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Lessons learned from a multi-year cookstove intervention trial in rural India: indoor $PM_{2.5}$ level and its link with cookstove emissions

Maksim Islam, Roshan Wathore, Grishma Jain, Karthik Sethuraman, Hisham Zerriffi, Julian D. Marshall, Rob Bailis, **Andrew P. Grieshop**

The 2020 ETHOS Conference, Kirkland, Washington

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Background

- Multidisciplinary multiyear cookstove intervention trial in India

- Different Aspects:
  - -Emission
  - -Indoor air quality
  - -Stove choice and adoption
  - -Stove use
  - -Fuel use

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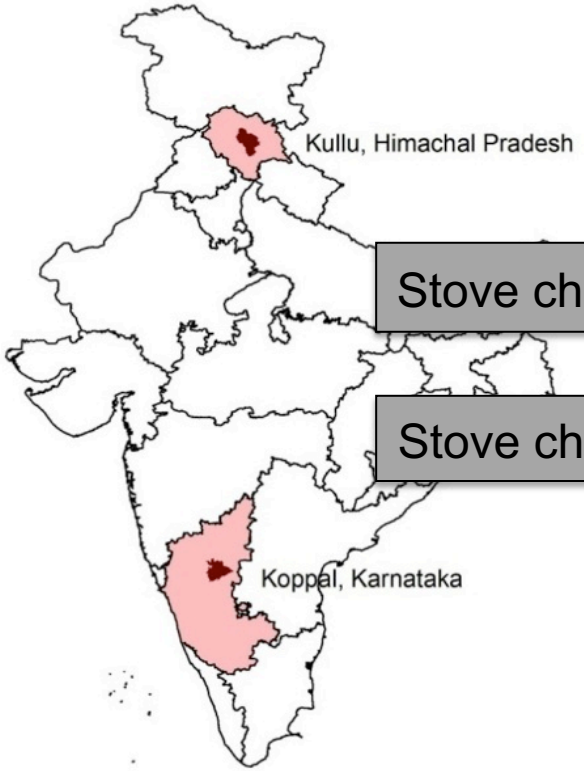
Study Design



Kullu (HP) | Koppal (KA)

Stove choice

Baseline (BL) → Baseline

Follow-up 1 (F1) → Follow-up 1

Stove choice

Follow-up 2 (F2) → Follow-up 2

Kullu/Koppal

stove pricing (free vs subsidized stove)

distribution model (one time vs periodic exchange

Community-1 → Control HHs(10)

Community-1 → Intervention HHs (50)

Community-2

Community-3

Community-4

Same as Community-1

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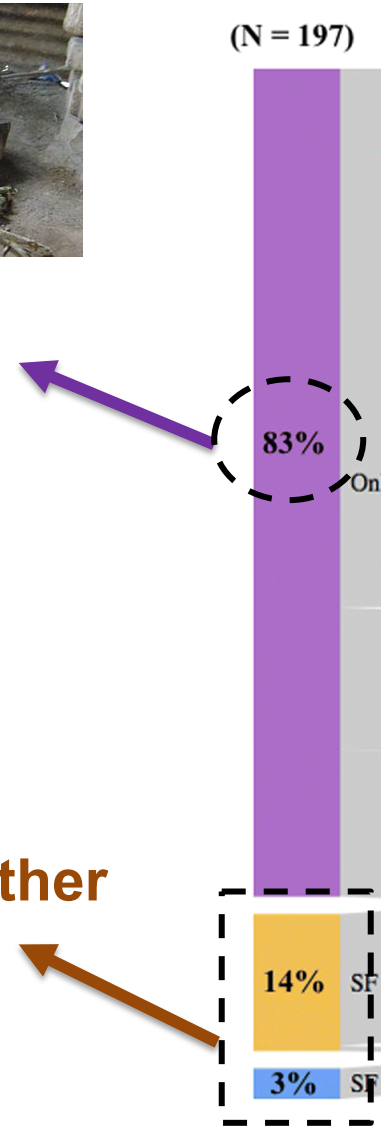
Stove Choice

LPG: the most popular choice

TSF



TSF + other

Baseline

Koppal

Follow up-1

LPG

Menghwani et al. (2019)

⇒ Converted to LPG at F2

https://servinghandskc.files.wordpress.com/2011/08/3-rock-fire.jpg

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Field Measurement

Indoor $PM_{2.5}$ Concentration: RTI microPEM (Personal Exposure Monitor)

Emissions: STEMS (STove Emission Measurement System)

6

Field Measurement

Emission measurement

- 40-50 tests/season (256 tests in total)
  - 250-350 measurement days/season
- **Real-time data**
  - 468 CO, CO$_2$, PM scattering, BC absorption
- **Teflon and Quartz Filters**
  - 1205 days personal and indoor PM$_{2.5}$ concentration measurement
  - PM/OC/EC
  - Real time and gravimetric PM$_{2.5}$ measurement
- **Result:** Emission Factor (EF) based on 'Carbon Balance'
  - Black carbon absorption

Indoor air quality measurement

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Objectives

Obj - 1	Evaluate indoor air quality effectiveness of intervention
Obj - 2	Identify factors influencing indoor $PM_{2.5}$ concentrations
Obj - 3	Linking cookstove emissions to indoor air quality

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Interventions are not always effective

Intrusion of LPG

Δ24-hr $PM_{2.5}$:

Control > Intervention

(during follow-up1)

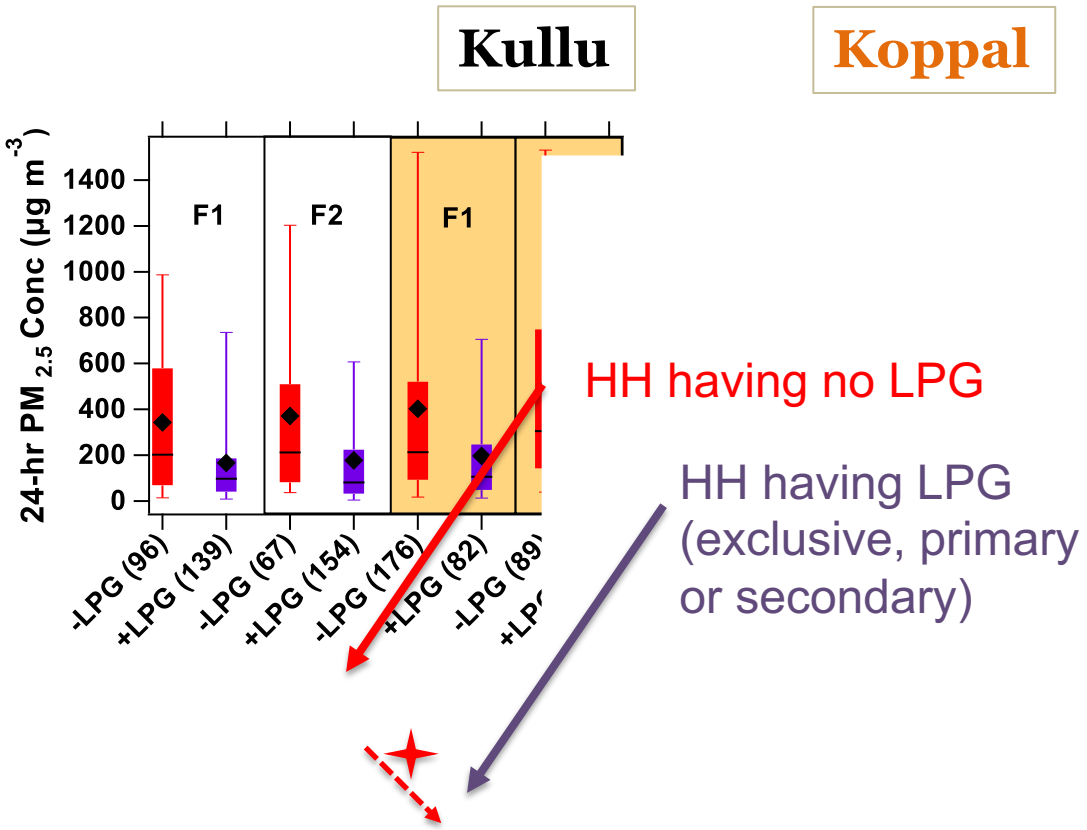
✦ Statistically significant

Cntl: Control HHs;

Int: Intervention HHs

(24-hr $PM_{2.5}$ at BL - 24-hr $PM_{2.5}$ at follow up)$_{same\ HH}$

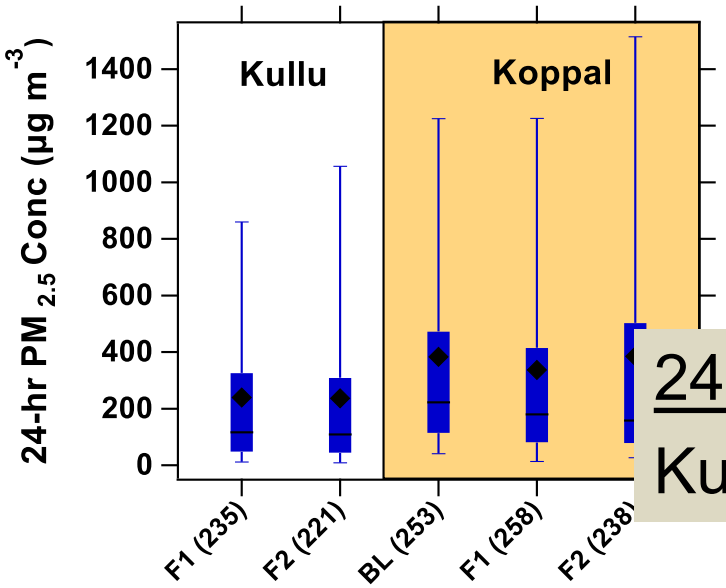
How different is indoor PM in homes with LPG?



- $PM_{2.5}$ is ~50% lower in HH with LPG than those without
- **Exclusive LPG use was linked to 75% reduction**

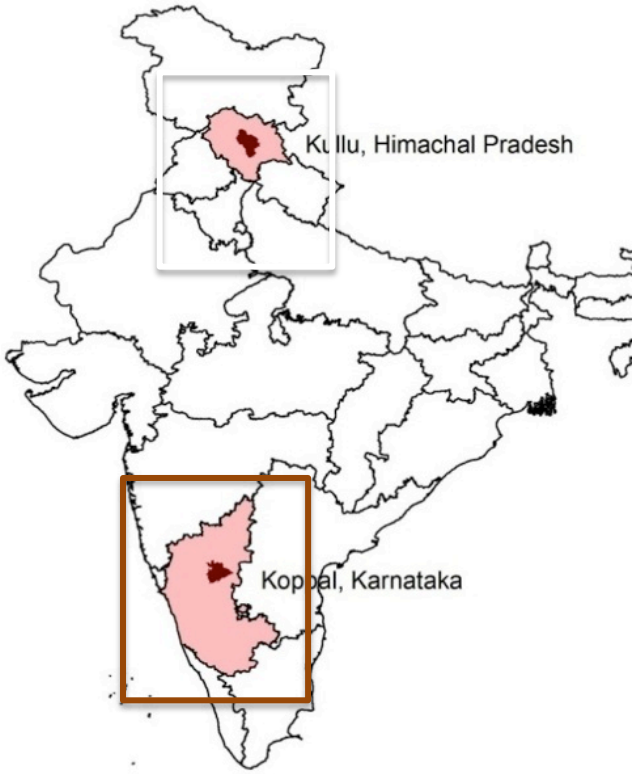
Statistically significant

Inter-site variability in indoor $PM_{2.5}$ concentration



24-hr $PM_{2.5}$:

Kullu < Koppal



WHO Guideline: 25 µg m^{-3}

True for 'exclusive TSF use group' too

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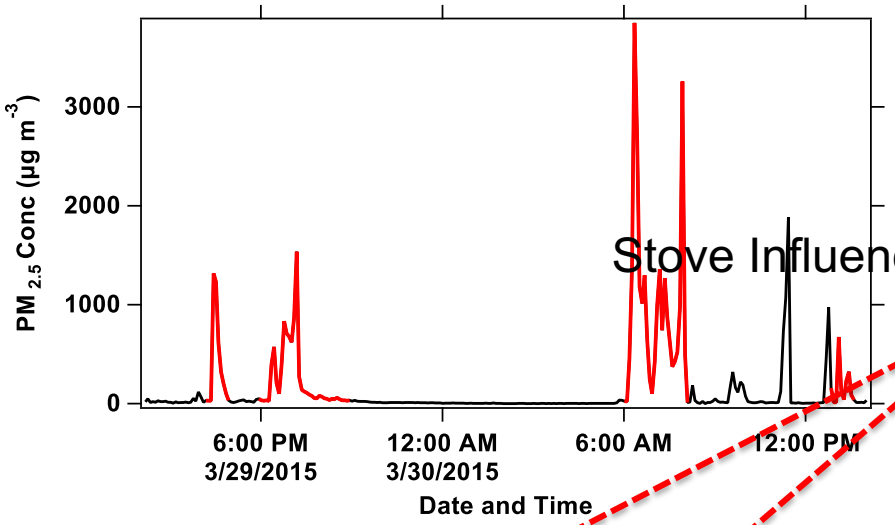
Can ventilation characteristics explain inter-site variability?

Real time indoor $PM_{2.5}$ concentration



Stove Influenced Period

AER
(PM decay)

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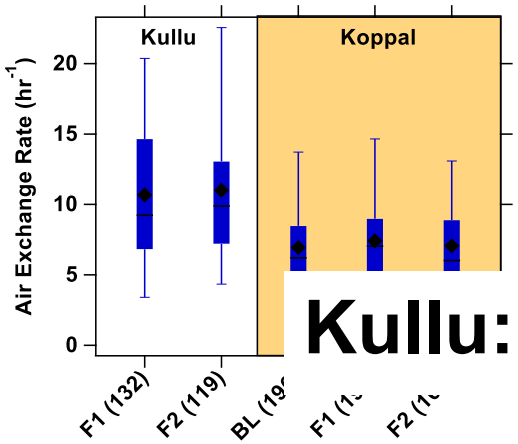
Improved ventilation helps reduce indoor PM concentration

AER distributions in two sites

%Wall Opening distributions in two sites



Kullu: AER↑ %wall open

AER: HP >> KA, opposite to indoor $PM_{2.5}$

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Objectives

Obj - 1	Evaluate indoor air quality effectiveness of intervention
Obj - 2	Identify factors influencing indoor $PM_{2.5}$ concentrations
Obj - 3	Linking cookstove emissions to indoor air quality

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Multilinear Regression modeling

Cooking characteristics
- Cooking duration
- # of cooking events

Ventilation characteristics
- Presence of chimney
- Air exchange rate
- % wall opening

Treatments
- Control HHs
- Intervention HHs

Indoor $PM_{2.5}$ model

Household characteristics
- Family size
- Kitchen volume

Emission characteristics
- Stove types (TSF, LPG)
- Other sources

Ambient conditions
- Relative humidity
- Temperature

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Multilinear Regression modeling

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- **Cooking duration**
- # of cooking events

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- **Presence of chimney**
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- **% wall opening**

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- Control HHs
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Indoor $PM_{2.5}$ model

R^2 = 24 – 44 %

Household characteristics
- Family size
- **Kitchen volume**

Emission characteristics
- **Stove types (TSF, LPG)**
- **Other sources**

Ambient conditions
- Relative humidity
- Temperature

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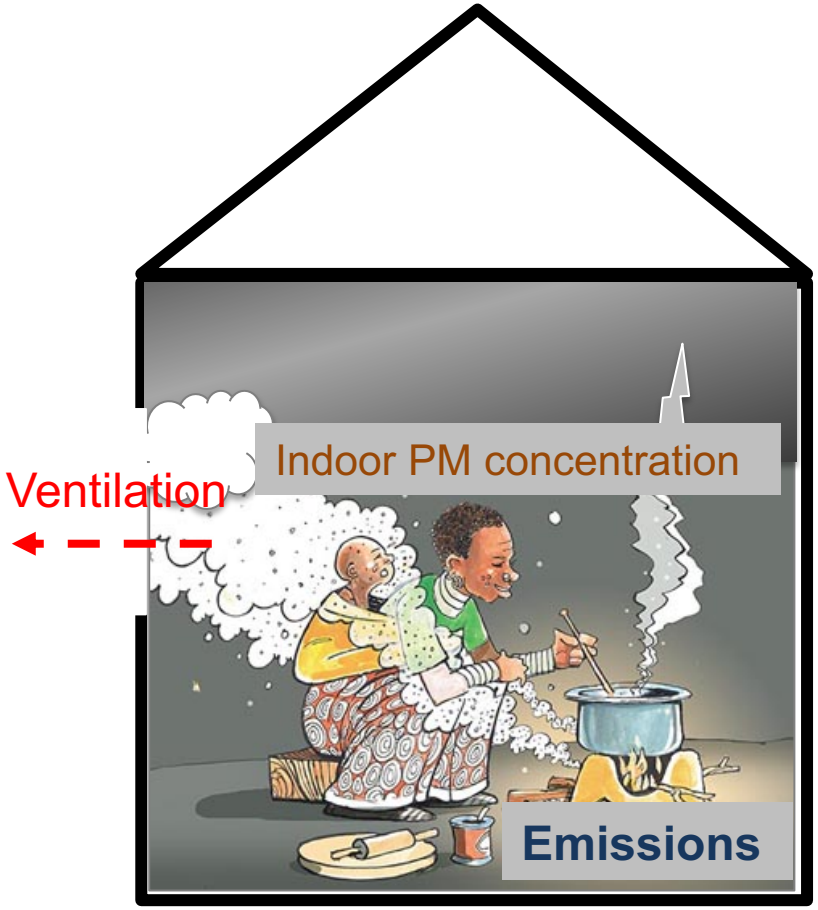
Monte Carlo Single Box Model

Monte Carlo:

- A problem solving algorithm
- Uses repeated random sampling of inputs to approximate the probability of certain outcomes

Assumptions

- Kitchen- a single box
- Single constant source (stove emission)
- Instantaneous mixing with zero backflow
- Well-mixed room
- Ventilation dominates the removal



Source: The Global Asthma report 2011

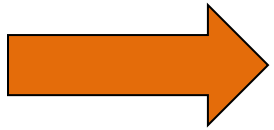
Monte Carlo Single Box Model

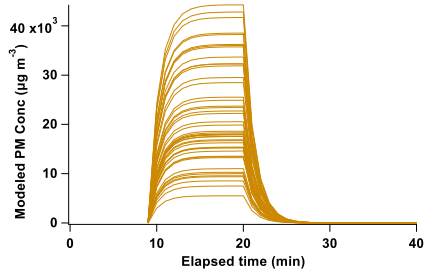
Household characteristics

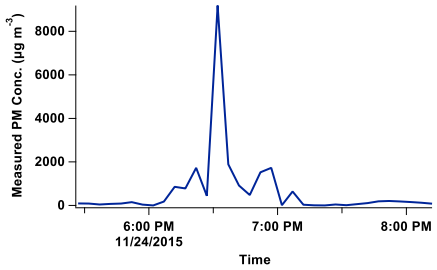
- Air exchange rate
- Kitchen volume
- Background concentration

Emission characteristics

- Cooking duration
- Emission rate







Median (24 hr avg PMs)

Compare

24 hr avg PM

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Single Box Model: data availability

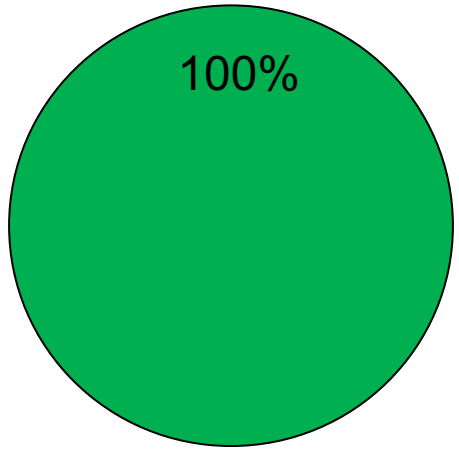
Household characteristics

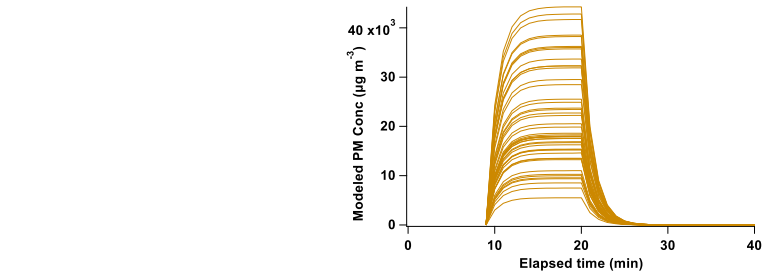
- Air exchange rate ✓
- Kitchen volume ✓
- Background concentration ✓

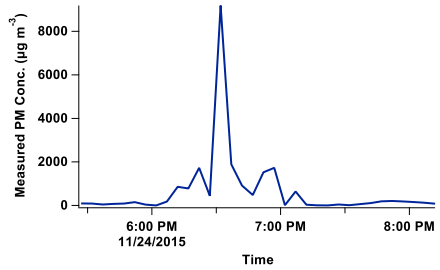
Emission characteristics

- Cooking duration ✓
- Emission rate

known for:







Median (24 hr avg PMs)

Compare

✓ **24 hr avg PM**

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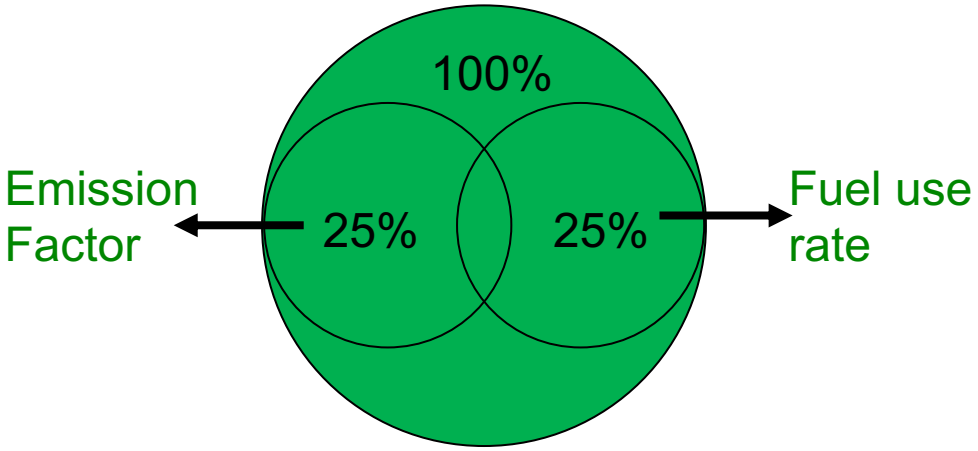
Single Box Model: data availability

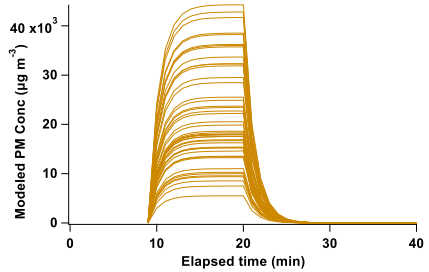
Household characteristics

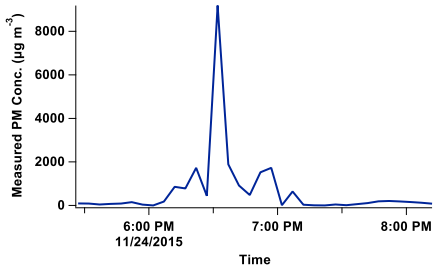
- Air exchange rate ✓
- Kitchen volume ✓
- Background concentration ✓

Emission characteristics

- Cooking duration ✓
- Emission rate





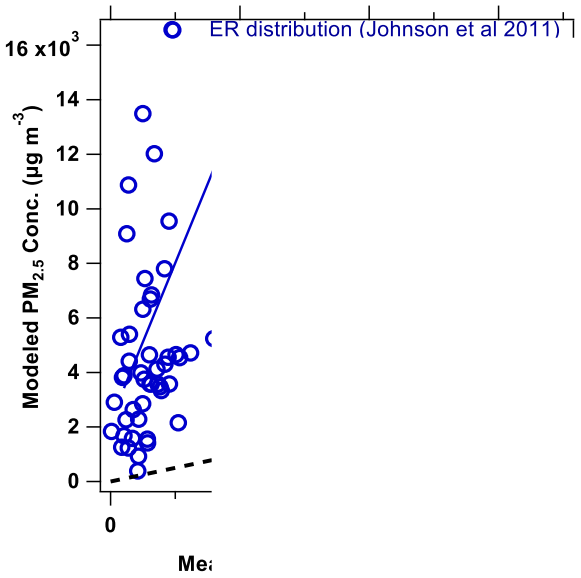


Median (24 hr avg PMs)

Compare

✓ **24 hr avg PM**

Model generally overestimates indoor PM by a factor of ~10



HHs with exclusive use of TSF

Model inputs

- Air exchange rate
- Kitchen volume
- Background concentration
- Cooking duration

→ This study

- Emission rate (ER) distribution

→ Johnson et al 2011

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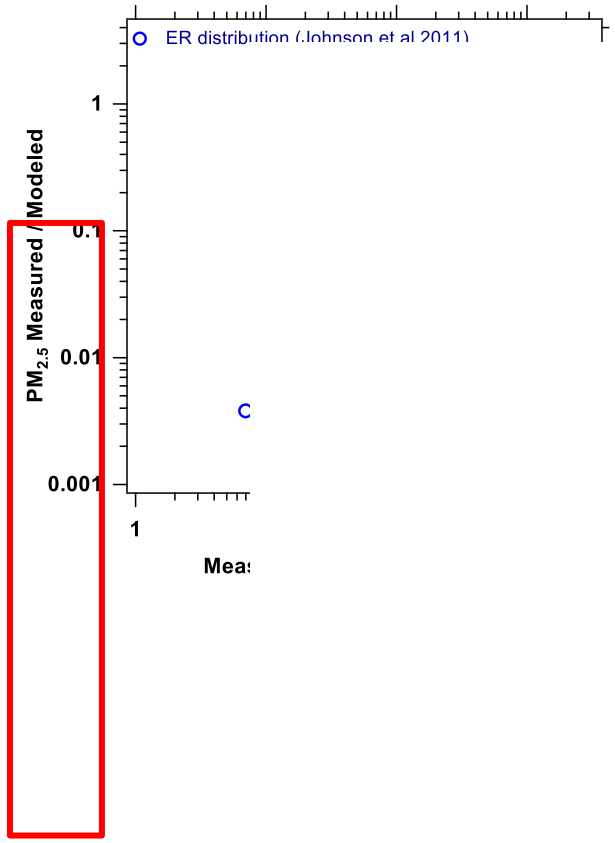

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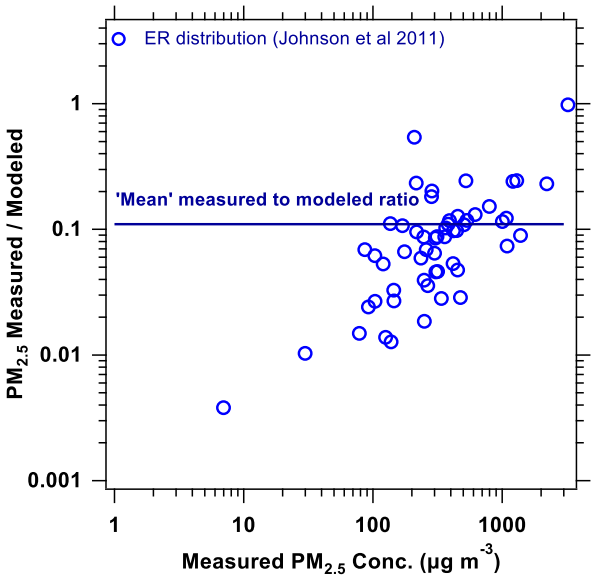


HHs with exclusive use of TSF

Model inputs

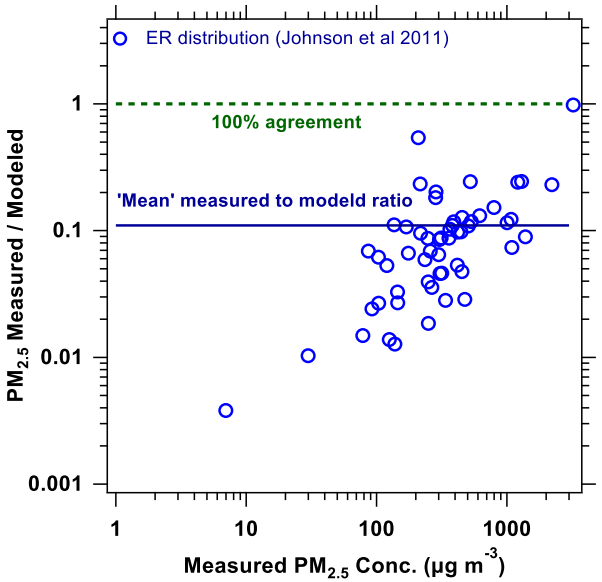
- Air exchange rate
- Kitchen volume
- Background concentration
- Cooking duration

→ This study

- Emission rate (ER) distribution

→ Johnson et al 2011

Model performs better at higher PM level



HHs with exclusive use of TSF

Model inputs

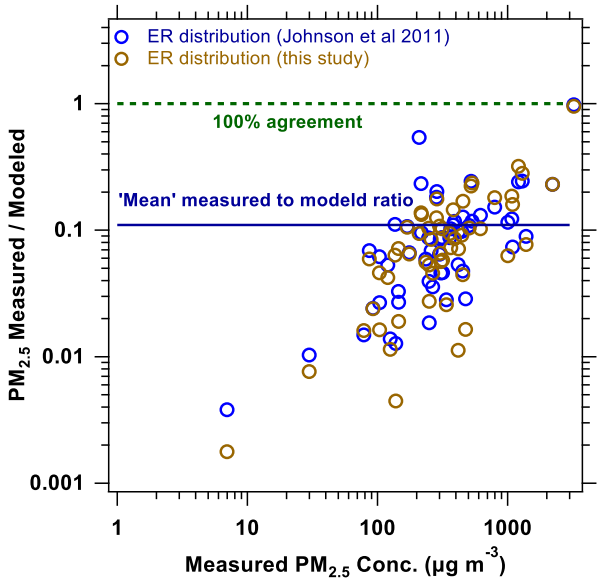
- Air exchange rate
- Kitchen volume
- Background concentration
- Cooking duration

→ This study

- Emission rate (ER) distribution

→ Johnson et al 2011

Model performance is similar for the emission rates of this study



HHs with exclusive use of TSF

Model inputs

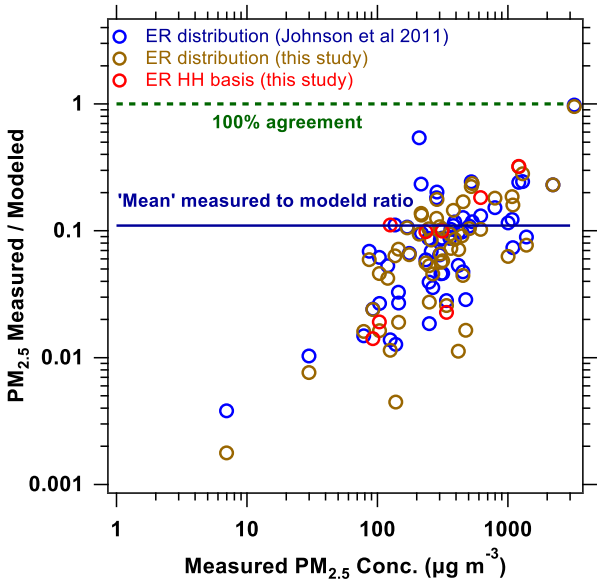
- Air exchange rate
- Kitchen volume
- Background concentration
- Cooking duration

→ This study

- Emission rate (ER) distribution

→ This study

Model performance is similar for the emission rates of this study



HHs with exclusive use of TSF

Model inputs

- Air exchange rate
- Kitchen volume
- Background concentration
- Cooking duration

→ This study

- Emission rate (ER)

→ This study

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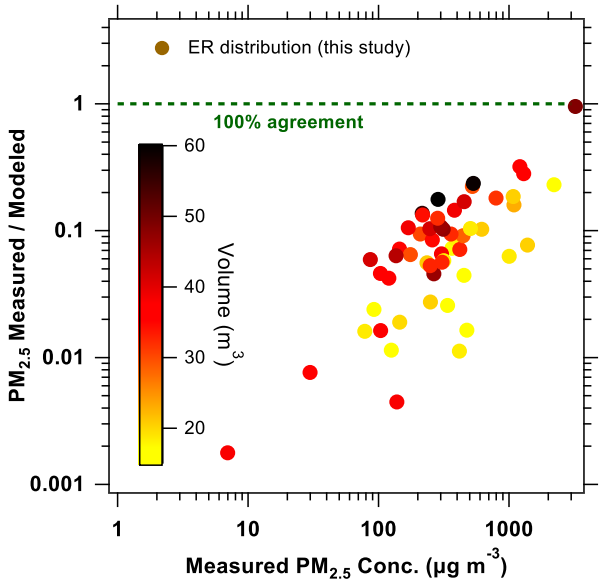
Model performs better for bigger kitchens



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Take home points

- Interventions are not always effective.

- 24-hr $PM_{2.5}$ is 50- 75% lower in HH with LPG than those without

- 'Cooking duration' and 'presence of chimney' are the two consistent predictors in indoor PM regression models in all seasons

- Monte Carlo single box model estimates are ~10x greater than measured kitchen concentration

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Acknowledgements

- US Environmental Protection Agency (EPA star grant # 83542102)
  - 500 community households in rural Kullu and Koppal
  - Numerous field managers/Staffs: Roshan Wathore, Grishma Jain, Karthik S., Abhishek Kar.
  - Partner NGOs: Samuha, Jagriti
- Grieshop Atmospheric Environment Lab (GAEL) group

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Thank you
Any questions ??

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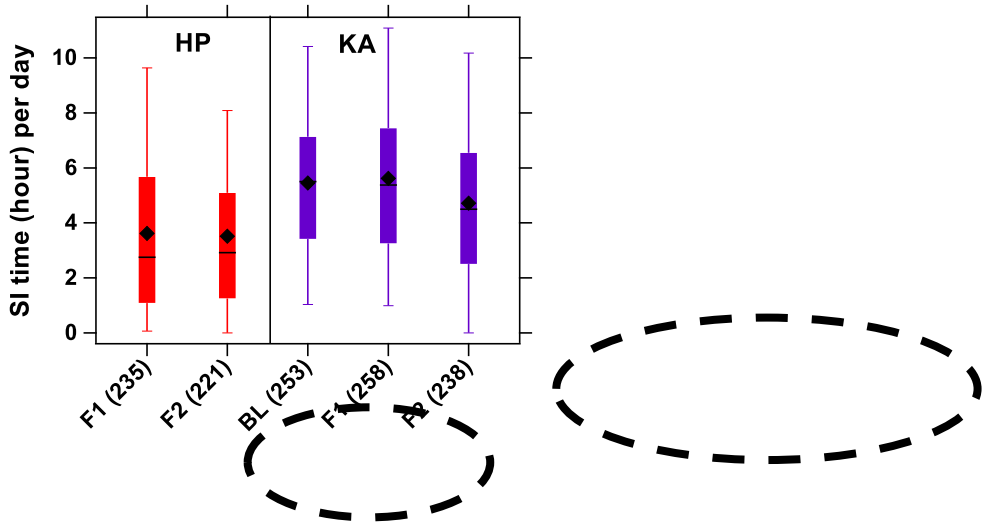
EXTRA

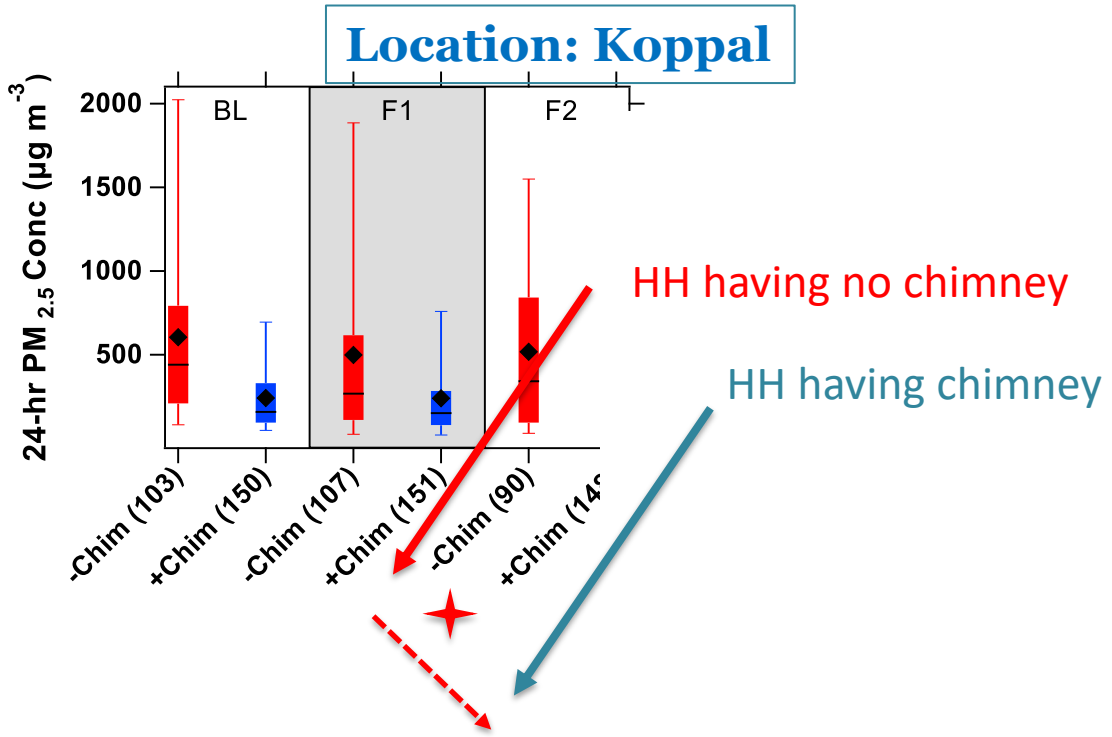
Stove use influences indoor PM concentration

SI time distributions in two sites



SI time: HP << KA, similar to indoor $PM_{2.5}$

Chimneys do matter…..



Statistically significant ($p<0.05$)

Stove use influences indoor PM concentration

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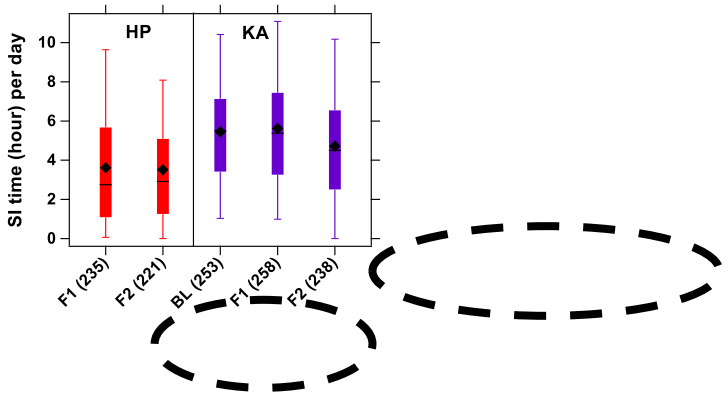
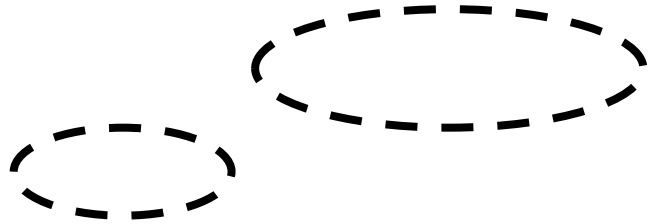


Non-SI PM distributions in two sites



SI time: HP << KA, similar to indoor PM2.5

Non-SI PM: HP << KA, similar to indoor PM2.5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