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Changes to indoor air quality as a result of relocating families from slums to public housing

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1.1. Introduction

The goal of most housing policies is to improve overall living conditions for poor families. One potential and often overlooked benefit of rehousing is improving indoor air quality (IAQ). The slum population is a group particularly vulnerable to pollution because the general characteristics are substandard housing and a gap in access to land, services, and security (MacDonald, 2004; Winchester, 2006). Slum families may also be exposed to higher levels and varieties of indoor pollutants, especially those resulting from the use of biomass fuels (Fullerton et al., 2008; Siddiqui et al., 2009). Furthermore, because slum housing is often poorly constructed from flimsy materials, these structures are more permeable to environmental pollutants from the outdoors. Rehoused families may enjoy better indoor air quality than families remaining in slums due to better housing infrastructure and increased opportunities to control emissions, including using windows for ventilation, opting to cook in differentiated areas, or reducing heating times. Rehoused families may also be motivated to smoke cigarettes outside their homes or change fuel practices in their new dwelling. The use of dirty fuels such as wood, dung, coal, or trash is likely to be abandoned due the territorial regulations about contaminants sources or by neighbors' pressure in the new neighborhood.

International evidence regarding the health effects of housing interventions includes studies involving rehousing/refurbishment, relocation from poor areas, rehousing by medical priority, and improving energy efficiency (Thomson et al., 2003). Improved mental health, reduced smoking, better respiratory health, and decreased school absences due to asthma have been attributed consistently to rehousing interventions (Thomson et al., 2001; Thomson et al., 2003). However, recent evidence regarding the environmental effects of rehousing on health is minimal, according to a systematic review of the literature based on forty-five

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studies identified (Thomson et al., 2009). A cross-sectional study, although inappropriate to ascertain the timing of effects associated with interventions, allows comparisons between different groups. Results can be examined further and used to prioritize research areas and identify populations with environmental vulnerabilities.

IAQ is one of the major contributors to disease burden in the world; in fact, an estimated 3.7% of the total burden of disease can be attributed to indoor smoke from solid fuels (Lopez et al., 2006). Observational evidence shows that several other housing characteristics are strongly associated with poor health, including substandard infrastructure and specific indoor agents such as particles, dust mites, allergens, and dampness (Institute of Medicine [IOM], 2000). Furthermore, the health effects of particulate matter and toxic gas concentrations have been described in studies comparing interventions involving woodstoves (Brauer et al., 1996; Naeher et al., 2000a; Naeher et al., 2000b; Clark et al., 2009; Siddiqui et al., 2009). Fine particulate matter (<2.5 μm) has been a focus of attention because of its ability to penetrate the lower respiratory tract.

In Chile, the number of slums increased from 490 to 706 between 2007 and 2011 (Ministerio de Vivienda y Urbanismo [MINVU], 2011). Slums have been the target of systematic intervention since 1996 (MINVU, 1997), but no evidence regarding IAQ in a rehousing context has been reported in Chile. The first public housing program in Chile (“Chile-Barrio”) was implemented during 1998-2007 to provide integrated support for slum families, including access to housing units. While the main goal of the program was social benefits, externalities of the intervention may have impacted other indicators of welfare including environmental quality. Therefore, the primary aim of the present study was to compare IAQ for relocated families with families remaining in slums, using particulate matter $PM_{2.5}$ and indoor air pollution sources as indicators of environmental change. A secondary aim was to identify potential predictors of $PM_{2.5}$ concentration related to the intervention.

1.2. Materials and methods

1.2.1. Study setting

The present study was conducted in Santiago, Chile in an urban area about 7 km^2 west of the city. It is an area in which the population with a majority of families lives below the poverty line, with lower family income (US$990) and fewer years of education (8.9 years) than others areas of Santiago (Ministerio de Planificación [MIDEPLAN], 2010). Santiago has a Mediterranean-temperate climate and topographic conditions that result in poor ventilation in the winter season. Local studies have indicated that the study area is exposed to higher accumulations of $PM_{2.5}$ than other areas of the city (Gramsch et al., 2004; Prieto et al., 2007).

1.2.2. Study design

A cross-sectional study was conducted to assess 169 houses in Santiago, Chile between June and September of 2009. The sample included 98 families who had completed the public housing tenancy process during 2000-2001 and 71 slum families still in the process of acquiring public housing. The families rehoused in public housing lived in the same general area as the slums in this study, with less than 5 km of distance between the communities’ two most extreme locations. The question addressed in the present work is part of a larger primary study whose purpose is to assess respiratory outcomes in children. Thus, an inclusion criterion for families was the presence of at least one child under the age of eight years who had been born in the current residence

Relocation was completed through the public housing program *Chile-Barrio*. The program assigned the intervention to communities according to an economic criterion (families were required to have savings of about US$300) and the technical feasibility for relocation (Saborido, 2005). The public housing consisted of apartments 46 to 69 m^2, organized in blocks with three floors and forming a cluster within a larger social village. With this housing solution, the program provided interventions in several domains: economic, educational, and social support, including proper maintenance and use of housing. Information on relocated families was provided by the Chile-Barrio Program and information about current slums was provided by a non-governmental organization, *Un Techo Para Chile* (CIS/UTCH, 2007).

Recruited families signed an informed consent document before participating. Study procedures were approved by the Ethics Committee of the University of Chile Medical School and Emory University Institutional Review Board. Of the 327 eligible families that had lived in the slums for at least two years and in the same geographical areas under study, 108 families were not invited to participate because no resident was available when the household was approached on multiple occasions. Of the total households invited to participate (N=219), 86% met the criteria for inclusion (home with children < 8 years) and accepted the particulate matter measurement and the interview. No differences in participation rates between the slums and public housing families were observed. Twenty households were subsequently removed from analysis because of incomplete data, resulting in a total of 169 complete questionnaires.

1.2.3. Air measurements

To determine PM$_{2.5}$ concentrations, we used a 230 volt pump (SKC 222-44XR, USA) with a vacuum range of 0.05 to 5 L/min and a gravimetric sampler (SKC Personal Environmental Monitor; PEM Sampler, USA). Pumps were installed in indoor and outdoor locations in each home. One measurement was taken each day at two slum homes and three public housing homes, respectively. PM$_{2.5}$ concentrations were measured during a 24-hour period during winter. Indoor locations for the pumps were placed in children's bedrooms at breathing height (about five feet above the ground). Outdoors, the pumps were installed in the backyards of the houses in the slums or on the balconies of the public houses.

Samples were collected using a 37 mm Teflon filter with 2.5 μm pore size at a rate of 4 L/min. The filters were weighed and analyzed by gravimetry at CHESTER LABnet laboratory (Tigard, Oregon, USA). Results were expressed in micrograms/cubic centimeter (μg/m^3). Pumps were adjusted to the target flow-rate at the start and the finish of each measurement. An electronic calibrator (SKC Ultraflow, USA) was used according to the manufacturer's calibration guide. Because the temperature and relative humidity affect the thermal environment, they were registered in real time with a portable recorder (Hobo V10-003 Data Loggers, USA), and the data was processed with commercial software for Windows (Hoboware Software BHW-Lite, USA).

1.2.4. Quality control of PM$_{2.5}$ measurements

Most of the samples (74.5%) were recollected in August and September. During these months, the average temperatures reached 12.8°C+2.7 outdoors, with a relative humidity of 62%. These values were significantly higher than June and July, when average temperatures were 9.9°C+2.7, with a relative humidity of 67%. These tendencies occurred both in public and slum housing. Weight (μg) samples were standardized based on the average weight of blanks and by sample volume in m^3 (time sample × average flow). The limit of detection (LOD) (24.5 μg/m^3), for PM2.5 concentrations, was three times the standard deviation of the blanks divided by the nominal volume. Nine percent of overall PM$_{2.5}$ samples were lower than the limit of detection. Two control measurements were employed: 10 filters to duplicate samples and 12 filters to assess measurement reliability, with a standard measurement from a central site (MACAM net monitoring) representative of the geographic area of Santiago. In this location, two types of samplers were used: continuous ambient particulate monitor (Monitor MP2.5 model TEOM 1400AB, series 647) and a dichotomic sampler (Sierra-Andersen Series 240) calibrated to 25°C, 1 atm.

The results of mass concentration uncertainty estimation by sampling in duplicate did not show significant differences between pairs of samples (p=0.169), according to a paired Wilcoxon Signed Rank test analysis. The variation in flow rates was within the range established at calibration. Only 10.1% of the measurements had durations shorter than 24 hours. However, $PM_{2.5}$ concentrations were similar for samples with the target duration and the shorter duration; thus, they were both included in the analysis. Reliability analysis showed that concentrations measured by the PEM Impactor compared with the time continue monitor and dichotomic standard sampler achieved good precision (R^2=87.9% and R^2=96.9%, respectively) in the punctual estimation.

1.2.5. Questionnaire

The questionnaire used in the present study included two sections. The first set of questions about asked the age and years of education of the informant, family income, years of residence in the home, family size, and age composition. Questions about total number of rooms in the home and rooms used most frequently were also included. During the pilot study, we noted other issues that were incorporated into the questionnaire, including perception of structural problems affecting ventilation (Yes/No), frequency of trash burning in the surrounding neighborhood (Always/Almost always/Sometimes/ Rare/Never), and water heating system (Nothing/Electricity/Traditional gas stoves/Open fire with wood or coal fuel). In the second set of questions, participants were asked about the number of cigarettes smoked indoors; the amount of time spent inside the home heating, cooking, and with the windows open during the 24 hours during the measurement; and type of fuel used to heat the home (Nothing/Electricity/Gas/Kerosene/Coal/Wood). Participants were surveyed while carrying out their normal activities so that the exposure measurements were realistic.

Questions were taken from a previous study on a population of children in Santiago regarding indoor air pollution (Pino et al., 2004). The key informants were children’s mothers, who were asked about family socioeconomic conditions; general home care practices, and activities that could influence the home environment during the 24 hours (National Research Council, 1991). The questionnaires were administered face-to-face in the families’ homes by two interviewers that were trained in a workshop before conducting the interviews for both the slum and public housing families. An environmental engineer trained in preparing and installing the pumps accompanied the visits.

1.2.6. Data analysis

Two variables regarding age composition of the family group were constructed to explore the issue of families with children living at home because they could modulate home practices. First was the proportion of children < 15 years with respect to total household members, and second was a dichotomous variable for the presence or absence of infants. Two income categories were constructed to describe the socioeconomic status of the family groups: income greater or less than US$300. Two predictors of density and space used were constructed: a Crowding Index, based on the number of residents per rooms used and a Space Used Index, based on the rooms used by the family compared to the total number of rooms. Three categories were constructed to describe the number of cigarettes smoked inside the home: None; 1-3 cigarettes, and > 3 cigarettes. For the use of indoor fuels, three categories were constructed, because we are interested in comparing a separate “no exposure” (none or electricity) category against intermediate fuel using (gas or kerosene) and the use of “dirty fuels,” which are known contributors to particles (coal, wood, or waste). The same three categories were used to describe the type of fuel used to heat water for bathing (excluding kerosene as a fuel from the second category). For this last situation, only three families reported “no” use of fuels, which provided a new argument for merging the category. To maximize the risk response, three categories were constructed to describe the frequency of trash burning: high (always or almost always), medium (sometimes), and low (rarely or never).

Public and slum housing were compared with non-parametric Mann–Whitney statistical tests of significance when variables were numerical and continuous (e.g., years of residence or index created). To compare dichotomous and categorical variables (e.g., fuel type used), differences in the distributions between public and slum housing were examined using a chi-square test. A *p*-value of < 0.05 was set as the level of significance. A descriptive analysis was conducted for indoor and outdoor $PM_{2.5}$ concentrations overall and by housing group. Arithmetic means and standard deviations, medians, and 75th and 25th percentiles were used to show patterns in public and slum housing. Indoor and outdoor $PM_{2.5}$ within and between groups were compared using the Mann–Whitney test.

A multiple linear regression model was also developed. Indoor $PM_{2.5}$ concentration was the dependent variable, and allocation to public housing was the principal predictor (Public Housing=1; Slum=0) to measure the importance of the allocation as a cumulative exposure. All potential $PM_{2.5}$ sources were explored in a preliminary analysis, independently as covariates adjusted by outdoor $PM_{2.5}$ concentration to explain indoor $PM_{2.5}$ concentration. Each proposed model was to identify the contribution of each predictor when they were present in the simplest model with the outdoor exposure. Predictors from the simplest model were selected to be included to the final model when the regression coefficients had a *p*-value <0.2. To create the final model (Appendix A), all variables previously shown to be associated with indoor $PM_{2.5}$ concentration were introduced one to one maintaining the housing predictor and the outdoor $PM_{2.5}$ effect in the model. We excluded model predictors with *p*-values of coefficients higher than the significance level of 0.05 and analyzed the slope variation of the housing variable when the indoor $PM_{2.5}$ sources and other variables were introduced into the model. We included the partial correlations between predictors explaining the pollutant to show the effect of a predictor when the remaining variability of the other predictor was removed.

Regression diagnostics were performed. To identify outliers, residual distributional graphs and Cook’s distance were used. Seven observations with values higher than 240 $\mu g/m^3$ increased heteroscedasticity, but models did not improve with the log transformation of the $PM_{2.5}$ variable. Eliminating the extreme values resulted in better-fitting models, and variance was robust in a standardized normal probability plot. All models were adjusted by outdoor $PM_{2.5}$ concentration because the effect of outdoor pollutants on indoor air was known. Increases in variance after introducing a new explanatory variable were assessed with the post-estimation likelihood-ratio test. A reduction in the coefficients of the variables was interpreted as an improvement to IAQ. Potential interactions between indoor $PM_{2.5}$ sources (smoking cigars, time home heating, bathing water, or cooking, and burning trash), infant presence and the allocation to public housing were also explored to evaluate the effect of the housing program on indoor $PM_{2.5}$ concentration. All analyses were carried out using STATA 10.0 software.

1.3. Results

1.3.1. Home conditions by housing group

No significant differences were observed in the age of informant, education, years of residence in the current home, age composition of family groups, and crowding and space indices between public and slum housing (Table 1). Cigarettes smoked, time spent cooking, and ventilation problems perceived were also similar between the two groups. However, the amounts of time spent heating the home and with windows open were higher in the slum group. The dominant fuel type used for home heating in slums was organic material (charcoal, wood, papers, or waste). In public housing, there was no combustion of solid fuels, and most preferred using no fuel or electric systems to heat the home. The main fuel used to heat water for bathing was gas in public housing. In slums, families used all methods to heat water, but mainly electric (boiler, thermo) or no water heating at all. Trash burning was more common in the slums than in public housing.

1.3.2. $PM_{2.5}$ concentrations

Average and median values of indoor and outdoor $PM_{2.5}$ concentrations were higher in slums than in public housing ($p<0.001$). Indoor and outdoor $PM_{2.5}$ concentrations were similar in public housing but significantly different in the slums ($p<0.05$). The correlation between indoor and outdoor $PM_{2.5}$ was moderate (rho=0.55, $p<=0.001$) and similar between the two groups (Table 2).

1.3.2. Public housing, indoor sources, and $PM_{2.5}$ concentrations

$PM_{2.5}$ concentration was associated with allocation to public housing in the preliminary analysis (Supplementary Table 3) including $PM_{2.5}$ sources such as the number of cigarettes smoked; method used to heat water for bathing and sampling month. The presence of infants was associated with decreased indoor $PM_{2.5.}$ The final regression model with covariates that were candidates explained about 41% of total variance (Table 4). The effect of the allocation to public housing decreased from 14.9 $\mu g/m^3$ (Supplementary Table 3) to 10.4 $\mu g/m^3$ in the model with more covariates, but was still a significant predictor of lower indoor $PM_{2.5}$ concentration. Outdoor $PM_{2.5}$ was the main predictor of $PM_{2.5}$ concentration ($\beta=0.5$, $p<0.001$, meaning 50% of outdoor PM2.5 is found indoors), followed by using dirty fuel to heat bathing water ($\beta=25.6$ ug/m^3, $p<0.05$,) and smoking more than three cigarettes indoors ($\beta=29.0$ ug/m^3, $p<0.05$). The presence of infants remained a protective factor in the model Beta which suggested a change of family habits for the baby's sake.

The partial correlation coefficient confirmed that outdoor $PM_{2.5}$ is the most important predictor of indoor $PM_{2.5}$ concentration (explaining 26.0% of variance), followed by using organic fuel to heat water (5.3%), and number of cigarettes in the highest risk category (4.8%). We tested interactions between the housing and indoor $PM_{2.5}$ sources; however, none were significant. We found that the interaction with the number of cigarettes smoked approached significance ($\beta=-17.2$, $p=0.07$), showing that indoor $PM_{2.5}$ contributed by smokers in public housing is lower than that of indoor smokers in slums. This interaction eliminated the independent effect of the allocation to public housing ($\beta=-5.641$, $p=0.289$).

1.4 Discussion

Average indoor $PM_{2.5}$ concentration was significantly higher in slum housing than public housing, and both groups far exceeded the standard acceptable levels for the 24-h average $PM_{2.5}$ set by the Environmental Protection Agency (35 $\mu g/m^3$) (U.S. EPA, 2009) and recommended by the World Health Organization (25 $\mu g/m^3$) (WHO, 2006). Furthermore, outdoor concentration was close to concentrations reported in previous studies in Santiago

(Pino et al., 2004; Koutrakis et al., 2005; Ruiz et al., 2010) and higher than the Chilean daily $PM_{2.5}$ standard (50 $\mu g/m^3$), particularly in slums whose families could be a focus group for the instruments that encourage the adoption of cleaner energy use in vulnerable environments (Organization for Economic Cooperation and Development [OECD], 2011).

Studies on indoor $PM_{2.5}$ concentration in Chile are rare, and this study is the first to report indoor air quality indicators in slums. In one study, Ruiz et al. (2010) assessed indoor pollutants in apartments in two areas of Santiago (Ruiz et al., 2010) and determined that average $PM_{2.5}$ concentration was between 42.1 and 86.3 $\mu g/m^3$. Apartments with only an electric system had lower $PM_{2.5}$ concentrations (42.1 $\mu g/m^3$), being higher in apartments with gas natural heaters (49.5 $\mu g/m^3$) and with kerosene users (86.3 $\mu g/m^3$). Our results are difficult to compare with this study, however, because some families used several fuels simultaneously. The results from public housing were closer to the concentrations assessed by Ruiz et al. (2010) in apartments with electric or gas heaters, while concentrations in slums were closer to concentrations in apartments using kerosene. $PM_{2.5}$ concentrations in slums were low compared to studies that have assessed stove systems such as open fire or coal/wood stoves (more than 528 $\mu g/m^3$) (Brauer et al., 1996; Naeher et al., 2000a; Naeher et al., 2000b; Siddiqui et al., 2009). We deduce that the lower concentrations are due to the influence of outdoor concentrations in the slum homes studied and the small amounts of time spent cooking and heating the home.

Differences between the indoor and outdoor $PM_{2.5}$ concentrations were significant in the slums but not in the public housing. This confirms that different sources are involved in determining not only indoor but also outdoor concentrations. Outdoor $PM_{2.5}$ concentrations in the slums were higher than in public housing, which suggests that the outdoor sources (e.g., trash burning) more prevalent in slums may influence outdoor PM concentrations directly. Outdoor $PM_{2.5}$ was the most important predictor of indoor $PM_{2.5}$. The correlation between indoor/outdoor concentrations was moderate, and this result is in accordance with other studies on the general populations of European and American cities (Leaderer et al., 1999; Johannesson et al., 2007) and with an earlier Chilean study (Ruiz et al., 2010). Homes with more restrictive environments, such as air flow controlled by air conditioning or central heating, reported low correlations between indoor and outdoor concentrations ($R^2<0.07$) (Chao & Wong, 2002; Miller et al., 2009).

We cannot explain the “lowering” of the indoor PM2.5 concentration associated to housing variable, based on IAQ conditions when comparing public housing to slum household, probably by study design. However the housing type and their thermal properties could be involved. Predictors related with building properties not measured could explain the effect attributable to the program housing variable. We did identify, however, specific $PM_{2.5}$ indoor sources that the intervention could impact. For example, some fuels to heat bathing water were used only in slums and were significantly associated with increased indoor $PM_{2.5}$. Thus, the intervention has a quantifiable benefit for air quality, as post-intervention this source of pollution was removed entirely.

Among all families, indoor PM concentration was 29.0 $\mu g/m^3$ 2.5 higher in homes with more than three cigarettes smoked inside compared with homes with no cigarettes smoked inside. In agreement with our results, a review of studies in the US estimated increases of 25 to 45 g/m^3 due to cigarette smoking (Wallace, 1996). Furthermore, smoking inside the home has been reported as a principal contributor to indoor $PM_{2.5}$ concentration in European cities (Gotschi et al., 2002; Lai et al., 2006; Saraga et al., 2009). However, overall cigarette consumption and indoor $PM_{2.5}$ are low in these cities. The European Exposure Assessment Project, EXPOLIS study (Lai et al., 2006) in six European cities reported that 17.7% of total $PM_{2.5}$ variance was attributable to smoking at home. In the present study, the percentage of variance explained by smoking cigarettes was lower, probably due to including outdoor PM concentrations and the method used to heat water as covariates. As we hypothesized, families living in the slums are at greater risk, because this group reported a slightly higher number of cigarettes consumed than families in public housing.

We did not identify significant interactions with smoking, probably because of the small sample size. However, a differential effect of cigarettes smoked in interaction with the housing variable could be explored in a larger sample. Smokers in public housing could exhibit different behavior with respect to pollutant habits in their spaces than smokers in slums. Indeed, rehousing has been shown to influence tobacco consume (Thomson et al., 2003). Moreover, slum families are a highly disadvantaged group and their smoking behavior could be linked to poor mental health as reported in other Chilean studies (Bedregal et al., 2006; Bedregal et al., 2009). Thus, we should not discard the possibility that a housing program could mediate a psychosocial process that influences habits and behaviors. The presence of infants, but not children of other ages, emerged as a possible moderator of response in this study. We did not identify similar findings in other studies. However, we introduced this variable because the behavior of family members, especially female caregivers, in public housing could be perceived as an opportunity to control environmental hazards (e.g., through window use, smoking outside of the home). Our results showed that this response was not exclusive to one group. The effects could be interpreted as a risk perceived in general by the families, who may cease polluting practices to reduce environmental risk for vulnerable family members.

One limitation of this study is the cumulative measure used, which limits the results to a period of 24 hours; however, we procured the measurements simultaneously in both home types. Activities in the home could change and influence $PM_{2.5}$ concentrations throughout the day; thus, we lost sensitivity to the effect of different $PM_{2.5}$ sources in real time. Family activities may also vary over longer periods of weeks or months, and we did not use time activity diaries. Real-time measurement correlated with a daily activities diary and different periods of the year could be more informative of behavior profiles of families living in both slum and public housing. A comprehensive daily home activity questionnaire might permit a more detailed exploration of the intervention effect seen in our analysis. For example, our study did not collect data about vehicular traffic. This $PM_{2.5}$ source, in particular diesel engines, is a major pollutant in Santiago (O'Ryan & Larraguibel, 2000). We evaluated communities located on similar roads with moderate levels of vehicular traffic by trucks, buses, and cars, but we did not consider their proximity to the highways crossing the city. An advantage of this study was recruiting populations not studied with respect to IAQ. A strong field deployment technician was required, especially in the slums where access to electricity is erratic and usually collective. Although the results of this study cannot be considered strictly a housing evaluation due the study design, all families were part of the same group because they were from slum communities. An adequate study design and selection of a control group could extend this study to other areas of the country. The indoor $PM_{2.5}$ sources did not constitute a large part of the explained variance. However, the effect of indoor and outdoor sources related in rural slums (not included in this sample) could be higher for the $PM_{2.5}$ and other pollutant concentrations for the availability of wood in forest areas, besides burning crop waste practices (Smith & Pillarisetti, 2012).

We showed that indoor air quality, as indicated by indoor $PM_{2.5}$ level and its predictors, can be used to evaluate other impacts and the social benefits of a housing intervention. We might expect some trends within each study group in the predictors in a secondary analysis, which could attend specific needs into the groups. Assessing other pollutants resulting from combustion practices as well as chemical and biological agents should be considered. A prospective study of families before and after intervention, with long-term follow-up, could also increase knowledge regarding benefits or negative impacts of re-housing programs on behavior and practices among slum families, highlighting the long-term health effects for families that remain in extreme poverty while waiting for a home. This information would also contribute to an understanding of barriers to overcome after relocation, in order to improve environmental quality inside homes and neighborhoods.

1.5. Conclusions

This study showed that average indoor and outdoor $PM_{2.5}$ concentrations (over 24 hours) were significantly higher in slums than in public housing. The main predictor of indoor $PM_{2.5}$ concentration in all homes was outdoor $PM_{2.5}$ concentration. The families' method of heating bathing water (dirty fuel) and the number of cigarettes smoked indoors (>3) were also determinants of high indoor concentrations. All families living in poverty are at risk, but families living in slums are at highest risk, because they remain for a long time with housing situations unresolved. Families in slums are not only exposed to higher outdoor contaminant levels, but are also more likely to engage in habits that directly impact indoor air quality. In contrast, the present study also showed that allocation to public housing and the presence of infants in the home predicted reduced indoor $PM_{2.5}$ concentration, implying that these conditions may offer protection.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Appendix

1.8. Appendix A:

Final model for Indoor $PM_{2.5}$ concentration model is represented in the following equation (Myers, 1990):

$$Y_i=\beta 0+\beta_1 X_1+\beta_2 X_1+\beta_3 X_3+\beta_4 X_4+\beta_5 X_5+\varepsilon$$

Where Y_i is the subject with the ith $PM_{2.5}$ result, $\beta 0$ the intercept and βn the regression coefficient for the Xn variable. Correspondingly, Xn (X_1, X_2, X_3, X_4, and X_5) represent the $PM_{2.5}$ sources (or a indoor air pollution modulator): $PM_{2.5}$ outdoor concentration, allocation in public housing (dichotomic), presence of infant (dichotomic), the type of fuel for heating bathing water (gas/coal, wood, or waste) with "nothing or electricity" as the reference category and the number of cigarettes smoked in 24 hours (1-3/>3) with "not smoking indoors" as the reference.

Abbreviations

IAQ	Indoor Air Quality
μg/m^3	Micrograms / cubic metric
PM	Particulate Matter

$PM_{2.5}$	Particulate Matter with diameter <2.5 micrometers (μm)

1.7. References

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Highlights

- We examine differences in the PM2.5 and their sources in slums houses and public housing
- Indoor and outdoor $PM_{2.5}$ were significantly higher in slums than in public housing
- Differences between indoor and outdoor $PM_{2.5}$ within homes were significant only in slum houses
- Outdoor PM2.5 and the method for bathing water heating were the main predictors in all homes
- A program that move slums families to public housing may improve indoor air quality

Table 1

Sociodemographic characteristics and $PM_{2.5}$ indoor sources reported for households, by housing groups (n=169)

	n	Public Housing (n=98)	n	Slum (n=71)	p-value
Home variables		%		%	
Age of informant [a] (years), *Mean (SD)*	98	31.1 (10.2)	71	32.5 (9.8)	0.38
Education (years) , *Mean (SD)*	98	8.3(2.9)	71	8.7 (2.4)	0.53
Proportion of children <15y[b], *Mean (SD)*	98	41.4 (15.4)	71	44.3 (14.7)	0.10
Crowding index [c], *Mean (SD)*	98	1.8(1.6)	71	2.2 (1.6)	0.11
Space used index [d], *Mean (SD)*	98	77.6 (37.2)	71	76.9 (32.1)	0.53
Family Income <300 US	40	61.9	21	70.8	0.22
Presence of infant	52	50.9	43	41.8	0.23
$PM_{2.5}$ Indoor sources					
Home heating hours	98	1.2(3.1)	71	4.1(8.9)	0.00 *
Cooking hours	98	1.2(1.1)	71	1.2(1.6)	0.50
Open windows hours	98	2.1 (2.9)	71	2.9(3.0)	0.01 *
Number of cigarettes					
None	81	83.0	54	75.7	0.22
1-3	12	12.3	10	13.5	
>3	5	4.7	8	10.8	
Home heating fuel					
None/electric	60	61.3	25	35.1	0.00 **
Gas/kerosene	38	38.7	15	21.6	
Coal/wood/waste	0	0.0	31	43.2	
Difficulty with ventilation	44	45.2	32	51.4	0.42
Bathing water heating fuel					
None/electric	19	19.0	29	40.3	0.00 **
Gas	79	81.0	22	31.9	
Coal/wood/waste	0	0.0	20	27.8	
Burning trash [e]					
Low	56	56.9	15	21.0	
Medium	22	22.0	10	14.5	0.00 **
High	20	21.1	46	64.5	

Abbreviations: SD, standard deviation; Med, median; Min, minimum value; Max, maximum value.

* Mann-Whitney test;

** Ji^2 Test.

[a] all informants were mothers of the child;

[b] number of children < 15/ total resident ;

[c] number of resident/rooms used ;

[d] number of total rooms/ rooms used;

[e] Low is Never/almost Never, Medium is sometimes, High is always/almost always.

Table 2

Indoor and outdoor concentrations of $PM_{2.5}$ (ug/m^3) in public and slum housing reported by households

Groups	**$PM_{2.5}$ ($\mu g/m^3$)**					
	N	**Mean**	**SD**	**Med**	**p_{25}**	**p_{75}**
Overall study						
Indoor	169	64.8	36.6	58.8	38.1	81.2
Outdoor	169	57.6	34.8	45.9	35.3	70.2
Differences Indoor-Outdoor	169	7.3	35.5	4.1	−7.1	20.4
Public housing						
Indoor	98	55.7 **	34.6	46.7	29.4	71.2
Outdoor	98	51.5 [1]	31.3	37.7	34.4	57.5
Differences Indoor-Outdoor	98	4.2	33.6	2.3	−7.5	15.6
Slum housing						
Indoor	71	77.8 **	35.7	67.8	54.9	101.1
Outdoor	71	66.1 [1]	37.9	59.4	39.2	80.5
Differences Indoor-Outdoor	71	11.6 *	37.8	6.5	−5.6	27.9

Abbreviations: SD, standard deviation; Med, median; p_{25}, 25th percentile; p_{75}, 75th percentile.

[*] Difference between indoor-outdoor within group is significant at Mann-Whitney test (* p-value <0.05)

[**] Difference between public housing's indoor vs slums houses's indoor is significant at Mann-Whitney test (**p-value<0.01)

[1] Difference between public housing's outdoor vs slums houses's outdoor is significant at Mann-Whitney test (**p-value<0.01)

Table 3

Predictors of Indoor $PM_{2.5}$ concentrations in public and slum housing, reported by households (n=169)

Variables	Intercept	Regression coefficient[a]	Standard Error	*p*
Housing intervention	45.3	−14.9	5.30	0.01 *
Home predictors				
Years of education (informant)	29.4	0.6	0.82	0.48
Years of residence	34.8	−0.1	0.31	0.73
Proportion of children <15[b]	29.8	9.4	1.75	0.59
Presence of infants	40.3	−14.1	4.85	0.00 *
Crowding Index [c]	33.3	0.4	1.48	0.79
Space used Index [d]	35.6	−2.1	7.41	0.78
Family income <300 USD [e]	46.0	8.7	5.12	0.09
Indoor predictors				
Daily home heating (hours)	33.7	0.4	0.34	0.24
Cooking duration (hours)	31.2	2.2	1.81	0.23
Open windows (hours)	31.2	0.9	0.83	0.26
Number of cigarettes				
1-3	31.6	3.2	9.1	0.72
>3		31.7	13.1	0.02 *
Home heating fuel				
Gas/kerosene [f]	34.2	−5.3	5.13	0.31
Coal/wood/waste [f]		1.4	7.36	0.07
Problems with ventilation(Self-report)	29.9	8.9	4.91	0.07
Bathing water heating fuel				
Gas [f]	29.5	4.1	5.02	0.42
Coal/wood/waste [f]		30.9	1.03	0.00 *
Trash burning				
Medium [g]	31.4	5.0	6.71	0.46
High [g]		1.0	6.20	0.09
Sampling month (Jun-Jul)[h]	33.9	13.3	5.92	0.03 *

[a] Adjusted by Outdoor $PM_{2.5}$ concentration;

[b] number of children < 15/ total residents;

[c] number of residents/rooms used

[d] number of total rooms/ rooms used;

[e] Income >300 USD ;

[f] Nothing or electric;

[g] Low (Never, rare) vs. High (always, almost always); Never vs. Medium (sometimes);

[h] Aug-Sep

[*] p-values<0.05

Table 4

Predictors of indoor PM2.5 in public and slum housing, reported by households (n=169)

						Partial Correlations	
Predictor	**β**	**SE**[a]	***P***	**95% CI**		**R^2 (%)**[*]	**p-value**
Allocation (Public houses) [b]	−10.4	5.1	0.04	−20.5	−0.3	2.2	0.07
Presence of infant	−9.5	4.6	0.04	−18.7	−0.3	2.6	0.05
Number of cigarettes							
1-3 [c]	4.1	7.9	0.61	−11.6	19.7	0.3	0.56
>3 [c]	29.0	11.0	0.01	7.3	50.6	4.8 [*]	0.01
Bathing water heating fuel							
Gas [d]	8.5	4.8	0.08	−1.0	18.0	1.4	0.15
Coal/wood/waste [d]	25.6	10.0	0.01	5.8	45.3	5.3 [**]	0.00
$PM_{2.5}$Outdoor	0.5	0.1	0.00	0.3	0.7	26.0 [**]	0.00
Intercept	36.5	8.0	0.00	20.7	52.3		

Abbreviations: SE, Standard error; CI, Confidence intervals; R2, Regression coefficient

[a] RL Variance robust; R^2: 41 %

[b] Control group: Slum houses

[c] Not smoke indoor

[d] Nothing or electricity

[*] Significant partial correlation ($p<0.05$) between $PM_{2.5}$ indoor and each variable holding the other variables constant.

[**] Significant partial correlation ($p<0.001$) between $PM_{2.5}$ indoor and each variable holding the other variables constant.