Impact of improved cookstoves on women's and child health in low and middle income countries

a systematic review and meta-analysis

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Impact of improved cookstoves on women's and child health in low- and middle-income countries: a systematic review and meta-analysis

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ABSTRACT

Objectives Improved biomass cookstoves may help reduce the substantial global burden of morbidity and mortality due to household air pollution (HAP) that disproportionately affects women and children in low- and middle-income countries.

Design Systematic review and meta-analysis of (quasi-)experimental studies identified from 13 electronic databases (last update: 6 April 2018), reference and citation searches, and via expert consultation

Setting Low- and middle-income countries

Participants Women and children

Interventions Improved biomass cookstoves

Main outcome measures Low birth weight, preterm birth, perinatal mortality, paediatric acute respiratory infections (ARIs), COPD among women.

Results We identified 53 eligible studies, including 24 that met pre-specified design criteria. Improved cookstoves had no demonstrable impact on paediatric lower ARIs (three studies; 11,560 children; incidence rate ratio (IRR)=1.02 (95%CI 0.84-1.24)), severe pneumonia (two studies; 11,061 children; IRR=0.88 (95%CI 0.39-2.01)), low birth weight (one study; 174 babies; odds ratio (OR)=0.74 [95%CI 0.33-1.66]) or miscarriages, stillbirths, and infant mortality (one study; 1176 babies; RR change=15% [95%CI –13-43]). No (quasi-)experimental studies assessed preterm birth or COPD. In observational studies, improved cookstoves were associated with a significant reduction in COPD among women: two studies, 9757 participants; RR=0.74 (95%CI 0.61-0.90). Reductions in cough (four studies, 1779 participants; risk ratio (RR)=0.72 [95%CI 0.60-0.87]), phlegm (four studies, 1779 participants; RR=0.65 [95%CI 0.52-0.80]), wheezing/breathing difficulty (four studies; 1779 participants; RR=0.41 [95%CI 0.29-0.59]) and conjunctivitis (three studies, 892 participants; RR=0.58 [95%CI 0.43-0.78]) were observed among women.

Conclusion Improved cookstoves provide respiratory and ocular symptom reduction and may reduce COPD risk among women, but had no demonstrable child health impact.

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What is the key question

- Pending the much-needed transition to using cleaner fuels, can improved cookstoves help reduce morbidity and mortality due to household air pollution from biomass combustion among women and children in low- and middle-income countries?

What is the bottom line

- Meta-analyses indicate that improved biomass cookstoves can decrease respiratory and ocular symptoms among women; no demonstrable impact on perinatal or child health was observed

Why read on

- This is the first meta-analysis assessing the health impact of improved cookstoves, providing valuable information for agenda-setting to reduce the substantial global burden of morbidity and mortality from household air pollution

INTRODUCTION

Solid biomass fuel is used as a primary cooking source by more than half of the world's population.[1-3] About three-fourths of this use occurs in developing countries.[1] The combustion of biomass fuels results in pollutants such as carbon monoxide (CO) and particulate matter (PM), creating household air pollution (HAP) when produced inside.[2] HAP results in a high burden of morbidity and mortality globally, disproportionately affecting low- and middle-income countries (LMICs).[1-5] Globally, HAP was estimated to have caused 2.8 million deaths and 85.6 million disability-adjusted life years (DALYs) in 2015.[4]

In LMICs, women are traditionally at home taking care of the household, cooking, and tending to the children, whereas men usually work during the day, away from home. Young children are often carried on their mother's back while the latter carry out household chores inside.[3,6] As a result women and young children are particularly exposed to HAP from cooking and heating and are therefore at highest risk of developing HAP-associated adverse health conditions.[2] Several studies have linked maternal exposure to biomass smoke during pregnancy to increased risks of stillbirth, preterm delivery, low birth weight (LBW), and other adverse health effects.[7-9] Exposure to biomass smoke furthermore increases the risk of respiratory infections among children and of chronic obstructive pulmonary disease (COPD) in adults.[3,7]

Switching the use of biofuels for cooking purposes towards clean(er) fuels such as liquefied petroleum gas (LPG), electricity, or solar energy would be the preferred solution to reduce HAP and improve population health.[3,10,11] However this transition is difficult in low-income countries, due to lack of infrastructure, financial constraints, and poor living conditions of households.[1,10,11] As a result, an estimated 1.8 billion people will still be reliant on solid biomass for cooking by 2040.[1] It is therefore essential that alongside facilitating the transition to cleaner fuel options, other measures continue to be developed, tested, and – when successful – implemented to reduce HAP from cooking using solid biomass.[5] Such biomass cookstove improvements include for example adding chimneys and using better combustion centres to increase efficiency. Biomass cookstove improvements are much more cost-effective than switching to cleaner fuels and may be the only affordable short-term solution to reduce HAP for billions of people living in LMICs.[3,11,12]

Several studies have examined the effectiveness of improved biomass cookstoves in reducing HAP and improving health outcomes among its users, yielding seemingly inconsistent findings.[3,11,13,14] Given the substantial global burden of death and disease associated with HAP and the significant contribution of biomass combustion – both current and projected – to this burden, a comprehensive assessment of the available evidence on the effectiveness of biomass fuel cookstove improvements in terms of health benefits is urgently needed. This will provide essential information to policy-makers to guide implementation of measures to reduce the burden from HAP associated with biomass combustion in LMIC areas where transition to cleaner fuels is not yet feasible. We conducted a highly comprehensive systematic review and meta-analysis to investigate the effectiveness of improved cookstoves to reduce adverse pregnancy outcomes and adverse health outcomes in women and children, as well as HAP exposure.

METHODS

Protocol and Registration

The systematic review protocol is registered with PROSPERO (CRD42016033075) and can be accessed at http://www.crd.york.ac.uk/PROSPERO/display_record.asp?ID=CRD42016033075.

Eligibility criteria

Following Cochrane Effective Practice and Organization of Care (EPOC) guidelines,[15] we included randomised controlled trials (RCTs), non-randomised controlled trials (NRCTs), and quasi-experimental studies (i.e. controlled before-after studies (CBA) and interrupted time series studies) studying the impact of an improved biomass cookstove on pregnancy outcomes, child and/or women's health, and/or exposure to HAP. We also identified any studies addressing the research question that had a longitudinal design but did not fit EPOC criteria. Studies were eligible when they were conducted in LMICs, and included women aged 15-65 years and/or children aged 0-14 years. Any study in which more than 50% of the study population fulfilled these age criteria was included. From studies performed among the general population (i.e. including men and women), only women were included, provided they had been analysed as a subgroup. Studies or study arms evaluating cookstoves that did not use solid biomass were not included.

Primary and secondary outcomes were selected based on their established associations with HAP and their relative contributions to the global burden of mortality and morbidity in the prenatal, paediatric, and adult periods.[3,4,7-9,16-18] The primary and secondary pregnancy, child, and women outcomes are listed in panel 1.

Information sources

We carried out a systematic and comprehensive bibliographic search using electronic databases: PubMed, EMBASE, Google Scholar, World Health Organization (WHO) Global Health Library (in addition to MEDLINE covering African Index Medicus (AIM), LILACS, Index Medicus for the Eastern Mediterranean Region (IMEMR), Index Medicus for South-East Asia Region (IMSEAR), Western Pacific Region Index Medicus (WPRIM), WHO Library Database (WHOLIS) and Scientific Electronic Library Online (SciELO)), and the Cochrane Central Register of Controlled trials (CENTRAL) for relevant published studies, and the WHO International Clinical Trials Registry Platform for unpublished studies. References and citations of each eligible study were also checked by hand for additional studies that met our eligibility criteria. An expert in the field was approached in an attempt to identify any additional eligible studies.

Search

The initial search was conducted on 22 February 2016 and was updated on6 April 2018. Full electronic searches for each database are provided in web appendix page 2-3. No restrictions were imposed with regard to language in which the report was published or publication date.

Study selection

The selection process consisted of two rounds: a selection based on title and abstract, and then screening of full-text articles for eligibility. Two reviewers (MT and PAWN) independently performed the searches and assessed eligibility. The final selection was based on consensus, with arbitration by a third reviewer (JVB or CPvS) in the case of disagreement.

Panel 1: Primary and secondary outcomes.		
Prenatal outcomes	*Primary outcomes*	Low birth weight (birth weight < 2500 grams) Preterm birth (birth before 37 weeks of gestation) Perinatal mortality (stillbirth + early neonatal mortality)
	Secondary outcomes	Small for gestational age (birth weight < 10th centile for gestational age) Stillbirth Early neonatal mortality (death within 7 days after birth) Neonatal mortality (death within 28 days after birth) Birth weight (continuous scale) Gestational age (continuous scale)
Child outcomes	*Primary outcome*	Acute respiratory infections (including pneumonia)
	Secondary outcomes	Otitis media with effusion Wheezing/asthma (including exacerbations) Conjunctivitis Death due to respiratory disease Chronic cough Lung function outcomes (PEFR, FEV1, FVC, FEV1/FVC) HAP concentrations ($PM_{2.5}$, PM_{10}, CO)
Outcomes in women	*Primary outcome*	Chronic obstructive pulmonary disease (COPD)
	Secondary outcomes	Chronic cough Chronic phlegm Acute respiratory infections (including pneumonia) Wheezing/asthma (including exacerbations) Death due to respiratory disease Conjunctivitis Lung function outcomes (PEFR, FEV1, FVC, FEV1/FVC) HAP concentrations ($PM_{2.5}$, PM_{10}, CO)

Abbreviations: PEFR= peak expiratory flow rate; FEV1= forced expiratory volume in 1 second; FVC = forced vital capacity; HAP= household air pollution; PM= particulate matter; CO= carbon monoxide

Data collection process

Two reviewers independently extracted relevant data from eligible studies (MT and PAWN for (quasi)experimental studies; JFK and EAB for longitudinal observational studies) using a customised form based on the Cochrane Public Health Group data extraction form.[19] Extracted data items were crosschecked between the reviewers, with any disagreement being resolved through consensus or via arbitration by a third reviewer if necessary (JVB or CPvS).

Data items

A comprehensive set of data items was extracted, including: full reference; publication type; year of publication; setting (country, rural vs. urban), study design, duration of the study, sample size, type of intervention, type of control, type of participants, outcomes (including definition and measurement level/location), and follow-up time.

Risk of bias in individual studies

Two reviewers independently assessed the risk of bias of individual studies (MT and PAWN for (quasi)experimental studies; JFK and EAB for longitudinal observational studies) using the Effective Public Health Practice Project (EPHPP) Quality Assessment Tool for Quantitative Studies.[20] Any disagreement was resolved by consensus or by consulting a third reviewer if necessary (JVB or CPvS). Risk of bias was not used to determine eligibility of individual studies to be included in this review.

Summary measures

The following effect measures were extracted: numbers of participants with adverse outcomes by intervention allocation and corresponding odds ratios (OR)/risk ratios (RR) for dichotomous outcomes; mean and standard deviation, and/or median and (inter-quartile) range for continuous outcomes within groups and corresponding between-group differences. Where possible, 95% confidence intervals (CI) were calculated for each measure if these had not been provided in the article. If relevant data items were missing from reports, authors were contacted to obtain these.

Statistical analysis

Main findings from the systematic review, including characteristics and key findings of individual studies are presented in tabular form. Where possible, we combined data from individual studies in random-effects meta-analysis. If authors adjusted for confounders, we selected the effect estimates of the most adjusted model presented. Effect estimates from cluster-RCTs were combined with those from non-clustered studies only when the cluster-RCTs had been analysed at the individual level, with clustering having been accounted for. One study reported separate effect estimates for two regions;[21] these were pooled using meta-analysis prior to pooling with effect estimates from other studies. Heterogeneity across studies was assessed both qualitatively as well as quantitatively using I^2 test. Due to the low number of studies in individual meta-analyses, I^2 results were not used to assess whether meta-analysis was appropriate. Risk of bias across studies was assessed visually using funnel plots when at least ten studies were available for an outcome. We pre-specified to conduct subgroup analyses for children under five years of age, and according to whether cooking was done in a separate kitchen. In an attempt to minimise risk of bias introduced by study designs with limited potential for attributing causality, our primary analyses were conducted using only (quasi)experimental studies. In a sensitivity analysis for the primary outcomes, we conducted separate meta-analyses also including any longitudinal observational studies. All analyses were done with Stata SE 14.

RESULTS

Study selection and characteristics

We screened 5195 records and identified 24 (quasi)experimental and 29 longitudinal observational studies as eligible for inclusion in our review (Figure 1). Five ongoing studies were identified (web appendix page 4). Study characteristics for (quasi)experimental studies are provided in Table 1 and for longitudinal observational studies in web appendix page 5-14. Among the (quasi)experimental studies, 21 were RCTs (six cluster RCTs),[22-42] two were NRCTs,[21,43] and one was a CBA study.[44] (Quasi)experimental studies were conducted in rural areas across Asia, Africa, and Central America:

China (n=1),[44] Ghana (n=2),[24,31] Guatemala (n=9),[25,28-30,36-39,43] India (n=2),[26,42] Malawi (n=2),[27,41] Mexico (n=3),[31,33,5] Pakistan (n=1),[21] Peru (n=1),[40] Rwanda (n=1),[34] and Senegal (n=2).[22,23] Eight reports described findings from the RESPIRE trial in Guatemala,[25,28-30,36-39] three were part of the same RCT in Mexico,[31,33,35] and two reports from Senegal described the same data.[22,23] All studies had traditional stove use as control group, including open fires, three-stone stoves, and brick, clay, or coal stoves. The most common cookstove improvements were: better conservation of heat, optimised combustion centres, and the addition of chimneys to vent smoke away (web appendix page 15-16). Pregnancy outcomes were assessed in two studies,[26,39] child health outcomes in six studies,[26,28,36,40,41,43] and health outcomes among women in sixteenstudies.[21,23-27,29,30,32-34,36,38,39,42,43] HAP was assessed at individual level in fourteen studies (two in children; [28,36] eleven in women[24,25,27,29-32,36,38,39,42]; and one in both women and children[26]) and at household level in five studies.[21,31,34,36,44] The 29 longitudinal observational studies included in this review were carried out in rural settings across Latin America (11 studies),[45-55] Asia (nine studies),[56-64] and Africa (nine studies).[65-73] Twenty-two were uncontrolled before-after studies,[45-49,51,53-56,58-61,63,65,66,68-73] four were prospective cohort studies,[50,52,64,67] and three were retrospective cohort studies.[57,61,62] Additional details on the longitudinal observational studies are provided in web appendix page 5-14.

Risk of bias assessment

Fourteen (quasi)experimental studies were deemed to have a low risk of bias, nine had moderate, and one had a high risk (web appendix page 17-18). Among longitudinal observational studies, risk of bias was high for four, moderate for nineteen, and low for six studies (web appendix page 19-20).

Impact of improved cookstoves on primary outcomes

Primary analyses using (quasi)experimental studies

Six (quasi)experimental studies reported effect estimates for the primary outcomes (Table 2).[26,35,37,39-41] All relevant cluster-RCTs were analysed at the individual level and accounted for clustering; effect estimates could thus be combined with those from individual-level RCTs in meta-analyses. Among the primary outcomes, meta-analysis of (quasi)experimental studies was only possible for paediatric ARIs. There was no significant change in paediatric lower ARIs (including pneumonia; three studies, 11,560 children; incidence rate ratio (IRR): 1.02 (95%CI 0.84 to 1.24; Figure 2A)[37,40,41] or in severe pneumonia in meta-analysis (two studies, 11,061 children; IRR 0.88 (95%CI 0.39 to 2.01; Figure 2B).[37,41] In another study, improved cookstoves significantly decreased the duration of upper and lower respiratory infections (IRR 0.79 [95%CI 0.70 to 0.89] and IRR 0.41 [95%CI 0.21 to 0.80], respectively), with evidence of a dose-response relationship, with health impact in the intervention group being larger in households using mainly the improved cookstove versus those co-using the traditional cookstove.[35]

No observable effects of cookstove improvements on low birth weight (174 babies; odds ratio (OR) 0.74 [95% confidence interval (CI) 0.33 to 1.66])[39] or infant mortality, stillbirths, and miscarriages (1176 babies; relative risk (RR) change 15% [95%CI –13 to 43])[26] were seen in individual studies. No (quasi)experimental studies assessed the impact of improved cookstoves on preterm birth or COPD among women. One study described a trend towards reduction in ‘respiratory system disease’ among women responsible for cooking who were allocated an improved cookstove: RR 0.51 (95%CI not reported, p=0.07).[23] This was defined as cough, wheezing, and/or difficulty breathing, and may in part reflect COPD.

Sensitivity analyses using (quasi)experimental and longitudinal observational studies

Consistent with our primary analyses, no significant impact of improved cookstoves on paediatric ARIs was observed in pre-specified sensitivity analyses including findings from longitudinal observational studies (Figure 3A+B). Improved cookstoves were however associated with a significant reduction in COPD among women when combining data from longitudinal observational studies: two studies,[57,64] 9757 participants; RR 0.74 (95%CI 0.61 to 0.90; Figure 3C).

Impact of improved cookstoves on secondary outcomes

Analyses using (quasi)experimental studies

Effect estimates from (quasi)experimental studies for the secondary outcomes are shown in web appendix page 21-28. Meta-analyses were possible for birth weight (continuous scale) and maternal respiratory and ocular symptoms. Improved cookstoves had no statistically significant impact on birth weight in meta-analysis (two studies, 694 babies; difference in means: 82 grams (95%CI –22 to 185 grams; Figure 4A).[26,39] Meta-analyses indicated that, among women, improved cookstoves significantly reduced the incidence of cough (four studies;[21,24,27,33] 1779 participants; RR 0.72 [95%CI 0.60 to 0.87; Figure 4B]), phlegm (fourstudies;[21,24,27,33]1779 participants: RR 0.65 [95%CI 0.52 to 0.80]; Figure 4C), wheezing/breathing difficulty (fourstudies;[21,24,27,33]1779 participants: RR 0.41 [95%CI 0.29 to 0.59]; Figure 4D), and conjunctivitis (three studies; 892 participants: RR 0.58 [95%CI 0.43 to 0.78], Figure 4E).[21,26,33]

Other secondary outcomes were only described in individual studies or in ways that precluded meta-analyses to be performed. Improved cookstoves had no impact on child deaths due to respiratory disease in one study (IRR 0.76 [95%CI 0.17 to 3.37]).[41] No significant impact on cough incidence or duration was observed among children in three studies,[26,40,43] although in a subgroup analysis a significant reduction in cough duration was observed among girls in one study.[43] CO exposure among children living in households with improved cookstoves was significantly decreased compared to controls in two reports from the same study (relative change in geometric means: −0.52% [95%CI −0.56 to −0.47]).[28,36] The impact of improved cookstoves on lung function was reported in four studies.[21,26,33,38] Decline in FEV1 across the study period was significantly smaller in women using an improved cookstove as compared to controls in one study: difference in FEV1 decline 31ml/year (95%CI 7 to 55).[33] In another study, mean peak expiratory flow rate (PEFR) improved significantly among women in one out of two communities where improved cookstoves were introduced.[21] Both studies assessing exhaled CO in women found significant reductions in those who had improved cookstoves.[25,27] Two out of seven studies found significant reductions in personal CO exposure,[36,38] and one out of three in cooking area CO levels.[34] All three studies assessing cooking area $PM_{2.5}$ levels found significant reductions in the improved stove group.[21,31,34] Four out of five studies assessing changes in personal $PM_{2.5}$ exposure found significant reductions in the intervention group.[30-32,34] No studies assessing any of the other pre-defined secondary outcomes were identified.

Findings from longitudinal observational studies

Overall, findings from the longitudinal observational studies suggest that improved cookstoves are associated with reductions in adverse respiratory health outcomes: one study found significant reductions in paediatric pneumonia and severe pneumonia;[67] two of three studies that evaluated chronic respiratory diseases found statistically significant decreases among improved stove users;[57,61,64] three out of six studies found significant improvements in lung function;[51,64,65] and four out of six studies found significant decreases in self-reported respiratory symptoms.[58,65-67] Additionally, these studies provide evidence that improved cookstoves reduce HAP levels: 12 out of 17 studies found that improved cookstoves were associated with significantly decreased kitchen levels of PM pollutants,[46,47,49,53,54,59,62,63,69-71,73] and 13 out of 17 studies found significant decreases in indoor CO levels among improved cookstove users.[45-47,49,50,54,59,60,63,69-71,73] Three out of five studies measuring PM levels,[47,49,54] and eleven out of twelve studies measuring CO levels,[46-50,54-56,68,71,73] found statistically significant reductions in personal exposure among improved cookstove users.

DISCUSSION

Our systematic review provides mixed evidence regarding the impact of improved biomass cookstoves on health outcomes among women and children in LMICs. Few methodologically robust studies assessed our pre-specified primary outcomes. Cookstove improvements had no demonstrable impact on child health outcomes in meta-analyses. No significant impact on adverse pregnancy outcomes was observed in individual studies, and no (quasi)experimental studies assessing COPD among women were identified. In a pre-specified sensitivity analysis, improved cookstoves were associated with a 26% reduction in the incidence of COPD among women. Meta-analyses of secondary outcomes among women further showed reductions in cough by 28%, phlegm by 35%, wheezing by 59%, and conjunctivitis by 42%. Many studies showed that improved cookstoves significantly reduced indoor CO and $PM_{2.5}$ levels and exposure, which likely mediated the observed health benefits.

To our knowledge, this is the first meta-analysis assessing the impact of improved biomass cookstoves on women's and child health in LMICs.[5,11,13] Using a highly comprehensive search strategy as part of a pre-specified review protocol we identified 53 studies relevant to our research question. In our interpretation we focused primarily on evidence derived from studies using the most robust designs as advocated by the EPOC group.[15] There was considerable variation between studies in which outcomes were evaluated and how these were defined, measured, and how effect estimates were expressed. Also, several included reports originate from the same studies, in particular many reports described various findings from a large-scale RCT conducted in rural Guatemala (RESPIRE).[25,29-31,36-39] These aspects eventually restricted the number of studies that could be combined in meta-analyses of individual outcomes, in particular of our pre-defined primary outcomes. For pragmatic reasons we sometimes combined in meta-analyses outcomes which were slightly diverse but likely to assess the same concept (e.g. conjunctivitis and sore eyes; wheezing and/or breathing difficulty). Conducting meta-analyses with few studies is methodologically sound,[74,75] however the findings should be interpreted with care and additional studies are needed – with several already being underway – to increase confidence in the effect estimates. It should furthermore be noted that our pre-specified primary outcomes were often not the primary outcomes of individual studies and hence these studies and the meta-analyses combining them may have had limited power to assess actual impact of the intervention. Follow-up time was likely too short in some studies to effectively assess health impact, whereas studies with longer term follow-up sometimes noted that the health impact waned off, as use of the improved cookstoves was not sustained. Ineffective and unsustained use of improved cookstoves affected outcomes from a number of studies and may have biased the findings towards the null, although at the same time these may be argued to reflect – to some extent – the real-world situation. Given the low number of studies that could be combined in meta-analysis we were unable to assess the relative effectiveness of the different cookstoves or cookstove improvements. Likewise, there were too few studies to allow for our pre-defined subgroup analyses by age group and cooking location to be conducted.

We are aware of two previous systematic reviews assessing the impact of improved biomass cookstoves on HAP indicators.[13,14] Meta-analyses from one review indicated significant reductions in personal PM exposure and kitchen CO and PM concentrations, but were not performed for health outcomes.[14] These HAP improvements are in line with our systematic review findings, where many studies reported positive findings in terms of HAP reduction. Similar to Thomas and colleagues,[13] we experienced that variations in measurement location, expression of between-group differences, and study set-up precluded pooling of HAP indicators in meta-analyses. We identified a greater number of eligible studies assessing the health impact of improved biomass cookstoves than previous reviews despite applying narrower study selection criteria,[13,14] making meta-analysis of health indicators possible for the first time. This is important because, contrary to Quansah and colleagues who based on their qualitative review conclude that "current stand-alone household air pollution interventions yield little if any health benefit",[14] findings from our meta-analyses in fact suggest that improved biomass cookstoves provide significant symptom relief and potential health benefits among women. Importantly, no adverse effects were identified. Ongoing work is thus needed to locally develop, tailor, evaluate, implement, and upscale effective cookstove improvement programs in close collaboration with end-users. Experiences from earlier programs across the globe have generated transferrable lessons in terms of which are the main facilitators and barriers to uptake of improved biomass cookstoves and these should be taken into account when designing local programs.[13,14,76] Likewise, a clear understanding of what enables or precludes sustained use of the improved stoves can help maximise long-term health benefits. Platforms such as the online HAP Intervention Tool enable policy-makers to estimate the potential health benefits of stove improvements locally, taking aspects such as acceptability and sustained use into account.[77]

Several knowledge gaps remain in understanding the health impact of improved cookstoves. Whereas many studies have evaluated their impact on HAP indicators, more work is needed to quantify the potential health benefits. In addition to evaluating health symptoms and short-term benefits, more studies should investigate long-term health impact. Significant reductions in COPD and lung cancer mortality among women were identified in studies in this review,[57,61,64] indicating that the potential health gain may indeed be substantial. Also, more work is needed on evaluating whether improved biomass cookstoves may help reduce adverse pregnancy outcomes. Comparative studies are required to study which particular cookstoves or cookstove improvements (e.g. stoves, more efficient combustion) are most effective, and more studies should take into account cost-effectiveness. It should furthermore be noted that no studies in urban areas were identified by our search. By 2030, an estimated five billion people will live in urban areas, of which two billion will live in slums in LMICs, mainly in Africa and Asia.[78] Many differences exist between rural and urban settings, for example regarding cooking location (e.g. in the possibilities to cook outside) and background environmental air pollution. It is therefore essential that the existing knowledge gap of the potential health impact of improved cookstoves in urban – in particular slum – areas is filled in future research.[79]

From both the health and the environmental perspective, switching from using solid fuels for cooking to using cleaner fuels would be preferred over using improved cookstoves for solid biomass combustion.[10] However as pointed out earlier, financial and infrastructural constraints will likely hamper the transition to cleaner fuel options in the near future.[1,10] Meanwhile, improved cookstoves can help temporarily and cost-effectively reduce some of the health risks associated with cooking using biomass.[12] The consistent signal of symptom reduction and potential health benefit observed among women in our meta-analyses suggest that future studies should move away from using control groups without intervention, at least in rural areas in LMICs. Rather, we suggest that outside the urban context, where randomised studies are still needed, implementation and upscaling studies including quasi-experimental evaluations may be a more appropriate approach to identify context-specific barriers and facilitators in developing culturally appropriate, locally relevant implementation while evaluating and expanding the associated health benefits to wider populations.

Conclusion

Improved biomass cookstoves had no demonstrable impact on child health but reduce airway symptoms and conjunctivitis, and potentially also COPD incidence, among women in LMICs. Considering that billions of people continue to rely on biomass combustion for cooking over the next decades, improved biomass cookstoves may help realise population health gains among women in LMICs pending the transition to using cleaner fuels.

CONTRIBUTORS

MT and PAWN performed electronic searches and study selection, extracted data and performed risk-of-bias assessment for (quasi)experimental studies, and wrote the first version of the manuscript. EAB and JFK extracted data and performed risk-of-bias assessment for longitudinal observational studies and assisted in updating electronic searches and study selection. TF checked the extracted data and performed meta-analyses. GRB co-wrote the manuscript. OCPvS and JVB supervised the various stages of the study and writing of the manuscript. All authors were involved in designing the study and interpreting the findings, and have read and approved the final version of the manuscript.

COMPETING INTEREST STATEMENT

All authors have completed the ICMJE uniform disclosure form at http://www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years, no other relationships or activities that could appear to have influenced the submitted work.

EXCLUSIVE LICENCE

TRANSPARENCY DECLARATION

OCPvS affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained. All authors had full access to the study data and can take responsibility for the integrity of the data and the accuracy of the data analysis.

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PATIENT INVOLVEMENT

No patients were involved in planning or undertaking this research.

DATA SHARING

Full dataset and statistical codes available from corresponding author.

Table 1. Characteristics of included (quasi)experimental studies

First author (year)	Country/ setting	Study design	Participants	Sample size	Study time frame	Type of intervention	Control situation	Outcomes			
								Level of outcome assessment	Eligible outcomes	Definition of outcome	Follow-up
Aung (2016)[42]	India, rural	RCT	Households with one female cook >25 yr who was neither pregnant at enrolment nor a current or previous smoker	N=187; C=91; I=96	Sept 2011-Aug 2012	CDM approved single-pot "rocket-style" biomass cookstove	Three stone stoves	Household	24-h $PM_{2.5}$ exposure	37 mm Teflon filters placed downstream of a cyclone with a 2.5 µm aerodynamic-diameter cut point connected to a battery-operated pump	1 yr
Bensch (2012)[22]	Sene-gal, rural	C-RCT (household level)	Households with no previous access to improved cookstoves	N=253 households; C=155 households; I= 98 households	Nov 2009-Nov 2010	Portable clay/metal firewood stove (Jambar)	Three-stone stoves; traditional metal wood stoves	Household	Respiratory system disease (cough, asthma, difficulty breathing); eye problems	Self-reported symptoms	1 yr
Bensch (2015)[23]	Sene-gal, rural	C- RCT (household level)	Households with no previous access to improved cookstoves	N=253 households; C=155 households; I= 98 households	Nov 2009-Nov 2010	Portable clay/metal firewood stove (Jambar)	Three-stone stoves and traditional metal wood stoves	Household; individual (women responsible for cooking)	Respiratory system disease (cough, asthma, difficulty breathing); eye problems	Self-reported symptoms	1 yr
Burwen (2012)[24]	Ghana, rural	RCT	One woman per household (most frequently responsible for cooking)	N= 768; C=366; I=402	Feb-May 2009	Improved cookstove (unspecified)	Traditional L-shaped or U-shaped three-stone fire	Individual	CO exposure during cooking; cough; difficulty breathing; chest pain; excessive mucus	CO: Gastec 1DL CO Passive Diffusion tubes; Self-reported symptoms	8 mo
Diaz (2007)[25]	Guate-mala, rural	RCT	Pregnant women or families with child <4 mo	Group A: N=300; C=147; I=153 Group B: N=204; C=98; I=106	Oct 2002-Dec 2004	Plancha stove	Traditional open fire	Individual	Sore eyes; exhaled CO	Sore eyes assessed with a health questionnaire, re-assessed every 6 mo; Exhaled CO measured with a Micro Medical Micro CO monitor	12 mo (group A); 18 mo (group B)
Hanna (2012)[26]	India, rural	C-RCT (household level)	Eligibility criteria not reported	N=2651 households; first 1/3 within each village received stoves at start of project, second 1/3 received stove two yr after the first wave, and remaining households at end of the study	Sep 2006-Mar 2007; May 2009-Apr 2010	ICS (ARTI)	Traditional stove	Individual (primary cooks, women, and children)	Exhaled CO; lung function; symptoms (cough, phlegm, wheezing, sore eyes, tightness in the chest); infant mortality, stillbirths and miscarriages	CO: Micro Medical CO monitor; Health symptoms and outcomes were self-reported; Lung function measured with spirometry	4 yr
Hartinger (2016)[40]	Peru, rural	C-RCT (commu-nity	Children aged 6-35 mo from households using solid fuels	N=503; C=253; I=250	Sept 2008-Jan	OPTIMA-improved ventilated solid-	Unventilated traditional stove or open	Individual	ARI; ALRI; chronic cough in children < 36 mo	ARI: child w/ cough and/or difficulty breathing. ALRI: child w/ cough and/or difficulty breathing, and raised	12 mo

		level)			2010	fuel stove	fire			resp rate	
Jamali (2017)[21]	Paki-stan, rural	NRCT	Households and one woman (main cook) per household	Sindh: N= 292; C= 209; I= 83 Punjab: N= 313; C= 179; I=134	Mar-Sept 2014	Chulhas	Traditional three-stone stove	Kitchen and individual (women responsible for cooking)	Respiratory symptoms (chest tightness, shortness of breath, phlegm, asthma, cough); lung function (PEF); eye symptoms; 24-h $PM_{2.5}$ and CO exposure	Symptoms: self-reported. Lung function: Philips Respironics peak flow meter; $PM_{2.5}$: RTI MicroPEM; CO: QRAE II multigas monitor.	3 mo
Jary (2014)[27]	Malawi, rural	RCT (feasibi-lity study)	Non-smoking women in Ntcheu district who cooked on traditional open wood fires, but wished to purchase a chitetezo stove	N=51; C=26; I=25	Nov-Dec 2011	Chitetezo stove	Traditional open wood fire	Individual	Exhaled CO; Cough, mucus, shortness of breath, wheezing; burning / watery eyes	$PM_{2.5}$: Sidepak monitor CO: Personal CO monitors Symptoms were self-reported	7 days
Ludwinski (2011)[43]	Guatemala, rural	Cluster NRCT (house-hold level)	Households with open fires or stoves in poor condition	N=73 households (477 members); C=45 households (284 members); I=28 households (193 members)	Aug 2008-Aug 2009	Onil stove	Traditional open fire	Individual	Health outcomes (number of days having cough and eye irritation) in women and children	Health outcomes assessed through an interview	1 yr
McCracken (2007)[30]	Guate-mala, rural	RCT	Women ≥38 years living in households participating in RESPIRE	N= 238; C= 115; I= 123	Jul 2003-Dec 2005	Plancha stove	Open fire	Individual	24-h average $PM_{2.5}$ exposure	Measured by air sampler pump	3 yr and 2 mo
McCracken (2009)[28]	Guate-mala, rural	RCT	Main study: 509 children 0–18 mo Validation study: 70 children randomly selected from main study population	Main study N= 509; 1932 observations, Validation study N=70; 270 observations	Jan 2003-May 2004	Plancha stove	Open fire	Individual	48-h CO exposure	Measured by Gastec 1DL passive diffusion tubes worn by the children during 48-hour periods	1.5 yr
McCracken (2013)[29]	Guate-mala, rural	RCT	Women ≥ 38 years living in households participating in RESPIRE	N= 238; C= 115; I= 123	Jul 2003-Dec 2005	Plancha stove	Open fire	Individual	24-h CO and $PM_{2.5}$ exposure	$PM_{2.5}$: gravimetric measure of 24hr personal exposure using Teflon filter CO: span-gas calibrated passive electrochemical data logger	1 yr
Mortimer (2017)[41]	Malawi, rural	C-RCT (community level)	Households with at ≥1 child aged ≤4.5 yr	N= 10,750; C= 5350; I= 5400	Dec 2013-Feb 2016	Two cleaner burning biomass-fueled cookstoves	Open fires	Individual	WHO IMCI defined pneumonia in children < 5 yr; WHO IMCI defined severe pneumonia; death due to pneumonia	Pneumonia: cough or difficulty breathing and fast breathing; Severe pneumonia: pneumonia plus chest in-drawing, stridor, or general danger sign (inability to drink or breastfeed, vomiting, convulsions, lethargy, or unconsciousness)	2 yr and 2 mo

Piedrahita (2017)[31]	Ghana, rural	C-RCT (house-hold level)	households using biofuels as main cooking fuel sources; ≥1 child <5 yr and one woman aged 18-55 yr	N= 200; C= 50; I= 150. 50 given two locally-made Gyapa rocket stoves (Gyapa/Gyapa), 50 given two Philips HD4012 LS stoves (Philips/Philips), 50 given one of each (Gyapa/Philips)	Nov 2013-Jan 2016	Gyapa rocket stoves, Philips HD4012 LS stoves	Three stone stoves	Individual (women and children) and kitchen	48-hour carbonaceous $PM_{2.5}$ exposure	Elemental and organic carbon in μg/m^3 measured by sampling packs (backpacks for children, waist packs for adults) using quartz filters	2 yr
Riojas-Rodriguez (2011)[32]	Mexico, rural	RCT	Subsample of 63 women from Romieu (2009)[33] RCT	N= 63 women, C= 20, I=43	Feb 2005-Jun 2006	Patsari Stove	Open wood fire	Individual	8-h CO exposure	Continuous data-logging electrochemical CO monitors	10 mo
Romieu (2009)[33]	Mexico, rural	RCT	Households/women using open wood fire and having a child < 5 yr	N= 668 households, C= 330, I= 338	Feb 2005-Jun 2006	Patsari stove	Open wood fire	Individual	Resp symptoms (phlegm, cough, wheezing, chest tightness); non-resp symptoms (eye burning, watery eyes); lung function	Clinical symptoms were assessed by a team of local nurses; Spirometry was performed to determine lung function	10 mo
Rosa (2014)[34]	Rwan-da, rural	C-RCT (household level)	Head of household >18 yr; no household members were community health worker	N=566; C=281; I=285 $PM_{2.5}$ was measured in N=121; C=61; I=60	1 yr and 7 mo	EcoZoom Dura Stove	Stone fires	Household	24-h average $PM_{2.5}$ exposure	$PM_{2.5}$: a semi-continuous, light scattering nephelometer (Berkeley particle and temperature sensor)	5 mo
Schilmann (2015)[35]	Mexico, rural	RCT	Fuelwood-using households/women with child < 4 yr in 6 rural communities in Purepecha region	N=668; C=330; I=338	Feb 2005-Jun 2006	Patsari stove	Open wood fire	Individual	Resp infections in children <5 yr	LRI: fast breathing and cough or difficult breathing in previous 15 d and/or observed by fieldworker URI: ≥2 of the following: cough, phlegm, nasal congestion or secretion and sore throat in previous 15 d and/or observed by fieldworker	10 mo
Smith (2010)[36]	Guate-mala, rural	RCT	Children living in homes with open fires or chimney stoves in 23 villages in San Marcos highlands; Children were in utero or ≤4 mo	N=534; C=265; I=269	Oct 2002-Dec 2004	Plancha stove	Open fire or chimney stove	Individual and kitchen	48-h CO exposure	Personal CO: Passive diffusion GASTEC tubes Kitchen CO: HOBO/ Onset CO monitor	Until child was 18 mo
Smith (2011)[37]	Guate-mala, rural	RCT	Households with a pregnant woman or a child <4 mo	N=534; C=265; I=269	Oct 2002-Dec 2004	Plancha stove	Open fire	Individual	Clinical, radiological, or fieldworker-assessed pneumonia	Fieldworker assessed pneumonia: child with cough and/or difficulty breathing meeting criteria for referral to study physician as possible ALRI	Until child was 18 mo
Smith-Sivertsen	Guate-mala,	RCT	Pregnant women or families with child <4 mo	Group A: N=300; C=147; I=153	Oct 2002-	Plancha stove	Traditional open fire	Individual	48-h CO exposure; chronic lung	CO: GASTEC carbon monoxide passive diffusion tubes	12 mo (group

(2009)[38]	rural			Group B: N=204; C=98; I=106	Dec 2004				symptoms (cough, phlegm, wheeze, tightness in the chest); lung function	Chronic lung symptoms assessed via questionnaire; Lung function: ATS criteria and spirometry	A); 18 mo (group B)
Thompson (2011)[39]	Guate-mala, rural	RCT	Households using open wood fires for cooking and having a pregnant woman or a child < 4 mo	N=266; C=120; I=134	Oct 2002-Dec 2004	Plancha stove	Open fire	Individual	48-h CO exposure during pregnancy; LBW (<2,500 g); birth weight	CO: passive diffusion colorimetric CO tubes; Birth weight: weighed by team staff within 48 h after birth	Until child was born
Zhou (2006)[44]	China, rural	CBA	Households that: (i) lived in the area for ≥1 yr; (ii) used coal and/or biomass as main energy source; (iii) had a female member >18 y and a child <14 y	Gansu: N=1009; C=509; I=500; Guizhou: N=1023; C=523; I=500; Shaanxi: N=1089; C=508; I=581	March 2003-April 2005	Gansu: unspecified stove; Guizhou: air circular stove; Shaanxi: unspecified stove	Gansu: brick/ clay stove; Guizhou: coal stove; Shaanxi: brick/ clay biomass/ coal stove	Household	24-h respirable particles (RPM) 24-h CO exposure	RPM: nylon cyclone equipped with a 37 mm diameter poly-vinyl-chloride (PVC) filter CO: long term diffusion tubes	12 mo

Specifications of improved cookstoves are reported in web appendix page 15-16.

Abbreviations

ALRI Acute Lower Respiratory Tract Infection
ARI Acute Respiratory Tract Infection
ARTI Appropriate Rural Technology Institute
ATS American Thoracic Society
CBA Controlled Before-After study
CDM Clean Development Mechanism
CO Carbon Monoxide
C-RCT Cluster Randomised Controlled Trial
IMCI Integrated Management of Childhood Illness
ICS Improved Cook Stoves
LBW Low Birth Weight
LPG Liquefied Petroleum Gas
LRI Lower Respiratory Tract Infection
NRCT Non Randomised Controlled Trial
PEF Peak Expiratory Flow
PM Particulate Matter
RCT Randomised Controlled Trial
URI Upper Respiratory Tract Infection

Table 2. Primary outcomes of included (quasi)experimental studies

First author (Year)	Events		Effect measures	Summary of findings
	Intervention	**Control**	**OR/RR (95%CI)**	
Pregnancy and infant outcomes				
Low birth weight (LBW)				
Thompson (2011)[39]	n/N (%): 13/69 (19%)	n/N (%): 26/105 (25%)	OR (95%CI): 0.74 (0.33, 1.66)	There was no statistically significant difference in LBW between infants born to mothers using wood-fuelled chimney stoves and those born to mothers using open fires
Infant mortality, stillbirths and miscarriages*				
Hanna (2012)[26]	14.7% (n/N not reported)	11.9% (n/N not reported)	Relative risk change (95%CI): 15% (-13, 43)	The study found no effect of randomly being offered a stove on infant mortality, stillbirths and miscarriages
Children				
Acute respiratory infections (including pneumonia)				
Hartinger (2016)[40]	N=248 Number of ARI episodes: 831 Number of ALRI episodes: 25/554 (554 ARI episodes seen with respiratory rate measurements)	N=251 Number of ARI episodes: 877 Total number of ALRI episodes: 10/563 (563 ARI episodes seen with respiratory rate measurements)	Number of ARI episodes Relative rate (95% CI): 0.95 (0.82, 1.10) Number of ALRI episodes Relative rate (95% CI): 2.47 (0.84, 7.29)	The study did not observe a reduction in paediatric ARI and ALRI episodes among improved stove users
Mortimer (2017)[41]	Number of IMCI defined pneumonia episodes in the overall intention to treat population: 1255/5297 Incidence rate (cases per 100 child-years) (95% CI): 15.76 (14.89, 16.63) Number of IMCI defined severe pneumonia episodes in the overall intention to treat population: 186/5297 Incidence rate (cases per 100 child-years) (95% CI): 2.33 (2.00, 2.67)	Number of IMCI defined pneumonia episodes in the overall intention to treat population: 1251/5246 Incidence rate (cases per 100 child-years) (95% CI): 15.58 (14.72, 16.45) Number of IMCI defined severe pneumonia episodes in the overall intention to treat population: 145/5246 Incidence rate (cases per 100 child-years) (95% CI): 1.80 (1.51, 2.09)	IMCI defined pneumonia IRR (95% CI): 1.05 (0.93, 1.18) IMCI defined severe pneumonia IRR (95% CI): 1.30 (0.99, 1.71)	The study found no evidence that an intervention comprising cleaner burning biomass-fuelled cookstoves reduced the risk of pneumonia in young children
Schilmann (2015)[35]	N= 287 (Prevalence not reported)	N= 272 (Prevalence not reported)	URI: Using mainly Patsari stove: OR (95%CI): 0.84 (0.69, 1.03) Combined use Patsari and traditional stove: OR (95%CI): 0.93 (0.76, 1.18) LRI: Using mainly Patsari stove: OR (95%CI): 0.61 (0.21, 1.81) Combined use Patsari and traditional stove: OR (95%CI): 0.88 (0.26, 2.99)	There was no significant impact on the incidence of respiratory infections among children of mothers using mainly the Patsari stove. There was however a reduction in the duration of both URIs and LRIs in Patsari users (IRR (95%CI): 0.79 (0.70, 0.89), and 0.41 (0.21, 0.80), respectively).

Smith (2011)[37]	N= 265 Clinical pneumonia: 124/15526 child weeks† 60/15553 child weeks‡ Radiological pneumonia: 41/15558 child weeks† 25/15559 child weeks‡ *RSV negative* 73/15542 child weeks† 27/15564 child weeks‡ *RSV positive* *43/15556* child weeks† *30/15568* child weeks‡ Fieldworker assessed pneumonia: 321/14379 child weeks† 26/14719 child weeks‡	N= 253 Clinical pneumonia*:* 139 /14871 child weeks† 76/14891 child weeks‡ Radiological pneumonia: 44 /14886 child weeks† 28/14891 child weeks‡ *RSV negative* 77/14877 child weeks† 42/14899 child weeks‡ *RSV positive* *43/14879* child weeks† *27/14897* child weeks‡ Fieldworker assessed pneumonia: 340/13939 child weeks† 45/14310 child weeks‡	Clinical pneumonia: IRR (95%CI): 0.78 (0.59, 1.06)† IRR (95%CI): 0.67 (0.45, 0.98) ‡ Radiological pneumonia: IRR (95%CI): 0.74 (0.42, 1.15) † IRR (95%CI): 0.68 (0.36, 1.33) ‡ *RSV negative* IRR (95%CI): 0.79 (0.53–1.07) † IRR (95%CI): 0.54 (0.31–0.91) ‡ *RSV positive* IRR (95%CI): 0.76 (0.42–1.16) † IRR (95%CI): 0.87 (0.46–1.51) ‡ Fieldworker assessed pneumonia: IRR (95%CI): 0.91 (0.74, 1.13) † IRR (95%CI): 0.56 (0.32, 0.97) ‡	Implementation of chimney stoves did not significantly impact the incidence of physician-diagnosed pneumonia (any severity) for children younger than 18 months. There were however significant reductions in the intervention group for severe fieldworker-assessed, physician-diagnosed, and RSV-negative pneumonia.

*Broader definition than the one pre-specified (perinatal mortality) in the protocol. †All cases of pneumonia. ‡Severe cases of pneumonia

Abbreviations
ALRI Acute Lower Respiratory Tract Infection
ARI Acute Respiratory Tract Infection
IMCI Integrated Management of Illness
IRR Incidence Rate Ratio
LBW Low Birth Weight
LRI Lower Respiratory Infections
RSV Respiratory Syncytial Virus
URI Upper Respiratory Infections

FIGURE LEGENDS

Figure 1. PRISMA diagram outlining study selection. Abbreviations: WHO: World Health Organization; GHL: Global Health Library; ICTRP: International Clinical Trial Registry Platform; LMIC: low- and middle-income countries

Figure 2. Meta-analyses of primary outcomes. A: acute lower respiratory tract infections in children; B: severe pneumonia in children

Figure 3. Sensitivity analyses of primary outcomes. A: acute lower respiratory tract infections in children; B: severe pneumonia in children; C: chronic obstructive pulmonary disease (COPD) in women

Figure 4. Meta-analyses of secondary outcomes. A: birth weight (continuous scale); B: cough in women; C: phlegm in women; D: wheezing/breathing difficulty in women; E: conjunctivitis in women

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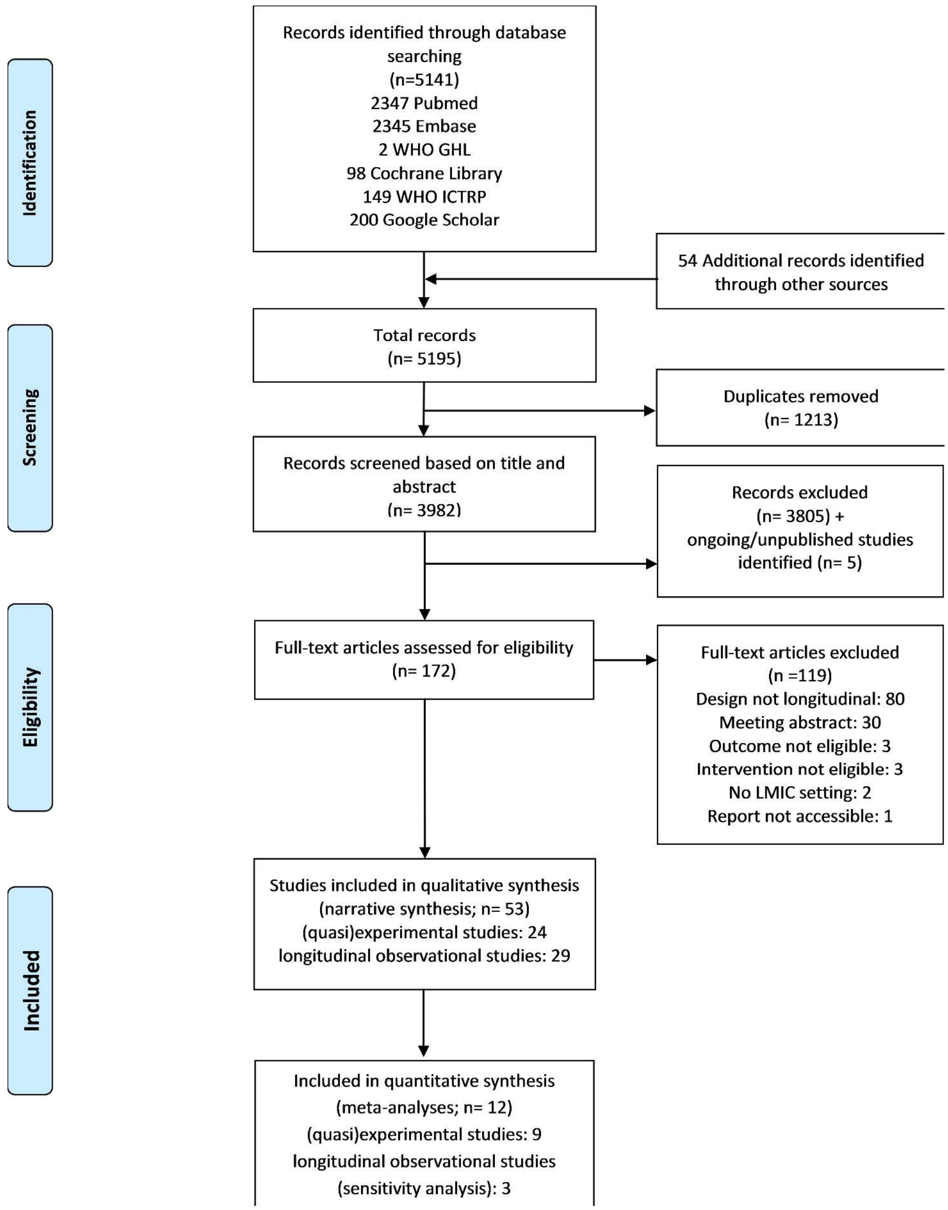

Figure 1. PRISMA diagram outlining study selection. Abbreviations: WHO: World Health Organization; GHL: Global Health Library; ICTRP: International Clinical Trial Registry Platform; LMIC: low- and middle-income countries

1077x1380mm (96 x 96 DPI)

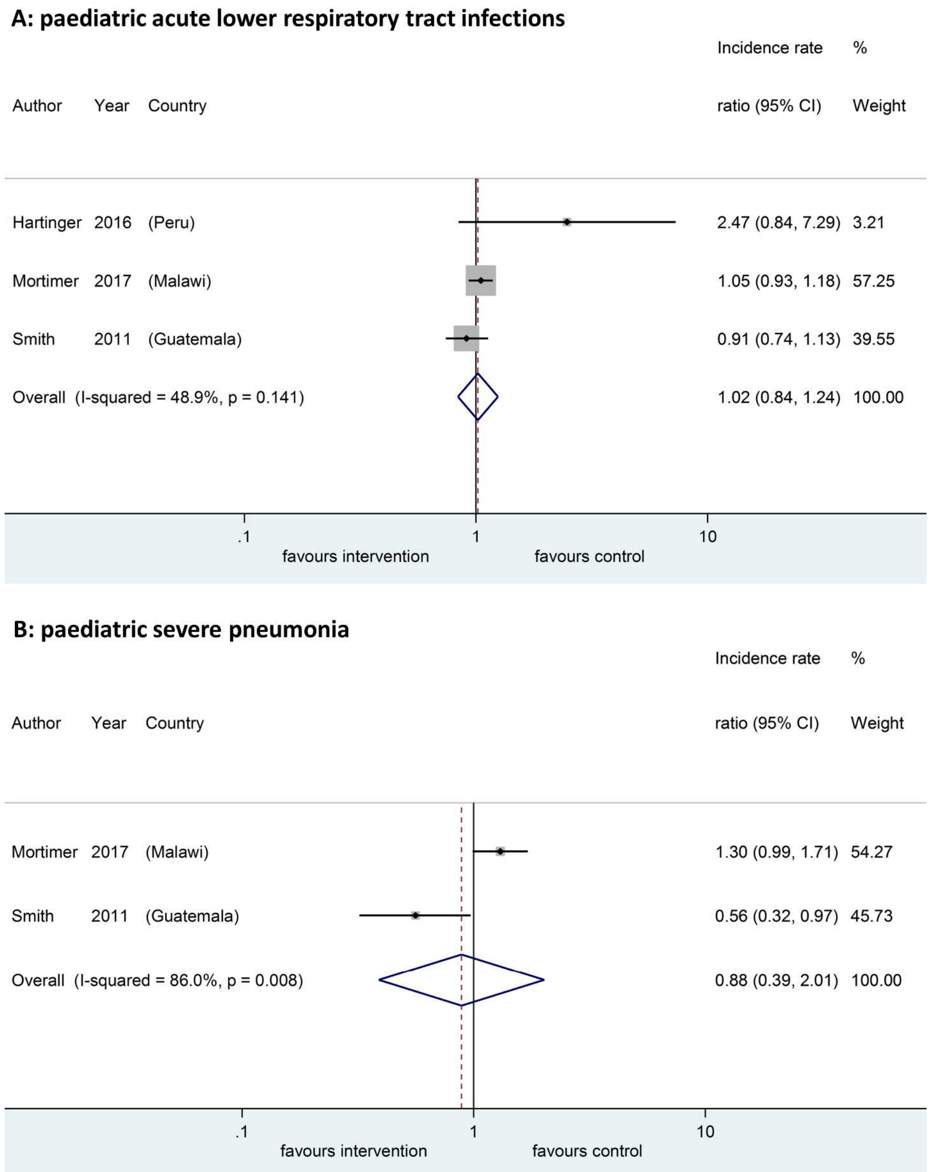

Figure 2. Meta-analyses of primary outcomes. A: acute lower respiratory tract infections in children; B: severe pneumonia in children

254x329mm (236 x 236 DPI)

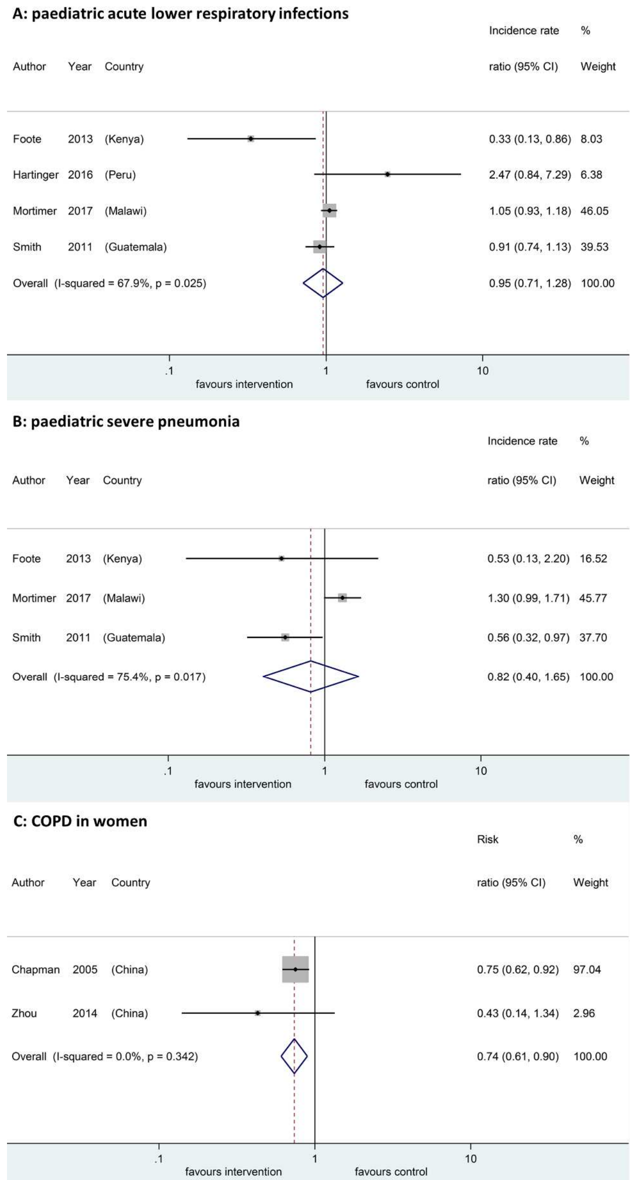

Figure 3. Sensitivity analyses of primary outcomes. A: acute lower respiratory tract infections in children; B: severe pneumonia in children; C: chronic obstructive pulmonary disease (COPD) in women

254x489mm (159 x 159 DPI)

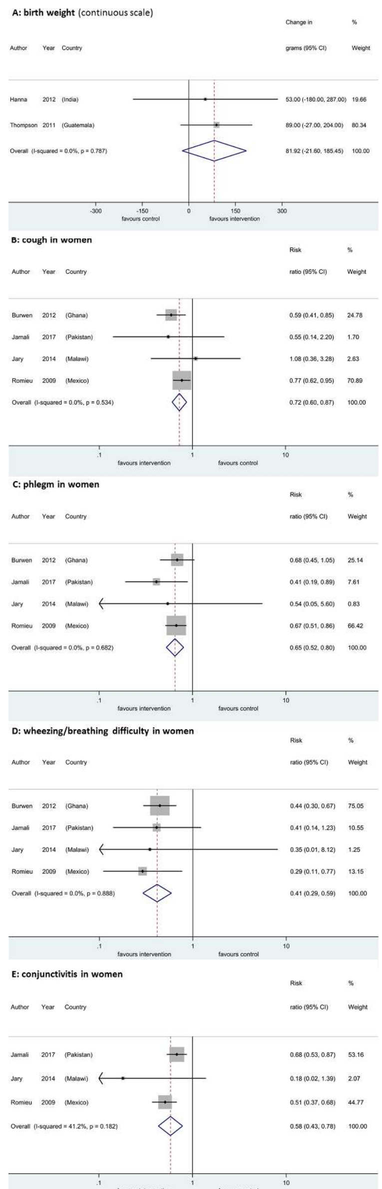

Figure 4. Meta-analyses of secondary outcomes. A: birth weight (continuous scale); B: cough in women; C: phlegm in women; D: wheezing/breathing difficulty in women; E: conjunctivitis in women

254x820mm (95 x 95 DPI)

Impact of improved cookstoves on women's and child health in low- and middle-income countries: a systematic review and meta-analysis

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Web Appendix

ELECTRONIC SEARCHES

1.Pubmed
(stove* OR cookstove* OR cooking OR furnace* OR chimney*)
AND
(pollut* OR air quality OR smoke OR expos*)
AND
(women* OR woman OR female* OR mother* OR maternal OR antenatal OR prenatal OR perinatal OR intrauterine OR fetal OR fetus* OR newborn OR neonatal OR neonate* OR baby OR babies OR infant* OR infancy OR child* OR adolescen* OR teen* OR minor OR youth OR underage OR pregnant OR pregnancy)
AND
(mortality OR death OR morbidity OR disease OR health OR outcome* OR respiratory OR pulmonary OR lung OR breath* OR infect* OR pneumonia OR cough* OR dyspn* OR phlegm OR COPD OR stillbirth OR birth weight OR preterm OR prematur* OR gestation* OR otitis OR OME OR glue ear OR conjunctivitis OR asthma* OR wheez* OR “particulate matter” OR PM10 OR PM25 OR CO or carbon monoxide OR spirometr* OR forced expiratory volume OR FEV OR FEV1 OR forced vital capacity OR FVC OR Tiffeneau)

2. EMBASE
#1
(stove* or cookstove* or cooking or furnace* or chimney*).mp. [mp=title, abstract, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword]
#2
(pollut* or air quality or smoke or expos*).mp. [mp=title, abstract, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword]
#3
(women* or woman or female* or mother* or maternal or antenatal or prenatal or perinatal or intrauterine or fetal or fetus* or newborn or neonatal or neonate* or baby or babies or infant* or infancy or child* or adolescen* or teen* or minor or youth or underage or pregnant or pregnancy).mp. [mp=title, abstract, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword]
#4
(mortality or morbidity or disease or health or adverse outcome or respiratory or pulmonary or lung or breathing or infection or pneumonia or coughing or dyspnea or phlegm or COPD or stillbirth or birth weight or preterm or premature or gestation or otitis or OME or glue ear or conjunctivitis or asthma or wheezing).mp. [mp=title, abstract, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword]
#5
(particulate matter or CO or carbon monoxide or spirometr* or forced expiratory volume or FEV or FEV1 or forced vital capacity or FVC or Tiffeneau).mp. [mp=title, abstract, heading word, drug trade name, original title, device manufacturer, drug manufacturer, device trade name, keyword]
Final search: 1 and 2 and 3 and (4 or 5)

3. Google Scholar
Key search terms “cook cooking stove intervention health women children”

4. World Health Organization (WHO) Global Health Library

(stove* OR cookstove* OR cooking OR furnace* OR chimney*)
AND
(pollut* OR “air quality” OR smoke OR expos*)
AND
(women* OR woman OR female* OR mother* OR maternal OR antenatal OR prenatal OR perinatal OR intrauterine OR fetal OR fetus* OR newborn OR neonatal OR neonate* OR baby OR babies OR infant* OR infancy OR child* OR adolescen* OR teen* OR minor OR youth OR underage OR pregnant OR pregnancy)
AND
(mortality OR death OR morbidity OR disease OR health OR outcome* OR respiratory OR pulmonary OR lung OR breath* OR infect* OR pneumonia OR cough* OR dyspn* OR phlegm OR COPD OR stillbirth OR birth weight OR preterm OR prematur* OR gestation* OR otitis OR OME OR “glue ear” OR conjunctivitis OR asthma* OR wheez* OR “particulate matter” OR PM10 OR PM2.5 OR CO or “carbon monoxide” OR spirometr* OR “forced expiratory volume” OR FEV OR FEV1 OR “forced vital capacity” OR FVC OR Tiffeneau)

6. Cochrane Library
CENTRAL
#1 stove*:ti,ab,kw or cookstove*:ti,ab,kw or furnace*:ti,ab,kw or chimney*:ti,ab,kw in Trials (90 hits)
#2 pollut*:ti,ab,kw or expos*:ti,ab,kw or air quality*:ti,ab,kw or smoke:ti,ab,kw or environment*:ti,ab,kw in Trials (49102 hits)
#3 women*:ti,ab,kw or woman:ti,ab,kw or female*:ti,ab,kw or mother*:ti,ab,kw or maternal*:ti,ab,kw or antenatal:ti,ab,kw and prenatal:ti,ab,kw and perinatal:ti,ab,kw or intrauterine*:ti,ab,kw or fetal*:ti,ab,kw or fetus*:ti,ab,kw or newborn:ti,ab,kw or neonat*:ti,ab,kw or infan*:ti,ab,kw or child*:ti,ab,kw or adoloscen*:ti,ab,kw or teen*:ti,ab,kw or underage:ti,ab,kw or pregnan*:ti,ab,kw in Trials (482363 hits)
#4 mortalit*:ti,ab,kw or morbidit*:ti,ab,kw or death*:ti,ab,kw or disease*:ti,ab,kw or health:ti,ab,kw or outcome*:ti,ab,kw or respiratory:ti,ab,kw or pulmonary:ti,ab,kw or lung:ti,ab,kw or breath or infect*:ti,ab,kw or pneumonia:ti,ab,kw or cough*:ti,ab,kw or dysp*:ti,ab,kw or phlegm:ti,ab,kw or COPD:ti,ab,kw or stillbirth:ti,ab,kw or birth weight:ti,ab,kw or preterm:ti,ab,kw or prematur*:ti,ab,kw or gestation*:ti,ab,kw or otitis:ti,ab,kw or OME:ti,ab,kw or glue ear conjunctivitis:ti,ab,kw or asthma*:ti,ab,kw or wheez*:ti,ab,kw or particulate matter:ti,ab,kw or PM10:ti,ab,kw or PM2.5:ti,ab,kw or CO:ti,ab,kw or carbon monoxide:ti,ab,kw or spirometr*:ti,ab,kw or forced expiratory volume:ti,ab,kw or FEV:ti,ab,kw or FEV1:ti,ab,kw or forced vital capacity:ti,ab,kw or FEV:ti,ab,kw or FEV1:ti,ab,kw or Tiffeneau:ti,ab,kw in Trials (510186 hits)
#5 #1 and #2 and #3 and #4

7. WHO International Clinical Trials Registry Platform
air pollution
cookstove

Table S1: Ongoing/unpublished studies

Title	Main ID	Registration date	Stage of trial	Study design	Setting	Intervention; Control	Relevant primary outcome(s)	Relevant secondary outcome(s)
Simple and Safe "100-dollar-kitchen" to Prevent Low-birth-weight in a Rural Area in Bangladesh: A Cluster Randomized Controlled Trial	NCT02923882	02/10/2016	Completed	Cluster-randomised controlled trial	Bangladesh, rural	I: $100 Kitchen and improved cookstove* C: No intervention	- Incidence of LBW	No relevant outcome
Feasibility intervention trial of two types of improved cookstoves in three developing countries	NCT01686867	10/09/2012	Completed	Randomised, crossover assignment, open label	Kenya, Nepal, Peru, rural	I: Commercially-made improved, ventilated cookstove (Envirofit G-3300/G-3355) ‡ and locally-made improved, ventilated cookstove C: No intervention	- Exposure to biomass fuel combustion (changes in levels of PM and CO) - Respiratory outcomes (spirometry for FEV1, peak expiratory flow rate, carboxyhemoglobin)	No relevant outcome
Use of Biomass briquettes: Its effect on indoor air pollution and on pneumococcal nasopharyngeal carriage. A randomized clinical trial	NCT01660659	18/05/2012	Completed	Randomised, parallel assignment, single blind (Investigator)	Gambia	I: Biomass briquettes and Rocket stove § C: No intervention	- $PM_{2.5}$ concentrations	- Prevalence of pneumococcal carriage in mothers and babies
Intervening to improve birth weight and infant respiratory health in rural Ghana[a]	NCT01335490	13/04/2011	Completed	Cluster-randomised trial	Ghana, rural	I: BioLite woodstove ± C: No intervention	- Incidence of LBW - Acute lower respiratory disease	No relevant outcome
Cookstove replacement for prevention of ALRI and low birthweight in Nepal[a]	NCT00786877	05/11/2008	Completed	Randomised, crossover assignment, open label	Nepal, rural	I: Improved biomass cookstove with exterior ventilation (Envirofit model G3555) ¶ C: No intervention	- Incidence of acute lower respiratory illness among children < 36 months of age - Incidence of LBW	- Incidence of pre-term birth

*The $100 kitchen and improved cookstove is an locally made inexpensive environment friendly prefabricated model kitchen with improved clean-combustion cookstoves. ‡Envirofit G-3300/3355 is a modified Stovetec cookstove with a chimney. §Biomass briquettes are made from dried peanut shells and Rocket stoves are designed to efficiently burn the briquettes. ± BioLite is efficient wood-burning stove with a L-shaped combustion chamber that increases heat transfer efficiency. ¶Envirofit model G3555 is vented to the exterior and has a higher efficiency. [a] Preliminary results have been published in the form of an abstract, but no final results have been published.

Table S2: Characteristics and outcomes of included longitudinal observational studies

First author (Year)	Country	Study Design	Study Duration (Dates)	Population Studied	Total number of Participants (in intervention and control groups)	Intervention and Control	Outcome(s) Measured	Results ('n' values noted when different from the reported in number of participants)[1]	Overall risk of bias assessment (expressed as study quality)
Alexander (2014)	Bolivia, rural	Uncontrolled before-and-after comparison	August 2009 - October 2010 (1 year follow-up)	Women who cooked indoors over open-pit fires	Women: n=20	Intervention: Ventilated cookstoves with chimney (Yanayo cookstove) Control: Same participants before the intervention (using open pit fires to cook)	24-h household CO levels (exact location not specified)	ΔMean CO levels: -8.5ppm (-20% relative change), 95%CI: -12.8 to -4.2	Moderate
Balakrishnan (2015)	India, rural	Uncontrolled before-and-after comparison	December 2011 - March 2013	Pregnant women (and a smaller number of non-pregnant women)	Pregnant women: n=50 Non-pregnant women: n=15	Intervention: Forced-draft advanced combustion cookstove (Philips model HD 4012) Control: Same participants before the intervention (pre-intervention participants used biomass as primary household fuel, type of cookstove not specified)	24-h personal $PM_{2.5}$ and CO exposures, and 24-h kitchen area $PM_{2.5}$ and CO levels	ΔMean personal CO exposure: -46% relative change, 95%CI: -81 to -11 (n=51) ΔMean personal $PM_{2.5}$ exposure: -13% relative change, 95%CI: -142 to 116 (n=8) ΔMean kitchen CO levels: -58% relative change, 95%CI: -157 to 41 (n=3) ΔMean kitchen $PM_{2.5}$ levels: -22% relative change, 95%CI: -157 to 113, (n=22)	Weak
Chapman (2005)	Xuanwei, China, rural	Retrospective cohort study	January 1976 - November 1992	Women resident of Xuanwei in 1976 who were born between 1917 and 1951, and who were lifetime smoky coal users	N=9668 women (no improved cookstove: n = 1800 women, improved cookstove with chimney: n=7868 women)	Intervention: Cookstove with chimney Control: Traditional cookstove using smoky coal as fuel	Incidence of COPD	RR of developing COPD after installing a chimney: 0.75, 95%CI: 0.62 to 0.92	Moderate
Cheng (2015)	Gansu, China, rural	Uncontrolled before-and-after comparison	April 2003 - April 2005 (8 months follow-up)	Women who used biomass for heating and who cooked in traditional cookstoves	PM_4 and CO levels: n=8 households Spirometry tests: n=49 women Phlegm prevalence: n=413	Intervention: Improved cookstove with chimney, and a health education component Control: Same participants before the	24-h kitchen CO levels, FVC, FEV_1 and phlegm prevalence	ΔMean CO kitchen levels: -0.81 ppm, 95%CI: -21.90 to 20.28 Lung function variables[2] ΔFVC (L): 0.09%, 95%CI: -0.07 to 0.25 ΔFEV_1 (L/s): 0.13%, 95%CI: -0.01 to 0.27 Change in self-reported symptom prevalence	Strong

						intervention (using open, unvented fire with biomass for heating and cooking)		Phlegm: -3.4%, (-50% relative change), 95%CI: -6.0 to -0.8	
Chengappa (2007)	Bundelkhand, India, rural	Uncontrolled before-and-after comparison	July 2004 - September 2005	Households using traditional cooking cookstoves	1 year after installation of new cookstove: n=15	Intervention: Improved cookstoves with chimney (Sukhad stove) Control: Same participants before the intervention (using traditional, single-pot, U-shaped cookstoves made of mud and clay)	48-h kitchen $PM_{2.5}$ and CO levels	ΔMean $PM_{2.5}$ kitchen levels: -0.18 mg/m^3 (-44% relative change), 95%CI: -0.32 to -0.04 ΔMean CO kitchen levels: -5.99 ppm (-69% relative change), 95%CI: -10.55 to -1.43	Moderate
Clark (2013)	Granada, Nicaragua, semi-rural	Uncontrolled before-and-after comparison	May 2008-June 2009 (272-383 days follow-up)	Non-smoking women primary cooks	$PM_{2.5}$: n=25 Indoor CO: n=32 Personal CO: n=30	Intervention: Improved cookstoves with combustion chamber and chimney (Eco-stove) Control: Same participants before the intervention (using traditional open fire cookstoves)	48-h indoor $PM_{2.5}$ and CO levels (exact location unclear), and 48-h personal CO exposure	ΔMean indoor $PM_{2.5}$ levels: -1.36 mg/m^3 (-77% relative change), 95%CI: -2.17 to -0.55 ΔMean indoor CO levels: -18.6 ppm (-72% relative change), 95%CI: -29.7 to -7.5 ΔMean personal CO exposure: -1.3 ppm (-62% relative change), 95%CI: -2.1 to -0.5	Moderate
Critchley (2015)	Kenya, rural	Uncontrolled before-and-after comparison	May 2011 - August 2013 (2 years follow-up)	Women aged 25-50 years, who were the primary cook in their household	Interview: n=25 Respiratory assessment: n=24 Thermal desorption tube (TDT) assessment: n=29	Intervention: Energy efficient cookstoves Control: Same participants before the intervention (using traditional three-stone open fire cookstoves)	Lung function (FVC, FEV_1, FEV_1/FVC, $PEFR_1$) Incidence of colds and coughs	Significantly less women had coughs, point estimate and 95%CI not given, p<0.05 Significantly less children had colds, p<0.01 and coughs, p<0.05, point estimate and 95%CI not given ΔFVC: 0.13, 95%CI and p-value not given, but not statistically significant (Units not reported) ΔFEV_1: 0.29, 95%CI and p-value not given, but not statistically significant (Units not reported) ΔFEV_1/ FVC: 0.05, 95%CI: 0.01 to 0.09 (Units not reported) Δ$PEFR_1$: 1.41, 95%CI: 0.34 to 2.48 (Units not reported)	Moderate
Cynthia (2008)	Michoacán, Mexico, rural	Uncontrolled before-and-after comparison	Specific dates not indicated (1 year follow-up)	Residents of households with enclosed kitchens common in the region	$PM_{2.5}$ personal exposure: n=26 women $PM_{2.5}$ kitchen levels: n=33 households	Intervention: Improved cookstove with chimney (Patsari stove) Control: Same	24-h personal $PM_{2.5}$ and CO exposures and 48-h kitchen $PM_{2.5}$ and CO levels	ΔMedian personal $PM_{2.5}$ exposure: -0.06 mg/m^3 (-35% relative change), p<0.001 ΔMean personal $PM_{2.5}$ exposure: -0.08 mg/m^3, 95%CI and p-value not given	Moderate

					CO personal exposure: n=24 women CO kitchen levels: n=32 households	participants before the intervention (using traditional open fire cookstoves surrounded by a U shape of mud/brick/cement blocks with iron bars on the top)		ΔMedian kitchen $PM_{2.5}$ levels: -0.67 mg/m^3 (-74% relative change), p<0.001 ΔMean kitchen $PM_{2.5}$ levels: -0.67 mg/m^3, 95%CI and p-value not given ΔMedian personal CO exposure: -1.8ppm (-78% relative change), p<0.0001 ΔMean personal CO exposure: -1.7ppm, 95%CI and p-value not given ΔMedian kitchen CO levels: -6.6ppm (-77% relative change), 95%CI: 0.0 to -13.2, p=0.05 ΔMean kitchen CO levels: -5.9ppm, 95%CI and p-value not given	
Dutta (2007)	Maharashtra, India, rural	Uncontrolled before-and-after comparison	October 2004 - July 2006 (1 year follow up)	Households using traditional cookstoves	Vented cookstoves: $PM_{2.5}$ levels: n=27 households CO levels: n=30 households Unvented cookstoves: n=21 households CO levels: n=22 households	Intervention: Vented, energy-efficient cookstoves (Laxmi stove) or unvented, energy efficient cookstoves (Bhagyalaxmi stove) Control: Same participants before the intervention (using unvented traditional fired clay cookstoves)	48-h kitchen $PM_{2.5}$ and CO levels	Vented (Laxmi) cookstoves: ΔMean kitchen $PM_{2.5}$ levels: -0.8 mg/m^3 (-45% relative change), 95%CI: -1.6 to 0.0 ΔMean kitchen CO levels: -6.93ppm (-45% relative change), 95%CI: -12.05 to -1.81 Unvented (Bhagyalaxmi) cookstoves: ΔMean kitchen $PM_{2.5}$ levels: -0.47 mg/m^3 (-49% relative change), 95%CI: -0.99 to 0.05 ΔMean kitchen CO levels: -4.2ppm (-38% relative change), 95%CI: -7.8 to -0.6	Moderate
Eppler (2013)	Santiago de Chuco Province, Peru, rural	Uncontrolled before-and-after comparison	June 2008-August 2008	Women of 18-45 years of age who used wood as cooking fuel in an open fire	n=30 women	Intervention: Improved cookstove with chimney (Juntos stove) Control: Same participants before the intervention (using open woodfire for cooking indoors)	Exhaled CO	ΔMean exhaled CO: -3.57 ppm (95%CI: -5.70 to -1.44)	Strong
Ezzati (2002)	Mpala Ranch/ Research Centre, Laikipia District, Kenya, rural	Uncontrolled Before-and-after comparison	1996-1999 (2 year follow-up)	Households using traditional cookstoves	0-4 year old: n=92 5-14 years old: n=109 15-49 years old: n=65 women	Intervention: Improved ceramic wood cookstoves Control: Same participants before the intervention (using firewood or charcoal	Daily PM_{10} personal exposure, and incidence of ARI and ALRI	ΔMean daily PM_{10} personal exposure: 0-4 year old girls: 42% relative reduction, 95%CI and p-value not given 0-4 year old boys: 42% relative reduction, 95%CI and p-value not given 5-14 year old girls: 46% relative reduction, 95%CI and p-value not given 5-14 year old boys: 41% relative reduction, 95%CI	Moderate

						traditional open fire cookstoves)		and p-value not given 15-49 year old women: 47% relative reduction, 95%CI and p-value not given (no overall estimates given) ΔARI incidence (per week)[3] 0 -4 year old girls: -0.09 (-24% relative change), 95%CI: -0.12 to -0.09 0 – 4 year old boys: -0.09 (-24% relative change), 95%CI: -0.13 to -0.09 5-14 year old girls: -0.05 (-12% relative change), 95%CI: -0.06 to -0.05 5-14 year old boys: -0.04 (-7% relative change), 95%CI: -0.04 to -0.03 15-49 year old women: -0.06 (-14% relative change), 95%CI: -0.07 to -0.04 (no overall estimates given) ΔALRI incidence (per week)[3] 0-4 year old girls: -0.04 (-21% relative change) 95%CI: -0.05 to -0.04 0-4 year old boys: -0.05 (-21% relative change), 95%CI: -0.06 to -0.04 5-14 year old girls: -0.01 (-19% relative change), 95%CI: -0.01 to -0.01 5-14 year old boys: -0.01 (-15% relative change), 95%CI: -0.01 to 0.0 15-49 year old women: -0.02 (-15% relative change), 95%CI: -0.02 to -0.01 (no overall estimates given)	
Fitzgerald (2012)	Santiago de Chuco, Peru, rural	Uncontrolled before-and-after comparison	June 2008 - October 2008 (4 months follow up)	Women aged 18-45 years using open woodfire for cooking indoors, and their kitchens	Juntos stove: $PM_{2.5}$ levels: n=26 households CO levels: n=25 households $PM_{2.5}$ exposure: n= 27 women CO exposure: n=25 women Barrick stove: $PM_{2.5}$ levels: n=19 households CO levels: n=17 households $PM_{2.5}$ exposure: n= 18 women CO exposure: n=19 women	Intervention: Two improved cookstoves with chimney (Juntos stove and Barrick stove) Control: Same participants before the intervention (using open woodfire for cooking indoors)	48-h personal $PM_{2.5}$ and CO exposures, and 48-h kitchen $PM_{2.5}$ and CO levels	Juntos stove: ΔMean kitchen $PM_{2.5}$ levels: -0.12 mg/m^3 (-59% relative change; 95%CI: -71% to -42%) ΔMean kitchen CO levels: -2.8ppm (-78% relative change; 95%CI: -86% to -65%) ΔMean personal $PM_{2.5}$ exposure: -0.05 mg/m^3 (-41% relative change; 95%CI: -56% to -21%) ΔMean personal CO exposure: -0.8ppm (-70% relative change; 95%CI: -84% to -42%) Barrick stove: ΔMean kitchen $PM_{2.5}$ levels: -0.12 mg/m^3 (-71% relative change; 95%CI: -84% to -46%) ΔMean kitchen CO levels: -1.7ppm (-66% relative change; 95%CI: -79% to -42%) ΔMean personal $PM_{2.5}$ exposure: -0.07 mg/m^3 (-54% relative reduction; 95%CI: -69% to -32%) ΔMean personal CO exposure: -0.2ppm (-26% relative change; 95%CI: -61% to 40%)	Moderate

Foote (2013)	Nyanza Province, Kenya, rural	Prospective cohort study	April 2010 - April 2011 (1 year follow up)	Children aged < 2 years	n=168 households	Intervention: Improved non-vented ceramic cookstoves (Upesi Jiko stove) Control: Traditional open firepits surrounded by stones (three-stone firepits)	Cough, pneumonia, and severe pneumonia	Consistent use of improved cookstove: Cough: RR 0.40, 95%CI: 0.16 to 1.03 Pneumonia: RR 0.33, 95%CI: 0.13 to 0.86 Severe pneumonia: RR 0.53, 95%CI: 0.13 to 2.20 Any use of improved cookstove: Cough: RR 0.42, 95%CI: 0.20 to 0.89 Pneumonia: RR 0.51, 95%CI: 0.21 to 1.20 Severe pneumonia: RR 0.51, 95%CI: 0.13 to 1.99	Moderate
Gitonga (2002)	Kajiado County, Kenya, rural	Uncontrolled before-and-after comparison	Specific dates not indicated. 6-9 months interventions (1 year follow-up)	Women and their households (that preferably included children under the age of 5 years)	Measurements at 4 ft above the cookstove: n=8 households and measurements at 2.5 ft above the cookstove: n=7 households	Intervention: Improved cookstove (Upesi Jiko stove) Control: Same participants before the intervention (using a three-stone open fire for cooking)	24-h kitchen PM_{10} and CO levels (measured 4 ft and 2.5 ft above the cookstove) and 24-h personal CO exposure	ΔMean PM_{10} kitchen levels: Measurement at 4 ft: -1.06 mg/m^3, 95%CI: -2.21 to 0.09 Measurement at 2.5 ft: -0.52mg/m^3, 95%CI: -1.28 to 0.24 ΔMean CO kitchen levels: Measurement at 4 ft: -4.53ppm, 95%CI: -30.26 to 21.20 Measurement at 2.5 ft: -2.74ppm, Not enough information was given to calculate 95%CI ΔMean CO personal exposure: -0.17ppm, 95%CI: -0.84 to 0.50	Weak
Guarnieri (2015)	Highlands of northwestern Guatemala, rural	Uncontrolled before-and-after comparison	Early intervention: cookstove received in October 2002. Follow up: October 2002 - December 2003 (18 month follow up) Delayed intervention: cookstove received in December 2003. Follow up: November 2008 - March 2009 (4 to 6 year follow up)	Women using traditional open wood fires for cooking	Early cookstove intervention: n=129 Delayed cookstove intervention: n=136	Intervention: Improved wood cookstove with chimney (Plancha stove) Control: Same participants before the intervention (using traditional open wood fires for cooking)	Exhaled breath CO, 48-h personal CO exposure, and lung function (FEV_1 and FVC; expressed as difference in lung function change over time, i.e. mL/y)	[4]ΔFEV_1: ß=-13.0, 95%CI: -41.1 to 15.4 ΔFinal FVC: ß=-9.4, 95%CI: -48.2 to 29.3 ΔFEV_1/FVC: ß=-0.058, 95%CI: -0.74 to 0.62 Early intervention: ΔMean exhaled breath CO: -1.21ppm, 95%CI: -2.07 to -0.35 ΔMean personal CO exposure: -0.89 ppm, 95%CI: -1.42 to -0.36 Delayed intervention: ΔMean exhaled breath CO: -2.11, 95%CI: -2.95 to -1.27 ΔMean personal CO exposure: 1.11 ppm, 95%CI: 0.52 to 1.70 For both, early and delayed intervention groups: ΔFEV_1 (mL/y): -11.1, 95%CI: -15.5 to -6.8 ΔFVC (mL/y): 15.9, 95%CI 10.7 to 21.1	Moderate
Hosgood (2008)	Xuanwei, China, rural	Retrospective cohort study	January 1976 - 1992 (vital status follow-up 1992-	Women residents of Xuanwei in 1976 who were	N= 4033 women (no cookstove	Intervention: Portable cookstoves (which were filled with coal	Lung cancer mortality	Women: HR 0.41, 95%CI: 0.29 to 0.57	Moderate

			1996)	born between 1917 and 1951, and who were lifetime smoky coal users	change: n=2061 women, change to portable cookstove: n=1972 women)	and lighted once daily outdoors and brought indoors after visible smoke has diminished) Control: Traditional cookstove using smoky coal as fuel			
Lan (2002)	Xuanwei, China, rural	Retrospective cohort study	January 1976 - 1992 Indoor pollution measurements carried out in 1995	Residents of Xuanwei in 1976 who were born between 1917 and 1951, who were lifetime smoky coal users, and had been born into homes with unvented firepits	N= 11064 women (no cookstove change: n=1888 women, change to cookstove with chimney: n=9176 women) Total number of households: n=28 15 households with unvented cookstoves 13 households with vented cookstoves	Intervention: Improved cookstove with chimney Control: Traditional cookstove using smoky coal as fuel	24-h kitchen PM_{10} levels	Difference in PM_{10} kitchen levels: -1.37 mg/m^3 (-66% relative change) 95%CI: - 2.09 to -0.65	Moderate
Li (2011)	Santiago de Chuco, Peru, rural	Uncontrolled before-and-after comparison	June 2008 - October 2008 (3 week follow up)	Women aged 18-45 years, who were using open woodfire for cooking indoors	n=44 women/ households	Intervention: Improved cookstove with chimney (Juntos stove and Barrick stove) Control: Same participants before the intervention (using open woodfire for cooking indoors)	48-h kitchen $PM_{2.5}$ and CO levels, 48-h personal $PM_{2.5}$ and CO exposures	ΔMedian kitchen $PM_{2.5}$ levels: -0.10 mg/m^3 (-57% relative change), p<0.001 ΔMedian personal $PM_{2.5}$ exposure: -0.06 mg/m^3 (-47% relative change), p<0.001 ΔMedian kitchen CO levels: -2.6ppm (-74% relative change), p<0.001 ΔMedian personal CO exposure: -0.6ppm (-50% relative change), p<0.01	Moderate
Northcross (2010)	San Marcos, Guatemala, rural	Prospective cohort study	May 2006 - December 2007 (measurements taken every 3 months)	Children 48-72 months of age, their mothers and their households	35 households with chimney cookstoves 28 households with open fire cookstoves	Intervention: Improved cookstoves with chimney Control: Traditional open wood fires	48-h kitchen $PM_{2.5}$ and CO levels, and 48-h personal CO exposures (CO levels were measured in an integrated manner using passive diffusion tubes and in a continuous manner using HOBO logging monitors)	Difference in mean:[5] Kitchen $PM_{2.5}$ levels: -0.56 mg/m^3 (-62% relative change), 95%CI: -0.70 to 0.42, (n=138 intervention, n=138 control) Kitchen CO levels (tube): -4.74 mg/m^3 (-66% relative change), 95%CI: -6.05 to -3.43, (n=123 intervention, n=130 control) Kitchen CO levels (HOBO): -4.92 mg/m^3 (-64% relative change), 95%CI: -6.11 to -3.73, (n=145) Mother CO exposure (tube): -0.73 mg/m^3 (-35% relative change), 95%CI: -1.1 to -0.36, (n=123 intervention, n=130 control)	Weak

								Mother CO exposure (HOBO): -0.94 mg/m^3 (-38% relative change), 95%CI: -1.35 to -0.53, (n=118 intervention, n=128 control) Child CO exposure (tube): -0.20 mg/m^3 (-22% relative change), 95%CI: -0.34 to -0.06, (n=124 intervention, n=128 control)	
Ochieng (2016)	Siaya Country, western Kenya, rural	Uncontrolled before-and-after comparison	December 2009-January 2011 (10 months follow up)	Primary cook, having a child below 5 years, living in the house, not owning an improved cookstove, but with an interest in owning one	n=23 households	Intervention: Rocket mud stove Control: Same participants before the intervention (using a traditional three-stone open fire)	48-h kitchen CO levels and 8-h personal CO exposures	ΔMean CO kitchen levels: -3.1 ppm (-28.1% relative change), 95%CI: -8.1 to 1.8 ΔMean personal CO exposure: -0.9 ppm (-11.6% relative change), 95%CI: -4.3 to 2.6	Moderate
Oluwole (2013)	Southwest Nigeria, rural	Uncontrolled before-and-after comparison	Specific dates not indicated (1 year follow up)	Households that had at least one mother-child pair with mother aged 20-60 years and child aged 6-17 years	n=59 households	Intervention: Low emission cookstove Control: Same participants before the intervention (using biomass fuels for cooking indoors; type of cookstove pre-intervention not specified)	1-h kitchen $PM_{2.5}$ and CO levels during cooking times, lung function (FVC, FEV_1, FEV_1/FVC)	ΔMedian kitchen $PM_{2.5}$ levels: -1.28 mg/m^3, p<0.0001 ΔMedian kitchen CO levels: -156.3ppm, p<0.0001 Lung function[2] Mothers (n=43) ΔFVC: (L/s): -2%, 95%CI: -9 to 5 ΔFEV_1 (L/s): -3%, 95%CI: -7 to 1 ΔPEFR (L/s): 1%, 95%CI: -5 to 7 Children (n=37) ΔFVC (L/s): -5%, 95%CI: -11 to 1 ΔFEV_1 (L/s): -3%, 95%CI: -7 to 1 ΔPEFR (L/s): -3%, 95%CI: -18 to 12	Moderate
Pennise (2009)	Ghana, rural	Uncontrolled before-and-after comparison	Dates not specified Follow up period not specified	Households that were heavily dependent on wood as fuel	n=36 households	Unvented wood burning rocket cookstove (Gyapa stove) Control: Same participants before the intervention (using traditional unvented cookstove or open fire for cooking)	24-h kitchen $PM_{2.5}$ and CO levels	ΔMean kitchen $PM_{2.5}$ levels: -0.33 mg/m^3 (-52% relative change), 95%CI: -0.56 to -0.10 ΔMean kitchen CO levels (HOBO): -4.9 ppm (-40% relative change), 95%CI: -8.6 to -1.2 ΔMean kitchen CO levels (tubes): -1.8 ppm (-27% relative change), 95%CI: -4.4 to 0.8	Moderate
Pilishvili (2016)	Nyanza Province, Kenya, rural	Uncontrolled before-and-after comparison (cross-over design)	Specific dates not indicated (2 weeks follow up per stove with a one week break	Households with women of 15-49 years of age and one or more children aged <5	n=45 households	Intervention: Six different improved cookstoves (Ecochula, Envirofit, EcoZoom, Philips, Prakti, Rocket	48-h kitchen CO and $PM_{2.5}$ levels and 48-h personal CO exposure	ΔMean kitchen $PM_{2.5}$ levels: Ecochula: -0.12 mg/m^3 (95%CI: -0.32 to 0.08; 19% relative reduction) (n=36) Envirofit: -0.28 mg/m^3 (95%CI: -0.47 to -0.09; 45% relative reduction) (n=35)	Strong

			in between)	years		with TECA) Control: Traditional 3-stone fire		EcoZoom: -0.11 mg/m^3 (95%CI: -0.27 to 0.05; 18% relative reduction) (n=37) Philips: -0.36 mg/m^3 (95%CI: -0.55 to -0.17; 59% relative reduction) (n=35) Prakti: -0.12 mg/m^3 (95%CI: -0.20 to -0.04; 32% relative reduction) (n=39) Rocket with TECA: -0.22 mg/m^3 (95%CI: -0.39 to -0.05; 38% relative reduction) (n=35) ΔMean kitchen CO levels: Ecochula: -1.7 ppm (95%CI: -3.9 to 0.5; 25% relative reduction) (n=34) Envirofit: -3.4 ppm (95%CI: -5.7 to -1.1; 51% relative reduction) (n=34) EcoZoom: 0.2 ppm (95%CI: -3.4 to 3.8; 3% relative increase) (n=37) Philips: -2.7 ppm (95%CI: -4.7 to -0.7; 42% relative reduction) (n=35) Prakti: -0.7 ppm (95%CI: -1.3 to -0.1; 11% relative reduction) (n=37) Rocket with TECA: -2.5 ppm (95%CI: -5.1 to 0.1; 42% relative reduction) (n=34) ΔMean personal CO exposure: Ecochula: -1.7 ppm (95%CI: -2.6 to -0.8; 68% relative reduction) (n=31) Envirofit: -1.3 ppm (95%CI: -2.0 to -0.6; 54% relative reduction) (n=30) EcoZoom: -0.7 ppm (95%CI: -1.1 to -0.3; 32% relative reduction) (n=31) Philips: -0.6 ppm (95%CI: -1.0 to -0.2; 29% relative reduction) (n=29) Prakti: -0.9 ppm (95%CI: -1.4 to -0.4; 45% relative reduction) (n=32) Rocket with TECA: -0.8 ppm (95%CI: -1.5 to -0.1; 35% relative reduction) (n=31)	
Rennert (2015)	Buenas Noches community, Honduras, rural	Uncontrolled before-and-after comparison	July 2013 - March 2014 (8 months follow-up)	Non-smoking women and children in the community formerly using traditional adobe cookstoves, aged 15 or older (children aged 6-14)	n=30 households, including 21 women and 59 children	Intervention: Improved cookstove with an improved combustion chamber and a chimney (Justa stove) Control: Same participants before the intervention (using simple wood-burning adobe cookstoves for cooking)	PEFR expressed as percentage of US standards for healthy individuals, self-reported cough, asthma diagnoses	ΔMean %PEFR for women: 14.7%; 95%CI: 6.8% to 22.6% ΔMean %PEFR for children: 12.7%; 95%CI: 7.6% to 17.8% Asthma (adults): RR: 1.25, 95%CI: 0.03 to 60.72 Asthma (children): RR: 1.58, 95%CI: 0.48 to 5.21 Cough (adults): RR: 1.26, 95%CI: 0.67 to 2.37 Cough (children): RR: 1.04, 95%CI: 0.66 to 1.63	Moderate
Riojas-	Chiapas, Mexico,	Prospective	April 1997 -	Households with	n=42 women (14 with	Intervention: Improved	16-h kitchen PM_{10}	Difference in mean kitchen PM_{10} levels	Weak

Rodriguez (2001)	rural	cohort study	December 1997	women and children	improved cookstove and 28 with traditional cookstove) and n=20 children (4 with improved cookstove and 16 with traditional cookstove)	cookstove (Ceta stove) Control: Open fire wood cookstoves	levels, common cold, cough, itching of the eyes, difficulty breathing	Dry season: -0.04 mg/m^3, 95%CI: -0.11 to 0.03 Rainy season: -0.08 mg/m^3, 95%CI: -0.20 to 0.04 Children: Common cold: RR (adjusted) 0.24, 95%CI: 0.05 to 1.02 Cough: RR 0.83, 95%CI: 0.34 to 2.05 Difficulty breathing: RR 0.61, 95%CI: 0.07 to 5.23 Women: Common cold: RR 1.07, 95%CI: 0.46 to 2.51 Cough: RR 1.09, 95%CI: 0.55 to 2.15 Itching of the eyes: RR (adjusted) 1.22, 95%CI: 0.59 to 2.50 Difficulty breathing: RR (adjusted) 1.63, 95%CI: 0.70 to 3.70	
Singh (2012)	Nepal, rural	Uncontrolled before-and-after comparison	February 2008 - March 2009 (1 year follow up)	Households using wood, dung or agricultural residue as fuel, and which had children aged < 5 years	n=34 households	Intervention: Two-pothole mud improved cookstove Control: Same participants before the intervention (using wood, sung, or agricultural residues for cooking; type of cookstove pre-intervention not specified)	24-h kitchen CO and $PM_{2.5}$ levels	ΔMean kitchen $PM_{2.5}$ levels: -1.31 mg/m^3 (-63% relative change), 95%CI: -2.05 to -0.57 ΔMean kitchen CO levels: -12.88ppm (-60% relative change), 95%CI: -20.13 to -5.63	Strong
Yip (2017)	Nyanza Province, Kenya, rural	Uncontrolled before-and-after comparison (cross-over design)	July 2012 – February 2013 (6 months follow-up)	Households with women of 15-49 years of age and one or more children aged <5 years	n=45 households	Intervention: Six different improved cookstoves (EcoZoom Dura cookstove, Philips model HD 4012, Eco Chula, Envirofit, Prakti, or RTI TECA) Control: Same participants before the intervention (traditional three stone fire)	48-h personal CO exposures, and 48-h kitchen area $PM_{2.5}$ and CO levels	ΔMedian personal CO exposure: -44.9% relative change, 95%CI: -57.1 to -37.5 (n=180) ΔMedian kitchen CO levels: -1.6 ppm (-27.1% relative change, 95%CI: -40.3 to -17.4 (n=211)) ΔMedian kitchen $PM_{2.5}$ levels: -177 mg/m^3 (-38.8% relative change, 95%CI: -45.2 to -29.5, (n=218))	Moderate
Zhou (2014)	Yunyan, China, rural	Prospective cohort study	November 2002 - November 2011 (9 year follow up)	Residents of Yunyan aged >40 years, who used biomass for cooking with poor ventilation	n=89 participants	Intervention: Cookstove with an exhaustion fan (chimney, air chute, surplus heat recovery system)	Lung function measures (FEV1, FVC, FEV_1/FVC; expressed as difference in lung function change over time, i.e. mL/y), and COPD incidence	Mean difference in lung function: FEV_1(mL/y): 13, 95%CI: 4 to 23 FVC (mL/y): 10, 95%CI: -4 to 22 FEV_1/FVC (mL/y): 0.2, 95%CI: 0.0 to 0.4 COPD: OR 0.43, 95%CI: 0.14 to 1.34	Strong

						Control: Open-fire traditional cookstove			
Zuk (2007)	Michoacán, Mexico, rural	Uncontrolled before-and-after comparison	November 2004 - May 2005, 2-3 months follow-up	Households with children aged less than 3 years and women of child-bearing age that used wood in open fires for cooking, and had kitchens with four walls and a roof	n=37 households	Intervention: Improved wood-burning cookstove with chimney (Patsari stove) Control: Same participants before the intervention (using wood in open fires for cooking)	48-h $PM_{2.5}$ levels next to the cookstove and in the kitchen	ΔMean $PM_{2.5}$ levels Next to cookstove: -0.45 mg/m^3, 95%CI: -0.57 to -0.32 Kitchen: -0.40 mg/m^3, 95%CI: -0.58 to -0.23 ΔMedian $PM_{2.5}$ levels Next to cookstove: -71% relative change; Range: -90% to 12%; p<0.05 (n=27) Kitchen: -58% relative change; Range: -90% to 72%; p<0.05 (n=24)	Moderate

[1] Δ is used for changes in before-and- after comparisons; the term 'differences' is used for prospective and retrospective cohort studies
[2] Percentage change in predicted normal values
[3] The uncertainty range was obtained using the 95% confidence interval of stove emissions and the 95% confidence interval of exposure–response parameters. The lower (or upper) confidence limit was obtained by simultaneous use of the lower (or upper) confidence limit for both stove emissions and exposure–response parameters. Therefore, these are lower and upper bounds on the confidence limits of the estimated disease rates, and the actual 95% confidence interval is smaller than those reported
[4] ß coefficients represent the change in lung function for each 1 unit increase in ln-transformed CO (1ppm) from an adjusted random effects model
[5] Multiple measurements in households; numbers in brackets represent the number of measurements considered for difference in mean calculations

Abbreviations

95%CI 95% Confidence Interval
ALRI Acute Lower Respiratory Infections
ARI Acute Respiratory Infections
CO Carbon Monoxide
COPD Chronic Obstructive Pulmonary Disease
FEV_1 Forced Expiratory Volume in One Second
FVC Forced Vital Capacity
HR Hazard Ratio
LBW Low Birth Weight
OR Odds Ratio
PEFR Peak expiratory flow rate
PM Particulate Matter
RR Relative Risk

DESCRIPTION OF IMPROVED COOKSTOVES FROM INCLUDED STUDIES

- **Barrick stove:**[1,2] Improved cookstove with a three-hole stove-top, and an aluminium chimney. Provided by the Barrick Gold Corporation.
- **Bhagyalaxmi stove:**[3] Unvented, two-pot cookstove with the combustion chamber directly below the first pot, and a smaller second pot connected to the first chamber via a duct.
- **CDM:**[4] clean development mechanism approved single-pot rocket-style biomass cookstove with an elbow-shape insulated combustion chamber made of lightweight ceramic.
- **Ceta stove:**[5] Improved wood-burning cookstove with chimney.
- **Chapman 2005:**[6] unnamed cookstove with chimney.
- **Chitetezo stove:**[7] A simple clay cookstove for burning solid fuels, that reduces fuel consumption by approximately 40% compared to a traditional 'three-stone' fire.
- **Critchley 2015:**[8] **(unnamed cookstoves provided by Farmers Helping Farmers):** energy-efficient cookstoves equipped with a chimney to carry much of the smoke outside the house, and that reduce the amount of wood required for heating and cooking.
- **Different cookstoves used in provinces of China:**[9] In *Gansu*,[10] the new stoves were constructed with stronger material and were insulated; they could be used with both biomass and coal. The size of the combustion chamber, and the diameter and height of chimney was designed for proper ventilation. In *Guizhou*, the air circular stove has an internal metal combustion chamber and outer metal body, separated by air. Insulated and has a multi-layered upper door to fit different cooking pots. There is a chimney connection spot. The chimney after the intervention was extended outside the house. In *Shaanxi*, cookstove improvements included constructing better insulated combustion chambers, with a chimney that goes out of the house and above the eave.
- **EcoChula:**[11,53] electric fan-assisted gasifier with ceramic chamber.
- **Eco-stove:**[12] Improved cookstove consisting of an enclosed elbow-shaped combustion chamber surrounded by insulation and a metal encasing, a griddle stove-top, and a chimney.
- **EcoZoom Dura cookstove:**[11,13,53] Based on the 'rocket' concept that uses an internal 'chimney' in the stove that directs air through the burning fuel (usually biomass), and encourages the mixing of gases and flame above it. Precise internal stove dimensions are used to achieve high combustion efficiency and transfer heat to the cooking pot.
- **Envirofit:**[11,53] Improved rocket with metal alloy chamber.
- **Ezzati 2002:**[14] unnamed unvented ceramic cookstove.
- **Firewood Jambar:**[15,16] Portable cookstove with a fired clay combustion center enclosed by a metal casing. Owing to basic design improvements of the Jambaar compared to traditional stoves, the woodfuel burns more efficiently and the heat is better conserved and focused towards the cooking pot.
- **Gyapa wood stove:**[17,50] Unvented wood-burning rocket cookstove.
- **Hosgood 2008 (unnamed portable cookstove):**[18] Portable cookstoves that were filled with coal and lighted once daily outdoors and brought indoors after visible smoke has diminished.
- **Improved cookstove (ARTI):**[19] Designed and tested by the Appropriate Rural Technology Institute (ARTI), a Non-Governmental Organization specializing in energy innovation for rural areas. Made of local materials, mainly mud. The base encloses the cooking flame and includes a chimney to vent smoke away from the user.
- **Improved chulha:**[51] This stove was adopted from the Indian National Programme on Improved Chulhas (NPIC). The stove was made of clay and husk and was characterized by a flat platform to place the pans with underneath an area for firewood. At the back of the stove there was a stack attached.
- **Juntos stove:**[1,2,20] Improved cookstove with a three-hole stove-top and an aluminium chimney. Offered by the Juntos Program in Peru.
- **Justa stove:**[21] Improved cookstove with an improved combustion chamber and a chimney.

- **Lan 2002:**[22] unnamed cookstove with chimney.
- **Laxmi stove:**[3] Two-pot cookstove with the combustion chamber directly below the first pot, and a smaller second pot connected to the first chamber via a duct. A second duct connected the second chamber to a chimney.
- **Northcross 2010 (unnamed cookstove with chimney):**[23] cookstoves with an enclosed combustion chamber connected to a chimney that directed smoke outside of the home.
- **Oluwole 2013 (unnamed cookstove manufactured by Stovetec):**[24] low-emission cooking stoves.
- **Onil stove:**[25] Designed for extremely high wood-burning efficiency. There are two sources of its efficiency. One is the fired-clay combustion chamber that burns pieces of firewood by utilizing the oxygen flow in the chamber. The second is that the cookstove design causes this heat to be efficiently transferred to the grill as the combustion gasses travel from the firebox to the chimney.
- **OPTIMA:**[26] Improved ventilated solid-fuel stove.
- **Patsari stove:**[27-31] Improved cookstove consisting of a closed combustion chamber surrounded by bricks, which has a smaller entrance for feeding fuel and a flue that passes through the roof and conveys the smoke outdoors. A flat pottery dish or metal hotplate is integrally built into the surface of the cookstove.
- **Philips model HD 4012:**[11,32,33,50,53] Forced-draft advanced combustion cookstove.
- **Philips:**[33] South Africa, Johannesburg with a solar panel to charge the battery for the stove fan.
- **Plancha stove:**[34-42] An exposure-reducing improved cookstove with chimney.
- **Prakti:**[11,53] Double pot rocket with chimney and steel alloy chamber.
- **Rocket mud stove:**[52] combines both clean burning and optimised heat transfer characteristics.
- **Rocket with TECA:**[11] Built-in rocket stove with thermoelectric-enhanced cookstove add-on (TECA) with brick/clay chamber.
- **Singh 2012 (unnamed cookstoves provided by the Energy Sector Assistance Programme of the Alternative Energy Promotion Centre in Nepal):**[43] A two-pothole improved cookstove with improved efficiency in fuel wood consumption and the presence of a chimney to vent smoke outside the kitchen.
- **Sukhad stove:**[44] A two-pot-hole improved cookstove with chimney that provides strong heat under both pot-holes. The Sukhad stove is designed so that the second pot-hole is raised by approximately 6 cm above the level of the first pot-hole with the aim of avoiding interference between pot rims when cooking with two large pots.
- **Unspecified ICS:**[45] Designed by Ghanian Council on Scientific and Industrial Research. To improve combustion efficiency, the cookstove uses a metal grate suspended above the ground to allow air to vent through the burning biomass. To vent smoke away from the user, cookstove walls are built to surround the main cooking pot and a chimney vents through a side wall. This design helps in enclosing the combustion chamber and forcing air to draft through the chimney.
- **Upesi jiko:**[46,47] Improved ceramic cookstove consisting of a ceramic liner made from clay. The liners are built into a permanent gravel and mud matrix in the cooking area of a dwelling. The upesi jiko burns unprocessed biomass fuel (e.g., charcoal, wood, crop waste) and does not ventilate smoke outside the home.
- **Yanayo cookstove:**[48] improved cooking stoves with roofs and chimneys designed by the University of Washington chapter of Engineers without Borders.
- **Zhou 2014 (unnamed cookstove with chimney):**[49] improved biomass stoves with a chimney, an air chute, and a surplus heat recovery system.

Table S3: Risk of bias assessment (quasi)experimental studies[1]

	A) Selection Bias			B) Study Design					C) Confounders			D) Blinding			E) Data collection methods			F) Withdrawals and Drop-outs			
First Author and Year	Are the selected individuals likely to be representative of the target population?	What percentage of selected individuals agreed to participate?	**Selection Bias Overall rating[2]**	Indicate the study design	Was the study described as randomised?	Was the method of randomisation described?	**Was the method appropriate?**	**Study Design Overall rating[2]**	important differences between groups prior to the intervention?	If yes, indicate the percentage of relevant confounders that were controlled	**Confounders Overall rating[2]**	Outcome assessor(s) aware of the intervention or exposure status of participants?	Were the study participants aware of the research question?	**Blinding Overall rating[2]**	Were data collection tools shown to be valid?	Were data collection tools shown to be reliable?	**Data Collection Methods Overall rating[2]**	Were withdrawals and drop-outs reported (numbers and/or reasons)?	Percentage of participants completing the study	**Withdrawals and Drop-outs Overall Risk[2]**	**Overall Quality Assessment[2]**
Aung 2016	Somewhat likely	92.6%	**M**	RCT	Yes	No	N/A	**M**	No	N/A	**S**	Can't tell	Can't tell	**M**	Yes	Yes	**S**	Yes	82-96%	**S**	**M**
Bensch 2012	Somewhat likely	Can't tell	**M**	RCT	Yes	Yes	Yes	**S**	No	N/A	**S**	Can't tell	No	**M**	No	No	**W**	Yes	89-92%	**S**	**S**
Bensch 2015	Somewhat likely	Can't tell	**M**	RCT	Yes	Yes	Yes	**S**	No	N/A	**S**	Can't tell	No	**M**	No	No	**W**	Yes	89-92%	**S**	**S**
Burwen 2012	Not likely	Can't tell	**W**	RCT	Yes	Yes	Yes	**S**	No	N/A	**S**	Can't tell	Can't tell	**M**	Can't tell	Can't tell	**W**	No	64-74%	**M**	**M**
Diaz 2007	Not likely	56%	**W**	RCT	Yes	Yes	Yes	**S**	No	N/A	**S**	Can't tell	Can't tell	**M**	No	Can't tell	**W**	Yes	88-91%	**S**	**S**
Hanna 2012	Very likely	93%	**S**	RCT	Yes	Yes	Yes	**S**	No	N/A	**S**	Can't tell	Can't tell	**M**	Yes	Yes	**S**	No	79-80%	**M**	**S**
Hartinger 2016	Somewhat likely	75-78%	**M**	RCT	Yes	Yes	Yes	**S**	No	N/A	**S**	Can't tell	Can't tell	**M**	Can't tell	Can't tell	**W**	Yes	92-94%	**S**	**S**
Jary 2014	Can't tell	Can't tell	**W**	RCT	Yes	Yes	Yes	**S**	Can't tell	Can't tell	**W**	Can't tell	Can't tell	**M**	Yes	Yes	**S**	Yes	98%	**S**	**S**
Ludwinski 2011	Not likely	Can't tell	**W**	CCT	Yes	Yes	No	**M**	No	N/A	**S**	Can't tell	Can't tell	**M**	No	Can't tell	**W**	No	Can't tell	**W**	**W**
Jamali 2017	Somewhat likely	Can't tell	**M**	CBA	No	N/A	N/A	**M**	Can't tell	N/A	**W**	Can't tell	Can't tell	**M**	Yes	Yes	**S**	No	Can't tell	**W**	**M**
McCracken 2007	Somewhat likely	65%	**M**	RCT	Yes	Yes	Yes	**S**	No	N/A	**S**	Can't tell	Can't tell	**M**	Yes	Yes	**S**	Can't tell	Can't tell	**W**	**S**
McCracken 2009	Somewhat likely	100%	**M**	RCT	Yes	No	N/A	**M**	Can't tell	Can't tell	**W**	Can't tell	Can't tell	**M**	Yes	Can't tell	**M**	No	Can't tell	**W**	**M**
McCracken 2013	Somewhat likely	Can't tell	**M**	RCT	Yes	No	N/A	**M**	Can't tell	Can't tell	**W**	Can't tell	Can't tell	**M**	Yes	Can't tell	**M**	No	Can't tell	**W**	**M**
Mortimer 2017	Very likely	Can't tell	**M**	RCT	Yes	Yes	Yes	**S**	No	N/A	**S**	No	Can't tell	**M**	Yes	Yes	**S**	Yes	98%	**S**	**S**
Piedrahita 2017	Somewhat likely	Can't tell	**M**	RCT	Yes	Yes	Yes	**S**	No	N/A	**S**	Can't tell	Can't tell	**M**	Yes	Yes	**S**	No	Can't tell	**W**	**S**
Riojas-Rodriguez 2011	Not likely	Can't tell	**W**	RCT	Yes	Yes	Yes	**S**	No	N/A	**S**	Can't tell	Can't tell	**M**	Yes	Yes	**S**	No	Can't tell	**W**	**S**
Romieu 2009	Very likely	75%	**M**	RCT	Yes	Yes	Yes	**S**	No	N/A	**S**	Can't tell	Can't tell	**M**	Yes	Yes	**S**	Yes	83%	**S**	**S**
Rosa 2014	Not likely	97%	**M**	RCT	Yes	Yes	Yes	**S**	No	N/A	**S**	Yes	Can't tell	**W**	Yes	Yes	**S**	Yes	93%	**S**	**S**
Schilmann 2015	Can't tell	100%	**M**	RCT	Yes	No	N/A	**M**	Yes	90-95%	**W**	Can't tell	Can't tell	**M**	Can't tell	Can't tell	**W**	Yes	84%	**S**	**M**
Smith KR 2010	Somewhat likely	Can't tell	**M**	RCT	Yes	No	N/A	**M**	No	N/A	**S**	Can't tell	Can't tell	**M**	Yes	Yes	**S**	Yes	83%	**S**	**M**
Smith KR 2011	Somewhat likely	69%	**M**	RCT	Yes	Yes	Yes	**S**	No	N/A	**S**	No	Can't tell	**M**	Yes	Yes	**S**	Yes	83%	**S**	**S**
Smith-Sivertsen 2009	Somewhat likely	94%	**M**	RCT	Yes	Yes	Yes	**S**	No	N/A	**S**	No	Can't tell	**M**	Can't tell	Can't tell	**W**	Yes	89-90%	**S**	**S**

Thompson 2011	Somewhat likely	Can't tell	**M**	RCT	Yes	No	N/A	**M**	Yes	80%	**W**	Can't tell	Can't tell	**M**	Yes	Can't tell	**M**	No	Can't tell	**W**	**M**
Zhou 2006	Very likely	Can't tell	**M**	CBA	No	N/A	N/A	**M**	Yes	Can't tell	**M**	Can't tell	Can't tell	**M**	Yes	Yes	**S**	Can't tell	Can't tell	**W**	**M**

[1] Risk of bias assessment tool for Quantitative Studies, Effective Public Health Practice Project (EPHPP)
[2] Quality assessment of studies: W=weak (high risk of bias), M=moderate (moderate risk of bias), S=strong (low risk of bias)

Table S4: Risk of bias assessment longitudinal observational studies[1]

First Author and Year	A) Selection Bias			B) Study Design			C) Confounders			D) Blinding			E) Data collection methods			F) Withdrawals and Drop-outs			Overall Quality Assessment[2]
	Are the selected individuals likely to be representative of the target population?	What percentage of selected individuals agreed to participate?	**Selection Bias Overall Risk[2]**	Indicate the study design	Was the study described as randomized?	**Study Design Overall Risk[2]**	Important differences between groups prior to the intervention?	If yes, indicate the percentage of relevant confounders that were controlled	**Confounders Overall Risk[2]**	Outcome assessor(s) aware of the intervention or exposure status of participants?	Were the study participants aware of the research question?	**Blinding Overall Risk[2]**	Were data collection tools shown to be valid?	Were data collection tools shown to be reliable?	**Data Collection Methods Overall Risk[2]**	Were withdrawals and drop-outs reported (numbers and/or reasons)?	Percentage of participants completing the study	**Withdrawals and Drop-outs Overall Risk[2]**	
Alexander 2014	Not likely	Can't tell	**W**	Cohort	No	**M**	No	N/A	**S**	Yes	Can't tell	**M**	Yes	Yes	**S**	Yes	60 - 79%	**M**	**M**
Balakrishnan 2015	Can't tell	Can't tell	**W**	Cohort	No	**M**	No	N/A	**S**	Yes	Can't tell	**M**	Yes	Yes	**S**	No	Can't tell	**W**	**W**
Chapman 2005	Very likely	Can't tell	**M**	Cohort	No	**M**	No	80 - 100%	**S**	Yes	Can't tell	**M**	Can't tell	Can't tell	**W**	Yes	80 -100%	**S**	**M**
Cheng 2015	Somewhat likely	Can't tell	**M**	Cohort	No	**M**	No	N/A	**S**	Yes	Can't tell	**M**	Yes	Yes	**S**	Yes	80 -100%	**S**	**S**
Chengappa 2007	Somewhat likely	80 - 100% agreement	**M**	Cohort	No	**M**	No	N/A	**S**	Yes	Can't tell	**M**	Yes	Yes	**S**	Yes	<60%	**W**	**M**
Clark 2013	Somewhat likely	Can't tell	**M**	Cohort	No	**M**	No	N/A	**S**	Yes	Can't tell	**M**	Yes	Yes	**S**	Yes	60 - 79%	**M**	**M**
Critchley 2015	Can't tell	Can't tell	**W**	Cohort	No	**M**	No	N/A	**S**	Yes	Can't tell	**M**	Yes	Yes	**S**	Yes	60 - 79%	**M**	**M**
Cynthia 2008	Somewhat likely	Can't tell	**M**	Cohort	No	**M**	No	N/A	**S**	Yes	Can't tell	**M**	Yes	Yes	**S**	Yes	< 60%	**W**	**M**
Dutta 2007	Somewhat likely	80 - 100% agreement	**M**	Cohort	No	**M**	No	N/A	**S**	Yes	Can't tell	**M**	Yes	Yes	**S**	Can't tell	Can't tell	**W**	**M**
Eppler 2013	Somewhat likely	Can't tell	**M**	Cohort	No	**M**	No	N/A	**S**	Yes	Can't tell	**M**	Yes	Yes	**S**	Yes	80 -100%	**S**	**S**
Ezzati 2002	Very likely	Can't tell	**M**	Cohort	No	**M**	No	N/A	**S**	Yes	Can't tell	**M**	Yes	Yes	**S**	Can't tell	Can't tell	**W**	**M**
Fitzgerald 2012	Can't tell	Can't tell	**W**	Cohort	No	**M**	No	N/A	**S**	Yes	Can't tell	**M**	Yes	Yes	**S**	Yes	60 - 79%	**M**	**M**
Foote 2013	Somewhat likely	Can't tell	**M**	Cohort	No	**M**	Yes	< 60%	**W**	Yes	Can't tell	**M**	Yes	No	**M**	Yes	80 -100%	**S**	**M**
Gitonga 2002	Not likely	Can't tell	**W**	Cohort	No	**M**	Can't tell	Can't Tell	**W**	Yes	Can't tell	**M**	Yes	Yes	**S**	Can't tell	Can't tell	**W**	**W**
Guarnieri 2015	Very likely	Can't tell	**M**	Cohort	No	**M**	No	N/A	**S**	Yes	Can't tell	**M**	Yes	Yes	**S**	Yes	< 60%	**W**	**M**
Hosgood 2008	Very likely	Can't tell	**M**	Cohort	No	**M**	Can't tell	Can't Tell	**W**	Yes	Can't tell	**M**	Yes	No	**M**	Yes	80 -100%	**S**	**M**
Lan 2002	Very likely	Can't tell	**M**	Cohort	No	**M**	Can't tell	Can't Tell	**W**	Yes	Can't tell	**M**	Yes	No	**M**	Yes	80 -100%	**S**	**M**
Li 2011	Can't tell	Can't tell	**W**	Cohort	No	**M**	No	N/A	**S**	Yes	Can't tell	**M**	Yes	Yes	**S**	Yes	80 -100%	**S**	**M**
Northcross 2010	Very likely	Can't tell	**M**	Cohort	No	**M**	Can't tell	N/A	**W**	Yes	Can't tell	**M**	Yes	Yes	**S**	No	Can't tell	**W**	**W**
Ochieng 2016	Somewhat likely	80 - 100% agreement	**M**	Cohort	No	**M**	No	N/A	**S**	Yes	Can't tell	**M**	Yes	Yes	**S**	Yes	< 60%	**W**	**M**
Oluwole 2013	Somewhat likely	80 - 100% agreement	**M**	Cohort	No	**M**	No	N/A	**S**	Yes	Yes	**W**	Yes	Yes	**S**	Yes	60 - 79%	**M**	**M**
Pennise 2009	Somewhat likely	Can't tell	**M**	Cohort	No	**M**	No	N/A	**S**	Yes	Can't tell	**M**	Yes	Yes	**S**	No	Can't tell	**W**	**M**
Pilishvili 2016	Very likely	80 - 100% agreement	**S**	Cohort	No	**M**	No	N/A	**S**	Yes	Can't tell	**M**	Yes	Yes	**S**	Yes	80 -100%	**S**	**S**

Rennert 2015	Very likely	80 - 100% agreement	**S**	Cohort	No	**M**	No	N/A	**S**	Yes	Can't tell	**M**	Yes	Yes	**S**	Yes	<60%	**W**	**M**
Riojas-Rodriguez 2001	Somewhat likely	80 - 100% agreement	**M**	Cohort	No	**M**	Can't tell	Can't Tell	**W**	Yes	Can't tell	**M**	Yes	No	**M**	No	Can't tell	**W**	**W**
Singh 2012	Somewhat likely	Can't tell	**M**	Cohort	No	**M**	No	N/A	**S**	Yes	Can't tell	**M**	Yes	Yes	**S**	Yes	60 - 79%	**M**	**S**
Yip 2017	Very likely	Can't tell	**M**	Cohort	No	**M**	No	N/A	**S**	Yes	Can't tell	**M**	Yes	Yes	**S**	Yes	60 - 79%	**M**	**M**
Zhou 2014	Somewhat likely	80 - 100% agreement	**M**	Cohort	No	**M**	Yes	80 - 100%	**S**	Yes	Can't tell	**M**	Yes	Yes	**S**	Yes	60 - 79%	**M**	**S**
Zuk 2007	Can't tell	Can't tell	**W**	Cohort	No	**M**	No	N/A	**S**	Yes	Can't tell	**M**	Yes	Yes	**S**	Yes	60 - 79%	**M**	**M**

[1] Quality assessment tool for Quantitative Studies, Effective Public Health Practice Project (EPHPP)
[2] Quality assessment of studies: W=weak (high risk of bias), M=moderate (moderate risk of bias), S=strong (low risk of bias)

Table S5. Secondary outcomes among (quasi)experimental studies

First author (year)	Events / means (95%CI)		Effect measure	Summary of findings
	Intervention	Control		
Pregnancy and infant outcomes				
Birth weight				
Hanna (2012)	Mean birth weight and SD not reported	Mean birth weight: 2921 grams (SD not reported)	Difference in means (95%CI): 53 grams (–180, 287)	The study found no significant impact of an improved cookstove on birth weight
Thompson (2011)	Mean birth weight (95%CI): 2797 grams (2697, 2896)	Mean birth weight (95%CI): 2729 grams (2654, 2804)	Difference in means (95%CI): 89 grams (–27, 204)	The study found no significant difference in birth weight between infants born to mothers using wood-fueled chimney stoves compared with those born to mothers using open fires
Children				
Death due to respiratory disease				
Mortimer (2017)	Deaths due to pneumonia: n/N (%): 3/5297 Incidence rate (95% CI): 0.04 (0.00-0.08)	Deaths due to pneumonia: n/N (%): 4/5246 Incidence rate (95% CI): 0.05 (0.00-0.10)	IRR (95% CI): 0.76 (0.17-3.37)	The study found no significant impact of an improved cookstove on child deaths due to pneumonia
Otitis media with effusion				
Hanna (2012)	Incidence of earache, children aged 13 and under at baseline: n/N not reported Incidence of earache, children aged 5 and under at baseline: n/N not reported	Incidence of earache, children aged 13 and under at baseline: 3.4% (n/N not reported) Incidence of earache, children aged 5 and under at baseline: 3.3% (n/N not reported)	Earache ARR, children aged 13 and under at baseline (percentage points; 95%CI): –0.1% (–0.9, 0.7) Earache ARR, children aged 5 and under at baseline (percentage points; 95%CI): –0.4% (–1.4, 0.6)	The study found no observable effects of an improved cookstove on earache
Chronic cough				
Hanna (2012)	Incidence of cough, children aged 13 and under at baseline: n/N not reported Children aged 5 and under at baseline: n/N not reported	Incidence of cough, children aged 13 and under at baseline: 26.2% (n/N not reported) Children aged 5 and under at baseline: 22.9% (n/N not reported)	Cough ARR, children aged 13 and under at baseline: ARR (percentage points; 95%CI): 1.1% (–1.1, 3.3) Cough ARR, children aged 5 and under at baseline (percentage points; 95%CI): 1.8% (–0.7, 4.4)	The study found no observable effects of an improved cookstove on chronic cough
Hartinger (2016)	Days with cough or difficulties breathing (median, IQR): 17 (8-25)	Days with cough or difficulties breathing (median, IQR): 14 (8-26)	Cough or difficulty breathing prevalence OR (95% CI): 0.97 (0.79, 1.19)	The study found no observable effects of an improved cookstove on chronic cough
Ludwinski (2011)	Coughing over the previous 21 days, children only: n/N not reported	Coughing over the previous 21 days, children only: n/N not reported	Days with cough over the previous 21 days (children only; 95%CI): –0.92 (–2.02, 0.18)	Onil stoves did not significantly reduce days of coughing in children, although a significant reduction was seen among girls
Indoor air pollution concentrations (PM2.5, PM10, CO)				
Hanna (2012)	Exhaled CO: Mean (SD) not reported	Exhaled CO: Mean (SD) not reported	Difference in mean exhaled CO (95%CI): –0.48 ppm (–1.42, 0.47)	There was no significant overall reduction in exhaled CO among children after implementation of improved stoves over the four-year study period
McCracken (2009)	Mean log personal 48-h CO exposure (95%CI): −0.03 ppm (−0.09, 0.04)	Mean log personal 48-h CO exposure (95%CI): 0.70 ppm (0.63, 0.78)	Difference in mean personal 48-h exposure (95%CI): –0.72 ppm equivalent to a 52% relative reduction	The stove intervention reduced child CO exposure by 52% compared to controls
Smith (2010)	48-h CO exposure (ppm): Mean (SD): 1.5 (1.9); Geometric Mean (SD): 1.0 (2.4)	48hr CO exposure (ppm); Mean (SD): 2.8 (2.5); Geometric Mean (SD): 2.0 (2.3)	Relative change in geometric mean (95%CI): −0.52% (−0.56, −0.47)	The stove intervention reduced child CO exposure by 52% compared to controls
Women				

Chronic cough				
Burwen (2012)	Bad cough or sore throat following cooking (number of days during previous week): Mean (SD): 0.7 (1.6) Proportion of women with bad cough outside of cooking in previous week (SD): 0.16 (0.02) Proportion of women with sore throat outside of cooking during previous week (SD): 0.1 (0.02)	Bad cough or sore throat following cooking (number of days during previous week): Mean (SD): 1.6 (2.4) Proportion of women with bad cough outside of cooking in previous week (SD): 0.27 (0.03) Proportion of women with sore throat outside of cooking during previous week (SD): 0.19 (0.02)	Bad cough or sore throat following cooking (number of days during previous week): difference in means (95%CI): −0.9 (−1.4, −0.4) Bad cough outside of cooking: RR (95%CI): 0.59 (0.41, 0.85)* Sore throat outside of cooking: RR (95%CI): 0.52 (0.32, 0.83)*	There was a statistically significant decline in self-reported bad cough and/or sore throat in the intervention group compared to the control group
Hanna (2012)	Incidence of cold or cough: n/N not reported	Incidence of cold or cough: 41% (n/N not reported)	Cold or cough ARR (percentage points; 95%CI): 0.50 (−2.44, 3.44)	There was no significant difference in cough or cold incidence between women using improved cookstoves and women using traditional cookstoves
Jamali (2017)	Cough in the morning during previous month, reported as: Sindh community: Incidence rate (episodes/month): 21.7 (N=83) Punjab community: Incidence rate (episodes/month): 30.6 (N=134)	Cough in the morning during previous month, reported as: Sindh community: Incidence rate (episodes/month): 48.3 (N=209) Punjab community: Incidence rate (episodes/month): 27.9 (N=179)	Sindh community: Adjusted RR (95%CI): 0.27 (0.20, 0.38) Punjab community: Adjusted RR (95%CI): 1.11 (0.87, 1.41)	Women using improved cookstoves had significantly lower cough incidence in the Sindh community, but not in the Punjab community
Jary (2014)	Cough incidence over the seven-day follow-up period, reported as n/N (%): 5/25 (21%)	Cough incidence over the seven-day follow-up period, reported as n/N (%): 5/26 (19%)	RR (95%CI): 1.08 (0.36, 3.28)*	There was no statistically significant difference in cough incidence between the intervention and control groups over the seven-day follow-up period
Ludwinski (2011)	Coughing over the previous 21 days, women only: n/N not reported	Coughing over the previous 21 days, women only: n/N not reported	Days with cough over the previous 21 days (women only; 95%CI): −1.14 (−2.26, −0.01)	Improved cookstoves significantly reduced the number of days women were coughing over the previous 21 days by just over one day
Romieu (2009)	Incidence of cough over the 15 days before each follow-up examination: N= 282; n not reported	Incidence of cough over the 15 days before each follow-up examination: N= 270; n not reported	Using mainly Patsari stove: RR (95%CI): 0.77 (0.62, 0.95) Combined use Patsari and open fire: RR (95%CI): 0.92 (0.72, 1.17)	Primary use of the Patsari stove significantly reduced cough incidence when compared to exclusive use of open fire
Smith-Sivertsen (2009)	Incidence of cough during the 6 months prior to follow-up examination: Recruitment group A (12-month follow-up): N=153; n not reported Recruitment group B (18-month follow-up): N=106; n not reported	Incidence of cough during the 6 months prior to follow-up examination: Recruitment group A (12-month follow-up): N=147; n not reported Recruitment group B (18-month follow-up): N= 98; n not reported	Not reported	There was no statistically significant change in cough incidence among women in the plancha intervention group compared to women in the open fire control group
Chronic phlegm				
Burwen (2012)	Proportion of women with excessive mucous in previous week (SD): 0.13 (0.02); N=225; n not reported	Proportion of women with excessive mucous in previous week (SD): 0.19 (0.03); N=255; n not reported	Excessive mucus: RR (95%CI): 0.68 (0.45, 1.05)*	There was no significant change in risk of excessive mucus in the intervention group versus controls

Hanna (2012)	Incidence of phlegm: n/N not reported	Incidence of phlegm: 5.4% (n/N not reported)	Phlegm ARR (percentage points; 95%CI): 0.6 (–1.0, 2.2)	There was no significant difference in phlegm incidence between women using improved cookstoves and women using traditional cookstoves
Jamali (2017)	Phlegm in the morning during previous month, reported as: Sindh community: Incidence rate (episodes/month): 12.1 (N=83) Punjab community: Incidence rate (episodes/month): 15.7 (N=134)	Phlegm in the morning during previous month, reported as: Sindh community: Incidence rate (episodes/month): 33.5 (N=209) Punjab community: Incidence rate (episodes/month): 19.6 (N=179)	Sindh community: Adjusted RR (95%CI): 0.27 (0.18, 0.40) Punjab community: Adjusted RR (95%CI): 0.60 (0.45, 0.81)	Women using improved cookstoves had significantly lower phlegm incidence in both Sindh and Punjab communities
Jary (2014)	Mucous incidence over the seven-day follow-up period, reported as n/N (%): 1/25 (4%)	Mucous incidence over the seven-day follow-up period, reported as n/N (%): 2/26 (8%)	RR (95%CI): 0.54 (0.05, 5.60)*	There was no significant difference in experience of mucous between the intervention and control groups over the seven-day follow-up period
Romieu (2009)	Incidence of phlegm over the 15 days before each follow-up examination: N= 282; n not reported	Incidence of phlegm over the 15 days before each follow-up examination: N= 272; n not reported	Using mainly Patsari stove: RR (95%CI): 0.67 (0.51, 0.86) Combined use Patsari and open fire: RR (95%CI): 0.91 (0.68, 1.21)	Primary use of the Patsari stove significantly reduced phlegm incidence when compared to exclusive use of open fire
Smith-Sivertsen (2009)	Incidence of phlegm during the 6 months prior to follow-up examination: Recruitment group A (12-month follow-up): N=153; n not reported Recruitment group B (18-month follow-up): N=106; n not reported	Incidence of phlegm during the 6 months prior to follow-up examination: Recruitment group A (12-month follow-up): N=147;n not reported Recruitment group B (18-month follow-up): N= 98; n not reported	Not reported	There was no significant reduction in phlegm incidence among women in the plancha intervention group compared to women in the open fire control group
Wheezing/breathing difficulty				
Burwen (2012)	Proportion of women with difficulty breathing (SD): 0.12 (0.02); N=225; n not reported	Proportion of women with difficulty breathing (SD): 0.27 (0.3); N=255; n not reported	Difficulty breathing: RR (95%CI): 0.44 (0.30, 0.67)*	There was a significant decline in self-reported difficulty breathing among users of improved stoves compared to users of traditional stoves after the intervention
Hanna (2012)	Wheeze incidence: n/N not reported	Wheeze incidence 0.5% (n/N not reported)	Wheeze ARR (percentage points; 95%CI): –0.1 (–0.5, 0.3)	There was no significant difference in wheeze incidence between women using improved cookstoves and women using traditional cookstoves
Jamali (2017)	Shortness of breath during previous month, reported as: Sindh community: Incidence rate (episodes/month): 31.3 (N=83) Punjab community: Incidence rate (episodes/month): 32.8 (N=134)	Shortness of breath during previous month, reported as: Sindh community: Incidence rate (episodes/month): 70.8 (N=209) Punjab community: Incidence rate (episodes/month): 27.4 (N=179)	Sindh community: Adjusted RR (95%CI): 0.23 (0.17, 0.31) Punjab community: Adjusted RR (95%CI): 1.35 (1.07, 1.70)	Women using improved cookstoves had significantly less shortness of breath in the Sindh community, but significantly more in the Punjab community
Jary (2014)	Wheezing incidence over the seven-day follow-up period, reported as n/N (%): 0/25 (0%)	Wheezing incidence over the seven-day follow-up period, reported as n/N (%): 1/26 (4%)	Wheezing or whistling in chest: RR (95%CI): 0.35 (0.01, 8.12)*	There was no significant difference in wheezing incidence between the intervention and control groups over the seven-day follow-up period
Romieu (2009)	Incidence of wheezing over the 15 days before each	Incidence of wheezing over the 15 days before	Using mainly Patsari stove: RR (95%CI): 0.29 (0.11, 0.77)	Primary use of the Patsari stove significantly reduced wheezing

	follow-up examination: N= 282; n/N not reported	each follow-up examination: N= 270; n/N not reported	Combined use Patsari and traditional stove: RR (95%CI): 0.62 (0.33, 1.17)	incidence when compared to exclusive use of open fire
Smith-Sivertsen (2009)	Incidence of wheezing during the 6 months prior to follow-up examination: Recruitment group A (12-month follow-up): N=153; n not reported Recruitment group B (18-month follow-up): N=106; n not reported	Incidence of wheezing during the 6 months prior to follow-up examination: Recruitment group A (12-month follow-up): N=147;n not reported Recruitment group B (18-month follow-up): N= 98; n not reported	RR (95%CI): 0.42 (0.25, 0.70)	There was a significant reduction in wheezing among women in the plancha intervention group compared to women in the open fire control group
Conjunctivitis				
Bensch (2015)**	Percentage of households presenting at least one women responsible for cooking with eye problems: 4.5% (N=86-90 observations) Incidence of eye problems among main cooks in households: 2.9% (N=778)	Percentage of households presenting at least one women responsible for cooking with eye problems: 14% (N=127-139 observations) Incidence of eye problems among main cooks in households: 9.8% (N=1199)	RR eye problems at household level: 0.32 (95%CI not provided); P= 0.02 RR eye problems at individual level (main cook): 0.30 (95%CI not provided); P= 0.01	In the intervention group there was a statistically significant reduction in eye problems at both the household and individual level
Burwen (2012)	Number of days in previous week respondent reported Irritated eyes: Mean (SD): 1.0 (2.1); N=225; n not reported	Number of days in previous week respondent reported Irritated eyes: Mean (SD): 2.7 (2.6); N=255; n not reported	Difference in means (95%CI): –1.7 (–5.0, 1.6)	There was no significant difference in self-reported irritated eyes between users of improved stoves compared to users of traditional stoves after the intervention
Diaz (2007)	Incidence of sore eyes over the six months prior to follow-up examinations, reported as n/N (%) At six-month follow-up: 48/236 (20%) At 12-month follow-up: 19/227 (8%) At 18-month follow-up: 7/89 (8%)	Incidence of sore eyes over the six months prior to follow-up examinations, reported as n/N (%) At 6-month follow-up: 92/234 (39%) At 12-month follow-up: 79/229 (35%) At 18-month follow-up: 31/91 (34%)	OR (95%CI) for the period 6-18 months after intervention: 0.18 (0.11, 0.29)	The odds of having sore eyes was significantly lower in the plancha group relative to the group using open fires across the 18-month follow-up period
Hanna (2012)	Incidence of sore eyes: n/N not reported	Incidence of sore eyes: 11.1% (n/N not reported)	Sore eyes ARR (percentage points; 95%CI): –0.5 (–2.5, 1.5)	There was no significant difference in the incidence of sore eyes between women using improved cookstoves and women using traditional cookstoves
Jamali (2017)	Sandy eyes during previous month, reported as: Sindh community: Incidence rate (episodes/month): 65.8 (N=83) Punjab community: Incidence rate (episodes/month): 43.4 (N=134)	Sandy eyes during previous month, reported as: Sindh community: Incidence rate (episodes/month): 69.9 (N=83) Punjab community: Incidence rate (episodes/month): 50.7 (N=134)	Sindh community: Adjusted RR (95%CI): 0.63 (0.47, 0.97) Punjab community: Adjusted RR (95%CI): 0.72 (0.51, 1.01)	Women using improved cookstoves significantly less often had sandy eyes in the Sindh community, but not in the Punjab community
Jary (2014)	Burning/watery eyes incidence over the seven-day follow-up period, reported as n/N (%): 1/25 (4%)	Burning/watery eyes incidence over the seven-day follow-up period, reported as n/N (%): 6/26 (23%)	Burning/watery eyes: RR (95%CI): 0.33 (0.07, 1.50)*	There were no significant difference in burning/watery eyes incidence between the intervention and control groups over the seven-day follow-up period
Ludwinski (2011)	Red eye over the previous 21 days, women only: n/N not reported	Red eye over the previous 21 days, women only: n/N not reported	Days with red eye symptoms over the previous 21 days (women only; 95%CI): –0.15 (–	There was no significant impact of an improved cookstove on the number of days women experienced red eye

			2.57, 2.27)	symptoms over the last 21 days
Romieu (2009)	Incidence of itchy and/or watery eyes over the 15 days before each follow-up examination: N= 282; n/N not reported	Incidence of itchy and/or watery eyes over the 15 days before each follow-up examination: N= 272; n/N not reported	Itchy eyes Using mainly Patsari stove: RR (95%CI): 0.51 (0.37, 0.68) Combined use Patsari and traditional stove: RR (95%CI): 0.69 (0.52, 0.91) Watery eyes Using mainly Patsari stove: RR (95%CI): 0.64 (0.49, 0.85) Combined use Patsari and traditional stove: RR (95%CI): 0.79 (0.58, 1.07)	Primary use of the Patsari stove significantly reduced the incidence of itchy eyes and watery eyes, when compared to exclusive use of open fire
Lung function outcomes				
Hanna (2012)	Mean FEV_1 not reported Mean FEV1/FVC x100 not reported	Mean FEV_1 (L): 1.92 Mean FEV_1/FVC x100: 0.86	Difference in mean FEV_1 (L; 95%CI): 0.003 (–0.03, 0.04) Difference in mean FEV_1/FVCx100 (L; 95%CI): –0.005 (–0.01, 0.00)	There was no significant difference in mean lung function measures between users of improved stoves and users of traditional stoves after the intervention
Jamali (2017)	Mean PEFR not reported	Mean PEFR not reported	Sindh community: Difference in mean PEFR (unit not reported): 31.6 (17.9, 45.3) Punjab community: Difference in mean PEFR (unit not reported): 12.0 (–2.5, 26.5)	Women using improved cookstoves had improved lung function in Sindh community, but not in the Punjab community
Romieu (2009)	Mean FEV1 decline rate: 31ml/year (SD not given), mean (SD) for FVC and FEV1/FVCx100 not reported; N=228	Mean FEV1 decline rate: 62ml/year (SD not given), mean (SD) for FVC and FEV1/FVCx100 not reported; N=198	Difference in FEV1 decline rate (ml/year; 95%CI): 31 (7, 55) Difference in FVC change (ml/year; 95%CI): 16 (–21, 54) Difference in FEV1/FVCx100 change (95%CI): 0.5%/year (–0.2, 1.1)	There was significantly less FEV1 decline among Patsari stove users than among the open fire users over one year of follow-up
Smith-Sivertsen (2009)	Mean FEV_1 not reported Change in mean FVC at 12-month follow-up: 136 mL Mean (FEV_1/FVC) x100 not reported	Mean FEV_1 not reported Change in mean FVC at 12-month follow-up: 180 mL Mean (FEV_1/FVC) x100 not reported	Difference in mean FEV_1, across 18-month follow-up (L; 95%CI): –0.02 (–0.09, 0.04) Difference in mean FVC, across 18-month follow-up (L; 95%CI): –0.04 (–0.10, 0.03) Difference in mean (FEV_1/FVC) x100 across 18-month follow-up (95%CI): 0.41 (–0.44, 1.27)	The plancha intervention had no statistically significant effects on lung function within the follow-up period
Indoor air pollution (PM_{10}, $PM_{2.5}$, CO)				
Aung (2016)	Change in median 24-h $PM_{2.5}$ exposure between post- and pre-intervention for exclusive intervention stove users (μg/m³; IQR): 51 (–58, 161)	Change in median 24-h $PM_{2.5}$ exposure between post- and pre-intervention (μg/m³; IQR): 139 (61, 229)	Percent difference in $PM_{2.5}$ concentrations (95% CI): –26% (–53, 18)	There was a significant increase in $PM_{2.5}$ in the control group, while the increase in the intervention group was not significant. There was however no difference in the changes in $PM_{2.5}$ between the two groups.
Burwen (2012)	CO personal exposure during cooking time (ppm/h); Mean (SD) not reported; N= 291	CO personal exposure during cooking time (ppm/h): Mean (SD) not reported; N= 249	Point estimate for treatment when cooking indoors (ppm/h; 95%CI): –16 (–34, 3)	There was no significant decline in personal exposures to CO among intervention group participants during cooking time compared to control group participants
Diaz (2007)	Median exhaled CO (ppm): 5; no IQR reported; N=89 Median exhaled CO measurements were the	Median exhaled CO (ppm): 7; no IQR reported; N= 91 Median exhaled CO measurements were the	Difference in median exhaled CO (ppm; no IQR reported): –2 (P=0.0005)	Median CO in exhaled breath was significantly lower among women in the plancha intervention group compared to women in the open fire control

	same at six, 12 and 18-month follow up	same at six, 12 and 18-month follow up		group 18 months after installation of planchas
Hanna (2012)	Personal CO exposure: mean and SD not reported	Personal CO exposure: mean and SD not reported	Difference in mean personal CO exposure (ppm; 95%CI): –0.56 (–1.40, 0.26)	There was no significant difference in personal CO exposure between users of improved stoves compared to users of traditional stoves
Jamali (2017)	Household (closed kitchen) CO 24-hr median concentration (IQR): 2.5 ppm (1, 6) Household (closed kitchen) $PM_{2.5}$ 24-hr median concentration (μg/m^3; IQR): 78.4 (45.4, 164.1)	Household (closed kitchen) CO 24-hr median concentration (IQR): 10 ppm (3.5, 14.7) Household (closed kitchen) $PM_{2.5}$ 24-hr median concentration (μg/m^3; IQR): 588 (250.4, 893.8)	Difference in median CO not reported Difference in median $PM_{2.5}$ not reported ($p<0.05$)	Women using improved cookstoves within closed kitchens had significantly lower $PM_{2.5}$ exposure
Jary (2014)	Median exhaled CO (IQR): 2.0ppm (1.0); N=25	Median exhaled CO (IQR): 3.0ppm (2.0); N=26	Difference in median change in CO over the study period (ppm IQR not reported): –0.5ppm (p= 0.03)	There was a significant decrease in median exhaled CO among improved cookstove users compared to traditional open fire users
McCracken (2007)	Mean 24-h personal $PM_{2.5}$ exposure (μg/m³; SD): 102 (130); N=115	Mean 24-h personal $PM_{2.5}$ exposure (μg/m³; SD): 264 (297); N=108	Difference in mean 24-h personal $PM_{2.5}$ exposures (μg/m³; 95%CI): –162 (–222, –102)	Personal $PM_{2.5}$ exposures were significantly lower among women in the plancha intervention group compared to women in the open fire control group
McCracken (2013)	Median 24-h personal $PM_{2.5}$ exposure (mg/m³; IQR): 0.07 (0.04, 0.12); N= 49 Median 24-h personal CO exposure (mg/m³; IQR): 0.63 (0.33, 1.22) ; N= 49	Median 24-h personal $PM_{2.5}$ exposure (mg/m³; IQR): 0.20 (0.11, 0.32); N=67 Median 24-h personal CO exposure (mg/m³; IQR): 2.02 (1.20, 3.35); N=67	Difference in median 24-h personal $PM_{2.5}$ exposure (mg/m³; IQR and p value not reported): –0.13 The chimney stove was associated with a –1.00 (95%CI –1.25, –0.74) reduction in 24-hour personal log $PM_{2.5}$ Difference in median 24-h personal CO exposure (mg/m³): –1.39; IQR and p value not reported	Median 24-h personal $PM_{2.5}$ and CO exposures were lower among women in the chimney cookstove intervention group compared to women in the open fire control group. This reduction was statistically significant for $PM_{2.5}$; statistical significance was not reported for CO
Piedrahita (2017)	Mean 48-h personal $PM_{2.5}$ OC concentration (μg/m^3; 95%CI): Gyapa/Gyapa: 27.8 (15.2, 50.9) Philips/Philips: 32.9 (19.6, 55.2) Gyapa/Philips: 23.9 (12.0, 47.7) Mean 48-h personal $PM_{2.5}$ EC concentration (μg/m^3; 95%CI): Gyapa/Gyapa: 1.4 (0.7, 2.6) Philips/Philips: 1.0 (0.6, 1.6) Gyapa/Philips: 1.0 (0.5, 2.1) Mean 48-h cooking area $PM_{2.5}$ OC concentration (μg/m^3; 95%CI): Gyapa/Gyapa: 33.3 (16.7, 66.4) Philips/Philips: 49.6 (25.3, 97.4) Gyapa/Philips: 57.3 (25.2, 130.7)	Mean 48-h personal $PM_{2.5}$ OC concentration (μg/m^3; 95%CI): 65.0 (28.6, 147.8) Mean 48-h personal $PM_{2.5}$ EC concentration (μg/m^3; 95%CI): 2.5 (1.0, 6.0) Mean 48-h cooking area $PM_{2.5}$ OC concentration (μg/m^3; 95%CI): 100.2 (41.7, 240.4)	Difference in mean 48-h personal $PM_{2.5}$ OC concentration (μg/m^3; 95%CI): Gyapa/Gyapa: –37.2 (–65.5, –8.9) Philips/Philips: –32.1 (–56.5, –7.7) Gyapa/Philips: –41.1 (–72.4, –9.8) Difference in mean 48-h personal $PM_{2.5}$ EC concentration (μg/m^3; 95%CI): Gyapa/Gyapa: –1.1 (–2.3, 0.1) Philips/Philips: –1.5 (–2.6, –0.4) Gyapa/Philips: –1.5 (–2.7, –0.2) Difference in mean 48-h cooking area $PM_{2.5}$ OC concentration (μg/m^3; 95%CI): Gyapa/Gyapa: –66.9 (–117.8, –16.0) Philips/Philips: –50.6 (–98.9, –2.31) Gyapa/Philips: –42.9 (–75.5, –10.3)	Mean 48-h personal $PM_{2.5}$ OC and EC, and mean 48-h cooking area $PM_{2.5}$ OC were significantly lower in households using improved cookstoves.

	Mean 48-h cooking area $PM_{2.5}$ EC concentration (μg/m^3; 95%CI): Gyapa/Gyapa: 4.2 (1.9, 9.4) Philips/Philips: 3.3 (1.5, 7.2) Gyapa/Philips: 5.1 (2.0, 13.0)	Mean 48-h cooking area $PM_{2.5}$ EC concentration (μg/m^3; 95%CI): 6.5 (2.2, 19.0)	Difference in mean 48-h cooking area $PM_{2.5}$ EC concentration (μg/m^3; 95%CI): Gyapa/Gyapa: –2.3 (–6.5, 1.9) Philips/Philips: –3.2 (–6.9, 0.5) Gyapa/Philips: –1.4 (–6.6, 3.8)	
Riojas-Rodriguez (2011)	Median 8-h personal CO exposure measurements using a continuous sampler (ppm): 1; no IQR reported Median 8-h CO personal exposure measurements using a passive sampler (ppm): 1; no IQR reported	Median 8-h personal CO exposure measurements using a continuous sampler (ppm): 4; no IQR reported Median 8-h CO personal exposure measurements using a passive sampler (ppm): 3; no IQR reported	Difference in median 8-h CO personal exposure measurements using a continuous sampler (ppm; IQR and p value not reported): –3 Median 8-h CO personal exposure measurements using a passive sampler (ppm; IQR and p value not reported): –2	Median 8-h personal CO exposures were lower among women in the Patsari cookstove intervention group compared to women in the open fire control group. Statistical significance was not reported
Rosa (2014)	Mean 24-h cooking area $PM_{2.5}$ levels (mg/m^3; SD): 0.49 (0.53); N= 60 Mean 24-h indoor kitchen $PM_{2.5}$ levels (mg/m^3; SD): 0.56 (0.56); N= 46	Mean 24-h cooking area $PM_{2.5}$ kitchen levels (mg/m^3; SD): 0.91 (1.05); N= 61 Mean 24-h indoor kitchen $PM_{2.5}$ levels (mg/m^3; SD): 0.91 (1.06); N= 60	Difference in mean 24-h cooking area $PM_{2.5}$ levels (mg/m^3; 95%CI): –0.42 (–0.71, –0.13) Difference in mean 24-h indoor kitchen $PM_{2.5}$ levels (mg/m^3; 95%CI): –0.35 (–0.74, 0.04)	Mean 24-h cooking area (indoors and outdoors combined) $PM_{2.5}$ levels were significantly lower among users of improved cookstoves compared to controls. However, when measurements were restricted to indoor cooking areas only, the reduction was not statistically significant
Smith (2010)	Mean 48-h personal CO exposure for mothers (ppm; SD): 2.2 (2.6); N= 597 measurements Mean (geometric) 48-h personal CO exposure for mothers (ppm; SD): 1.4 (2.5) Mean 48-h kitchen CO levels (ppm; SD): 1.1 (1.4) Mean (geometric) kitchen CO levels (ppm; SD): 0.8 (2.3)	Mean 48-h personal CO exposure for mothers (ppm; SD): 4.8 (3.6); N= 589 measurements Mean (geometric) 48-h personal CO exposure for mothers (ppm; SD): 3.6 (2.2) Mean 48-h kitchen CO levels (ppm; SD): 8.6 (4.0) Mean (geometric) 48-h kitchen CO levels (ppm; SD): 7.5 (1.8)	Difference in mean (geometric) 48-h personal CO exposure for mothers (ppm; 95%CI): –0.61 ppm (–0.65, –0.57) Difference in mean (geometric) kitchen CO levels (ppm; 95%CI): –0.90 (–0.92, –0.87)	Mean (geometric) 48-h personal CO exposures for mothers, and 48-h kitchen CO levels were significantly lower among participants in the plancha intervention group compared to participants in the open fire control group
Smith-Sivertsen (2009)	Median 48-h personal CO exposure (ppm): 1.63 (IQR not reported)	Median 48-h personal CO exposure (ppm): 4.24 (IQR not reported)	Difference in median 48-h personal CO exposure (ppm; IQR not reported): -2.61 (p=0.0001)	Median 48-h CO personal exposure was significantly lower among women in the plancha intervention group compared to women in the open fire control group after an 18-month follow-up period
Thompson (2011)	Mean personal 48-h CO exposure during pregnancy (ppm; SD): 2.5 (2.5); N=46 measurements Mean personal 48-h CO exposure at different time points during pregnancy (ppm; SD): First trimester: 2.9 (1.1); N= 4 measurements Second trimester: 1.2 (0.7);	Mean personal 48-h CO exposure during pregnancy (ppm; SD): 4.1 (3.2); N=54 measurements Mean personal 48-h CO exposure at different time points during pregnancy (ppm) (SD): No measurements reported for first trimester Second trimester: 2.9	Difference in mean personal 48-h CO exposures during pregnancy (ppm; 95%CI): –1.6 (–6.0, 2.8) Difference in mean personal 48-h CO exposure at different time points during pregnancy (ppm; SD): Second trimester: –1.7 (–3.3, –0.1) Third trimester: –1.6 (–3.7, 0.5)	There was no significant difference in mean 48-h personal CO exposures between pregnant mothers in the chimney cookstove intervention group and mothers in the open fire control group. However, mean 48-h personal CO exposure for mothers in the second trimester of their pregnancy was significantly lower among participants in the chimney cookstove intervention group compared to mothers in the open fire control group.

	N= 7 measurements Third trimester: 2.7 (2.7); N= 35 measurements	(1.6); N= 6 measurements Third trimester: 4.3 (3.4); N= 48 measurements		
Zhou (2006)	Mean 24-h CO exposure in cooking room Change between post- and pre-intervention in different provinces: Gansu: –1.9 ppm (–29%; p = 0.02) Guizhou (cooking/living room): 0.52 ppm (36%; p = 0.33) Shaanxi: 0.9 ppm (45%; p = 0.28)	Mean 24-h CO exposure in cooking room Change between post- and pre-intervention in different provinces: Gansu: –0.7 ppm (–11%; p = 0.74) Guizhou (cooking/living room): –0.27 ppm (–22%; p = 0.20) Shaanxi: 2.5 ppm (100%; p = 0.08)	Mean 24-h CO exposure in cooking room Difference in change between intervention group and control group (ppm): Gansu: –1.2 ppm (p = 0.53) Guizhou (cooking/living room): 0.79 ppm (p = 0.16) Shaanxi: –1.6 ppm (p = 0.40)	In Gansu, use of the improved stove was associated with a significant decline in CO exposure in the cooking room, but the difference was not significant when compared to controls. No significant declines or differences compared to controls were observed in the other provinces/cookstoves.

*Risk ratios and corresponding 95% confidence intervals were calculated using the data from the article **Bensch 2012 is not included in the table since the results reported are the same as those reported in Bensch 2015

Abbreviations

ARR Absolute Risk Reduction
CI Confidence Interval
CO Carbon Monoxide
EC Elemental Carbon
FEV1 Forced Expiratory Volume in one second
FVC Forced Vital Capacity
IQR Inter-Quartile Range
PEFR Peak Expiratory Flow Rate
OC Organic Carbon
OR Odds Ratio
PM Particulate Matter
RR Risk Ratio

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