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Luis Teles de Carvalho, Ricardo; Jensen, Ole Michael; Tarelho, Luis A. C.; Cabral da Silva, Adeildo

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IMPACTS OF TWO IMPROVED WOOD-BURNING STOVES ON THE INDOOR AIR QUALITY: PRACTICES IN PERU AND BRAZIL

Ricardo L CARVALHO^{1,*}, Ole M JENSEN¹, Luís A C TARELHO², Adeildo C SILVA³

¹Department of Energy and Environment, Danish Building Research Institute, Aalborg University, Copenhagen, Denmark

²Department of Environment and Planning, Centre for Environmental and Marine Studies, University of Aveiro, Aveiro, Portugal

³Department of Civil Engineering, Federal Institute of Education, Science and Technology of Ceará, Fortaleza, Brazil

*Corresponding email: rlc@sbi.aau.dk

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SUMMARY

Large amounts of forest wood is still being used in rural housing in low and mid-income countries in South America - 36% in Peru and 6% in Brazil - generating hazardous wood smoke.

Interviews were conducted to the users of improved stoves in 20 rural households. In Peru, the field study was carried out during the heating season. Real time concentrations of carbon monoxide were measured using HOBO data loggers while fine particles concentrations were measured in Brazil using a TSI Dust-track monitor before and during the stove operation.

The adoption of improved stoves is limited by women cooking habits, safety aspects and the transition to LPG. CO concentrations never exceeded 60 mg/m³ (30 minutes) while increased PM_{2.5} concentrations exceeded 160 µg/m³ (1-hour) in 4 dwellings.

Indoor emissions from heating stoves were reported in closed rooms while outdoor-indoor transport was the main source of fine particle in open kitchen balconies.

INTRODUCTION

It is estimated that 2.7 billion people is still relying on solid-fuels for cooking/heating purposes in the developing countries while it is still underestimated the substantial amount of people using traditional fuels such as wood and charcoal for residential heating in developing countries (WHO, 2010).

Approximately half of these people are inhabitants of countries such as India (58% of the population) and China (46% of the population).

The other half of the people still relying on biomass is located in Africa (660 million people), Eastern Mediterranean (179 million people) and in Latin America (80 million people) (WHO, 2010; UN, 2012).

Domestic heating in large populated mid-income countries in Asia and Latin America might be an issue of relevance (not deeply studied yet) that contribute to forest depletion and household air pollution (HAP) due to the fact that heating stoves require larger amount of fuel and operate during the all day during the heating season.

TRANSITION TO MODERN FUELS AND HAP

During the decades, development processes have been accelerated in South and Central America where the economic expansion in many countries was reflected in the implementation of energy infra-structures and the growth in the population income. Some countries such as Mexico and Brazil have today most of their population agglomeration in cities with almost 100% access to electricity.

In many countries in South-America, the daily life style of communities has been changing quite much in the last decade, with the entrance of women in the labour market and the increase in people's mobility as well as the migration from the rural areas to the largest cities.

We might expect that rather than having a complete transition to costly modern fuels, families living in rural areas will continue to seek for the cheapest energy sources without concerning too much about the environment. However, practicality is a very relevant issue in the current days that might be appropriately framed to the modern lifestyle of rural families.

The comprehension of these transition processes seems to be a niche to be observed when seeking for new solutions to change from a regime of inefficient use of household solid-fuels to renewable energy systems. In that way, South-American successful experiences might be of great interest to the overpopulated regions of the world affected by this energy issue.

Why Brazil and Peru?

Countries such as Brazil and Peru have increased their urban populations, but rural communities still depend on wood for domestic cooking and heating (in cold climates of Peru).

During the last decade, many remote communities in these two countries have been experiencing a partial transition to modern fuels; reason why it becomes their contexts very relevant to understand how these changes can be scaled up in developing countries.

In Peru, biomass is the main source of energy for both household cooking and heating, being this country the largest consumer of solid-fuels in Latin America for residential heating. In Peru, the most common wood species are the Chachacomo and Eucalyptus, most commonly used for cooking (all over the country) and for heating/cooking (mainly in the Andean cordillera in high altitudes) (Pacheco P Z, 2008). The most recent estimations for the household cooking fuel sector (WHO, 2010) revealed that about 37% of the population is still relying on traditional solid-fuels (Li et. al., 2011).

This low-income country is considered such as Brazil an emerging economy, initiating a transition to modern fuels in the household energy sector with a population of approximately 29 million inhabitants – 45% living in rural areas (Legros G et al, 2009).

Brazil has the largest forest in the world and a population of 195 million inhabitants where 97.8% of the population has access to electricity and 15% living in rural areas (Legros G, Havet I et al, 2009; UN, 2012). In Brazil, the most common solid-fuels are the charcoal and firewood, most commonly used for cooking (80% mainly in northeast and north of the country) and about 4 times less for heating (20% mainly in the south and southeast of the country). The most recent estimations revealed that about 6% of the population is still relying on traditional solid-fuels, in spite of the evident transition to LPG (Scarbi, 2013).

Improved wood-burning stoves

There is a wide range of improved stoves that can be adapted to specific cooking applications. The change from mud to cast-iron combustion chambers can be a step stone towards the heat appropriation for cooking faster within the new daily life styles of rural populations.

In the recent years, the integration of chimneys through stove programs was a large step regarding the mitigation of indoor air pollution and consequently the hazardous health effects of fine particles on women and children.

Along the years stove designers have worked on the improvement of the thermal efficiency and the energy conversion performance to reduce the human exposure to carbon monoxide and indoor particles.

In Peru, the Centre of Capacity Building for Development have been promoting during the last 10 years a stove development program by designing and installing improved heating/cooking stoves, while in Brazil the largest efficient wood cooking stove program has been being developed by the Institute of Sustainable Development and Renewable Energy in north-east Brazil where the population is still cooking with residual wood.

STUDY DESIGN

Two different practices of domestic wood-burning were monitored and analysed through qualitative interviews in 20 rural single-family houses granted in 2008 with improved stove programmes in Brazil and Peru. Table 1 presents general information about the stove programs analysed on this study.

In northeast Brazil, the village of Km60/Limoeiro do Norte in Ceará was selected as a case study, representing a mid-income community using improved cooking stoves in mud-concrete houses where the families are exposed to a transition to LPG.

In the Andean mountains of Peru, the village of Yaurisque/Cusco in Paruro was chosen as a low-income Peruvian community using improved heating stoves in mud houses.

Table 1. General specifications of improved stoves in Peru and Brazil.

Case study	Solid-fuels	Cooking efficiency (%)	Energy savings (%)	Cost (€)	Users (people)
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Improved Nina (Paruro/Peru)	Eucalytus and Chachacomo	25-30	30	15	2000
Efficient IDER (Ceará/Brazil)	Eucalytus and Mameleiro	30-35	40	20	26 000

In the two programs, mass brick stoves from 2008 with a cast-iron combustion chamber were installed widely in more than 25000 households across the countryside.

The Peruvian stoves Nina were 2-pot cooking stoves that were used for complementary household heating while the Brazilian appliances were 3-pot stoves with a narrower and longer combustion chamber adapted for the regional meals of Ceará.

Table 1 describes the cooking efficiency of the 3-pot and 2-pot stoves, being the first one slightly higher than the second one while the cost of the 2-pot stove in lower than the 3-pot stove.

Moreover, exploratory indoor air quality (IAQ) measurements were carried in 10 households in order to trace the influence of critical practices on the performance of domestic wood combustion, according to the Table 2.

The number of measurements was limited by the available instruments for performing the experiment in all the households, being this study considered as a preliminary research.

Table 2. Indoor air quality study design.

Case study	Interviews	Temperature and Relative Humidity	Particles PM _{2.5}	Carbon Monoxide
Limoeiro do Norte/CE (Brazil)	10	7 households	6 households	6 households
Yaurisque/Paruro (Peru)	10	3 households	-	1 households

In Brazil, both the concentrations of fine particles and CO were measured continuously 30 minutes before lightning the stove without any other indoor sources and during the stove operation for 1-hour using respectively a Dust-track and Wolf sense monitors placed in the centre of the living room where normally the family is exposed to indoor air pollutants.

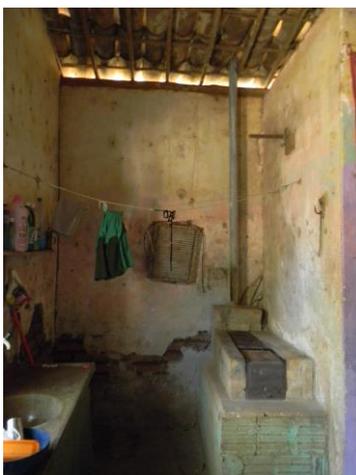


Figure 1. Improved cooking stove efficient IDER on the left (Pragmacio, 2012) and improved heating stove Nina/CECADE on the right (Barbosa, 2012).

In Peru, the CO concentration was measured under the same procedure with an HOBO logger.
HOUSEHOLD ENERGY CONSUMPTION

The household energy mix in rural houses in Peru and Brazil reflects an increasing consumption of electricity and LPG due to the current economic growth. A diversity of configurations was found for the energy mix in many households.

In northeast Brazil, some mid-income families recently begun to have access to modern fuels, however, without support from the government they cannot use LPG bottles for fulfilling all their cooking needs. In Peruvian low-income families, liquid fuels are still too expensive.

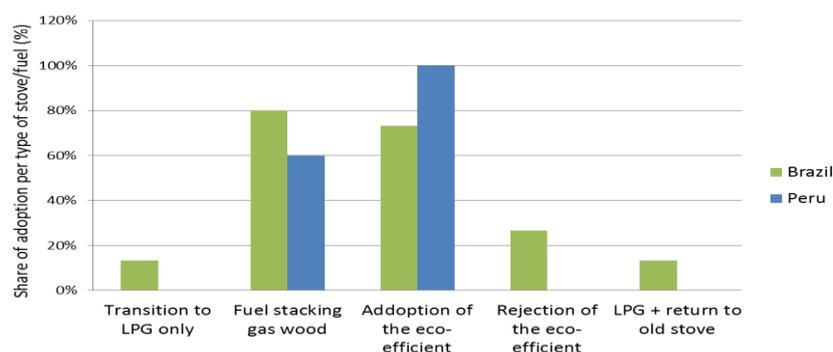


Figure 2. Share of household energy by type of fuel/stove.

Wood combustion still continues to be an important energy source accounting about 28% of the total primary energy consumption in Yaurisque/PU for heating/cooking purposes and 16% in Limoeiro do Norte/CE only for cooking activities, with a small share of households only using LPG.

Figure 2 also illustrates that a large share of the studied populations (over 60%) is depending on fuel stacking. In Brazil, 80% of the interviewed people are now using both wood and gas in their kitchens.

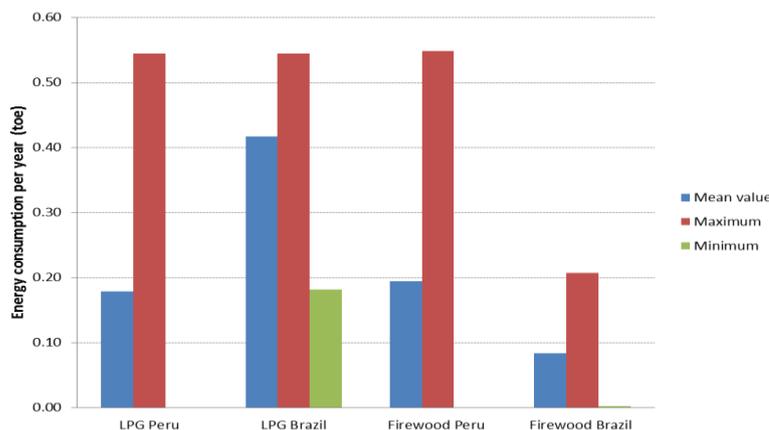


Figure 3. Household primary energy consumption in the case studies (excluding electricity).

The adoption rate of improved cooking stoves is larger in Peru than in Brazil, since all the interviewed people confirmed to be using the improved stoves (100% of the families) while in Brazil just 73% of the people fully adopted the new stoves. Only few people in Brazil has left the improved stoves to return to the traditional ones, mainly because women cooking habits did not fit to the practices necessary to operate the new model.

In general, the Peruvian household consumption of wood (used for cooking/heating and 60% fuel stacking equal to 0.19 toe per house year) was more than twice larger than in the Brazilian one (only used for cooking and 80% fuel stacking equal to 0.8 toe per house year).

INDOOR AIR QUALITY

In both case studies it was observed a variation in the indoor concentration CO that gives a picture about the indoor activities associated mainly to the daily cooking practices. This is an important indicator concerning the performance of wood combustion during a day.

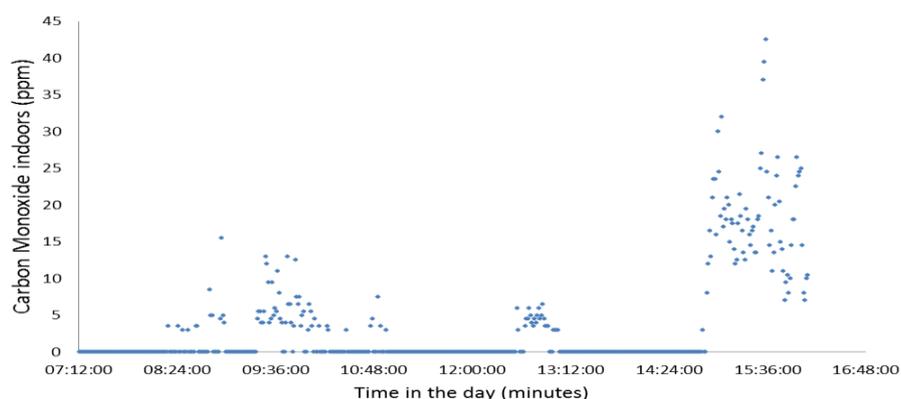


Figure 4.CO concentrations during the day by the improved heating stove in Peru.

In Peru, the improved heating stoves were the main indoor sources in the Andean households mainly during stove lightning and operation mainly during the cooking schedules, three times per day (breakfast, lunch and dinner). The CO concentrations observed during the dinner event revealed to be lower than the WHO guidelines for 30 minutes average (60 mg/m^3). The indoor temperatures varied between 15 and 24 °C while the outdoor temperatures ranged between 10 and 20 °C. The mean relative humidity was 58%.

Although heating stoves operate during longer hours when compared with cooking stoves, indoor emissions occurred mainly during lightning and refilling for the purpose of cooking, being the residual heat of cooking also used for heating the house during the all day, since the heat comes naturally from its accumulation on the thermal mass of the 2-chamber brick stove.

In Brazil, the CO concentrations were down below the levels found when operating Peruvian stoves and never exceeded the 20 mg m^{-3} during and after the stove operation. As this is considered as an exploratory field study, it does not contain a statistical analyses.

The concentration of fine particles measured in Brazil increased more than 5 times for all the households where improved cooking stoves were installed from the background levels of $35\mu\text{g}/\text{m}^3$ (before lightning) to values exceeding $200\mu\text{g}/\text{m}^3$. The mean concentration of $\text{PM}_{2.5}$ for 1-hour average can be twice larger than the air quality guidelines for Canada of $80\mu\text{g}/\text{m}^3$ (Aberta Environment, 2007). However, the WHO guidelines for fine particles are associated to exposure periods of 24-hour average, on this study the $\text{PM}_{2.5}$ concentrations were measured for short-term periods before, during and after wood cooking cycle at once on each house, since this research is considered as an exploratory field study. The indoor temperatures varied between 25 and 36 °C while the outdoor temperatures ranged between 25 and 38 °C. The mean relative humidity was 30%.

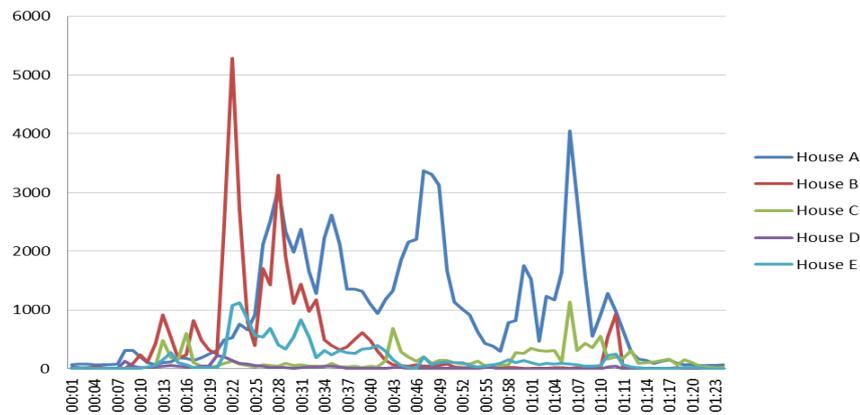


Figure 5. $\text{PM}_{2.5}$ concentrations during the day by the improved cooking stove in Brazil.

In the house B and A the peak concentrations reached the $3000\mu\text{g}/\text{m}^3$ (1-5 minutes) even though these stoves were installed in a balcony outside the kitchen. In those cases the emission of fine particles is not associated to the low air-exchange in the households, but to the outdoor-indoor pressure in that day (natural ventilation dragged emissions from outdoor balcony to the kitchen where the Dust-tracker was located).

Although domestic wood-burning is usually associated to direct emissions indoors, this result has shown how outdoor-indoor transport might affect the indoor spaces in tropical climates, even if the stove installation is located in a balcony outdoors.

CONCLUSIONS

The improvements made in two models of improved stoves used for different purposes in South-America revealed to have larger performance in terms of wood savings rather than on the indoor air quality, since the second issue is strongly correlated with the household interventions and user practices when lightning and operating smaller combustion chambers.

The users were satisfied with having more efficient stoves used for cooking large meals that require about 40% less amount of wood, task that can be combined with the use of LPG stoves in short-term cooking events such as water boiling for making coffee or tea.

Improved heating stoves revealed to have a wood consumption more than two times larger than improved cooking stoves. This preliminary field studies has shown that improved wood-burning stoves can cause higher concentration levels of particles when compared with the international guidelines of Canada.

Stove improvements are needed to increase the air-tightness of the combustion chambers in order to avoid leakage of gases from the stove to the ambient air in both contexts.

Moreover, proper stove/chimney installations might be considered in order to improve the flue gas draft towards a better dispersion of fine particles in the atmosphere, avoiding outdoor-indoor transport.

Further research is needed to understand the real impacts of the usage of improved stoves on the indoor air quality by increasing the time and number of samplings and through a statistical analysis of the data. IAQ monitoring programs can be a relevant tool as a form of technical guidance concerning the indoor climate performance of large scale stove programs.

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