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Literature review: Potential health effects of exposure to gas emissions in new developments 2024

A report for the Hornsby Shire Council

by

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Executive Summary

The aim of this report is to give Council evidentiary basis for the health benefits of mandating all electric buildings. This has been based on a review of the literature on the potential adverse health impacts of exposure to emissions from gas heating and cooking.

The review of the many studies examined highlighted the emission levels of gases from gas appliances can be significant. The main gases of concern are carbon monoxide (CO) and nitrogen dioxide (NO_2). Exposure to carbon monoxide (CO), which is odourless, must be kept to a minimum to avoid health impacts such as headaches, nausea, vomiting, dizziness, malaise, confusion and occasionally death. Nitrogen dioxide (NO_2) exposure is easier to keep to a minimum level due to its pungent odour and at normal exposures will not cause death but may aggravate underlying medical conditions such as respiratory and cardiovascular diseases.

The review has shown that emissions from gas heaters can be variable depending on the levels of ventilation and maintenance of the gas heaters. A major concern is the reports of deaths due to excessive exposure to CO, and the exacerbation of underlying respiratory conditions due to NO_2 exposure. The levels reported highlight the importance of the removal of unflued or open flued gas heaters from homes and schools, or at least restrict their future installation.

The majority of the literature reviewed looked at emissions from gas stoves, and the majority showed a link between using a gas stove. Unlike gas heaters the main emission from gas stoves is nitrogen dioxide. The levels of emissions is higher from gas stoves when a gas oven is used rather than an electric oven, in conjunction with the gas hobs. It also depends on the cooking techniques being undertaken.

Unfortunately, there are few studies that have looked at emissions in commercial kitchens and therefore no specific recommendation can be made about the use of the gas stoves in these premises.

The significant volume of literature on the adverse health impacts of emissions from gas appliances gives strength to the concept that gas appliances should be banned from modern tight homes where ventilation is normally restriction with air movement limited to mechanical ventilation.

Based on the review it is recommended that Hornsby Shire Council should:

1. Review planning rules and building regulations to encourage the installation of non-gas-powered heating and cooking in all new homes.

2. Develop a health promotion program on the importance of all households, who currently have gas heaters and/or gas stoves, installing CO monitors in the homes, similar to the requirements for smoke alarms.

3. Transition away from the use of gas by switching council-owned buildings to alternatives like reverse cycle air conditioning and heat pumps.

4. Should lobby the NSW state government to investigate:
    a. the removal of rules that restrict local governments from banning gas connections in new residential developments;
    b. the provision of incentives for homes, schools and businesses to switch to electric appliances, including subsidies for low-income households; and
    c. the acceleration of the replacement of unflued gas heaters in NSW public schools with zero emission heating.

5. Until such times as gas installations in homes is banned, no installations should be approved, by local councils, that don't meet the appropriate Australian Standards.

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Abbreviations

%	Percentage
µg	Micrograms
µg/m^3	Micrograms per cubic metre
µm	Micrometre
ABCB	Australian Building Codes Board
ACGIH	American Conference of Governmental Industrial Hygienists
AS	Australian Standards
AS/NZS	Australian Standards/ New Zealand Standards
CARB	California Air Resources Board
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COPD	Chronic Obstructive Pulmonary Disease
DECCA	Department of Energy, Environment and Climate Action
EPA(US)	Environmental Protection Agency (United States)
ES	Exposure Standards
Exposure	Contact between an agent and a target
FEV_1	Forced expiratory volume in 1 second
FVC	Forced expiratory vital capacity
HCHO	Formaldehyde (CH_2O)
HSC	Hornsby Shire Council
LPG	Liquid Petroleum Gas
mg/m^3	Milligrams per cubic metre
MJ/h	megajoules per hour
mL	Millilitre
mL/min	Millilitre per minute
n	Number of samples
NEPM	National Environment Protection Measure
ng/m^3	Nanograms per cubic metre
nm	nanometres
NO	Nitrogen oxide
NO_2	Nitrogen dioxide
NO_x	Nitrous oxides
OEHHA	California's Office of Environmental Health Hazard Assessment
OR	Odds ratio
PM_{10}	Particles less than 10 µm aerodynamic diameter, also called the thoracic curve
$PM_{2.5}$	Particles less than 2.5 µm aerodynamic diameter, also called the high risk

	respirable curve
ppb	Parts per billion
ppm	Parts per million
SD	Standard Deviation
SWA	Safe Work Australia
TLV’s	Threshold Limit Values
UFGH	Unflued Gas Heater
US	United States of America
US EPA	U.S. Environmental Protection Agency
VOCs	Volatile organic compounds
WHO	World Health Organisation

Chapter 1: Introduction to the problem

Issues relating to gas heating and gas cooking has been an issue for over 30 years. Initially, the main concern was with unflued heating and cooking due to indoor emissions. In the 1990's, Victoria had restrictions on the use of unflued gas heaters in the Melbourne area residences, but with the design of gas heaters to meet stringent Australian standards this was relaxed. The Victorian government reviewed this following a Coroner's report and on the 1st August 2022 it became illegal to sell, supply or install any open flued gas heaters which do not meet the new improved safety requirements including a safety shut off device, as required by AS/NZS5263.1.3: 2021 (DECCA, 2023). However, there are currently no similar restrictions, or proposed restriction, in NSW at a state government level. Several councils, eg City of Sydney, Waverley Council and Parramatta Council, have proposed that all new developments should only include electric heating and cooking appliances (Shatssoon, 2023).

The Australian standard, AS/NZS 5263.0: 2023, definition of a unflued or flueless appliance is an appliance that is designed to emit its flue gasses directly into the space (room) that the appliance is located. A flued appliance is designed to emit its flue gases into a flue system eg chimney (Standards Australia, 2023).

Leber (2021) in a report for use in the US proposed changing the building codes to ban the installation of new gas stoves. When this recommendation on the ban on gas stoves was received the gas industry flooded the communities with scare tactics. The California Air Resources Board then proclaimed that gas stoves cause indoor air pollution and the California Energy Commission proposed the inclusion of subsidies for the installation electric home heating and hot water when updating to the Californian state building code, for a proposed implementation by 2026.

Bambrick et al (2021), in a report for the Climate Council of Australia, indicated that gas cooking in the home is responsible for up to 12% of childhood asthma, and is responsible for significant levels of methane a major greenhouse gas. They made a number of recommendations to the NSW state government on the replacement of gas heating and cooking in homes and schools.

1.1 Aims and objectives

The aim of this report to give Council a substantiated and reasonable evidentiary basis for the health benefits of mandating all electric buildings. This will be based on a scoping review of the literature on the potential adverse health impacts of exposure to emissions from gas heating and cooking.

To meet the aim the report will:

- Summarise the literature on the emissions for gas heating in residential premisses.
- Summarise the literature on the emissions for gas cooking in residential premisses.
- Summarise the literature on the emissions for gas cooking in commercial premisses.
- Provide recommendations potential changing of building guidelines in relation to heating and cooking appliances in building.

1.2 Exposure standards for contaminant emissions natural gas heating and cooking

There are no specific air exposure standards for indoor environments in Australia, except for workplaces, other than the guidelines published by the Australian Building Codes Board in their *Indoor Air Quality Handbook* (2nd Ed.) (ABCB, 2021).

The main gases/vapours emitted from gas heating and or cooking are:

- Carbon monoxide
- Nitrogen dioxide
- Formaldehyde
- VOC's (in very limited amounts)

Table 1.1 summaries recommended exposure standards published by a number the sources which have been based on epidemiological studies (ABCB, 2021; ACGIH, 2024; NEPM, 2021; Safe Work Australia, 2024; WHO, 2009; WHO, 2010; WHO, 2021). These recommendations have been suggested to minimize health effects, such as the indoor air exposure standard for carbon monoxide which should be kept below an 8-hour guideline, for workplaces, of 9.3 ppm (10.5 mg/m^3) and possibly as low as 4.1 – 5.1 ppm (4.6–5.8 mg/m^3). The lower level may be considered essential as the exposure time to carbon monoxide in a general indoor environment, as the result of gas emissions, may be three (3) times longer, especially for at risk populations (very young and very old) during winter months. The nitrogen dioxide (NO_2) indoor air exposure standard recommended by WHO (2021) for long term exposure is 5.3 ppb (10 µg/m^3) and is based on limited impact on non-accidental mortality.

Table 1.1: International exposure standards for contaminants that may be emitted from natural gas heating and cooking

Contaminant	Source	Concentration	Time Period	Comments
Carbon Monoxide (CO)	WHO, 2010	100 ppm	15 minutes	Light exercise: excursions to this level should not occur more than once per day
		35 ppm	1 hour	Light exercise: Excursions to this level should not occur more than once per day
		10 ppm	8 hour	Light to moderate exercise: Arithmetic mean concentration
		7 ppm	24 hours	Awake and alert but not exercising: Arithmetic mean concentration
	ABCB, 2021 WHO, 2021	90 ppm	15 minutes	Based on WHO Guidelines
		50 ppm	30 minutes	Based on WHO Guidelines
		25 ppm	1 hour	Based on WHO Guidelines
		10 ppm	8 hour	Based on WHO Guidelines
		6 ppm	24 hour	Interim ambient level
		3.4 ppm	24 hour	Air Quality Guidelines Long term goal
	NEPM, 2021	9 ppm	8 hour	Based on WHO Guidelines
	SWA, 2024	30 ppm	8 hour	Levels of carboxy haemoglobin (COHb-emia)
	ACGIH, 2024	25 ppm	8 hour	
Carbon dioxide (CO_2)	ABCB, 2021	850 ppm	8 hour	Used as an indicator of human occupancy and if sufficient fresh air is entering the space
	ACGIH, 2024 SWA, 2024	5000 ppm	8 hour	Asphyxia
	ACGIH, 2024 SWA, 2024	30,000 ppm	15 minutes	Asphyxia
Formaldehyde, ($HCHO/CH_2O$)	ABCB, 2021	0.1 mg/m^3	30 minutes	Based on the WHO recommendations
	WHO, 2009	0.1 mg/m^3	30 minutes	Based on potential sensory irritation in the general population
	NEPM	0.04 ppm	24 hr	
	ACGIH, 2024	0.1 ppm	8 hour	Upper respiratory tract & eye irritant
	ACGIH, 2024	0.3 ppm	15 minutes	Upper respiratory tract & eye irritant
	SWA, 2024	1 ppm	8 hour	Sensitiser
	SWA, 2024	2 ppm	15 minutes	Sensitiser
Nitrogen dioxide (NO_2)	WHO 2021	0.021 ppm	annual	Interim ambient level
		0.005 ppm	annual	Air Quality Guidelines Long term goal
		0.064 ppm	24 hour	Interim ambient level
		0.013 ppm	24 hour	Air Quality Guidelines Long term goal
	ABCB, 2021	0.0987 ppm	1 hour	Based on the WHO recommendations
		0.0197 ppm	1 year	Based on the WHO recommendations
	NEPM, 2021	0.08 ppm	1 hour	The levels have been reduce to better reflect health evidence emerging adverse health impacts of exposure to NO_2
		0.015 ppm	1 year	
	SWA, 2024	3 ppm	8 hour	
		5 ppm	15 minutes	
	ACGIH, 2024	0.2 ppm	8 hour	Lower respiratory irritant
VOCs	ABCB, 2021	500 µg/m³	1 year	Based on a previous recommendation of NH&MRC that was rescinded in 2002

Table 1.2 summarises the recommended indoor exposure standards for use in the US, but these need to be adopted at a state level and in many US states this has not been the case. Two states that have been very proactive in promulgating indoor air standards are California and Texas.

Table 1.2: Indoor pollutant standards recommended for use in the United States of America (Logue et al 2014, p46)

Pollutant	1 hour average (acute)	8 hour average (acute)	Annual average (chronic)	Standard
CO	20 ppm	9 ppm	NA	CAAQS (CARB 2016)
	35 ppm	9 ppm	NA	NAAQS (U.S. EPA 2023)
HCHO	45 ppb	7.3 ppb	7.3 ppb	Non-cancer REL (OEHHA 2024)
NO_2	100 ppb	NA	53 ppb	CAAQS (CARB 2016)
	100 ppb	NA	53 ppb	NAAQS (U.S. EPA 2023)

California Air Resources Board (CARB) 2016. *Ambient Air Quality Standards (ACCQS)* <https://ww2.arb.ca.gov/sites/default/files/2020-07/aaqs2.pdf> [7 February 2023]
California's Office of Environmental Health Hazard Assessment (OEHHA) 2024. *OEHHA Acute, 8-hour and Chronic Reference Exposure Level (REL) Summary,* <https://oehha.ca.gov/air/general-info/oehha-acute-8-hour-and-chronic-reference-exposure-level-rel-summary, [7 February 2023].
U.S. Environmental Protection Agency (U.S. EPA) 2023. *National Ambient Air Quality Standards (NAAQS).* <https://www.epa.gov/criteria-air-pollutants/naaqs-table [7 February 2023]

1.3 Recommendation on indoor air exposure standards

Based on a review of the exposure standards, it is recommended that until such time as a national indoor exposure standard for homes is published by an Australian government department, that the recommendations of the Australian Building Codes Board be adopted. The indoor exposure standards recommended for adoption by Hornsby Shire Council are defined in Table 1.3.

Table 1.3 Recommended Indoor Air Exposure Levels for Homes (Adapted from: ABCB, 2021)

Contaminant	Concentration	Time Period	Comments
Carbon monoxide (CO)	90 ppm	15 minutes	Based on WHO Guidelines
	50 ppm	30 minutes	
	25 ppm	1 hour	
	10 ppm	8 hours	
Carbon dioxide (CO_2)	850 ppm	8 hours	Used as an indicator of sufficient fresh air entering the space occupied by humans.
Formaldehyde (HCHO/CH_2O)	0.08 ppm 80 ppb	30 minutes	Based on the WHO recommendations to protect against the sensory irritation
Nitrogen dioxide (NO_2)	0.0987 ppm 98.7 ppb	1 hour	Based on the WHO recommendations to protect against the health effects of NO_2
	0.0197 ppm 19.7 ppb	1 year	
VOCs	500 μg/m³	1 year	Based on rescinded NH&MRC guidelines

Chapter 2: Methodology

The literature review was conducted by searching the Scopus database and Google Scholar (to collect grey literature) using a broad keyword search to collect information that can be used to inform the report. The purpose of this multifaceted approach was to obtain a comprehensive range of publications and information to enable a current assessment of the relevant information required with which to address the objectives of the study.

The following inclusion criteria were applied:

- gas heater emissions;
- gas cooking emissions; and
- health impacts of gas emissions.

In addition to the review of identified scientific papers, the references listed in some studies were examined to source additional information where deemed appropriate. This review concentrates on the potential health impacts of emissions from gas heaters and gas stoves in residential premises, with several sources of literature discussing emissions from gas cooking in commercial premises.

The review involved accessing 120 sources that indicated in the literature search that they discussed the potential impacts of gas heaters and/or on respiratory health and the related emissions. Of the 120 sources reviewed only 77 (64.2%) sources had information that related directly to the project and are therefore cited in this report.

A number of sources (Basinger et al, 2023; Bass et al, 2021; Fischer et al, 2018; Kashtan et al, 2023; Lebel et al 2020; Lebel et al 2022; Merrin and Francisco, 2019; Nadel, 2018; Traynor et al, 1985; Traynor et al, 1996) have reported on emissions from gas heaters or gas water heaters, but they are centred on:

- what type is the most energy efficiency type of energy supply;
- can the natural gas be replaced with hydrogen; or
- the impact of gas heating and cooking on greenhouse gases.

The data modelled in these studies will not be reported in this report.

One of the issues with many reports is that they use different emission units, which makes it at times difficult to compare. For this report the majority of the units that have been used are parts per billion (ppb) or parts per million (ppm), except for VOCs which are always reported in micrograms per metre cubed ($\mu g/m^3$). Table 2.1 shows the conversion units for the main emissions of interest.

Table 2.1: Emissions Unit Conversions

Contaminant	ppm	μg/m^3	ppb	μg/m^3
Carbon monoxide (CO)	1 ppm	1150 μg/m^3	1 ppb	1.15 μg/m^3
Formaldehyde (HCHO)	1 ppm	1228 μg/m^3	1 ppb	1.228 μg/m^3
Nitrogen dioxide (NO_2)	1 ppm	1880 μg/m^3	1 ppb	1.88 μg/m^3
Nitrogen oxide (NO)	1 ppm	1230 μg/m^3	1 ppb	1.23 μg/m^3

Chapter 3: Gas heating emissions

3.1 How does a flued and unflued gas heater work

Unflued gas heaters became popular due to the cost and ease of installation. Gas was also seen in the 1990s as a cheaper form of energy for heating in Australia, and many residents and schools installed the heaters. In more recent times there has been concerns raised about the potential impacts on health from the emissions from the unflued heaters as well as gas stoves, especially on individuals who already of respiratory issues.

Figure 3.1 shows how each of the three main types of gas heaters work and how emissions may get released into the indoor environment.

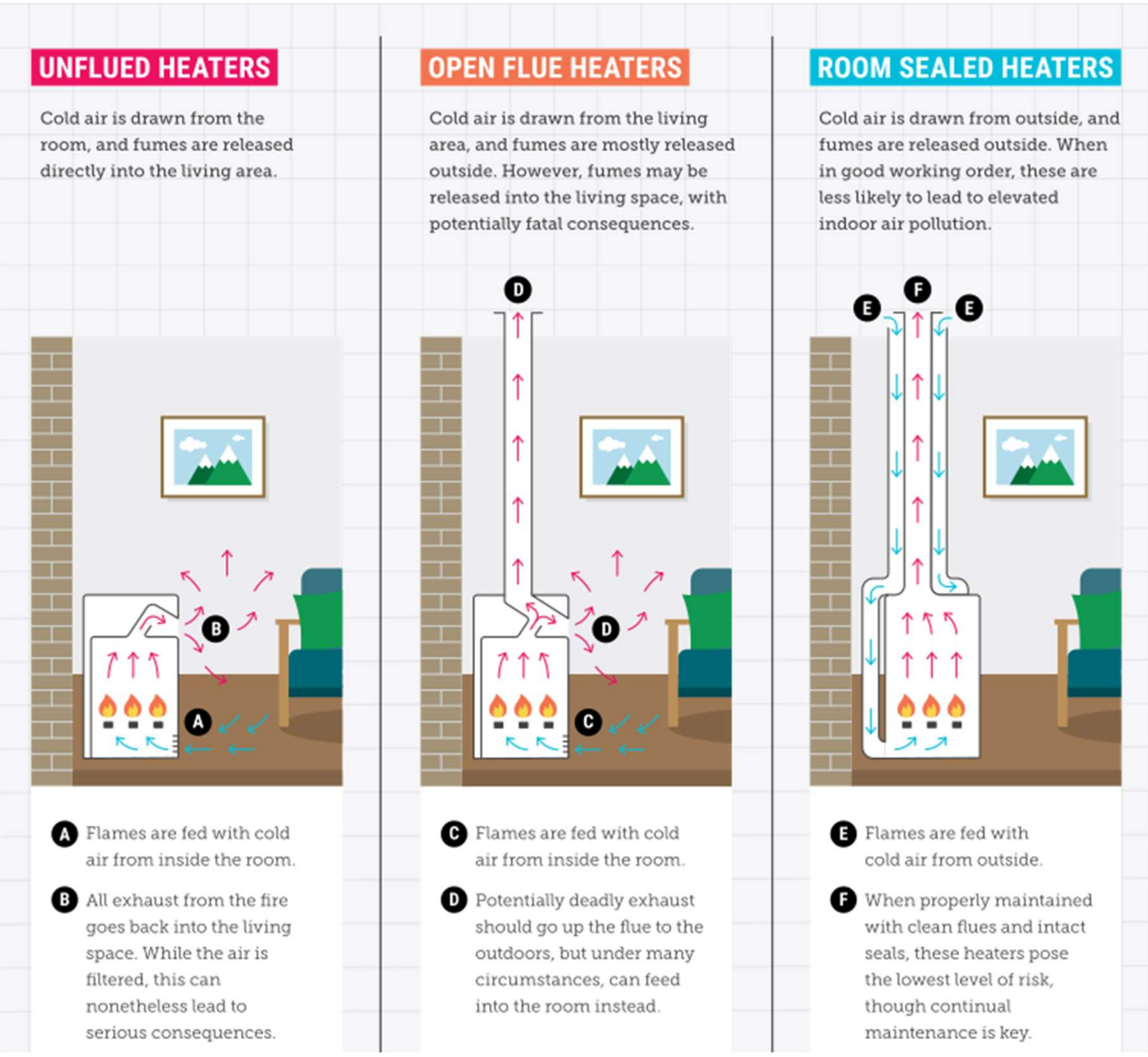

Figure 3.1: Operation of difference types of gas heaters

(Source: Bambrick et al 2021, p. 26, Figure 11)

The selling and installation of gas heaters in Australia today must meet the relevant Australian Standards, which are:

AS/NZS 5263.0:2023, *Gas appliances General requirements*, SAI Global, Sydney

AS/NZS 5263.1.3:2021, *Gas appliances Gas space heating appliances,* SAI Global, Sydney

AS/NZS 5263.1.4:2017, *Gas Appliances, Part 1.4: Radiant gas heaters*, SAI Global, Sydney

AS/NZS 5263.1.6:2020, *Gas appliances Indirect gas-fired ducted air heaters*, SAI Global, Sydney

AS/NZS 5263.1.8:2021, *Gas appliances Decorative effect gas appliances*, SAI Global, Sydney

AS/NZS 5263.1.10:2019, *Gas appliances, Part 1.10: Gas direct fired air heaters*, SAI Global, Sydney

In 2022, the Victorian Department of Energy, Environment and Climate Action (DEECA, 2023) made it illegal to sell, supply or install new or second-hand open-flued gas space heaters that do not meet new and improved safety requirements, as specified in the Australian Standards. This was in response to a Coroner's report where a person died from carbon monoxide poisoning. The coroner found that as a result of the improved building standards for modern homes resulting in better sealed homes, to improve energy efficiency, has resulted in the build-up of indoor pollutants, such as carbon monoxide (Coroners Court of Victoria, 2013)

WorkSafe ACT (2016) defines unflued gas heaters as a gas heater that has no flue or chimney to remove the combustions emissions from the space the heater is located in. Many of the economical gas heaters are unflued, portable and can be plugged into a wall or floor socket using a flexible hose, in some cases they have been fixed to the wall. Unflued gas heaters are also known to produce water vapour that can increase mould and dust mite in indoor environments.

Gas heaters that are designed to be use outside normally on patios (patio heaters) should never be used inside. Unfortunately, patio heaters have been used indoors and the unfortunate outcome has been either severe illness or death due to carbon monoxide and nitrogen dioxide build-up indoors.

Choice (2024) has recently provided guidance on the pros and cons of different types of gas heaters, as shown in Table 3.1.

Table 3.1: Pros and cons of flued versus unflued gas heaters

(Adapted from: Choice, 2024)

Unflued (portable) gas heaters	**Flued gas heaters**
Pros	**Pros**
• Easier to move – you can point them in different directions, move them from room to room, store them away in summer and take them with you when you move house.	• Same points as unflued gas heaters in relation to heating effectiveness and efficiency.
• Very efficient compared to a portable electric heater – about 90% of the energy content of the gas is transformed into heat.	• Can be installed in a smaller room where an unflued heater is not permitted.
• Provide instant heat – and lots of it. Unflued gas heaters come with a capacity of up to 25 MJ/h. (Equivalent to more than 6kW of electric heating.	• Minimal risk of harmful emissions and water vapour escaping into the room (they exit via the flue).
• Cheaper to run than portable electric heaters even though they're a lot more expensive to buy.	• Can be an attractive "fireplace" feature in the room.
• Produce a quarter to a third of the carbon of an equivalent electric heater.	
• Range of safety features (in modern models) that switch the heater off in case something's wrong. For example, an oxygen depletion sensor if the oxygen level in the room gets too low, flame failure protection in case the flame gets extinguished, and a tilt switch in case the heater tips over. But make sure that you install a carbon monoxide alarm as well, just in case.	
Cons	**Cons**
• Emissions from the gas combustion process in the heater are vented back into your room.	• Usually more expensive to buy and install than an unflued/portable gas heater.
• Produces carbon monoxide (CO) and nitrous oxides (NOx), in small quantities (unless the heater is faulty or poorly maintained).	• Emissions from the gas combustion process in the heater are not normally vented back into your room.
• They can still lead to or exacerbate asthma and other respiratory problems, especially in children	• While the risk of harmful emissions escaping into the room is lower than for an unflued gas heater, it can still happen if the heater is faulty or poorly maintained.
• Illegal to use in bedrooms, bathrooms and other small or badly ventilated rooms, so for those areas you need a flued heater, or an electric heater, or reverse-cycle air conditioning.	• Some heat is lost through the flue (chimney) so this type is a bit less energy efficient than an equivalent unflued gas heater.
• Regular maintenance every couple of years or so is required to avoid problems with the emissions mentioned above.	• Regular maintenance is important for flued gas heaters
• Water vapour from the combustion process can condense on walls and ceilings and cause mould, which is why ventilation is so important.	
• Gas has to be bought from a gas supplier, while with electricity you have the option of generating it at home with solar panels. Gas is a non-renewable resource, which is an increasingly important consideration for many people.	
• Restrictions on using this type heater apply in some states. Check with a gas plumber or retailer. Victoria no longer allows gas bayonets to be installed for the purpose of an unflued gas heater.	

3.2 Exposure data literature on gas heaters

Little literature has been published on the levels of emissions from gas heating especially in Australia, though several studies discuss the impacts of gas heater emissions in general on respiratory health, especially in children. This is despite the volume of publicity, in popular press, on issues relating to gas heating emissions and potential health impacts. Gas heaters are not commonly used in Europe and US so don't appear as a central issue in research, whereas as gas is commonly used to cook with.

In an early study by Girman et al (1983) the emissions from eight (8) types of US gas heaters over a series of four tests were measured. The initial tests were conducted on well-tuned heaters operated at full input, two under low input, three under medium input and three under high-ventilation conditions. The second series of tests was conducted on the same heaters at partial input with the same ventilation conditions. The third series involved two of the heaters operating under the condition of maltuning (supply of excess air), with the air shutters fully open and then fully closed. Finally, three heaters were tested under equilibrium conditions (steady-state) at several O_2 levels (18%-20%) and at several different air-shutter settings. All emission rate tests were conducted in a 27 m^3 environmental chamber, inside another building, and the emissions of carbon monoxide, carbon dioxide, nitrogen oxide, nitrogen dioxide, formaldehyde, respirable particles as well as oxygen levels, were measured. The levels of emissions above the background that were reported for unvented gas fired space heaters operating near steady state conditions are shown in Table 3.2.

Table 3.2: Average heater emission concentrations from specific unvented gas-fired space heaters operating continuously in a house well mixed air
(Adapted from: Girman et al 1983, p. 49)

Heater	Carbon Monoxide [CO] (ppm)	Carbon Dioxide [CO_2] (ppm)	Nitrogen Dioxide [NO_2] (ppm)	Formaldehyde [HCHO] (ppm)	Oxygen [O_2] (%)
Well tuned heater					
12A	3.2	880	0.13	0.080	20.7
16B	8.1	1570	0.24	0.018	20.6
20C	0.9	2000	0.18	0.039	20.5
30A	2.4	2730	0.29	0.039	20.3
40B	7.8	4000	0.67	0.081	20.2
40C	1.5	4120	0.31	0.049	20.2
Average	*4.0*	*2550*	*0.30*	*0.051*	*20.4*
Poorly tuned heater					
30A	49.0	2610	0.29	1.300	20.4
40C	1.0	4550	0.27	0.040	20.2
30A	15.0	3090	0.34	0.070	20.3
40C	4.2	3770	0.36	0.018	20.2
Average	*14.6*	*3314*	*0.31*	*0.296*	*20.3*

More recently, a South Australian study, by Pilotto et al (2003), investigated the impact of replacing un-flued gas heaters (controls) with either flued gas heaters or electric heating (intervention) showed that the levels of NO_2 were reduced significantly. The study measured the levels of NO_2 both in the classroom and the participants homes, as well as collecting symptom diaries. The levels of NO_2 in the control classroom had a mean of 47 ppb (ranging from 12 to 116 ppb) and the intervention classrooms had a mean of 15.5 ppb (ranging from 7 to 38 ppb). The mean NO_2 levels in the kitchen at home were 14.6 ppb for the control group and 13.7 ppb for the intervention group, with the personal monitors recording 12.9 ppb for the control and 12.8 ppb for the intervention group. The outcomes of the study showed that the replacement of the unflued gas heaters in schools reduced the incident of asthma symptoms.

Carcia-Alager et al (2003) in a study on NO_2 levels in Spanish homes reported average levels of 26.46 ppb for homes with a gas heater/fire and 24.1 ppb for homes with a gas stove.

Brown, Mahoney and Cheng (2004) assessed the levels of emissions from unflued gas heaters in an environmental chamber. The gas stoves tested varied in age of operation from less than 20 hours to 1400 hours, in addition a 9 year old LPG heater was tested. Their study showed that the carbon monoxide (CO) levels varied from 1 to 18 ppm for unflued gas heaters and 4 ppm for 9 year old LPG gas heater. The nitrogen dioxide (NO_2) levels varied from approximately 146 ppb (180 $\mu g/m^3$) to 431 ppb (530 $\mu g/m^3$), for the unflued gas heaters, and 659 ppb (810 $\mu g/m^3$) for the 9 year old LPG gas heater. It should be noted that they also detected levels of formaldehyde as well as a range of VOCs.

In an Australian study in twenty two (22) NSW schools, by Marks et al (2010), the concentrations of NO_2 and formaldehyde were measured in classrooms being heated using either a flued or unflued heater, are shown in Table 3.3. The study also showed that there was no measurable changes in lung function in children, between the type of heater in use, but a unflued gas heater, even the lower NO_2 style, increased respiratory symptoms especially in atopic children.

Table 3.3: Concentrations of NO_2 and formaldehyde in classroom

(Adapted from Marks et al 2010, p1478, Table 2)

Contaminant (ppb)	Flued Heater		Unflued heater	
	Mean	95% Geometric range	Mean	95% Geometric range
NO_2 (ppb)	17.5	3.5 – 88.4	31.6	7.4 – 135.2
Formaldehyde (HCHO) (ppb)	24.7	3.3 – 46.1	32.6	3.1 – 62.1

A study in Chile looking at the impact of types of heaters on air quality, by Ruiz et al (2010), primarily looked at the levels of $PM_{2.5}$ and the related chemical speciation. The results are summarised in Table 3.4. The types of fuel used in the study were Compressed Natural Gas (CNG), Liquefied petroleum gas (LPG) and Kerosene. The control homes were all electric. The monitoring undertaken used real time monitors which showed that when the heaters were on, the room temperature was raised, concentrations of emissions was elevated but when the heaters were turned off the emissions returned to background/outdoor levels.

Table 3.4: Summary of indoor air pollutants based on heater type in Chile
(Adapted from: Ruiz et al, 2010)

Pollutant	Outdoor	Control Homes	CNG	LPG	Kerosene
NO_2 (ppb)	41.4 ± 9.3	26.2 ± 6.2	54.7 ± 11.3	50.8 ± 21.3	65.4 ± 15.4
SO_2 (ppb)	0.2 ± 0.1	-0.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.1	5.4 ± 5.9
Benzene (ng/m^3)	7.1 ± 1.7	10.5 ± 3.1	8.5 ± 2.7	9.0 ± 2.2	13.6 ± 5.7
Ethyl benzene (ng/m^3)	6.3 ± 2.3	12.3 ± 6.6	10.5 ± 5.5	9.0 ± 3.6	10.5 ± 4.2
Toluene (ng/m^3)	28.6 ± 11.3	89.9 ± 82.7	44.1 ± 21.7	39.6 ± 18.2	39.6 ± 6.4
$PM_{2.5}$ (µg/m^3)	55.9 ± 27.2	42.1 ± 18.2	49.5 ± 19.9	61.3 ± 24.6	86.3 ± 24.5
UFP (counts/cm^3)	Not Available	16,300 ± 14,600	52,800 ± 29,400	62,900 ± 41,100	163,800 ± 59,300

A WA health study in 2007 & 2008, undertaken by Franklin et al (2012) looked at the respiratory health of participants over 55 years old who were on the patient database at the Lung Institute of Western Australia (LIWA), and were not smokers or had comorbidities such as COPD. They found that there was a dose response relationship between hours of unflued gas heater (UFGH) use and lung function measurements. Similar responses were not found in other types of heaters. Unfortunately, this study did not measure levels of CO or NO_2 in the participant homes.

A New Zealand study published in 2016 on the impact of the indoor environments on respiratory health in children found a link between acute respiratory infections (ARIs) hospitalisations in children less than 5 years and the use of gas heaters as the sole form of household heating (Tin Tin et al, 2016).

Sun et al (2022) when investigating the impact of adding hydrogen gas to the natural gas supply to improve the efficiency of gas heaters, also measured the impact of the increased percentage (%) of hydrogen in the natural gas supply on the pollutants emitted. They found that up to 23% of hydrogen gas could be added without affecting efficiency, and that thermal efficiency of the heaters was enhanced. The emissions of CO & CO_2 were decreased with increased % of hydrogen gas but there was no significant reduction in NO_2.

Ewald, Crisp and Carey (2022) highlighted that in developed countries, the primary source of exposure to CO in the indoor air is from faulty, incorrectly installed, poorly maintained or poorly ventilated cooking or heating appliances.

Many of the studies obtained related mainly to the use of gas in cooking and not heating as gas heaters are more commonly used in Australia, though gas is used for cooking in most countries worldwide.

3.3 Summary of emissions from gas heaters

The study by Girman et al (1983) reported the average measured levels in a well maintained gas heater were 0.3 ppm (300 ppb) for nitrogen dioxide (NO_2), 4.0 ppm for carbon monoxide (CO), and 0.051 ppm (51 ppb) for formaldehyde (HCHO). Whereas for a poorly maintained gas heater the average measured levels for nitrogen dioxide (NO_2) were similar at 0.31 ppm (310 ppb), but the other emissions significantly higher with the average level for carbon monoxide (CO) being 14.6 ppm and for formaldehyde (HCHO) it was 0.296 ppm (296 ppb). These results show that even a well-maintained heater had NO_2 levels well above the recommended 1 hour guideline of 0.0987 ppm (98.7 ppb). However the poorly maintained gas heater was also above the CO 8 hour guideline of 10 ppm and for formaldehyde above the 30 minute guideline of 0.08 ppm (80 ppb)

The South Australian study, by Pilotto et al (2003), showed the classroom with unflued un-flued gas heaters had levels (ave. 47 ppb) of NO_2 at 50 % of the recommended guidelines whereas flued gas heaters or electric gas heaters at levels significantly lower at 15.5 ppb and reduce the frequency of asthma symptoms.

At another study (Brown et al, 2004) looking at the emissions from unflued gas heaters in a chamber showed assessed the levels of emissions from unflued gas heaters for carbon monoxide (CO) levels varied from 1 to 18 ppm for unflued gas heaters and for nitrogen dioxide (NO_2) levels varied from approximately 0.146 ppm (146 ppb) to 0.431 ppm (431 ppb), for the unflued gas heaters. All the results are above the recommended guidelines for NO_2 and some were above for CO.

A study (Marks et al, 2010) in NSW schools on the emission from flued and unflued heaters showed the levels of NO_2 and formaldehyde emitted from flued heaters was generally below the recommended guides where are the emissions from the unflued heaters were on average below the guidelines but at times for NO_2 above the above the 1 hour guideline. The study also showed that there was no difference between the type of stove and the increase in respiratory symptoms observed in atopic (predisposition to develop allergic reaction when exposed to environmental stressors) children.

A WA health study (Franklin et al, 2012) found there was a dose relationship between the hours of unflued gas heater (UFGH) use and lung function measurements, in over 55 year olds.

Chapter 4: Gas Cooking Emissions

4.1 How does a gas stove work

Gas stoves come in two types. Gas top and electric oven or a gas top and gas oven. Gas cooking is popular because of ease of control of cooking on a stove top. The selling and installation of gas stoves in Australia must meet the relevant Australian Standards, the main ones are:

AS/NZS 5263.0:2023, *Gas appliances General requirements*, SAI Global, Sydney

AS/NZS 5263.1.1:2020 *Gas appliances Domestic gas cooking appliances*, SAI Global, Sydney

4.2 Exposure data literature on gas stoves in homes

Cyrys et al (2000) looked at sources of NO_2 indoors and reported that residences in which gas was used for cooking, or in which occupants smoked, had substantially higher indoor NO_2 concentrations. It should be noted that in the cities measured, the average outdoor concentrations of NO_2 are higher that indoors. The median of the outdoor NO_2 concentration was 16 ppb whereas the measured concentrations in the living room averaged 8.5 ppb and in the bedroom averaged 9 ppb. This is below the recommended ABCB (2021) guidelines. This may relate more to the traffic levels in the cities measured than to the indoor gas use for cooking.

In a study (Ng et al, 2001) looking at impacts of NO_2 exposure from gas cooking on asthmatic women found that the average exposure to NO_2 during cooking was 98.54 ppb (121.2 μg/m^3) and ranged from 0.024 ppb (0.03 μg/m^3) to 399.11 ppb (490.9 μg/m^3). The women recorded reductions in the peak expiratory flow rates (PEFR) during the cooking period which ranged for 5 to 34 minutes (average of 15 minutes). The study was undertaken over a two week period with the mean average exposure of 65.44 ppb (80.49 μg/m^3) ranging from 30.33 ppb (37.3 μg/m^3) to 110.24 ppb (135.6 μg/m^3). These levels positively correlated with the frequency of rescue bronchodilator use but negatively correlated with mean PEFR variability and total symptom severity score. The average level is at the recommended ABCB (2021) guideline of 98.7 ppb (1 hour), with many of the exposures above this.

Table 4.1 shows a comparison between the different types of cooking techniques and emissions for NO_2, NO and fine particles for gas cooking, unfortunately only fine particles are reported on for electric cooking, as there was no rise in NO_2 or NO during the cooking processes. (Dennekamp et al, 2001)

Table 4.1: Mean peak 5 minute concentrations of NO_2, NO and Ultra Fine Particles during cooking using gas or electric stoves (with standard deviation in (SD)) (Adapted from: Dennekamp et al, 2001)

Experiment	Gas Stove			Electric Stove
	NO_2 ppb	NO ppb	Fine particles UFP/cm^3	Fine particles UFP/cm^3
Cook top				
1 cooking ring	437 (219)	572 (139)	2.6 (1.2)	9.4 (7.2)
2 cooking rings	310 (52)	189 (30)		
3 cooking rings	584 (13)	1378 (172)		
4 cooking rings	996 (139)	2060 (293)	14.6 (8.3)	11.1 (10.4)
Boiling water	184 (52)	402 (150)	13.3 (8.1)	#
Stir frying	92 (5)	114 (15)	13.7 (12.6)	1.1 (0.2)
Frying bacon	104 (19)	120 (7)	59.0 (14.7)	15.9 (5.0)
Oven				
Bake cake	230 (13)	627 (44)	9.8 (0.9)	3.0 (0.1)
Roast meat	296 (52)	892 (174)	12.4 (2.0)	2.4 (1.4)
Bake potatoes	373 (70)	1047 (164)	12.5 (5.5)	1.6 (1.2)
Grill				
Grill only			10.3 (12.4)	7.7 (11.1)
Toast			13.8 (13.9)	13.4 (4.0)
Grill bacon			41.3 (10.8)	53.0 (3.8)

Note: # no rise in concentration due to cooking method

Hazenkamp-von Arx et al (2004) and WHO (2010) reported that in most countries the main source of NO_2 in homes, is from cooking using gas, in some countries, like Australia, it is also used for heating. Indoor levels of NO_2 are commonly higher in homes in winter than in summer due to lower ventilation rates and in some countries the increased use of heating. In the ECRHS II study carried out in 21 cities, the NO_2 concentrations in winter exceeded summer values by 50%.

A study of air pollutants in English homes found that the main indoor sources were gas stoves and unflued gas heaters, as shown in Table 4.2 (Raw et al, 2004). All the levels reported were below the ABCB (2021) guidelines.

Table 4.2: Level of air pollutants in English homes based on cooking fuel and type of heating (Adapted from: Raw et al, 2004)

Emission source	Spring		Summer		Autumn		Winter		Average	
	CO ppm	NO_2 ppb	CO ppm	NO_2 ppb	CO ppm	NO_2 ppb	CO ppm	NO_2 ppb	CO ppm	NO_2 ppb
Natural gas cooktop and oven	0.53	17.23	0.44	21.81	0.77	24.15	0.92	26.81	0.67	22.77
Natural gas cooktop but no gas oven	0.36	10.16	0.17	11.65	0.52	12.29	0.50	12.50	0.41	11.97
No fossil fuel cooking	0.17	4.79	0.12	6.97	0.38	7.50	0.34	5.32	0.26	6.12
All bedrooms	0.24		0.18		0.46		0.46		0.32	
Use of portable or other unflued heater for heating measured in kitchen									0.77	23.78
Use of portable or other unflued heater for heating measured in bedroom									0.54	9.15

A study undertaken in Australia looking at exposures to NO_2, as well a house dust mite (HDM), for a group of children aged between 5 and 12 years, found that the main source in schools was NO_2 from unflued gas heaters and in the home was gas cooking in the kitchen. The average measured levels of NO_2 in the school were 34 ppb (7 to 117 ppb) and in the home kitchen was 20 ppb (3 to 147 ppb). The average maximum classroom levels in the school were 69 ppb (9 to 307 ppb) and in the home kitchen was 38 ppb (9 to 423 ppb). This shows that for most children their exposure to NO_2 was highest at school. The study found that there was a statistically significant relationship between the classroom levels of NO_2 and difficulty breathing during the day, especially after exercise. The study also showed that the impact on respiratory symptoms by NO_2 and house dust mites was different (Nitschke et al, 2006).

A US study (Belenager et al, 2006) found a significant link between gas stoves and parents reporting a wheeze in their children who were less than 12 years old, as well as shortness of breath, and use of gas fired dryer was related to reported chest tightness. There was a significant link between chest tightness and indoor NO_2 greater than 20 ppb. This relationship though only occurred in multifamily housing (eg flats, duplexes etc) but no similar link in single family housing (stand-alone housing). The type of housing may relate to the residents socio economic group.

In the Netherlands, they measured CO_2 and CO, for a 72 hour period, and NO, NO_2 and nitrous acid (HONO), for 48 hours, in 69 homes. A summary of the results is shown in Table 4.3 (Willers et al, 2006a). The measurements were collected along with an activity diary and questionnaire on symptoms and activities. Another part of the study (Willers et al, 2006b) involved a survey looking at respiratory symptoms in relation to the use of cooking appliances, which found that only nasal symptoms were significantly associated. The levels of CO and formaldehyde measured were well below the ABCB guidelines, whereas the CO_2 was above guidelines during the cooking process, and the NO_2 48 hour average was above the ABCB guideline for 1year but below the 1 hour guideline.

Table 4.3: Summary of average results for measurements of CO, CO_2, H_2O, NO, NO_2 and HONO in kitchens
(Adapted from: Willers et al, 2006a)

Pollutant	Sampling period	Gas stove (n= 50)	Electric stove (n= 19)
CO_2 Mean (SD) (ppm)	72 hour average	654.16 (164.43)	671.47 (201.41)
	During cooking	906.36 (280.59)	743.68 (193.39)
CO Mean (SD) (ppm)	72 hour average	0.37 (1.01)	0.03 (0.08)
	During cooking	0.67 (1.25)	0.01 (0.06)
H_2O Mean (SD) (ppm)	72 hour average	11.01 (1.51)	10.99 (1.34)
	During cooking	12.06 (1.97)	11.66 (1.97)
NO Geometric Mean (GSD) (ppb)	48 hour average	14.94 (2.47)	16.58 (2.86)
NO_2 Geometric Mean (GSD) (ppb)	48 hour average	21.62 (1.66)	18.22 (2.02)
HONO Geometric Mean (GSD) (ppb)	48 hour average	3.67 (0.79)	3.03 (0.68)

In a study of personal exposures to NO_2 in the northern London area by Kornartit et al (2010), it was reported that the personal exposure to NO_2 at home was higher in summer than winter and higher in homes with gas cooking that electric cooking. This would be due to the increase exposures from ambient NO_2 from traffic due to increase room ventilation. Table 4.4 also highlights the higher levels of NO_2 from gas cooking during winter when windows are closed. These results are similar to those reported by Raw et al (2004) for winter exposures, when using a gas stove.

Table 4.4: Average Personal exposures to NO_2 in different house areas and between seasons, over a 7 day period
(Adapted from: Kornartit et al, 2010, p.40)

	Average NO_2 concentrations (ppb)					
	Electric Stoves			Gas Stoves		
	Mean	St. Dev.	Range	Mean	St. Dev.	Range
Measured during winter						
Personal exposure to NO_2 over 7 days	8.1	1.8	5.7 – 11.0	11.2	2.3	6.3 – 15.4
Bedroom	7.8	2.0	3.2 – 11.1	10.8	2.3	6.3 – 15.5
Living Room	7.9	2.1	4.1 – 11.4	13.7	5.5	6.1 - 30.1
Kitchens	7.1	2.8	4.1 – 9.7	20.6	6.9	12.9 – 38.8
Measured during summer						
Personal exposure to NO_2 over 7 days	13.3	1.2	11.3 – 15.3	14.6	1.6	12.7 – 18.1
Bedroom	12.7	1.3	10.6 – 14.8	14.3	1.4	12.5 – 17.3
Living Room	13.1	1.5	10.8 – 15.4	14.7	1.4	13.2 – 18.2
Kitchens	11.0	1.7	8.0 – 13.3	14.2	1.3	12.8 – 17.7

Heinrich (2011) in their review found that in European homes using gas cooking and heating the NO_2 levels ranged from 95.7 to 1329.8 ppb (180 to 2500 µg/m^3) whereas the homes with no gas appliances the NO_2 levels only ranged from 6.9 to 33 ppb (13 to 62 µg/m^3). He also reported that a number of studies reported an association between the use of gas appliances in the home and an increase in respiratory illness.

To and Yeung (2011) looked at the effect of fuel type on emissions from commercial and domestic cooking, in Hong Kong, using different cooking techniques. Table 4.5 summarises the outcomes of the study for domestic cooking which shows increased levels of PM_{10} as well as TVOC (total volatile organic compounds). Unfortunately, they did not measure NO_2 and CO, as did other studies. The results from cooking in the commercial kitchens is presented in Section 4.3.

Table 4.5: Emissions for domestic cooking using gas or electric stoves using different cooking techniques
(Adapted from: To & Yeung, 2011)

	Gas cooking		Electric cooking		Background Levels	
	PM_{10} (mg/m^3)	TVOC (ppb)	PM_{10} (mg/m^3)	TVOC (ppb)	PM_{10} (mg/m^3)	TVOC (ppb)
Commercial					0.156	123
Deep frying of tofu	4.72	2460	3.98	2230		
Griddle frying of meat	2.26	2150	2.60	1590		
Broiling of beef satay	Out of range	Out of range	Out of range	Out of range		

Logue et al (2014) estimated exposures using modelling, supported by some monitoring, showed that homes that used natural gas cooking burners (NGCB) for cooking and did not use venting (extraction) hoods that the levels of pollutants health-based guidelines, especially for NO_2 and CO, during winter.

Less et al (2015) reported on the emissions in houses designed to meet high performance standards, and the use of gas stoves versus electric stoves which showed that the ventilation rates required for high performance homes kept NO_2 levels low. Homes with gas stoves were measured over 6 days to have an average of NO_2 of 41.8 ppb (1.9 to 57.9 ppb) whereas the homes with electric stoves had an average of 23.6 ppb (1.9 to 23.8 ppb). This shows that the homes with electric stoves had significantly lower NO_2 levels, unfortunately they did not report on CO.

A study in Lithuania by Dėdelė and Miškinytė (2016) looked at the levels of NO_2 in homes using gas stoves (7) and electric stoves (5). The sampling was undertaken in similar style of homes and no other heating appliances present that would generate NO_2 emissions, and all sites were naturally ventilated. Passive sampling was undertaken, for 14 days during each of four seasons, to determine average NO_2 levels inside in 3 rooms (kitchen, living room, and bedroom) and also outside of the homes. The passive samplers gave similar results to the ambient air monitors. The results showed that the homes with gas stoves had significantly higher levels of NO_2 compared to the electric stove homes. They found the levels of NO_2 (16.97 ppb [31.9 µg/m^3]) in homes with a gas stove was 2.5 times the levels in electric stove (5.6 ppb [10.6 µg/m^3]) homes. The levels measured were lowest in summer. The lowest levels were measured in the bedroom as well as outdoors.

Singer et al (2017) looked at natural gas cooking burners (NGCBs) during different types of cooking activities, boil simultaneously with Sautee, roast and broil. The outcome of their study was that natural gas stoves are a source of indoor air pollutants that can be controlled if an appropriately size venting hood is installed and used. A minimum flow rate 95 L/s is recommended over the stoves front burners.

Paulin et al (2017) when investigating asthma in children found that those living in homes with gas stoves were more likely to use an overnight inhaler to reduce symptoms for each 10 fold increase in 24-h indoor NO_2 concentration. The levels of measured 24-h NO_2 increased with length of time that the gas stove was used. When time of use was compared against the season it was found that general exposure levels were higher in the colder seasons as highlighted in Table 4.6. It is important to observe that the average concentrations in the non-cold period when cooking for longer were lower and this may be due to increase ventilation to remove cooking odours and/or heat in the kitchen.

Table 4.6: 24 hour average NO_2 concentration based on time of use of gas appliance and time of year
(Adapted from: Paulin et al, 2017)

Time of use of gas appliances	Non-cold season	Cold Season
No use	26 ppb	47 ppb
15 to 90 minutes of use	58 ppb	56 ppb
90 to 150 minutes of use	46 ppb	79 ppb
> 150 minutes of use	35 ppb	197 ppb

An Australian study, on the use of gas stoves and heaters, and their impact on childhood asthma in primary aged children living in NSW (Belmont) found that there is a strong association between the use of fume emitting heaters (including non-flued gas heaters) during the first year of life and the presence of AHR (Airway hyperresponsiveness), recent wheeze, and current asthma in children aged 8–11 years (Phoa et al 2004). This effect was not seen with the current use of fume emitting heaters. It should be noted that the heaters were defined as:

- Non-fume emitting types: including central heating, electric heating and reverse cycle heating.
- Fume emitting types including flued gas, non-flued gas, open fire, wood stove, and kerosene heaters. The main types of fume emitting heaters were the non-flued gas heaters (13.7%) and wood stoves (14.2%).

Amirkhani Ardehet et. al. (2020) estimated levels of emissions from gas cooking by modelling indoor levels in Tehran homes. The model used the length of time the gas stove was in use, as well as the estimated ventilation rate, in the area of the gas stove. The concentrations reported for carbon monoxide [CO] 3.0 ppm (2.0 – 6.0 ppm), nitrogen dioxide [NO_2] 70.73 ppb (45.5 ppb – 137.40 ppb), and formaldehyde [HCHO] 2.44 ppb (0.81 – 16.29 ppb). The modelling showed that natural gas cooking is a major source of exposure to CO, NO_2 and HCHO, the NO_2 levels would possibly be above the ABCB (2021) guidelines.

A recent study was undertaken by Zhao et al (2021) on emissions from gas stoves in newly constructed or renovated apartments (2011 – 2016) and houses (2011 – 2017) in California, that were designed to meet the state regulations for mechanical ventilation. Each cooking event was checked by a temperature monitor to determine length of time of cooking. The average weekly emissions to nitrogen dioxide (NO_2), formaldehyde (HCHO), carbon dioxide (CO_2) and $PM_{2.5}$, are shown in Table 4.7. The study showed that the levels in NO_2 and was higher in apartments, but HCHO was higher in houses. This may relate to the differences in the design characteristics of the residences. The apartments were smaller in area and had more residents than the houses, as well as higher ventilation rates.

Table 4.7: Average air concentrations over a one week period in apartments and houses using gas burners to cook in California.
(Adapted from: Zhao et al, 2021)

		NO_2 (ppb)	HCHO (ppb)	CO_2 (ppm)	$PM_{2.5}$ (µg/m^3)
Apartments (n=21)	Indoor	18.8 (10.8-30)	14.1 (8.1-22.4)	741 (584-955)	7.7 (1.8-15.0)
	Outdoor	10.1 (4.5-20)	1.7 (0.8-2.8)		7.5 (4.8-14.2)
Houses (n=40)	Indoor	7.1 (1.5-14.2)	18.7 (12.8-27.2)	628 (519-765)	8.0 (2.4-17.9)
	Outdoor	6.1 (0.1-13.4)	2.2 (1.5-2.9)		10.1 (5.3-16.4)

4.3 Exposure data literature on gas stoves in commercial premises

Few studies have been published which presents information on the levels of emissions from stoves and/or compared to respiratory health outcomes. Most that have been published have measured the levels of particulates in the kitchens and in some the speciation (chemical composition) of the particulates, such as Li et al (2021) who looked at the chemical characterisation of the particulate emissions, including PAHs. They found that the emissions from gas cooking in a commercial restaurant are higher than other emission sources such as coal, combustion, vehicles, wood and grass combustion.

In the study by To and Yeung (2011), who investigated the effect of fuel type on emissions from cooking in commercial kitchens in Hong Kong using different cooking techniques, they found increased levels of PM_{10} as well as TVOC (total volatile organic compounds) in gas stove cooking compared to electric stove cooking, as shown in Table 4.8. Unfortunately, they did not measure NO_2 and CO as did other studies.

Table 4.8: Emissions for different type of cooking in commercial premises using different types of fuel
(Adapted from: To & Yeung, 2011)

	Gas cooking		Electric cooking		Background Levels	
	PM_{10} (mg/m^3)	TVOC (ppb)	PM_{10} (mg/m^3)	TVOC (ppb)	PM_{10} (mg/m^3)	TVOC (ppb)
Commercial					0.156	123
Deep frying of tofu	4.72	2460	3.98	2230		
Griddle frying of meat	2.26	2150	2.60	1590		
Broiling of beef satay	Out of range	Out of range	Out of range	Out of range		

4.4 Literature related to the health impacts of using gas stoves in homes

The following is a summary of the wide number of studies that looked at the use of gas stoves and the reported respiratory health impacts. Unfortunately, these studies did not measure and/or report levels of emissions at the same time.

A study by Dekker et al (1991) found an association in Canada between using gas cooking at home and childhood asthma. Leynaert et al (1996) reported an increased risk of respiratory disease in women using gas for cooking. This included waking up with shortness of breath and having asthma, including the need to take asthma medication. A similar result was not seen in men, of similar age who were not involved in the cooking.

In a British study, undertaken in 1992 to 1993, of people who had been followed regularly since birth in 1958, looked at the potential impacts of cooking fuel type on respiratory health and sensitization. The study examined the incidence of both childhood (at 11 years) and adulthood respiratory issues. Moran et al (1999) stated that they did not find a link between gas cooking in either childhood or adulthood, and the subjects reporting respiratory issues such as asthma and allergic sensitisation, but they did find a link between gas stove use in adulthood and reduce lung function.

Gas cooking has been found to have a harmful effect on the lung function of girls with a high serum level of IgE, which maybe an indicator that the body maybe overreacting to allergens.

It is not known whether the serum IgE, is a marker of a simple indicator that an inflammatory process is in progress, allergic susceptibility or whether it is involved in the processes that lead to bronchial obstruction. This study was undertaken in Italy where they reviewed the time that the girls had access to the kitchen during cooking, using gas stove (Corbo et al., 2001).

In a large study on children across 9 countries in Europe and the US showed small reduction in lung function (FVC and FEV_1) in children where gas was used as the cooking fuel. Children who were atopic showed a stronger impact (Moshammer et al, 2010).

Casas et al (2012) looked at the impact of gas cooking on children's respiratory health in Germany and showed that there was an indication of prevalence of asthma and wheezing in children exposed to gas cooking, but it was not found to be statistically significant. They did find an association between the use of gas cooking and other indoor factors such as dampness, visible mould, environmental tobacco smoke (ETS) and pets. This highlights the significance of considering other indoor factors when evaluating potential impacts of gas cooking emissions on health effects.

Nicole (2014) summarised the outcomes from a number of studies investigating emissions, CO, NO_2 and formaldehyde (HCHO), from gas stoves in the U.S. The main emissions are all reported to cause respiratory issues. She summarised that in a third of US homes gas stoves accounted for between 25 to 39% of NO_2 emissions, 21 to 30% of CO emissions, depending on the season, and negotiable for HCHO as other sources, eg furniture and building materials, in the homes are greater emitters. She also noted that just switching fuel type will not remove all the emissions issues with cooking, as the cooking type has an impact as well.

Studies looking at indoor exposures to NO_2 and impacts on health are not as clear, as NO_2 is also major environmental pollution and when discussing the impacts on respiratory health total NO_2 must be considered (Ewald et al, 2021) and not the individual sources of NO_2.

Pan et al (2024) used data collected from the questionnaires used in both the ECRHSII (1999-2003) as well as the ECRHSIII (2010-2014) studies to investigate the impacts of gas stoves on respiratory health. It is interesting to note that the percentage (%) of participants using gas stoves had reduced by approximately 10% between the two studies. It was also noted that of the participants who use gas to cook with were most were likely to use a gas hob connected to mains gas. They also showed that users of gas stoves were more likely to report shortness of breath when resting, and the association was stronger for those who use a gas oven as well, or bottle gas as the source. The study showed that improved ventilation rates reduced the risk, but increased cooking time (> 60 mins) resulting in a greater risk overall, which were significant for wheezing and a cough in winter.

4.5 Summary of emissions from gas cooking

All the studies reviewed highlighted that there was a link between using a gas stove and respiratory health. The direct relationship between exposure and impact was not as clear as the pollutants of concern are also outdoor environmental pollutants mainly from traffic.

Exposure to nitrogen dioxide (NO_2) during cooking using a gas stove have been shown to range significantly depending on whether it is a gas cook top only or a gas cook top and oven. It also depends significantly on the type of cooking being undertaken. Most stoves in the studies were gas cook top only as this is the style that is common in Europe and the US where most studies have been completed.

In 2001, average levels of NO_2 around 100 ppb, during cooking, have been shown to correlate with an increased frequency in the use of a rescue bronchodilator, with exposures ranging from negligible (0.024 ppb) to over 4 times the recommended ABCB (2021) guideline (399.11 ppb). The participants also logged declines in their peak expiratory flow rates (PEFR) during the cooking period which ranged for 5 to 34 minutes (Ng et al, 2001).

Studies looking at the impacts of cooking techniques on emissions have shown that the greater the number of hobs used the higher the emission rate of NO_2, and a gas oven will result in significant emissions compared to an electric oven. The main type of emission pollutant from an electric stove is fine particles (UFP) whereas the gas stove has both fine particles (UFP) and high NO_2 and NO emissions (Dennekamp et al, 2001).

A English study found that the main indoor sources, in homes, were from gas stoves and unflued gas heaters (Raw et al, 2004). All the levels reported were below the ABCB (2021) guidelines.

In an Australian study looking at NO_2 exposures to emissions in schools and homes found that there was a relationship between the levels of NO_2 in classrooms and difficulty breathing during the day, especially after exercise. The main NO_2 emission source in schools was unflued gas heaters whereas in the home it was gas cooking in the kitchen.

In the home kitchen, with gas stove, the average measured levels of NO_2 was 20 ppb (3 to 147 ppb), with the average maximum of 38 ppb (9 to 423 ppb). Whereas at school, the average measured levels of NO_2 in the classroom was 34 ppb (7 to 117 ppb), the average maximum levels were 69 ppb (9 to 307 ppb) (Nitschke et al, 2006).

A US study found a link between gas stoves and the reporting of a wheeze in children less than 12 years old, as well as shortness of breath, and use of gas fired dryer was related to reported chest tightness, when the indoor levels of NO_2 were greater than 20 ppb. This relationship though only occurred in multifamily housing (eg flats, duplexes etc) but this may relate to the resident's socio economic group (Belenager et al, 2006).

In a Netherlands study of emissions from gas stoves in homes, it was shown that the average levels of CO (0.37 ppm) and formaldehyde (3.67 ppb) measured were well below the ABCB guidelines, whereas the CO2 (906 ppm) was above guidelines during the cooking process, and the NO2 48 hour average (21.62 ppb) was above the ABCB guideline for 1 year but below the 1 hour guideline (Willers et al, 2006a). The study also looked at respiratory impacts which showed that only nasal symptoms were significantly associated with gas stove usage (Willers et al, 2006b).

A study in London which involved air sampling over seven days showed that the average emissions of NO_2 in kitchens with a gas stove (20.6 ppb) were significantly higher than kitchens with an electric stove (7.1 ppb) (Kornartit et al, 2010).

In a review of exposures in European homes using gas cooking and heating the NO_2 levels ranged from 95.7 to 1329.8 ppb (180 to 2500 $\mu g/m^3$) whereas the homes with no gas appliances the NO_2 levels only ranged from 6.9 to 33 ppb (13 to 62 $\mu g/m^3$). It was also reported that a number of studies showed an association between the use of gas appliances in the home and an increase in respiratory illness (Heinrich, 2011).

When looking at homes that are designed to meet new building design criteria, for tight structures, it has been shown that even in homes that have ventilation rates designed to keep emissions at minimal levels that NO_2 levels can be significant. Homes with gas stoves measured over 6 days have an average of NO_2 of 41.8 ppb (1.9 to 57.9 ppb) whereas the homes with electric stoves have an average of 23.6 ppb (1.9 to 23.8 ppb) (Less et al, 2015).

A Lithuanian study on NO_2 emissions in homes showed the average levels for NO_2 in homes with a gas stove was16.97 ppb, which was 2.5 times the levels in homes with an electric stove which was 5.6 ppb (Dėdelė & Miškinytė, 2016).

In a study investigating asthma in children found that those living in homes with gas stoves were more likely use of an overnight inhaler to reduce symptoms for each 10 fold increase in 24-h indoor NO_2 concentration. The study also demonstrated that the levels of measured NO_2 increased with length of time that the gas stove was used, within a day and that general exposure levels were higher in the colder seasons (Paulin et al, 2017).

An Australian study, found a strong association between exposure to fume emitting heaters during the first year of life and the presence of AHR, recent wheeze, and current asthma in children aged 8–11 years (Phoa et al 2004).

Amirkhani Ardehet et. al. (2020) estimated levels of emissions from gas cooking by modelling indoor levels in Tehran homes. The model used the length of time the gas stove was in use as well as estimated ventilation rate in the area of the gas stove. The concentrations reported for carbon monoxide [CO] 3.0 ppm (2.0 – 6.0 ppm), nitrogen dioxide [NO_2] 70.73 ppb (45.5 ppb – 137.40 ppb), and formaldehyde [HCHO] 2.44 ppb (0.81 – 16.29 ppb). The modelling showed that natural gas cooking is a major source of exposure to CO, NO_2 and HCHO, the NO_2 levels would possibly be above the ABCB (2021) guidelines.

Chapter 5: Health impacts of the main emissions from gas heating & cooking

The health impacts of being exposed to emissions from gas appliances may depend on the underlying health conditions of the occupants. It has been shown in a wide number of studies that exposure to lower-level concentrations of nitrogen dioxide and carbon monoxide may aggravate underlying respiratory symptoms, especially in children. In addition to carbon monoxide and nitrogen dioxide, low levels of exposure to $PM_{2.5}$ have been reported but there has not been a clear link shown in regards to gas appliances due to $PM_{2.5}$ occurring in the outdoor environment at levels well above the indoor environment. Therefore, this section is concentrating to the potential health impacts of carbon monoxide and nitrogen dioxide.

5.1 Carbon monoxide toxicity

Carbon monoxide (CO) is a colourless, odourless, non-irritating gas which may be produced by incomplete combustion of any carbonaceous fossil fuel. Due to these physical properties, it is easy for concentrations of CO to buildup to toxic levels with no warning signs (Nañagas et al, 2022).

It has been recognised that CO poisoning can occur in minutes, with fatality at 2000 ppm for 15 minutes with light work, in people with pre-existing coronary disease. The ACGIH (1992) recommendation an 8 hr workplace exposure standard 25 ppm to minimise adverse neurobehavioral changes and to maintain cardiovascular health. The average concentration of 25 ppm is the suggested by the WHO (2010) for the general public for only 1 hour and for 8 hour exposures they recommend that the average level should not exceed 10 ppm.

In an unfortunate case in Victoria, the Coroners Court of Victoria (2013) provided insight into a tragic incident where two brothers, aged six and eight years, died after going to sleep in a bedroom with an open flued gas heater. The Coroners report indicated that mild exposure to CO can cause headache, nausea, vomiting, dizziness, malaise and confusion is often mistaken for common conditions such as influenza or gastroenteritis. Severe poisoning can lead to chest pain, cardiovascular disease, coma and death. Headaches are the most common symptom of CO poisoning, with CO exposure found in approximately 6% of people presenting with headache to an emergency department. In some 10–30% of patients with acute CO poisoning, a delayed neurological syndrome – including cognitive and personality change, dementia and parkinsonism – may develop after a period of initial recovery. The issue with CO poisoning is that as CO is odourless people do not smell it then high exposures can occur rapidly especially if people are asleep as it will not wake them up. WHO (2010) also reported that sustained chronic exposure to CO can have impacts on the functional and developmental growth of children even at low levels.

Prochop (2005) investigated the impact of chronic exposure to carbon monoxide in nine (9) people as the result of a faulty gas heater in an apartment building in Florida. Four people suffered some loss of consciousness just prior to discovery of the problem and then incurred intellectual impairment following moderate level CO exposure. Of the other five (5) people who were exposed to high levels for approximately 12 hours, one died initially, one suffered a coma but luckily recover, and the other three who were initially unconscious have all been intellectually impaired. This indicates that high uncontrolled exposures to CO can result in brain damage.

The impact on the neurological system is mainly due to how exposure to carbon monoxide (CO) is handled by the body. When carbon monoxide is absorbed into the body it adheres to the haemoglobin cells in the blood in place of oxygen, which becomes Carboxyhemoglobin (COHb). As the level of COHb increases it becomes more difficult for the body to transport oxygen to the required organs in the body.

WHO (2010) indicated that it is crucial to recognize the onset of carbon monoxide poisoning symptoms as it can be fatal in just a few minutes. The symptoms of carbon monoxide poisoning are non-specific and involve many of the body systems. Common symptoms include headache, lethargy/fatigue, nausea, dizziness and confusion. If exposure is significant then they may also suffer from shortness of breath, cardiac palpitations, convulsion, paralysis, loss of consciousness, coma and eventually death. Age, anaemia, increased elevation, cardiopulmonary disease, and prior exposure to carbon monoxide can increase susceptibility to carbon monoxide toxicity. The median level of COHb in people dying of uncomplicated carbon monoxide poisoning is 53–55%. When identifying carbon monoxide poisoning it is crucial to look at the victim's environment and immediate past living or work situation. Issues such as, has the victim been exposed to sources of carbon monoxide such as uncontrolled fires, motor vehicles, fuel-burning heaters or other internal combustion engines in a poorly ventilated enclosed space must be considered. You also need to determine if others in that environment (e.g. family members or pets living in the same house) are displaying similar symptoms. These facts are critical in accurately identifying carbon monoxide poisoning.

ABCB (2021) highlights that CO may impact both healthy and unhealthy people. When inhaled, CO quickly mixes with haemoglobin in the blood, inhibiting the blood's ability to carry and exchange oxygen. Once more than 2.5% of haemoglobin is bound to carbon monoxide health effects become noticeable. High concentrations can cause headaches, fatigue, confusion, and drowsiness. Prolonged and repeated exposure can affect the heart. When exposed to high concentrations of CO, up to 40% of the haemoglobin can be bound to carbon monoxide. At this level very high concentrations will almost certainly kill. People with heart problems, children and unborn babies are particularly at risk. CO does not readily leave the body once it enters.

The Coroners Court of Victoria (2013) report highlights the importance of using licensed gas plumbers to regularly inspect all gas appliances, including measuring levels of CO.

5.2 Nitrogen dioxide toxicity

Exposure to nitrogen dioxide is often identified by its pungent odour. Hesterberg et al (2009) in a review of 50 studies investigating the impact of inhaling NO_2 on respiratory health, and to determine if a No Observed Effect Level (NOEL) could be established. In their review they came up with a number of observations:

"For lung immune responses and inflammation:

1) *healthy subjects exposed to NO_2 below 1 ppm do not show pulmonary inflammation;*
2) *at 2 ppm for 4 h, neutrophils and cytokines in lung-lavage fluid can increase, but these changes do not necessarily correlate with significant or sustained changes in lung function;*
3) *there is no consistent evidence that NO_2 concentrations below 2 ppm increase susceptibility to viral infection;*
4) *for asthmatics and individuals having chronic obstructive pulmonary disease (COPD), NO_2 - induced lung inflammation is not expected below 0.6 ppm, although one research group reported enhancement of proinflammatory processes at 0.26 ppm. With regard to NO_2-induced AHR:*
5) *(studies of responses to specific or nonspecific airway challenges (e.g., ragweed, methacholine) suggest that asthmatic individuals were not affected by NO_2 up to about 0.6 ppm, although some sensitive subsets may respond to levels as low as 0.2 ppm. And finally, for extra-pulmonary effects:*
6) *such effects (e.g., changes in blood chemistry) generally required NO_2 concentrations above 1–2 ppm. (Hesterberg et al, 2009, p. 742-743)*

In a meta-analysis of 41 studies, between 1977 and 31 March 2013, to a range of studies from around the world, including Australia, Lin et al (2013) found that children living in homes that use gas for cooking, that 42% have an increased risk of current asthma and 24% increased risk of life time asthma per 15 ppb increase levels of NO_2.

5.3 Summary of health impacts from emissions from gas cooking & heating

The has clearly shown that exposure to carbon monoxide (CO) must be kept to a minimum to avoid health impacts, which can look like symptoms of influenza or gastroenteritis which at times make it difficult to identify. It should always be considered when a number of normally healthy occupants, in a space, are reporting similar non-description symptoms such as headache, nausea, vomiting, dizziness, malaise and confusion. Potential sources of CO should be identified and removed if possible but initially improve the ventilation of the space. It is important to keep issues down to a minimum that exposure to CO should be kept below the ABCB (2021) guideline of:

- Maximum of 90 ppm for average of 15 minutes
- Maximum of 50 ppm for average of 30 minutes
- Maximum of 25 ppm for average of 1 hour
- Maximum of 10 ppm for average of 8 hours

Exposure to nitrogen dioxide (NO_2) is easier to be keep to a minimum due to its pungent odour. NO2 at the levels of normal exposures will not normally cause death but will exacerbate underlying medical conditions such as respiratory disease, ad cardiovascular.

It is important to keep issues down to a minimum that exposure to NO_2 should be kept below the ABCB (2021) guideline of:

- Maximum of 0.0987 ppm (98.7 ppb) for average of 60 minutes
- Maximum of 0.0197 ppm (19.7 ppb) for average 1 year

Chapter 6: Conclusion and Recommendations

The review of the many studies examined highlighted the emissions gases from gas appliances can be significant. The main gases of concern are carbon monoxide and nitrogen dioxide. Exposure to carbon monoxide (CO), which is odourless, must be kept to a minimum to avoid health impacts such as headaches, nausea, vomiting, dizziness, malaise, confusion and occasionally death. Nitrogen dioxide (NO_2) exposure is easier to keep to a minimum level due to its pungent odour and at normal exposures will not cause death but may aggravate underlying medical conditions such as respiratory disease, ad cardiovascular.

The review has shown that emissions from gas heaters can be variable depending on the levels of ventilation and maintenance of the gas heaters. If concern is the reports of deaths due to excessive exposure to CO or exacerbate underlying respiratory conditions due to NO_2 exposure. The levels reported highlight the importance of the removal of unflued or open flued gas heaters from homes and schools, or at least restrict their future installation.

The majority of the literature reviewed looked at emissions from gas stoves, and the majority showed a link between using a gas stove. Unlike gas heaters the main emission from gas stoves is nitrogen dioxide. The levels of emissions from gas stoves when a gas oven is used rather than an electric oven in conjunction with the gas hobs. It also depends on the cooking techniques being undertaken.

The significant volume of literature on the adverse health impacts of emissions from gas appliances gives strength to the concept that gas appliances should be banned from modern tight homes where ventilation is normally restriction with air movement limited to mechanical ventilation.

The evidence on the emissions from gas stoves in kitchens is clear but due to limited number of studies that could be located that looked at emissions in commercial kitchens no specific recommendation can be made about the use of the gas stoves in these premises.

6.2 Recommendations for Hornsby Shire Council

Based on the review it is recommended that Hornsby Shire Council should:

1. Review planning rules and building regulations to encourage the installation of non-gas-powered heating and cooking in all new homes.

2. Develop a health promotion program on the importance of all households, who currently have gas heaters and/or gas stoves, installing CO monitors in the homes, similar to the requirements for smoke alarms.

3. Transition away from the use of gas by switching council-owned buildings to alternatives like reverse cycle air conditioning and heat pumps.

4. Should lobby the NSW state government to investigate:
    a. the removal of rules that restrict local governments from banning gas connections in new residential developments;
    b. the provision of incentives for homes, schools and businesses to switch to electric appliances, including subsidies for low-income households; and
    c. the acceleration of the replacement of unflued gas heaters in NSW public schools with zero emission heating.

5. Until such times as gas installations in homes is banned, no installations should be approved, by local councils, that don't meet the following Australian Standards.

AS/NZS 5263.0:2023 *Gas appliances General requirements*, SAI Global, Sydney

AS/NZS 5263.1.1:2020 *Gas appliances Domestic gas cooking appliances*, SAI Global, Sydney

AS/NZS 5263.1.4:2017 *Gas Appliances, Part 1.4: Radiant gas heaters*, SAI Global, Sydney

AS/NZS 5263.1.3:2021 *Gas appliances Gas space heating appliances,* SAI Global, Sydney

AS/NZS 5263.1.6:2020 *Gas appliances Indirect gas-fired ducted air heaters*, SAI Global, Sydney

AS/NZS 5263.1.8:2021 *Gas appliances Decorative effect gas appliances*, SAI Global, Sydney

AS/NZS 5263.1.10:2019 *Gas appliances, Part 1.10: Gas direct fired air heaters*, SAI Global, Sydney

References

American Conference of Governmental Industrial Hygienists (ACGIH) (1992), *Carbon Monoxide*, ACGIH®, Cincinnati, OH

American Conference of Governmental Industrial Hygienists (ACGIH) (2001), *Carbon Dioxide*, ACGIH®, Cincinnati, OH

American Conference of Governmental Industrial Hygienists (ACGIH) (2017), ACGIH®, *Formaldehyde*, Cincinnati, OH

American Conference of Governmental Industrial Hygienists (ACGIH) (2024), *Threshold Limit Values and Biological Exposure Indices*, ACGIH®, Cincinnati, OH

Amirkhani Ardeh, S., Khaloo, S. S., Gholamnia, R., Abtahi, M. & Saeedi, R. (2020). Assessment of indoor air pollutant concentrations and emissions from natural gas cooking burners in residential buildings in Tehran, Iran. *Air Quality, Atmosphere & Health: An International Journal*, *13*(4), 409–420. https://doi.org/10.1007/s11869-020-00804-y

Australian Building Codes Board (ABCB) (2021). *Indoor Air Quality Handbook* (2nd Ed.), https://www.abcb.gov.au/sites/default/files/resources/2022/Handbook-indoor-air-quality.pdf [4 February 2024]

Bambrick, H., Charlesworth, K., Bradshaw, S. & Baxter, T. (2021). *Kicking the gas habit: How gas is harming our health,* <https://www.greenpolicyplatform.org/sites/default/files/downloads/resource/Kicking%20the%20Gas%20Habit.pdf> [25 January 2024]

Basinger, E., Hickey, B. & McDonell, V. (2023). A compilation of operability and emissions performance of residential water heaters operated on blends of natural gas and hydrogen including consideration for reporting bases. *International Journal of Hydrogen Energy*, *48*(51), 19733–19749. https://doi.org/10.1016/j.ijhydene.2023.02.018

Bass, B., New, J. & Copeland, W. (2021). Potential energy, demand, emissions, and cost savings distributions for buildings in a utility's service area. *Energies*, *14*(1), 132–132. https://doi.org/10.3390/en14010132

Belanger, K., Gent, J.F., Triche, E.W., Bracken, M.B. & Leaderer, B.P. (2006). Association of indoor nitrogen dioxide exposure with respiratory symptoms in children with asthma. *American Journal of Respiratory and Critical Care Medicine*, *173*(3), 297–303. https://doi.org/10.1164/rccm.200408-1123OC

Brown, S.K., Mahoney, K.J. & Cheng, M. (2004). Room chamber assessment of the pollutant emission properties of (nominally) low-emission unflued gas heaters. *Indoor Air*, *14 Suppl 8*, 84–91.

Casas, L., Tischer, C., Tiesler, C., Brüske, I., Koletzko, S., Bauer, C.P., Wichmann, H.E., von Berg, A., Berdel, D., Krämer, U., Schaaf, B., Lehmann, I., Herbarth, O., Heinrich, J. & GINIplus and LISAplus Study Group. (2012). Association of gas cooking with children's respiratory health: results from giniplus and lisaplus birth cohort studies. *Indoor Air*, *22*(6), 476–82. https://doi.org/10.1111/j.1600-0668.2012.00784.x

Choice (2024). *How to buy the best gas heater*, <https://www.choice.com.au/home-and-living/heating/gas-heaters/buying-guides/gas-heaters>, [25 January 2024]

Corbo, G.M., Forastiere, F., Agabiti, N., Dell'Orco, V., Pistelli, R., Aebischer, M.L., Valente, S. & Perucci, C.A. (2001). Effect of gas cooking on lung function in adolescents: modifying role of sex and immunoglobulin e. *Thorax*, *56*(7), 536–536. https://doi.org/10.1136/thorax.56.7.536

Coroners Court of Victoria (2013). Inquest into the death of Tyler Robinson. Southbank, Vic: Coroners Court of Victoria, 2013. <www.coronerscourt.vic.gov.au/sites/default/files/2018-12/tylerrobinson_203810.pdf> [4 February 2024].

Cyrys, J., Heinrich, J., Richter, K., Wölke, G. & Wichmann, H.E. (2000). Sources and concentrations of indoor nitrogen dioxide in Hamburg (West Germany) and Erfurt (East Germany). *The Science of the Total Environment*, *250*(1-3), 51–62.

Dėdelė, A. & Miškinytė, A. (2016). Seasonal variation of indoor and outdoor air quality of nitrogen dioxide in homes with gas and electric stoves. *Environmental Science and Pollution Research*, *23*(17), 17784–17792. https://doi.org/10.1007/s11356-016-6978-5

Dekker, C., Dales, R., Bartlett, S., Brunekreef, B., & Zwanenburg, H. (1991). Childhood asthma and the indoor environment. *Chest*, *100*(4), 922–6.

Dennekamp, M., Howarth, S., Dick, C.A.J., Cherrie, J.W., Donaldson, K. & Seaton, A. (2001). Ultrafine particles and nitrogen oxides generated by gas and electric cooking. *Occupational and Environmental Medicine*, *58*(8), 511–511. https://doi.org/10.1136/oem.58.8.511

Department of Energy, Environment and Climate Action (DEECA) (2023). *Gas heater safety* <https://www.energy.vic.gov.au/safety/gas-heater-safety>, [25 January 2024]

Deymi-Dashtebayaz, M., Rezapour, M., Sheikhani, H., Afshoun, H.R. & Barzanooni, V. (2023). Numerical and experimental analyses of a novel natural gas cooking burner with the aim of improving energy efficiency and reducing environmental pollution. *Energy*, *263*. https://doi.org/10.1016/j.energy.2022.126020

enHealth Council (2007). *The health effects of unflued gas heater use in Australia*, Dept. Health & Ageing, Commonwealth of Australia, Canberra. <https://www.vgls.vic.gov.au/client/en_AU/search/asset/1291947/0>, [26 January 2024]

Ewald, B., Crisp, G. & Carey, M. (2022). Health risks from indoor gas appliances. *Australian Journal of General Practice*, *51*(12), 935–938.

Ewald, B., Knibbs, L. & Marks, G. (2021). Opportunity to reduce paediatric asthma in new south wales through nitrogen dioxide control. *Australian and New Zealand Journal of Public Health*, *45*(4), 400–402. https://doi.org/10.1111/1753-6405.13111

Fischer, M.L., Chan, W.R., Delp, W., Jeong, S., Rapp, V. & Zhu, Z. (2018). An estimate of natural gas methane emissions from California homes. *Environmental Science & Technology*, *52*(17), 10205–10213. https://doi.org/10.1021/acs.est.8b03217

Franklin, P.J., Loveday, J. & Cook, A. (2012). Unflued gas heaters and respiratory symptoms in older people with asthma. *Thorax*, *67*(4), 315–315. https://doi.org/10.1136/thoraxjnl-2011-200236

Garcia-Algar, O., Zapater, M., Figueroa, C., & Vall, O. (2003). Sources and concentrations of indoor nitrogen dioxide in Barcelona, Spain. *Journal of the Air & Waste Management Association*, *53*(11), 1312–17. https://doi.org/10.4102/hts.v78i2.7708

Girman, J.R., Allen, J.R., Apte, M.G., Martin, V.M. & Traynor, G.W. (1983). *Pollutant Emission Rates from Unvented Gas-Fired Space Heaters: a Laboratory Study*. <https://escholarship.org/uc/item/5zh185gt> [15 Jan]

Heinrich, J. (2011). Influence of indoor factors in dwellings on the development of childhood asthma. *International Journal of Hygiene and Environmental Health*, *214*(1), 1–25. https://doi.org/10.1016/j.ijheh.2010.08.009

Hesterberg, T.W., Bunn, W.B., McClellan, R.O., Hamade, A.K., Long, C.M. & Valberg, P.A. (2009). Critical review of the human data on short-term nitrogen dioxide (NO_2) exposures: evidence for NO_2 no-effect levels. *Critical Reviews in Toxicology*, *39*(9), 743–781. https://doi.org/10.3109/10408440903294945

Hazenkamp-von Arx, M. E., Götschi, T., Ackermann-Liebrich, U., Bono, R., Burney, P., Cyrys, J., Jarvis, D., Lillienberg, L., Luczynska, C., Maldonado, J. A., Jaén, A., de Marco, R., Mi, Y., Modig, L., Bayer-Oglesby, L., Payo, F., Soon, A., Sunyer, J., Villani, S., … Künzli, N. (2004). $PM_{2.5}$ and NO_2 assessment in 21 European study centres of ECRHS II: annual means and seasonal differences. *Atmospheric Environment*, *38*(13), 1943–1953. https://doi.org/10.1016/j.atmosenv.2004.01.016

Kashtan, Y.S., Nicholson, M., Finnegan, C., Ouyang, Z., Lebel, E.D., Michanowicz, D.R., Shonkoff, S.B.C. & Jackson, R.B. (2023). Gas and propane combustion from stoves emits benzene and increases indoor air pollution. *Environmental Science & Technology*, *57*(26), 9653–9663. https://doi.org/10.1021/acs.est.2c09289

Knibbs, L. D., Woldeyohannes, S., Marks, G. B., & Cowie, C. T. (2018). Damp housing, gas stoves, and the burden of childhood asthma in Australia. *Medical Journal of Australia*, *208*(7), 299–302. https://doi.org/10.5694/mja17.00469

Kornartit, C., Sokhi, R.S., Burton, M.A. & Ravindra, K. (2010). Activity pattern and personal exposure to nitrogen dioxide in indoor and outdoor microenvironments. *Environment International*, *36*(1), 36–45. https://doi.org/10.1016/j.envint.2009.09.004

Lebel, E.D., Finnegan, C.J., Ouyang, Z. & Jackson, R.B. (2022). Methane and NOx emissions from natural gas stoves, cooktops, and ovens in residential homes. *Environmental Science & Technology*, *56*(4), 2529–2539. https://doi.org/10.1021/acs.est.1c04707

Lebel, E.D., Lu, H.S., Speizer, S.A., Finnegan, C.J. & Jackson, R.B. (2020). Quantifying methane emissions from natural gas water heaters. *Environmental Science & Technology*, *54*(9), 5737–5745. https://doi.org/10.1021/acs.est.9b07189

Leber, R. (2021). Gaslit: how the fossil fuel industry convinced Americans to love their toxic stoves. *Mother Jones*, *46*(4), 42–47.

Less, B., Mullen, N., Singer, B. & Walker, I. (2015). Indoor air quality in 24 California residences designed as high-performance homes. *Science and Technology for the Built Environment*, *21*(1), 14–14.

Leynaert, B., Liard, R., Bousquet, J., Mesbah, H. & Neukirch, F. (1996). Gas cooking and respiratory health in women. *Lancet (London, England)*, *347*(9007), 1052–3.

Li, Y., Wu, Y., Xu, J., Wu, A., Zhao, Z., Tong, M. & Luan, S. (2021). Chemical characterization of particulate organic matter from commercial restaurants: alkyl PAHs as new tracers for cooking. *Science of the Total Environment*, *770*. https://doi.org/10.1016/j.scitotenv.2021.145308

Lin, W., Brunekreef, B. & Gehring, U. (2013). Meta-analysis of the effects of indoor nitrogen dioxide and gas cooking on asthma and wheeze in children. *International Journal of Epidemiology*, *42*(6), 1724–1737. https://doi.org/10.1093/ije/dyt150

Logue, J.M., Klepeis, N.E., Lobscheid, A.B. & Singer, B.C. (2014). Pollutant exposures from natural gas cooking burners: a simulation-based assessment for southern California. *Environmental Health Perspectives*, *122*(1), 43–50. https://doi.org/10.1289/ehp.1306673

Marks, G.B., Ezz, W., Aust, N., Toelle, B.G., Xuan, W., Belousova, E., Cosgrove, C., Jalaludin, B. & Smith, W.T. (2010). Respiratory health effects of exposure to low-NOx unflued gas heaters in the classroom: a double-blind, cluster-randomized, crossover study. *Environmental Health Perspectives*, *118*(10), 1476–82. https://doi.org/10.1289/ehp.1002186

Merrin, Z. & Francisco, P.W. (2019). Unburned methane emissions from residential natural gas appliances. *Environmental Science & Technology*, *53*(9), 5473–5482. https://doi.org/10.1021/acs.est.8b05323

Moran, S.E., Strachan, D.P., Johnston, I.D.A. & Anderson, H.R. (1999). Effects of exposure to gas cooking in childhood and adulthood on respiratory symptoms, allergic sensitization and lung function in young British adults. *Clinical and Experimental Allergy*, *29*(8), 1033–1031.

Moshammer, H., Fletcher, T., Heinrich, J., Hoek, G., Hruba, F., Pattenden, S., Rudnai, P., Slachtova, H., Speizer, F. E., Zlotkowska, R. & Neuberger, M. (2010). Gas cooking is associated with small reductions in lung function in children. *The European Respiratory Journal*, *36*(2), 249–54. https://doi.org/10.1183/09031936.00102409

Nadel, S. (2018). *Energy Savings, Consumer Economics, and Greenhouse Gas Emissions Reductions from Replacing Oil and Propane Furnaces, Boilers, and Water Heaters with Air-Source Heat Pumps.* American Council for an Energy-Efficient Economy

<https://www.aceee.org/sites/default/files/publications/researchreports/a1803.pdf> [15 January 2024]

National Environment Protection Council (2021). *National Environment Protection (Ambient Air Quality) Measure*, https://www.nepc.gov.au/nepms/ambient-air-quality [27 January 2024]

Ng, T.P., Seet, C.S.R., Tan, W.C. & Foo, S.C. (2001). Nitrogen dioxide exposure from domestic gas cooking and airway response in asthmatic women. *Thorax*, *56*(8), 596–596. https://doi.org/10.1136/thorax.56.8.596

Nicole, W. (2014). Cooking up indoor air pollution: emissions from natural gas stoves. *Environmental Health Perspectives*, *122*(1), 27. https://doi.org/10.1289/ehp.122-A27

Nitschke, M., Pilotto, L.S., Attewell, R.G., Smith, B.J., Pisaniello, D., Martin, J., Ruffin, R.E. & Hiller, J.E. (2006). A cohort study of indoor nitrogen dioxide and house dust mite exposure in asthmatic children. *Journal of Occupational and Environmental Medicine*, *48*(5), 462–469. https://doi.org/10.1097/01.jom.0000215802.43229.62

Pan, H., Jarvis, D., Potts, J., Casas, L., Nowak, D., Heinrich, J., Aymerich, J. G., Urrutia, I., Martinez-Moratalla, J., Gullón, J.-A., Pereira-Vega, A., Raherison, C., Chanoine, S., Demoly, P., Leynaert, B., Gislason, T., Probst, N., Abramson, M. J., Jõgi, R., … Fuertes, E. (2024). Gas cooking indoors and respiratory symptoms in the ecrhs cohort. *International Journal of Hygiene and Environmental Health*, *256*. https://doi.org/10.1016/j.ijheh.2023.114310

Paulin, L.M., Williams, D. 'Ann L., Peng, R., Diette, G.B., McCormack, M.C., Breysse, P. & Hansel, N.N. (2017). 24-h nitrogen dioxide concentration is associated with cooking behaviors and an increase in rescue medication use in children with asthma. *Environmental Research*, *159*, 118–123. https://doi.org/10.1016/j.envres.2017.07.052

Phoa, L.L., Toelle, B.G., Ng, K. & Marks, G.B. (2004). Effects of gas and other fume emitting heaters on the development of asthma during childhood. *Thorax*, *59*(9), 741–741. https://doi.org/10.1136/thx.2003.014241

Pilotto, L.S., Nitschke, M., Smith, B.J., Pisaniello, D., Ruffin, R.E., McElroy, H.J., Martin, J. & Hiller, J.E. (2003). Randomized controlled trial of unflued gas heater replacement on respiratory health of asthmatic schoolchildren. *International Journal of Epidemiology*, *33*(1), 208–14.

Prockop, L. D. (2005). Carbon monoxide brain toxicity: clinical, magnetic resonance imaging, magnetic resonance spectroscopy, and neuropsychological effects in 9 people. *Journal of Neuroimaging: Official Journal of the American Society of Neuroimaging*, *15*(2), 144–9.

Raw, G.J., Coward, S.K.D., Brown, V.M. & Crump, D.R. (2004). Exposure to air pollutants in English homes. *Journal of Exposure Science & Environmental Epidemiology: Official Journal of the International Society of Exposure Science*, *14*(Suppl 1), 94. https://doi.org/10.1038/sj.jea.7500363

Ruiz, P.A., Toro, C., Cáceres, J., López, G., Oyola, P. & Koutrakis, P. (2010). Effect of gas and kerosene space heaters on indoor air quality: a study in homes of Santiago, Chile. *Journal of the Air & Waste Management Association*, *60*(1), 98–108. https://doi.org/10.3155/1047-3289.60.1.98

Safe Work Australia (SWA) 2022, Workplace exposure standards for airborne contaminants, SWA, Canberra <https://www.safeworkaustralia.gov.au/doc/workplace-exposure-standards-airborne-contaminants-2022> [27 December 2023]

Singer, B.C., Pass, R.Z., Delp, W.W., Lorenzetti, D.M., Maddalena, R.L. & Lawrence Berkeley National Lab. (LBNL), Berkeley, CA (United States). (2017). Pollutant concentrations and emission rates from natural gas cooking burners without and with range hood exhaust in nine California homes. *Building and Environment*, *122*(C). https://doi.org/10.1016/j.buildenv.2017.06.021

Shatssoon, J. (2023), *Councils throw down gauntlet to state government over gas ban*, <https://www.governmentnews.com.au/councils-throw-down-gauntlet-to-state-government-over-gas-ban/>, [11th February 2024]

Standards Australia (2017), *Gas Appliances, Part 1.4: Radiant gas heaters*, AS/NZS 5263.1.4:2017, SAI Global, Sydney

Standards Australia (2019), Gas appliances, Part 1.10: Gas direct fired air heaters, AS/NZS 5263.1.10:2019, SAI Global, Sydney

Standards Australia (2020), *Gas appliances Domestic gas cooking appliances*, AS/NZS 5263.1.1:2020, SAI Global, Sydney

Standards Australia (2020), *Gas appliances Indirect gas-fired ducted air heaters*, AS/NZS 5263.1.6:2020, SAI Global, Sydney

Standards Australia (2021), *Gas appliances Decorative effect gas appliances*, AS/NZS 5263.1.8:2021, SAI Global, Sydney

Standards Australia (2021), *Gas appliances Gas space heating appliances,* AS/NZS 5263.1.3:2021, SAI Global, Sydney

Standards Australia (2023), *Gas appliances General requirements*, AS/NZS 5263.0:2023, SAI Global, Sydney

Sun, M., Huang, X., Hu, Y. & Lyu, S. (2022). Effects on the performance of domestic gas appliances operated on natural gas mixed with hydrogen. *Energy*, *244*. https://doi.org/10.1016/j.energy.2021.122557

Tin Tin, S., Woodward, A., Saraf, R., Berry, S., Atatoa Carr, P., Morton, S.M.B. & Grant, C.C. (2016). Internal living environment and respiratory disease in children: findings from the growing up in New Zealand longitudinal child cohort study. *Environmental Health*, *15*(1), 1–10. https://doi.org/10.1186/s12940-016-0207-z

To, W.M. & Yeung, L.L. (2011). Effect of fuels on cooking fume emissions. *Indoor and Built Environment*, *20*(5), 555–563. https://doi.org/10.1177/1420326X11409462

WHO 2010, WHO guidelines for indoor air quality: selected pollutants, World Health Organization https://www.who.int/publications/i/item/9789289002134, [4 December 2023]

WHO 2021 *WHO global air quality guidelines: Particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*, World Health Organization, <https://www.who.int/publications/i/item/9789240034228> [25 January 2024]

Willers, S.M., Brunekreef, B., Oldenwening, M., Smit, H.A., Kerkhof, M. & Vries, H. (2006a), Gas cooking, kitchen ventilation, and exposure to combustion products, *Indoor Air*, 16, pp. 65-73

Willers, S.M., Brunekreef, B., Oldenwening, M., Smit, H.A., Kerkhof, M., De Vries, H., Gerritsen, J. & De Jongste, J.C. (2006b). Gas cooking, kitchen ventilation, and asthma, allergic symptoms and sensitization in young children - the piama study. *Allergy*, *61*(5), 563–568.

WorkSafe ACT 2016, *Unflued gas heaters and your health*, <https://www.worksafe.act.gov.au/health-and-safety-portal/safety-alerts/unflued-gas-heaters-and-your-health> [25 January 2024]

Zhao, H., Chan, W.R., Cohn, S., Delp, W.W., Walker, I.S. & Singer, B.C. (2021). Indoor air quality in new and renovated low-income apartments with mechanical ventilation and natural gas cooking in California. *Indoor Air*, *31*(3), 717–729. https://doi.org/10.1111/ina.12764