Replacing Windows Reduces Childhood Lead Exposure: Results From a State-Funded Program

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Context: Despite considerable evidence that window replacement reduces childhood lead exposure and improves energy conservation and market value, federal policies in childhood lead poisoning, home improvement, and weatherization programs all tend to discourage it. **Objective and Intervention:** To evaluate a state bond-financed pilot program that replaced old lead-contaminated windows with new lead-free energy efficient ones. **Design and Setting:** Pre-/post evaluation in 1 urban and 1 rural jurisdiction. **Participants:** Low-income households (n = 96). **Main Outcome Measures:** Dust wipe sampling, visual assessment, and physical and mental self-reported health at baseline and 1 year. **Results:** Geometric mean lead dust (PbD) from baseline to 1 year for interior floors, interior sills, and exterior troughs declined by 44%, 88%, and 98%, respectively ($P < .001$); 1 year later, levels remained well below baseline but rose slightly compared with clearance sampling just after intervention. PbD declined significantly on both sills and troughs in both the urban and rural jurisdictions from baseline to 1 year. On interior floors, PbD significantly declined by 58% ($P = .003$) in the rural area and 25% ($P = .38$) in the urban area, where the decline did not reach statistical significance. Households reported improvements in uncomfortable indoor temperatures ($P < .001$) and certain health outcomes. Economic benefits were estimated at $5 912 219 compared with a cost of $3 451 841, resulting in a net monetary benefit of $2 460 378. Residents reported that they were "very satisfied" with the window replacement work (87%). **Conclusion:** Local and state governments should fund and operate window replacement programs to eliminate a major source of childhood lead exposure, improve energy bills, increase home market value, and create local construction and industrial jobs. Federal agencies should encourage (not discourage) replacement of old windows contaminated with lead. In budget climates such as Illinois with reduced public expenditures, making wise investments such as lead-safe window replacement is more important than ever.

KEY WORDS: **childhood lead poisoning prevention, healthy housing, housing, lead, lead dust, lead poisoning, windows**

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The most recent data from the Centers for Disease Control and Prevention show that 535 000 children in the United States younger than 6 years have blood lead levels above the CDC reference value of

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5 μg/dL.[1] The 2 main sources of childhood lead exposure during the past few decades in the United States were leaded gasoline and lead paint.[2,3] Today, deteriorated lead-based paint and the contaminated residential dust and soil it generates are responsible for the majority of elevated blood lead levels.[4] The main childhood exposure pathway is normal hand-to-mouth contact and ingestion of lead-contaminated settled dust.[5-8]

A national housing survey shows that windows have average paint lead loadings about twice that of other building components.[9] Windows are also the most likely building component to be rated in "poor" condition. In homes constructed before 1940, 41% of window exteriors and 21% of window interiors have lead-based paint. Geometric mean (GM) sill and trough lead dust (PbD) loadings (μg/ft^2) are roughly 10 and 100 times higher than on floors, respectively.[9,10] Loading means unit weight of lead (micrograms) divided by unit surface area (square feet) and is how US regulatory PbD standards are expressed. These national findings are similar to earlier data in Illinois, where the present study was conducted.[11] Floor, sill, and trough PbD are all significantly correlated with children's blood lead levels, making PbD a good exposure metric.[7,8,12]

Abatement of leaded components, especially window replacement, is the most durable, longest-lasting option[13] but can be more expensive than other control methods such as paint stabilization. Beyond lead poisoning prevention, window replacement is also known to improve energy conservation and the market value of homes.[14]

However, federal programs have tended to discourage window replacement. For example, the Department of Energy's weatherization programs do not typically replace windows, because larger energy savings may be accomplished through insulation and air sealing, and weatherization assistance programs have a "walk away" policy if the cost of lead hazard control is deemed to be too large.[15] The Department of Housing and Urban Development's (HUD) lead hazard control program guidance requires time-consuming testing and photographing of virtually all windows before replacement, which is not required for any other building component.[16] Such federal weatherization and lead poisoning program policies discourage window replacement. This present study examines a state bond program that could help fill that gap.

In 2007, the Illinois General Assembly passed Public Act 095-0492, establishing the Comprehensive Lead Education, Reduction, and Window Replacement Program (ClearWin). The primary stated goal of ClearWin is "to assist residential property owners to reduce lead paint hazards through window replacement in pilot communities." The ClearWin program is a primary lead poisoning prevention program focusing on proactive window replacement in low-income, high-risk neighborhoods, instead of responding only to children who have already been poisoned. The Assembly mandated that the Illinois Department of Public Health administer the first window replacement program to be run by a public health agency in the nation.

The primary objectives were (1) to determine whether a state health department can cost-effectively conduct a window replacement program in both small and large cities such as Peoria and Chicago (Englewood neighborhood) using state bond financing; and (2) to quantify reductions in PbD in homes where windows are replaced from baseline to 1 year after treatment.

Methods

The study, approved by an institutional review board, examined approximately 100 housing units, equally divided between Chicago and Peoria, a convenience sample drawn from the 466 units treated under the larger ClearWin Program. PbD wipe samples were collected before, immediately after (clearance sampling), and nominally 1 year after window work was completed. Health interviews and housing condition visual assessments were done before the work and nominally 1 year after window replacement.

PbD was measured using the standard HUD wipe method, with analysis in laboratories accredited by the US Environmental Protection Agency National Lead Laboratory Accreditation program.[17] Interior floor, window sill, and window trough samples were collected at the interior entryway, in the living room, bedroom, and kitchen. Bare floors were preferred over carpets. For PbD values below the detection limit, the uncensored laboratory instrument output value was used if available, or if not, it was replaced with detection limit/$\sqrt{2}$. Fifty-five percent of the samples were below the detection limit, and instrument values were used for 99% of these measurements. For each sample type (entry floor, interior floor, interior window sill, and exterior window trough), the dwelling average PbD was calculated for each visit and transformed using the natural logarithm.

All ClearWin contractors were trained and followed "lead-safe window replacement" work practices that established containment to prevent the spread of lead dust during the work. To maximize energy benefits, the ClearWin protocol required high-efficiency (R-5) replacement windows, exceeding US Environmental Protection Agency's Energy Star standard (R-3.3) for efficient windows in Illinois' climate zone. The windows were manufactured in Illinois to maximize the program's job creation potential within the state. Contractors replaced old, painted, single-pane windows with new energy-efficient windows, removed debris, and conducted specialized cleaning. Clearance PbD testing was done either by or under the supervision of the Chicago or Peoria Health Departments to determine whether cleanup was adequate and to document compliance with Illinois clearance standards (40 $\mu g/ft^2$ on floors, 200 $\mu g/ft^2$ on interior window sills, and 400 $\mu g/ft^2$ on exterior window troughs).[18] For all analyses, the final clearance PbD value was used if recleaning and resampling was conducted. Clearance sampling ranged from 1 to 14 months after preintervention sampling (dependent on when windows were replaced), and 1 year postintervention interview data were collected from 5 to 22 months after window replacement (mean, 13 months).

Multivariable models were used to predict 1-year PbD and expressed the natural log-transformed PbD loading as a function of potential variables. These included variables, such as site, housing conditions, and characteristics (eg, building type [single family, 2-4 units or >4 units]), wiped surface types and conditions, time since clearance, seasonality, paint conditions (from visual paint inspection) in the home, resident characteristics, and reported cleaning habits. Backward elimination of nonsignificant independent variables ($P > .1$) was performed for the multivariable models, followed by additional steps to allow the addition and/or removal of variables with the SAS procedure PROC MIXED. A seasonality variable was retained regardless of significance because it has been shown to be important in other lead dust studies. For nominal variables with a missing category, the P value used tests for a significant difference between the nonmissing categories (ie, missing category was disregarded). For continuous variables with a dummy variable for missing values, the P values used tests for a significantly nonzero slope.

A standardized health interview was drawn from the CDC National Health Interview Survey, the Behavioral Risk Factor Surveillance System, and the HUD National Survey of Lead and Allergens in Housing and previously used in several other healthy housing studies. It included physical and mental health questions about 1 adult and up to 4 children per household and also housing condition measures. The interview was used in an exploratory analysis to determine whether self-reported housing conditions and physical and mental health of adult and child residents changed between baseline and follow-up. For the Chicago urban group, interview data were available for 44 adults and 73 children living in 44 dwellings. For the Peoria rural group, interview data were available for 48 adults and 98 children living in 48 dwellings (totals: 92 dwellings, 92 adults, 171 children).

To assess mental health, the health interview included a measure of "serious psychological distress (SPD)" in adults and a "strengths and difficulties" score for children. Adult SPD included 6 measures (feeling sad, nervous, restless, hopeless, worthless, or that everything was an effort).[19] Each question asked how often the respondent experienced this symptom during the past 30 days (score 0-4), and the 6 scores were summed to yield a total score ranging from 0 to 24. Kessler's definition of SPD as a score of more than 13 was used.[20] To assess child behavior and emotions, adult participants were asked 4 questions from the "Strength and Difficulties Questionnaire," asking the respondent whether their child was poorly behaved, worried, unhappy, depressed or tearful, or had a poor attention span. The 4 responses were summed to yield a total Strength and Difficulties Questionnaire score ranging from 0 to 8, with higher scores indicating more difficulties.[21]

For dichotomous variables (eg, yes/no), the Cochran-Mean Haenszel test determined whether the percent "yes" was different at baseline versus 1 year postintervention. Weighted least squares determined whether the change in percent "yes" from baseline to 1 year postintervention differed for the Chicago and Peoria groups. For ordinal variables (eg, frequency of exhaust fan use, frequency of asthma symptoms), the Cochran-Mean Haenszel test determined whether mean pre- and postintervention scores differed. For continuous variables (eg, age), a 2-sample t test determined whether the Chicago and Peoria group mean differed. For nominal variables, the Fisher exact test determined whether the percentages in the Chicago and Peoria groups differed. We used SAS version 9.4 for all analyses.[22] Statistical significance is defined as $P < .05$ while marginal significance is defined as $.05 \le P < .1$.

Results

Demographics

Nearly 100 homes had PbD sampling at baseline and 1 year (Chicago, n = 47; Peoria, n = 49) (see Supplemental Digital Content Table 1, available at: http://links.lww.com/JPHMP/A195). Of these, 92 households with 92 adults and 171 children completed health interviews administered by researchers, with the adult responding for both themselves and their children. The data show that the program succeeded in targeting

TABLE 1 ● Lead Dust by Sample Type, Time of Visit, and Jurisdiction

Sample Type and Visit	ClearWin N	ClearWin % Exceed Standard[a]	ClearWin GM (95% CI)	HUD Natl Eval N	HUD Natl Eval GM (95% CI)	ClearWin GM Versus Natl Eval GM P^b	ClearWin Chicago N	ClearWin Chicago % Exceed Standard[a]	ClearWin Chicago GM (95% CI)	ClearWin Peoria N	ClearWin Peoria % Exceed Standard[a]	ClearWin Peoria GM (95% CI)	ClearWin Chicago Versus Peoria, P^c
Entry floor													
Baseline	95	15%	5.7 (4.0-8.1)	98	19.4 (14.0-26.8)	<.001	46	15%	6.6 (4.2-10.3)	49	14%	5.1 (2.9-8.7)	.438
Clearance	89	7%	2.4 (1.6-3.5)	98	8.4 (6.7-10.5)	<.001	44	11%	3.5 (2.0-6.1)	45	2%	1.6 (1.0-2.7)	.023
1 y	95	6%	3.5 (2.6-4.7)	98	12.0 (9.2-15.7)	<.001	46	9%	5.5 (3.5-8.6)	49	4%	2.3 (1.6-3.3)	.009
Interior floor													
Baseline	96	17%	7.5 (5.2-10.7)	98	18.3 (13.8-24.3)	<.001	47	17%	9.9 (5.9-16.7)	49	16%	5.7 (3.4-9.5)	.069
Clearance	96	2%	2.5 (1.9-3.3)	98	8.2 (6.8-9.9)	<.001	47	4%	3.1 (2.0-4.7)	49	0%	2.0 (1.4-2.9)	.155
1 y	96	5%	4.1 (3.1-5.6)	98	7.8 (5.8-10.4)	<.001	47	11%	7.5 (4.8-11.6)	49	0%	2.4 (1.7-3.3)	<.001
Window sill													
Baseline	96	38%	144 (94-223)	49	130 (67-252)	.540	47	34%	161 (89-288)	49	41%	130 (67-252)	.587
Clearance	96	3%	5 (4-7)	49	4 (3-7)	<.001	47	6%	6 (3-10)	49	0%	4 (3-7)	.455
1 y	96	8%	17 (12-25)	49	9 (5-16)	<.001	47	11%	32 (20-52)	49	6%	9 (5-16)	.001
Window trough													
Baseline	94	78%	2737 (1638 -4572)	77	1,984 (1046-3763)	.547	45	78%	2415 (1311-4451)	49	78%	3069 (1339-7037)	.579
Clearance	87	2%	7 (4-10)	77	14 (10-20)	.058	38	5%	13 (6-28)	49	0%	4 (3-6)	.009
1 y	94	11%	46 (29-73)	77	302 (206-443)	<.001	45	13%	171 (116-252)	49	8%	14 (7-27)	<.001

Abbreviations: CI, confidence interval; GM, geometric mean; HUD, Department of Housing and Urban Development.
[a]Federal clearance standards: floor = 40 μg/ft^2; interior window sill = 250 μg/ft^2; exterior window trough = 400 μg/ft^2.
[b]P value from the test that GM PbD for ClearWin is different from the National Evaluation for a specific visit.
[c]P value from the test that GM PbD for Chicago is different from Peoria for a specific visit.

high-risk, low-income households with young children as intended. The majority of adults (67%) had an annual household income of less than $30 000. Adults in both groups were mostly female (79%), and approximately 41% had a high school education or less. Chicago and Peoria adults differed by age (Chicago adults 60 years of age versus Peoria adults 42 years of age, $P < .001$), but children in both cities averaged between 7 and 8 years. All Chicago participants were black, while Peoria participants were split almost evenly between non-Hispanic white and black. Chicago residents lived in their homes about 3 times longer on average ($P < .001$), and overall 93% of homes were in single family buildings (see Supplemental Digital Content Table 1, available at: http://links.lww.com/JPHMP/A195).

Trends in lead dust

There were large statistically significant reductions in interior floor, window sill, and window trough PbD from baseline to clearance, and those reductions were sustained through 1 year (Tables 1 and 2). Between baseline and 1 year postintervention, GM PbD for interior floors, interior sills, and exterior troughs declined by 44% ($P = .006$), 88% ($P < .001$) and 98% ($P < .001$), respectively. At baseline, the percentage of ClearWin units above clearance dust standards for floors, sills, and troughs was 17%, 38%, and 78%, but immediately following cleanup and window replacement, it declined to 2%, 3%, and 2% of the units, respectively. A year later, the percentage with PbD greater than clearance thresholds rose slightly on floors, sills, and troughs to 5%, 8%, and 11%, respectively, suggesting that levels remained well below baseline but that even with window replacement, ongoing cleaning by residents is still needed.

Baseline GM PbD was marginally significantly higher on interior floors in Chicago than Peoria ($P = .069$), but there were no significant differences on other surfaces. Although Peoria generally had lower GM PbD at subsequent visits than Chicago, the only statistically significant difference in the change in GM PbD between visits was for window troughs, which had greater reductions from baseline to clearance and 1 year postintervention than Chicago ($P = 0.024$ and $P < 0.001$, respectively). On window sills, Peoria had marginally greater reduction from baseline to 1 year ($P = .05$) and a marginally smaller increase from clearance to 1 year ($P = .06$); that is, the reduction on window surfaces in both urban and rural areas is not much different,

TABLE 2 Changes in Geometric Mean Lead Dust

	ClearWin		HUD Natl Eval		ClearWin Versus Natl Eval *P*	ClearWin Chicago		ClearWin Peoria		ClearWin Chicago Versus Peoria P^b
Sample Type and Visit	% Change	P^a	% Change	P^a		% Change	P^a	% Change	P^a	
Entry floor										
Overall	. . .	.002	. . .	<.001	.875	. . .	.179	. . .	.003	.368
Baseline to clearance	– 59%	<.001	– 57%	<.001	NA	– 46%	NA	– 68%	<.001	NA
Baseline to 1 y	– 39%	.039	– 38%	.069	NA	– 16%	NA	– 55%	.016	NA
Clearance to 1 y	46%	.120	44%	.022	NA	55%	NA	41%	.312	NA
Interior floor										
Overall	. . .	<.001	. . .	<.001	.287	. . .	.001	. . .	<.001	.224
Baseline to clearance	– 67%	<.001	– 55%	<.001	NA	– 69%	<.001	– 65%	<.001	NA
Baseline to 1 y	– 44%	.006	– 57%	<.001	NA	– 25%	.373	– 58%	.003	NA
Clearance to 1 y	67%	.031	– 5%	.743	NA	140%	.007	18%	.155	NA
Window Sill										
Overall	. . .	<.001	. . .	<.001	.004	. . .	<.001	. . .	<.001	.096
Baseline to clearance	– 96%	<.001	– 92%	<.001	.010	– 96%	<.001	– 97%	<.001	.885
Baseline to 1 y	– 88%	<.001	– 70%	<.001	.002	– 80%	<.001	– 93%	<.001	.052
Clearance to 1 y	230%	<.001	285%	<.001	.587	443%	<.001	105%	.063	.072
Window trough										
Overall	. . .	<.001	. . .	<.001	.002	. . .	<.001	. . .	<.001	<.001
Baseline to clearance	– 100%	<.001	– 99%	<.001	.347	– 99%	<.001	– 100%	<.001	.024
Baseline to 1 y	– 98%	<.001	– 85%	<.001	<.001	– 93%	<.001	– 100%	<.001	<.001
Clearance to 1 y	586%	<.001	1,993%	<.001	.015	1,203%	<.001	246%	.007	.034

Abbreviation: HUD, Department of Housing and Urban Development; NA, not applicable.
[a] *P* value from the test that the relative change in GM PbD between the visits for the study group is nonzero.
[b] *P* value from the test that the relative changes in GM PbD between the visits are different for 2 jurisdictions.

suggesting that the program worked well in both (Table 2).

Entry floors were analyzed separately from interior floors because of the potential for track-in. The change in GM PbD for entry floors over the 3 visits was significant for both cities combined ($P = .002$) and for Peoria (55% reduction; $P = .003$) but not for Chicago (16% reduction; $P = .18$). For both cities combined, baseline GM PbD on entry floors (5.7 $\mu g/ft^2$) was significantly greater than 1 year postintervention GM PbD (3.5 $\mu g/ft^2$) ($P = .04$) (Tables 1 and 2).

Comparing these results to the National Evaluation of the HUD Lead Hazard Control Grant program,[8] with the exception of baseline window sill ($P = .54$) and window trough GM PbD ($P = .55$), the National Evaluation had significantly higher GM PbD on entry floors, interior floors, sills, and troughs at all 3 visits (Table 1). The changes in GM PbD across the 3 visits for the National Evaluation were not significantly different from ClearWin on entry floors ($P = .88$) or interior floors ($P = .29$); however, on window sills and troughs, the reductions in GM PbD from baseline to clearance and baseline to 1 year were greater for ClearWin and the increases from clearance to 1 year were smaller for ClearWin (all $P < .001$) (Table 2).

Predictors of lead dust

The ClearWin only and combined interior floor models were very similar. Carpeting had lower PbD than hard surfaces while controlling for other predictors (see Supplemental Digital Content Table 2, available at: http://links.lww.com/JPHMP/A196). The higher PbD was on sills and entry floors, the higher it was on interior floors (all $P < .001$) (see Supplemental Digital Content Table 2, available at: http://links.lww.com/JPHMP/A196). Surprisingly, season was not a significant influence. In the combined model, site was significant ($P < .001$) but floor PbD was not significantly different for Chicago homes in ClearWin and the National Evaluation ($P = .3$).

The ClearWin only and combined window sill models were also very similar. The worse the condition of the wiped sills, the higher the sill PbD while controlling for other predictors. At 1 year, the higher the 1-year trough level was, the higher the sill PbD (both $P < .001$). The interaction of site (city) and baseline sill PbD was significant in the ClearWin only model ($P < .001$). In Chicago, higher baseline sill PbD was associated with higher 1-year sill PbD ($P < .001$), but in Peoria, they were not significantly associated ($P = .52$) (see Supplemental Digital Content Table 3, available at: http://links.lww.com/JPHMP/A197). In the combined model, higher baseline sill PbD was significantly associated with higher 1-year sill PbD ($P < .001$), but the interaction between site and baseline sill PbD was not significant. In the combined model, site was significant ($P < .001$) but sill PbD was not significantly different for Chicago homes in ClearWin and the National Evaluation ($P = .16$).

TABLE 3 ● Costs and Benefits (N = 466 units)

ClearWin Long-Term Monetized Benefits	Total
Installed window cost (A)	\$3 071 841
Number of windows replaced	7747
Long-term energy benefit	\$1 529 974
Other market (home resale) value	\$770 885
Total market and energy value at \$297/window (B)	\$2 300 859
Housing built before 1940 (health benefit = \$24 571 per child)	\$3 341 656
Housing built 1940-1959 (health benefit = \$10 068 per child)	\$251 700
Housing built 1960-1979 (health benefit = \$2572 per child)	\$18 004
Total monetized health benefit (C)[a]	\$3 611 360
Administrative cost (D)[b]	\$380 000
Total benefits (B + C)	\$5 912 219
Total costs (A + D)	\$3 451 841
Net benefits (B + C − A − D)	\$2 460 378

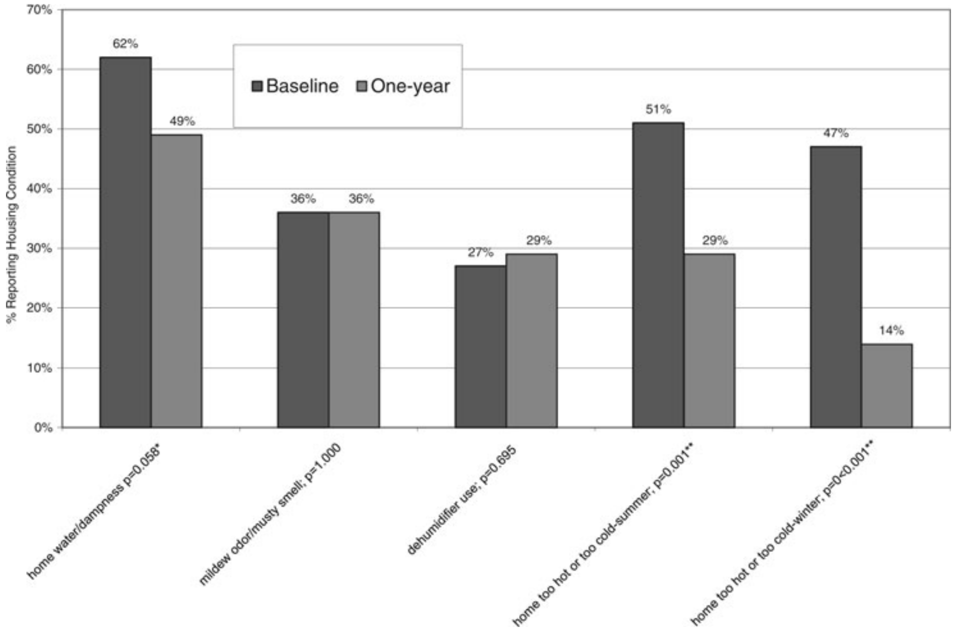
[a]Health benefits calculated from number of actual children living in ClearWin homes by age of housing.
[b]Costs do not include minor repairs and mandated program evaluation costs.

Health and housing condition

The overall mean score for satisfaction with window replacement was 1.2, between very satisfied (score of 1) and satisfied (score of 2) out of a 5-point scale from very satisfied to very unsatisfied. Chicago's mean score was 1.3, while Peoria's was 1.1 ($P = .17$, comparing the 2 mean scores), showing that people in both jurisdictions were equally satisfied with the program (data not shown). The percentage of people reporting uncomfortable indoor temperatures in both summer and winter improved greatly, as did dampness (Figure). At 1 year postintervention, fewer participants reported water or dampness issues in their homes ($P = .06$), and the percentage of people reporting uncomfortable indoor temperatures in both summer and winter significantly decreased ($P = .001$ and $P < .001$, respectively) (Figure).

The percentage of children experiencing headaches, respiratory allergies, and 3 or more ear infections significantly improved between baseline and 1 year postintervention (7% improved, $P = .02$; 12% improved, $P < .001$; and 5% improved, $P = .06$, respectively). Mental health significantly improved for children in Chicago but not those in Peoria ($P = .01$ and $P = .32$,

FIGURE ● Housing Moisture and Comfort Conditions From Baseline to 1 Year Postintervention



respectively). The general health score of children improved significantly at the 1-year postintervention visit ($P = .013$) (see Supplemental Digital Content Table 4, available at: http://links.lww.com/JPHMP/A198).

The percentage of adults experiencing sinusitis and hay fever improved from pre- to 1-year postintervention (18%, $P = .001$; and 5%, $P = .096$, respectively), although the percentage of those reporting hypertension ($P = .025$) and a heart condition marginally increased ($P = .08$) (see Supplemental Digital Content Table 5, available at: http://links.lww.com/JPHMP/A199). Both of these chronic ailment increases were primarily found in the Chicago group, whose mean age was more than that of the Peoria group. Overweight and chronic bronchitis also saw reductions in both groups combined, but these improvements did not reach statistical significance. There was no significant change in adult mental health as reflected in the SPD score.

Economic costs and benefits

Using a previously validated methodology,[23] total benefits are at least $6 million and net benefits are nearly $2.5 million (Table 3). The health economic benefit is predominately associated with gains in lifetime earnings due to avoided loss of IQ (higher IQ is associated with both higher lifetime earnings and reduced exposure to lead). The cost data show an installed window cost of approximately $400/window, demonstrating the savings from bulk purchase programs for window replacement as was done for ClearWin. Benefits are likely underestimated because factors such as reduced need for special education, reduction in stress, reduced property management costs, avoided litigation from lead poisoned children, reduced cardiovascular disease associated with reduced blood lead level, reduced criminal and antisocial behavior in later life associated with early childhood lead exposure, and others could not be assigned a dollar value easily.

● Discussion

The economic analysis clearly shows that Illinois' investment in windows is dwarfed by the benefits of the program and that the program is ready to expand beyond its pilot phase, which was limited to Chicago and Peoria. In difficult budget climates in states such as Illinois, making wise investments such as those in ClearWin is more important than ever.

There was very little attrition in the ClearWin study (100 homes enrolled at baseline, 96 homes had PbD data at both baseline and 1 year [Chicago: N = 47, Peoria: N = 49], and 92 completed health interviews, including 44 adults and 73 children in Chicago; in the Peoria group, interview data were available for 48 households with 48 adults and 98 children).

This study shows that window replacement achieves large sustained reductions in PbD on window sills and troughs over at least a year and probably much longer given the low levels of reaccumulation. Reductions on floors tended to be less than those on windows, especially in Chicago perhaps because of track-in of exterior PbD or other factors. In Peoria, the reduction in interior floor GM PbD from baseline to 1 year was 58% ($P = .003$), compared with 25% in Chicago ($P = .37$). For entry floor GM PbD from baseline to 1 year, Peoria declined by 55% ($P = .02$) and Chicago declined by 16% ($P = .18$). The data also show that clearance testing is needed for window replacement programs to ensure that cleanup is done properly (initial failure rates were as high as 30% for some contractors). One possible reason for the slightly better PbD trends in Peoria may be due to smaller size of urban area.

A 6-year follow-up study of lead hazard control in units treated under the HUD Lead Hazard Control Grant program found that window replacement, sash replacement, and/or window jamb liners yield lower PbD on window sills and troughs than window painting and/or cleaning, although that study combined replacement with friction reduction and was thus limited in its ability to examine the independent effect of window replacement.[24] A more recent study of 12-year follow-up data showed that lower floor PbD levels were associated with window replacement performed as part of federally funded lead hazard control programs aimed mostly at already poisoned children.[25]

There are several possible explanations for the lower sill PbD values observed in ClearWin. The National Evaluation units likely had higher PbD after window work because clearance standards were higher in the 1990s and ambient air lead standards were also higher in the 1990s than during the more recent ClearWin study. The National Evaluation study data were mostly collected during the mid- to late-1990s.

For the ClearWin health interview data, the exploratory analysis suggested that some health improvements could conceivably be related to window replacement, such as headaches and sinus problems, perhaps due to the effect of less drafty homes associated with improved windows, although another possible explanation could be seasonal influences or other influences not measured. It also showed other health improvements that could less plausibly be associated with window replacement, such as overweight or increased use of bait traps (data not shown). The percentage of children with learning disabilities and with asthma increased slightly between the 2 visits ($P = .025$ and $.046$, respectively), but it seems unlikely that this would be due to window replacement and may be spurious.

Limitations

A limitation of this study is that there were no soil or blood lead measurements, although it is known that PbD is correlated with both[26] and is thus a good marker for housing-related lead dust exposures. Indeed, blood lead measurements are confounded by other nonhousing sources of exposure such as diet. Soil measurements may have been able to show why window trough levels increased slightly over the follow-up period if reentrainment of soil lead occurred and then settled onto window troughs.

Another limitation of the present study was that Pb levels in paint and exterior dust could not be collected. ClearWin homes focused on window replacement, but the Evaluation housing units typically had additional lead hazard controls implemented, although clearance standards for the latter were higher, suggesting that Evaluation homes may have had higher PbD at postintervention. The homes studied here were a convenience sample that may reduce the generalizability of the results to the broader cohort of ClearWin homes due to unknown sources of bias, although nearly all homes in both groups were single family houses in low-income neighborhoods at high risk of lead poisoning with a high prevalence of lead-based paint hazards. Lead-based paint hazards (including high dust lead levels) are present in 24 million housing units, including both low- and moderate-income populations.[9]

The time frame for various interview questions fluctuated. For example, preintervention questions about certain health conditions (eg, headaches in children and sinusitis in adults) asked whether the person had experienced the condition in the "last 12 months." In the 1-year postintervention interview, this phrase was changed to "since window replacement." In some of the housing condition questions (eg, resident used traps, bait stations, or poisons to control mice/rats), no time frame was specified in the preintervention question but the phrase "since window replacement" was added to the 1-year postintervention question. Because the 1-year postintervention visits were conducted between 5 and 22 months after window replacement work was completed (mean 13 months), the preintervention and 1-year postintervention time frames for such questions were not always equal. The impact of unequal time periods on participants' answers is unknown but likely had some minor effect.

The exploratory analysis on health outcomes associated with window replacement requires further research. Although reduced drafts and moisture intrusion could plausibly be associated with respiratory conditions, such as ear infections or respiratory allergies, asthma and overweight indicators showed conflicting trends, perhaps due to nonwindow unmeasured factors such as medication and diet.

Conclusions

The results show that a state health department can successfully implement a window replacement program that dramatically reduces childhood lead exposure. This pilot program in 2 communities shows that the program should be expanded. Dust lead levels declined and the reductions were sustained, showing that children benefited from the program. Because dust lead is significantly correlated with blood lead levels, it is likely that children in the present study had a decline in blood lead level. Furthermore, the economic benefits far outweigh the costs, making investment in window replacement a wise use of funds.

On average, residents gave the program high marks, reporting that they were "very satisfied" with the window replacement using a 5-point scale (very satisfied, satisfied, neither satisfied nor dissatisfied, somewhat dissatisfied, very dissatisfied).

Local and state governments should fund such window replacement programs to eliminate a major source of childhood lead exposure, create jobs, and improve energy efficiency, and federal agencies should encourage window replacement in order to prevent exposure and realize large monetary benefits for the nation.

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