Quantifying the Potential Health Impacts of Unvented Combustion in Homes

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Combustion-Related Contaminants



- PM_{2.5} (and PM₁₀/ultrafine) ► Generally, the most important contaminant of concern for health impacts
- NO₂ ► is an irritant to the respiratory tract
- VOCs ► health impact minimal compared with PM_{2.5} and NO₂
- Water vapor and odours not directly health-related and not the subject of this paper

This Study:

- Combustion of Gas not oil / wood / propane, etc.
- NO₂ only to disambiguate between gas and electric cooking, PM common to all cooking



What is "Unvented"



Most combustion equipment has a vent to outside:

- Boilers
- Furnaces
- Water heaters

This study is about unvented combustion:

- Cooking with gas
- Room heaters



Methodology: Meta-Analysis

- Review of publications since the year 2000.
- Literature related to:
 - Interventions where gas combustion appliances were replaced.
 - Effective engineering controls were implemented.
 - Measured NO₂ was taken as the main exposure variable.
 - Meta-analysis focused on gas stove effects on cough and wheeze.

Studies that used epidemiologic methods:

Associations between <u>health outcomes</u> and the presence or use of unvented gas combustion appliances and/or measured NO_2 with results presented as effect estimates with confidence intervals.

Summary of relevant articles

TOTAL 29 Studies

- 10 meta-analyses
- 12 observational studies
- 7 RCTs or quasi-experimental studies

TOTAL ► 184 effect estimates





Types of Studies



- Primarily Acute exposures monitoring over several years
- RCT and observational studies isolated exposure from unvented appliances
 - Does not include exposure to contaminants from vented sources that enter a building from outdoors.
 - Studies compared home with indoor unvented combustion to homes without, for the same outdoor conditions
- Meta-analyses based on overall NO₂ concentrations and presence of unvented appliances







Health Outcomes: 12 categories

- All-cause mortality.
- Cardiovascular mortality.
- Respiratory mortality.

- 1. Mortality
- 2. Hospital visits
- 3. Health symptoms
- 4. Others
- Healthcare visits or emergency room visits or changes to asthma management.
- Hospitalization or emergency room visits
- Asthma symptoms including wheeze, cough, shortness of breath, chest tightness, respiratory symptoms, nasal symptoms, and difficulty breathing.
- Asthma symptom scores including ordinal scores 0-3 (3 as the most severe and 0 as no symptom)
- Systemic symptoms including poor/fair health, diarrhea, vomiting, ear infection stomach ache, eczema, sensitization, allergies, night-time waking, and steroid use.
- Medication use including asthma preventer and reliever use.
- Nonpharmaceutical interventions including limiting activity.
- Neurological disease development including schizophrenia.
- Absences from school.





Combining results from different studies

- Convert effect estimates into continuous, independent variables.
 e.g., effect per 20 ppb increase in NO₂.
- Convert intervention studies to consider control groups as the numerator in effect estimate ratios.
- Use effect estimates adjusted for confounders: (e.g., age, season, mold exposure, etc.)
- Stratified pooled estimates by:
 - Health outcome
 - Categorical or continuous exposure.
 - Effect estimate type:
 - Odds ratios (OR)
 - Risk ratios (RR)
 - Incident rate ratios (IRR)

Geographical Distribution

Gas Cooking

The Netherlands

Gas Stove

- USA: New York
- Global

Room Heater

- Australia: Adelaide; New South Wales
- New Zealand
- USA: Connecticut; Massachusetts

Indoor

- USA: Connecticut; Massachusetts; Maryland
- Japan

Ambient (exterior)

- Australia: Adelaide
- Denmark
- USA: Maryland; Massachusetts





Results

Odds ratios for combustion cooking and/or heating on asthma symptoms

Overall.... Gas vs Electric Appliances (both vented AND unvented) Associated with 1.16 times the odds of reporting asthma symptoms (95% CI 1.06-1.28)

Study	Follow-up length Combus	tion Outcome	Age	Subgroup	N participants	% with asthma	Odds Ratio	OR	95%-CI W	Veight
design_type = RCT howden-chapman_200 marks_2010 marks_2010 marks_2010 marks_2010 Random effects mod Heterogeneity: / ² = 70%	08 52 weeks heat 6 weeks heat 6 weeks heat 6 weeks heat 6 weeks heat 10 metric definition of the second 6 weeks heat	wheezeing attack morning wheeze or cough evening wheeze or cough morning wheeze or cough evening wheeze or cough	6-12 8-12 8-12 8-12 8-12	atopy atopy	349 400 400 152 152	100 15 15 15 15		1.41 0.94 0.96 1.85 1.14 1.16	[0.90; 2.22] [0.80; 1.10] [0.85; 1.09] [1.26; 2.72] [0.81; 1.61] [0.91; 1.47]	3.0% 7.2% 7.8% 3.7% 4.2% 25.9%
design_type = observ belanger_2006 belanger_2006 belanger_2006 belanger_2006 belanger_2006 belanger_2006 belanger_2006 willers_2006 willers_2006 willers_2006 willers_2006 willers_2006 willers_2000 rice_2020 rice_2020 rice_2020 rice_2020 lu_2018 lu_2018 paulin_2017 boulic_2012 boulic_2012 boulic_2012	vational 2 weeks stove 2 weeks stove 8 years sto	 wheeze persistent cough shortness of breath chest tightness wheeze persistent cough shortness of breath chest tightness masal symptoms wheeze transient early wheeze persistent wheeze persitent wheeze wheeze or cough nighttime respiratory symptom asthma-like symptoms daytime asthma symptoms current asthma symptoms current 	0-12 0-12 0-12 0-12 0-12 0-12 0-12 0-12	multifamily multifamily multifamily singlefamily singlefamily singlefamily singlefamily bpd bpd bpd bpd bpd bpd with resp support bpd with resp support bpd with resp support bpd bpd with resp support bpd bpd with resp support bpd with resp support bpd bpd bpd bpd bpd bpd bpd bpd bpd bpd	242 242 242 242 486 486 3148 3148 3148 3148 3148 3148 244 244 114 114 231 244 244 114 114 231 242 30 3874 3874 3874 3874	100 100 100 100 100 100 100 4 4 4 4 4 4 4 4 4 4 5		2.27 1.19 2.38 - 4.34 0.61 0.92 0.91 0.99 0.91 0.89 1.06 1.21 1.64 1.29 2.24 - 2.62 - 2.62 - 2.62 1.58 1.29 1.58 1.29 1.58 1.29 1.58 1.29 1.58 1.29 1.21 1.34 1.58		1.7% 2.0% 1.4% 2.3% 2.6% 2.6% 1.7% 5.8% 6.1% 1.4% 2.9% 1.4% 0.6% 0.6% 0.6% 0.2% 3.1% 5.9% 4.4% 2.2% 3.1% 5.9% 0.6% 0.2% 3.1% 5.9% 0.6% 3.1% 5.9% 5.2% 0.6% 0.2% 3.1% 5.9% 5.2% 0.6% 3.1% 5.9% 5.2% 0.6% 3.1% 5.2% 5.2% 5.2% 0.5% 0.6% 3.1% 5.2% 5.2% 5.2% 0.5%
boulic_2012 Random effects mod Heterogeneity: I ² = 45%, Random effects mod	0 weeks heat lel , τ ² = 0.0179, p < 0.01	asthma symptoms ever	6-12	unflue vs flue combustion heat	3874		\$	1.05 1.17 1.16	[0.88; 1.26] [1.05; 1.29]	6.8% 74.1% 00.0%



Random effects model Heterogeneity: $l^2 = 52\%$, $\tau^2 = 0.0271$, p < 0.01Test for subgroup differences: $\chi_1^2 = 0.00$, df = 1 (p = 0.96)

0.1 0.5 1 2 10

Results – Asthma Symptoms

20 ppb increase in NO_2 = It is an increase in the odds of asthma symptoms by 33%

Asthma Symptoms and Symptom Scores

Study	Follow-up length Co	ombustion	Outcome	Age	Subgroup	N participants	% with asthma	Odds Ratio	OR	95%-CI	Weight
design_type = RCT gillespie-bennet_2011 gillespie-bennet_2011 gillespie-bennet_2011 gillespie-bennet_2011 gillespie-bennet_2011 Bandom effects mode Heterogeneity: I ² = 49%,	4 months 4 months 4 months 4 months 4 months 4 months 1 $t^2 = 0.0070, p = 0.08$	heat heat heat heat heat	nighttime cough daytime cough cough with waking nighttime wheeze daytime wheeze wheeze with waking	6-13 6-13 6-13 6-13 6-13 6-13	- - - -	344 358 344 343 365 343	100 100 100 100 100 100		1.73 1.52 1.73 1.52 1.24 1.52 1.55	[1.52; 2.03] [1.33; 1.73] [1.47; 1.96] [1.24; 1.90] [1.04; 1.52] [1.24: 1.85] [1.41; 1.71]	6.4% 6.5% 6.4% 5.7% 5.9% 5.8% 36.7%
design_type = observa belanger_2006 belanger_2006 belanger_2006 belanger_2006 belanger_2006 belanger_2006 belanger_2013 belanger_2013 belanger_2013 belanger_2013 permaul_2020 permaul_2020 permaul_2020 permaul_2020 permaul_2020	ational 2 weeks 2 weeks 2 weeks 2 weeks 2 weeks 2 weeks 2 weeks 2 weeks 4 months 4 months 5 years 5 years	stove stove stove stove stove stove stove stove stove stove stove stove both both both both both	wheeze persistent cough shortness of breath chest tightness wheeze persistent cough shortness of breath chest tightness wheeze nighttime asthma symptoms days of asthma symptoms days of asthma symptoms wheeze, cough, or chest tightness nighttime asthma symptoms wheeze, cough, or chest tightness days of asthma symptoms	0-12 0-12 0-12 0-12 0-12 0-12 0-12 0-12	multifamily multifamily multifamily singlefamily singlefamily singlefamily singlefamily obese obese obese obese overweight overweight normalweight	242 242 242 486 486 486 1342 1342 97 97 97 97 97 41 41 41 41 33	100 100 100 100 100 100 100 100 100 100		1.52 1.06 1.28 1.61 1.33 1.07 1.23 1.61 3.78 4.04 3.46 2.02 0.96 0.61 0.36 0.94 0.81	[1.04; 2.21] [0.75; 1.49] [0.85; 1.91] [1.04; 2.49] [1.05; 1.68] [0.84; 1.35] [0.95; 1.59] [1.04; 2.49] [1.04; 2.49] [1.04; 2.49] [1.04; 2.49] [1.04; 2.49] [1.04; 2.49] [1.05; 1.08] [0.77; 5.20] [0.85; 1.08] [0.10; 3.76] [0.76; 1.85] [0.10; 3.76] [0.86; 1.02] [0.32; 2.02]	4.0% 4.3% 3.7% 3.4% 5.4% 5.2% 3.4% 1.0% 1.1% 1.2% 6.6% 0.4% 0.4% 0.4% 0.4% 1.2%
permaul_2020 Random effects mode Heterogeneity: I ² = 65%,	5 years 5 years Ι τ ² = 0.0354, <i>p</i> < 0.01	both	nighttime asthma symptoms	4-13	normalweight	133	100	¢	1.02	[0.32, 1.85] [0.96; 1.06] [1.06; 1.37]	7 1% 63.3%

Random effects model

Heterogeneity: $l^2 = 86\%$, $\tau^2 = 0.0457$, p < 0.01Test for subgroup differences: $\chi_1^2 = 9.42$, df = 1 (p < 0.01)

> Odds ratios for a 20 ppb increase in average <u>NO₂ exposure</u> linked with <u>combustion cooking and/or unvented heating</u>

10

0.1

0.5 1 2

1.33 [1.19; 1.49] 100.0%



Results - Death

• Meta-analyses mostly used a continuous NO₂ exposure variable to evaluate risk of mortality, asthma incidence, emergency room visits, and hospitalizations.

Study	Subgroup	N Effect Sizes	Risk	Ratio	RR	95%-CI	Weight
huangfu_2020		15		<u> </u>	1.12	[1.00; 1.21]	10.0%
orellano_2020	1-hr max	10		+	1.01	[1.00; 1.02]	18.3%
orellano_2020	24-hr avg	54		4	1.03	[1.02; 1.03]	18.4%
orellano_2020	O3 adj	6		-	1.05	[1.02; 1.08]	17.1%
atkinson_2018		48			1.08	[1.04; 1.12]	16.4%
faustini_2014		10			1.16	[1.05; 1.29]	9.3%
hoek_2013		13		-	1.21	[1.12; 1.34]	10.5%
Random effects mode	l,			\Rightarrow	1.08	[1.03; 1.12]	100.0%
Heterogeneity: I ² = 86%, 1	r ^e = 0.0028, p	< 0.01	1				
			0.8	1 1.25			

20 ppb increase in NO_2 = 8% increase of DEATH overall



Pooled meta-analysis all-cause mortality risk ratios for 20 ppb increases in indoor NO₂

Summary

• We found an increased likelihood of using asthma medication across both randomized controlled trials (RCTs) and observational studies, with a combined confidence interval showing 7-81% higher odds when gas appliances were present.

Study	Follow-up length	Combustion	Outcome	Age	Subgroup	N participants	% with asthma		Odds Ratio	OR	95%-CI	Weight
design_type = RCT howden-chapman_2008 marks_2010 marks_2010 Random effects model Heterogeneity: l ² = 68%, t ²	52 weeks 6 weeks 6 weeks 2 = 0.1369, p = 0.04	heat heat heat	reliever use at night reliever use reliever use	6-12 8-12 8-12	atopy	349 400 152	100 15 15			1.82 0.89 1.87 1.38	[0.93; 3.57] [0.60; 1.30] [1.08; 3.25] [0.82; 2.32]	9.8% 17.0% 12.4% 39.1%
design_type = observa rice_2020 rice_2020 rice_2020 rice_2020 schachter_2020 schachter_2020 paulin_2017 Random effects model Heterogeneity: <i>I</i> ² = 37%, rc	tional 2 months 2 months 2 months 2 months 2 weeks 2 weeks 0 weeks 0 weeks 0 weeks 2 weeks 0 weeks 1 months 2 months 2 months 2 months 2 months 2 months 2 months 2 months 2 weeks 0 weeks 0 weeks 0 weeks 0 weeks 0 weeks 1 months 1 months 2 months	both both both stove stove both both	systemic steroid use reliever use systemic steroid use reliever use summertime asthma medication puffs per day wintertime asthma medication puffs per day reliever use at night reliever use at day	0-16 0-16 0-16 6-14 6-14 5-12 5-12	bpd bpd bpd with resp suppor bpd with resp suppor	244 244 t 114 t 114 36 36 30 30	100 100 100 100			1.34 1.02 1.44 0.85 2.53 - 5.39 - 4.90 1.96 1.37	[0.86; 2.07] [0.65; 1.61] [0.71; 2.95] [0.43; 1.69] [0.73; 8.86] [1.36; 21.28] [1.09; 22.00] [0.34; 11.29] [1.02; 1.85]	15.4% 15.0% 9.1% 9.6% 3.8% 3.2% 2.8% 2.1% 60.9%
Random effects model Heterogeneity: $I^2 = 42\%$, τ^2	² = 0.0673, p = 0.07								*	1.39	[1.07; 1.81]	100.0%
Test for subgroup difference	ces: χ ₁ ² = 0.00, df = 1 (p = 0.98)						0.1	0.5 1 2 10			

Summary

- **Findings** ► Foundation for extrapolating the potential health advantages of broad-scale initiatives aimed at mitigating the effects of unvented combustion.
- Initiatives ► Enhancing ventilation and source control, transitioning to vented appliances, improving regulations governing device emissions, and quantifying the advantages of electrifying various enduses.



QUESTIONS...?

