Household Air Pollution from Humanity's Oldest Occupation

A Brief History

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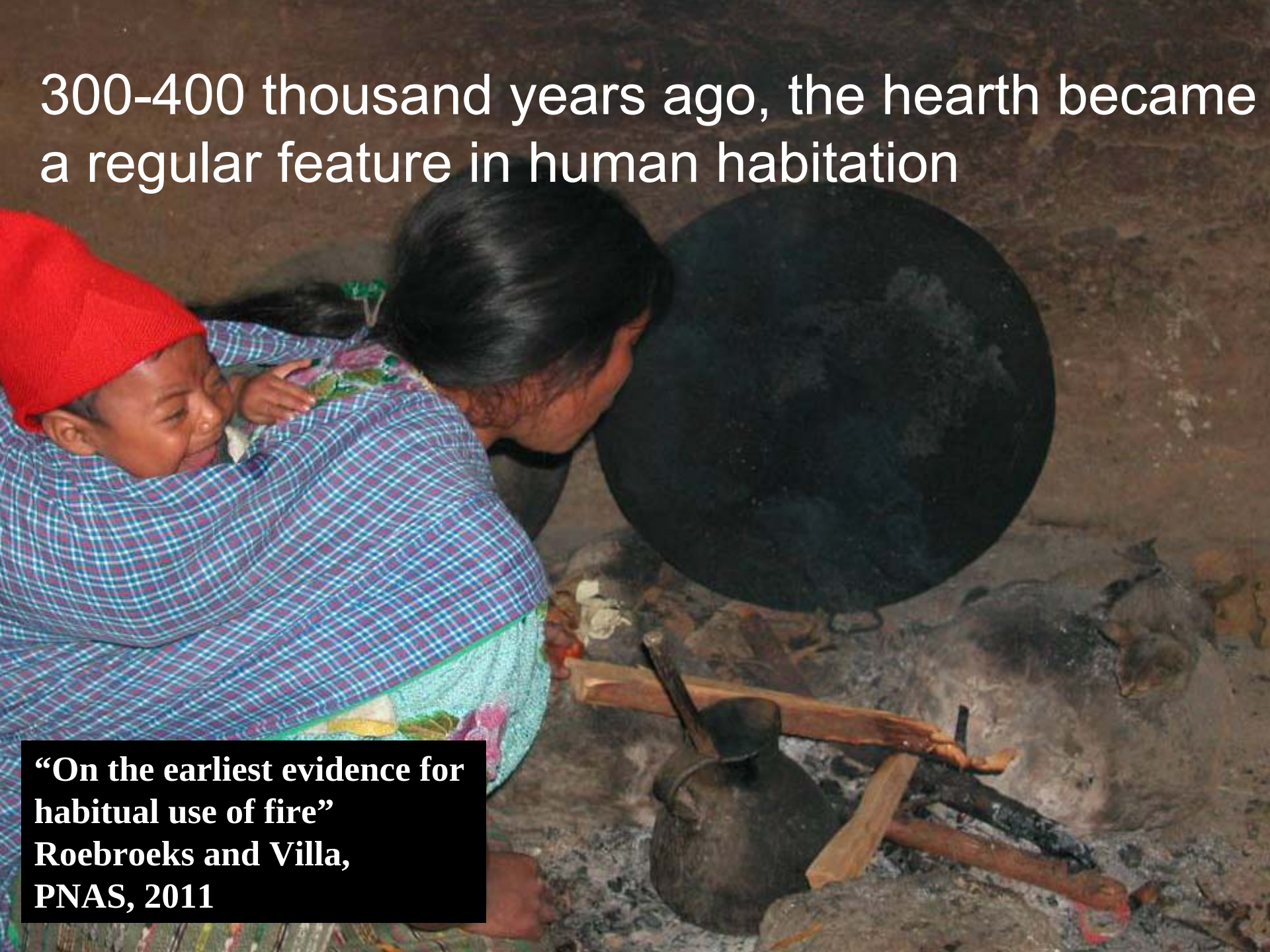
Indoor Air 2011
Student Symposium
Austin Texas

Road Map

- Global history of solid cooking fuels
- Brief discussion of what pollution is involved.
- History of the first exposure study
- How do the results of first study appear today
- Only a bit about impacts: health and climate

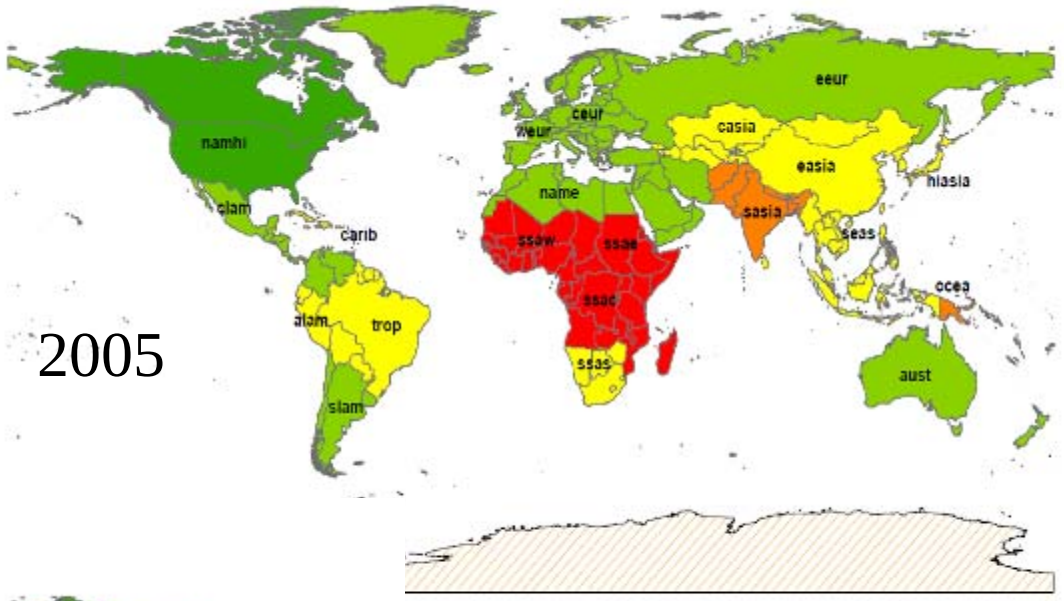
300-400 thousand years ago, the hearth became a regular feature in human habitation

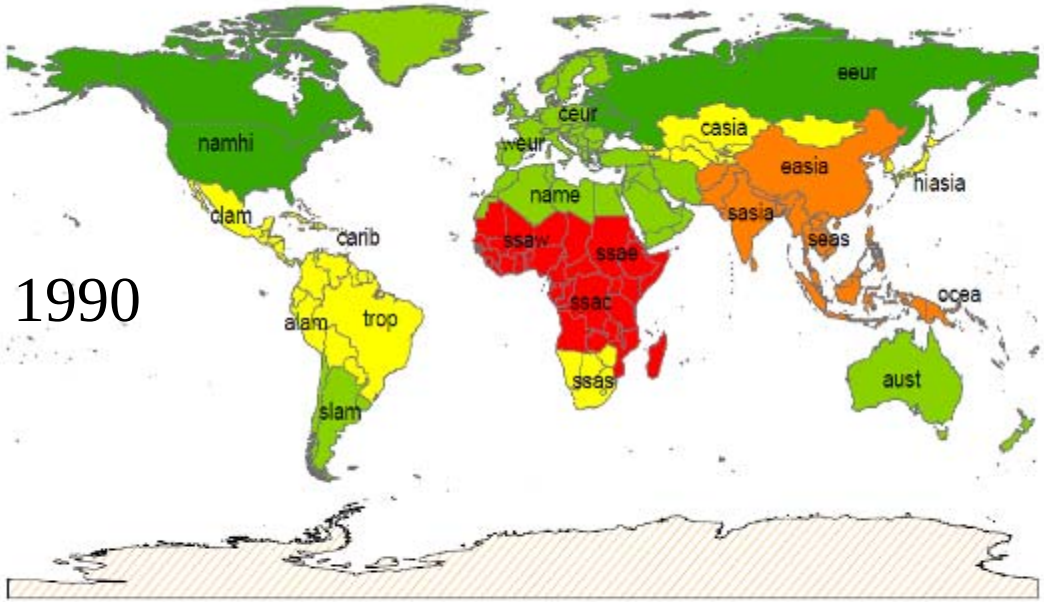


“On the earliest evidence for habitual use of fire” Roebroeks and Villa, PNAS, 2011


Three main types of household solid fuel

Households using biomass or coal to cook today



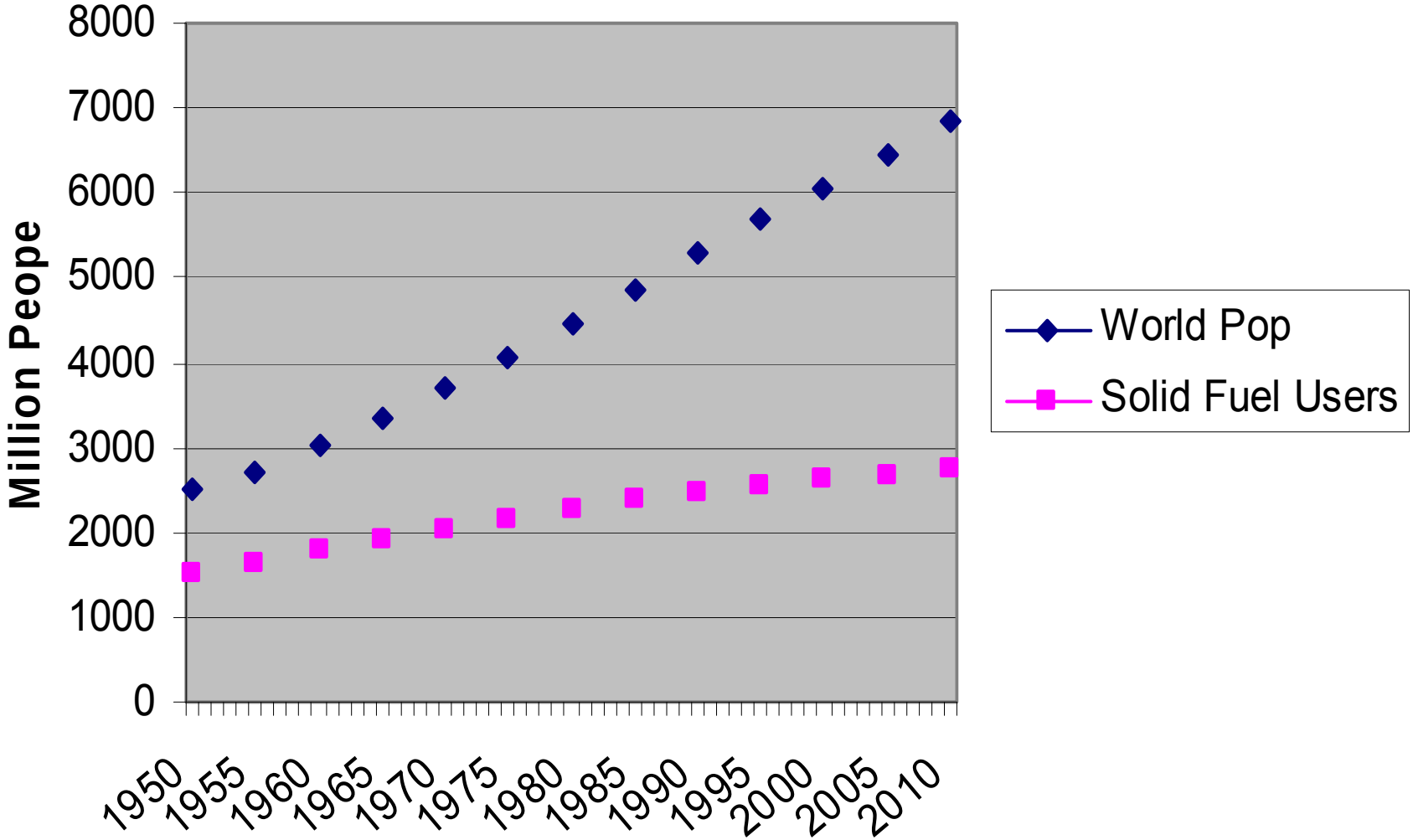


% of HH Exposed to HAP

<5	51 - 75
6 - 20	76 - 94
21 - 50	No Data

Comparative Risk Assessment (CRA) 2011- preliminary,

World Population Using Solid Fuels



Biomass Cooking in History

- **Only quite recently in human history did more than half of households use non-solid fuels for cooking – perhaps around 1980.**
- **Today, ~40% use solid fuels, about 2.7 billion people**
- **Although the percentage is dropping, the absolute number is still rising.**
- **Perhaps 10-15 million people a year are added to the total each year.**
- **Indeed, there are more people using solid fuels today for cooking than the total world population in 1950**
- **Or any year previously**

A problem that has lasted one-third of a million years and is showing no sign of quickly going away by itself.

Woodsmoke is natural – how can it hurt you?

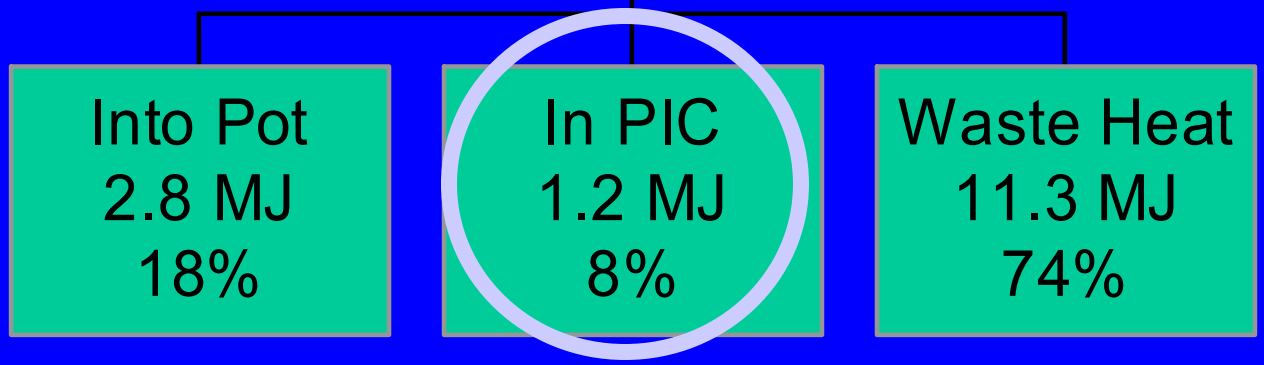
Or, since wood is mainly just carbon, hydrogen, and oxygen, doesn't it just change to CO_2 and H_2O when it is combined with oxygen (burned)?

Reason: the combustion efficiency is far less than 100%

Energy flows in a well-operating traditional wood-fired Chinese cooking stove

A Toxic Waste Factory!!

Typical biomass cookstoves convert 6-20% of the fuel carbon to toxic substances



PIC = products of incomplete combustion = CO, HC, C, etc.

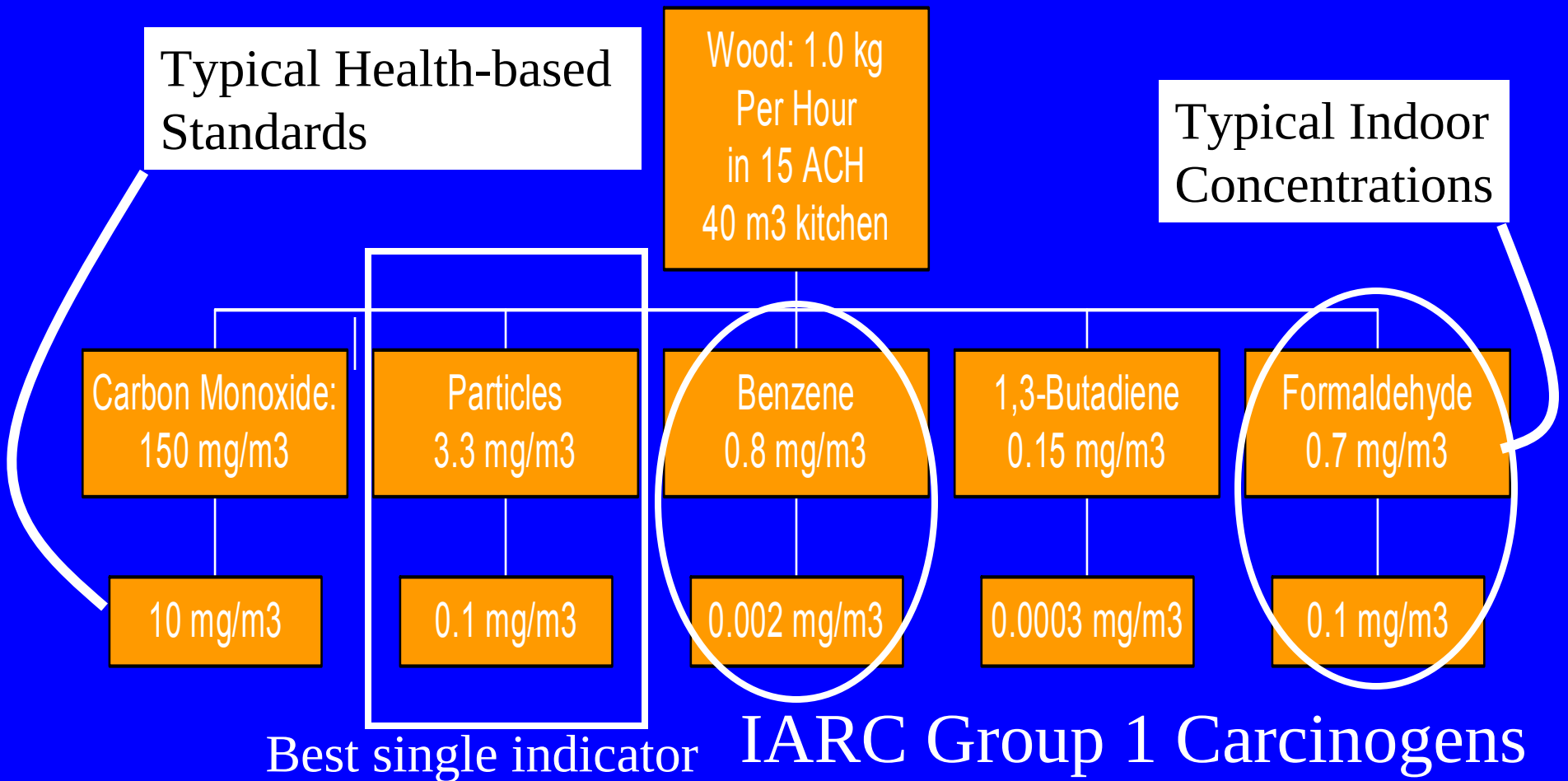
Source: Zhang, et al., 2000

Toxic Pollutants in Biomass Fuel Smoke from Simple (poor) Combustion

- Small particles, CO, NO_2
- Hydrocarbons
  - 25+ saturated hydrocarbons such as *n-hexane*
  - 40+ unsaturated hydrocarbons such as *1,3 butadiene*
  - 28+ mono-aromatics such as *benzene & styrene*
  - 20+ polycyclic aromatics such as *benzo(α)pyrene*
- Oxygenated organics
  - 20+ aldehydes including *formaldehyde* & *acrolein*
  - 25+ alcohols and acids such as *methanol*
  - 33+ phenols such as *catechol* & *cresol*
  - Many quinones such as *hydroquinone*
  - Semi-quinone-type and other radicals
- Chlorinated organics such as *methylene chloride* and *dioxin*

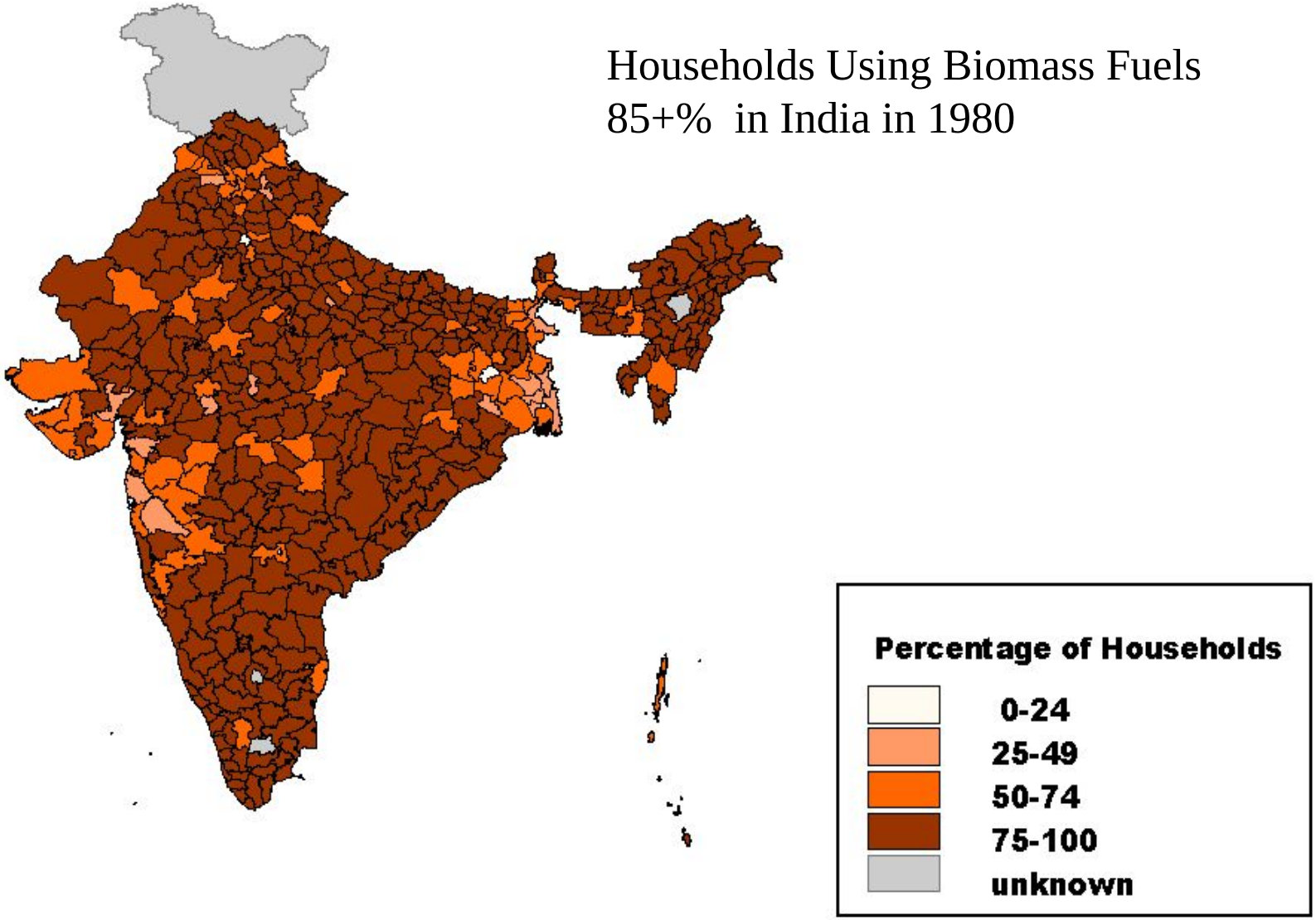
Source: Naeher et al, *J Inhal Tox*, 2007

Health-Damaging Air Pollutants From Typical Woodfired Cookstove in China.



History of First Study

Households Using Biomass Fuels
85+% in India in 1980

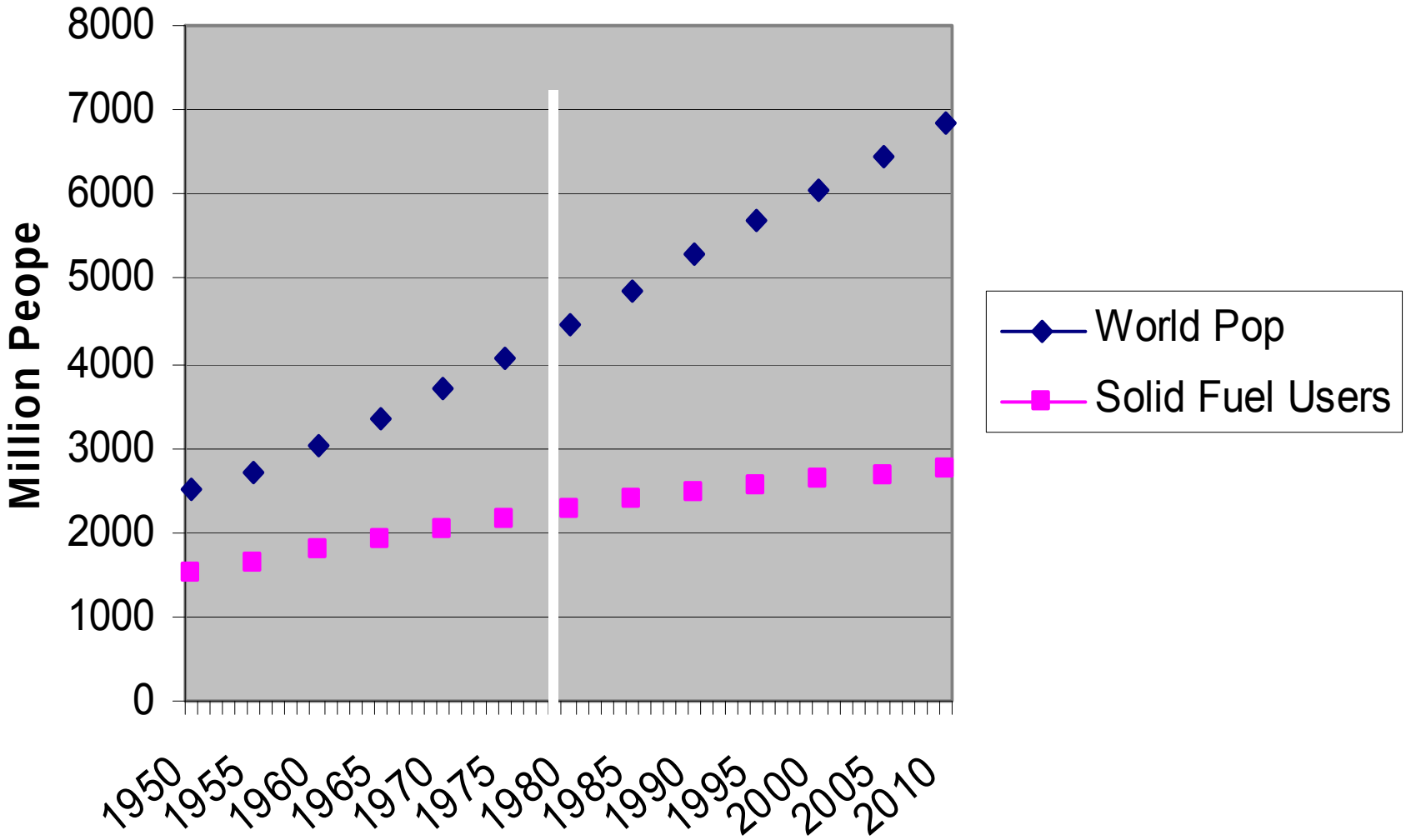



Does Not Take Much Time in Villages
to See Smoky Households

How Smoky?

- Large population with daily exposures
- No measurements apparently done, but
- We can estimate using things we do know
- Fuel Use
- Emission Factors
- Household Volume
- Ventilation?

When were the first measurements of exposure?



Atmospheric Environment Vol. 17, No. 11, pp. 2343–2362, 1983
Printed in Great Britain.

0004–6981/83 $3.00 + 0.00
Pergamon Press Ltd.

AIR POLLUTION AND RURAL BIOMASS FUELS IN DEVELOPING COUNTRIES: A PILOT VILLAGE STUDY IN INDIA AND IMPLICATIONS FOR RESEARCH AND POLICY

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(*First received* 7 *December* 1982 *and received for publication* 26 *May* 1983)

Atmospheric Environment, 1983

Indoor concentrations (Xi) could be expected to be dependent on a number of factors (see the discussion in WHO, 1979, 1982):

$$Xi = f(Xo, Q, D, V, S, M), \quad (1)$$

where Xo is the outside concentration and Q is the indoor source term, which is a function of the emission factor (E), fuel type (Ft), fueling rate (Fr) and combustion conditions (C)

$$Q = f(E, Fr) \quad (2)$$

$$E = f(Fr, C, Ft). \quad (3)$$

The depletion (D) (net removal by physical deposition or chemical change) of pollutants inside the room depends on the physical and chemical conditions of the room, the air, and the fire. The removal of pollutants from the room (mass transfer) depends upon the room volume (V), the effective air exchange rate (S), and the conditions of the room, air and fire that induce mixing (here summarized as M). Modeling the distribution of concentration in time and space would require consideration of all of these parameters.

To gain a rough idea of the potential concentration that might exist during indoor cooking with biomass fuels, it has been useful to adopt a simplification of Equation (1)

$$Xi = Fr \quad E \quad V^{-1} \quad S^{-1}. \quad (4)$$

Equation (4) assumes that outside concentrations are negligible, there are no other inside sources, dynamic equilibrium has been reached inside, mixing is perfect and no depletion is occurring.

Using the Box Model To Make Hypothesis On IAP

Smith, et al., 1983

Air Pollution Box Model

- **V**olume in m3
- **A**ir **E**xchange **R**ate in (hour)$^{-1}$
- **E**missions in g/hour

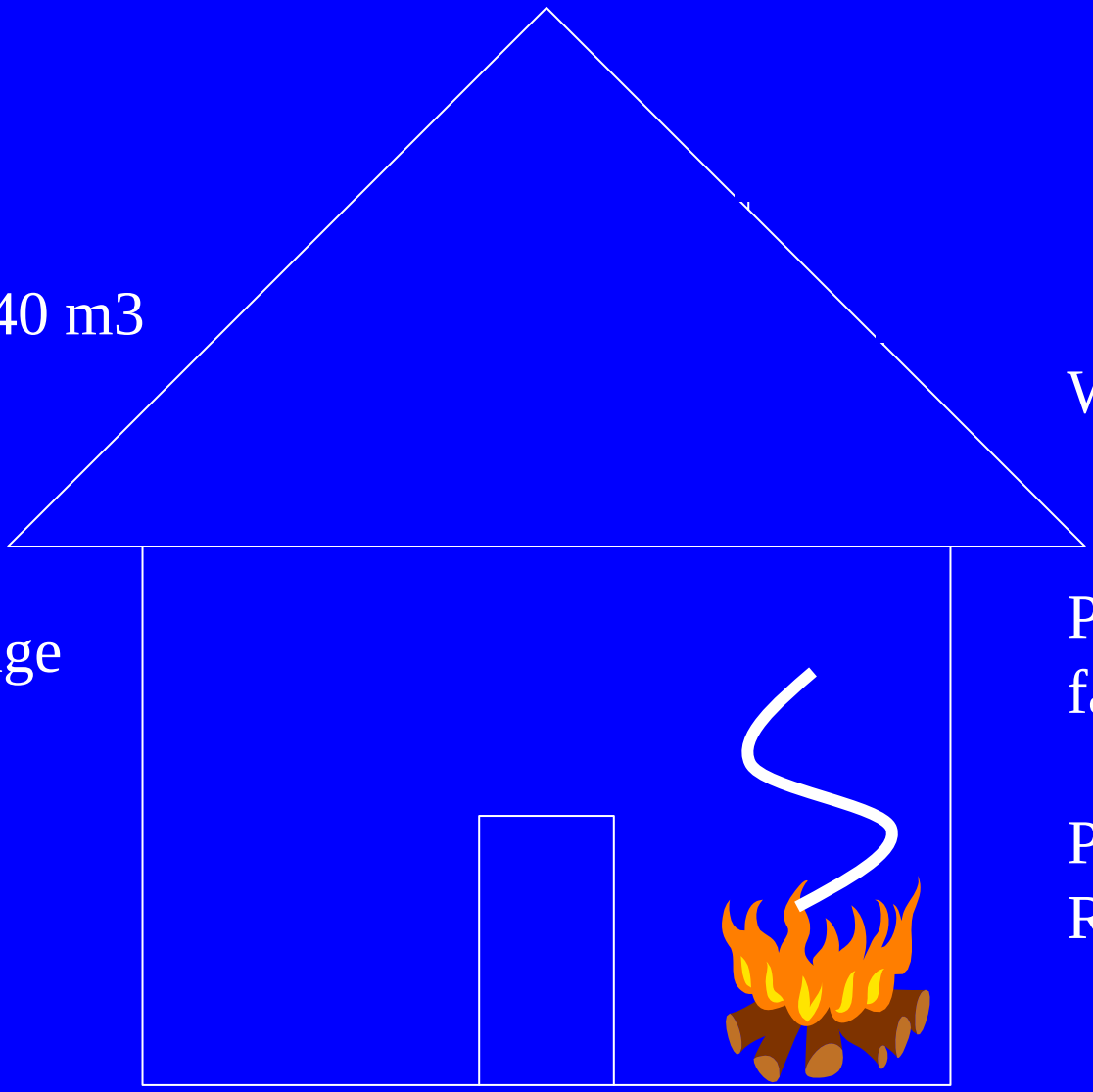
- Concentration = C = E/(AER*V) =

- C = (g/hour) / ((#/hour)*m3) = g/m3

Typical Village Cooking Situation, based on Indian surveys in late 1970s

Volume ~ 40 m3

Air Exchange Rate ~ ??



Wood use ~ 1 kg/h

PM emission factor ~ 2 g/kg*

↓

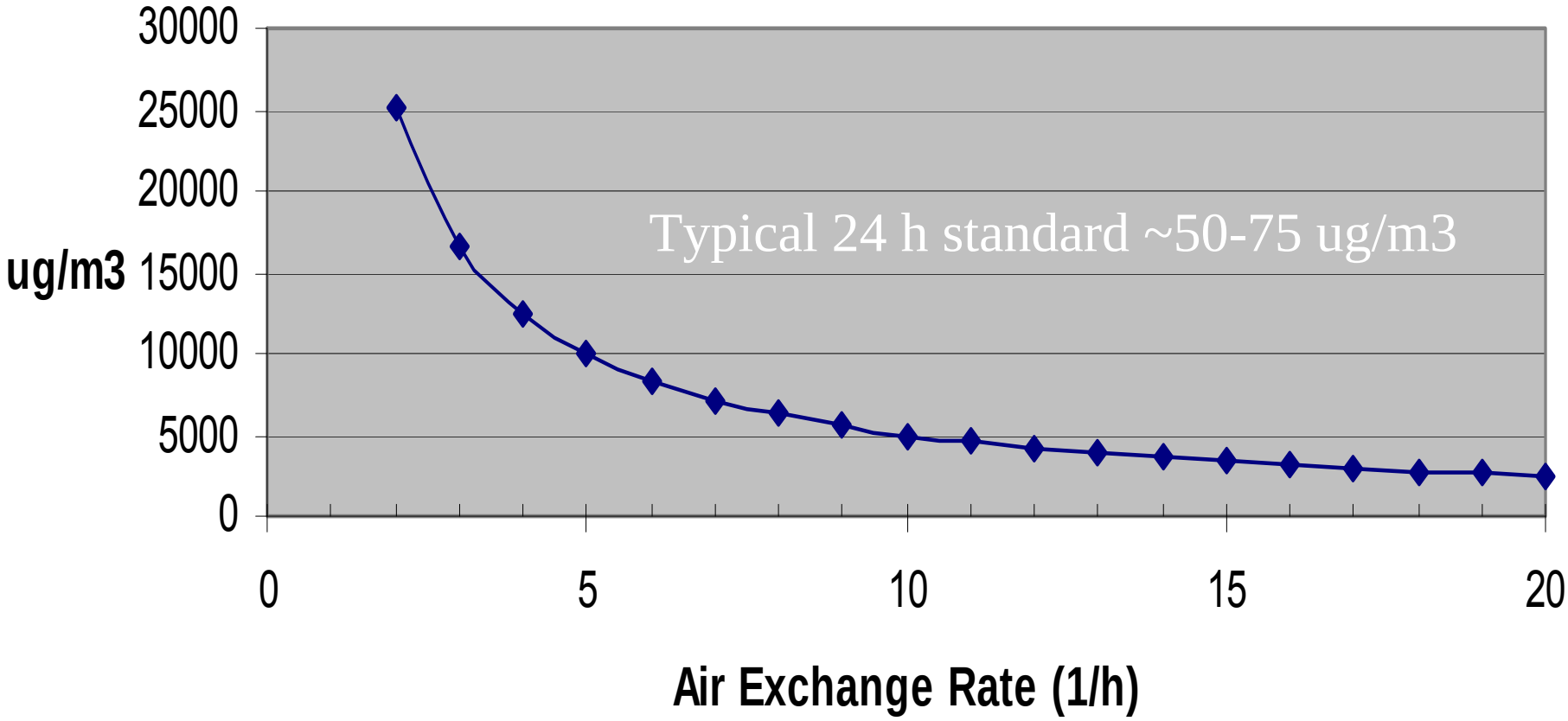
PM emission Rate ~ 2 g/h

*Based on USEPA studies of fireplaces

Concentration (C) = E/(AER*V)

AER	Concentration
1	50000
2	25000
3	16667
4	12500
5	10000
6	8333
7	7143
8	6250
9	5556
10	5000
11	4545
12	4167
13	3846
14	3571
15	3333
16	3125
17	2941
18	2778
19	2632
20	2500

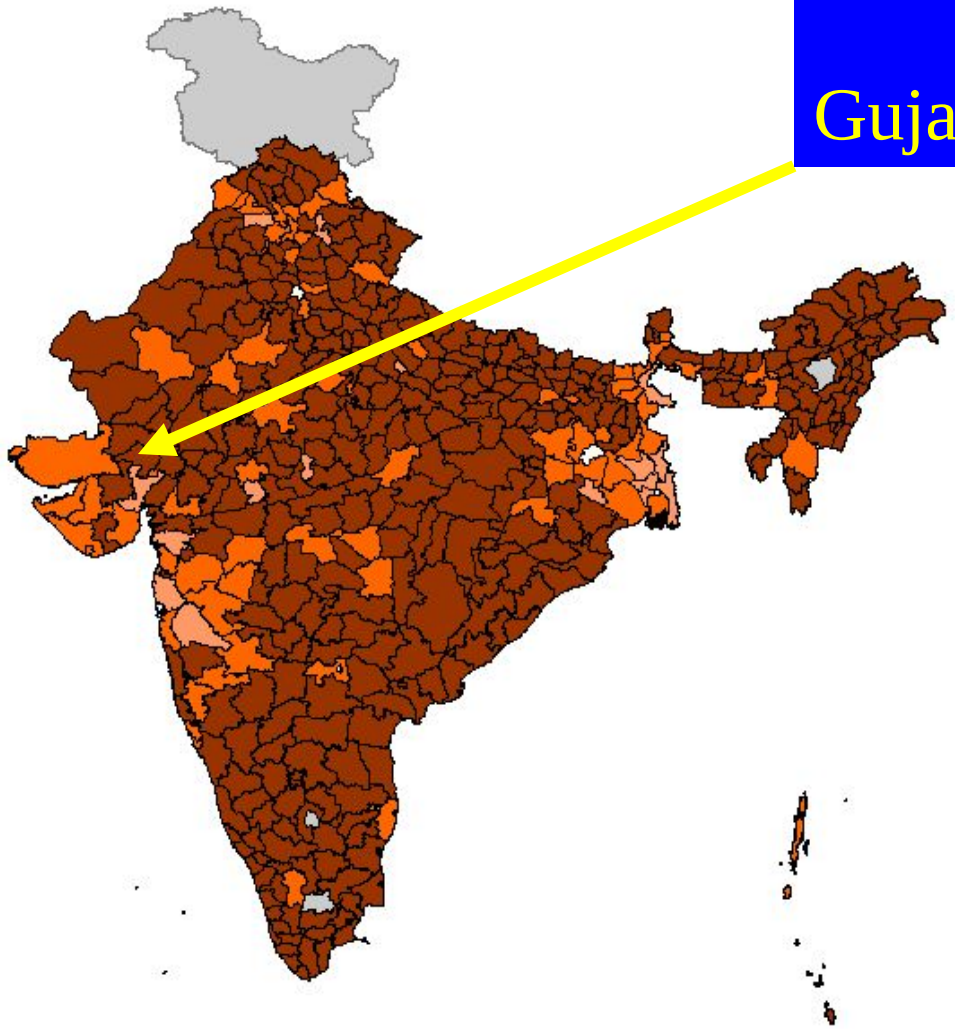
Hypothetical Indoor PM Concentrations in Village Hut

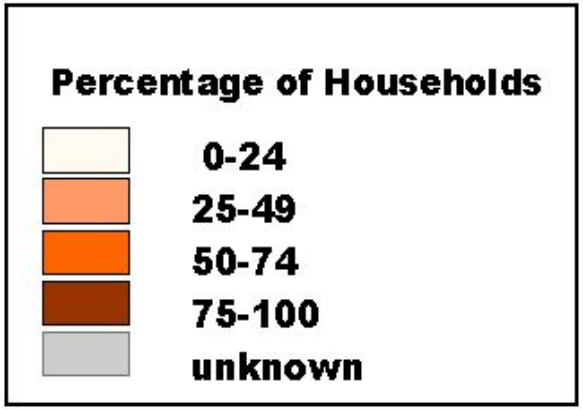


Assumptions: Vol = 40 m3; Fuel burn rate = 1.0 kg/h; EF = 2 g/kg

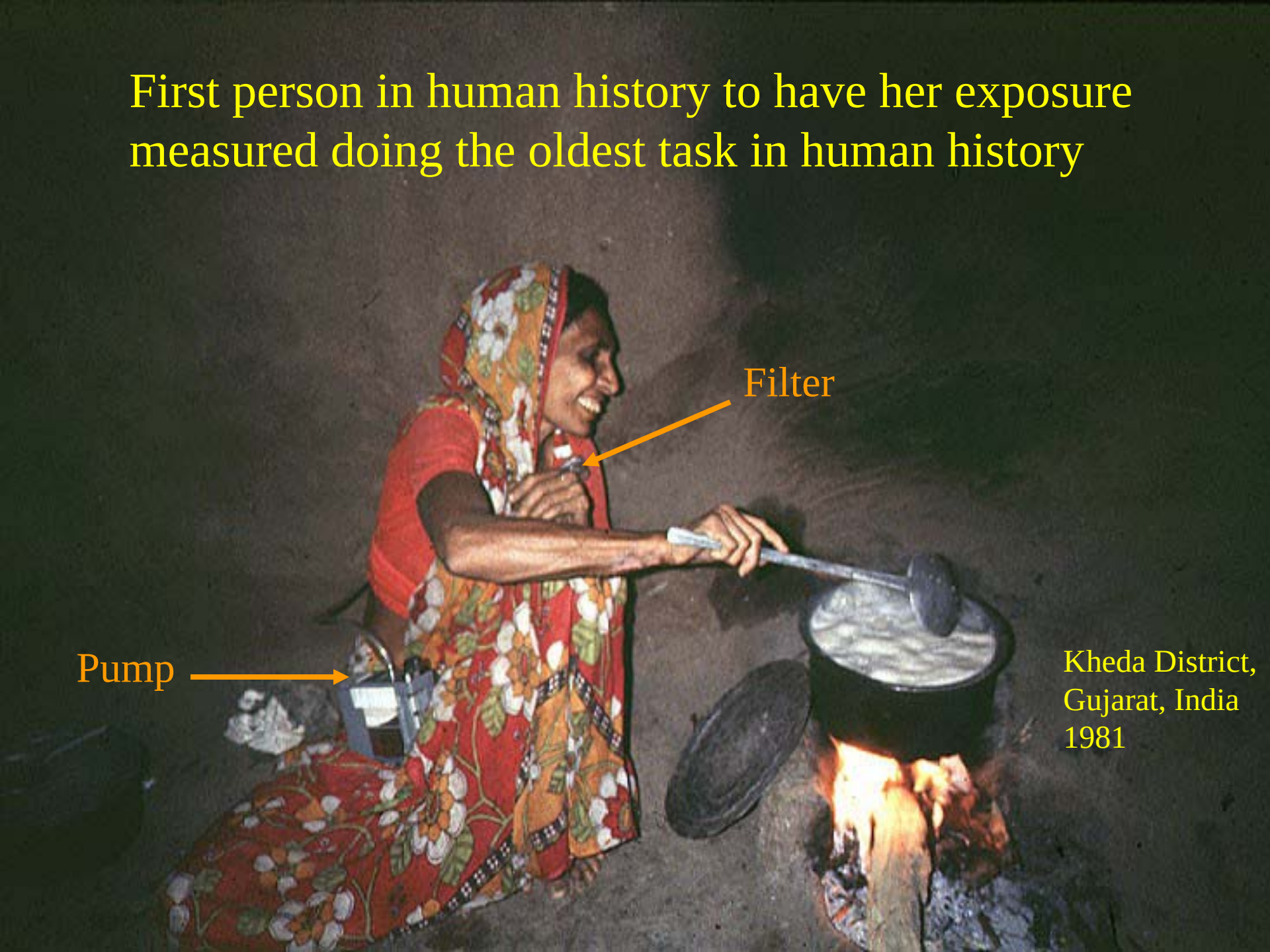
Location of First Study

Gujarat India, 1981





First person in human history to have her exposure measured doing the oldest task in human history

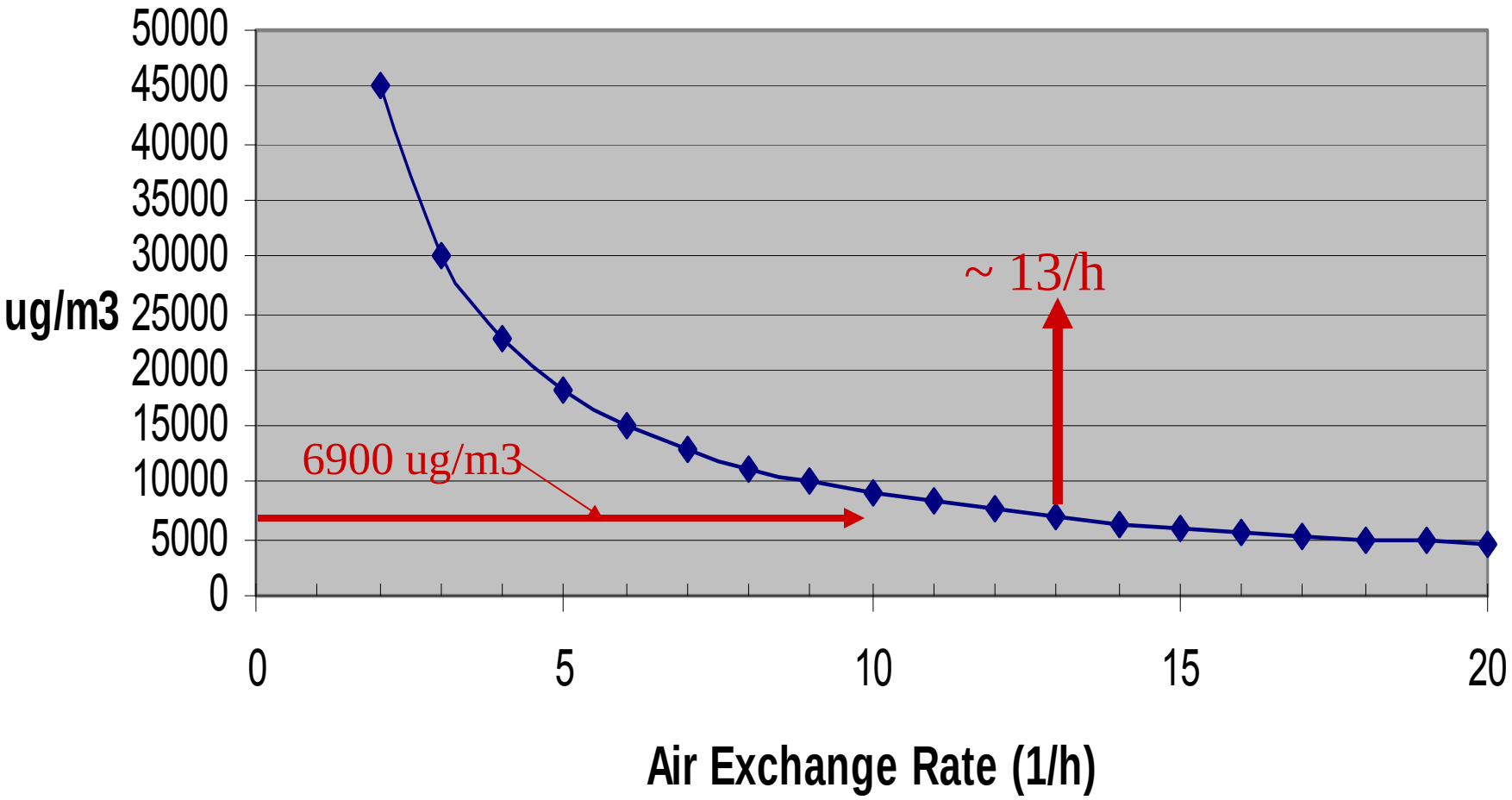


Kheda District,
Gujarat, India
1981

How Well did We Do On Estimating Model Inputs?

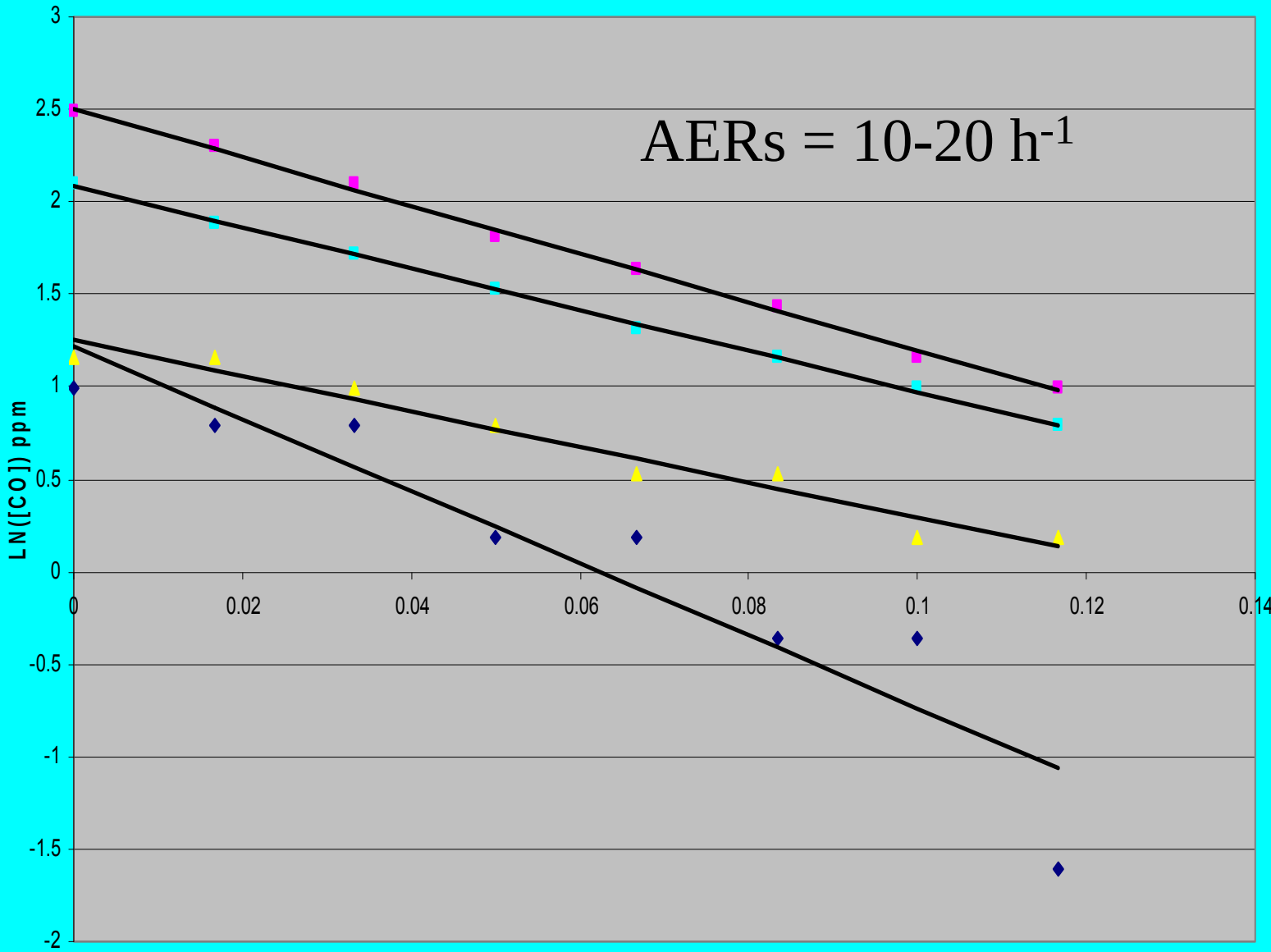
	Assumed	Measured	Standard Deviation
Kitchen Volume	40	42 m3	+/- 19
Fuel Use	1	1.9 kg/h	+/- 0.8
Concentration	??	6900 ug/m3	+/- 7500

Apparent air exchange rate ~ 13/h = 3,800,000/(42 x 6900)



Vol = 42 m3; Fuel burn rate = 1.9 kg/h

Ventilation experiment
(Data From HH07, Kaldari, India, July, 2003)



y(P1) = **-19.56**x + 1.22
R^2 = 0.88

y(P2) = **-13.06**x + 2.50
R^2 = 0.99

y(P3) = **-9.58**x + 1.25
R^2 = 0.96

y(P4) = **-11.06**x + 2.08
R^2 = 0.99

Seema Bhangar, 2004

Cooking Outdoors Does Not Help Much

Table 11. Personal exposure variation due to kitchen location*

	Inside (I)	Verandah (V)	Separate room (K)
Kitchen volume (m^3)			
Mean	46	41	37
TSP ($mg\ m^{-3}$)			
Mean	6.1	5.2	6.1
Standard deviation	(4.1)	(2.2)	(4.9)
a.m.	4.8	4.4	4.0
p.m.	7.1	5.9	7.7

Smith, et al., 1983

Assessment of Relation to Housing and Poverty

Table 12. Summary of household data and measured exposure by house type

	Kucha	Pucca
Family		
Size	6.4	6.2
Income (rupees)	4100	11000
Age (years)		
Of cook	32	35
Began cooking	13	13
Cooking		
Fuel use (kg)		
per day	6.3	6.9
per hour (during sampling)	2.1	1.6
Size of kitchen (m^3)	44	39
Time (h)		
Cooking	2.6	3.3
Other use of *chula*	1.5	2.1
Indoor exposures		
TSP ($mg\ m^{-3}$)	5.7	6.4
BaP ($ng\ m^{-3}$)	3900	3100
BaP/TSP ($\mu g\ g^{-1}$)	1000	600

Smith, et al., 1983

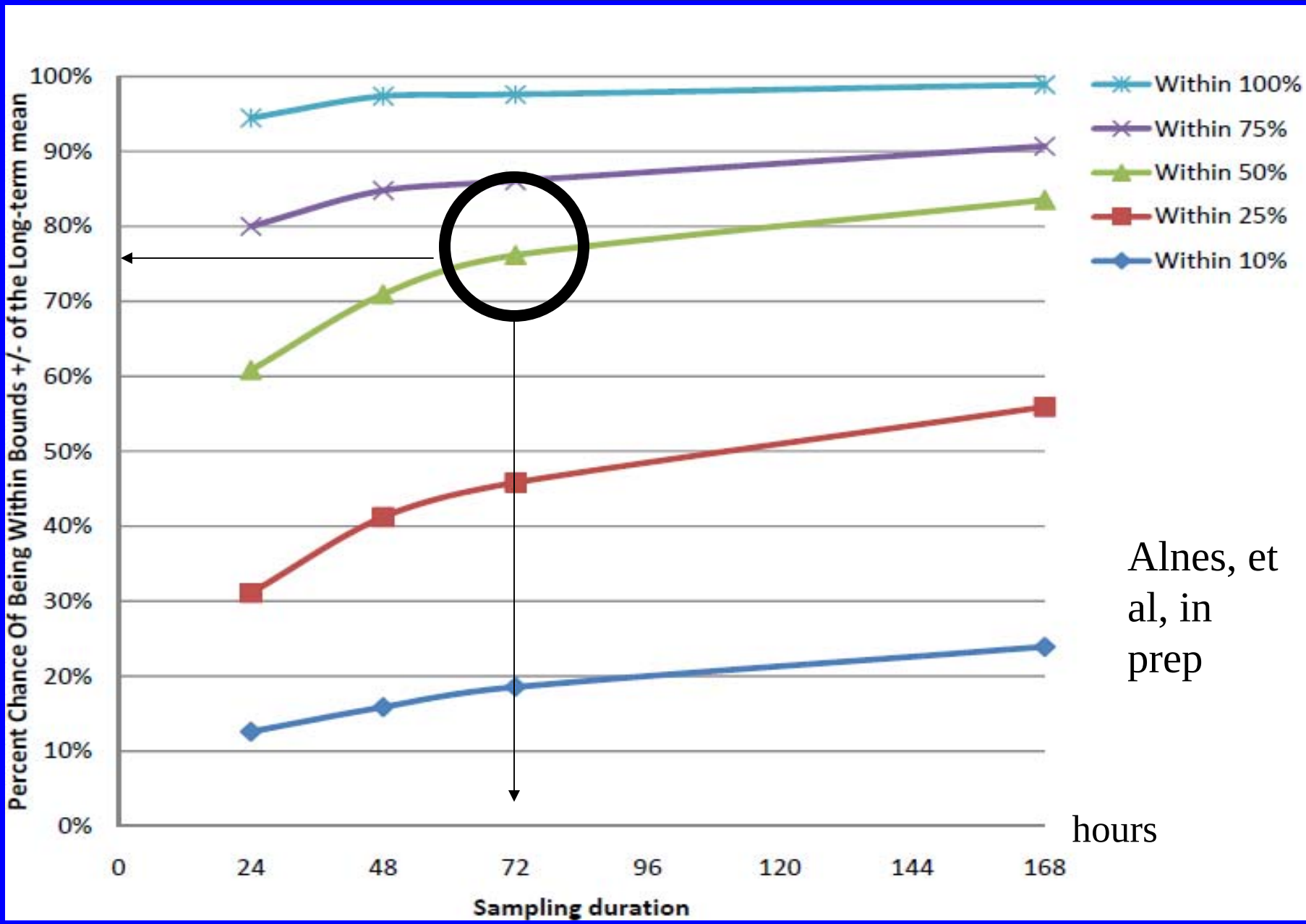
Assessment of “Improved Stoves”

Table 10. Exposure and fuel use variations due to cookstove type*

	Smokeless	Regular	Pit
TSP (mg m^{-3})			
Mean	4.6	6.4	6.2
Standard deviation	(2.9)	(4.6)	(1.9)
a.m. (mean)	3.0	4.7	7.1
p.m. (mean)	5.8	7.7	5.3

Smith, et al., 1983

How Close to the True Mean With One Measurement?

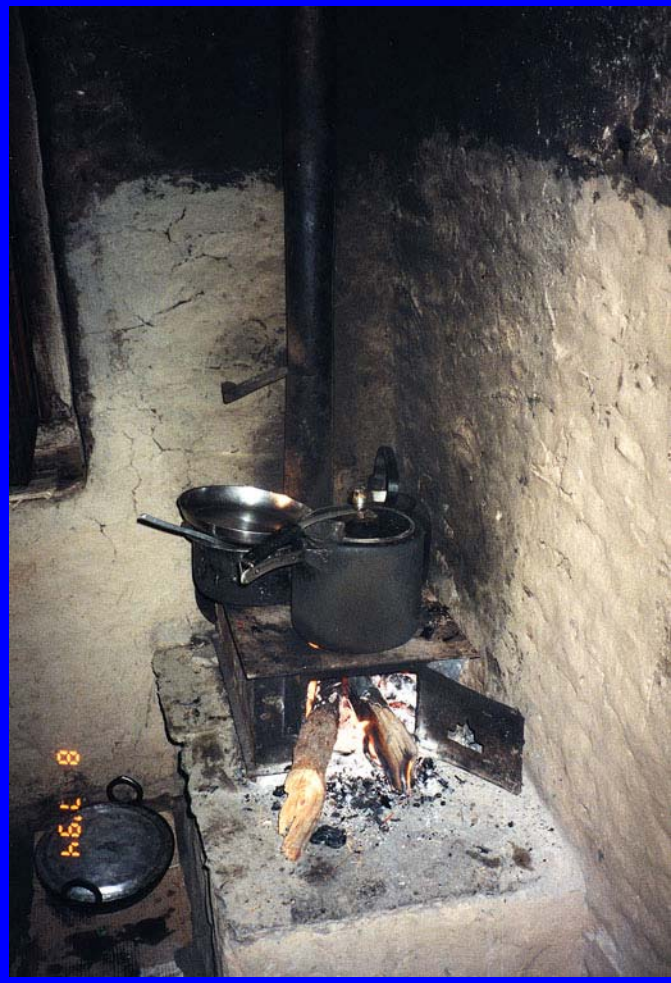


Alnes, et al, in prep

Improved Stoves in Gujarat?

So-called Improved Stoves

Often are Not



Measurement of Neighborhood Pollution

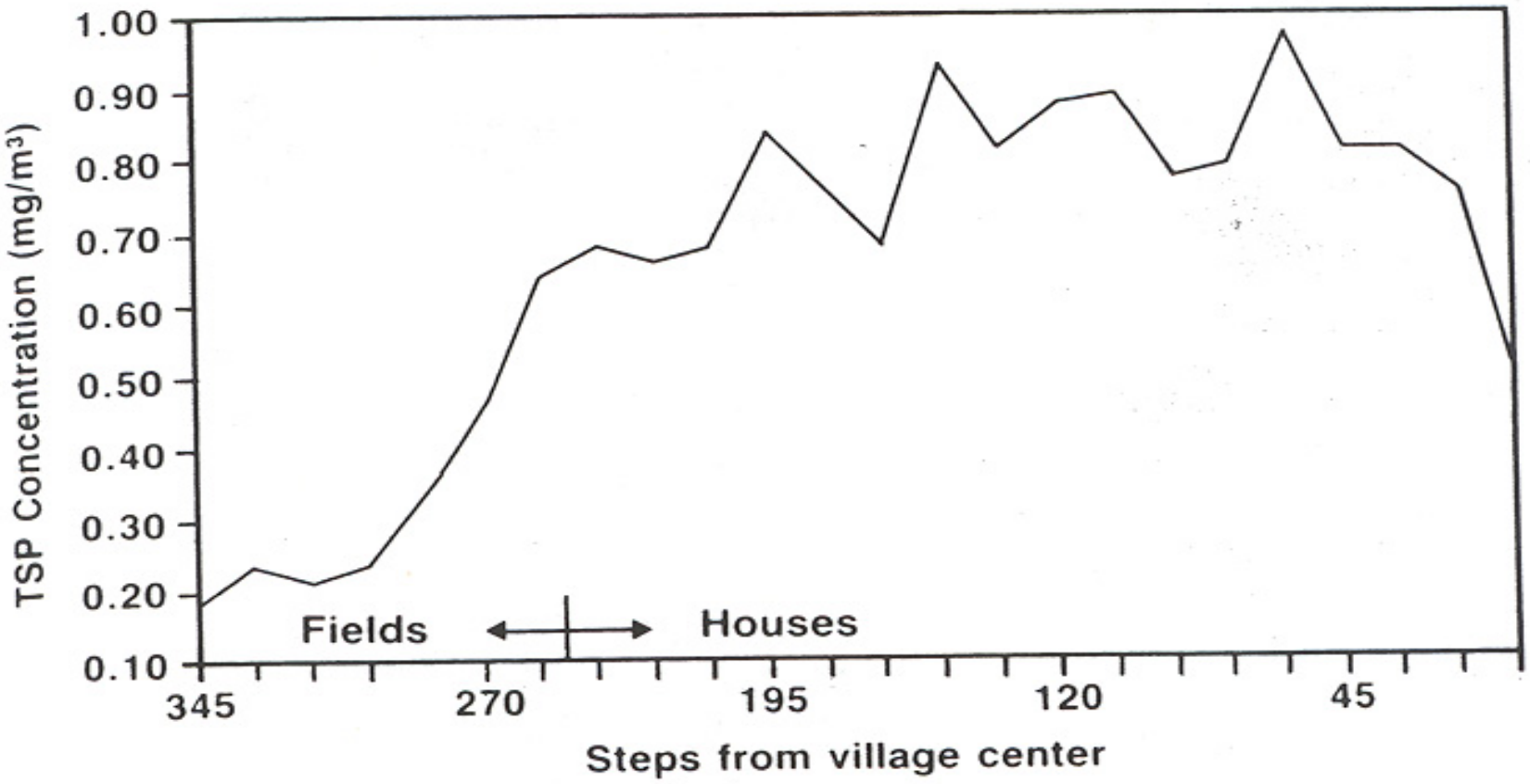
Table 5. TSP and BaP measurements: ambient levels

Village	Height (m)	Time at start	Duration (minutes)	TSP mg m^{-3}
Meghva	2.5	7:00 p.m.	—	1.48
Denapura	2.5	6:40 p.m.	58	1.14
Denapura	2.5	6:40 p.m.	50	0.50
Rampura	3.5	6:23 p.m.	50	2.5
Rampura	1.5	5:50 p.m.	51	2.5
Vallabh Vidyanagar*	1.5	5:55 p.m.	150	0.6

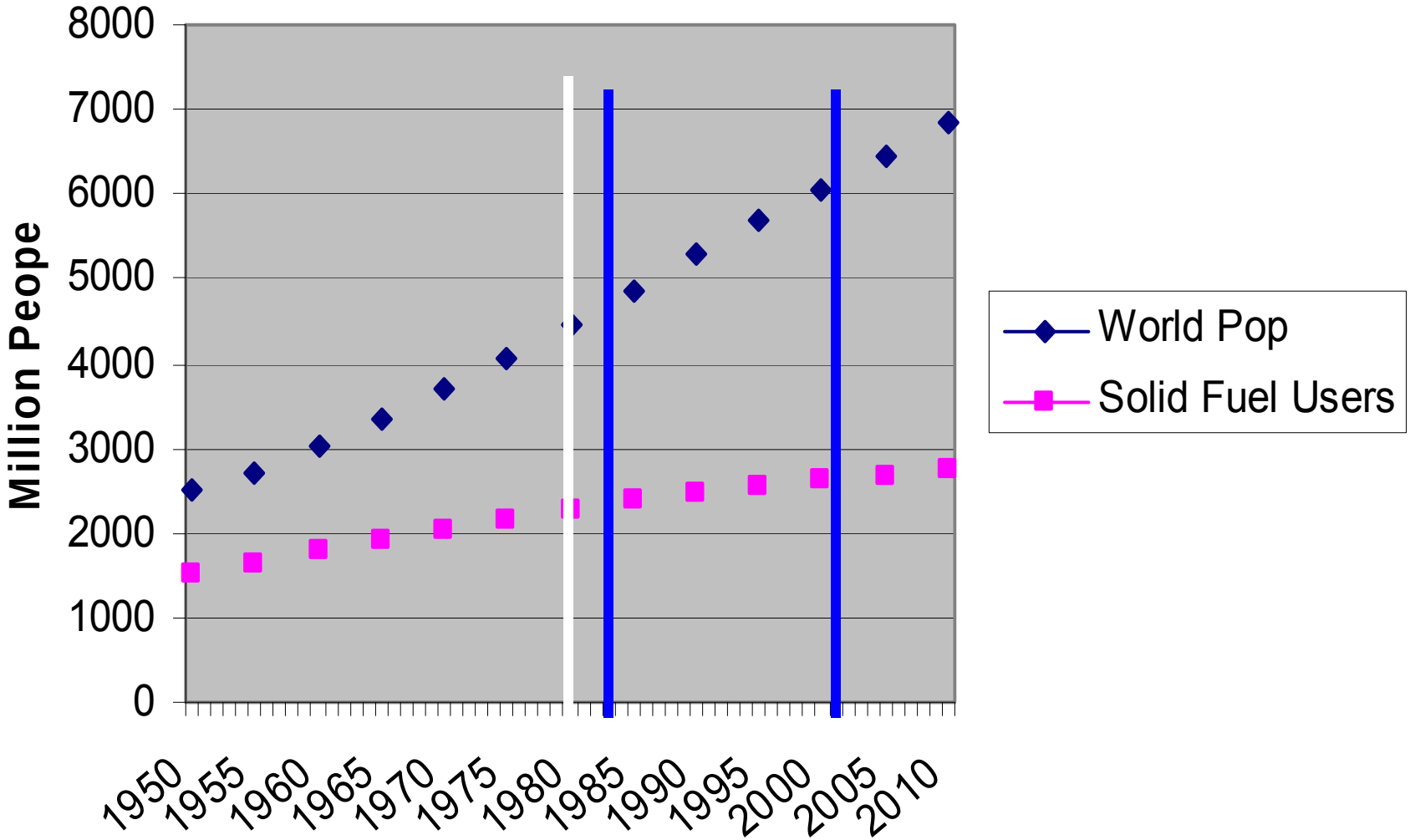
* Semi-urban area.

Smith, et al., 1983

Neighborhood Pollution in an Indian Village



First Randomized Controlled Trial



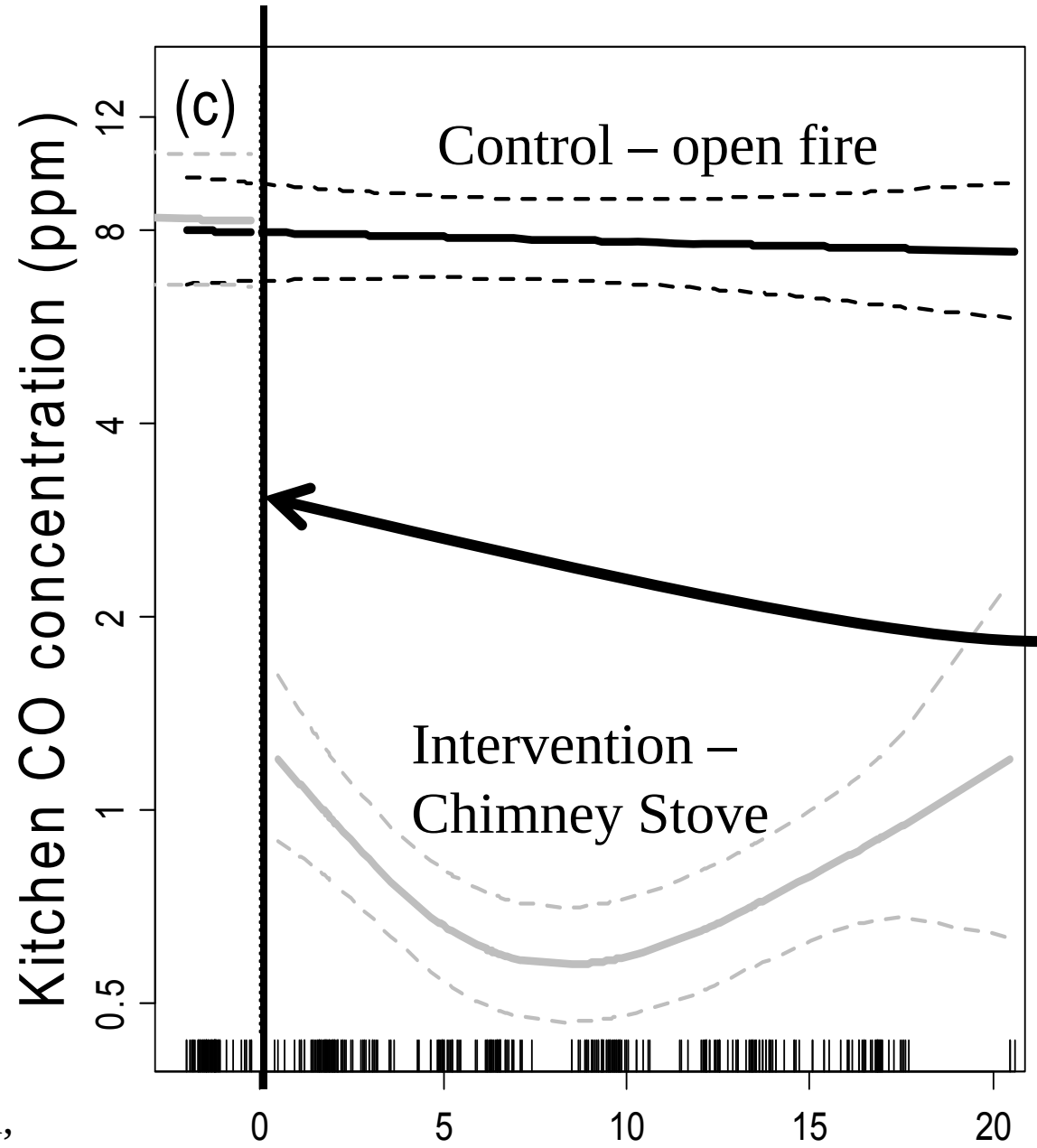
Now We Know That Even Good Chimney Stoves are not Enough

Traditional open 3-stone fire: kitchen 48-hour $PM_{2.5}$ levels of 600 - 1200 $\mu g/m^3$

Chimney wood stove, locally made and popular with households


Tubito
Tubito

Guatemala RCT: Kitchen Concentrations

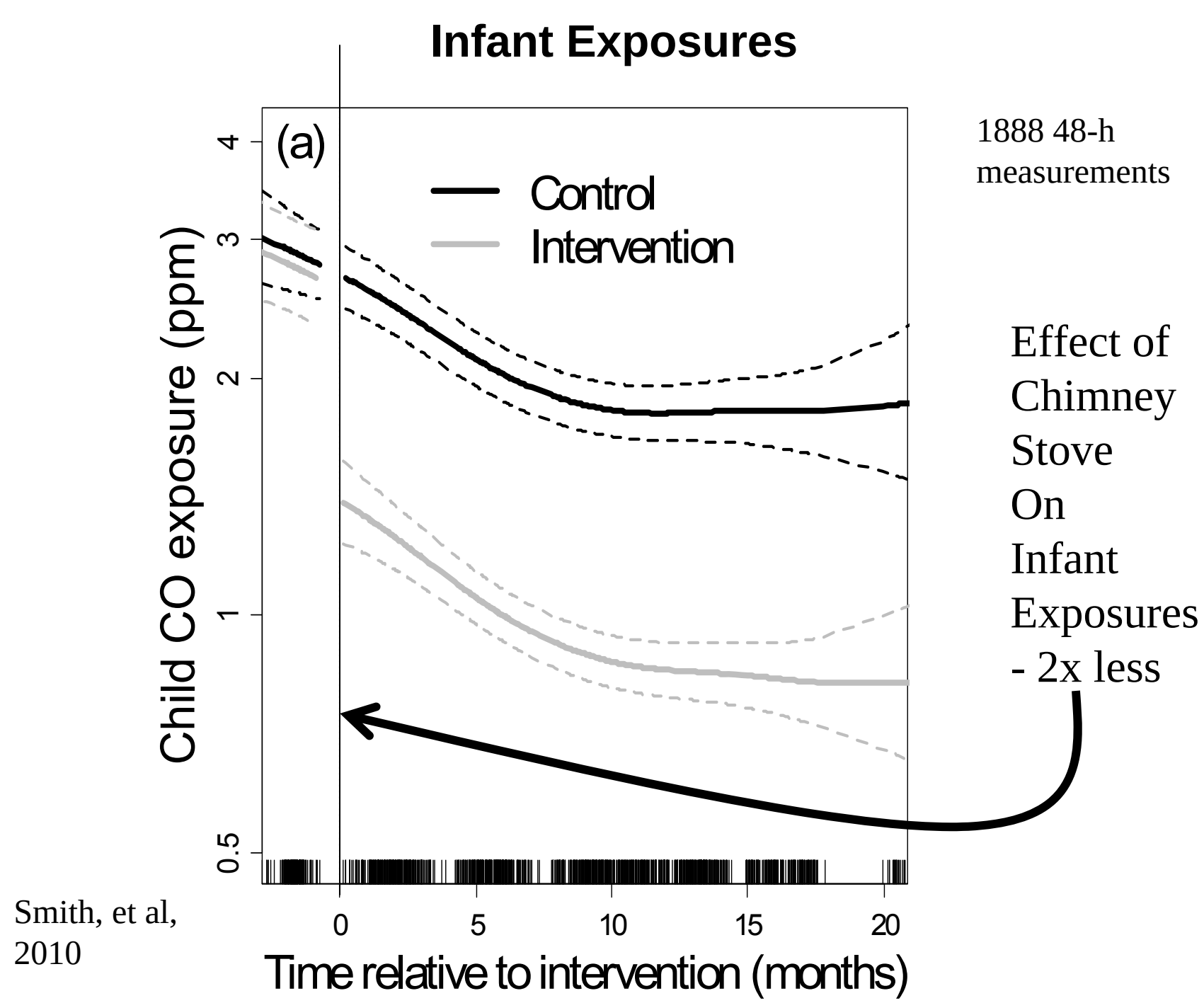


Effect of Chimney Stove On Kitchen CO Levels

Factor of ~10 less

285 48-h measurements

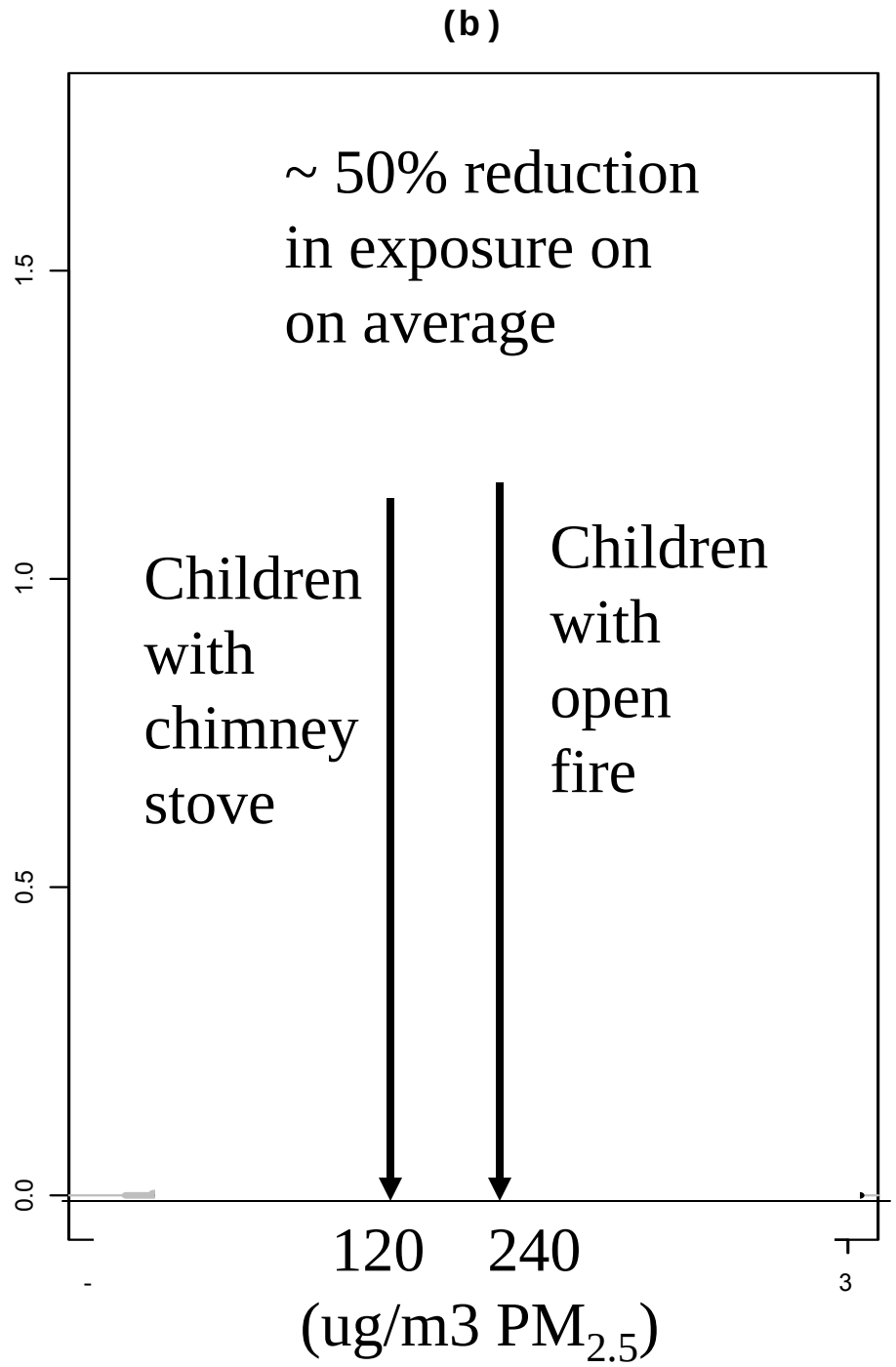
Smith, et al, 2010



1888 48-h measurements

Effect of Chimney Stove On Infant Exposures - 2x less

Smith, et al, 2010



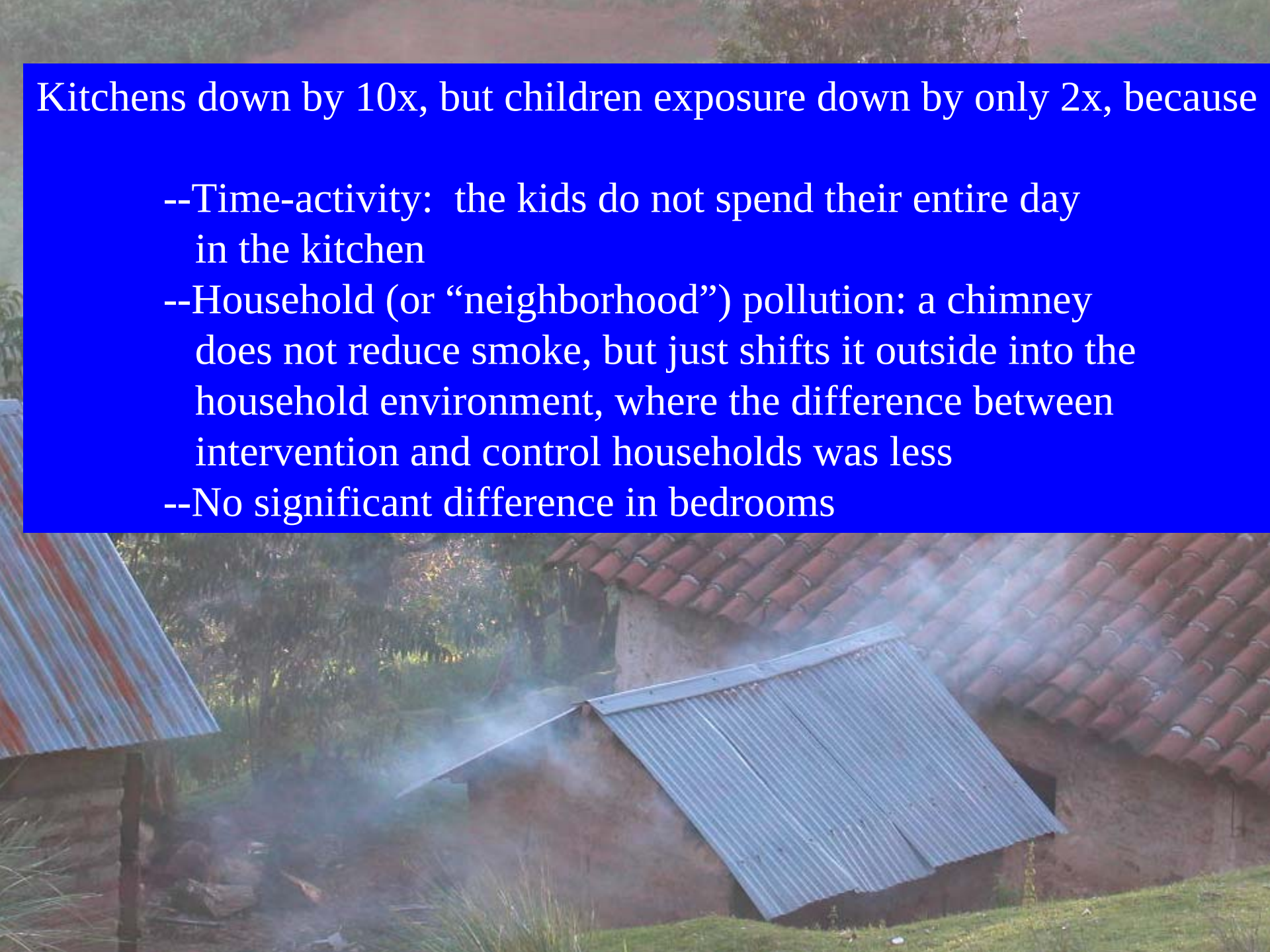
Chimney stove did not protect all children

Kitchens down by 10x, but children exposure down by only 2x, because

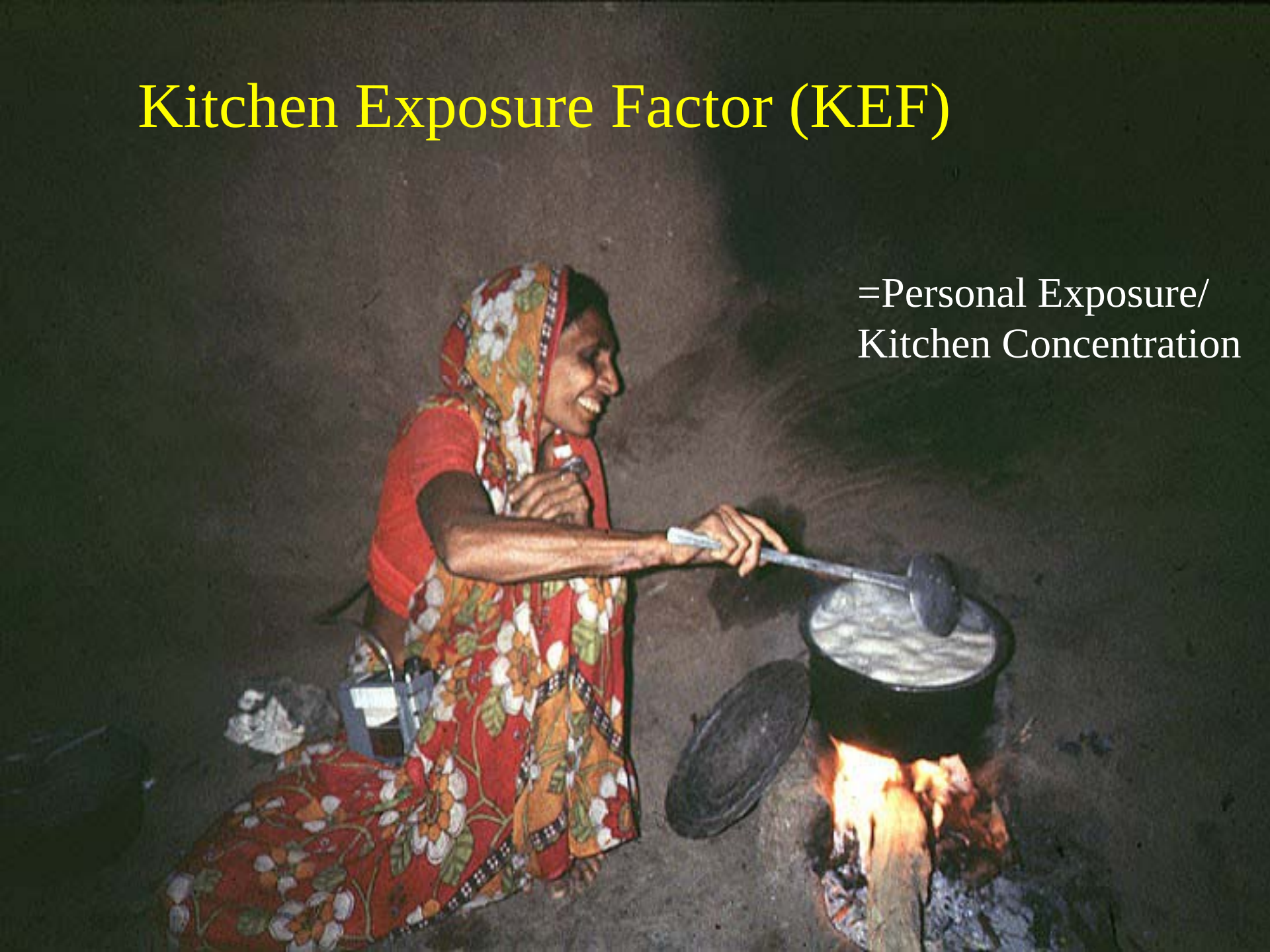
--Time-activity: the kids do not spend their entire day in the kitchen

--Household (or “neighborhood”) pollution: a chimney does not reduce smoke, but just shifts it outside into the household environment, where the difference between intervention and control households was less

--No significant difference in bedrooms



Kitchen Exposure Factor (KEF)

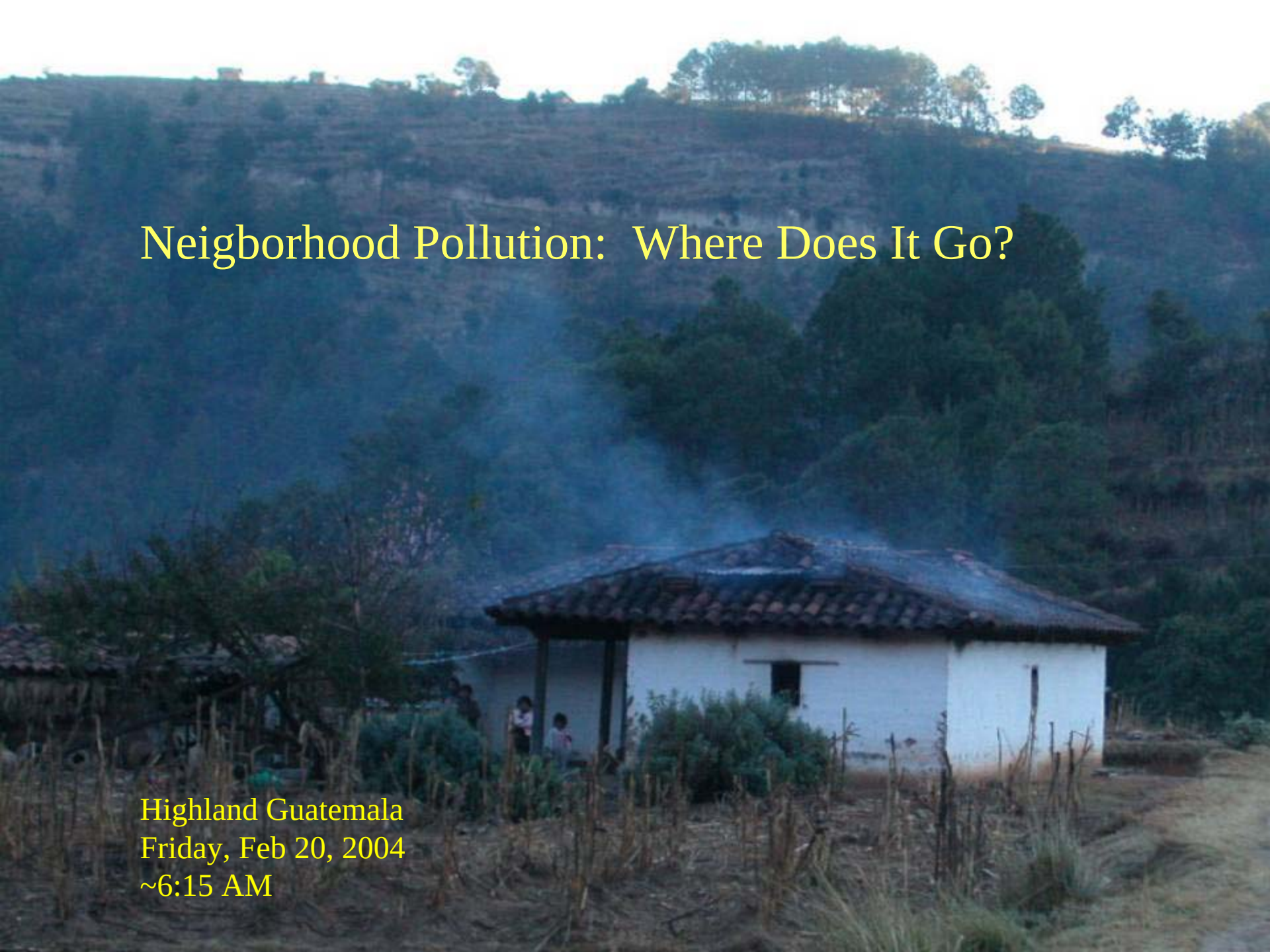


=Personal Exposure/
Kitchen Concentration

Kitchen Exposure Factor (KEF)

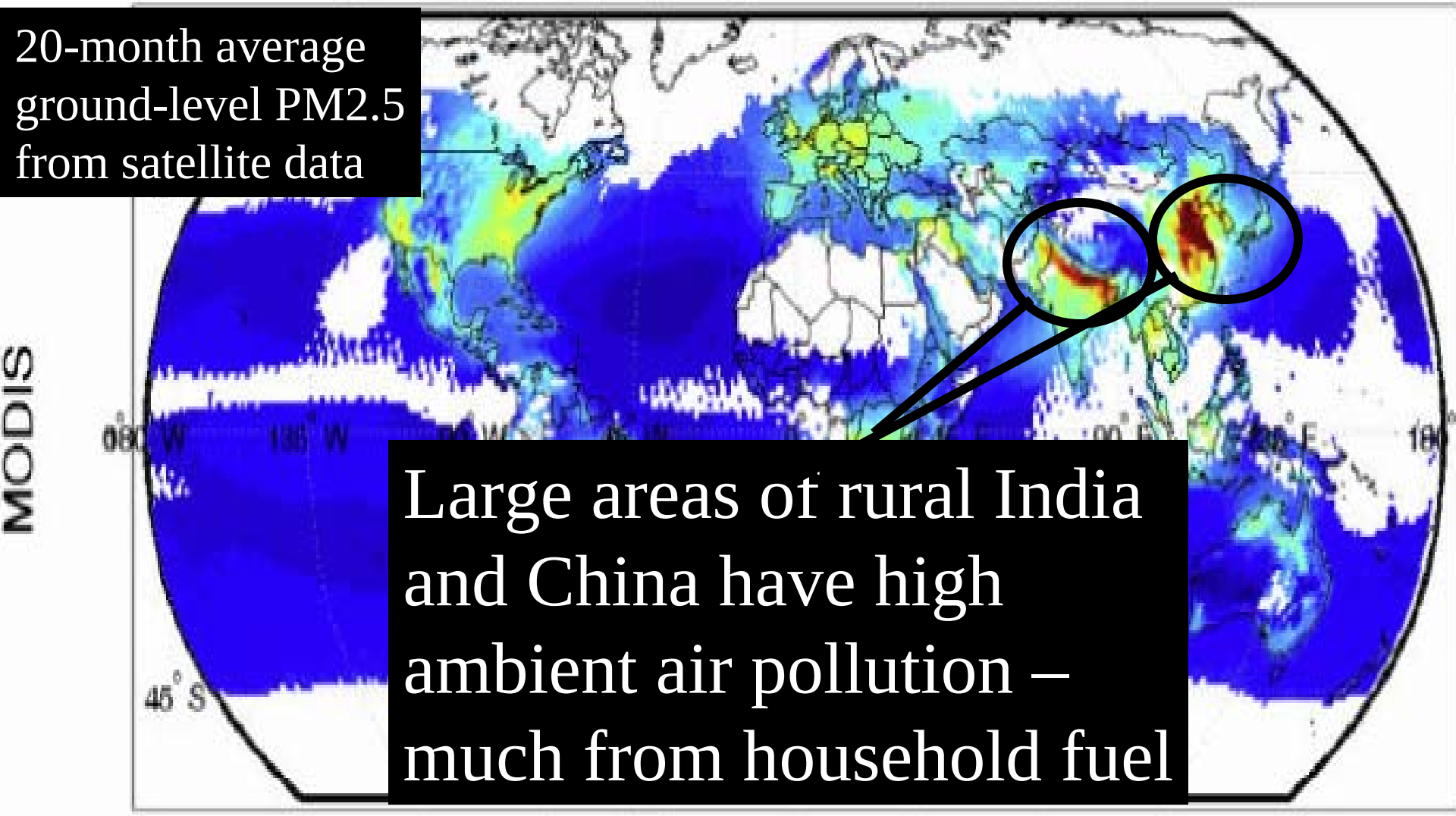
- In RESPIRE, kitchen levels went down by a factor of ten due to the chimney stoves
- But the KEF went up by a factor of five
- Result was only a factor of 2 improvement in exposure

Neigborhood Pollution: Where Does It Go?

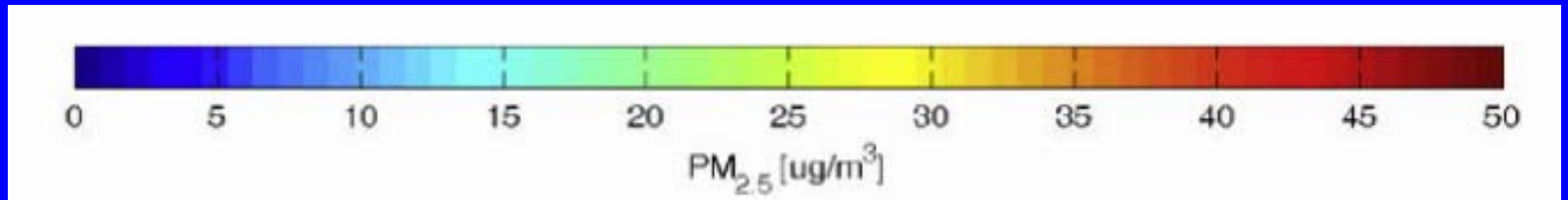


Highland Guatemala
Friday, Feb 20, 2004
~6:15 AM

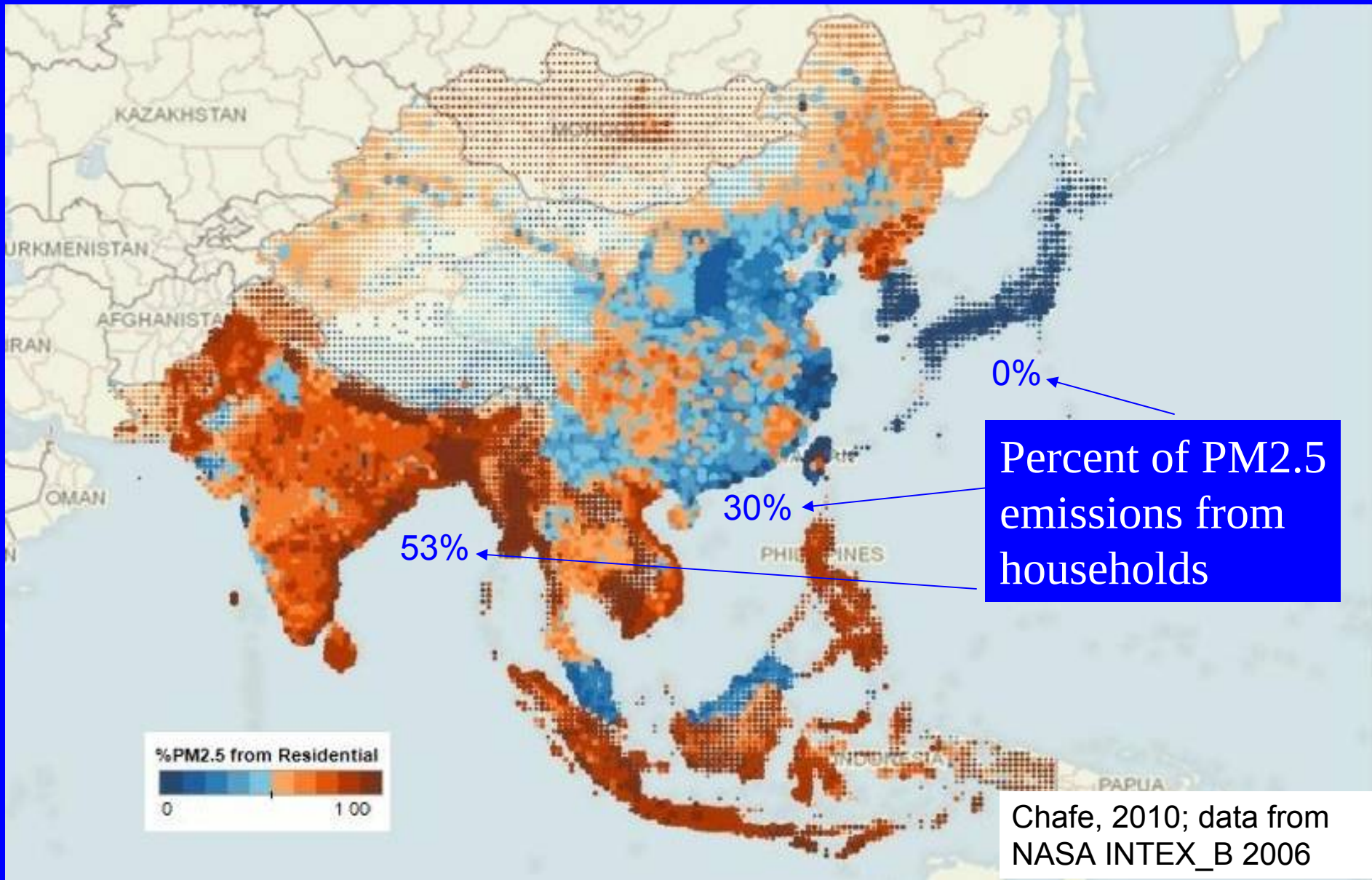
20-month average ground-level PM2.5 from satellite data



Large areas of rural India and China have high ambient air pollution – much from household fuel



NASA INTEX_B Database
Percent $PM_{2.5}$ emissions from households

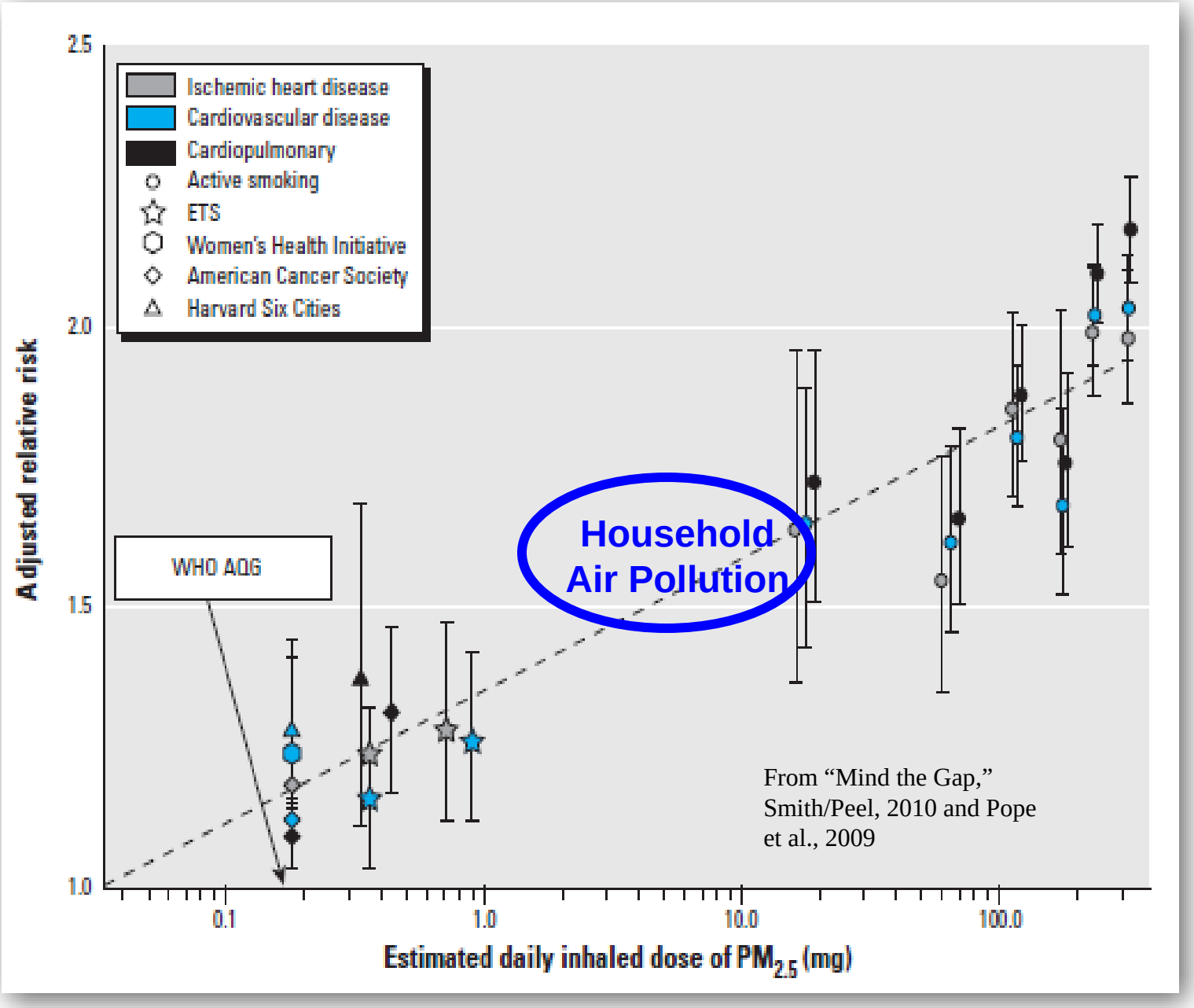


Chafe, 2010; data from NASA INTEX_B 2006

Why we need really clean combustion

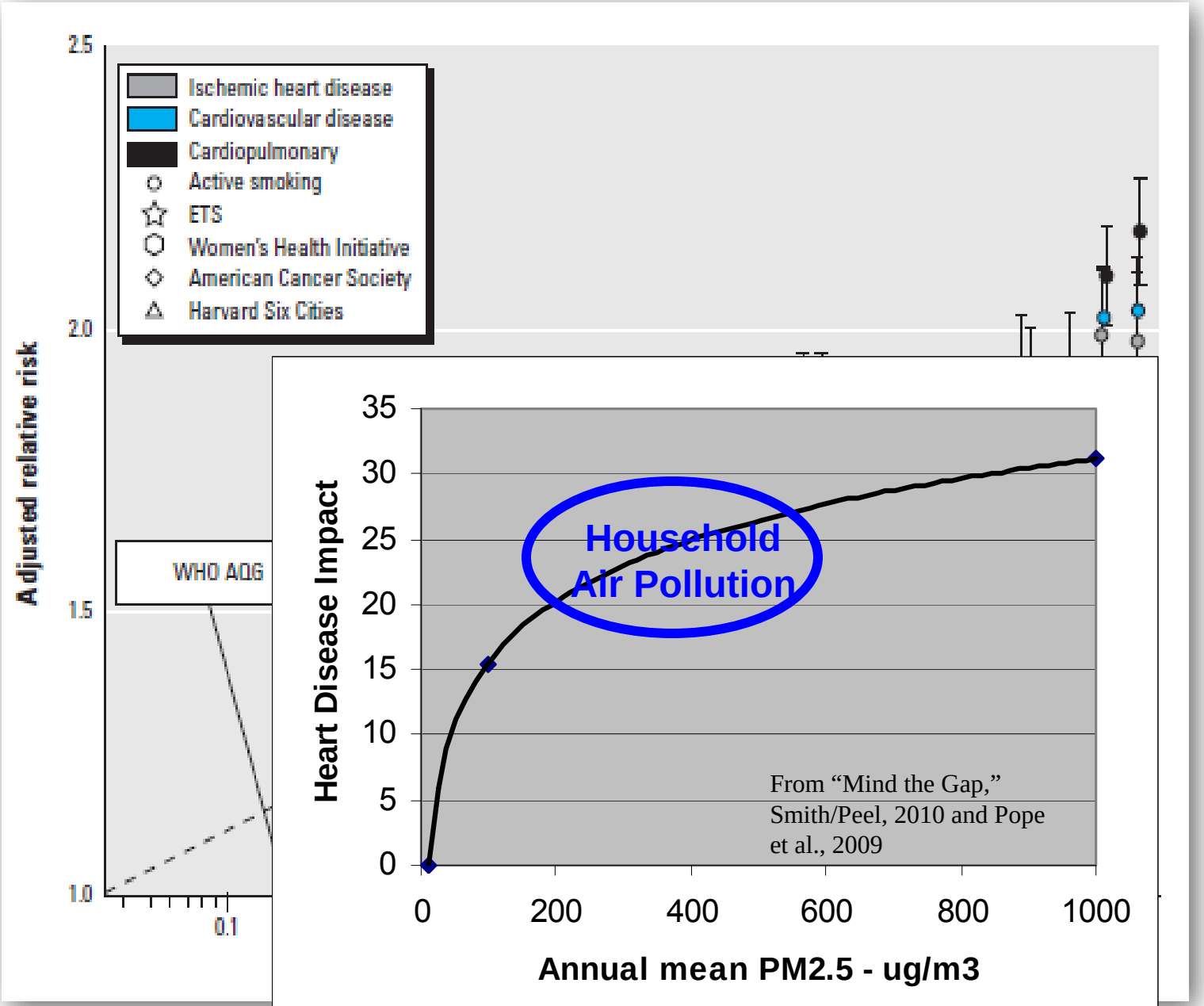
- Chimneys by themselves do nothing for outdoor air pollution or climate
- We now know they do not help very much with health – only a factor of two reduction in exposure
- This is not enough to either reach WHO Air Quality Guidelines
- Or to obtain the health benefits needed

Heart Disease and Combustion Particle Doses



From "Mind the Gap," Smith/Peel, 2010 and Pope et al., 2009

Heart Disease and Combustion Particle Doses



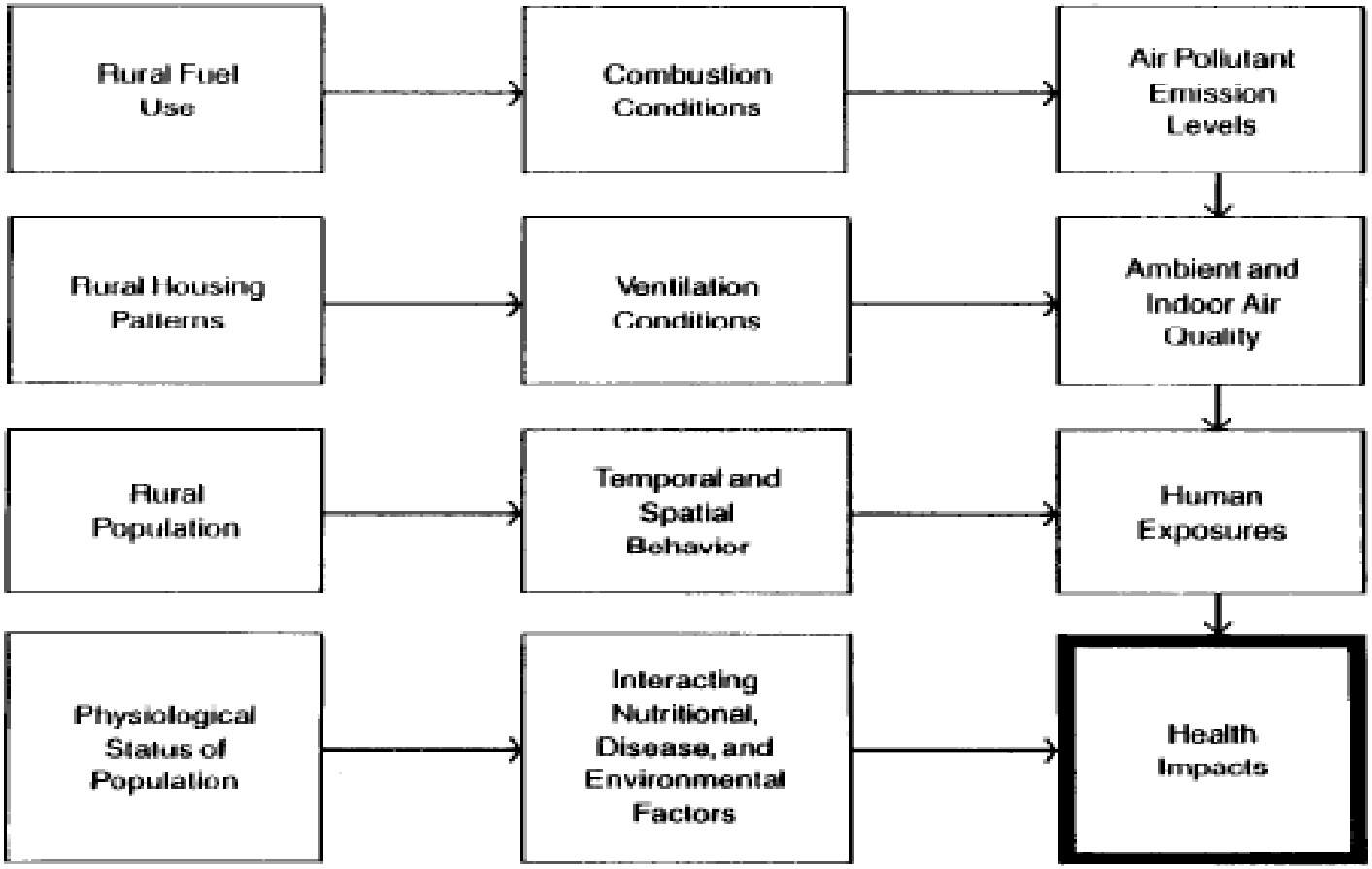


Fig. 1. Categories of research topics for investigating the extent and impact of air pollutant exposures from combustion of traditional biomass fuel in developing countries.

Smith, et al., 1983

Wood is the fuel that

- Heats you twice as Thoreau said?
  - Once when you chop it and
  - Once when you burn it
- Or four times?
  - The fever from respiratory infection and
  - Global warming
- Better combustion will get rid of the second pair

Publications (including the 1983 paper) and presentations available at my website. Just “google” Kirk R. Smith

Thank You