the same reasons, the advised methane leakage measurements have been also left out.

2.1.4 Timeline

To limit the amount of sensors two sets of 40 sensor boxes have been prepared at the TNO laboratory. The sensor boxes were sent out in four testing rounds according to the scheme in Table 2.1. In total the sensor boxes have been sent out to 276 households. At the end of the measurement period the sensors were send back using a return label.

Table 2.1 sensor drop off and pick up dates for the four test rounds, between brackets the number of sensor boxes send out.

Round	1	2	2	4
Drop off Pick up	27 January – 13 February 2023	3 March – 17 March 2023	7 April – 21 April 2023	12 May – 26 May 2023
Set #1	The Netherlands (40)	Italy (40)	France (40)	UK (40)
Set #2	-	Spain (35)	Slovakia (41)	Romania (40)

2.2 Recruitment and description of households

Households have been recruited by Opinium, a UK based marketing research firm. The households have been recruited from existing panels of volunteers. The following criteria have been used and were introduced in agreement with a peer review panel of experts:

- Non-smoking households;
- Not living near a busy main road or an industrial complex;
- Cooking at least three times a week.
- About 80% cooking on gas and about 20% cooking on electric hobs.

Interested households have been asked to fill in a screening questionnaire, see Appendix C.

As in previous lab research[2] cooking on electric hobs itself, e.g. during boiling water, did not generate any contaminant emissions, it has been decided to put the focus in the field study on cooking on gas and to recruit only 20% households cooking on electric to include the effect of other indoor and outdoor sources aside cooking as reference.
To be able to study the concentration difference between households cooking on gas and electric, the effect of cooking should be large enough compared to other disturbing effects. For this reason only households were included that indicated that they cook at least three times a week. To reduce disturbing effects on $PM_{2.5}$ and CO smoking households were excluded and households living near a busy main road or an industrial complex as they may indoors be exposed to high NO_2 concentrations from outside.

Forty households were selected for each country maximizing the following recruitment criteria:

- 32 households (80%) cooking with a gas hob and gas oven were possible;
- 8 households (20%) with an electric hob and electric oven
- Minimum 15 households using an extraction hood;
- Minimum 15 households not using or having an extraction hood;
- Minimum 10 households with children under the age of 16;
- Minimum 15 households living in social/affordable housing;
- Minimum 10 living in rented housing.

[2] Jacobs P., Cornelissen H.J.M., Effect of hydrogen gas mixes on gas hob emissions, TNO report 2022 R12248.

For each country a list of households has been generated and anonymized by Opinium by numbering from 01 to 40. The selected households had to complete a questionnaire during the measurement period to gain information about the house they live in e.g. the size of the kitchen, the kitchen equipment, cooking and ventilation habits. The questionnaire is listed in Appendix D. In the recruitment screener and the questionnaire a minimal amount of information has been given about emissions due to cooking and possible health effects in order not to alter the participant cooking behaviour.

At the end of the monitoring period after completion of the questionnaire and return of the equipment to TNO the households got from Opinium an incentive equivalent to 100 euro. Households that did not deliver any concentration data at all were excluded from analysis.

2.3 Monitoring procedure and equipment

A protective case containing passive and active air quality sensors was sent to each of the participants' homes, see Figure 2.1. The passive sensors are Gradko sampler tubes based on diffusion principle and laboratory analysis afterwards. The active sensors from ENVEA and IQAir contained a small fan to suck in the kitchen air. An overview of the sensors used in this study is given in Table 2.2.

Figure 2.1 Sensor box with active and passive sensors.

Table 2.2: summary of pollutant and environmental instruments used in this study.

Parameter	Manufacturer, model	Data resolution	Location of deployment
NO_2	Gradko, DIF100-20FILTER	Integrated over sample period	Kitchen, living room, bedroom, outdoor
NO_2	ENVEA, Cairsens	1 min	Kitchen
CO	ENVEA, Cairsens	1 min	Kitchen
$PM_{2.5}/CO_2$	IQAir AirVisual Pro	5 min	Kitchen
T	iButton, DS1922L-F5#	3 min	Cooktop, oven

To a small number of participants, about 4 per country, an additional field blank passive sampler has been sent out for quality control. The participants were instructed not to open this additional tube.

Two iButton temperature sensors were supplied to be placed on the hobs. If a participant had a gas oven a third Ibutton for the oven was supplied. For the Netherlands also IButtons were supplied for electric ovens to get insight in oven use. Due to limitations on the number of iButtons availabe, it has been decided for the last wave to give priority to UK participants with a gas oven. Figure 2.2 shows two examples of Ibutton placements. Figure 2.3 shows two examples of the active sensors. To prevent measuring undilluted peak concentrations the participants have been instructed to place the sensors at least 1 m away from the hob and not directly above. However due to space limitations this was not always possibe (e.g. right side of Figure 2.3).

Figure 2.2 Left: ideal placement of Ibuttons on gas hob. Right: due to the construction of the gas hob the two Ibuttons could not be placed between the burners and had to be placed on the sides. Note: on the oven door a third Ibutton was placed.

Figure 2.3 typical placements of active NO_2 and CO sensors and the $PM_{2.5}/CO_2$ sensor. Left photo: the passive NO_2 tube can be seen at the top fixed to the tiles.

Measurements were conducted for 13 days. After this period the participants returned the sensors to TNO for data retrieval. During the measurement period the participants were asked to cook and behave as they normally do. In addition, the participants were asked to fill in questionnaires with details about their kitchen installations, kitchen dimensions, ventilation system and cooking behaviour. Further they were asked to upload photos of the sensor placement and every day the hob or oven during cooking.

In the Netherlands, participants found difficulties in answering a question about their kitchen dimensions. In many cases the kitchen was next to the living room, divided with a wall with an opening. If they described that there was no door between living room and kitchen, then it was considered as an 'open kitchen'. With a door in the dividing wall, it was considered as 'closed'. In case of an open kitchen the volume of the kitchen comprised both the kitchen and the living room. Therefore, this question has been updated for the next rounds of the field testing and repeated in the Netherlands.

2.4 Data analysis

Below is reported the process followed by TNO for data analysis. Results are included per country in Chapter 5. Statistical analysis carried out on the total dataset are reported in Chapter 6. Excluded data has been described in Appendix E.

Process followed for data retrieval
Passive samplers that were returned unsealed were flagged as invalid. The sealed passive sampler tubes were sent directly to the Gradko analytical lab for analysis.

Data from the Cairsens, AirVisual Pro and the iButton monitoring data loggers were downloaded and all compiled in a database. The Cairsens NO_2 and CO sensors have been calibrated and corrected after each use against a Thermo model 42i NO-NO_2-NOx and a Picarro G2401 CO analyzer.

Process followed for data quality check
The data was visually reviewed and if necessary excluded with regard to "frozen" data and "the 4 a.m. criterium". Data are considered as frozen and excluded when the signal is constant during several days. The 4 a.m. criterium assumes that in the middle of the night there is no cooking or other activity in the kitchen. High and/or strongly deviating concentrations at that time indicate abnormal sensor behavior. In situations with extreme low or high measurement data the logbook and the Ibutton data was used to clarify the data and or to decide to exclude the data from that household from the analysis. Sensors with less than 7 measurement days were excluded.

NO_2 was measured with passive and active sensors. Appendix B gives a comparison of the passive and active sensor results.

Determination of hob usage
The usage of the hob cooktop and oven has been determined based on the iButton temperature data. Usage was inferred from analysis of the temperature signals.

Calculation of ventilation air change rate in kitchen
Based on CO_2 decay data the ventilation air change rate of the room in which the kitchen is situated has been estimated. The participants have also reported the ventilation provisions such as window opening, range hood use and use of whole house ventilation system while cooking. A small part of these qualitive data have in this report been used to describe the case studies in chapter 4.
Unfortunately, we could not use the rest of this data about the use of ventilation provisions during cooking for the statistical analysis in chapter 6. This because only a minority of the

participants did use the questionnaire's multiple choice predefined answers: A, B, C, D or E. The majority made up their own text answer in the open text box field, or in some cases added a photograph of their cooking hob instead of the requested photo indicating use of ventilation provisions. This hampered the analysis of this data.

2.5 Average values and exceedance of WHO guidelines and EU limit values

The concentrations of NO_2 from the passive sampler measurements in the kitchen, living room, bedroom and outside have been compared against each other. Average values with standard deviations for these four measurement locations are reported in Chapter 5. Whether the average values for cooking on gas differ significantly from electric cooking is tested with the Kruskal-Wallis test.

To assess the severity of indoor air pollution from gas cooking in European households, TNO compared the field test results against the pollutant limit values in the 2021 WHO Air Quality Guidelines (AQG)[4] and the European Ambient Air Quality Directive[5] (EU 2008/EC/50). The WHO AQG were updated in 2021 to reflect new scientific evidence on health effects by air pollution. These WHO's AQG are intended as guidance to help reduce levels of air pollutants in order to decrease the enormous health burden resulting from exposure to air pollution both outdoors and indoors. The European limit values (i.e. maximum concentrations) set out in EU 2008/EC/50 are intended for exposures outdoors.

Passive and active sensor data are compared with above mentioned relevant WHO guidelines and EU limit values (i.e. maximum concentrations), see Table 2.3, Table 2.4 and Table 2.5. The measurement data are not tested with the yearly values as the measurement period was only 13 days and thus not representative for a whole year average.

Table 2.3: European limit values and WHO guidelines for nitrogen dioxide (1 μg/m³ = 0.523 ppb).

	Indoor/ outdoor	yearly [μg/m³]	24 hour [μg/m³]	1 hour [μg/m³]
EU 2008/EC/50	outdoor	40	-	200*
WHO 2021	both	10	25	200

* not to be exceeded more than 18 times during a calendar year.

Table 2.4: European limit values and WHO guidelines for carbon monoxide (1 mg/m³ = 0.858 ppm).

	Indoor/ outdoor	24 hour [mg/m³]	8 hour [mg/m³]	1 hour [mg/m³]	15-minute mg/m³]
EU 2008/EC/50	outdoor	-	10	-	-
WHO 2021	both	4	10	35	100

Table 2.5: European limit values and WHO guidelines for $PM_{2.5}$.

	Indoor/ outdoor	yearly [μg/m³]	24 hour [μg/m³]
EU 2008/EC/50	outdoor	25	-
WHO 2021	both	5	15

Note that the standards for $PM_{2.5}$ are based on gravimetric measurement. In this study an AirVisual optical particle counter has been used. In comparison with gravimetric measurement the response of an optical particle counter varies with the mass distribution of the source. The response is almost always less than one[6], so the AirVisual may underestimate the true mass from cooking.

Both the EU 2008/EC/50 and the WHO 2021 Air Quality Guidelines do not define the determination of the 1-hour NO_2 limit value. In this report the EU 1-hour NO_2 limit value is interpreted as the average concentration during a clock hour. E.g. between 18.00 and 19.00 hour. Although there is also not a definition given by WHO, their hourly NO_2 guideline value is interpreted as an 1-hour moving average concentration. E.g. if a meal was cooked and this has caused the highest hourly average concentration between 18.30 and 19.30 hour then this time interval has been selected to determine the hourly average. Based on these definitions the number of exceedance hours of the WHO 1-hour guideline value will be equal or higher than the EU 1-hour limit value.

3 Participant characteristics

The recruitment process has been described in paragraph 2.2. Table 3.1 lists the details of the recruited participants that met the inclusion criteria.

The country averaged age of the participants is between 39.2 for Slovakia and 47.3 years for Spain. Between 2.9 and 26.5% of the participants lived alone. In all countries more than 40% of the participants have children under 16.

With regard to housing characteristics there are large difference between the countries. In France and Romania a large part of the participants live in a detached house. While in Spain and in the Netherlands this percentage is much lower. A large part of the Dutch participants are living in terraced houses. While in Spain 94% of the participants resides in flats.

With regard to open or closed kitchen there are also large differences between the countries. In the Netherlands 75.7% of the participants have an open kitchen, while in Romania this percentage is only 5.9%. This has also an effect on the kitchen size. Open kitchens are related to a larger average kitchen size, around 60 m^3, as it then also incorporates the size of the living room. While in countries with more closed kitchen the average kitchen size is 35 – 40 m^3.

As aimed during the recruitment process in each country about 80% is cooking on gas and 20 % on electric. Exceptions are Spain and France. In Spain it was difficult to find sufficient participants cooking on gas as there is a shift going on from cooking on gas bottles to electric. This is the reason that only 35 sensor boxes have been sent out to Spain. In France according to the recruitment info 80% of households were supposed to be cooking on gas. However it turned out during the analysis that in a number of cases these households were cooking on electric hobs. The percentage participants having a gas oven was the lowest in the Netherlands and Spain (0%) and the highest in the UK and Romania, where the percentage was about 60%.

With regard to the use of extraction hood, the participants that during the recruitment indicated “Rarely”,” Never” or “Don’t know” were considered as not using or having an extraction hood. This percentage is 40% or higher in Slovakia, the Netherlands, UK, France and Romania. While in Italy and Spain nearly all participants used an extraction hood. This is probably also connected with the high percentage own houses in Italy and Spain. In your own house it is probably more attractive to invest in an exhaust hood. On the other side in the Netherlands in social housing standard no exhaust hood is present. In most countries the majority of the exhaust hood vent to outside. An exception to this is Italy where the percentage recirculation hood under the participants is nearly as large as venting to outside. Use of kitchen extraction fans is only mentioned in the UK and Spain. Such a fan is mostly placed near the ceiling in the wall above the hob and is normally the only way to ventilate the kitchen.

Table 3.1: self-reported homeowner and housing characteristics, for age and volume the standard deviation is reported in brackets.

	The Netherlands (n=37)	Italy (n=36)	Spain (n=34)	France (n=35)	Slovakia (n=36)	UK (n=35)	Romania (n=34)
Homeowner characteristics							
Average age (year)	47.1 (13)	41.1 (9)	47.3 (11)	43.3 (12)	39.2 (12)	42.7 (11)	42.5 (12)
Living alone (%)	21.6	13.9	26.5	17.1	13.9	2.9	17.6
Living with partner (%)	24.3	33.3	23.5	20.0	33.3	57.1	35.3
Children over 16 (%)	8.1	8.3	8.8	20.0	11.1	-	-
Children under 16 (%)	45.9	44.4	41.2	42.9	41.7	40.0	50.0
Housing characteristics							
Detached house (%)	8.1	22.2	5.9	51.4	27.8	22.9	38.2
Terraced house (%)	64.9	13.9	-	8.6	5.6	34.4	-
Apartment/flat (%)	27	63.9	94.1	40.0	66.7	42.9	61.8
Kitchen characteristics							
Open kitchen (%)	75.7	55.6	20.6	37.1	38.9	20.0	5.9
Kitchen volume (m^3)	57 (47)	59 (42)	38 (34)	64 (58)	51 (44)	40 (36)	35 (28)
Cooking on gas (%)	78.4	86.1	44.1	68.6	83.3	80.0	85.3
Gas oven (%)	0	5.6	0	5.7	25.0	60.0	55.9
Electric cooking (%)	21.6	13.9	55.9	31.4	16.7	20.0	14.7
Using an extraction hood (%)	43.2	97.2	85.3	60.0	52.8	57.1	58.8
Recirculation hood (%)	14.3	48.6	3.4	38.1	26.3	22.2	5.0
Extraction hood to outside (%)	85.7	51.4	96.6	61.9	73.7	77.8	95.0
Extraction fan to outside (%)			2.9			5.7	
Housing status							
Own house (%)	24.3	91.7	76.5	48.6	58.3	28.6	76.5
Social housing (%)	40.5	-	2.9	22.9	13.9	51.4	
Rented from private landlord (%)	35.1	8.3	20.6	28.6	27.8	20.0	23.5*

**Rented, no subdivision between social housing and rented from private landlord*

4 Case study examples

Due to the large amount of participants, in total 247 have been included, it is practically not feasible to show all the time series graphs. With time series it is meant that the pollutant concentration over time is displayed. In the next chapter the average cooking times, time averaged concentrations and exceedance percentage of WHO guidelines and EU limit values per country are presented. To give more insight in the dynamic effects and differences between cooking on gas and on electric in this chapter five case studies are shown. The first case study is an example of cooking on gas and high pollutant concentrations. The second case study is an example of cooking on electric leading to low pollutant concentrations. In this case study also the sensitivity of the CO sensor for ethanol is shown. In the third case study, the effects of other sources such as outdoor air infiltration and other contaminant sources other than cooking are illustrated. In the fourth example the positive effect of range hoods is illustrated. In the fifth and last example the effect of a gas oven compared to a gas hob is shown.

4.1 Example Cooking on gas with high pollutant levels

This first case study is an example of cooking on gas and high pollutant concentrations. Participant NL03 lives in a social housing apartment. The kitchen is relatively small with 16 m^3. Above the gas hob no range hood is present. The combination of these factors in this household presents an example of very high NO_2 concentrations, see Figure 4.1. Most peaks coincide well with the cooking periods (grey lines) determined with the Ibuttons. In total during the 14 measurement days there are respectively 6 hours and 4 clock hours that the NO_2 concentration is above respectively the WHO and EU limit value of 200 µg/m^3. And during 5 days the WHO 24-h guideline NO_2 value of 25 µg/m^3 is exceeded. The average concentration in the kitchen during the 14 days measurement period amounts 19.7 µg/m^3. This is below the value of 27,1 µg/m^3 of the passive sampler in the kitchen. The difference can be explained by the fact that the peaks in Figure 4.1 are well above the maximum range of the ENVEA sensor of 250 ppb = 478 µg/m^3, resulting in that the ENVEA sensor gives lower values than the passive sensor. The NO_2 passive sensor results for the living room, sleeping room and outside are respectively 22.5, 23.3 and 30.3 µg/m^3.

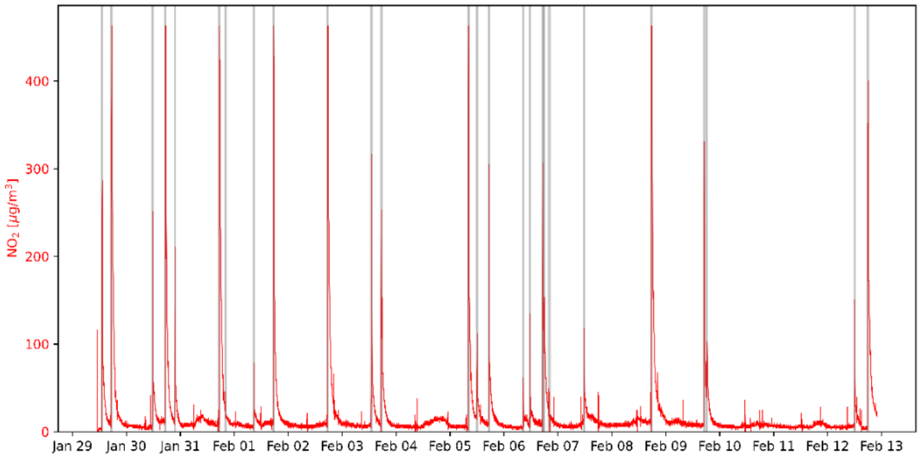


Figure 4.1 NO_2 in the kitchen due to cooking on gas (participant NL03). The grey lines indicate cooking activity.

Figure 4.2 shows the CO and NO_2 concentration over time. The CO peaks overlap the NO_2 peaks. The CO concentration drops more slowly than the NO_2 concentration. This can be explained by the fact that NO_2 deposits on the available surfaces and depletes[7], while CO is only diluted by ventilation. The highest 1-hour CO concentration for participant NL03 is 10 mg/m^3. This is below the WHO guideline value of 35 mg/m^3. Also the WHO 8 hour and 24 hour guideline values are not exceeded.

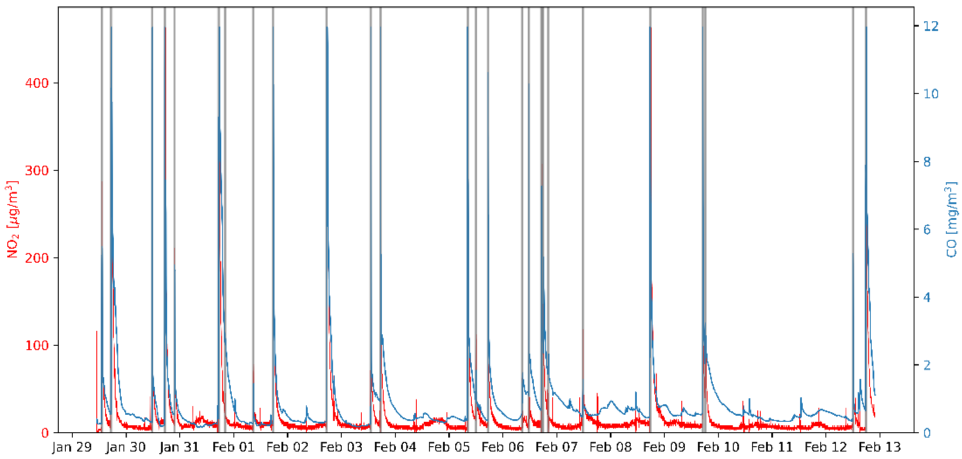


Figure 4.2 CO and NO_2 in the kitchen due to cooking on gas (participant NL03). The grey lines indicate cooking activity.

Figure 4.3 shows the $PM_{2.5}$ and CO_2 concentration profile for participant NL03 cooking on gas. Most cooking activities, indicated by the grey lines, are in the evening. Nearly all cooking activities involved an increase in $PM_{2.5}$ and CO_2 concentration. Some cooking activities involved a $PM_{2.5}$ concentration increase up to 5000 µg/m^3. These peaks are being caused by frying meat and vegetables. The $PM_{2.5}$ concentration in the kitchen exceeds the WHO daily value of 15 µg/m^3 during 8 days of the 14 day measurement period. On the average the $PM_{2.5}$ concentration amounts 45 µg/m^3. The CO_2 rise is caused by at least the presence of the cook and also by the gas burning. Based on the decay curves an average air change rate in the kitchen is estimated at 0,22 1/h, see Figure 4.4. This is a rather low value and may explain the rather slow CO decay in Figure 4.2.

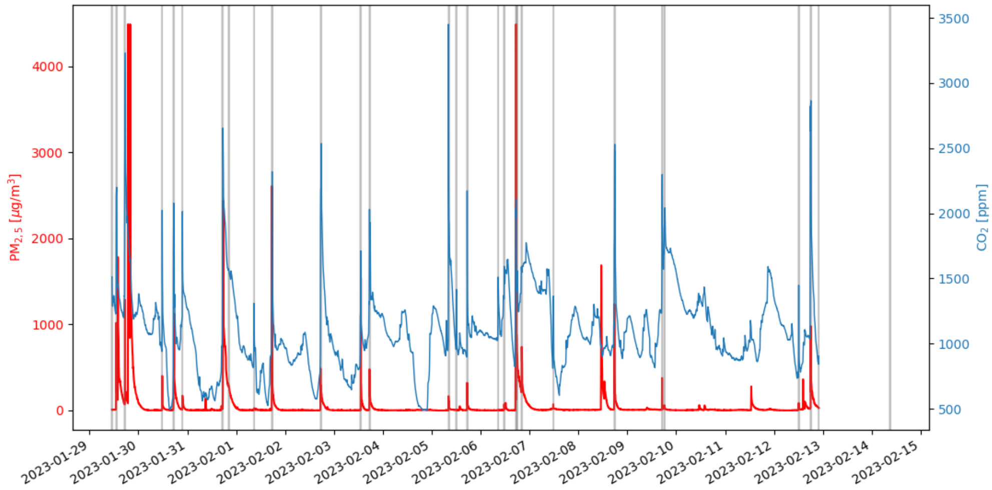


Figure 4.3 $PM_{2.5}$ (red line) and CO_2 concentration (blue line) for cooking on gas (participant NL03). The grey lines indicate cooking activity.

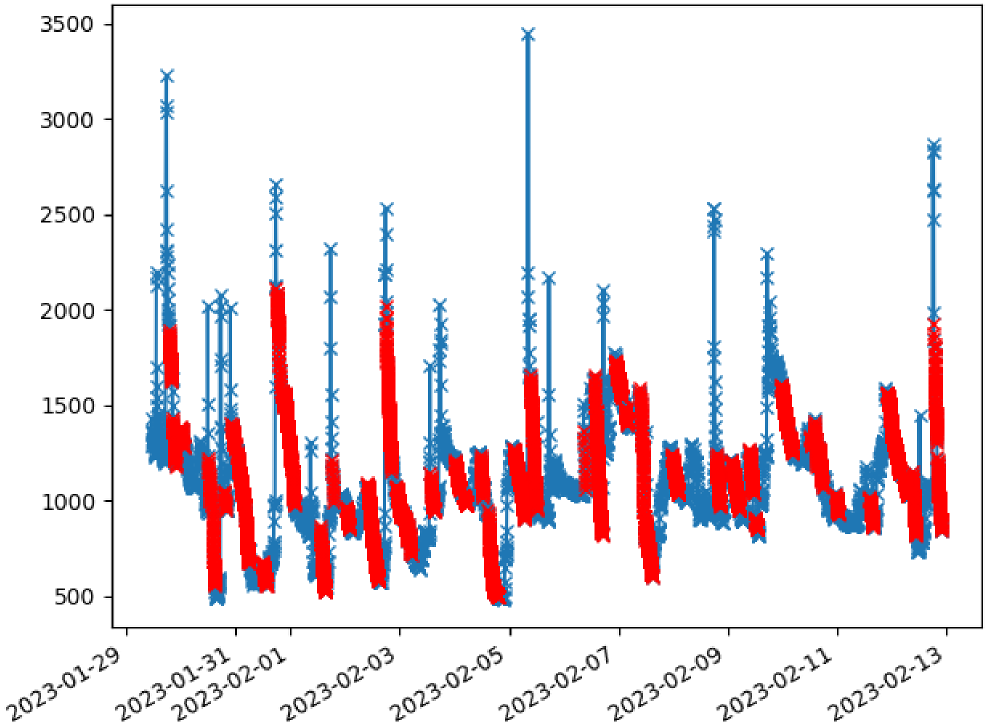


Figure 4.4 CO_2 concentration (blue line (participant NL03), the red lines indicate the CO_2 decay curves that have been used to determine the average ventilation rate.

4.2 Example of Cooking on electric with low pollutant levels

Participant NL33 lives in a terraced house. The kitchen volume is 88 m^3, which is a typical value for an open kitchen in the Netherlands. Cooking is on electric with above the hob an exhaust hood venting to outdoor. The combination of these factors in this household presents an example of low NO_2 concentrations, see Figure 4.5.
In this figure CO peaks up to 12 µg/m^3 are shown. Some of these peaks are related to cooking activities while others are not. These peaks may be explained with the sensitivity of the CO sensor for alcohols generated during the cooking[3] or present in cleaning agents and alcoholic drinks[8]. For more information see Appendix F. Due to this sensitivity the CO concentrations are over estimated.

During the measurement period the NO_2 and CO concentrations never exceeded the WHO guideline values or the EU limits. The average NO_2 concentration in the kitchen amounts 7.5 µg/m^3. This is just above the value of 5.4 µg/m^3 of the passive sampler in the kitchen. The passive sensor results for the living room, sleeping room and outside are respectively 5.6, 6.2 and 14.3 µg/m^3. The value in the living room is nearly the value in the kitchen, which is logical as both passive sensors were in the same room. The value in the sleeping room is slightly higher, this may be caused by more ventilation in the bedroom and the higher ambient value.

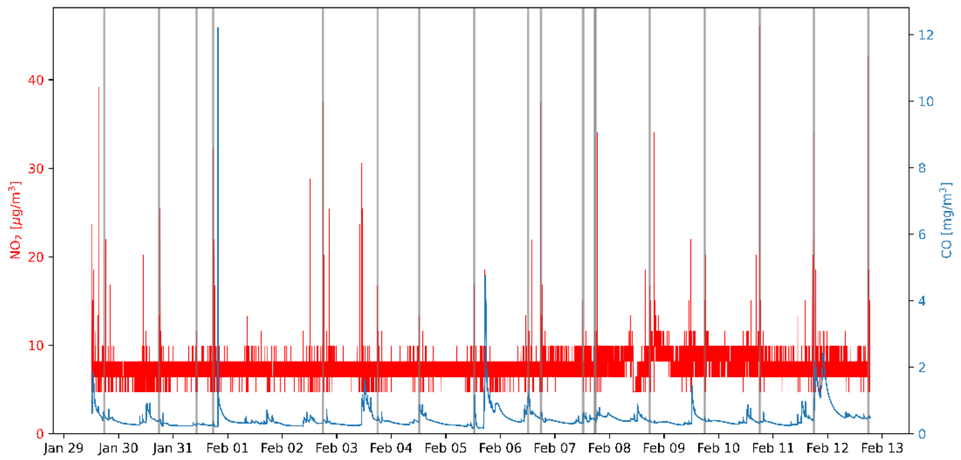


Figure 4.5 NO_2 and CO for electric cooking (participant NL33). The grey lines indicate cooking activity.

Figure 4.6 shows the $PM_{2.5}$ and CO_2 concentration profile for participant NL33. The high $PM_{2.5}$ peak on January 31 was caused by burned fried meat with fried potatoes. When the meat burned the participant mentioned that he had increased the speed of the exhaust hood.

The $PM_{2.5}$ concentration in the kitchen exceeds the WHO daily value of 15 µg/m^3 during 5 days of the 14 day measurement period. On the average the $PM_{2.5}$ concentration amounts 14.3 µg/m^3. During the day the CO_2 concentration increases due to the presence of one or

[3] Davies et al, A measurement and modelling investigation of the indoor air chemistry following cooking activities, DOI: 10.1039/d3em00167a

more persons. During the cooking the CO_2 concentration drops due to the additional ventilation due the activation of exhaust hood.

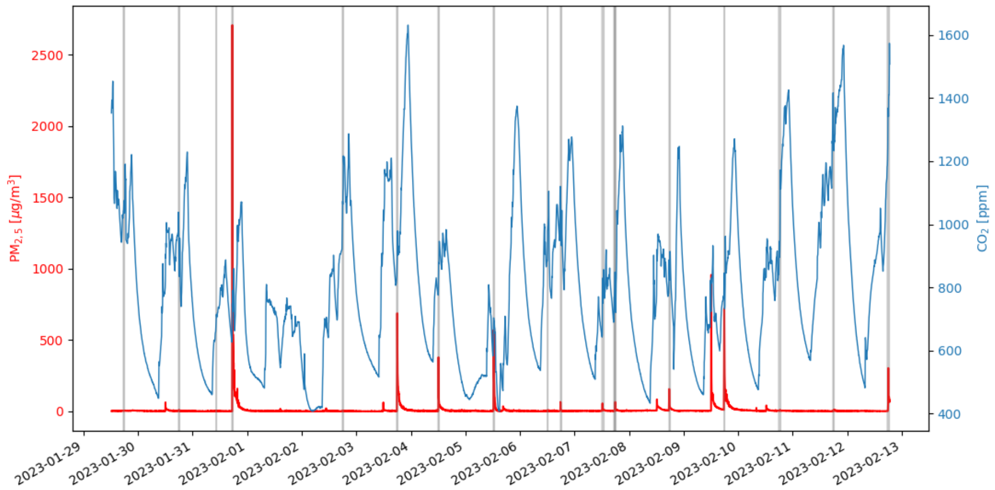


Figure 4.6 $PM_{2.5}$ (red line) and CO_2 concentration (blue line) for electric cooking (participant NL33). The grey lines indicate cooking activity.

Based on the decay curves the average air change rate in the kitchen is estimated at 0,24 1/h, see Figure 4.7. This seems to be a rather low value. However compared to the first case study due to the larger volume of the open kitchen the ventilation flow is a factor 6 higher.

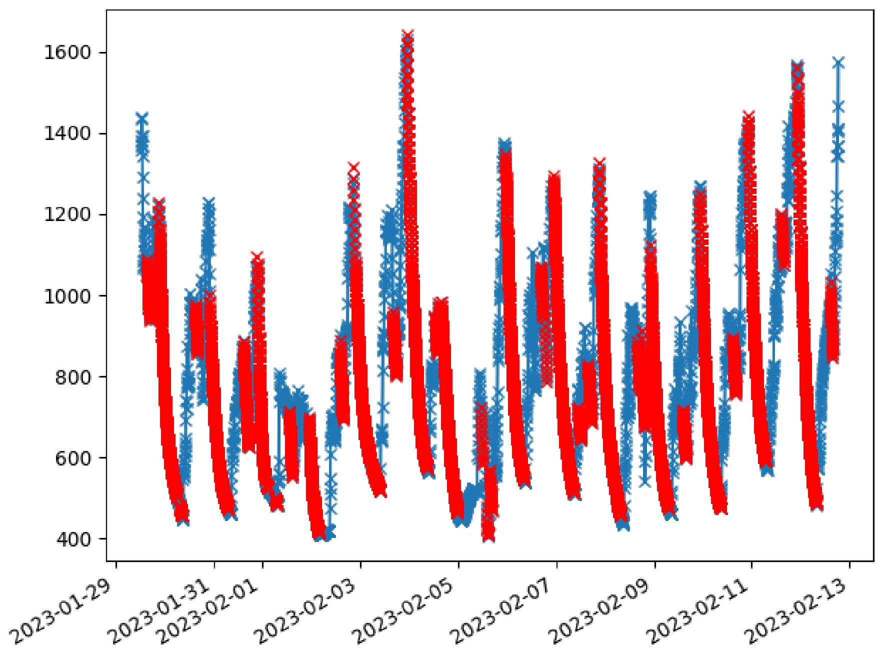


Figure 4.7 CO_2 concentration (blue line (participant NL33), the red lines indicate the CO_2 decay curves that have been used to determine the average ventilation rate.

4.3 Cooking on electric – effect of ambient

Figure 4.8 shows the NO_2 concentration time series of participant NL40. This example is shown to demonstrate the effect of ambient. This participant cooked in an open kitchen (163 m^3) on electric and used a hood connected to the dwelling ventilation system, therefore there are no internal NO_2 sources. The average concentration in the kitchen during the measurement period amounts 24.8 µg/m^3. The average outdoor concentration in this period was 24.9 µg/m^3. During the measurement period the NO_2 indoor concentration was 6 days above the WHO daily guideline value. The participant reported opening a window in the kitchen on February 2nd. Through this open window most probably NO_2 infiltrated from outside. Further due to the ventilation system continuously air was drawn into the kitchen. During the monitoring period the outdoor NO_2 concentration from a nearby outdoor monitoring station reached peaks up to 65 µg/m^3. This also explains the shape of the NO_2 peaks in Figure 4.8, the indoor concentration slowly follows the outdoor concentration as it takes several hours to build up the concentration due to infiltration. The shape of a NO_2 peak due to cooking on gas is different than the one observed here: a sharp increase due to the start of the cooking is followed by an exponential decay.

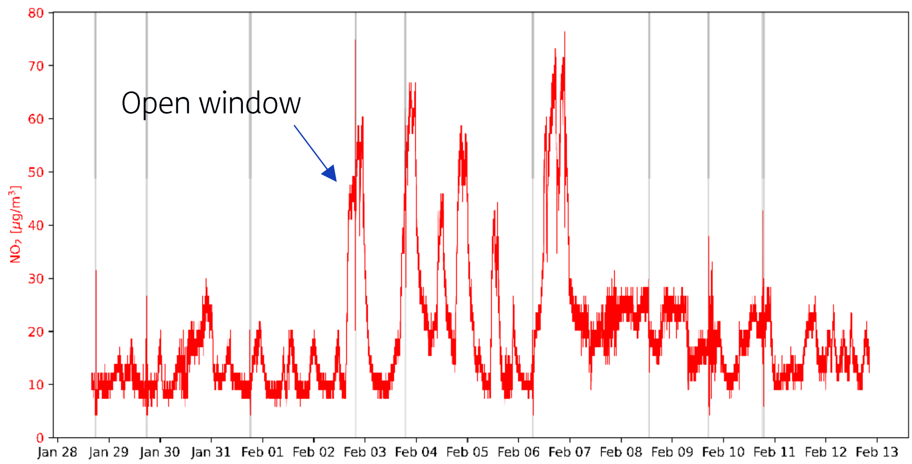


Figure 4.8 NO_2 and CO for electric cooking (participant NL40). The grey lines indicate cooking activity.

4.4 Cooking on gas – effect of range hood

Participant NL04 lives in a detached house. The kitchen volume is 64 m^3. Cooking is on a gas hob. An exhaust hood venting to outside is located above the hob. The exhaust hood, see Figure 4.9, covers all burners with is beneficial for the capture efficiency of cooking fumes.

Figure 4.9 example of an effective range hood covering all burners.

Due to the effective range hood and the consequent use during cooking the pollutant concentrations are rather low and no exceedances of guideline values for NO_2, CO or $PM_{2.5}$ occurred (see Figure 4.10 and Figure 4.11).

For this participant a part of the CO peaks is linked to cooking activity, since some of the peaks align with the grey lines indicating cooking activities in Figure 4.10. While another part of the peaks registered by the CO sensor may be linked to CO from outdoors entering or linked to other compounds in the indoor air such as alcohol[8].

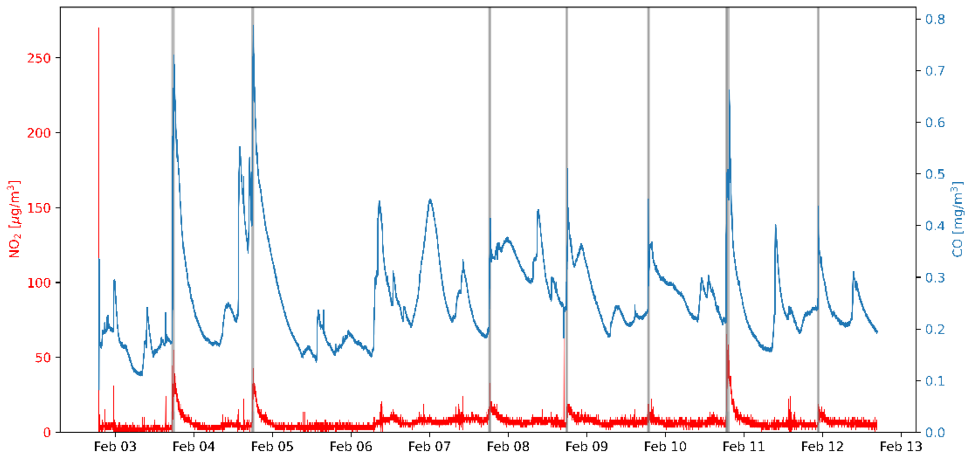


Figure 4.10 NO_2 and CO for cooking on gas with an effective range hood (participant NL04). The grey lines indicate cooking activity.

The slow rise of $PM_{2.5}$ in Figure 4.11 on February 8 and 10 may be caused by infiltration of outdoor $PM_{2.5}$.

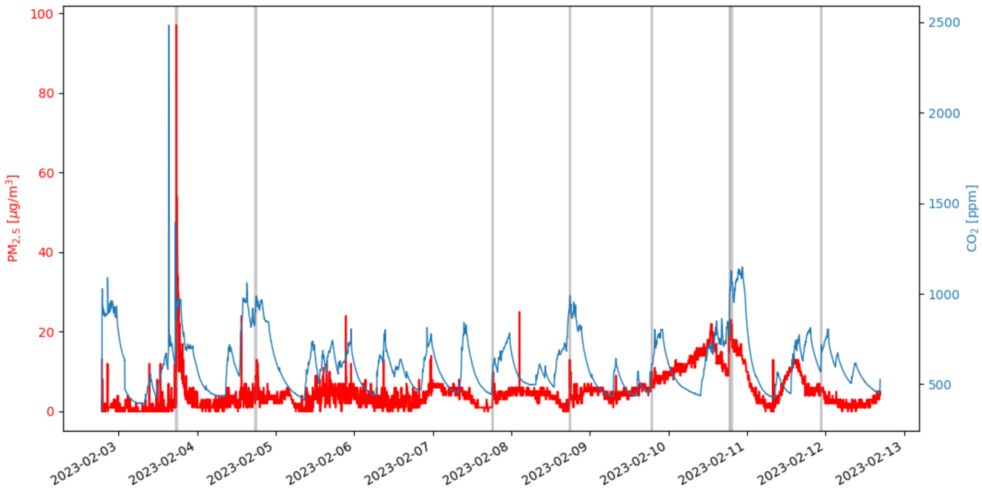


Figure 4.11 $PM_{2.5}$ (red line) and CO_2 concentration (blue line) for cooking on gas (participant NL04). The grey lines indicate cooking activity.

4.5 Cooking on gas – effect of gas oven

Participant UK30 lives in a terraced house rented from a housing corporation. The kitchen size is 32 m^3. Below the gas hob a gas oven is situated, above the gas hob no range hood is present. Figure 4.12 shows the NO_2 concentration. The grey lines indicate cooking activity. During the measurement period 32 minutes per day the gas oven has been used and 40 minutes per day the gas hob. Based on the photographs taken during the cooking it could be traced whether the peaks belong to gas hob or gas oven use. Use of the gas oven resulted in high peaks, even above the measurement range of the active NO_2 sensor, this is the reason why the peaks are 'truncated'. This effect can also be seen from the large difference in NO_2 concentration measured with the active sensor (22.1 μg/m^3) and with the passive sensor (46.1 μg/m^3).

In total during the 12 measurement days there are respectively 6 hours and 3 clock hours that the NO_2 concentration is above respectively the WHO and EU limit value of 200 μg/m^3. And during 5 days the WHO 24-h guideline NO_2 value of 25 μg/m^3 is exceeded. Most likely these exceedances of the 1 h WHO guideline and EU limit are being underestimated due to the limited measurement range of the active sensor.

Figure 4.13 shows the CO concentration. Most CO peaks are aligned with cooking activities. There is no clear distinction in peak height between use of the gas oven or use of the gas hob. No exceedance of CO guideline values occurred. The highest 1-hour CO concentration for participant UK30 was 2.0 mg/m^3.

With regard to $PM_{2.5}$ during 7 days the WHO daily guideline value has been exceeded. All cooking activities were associated with an increase in CO_2 concentration, see Figure 4.14.

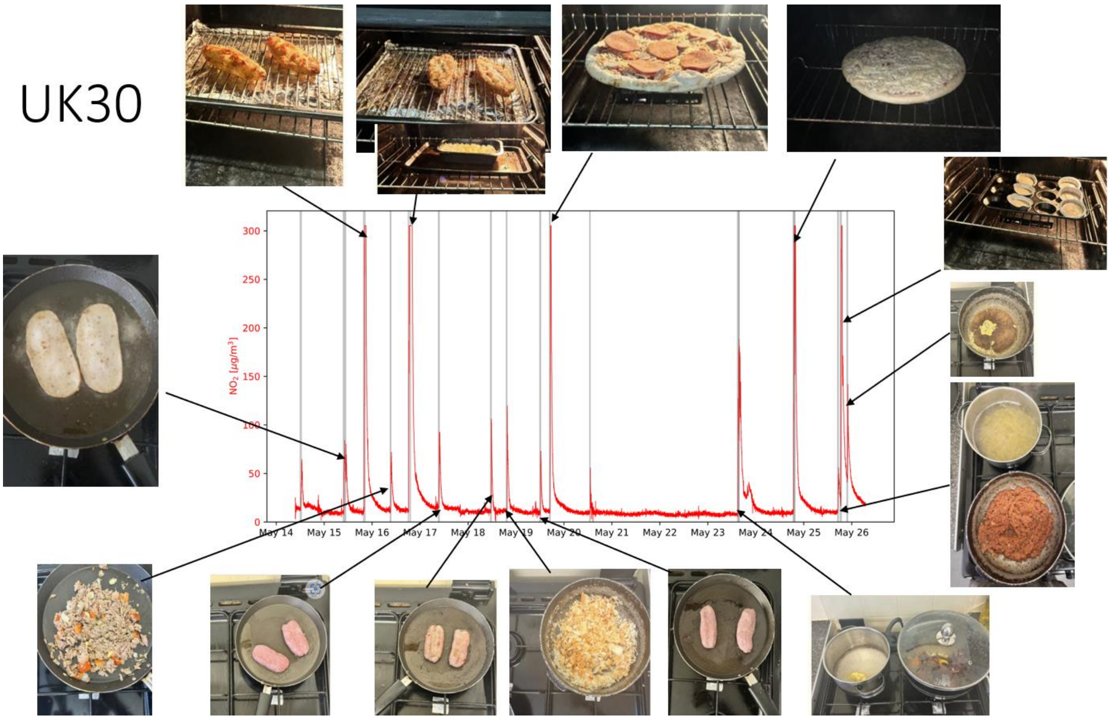


Figure 4.12 NO_2 concentration for participant UK30. The grey lines indicate cooking activity of either the gas hob (photos above figure) or on the gas hob (photos aside and under figure).

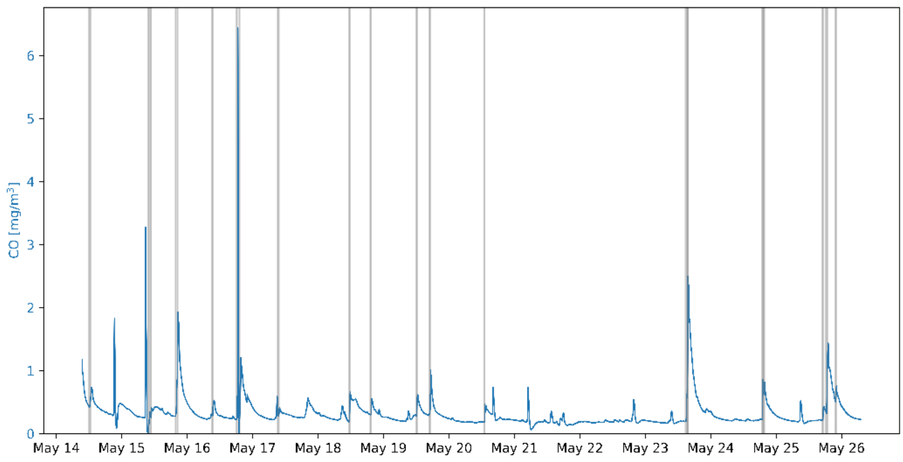


Figure 4.13 CO concentration for participant UK30. The grey lines indicate cooking activity of either the gas hob or on the gas hob.

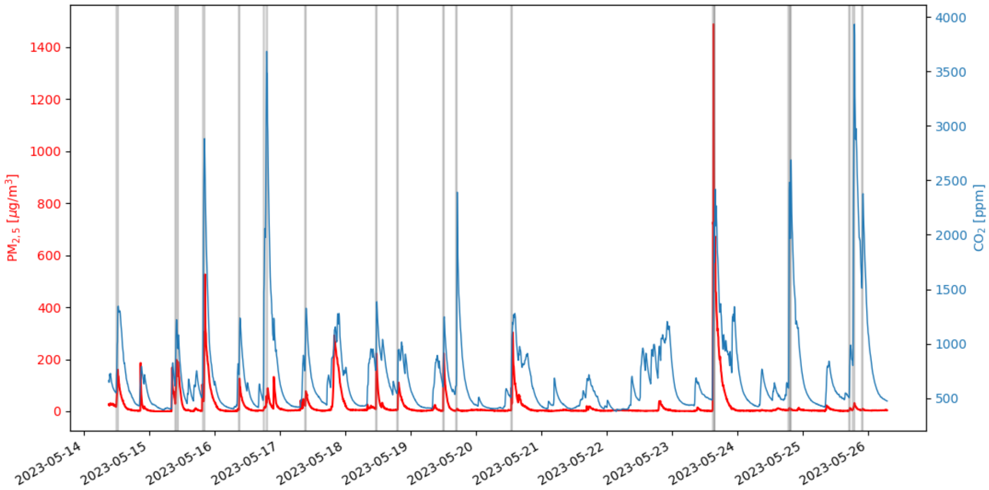


Figure 4.14 $PM_{2.5}$ (red line) and CO_2 concentration (blue line) for cooking on gas (participant UK30). The grey lines indicate cooking activity.

5 Results per country

5.1 the Netherlands

5.1.1 Summary

Measurement results regarding to 29 Dutch households cooking on gas and 8 household cooking on electric hobs have been obtained. Cooking on gas clearly led to significant deterioration of the indoor air quality with regard to NO_2:

- The households cooking on gas have a significant ($p < 0.05$) higher nitrogen dioxide (NO_2) concentration in their kitchen and living room than households cooking with electric cooking appliances.
- In more than half of the Dutch households cooking on gas the WHO daily guideline value for nitrogen dioxide was exceeded. For electric cooking only in one household this guideline value was exceeded.
- The WHO hourly guideline value for NO_2 was exceeded in 31% of the houses cooking on gas and not in any house cooking electric.
- In 27% of the investigated houses cooking on gas the EU hourly limit value for NO_2 in ambient air was exceeded, while in houses cooking electric no exceedances have been registered. Based on the number of exceedance hours during the measurement period it is likely that for most of these houses the hourly EU limit value is exceeded more than 18 hours per year.

With regard to carbon monoxide (CO) no significant difference between houses cooking on gas and cooking electric could be distinguished. The mean values are almost identical. Based on the results, and acknowledging the fact that the CO sensor is also sensible for ethanol, cooking on gas in the measured households probably did not lead to exceedance of CO guideline and limit values.

Also for fine particulate matter ($PM_{2.5}$) no significant concentration difference between houses cooking on gas and cooking electric could be distinguished. The mean values are almost identical. All investigated houses cooking electric exceeded the WHO daily guideline value for fine particulate matter ($PM_{2.5}$). Of the houses cooking on gas 80% exceeded this guideline value.

5.1.2 Household Environmental Conditions

5.1.2.1 Estimated hob use

Based on the iButton temperature readings, the hob and oven cooking time per day have been estimated, see Figure 5.1. The relative long cooking time for participant N10 can be explained by the fact that this participant is not only cooking meals, but also cooking water for tea on the electric hob.

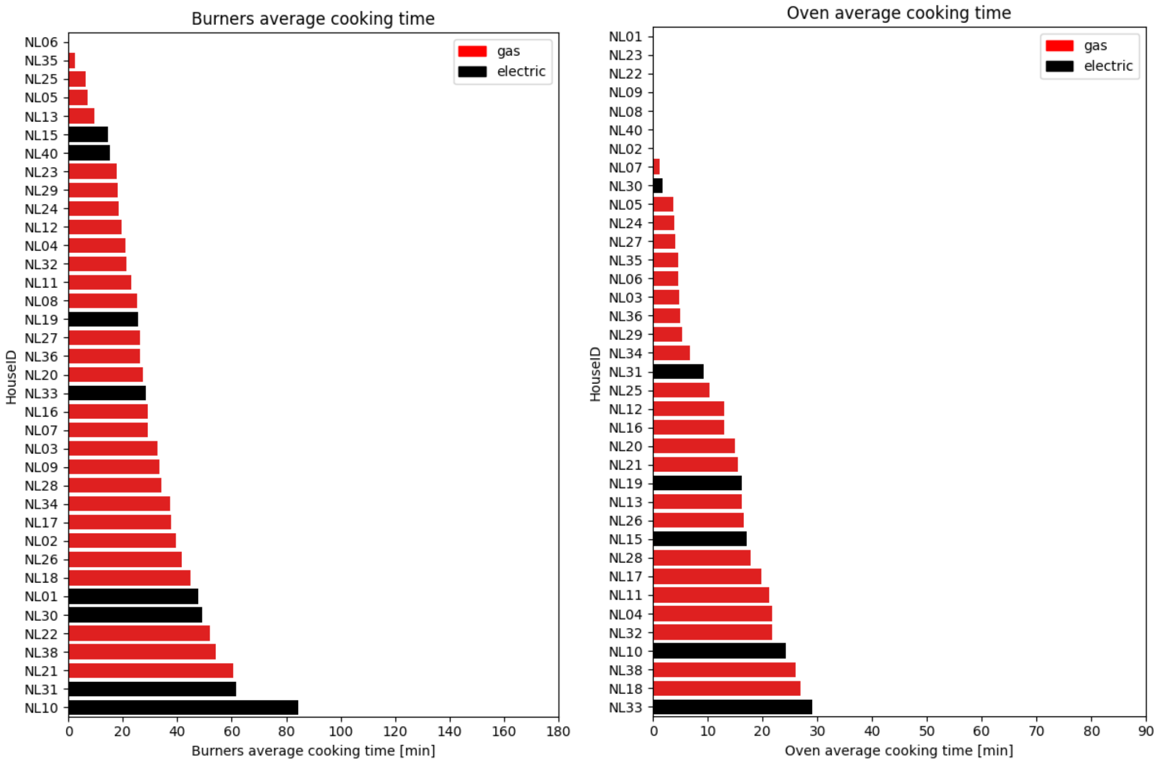


Figure 5.1 Estimated hob and oven use for each participating household. Note that all ovens are electric. The red oven gas indications are based on the fact that in those households gas hobs were present.

5.1.2.2 Kitchen estimated ventilation rate

Table 5.1 and Figure 5.2 list the estimated ventilation rate in the kitchen/living room.

Table 5.1: overview of estimated ventilation flow in kitchen and or living room, number of measurements, arithmetic mean, geometric mean and geometric standard deviation.

	n	mean	median	mean SD
Ventilation rate [ACH]	36	0.37	0.35	0.16

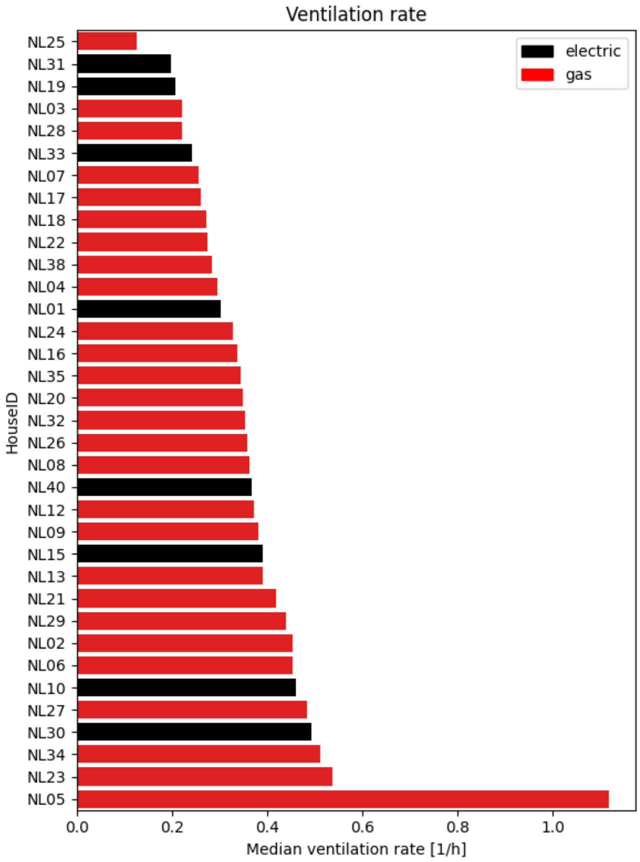
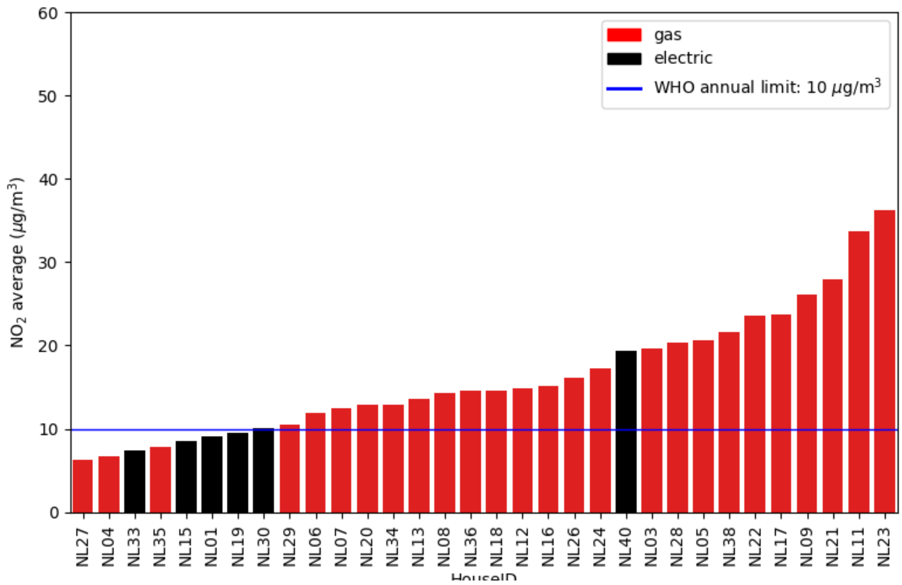


Figure 5.2 calculated median ventilation rate for each participating household.

5.1.3 Pollutant concentrations

5.1.3.1 Nitrogen Dioxide (NO_2)

Figure 5.3 and Table 5.2 list the average NO_2 concentrations measured by the active and passive sensors. In Figure 5.3 the cooking method is indicated by the colour of the bars. For illustration also the WHO annual guideline value of 10 µg/m^3 is indicated as blue line in the graphs. A direct comparison with the annual guideline is not possible as we have only measured during 13 days and the expectation based on literature data[9] is that during summer the indoor NO_2 concentration is lower than during the heating season.



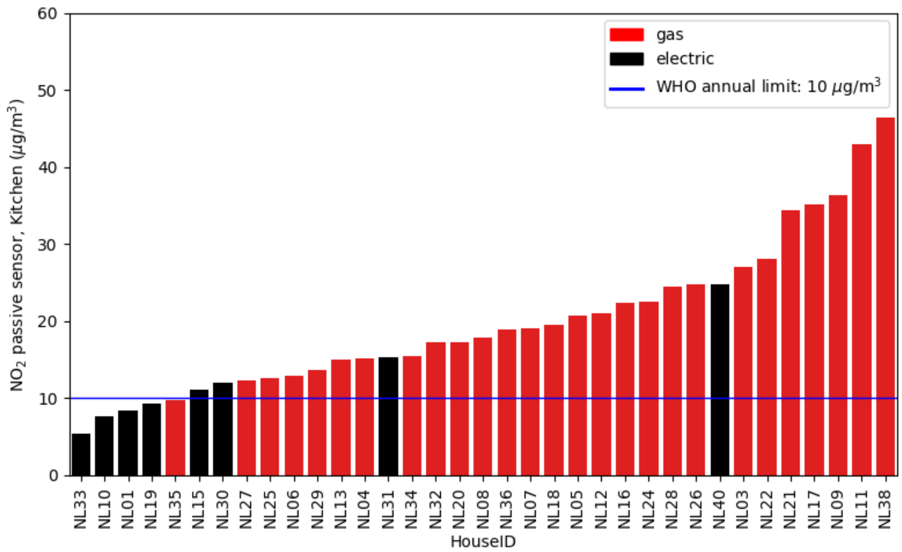


Figure 5.3 average NO_2 concentration in the kitchen per household measured with active (upper graph) and passive (lower graph) samplers (households ordered by average concentration). The blue lines indicate the WHO annual limit value of 10 µg/m³.

Table 5.2: average NO_2 concentration (incl. standard deviation SD and number of measurements n) in the kitchen, living room, bedroom and outdoor for households with electric cooking and with cooking on gas, including the p-value.

NO_2 in µg/m³	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen – active sensor	6	10.70	4.37	26	17.52	7.60	0.012*
Kitchen - passive sensor	8	11.74	6.08	27	22.32	9.52	0.001*
Living room - passive sensor	8	12.26	6.12	27	20.67	9.19	0.008*
Bedroom - passive sensor	8	11.15	4.07	27	15.17	7.26	0.06
Outdoor - passive sensor	8	21.25	5.63	27	21.99	6.59	0.76

**significant, p-value < 0.05*

According Table 5.2 the concentration difference between households cooking on gas and cooking on electric are for the kitchen active and passive sensor 6.8 and 10.6 µg/m³ respectively. For the living room the concentration increase in households cooking on gas is 8.4 µg/m³. For the bedroom a non-significant (p=0.06) increase of 4.0 µg/m³ has been found.

5.1.3.2 Carbon Monoxide (CO)

Figure 5.4 and Table 5.3 list the average carbon monoxide (CO) concentration in the kitchen measured with active samplers. In Figure 5.4 the cooking method is indicated by the colour of the bars.

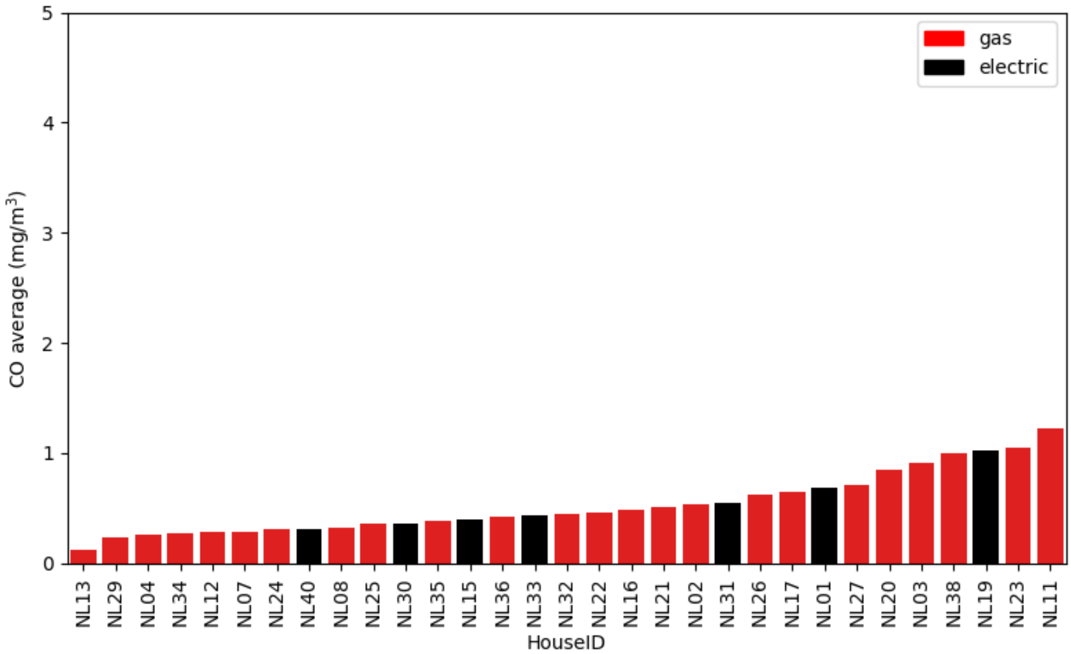


Figure 5.4 average CO concentration in the kitchen per household measured with active samplers (households ordered by average concentration).

Table 5.3: average value and highest 1-h value of CO concentration measurement in the kitchen, number of measurements n and standard deviation SD for households with electric cooking and with cooking on gas, including the p-value. Mean and standard deviation values are in mg/m³.

CO in mg/m³	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen – mean value	7	0.54	0.25	24	0.53	0.29	0.930
Kitchen - highest 1 h value	7	3.34	1.35	24	4.17	2.76	0.288

** significant, p-value < 0.05*

5.1.3.3 Fine Particulate Matter ($PM_{2.5}$)

Figure 5.5 and Table 5.4 list the $PM_{2.5}$ concentration in the kitchen. In Figure 5.5 the cooking method is indicated by the colour of the bars.

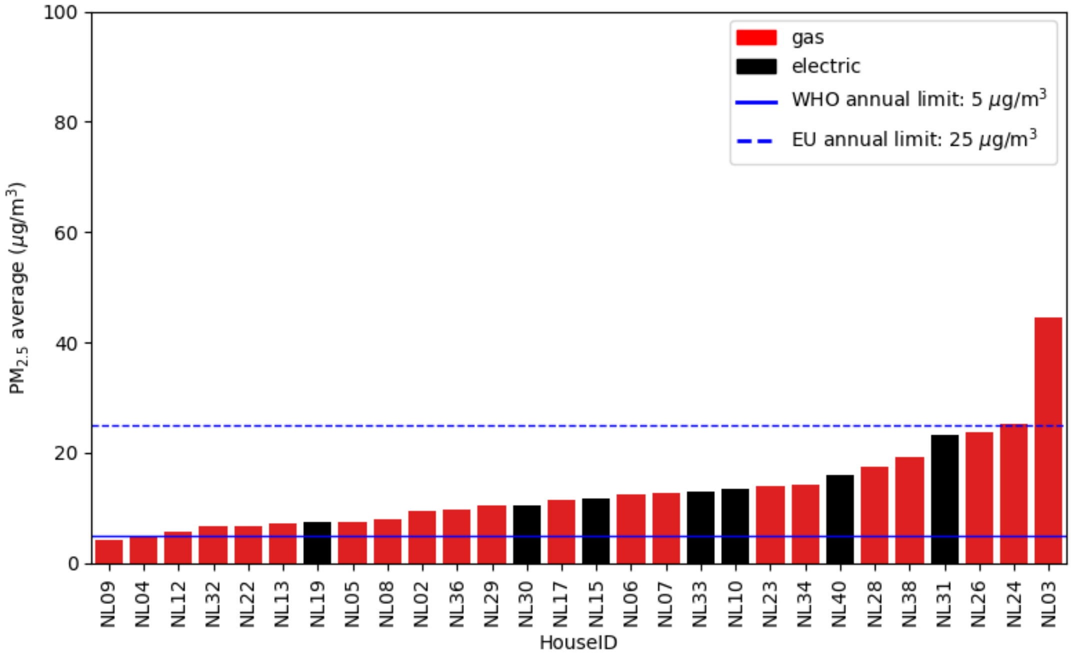


Figure 5.5 average $PM_{2.5}$ concentration in the kitchen per household (households ordered by average concentration).

Table 5.4: average $PM_{2.5}$ concentration in kitchen, number of measurements n and standard deviation SD for households with electric cooking and with cooking on gas, including the p-value.

$PM_{2.5}$ in μg/m^3	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen	7	13.6	5.0	21	13.1	9.3	0.85

** significant, p-value < 0.05*

5.1.4 Comparison with limit and guideline values

5.1.4.1 Nitrogen Dioxide (NO_2)

Table 5.5 lists the exceedance of the daily WHO guideline and EU NO_2 limit values in the kitchen during the 13 days measurement period based on the active sensor results.

Table 5.5: percentage of kitchens with NO_2 concentration above the WHO daily limit value and estimated percentage of kitchens above the WHO guideline and the EU NO_2 limit values based on **active sensor** results.

NO_2 Limit values	% of households above limit value	
	Electric cooking	Cooking on gas
WHO daily guideline value 25 µg/m^3	17	54
WHO hourly guideline value 200 µg/m^3	0	31
>18 hours above EU hourly limit 200 µg/m^3	0	27*

**Extrapolation of 13 days of measurement data to yearly exceedance*

In more than 50% of the houses cooking on gas the WHO daily guideline value is exceeded. Also in one of the six houses with electric cooking the WHO daily guideline value is exceeded during three days. This exceedance may be explained by infiltration of NO_2 from outdoors. Based on data from governmental outdoor measurement stations (www.luchtmeetnet.nl) during the measurement period the ambient concentration was relatively high, reaching peak values of 60 – 80 µg/m^3 during several days in the nearby air quality station.

The WHO hourly guideline value is exceeded in almost one in three houses cooking on gas and not exceeded in any house cooking electric.

Figure 5.6 shows the distribution of days that the NO_2 concentration during the measurement period is above the WHO daily guideline value. Figure 5.7 and Figure 5.8 give respectively the number of hours and the number of clock hours that the NO_2 concentration during the measurement period is above the EU limit value or the WHO guideline value of 200 µg/m^3.

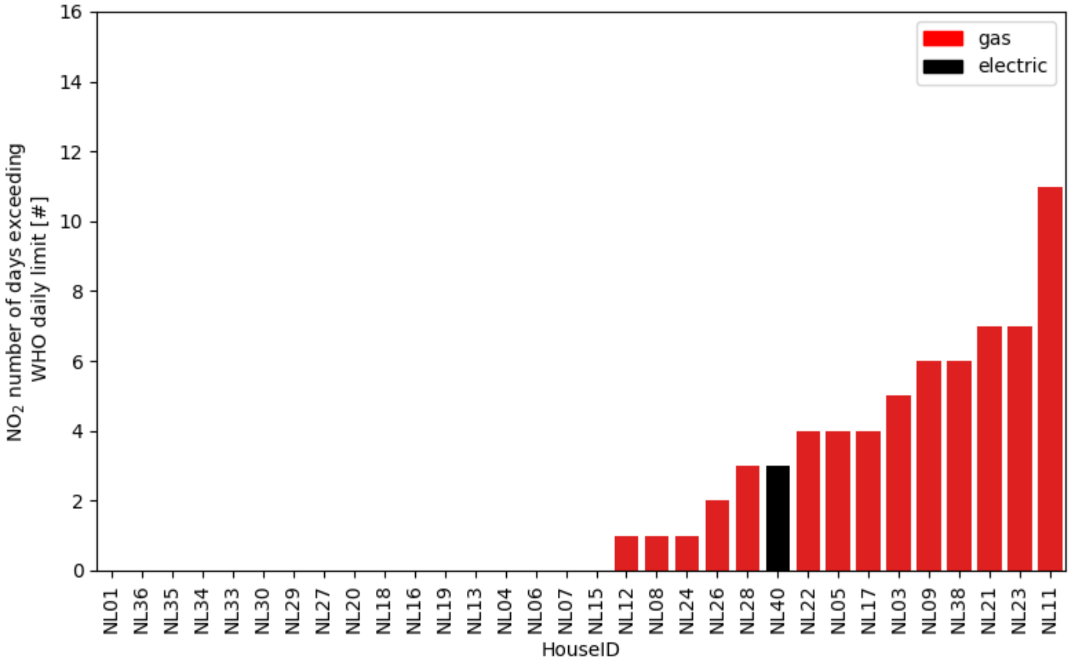


Figure 5.6 number of days that the WHO NO_2 daily limit value of 25 µg/m^3 has been exceeded during the measurement period.

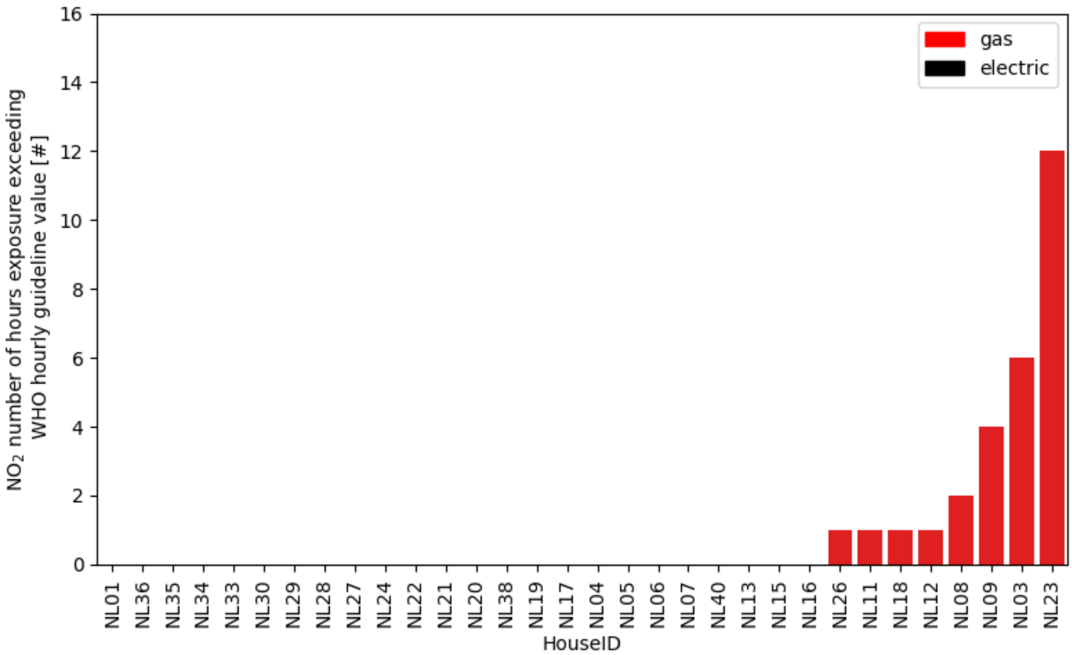


Figure 5.7 number of hours that the WHO NO_2 hourly guideline value of 200 µg/m^3 has been exceeded during the measurement period.

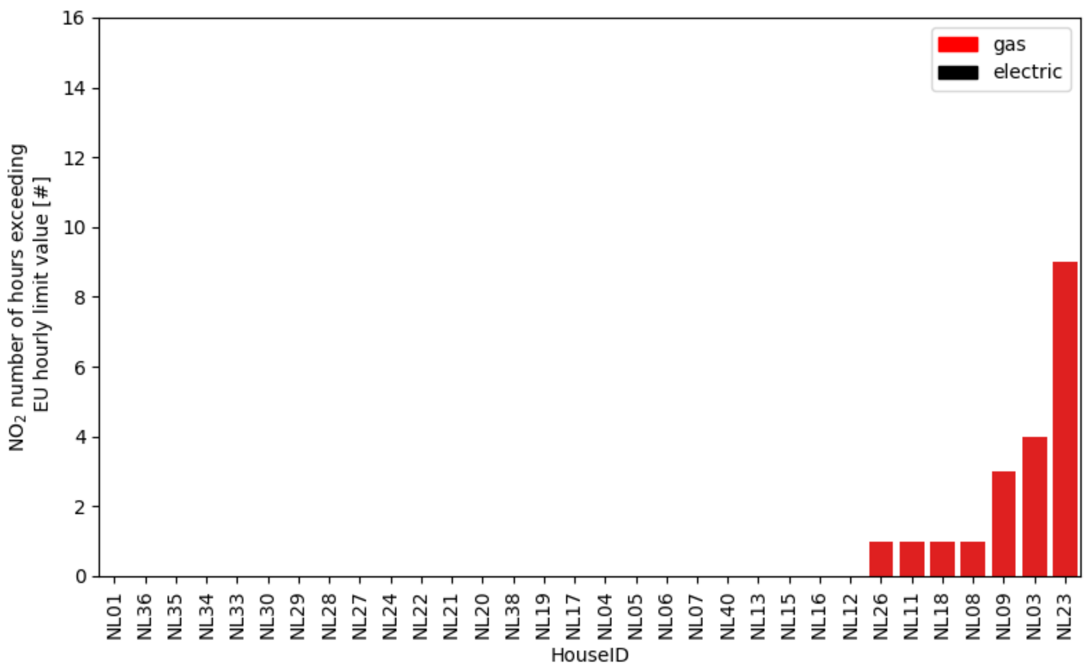


Figure 5.8 number of **clock** hours that the EU outdoor NO_2 hourly limit value of 200 µg/m^3 has been exceeded during the measurement period.

5.1.4.2 Carbon Monoxide (CO)

Table 5.6 lists the exceedance of the WHO guideline values and EU CO limit value in the kitchen during the 13 days measurement period based on the active sensor results. The daily guideline value was exceeded in one house cooking on gas. This house (NL11) was located aside a restaurant. The exceedances were mainly in the weekends. Therefore it is very likely that the CO sensor was influenced by evaporation of alcohol from client consumptions and from evaporation of cleaning products. Based on the results, and acknowledging the fact that the CO sensor is also sensible for ethanol[8], cooking on gas in in the measured households probably did not lead to exceedance of guideline and limit values.

Table 5.6: percentage of kitchens with CO concentrations above WHO guideline and EU limit values.

CO Limit values	% of households above limit value	
	Electric cooking	Cooking on gas
WHO daily guideline value of 4 mg/m^3	0	4.2
WHO/EU 8 h limit of 10 mg/m^3	0	0
WHO 1h guideline value of 35 mg/m^3	0	0

5.1.4.3 Fine Particulate matter ($PM_{2.5}$)

Table 5.7 lists the exceedance of the daily WHO $PM_{2.5}$ guideline values in the kitchen during the 13 days measurement period. Figure 5.9 shows the distribution of the exceedance days, the cooking method is indicated by the colour of the bars. A large part of the investigated households exceeds the daily WHO guideline value, both by household cooking on gas as electric.

Table 5.7: percentage of kitchens with $PM_{2.5}$ concentrations above WHO guideline value.

$PM_{2,5}$ Limit values	% of households above limit value	
	Electric cooking	Cooking on gas
WHO daily guideline value 15 µg/m³	100	81

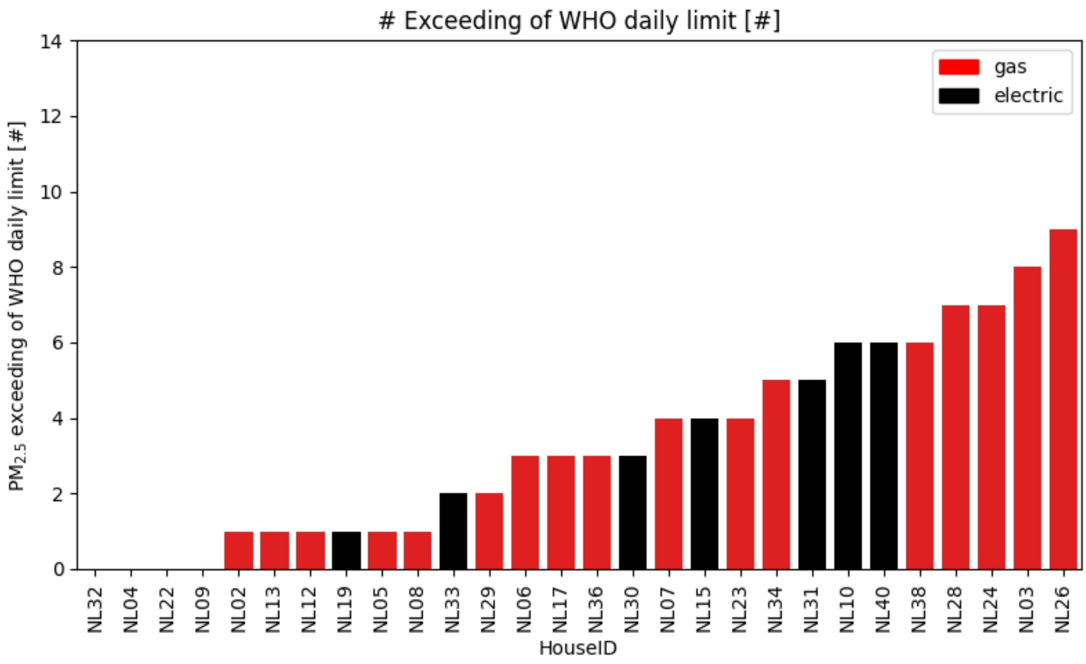


Figure 5.9 number of days that the $PM_{2.5}$ daily guideline value of 15 µg/m³ has been exceeded during the measurement period.

5.2 Italy

5.2.1 Summary

Measurement results regarding to 31 Italian households cooking on gas and 5 household cooking electric have been obtained. Cooking on gas clearly led to significant deterioration of the indoor air quality with regard to NO_2:

- The households cooking on gas have a significant ($p < 0.05$) higher nitrogen dioxide (NO_2) concentration in their kitchen and living room than households cooking with electric cooking appliances.
- The WHO daily guideline value for nitrogen dioxide was exceeded in 72% of the measured Italian households cooking on gas. For electric cooking no exceedances were registered.
- The WHO hourly guideline value for NO_2 was exceeded in 28% of the houses cooking on gas and was not exceeded in any house cooking electric.
- The EU hourly limit value for NO_2 in ambient air was exceeded in 24% of the investigated houses cooking on gas, while in houses cooking electric no exceedances have been registered. Based on the number of exceedance hours during the measurement period it is likely that for most of these houses the hourly EU limit value is exceeded more than 18 hours per year.

With regard to carbon monoxide (CO) a significant concentration differences between houses cooking on gas and cooking electric could be distinguished. However the number of participants cooking on electric is small. Two households cooking on gas may have exceeded the WHO daily guideline value for CO. For one household the exceedance may partly be caused by sensitivity of the sensor for ethanol.

The fine particulate matter ($PM_{2.5}$) concentration in kitchens from households cooking on gas was significantly higher than in households cooking on electric. This can be explained with a longer cooking duration for these households compared to the households cooking on electric hobs. Nearly all investigated houses, both cooking on gas as electric, exceeded the WHO daily guideline value for fine particulate matter ($PM_{2.5}$).

5.2.2 Household Environmental Conditions

5.2.2.1 Estimated hob use

Based on the iButton temperature readings, the hob and oven cooking time per day have been estimated, see Figure 5.10. The cooking time per day in Italy is longer than in the Netherlands. For one household the cooking time of the gas oven has been logged.

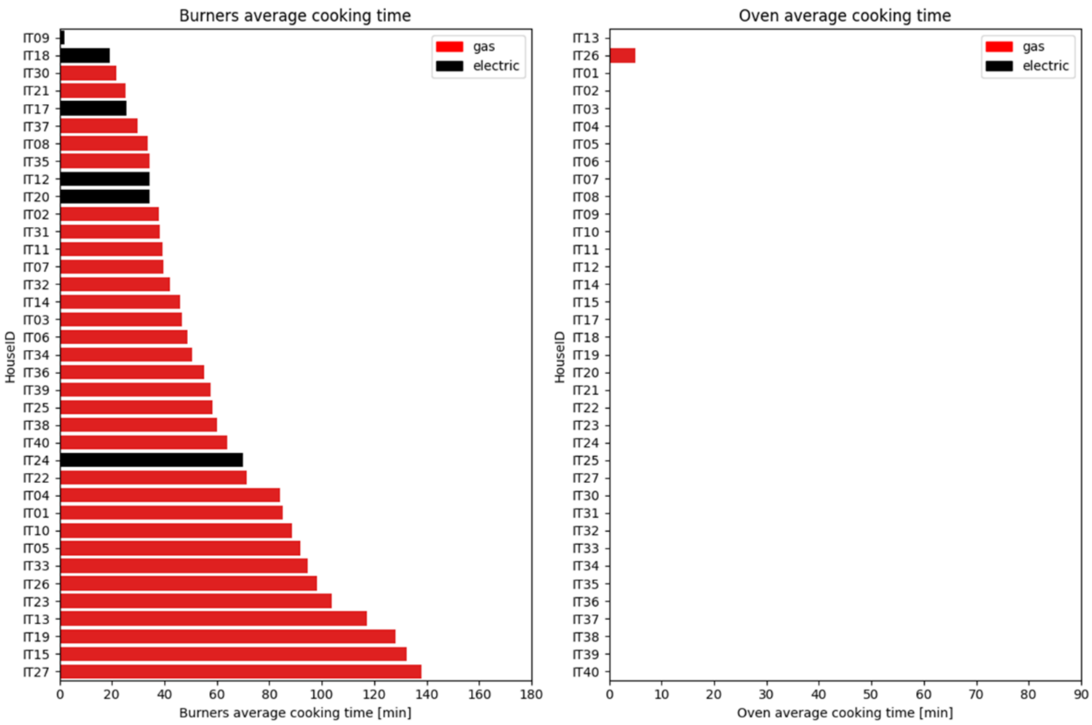


Figure 5.10 Estimated hob and oven use for each participating household.

5.2.3 Kitchen estimated ventilation rate

Table 5.8 and Figure 5.11 list the estimated ventilation rate in the kitchen/living room.

Table 5.8: overview of estimated ventilation flow in kitchen and or living room, number of measurements, arithmetic mean, geometric mean and geometric standard deviation.

	n	mean	median	mean SD
Ventilation rate [ACH]	29	0.33	0.22	0.30

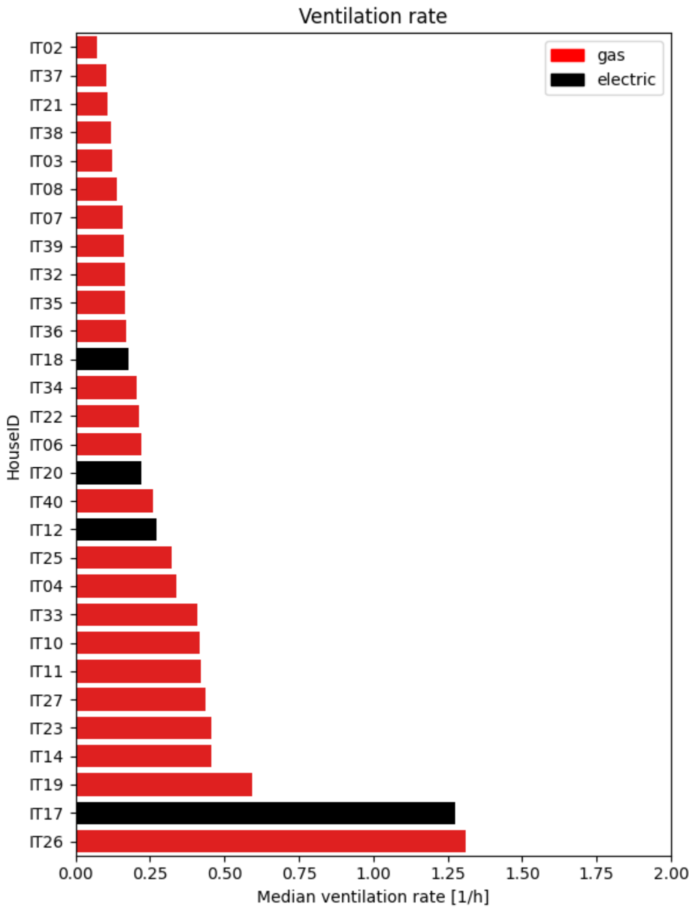
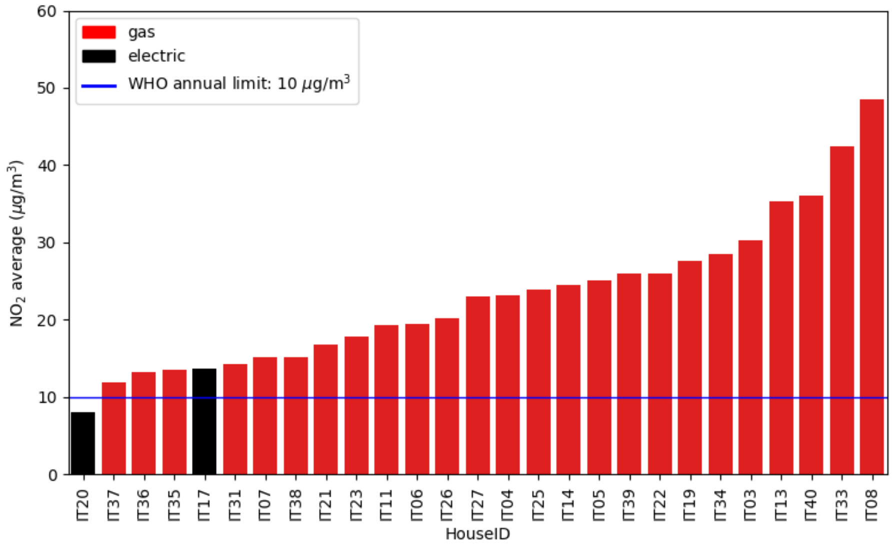


Figure 5.11 calculated median ventilation rate for each participating household.

5.2.4 Pollutant concentrations

5.2.4.1 Nitrogen Dioxide (NO_2)

Figure 5.12 and Table 5.9 list the mean NO_2 concentrations measured by the active and passive sensors. In Figure 5.12 the cooking method is indicated by the colour of the bars. For illustration also the WHO annual guideline value of 10 µg/m^3 is indicated as blue line in the graphs. A direct comparison with the annual guideline is not possible as we have only measured during 13 days and the expectation based on literature data[9] is that during summer the indoor NO_2 concentration is lower than during the heating season.



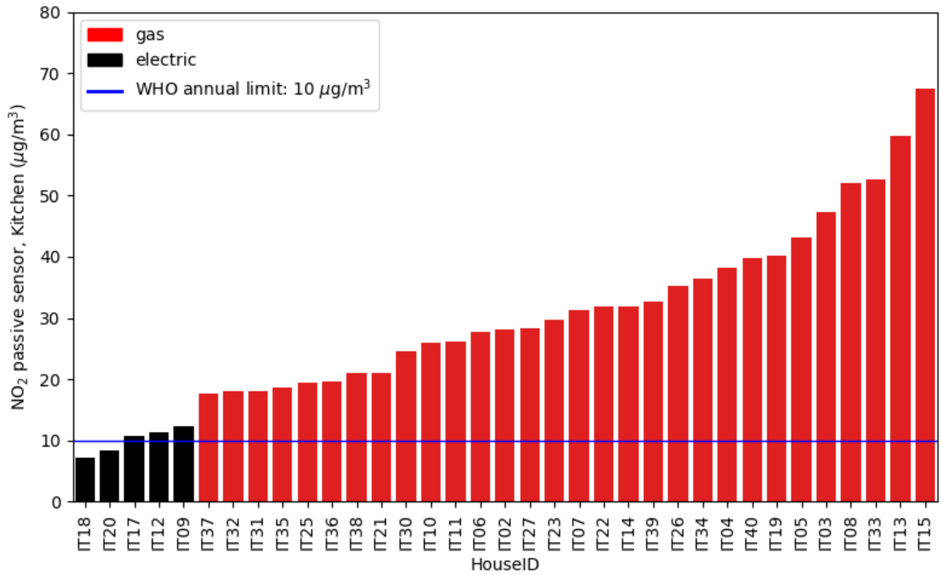


Figure 5.12 average NO_2 concentration in the kitchen per household measured with active (upper graph) and passive (lower graph) samplers (households ordered by average concentration). The red line indicates the WHO annual limit value of 10 µg/m^3.

Table 5.9: average NO_2 concentration (incl. standard deviation SD and number of measurements n) in the kitchen, living room, bedroom and outdoor for households with electric cooking and with cooking on gas, including the p-value.

NO_2 in µg/m^3	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen – active sensor	2	10.8	4.0	25	23.9	9.3	0.058
Kitchen - passive sensor	5	10.0	2.2	30	32.8	13.0	<0.001
Living room - passive sensor	4	9.5	1.8	30	27.5	9.3	<0.001
Bedroom - passive sensor	4	13.1	7.9	30	21.3	9.2	0.124
Outdoor - passive sensor	4	17.2	11.7	29	21.2	10.4	0.554

**significant, p-value < 0.05*

According Table 5.9 the concentration increases due to cooking on gas compared to electric cooking are for the kitchen active and passive sensor 13.1 and 22.8 μg/m^3 respectively. For the living room the concentration increase due to cooking on gas is 18.0 μg/m^3. For the bedroom a non-significant (p=0.124) increase of 8.2 μg/m^3 has been found.

5.2.4.2 Carbon Monoxide (CO)

Figure 5.13 and Table 5.10 list the average carbon monoxide (CO) concentration in the kitchen measured with active samplers. With regard to IT07 the CO peaks were only party aligned with cooking events. Therefore it is very probably that some of the peaks were caused by alcohol in cleaning agents or alcoholic drinks.

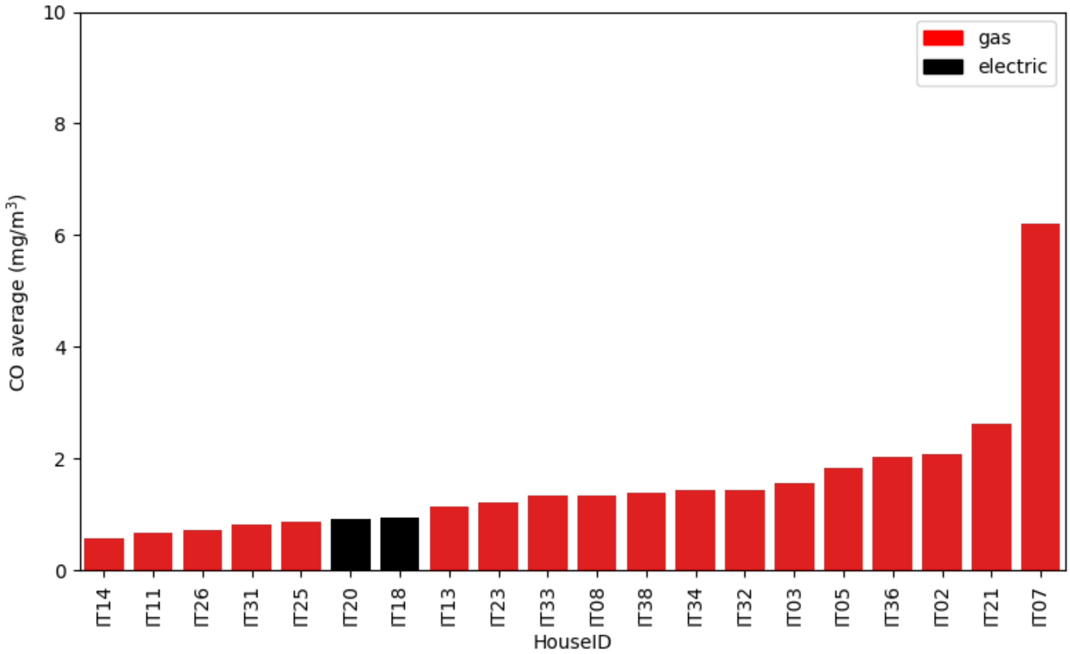


Figure 5.13 average CO concentration in the kitchen per household measured with active samplers (households ordered by average concentration).

Table 5.10: average value and highest 1-h value of CO concentration measurement in the kitchen, number of measurements n and standard deviation SD for households with electric cooking and with cooking on gas, including the p-value. Mean and standard deviation values are in mg/m^3.

CO in mg/m^3	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen – mean value	2	0.95	0.01	18	1.63	1.26	0.035
Kitchen - highest 1 h value	2	7.52	5.12	18	7.64	3.28	0.979

** significant, p-value < 0.05*

5.2.5 Fine Particulate Matter ($PM_{2.5}$)

Figure 5.14 and Table 5.11 list the $PM_{2.5}$ concentration in the kitchen. The cooking method is indicated by the colour of the bars. The significant higher $PM_{2.5}$ value for cooking on gas hobs can be explained by a longer cooking duration for these households compared to the four households cooking on electric hobs for which the $PM_{2.5}$ concentration is reported.

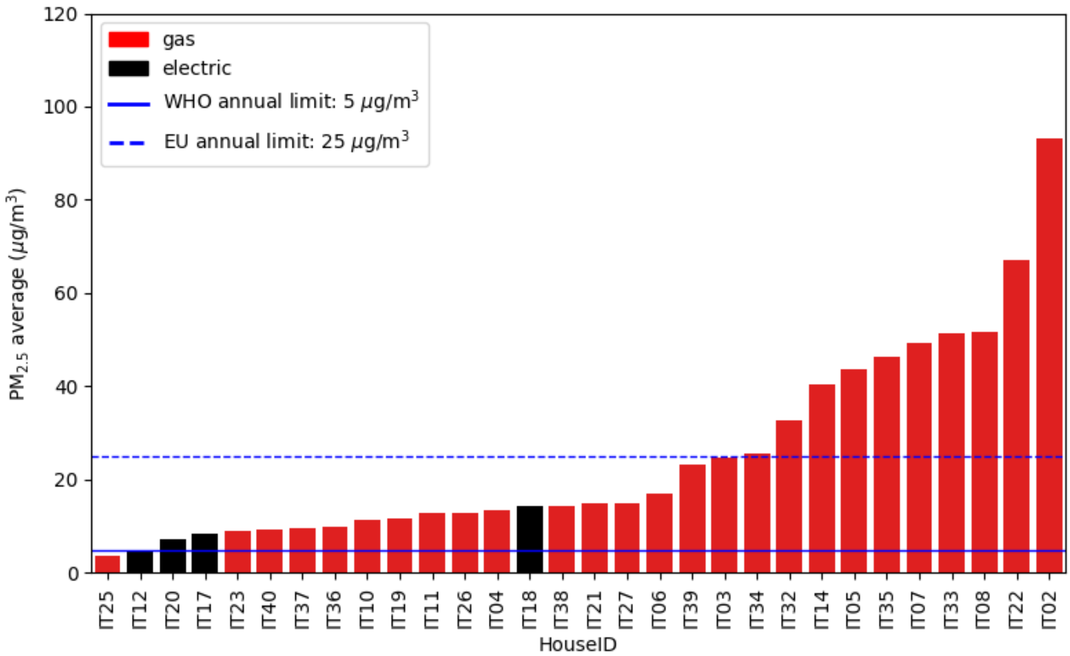


Figure 5.14 average $PM_{2.5}$ concentration in the kitchen per household (households ordered by average concentration).

Table 5.11: average $PM_{2.5}$ concentration in kitchen, number of measurements n and standard deviation SD for households with electric cooking and with cooking on gas, including the p-value.

$PM_{2.5}$ in µg/m^3	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen	4	8.7	4.14	26	27.5	21.8	<0.001

** significant, p-value < 0.05*

5.2.6 Comparison with limit and guideline values

5.2.6.1 Nitrogen Dioxide (NO_2)

Table 5.12 lists the exceedance of the daily WHO guideline and EU NO_2 limit values in the kitchen during the 13 days measurement period based on the active sensor results. In 72% of the houses cooking on gas the WHO daily guideline value is exceeded whereas in none of the houses cooking electric was the case.

The WHO hourly guideline value is exceeded in 28% of the Italian houses cooking on gas and not in any house cooking electric.

The EU limit value exceedance is smaller than the WHO guideline value exceedance as the exceedance based on clock hours is smaller than the WHO guideline value exceedance which is based on exposure hours. See for more information paragraph 2.5.

Table 5.12: percentage of kitchens with NO_2 concentration above the WHO daily limit value and estimated percentage of kitchens above the WHO guideline and the EU NO_2 limit values based on **active sensor** results.

NO_2 Limit values	% of households above limit value	
	Electric cooking	Cooking on gas
WHO daily guideline value 25 µg/m^3	0	72
WHO hourly guideline value 200 µg/m^3	0	28
>18 hours above EU hourly limit 200 µg/m^3	0	24*

**Extrapolation of 13 days of measurement data to yearly exceedance*

Figure 5.15 shows the distribution of days that the NO_2 concentration during the measurement period is above the WHO daily guideline value. Figure 5.16 and Figure 5.17 give respectively the number of hours and the number of clock hours and the that the NO_2 concentration during the measurement period is above the WHO guideline / EU limit value of 200 µg/m^3.

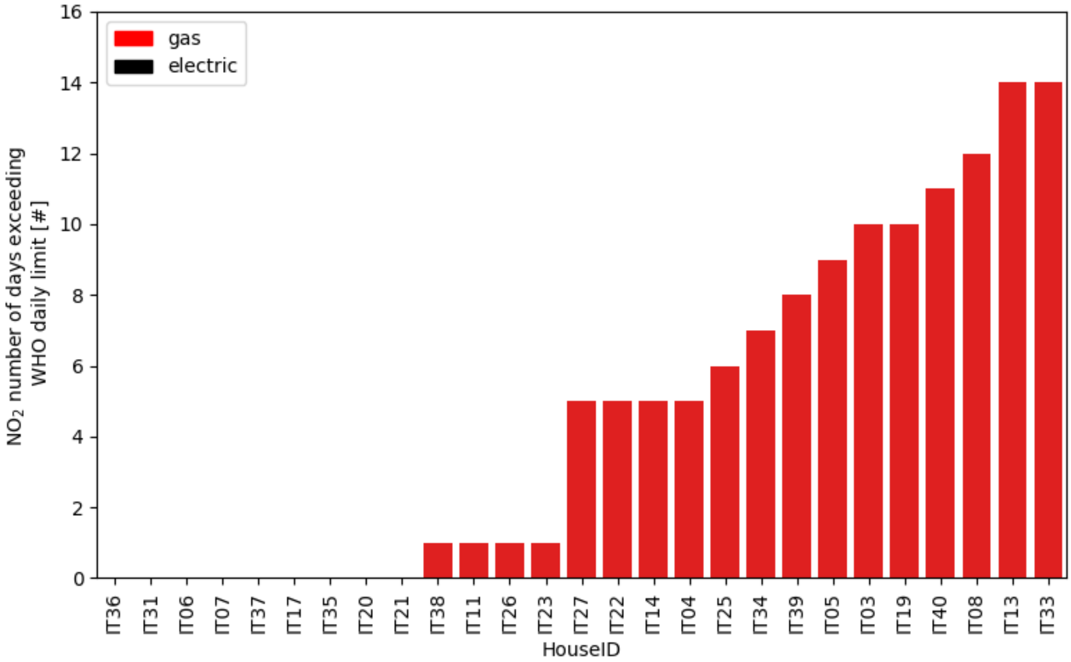


Figure 5.15 number of days that the WHO NO_2 daily limit value of 25 µg/m^3 has been exceeded during the measurement period.

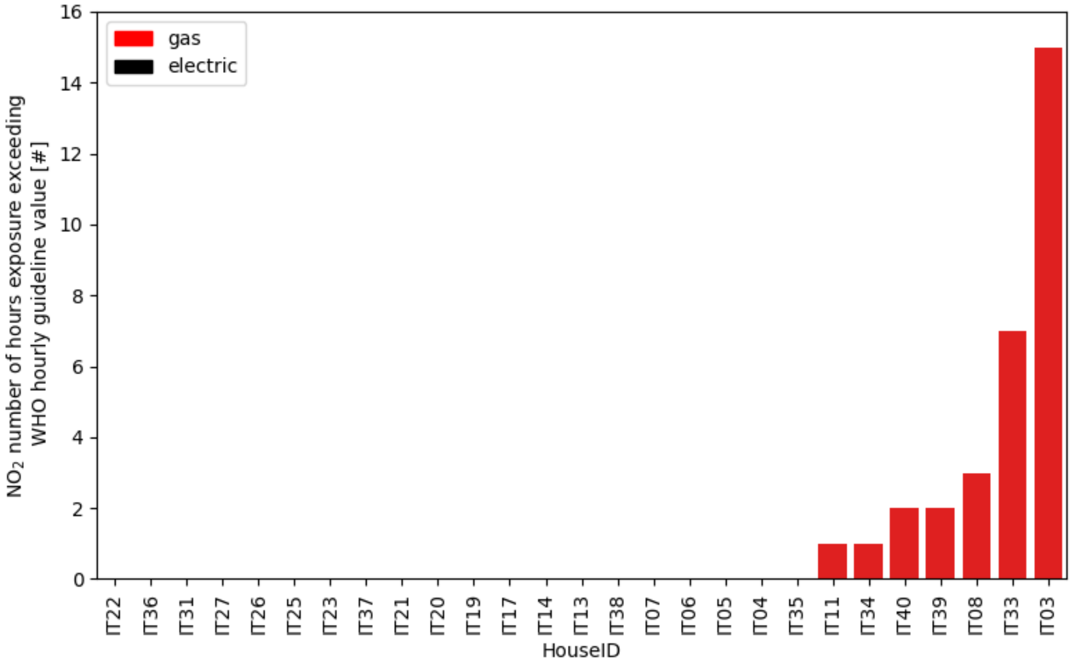


Figure 5.16 number of hours that the WHO NO_2 hourly guideline value of 200 µg/m^3 has been exceeded during the measurement period.

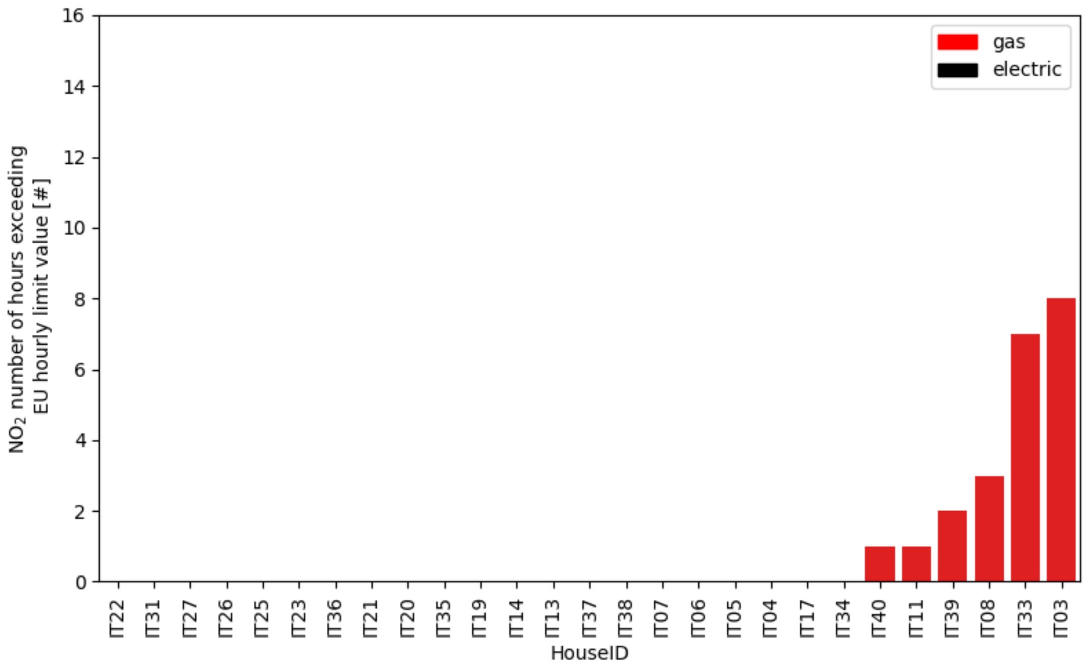


Figure 5.17 number of **clock** hours that the EU outdoor NO_2 hourly limit value of 200 µg/m^3 has been exceeded during the measurement period.

5.2.6.2 Carbon Monoxide (CO)

Table 5.13 lists the exceedance of the WHO guideline values and EU CO limit value in the kitchen during the 13 days measurement period based on the active sensor results. Two participants exceeded the WHO daily guideline value. As mentioned earlier for participant IT07, the CO peaks were only party aligned with cooking events. Therefore it is very probably that part of this exceedance was caused by alcohol in cleaning agents or alcoholic drinks. For participant IT02 all the CO peaks are well aligned with cooking events.

Table 5.13: percentage of kitchens with CO concentrations above WHO guideline and EU limit values.

CO Limit values	% of households above limit value	
	Electric cooking	Cooking on gas
WHO daily guideline value of 4 mg/m^3	0	11
WHO/EU 8 h limit of 10 mg/m^3	0	0
WHO 1h guideline value of 35 mg/m^3	0	0

5.2.6.3 Fine Particulate matter ($PM_{2.5}$)

Table 5.14 lists the exceedance of the daily WHO $PM_{2.5}$ guideline values in the kitchen during the 13 days measurement period. Figure 5.18 shows the distribution of the exceedance days, the cooking method is indicated by the colour of the bars

Table 5.14:centage of kitchens with $PM_{2.5}$ concentrations above WHO guideline value.

$PM_{2,5}$ Limit values	% of households above limit value	
	Electric cooking	Cooking on gas
WHO daily guideline value 15 µg/m³	100	96

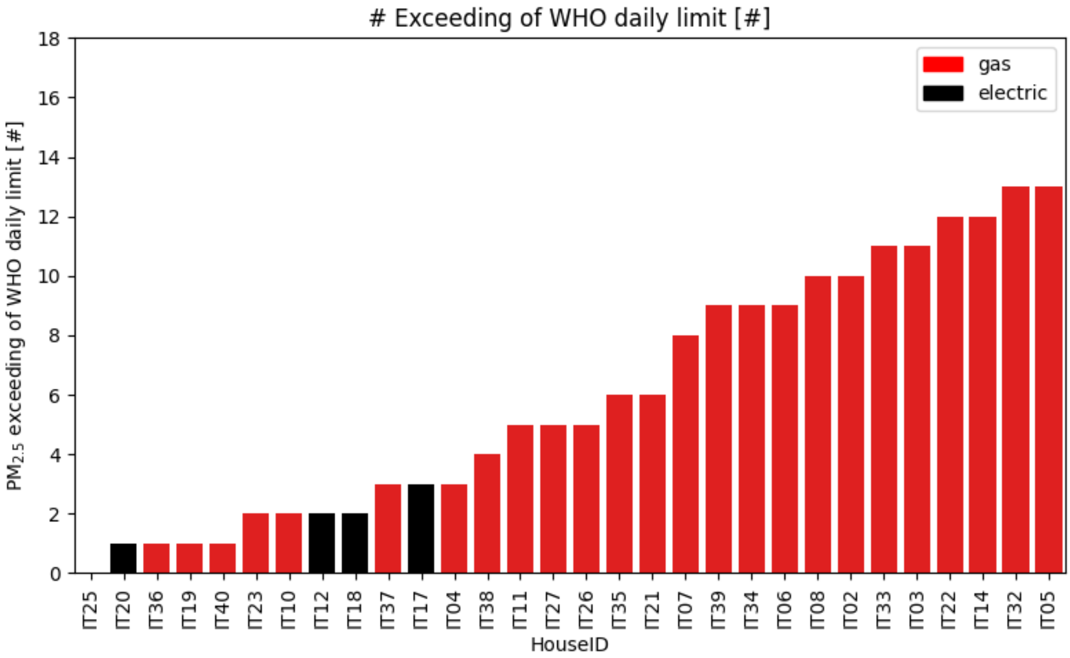


Figure 5.18 number of days that the $PM_{2.5}$ daily guideline value of 15 µg/m³ has been exceeded during the measurement period.

5.3 Spain

5.3.1 Summary

Measurement results regarding to 15 Spanish households cooking on gas and 19 households cooking electric have been obtained. Cooking on gas clearly led to significant deterioration of the indoor air quality with regard to NO_2:

- The households cooking on gas have a significant ($p < 0.05$) higher nitrogen dioxide (NO_2) concentration in their kitchen than households cooking with electric cooking appliances.
- The WHO daily guideline value for nitrogen dioxide was exceeded in 85% of the households cooking on gas. For electric cooking the exceedance was 50%. Most probably this exceedance was caused by a relatively high outdoor NO_2 concentration.
- The WHO hourly guideline value for NO_2 was exceeded in 77% of the houses cooking on gas and not in any house cooking electric.
- The EU hourly limit value for NO_2 in ambient air was exceeded in 69% of the investigated houses cooking on gas, while in houses cooking electric no exceedances have been registered. Based on the number of exceedance hours during the measurement period it is likely that for most of these houses the hourly EU limit value is exceeded more than 18 hours per year.

With regard to carbon monoxide (CO) no significant difference between houses cooking on gas and cooking electric could be distinguished. The mean values are almost identical. Based on the results, and acknowledging the fact that the CO sensor is also sensible for ethanol, cooking on gas in in the measured households probably did not lead to exceedance of CO guideline and limit values.

Also for fine particulate matter ($PM_{2.5}$) no significant concentration difference between houses cooking on gas and cooking electric could be distinguished. Of the investigated houses cooking electric 69% exceeded the WHO daily guideline value for fine particulate matter ($PM_{2.5}$). Of the houses cooking on gas 92% exceeded this guideline value.

5.3.2 Household Environmental Conditions

5.3.2.1 Estimated hob use

Based on the iButton temperature readings, the hob and oven cooking time per day have been estimated, see Figure 5.19.

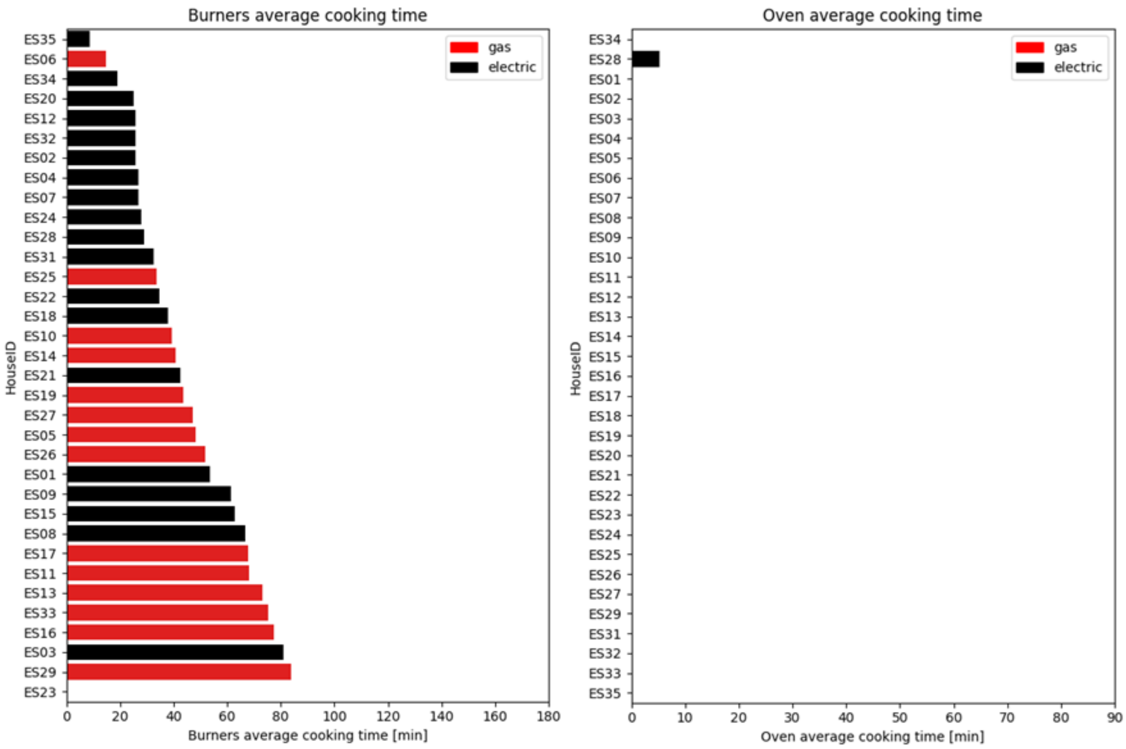


Figure 5.19 Estimated hob and oven use for each participating household.

5.3.2.2 Kitchen estimated ventilation rate

Table 5.15 and Figure 5.20 list the estimated ventilation rate in the kitchen/living room. This air change rate has mainly been estimated from the CO_2 decay at the end of the evening. At this time people may close windows or turn the ventilation system to a lower setting. Therefore this estimate might be lower than the ventilation flow during the day and during cooking.

Table 5.15: overview of estimated ventilation flow in kitchen and or living room, number of measurements, arithmetic mean, geometric mean and geometric standard deviation.

	n	mean	median	mean SD
Ventilation rate [ACH]	29	0.32	0.31	0.15

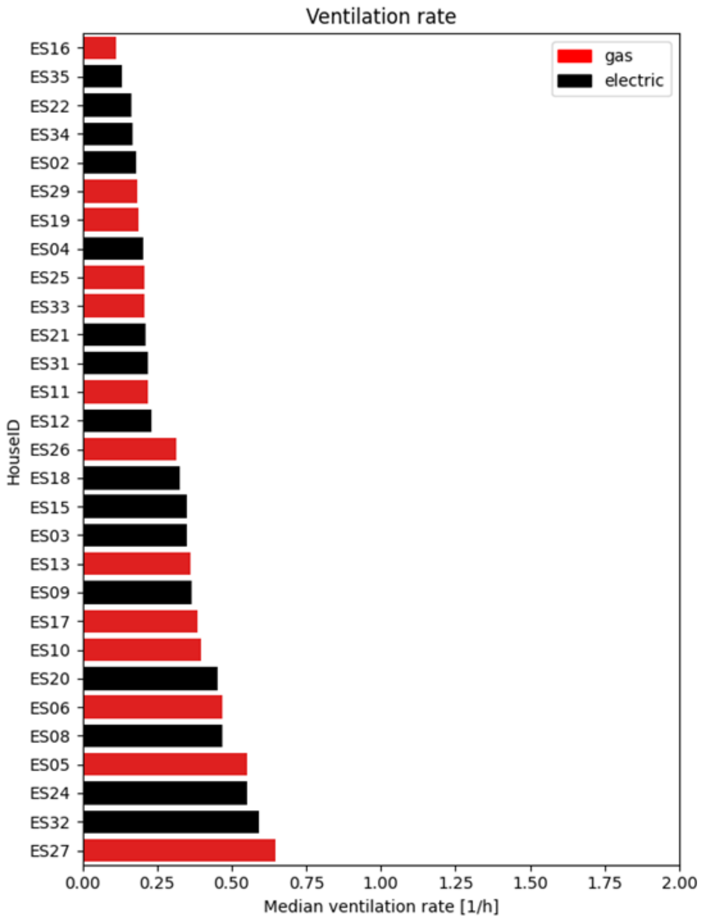
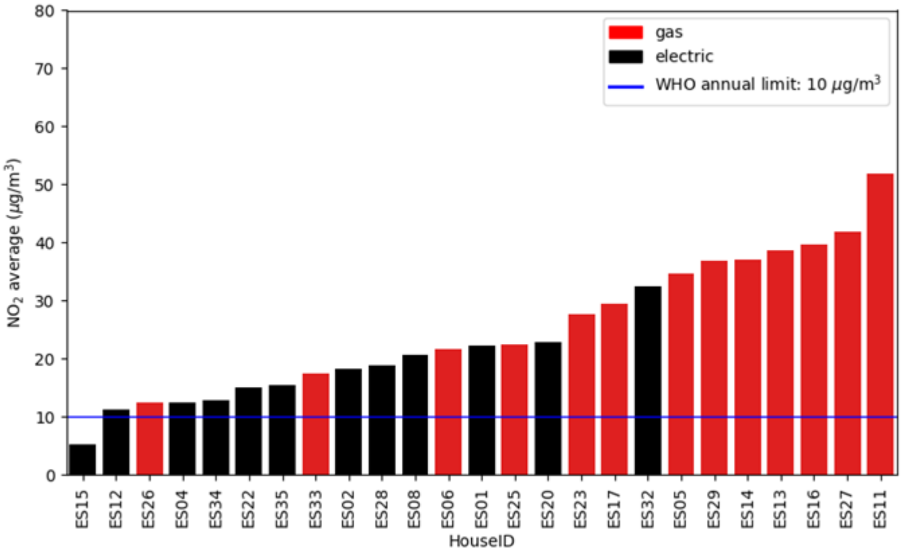


Figure 5.20 calculated median ventilation rate for each participating household.

5.3.3 Pollutant concentrations

5.3.3.1 Nitrogen Dioxide (NO_2)

Figure 5.21 and Table 5.16 list the mean NO_2 concentrations measured by the active and passive sensors. For illustration in Figure 5.21 also the WHO annual guideline value of 10 µg/m³ is indicated as blue line in the graphs. A direct comparison with the annual guideline is not possible as we have only measured during 13 days and the expectation based on literature data[9] is that during summer the indoor NO_2 concentration is lower than during the heating season.



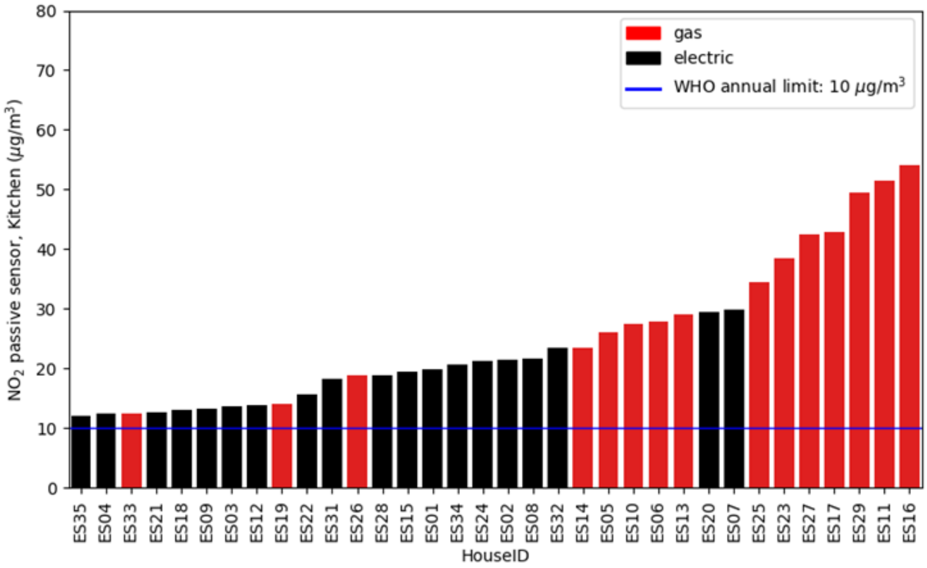


Figure 5.21 average NO_2 concentration in the kitchen per household measured with active (upper graph) and passive (lower graph) samplers (households ordered by average concentration). The red line indicates the WHO annual limit value of 10 µg/m³.

Table 5.16: average NO_2 concentration (incl. standard deviation SD and number of measurements n) in the kitchen, living room, bedroom and outdoor for households with electric cooking and with cooking on gas, including the p-value.

NO_2 in µg/m³	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen – active sensor	12	17.3	6.9	13	31.7	11.1	0.001
Kitchen - passive sensor	19	18.5	5.4	15	32.9	13.3	0.001
Living room - passive sensor	19	17.8	6	15	28.5	11.7	0.004
Bedroom - passive sensor	18	15.8	5.7	15	22.9	11.4	0.040
Outdoor - passive sensor	19	26.7	17	15	23.2	9.3	0.455

significant, p-value < 0.05

According Table 5.16 the concentration increases due to cooking on gas compared to electric cooking are for the kitchen active and passive sensor 14.4 and 14.4 µg/m³ respectively. For the living room a significant (p=0,004) increase of 10.7 µg/m³ has been found. For the bedroom a significant (p=0.04) increase of 7.1 µg/m³ has been found.

Interesting to see is that the outdoor concentration of houses cooking electric is higher, although the difference is not significant.

5.3.3.2 Carbon Monoxide (CO)

Figure 5.22 and Table 5.17 list the average carbon monoxide (CO) concentration in the kitchen measured with active samplers. In Figure 5.4 the cooking method is indicated by the colour of the bars.

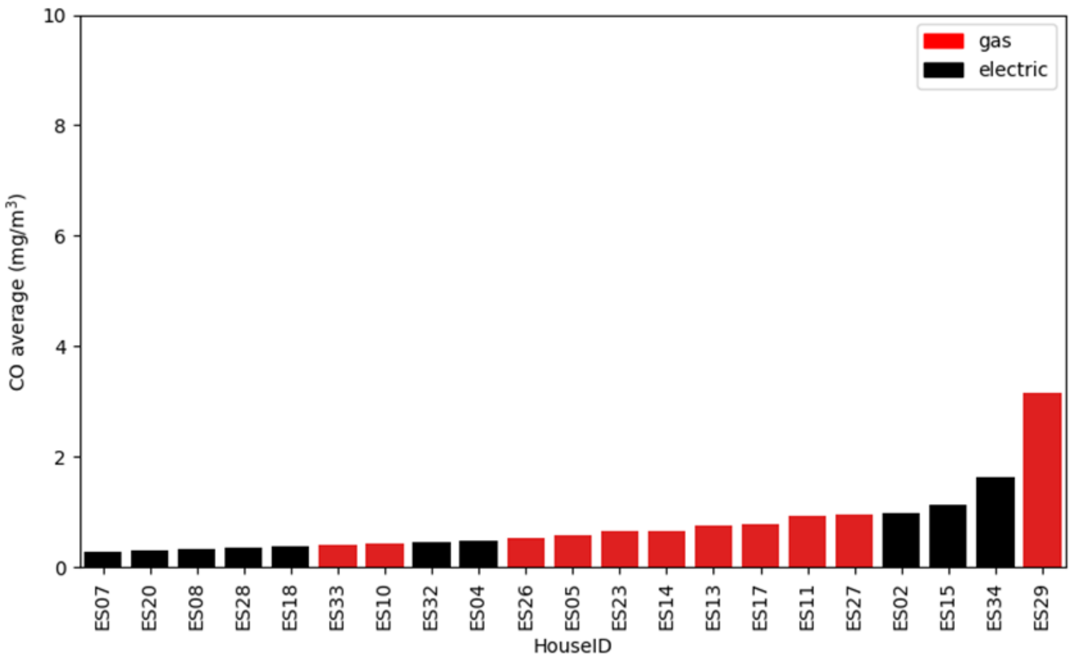


Figure 5.22 average CO concentration in the kitchen per household measured with active samplers (households ordered by average concentration).

Table 5.17: average value and highest 1-h value of CO concentration measurement in the kitchen, number of measurements n and standard deviation SD for households with electric cooking and with cooking on gas, including the p-value. Mean and standard deviation values are in mg/m³.

CO in mg/m³	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen – mean value	10	0.6	0.5	11	0.9	0.8	0.349
Kitchen - highest 1 h value	10	5.9	3.9	11	6.3	3.9	0.786

** significant, p-value < 0.05*

With regard to CO there is no significant concentration difference in the investigated houses cooking on gas or electric.

5.3.3.3 Fine Particulate Matter ($PM_{2.5}$)

Figure 5.23 and Table 5.18 list the $PM_{2.5}$ concentration in the kitchen. Cooking on gas results in a higher concentration, although the difference is not significant.

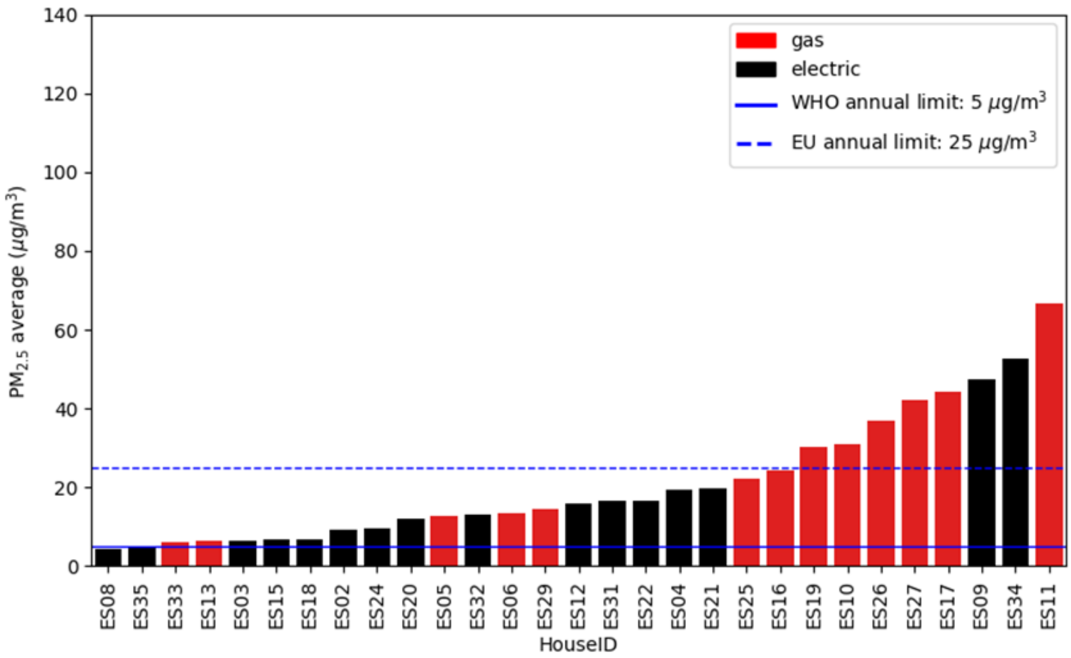


Figure 5.23 average $PM_{2.5}$ concentration in the kitchen per household (households ordered by average concentration).

Table 5.18: average $PM_{2.5}$ concentration in kitchen, number of measurements n and standard deviation SD for households with electric cooking and with cooking on gas, including the p-value.

$PM_{2.5}$ in μg/m³	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen	16	16.4	14.1	13	27	17.5	0.09

** significant, p-value < 0.05*

5.3.4 Comparison with limit and guideline values

5.3.4.1 Nitrogen Dioxide (NO_2)

Table 5.19 lists the exceedance of the daily WHO guideline and EU NO_2 limit values in the kitchen during the 13 days measurement period based on the active sensor results.

The EU limit value exceedance is smaller than the WHO guideline value exceedance as the exceedance based on clock hours is smaller than the WHO guideline value exceedance which is based on exposure hours. See for more information paragraph 2.5.

Table 5.19: percentage of kitchens with NO_2 concentration above the WHO daily limit value and estimated percentage of kitchens above the WHO guideline and the EU NO_2 limit values based on **active sensor** results.

NO_2 Limit values	% of households above limit value	
	Electric cooking	Cooking on gas
WHO daily guideline value 25 µg/m^3	50	85
WHO hourly guideline value 200 µg/m^3	0	77
>18 hours above EU hourly limit 200 µg/m^3	0	69*

**Extrapolation of 13 days of measurement data to yearly exceedance*

Figure 5.24 shows the distribution of days that the NO_2 concentration during the measurement period is above the WHO daily guideline value. Figure 5.25 and Figure 5.26 give respectively the number of hours and the number of clock hours that the NO_2 concentration during the measurement period is above the WHO guideline value / EU limit value of 200 µg/m^3.

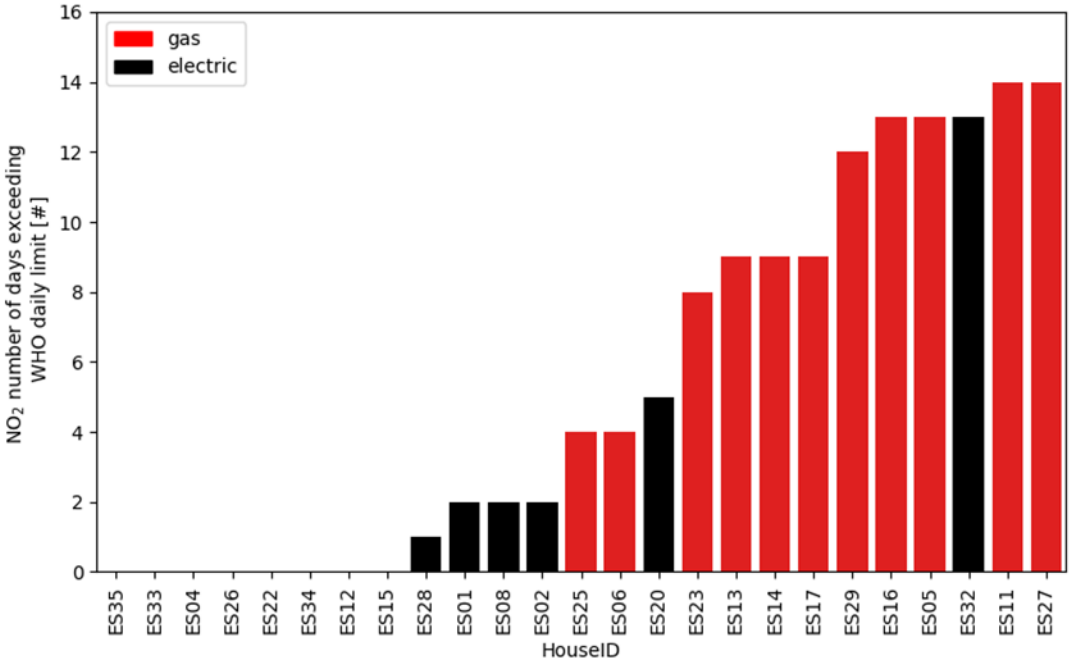


Figure 5.24 number of days that the WHO NO_2 daily limit value of 25 µg/m^3 has been exceeded during the measurement period.

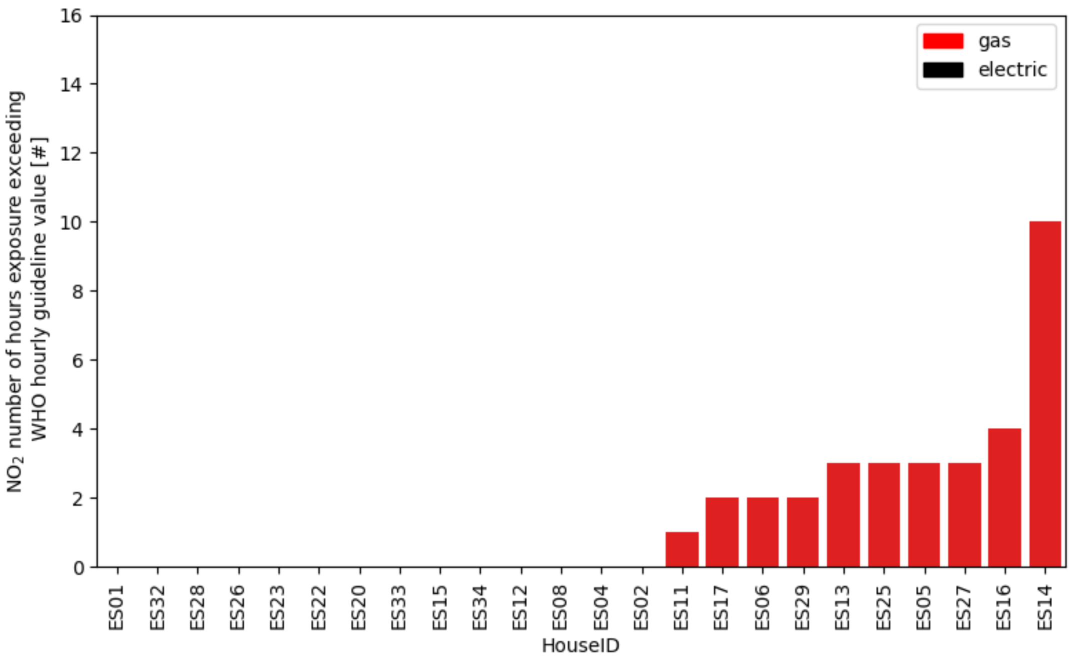


Figure 5.25 number of hours that the WHO NO_2 hourly guideline value of 200 µg/m^3 has been exceeded during the measurement period.

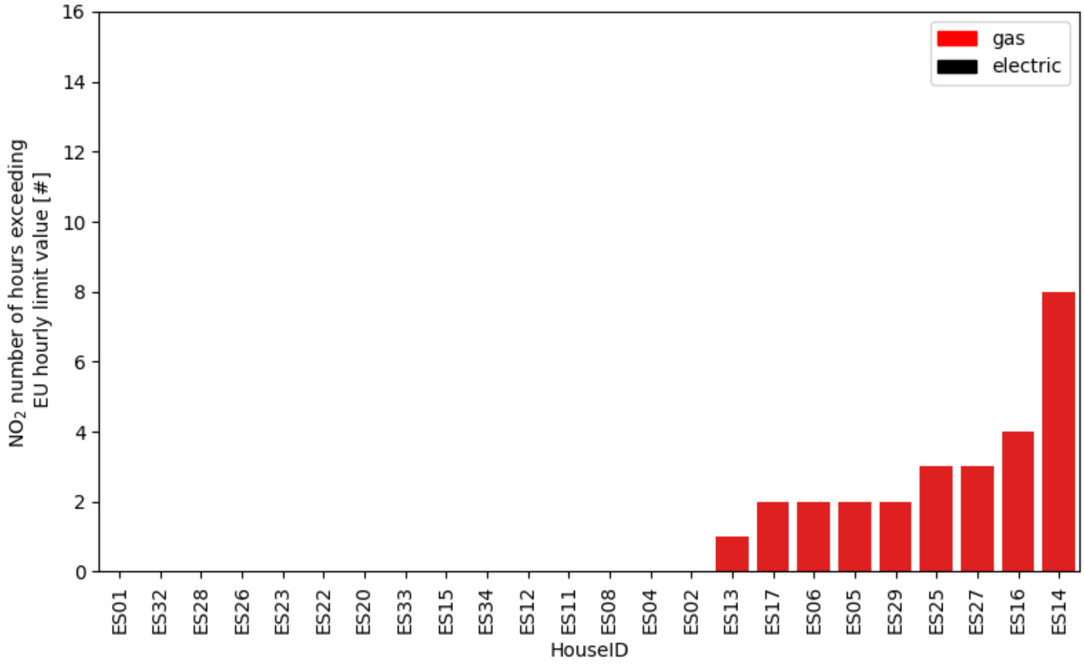


Figure 5.26 number of **clock** hours that the EU outdoor NO_2 hourly limit value of 200 µg/m^3 has been exceeded during the measurement period.

5.3.4.2 Carbon Monoxide (CO)

Table 5.20 lists the exceedance of the WHO guideline values and EU CO limit value in the kitchen during the 13 days measurement period based on the active sensor results. In case of cooking on gas one household (ES29) exceeded the WHO daily limit. For this household most but not all of the CO peaks aligned with cooking activities measured with the ibutton temperature sensors on the gas hob. Some of the peaks may correspond with cleaning activities or alcohol consumption.

Table 5.20: percentage of kitchens with CO concentrations above WHO guideline and EU limit values.

CO Limit values	% of households above limit value	
	Electric cooking	Cooking on gas
WHO daily guideline value of 4 mg/m^3	0	9
WHO/EU 8 h limit of 10 mg/m^3	0	0
WHO 1h guideline value of 35 mg/m^3	0	0

5.3.4.3 Fine Particulate matter ($PM_{2.5}$)

Table 5.21 lists the exceedance of the daily WHO $PM_{2.5}$ guideline values in the kitchen during the 13 days measurement period. Figure 5.27 shows the distribution of the exceedance days, the cooking method is indicated by the colour of the bars

Table 5.21: percentage of kitchens with $PM_{2.5}$ concentrations above WHO guideline value.

$PM_{2,5}$ Limit values	% of households above limit value	
	Electric cooking	Cooking on gas
WHO daily guideline value 15 µg/m³	69	92

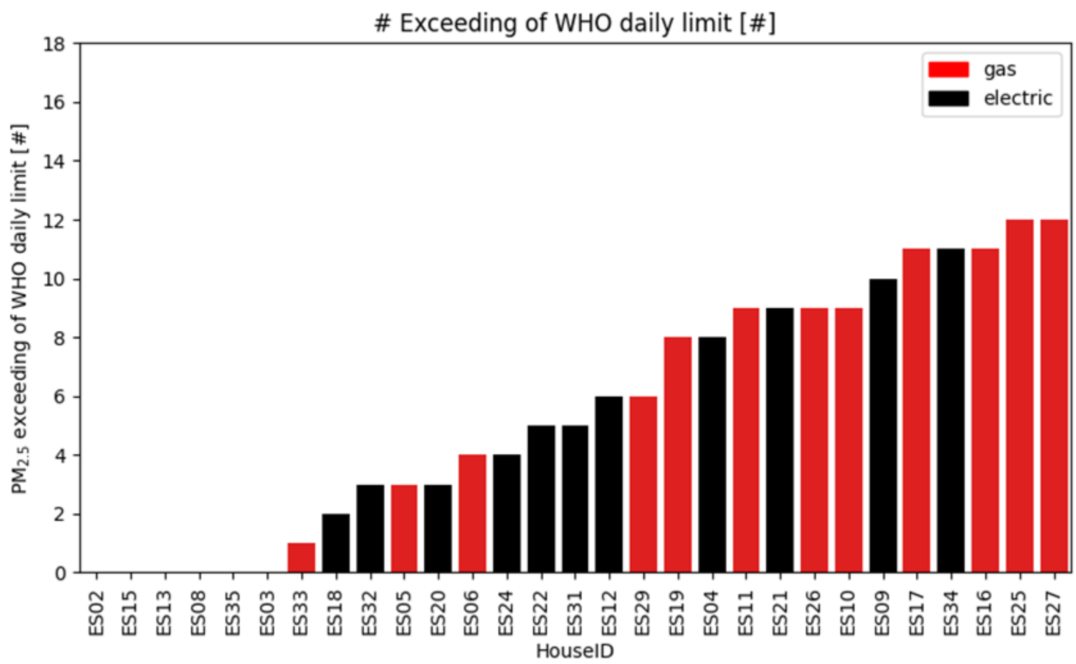


Figure 5.27 number of days that the $PM_{2.5}$ daily guideline value of 15 µg/m³ has been exceeded during the measurement period.

5.4 France

5.4.1 Summary

Measurement results regarding to 24 French households cooking on gas and 11 households cooking electric have been obtained. Cooking on gas clearly led to significant deterioration of the indoor air quality with regard to NO_2:

- The households cooking on gas have a significant ($p < 0.05$) higher nitrogen dioxide (NO_2) concentration in their kitchen than households cooking with electric cooking appliances.
- The WHO daily guideline value for nitrogen dioxide was exceeded in 53% of the households cooking on gas. For electric cooking no exceedances occurred.
- The WHO hourly guideline value for NO_2 was exceeded in 29% of the houses cooking on gas and not in any house cooking electric.
- The EU hourly limit value for NO_2 in ambient air was exceeded in 29% of the investigated houses cooking on gas, while in houses cooking electric no exceedances have been registered. Based on the number of exceedance hours during the measurement period it is likely that for most of these houses the hourly EU limit value is exceeded more than 18 hours per year.

With regard to carbon monoxide (CO) no significant difference between houses cooking on gas and cooking electric could be distinguished. The mean values are almost identical. In none of the households exceeding of CO guideline and limit values occurred.

Also for fine particulate matter ($PM_{2.5}$) no significant concentration difference between houses cooking on gas and cooking electric could be distinguished. Of the investigated houses cooking electric 89% exceeded the WHO daily guideline value for fine particulate matter ($PM_{2.5}$). Of the houses cooking on gas 83% exceeded this guideline value.

5.4.2 Household Environmental Conditions

5.4.2.1 Estimated hob use

Based on the iButton temperature readings, the hob and oven cooking time per day have been estimated, see Figure 5.28. Only FR10 and FR18 use a gas oven, the other ovens are electric.

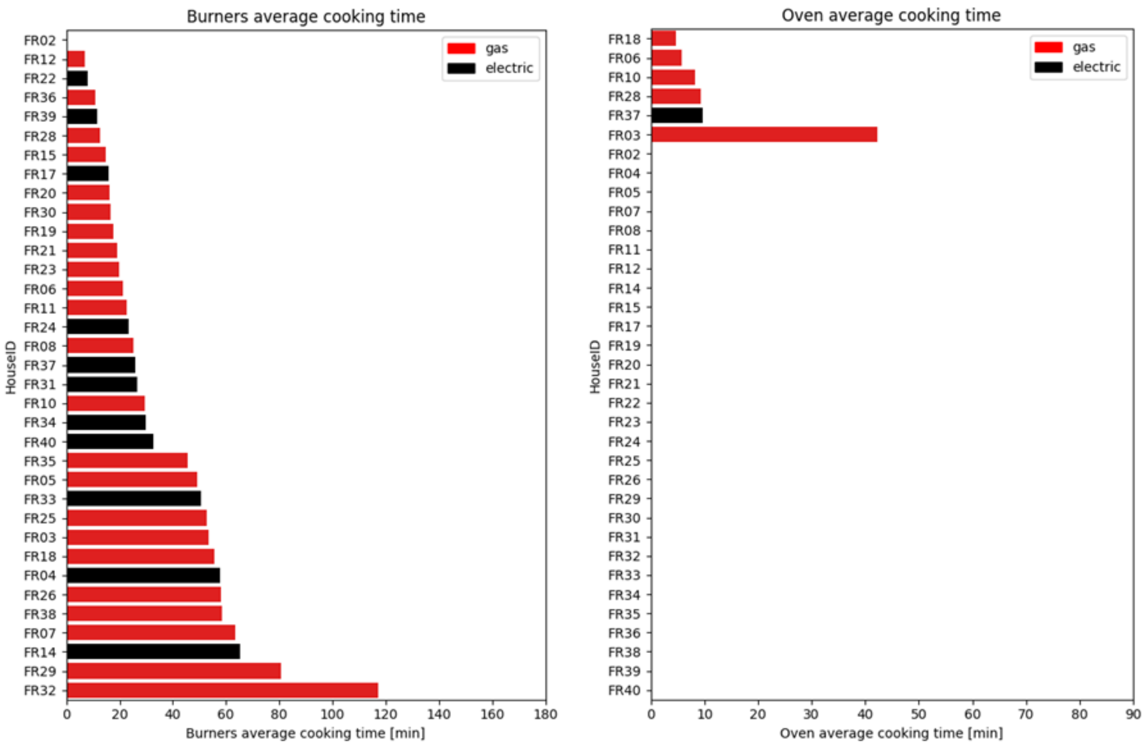


Figure 5.28 Estimated hob and oven use for each participating household.

5.4.2.2 Kitchen estimated ventilation rate

Table 5.22 and Figure 5.29 list the estimated ventilation rate in the kitchen/living room.

Table 5.22: overview of estimated ventilation flow in kitchen and or living room, number of measurements, arithmetic mean, geometric mean and geometric standard deviation.

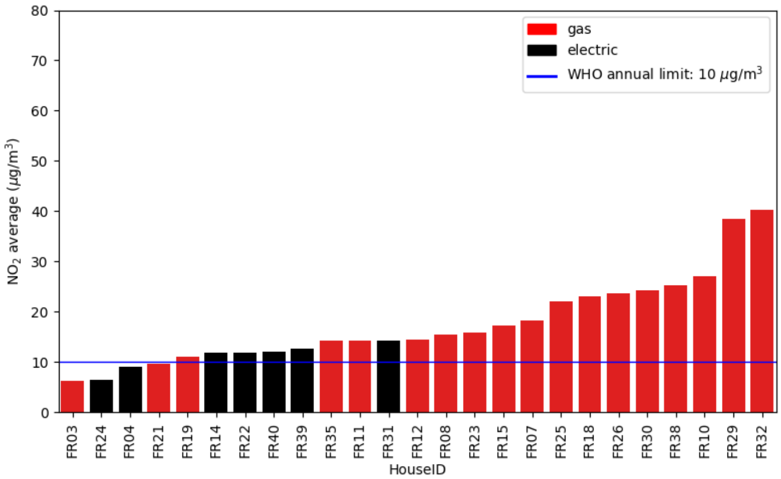
	n	mean	median	mean SD
Ventilation rate [ACH]	31	0.34	0.33	0.16

Figure 5.29 calculated median ventilation rate for each participating household.

5.4.3 Pollutant concentrations

5.4.3.1 Nitrogen Dioxide (NO_2)

Figure 5.30 and Table 5.23 list the mean NO_2 concentrations measured by the active and passive sensors. For illustration also the WHO annual guideline value of 10 µg/m^3 is indicated as blue line in the graphs. A direct comparison with the annual guideline is not possible as we have only measured during 13 days and the expectation based on literature data[9] is that during summer the indoor NO_2 concentration is lower than during the heating season.



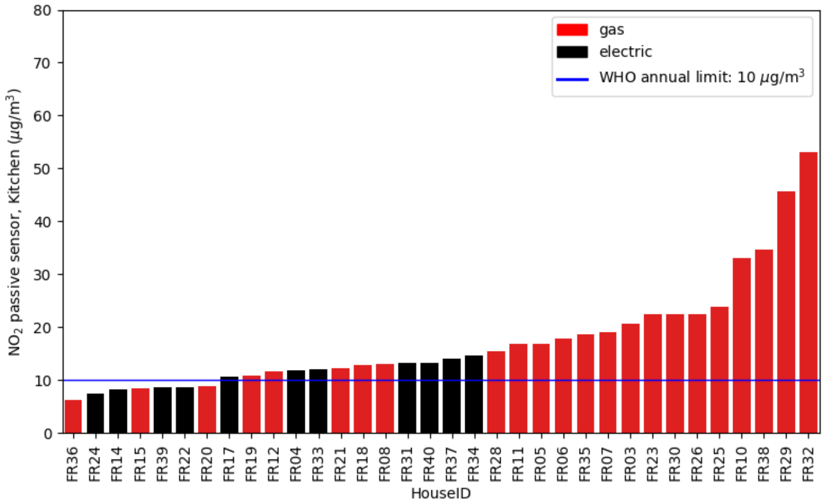


Figure 5.30 average NO_2 concentration in the kitchen per household measured with active (upper graph) and passive (lower graph) samplers (households ordered by average concentration). The red line indicates the WHO annual limit value of 10 µg/m³.

Table 5.23: average NO_2 concentration (incl. standard deviation SD and number of measurements n) in the kitchen, living room, bedroom and outdoor for households with electric cooking and with cooking on gas, including the p-value.

NO_2 in µg/m³	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen – active sensor	7	11.2	2.6	18	20.1	9.0	0.001
Kitchen - passive sensor	11	11.2	2.6	23	20.3	11.6	0.001
Living room - passive sensor	11	11.1	3.1	23	18.7	8.8	0.001
Bedroom - passive sensor	11	10.3	2.8	23	15.4	10.3	0.035
Outdoor - passive sensor	11	13.3	5.9	22	13.3	5.8	0.983

**significant, p-value < 0.05*

According Table 5.23 the concentration increases due to cooking on gas compared to electric cooking are for the kitchen active and passive sensor 8.9 and 9.1 µg/m³ respectively. For the living room the concentration increase due to cooking on gas is 7.6 μg/m³. For the bedroom an increase of 5.1 μg/m³ has been found.

5.4.3.2 Carbon Monoxide (CO)

Figure 5.31 and Table 5.24 list the average carbon monoxide (CO) concentration in the kitchen measured with active samplers. In Figure 5.31 the cooking method is indicated by the colour of the bars.

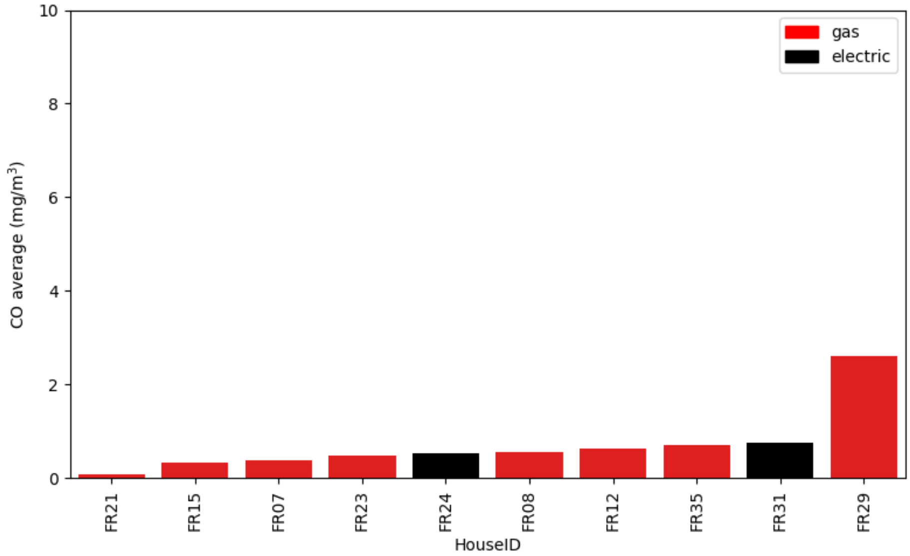


Figure 5.31 average CO concentration in the kitchen per household measured with active samplers (households ordered by average concentration).

Table 5.24: average value and highest 1-h value of CO concentration measurement in the kitchen, number of measurements n and standard deviation SD for households with electric cooking and with cooking on gas, including the p-value. Mean and standard deviation values are in mg/m³.

CO in mg/m³	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen – mean value	2	0.64	0.17	8	0.73	0.78	0.785
Kitchen - highest 1 h value	2	4.78	2.02	8	5.02	3.99	0.913

** significant, p-value < 0.05*

With regard to CO there is no significant concentration difference in the investigated houses cooking on gas or electric.

5.4.3.3 Fine Particulate Matter ($PM_{2.5}$)

Figure 5.32 and Table 5.25 list the $PM_{2.5}$ concentration in the kitchen. In Figure 5.5 the cooking method is indicated by the colour of the bars.

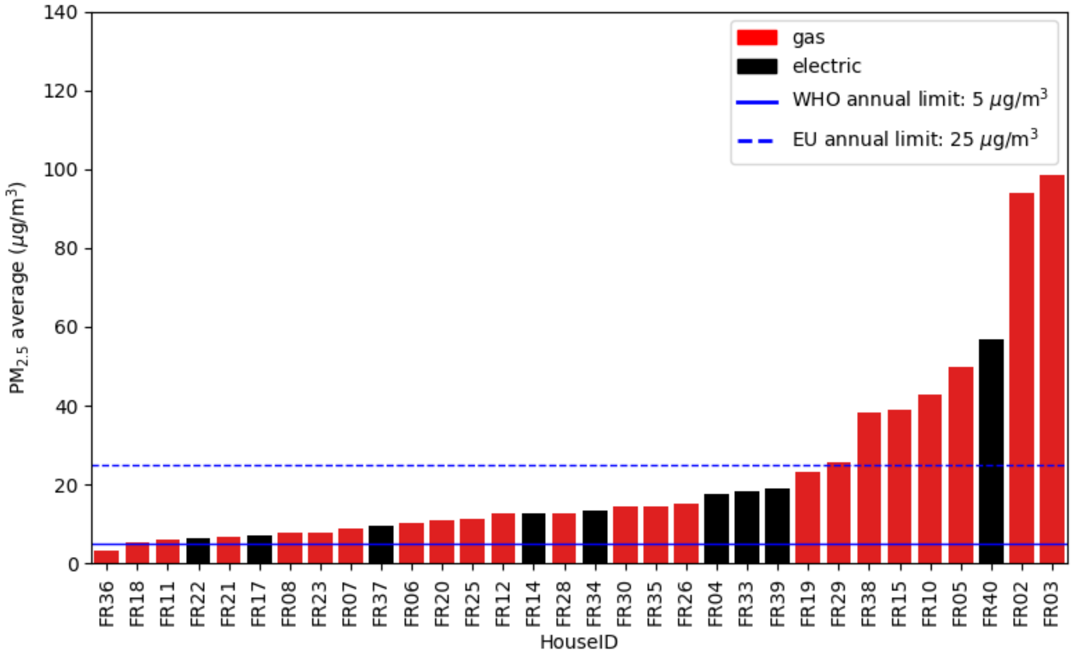


Figure 5.32 average $PM_{2.5}$ concentration in the kitchen per household (households ordered by average concentration).

Table 5.25: average $PM_{2.5}$ concentration in kitchen, number of measurements n and standard deviation SD for households with electric cooking and with cooking on gas, including the p-value.

$PM_{2.5}$ in µg/m³	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen	9	18.0	15.3	23	24.3	26.2	0.400

** significant, p-value < 0.05*

5.4.4 Comparison with limit and guideline values

5.4.4.1 Nitrogen Dioxide (NO_2)

Table 5.26 lists the exceedance of the daily WHO guideline and EU NO_2 limit values in the kitchen during the 13 days measurement period based on the active sensor results. In 53% of the houses cooking on gas the WHO daily guideline value is exceeded whereas in none of the houses cooking electric was the case.
The WHO hourly guideline value / EU hourly limit is exceeded in 29% of the French participants cooking on gas and not in any house cooking electric.

Table 5.26: percentage of kitchens with NO_2 concentration above the WHO daily limit value and estimated percentage of kitchens above the WHO guideline and the EU NO_2 limit values based on **active sensor** results.

NO_2 Limit values	% of households above limit value	
	Electric cooking	Cooking on gas
WHO daily guideline value 25 µg/m³	0	53
WHO hourly guideline value 200 µg/m³	0	29
>18 hours above EU hourly limit 200 µg/m³	0	29

**Extrapolation of 13 days of measurement data to yearly exceedance*

Figure 5.33 shows the distribution of days that the NO_2 concentration during the measurement period is above the WHO daily guideline value. Figure 5.34 and Figure 5.35 give respectively the number of hours and the number of clock hours that the NO_2 concentration during the measurement period is above the WHO guideline value / EU limit value of 200 µg/m³.

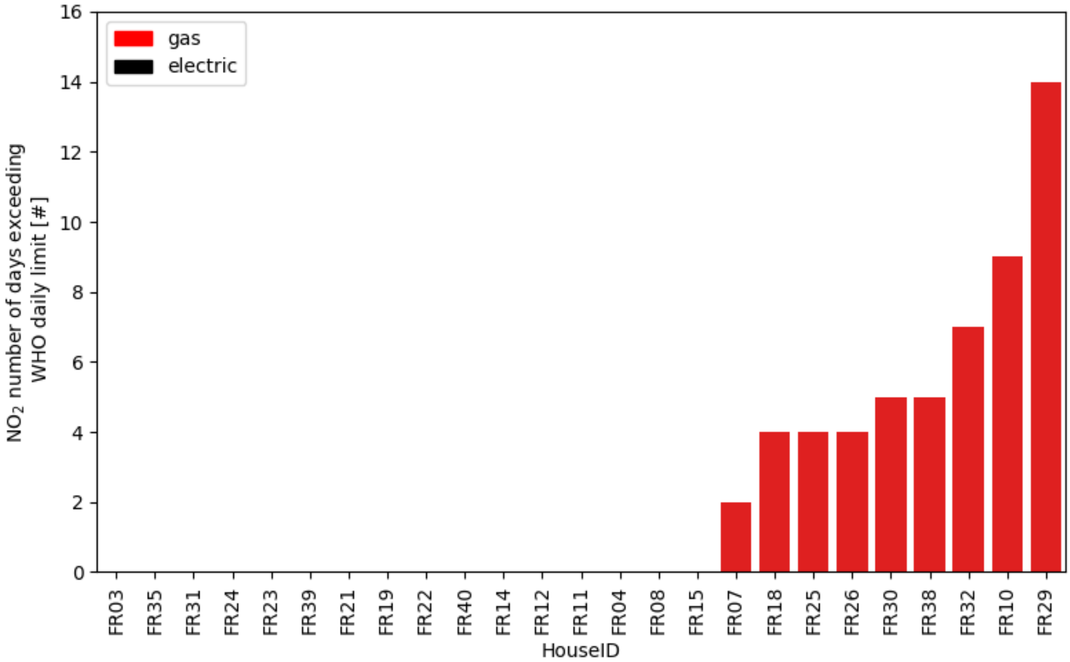


Figure 5.33 number of days that the WHO NO_2 daily limit value of 25 µg/m³ has been exceeded during the measurement period.

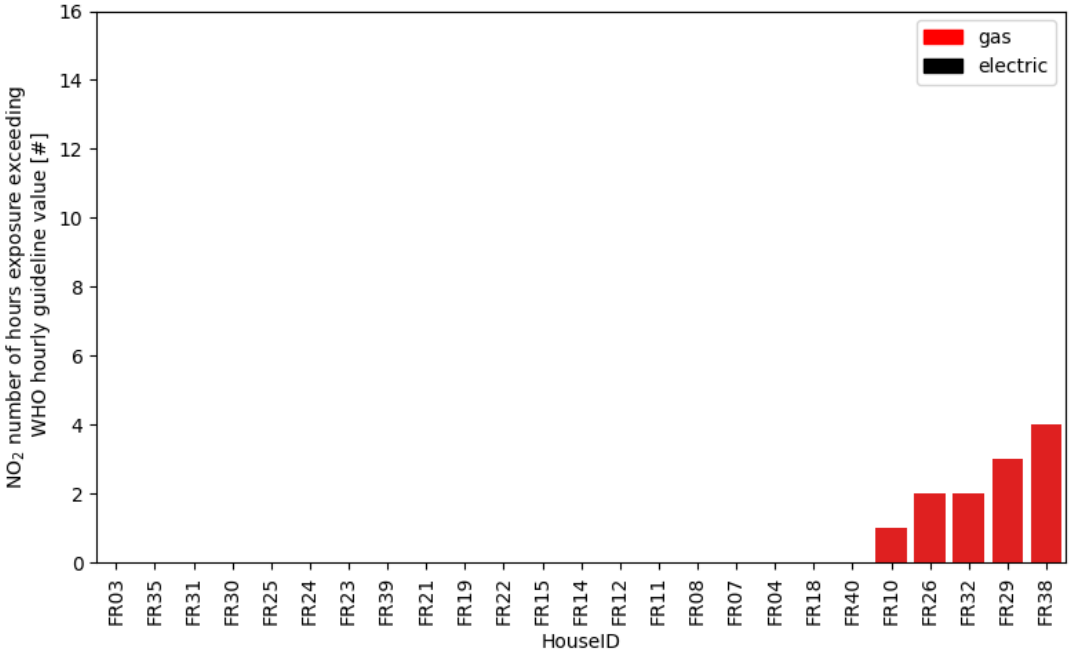


Figure 5.34 number of hours that the WHO NO_2 hourly guideline value of 200 μg/m^3 has been exceeded during the measurement period.

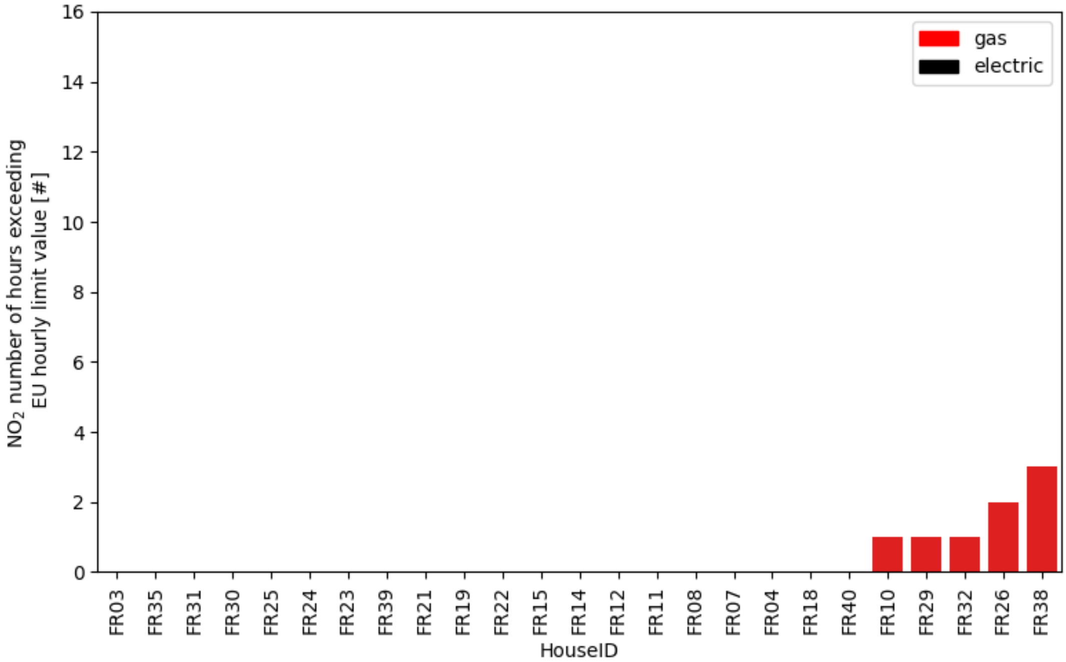


Figure 5.35 number of **clock** hours that the EU outdoor NO_2 hourly limit value of 200 μg/m^3 has been exceeded during the measurement period.

5.4.4.2 Carbon Monoxide (CO)

Table 5.27 lists the exceedance of the WHO guideline values and EU CO limit value in the kitchen during the 13 days measurement period based on the active sensor results.

Table 5.27: percentage of kitchens with CO concentrations above WHO guideline and EU limit values.

CO Limit values	% of households above limit value	
	Electric cooking	Cooking on gas
WHO daily guideline value of 4 mg/m^3	0	0
WHO/EU 8 h limit of 10 mg/m^3	0	0
WHO 1h guideline value of 35 mg/m^3	0	0

5.4.4.3 Fine Particulate matter ($PM_{2.5}$)

Table 5.28 lists the exceedance of the daily WHO $PM_{2.5}$ guideline values in the kitchen during the 13 days measurement period. Figure 5.36 shows the distribution of the exceedance days, the cooking method is indicated by the colour of the bars

Table 5.28: percentage of kitchens with $PM_{2.5}$ concentrations above WHO guideline value.

$PM_{2,5}$ Limit values	% of households above limit value	
	Electric cooking	Cooking on gas
WHO daily guideline value 15 µg/m^3	89	83

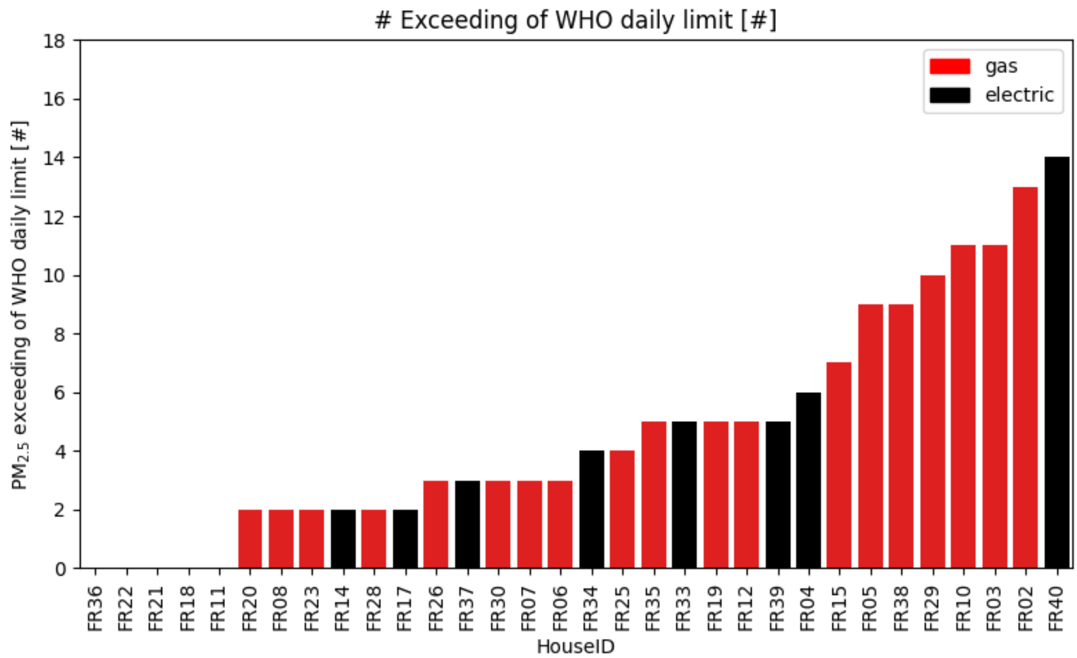


Figure 5.36 number of days that the $PM_{2.5}$ daily guideline value of 15 µg/m^3 has been exceeded during the measurement period.

5.5 Slovakia

5.5.1 Summary

Measurement results regarding to 30 households cooking on gas and 6 households cooking electric have been obtained. Cooking on gas clearly led to significant deterioration of the indoor air quality with regard to NO_2:

- The households cooking on gas have a significant ($p < 0.05$) higher nitrogen dioxide (NO_2) concentration in their kitchen than households cooking with electric cooking appliances.
- The WHO daily guideline value for nitrogen dioxide was exceeded in 44% of the households cooking on gas. For electric cooking no exceedances occurred.
- The WHO hourly guideline value for NO_2 was exceeded in 22% of the houses cooking on gas and not in any house cooking electric.
- The EU hourly limit value for NO_2 in ambient air was exceeded in 15% of the investigated houses cooking on gas, while in houses cooking electric no exceedances have been registered. Based on the number of exceedance hours during the measurement period it is likely that for most of these houses the hourly EU limit value is exceeded more than 18 hours per year.

With regard to carbon monoxide (CO), participants cooking on gas had a significant higher concentration then those cooking electric. However, in none of the households exceeding of CO guideline and limit values occurred.

For fine particulate matter ($PM_{2.5}$) no significant concentration difference between houses cooking on gas and cooking electric could be distinguished. Of the investigated houses cooking electric 100% exceeded the WHO daily guideline value for fine particulate matter ($PM_{2.5}$). Of the houses cooking on gas 76% exceeded this guideline value.

5.5.2 Household Environmental Conditions

5.5.2.1 Estimated hob use

Based on the iButton temperature readings, the hob and oven cooking time per day have been estimated, see Figure 5.37.

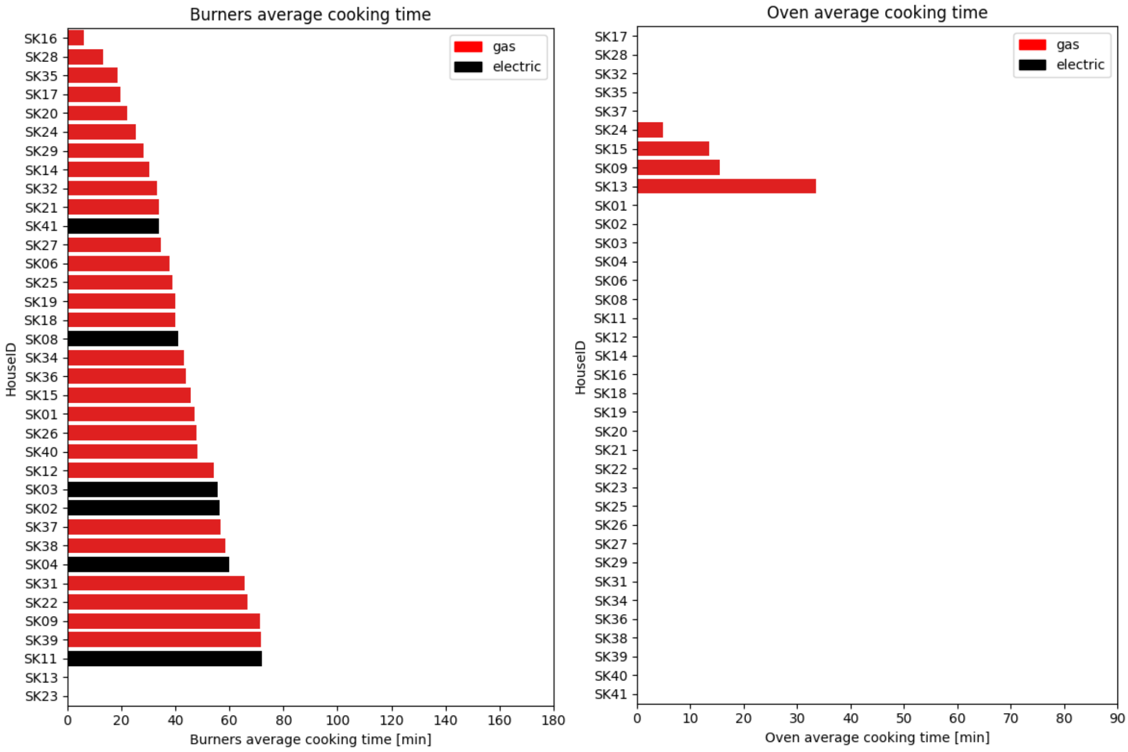


Figure 5.37 Estimated hob and oven use for each participating household.

5.5.2.2 Kitchen estimated ventilation rate

Table 5.29 and Figure 5.38 list the estimated ventilation rate in the kitchen/living room.

Table 5.29: overview of estimated ventilation flow in kitchen and or living room, number of measurements, arithmetic mean, geometric mean and geometric standard deviation.

	n	mean	median	mean SD
Ventilation rate [ACH]	29	0.2	0.18	0.16

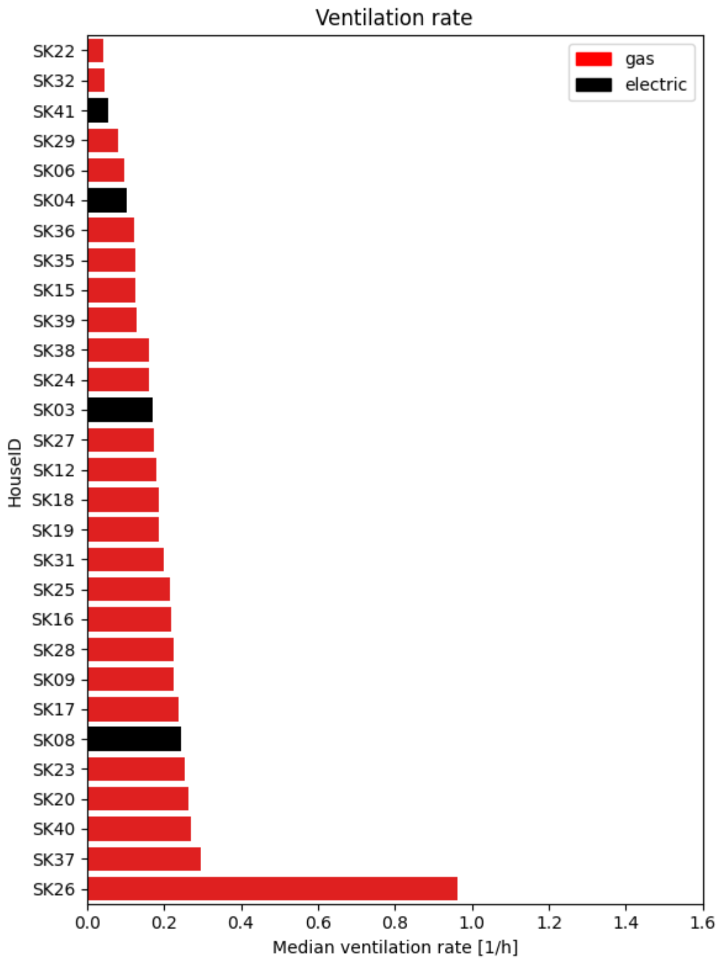


Figure 5.38 calculated median ventilation rate for each participating household.

5.5.3 Pollutant concentrations

5.5.3.1 Nitrogen Dioxide (NO_2)

Figure 5.39 and Table 5.30 list the mean NO_2 concentrations measured by the active and passive sensors. For illustration in Figure 5.39 also the WHO annual guideline value of 10 µg/m^3 is indicated as blue line in the graphs. A direct comparison with the annual guideline is not possible as we have only measured during 13 days and the expectation based on literature data[9] is that during summer the indoor NO_2 concentration is lower than during the heating season.

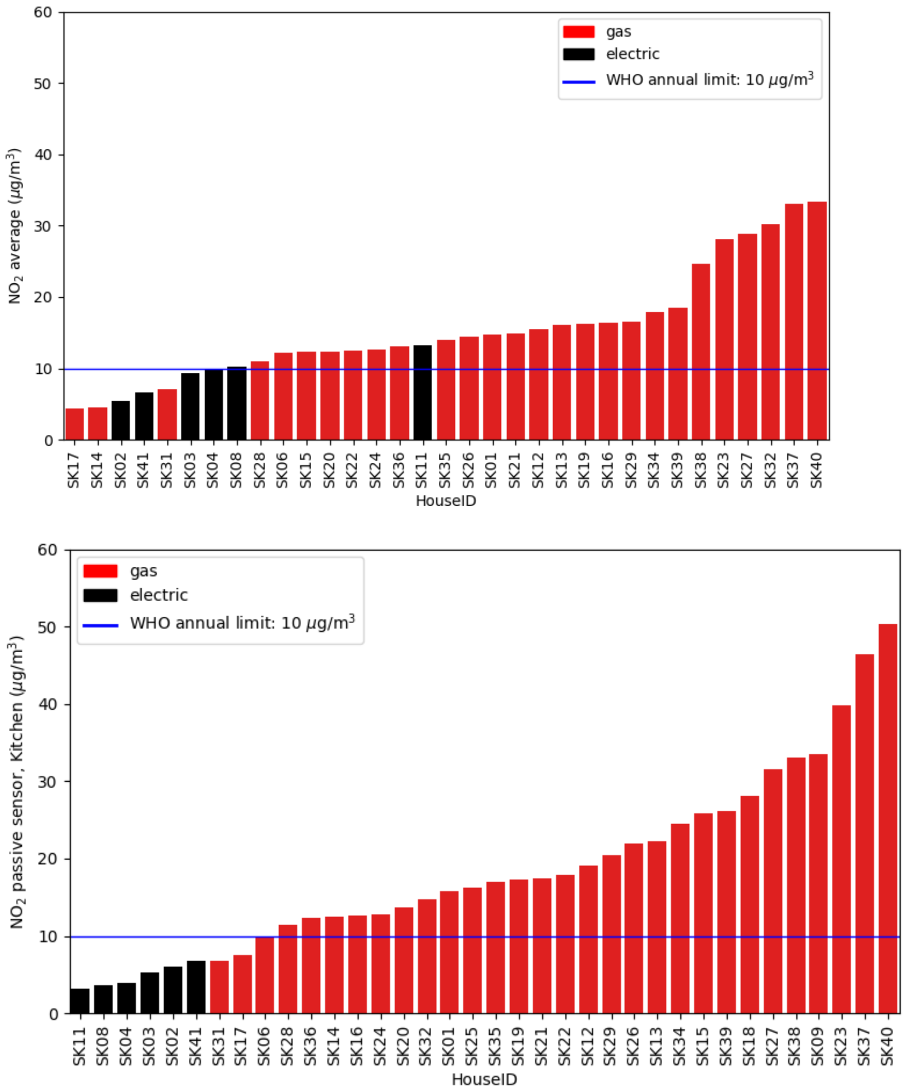


Figure 5.39 average NO_2 concentration in the kitchen per household measured with active (upper graph) and passive (lower graph) samplers (households ordered by average concentration). The red line indicates the WHO annual limit value of 10 μg/m³.

Table 5.30: average NO_2 concentration (incl. standard deviation SD and number of measurements n) in the kitchen, living room, bedroom and outdoor for households with electric cooking and with cooking on gas, including the p-value.

NO_2 in μg/m³	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen – active sensor	6	9.2	2.8	27	16.9	7.9	0.000
Kitchen - passive sensor	6	4.8	1.4	30	21.3	10.9	0.000
Living room - passive sensor	6	4.7	1.4	30	16.4	7.2	0.000
Bedroom - passive sensor	6	4.3	1.3	30	13.4	6.2	0.000
Outdoor - passive sensor	6	6.7	3.8	30	11.8	5.5	0.019

**significant, p-value < 0.05*

According Table 5.30 the concentration increases due to cooking on gas compared to electric cooking are for the kitchen active and passive sensor 7.7 and 16.5 µg/m^3 respectively. For the living room the concentration increase due to cooking on gas is 11.7 µg/m^3. For the bedroom an increase of 9.1 µg/m^3 has been found. Remarkably also for the outdoor concentration there was a significant difference between cooking on gas and on electric.

5.5.3.2 Carbon Monoxide (CO)

Figure 5.40 and Table 5.31 list the average carbon monoxide (CO) concentration in the kitchen measured with active samplers. In Figure 5.40 the cooking method is indicated by the colour of the bars.

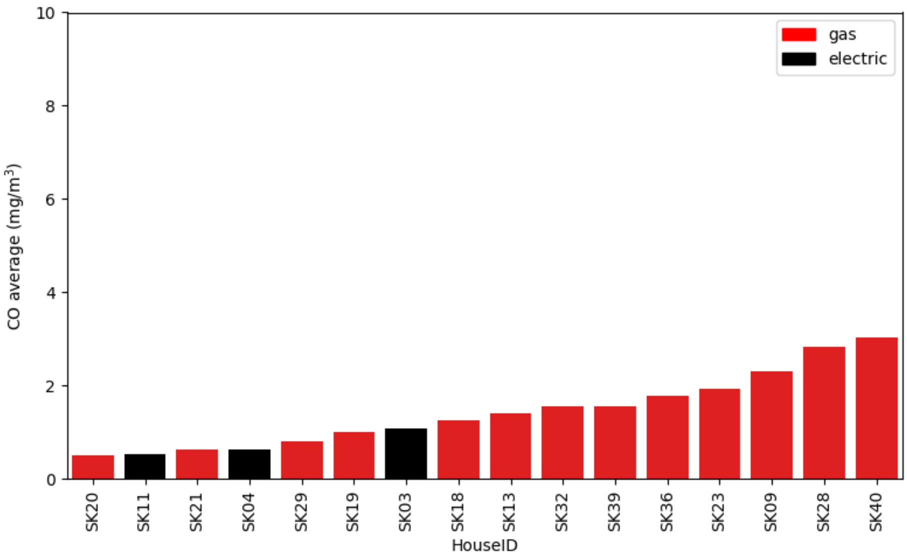


Figure 5.40 average CO concentration in the kitchen per household measured with active samplers (households ordered by average concentration).

Table 5.31: average value and highest 1-h value of CO concentration measurement in the kitchen, number of measurements n and standard deviation SD for households with electric cooking and with cooking on gas, including the p-value. Mean and standard deviation values are in mg/m^3.

CO in mg/m^3	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen – mean value	3	0.75	0.29	13	1.58	0.79	0.012
Kitchen - highest 1 h value	3	2.45	0.94	13	5.72	3.98	0.019

** significant, p-value < 0.05*

With regard to CO a significant concentration difference in the investigated houses between cooking on gas or electric has been found.

5.5.3.3 Fine Particulate Matter ($PM_{2.5}$)

Figure 5.41 and Table 5.32 list the $PM_{2.5}$ concentration in the kitchen. In Figure 5.41 the cooking method is indicated by the colour of the bars.

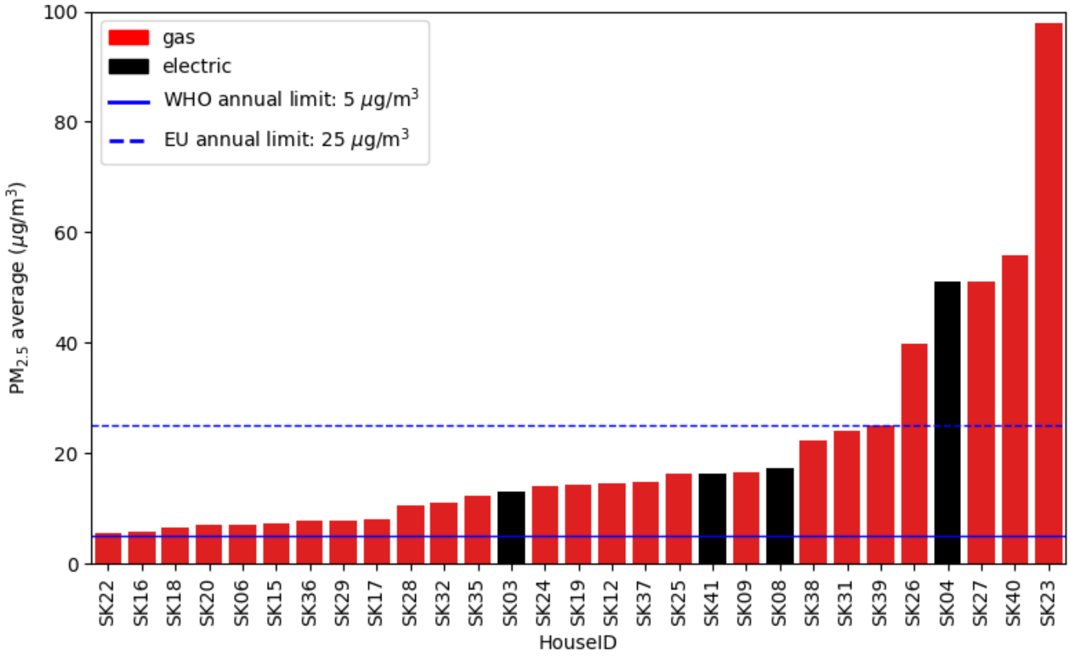


Figure 5.41 average $PM_{2.5}$ concentration in the kitchen per household (households ordered by average concentration).

Table 5.32: average $PM_{2.5}$ concentration in kitchen, number of measurements n and standard deviation SD for households with electric cooking and with cooking on gas, including the p-value.

$PM_{2.5}$ in μg/m³	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen	4	24.5	17.8	25	20.2	21.1	0.682

** significant, p-value < 0.05*

5.5.4 Comparison with limit and guideline values

5.5.4.1 Nitrogen Dioxide (NO_2)

Table 5.33 lists the exceedance of the daily WHO guideline and EU NO_2 limit values in the kitchen during the 13 days measurement period based on the active sensor results.

In 44% of the houses cooking on gas the WHO daily guideline value is exceeded whereas in none of the houses cooking electric was the case. The WHO hourly guideline values is exceeded in 22% of the participants houses cooking on gas and not in any house cooking electric.

The EU limit value exceedance is smaller than the WHO guideline value exceedance as the exceedance based on clock hours is smaller than the WHO guideline value exceedance which is based on exposure hours. See for more information paragraph 2.5.

Table 5.33: percentage of kitchens with NO_2 concentration above the WHO daily limit value and estimated percentage of kitchens above the WHO guideline and the EU NO_2 limit values based on **active sensor** results.

NO_2 Limit values	% of households above limit value	
	Electric cooking	Cooking on gas
WHO daily guideline value 25 µg/m^3	0	44
WHO hourly guideline value 200 µg/m^3	0	22
>18 hours above EU hourly limit 200 µg/m^3	0	15

**Extrapolation of 13 days of measurement data to yearly exceedance*

Figure 5.42 shows the distribution of days that the NO_2 concentration during the measurement period is above the WHO daily guideline value. Figure 5.43 and Figure 5.44 give respectively the number of hours and the number of clock hours that the NO_2 concentration during the measurement period is above the WHO guideline value / EU limit value of 200 µg/m^3.

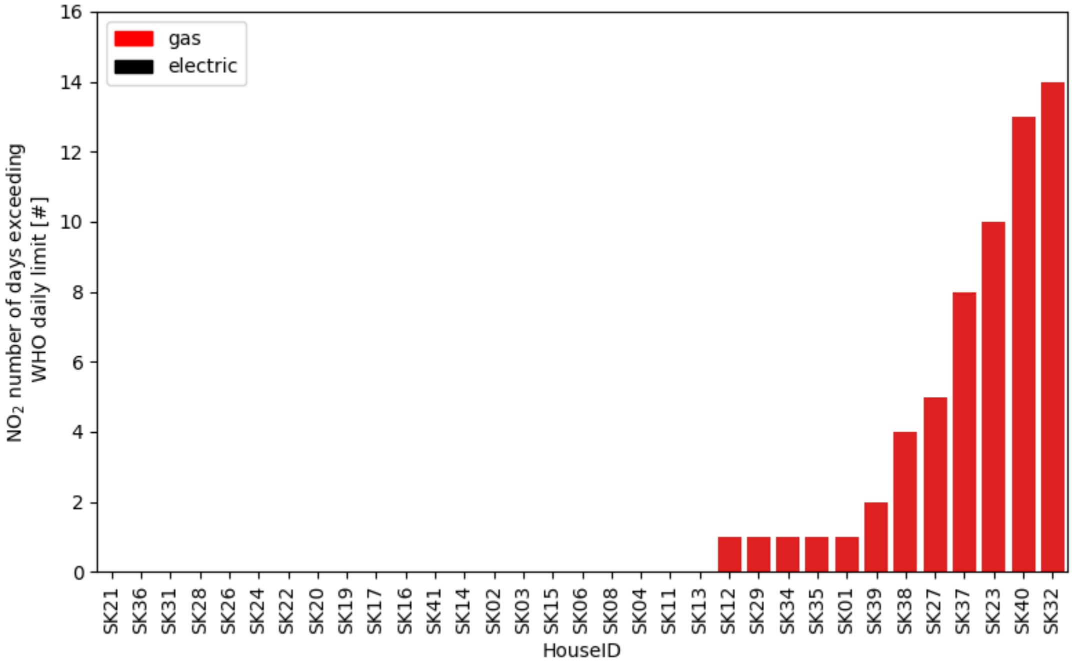


Figure 5.42 number of days that the WHO NO_2 daily limit value of 25 µg/m^3 has been exceeded during the measurement period.

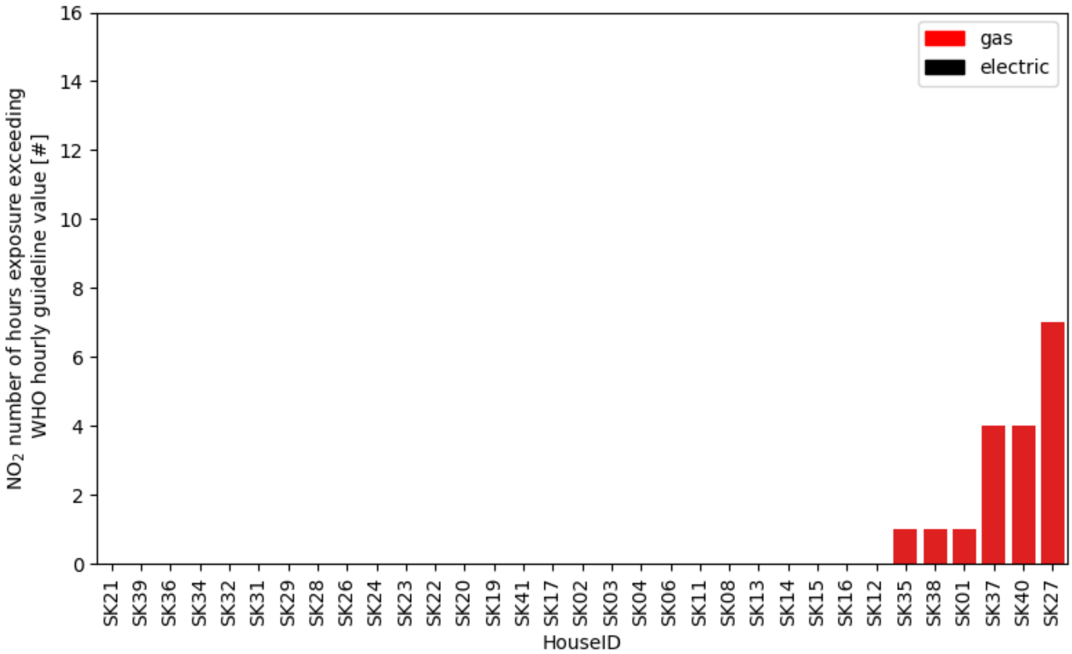


Figure 5.43 number of hours that the WHO NO_2 hourly guideline value of 200 µg/m^3 has been exceeded during the measurement period.

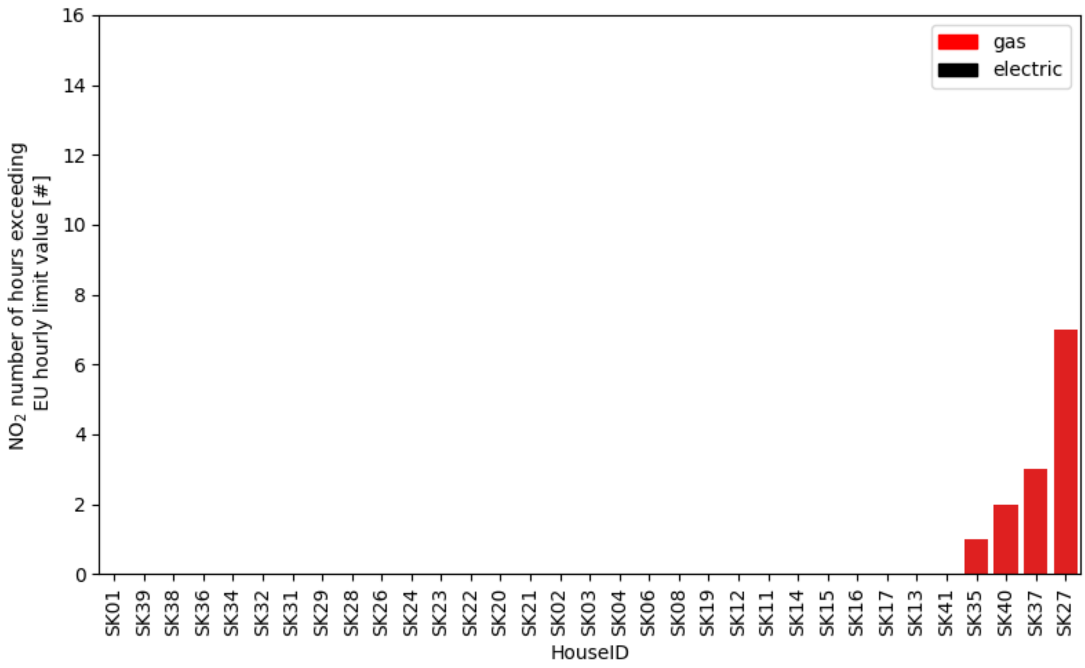


Figure 5.44 number of **clock** hours that the EU outdoor NO_2 hourly limit value of 200 µg/m^3 has been exceeded during the measurement period.

5.5.4.2 Carbon Monoxide (CO)

Table 5.34 lists the exceedance of the WHO guideline values and EU CO limit value in the kitchen during the 13 days measurement period based on the active sensor results. No exceedances have been registered.

Table 5.34: percentage of kitchens with CO concentrations above WHO guideline and EU limit values.

CO Limit values	% of households above limit value	
	Electric cooking	Cooking on gas
WHO daily limit of 4 mg/m^3	0	0
WHO/EU 8 h limit of 10 mg/m^3	0	0
WHO 1h limit of 35 mg/m^3	0	0

5.5.4.3 Fine Particulate matter ($PM_{2.5}$)

Table 5.35 lists the exceedance of the daily WHO $PM_{2.5}$ guideline values in the kitchen during the 13 days measurement period. Figure 5.45 shows the distribution of the exceedance days, the cooking method is indicated by the colour of the bars.

Table 5.35: percentage of kitchens with $PM_{2.5}$ concentrations above WHO guideline value.

$PM_{2,5}$ Limit values	% of households above limit value	
	Electric cooking	Cooking on gas
WHO daily guideline value 15 µg/m^3	100	76

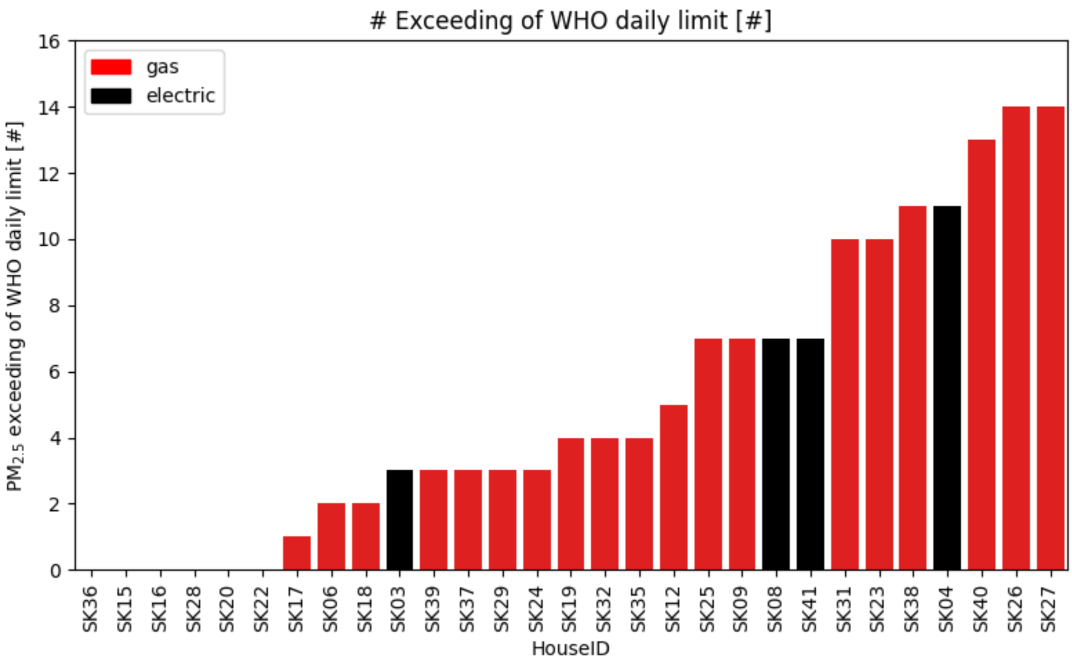


Figure 5.45 number of days that the $PM_{2.5}$ daily guideline value of 15 µg/m^3 has been exceeded during the measurement period.

5.6 UK

5.6.1 Summary

Measurement results regarding to 28 households cooking on gas and 7 households cooking electric have been obtained. Cooking on gas clearly led to significant deterioration of the indoor air quality with regard to NO_2:

- The households cooking on gas have a significant ($p < 0.05$) higher nitrogen dioxide (NO_2) concentration in their kitchen than households cooking with electric cooking appliances.
- The WHO daily guideline value for nitrogen dioxide was exceeded in 55% of the households cooking on gas. For electric cooking no exceedances occurred.
- The WHO hourly guideline value for NO_2 was exceeded in 25% of the houses cooking on gas and not in any house cooking electric.
- Also the UK/EU hourly limit value for NO_2 in ambient air was exceeded in 25% of the investigated houses cooking on gas, while in houses cooking electric no exceedances have been registered. Based on the number of exceedance hours during the measurement period it is likely that for most of these houses the hourly EU limit value is exceeded more than 18 hours per year.

With regard to carbon monoxide (CO) no significant difference between houses cooking on gas and those cooking electric could be distinguished. The mean values are almost identical. Further, in none of the households exceeding of CO guideline and limit values occurred.

Also for fine particulate matter ($PM_{2.5}$) no significant concentration difference between houses cooking on gas and cooking electric could be distinguished. Of the investigated houses cooking electric 85.7% exceeded the WHO daily guideline value for fine particulate matter ($PM_{2.5}$). Of the houses cooking on gas 68.2% exceeded this guideline value.

5.6.2 Household Environmental Conditions

5.6.2.1 Estimated hob use

Based on the iButton temperature readings, the hob and oven cooking time per day have been estimated, see Figure 5.46.

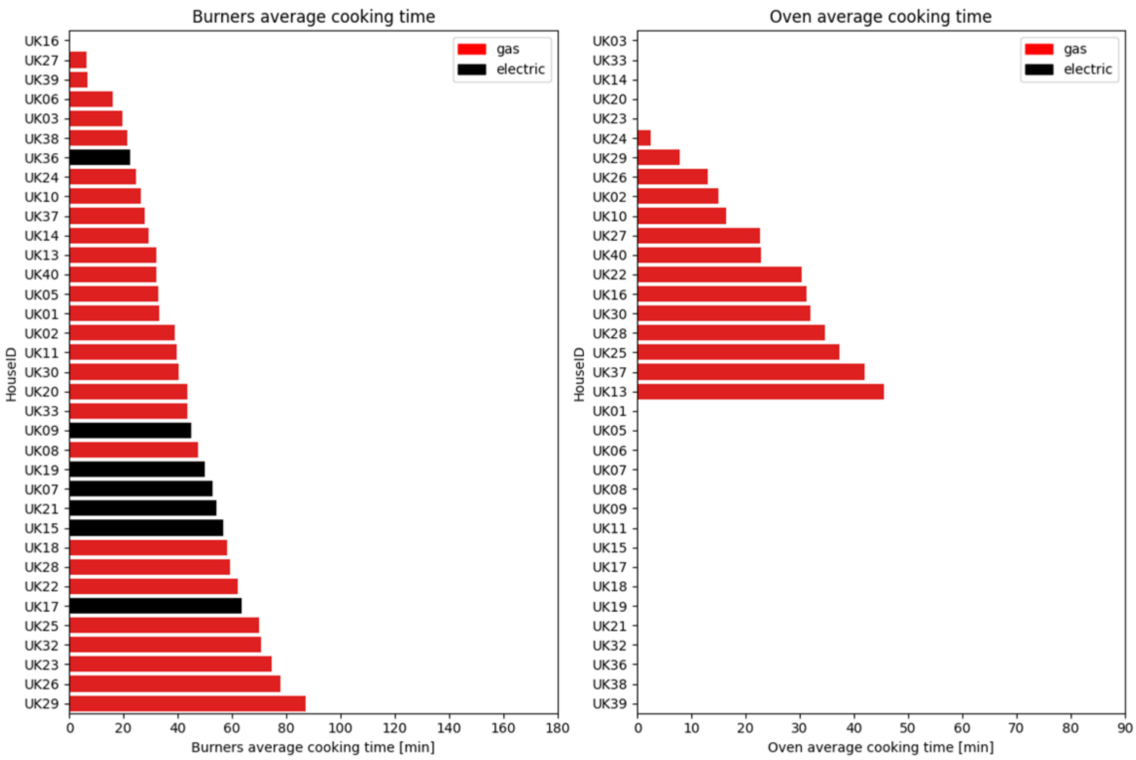


Figure 5.46 Estimated hob and oven use for each participating household.

5.6.2.2 Kitchen estimated ventilation rate

Table 5.36 and Figure 5.47 list the estimated ventilation rate in the kitchen/living room.

Table 5.36: overview of estimated ventilation flow in kitchen and or living room, number of measurements, arithmetic mean, geometric mean and geometric standard deviation.

	n	mean	median	mean SD
Ventilation rate [ACH]	29	0.43	0.39	0.24

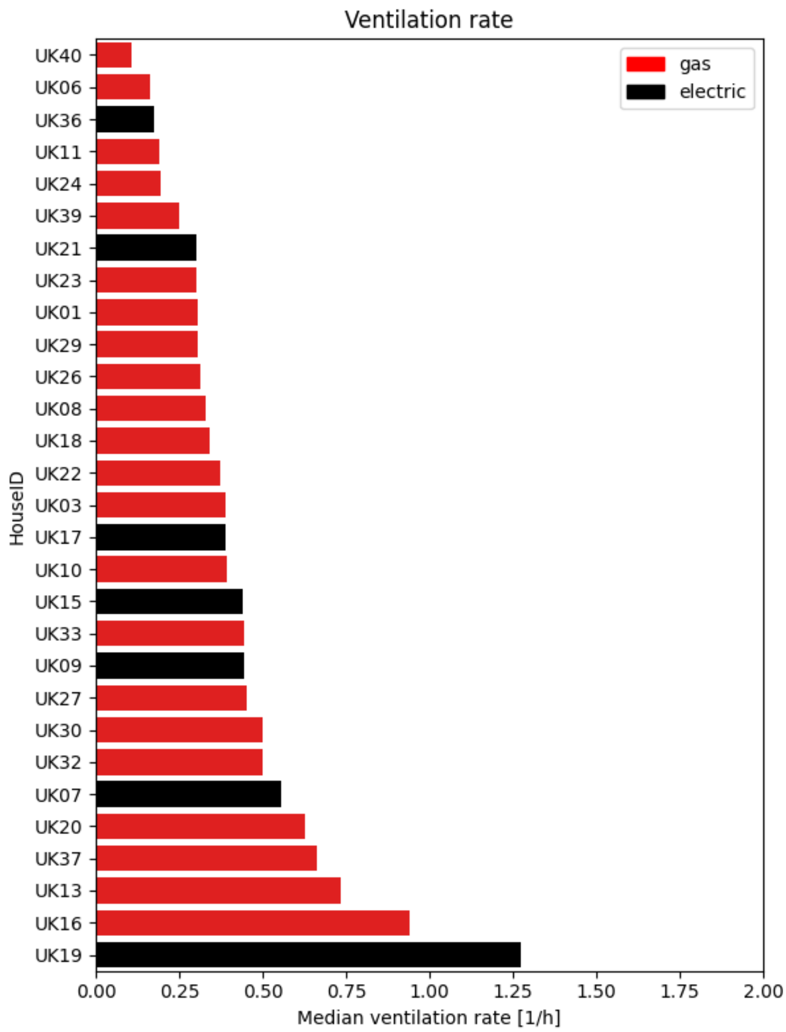
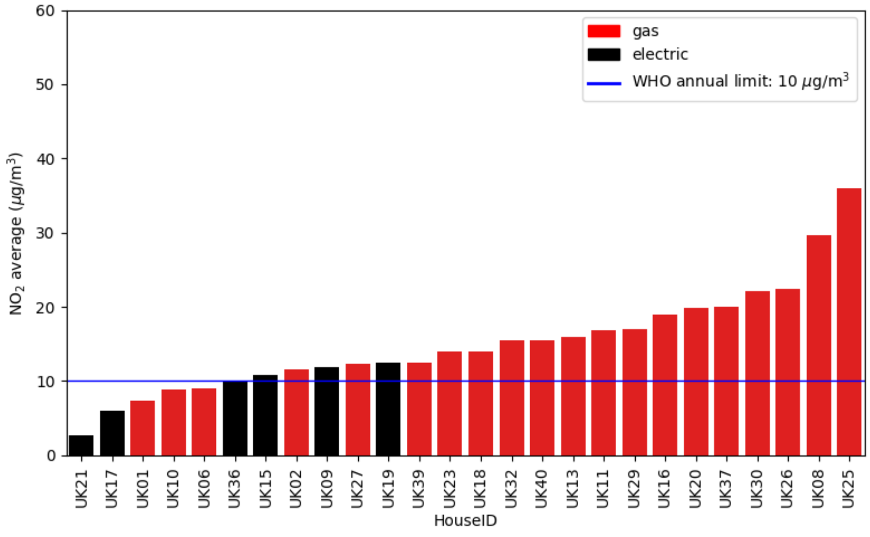


Figure 5.47 calculated median ventilation rate for each participating household.

5.6.3 Pollutant concentrations

5.6.3.1 Nitrogen Dioxide (NO_2)

Figure 5.48 and Table 5.37 list the mean NO_2 concentrations measured by the active and passive sensors. For illustration also the WHO annual guideline value of 10 µg/m^3 is indicated as blue line in the graphs. A direct comparison with the annual guideline is not possible as we have only measured during 13 days and the expectation based on literature data[9] is that during summer the indoor NO_2 concentration is lower than during the heating season.



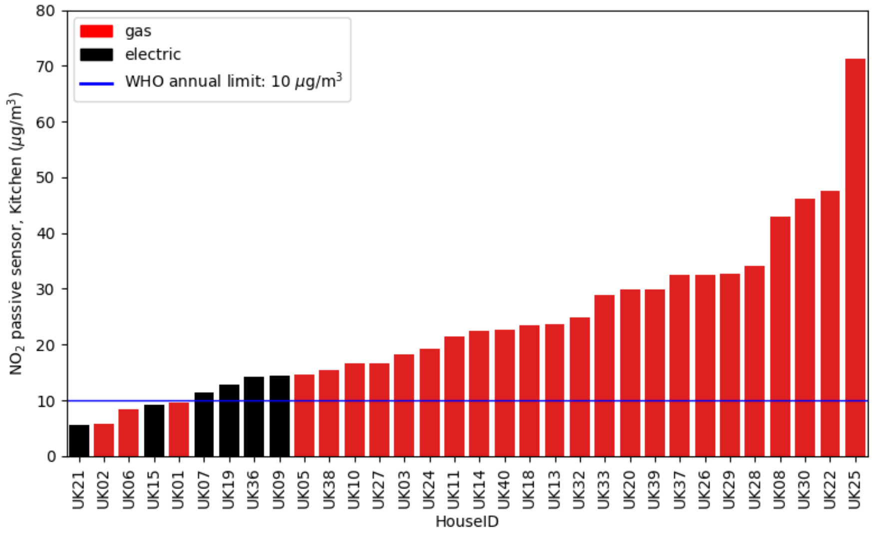


Figure 5.48 average NO_2 concentration in the kitchen per household measured with active (upper graph) and passive (lower graph) samplers (households ordered by average concentration). The red line indicates the WHO annual limit value of 10 µg/m³.

Table 5.37: average NO_2 concentration (incl. standard deviation SD and number of measurements n) in the kitchen, living room, bedroom and outdoor for households with electric cooking and with cooking on gas, including the p-value.

NO_2 in µg/m³	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen – active sensor	6	9.0	3.8	20	17.0	6.9	0.002
Kitchen - passive sensor	6	11.3	3.4	26	26.6	14.1	0.000
Living room - passive sensor	6	12.2	3.8	26	23.4	13.2	0.001
Bedroom - passive sensor	6	10.5	2.3	26	18.7	8.3	0.000
Outdoor - passive sensor	6	12.5	4.2	26	13.5	4.5	0.606

**significant, p-value < 0.05*

According Table 5.37 the concentration increases due to cooking on gas compared to electric cooking are for the kitchen active and passive sensor 8.0 and 15.3 µg/m^3 respectively. For the living room the concentration increase due to cooking on gas is 11.2 µg/m^3. For the bedroom an increase of 8.2 µg/m^3 has been found. The outdoor concentration for those cooking on electric and those cooking on gas were almost identical.

5.6.3.2 Carbon Monoxide (CO)

Figure 5.49 and Table 5.38 list the average carbon monoxide (CO) concentration in the kitchen measured with active samplers. In Figure 5.49 the cooking method is indicated by the colour of the bars.

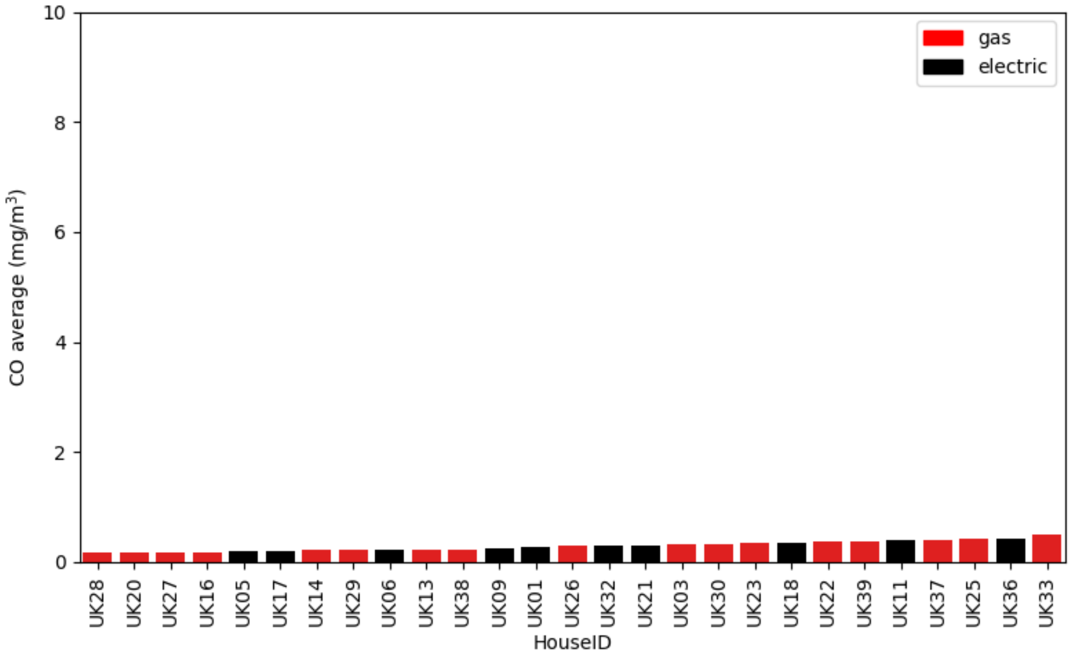


Figure 5.49 average CO concentration in the kitchen per household measured with active samplers (households ordered by average concentration).

Table 5.38: average value and highest 1-h value of CO concentration measurement in the kitchen, number of measurements n and standard deviation SD for households with electric cooking and with cooking on gas, including the p-value. Mean and standard deviation values are in mg/m^3.

CO in mg/m^3	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen – mean value	4	0.30	0.10	23	0.29	0.10	0.852
Kitchen - highest 1 h value	4	1.42	0.72	23	1.43	0.68	0.967

** significant, p-value < 0.05*

With regard to CO a significant concentration difference in the investigated houses between cooking on gas or electric has been found.

5.6.3.3 Fine Particulate Matter ($PM_{2.5}$)

Figure 5.50 and Table 5.39 list the $PM_{2.5}$ concentration in the kitchen. In Figure 5.50 the cooking method is indicated by the colour of the bars.

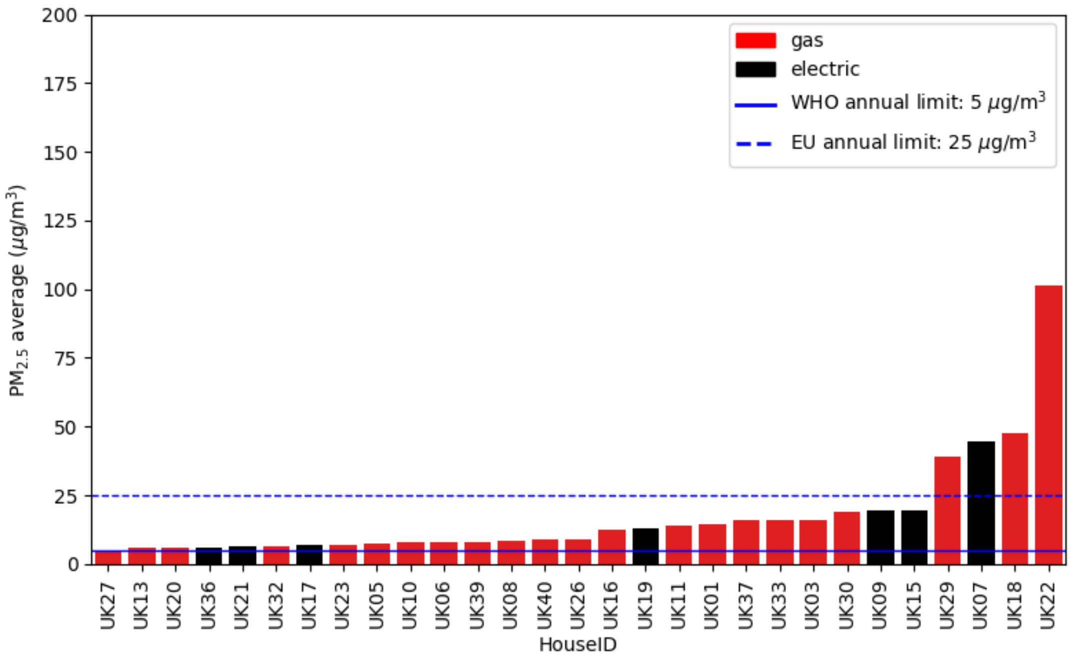


Figure 5.50 average $PM_{2.5}$ concentration in the kitchen per household (households ordered by average concentration).

Table 5.39: average $PM_{2.5}$ concentration in kitchen, number of measurements n and standard deviation SD for households with electric cooking and with cooking on gas, including the p-value.

$PM_{2.5}$ in μg/m³	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen	7	16.6	13.8	22	17.4	21.5	0.906

** significant, p-value < 0.05*

5.6.4 Comparison with limit and guideline values

5.6.4.1 Nitrogen Dioxide (NO_2)

Table 5.40 lists the exceedance of the daily WHO guideline and UK air quality standards regulations 2010 NO_2 limit values in the kitchen during the 13 days measurement period based on the active sensor results. The UK hourly limit value is the same as in the EU directive.

In 55% of the houses cooking on gas the WHO daily guideline value is exceeded whereas in none of the houses cooking electric was the case. The WHO and UK hourly guideline value is exceeded in 25% of the participants houses cooking on gas and not in any house cooking electric.

Table 5.40: percentage of kitchens with NO_2 concentration above the WHO daily limit value and estimated percentage of kitchens above the WHO guideline and the UK NO_2 limit values based on **active sensor** results.

NO_2 Limit values	% of households above limit value	
	Electric cooking	Cooking on gas
WHO daily guideline value 25 µg/m^3	0	55
WHO hourly guideline value 200 µg/m^3	0	25
>18 hours above UK hourly limit 200 µg/m^3	0	25

**Extrapolation of 13 days of measurement data to yearly exceedance*

Figure 5.51 shows the distribution of days that the NO_2 concentration during the measurement period is above the WHO daily guideline value. Figure 5.52 and Figure 5.53 give respectively the number of hours and the number of clock hours that the NO_2 concentration during the measurement period is above the WHO guideline value / UK limit value of 200 µg/m^3.

Based on the number of exceedance hours during the 13 day measurement period it is likely that in the houses in which the hourly UK limit value is exceeded, this exceedance will be more than 18 hours per year. Thus it can be assumed that the UK hourly limit value is also exceeded in 25% of the participants houses cooking on gas and not in any house cooking electric.

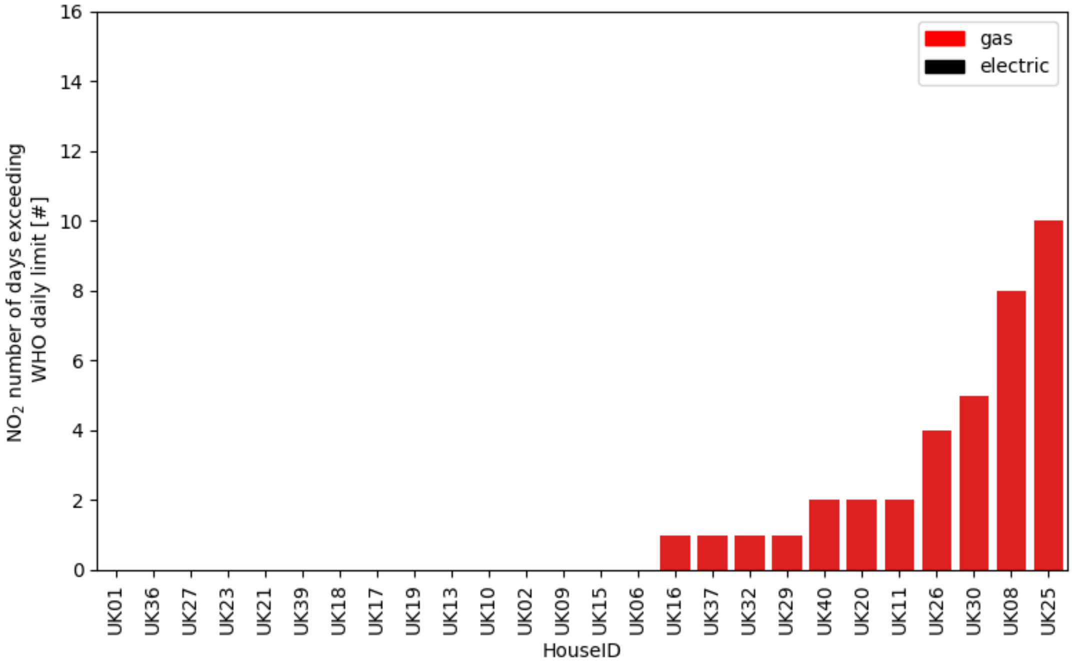


Figure 5.51 number of days that the WHO NO_2 daily limit value of 25 µg/m^3 has been exceeded during the measurement period.

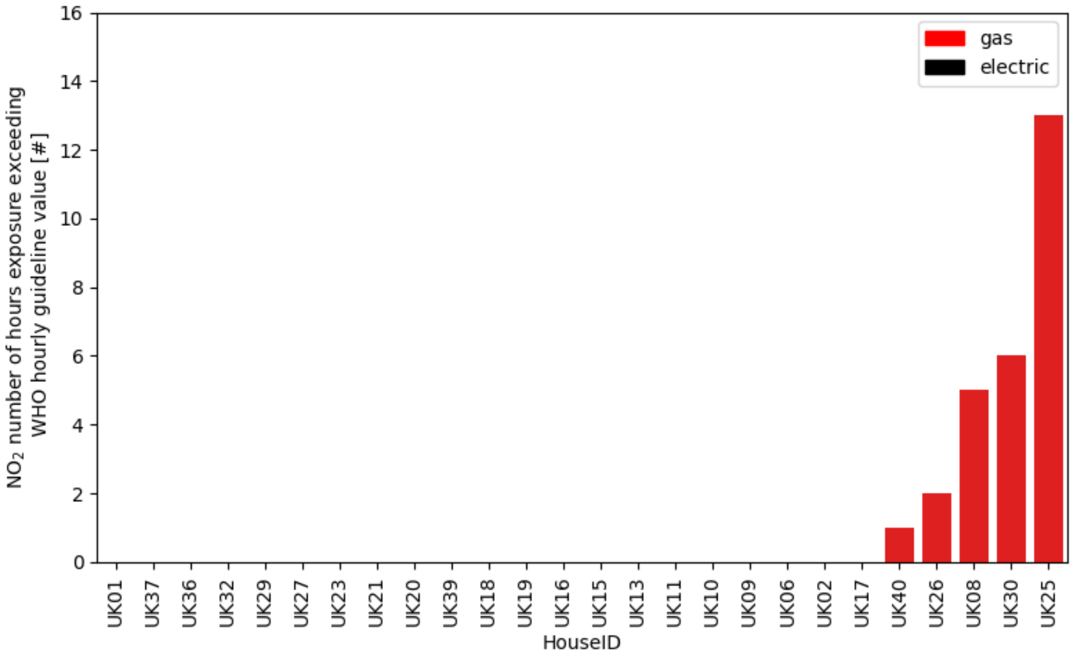


Figure 5.52 number of hours that the WHO NO_2 hourly guideline value of 200 µg/m^3 has been exceeded during the measurement period.

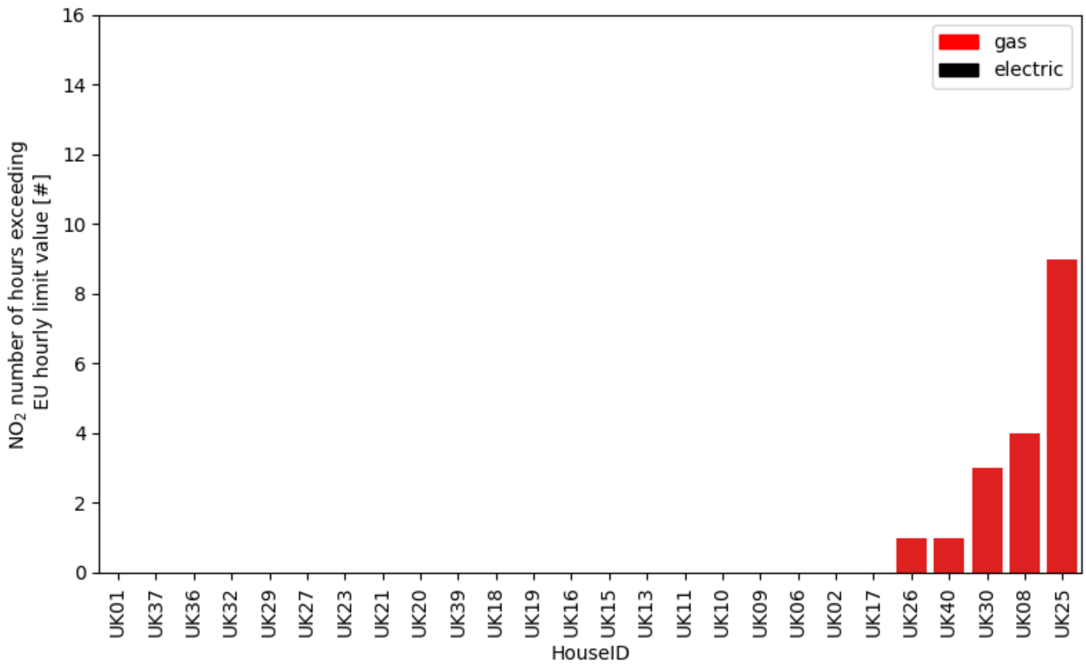


Figure 5.53 number of **clock** hours that the EU outdoor NO_2 hourly limit value of 200 µg/m^3 has been exceeded during the measurement period.

5.6.4.2 Carbon Monoxide (CO)

Table 5.41 lists the exceedance of the WHO guideline values and the UK air quality standards regulations 2010 CO limit value in the kitchen during the 13 days measurement period based on the active sensor results. The UK hourly limit value is the same as in the EU directive. No exceedances have been registered.

Table 5.41: percentage of kitchens with CO concentrations above WHO guideline and EU limit values.

CO Limit values	% of households above limit value	
	Electric cooking	Cooking on gas
WHO daily limit of 4 mg/m^3	0	0
WHO/EU 8 h limit of 10 mg/m^3	0	0
WHO 1h limit of 35 mg/m^3	0	0

5.6.4.3 Fine Particulate matter ($PM_{2.5}$)

Table 5.42 lists the exceedance of the daily WHO $PM_{2.5}$ guideline values in the kitchen during the 13 days measurement period. Figure 5.54 shows the distribution of the exceedance days, the cooking method is indicated by the colour of the bars.

Table 5.42: percentage of kitchens with $PM_{2.5}$ concentrations above WHO guideline value.

$PM_{2,5}$ Limit values	% of households above limit value	
	Electric cooking	Cooking on gas
WHO daily guideline value 15 µg/m^3	86	68

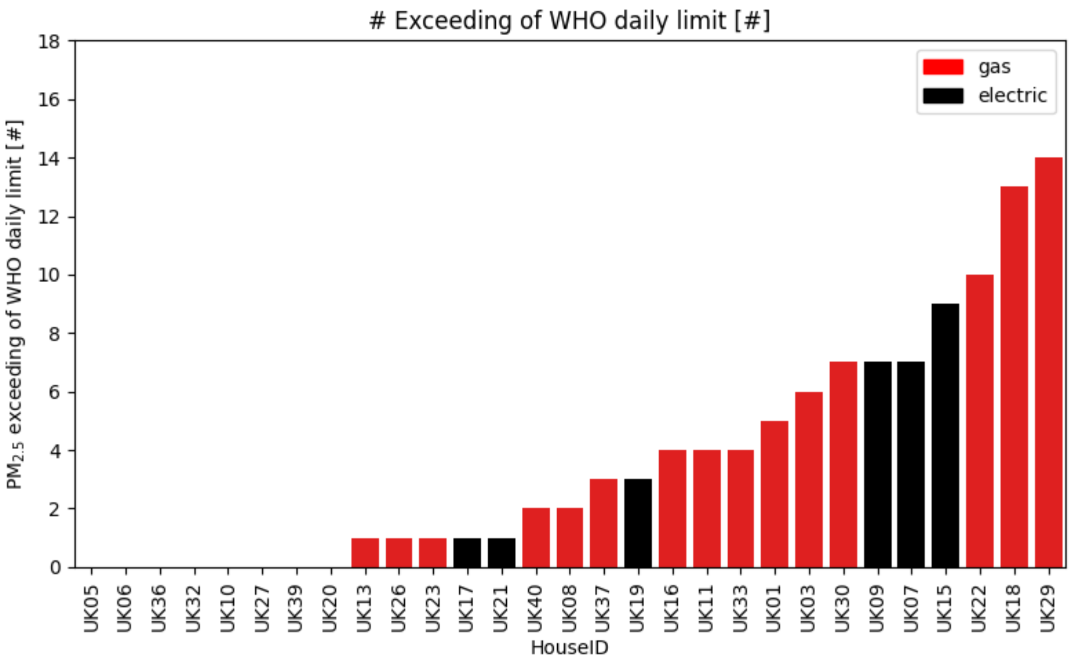


Figure 5.54 number of days that the $PM_{2.5}$ daily guideline value of 15 µg/m^3 has been exceeded during the measurement period.

5.7 Romania

5.7.1 Summary

Measurement results regarding to 29 households cooking on gas and 5 households cooking electric have been obtained. During the measurement period the NO_2 outdoor concentration was relatively high. And the five households cooking on electric were located in neighbourhoods with an elevated outdoor concentration. On the average the outdoor concentration was there 10 $\mu g/m^3$ higher.

Cooking on gas clearly led to significant deterioration of the indoor air quality with regard to NO_2:

- After correction for the outdoor concentration, the households cooking on gas have a significant ($p < 0.05$) higher nitrogen dioxide (NO_2) concentration in their kitchen than households cooking with electric cooking appliances.
- The WHO daily guideline value for nitrogen dioxide was exceeded in 52% of the households cooking on gas. For electric cooking no exceedances occurred.
- The WHO hourly guideline value for NO_2 was exceeded in 24% of the houses cooking on gas and not in any house cooking electric.
- The EU hourly limit value for NO_2 in ambient air was exceeded in 19% of the investigated houses cooking on gas, while in houses cooking electric no exceedances have been registered. Based on the number of exceedance hours during the measurement period it is likely that for most of these houses the hourly EU limit value is exceeded more than 18 hours per year.

With regard to carbon monoxide (CO) participants cooking on gas had a significant higher concentration and highest 1-h value then those cooking electric. However, in none of the households exceeding of CO guideline and limit values occurred.

For fine particulate matter ($PM_{2.5}$) no significant difference between houses cooking on gas and cooking electric could be distinguished. Of the investigated houses cooking electric 100% exceeded the WHO daily guideline value for fine particulate matter ($PM_{2.5}$). Of the houses cooking on gas 96.1% exceeded this guideline value.

5.7.2 Household Environmental Conditions

5.7.2.1 Estimated hob use

Based on the iButton temperature readings, the hob and oven cooking time per day have been estimated, see Figure 5.55.

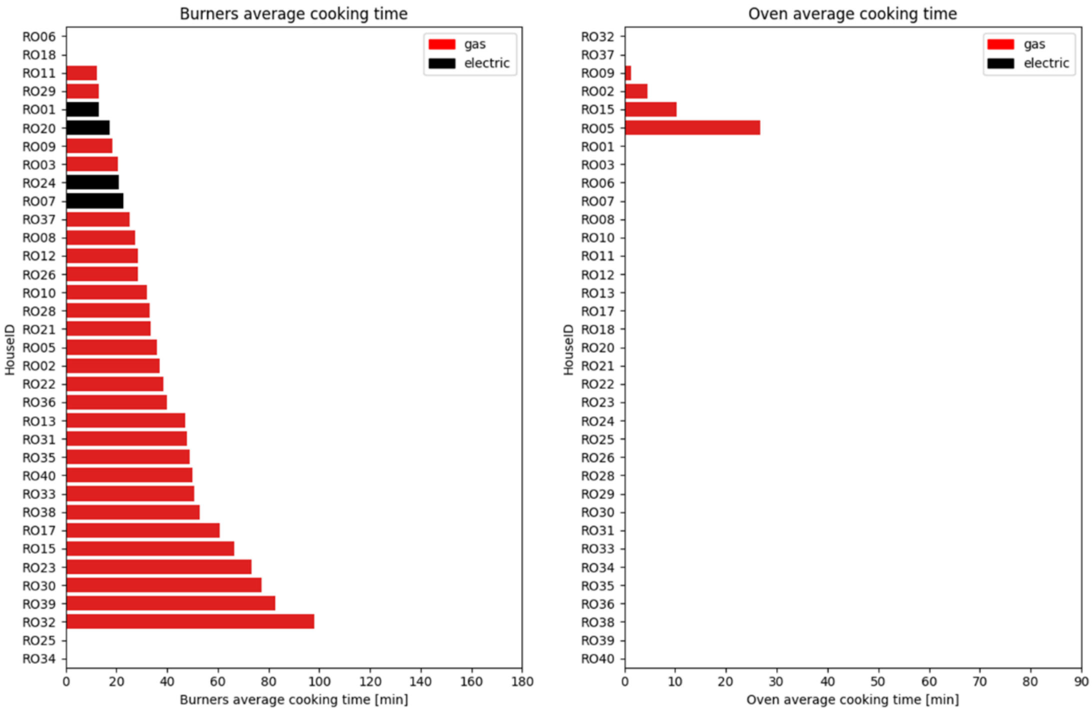


Figure 5.55 Estimated hob and oven use for each participating household.

5.7.2.2 Kitchen estimated ventilation rate

Table 5.43 and Figure 5.56 list the estimated ventilation rate in the kitchen/living room.

Table 5.43: overview of estimated ventilation flow in kitchen and or living room, number of measurements, arithmetic mean, geometric mean and geometric standard deviation.

	n	mean	median	mean SD
Ventilation rate [ACH]	32	0.67	0.53	0.47

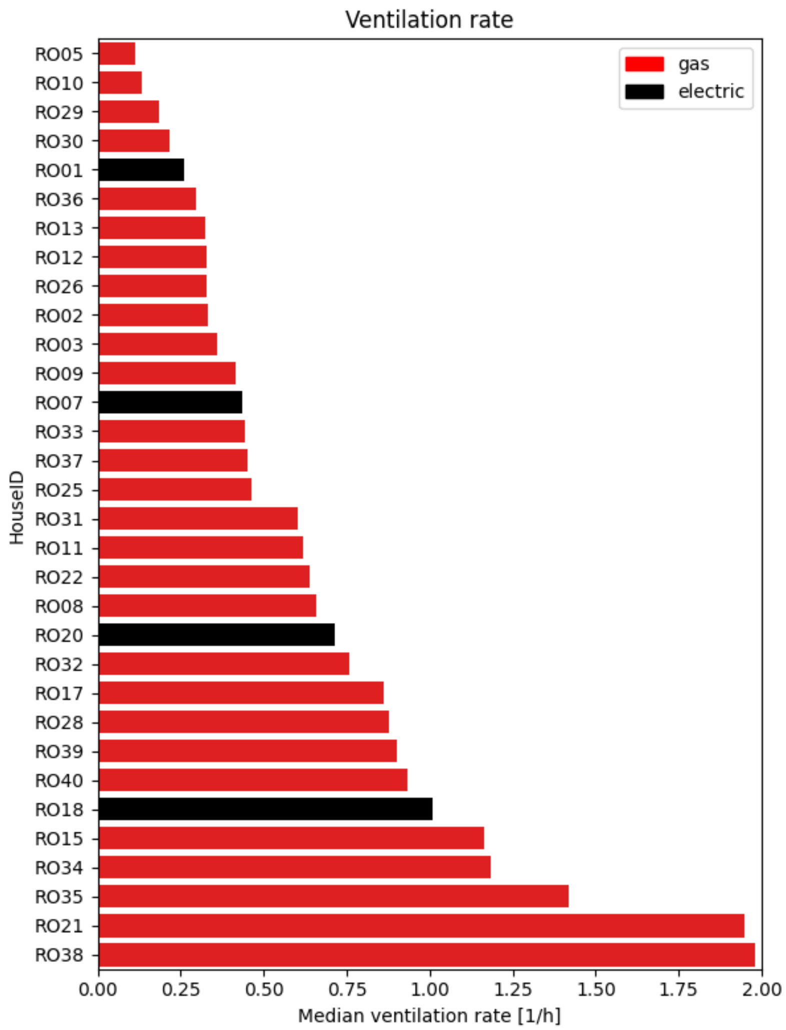


Figure 5.56 calculated median ventilation rate for each participating household.

5.7.3 Pollutant concentrations

5.7.3.1 Nitrogen Dioxide (NO_2)

Figure 5.57 and Table 5.44 list the mean and medium NO_2 concentrations measured by the active and passive sensors. For illustration in Figure 5.57 also the WHO annual guideline value of 10 µg/m^3 is indicated as blue line in the graphs. A direct comparison with the annual guideline is not possible as we have only measured during 13 days and the expectation based on literature data[9] is that during summer the indoor NO_2 concentration is lower than during the heating season.

RO18 has a relative high NO_2 concentration for a household cooking on electric. Cooking on electric has been checked with uploaded photos. The high concentration can partly be explained by the fact that it is located in the center of Bucharest. Based on the outdoor concentration and the ventilation rate an indoor concentration of 34 µg/m^3 could be expected. For more information about the calculation see paragraph 6.1.

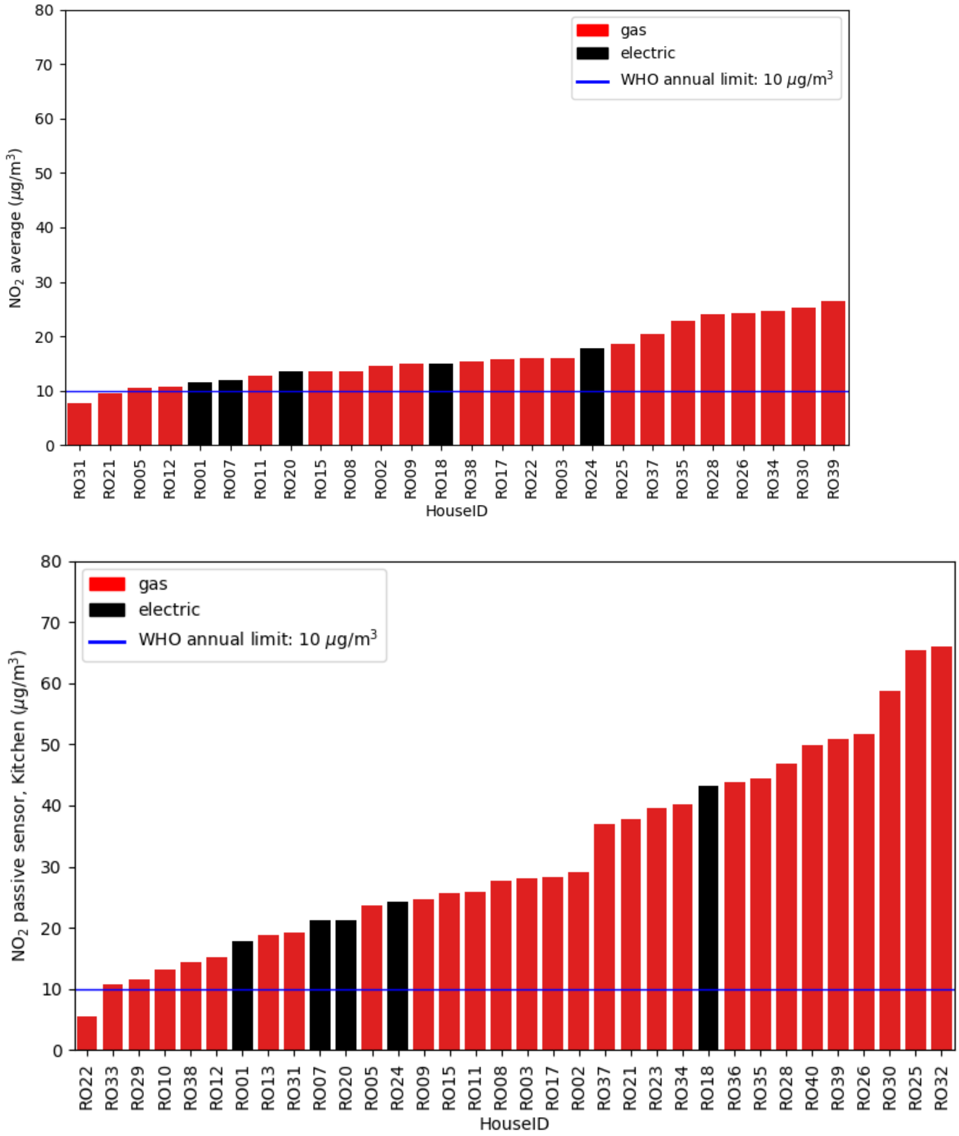


Figure 5.57 average NO_2 concentration in the kitchen per household measured with active (upper graph) and passive (lower graph) samplers (households ordered by average concentration). The red line indicates the WHO annual limit value of 10 µg/m^3.

Table 5.44: average NO_2 concentration (incl. standard deviation SD and number of measurements n) in the kitchen, living room, bedroom and outdoor for households with electric cooking and with cooking on gas, including the p-value.

NO_2 in µg/m^3	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen – active sensor	5	14.0	2.5	21	17.1	5.7	0.085
Kitchen - passive sensor	5	25.5	10.2	29	32.9	16.7	0.217
Living room - passive sensor	5	21.4	10.4	28	22.8	14.6	0.807
Bedroom - passive sensor	5	20.9	8.1	27	19.0	11.7	0.658
Outdoor - passive sensor	5	28.5	17.1	29	18.5	11.1	0.266

**significant, p-value < 0.05*

According Table 5.44 no statistic significant concentration increases have been found due to cooking on gas compared to electric. This is most likely caused by outdoor effects. During the measurement period the outdoor concentration was relatively high. And the five households cooking on electric were located in neighbourhoods with an elevated outdoor concentration. On the average the outdoor concentration is there 10 µg/m^3 higher.

After correction for the outdoor concentration, see Table 5.45, significant differences have been found for the kitchen and living room due to cooking on gas compared to electric. RO24 has been omitted as no correction could be made as no value for the ventilation rate was available.

Table 5.45: average NO_2 concentration (incl. standard deviation SD and number of measurements n) in the kitchen, living room, bedroom and outdoor for households with electric cooking and with cooking on gas, including the p-value.

NO_2 – attributed in µg/m^3	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen - passive sensor	4	11.69	1.62	28	25.0	15.7	<0.001
Living room - passive sensor	4	6.42	2.85	27	14.2	11.3	0.007
Bedroom - passive sensor	4	6.71	3.99	27	11.3	9.4	0.123

**significant, p-value < 0.05*

5.7.3.2 Carbon Monoxide (CO)

Figure 5.58 and Table 5.46 list the average carbon monoxide (CO) concentration in the kitchen measured with active samplers. The cooking method is indicated by the colour of the bars.

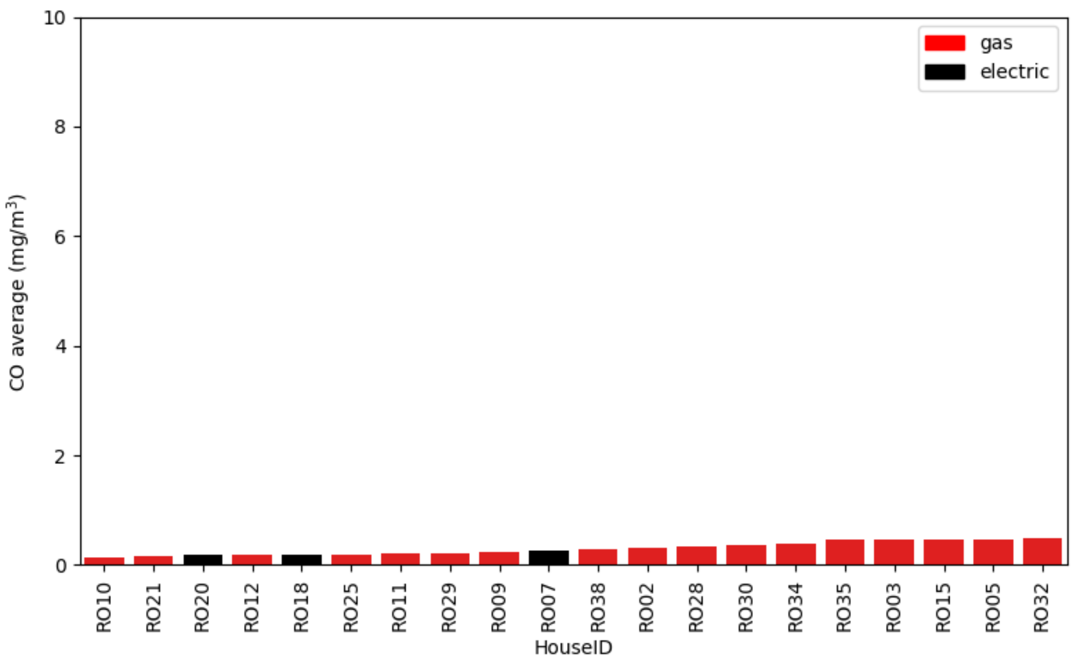


Figure 5.58 average CO concentration in the kitchen per household measured with active samplers (households ordered by average concentration).

Table 5.46: average value and highest 1-h value of CO concentration measurement in the kitchen, number of measurements n and standard deviation SD for households with electric cooking and with cooking on gas, including the p-value. Mean and standard deviation values are in mg/m³.

CO in mg/m³	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen – mean value	3	0.21	0.04	17	0.32	0.12	0.016
Kitchen - highest 1 h value	3	0.86	0.33	17	1.58	0.79	0.031

** significant, p-value < 0.05*

With regard to CO a significant concentration difference in the investigated houses between cooking on gas or electric has been found.

5.7.3.3 Fine Particulate Matter ($PM_{2.5}$)

Figure 5.59 and Table 5.47 list the $PM_{2.5}$ concentration in the kitchen. The cooking method is indicated by the colour of the bars.

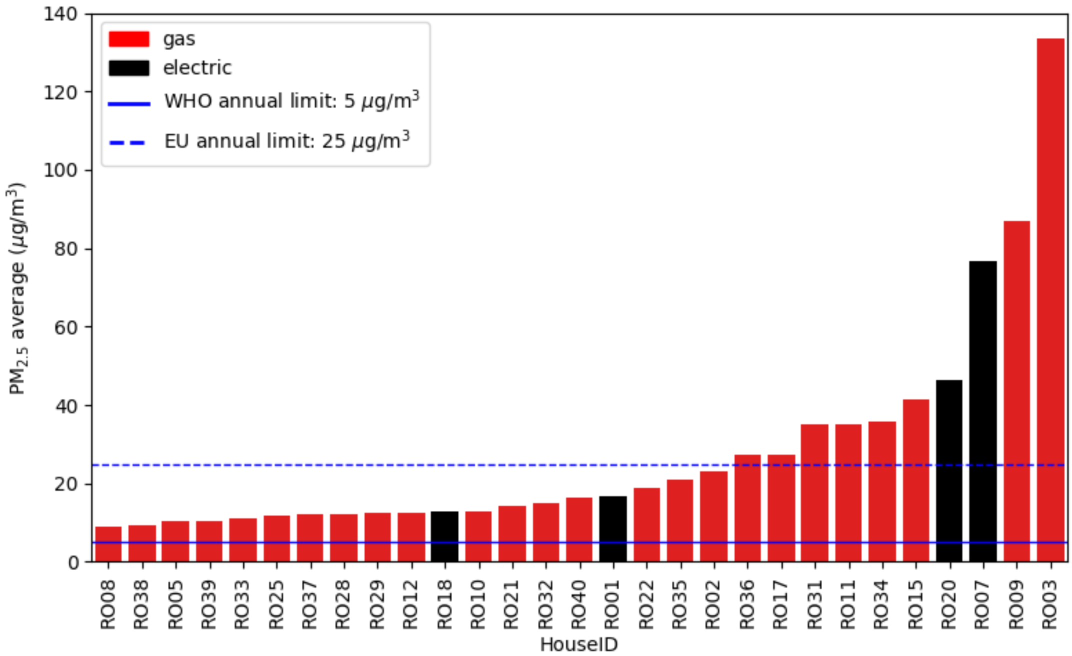


Figure 5.59 average $PM_{2.5}$ concentration in the kitchen per household (households ordered by average concentration).

Table 5.47: average $PM_{2.5}$ concentration in kitchen, number of measurements n and standard deviation SD for households with electric cooking and with cooking on gas, including the p-value.

$PM_{2.5}$ in µg/m³	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen	4	38.1	29.8	25	26.2	27.9	0.4971

** significant, p-value < 0.05*

5.7.4 Comparison with limit and guideline values

5.7.4.1 Nitrogen Dioxide (NO_2)

Table 5.48 lists the exceedance of the daily WHO guideline and EU NO_2 limit values in the kitchen during the 13 days measurement period based on the active sensor results.

In 52% of the houses cooking on gas the WHO daily guideline value is exceeded whereas in none of the houses cooking electric was the case. The WHO hourly guideline value is exceeded in 24% of the participants houses cooking on gas and not in any house cooking electric.

The EU limit value exceedance is smaller than the WHO guideline value exceedance as the exceedance based on clock hours is smaller than the WHO guideline value exceedance which is based on exposure hours. See for more information paragraph 2.5.

Table 5.48: percentage of kitchens with NO_2 concentration above the WHO daily limit value and estimated percentage of kitchens above the WHO guideline and the EU NO_2 limit values based on **active sensor** results.

NO_2 Limit values	% of households above limit value	
	Electric cooking	Cooking on gas
WHO daily guideline value 25 µg/m^3	0	52
WHO hourly guideline value 200 µg/m^3	0	24
>18 hours above EU hourly limit 200 µg/m^3	0	19

**Extrapolation of 13 days of measurement data to yearly exceedance*

Figure 5.60 shows the distribution of days that the NO_2 concentration during the measurement period is above the WHO daily guideline value. Figure 5.61 and Figure 5.62 give respectively the number of hours and the number of clock hours that the NO_2 concentration during the measurement period is above the WHO guideline value / EU limit value of 200 µg/m^3.

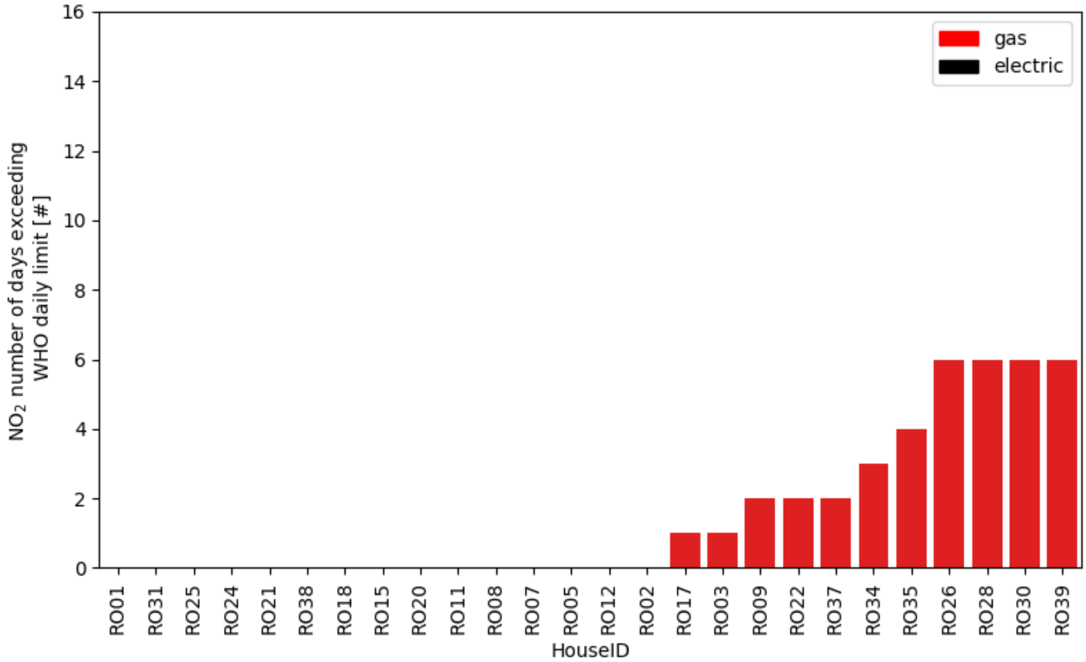


Figure 5.60 number of days that the WHO NO_2 daily limit value of 25 µg/m³ has been exceeded during the measurement period.

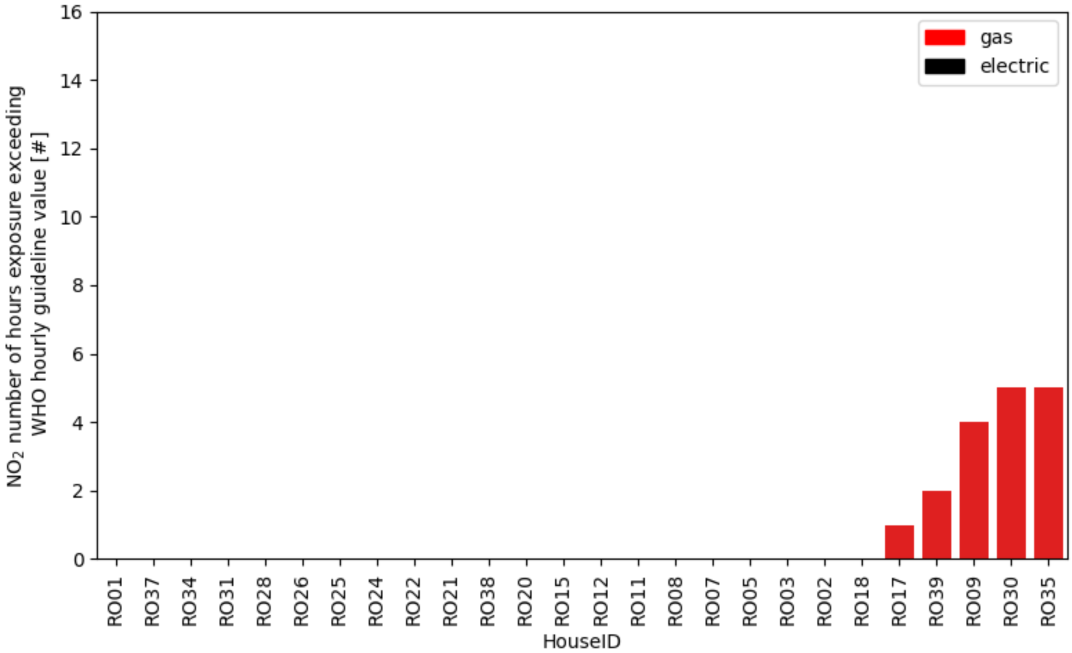


Figure 5.61 number of hours that the WHO NO_2 hourly guideline value of 200 µg/m³ has been exceeded during the measurement period.

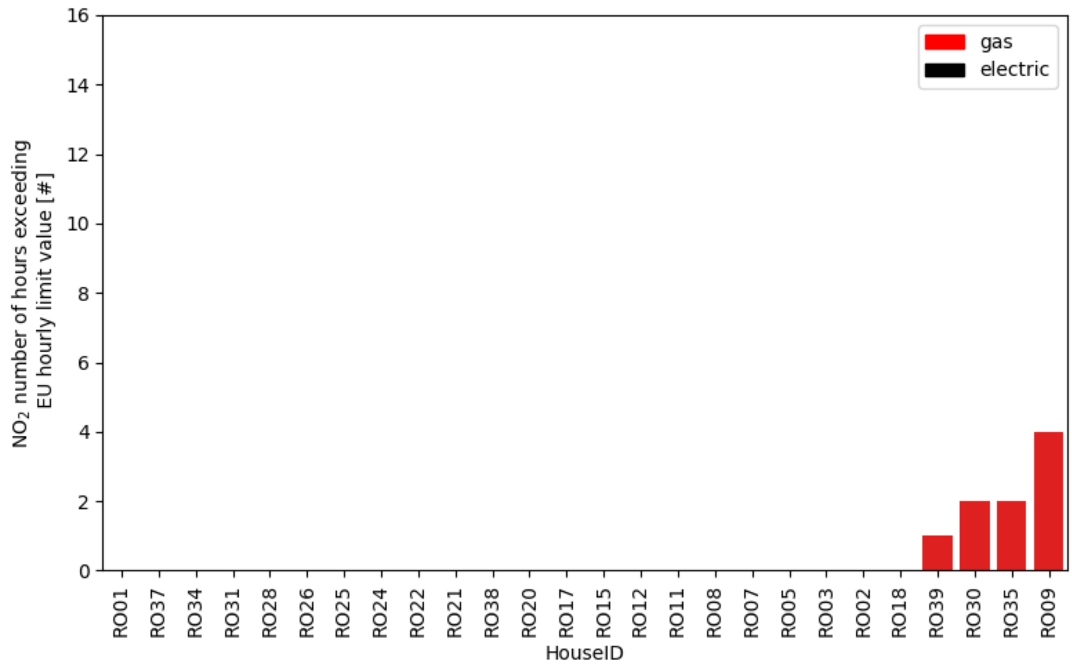


Figure 5.62 number of **clock** hours that the EU outdoor NO_2 hourly limit value of 200 µg/m^3 has been exceeded during the measurement period.

5.7.4.2 Carbon Monoxide (CO)

Table 5.49 lists the exceedance of the WHO guideline values and EU CO limit value in the kitchen during the 13 days measurement period based on the active sensor results. No exceedances have been registered.

Table 5.49: percentage of kitchens with CO concentrations above WHO guideline and EU limit values.

CO Limit values	% of households above limit value	
	Electric cooking	Cooking on gas
WHO daily limit of 4 mg/m^3	0	0
WHO/EU 8 h limit of 10 mg/m^3	0	0
WHO 1h limit of 35 mg/m^3	0	0

5.7.4.3 Fine Particulate matter ($PM_{2.5}$)

Table 5.50 lists the exceedance of the daily WHO $PM_{2.5}$ guideline values in the kitchen during the 13 days measurement period. Figure 5.63 shows the distribution of the exceedance days, the cooking method is indicated by the colour of the bars.

Table 5.50: percentage of kitchens with $PM_{2.5}$ concentrations above WHO guideline value.

$PM_{2,5}$ Limit values	% of households above limit value	
	Electric cooking	Cooking on gas
WHO daily guideline value 15 µg/m^3	100	96

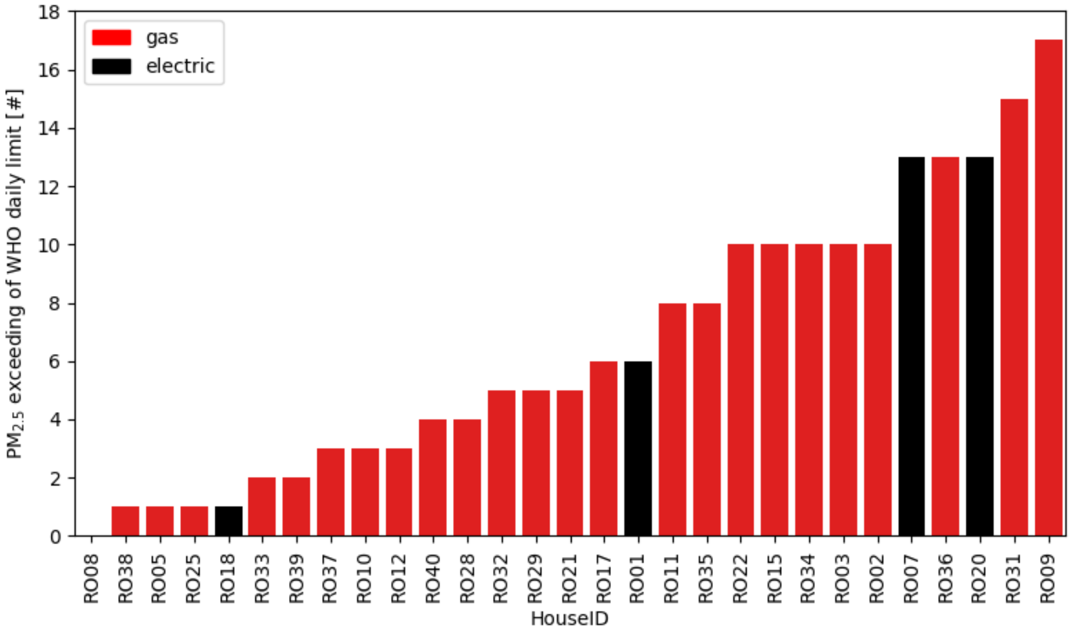


Figure 5.63 number of days that the $PM_{2.5}$ daily guideline value of 15 µg/m^3 has been exceeded during the measurement period.

6 Statistical analysis

6.1 Approach

For both the passive and the active sensor data statistical analysis is carried out on the total dataset with all countries pooled together. The statistical analyses have not been carried out on national level as it is anticipated that then the statistical power will be insufficient.

The (indoor-attributed) NO_2 and highest 1-h CO concentration dependency/relation to the following variables is statistically tested:
- Cooking on gas or cooking electric;
- Total cooking time reported by hob temperature sensor;
- Presence of a gas oven;
- Kitchen volume;
- Ventilation flow in kitchen/living room;
- Presence of a cooker hood;

Statistical tests have been carried out whether a significant difference exists in $PM_{2.5}$ concentration in houses cooking on gas or electric, e.g. due to a higher pan temperature. For confounding factors such as the ambient $PM_{2.5}$ contribution no correction has been made as this have not been measured.

Indoor attributed NO_2
Outdoor NO_2 can have a major impact on indoor levels. Therefore the indoor levels were corrected for outdoor concentrations. These so called indoor NO_2 concentrations attributed to indoor sources[2] were calculated by subtracting the measured outdoor value multiplied with the infiltration factor F. The infiltration factor is obtained by dividing the measured ventilation air exchange rate λ with the sum of the ventilation air exchange rate and indoor deposition rate k_d.

$$IndoorAttributed\ NO_2 = Indoor\ NO_2 - F \cdot outdoor\ NO_2$$

$$F = \frac{\lambda}{\lambda + k_d}$$

Based on literature[1] the deposition typically amounts 0.75 per hour. With for example an air exchange rate of 0.5 the infiltration factor amounts 0.4.

In the next three paragraphs per contaminant (NO_2, CO and $PM_{2.5}$) possible relations with determining variables are tested. The results are integrally discussed in chapter 7.3 and compared with literature results.

6.2 NO_2 and Indoor-Attributed NO_2

6.2.1 Cooking method

Pooled all country data together, Table 6.1 and Table 6.2 clearly show that the NO_2 concentration in households cooking on gas is significantly higher than those cooking on electric. The indoor-attributed NO_2 data in Table 6.2 has a smaller standard deviation than the NO_2 data in Table 6.1. Note that the number of measurements in Table 6.2 is reduced due to missing CO_2 and outdoor NO_2 values, for these households it was not possible to calculate the indoor-attributed NO_2 concentration.

Table 6.1: average NO_2 concentration (incl. standard deviation SD and number of measurements n) in the kitchen, living room, bedroom and outdoor for households with electric cooking and with cooking on gas, including the p-value for all countries pooled together.

NO_2 in µg/m³	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen – active sensor	44	12.5	5.5	150	19.9	9.2	<0.001
Kitchen - passive sensor	60	14	7.3	180	26.8	13.8	<0.001
Living room - passive sensor	58	12.6	6.3	178	17.7	9.5	<0.001
Bedroom - passive sensor	59	13.6	6.9	179	22.2	11.3	<0.001
Outdoor – passive sensor	59	19.5	13.5	178	17.4	8.9	0.265

**significant, p-value < 0.05*

Table 6.2: average Indoor-Attributed NO_2 concentration (incl. standard deviation SD and number of measurements n) in the kitchen, living room and bedroom for households with electric cooking and with cooking on gas, including the p-value for all countries pooled together.

Indoor-Attributed NO_2 in µg/m³	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen - passive sensor	51	7.9	4.6	155	21.1	12.1	<0.001
Living room - passive sensor	51	7.3	4.6	154	16.4	9.8	<0.001
Bedroom - passive sensor	50	6.6	4.8	154	11.9	8.1	<0.001

**significant, p-value < 0.05*

6.2.2 Self-reported use of a cooker hood

Table 6.3 shows that there is not a significant difference in indoor-attributed NO_2 concentration when comparing participants reporting the use of a cooker hood and those that did not. These tables contain households that cook on gas as well as electrically.

Table 6.3: average Indoor-Attributed NO_2 concentration (incl. standard deviation SD and number of measurements n) in the kitchen, living room, bedroom for households with and without using a cooker hood, including the p-value for all countries pooled together.

Indoor-Attributed NO_2 in µg/m³	Cooker hood ducted to outside (HO)			No use of cooker hood			p-value*
	N	mean	SD	n	mean	SD	
Kitchen - passive sensor	104	17,8	11,7	68	17,7	12,9	0,993
Living room - passive sensor	103	13,4	9,3	68	15	10,2	0,287
Bedroom - passive sensor	103	10,2	7,9	67	10,7	7,6	0,712

Indoor-Attributed NO_2 in µg/m³	Recirculation hood (HR)			No use of cooker hood			p-value*
	N	mean	SD	n	mean	SD	
Kitchen - passive sensor	30	18,7	12,6	68	17,7	12,9	0,729
Living room - passive sensor	30	15,3	9,7	68	15	10,2	0,901
Bedroom - passive sensor	30	11,6	7,9	67	10,7	7,6	0,579

**significant, p-value < 0.05*

When restricting the comparison to those households cooking on gas, see Table 6.4, there still is no significant difference between those reporting the use of a cooker hood ducted too outside and those who are not. The indoor-attributed NO_2 concentrations are almost equal. However, there is a not significant (P=0.253) increase of 3.4 µg/m³ in the kitchen for participants using a recirculation hood compared to those not using a cooker hood. Smaller also non-significant increases exists for the living room and the bedroom.

Table 6.4: average Indoor-Attributed NO_2 concentration (incl. standard deviation SD and number of measurements n) in the kitchen, living room, bedroom for households with cooker hood and cooking on gas, including the p-value for all countries pooled together.

Indoor-Attributed NO_2 in µg/m³	Cooker hood ducted to outside (HO)			No use of cooker hood			p-value*
	n	mean	SD	n	mean	SD	
Kitchen - passive sensor	76	21.1	11.8	55	20.4	12.9	0.739
Living room - passive sensor	75	15.4	9.9	55	17	10.3	0.375
Bedroom - passive sensor	75	11.2	8.5	55	11.8	7.8	0.692

Indoor-Attributed NO_2 in µg/m³	Recirculation hood (HR)			No use of cooker hood			p-value*
	n	mean	SD	n	mean	SD	
Kitchen - passive sensor	21	23.8	11.1	55	20.4	12.9	0.253
Living room - passive sensor	21	19.2	8.1	55	17	10.3	0.326
Bedroom - passive sensor	21	14.5	7.4	55	11.8	7.8	0.175

**significant, p-value < 0.05*

6.2.3 Hob temperature reported total cooking time

Figure 6.1 shows that with increasing daily cooking duration, registered with temperature sensors on the hob, for cooking on gas the indoor-attributed NO_2 concentration in the kitchen increases. This increase is not visible for cooking on electric hobs.

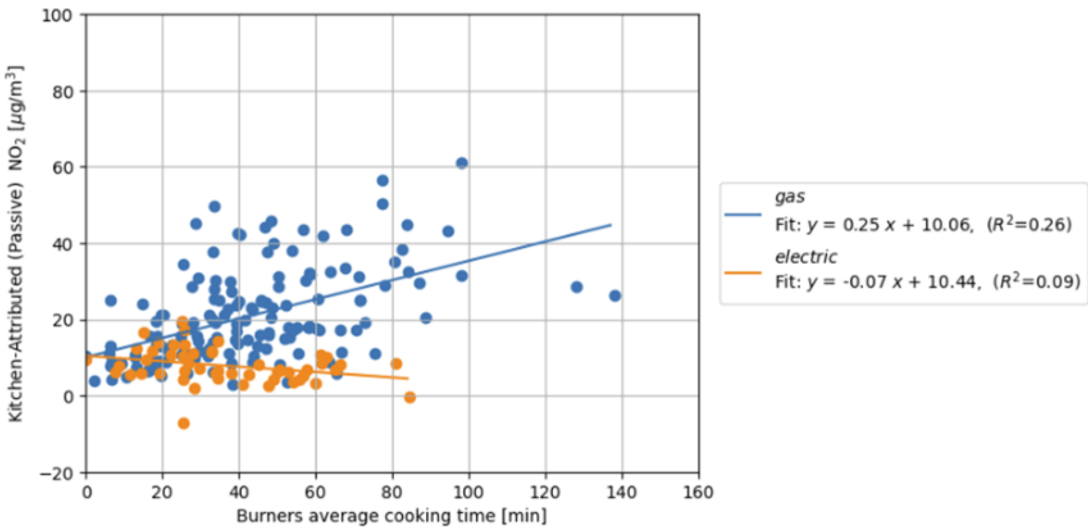


Figure 6.1 Indoor-attributed kitchen NO_2 concentration for households cooking on gas and on electric as function of burners average cooking time.

6.2.4 Kitchen volume

Figure 6.2 shows that for cooking on gas with increasing kitchen volume there is a large spread in indoor-attributed NO_2 concentration. With increasing volume the maximum values are reduced. This effect is not visible for cooking on electric.

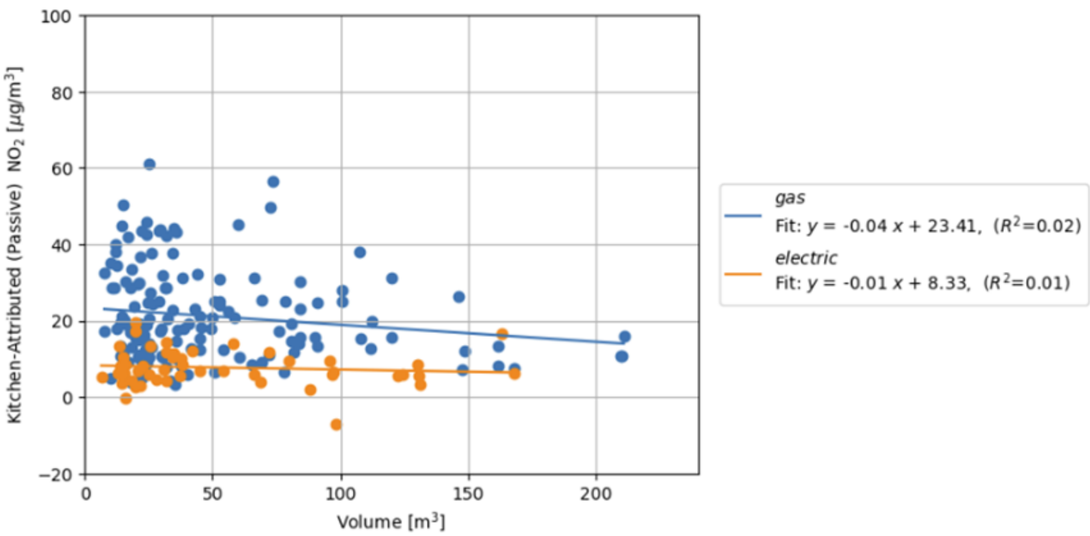


Figure 6.2 Indoor-attributed kitchen NO_2 concentration for households cooking on gas and on electric as function of the kitchen volume.

6.2.5 Ventilation flow in kitchen

Figure 6.3 shows that for cooking on gas with increasing ventilation flow there is a large spread in indoor-attributed NO_2 concentration. With increasing ventilation flow the maximum values are reduced. This effect is not visible for cooking on electric.

Ventilation flow = air change rate x kitchen volume x 1000/3600 [dm^3/s]

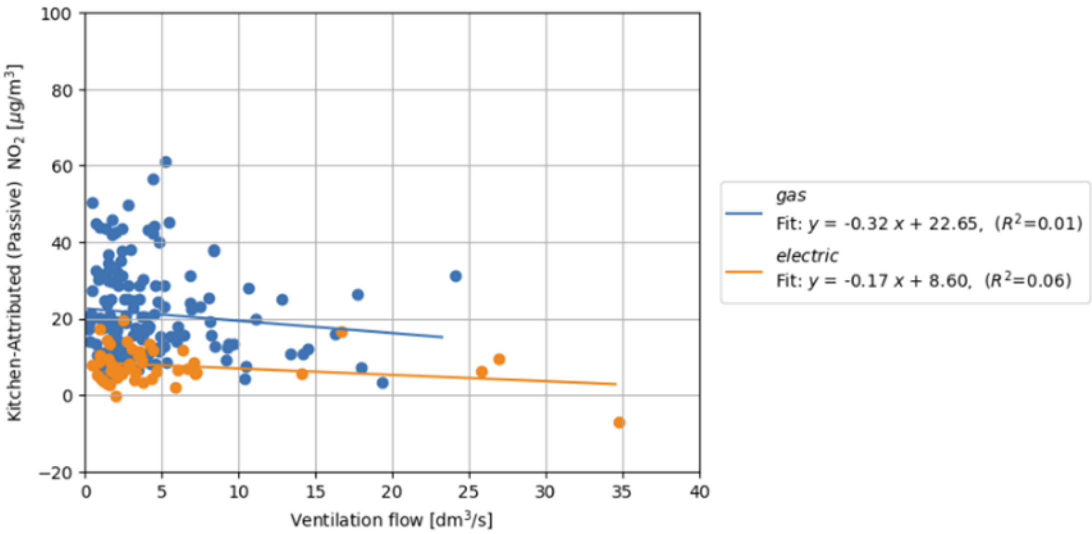


Figure 6.3 kitchen attributed NO_2 concentration for households cooking on gas and on electric as function of the estimated kitchen ventilation flow.

6.2.6 Presence and use of a gas oven

The presence of a gas oven does not significantly ($p=0.074$) increase the indoor-attributed NO_2 concentration in the kitchen with 4 µg/m^3, see Table 6.5.

Table 6.5: average indoor-attributed NO_2 concentration (incl. standard deviation SD and number of measurements n) in the kitchen, living room and bedroom for households with cooking on gas hob and with cooking on gas hob and gas oven, including the p-value for all countries pooled together.

Indoor-Attributed NO_2 in µg/m^3	Presence of gas hob			Presence of gas hob and gas oven			p-value*
	n	mean	SD	n	mean	SD	
Kitchen - passive sensor	110	20.0	11.6	45	24.0	12.9	0.074
Living room - passive sensor	110	16.3	10	44	16.7	9.5	0.818
Bedroom - passive sensor	109	11.6	8.2	45	12.5	7.7	0.525

**significant, p-value < 0.05*

The effect of the use of gas ovens on the indoor-attributed NO_2 concentration in the kitchen has been analysed for the UK participants with a gas oven. Figure 6.4 shows that there is a weak (R^2 = 0,195) positive relation between the oven cooking time and the indoor-attributed kitchen NO_2 concentration.

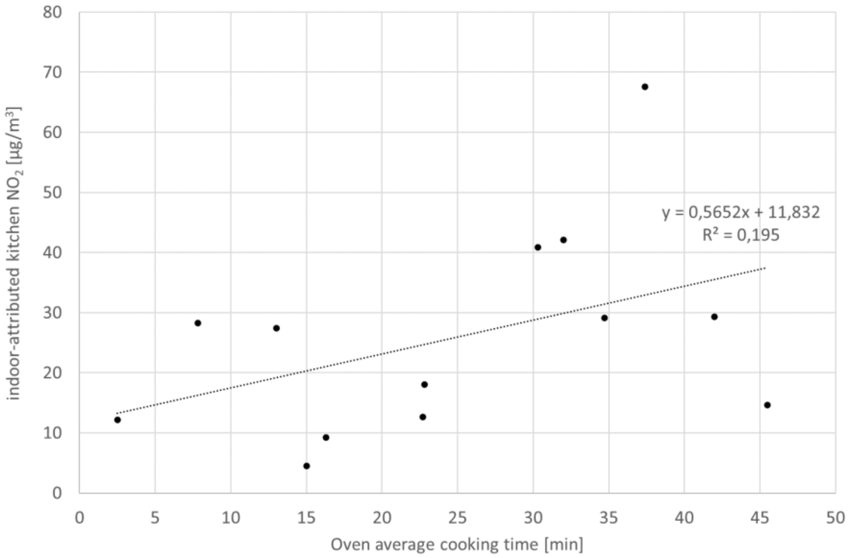


Figure 6.4 kitchen attributed NO_2 concentration for UK households using a gas oven as function of the oven cooking time.

A similar figure can be set up for the relation between the gas hob burners average cooking time and the indoor-attributed kitchen NO_2 concentration, see Figure 6.5. Here the correlation coefficient R^2 amounts 0.327.

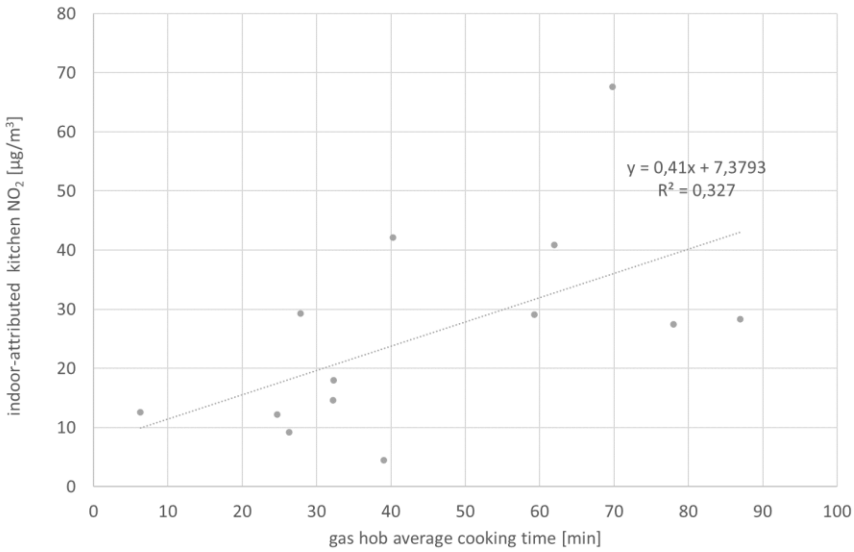


Figure 6.5 kitchen attributed NO_2 concentration for UK households using a gas oven and gas hob as function of the gas hob cooking time.

The strongest correlation ($R^2 = 0.56$) with the indoor-attributed kitchen NO_2 concentration can be obtained by adding up the gas hob and oven average cooking times, see Figure 6.6.

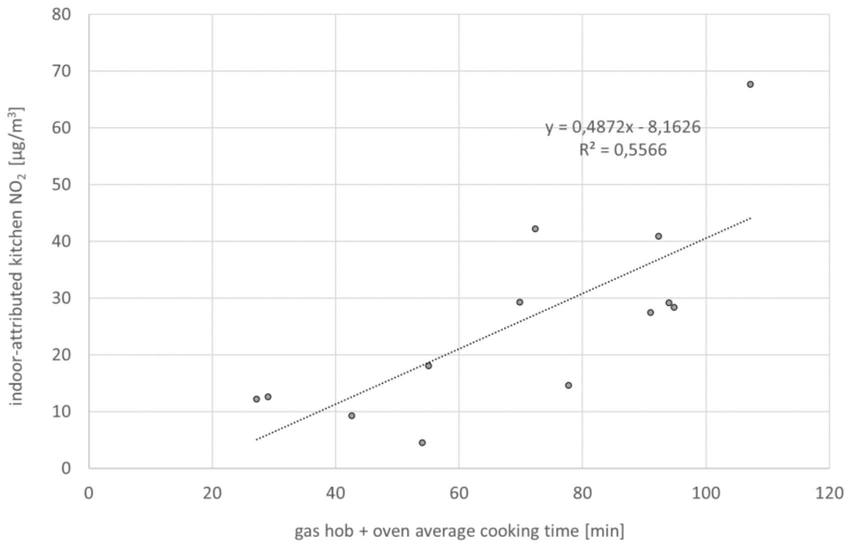


Figure 6.6 kitchen attributed NO_2 concentration for UK households using a gas oven as function of the sum of the gas oven and gas hob cooking times.

6.3 CO and highest 1-hour CO

When taken all participants together, see Table 6.6, a small but significant difference has been found for the mean CO concentrations between those cooking on gas and those on electric. However no statistically significant difference has been found for the CO highest 1-h value.

Table 6.6: average value and highest 1-h value of CO concentration measurement in the kitchen, number of measurements n and standard deviation SD for households with electric cooking and with cooking on gas, including the p-value for all countries pooled together. Mean and standard deviation values are in mg/m^3.

CO in mg/m^3	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen – mean value	31	0.6	0.3	114	0.8	0.8	0.022
Kitchen - highest 1 h value	31	3.9	3.2	114	4.2	3.5	0.677

** significant, p-value < 0.05*

6.4 $PM_{2.5}$

Pooled all country data together, see Table 6.7, with regard to $PM_{2.5}$ a non-significant difference of 4.2 µg/m^3 between houses cooking on gas and cooking electric could be distinguished.

Table 6.7: average $PM_{2.5}$ concentration in kitchen, number of measurements n and standard deviation SD for households cooking on gas and on electric hobs, including the p-value for all countries pooled together.

$PM_{2.5}$ in µg/m^3	Electric cooking			Cooking on gas			p-value*
	n	mean	SD	n	mean	SD	
Kitchen	51	18	15.6	156	22.2	22	0.142

** significant, p-value < 0.05*

The use of a cooker hood ducted to outside does not lead to significantly lower $PM_{2.5}$ concentration in the kitchen compared to not using a cooker hood, see Table 6.8. The mean concentrations are almost identical. Participants using a recirculation hood have a 2.1 µg/m^3 higher $PM_{2.5}$ concentration compared to those not using a cooker hood. Although this difference is not significant (p=0.632).

Table 6.8: average $PM_{2.5}$ concentration in kitchen, number of measurements n and standard deviation SD for households cooking on gas and on electric hobs, including the p-value for all countries pooled together.

average $PM_{2.5}$ (ug/m3)	Cooker hood ducted to outside (HO)			No use of cooker hood			p-value*
	n	mean	SD	n	mean	SD	
Kitchen	103	21,1	21,3	68	20,9	20,8	0,947

average $PM_{2.5}$ (ug/m3)	Recirculation hood (HR)			No use of cooker hood			p-value*
	n	mean	SD	n	mean	SD	
Kitchen	32	23	19,9	68	20,9	20,8	0,632

**significant, p-value < 0.05*

Figure 6.7 shows that there is not a clear effect of the cooking time on the $PM_{2.5}$ concentration in the kitchen.

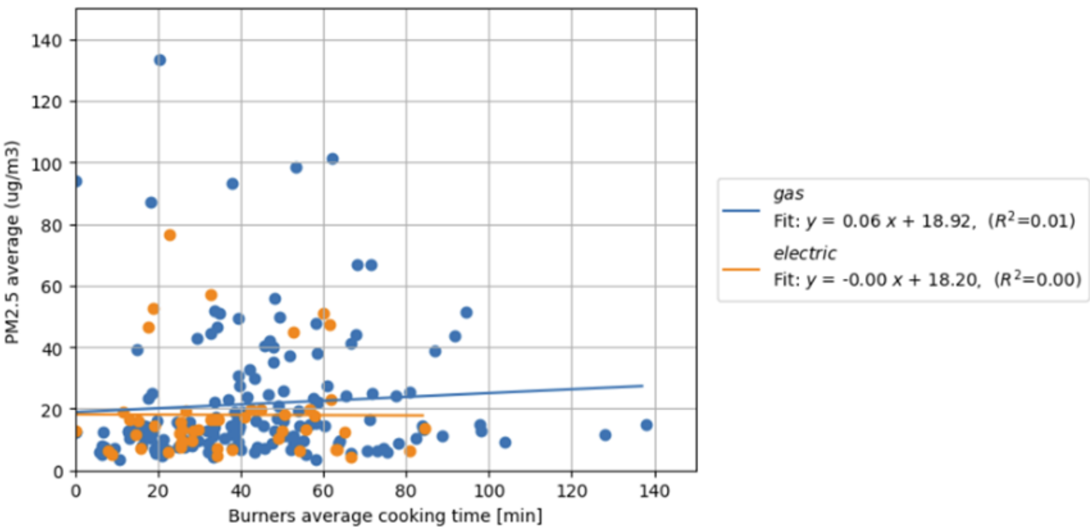


Figure 6.7 Kitchen $PM_{2.5}$ concentration for households cooking on gas and on electric as function of burners average cooking time.

7 Discussion of research questions

7.1 What are the concentrations of air pollutants released when cooking on gas compared to electric cooking across several European countries ?

Nitrogen dioxide (NO_2):
Table 7.2 lists per country and per cooking method the average NO_2 concentration in the kitchen, living room, bedroom and outside. For six out of seven countries (all except Romania) a significant ($p < 0.05$) higher nitrogen dioxide (NO_2) concentration has been found in the kitchen for households cooking on gas compared to cooking on electric. Correcting for the outdoor concentration also for the measured households in Romania a significant higher concentration in the kitchen and living room has been found for those cooking on gas compared to cooking on electric (see paragraph 5.7.3.1).

Comparable with earlier field studies[2,9] the highest NO_2 concentrations in houses cooking on gas were found in the kitchen and the lowest in the sleeping room. The increased concentration in the living room can be explained by the fact that many houses are equipped with an open kitchen. Pollutants emitted in the kitchen are readily transported and mixed up in this open space. Bedrooms have the lowest concentration as they are usually farthest from the kitchen and their doors are more likely to be closed.
The outdoor NO_2 concentration plays a role on the resulting indoor concentration on households. Due to infiltration in houses cooking on electric, outdoor NO_2 can enter indoors. For this reason in chapter 6 in the statistical analysis the indoor concentration is corrected for the outdoor concentration, the so called indoor attributed NO_2 concentration.

The measured concentration increase due to cooking on gas is in accordance with the simulation concentrations calculated during the first phase of this study with and without range hood, see Table 7.1.This coincides with the fact that 50% of the participants used a range hood venting to outside.

Table 7.1: NO_2 concentration increase due to cooking on gas compared with phase 1 simulation results[1].

	Simulation with range hood [μg/m³]	Measured in field study [μg/m³]	Simulation without range hood [μg/m³]
Western Europe (FR & NL)	6	9.1 & 10.6	13
Southern Europe (IT & ES)	7	22.8 & 14.4	20
Eastern Europe (RO & SK)	10	7.4 & 16.5	30
UK	11	15.3	45

Table 7.2: average NO_2 concentrations per country and per cooking method in different rooms.

Passive sensor	average NO_2 concentration in µg/m³													
	The Netherlands		Italy		Spain		France		Slovakia		UK		Romania	
	electric	gas	electric	gas	electric	gas	electric	gas	electric	gas	electric	gas	electric	gas
Kitchen	11.7	**22.3***	10.0	**32.8***	18.5	**31.7***	11.2	**20.3***	4.8	**21.3***	11.3	**26,6***	25.5	32.9
Living room	12.3	**20.7***	9.5	**27.5***	17.8	**32.9***	11.1	**18.7***	4.7	**16.4***	12.2	**23,4***	21.4	22.8
Sleeping room	11.2	15.2	13.1	21.3	15.8	**28.5***	10.3	**15.4***	4.3	**13.4***	10.5	**18,7***	20.9	19.0
Outdoor	21.3	22.0	17.2	21.2	26.7	22.9	13.3	13.3	6.7	**11.8***	12.5	13,5	28.5	18.5

**Significant difference, p-value < 0.05*

Table 7.3: kitchen average CO and highest 1-hour concentration measured with ENVEA Cairsens, per country and per cooking method.

CO sensor	CO concentration in mg/m³													
	The Netherlands		Italy		Spain		France		Slovakia		UK		Romania	
	electric	gas	electric	gas	electric	gas	electric	gas	electric	gas	electric	gas	Electric	gas
Mean value	0.54	0.53	0.95	**1.63***	0.60	0.90	0.64	0.73	0.75	**1.58***	0.30	0.29	0.21	**0.32***
Highest 1 h value	3.34	4.17	7.52	7.64	5.90	6.30	4.78	5.02	2.45	**5.72***	1.42	1.43	0.86	**1.58***

Table 7.4: kitchen average $PM_{2.5}$ concentration per country and per cooking method.

$PM_{2.5}$ sensor in	Average $PM_{2.5}$ concentration in µg/m³													
	The Netherlands		Italy		Spain		France		Slovakia		UK		Romania	
	electric	gas	electric	gas	Electric	gas	electric	gas	electric	gas	electric	gas	electric	gas
Kitchen	13.6	13.1	8.7	**27.5***	16.4	27.0	17.9	24.3	24.5	20.2	16.6	17.4	38.1	26.2

Carbon monoxide (CO):

With regard to carbon monoxide (CO) in three of seven countries a significant difference with regard to the mean and the highest 1 hour concentration between houses cooking on gas and cooking on electric could be distinguished, see Table 7.3.

A confounding factor in the current study is that the Cairsens CO sensor from ENVEA used to sample CO is sensible for ethanol and maybe also for other volatile organic compounds[8], see also Appendix F. During cooking[4] volatile organic compounds including alcohols can be generated from the food. Further, due to use of cleaning agents and or by alcohol consumption this interference for ethanol can be significant and may increase the standard deviation. Due to this sensitivity the CO concentrations are also over estimated. We assume that this interference is similar for households cooking on gas or on electric hobs, thus still making a comparison of average concentrations meaningful.

The average CO concentration is of the same order as in two older Dutch studies. Willers[10] measured a weekly average concentration of 0.4 ppm (0.47 mg/m^3) with a maximum of 5.2 ppm (6 mg/m^3) in 74 households of which 53 cooked on gas during the winter season of 2003–2004. Lebret[11] found during the winter of 1981-1982 and 1983-1984 a weekly average CO concentration of 1.7 ppm (2.0 mg/m^3) with a maximum of 3.5 ppm (4 mg/m^3) in rural post-war homes and a weekly average concentration of 1.7 ppm (2.0 mg/m^3) with a maximum of 7.8 ppm (9.1 mg/m^3) in urban pre-war homes. In the study of Lebret aside gas hobs also gas ovens, geysers and tobacco smoking were important CO sources.

Fine particulate matter ($PM_{2.5}$):

With regard to fine particulate matter ($PM_{2.5}$) in six out of seven countries no significant difference between houses cooking on gas and cooking electric could be distinguished, see Table 7.4. Only in Italy a significant difference has been measured. The significant higher $PM_{2.5}$ value for cooking on gas hobs in Italy can be explained by a longer cooking duration for these households compared to those cooking on electric hobs. Pooled all country data together (see paragraph 6.4) with regard to $PM_{2.5}$ no significant difference between houses cooking on gas and cooking electric could be distinguished. This is consistent with the fact that gas burners emit a negligible amount of $PM_{2.5}$[12]. During cooking $PM_{2.5}$ is mainly formed due to evaporation of the oil and ingredients in the pan[13]. Thus if the same pan temperature and cooking procedure is used, cooking food with a gas hob or with an electric hob is expected to emit the same amount of $PM_{2.5}$.

The average fine particulate matter concentration ($PM_{2.5}$) in the Dutch participant kitchens is higher than measured in a recent Dutch study[14], were an average of 9 µg/m^3 has been determined in 268 dwellings during the heating season. This might be caused by the fact that in that earlier study a much higher percentage of homeowners was incorporated. In 92% of these houses an exhaust hood was present and most likely the volume of these houses was larger.

[4] Davies et al, A measurement and modelling investigation of the indoor air chemistry following cooking activities, DOI: 10.1039/d3em00167a

7.2 Do European households cooking on gas exceed the relevant WHO and EU limit concentrations of air pollutants more often?

Nitrogen dioxide (NO_2):
Table 7.5 shows that the WHO hourly guideline value for NO_2 is exceeded for 22 – 77% of the investigated households cooking on gas and by none of the households cooking on electric. The same applies for the exceedance of the EU hourly limit value for outdoor air, here the exceedance varies between 15 – 69%. Based on the number of exceedance hours and the duration of the measurement period it is likely that those houses exceeding the EU hourly NO_2 limit for ambient will exceed this limit for more than the allowed 18 hours per year. For reference, in 2021 in 0.5% of the EU outdoor monitoring stations concentrations above the EU hourly limit were reported by the European Environmental Agency[15]. Preliminary 2022 data even show zero exceedances of the hourly limit within the EU.

In all seven countries the majority of the households cooking on gas do exceed the daily guideline limit value, while in 5 countries households cooking on electric hobs do not have any exceedance at all. The exceedances of the daily guideline value in the Netherlands and Spain for houses cooking electric may be caused by opening windows and the relatively high ambient concentrations during the measurement period in these two countries. In Spain the participants cooking on electric hobs had a non-significant higher outdoor concentration than the participants cooking on gas hobs. The outdoor concentration in Spain for the participants cooking on electric hobs was even above the WHO daily guideline value. As only the average outdoor NO_2 concentration over the full measurement period is known, it was not possible to correct the daily guideline value for the outdoor concentration.

Carbon monoxide (CO):
For both households cooking on gas as on electric Table 7.6 shows no exceedance of the 8-h WHO/EU and 1-h WHO CO guideline value. The last observation is comparable with the US field study[2].
None of the households cooking on electric exceeded the daily WHO guideline value. Whereas four households cooking on gas did exceed this. However, as mentioned earlier the applied Cairsens CO sensor from ENVEA is sensible for ethanol and maybe also for other volatile organic compounds[8], see also Appendix F. During normal use of cleaning agents and or by alcohol consumption this interference for ethanol can be significant. The reported values may therefore include the presence of ethanol, therefore the real CO value could be lower. For the Netherlands the exceedance is most likely a consequence of alcohol consumption in a restaurant next door. Alcohol consumption or cleaning activities may also play a role for one of the two exceedances in Italy as the CO peaks were only party aligned with the cooking event registration. In case of the Spanish household, most of the peaks were well aligned with cooking events. However, these peaks may also be caused by VOC's present in cooking fumes.

Fine particulate matter ($PM_{2.5}$):
Table 7.7 shows that in all countries a large part of the investigated households exceeds the daily WHO guideline value, both by household cooking on gas as electric. Note that a part of the exceedance can be explained due to $PM_{2.5}$ emission during cooking. These cooking fumes could be captured with a range hood. These results and also other studies[14,16] clearly confirm the need for effective cooking exhaust.

Table 7.5: exceedance of NO_2 limit and guideline values in the kitchen..

NO_2 limit/guideline value	% of households above limit value (el = electric)													
	The Netherlands		Italy		Spain		France		Slovakia		UK		Romania	
	El	Gas	El	Gas	El	Gas	El	Gas	El	Gas	El	Gas	El	Gas
WHO daily 25 µg/m^3	17	54	0	72	50	85	0	53	0	44	0	55	0	52
WHO hourly 200 µg/m^3	0	31	0	28	0	77	0	29	0	22	0	25	0	24
EU hourly limit 200 µg/m^3	0	27*	0	24*	0	69*	0	29*	0	15*	0	25	0	19*

**Extrapolation of 13 days of measurement data to yearly exceedance*

Table 7.6: exceedance of WHO CO guideline values in the kitchen measured with ENVEA Cairsens. Between brackets the number of exceeding households

CO limit/guideline value	% of households above limit value (el = electric)													
	The Netherlands		Italy		Spain		France		Slovakia		UK		Romania	
	El	Gas	El	Gas	El	Gas	El	Gas	El	Gas	El	Gas	El	Gas
WHO daily 4 mg/m^3	0	4 (1)	0	11 (2)	0	9 (1)	0	0	0	0	0	0	0	0
WHO/EU 8 h 10 mg/m^3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WHO 1-h 35 mg/m^3	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 7.7: exceedance of the WHO daily $PM_{2.5}$ guideline value in the kitchen.

$PM_{2.5}$ sensor in	% of households above limit value (El = electric)													
	The Netherlands		Italy		Spain		France		Slovakia		UK		Romania	
	El	Gas	El	Gas	El	Gas	El	Gas	El	Gas	El	Gas	El	Gas
WHO daily 15 µg/m^3	100	81	100	96	69	89	92	83	100	76	86	68	100	96

7.3 Which parameters have a statistical significant effect on the (indoor-attributed) NO_2, (highest 1-h) CO and $PM_{2.5}$ concentration?

Nitrogen dioxide (NO_2)
The statistical analysis is carried out on the total dataset with all countries pooled together. The parameter cooking method has the largest effect on the indoor NO_2 concentration. The NO_2 concentration in households cooking on gas is significantly higher than those cooking on electric. In households cooking on gas the indoor-attributed NO_2 concentration increases with longer daily average burner cooking time on the hob and /or gas oven. This increase is not visible for cooking on electric hobs. These findings correspond with research carried out in Californian homes[17].

Contrary to the Californian study[17], the European participants cooking on gas and reporting the use of a cooker hood ducted to outside do not have significant lower indoor-attributed NO_2 concentration. The indoor concentration of participants mentioning using hoods is even a slightly higher, although not significant. There was a small difference in cooking time per day: the group using a cooker hood used the gas hob or gas oven during 41.7 min/day and for those not using a hood 38.1 min/day. A similar non-significant increase has been measured during a intervention study in which range hoods have been placed in Baltimore City[18]. It was unclear if the lack of efficiency was due primarily due to lack of use of range hoods as this was similar to the present field study not monitored. In a German study[19] range hoods were only turned on during 29% of the cooking activities. In a Canadian study[20] only 10% of the cooking activities were conducted with a range hood in a population with more than 80% having a range hood. In 15% of the Canadian households participating in that study windows were opened during the cooking. These studies suggest that people do not always automatically switch on the range hood.

Surprisingly, there is a non-significant ($P=0.253$) increase of 3.4 $\mu g/m^3$ in the kitchen for participants reporting the use of a recirculation hood compared to those not using a cooker hood. Smaller also non-significant increases exist for the living room and the bedroom. These effects might be explained by the fact that these recirculation hoods equipped with activated carbon filters do only partly remove odours and also partly remove NO_2. Initially a new activated carbon filter can reduce the NO_2 peak concentration with 56 - 67%. However, after 19 days of use with artificial cooking in the lab this reduction dropped to only 19%[21]. The main purpose of the activated carbon filter is to remove odours. It is therefore likely that the odour removal efficiency is preserved longer than the NO_2 removal. If this is the case then the recirculation hood ‘masks’ the NO_2 pollution caused by cooking on gas by taking away the odour. By this effect the cook is less urged to open windows, causing a higher NO_2 concentration during and after cooking.
Another explanation might be that those cooking on gas and using a recirculation hood have an 11 minutes longer average cooking time per day compared to those cooking on gas and not using a cooker hood.

Although theoretically expected[1], kitchen volume and kitchen ventilation flow did not have a clear effect on the kitchen indoor-attributed NO_2 concentration.

With regard to the indoor-attributed NO_2 concentration one would expect that it would be close to zero for households cooking on electric. Median values close to zero for bedrooms in all-electric homes have been reported by Mullen[2]. Mullen has used a fixed infiltration factor of 0.4. Here we used the calculated air exchange rate for the kitchen and a literature[1] based deposition value. Based on the resulting mean indoor-attributed values of 7.9, 7.3 and 6.6 µg/m³ respectively for the kitchen, living room and bedroom in Table 6.2 it might be concluded that other unvented burning processes are present in households cooking on electric. This could be due to the burning of candles[22], but it might also be due to the presence of unvented or leaking gas appliances such as geysers and heating furnaces in these dwellings. The use of candles and the presence and use of these appliances has not been questioned in the recruitment screener. Another explanation for the relatively high mean indoor-attributed NO_2 value for households cooking on electric might be that be that the calculated air exchange rates are too low or the assumed deposition value is too high.

Carbon monoxide (CO)

A small but significant difference has been found for the mean CO concentrations between those participants cooking on gas and those on electric. However no statistically significant difference has been found for the CO highest 1-h value. This last result deviates from results obtained in the US where a significant difference has been found for the CO highest 1-hour value between homes cooking on gas and on electric[2]. The CO sensor sensitivity for alcohol might have affected the highest 1 h value.

Fine particulate matter ($PM_{2.5}$)

With regard to $PM_{2.5}$ no significant difference between houses cooking on gas and cooking electric could be distinguished. Surprisingly, the statistical analysis in paragraph 6.4 also does not show a significant effect of using a range hood ducted too outside. This may be caused by not turning on the range hood on time or turning off during cooking[20,23]. Further the capture efficiency largely depends on hood geometrics, exhaust flow and burner position[24,25].
A second explanation is that it was not possible to correct for the influence of the outdoor air $PM_{2.5}$ concentration as this has not been measured. Outdoor air can have an important effect on the indoor $PM_{2.5}$ concentration. In a recent Dutch study[14] in 268 dwellings during the heating season outdoor sources contributed for 59% to the indoor concentration. A third explanation is that the amount of $PM_{2.5}$ emitted during cooking depends on the cooking conditions: the cooking style and temperature, type of oil used and the fat content of the food[13]. These conditions may vary for each participant.

8 Conclusions & recommendations

8.1 Conclusions

1. *What are the concentrations of air pollutants – specifically, nitrogen dioxide (NO_2), carbon monoxide (CO) and fine particulate matter ($PM_{2.5}$) – released when cooking on gas compared to electric cooking in households across several European countries?*

For the concentration of the three air pollutants reference is made to Table 7.2 to Table 7.4.

Nitrogen dioxide (NO_2):
For six out of seven countries (all except Romania) a significant ($p < 0.05$) higher nitrogen dioxide (NO_2) concentration has been found in the kitchen for households cooking on gas compared to cooking on electric. Correcting for the outdoor concentration, also for the measured households in Romania a significant higher concentration in the kitchen and living room has been found for those cooking on gas compared to cooking on electric.

The highest average NO_2 concentrations in houses cooking on gas were found in the kitchen, these concentrations were even higher than outside. In contrast, in houses cooking on electric the indoor NO_2 concentrations were below the outside concentration.
Higher NO_2 concentrations in the living room in houses cooking on gas can be explained by the fact that many houses are equipped with an open kitchen. Pollutants emitted in the kitchen will then mix up in this open space. Bedrooms have the lowest concentration as they are usually furthest away from the kitchen and their doors are more likely to be closed. Furthermore, a ventilation system or an open window can supply outside air to the bedroom.

Carbon monoxide (CO):
In three out of seven countries a significant difference with regard to the mean and/or the highest 1 hour concentration between houses cooking on gas and cooking on electric could be distinguished with the Cairsens CO sensor. When taking all countries together a small but significant difference has been found for the mean CO concentrations between those cooking on gas and those cooking on electric. However no statistical significant effect has been found for the CO highest 1-h value. This result deviates from results obtained in a fieldstudy in the US where a significant difference has been found for the CO highest 1-hour value between homes cooking on gas and homes cooking on electric hobs.

A confounding factor in the current study is that the applied Cairsens CO sensor from ENVEA is sensible for ethanol and maybe also for other volatile organic compounds. During normal use of cleaning agents and by alcohol consumption this interference for ethanol can be significant. We assume that this interference is similar for households cooking on gas or on electric hobs, thus still making a comparison of average concentrations meaningful.

Fine particulate matter ($PM_{2.5}$):
Table 1.3 lists per country the average kitchen fine particulate matter ($PM_{2.5}$) concentration. It ranges between 8.7 and 38 μg/m^3. Taking all country data together with regard to $PM_{2.5}$ no significant difference between houses cooking on gas and cooking electric could be distinguished. This is consistent with the fact that gas burners emit a negligible amount of $PM_{2.5}$ compared to the emissions from the cooking ingredients. During cooking $PM_{2.5}$ is mainly formed due to evaporation of the oil and ingredients in the pan. Thus if the same pan temperature and cooking practice is used, cooking food with a gas hob or with an electric hob is expected to emit a similar amount of $PM_{2.5}$. The significant higher $PM_{2.5}$ concentration in Italy for households cooking on gas can be explained with a longer cooking duration for these households compared to the households cooking on electric hobs.
Also here the outdoor concentration may have an effect, however this concentration has not been measured. We assume that this interference is similar for households cooking on gas or on electric hobs, thus still making a comparison of average concentrations meaningful. Furthermore, aside cooking also other indoor sources of $PM_{2.5}$ may contribute to the $PM_{2.5}$ concentration.

2. *Do European households cooking on gas exceed the relevant WHO and EU limit concentrations of air pollutants more often than households cooking electric?*

For the exceedance of limit and guideline values reference is made to Table 7.5 to Table 7.7.

Nitrogen dioxide (NO_2):
In none of the kitchens of households cooking on electric the WHO hourly guideline value or the EU 1 h limit value of 200 μg/m^3 has been exceeded. In contrast, in all seven countries the WHO hourly guideline value for NO_2 of 200 μg/m^3 was exceeded in kitchens of households cooking on gas. The exceedance of the EU 1h limit value is lower than the WHO exceedance as it is based on the average concentration during clock hours[5], whereas the WHO guideline value is interpreted as a 1- hour moving average concentration. In all seven countries the majority of the households cooking on gas do exceed the WHO daily guideline value of 25 μg/m^3, while in 5 countries households cooking electric do not have any exceedance at all. The exceedances of the daily guideline value in the Netherlands and Spain for houses cooking with electric hobs may partly be caused by opening windows and the relatively high outdoor concentrations during the measurement period in these two countries, with mean ambient concentrations of 21 and 27 μg/m^3, respectively.

Carbon monoxide (CO):
No exceedances of the 8-h and 1-h WHO CO guideline value (10 and 35 mg/m^3, respectively) have been recorded in household cooking on gas or electric hobs. None of the households cooking electric exceeded the daily WHO CO guideline value of 4 mg/m^3. Whereas four of all the households cooking on gas did exceed this guideline value. However, as mentioned earlier the applied Cairsens CO sensor from ENVEA is sensible for ethanol and maybe also for other volatile organic compounds. During normal use of cleaning agents and by alcohol consumption this interference for ethanol can be significant. The reported values may therefore include the presence of ethanol. As a consequence the real CO value might be lower than the measured value and maybe stay under the daily guideline value.

Fine particulate matter ($PM_{2.5}$):

[5] E.g. the average concentration between 18.00 and 19.00 hour.

In all countries the majority (68% -100%) of the investigated households exceeds the daily WHO guideline value of 15 µg/m^3, independently of households cooking on gas or electric hobs. The outdoor concentration may have contributed to the exceedance, however this concentration has not been measured. Part of the exceedance in the kitchen can be explained by $PM_{2.5}$ emission during cooking. These results confirm the need for providing effective cooking exhaust above cooking areas.

3. *Which parameters have a statistical significant effect on the (indoor-attributed) NO_2, (highest 1-h) CO and $PM_{2.5}$ concentration?*

Cooking method
There is a significant ($p<0.001$) difference in the kitchen NO_2 concentration between households cooking on gas and cooking electric. The NO_2 concentration in kitchens cooking on gas hobs is almost 13 µg/m^3 higher than those cooking on electric hobs.
A small but significant difference has been found for the mean CO concentrations between those participants cooking on gas and those on electric. However, no statistical significant difference has been found for the CO highest 1-h value. The CO sensor sensitivity for alcohol might have affected the highest 1-h value.
With regard to $PM_{2.5}$ no significant difference between houses cooking on gas and cooking electric could be distinguished.

Cooking time
In households cooking on gas the indoor-attributed NO_2 concentration increased with longer daily average burner cooking time on the hob and /or gas oven. This increase was not visible for cooking on electric hobs.

Presence of a gas oven
There is an almost significant ($p=0.074$) difference in NO_2 concentration in houses with and without a gas oven. In houses with a gas oven the indoor-attributed NO_2 concentration in the kitchen was 4 µg/m^3 higher.

Presence and type of cooker hood
Surprisingly, participants cooking on gas and reporting the use of a cooker hood ducted to outside did not have a significant lower indoor-attributed NO_2 or a lower $PM_{2.5}$ concentration. Participants mentioning using a recirculation hood had even a non-significant higher concentration for these two pollutants compared to those reporting not using a cooker hood.

Kitchen volume & ventilation flow
Although theoretically expected, kitchen volume and estimated kitchen ventilation flow did not have a clear effect on the kitchen indoor-attributed NO_2 concentration.

8.2 Recommendations

Promote electric cooking
The largest reduction of the NO_2 concentration indoors can be reached by switching from cooking on gas to electric cooking. This can be input for requirements in both the EU and UK law that necessitate domestic applicances to prevent exposure of users to harmful levels of indoor air pollution.

Promote effective and user friendly kitchen range hoods and ventilation provisions
In all countries the majority (68% -100%) of the investigated households exceeded the daily WHO $PM_{2.5}$ guideline value of 15 µg/m^3, independently of households cooking on gas or electric hobs. A part of the exceedance is caused by outdoor infiltration. Since cooking on electric burners, especially during frying, also produces $PM_{2.5}$ effective and user friendly kitchen range hoods should be available in all homes and operated as precaution whenever cooking occurs. As range hoods are often not switched on, or switched on too late, automated controll should be stimulated. Further the capture efficiency should be sufficiently large, e.g. 75%. This requires an efficient hood geometry and a sufficient high exhaust flow rate without causing discomfort due to noise. Conditioned make up air through to well designed providisions, must be provided to prevent discomfort from draft. Legislation with regard to ventilation provisions (both for suply and exhaust of air) should be initiated to make sufficient capture efficiency in dwellings possible.

9 Limitations

Measurement period of 13 days

Due to the 13 days measurement period it was possible to compare the measurement data with hourly and daily limit values. However it was not possible to make a comparison with the NO_2 and $PM_{2.5}$ yearly limit values. Extrapolating the data of the 13 days measurement period may lead to too high estimates as a large part of the measurements have been carried out in the heating season. The first measurement period started in the Netherlands on January 27, 2023. Italy and Spain started on March 3, 2023. France and Slovakia started on April 7, 2023 and UK and Romania started on May 12, 2023. In the non-heating season due to higher temperatures more ventilation may occur due to additional opening of windows and doors, leading to dilution of cooking contaminants and thus lower concentrations. Due to the difference in outdoor temperature between countries the hourly and daily value can be biased by the outdoor temperature. This limits the possibility to make a direct comparison of contaminant concentrations between countries. However it still allows to make a comparison between cooking on gas and cooking on electric.

Active NO_2 sensor

The measurement range of the active sensor for NO_2 is limited to 250 ppb = 478 µg/m^3. This limitation may lead to an underestimation of the number of hours/days exceedance of WHO and EU guideline and limit values. As in some houses the NO_2 concentration during and after cooking on gas is higher than the measurement range, this limitation may (partly) explain the difference between the kitchen active and passive sensor results as shown in Appendix B. This is supported by the results in e.g. Table 5.2 that show that in the houses with electric cooking, where the concentrations are well below 250 ppb, the difference between active and passive sensors is much smaller than in houses cooking on gas.

Active CO sensor

The measurement range of the CO sensor is limited to 20 ppm = 23,3 mg/m^3. In a small number of houses this limit is reached. In these houses the real CO concentration may be higher than measured by the senor. On the other side the ENVEA Cairsens CO sensor is sensitive for at least ethanol and maybe also be sensible for other volatile organic compounds (see Appendix F). This limits the practical application of this sensor for indoor application as many cleaning agents used in the kitchen as well as alcoholic drinks contain ethanol. We assume that this interference is similar for households cooking on gas or on electric hobs, thus still making a comparison of average concentrations meaningful.

Determination of cooking activity

The participants placed the temperature sensors at their cooking equipment, by themselves according to instructions prepared by the project team both through a video and in written form. However the geometry of the cooking hob may be such that it is not possible to determine cooking activities on all burners. Further the temperature sensors may have been placed in such a way that they are too far off to detect temperature increase during cooking. This may have had an effect on the statistical analysis that assessed the relation between cooking time and concentrations, with the likelihood of being less significant. On the other hand it does not have an effect on the overall conclusions of the study with regard to research question 1 and 2 as cooking activity and duration is not being used there.

Self-reported housing characteristics

Housing and installation characteristics such as kitchen volume and type of exhaust hood are self-reported. This may give deviations between participants due to interpretation differences. For instance what is the kitchen volume in case of an open kitchen? Or what is the kitchen volume if the kitchen is irregularly shaped? This does not have an effect on the conclusions with regard to research question 1 and 2. However it may have affected the statistical analysis of which parameters have a statistically significant effect on the concentrations.

Use of ventilation provisions in diary

The use of cooker hoods has been based on the information that the participants supplied during the recruitment phase. In the questionnaire a further specification could be made in what type of hood they were using: ducted to outside or recirculation. During the study the participant could fill in a daily diary what kind of ventilation they did use during cooking in the morning (breakfast), afternoon (lunch) and evening (dinner). For our field study we were not able to automatically extract this data about window opening in the kitchen, use of the exhaust hood, local extraction fans or use of a whole house ventilation system during the preparation of meals in the 13 day period. Only a minority of the participants did use the diary's multiple choice predefined answers: A, B, C or D. The majority made up their own text answer in the open text box field, or in some cases added a photograph of their cooking hob instead of the requested photo indicating use of ventilation provisions. This hampered the analysis of these data. Based on the current analysis we therefore could not include the reported use of ventilation provisions during cooking based on the diary as a parameter in the statistical analysis in chapter 6.

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Signature

TNO › Mobility & Built Environment › Delft, 28 September 2023

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Regien Kroeze Research manager	Piet Jacobs Author

Appendix A
Measurement data per participant

Per country a summary of the self-reported data, the estimated hob use, the kitchen air change rate and the average NO_2, CO and $PM_{2,5}$ concentration during the measurement period is given. Further the number of exceedances of WHO guideline and EU limit values during the measurement period has been given.

Excluded participants are not listed in the table. In case no or not sufficient data has been obtained the cell is empty. See appendix E for an overview of excluded concentration data.

Based on the exceedance of WHO guideline and EU limit values the following color coding to each participant has been applied:

- Green: no exceedance of WHO guideline and EU limit values for NO_2, CO or $PM_{2.5}$;
- Yellow: exceedance of one or more WHO daily guideline values for NO_2, CO or $PM_{2.5}$;
- Orange: exceedance of WHO hourly NO_2 guideline value.

Note: for a number of participants a green color code has been applied while concentration data for one or two of the three contaminants are missing e.g. due to malfunctioning equipment or a too short measurement period. A green code does therefore not exclude the possibility that the concentration(s) for these missing contaminants were above the WHO guideline and EU limit values.

The exceedance of the WHO guideline values and EU limit value is primarily based on the active sensors. There are a limited number of households for which the passive NO_2 concentration in the kitchen is above 25 µg/m³, indicating that during at least one or more days the daily average value has been exceeded.

The Netherlands

Part. nr.	Gas (G) / Electric (E)	Estimated hob use [min/day]	Kitchen volume [m³]	Air change rate [1/h]	Hood	Average NO_2 [µg/m³]					NO_2			CO			$PM_{2.5}$	
						Kitchen active	Kitchen passive	Living room	Bed room	Out side	# days above 25 µg/m³	# hours above 200 µg/m³ WHO	# hours above 200 µg/m³ EU	Average	# days above 4 mg/m³	# 8 hour periods above 10 mg/m³	Average	# days above 15 µg/m³
NL01	electric	48	20	0,3	NU	9,1	8,4	9,9	9,4	20,4	0	0	0	0,7	0	0		
NL02	gas	40	50	0,45	NU					27.3				0,5	0	0	9,4	1
NL03	gas	33	16	0,22	NU	19,7	27,1	22,5	23,3	30,3	5	6	4	0,9	0	0	44,6	8
NL04	gas	21	65	0,3	HO	6,7	15,2	15,1	10,7	23,1	0	0	0	0,3	0	0	4,8	0
NL05	gas	7	34	1,12	NU	20,6	20,7	19,5	19,6	27,5	4	0	0				7,6	1
NL06	gas	0	25	0,45	NU	12	12,8	11,3	9,5	6,7	0	0	0				12,4	3
NL07	gas	29	84	0,25	NU	12,5	19	18,6	30	19	0	0	0	0,3	0	0	12,7	4
NL08	gas	25	14	0,36	HO	14,3	17,9	16,2	18,6	22,2	1	2	1	0,3	0	0	8,1	1
NL09	gas	33	101	0,38	NU	26,1	36,4	32,6	17,3	24,8	6	4	3				4,3	0
NL10	electric	84	16	0,46	NU		7,6	7,9	7,6	20,9							13,6	6
NL11	gas	23	10		NU	33,6	42,9	33,9	14,8	32,7	11	1	1	1,2	0	0		
NL12	gas	19	91	0,37	NU	14,9	21	20,5	15,6	23,2	1	1	0	0,3	0	0	5,7	1
NL13	gas	9	23	0,39	NU	13,6	15	15,2	12,8	18,9	0	0	0	0,1	0	0	7,2	1
NL15	electric	15	131	0,39	NU	8,5	11,1	12,9	7,2	15,5	0	0	0	0,4	0	0	11,8	4
NL16	gas	29	20	0,34	NU	15,1	22,4	20,1	19,2	21,6	0	0	0	0,5	0	0		
NL17	gas	38	21	0,26	HO	23,7	35,1	36	18,9	19,5	4	0	0	0,6	0	0	11,5	3
NL18	gas	45	112	0,27	HO	14,6	19,5	17,8	12,5	25	0	1	1					
NL19	electric	26	19	0,21	HO	9,5	9,3	9,3	13,1	22,7	0	0	0	1	0	0	7,5	1
NL20	gas	27	23	0,35	HO	12,9	17,2	17,3	7	20,6	0	0	0	0,8	0	0		

RH = hood based on recirculation, HO = hood venting to outdoor, NU = not used or not having an extraction hood

Part. nr.	Gas (G) / Electric (E)	Estimated hob use [min/day]	Kitchen volume [m³]	Air change rate [1/h]	Hood	Average NO_2 [µg/m³]					NO_2			CO			$PM_{2.5}$	
						Kitchen		Living room	Bed room	Out side	# days above 25 µg/m³	# hours above 200 µg/m³		Aver age	# days above 4 mg/m³	# 8 hour periods above 10 mg/m³	Aver age	# days above 15 µg/m³
						active	passive					WHO	EU					
NL21	gas	61	69	0,42	HO	28	34,4	29,5	22,2	25,2	7	0	0	0,5	0	0		
NL22	gas	52	19	0,27	HO	23,6	28,1	24,4	7,3	16,2	4	0	0	0,5	0	0	6,8	0
NL23	gas	18	16	0,54	HO	36,2					7	12	9	1	1	0	13,9	4
NL24	gas	18	26	0,33	NU	17,2	22,5	22,2	16,5	30,9	1	0	0	0,3	0	0	25,2	7
NL25	gas	6	32	0,12	NU		12,6	12,3	9,9	34,2				0,4	0	0		
NL26	gas	42	112	0,36	NU	16,1	24,7	28	12,9	14,9	2	1	1	0,6	0	0	23,7	9
NL27	gas	26	15	0,48	HO	6,3	12,4	8,1	7,3	16,2	0	0	0	0,7	0	0		
NL28	gas	34	21	0,22	HO	20,3	24,4	15,5	20,8	23,1	3	0	0				17,4	7
NL29	gas	18	148	0,44	HO	10,5	13,7	13,6	10	17,5	0	0	0	0,2	0	0	10,4	2
NL30	electric	49	32	0,49	HO	10,1	12	12,2	13	19,2	0	0	0	0,4	0	0	10,5	3
NL31	electric	62	130	0,2	HR		15,3	14,8	16,4	32,2				0,5	0	0	23,2	5
NL32	gas	22	148	0,35	HR		17,2	17,3	10,8	16,3				0,5	0	0	6,6	0
NL33	electric	28	88	0,24	HO	7,5	5,4	5,6	6,2	14,3	0	0	0	0,4	0	0	12,9	2
NL34	gas	38	15	0,51	HO	13	15,4	15,1	7,1	10,7	0	0	0	0,3	0	0	14,3	5
NL35	gas	2	18	0,34	HO	7,9	9,7	9,6	5,4	17,9	0	0	0	0,4	0	0		
NL36	gas	26	65		HO	14,5	18,9	16,4	13,5	25,6	0	0	0	0,4	0	0	9,7	3
NL38	gas	54	107	0,28	NU	21,6	46,4	49,2	36,1	30,1	6	0	0	1	0	0	19,3	6
NL40	electric	15	163	0,37	HO	19,4	24,8	25,6	16,2	24,9	3	0	0	0,3	0	0	16,1	6

HR = hood based on recirculation, HO = hood venting to outdoor, NU = not used or not having an extraction hood

Italy

Part. nr.	Gas (G) / Electric (E)	Estimated hob use [min/day]	Kitchen volume [m³]	Air change rate [1/h]	Hood	Average NO_2 [µg/m³]					NO_2			CO			$PM_{2.5}$	
						Kitchen active	Kitchen passive	Living room	Bed room	Out side	# days above 25 µg/m³	# hours above 200 µg/m³ WHO	# hours above 200 µg/m³ EU	Average	# days above 4 mg/m³	# 8 hour periods above 10 mg/m³	Average	# days above 15 µg/m³
IT01	gas	85	20		NU			13	23	15,2								
IT02	gas	38	26	0,07	HO		28,2	26,4	20,6	11,3				2,1	1	0	93,2	10
IT03	gas	47	29	0,12	HR	30,2	47,3	33,8	18,5	22,8	10	15	8	1,6	0	0	24,7	11
IT04	gas	84	8	0,34	HR	23,1	38,3	19,8	15,6	18,2	5	0	0				13,4	3
IT05	gas	92	12		HR	25,2	43,2	46,2	34,5	29,4	9	0	0	1,8	0	0	43,6	13
IT06	gas	49	84	0,22	HO	19,5	27,7	32,7	18	20,3	0	0	0				17,1	9
IT07	gas	40		0,16	HO	15,1	31,3	27	21,6	43,3	0	0	0	6,2	7	0	49,4	8
IT08	gas	34	73	0,14	HO	48,6	52	49	40	14,5	12	3	3	1,4	0	0	51,7	10
IT09	electric	2	24		HO		12,4											
IT10	gas	89	32	0,42	HO		25,9	24,9	8,8	14,9							11,4	2
IT11	gas	39	18	0,42	HO	19,3	26,2	25,8	21,5	26	1	1	1	0,7	0	0	12,8	5
IT12	electric	34	28	0,27	HO		11,3	11,2	9,6	25,7							4,6	2
IT13	gas	117	18		HR	35,3	59,7	32,3	30,1	8,2	14	0	0	1,2	0	0		
IT14	gas	46	101	0,46	HO	24,5	31,8	29,8	23,2	17,8	5	0	0	0,6	0	0	40,4	12
IT15	gas	132	11		HR		67,4	39,1	43,8	32,3								
IT17	electric	26	98	1,27	HR	13,6	10,8	10,6	11,7	28,7	0	0	0				8,5	3
IT18	electric	19	66	0,18	HR		7,2	7,2	6,4	6,6				1	0	0	14,4	2
IT19	gas	128	32	0,59	HR	27,7	40,3	32,9	27,8	26,3	10	0	0				11,6	1

RH = hood based on recirculation, HO = hood venting to outdoor, NU = not used

Part. nr.	Gas (G) / Electric (E)	Estimated hob use [min/day]	Kitchen volume [m^3]	Air change rate [1/h]	Hood	Average NO_2 [µg/m^3]					NO_2			CO			$PM_{2.5}$	
						Kitchen		Living room	Bed room	Out side	# days above 25 µg/m^3	# hours above 200 µg/m^3		Aver age	# days above 4 mg/m^3	# 8 hour periods above 10 mg/m^3	Aver age	# days above 15 µg/m^3
						active	passive					WHO	EU					
IT20	electric	34	97	0,22	HO	8	8,4	8,9	24,5	7,7	0	0	0	0,9	0	0	7,2	1
IT21	gas	25		0,11	HO	16,8	21,1	15,6	13,3	18,2	0	0	0	2,6	0	0	15	6
IT22	gas	71	29	0,21	HO	26	31,8	27,8	24,9	30,9	5	0	0				67	12
IT23	gas	104	18	0,46	HR	17,8	29,7	22,7	24,2		1	0	0	1,2	0	0	9,1	2
IT25	gas	58	46	0,32	HO	24	19,4	15,7	8,9	4,2	6	0	0	0,9	0	0	3,7	0
IT26	gas	98	66	1,31	HO	20,2	35,3	35,5	16,4	6,2	1	0	0	0,7	0	0	13	5
IT27	gas	138	146	0,44	HR	23	28,4	23,5	22,7	5,9	5	0	0				15,1	5
IT30	gas	22	135		HO		24,6	23,5	18,7	25,9								
IT31	gas	38	158		HO	14,3	18,1	18,4	15,1	25,7	0	0	0	0,8	0	0		
IT32	gas	42	81	0,16	HR		18	20,5	9,8	18,3				1,4	0	0	32,8	13
IT33	gas	94	36	0,41	HR	42,5	52,6	43,8	38	26,5	14	7	7	1,3	0	0	51,4	11
IT34	gas	50	120	0,21	HR	28,5	36,4	37,9	24,6	23,7	7	1	0	1,4	0	0	25,7	9
IT35	gas	34	108	0,16	HR	13,5	18,7	16,8	15	19	0	0	0				46,4	6
IT36	gas	55	30	0,17	HO	13,3	19,6	18,7	11,4	9,6	0	0	0	2	0	0	9,8	1
IT37	gas	30	82	0,1	HR	11,9	17,6	17	8,7	48,2	0	0	0				9,7	3
IT38	gas	60	36	0,12	HO	15,2	21	18,5	18,2	24,9	1	0	0	1,4	0	0	14,5	4
IT39	gas	58	84	0,16	HR	25,9	32,7	19,4	18,3	13,2	8	2	2				23,2	9
IT40	gas	64		0,26	HR	36,1	39,9	28,8	28	28,3	11	2	1				9,5	1

HR = hood based on recirculation, HO = hood venting to outdoor, NU = not used

Spain

Part. nr.	Gas (G) / Electric (E)	Estimated hob use [min/day]	Kitchen volume [m³]	Air change rate [1/h]	Hood	Average NO_2 [µg/m³]					NO_2			CO			$PM_{2.5}$	
						Kitchen		Living room	Bed room	Out side	# days above 25 µg/m³	# hours above 200 µg/m³		Aver age	# days above 4 mg/m³	# 8 hour periods above 10 mg/m³	Aver age	# days above 15 µg/m³
						active	passive					WHO	EU					
ES01	electric	53	101		HO	22,1	19,9	19,5	13,9	88,2	2	0	0					
ES02	electric	26	20	0,18	HO	18,2	21,5	23,2	16,1	22,3	2	0	0	1	0	0	9,2	0
ES03	electric	81	38	0,35	HR		13,8	16,7	14,8	16,2							6,6	0
ES04	electric	27	16	0,2	HO	12,4	12,5	15,9	13,6	18,2	0	0	0	0,5	0	0	19,3	8
ES05	gas	48	25	0,55	EF	34,6	26,1	27,3	17	13,4	13	3	2	0,6	0	0	12,7	3
ES06	gas	15	52	0,47	NU	21,7	27,9	27,5	7	9,6	4	2	2				13,4	4
ES07	electric	27	150		HO		29,9	33,7	29,7	27,6				0,3	0	0		
ES08	electric	67	23	0,47	HO	20,6	21,7	20,1	17,8	34,9	2	0	0	0,3	0	0	4,3	0
ES09	electric	61	34	0,37	HO		13,3	11,3	10,9	8,2							47,4	10
ES10	gas	39	24	0,4	HO		27,5	25	26	24,5				0,4	0	0	30,9	9
ES11	gas	68	22	0,22	HO	51,8	51,5	33,5	37,4	34,3	14	1	0	0,9	0	0	66,7	9
ES12	electric	26	15	0,23	HO	11,3	14	13,8	22,8	14,7	0	0	0				15,8	6
ES13	Gas	73	81	0,36	HO	38,7	29,2	34,1	28,9	30,9	9	3	1	0,8	0	0	6,5	0
ES14	Gas	41	12		HO	37,1	23,5	18,3	16	30,5	9	10	8	0,7	0	0		
ES15	electric	63	38	0,35	HO	5,3	19,4	17,5	15,7	29,5	0	0	0	1,1	0	0	6,8	0
ES16	Gas	78	15	0,11	HO	39,7	54	51,3	40,3	28	13	4	4				24,4	11
ES17	Gas	68	18	0,38	HO	29,5	42,9	35,1	36,6	27,3	9	2	2	0,8	0	0	44,3	11

HR = hood based on recirculation, HO = hood venting to outdoor, EF = exhaust fan, NU = not used

Part. nr.	Gas (G) / Electric (E)	Estimated hob use [min/day]	Kitchen volume [m³]	Air change rate [1/h]	Hood	Average NO_2 [µg/m³]					NO_2			CO			$PM_{2.5}$	
						Kitchen		Living room	Bed room	Out side	# days above 25 µg/m³	# hours above 200 µg/m³		Aver age	# days above 4 mg/m³	# 8 hour periods above 10 mg/m³	Aver age	# days above 15 µg/m³
						active	passive					WHO	EU					
ES18	Electric	38	25	0,33	HO		13	10,6	12,8	23,5				0,4	0	0	6,9	2
ES19	Gas	44		0,19	HO		14,1	14,4	7,1	25,8							30,1	8
ES20	Electric	25	20	0,45	HO	22,7	29,5	27,1	25,2	26,1	5	0	0	0,3	0	0	12	3
ES21	Electric	43	122	0,21	HO		12,7	12,2	11	31,8							19,8	9
ES22	Electric	35	32	0,16	HO	15,1	15,8	16,2	11,9	8,5	0	0	0				16,7	5
ES23	gas		14		HO	27,6	38,5	39,3	33,1	22,1	8	0	0	0,7	0	0		
ES24	electric	28		0,55	HO		21,2	14,3	15,4	24,3							9,7	4
ES25	gas	34	16	0,21	NU	22,4	34,5	20,3	14,4	19,7	4	3	3				22,4	12
ES26	gas	52	21	0,31	HO	12,3	18,8	14,9	15,7	12,6	0	0	0	0,5	0	0	37,1	9
ES27	gas	47	27	0,65	HO	41,9	42,5	32,2	24,7	39,1	14	3	3	1	0	0	42,2	12
ES28	electric	29	12		HO	18,8	19	18,8	16,1	15,1	1	0	0	0,4	0	0		
ES29	gas	84	14	0,18	HO	36,8	49,4	44,2	29,9	23,6	12	2	2	3,2	1	0	14,5	6
ES31	electric	33	72	0,22	HO		18,2	12,4	6	28,7							16,5	5
ES32	electric	26	26	0,59	HO	32,3	23,5	22,8		23,2	13	0	0	0,5	0	0	13,2	3
ES33	gas	75	72	0,21	HO	17,4	12,6	9,8	8,6	7	0	0	0	0,4	0	0	6,1	1
ES34	electric	19	58	0,17	HO	12,8	20,7	21	19,5	37,2	0	0	0	1,6	0	0	52,8	11
ES35	electric	9	14	0,13	HO		12,1	11	10,3	29,1							5,1	0

HR = hood based on recirculation, HO = hood venting to outdoor, NU = not used

France

Part. nr.	Gas (G) / Electric (E)	Estimated hob use [min/day]	Kitchen volume [m³]	Air change rate [1/h]	Hood	Average NO_2 [µg/m³]					NO_2			CO			$PM_{2.5}$	
						Kitchen		Living room	Bed room	Out side	# days above 25 µg/m³	# hours above 200 µg/m³		Aver age	# days above 4 mg/m³	# 8 hour periods above 10 mg/m³	Aver age	# days above 15 µg/m³
						active	passive					WHO	EU					
FR02	gas	0	195	0,27	NU												94,1	13
FR03	gas	53	45	0,44	HO	6,3	20,8	16,8	9,3	15	0	0	0				98,4	11
FR04	electric	58	21	0,36	HR	9	11,8	11,9	11,8	15,1	0	0	0				17,7	6
FR05	gas	49	35		NU		17	17,5	10,5	11,9							50	9
FR06	gas	21	45	0,74	HO		17,9	15,9	12,8	11,3							10,2	3
FR07	gas	64	24	0,43	HO	18,2	19,1	19,2	17,3	28,2	2	0	0	0,4	0	0	9	3
FR08	gas	25	210	0,24	HO	15,5	13,1	13,4	4,2	9,5	0	0	0	0,6	0	0	7,7	2
FR10	gas	29	52	0,15	NU	27	33	33,9	13,2	13,8	9	1	1				42,7	11
FR11	gas	22	162	0,22	HO	14,3	16,9	16,5	13,3	16,2	0	0	0				6,2	0
FR12	gas	7	24	0,28	NU	14,6	11,7	10,6	9,9	10,6	0	0	0	0,6	0	0	12,6	5
FR14	electric	65	45	0,24	NU	11,8	8,3	7,5	7,3	6,3	0	0	0				12,7	2
FR15	gas	15	44	0,5	HO	17,3	8,5	7,7	7,5		0	0	0	0,3	0	0	39,2	7
FR17	electric	16	80	0,07	NU		10,6	10,8	10,7	12,2							7,1	2
FR18	gas	56	209	0,23	HO	23,1	12,9	23,8	23,7	8,6	4	0	0				5,3	0
FR19	gas	18	69	0,48	NU	11	10,8	8,6	7,5	4,1	0	0	0				23,4	5
FR20	gas	16	51	0,17	NU		8,8	19,2	11,4	12,1							11,1	2
FR21	gas	19	17	0,49	HR	9,6	12,3	12	10,1	7,6	0	0	0	0,1	0	0	6,8	0
FR22	electric	8	97	0,27	HR	11,9	8,6	8,4	7	9,8	0	0	0				6,5	0

HR = hood based on recirculation, HO = hood venting to outdoor, NU = not used

Part. nr.	Gas (G) / Electric (E)	Estimated hob use [min/day]	Kitchen volume [m³]	Air change rate [1/h]	Hood	Average NO_2 [µg/m³]					NO_2			CO			$PM_{2.5}$	
						Kitchen		Living room	Bed room	Out side	# days above 25 µg/m³	# hours above 200 µg/m³		Aver age	# days above 4 mg/m³	# 8 hour periods above 10 mg/m³	Aver age	# days above 15 µg/m³
						active	passive					WHO	EU					
FR23	gas	20	58	0,16	HO	16	22,4	17,1	17,1	8	0	0	0	0,5	0	0	7,7	2
FR24	electric	23	30		HO	6,5	7,5	7,4	6,5	8,8	0	0	0	0,5	0	0		
FR25	gas	53	39	0,38	NU	22,1	23,8	20,1	9,9	17,6	4	0	0				11,4	4
FR26	gas	58	49	0,44	NU	23,7	22,5	17	16,3	12,3	4	2	2				15,2	3
FR28	gas	13	30	0,32	HO		15,4	14,4	14,6	15,5		6					12,8	2
FR29	gas	81	10	0,82	HO	38,5	45,8	38,3	40,2	20,4	14	3	1	2,6	0	0	25,6	10
FR30	gas	17	84	0,35	HR	24,2	22,5	23,7	24,5	21,1	5	0	0				14,5	3
FR31	electric	27	72		NU	14,3	13,2	12,6	10,9	15,1	0	0	0	0,8	0	0		
FR32	gas	117	19		HR	40,2	53,1	38,7	46,3	21,4	7	2	1					
FR33	electric	51	54	0,45	HR		12,1	9,6	9,7	13,9							18,2	5
FR34	electric	30	31	0,33	HO		14,7	14,9	14,5	24,3							13,4	4
FR35	gas	46	211	0,28	NU	14,2	18,6	15,3	12,9	10,1	0	0	0	0,7	0	0	14,6	5
FR36	gas	11	10	0,35	NU		6,3	5,6	3,5	4,6							3,3	0
FR37	electric	26	15	0,4	NU		14,1	15,9	13,4	22,1							9,7	3
FR38	gas	58	44	0,17	HR	25,3	34,6	24,8	17,9	12,8	5	4	3				38,2	9
FR39	electric	12	37	0,23	HR	12,6	8,6	9	8,7	12,7	0	0	0				19	5
FR40	electric	33	35	0,37	HO	12,1	13,3	14,5	13,1	5,6	0	0	0				56,9	14

HR = hood based on recirculation, HO = hood venting to outdoor, NU = not used

Slovakia

Part. nr.	Gas (G) / Electric (E)	Estimated hob use [min/day]	Kitchen volume [m³]	Air change rate [1/h]	Hood	Average NO_2 [µg/m³]					NO_2			CO			$PM_{2.5}$	
						Kitchen		Living room	Bed room	Out side	# days above 25 µg/m³	# hours above 200 µg/m³		Aver age	# days above 4 mg/m³	# 8 hour periods above 10 mg/m³	Aver age	# days above 15 µg/m³
						active	passive					WHO	EU					
SK01	gas	47	25		HO	14,7	15,7	9,9	8,8	9,3	1	1	0					
SK02	electric	56	14		HO	5,5	6	5,9	5,6	5	0	0	0					
SK03	electric	56	69	0,17	HO	9,4	5,3	5,1	3,4	6,1	0	0	0	1,1	0	0	13,1	3
SK04	electric	60	131	0,1	NU	10	3,9	4,1	5,7	4,3	0	0	0	0,6	0	0	51	11
SK06	gas	38	162	0,1	NU	12,2	9,7	9,8	8,1	12,3	0	0	0				7,1	2
SK08	electric	41	22	0,25	NU	10,3	3,7	3,8	3,4	3,3	0	0	0				17,3	7
SK09	gas	71	38	0,23	HO		33,6	28,7	14,9	10,7				2,3	0	0	16,5	7
SK11	electric	72	150		NU	13,3	3,2	2,9	2,7	7,9	0	0	0	0,5	0	0		
SK12	gas	54	76	0,18	NU	15,5	19	18,2	11,7	9	1	0	0				14,6	5
SK13	gas		28		HR	16,1	22,3	16,6	13,1	10,6	0	0	0	1,4	0	0		
SK14	gas	30	21		HR	4,6	12,5	11,6	8,8	12,8	0	0	0					
SK15	gas	46	91	0,13	HO	12,3	25,9	25,8	19,1	8	0	0	0				7,2	0
SK16	gas	6	22	0,22	HR	16,4	12,7	12,8	9,4	7	0	0	0				5,9	0
SK17	gas	20	22	0,24	NU	4,3	7,6	4,8	7,6	10,4	0	0	0				8,1	1
SK18	gas	40	25	0,19	HR		28,1	19,5	20	17,3		0		1,3	0	0	6,6	2
SK19	gas	40	14	0,19	HR	16,2	17,3	13,4	11,1	18,8	0	0	0	1	0	0	14,3	4
SK20	gas	22	31	0,26	HO	12,4	13,7	12,7	13,2	12,3	0	0	0	0,5	0	0	6,9	0
SK21	gas	34	24		HO	14,9	17,4	14	13	13,5	0	0	0	0,6	0	0		

HR = hood based on recirculation, HO = hood venting to outdoor, NU = not used

Part. nr.	Gas (G) / Electric (E)	Estimated hob use [min/day]	Kitchen volume [m³]	Air change rate [1/h]	Hood	Average NO_2 [μg/m³] Kitchen active	Kitchen passive	Living room	Bed room	Out side	NO_2 # days above 25 μg/m³	# hours above 200 μg/m³ WHO	EU	CO Average	# days above 4 mg/m³	# 8 hour periods above 10 mg/m³	$PM_{2.5}$ Average	# days above 15 μg/m³
SK22	gas	67	21	0,04	HO	12,6	17,8	14,5	8,5	8,6	0	0	0				5,5	0
SK23	gas		22	0,25	NU	28,2	39,8	18	16,6	11,7	10	0	0	1,9	0	0	97,9	10
SK24	gas	25	22	0,16	HO	12,6	12,7	8,3	9,2	8,3	0	0	0				14,2	3
SK25	gas	39	36	0,21	NU		16,2	13	9,7	6,2							16,3	7
SK26	gas	48	23	0,96	HO	14,5	22	16	15,4	9,9	0	0	0				39,9	14
SK27	gas	35	52	0,17	NU	28,8	31,6	31	25,9	34,5	5	7	7				51,1	14
SK28	gas	13	168	0,23	NU	11	11,5	11,3	10,7	16,8	0	0	0	2,8	0	0	10,6	0
SK29	gas	28	15	0,08	HO	16,6	20,4	13,7	10,9	11,4	1	0	0	0,8	0	0	7,9	3
SK31	gas	66	40	0,2	NU	7	6,8	6,8	4,7	4,6	0	0	0				24,1	10
SK32	gas	33	25	0,05	NU	30,2	14,7	13,2	11,2	12,6	14	0	0	1,6	0	0	11,1	4
SK34	gas	43	23		NU	17,9	24,5	25,3	24,9	14,3	1	0	0					
SK35	gas	19	90	0,13	NU	14	17,1	18,2	11,5	10,4	1	1	1				12,3	4
SK36	gas	44	60	0,12	NU	13,1	12,3	12,3	8,8	12,6	0	0	0	1,8	0	0	7,8	0
SK37	gas	57	29	0,3	NU	33	46,4	23	32,3	9,8	8	4	3				14,9	3
SK38	gas	59	30	0,16	NU	24,6	33	33,4	20,6	6,9	4	1	0				22,3	11
SK39	gas	72	78	0,13	HO	18,5	26,2	25,1	13,3	7,7	2	0	0	1,6	0	0	25,2	3
SK40	gas	48	24	0,27	HO	33,4	50,3	10,1	9,9	16,5	13	4	2	3	0	0	56	13
SK41	electric	34	124	0,06	HO	6,6	6,7	6,6	5,2	13,7	0	0	0				16,4	7

HR = hood based on recirculation, HO = hood venting to outdoor, NU = not used

UK

Part. nr.	Gas (G) / Electric (E)	Estimated hob use [min/day]	Kitchen volume [m³]	Air change rate [1/h]	Hood	Average NO_2 [µg/m³]					NO_2			CO			$PM_{2.5}$	
						Kitchen		Living room	Bed room	Out side	# days above 25 µg/m³	# hours above 200 µg/m³		Aver age	# days above 4 mg/m³	# 8 hour periods above 10 mg/m³	Aver age	# days above 15 µg/m³
						active	passive					WHO	EU					
UK01	gas	33	22	0,3	HO	7,4	9,6	9,4	6	11,8	0	0	0	0,3	0	0	14,4	5
UK02	gas	39	12		NU	11,6	5,9	4,8	25,3	3,4	0	0	0					
UK03	gas	20	18	0,39	EF		18,3	19,8	15,8	15				0,3	0	0	16	6
UK05	gas	33	133		HO		14,7	14,2	12	9,8				0,2	0	0	7,4	0
UK06	gas	16	78	0,16	EF	9,1	8,3	4	6,7	10,5	0	0	0	0,2	0	0	7,9	0
UK07	electric	53	168	0,55	NU		11,3	16,6	13,2	12,1							44,8	7
UK08	gas	48	26	0,33	NU	29,6	42,9	42,8	25,6	16,7	8	5	4				8,7	2
UK09	electric	45	14	0,45	HO	11,8	14,4	14,4	9	16,8	0	0	0	0,3	0	0	19,6	7
UK10	gas	26	23	0,39	HO	8,9	16,5	16,2	15,4	18,2	0	0	0				7,8	0
UK11	gas	40	41	0,19	HR	16,8	21,4	23,9	19,9	11,1	2	0	0	0,4	0	0	14,1	4
UK13	gas	32	24	0,73	HO	15,9	23,6	25,3	30,5	22,5	0	0	0	0,2	0	0	6	1
UK14	gas	29	58		HO		22,4	24,8	21,9	15,8				0,2	0	0		
UK15	electric	57	7	0,44	HO	10,8	9,3	10,2	10,2	10,6	0	0	0				19,7	9
UK16	gas	0	20	0,94	HO	18,9					1	0	0	0,2	0	0	12,6	4
UK17	electric	63	58	0,39	NU	6					0	0	0	0,2	0	0	6,7	1
UK18	gas	58	13	0,34	HR	14	23,4	18,3	17,7	18	0	0	0	0,3	0	0	47,8	13
UK19	electric	50	13	1,27	NU	12,5	12,8	10,8	11,3	10,3	0	0	0				12,8	3
UK20	gas	43	43	0,63	NU	19,9	29,9	33,6	17,1	14,8	2	0	0	0,2	0	0	6,1	0

HR = hood based on recirculation, HO = hood venting to outdoor, EF = exhaust fan, NU = not used

Part. nr.	Gas (G) / Electric (E)	Estimated hob use [min/day]	Kitchen volume [m³]	Air change rate [1/h]	Hood	Average NO_2 [μg/m³]					NO_2			CO			$PM_{2.5}$	
						Kitchen		Living room	Bed room	Out side	# days above 25 μg/m³	# hours above 200 μg/m³		Aver age	# days above 4 mg/m³	# 8 hour periods above 10 mg/m³	Aver age	# days above 15 μg/m³
						active	passive					WHO	EU					
UK21	electric	54	14	0,3	HO	2,7	5,5	6,2	7,1	6,9	0	0	0	0,3	0	0	6,5	1
UK22	gas	62	17	0,37	HR		47,6	40,6	37,4	16,9				0,4	0	0	101	10
UK23	gas	74	30	0,3	HO	13,9					0	0	0	0,3	0	0	7	1
UK24	gas	25	120	0,19	NU		19,2	21,6	12	17,5							15,9	6
UK25	gas	70	20		NU	36	71,2	59,3	22	9	10	13	9	0,4	0	0		
UK26	gas	78	32	0,31	NU	22,5	32,5	19,8	25,8	12,6	4	2	1	0,3	0	0	8,9	1
UK27	gas	6	41	0,45	HO	12,3	16,6	10	6,4	10	0	0	0	0,2	0	0	5,1	0
UK28	gas	59	62		NU		34,2	36,3	35,4	12,7				0,2	0	0		
UK29	gas	87	21	0,31	NU	17,1	32,7	38,1	25,1	11	1	0	0	0,2	0	0	38,8	14
UK30	gas	40	32	0,5	NU	22,1	46,1	37,5	17	9,9	5	6	3	0,3	0	0	18,9	7
UK32	gas	71	29	0,5	NU	15,4	24,9	24	12,8	19,3	1	0	0	0,3	0	0	6,5	0
UK33	gas	44	56	0,44	HR		28,9	26,1	19	17,5				0,5	0	0	16	4
UK36	electric	22		0,17	NU	10	14,3	14,8	12,5	18,1	0	0	0	0,4	0	0	6,2	0
UK37	gas	28	12	0,66	HO	20	32,5	6,9	6,8	8	1	0	0	0,4	0	0	15,9	3
UK38	gas	21	27		HO		15,4	16,4	17,2	8,6				0,2	0	0		
UK39	gas	7	51	0,25	HO	12,5	29,9	13,2	16,4	19,1	0	0	0	0,4	0	0	7,9	0
UK40	gas	32	15	0,11	NU	15,5	22,6	20,8	18,2	11,5	2	1	1				8,8	2

HR = hood based on recirculation, HO = hood venting to outdoor, NU = not used

Romania

Part. nr.	Gas (G) / Electric (E)	Estimated hob use [min/day]	Kitchen volume [m³]	Air change rate [1/h]	Hood	Average NO_2 [µg/m³]					NO_2			CO			$PM_{2.5}$	
						Kitchen		Living room	Bed room	Out side	# days above 25 µg/m³	# hours above 200 µg/m³		Average	# days above 4 mg/m³	# 8 hour periods above 10 mg/m³	Average	# days above 15 µg/m³
						active	passive					WHO	EU					
RO01	electric	13	42	0,26	HO	11,6	17,9	15,6	15,1	21,9	0	0	0				16,6	6
RO02	gas	37	34	0,33	HO	14,7	29,1		27,7	20,8	0	0	0	0,3	0	0	23,2	10
RO03	gas	20	45	0,36	HO	16,1	28,1	25,4		21	1	0	0	0,5	0	0	133	10
RO05	gas	36	50	0,11	HO	10,6	23,7	20,2	22,7	20,2	0	0	0	0,5	0	0	10,3	1
RO07	electric	23	13	0,43	NU	11,9	21,2	11,9	17,3	21,5	0	0	0	0,3	0	0	76,7	13
RO08	gas	28	18	0,66	HO	13,6	27,7	18	16,5	21,5	0	0	0				8,9	0
RO09	gas	18	14	0,41	NU	14,9	24,7	15,4	12,7	14,9	2	4	4	0,2	0	0	87,1	17
RO10	gas	32	21	0,13	HO		13,2	12,9	13,1	19,2				0,1	0	0	12,8	3
RO11	gas			0,62	NU	12,8	25,9	22,7	24,6	26,2	0	0	0	0,2	0	0	35,2	8
RO12	gas	28	22	0,33	HO	10,9	15,2	10,5	8,8	18,2	0	0	0	0,2	0	0	12,6	3
RO13	gas	47	54	0,32	HO		18,8	10,1	11	21,2								
RO15	gas	67	15	1,17	HO	13,6	25,6	22,3	16	23,4	0	0	0	0,5	0	0	41,3	10
RO17	gas	61	8	0,86	HO	15,8	28,3	18,9	16,9	20,6	1	1	0				27,4	6
RO18	electric	0	96	1,01	HO	15	43,3	38	34,8	59	0	0	0	0,2	0	0	12,8	1
RO20	electric	18	32	0,71	HR	13,6	21,2	16,9	16,4	19,4	0	0	0	0,2	0	0	46,4	13
RO21	gas	34		1,95	NU	9,6	37,7	29	14,5	16,9	0	0	0	0,2	0	0	14,1	5
RO22	gas	38		0,64	NU	15,9	5,5	9,7	13,2	5,8	2	0	0				19	10

HR = hood based on recirculation, HO = hood venting to outdoor, NU = not used

Part. nr.	Gas (G) / Electric (E)	Estimated hob use [min/day]	Kitchen volume [m³]	Air change rate [1/h]	Hood	Average NO_2 [µg/m³]					NO_2			CO			$PM_{2.5}$	
						Kitchen		Living room	Bed room	Out side	# days above 25 µg/m³	# hours above 200 µg/m³		Aver age	# days above 4 mg/m³	# 8 hour periods above 10 mg/m³	Aver age	# days above 15 µg/m³
						active	passive					WHO	EU					
RO23	gas	73	24		HO		39,6	46,1		36,8								
RO24	electric		148		NU	17,7	24,2	24,5	21	20,7	0	0	0					
RO25	gas		35	0,46	NU	18,7	65,4	75,8	62	55,7	0	0	0	0,2	0	0	11,9	1
RO26	gas	29	60	0,33	NU	24,3	51,6	39,3	35	21,3	6	0	0					
RO28	gas	33	34	0,88	HO	24,1	46,9	22,9	13,3	17,1	6	0	0	0,3	0	0	12,1	4
RO29	gas	13	36	0,19	HO		11,6	12,1	6,3	7,4				0,2	0	0	12,6	5
RO30	gas	77	74	0,22	HO	25,2	58,8	21,6	14,6	9,9	6	5	2	0,4	0	0		
RO31	gas	48	22	0,6	HO	7,8	19,3	7,3	5,7	7,3	0	0	0				35,2	15
RO32	gas	98	25	0,76	NU		66,1	26	19,4	9,9				0,5	0	0	14,9	5
RO33	gas	51	38	0,44	NU		10,7	8,3	6,6	6,5							11,2	2
RO34	gas		11	1,19	HO	24,7	40,3	15,6	13,9	18,9	3	0	0	0,4	0	0	35,9	10
RO35	gas	49	12	1,42	NU	22,8	44,4	29,9	22	6,8	4	5	2	0,5	0	0	21	8
RO36	gas	40	24	0,3	HO		43,8	11,7	21,2	4,9							27,4	13
RO37	gas	25	12	0,45	NU	20,4	37	26,4	21	6,6	2	0	0				12	3
RO38	gas	53	35	1,98	NU	15,4	14,5	13	15,1	15,2	0	0	0	0,3	0	0	9,4	1
RO39	gas	82	12	0,9	HO	26,4	51	20,9	18,2	23,4	6	2	1				10,4	2
RO40	gas	50	18	0,93	NU		49,8	45,5	39,8	38							16,3	4

HR = hood based on recirculation, HO = hood venting to outdoor, NU = not used

Appendix B

Active/passive NO_2

This appendix compares the data measured by the calibrated active sensors with the passive sensors data obtained in the same experimental campaign. The calibration of the active sensors against research grade equipment was performed in 4 batches:

- The Netherlands
- Italy and Spain
- France and Slovakia
- UK and Romania

Figure B.1 to Figure B.4 present the average concentration of NO_2 ($\mu g/m^3$) measured with the calibrated active sensors (Y-axis) against the average concentration measured using passive sensors (X-axis) for the 4 batches of measurements and calibrations performed during the measurement campaign.
The correlation in batch 4 and also the slope is less than in the other batches. This might be caused by the presence of many gas ovens in the UK and Romania, causing concentrations above the measurement range of the NO_2 sensor, which is limited to 250 ppb = 478 µg/m³.

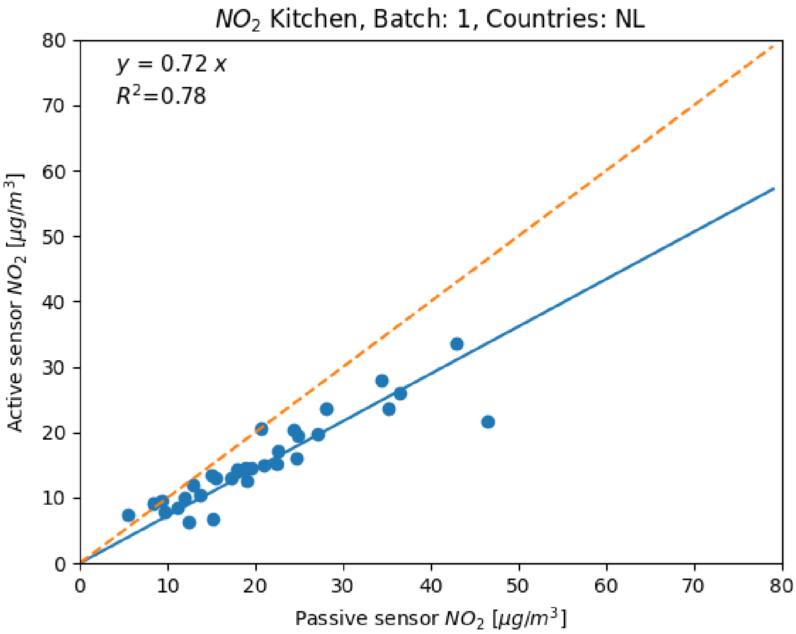


Figure B.1 the Netherlands, NO_2 measured with passive sensors (X-axis) versus NO_2 measured with active sensors (Y-axis).

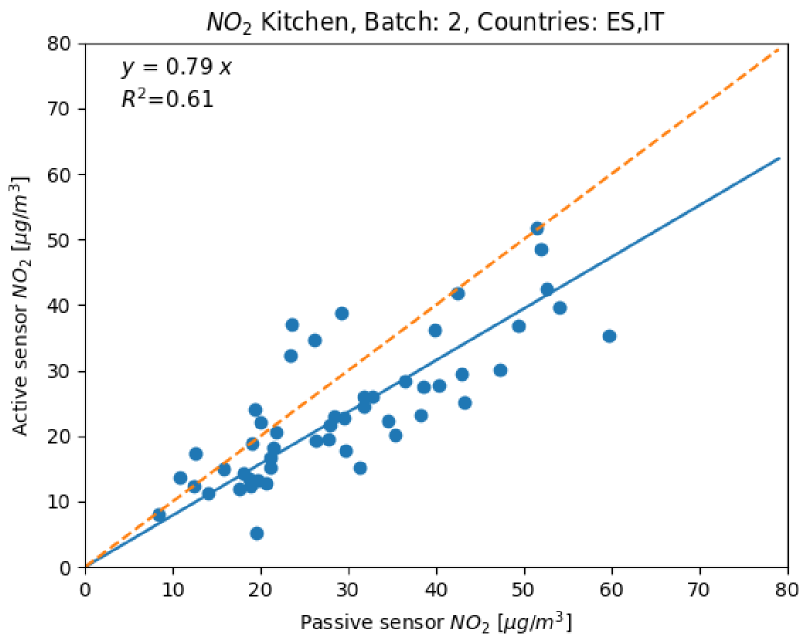


Figure B.2 NO_2 measured with passive samplers (X-axis) versus NO_2 measured with active samplers (Y-axis) during the experimental campaign performed in Italy and Spain.

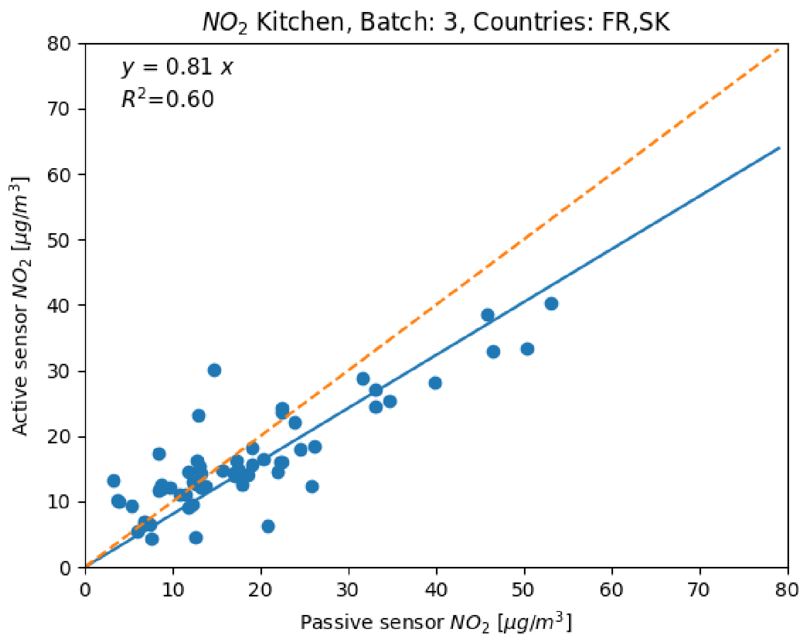


Figure B.3 NO_2 measured with passive samplers (X-axis) versus NO_2 measured with active samplers (Y-axis) during the experimental campaign performed in France and Slovakia.

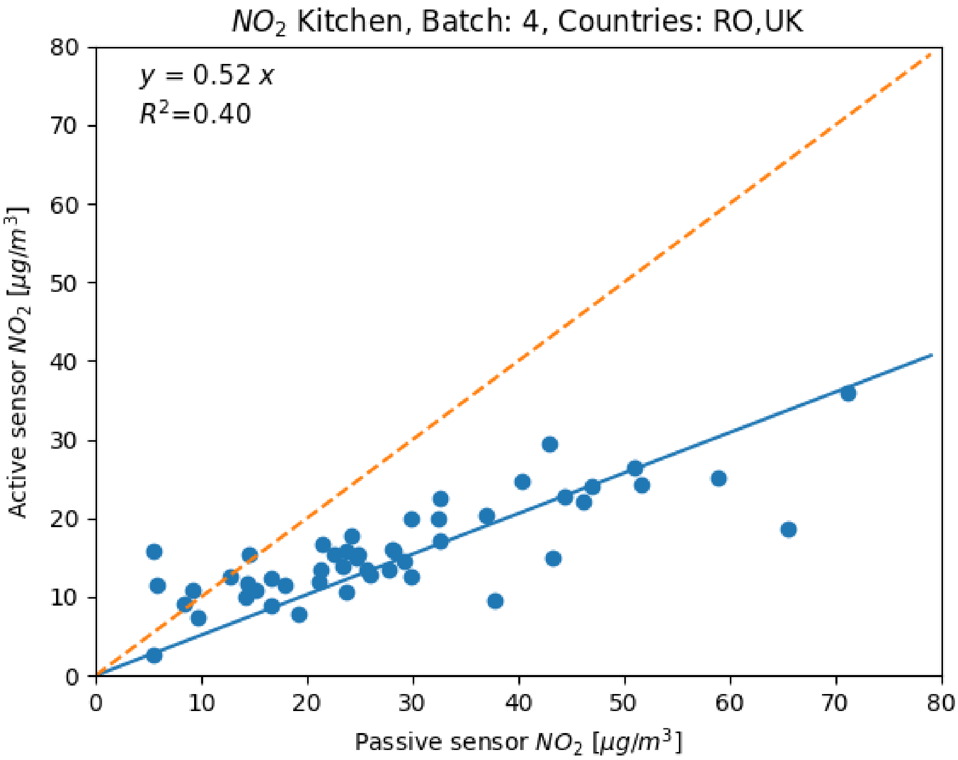


Figure B.4 NO_2 measured with passive samplers (X-axis) versus NO_2 measured with active samplers (Y-axis) during the experimental campaign performed in Romania and United Kingdom.

Appendix C
Recruitment screener

The recruitment screener has been set up by Opinium in collaboration with CLASP and TNO.

Project details

SAMPLE

40 households across 7 markets will be recruited to take part in a 2-week study that will involve them passively tracking in-home emissions and completing an online diary telling us about their cooking and ventilating behaviours.

The markets for this study are:

1. France
2. Italy
3. Netherlands
4. Slovakia
5. Spain
6. UK
7. Poland or Romania.

Opinium will recruit 40 households for 35 – 40 to participate in each market.

NB: Romania or Poland will be excluded from the research.

Market	**France**	**Italy**	**Netherlands**	**Poland**	**Romania**	**Slovakia**	**Spain**	**UK**
Total number of households	**40**	**40**	**40**	**40**	**40**	**40**	**40**	**40**
Recruitment criteria	All must cook dinner at home at least 3 - 4 times a week All must be from non-smoking households Recruit a mix of location - included a rural / urban mix but exclude those how live next to a busy main road or on an industrial site.							
Quotas	**Number of households per market**							
Number of households cooking with a gas cooker	32	32	32	32	32	32	32	32
Household with a gas oven (enclosed compartment)	min 5	min 5	min 5	min 5	min 15	min 5	min 5	min 5
Number of households cooking with an electric cooker	8	8	8	8	8	8	8	8
Recruit a mix of those who cook with / without an extraction hood								
with an extraction hood	min 15	min 15	min 15	min 15	min 15	min 15	min 15	min 15
without an extraction hood	min 15	min 15	min 15	min 15	min 15	min 15	min 15	min 15
Recruit a mix of households								
Living with children under the age of 16	min 10	min 10	min 10	min 10	min 10	min 10	min 10	min 10
Recruit a mix of household tenure								
Living in social / affordable housing	min 15	min 15	min 15	min 15	min 15	min 15	min 15	min 15
Living in rented housing	min 10	min 15	min 15	min 15	min 15	min 15	min 15	min 15
Recruit a mix of demographics								
C2DE	min 20	min 20	min 20	min 20	min 20	min 20	min 20	min 20
Household income	A good spread across location							

Research will be conducted in markets on a rolling basis. Opinium will take CLASP's lead on the order of markets to be included in the research. An overview of the time-line is included in the statement of work.

Recruitment screener

Opinium, an independent insight agency, is conducting paid research on behalf of an environmental not-for-profit organisation, CLASP, to better understand the experiences of people who use gas or electric hobs and/or ovens to cook food at home.

The research will involve taking part in 2-week study that will involve you using air quality monitoring equipment(which will be supplied by the client) to monitor emissions created when using your gas or electric cooking appliances, and to complete an online welcome activity, telling us about you and your oven, and an online app-based diary telling us about your cooking habits.

You will be asked to cook as normal during this period.

The study will take place between [dates].

If you are selected to take part and complete the research, we are pleased to offer you [incentive] as a thank you for your time and feedback.

If you are interested in taking part, we will need to ask you a some follow up questions to check your eligibility and availability for the interview. These questions will take 2 minutes to answer.

Are you interested in finding out more?
1. Yes
2. No [SCREEN OUT]

Main criteria

Q1 ASK ALL
MULTI
Do you live next to any of the following?
1. A busy main road [SCREEN OUT]
2. An industrial estate [SCREEN OUT]
3. None of the above

Q2 ASK ALL
SINGLE
Does anyone in your household smoke?
1. Yes [SCREEN OUT]
2. No

Q3 ASK ALL
SINGLE
How, if at all, do you access the internet?
1. Fixed broadband through a phone line or cable - e.g. using a Wi-Fi router

2. Phone line dialup accessMobile broadband from a mobile network via a USB stick, dongle or built in connectivity with a SIM card
3. Access the internet using a mobile phone or smartphone - e.g. using 3G or 4G mobile network
4. Access the internet on a device such as a laptop or tablet using your mobile phones internet connection
5. Other (e.g. internet café, a connection at work, a friend or relative’s house) [SCREEN OUT]
6. N/A – I don’t use the internet at all [SCREEN OUT]

TEXT INTRO
The next few questions will ask you about your cooking habits.

Q4 ASK ALL
SINGLE
1. On average, how many days per week is your oven or hob used to cook a main meal in your home? Never [SCREEN OUT]
2. Once a week [SCREEN OUT]
3. Twice a week [SCREEN OUT]
4. Three times a week
5. Four times a week
6. Five times a week
7. Six times a week
8. Seven times a week

Q5 ASK ALL THAT COOK
GRID
Which of the following best describes the fuel that your hob and oven uses to cook? If you use more than one hob/oven, please think about the one that you use the most.

	Hob (the top part of your cooker)	**Oven (the enclosed compartment on your cooker)**

	 	
Gas		
Electric		
Other	**[SCREEN OUT]**	**[SCREEN OUT]**
Don't know	**[SCREEN OUT]**	**[SCREEN OUT]**

#32 households per market to cook with a gas oven / hob
Aim to recruit the following with a **gas oven (enclosed compartment)**:

- Min 15 to have a gas oven in Romania
- Min 5 to have a gas oven in Poland
- Min 5 to have a gas oven in Italy
- Min 5 to have a gas oven in France
- Min 5 to have a gas oven in UK (best efforts)
- Best efforts basis in Spain
- Best efforts basis in Netherlands

#8 household per market to cook with an electric oven and hob

Q6 ASK ALL
Do you use an extraction hood when you cook?

1. Yes, all of the time
2. Yes, most of the time
3. Yes, some of the time
4. Rarely
5. Never
6. Don't know [SCREEN OUT]

#Min 15 to answer 1 – 2
#Min 15 to answer 4 – 5

Q8 ASK ALL
[OPEN]

What are your views on gas cookers? What are the benefits of gas cookers? What are the draw backs of gas cookers? Do you have any concerns?

#All must be able to share an opinion

Demographics

TEXT INTRO
We would now like to find out a little about you and your household.

D1 REGION ASK ALL
SINGLE
I live in…

1. North East
2. North West
3. Yorkshire & Humberside
4. East Midlands
5. West Midlands
6. East of England
7. London
8. South East
9. South West
10. Wales
11. Scotland
12. Northern Ireland
13. Not in the UK [SCREEN OUT]

D2 ASK ALL
SINGLE
Which one of these best describes the area where you live?

1. Urban area – larger cities or towns
2. Suburban area – residential areas on the outskirts of cities and towns
3. Rural area – villages or hamlets

#Recruit a mix

D3 ASK ALL
MULTI
Which of the following people do you live with?

1. I live alone
2. Partner (girlfriend / boyfriend / wife / husband)
3. Child(ren) under 16
4. Child(ren) over 16

5. Friends
6. Parents
7. Other

#Recruit a min of 10 with children under 16
#Monitor – no more than 5 to live only with friends / other

D4 ASK ALL
SINGLE

Which of the following best describes your main home?

1. Own outright
2. Own with a mortgage / loan
3. Rented from local authority or living in social housing
4. Rented from private landlord
5. Rented from housing association or living in affordable housing
6. Live rent-free (including rent-free in your parents /another relative's / a friend's property
7. Other
8. Live in no fixed accommodation

#Min 15 to live on social / affordable housing
#Min 10 to live in rented housing

D5 ASK ALL
SINGLE

Thinking about your main home, what type of property is it?

1. Bungalow
2. Flat (basement)
3. Flat (ground)
4. Flat (first floor or above)
5. Maisonette
6. Detached house
7. Semi-detached house
8. Terraced house
9. Other (e.g. university hall of residence, care home)

#RECORD

D6 ASK ALL
SINGLE
What is your annual pre-tax household income?

By 'household income' we mean the total income received from all sources, including wages earnt by you, your partner and/or any other earner in the household, bonuses, pension income, benefits or rents and before tax deductions.

Your data will be kept confidential and not passed on to any third parties.

1. Less than £5,000 a year or per annum (pa)
2. £5,000 to £9,999 pa
3. £10,000 to £14,999 pa
4. £15,000 to £19,999 pa
5. £20,000 to £29,999 pa
6. £30,000 to £39,999 pa
7. £40,000 to £49,999 pa
8. £50,000 to £59,999 pa
9. £60,000 to £69,999 pa
10. £70,000 to £99,999 pa
11. £100,000 to £149,999 pa
12. £150,000 to £249,999 pa
13. £250,000 or more pa
14. Don't know
15. Prefer not to say

#recruit a mix

D7 – SOCIAL GRADE
SINGLE
We would now like you to think about the chief income earner in your household, that is the person with the highest income. This may be you or it might be someone else.

Which of the following groups does the chief income earner in your household belong to?

[If the chief income earner is retired with an occupational pension, please enter their former occupation. Please only enter 'retired' if the chief income earner is only

receiving the state pension. If the chief income earner has been unemployed for a period of less than 6 months, please answer based on their previous occupation.]

1. Higher managerial/ professional/ administrative (e.g. established doctor, solicitor, board director in large organisation (200+ employees), top level civil servant/ public service employee, head teacher etc.)
2. Intermediate managerial/ professional/ administrative (e.g. newly qualified (under 3 years) doctor, solicitor, board director of small organisation, middle manager in large organization, principal officer in civil service/ local government etc.
3. Supervisory or clerical/ junior managerial/ professional/ administrator (e.g. office worker, student doctor, foreman with 25+ employees, sales person, student teacher etc.)
4. Skilled manual worker (e.g. skilled bricklayer, carpenter, plumber, painter, bus/ ambulance driver, HGV driver, unqualified teaching assistant, pub/ bar worker etc.)
5. Semi-skilled or unskilled manual worker (e.g. manual jobs that require no special training or qualifications, apprentices to be skilled trades, caretaker, cleaner, nursery school assistant, park keeper, non-HGV driver, shop assistant etc.)
6. Student
7. Retired and living on state pension only
8. Unemployed for over 6 months or not working due to long term sickness

#Min 20 to be C2DE or equivalent
Please note social grade is a British centric measure. In other markets we will identify C2DE equivalents using a combination of household income, education level and they type of work they do.

D8 – EDUCATION LEVEL
SINGLE

Please select the highest level of qualification of academic or professional qualification you have completed.

1. No formal qualifications
2. GCSE, Standard Grades or equivalent (e.g. BTEC, S/NVQ level 2)
3. A Level, Highers or equivalent (e.g. BTEC, S/NVQ level 3)
4. Certificate of Higher Education or equivalent (e.g. HNC, BTEC, S/NVQ level 4)
5. Diploma of Higher Education or equivalent (e.g. HND/Foundation Degree, BTEC, S/NVQ level 5)
6. Undergraduate Degree or equivalent (e.g. BA, BSc)
7. Postgraduate Cert or Dip
8. MBA

9. Other Master's Degree (e.g.MA, MSc, PGCE, PGDE)
10. Doctoral Degree (e.g. PhD, DBA)
11. Professional qualifications (e.g. CIMA, ACCA)

#Recruit a mix – at least 20 to answer 1 – 4.

D9 ASK ALL
SINGLE
What is your gender?

4. Male
5. Female
6. Other
7. Prefer not to say

#Record

D10 ASK ALL
SINGLE
Please state your age
Under 18 [SCREEN OUT]
18
19
20
21
22
23
24
25
26
[ETC TO 80]
Over 80

OPT IN

Thank you for answering these questions.

Based on your responses, we would like to invite you to take part in some research CLASP, a Non-Government Organisation focussed on appliance and energy performance, is conducting around in-home cooking.

CLASP campaign for and make recommendations for efficient in-home cooking appliances. This research will feed into a larger body of work that CLASP is conducting around measuring cooking appliance emissions and their impact on the environment. On completion of the research CLASP will produce a report that will be published on its website and used as part of a broader campaign n indoor air pollution.

There are three parts to this research:

- Part 1: Welcome activity
- Part 2: Passive tracking of in-home cooking emissions
- Part 3: 2-week cooking diary

The research will take place between [DATES]

In order to take part in this research, you must be willing and able to participate in all three parts of the research. More detail on what each part of the research involves, the data we collect and how it will be used is outlined below.

Part 1: Welcome Activity

You would be required to log **onto an online platform** to answer a short set of open ended and task-based questions telling us more about you, your household, your cooking set up and cooking habits.

Some of the tasks may ask you to record a short video or upload pictures of the kitchen set up (or alternative) to help us learn more about your cooking set up and equipment.

This welcome activity would take around 30 minutes to complete. You would be able to complete the activity at a time most convenient for you.

We ask that you complete the welcome activity by [deadline].

What data will we collect and how will it be used?

To set you up on the platform, we will need to collect your **name and email address**. Your name and email address will be shared with Opinium (the market research agency organising this research) and Recollective (the online platform company).

The welcome activity will be private. You won't be able to see the responses from others taking part and they won't be able to see your answers either.

Opinium, the research agency, will log in and read your responses and may ask you additional follow up questions. TNO (a specialist consultant in applied sciences working with CLASP) may also log in and observe the research as it takes place so may also have access to your first name (or the name you set your profile up in, your **profile picture** and any **videos or photographs that you upload** as part of the research).

On completion of the research, transcripts and any images / videos uploaded in the welcome activity will be shared with TNO, who will write a report for CLASP.

Part 2: Passive tracking on in-home cooking emissions

As part of this research you will be required to plug a series of sensors into your kitchen. These sensors will track the emissions let off by your oven / hob when you cook.

You will be sent a briefcase containing:

- 4 plastic tubes (to be mounted to the wall in your kitchen, living room, bedroom and outdoors)
- 2 small sensors (to record carbon monoxide and nitrogen dioxide levels, to be plugged in your kitchen)
- A small air quality monitor (to be plugged in your kitchen)
- 3 button-sized sensors to be taped on to your hob (or gas oven door, if available)
- A plug for you to plug in the devices

Full video and written instructions on how to install the sensors around your home will be provided. You will also have access to an online support community and a dedicated point of contact to help with any issues or queries.

Once in the sensors are set up you don't need to do anything else. You will be asked to cook as normal during this period. At the end of the 2-week period you will be asked to return the equipment so that TNO can download and analyse your data.

To take part in the study you must be able to collect the monitoring equipment, which will be delivered to your home on [date].

Return postage for the monitoring equipment is pre-paid and the courier will collect the package from your home.

To take part in the study you must be able to re-package the equipment and be available for the courier to collect the package from your home address on [date].

What data will we collect and how will it be used?

To send you the monitoring equipment we need to collect your **name and address**. Your details will be shared with Opinium and TNO (to organise delivery and for analysis) and FedEx (the delivery company).

Please note that you must return your monitoring equipment to be eligible for the incentive. Full instructions for organising collection and return postage of the sensor will be provided.

On completion of the research, your anonymised data will be shared with the CLASP team. Your emissions data will be appended to some of the information collected in the recruitment screener and welcome activity (such as location and social data). You won't be personally identified by your name, email or address.

Part 3: 2-week cooking diary

Alongside passively tracking your in-home emissions, we ask that you complete a daily cooking diary telling us about what you have cooked and how. The cooking diary will last for 2 weeks and will take place between [dates].

The diary will involve you downloading an app, to answer a short series of questions each day of the research. This diary will help us understand more about the emissions in your home.

What data will we collect and how will it be used?

To set you up on the platform, we will need to collect your **name and email address**.

Your name and email address will be shared with Opinium (the market research agency) and Indeemo (the app-based diary company). Throughout the research you will be identified by your first name and second name (if registered).

The diary activities will be private. You won’t be able to see the responses from others taking part and they won’t be able to see yours either.

TNO may log in and observe the research as it takes place so may also have access to your first name (or the name you set your profile up in and any **videos or photographs that you upload as part of the research**).

On completion of the research, your responses will be shared with CLASP and TNO. Your diary data will be appended to some of the information collected in the recruitment screener and welcome activity (such as location and social data). You won’t be personally identified by your name, email or address.

For further information about your legal rights and how to exercise these, please **see:**

CLASP’s privacy policy here: https://www.clasp.org/privacy-policy/#:~:text=Information%20Collection%20and%20Use,different%20points%20on%20our%20website.

TNO’s privacy policy here: Privacy statement | TNO

Opinium privacy policy here: https://www.opinium.co.uk/privacy-policy/

Next steps

If you are selected to take part and complete all 3 elements of the research and organise collection of the sensor, we are pleased to offer you [incentive].

Please note that you are free to withdraw at any time, however, if you do decide to withdraw you will no longer be eligible for your incentive.

Are you interested and able to take part in the welcome activity, passive tracking of household emissions and 2 week online diary between [dates]?

Please note that expressing an interest to take part won't guarantee your participation but it will ensure you are shortlisted as a potential participant.

1. Yes, I am interested in taking part
2. No, I am not interested in taking part

After the research has taken place

CLASP will use the findings of this research to feed into a report that will be published on its website and used at industry events. The report will include anonymised findings from this research.

With your permission CLASP may also use the following in the report to bring peoples' experiences to life:

- Images that have been uploaded in the welcome and diary activities
- Videos that have been uploaded in the welcome and diary activities

Optin_2

- Will you or someone else be at home to collect the monitoring equipment on [date]?
  - Yes
  - No

- Will you or someone else be at home to return the monitoring equipment to the courier on [date]?
  - Yes
  - No

Optin_3

Thank you for expressing an interest in taking part in this study. To help us organise this with you we need to ask you for some personal details.

Your details will only be used for the **purposes of contacting you for this study.** Your details will be stored securely and will be deleted on completion of the study.

1. First name:
2. Last name:
3. Email Address:
4. Phone Number:
5. Address:
6. I do not wish to give my contact details and am no longer willing to take part [THANK & CLOSE]

RECONTACT

CLASP are interested in conducting a small number of media interviews with people who have taken part in the research.

A media interview will involve someone from the CLASP team coming into your home to conduct a filmed one-on-one interview.

The interview will be edited to create shorter sound bites that will be used by CLASP in campaigns and marketing, including being published on their website, social media and being used at industry events.

Are you interested in being a media case study?
Please note that by agreeing to be re-contacted to be a case study you give permission for your contact details (name, email, phone number and address) to be shared with CLASP for the purposes of organising and conducting a filmed interview.

1. Yes, I am happy to be re-contacted
2. No, I do not want to be re-contacted

NOTE: Collect interest in sharing personal emissions data alongside regional data with the participants as part of the research.

- END OF SURVEY -

Appendix D
Questionnaire

The questionnaire has been set up by Opinium in collaboration with CLASP and TNO.

Welcome activity

Homepage

Hi everyone and welcome to this research.

We are delighted to have you on this project. We are conducting this research on behalf of CLASP, an environmental not-for-profit organisation, to better understand the experiences of people who use gas or electric hobs and/or ovens to cook food at home.

As a reminder, there are 2 parts to this study:

- **Part 1: The Welcome Activity**
- **Part 2: The Cooking Diary**

As a thank you for your full participation in both part 1 and part 2, we are pleased to offer you a [incentive] incentive.

Your incentive will be paid after your in-home monitoring equipment has been collected from your home.

Return postage of the monitoring equipment will take place on Monday 13th February.

The courier will come to your address to collect the equipment. **Please ensure that you have packaged up the equipment in time for collection.**

Part 1: The Welcome Activity

The welcome activity involves you logging onto an online platform to answer a set of questions telling us more about your home, your cooker and any cooking ventilation you may have.

The welcome activity will be hosted in this online community. To find the questions, click on the 'Activities' tab at the top of this screen.

The welcome activity will take around 30 minutes to complete.

You can log in and complete the activity at a time most convenient for you. We ask that you complete the welcome activity by **[deadline].**

Who can see your responses to the welcome activity?

The welcome activity will be private. You won't be able to see the responses from others taking part and they won't be able to see your answers either.

Opinium, the research agency, will log in and read your responses and may ask you additional follow up questions. TNO (a specialist consultant in applied sciences working with CLASP) may also log in and observe the research as it takes place so may also have access to your first name (or the name you set your profile up in), your profile picture and any videos or photographs that you upload as part of the research.

Help and support

In the community on the 'help and support tab' you will also find:

1. **Instructions for setting up monitoring equipment (for part 2)**

2. **An FAQs document**

3. **A support forum, where you can ask questions about the research to your dedicated support team. Questions posted here will also be seen by others taking part in the research.**

Part 2: Cooking diary

Part 2 will involve you using air quality monitoring equipment to monitor emissions created when using your gas or electric cooking appliances. At the same time, we would like you to complete an online app-based diary telling us about what you cooked each day to help us better understand the data that the monitors collect.

The diary will involve you taking and uploading a picture of the meals that have been cooked each day and answering a few follow-up questions. You will be prompted to complete the diary in the morning, afternoon and evening.

Setting up the sensors
We are sending you the monitoring equipment for part 2 by DHL Express. If you have any questions or issues, please let us know on the support page (which can be found in the activities tab).

You will find full set up instructions (both written and in video) for setting up your in-home monitoring equipment in this community by clicking on the help and support' tab at the top of this page. This information was also shared in your invitation email.

Setting up the app-based diary
You will find full set up instructions for setting up the app-based diary in this community by clicking on the help and support' tab at the top of this page. This information was also shared in your invitation email.

Getting in touch

If you have any questions, queries, or issues during the community, about how your data will be used or if you choose to withdraw from the research do send a message on support page and we will get back to you as soon as possible.

Alternatively you can email [email].

You have the right to withdraw at any point. Please note that if you do decide to withdraw you may not be eligible for the full incentive.

That's all the admin for now. Please move on to the welcome activity....

Welcome

1.1 [OPEN TEXT / POLL] ABOUT YOUR HOME

TASK RATIONALE: To understand the makeup of their family and property
TASK OUTPUT: Poll response, Verbatim
SCRIPTING NOTES: Sentence completion format

I'd like to begin by asking you questions about you, your household and about the physical characteristics of your home…

1. **[OPEN]** Please tell us a little bit about your household. Who do you live with? (If you have children, please tell us their ages).
   [INSERT TEXT BOX]

2. **[OPEN]** [ROUTE FROM QUESTION D5 IN THE SCREENER – ask if live in a flat (first floor or above, maisonette, other)] If you live in a building that houses multiple homes (e.g. in a maisonette or block of flats), how many stories does the main building have?
   [INSERT TEXT BOX]
   1.
3. **[OPEN]** [ROUTE FROM QUESTION D5 IN THE SCREENER – ask if live in a flat (first floor or above, maisonette, other)] And on which story do you live?
   [INSERT TEXT BOX]

4. **[OPEN]** Roughly how old would you say the property is? If you don't know, please give us your best estimate.

   [INSERT TEXT BOX]

5. **[Single poll]** How many stories / floors are there inside your home?
   a. 1 story / floor
   b. 1 ½ story / floor split level
   c. 2 stories
   d. 2 ½ story split level
   e. 3 stories
   f. More than 3 stories

1.2 [OPEN TEXT / POLL] ABOUT YOUR KITCHEN AND COOKER

TASK RATIONALE: To understand the kitchen, cooktop / oven details
TASK OUTPUT: Poll response, Verbatim
SCRIPTING NOTES: Sentence completion format

The next few questions are about the layout of your kitchen and the physical appliances you use.

We will ask you some questions about your cook top (i.e. the top part of your cooker)


And we will ask you some questions about the oven (i.e. the enclosed compartment on your cooker

These questions may be easier to answer while in the kitchen.

Your answers to these questions will help us analyse the measurements we make in your home to better understand the air quality in other homes and households with similar characteristics.

1. [OPEN] Is your kitchen in the same room as your living room, or separate?
   [INSERT TEXT BOX]

2. [POLL] Thinking about your **cooktop**, how many burners are on the cook-top? (Central griddle or grill counts as 1 burner).
    a. 1
    b. 2
    c. 3
    d. 4
    e. 5
    f. 6
    g. More than 6

3. [POLL] Approximately how old is the **cooktop**? If you are unsure, please feel free to estimate and note that you are unsure.
    a. 0 - 5 years old
    b. 6 – 10 years old
    c. 11 – 15 years old
    d. 16+ years old
    e. Don't know

4. [POLL] **[ROUTE FROM QUESTION Q5 IN THE SCREENER** – ask if have a gas cook top] Do your **cooktop burners** have a pilot flame, electronic ignition or do you light them by match / hand-held lighter? (Electronic ignition uses a small spark to light the flame. If the cooktop makes a clicking sound when you turn the knob to start the flame, it is electronic spark ignition.)

    a. Electronic spark
    b. Pilot flame
    c. Match / hand-held lighter

5. [POLL] When cooking on your **cooktop**, do you more often use the front or back burners, or do you use all the burners equally?
    a. Front burners
    b. Back burners
    c. Use both equally
    d. I don't know

6. [POLL] Looking at your **oven**, does the oven have a broiler / grill function with controls that are separate from the rest of the oven?
    a. Yes
    b. No
    c. Don't know

7. **[POLL] [ROUTE FROM QUESTION Q5 IN THE SCREENER** – ask if have a gas oven] Does the **oven** burner have a pilot flame, electronic spark ignition or do you light it by match / hand-held lighter?
    a. Electronic spark
    b. Pilot flame
    c. Match / hand-held lighter

8. **[POLL]** Does the oven have a self-clean setting?
    a. Yes
    b. No
    c. Don't know

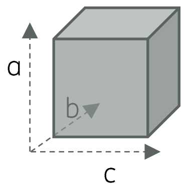
9. **[MULTI MEDIA]** Please upload a picture of both your cook top and your oven.

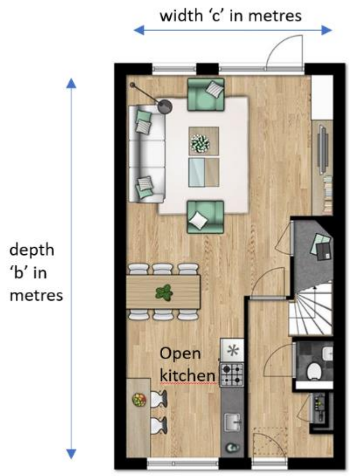
1.3 [OPEN TEXT] KITCHEN SIZE

TASK RATIONALE: To understand the volume (m3) of kitchen
TASK OUTPUT: Verbatim

To make sense of the data recorded by your sensors, it's important that we know the size of your kitchen.

So that we can calculated the volume (m^3) of your kitchen, please tell us the height, depth and width of your kitchen. In case you have an open kitchen, please give the size of kitchen including the living room.





To measure the heigh, depth and width please use a measuring tape or a measuring app on your phone to measure point a, b and c shown in the image above.

1. [OPEN] What is the height of your kitchen in meters? **[INSERT TEXT BOX]**
2. [OPEN] What is the depth of your kitchen (+ living room in case of an open kitchen) in meters? **[INSERT TEXT BOX]**
3. [OPEN] What is the width of your kitchen (+ living room in case of an open kitchen) in meters? **[INSERT TEXT BOX]**

In case of an l-shaped open kitchen, in which the kitchen is smaller than the living room, please take the width of the living room.

1.4 [OPEN TEXT / POLL] MODIFICATIONS MADE

TASK RATIONALE: To understand actions taken to improve air quality
TASK OUTPUT: Poll response, Verbatim
SCRIPTING NOTES: Sentence completion format

The next set of questions ask you about ventilation and the air quality in your home….

1. **[MULTI MEDIA UPLOAD] [ROUTE FROM QUESTION Q6 IN THE SCREENER –** ask those who use an extraction hood all, most or some of the time**]** Please upload a picture of your extraction / exhaust hood.

2. [POLL] [ROUTE FROM QUESTION Q6 IN THE SCREENER – ask those who use an extraction hood all, most or some of the time] Which of the following best describes your extraction /exhaust hood?
   a. Range hood above the cooktop
   b. Microwave and exhaust fan combination above the cooktop
   c. Downdraft exhaust at the back of the cooktop
   d. Downdraft exhaust in the middle of the cooktop
   e. Exhaust fan in ceiling or wall above cooktop
   f. Exhaust fan in ceiling or wall not above the cooktop
   g. Other (please describe in the text box below)
   h. Don't know

   [INSERT TEXT BOX]

3. [POLL] [ROUTE FROM QUESTION Q6 IN THE SCREENER – ask those who use an extraction hood all, most or some of the time] If you have a range hood or microwave exhaust fan above the cooktop, does it exhaust to the outdoors or does it have grills or holes in the front where it blows filtered air back into the kitchen?

   If you are uncertain, please switch on the range hood / exhaust fan to test it. If you can feel air being blown back into the room through a grill or set of holes at the top, it does not exhaust to the outdoors. Alternatively, if you can see a duct going from the top of the hood up toward the roof or back into the wall, it exhausts to the outside. This duct may be inside a cabinet above the hood.

   a. Exhaust to the outdoors
   b. Blows air back to the kitchen
   c. N/A – it doesn't work
   d. N/A – I don't have this type of hood / exhaust
   e. Don't know

4. [OPEN] To your knowledge, has the home or building been renovated by a contractor to reduce air leakage (for example, weather-stripping on doors and windows, caulking to seal cracks, addition of insulation, and sealing of heating ducts)? If yes, approximately how many years ago was this done?

5. **[Poll]** To your knowledge, does your home have a whole-house ventilation fan that operates continuously or on a set schedule? These devices are most commonly found in very new houses, in homes that have been "air sealed" for energy efficiency and in some apartment buildings.
   a. Yes, my home has a ventilation fan that runs continuously
   b. Yes, my home has a ventilation fan that runs with a set schedule
   c. Yes, my home has a ventilation fan but I'm not sure how it runs
   d. My home has a ventilation fan but I have disabled it / turned it off
   e. No, my home does not have a ventilation fan
   f. I don't know if my home has a ventilation fan

6. **[Poll]** How often do you have windows open in your house during this time of year (in the month of February)?
   a. Less than 1 hour a day
   b. 1 hour a day
   c. 2 hours a day
   d. 3 hours a day
   e. 4 hours a day
   f. 5 hours a day
   g. More than 5 hours a day
   h. Not applicable – I don't have my windows open

1.5 [MEDIA UPLOAD] HOUSEHOLD ELECTRICAL CAPACITY

We need to record the rated electrical capacity (Amperage) of the households participating in the study.

Please locate the electrical switchbox for your house – this is a metal or plastic rectangular box affixed to a wall in your house which contains circuit breakers or fuses.

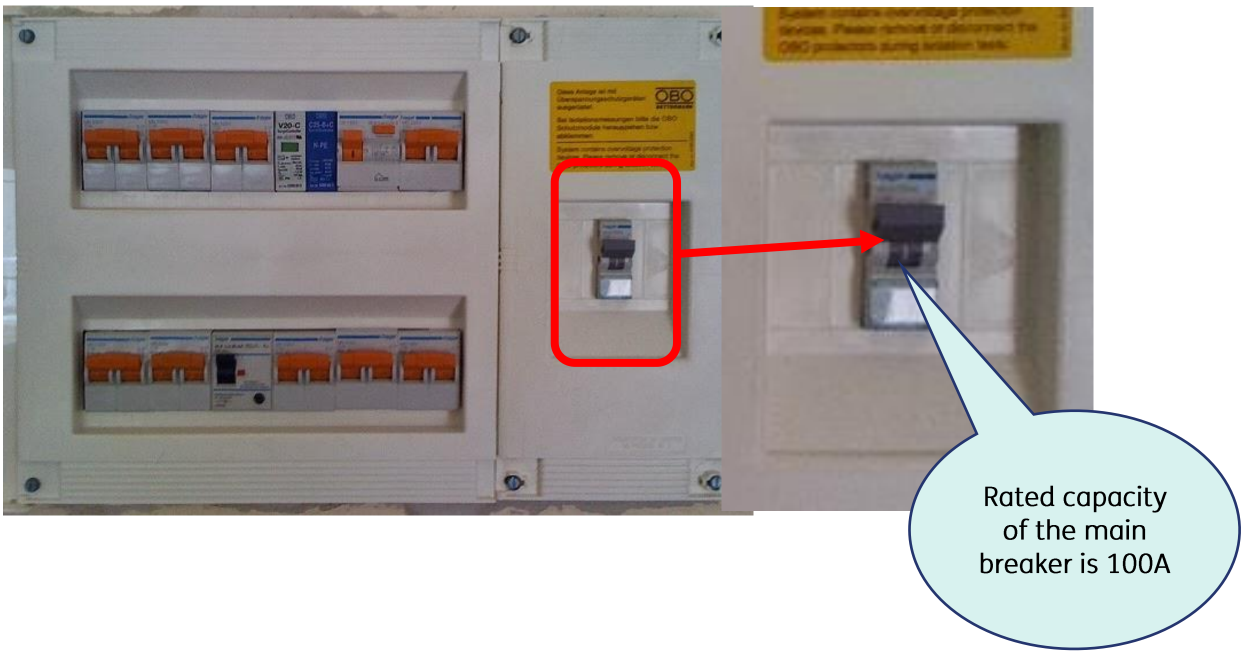
In order for our researchers to determine the rated capacity of your home, we need **a few photos of the circuit breakers/fuses in your switchbox.**

Please take and upload the following:

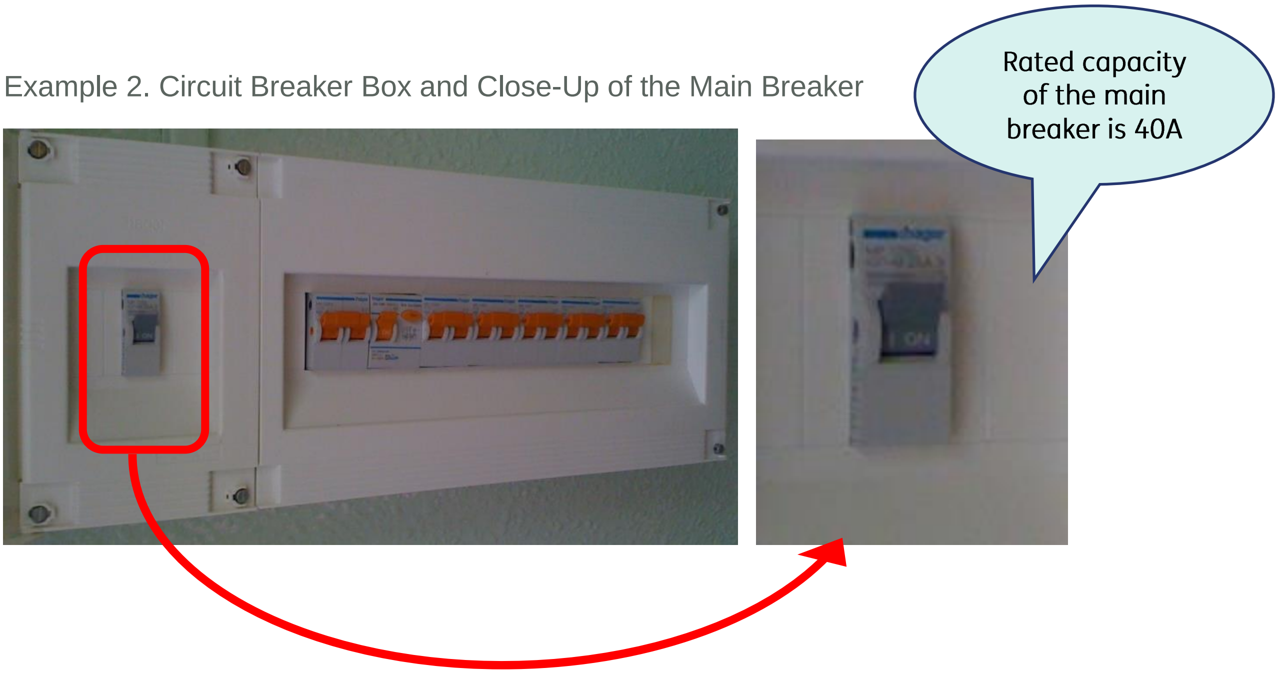
1) One or more steady, non-blurry photos of the whole board with all the breakers/fuses for your home visible. If you are taking multiple photos, please ensure the photos overlap so we can read the text and numbers on all of the breakers / fuses.

2) A steady / non-blurry photo of the main breaker for your house / apartment. The main breaker has the highest rated capacity. It is usually located at one end of a row of switches, and is typically larger and/or can take up two positions. Please see some examples of photos below and let us know if you have any questions.

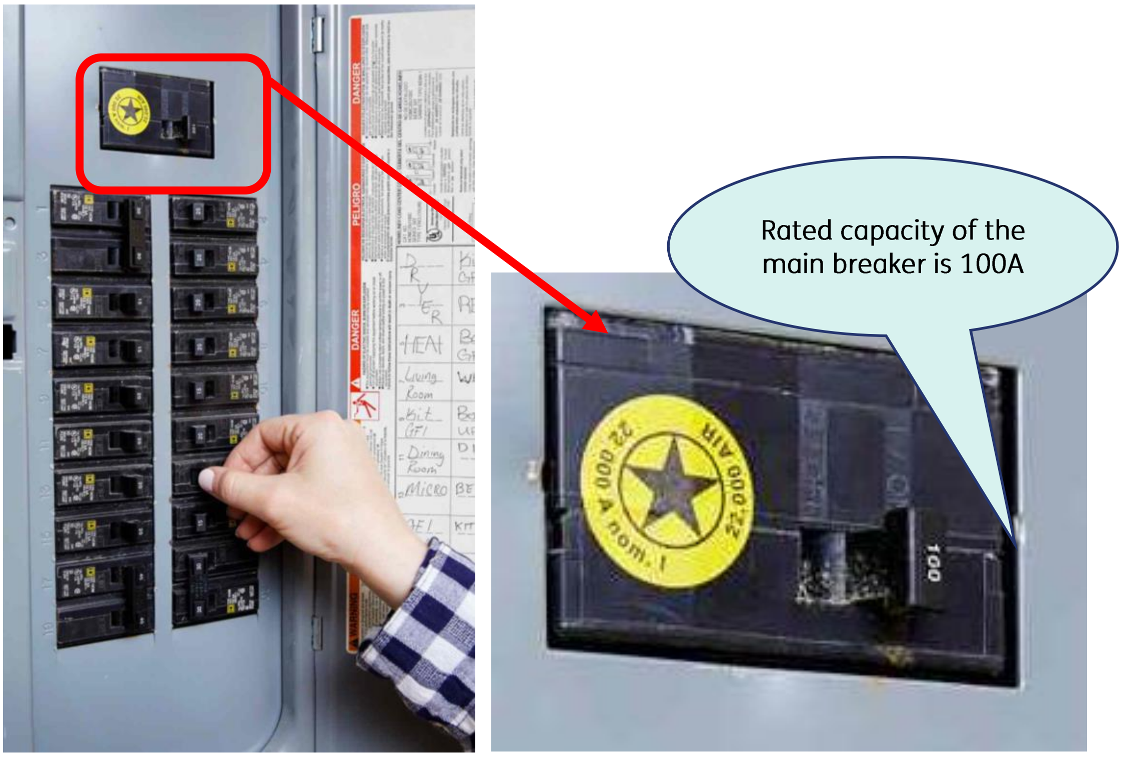
Example 1. Circuit Breaker Box and Close-Up of the Main Breaker



Example 2. Circuit Breaker Box and Close-Up of the Main Breaker



Example 3. Circuit Breaker Box and Close-Up of the Main Breaker



1.6 [MEDIA UPLOAD] SENSOR SET UP

Please take a picture or video of the setup of your two blue and the white sensors in the kitchen so we can see their placement in relation to the hob.

[END PAGE]

Thank you for completing the welcome activity. We have enjoyed learning more about you and your home.

We look forward to hearing more from you in part 2.

Please see the 'help and support' tab for instructions on how to set up the monitoring equipment and the download the Indeemo app that we will use for the daily cooking diary.

[HELP AND SUPPORT PAGE]

Welcome the support forum – here you will find

- Instructions for setting up the sensors for the monitoring the air quality whilst you cook
- A FAQs document on setting up the sensors
- Instructions for downloading the app

If you have any questions, concerns or queries, please post a comment in the support forum and someone will get back to you. Others taking part in the research will see the questions and answers posted here.

Diary

INTRO

Welcome to part 2 of this research – we're so pleased to see you back here!

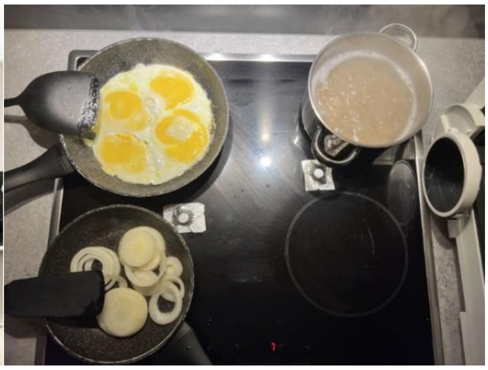
You should have now set up your monitoring equipment. If you have any questions on the set up, please go back into the welcome activity and post your question in the support forum.

To help us understand the data that the sensors pick up when you are cooking, we ask that you complete daily cooking diaries. The diary will involve you uploading a picture of the hot meals you have cooked during the day and answering a few follow-up questions.

You can take your picture live or upload it from your camera reel. We look forward to hearing from you each day.

DAY PART 1

1. OPEN TEXT/ PHOTO: If you cooked a meal between 6am and 12pm (noon) today, please upload one or more pictures of the cooking that was done so we can see how you used your cooktop or oven today and what you were cooking.
Please note this should be a picture of your hob whilst cooking your food (not of your meal after you have cooked it). Please see below for two examples:

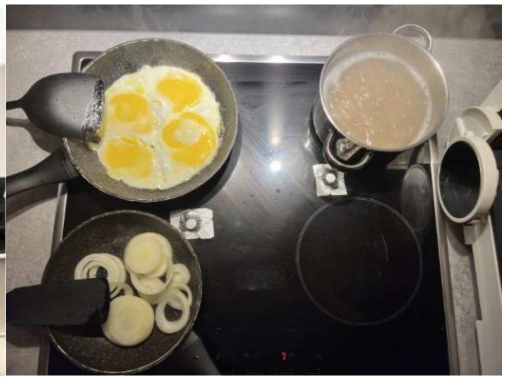
Only if you are unable to upload a picture, please briefly describe the cooking / heating that took place this morning.

2. OPEN TEXT/ PHOTO: What ventilation, if any, did you use when you cooked / heated a hot meal using your cooktop or oven between 6am and 12pm (noon)? Please write the letter of the answer that best describes what you did in the open text box below:
A. I switched on the exhaust hood over the cooker
B. I switch on or increased the setting of my whole-house ventilation fan
C. I turned on the exhaust device in the kitchen or in the adjacent room
D. I opened a window
E. I didn't use any additional ventilation

DAY PART 2

1. OPEN TEXT/ PHOTO: If you cooked a meal between 12pm and 5pm today, please upload one or more pictures of the cooking that was done so we can see how you used your cooktop or oven today and what you were cooking.

Please note this should be a picture of your oven or hob whilst cooking your food (not of your meal after you have cooked it). Please see below for two examples:

Only if you are unable to upload a picture, please briefly describe the cooking / heating that took place this afternoon.

2. OPEN TEXT/ PHOTO: What ventilation, if any, did you use when you cooked / heated a hot meal using your cooktop or oven between 12pm and 5pm?

Please write the letter of the answer that best describes what you did in the open text box below:

A. I switched on the exhaust hood over the cooker
B. I switch on or increased the setting of my whole-house ventilation fan
C. I turned on the exhaust device in the kitchen or in the adjacent room
D. I opened a window
E. I didn't use any additional ventilation

DAY PART 3

1. **OPEN TEXT/ PHOTO: If you cooked a meal between after 5pm today, please upload one or more pictures of the cooking that was done so we can see how you used your cooktop or oven today and what you were cooking.**

Please note this should be a picture of your oven or hob whilst cooking your food (not of your meal after you have cooked it). Please see below for two examples:

Only if you are unable to upload a picture, please briefly describe the cooking / heating that took place this evening.

2. **OPEN TEXT/ PHOTO: What ventilation, if any, did you use when you cooked / heated a hot meal using your cooktop or oven between after 5pm?**

Please write the letter of the answer that best describes what you did in the open text box below:

A. I switched on the exhaust hood over the cooker
B. I switch on or increased the setting of my whole-house ventilation fan
C. I turned on the exhaust device in the kitchen or in the adjacent room
D. I opened a window
E. I didn't use any additional ventilation

Reminder

Thank you so much for all your uploads so far. We greatly appreciate your attention to these details as they are critical to the research.

Please don't forget to keep uploading to your daily diary tasks so we can keep match up the meals with the emissions. If you have any questions, please visit the support page or contact us.

END

Thank you again for your participation in this research. Your feedback has been very valuable.

As a reminder, your incentive will be paid after your in-home monitoring equipment has been collected from your home.

Return postage of the monitoring equipment will take place on DATE. Please contact the courier by phone at least one day before pickup to discuss the optimal pick up time and place. E.g. it is also possible to let the pickup to take place at your work. The phone number is mentioned in the DHL document in the experiment box.

A courier will come to home to collect the equipment. Please ensure that you have packaged up the equipment in time for collection.

Appendix E
Data quality and excluded data per country

Excluded data

The table on the next page describes which data has been excluded based on the criteria as described in paragraph 2.4.

A part of the CO sensor data and to a lesser extent the NO_2 sensor data has been excluded as time and date have been lost during or after the measurement period, probably due to a loose internal battery connection. In the last round (UK & Romania) a part of these defective sensors has been replaced by new sensors.

NO_2 field blanks

Only one of the five blanks for the Netherlands had higher values than the detection limit. This blank, with a concentration of 7.1 µg/m^3, may have been opened by the participant. The average value of the four other blanks was 0.52 µg/m^3. The same applies for Romania, one blank had a high value of 2.8 µg/m^3 and was probably opened.

	average value of field blanks [µg/m^3]
the Netherlands	0.52
Italy	0.58
Spain	0.48
France	0.73
Slovakia	0.64
UK	1.00
Romania	0.85

Due to the low values of the blanks, the measured concentrations were not adjusted for the values measured on field blanks.

	The Netherlands	Italy	Spain	France	Slovakia	UK	Romania
Withdrawals[1]	14, 37, 39	16, 24, 28, 29	30	1, 9, 13, 16, 27	5, 7, 10, 30, 33	4, 12, 31, 34, 35	4, 6, 14, 16, 19, 27
Passive NO_2	2k , 23	1k, 9lbo, 23o, 24	32s	2, 15o	18o	16, 17, 23k,	2l, 3b, 13b
Active NO_2	2, 10, 25, 31, 32	1, 2, 9, 10, 12, 15, 18, 24, 30, 32	3, 7, 10, 18, 19, 21, 24, 31	2, 6, 17, 20, 27, 28, 32, 33, 34, 35, 36, 37	9, 18	3, 5, 7, 14, 28, 33, 38	6, 10, 32, 40
Active CO	5, 6, 9, 10, 18 28	1, 4, 6, 9, 10, 12, 15, 17, 19, 22, 24, 27, 30, 35, 39, 40	1, 3, 6, 9, 12, 16, 19, 21, 22, 24, 25, 31, 35,	2, 3, 4, 5, 10, 11, 14, 17, 18, 19, 20, 22, 25, 26, 27, 28, 29 30, 32, 34, 36, 37, 38, 39, 40	1, 2, 6, 8, 9, 12, 14, 15, 16, 17, 22, 24, 25, 26, 27, 28, 31, 34, 37, 38, 39, 41	2, 7, 15, 19, 24, 40	1, 6, 23, 26, 37, 39, 40
$PM_{2.5}$	1, 11, 16, 18, 20, 21, 25, 27, 35	1, 2, 9, 13, 15, 24, 30, 31	1, 4, 7, 23, 24, 25, 28	31	4, 17, 25, 28	2, 14, 28	6, 13, 24,26, 40
CO_2	11, 36	1, 2, 5, 9, 13, 15, 24, 30, 31	1, 4, 7, 23, 24, 25, 28	31		2, 5, 14, 28	13, 24, 40

[1]Including participants that did not deliver any data or did not return the sensor box

Passive NO_2:
k = kitchen
l = living room
b = bedroom
o = outside

Appendix F

Cross sensitivity of CO sensor for alcohol

Electrochemical CO sensors are known to be sensitive towards alcohols, VOC's and hydrogen[8]. Envea mentions in their technical manual[26] only a cross sensitivity for H_2. This Appendix describes explorative measurements to determine the sensitivity of the Envea NO_2 and CO sensor towards Volatile Organic Compounds (VOC's) and specifically towards ethanol. For this a number of typical cleaning agents have been selected, see Figure 10.5.

Figure 10.5 typical cleaning agents and whine being used in kitchen, from left to right Dubro cleaning tissues, hand cleaning alcohol, bottle of red wine and CIF kitchen cleaning spray.

The indicative measurements have been carried out during the calibration after return of the sensors from the UK and Romania. The time scheme with a number of events is given in Table 10.1. After each of the events which lead to an increase of the concentration measured by the Cairsens sensor the 46 m^3 experimental room was vented.

Table 10.1: time scheme of calibration and indicative sensitivity measurements.

Time	Pollutant
09:00 – 11.00	Base line value without introduction of pollutants
12.30 – 14.00	Gas hob, gas flow 2.6 liter/min, ventilation 67 dm^3/s
14.45 – 16.15	Gas hob, gas flow 2.6 liter/min, ventilation 29 dm^3/s
17.00 – 17.10	CIF – 2 puffs, ventilation 67 dm^3/s
17.10 – 17.15	6 Dubro cleaning tissues, ventilation 67 dm^3/s
17.40 – 17.51	2 puffs of hand cleaning alcohol, ventilation 67 dm^3/s
18.15 – 18.30	2 glasses of red wine and open bottle, ventilation 67 dm^3/s

Figure 10.6 and Figure 10.7 show as an example the calibration curves of the sensors applied in the first UK household UK01. The curves of the other sensors have the same shape. For these two figures a linear calibration curve has been derived for which the curves of the Envea sensor optimally overlaps the reference instrument curve during use of the gas hob.

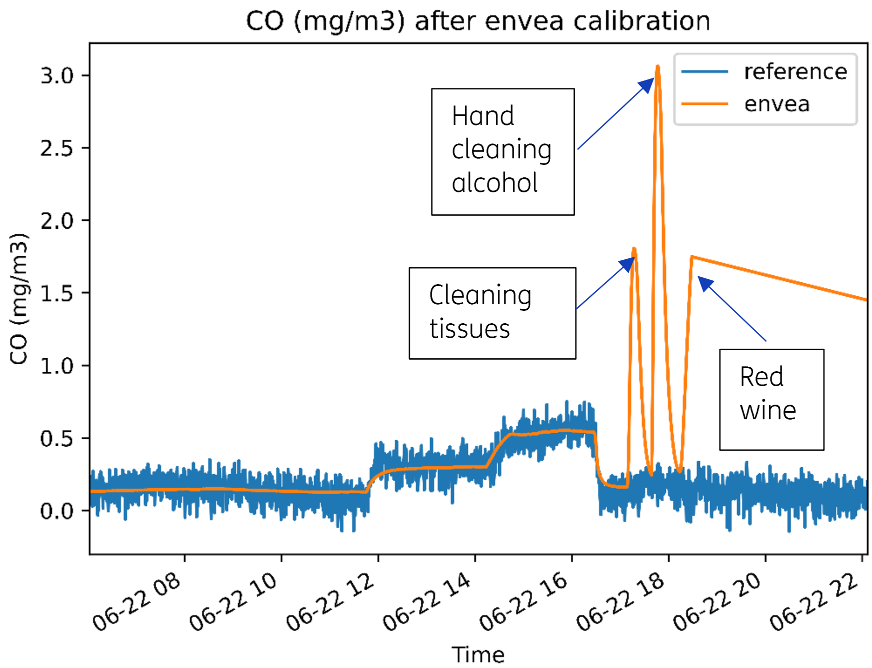


Figure 10.6 calibration curve for UK1 CO sensor (slope: 0.20, intercept: -0.04). Reference instrument Picarro G2401.

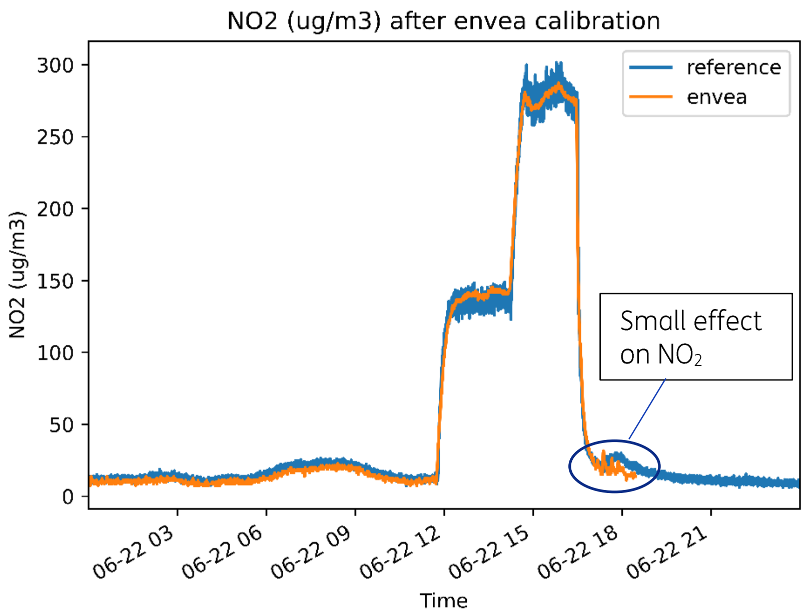


Figure 10.7 calibration curve for UK1 NO_2 sensor (slope: 0.65, intercept: -1.6). Reference instrument Thermo model 42i.

The calibration curve for the CO sensor clearly shows a high sensitivity for two of the cleaning agents and the red wine, all containing ethanol. The CIF kitchen spray did not induce a reaction from the CO sensor. According to the label it contains limonene, but no ethanol. During these indicative tests the effect of ethanol on the “CO” concentration is much higher than the effect of using the gas hob. The gas hob use and ventilation in the lab are comparable with what is found in common households.

In the calibration curve for the NO_2 sensor there is only a small effect visible of the events with the cleaning agents and the wine on the NO_2 concentration. The effect is much smaller than the effect of using the gas hob. The small fluctuations in NO_2 concentration could be caused by venting the experimental after each event room with outdoor air at high speed in combination with opening the door of the room to the rest of the laboratory.

From the experiments it can be concluded that the CO sensor is at least sensible for ethanol. And that during normal use of cleaning agents and or by alcohol consumption this interference can be significant.

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