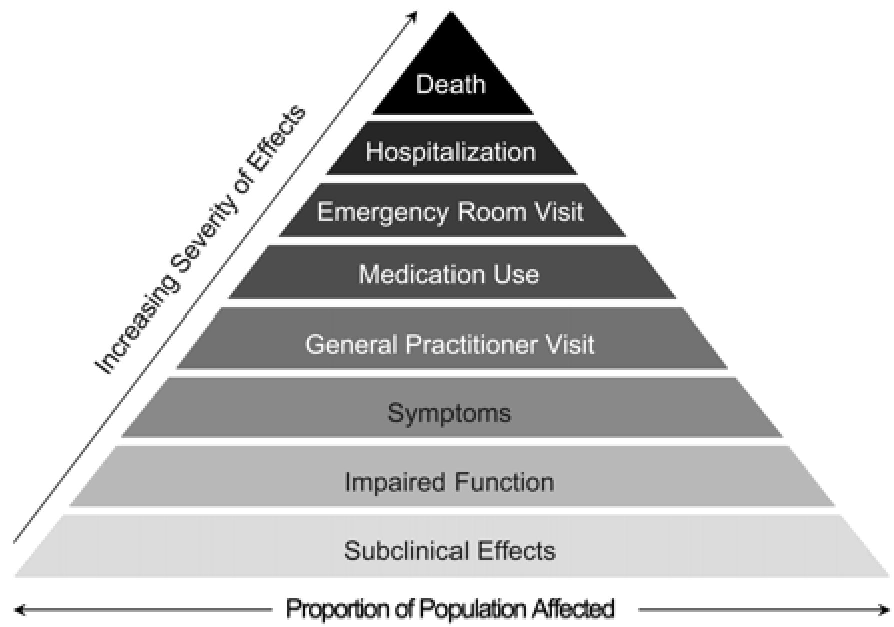
Woodsmoke and health

Michael Brauer

BC Lung Association Webinar
February 9, 2012

Air pollution and health

- Air pollution (individual) **risk** is small…but large **exposed population = large population risk**
  - Smoking: Larger risk, smaller exposed population
- On **days** with worse air quality, more people die*
- In **more polluted cities**, people die earlier than in less polluted cities…
- …and, in the **most polluted areas** of cities, there is an increased risk of dying

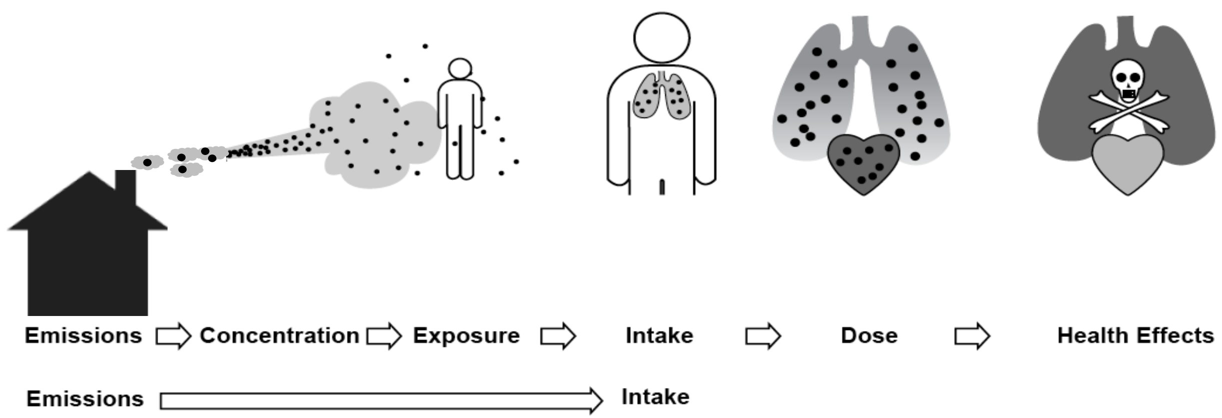


Larrieu et al. Am J Epidemiol, 2009

*out-of-hospital, >65 yrs

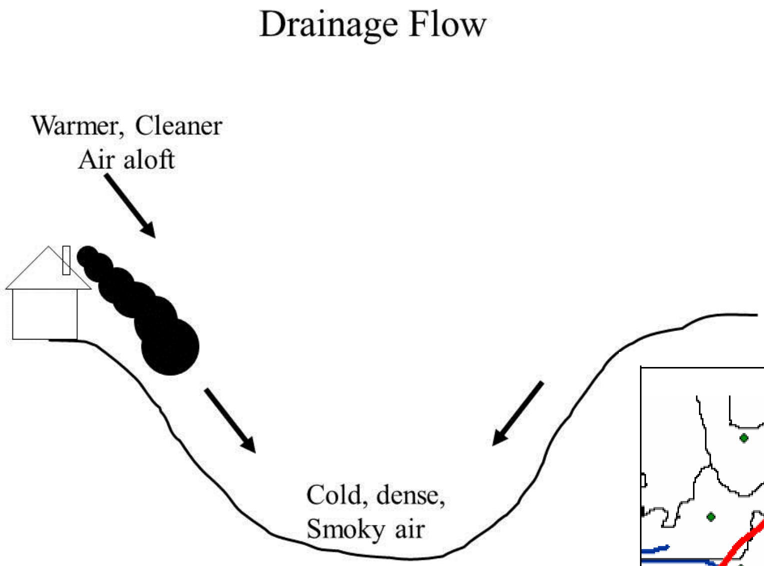
Wood biomass in context

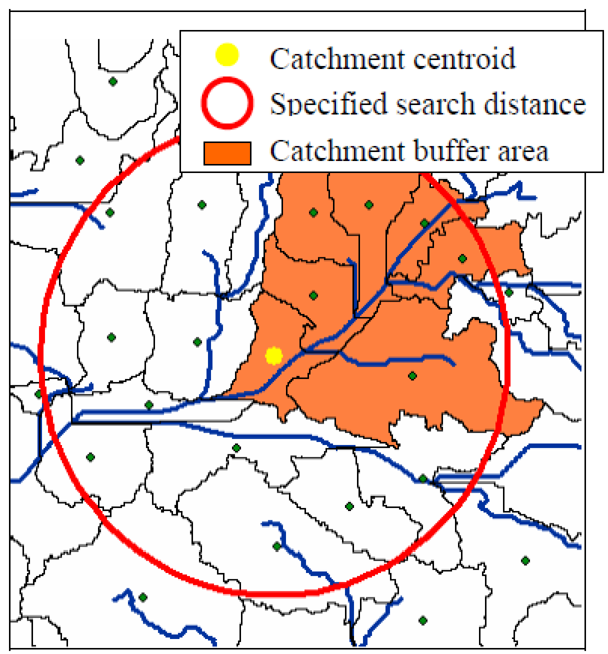
- Available, inexpensive, secure residential fuel
  - Increasing/fluctuating costs & taxes for other fuels
- Promoted as a renewable, GHG neutral fuel
- Relatively unregulated source
- Impact on winter air quality coinciding with stagnation
- Exposure proximity, high "intake fraction"



Ries F, Marshall J, Brauer M. Intake fraction of urban wood smoke. Environ Sci Technol, 2009 Jul 1;43(13):4701-6; Brauer M, Miller P, Allen G, Rector L. Modeling Pollution from Residential Wood Combustion. EM Magazine (Air and Waste Management Association). May, 2010. pp 24-28

Spatial extent





For typical drainage wind speed (1 m/s) maintained over a 3 hour period, upslope influence ~ **10 km**

Catchment modeling[1,2] suggests upslope influence of **4 – 8 km**

Semivariogram analysis[3] suggests spatial extent of **2.7 km**

[1]Larson T, Su J, Baribeau A-M, Buzzelli M, Setton E, Brauer M. A Spatial Model of Urban Winter Woodsmoke Concentrations. Environmental Science and Technology. 2007; 41 (7): 2429 -2436.
[2]Su JG, Allen GA, Miller PJ, Brauer M. Spatial modeling of residential woodsmoke across a non-urban upstate New York region. Air Quality, Atmosphere and Health, 2011 http://dx.doi.org/10.1007/s11869-011-0148-1
[3]Lightowlers, C et al. Determining the spatial scale for analysing mobile measurements of air pollution. Atmospheric Environment 42 (2008)

WOOD-BURNING

Vital cultural practice

If you can't burn wood in a Canadian winter, what else is there? For all the propaganda about the boundless joys of seasonal sports, the truth for many people is more mundane; if you don't get your kicks snowboarding or commuting by skates or Skidoo, winter can be a long, cold and dreary fact of Canadian life that must be endured – or, if one has the money and it's practicable, avoided.

There is, however, some consolation found for those who brave our severe winters, beyond donning woolies or huddling under a Hudson's Bay Company point blanket. It takes the form of a wood-burning fireplace or stove. Montreal politicians, however, want to put an end to this time-honoured practice.

"People see it as natural, as romantic, as creating ambience," says Alan DeSousa, of Montreal's executive committee. "I don't think people realize the impact."

Montreal has been plagued by smog alerts this year, and studies show that in the winter nearly half of air pollution is traced to wood-burning, more than either industry or automobiles. The health issues raised by this are not insignificant and should not be belittled. As Louis Brisson, president of the Quebec Lung Association, said: "Some people are choking and dying. It is not a fallacy, it's a fact."

The municipality wants to ban fireplaces and wood-burning stoves in new homes, and prevent their replacement in old ones.

It should reflect carefully before taking such extreme measures.

Canada is not unique for its love of the crackle of a fireplace or the whiff of wood smoke. But because of the severity of the climate, it holds a peculiarly important place in our lives. It is prominent in our history – the only remaining feature of the early Rocky Mountain House fur-trade post in Alberta is its fireplaces. The ruins of English explorer James Knight's 1719 winter shelter on Marble Island in Nunavut largely consists of a fireplace. Settlers relied on firewood, too. And while it may not be the main heat source in modern homes or most cottages today, it is still part of the Canadian way of life.

The assault on wood-burning fireplaces and stoves under way in Montreal is more than a public health matter, then; it strikes at the very core of Canadian identity. Montreal's measures are extreme. The city needs to consider how it would police its rules, particularly around the refurbishment of fireplaces and stoves. It also needs to look at other measures that could help, such as a new law proposed by Quebec's Environment Department that would make it illegal to sell wood stoves in the province that don't meet high environmental standards.

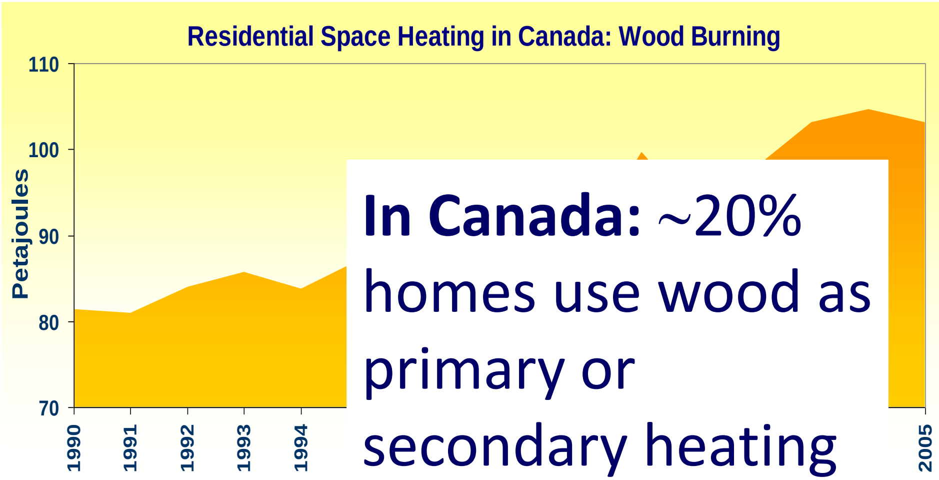
Finally, Montreal politicians must also consider the social and psychological implications of such a crackdown. Seasonal affective disorder is a real condition, and it is hard enough to get through a Canadian winter. For some people, the absence of fireplaces may make it well-nigh impossible.

Globe and Mail. February 9, 2009

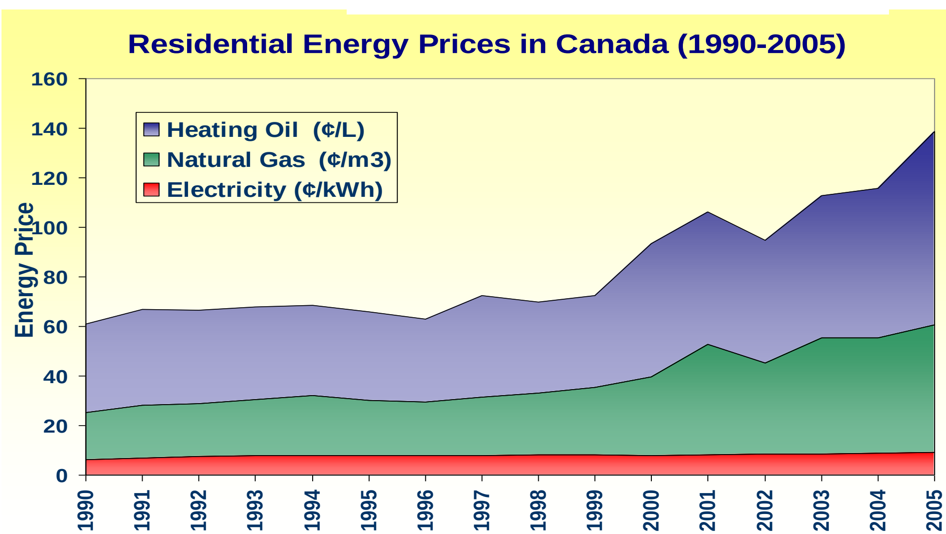
If you can't burn wood in a Canadian winter, what else is there?..... And while it may not be the main heat source in modern homes or most cottages today, it is still part of the Canadian way of life.
The assault on wood-burning fireplaces and stoves under way in Montreal is more than a public health matter, then; it strikes at the very core of Canadian identity

<u>Comment in response to article:</u> "We burn about 10 cords every winter…but we live in a rural area. It's messy, it's hard work to pile and haul in all that wood, and believe me after 20 years of doing that it has lost ALL its romantic charm. Throw in the pollution factor and the picture is complete. Wood burning sucks…"

Residential Wood Combustion is increasing



In Canada: ~20% homes use wood as primary or secondary heating source



[2]Hedberg et al. (2008)

The New York Times

With Oil Prices Rising, Wood Makes a Comeback

By KATIE ZEZIMA
Published: February 19, 2008

NEWPORT, Vt. — As a child, Brian Cook remembers hurling wood into the big orange boiler his father bought during the oil crisis of the late 1970s, helping feed the fire that provided heat and hot water to his family.

Taylor Swartz, 15, carted wood from the backyard for a furnace in the garage of the family home in Orleans, Vt.

Karen Pike for The New York Times

"I see a lot more people burning wood this year."

Randy Swartz feeding wood to the furnace, which he bought for over $6,000 because of high oil prices.

Karen Pike for The New York Times

... There's a lot of people buying big stoves, planning on tackling oil head-on," said Roy L'Esperance, owner of the Chimney Sweep in Shelburne, Vt., who has seen **sales of wood stoves increase nearly 20 percent this year**. "They say, 'I just got a new house and I'm getting killed with oil bills, and propane is just as bad.' " ... Generally, say they burn a cord of wood a year, this year they are already on their second cord," one of the owners, Michael Moore, said. **"Some people are planning on burning two or three times more wood than they have in the past."**

Statistics from the last survey about the use of wood for heat, conducted in 2006, are not yet public, but the **number of households that report using wood as their primary source of heat is expected to jump sharply**, said Marie LaRiviere of the Energy Information Administration. ...

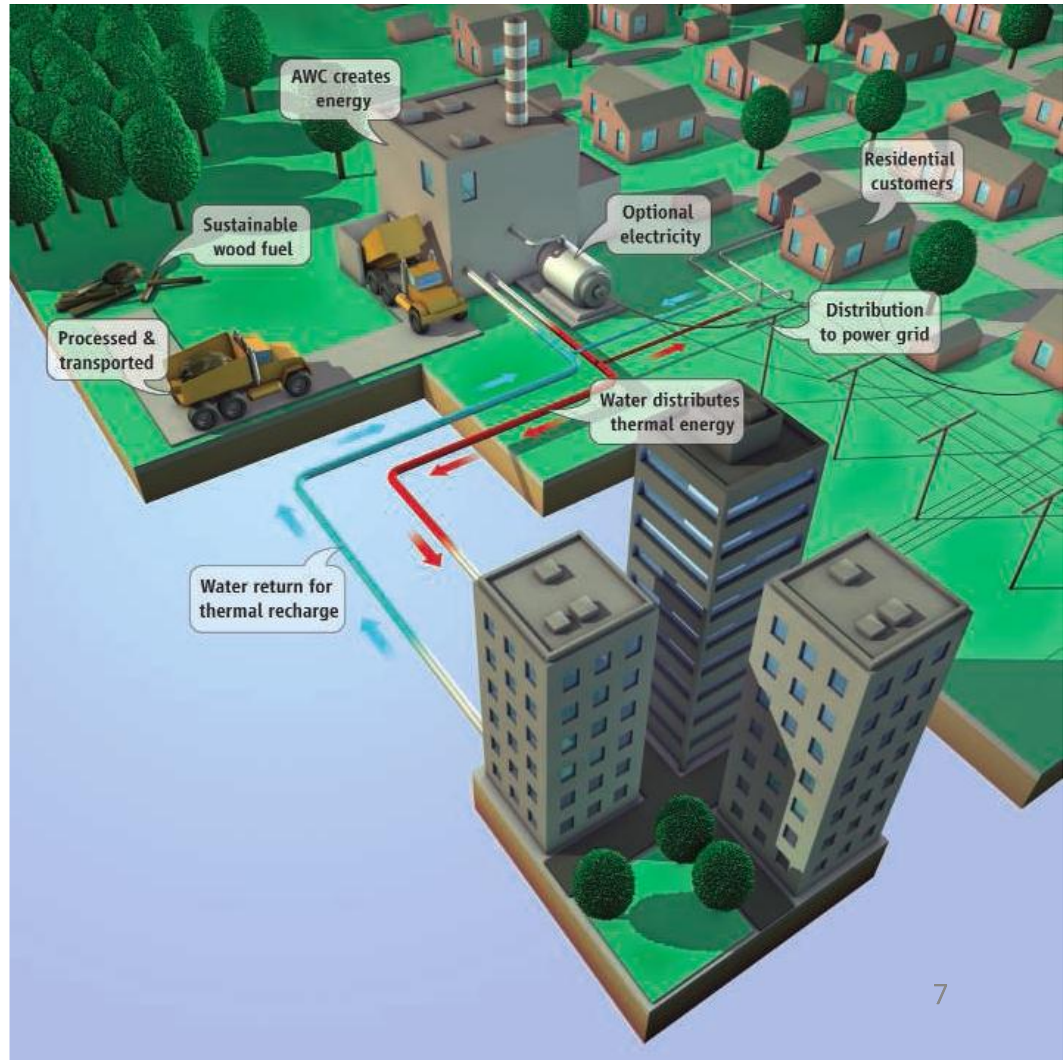
POLICYFORUM

13 MARCH 2009 VOL 323 SCIENCE www.sciencemag.org

RESOURCE POLICY

Wood Energy in America

Daniel deB. Richter Jr.,[1*] Dylan H. Jenkins,[2] John T. Karakash,[3] Josiah Knight,[4]
Lew R. McCreery,[5] Kasimir P. Nemestothy[6]



Issues raised in response:

- Is biomass really inexpensive?
    - more $ than oil, nat. gas
- Sufficient supply?
- Emissions of current technologies > emissions of oil, natural gas
    - need cleanest fuels/emissions controls when burned in populated areas and with distributed sources
- Carbon neutrality
    - Stock replacement
    - Black Carbon

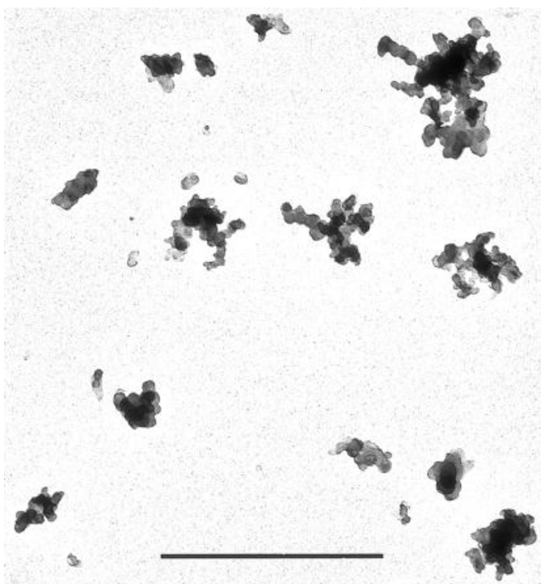
Biomass smoke and health: evidence

- Constituents/Composition ($PM_{2.5}$, aldehydes, PAHs)
- Toxicology
- High concentration, chronic exposures – developing countries
- High concentration acute/sub-chronic exposures – wildland firefighters
- Firesmoke, agricultural burning
- Controlled human exposures
- Residential woodsmoke epidemiology

Do woodsmoke particles pose different levels of risk from other particles?

- **Respiratory disease: No**
- **Cardiovascular disease: ?**

Woodsmoke Particles



Bar = 1 µm = 1/1000 of 1mm

Inhalation Toxicology, 19:67–106, 2007

ISSN: 0895-8378 print / 1091-7691 online
DOI: 10.1080/08958370600985875

Woodsmoke Health Effects: A Review

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PAH content: **WS >Traffic PM**

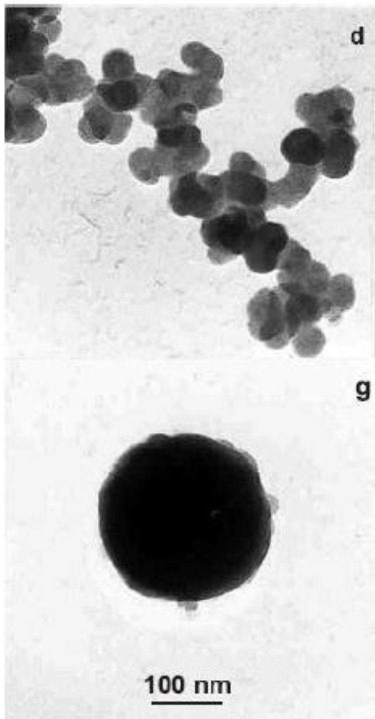
Inflammatory potential: **WS ≈ Traffic PM**

WS: organic fraction / Traffic PM: endotoxin

Kocbach et al. Toxicology. 2008, 247(2-3):123-132

Naeher LP, Brauer M, Lipsett M, Zelikoff JT, Simpson CD, Koenig JQ, Smith KR. Woodsmoke health effects: A review. Inhal Toxicol. 2007 Jan;19(1):67-106.

PM composition

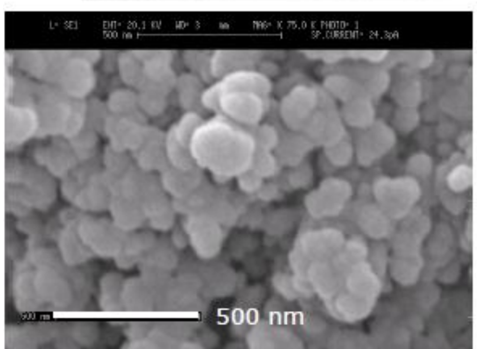


Wood smoke soot

Wood smoke organic particles (low-temp combustion)

“conventional”

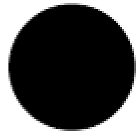
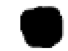
from *Kocbach et al, Science of the Total Environment, 2005*)



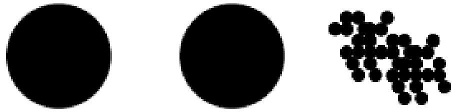
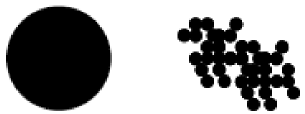
”Good” wood pellet combustion PM (alkali salt particles)

“advanced”

from *Boman et al, Energy and Fuels 2011;25:(1):307-314*

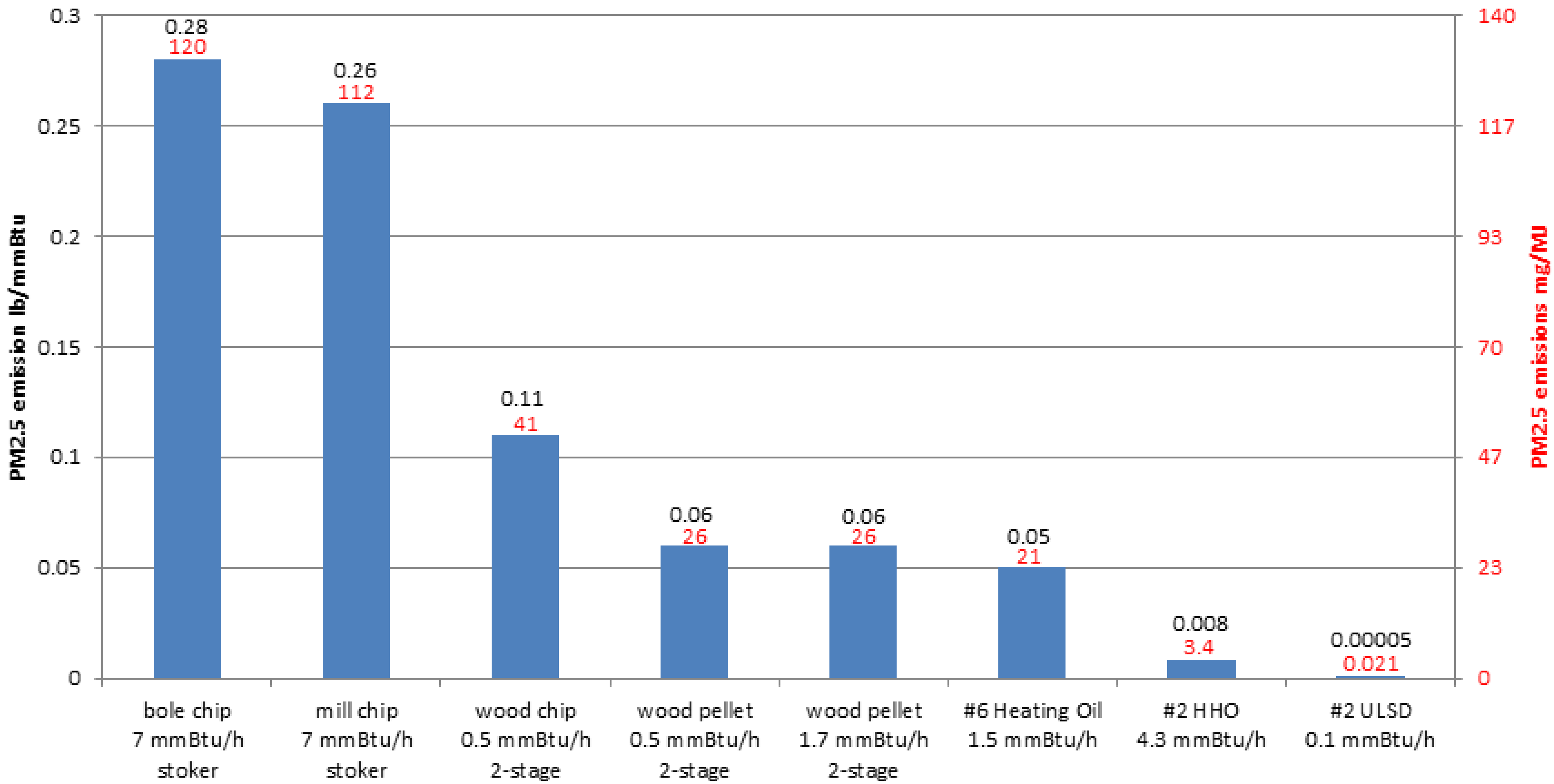
	Spherical organic carbon particles	Soot (elemental carbon aggregates)	Inorganic ash particles
Schematic drawing			
Diameter measured by electron microscopy*	50-600 nm [52, 53]	20-50 nm [52, 73]	50-125 nm [97]
Mobility diameter	100-300 nm [68-70]	50-300 nm [68, 76]	50-125 nm [69, 98, 99]
Internal turbostratic microstructure	No [61]	Yes / No [81-83]	No
Solubility (H_2O)	Depends on ageing [61]	Insoluble	Soluble
Main chemical characteristic	Organic carbon [62, 64, 67] (Most abundant organic compounds: metoxyphenols and monosaccaride anhydrides) [57-60]	Elemental carbon with variable amounts of organics condensed on the surface [12, 62, 81] (Most abundant organic compounds: hydrocarbons and polycyclic aromatic hydrocarbons) [84, 85]	Alkali salts (mainly KCl and K_2SO_4 with small amounts of trace elements (e.g. Zn)) [78, 92]
Combustion conditions	Low-temperature, incomplete combustion [11, 52-56]	High-temperature, incomplete combustion [52]	High-temperature, complete combustion [120]
Possible sources	Air starved combustion or start-up phase of batch wise combustion in conventional stoves, open fireplaces [58,62,64,67]	Combustion in conventional stoves, open fireplaces, boilers for wood, wood chips and pellets [14, 52, 75-79]	Combustion in pellets stoves, boilers for wood, wood chips and pellets [69, 120]

Kocbach Bølling et al. 2009

Combustion source	Emissions (mg/MJ)	Composition
Open fireplace	160 – 910 (0.38-2.2 lb/mmBTU)	
Conventional woodstove	50 – 2100 (0.38-2.2 lb/mmBTU)	
Conventional log boilers	50 – 2000 (50 – 250)	
‘Modern” woodstoves log/chip boilers	34 – 330 5 – 450	
Pellet stoves/boilers	10 – 50	

adapted from: Kocbach Bølling et al. 2009

PM 2.5 emissions input basis



Acknowledgements
Lisa Rector, NESCAUM
Phil Hopke, Clarkson University
Tom Butcher, BNL

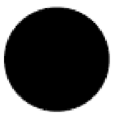
nyserda Energy. Innovation. Solutions.

Source: Ellen Burkhard

Animal/Cellular Toxicology

Inflammation: Medium Temp > High Temp

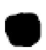
Low oxygen > High oxygen

 > 

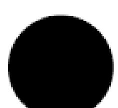
Soluble inorganic ash particles:

– inflammation in cell culture

– no inflammation in animal inhalation studies

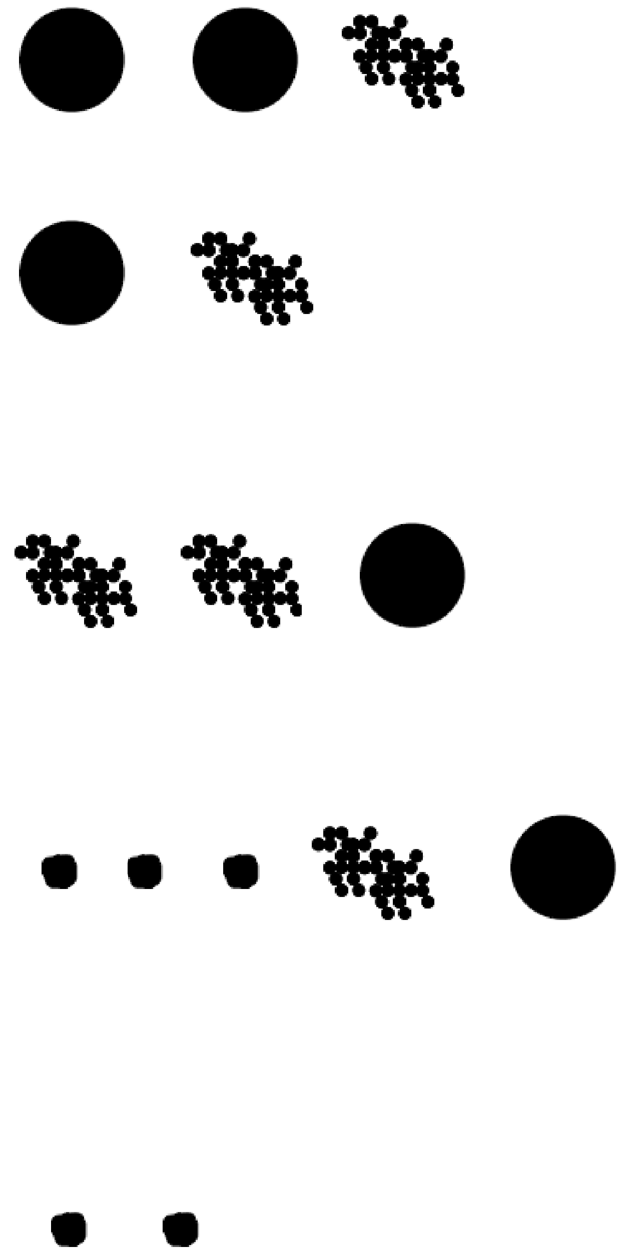
 soluble and cleared from lungs

Cell cytoxicity:

 > Diesel >  > 

adapted from: Kocbach Bølling et al. 2009

Combustion source	Emissions (mg/MJ)	Composition
Open fireplace	MORE TOXIC	
Conventional woodstove		
Conventional log boilers		
'Modern" woodstoves log/chip boilers		
Pellet stoves/boilers	LESS TOXIC	



adapted from: Kocbach Bølling et al. 2009

Experimentally Determined Human Respiratory Tract Deposition of Airborne Particles at a Busy Street

Environ. Sci. Technol. **2009**, *43*, 4659–4664

JAKOB LÖNDAHL,*,†
ANDREAS MASSLING,†
ERIK SWIETLICKI,†
ELVIRA VACLAVIK BRÄUNER,‡
MATTHIAS KETZEL,§ JOAKIM PAGELS,∥
AND STEFFEN LOFT‡

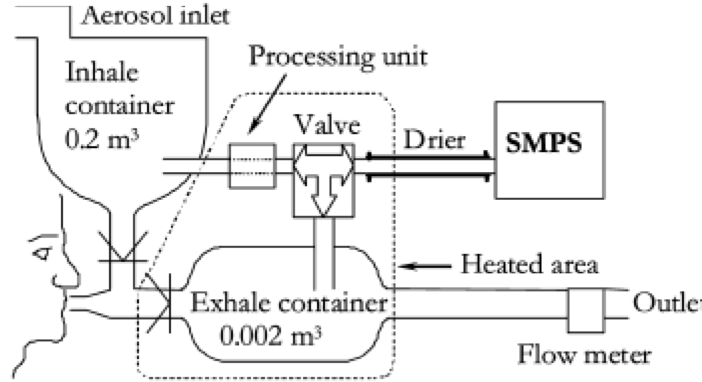


TABLE 2. Total Deposition Fractions ($TDF_{measured}$) and Deposited Dose (In 1-Hour, Inhaled Total Particle Mass Concentration of 100 μg/m³) of 12−580 nm Particles from the Curbside of a Busy Street, from Traffic Exhaust and, for Comparison, from Biomass Combustion (Mean Values for All Subjects)[a]

	total deposition fractions ($TDF_{measured}$)			dose/h (if 100 μg/m3)		
	number	surface area	mass	number ($\times 10^9$)	surface area (mm²)	mass (μg)
curbside	0.60 ± 0.04	0.29 ± 0.04	0.23 ± 0.05	80 ± 15	610 ± 160	10.8 ± 3.4
traffic exhaust (hydrophobic)	0.68 ± 0.08	0.35 ± 0.03	0.28 ± 0.03	103 ± 15	770 ± 100	12.6 ± 1.8
biomass combustion	0.22 ± 0.07	0.23 ± 0.07	0.24 ± 0.07	6.5 ± 4.5	280 ± 91	11.7 ± 3.7

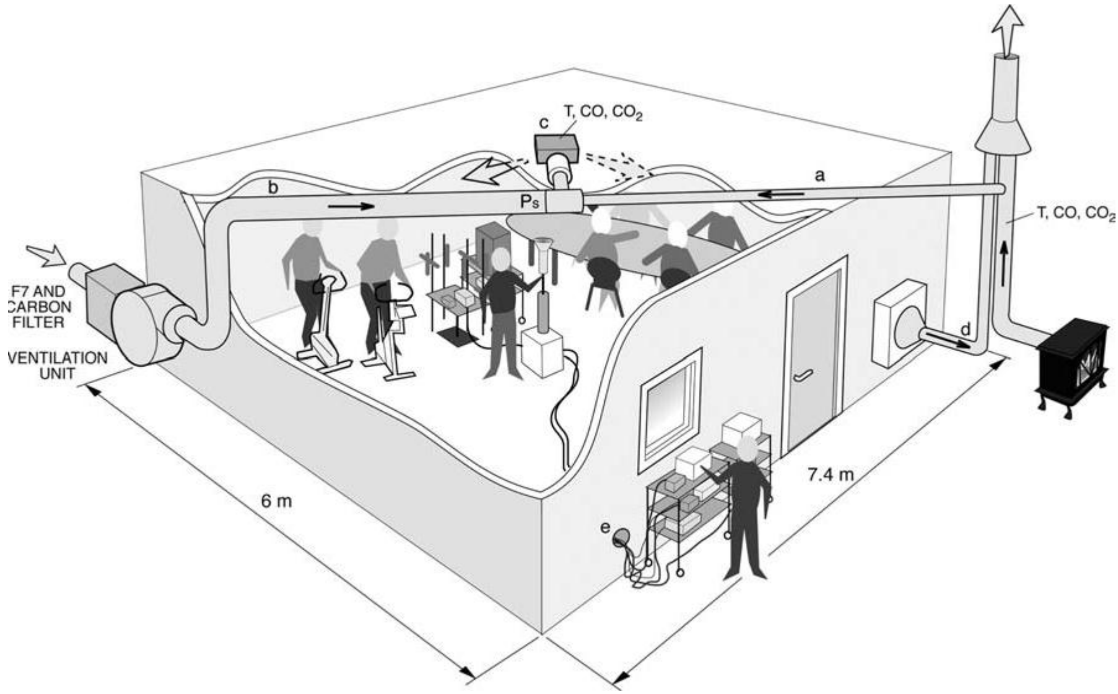
[a] The traffic exhaust particles are assumed to be the "hydrophobic" fraction of the curbside particles as measured with the H-TDMA. As for the curbside and biomass combustion particles the mass concentration of the traffic exhaust particles is normalized to 100 μg/m³. The total deposition fraction and dose for biomass combustion particles was measured in a previous study using the same RESPI setup, but with 10 other subjects (*12*).

- **For equal mass: 16X lower (by number), 3x lower (by surface area) dose/hr, biomass particles relative to traffic exhaust PM**
- (lower deposition probability and lower number/surface area concentration per unit mass)
- **Biomass particles largely water soluble**

…may impact toxicity

Controlled human exposure studies

- **Subjects exposed to realistic (high) concentrations (~250 $\mu g/m^3$) of woodsmoke for 4 hrs**
  - **Increases in measures of inflammation, oxidative stress post-exposure compared to clean air**



- **Pellet stove incomplete combustion**
  - **No inflammation**
  - **Early adaptive protective response**

Sallsten, G et al. Experimental wood smoke exposure in humans. *Inhal. Toxicol*. 18(11):855–864.; Barregard L et al. Experimental exposure to wood-smoke particles in healthy humans: effects on markers of inflammation, coagulation, and lipid peroxidation. Inhal Toxicol. 2006 Oct;18(11):845-53.; Danielsen PH et al. Oxidatively damaged DNA and its repair after experimental exposure to wood smoke in healthy humans.. Mutat Res. 2008 Jul 3;642(1-2):37-42.; Barregard L et al. Experimental exposure to wood smoke: effects on airway inflammation and oxidative stress.. Occup Environ Med. 2008 May;65(5):319-24.

Sehlstedt, M., R. Dove, et al. (2010). "Antioxidant airway responses following experimental exposure to wood smoke in man." Particle and Fibre Toxicology 7(1): 21.

Biomass smoke epidemiology

” …..epidemiologic studies of indoor and community exposure to biomass smoke indicate a generally consistent relationship between exposure and increased **respiratory symptoms, increased risk of respiratory illness, including hospital admissions and emergency room visits, and decreased lung function**. Several studies suggest that **asthmatics** are a particularly susceptible subpopulation with respect to smoke exposure…The effects of community exposure to biomass air pollution (from wildfires) on **mortality** have not been sufficiently studied to support general conclusions.”

Woodsmoke health effects: a review. Naeher LP, Brauer M, Lipsett M, Zelikoff JT, Simpson CD, Koenig JQ, Smith KR. Inhal Toxicol. 2007 Jan;19(1):67-106. Review.

Adapted, from Fay Johnston

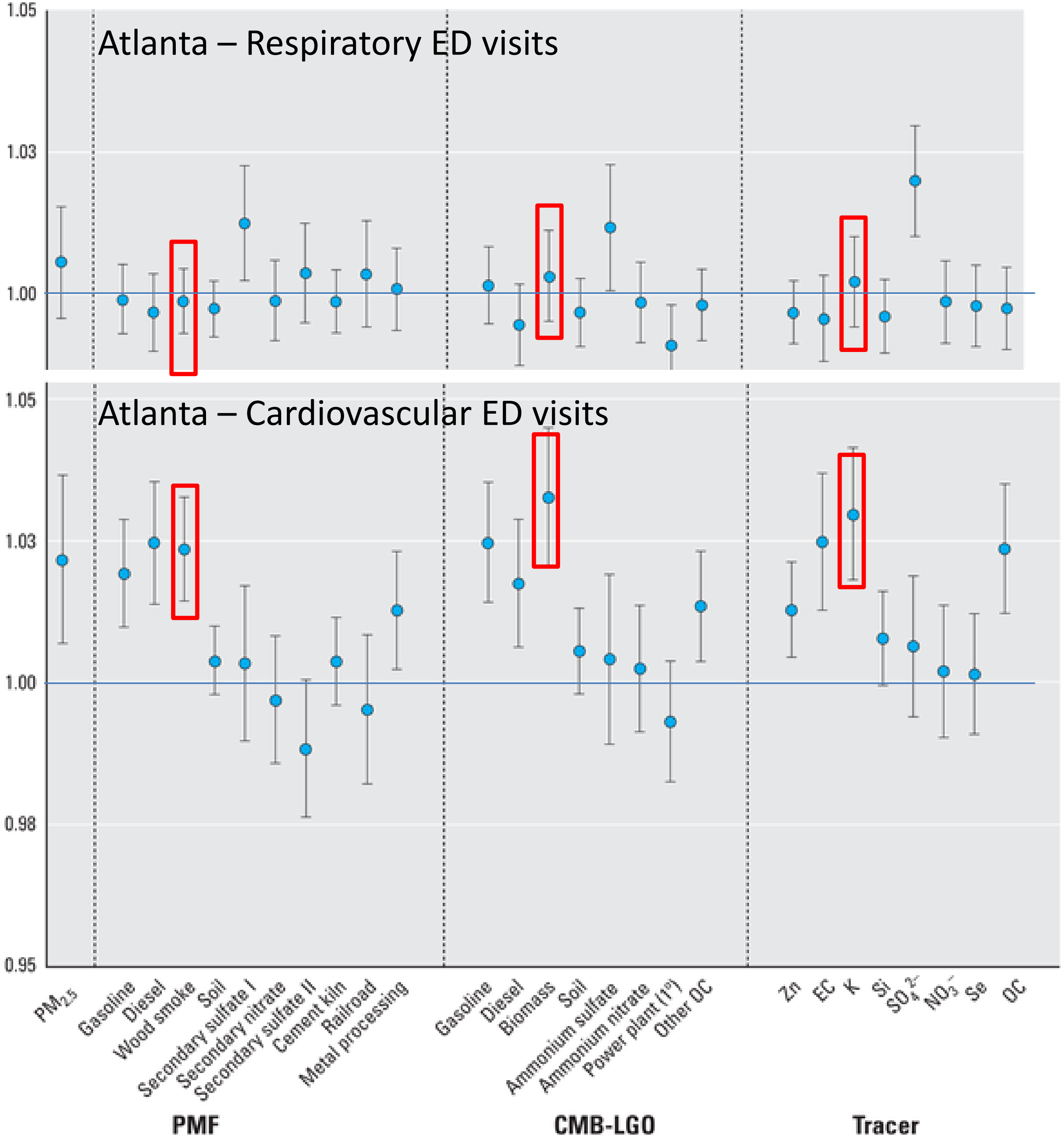
Biomass combustion and CVD

Country	Study	Exposure	Outcome	Result
New Zealand	McGowan (2002)	Outdoor PM_{10} (90% from biomass in winter)	CVD admissions	+
New Zealand	Barnett (2006)	Outdoor PM_{10}	CVD admissions	-
Chile	Sanhueza (2009)	Outdoor PM_{10} (90% from biomass in winter)	CVD admissions CVD mortality	+ +
Canada	Allen (2011)	Indoor $PM_{2.5}$ intervention study	Markers of inflam & endothelial function	+
India	Ray (2006)	Biomass vs non biomass fuel use	Markers of thrombosis risk	+
Turkey	Emiroglu (2010)	Biomass vs non biomass fuel users	Ventricular dysfunction	+
Guatemala	McCracken (2007, 2011)	Biomass smoke chimney intervention	Blood pressure, ST-segment depression	+

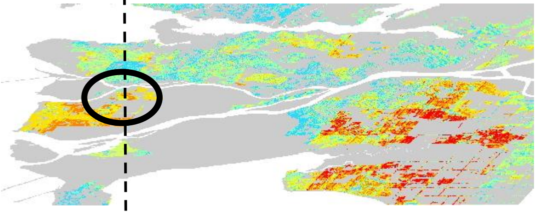
Adapted, from Fay Johnston

Firesmoke and CVD?

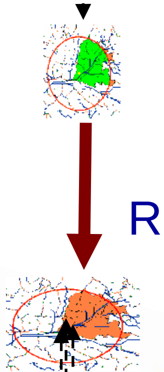
Country	Study	Exposure	Outcome	Result
Australia	LFS project	Bushfire smoke (PM_{10} $PM_{2.5}$, event)	CVD admissions CVD mortality	- inconclusive
Australia	Morgan 2010	Bushfire smoke (PM_{10})	CVD admissions IHD admissions	- inconclusive
Australia	Dennekamp 2010	Bushfire smoke (PM_{10} $PM_{2.5}$, event)	Out of hospital cardiac arrest	+
Brazil	Arbex 2010	Sugar cane burning (TSP harvest vs non-harvest periods)	Admissions for hypertension	+
Canada	Henderson 2011	Forest fire smoke	CVD physician and hospital visits	-
Canada	Moore 2006	Forest fire smoke episode	CVD physician billing	-
Malaysia	Mott 2005	Forest fire smoke episode	CVD admissions	-
Malaysia	Sastry 2002	PM_{10},/visibility	Daily (all-cause/CVD) mortality	+
USA	Delfino 2009	Forest fire smoke ($PM_{2.5}$)	CVD admissions	inconclusive
Canada	Swiston (2007)	Fire-fighters: smoke exposure during a shift	Markers of systemic inflammation	+



Sarnat JA, Marmur A, Klein M, Kim E, Russell AG, et al. 2008 Fine Particle Sources and Cardiorespiratory Morbidity: An Application of Chemical Mass Balance and Factor Analytical Source-Apportionment Methods. Environ Health Perspect 116(4): doi:10.1289/ehp.10873

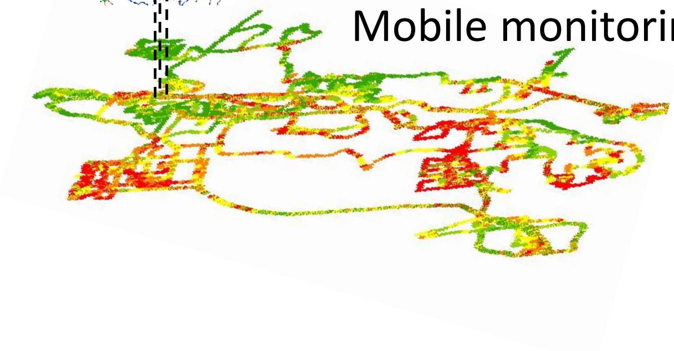


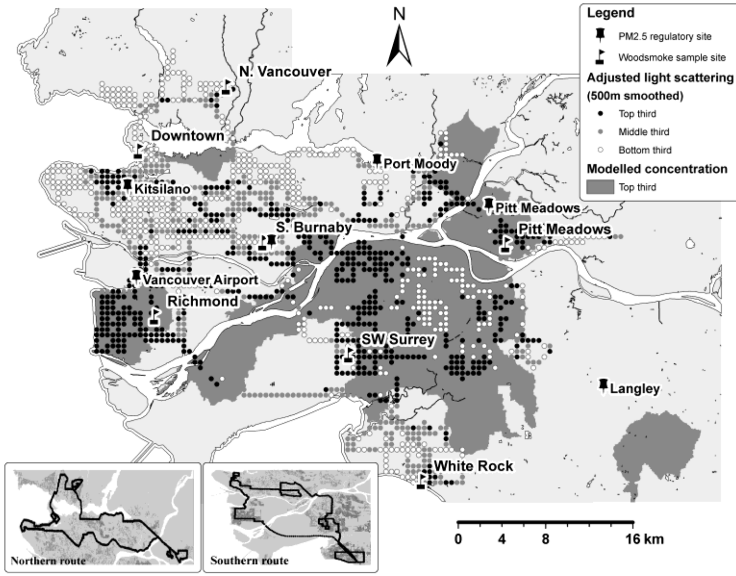
Border Air Quality Study



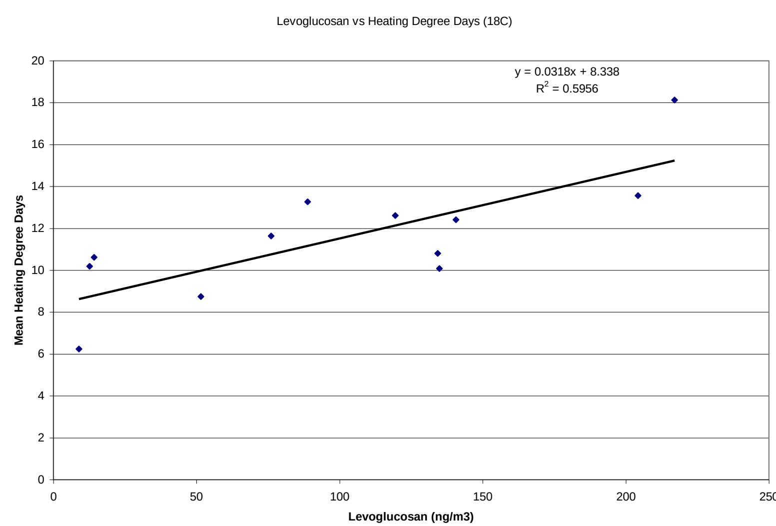
Regression Model

Mobile monitoring ~12,000 points





Woodsmoke nights



HDD > 12.0 ~ Levoglucosan > 115 ng/m^3

~72 nights/year, ~5x increase in PM

Larson T, Su J, Baribeau A-M, Buzzelli M, Setton E, Brauer M. A Spatial Model of Urban Winter Woodsmoke Concentrations. Environmental Science and Technology. 2007; 41 (7):2429 -2436

Woodsmoke & multiple health measures

- 32% increase in middle ear infections[**]
  - Top reason for children < 2 yrs to see physician, be prescribed antibiotics
- 8% increase in bronchiolitis[*]
  - Top reason for children < 1 yr to be hospitalized
- No associations with:
  - low birthweight[#]
  - asthma *incidence*[#]
  - cardiovascular mortality[#]

[**] > traffic pollution, [*]~traffic, [#]<traffic

MacIntyre EA, Karr CJ, Demers P, Koehoorn M, Lencer C, Tamburic L, Brauer M. Exposure to residential air pollution and otitis media during the first two years of life. Epidemiology. 2011 Jan;22(1):81-9.; Karr CJ, Demer PA, Koehoorn MW, Lencar CC, Tamburic L, Brauer M. Influence of ambient air pollutant sources on clinical encounters for infant bronchiolitis. American Journal of Respiratory and Critical Care Medicine, 2009, 180(10):995-1001.; Clark NA, Demers P, Karr C, Koehoorn M, Lencar C, Tamburic L. Brauer M. Effect of early life exposure to air pollution on development of childhood asthma. Environmental Health Perspectives 2010, 188(2): 118:284-290.

Otitis media impact

- Woodsmoke estimated to account for 10% of incidence (~$250,000/yr in Metro Vancouver)
- Eliminating woodsmoke exposure has larger benefits than:
  - Pneumococcal conjucate vaccine (~ 6-7% reduction)
  - Eliminating maternal smoking during pregnancy or ETS exposure (~ 2% reduction)

E. MacIntyre, PhD Thesis, UBC, 2010

Mitigation

- Appliance Regulations
  - Wood stove/fireplace bans (existing/resale/new appliances and homes)
  - EPA/CSA certified stove sales (BC since 1994)
- Model municipal bylaw
- Fuel switching
- Burn bans (Seattle, N. California)
- Stove exchange programs
- Burning practices (eg. Burn It Smart)
- Air cleaners

Strategy[A]	Degree of Effectiveness	Rationale	Potential Barriers
Awareness, Education, and Communication	Low	May not result in any change in behavior	Requires commitment of public to participate in education efforts
Restrictions on Some Fuels	Low	Only acheives a small reduction in emissions and does not address older wood-burning appliances	Difficult to enforce and potential lack of availability of acceptable fuels
No-Burn Days Option A) Voluntary Curtailment Option B) Mandatory Curtailment	Low to Moderate	Will reduce emissions at critical times (especially if mandatory), but does not address older wood-burning appliances	Difficult to enforce and potential lack of other available heating source
Installation of Wood-Burning Appliances Option A) All Appliances Option B) New Construction Option C) Total Ban	Moderate	Will result in some guaranteed emission reductions, but does not address older wood-burning appliances (which contribute the most to total emissions)	No incentive to replace older appliances, which have slow turnover
Outdoor Solid-Fuel Combustion Appliances	Moderate	Will result in some guaranteed emission reductions, but does not address older wood-burning appliances (which contribute the most to total emissions)	No incentive to replace older appliances, which have slow turnover
Non-Certified Appliance Removal Option A) Removal Program (Change-Out) Option B) Time Limit Option C) Prior Sale or Transfer of Real Property	High	Relatively easy to implement and removes the older, highest emitting wood-burning appliances	May face public resistance and puts financial burden on public

[A]Based on strategies identified in *Model Municipal Bylaws* document (EC 2006)

Residential Use of Wood-Burning Appliances in Canada: Emissions, Health Effects, and Intervention Strategies, E Risk Sciences, LLP 2009. http://www.ncceh.ca/en/practice_policy/ncceh_reviews/wood-burning_appliances

Table 6. Summary of Wood-Burning Appliance and Building Code By-Laws in British Columbia (*source: Alderson 2007*)

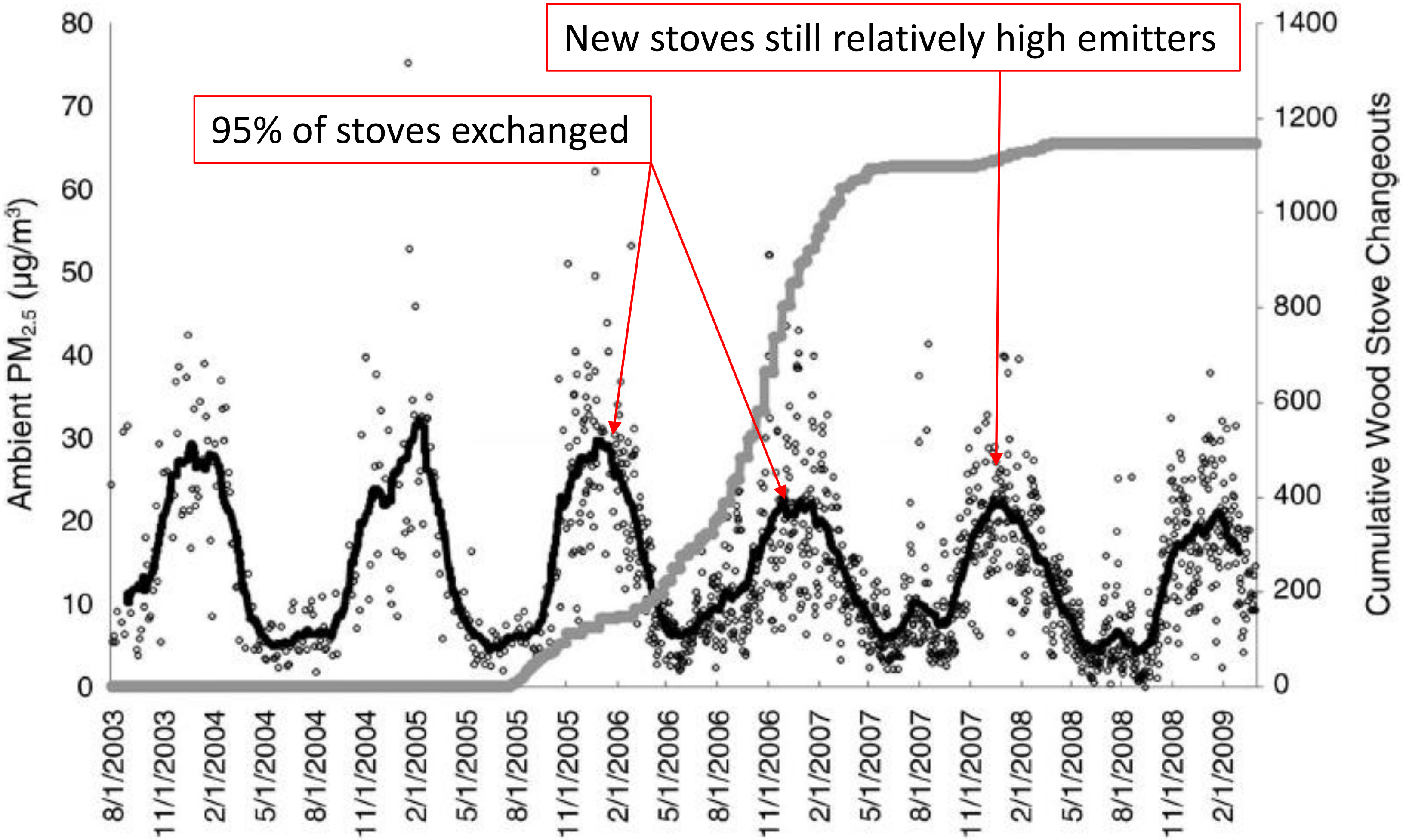
Community	Total # of Communities	# Wood-Burning Appliance By-laws	# Building Code By-laws	Percent with By-laws
Cities	48	16	2	38%
Districts	52	3	2	10%
Towns	15	5	5	67%
Villages	42	3	1	10%
Regional districts	28	3	2	18%
Total	185	30	12	23%

Some mandated removal dates for non-certified stoves

Very little / no focus on fireplaces

From: Systematic Review of Education Programs and Intervention Strategies in Canada Related to Residential Use of Wood-Burning Appliances, E Risk Sciences, LLP 2009 – NCCEH

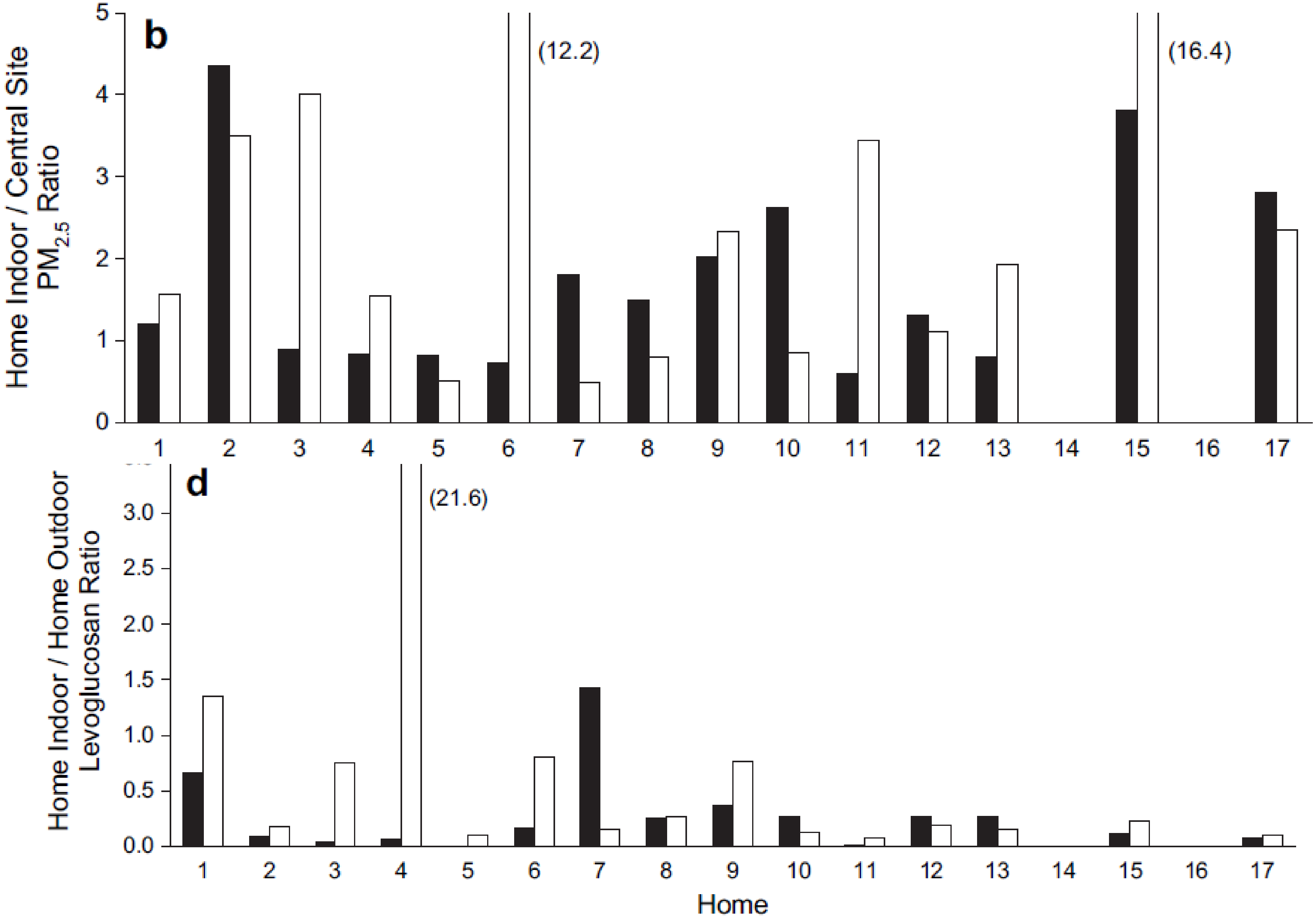
Libby, Montana stove exchange



- ~30% reduction in winter $PM_{2.5}$
- ↓ in childhood wheeze, itchy eyes, sore throat, cold, bronchitis, influenza, throat infections
- School absence associations inconsistent

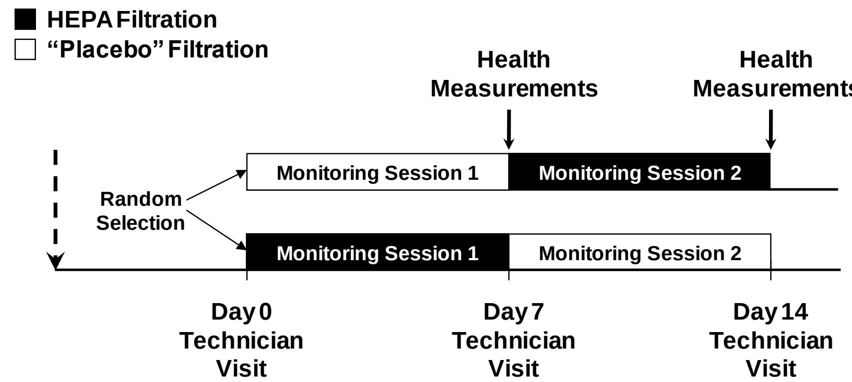
A rural community intervention targeting biomass combustion sources: effects on air quality and reporting of children's respiratory outcomes. **Noonan CW**, Ward TJ, Navidi W, Sheppard L. Occup Environ Med. 2012

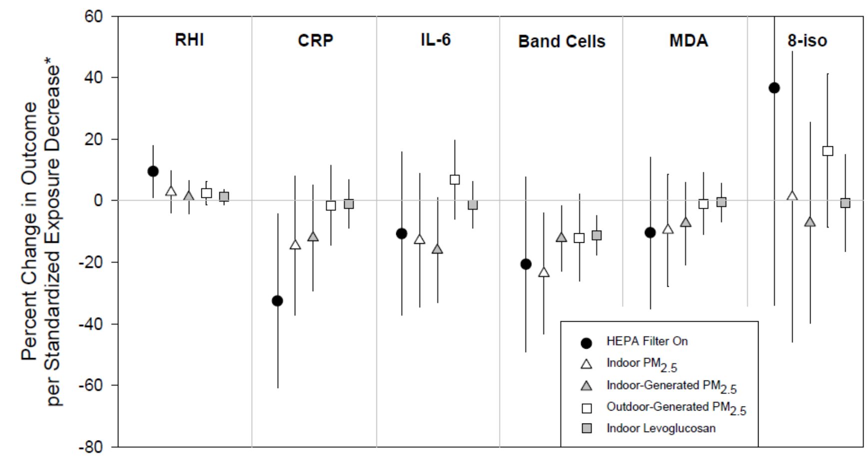
Stove exchange and indoor levels

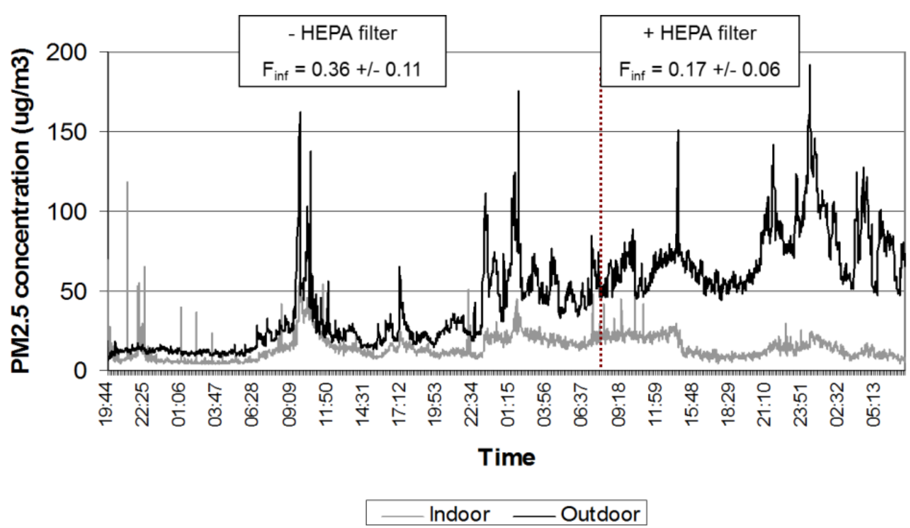


Air filtration

- Portable HEPA filters 60% ↓ in indoor $PM_{2.5}$
- Increases in endothelial function and decreases in systemic inflammatory markers







11.2 → 4.6 ug/m³ $PM_{2.5}$
127 → 33 ng/m³ levoglucosan

Allen et al., AJRCCM 2011

Towards healthier wood heat & energy

- Location matters!!
  - Distributed sources – high intake fraction
  - Benchmark against natural gas to assess ($PM_{2.5}$) emissions and impacts
- Health impacts
  - Respiratory disease (+++)
  - Systemic inflammation (+)
  - Cardiovascular disease (+/-)
- Advanced technology
  - Lower mass emissions
  - Different composition → suggestions of lower toxicity

(Some) Key Knowledge Gaps

- Cardiovascular impacts?
- Health impacts of short-term peak exposures
- Magnitude of population exposure
- Epidemiological and exposure studies of "advanced" combustion technologies

Thank you!

More questions?

michael.brauer@ubc.ca

EXTRA SLIDES

IARC Monographs on the Evaluation of Carcinogenic Risks to Humans **VOLUME 95: INDOOR AIR POLLUTION FROM HOUSEHOLD COOKING AND HEATING: SOLID-FUEL USE AND HIGH-TEMPERATURE FRYING Lyon, France: 10-17 October 2006**

Combustion of biomass

- There is *limited evidence* in humans for the carcinogenicity of household combustion of biomass fuel (primarily wood). Household combustion of biomass fuel (primarily wood) is associated with cancer of the lung.
- There is *limited evidence* in experimental animals for the carcinogenicity of emissions from combustion of wood.
- There is *sufficient evidence* in experimental animals for the carcinogenicity of wood smoke extracts.

- **Overall evaluation:** Indoor emissions from household combustion of biomass fuel (primarily wood) are *probably carcinogenic to humans (Group 2A*).

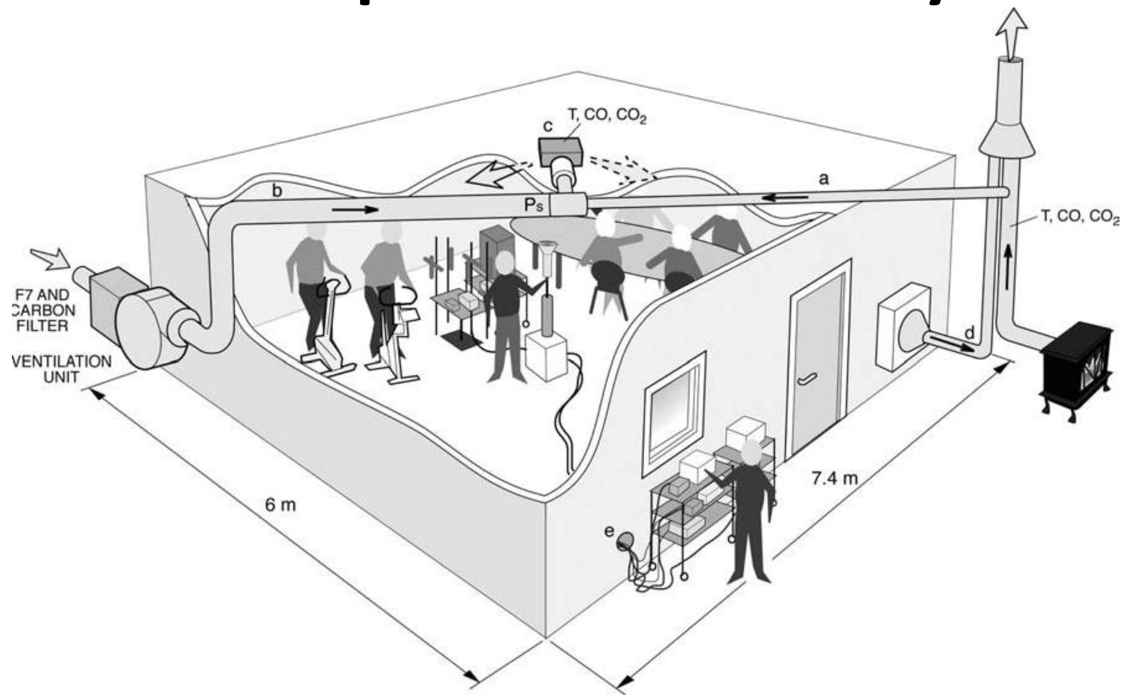
Outcome	Exposure window	N (n cases)	Design	Mean Days exposed [IQR]	Adjusted# OR (95% CI)
SGA birth	Pregnancy	70,249 (6,939)	Cohort	65 [43]	1.00 (0.91 - 1.09)
				Exposed 30% of pregnancy	1.05 (0.98 - 1.12)
Bronchiolitis[1]	2 – 12 months	86,337 (10,485)	Nested C-C*	54 [45]	**1.08 (1.04 - 1.11)**
Otitis Media[2] (1 – 24 mos.)	1 month pre-diagnosis	45,513 (19,115)	Cohort	15 [16]	**1.32 (1.27 - 1.36)**
Asthma[3] (0 – 48 mos.)	All pregnancy 0 -12 months	37,401 (3,482)	Nested C-C**	60 [33] 89 [17]	1.00 (0.94 - 1.07) 1.00 (0.98 - 1.02)
CHD Mortiality					

per IQR increase, adjusted for covariates: Infant sex (SGA, B, OM) First Nations Status (SGA, B, OM), Parity (SGA, B, A), Maternal age (SGA, B, OM), Maternal smoking during pregnancy (SGA, B, OM), Month-year of birth (SGA), maternal initiation of breastfeeding at birth (B, OM, A), Income (SGA, B, OM, A), Maternal education (SGA, B, OM, A), older siblings (OM), birth season (OM), birthweight (OM, A), gestational duration (OM, A). *incidence-density matching (up to 1:10) on date of birth **matched 1:5 by sex, month-yr of birth

[1]Karr et al., AJRCCM 2009; [2] MacIntyre et al., Epidemiology 2011; [3]Clark et al., EHP 2010

Controlled human exposure study

- **13 subjects exposed to realistic (high) concentrations (250 $\mu g/m^3$) of woodsmoke for 4 hrs**
- **Increases in measures of inflammation, oxidative stress post-exposure compared to clean air**



Sallsten, G et al. Experimental wood smoke exposure in humans. *Inhal. Toxicol*. 18(11):855–864.; Barregard L et al. Experimental exposure to wood-smoke particles in healthy humans: effects on markers of inflammation, coagulation, and lipid peroxidation. Inhal Toxicol. 2006 Oct;18(11):845-53.; Danielsen PH et al. Oxidatively damaged DNA and its repair after experimental exposure to wood smoke in healthy humans.. Mutat Res. 2008 Jul 3;642(1-2):37-42.; Barregard L et al. Experimental exposure to wood smoke: effects on airway inflammation and oxidative stress.. Occup Environ Med. 2008 May;65(5):319-24.

Health Effects of Woodsmoke

Experimental Exposure to Wood-Smoke Particles in Healthy Humans: Effects on Markers of Inflammation, Coagulation, and Lipid Peroxidation

- 13 subjects exposed to wood smoke and clean air
  - 240–280 μg/m^3
  - 4-hour sessions, 1 week apart

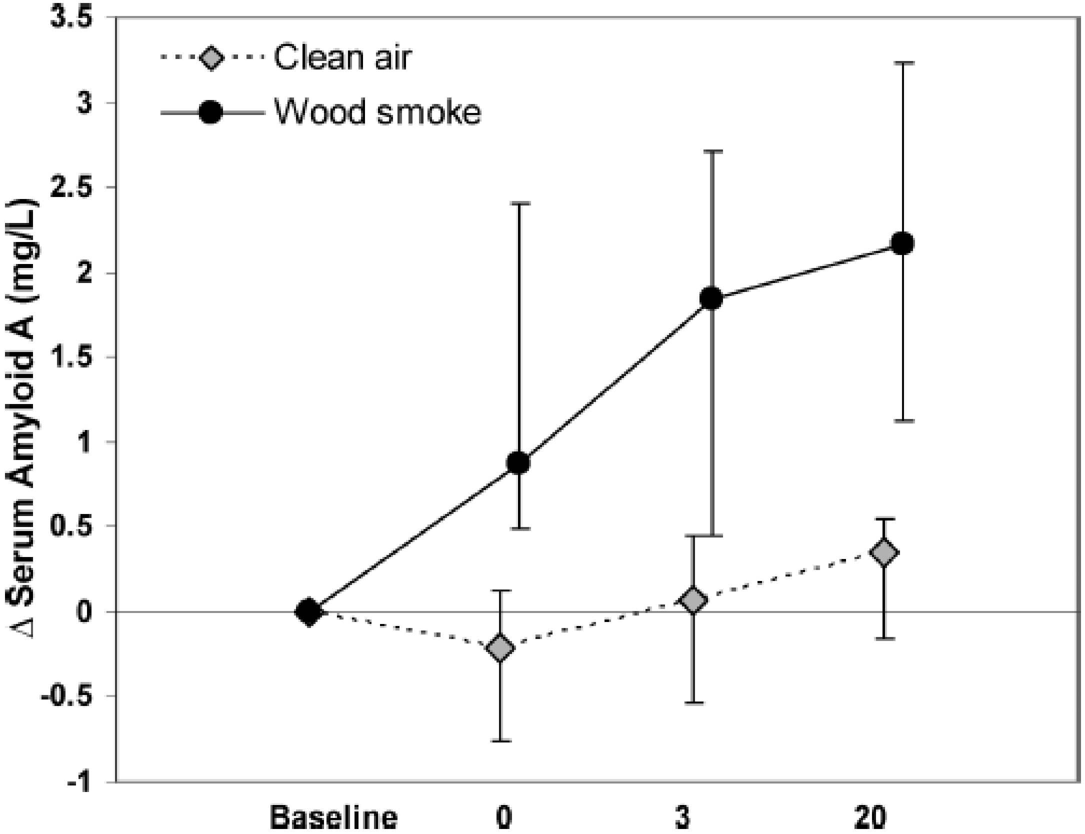
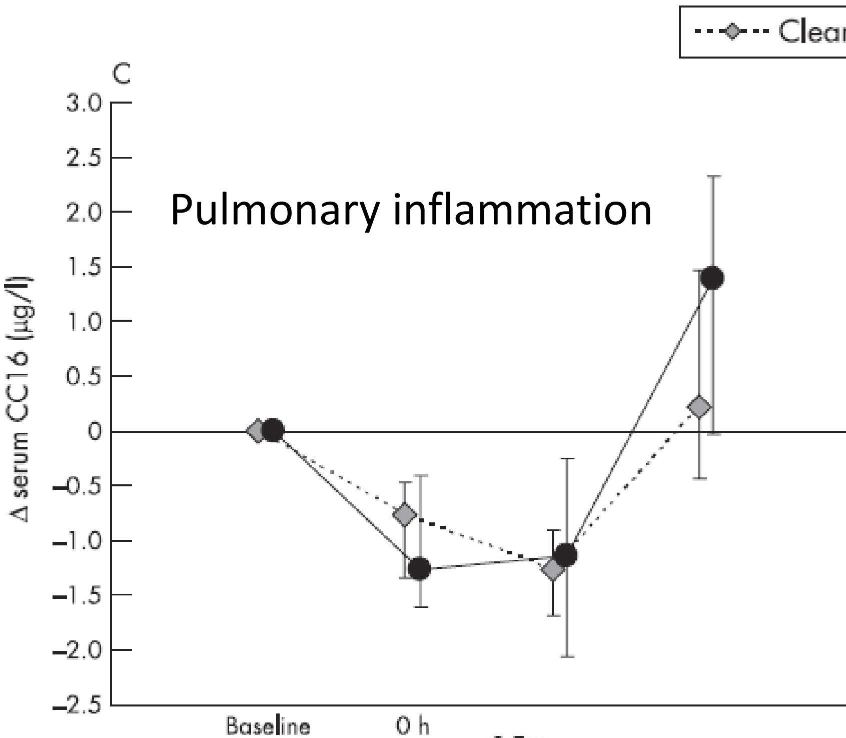
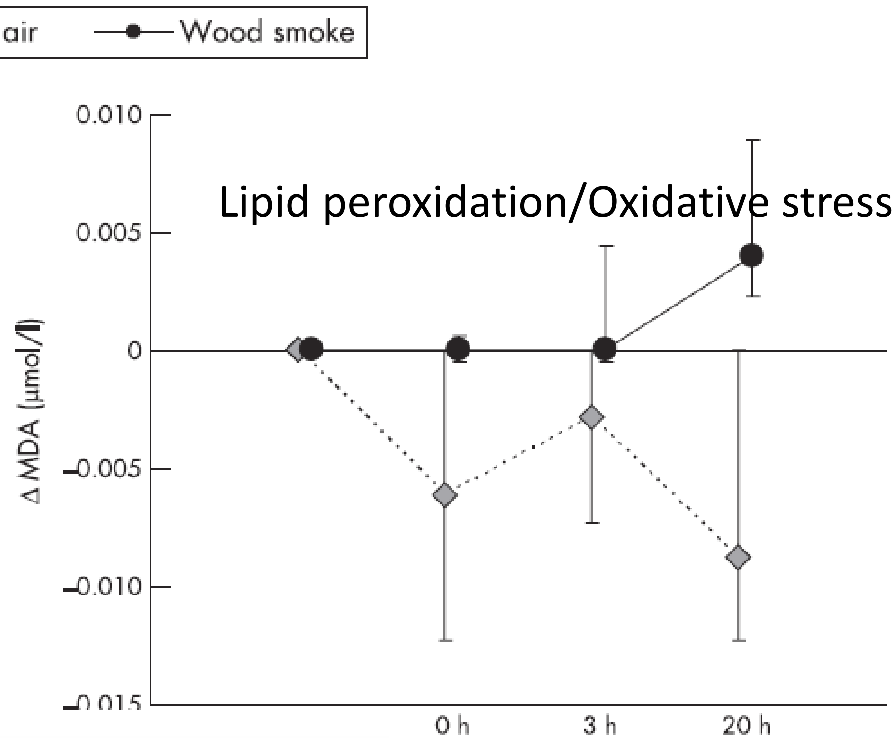
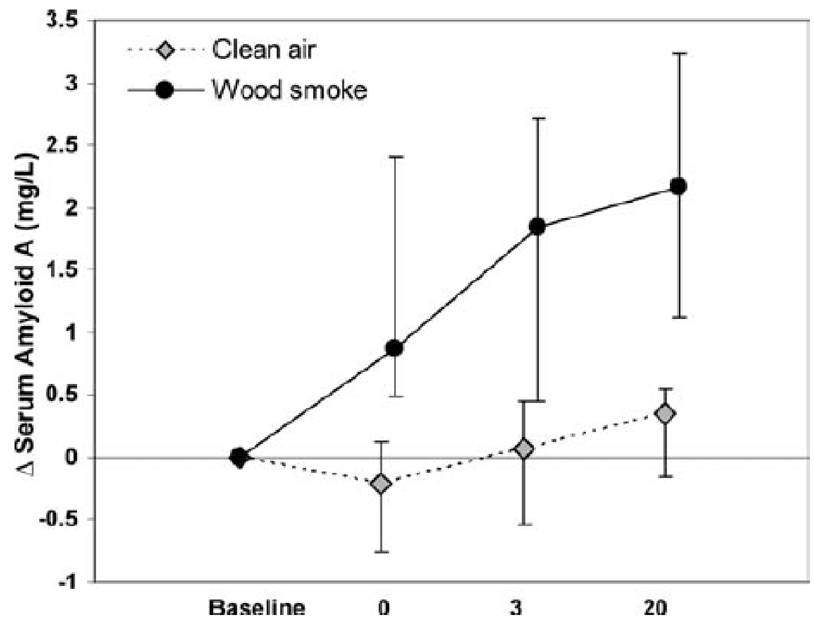


FIG. 1. Differences (Δ) in serum amyloid A immediately (0) and 3 and 20 h after exposure to clean air and wood smoke, and the respective baseline concentrations. The graphs represent medians with 90% confidence intervals in 13 healthy subjects.

Barregard et al., 2006





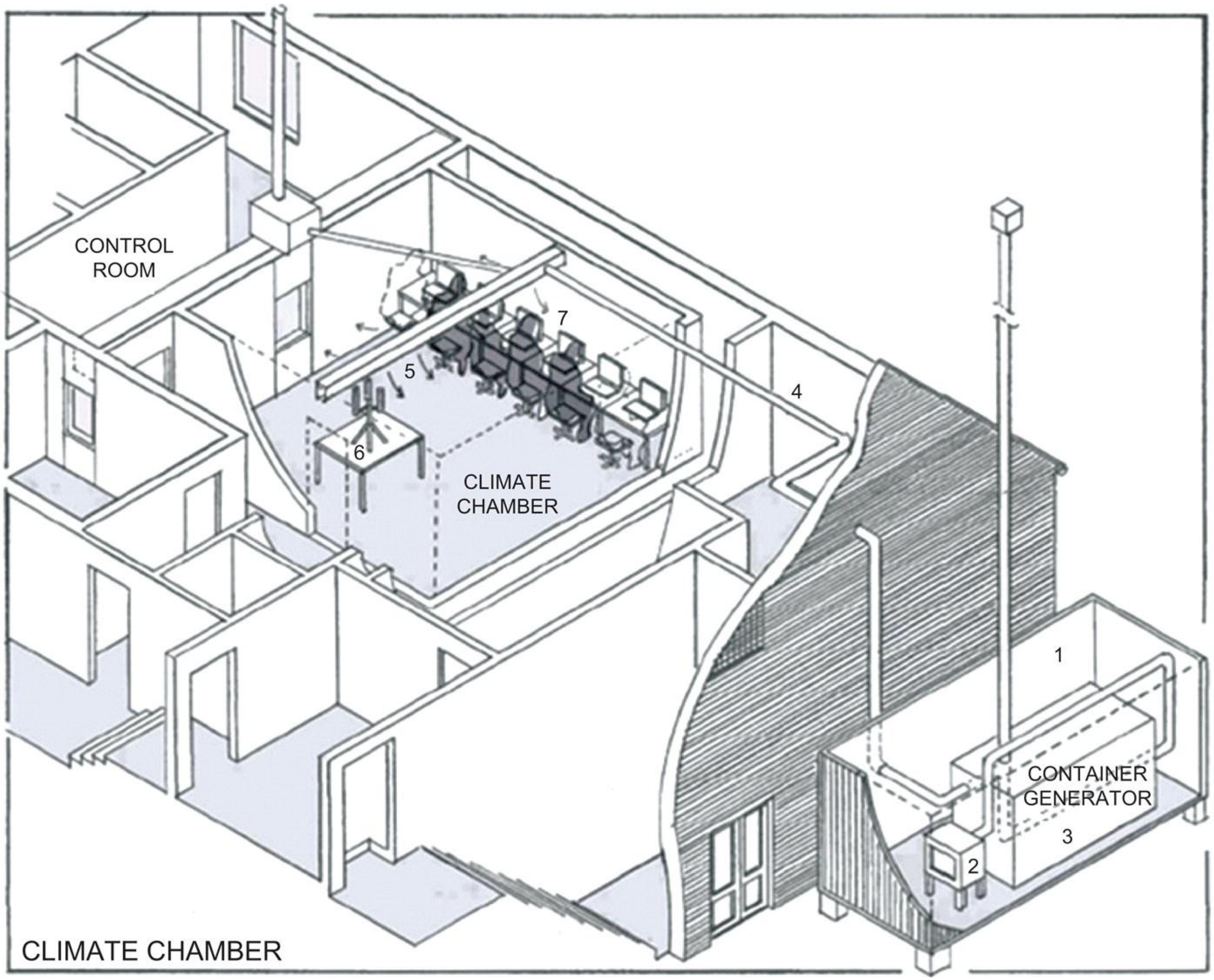


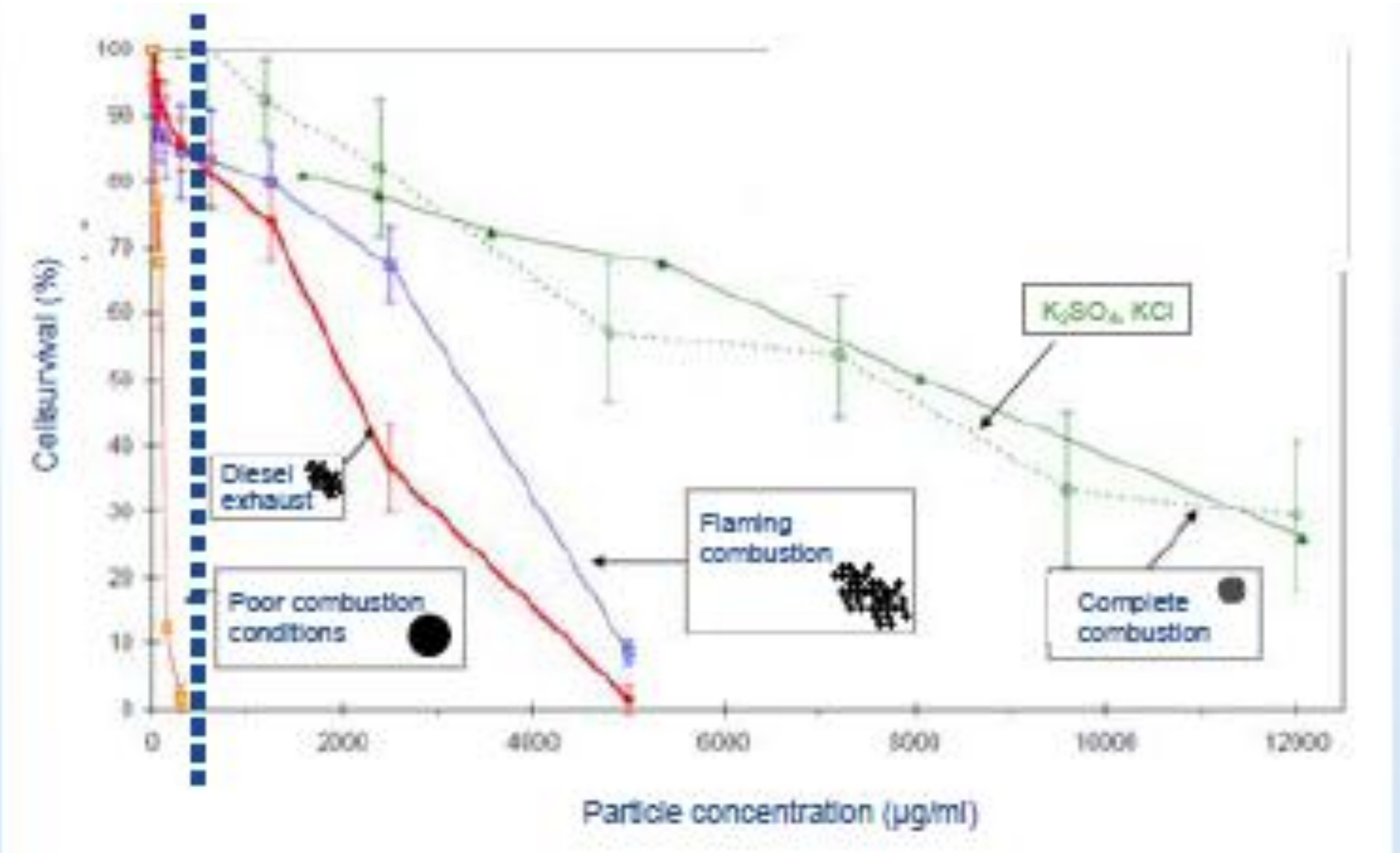
CVD risk factor

Pellet stove exposure

- N=19 healthy adults
- 3 hrs (w/exercise) $PM_{2.5}$ = 224 µg/m^3
- ”Incomplete” combustion: emissions dominated by organic carbon
- Mild symptoms. No impact on lung function, FENO
- •Bronchoscopy 24 hrs post-exposure
  - GSH ↑ in BAL
  - No impact on cell counts, airway inflammatory markers
- No inflammation/cardiovascular effects
- Early adaptive protective response.

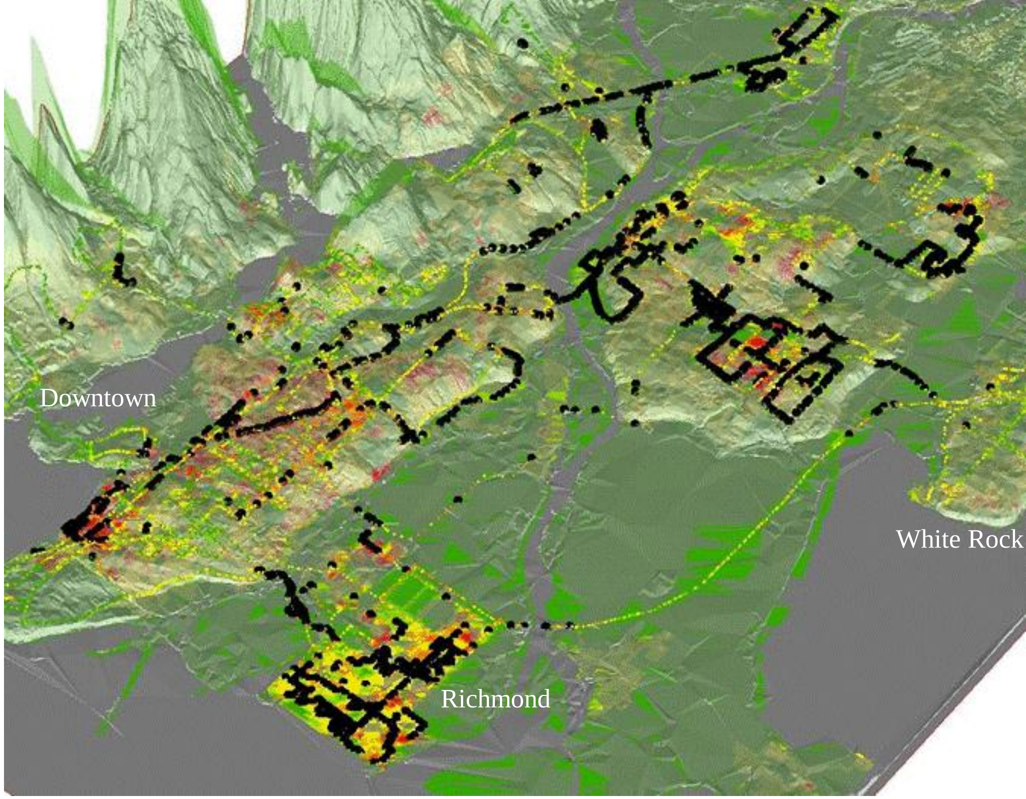
Sehlstedt, M., R. Dove, et al. (2010). "Antioxidant airway responses following experimental exposure to wood smoke in man." Particle and Fibre Toxicology 7(1): 21.


CONTROL ROOM
7
5
4
6
CLIMATE CHAMBER
1
CONTAINER GENERATOR
3
2
CLIMATE CHAMBER

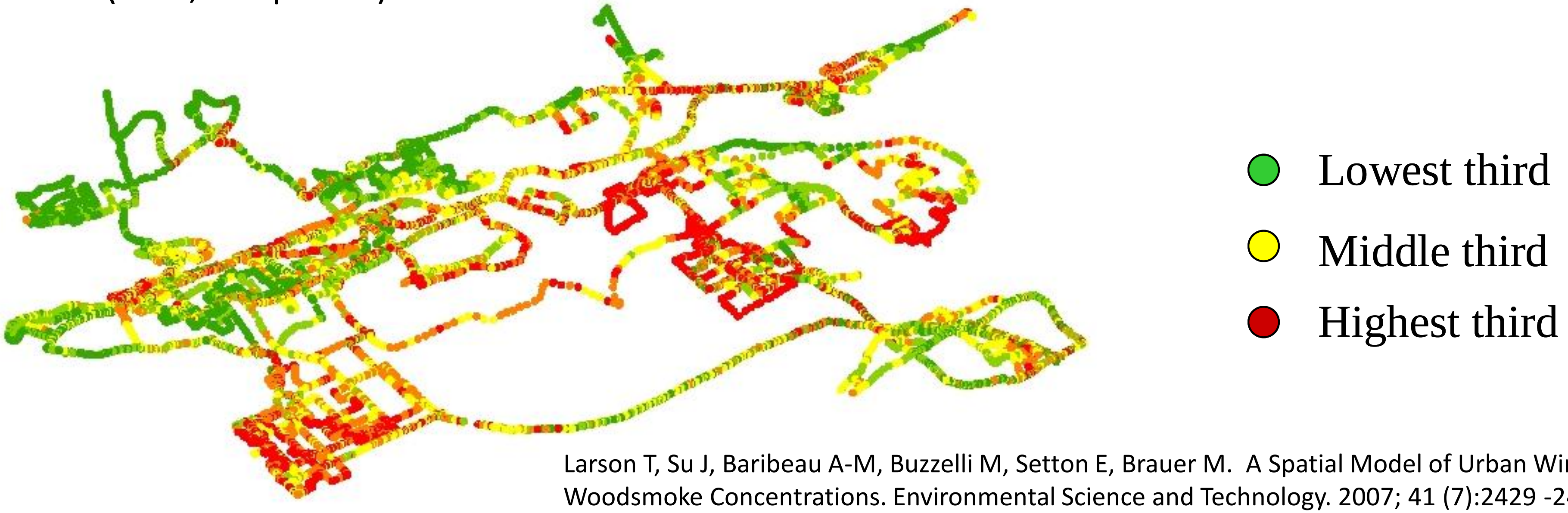


Cellsurvival (%)
Particle concentration (µg/ml)
Diesel exhaust
Flaming combustion
Poor combustion conditions
Complete combustion
K2SO4, KCl

Mobile Monitoring on Cold, Clear Winter Evenings

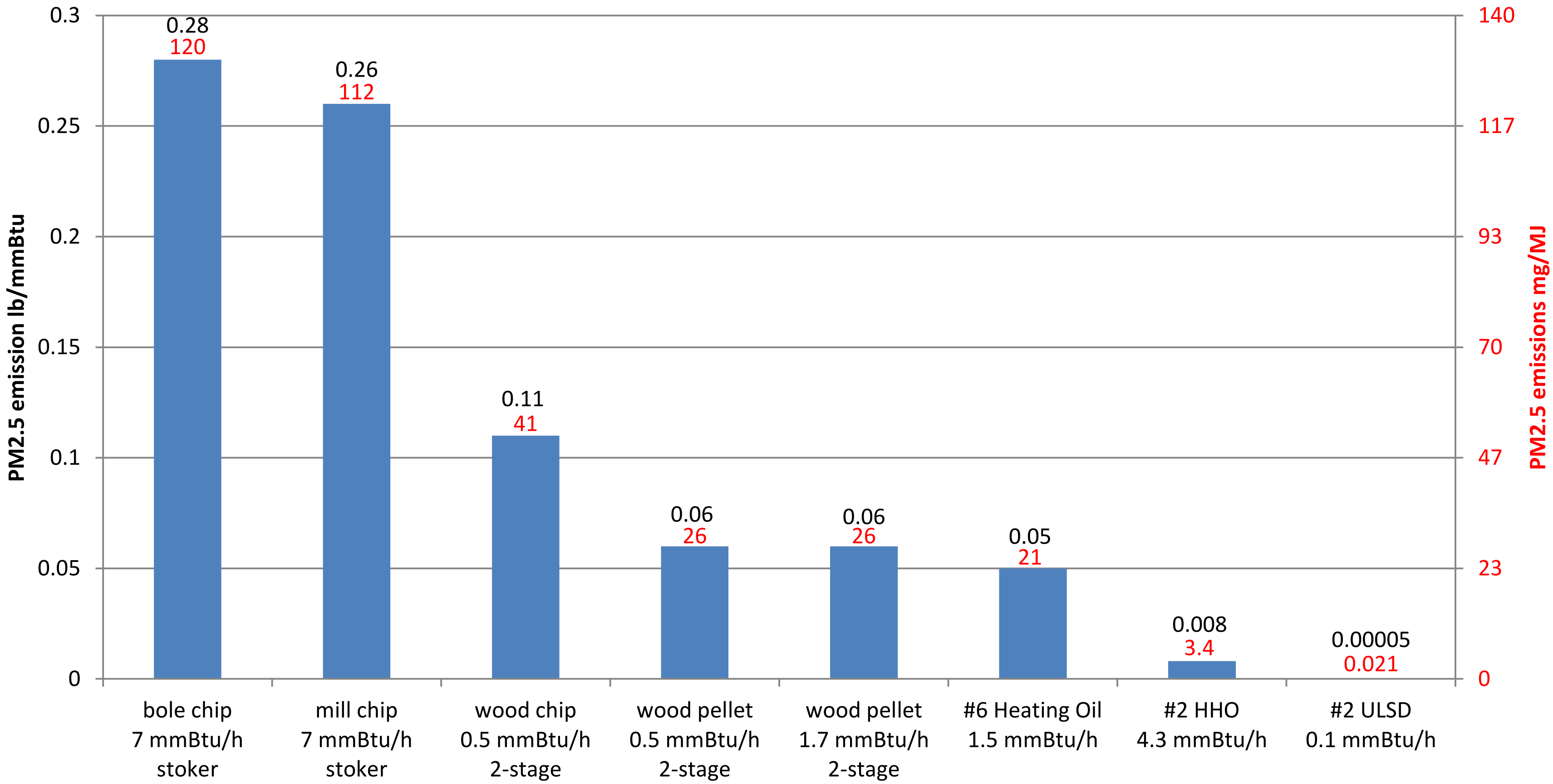


(~ 12,000 points)



Larson T, Su J, Baribeau A-M, Buzzelli M, Setton E, Brauer M. A Spatial Model of Urban Winter Woodsmoke Concentrations. Environmental Science and Technology. 2007; 41 (7):2429 -2436

PM 2.5 emissions input basis



Acknowledgements
Lisa Rector, NESCAUM
Phil Hopke, Clarkson University
Tom Butcher, BNL

nyserda
Energy. Innovation. Solutions.

Cardiovascular effects

- Community wildfire exposure (+/-):
  - mixed results for CVD association (mortality, cardiac arrest)
  - high bushfire exposures in Australia: (+)
- Wildland firefighters (+):
  - systemic inflammation
- Controlled exposures: (+/-):systemic inflammation

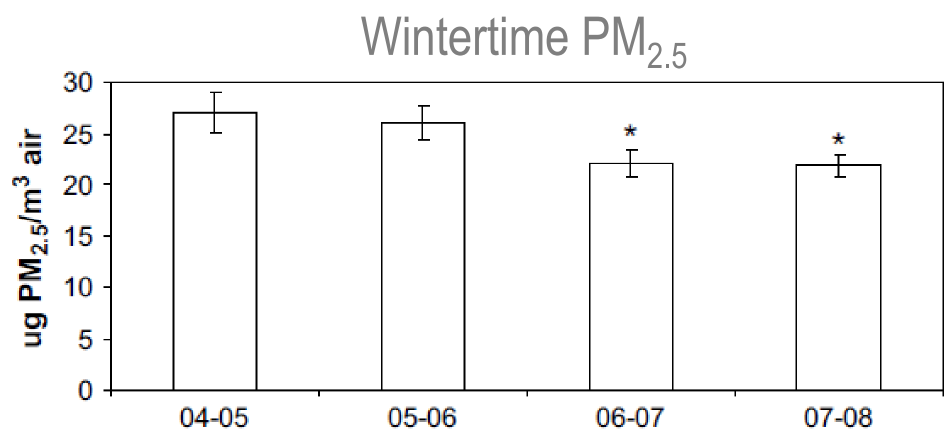
Swiston JR et al. Acute Pulmonary and Systemic Inflammatory Response Induced by Exposure to wood smoke. European Respiratory Journal, 2008; 32: 129-
Sallsten, G et al. Experimental wood smoke exposure in humans. *Inhal. Toxicol*. 18(11):855–864.; Barregard L et al. Experimental exposure to wood-smoke particles in healthy humans: effects on markers of inflammation, coagulation, and lipid peroxidation. Inhal Toxicol. 2006 Oct;18(11):845-53.; Barregard L et al. Experimental exposure to wood smoke: effects on airway inflammation and oxidative stress.. Occup Environ Med. 2008 May;65(5):319-24;
Allen RW, Carlsten C, Karlen B, Leckie S, van Eeden S, Vedal S, Wong I, Brauer M. An Air Filter Intervention Study of Oxidative Stress, Endothelial Dysfunction, and Inflammation Among Healthy Adults in a Woodsmoke-Impacted Community. American Journal of Respiratory and Critical Care Medicine, 2011. 183, 1222-1230.

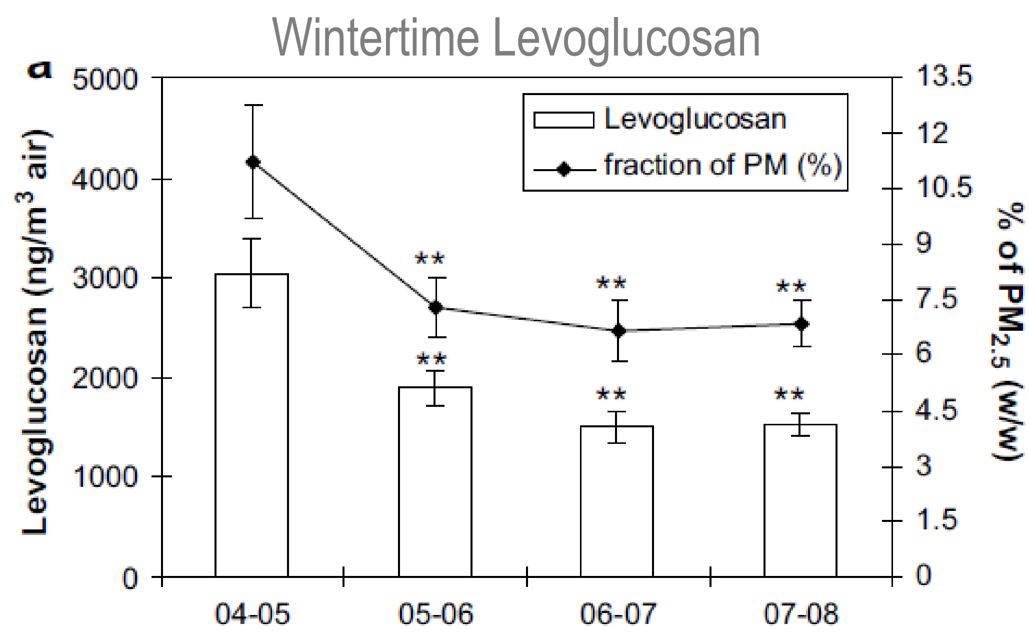
Stove Exchange Programs

Libby, Montana

- Woodstoves are the biggest $PM_{2.5}$ source in Libby, MT
- Exchanged 1,200 out of 1,300 non-certified wood stoves
- Winter $PM_{2.5}$ decreased by 20% (27 → 22 ug/m³)
- Winter levoglucosan decreased by 50%

Community-level Impacts





Bergauff et al., 2009

Stove Exchange Programs

Libby, Montana

Household-level Impacts

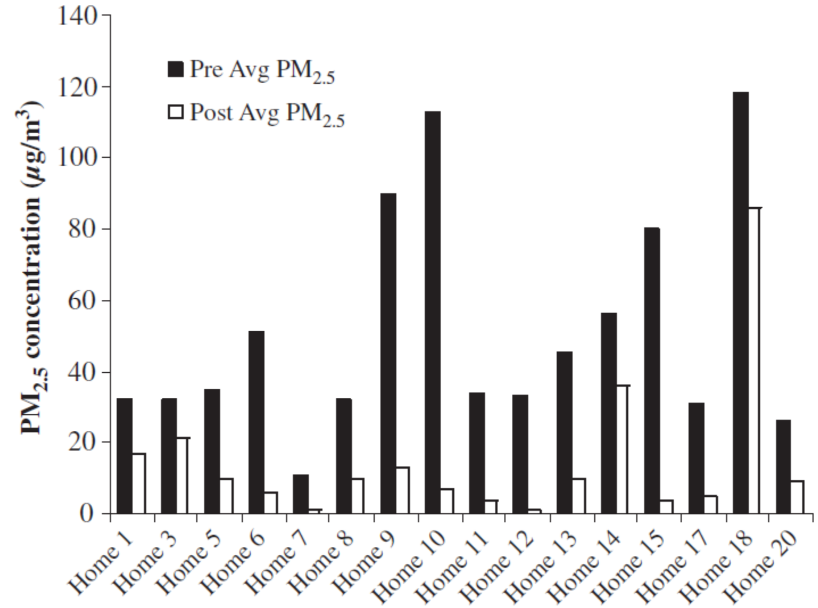


Fig. 1 $PM_{2.5}$ – mass results, pre- and post-woodstove changeout

Table 3 Concentrations, average changes (%), and minimum detection limits of measured parameters prior to and following woodstove changeouts in 16 homes

	Before changeout		After changeout			
Parameter	Mean ± s.d.	Median	Mean ± s.d.	Median	Percent change	*P*-value[a]
Average $PM_{2.5}$ ($\mu g/m^3$)	51.2 ± 32.0	34.5	15.0 ± 20.8	9.5	−71%	0.0001
Maximum $PM_{2.5}$ ($\mu g/m^3$)	434 ± 419	266	103 ± 167	51.5	−76%	0.0002
Organic carbon (OC) ($\mu g/m^3$)	17.6 ± 8.2	14.4	12.5 ± 10.6	9.4	−26%	0.007
Elemental carbon (EC) ($\mu g/m^3$)	0.94 ± 0.90	0.68	0.88 ± 1.87	0.29	−6%	0.054
Levoglucosan (ng/m^3)	1050 ± 1027	652	577 ± 988	321	−45%	0.001
Dehydroabietic acid (ng/m^3)	80.2 ± 61.1	74.1	187 ± 128	154	+133%	0.0001
Abietic acid (ng/m^3)	3.7 ± 5.7	2.8	14.5 ± 22.7	5.20	+292%	0.153

Ward et al., 2008

Woodstove Exchange Study (WESt)

Winter 2008 – 2009

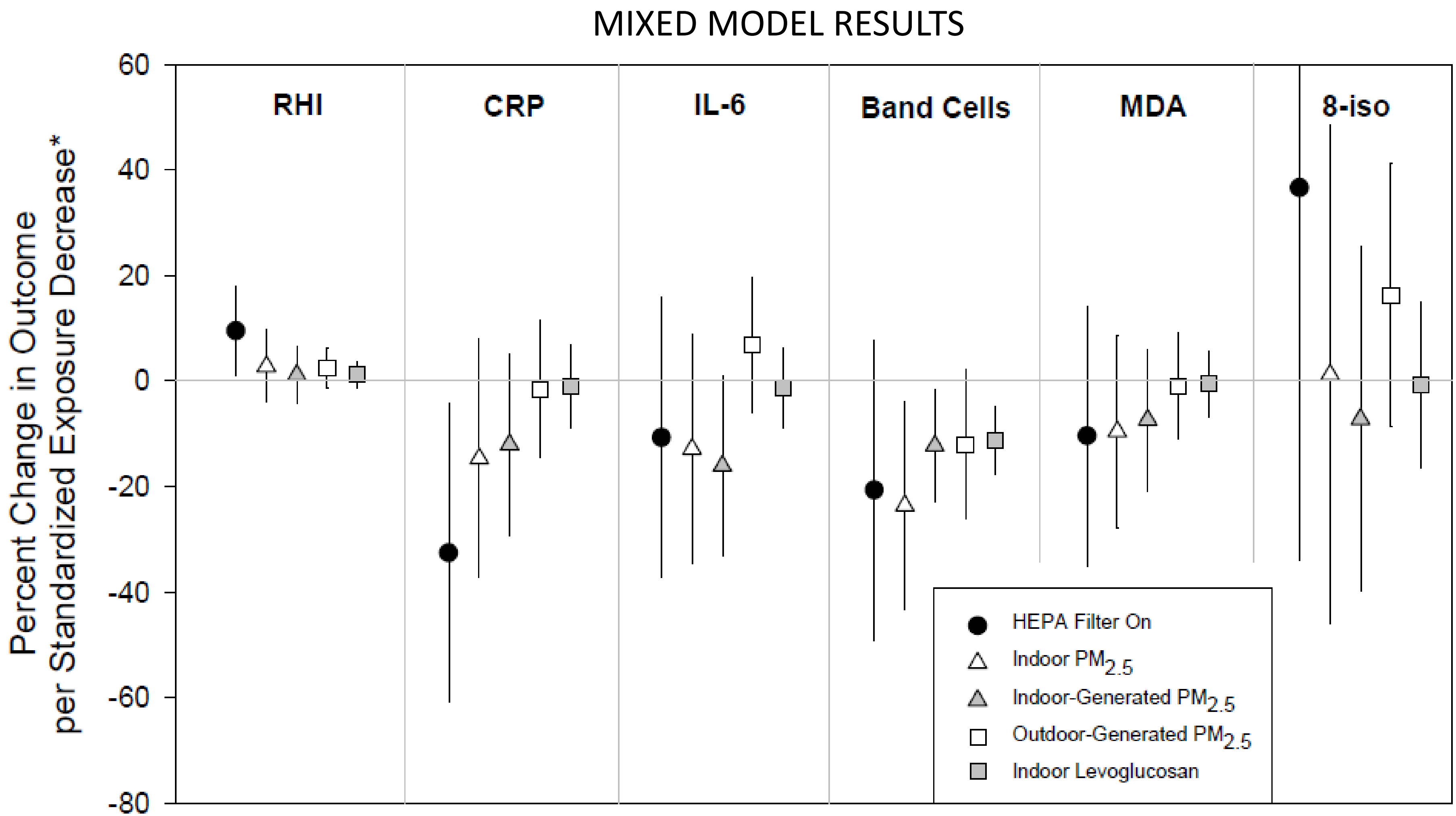
POLLUTION MEASUREMENTS IN 25 HOMES

Variable	**HEPA Off**		**HEPA On**		**Paired t-test p-value**
	Mean ± SD	Median	Mean ± SD	Median	
7-day Avg. Indoor Temperature (^{0}C)[a]	19.7 ± 1.4	19.4	19.8 ± 1.7	19.4	0.75
7-day Avg. Indoor Relative Humidity (%)*	35.1 ± 3.3	36.0	35.3 ± 3.4	33.7	0.90
$PM_{2.5}$ Outdoors (ug/m^3)	10.8 ± 5.0	9.0	9.8 ± 4.2	8.9	0.26
$PM_{2.5}$ Infiltration Efficiency (unitless)	0.34 ± 0.17	0.30	0.20 ± 0.17	0.13	<0.01
$PM_{2.5}$ Indoors (ug/m^3)	11.2 ± 6.1	10.5	4.6 ± 2.6	3.9	<0.01
$PM_{2.5}$ Outdoor-Generated (ug/m^3)	3.5 ± 2.3	3.6	1.5 ± 0.9	1.4	<0.01
$PM_{2.5}$ Indoor-Generated (ug/m^3)	7.6 ± 6.6	6.3	3.0 ± 2.8	2.1	<0.01
Levoglucosan Outdoors (ng/m^3)[a]	613 ± 548	415	530 ± 358	471	0.18
Levoglucosan Indoors (ng/m^3)	127 ± 191	73	33 ± 39	19	0.01
Levoglucosan / $PM_{2.5}$ Outdoors (%)[†]	5.1 ± 2.8	5.3	5.3 ± 1.8	5.1	0.79
Levoglucosan / $PM_{2.5}$ Indoors (%)	1.0 ± 1.1	0.7	0.9 ± 1.3	0.7	0.61

Allen et al., AJRCCM 2011

Woodstove Exchange Study (WESt)

Winter 2008 – 2009



Adjusted for age, BMI, gender, temperature

Allen et al., AJRCCM 2011