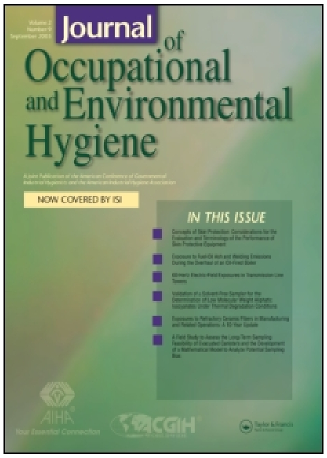

Journal of Occupational and Environmental Hygiene
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713657996

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First Published on: 01 August 2008

To cite this Article: Dixon, Sherry, Wilson, Jonathan, Kawecki, Carol, Green, Rodney, Phoenix, Janet, Galke*, Warren, Clark, Scott and Breysse, Jill (2008) 'Selecting a Lead Hazard Control Strategy Based on Dust Lead Loading and Housing Condition: I. Methods and Results', Journal of Occupational and Environmental Hygiene, 5:8, 530 — 539

To link to this article: DOI: 10.1080/15459620802219799
URL: http://dx.doi.org/10.1080/15459620802219799

Journal of Occupational and Environmental Hygiene, 5: 530–539
ISSN: 1545-9624 print / 1545-9632 online
DOI: 10.1080/15459620802219799

Selecting a Lead Hazard Control Strategy Based on Dust Lead Loading and Housing Condition: I. Methods and Results

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A methodology was developed to classify housing conditions and interior dust lead loadings, using them to predict the relative effectiveness of different lead-based paint hazard control interventions. A companion article in this issue describes how the methodology can be applied. Data from the National Evaluation of the HUD Lead Hazard Control Grant Program, which covered more than 2800 homes in 11 U.S. states, were used. Half these homes (1417) met the study's inclusion criteria. Interior interventions ranged from professional cleaning with spot painting to lead abatement on windows, and enclosure, encapsulation, or removal of other leaded building components. Modeling was used to develop a visual Housing Assessment Tool (HAT), which was then used to predict relative intervention effectiveness for a range of intervention intensities and baseline floor and windowsill dust lead loadings in occupied dwellings. More than 117,000 potential HATs were considered. To be deemed successful, potential HATs were required to meet these criteria: (1) the effect of interior strategy had to differ for HAT ratings of good vs. poor building condition and/or baseline dust lead loadings; (2) the HAT rating had to be a predictor of one year post-intervention loadings; (3) interior intervention strategy had to be a predictor of one-year loadings; (4) higher baseline loadings could not be associated with lower one-year loadings; and (5) neither exterior work nor site/soil work could result in higher predicted one-year loadings for either HAT rating. Of the 1299 HATs that met these criteria, one was selected because it had the most significant differences between strategy intensities when floors and sills were considered together. For the selected HAT, site/soil work was a predictor of one-year loadings for floors ($p = 0.009$) but not for sills ($p = 0.424$). Hazard control work on the building exterior was a predictor of both sill and floor one-year loadings ($p = 0.004$ and $p < 0.001$, respectively). Regardless of the type of interior intervention strategy, interior work was a predictor of both floor and sill one-year loadings (each $p \leq 0.001$).

Keywords housing condition, interim control, intervention, lead abatement, lead hazard control

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INTRODUCTION

In most U.S. states, property owners planning to address residential lead hazards have the option either to abate the lead permanently or to use interim controls to manage and control the lead hazard on an ongoing basis. If the property owner hires a certified lead risk assessor or is supported by a government program, the assessor or program staff is expected to describe treatment options and make recommendations. Further empirical evidence, however, is needed to support such recommendations. This study used data from the National Evaluation of the U.S. Department of Housing and Urban Development (HUD) Lead Hazard Control Program (Evaluation) to develop a methodology to classify baseline housing condition and to use that information to compare the effectiveness of different lead hazard control (LHC) options on the different housing condition categories.

Two types of evaluations can be performed in and around residential housing: risk assessment and paint inspections; sometimes both are performed together. The Residential Lead-Based Paint Hazard Reduction Act of 1992, also known as "Title X," required the U.S. Environmental Protection Agency (EPA) to establish regulations defining how paint inspectors and risk assessors would be trained and certified.(1) EPA also detailed the requirements for conducting LHC activities.(2) Within those rules, EPA referenced other sources, including the *HUD Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing*,(3) to further define the lead hazard evaluation and control process. Under the EPA regulations, paint inspectors are considered technicians who may test paint and collect other samples and report locations with lead-based paint (LBP) in a building but typically do not make treatment recommendations. Risk assessors complete their work by issuing a report identifying LBP hazards and making recommendations about LHC options to the property owner. However, unless there is an obvious underlying structural problem (e.g., a window that not only has deteriorated LBP but is badly damaged and needs replacement), risk assessors may be reluctant to offer a specific recommendation, instead offering a number of options and leaving the specific treatment choice to the owner, property manager, or rehab specialist.

LHC intervention options range in intensity from professional cleaning to lead abatement in the entire dwelling (i.e., removal of the building LBP component(s), the LBP on the component, or near-permanent enclosure of LBP hazards). Intermediate strategies may include paint stabilization, installation of jamb liners to reduce friction of painted surfaces rubbing against each other and producing lead contaminated dust, or window replacement. Previous studies have demonstrated that when proper work site containment and cleaning is done, both low and high intensity interventions can reduce and maintain low dust lead loadings for at least 2 years.[4,5] For the Evaluation dwellings with 6-year data, post-intervention geometric mean (GM) dust lead loadings on floors and windowsills did not change significantly from 1 to 6 years post-intervention for intervention intensities ranging from professional cleaning with spot painting to lead abatement in the entire dwelling.[6] However, it is not clear if lower intensity interventions are effective in poorly maintained properties.

In this article, statistical models were used to identify a simple visual assessment of interior and exterior housing condition, referred to as a Housing Assessment Tool (HAT), which can predict intervention effectiveness for a range of intervention intensities and baseline dust lead loadings in occupied dwellings. The tool identified by the modeling then can be used in the field to predict one year post-intervention dust lead loadings and the probability that those loadings will exceed current federal lead hazard standards. (A companion article in this issue describes the field application of the selected HAT.) This information can be used to help practitioners determine the minimum intervention intensity needed in a home to lower dust lead loadings to “acceptable” post-intervention levels, where each practitioner defines what is acceptable based on the specific project, as well as local needs, regulations, and resource constraints.

An earlier article[7] presented models to predict post-intervention dust lead loadings based on baseline dust lead loadings, building conditions, and housing characteristics and found that various baseline conditions were significant predictors of post-intervention loadings. Although such models are helpful in developing theory, they are difficult to use in the field to help determine the optimum control strategy because detailed computations using more than a dozen variables are needed to make model-based predictions. The HAT methodology described here is advantageous because visual assessments and dust sampling can be performed easily at a single home visit. To the authors’ knowledge, no other studies have presented practical field procedures for using building assessment data to determine treatment options.

METHODS

Data Source

The data reported in this study was collected as part of the evaluation, which was conducted to determine the effectiveness of treatments conducted during the first two rounds of HUD’s Lead Hazard Control Grant Program that began in 1993.[8,9] Fourteen grantees and approximately 2,900 dwellings were enrolled in the Evaluation: Alameda County, California; Baltimore, Maryland; Boston, Massachusetts; California; Chicago, Illinois; Cleveland, Ohio; Massachusetts; Milwaukee, Wisconsin; Minnesota; New Jersey; New York City; Rhode Island; Vermont; and Wisconsin. Homes occupied or expected to be occupied by households with low or moderate incomes were eligible for treatment.

Baseline home evaluations were conducted between 1994 and 1997 by certified and trained LBP inspectors or risk assessors. Grantees were trained in Evaluation protocols, collected all Evaluation data, performed project-wide quality assurance and quality control (QA/QC) checks, and analyzed and reported the collected data.[10]

Immediately after treatment, all dwellings were required to pass either the clearance thresholds established for Evaluation HUD Grantees (floors 200 μg/ft^2; windowsills 500 μg/ft^2; and window troughs 800 μg/ft^2) or local floor clearance standards in effect at the time the work was conducted, if more stringent.[9] More stringent local floor standards were 80 μg/ft^2 in Minnesota (statewide regulation) and 100 μg/ft^2 (voluntary guidance level) in Cleveland, New Jersey, and New York City. In 2001, the EPA reduced clearance standards to 40, 250, and 400 μg/ft^2 on floors, windowsills and window troughs, respectively.[11] In homes where re-cleaning was required after initial clearance test results exceeded standards, the final clearance sample results were used.

Visual Assessment

In the Evaluation, a baseline LBP inspection and risk assessment was conducted in each enrolled dwelling and in the exterior and common areas of the building in which the enrolled dwellings were located. As specified in the HUD Guidelines,[3] inspectors performed a room-by-room and exterior inventory of each type of painted building component (e.g., walls, window casings, baseboards) that had a distinct painting history, checking all exterior sides of the building and all interior rooms before assigning a condition code for a particular component. Components that were not present or not visible were coded as not applicable (NA). For analysis purposes, components coded as NA were assumed to have no deterioration.

Lead inspectors rated component paint condition on a three-point scale (poor, fair, intact). To better reflect current regulatory requirements, paint condition was collapsed to either non-intact or intact (i.e., less than 0.5 ft^2 of deteriorated paint on large surfaces, or less than 1% of the total surface area on small building components). This is more stringent than the *de minimus* amounts defined in HUD's Lead Safe Housing Rule.(12) Paint condition variables for the windows and interior and exterior components were constructed for this analysis using the baseline paint inspection data (Table I). Table I also lists the exterior and interior building components visually assessed at baseline.

Dust Lead Sampling

In each dwelling, single-surface dust wipe samples were collected as specified in the HUD Guidelines.(3) Floor samples were collected from the principal playroom, kitchen, bedroom, entryway, and second bedroom (if available), while sill samples were collected from the kitchen and in the youngest child's bedroom (or smallest bedroom). On average, five floor samples and two windowsill samples were collected from each dwelling. To reduce the effect of earlier sampling from the same surface, at each visit, samples were taken from half of each test surface, with the half sampled alternating at each visit.

Dust wipe samples were prepared and analyzed for total lead as required in the HUD Guidelines or by equivalent methods. Laboratories were required to meet Evaluation QA/QC guidelines documented elsewhere.(10)

Intervention Strategies

LHC strategies used by Evaluation grantees ranged from low-intensity professional cleaning to high-intensity, lead-paint abatement in the entire dwelling. The Evaluation defined interim control and abatement LHC options in accordance with the HUD Guidelines.(3) The grantees reported the strategies applied at each dwelling using "strategy codes." Higher strategy code numbers indicated higher intensity interventions. Interior strategies ranged from cleaning/spot painting (Interior

TABLE I. Definitions of Deterioration Variables

Location	Variable	Assessment Question
Exterior	Roof/gutters/downspouts or chimney	Roof missing parts, has weathering surfaces, or has holes or cracks, and/or gutters or downspouts broken. Chimney masonry cracked, bricks coming loose or missing; obviously out of plumb and not stable.
	Walls/siding	Obvious large cracks or holes in masonry requiring extensive patching, more than routine painting. Siding has numerous boards or shingles broken or missing. Obviously out of plumb or with bulges and not stable.
	Windows/doors	Two or more windows or doors broken, missing, or boarded up.
	Porch/steps	Major elements broken, missing, or out of plumb.
	Foundation	Foundation has major, visible cracks; missing materials and/or structure leans or is visibly unsound.
	Paint condition: Avg number non-intact exterior per building side tested[B]	Average number of non-intact,[A] non-window exterior building components per side of the exterior building structure inspected is five or more.
Interior	Walls/Ceilings/Doors	Obvious cracks in the plaster requiring extensive patching, more than routine painting, missing trim, or doors requiring major repair or replacement
	Floors	Loose, missing, or cracked floor surfaces; finish is worn; deteriorated carpeting.
	Water damage	Heating/cooling, and plumbing. Obvious need for expensive repair of water damage
	Roof leak	Obvious need for extensive repairs as a result of roof leak.
	Paint condition: Avg number non-intact interior paint per room[B]	Average number of non-intact,[A] painted interior non-window components per room (of the three standard dust testing rooms: kitchen, playroom, child's bedroom) is two or more.
	Paint condition: Percentage of rooms with non-intact window paint[B]	Percent of rooms with any non-intact[A] painted window components of the rooms in the dwelling with any window component is 50% or higher.

[A]Non-intact is defined as 0.5 ft^2 or more of deteriorated paint on large surfaces, or 1% or more of the total surface area of small building components.
[B]This information was gleaned from the Evaluation paint inspection forms.

TABLE II. Strategy Code Definitions Used in HAT Models

Code	Definition
02	Cleaning only or spot paint stabilization[A] with replacement[B] of a limited number of small painted components
03	Complete paint stabilization
04	Strategy 03 plus window treatments[C] (i.e., jamb liner installation, sash replacement, paint removal[D] from sashes, and stripping or capping of window sills and or troughs) and paint removal on other components
05	Replacement of most windows or off-site window paint removal, replacement/enclosure[E] of some doors/trim, floor and walls

[A]Paint Stabilization—The process of repainting surfaces coated with lead-based paint, which includes the proper removal of deteriorated paint and priming. Complete paint stabilization is the repainting of all of a surface, while spot painting is repainting part of a surface.
[B]Replacement—The removal/replacement of a building component that was coated with lead-based paint.
[C]Window Treatments—The process of eliminating lead-containing surfaces on windows that are subject to friction or impact through the removal of paint or enclosure of certain window components.
[D]Paint Removal—The complete removal of lead-based paint by wet scraping, chemical stripping, or contained abrasives.
[E]Enclosure—The application of rigid, durable construction materials that are mechanically fastened to the substrate to act as a barrier between lead-based paint and the environment.

Strategy 02) to window lead abatement plus other treatments (Strategy 05) (Table II). Strategy 01 (no lead work) was not included because all dwellings had some interior work done. Strategy 06 (complete lead abatement) was not included because too few units had this intervention.

Exterior treatment strategies ranged from no exterior work to all LBP removed. Site/soil treatments (i.e., treatment of soil, fences, or outbuildings) ranged from no site/soil work to complete soil removal or enclosure with asphalt or concrete. For this article, exterior and site/soil work were classified simply as each having been performed or not, regardless of intensity.

Additional grantee-specific information is available in the Evaluation Final Report.[13]

Housing Assessment Tools

General HAT Structure

Potential HATs were designed to yield a dwelling rating of either good or poor based on responses to a series of observations. Each potential HAT was developed using both interior and exterior assessments, with each dwelling assigned an interior assessment result and an exterior assessment result of pass or fail (as defined below). Based on the interior and exterior assessments, the dwelling was rated as either good or poor. If *either* or *both* of the interior and exterior assessments failed, then the dwelling condition was rated poor.

This study also included potential HATs that had only an interior or only an exterior assessment. In these situations, dwelling condition was rated poor if the single assessment failed and good if the single assessment passed. Of the 117,232 potential HATs, 304 were based solely on an exterior assessment, 192 were based solely on an interior assessment, and 116,736 were based on both interior and exterior assessments.

Exterior and Interior Assessments Included in Potential HATs

A unique exterior assessment was established for each possible combination (or set) of the six exterior deterioration variables listed in Table I, and a defined minimum number of deterioration variables indicating failure. For example, one set of exterior deterioration variables might include three elements: (1) walls/siding, (2) foundations, and (3) porch/steps. Three exterior assessments could be created from this single set because failure could be defined as a dwelling having at least one, at least two, or at least three deteriorations. The minimum number of deteriorations that indicate failure is referred to as the cut point. If the number of deterioration variables in the set met or exceeded a given cut point, then a building failed the exterior protocol. For example, if a cut point of two was set for the above example, then the dwelling would fail the exterior assessment if at least two of the three exterior deterioration variables were observed. Interior assessment pass/fail criteria were generated in the same way based on the six interior deterioration variables shown in Table I.

STATISTICAL METHODS

To be included in this analysis, a dwelling had to be occupied at baseline, have floor and sill dust lead loadings for baseline and one year post-intervention, have baseline exterior and interior visual inspections completed, and have received one of interior strategies 02, 03, 04, or 05. No requirements were set for exterior or site/soil work.

Analyses were based on the household arithmetic mean dust lead loading for each of four visits (baseline, clearance, one year and three years post-intervention) and two surface types (floor and windowsill). The household arithmetic mean value on a surface type was used because federal risk assessment standards apply to the average loading for a component within a home.[11] The geometric mean of the household arithmetic means was used as the primary measure of central tendency due to the underlying lognormal distribution. Statistical significance was defined as $p < 0.05$.

The three paint condition variables (two interior and one exterior) listed in Table I were created as averages or percents then converted to yes/no variables based on cut points (e.g., deteriorated if average ≥ 3: yes or no). The three quartile values and selected values between the quartiles were examined as possible cut points.

For Steps 2 and 3 described below, least squares regression modeling was employed, with baseline and one year post-intervention average dust lead loadings transformed to their natural logarithms. Type III F-tests were used to test significance of effects. Type III t-tests were used to compare GM predicted one-year dust lead loadings between two groups.

Step 1: Initial Qualification

For a potential HAT to qualify for statistical modeling (Step 2), sample size requirements had to be met. Specifically, there had to be at least 10 dwellings within each HAT rating (good and poor) for each of the four interior strategy codes. There also had to be at least 10 dwellings for each HAT rating and exterior work (yes/no) combination. Interior intervention strategy was not randomly assigned to enrolled dwellings in the Evaluation. Higher intensity strategies tended to occur in dwellings with poor baseline conditions and higher baseline dust lead loadings. To minimize this effect, these minimum sample size requirements were placed on HAT-by-interior-strategy analysis cells. Nonetheless, data was limited in some of these cells.

Step 2: Creation of HAT Models and Identification of Successful HATs Based on Model Results

A regression model to predict one-year floor dust lead loading was created using the following predictors:

- The effect of interior strategy may depend on the HAT rating and the baseline floor dust lead loading;
- The effect of exterior work may depend on the HAT rating and the baseline floor dust lead loading; and
- The effect of site/soil work may depend on the baseline floor dust lead loading.

An analogous model was run for sills.

For a HAT to be considered successful and further analyzed in Step 3 below, the HAT rating and interior strategy had to be significant predictors of one-year dust lead loading in the models, and the direction of effects had to be logical (e.g., a dwelling with a poor HAT rating would be predicted to have a higher one-year loading than a dwelling with a good HAT rating and all other factors equal). The distribution of baseline loading was highly skewed with a substantial right tail. Hypothesis testing for effects involving baseline dust lead loading was performed at the three baseline loading quartiles (9, 22, and 55 $\mu g/ft^2$ for floors and 90, 245, and 992 $\mu g/ft^2$ for sills) because these levels covered the range of data available, and testing at the quartiles eliminated the possibility that the baseline dust lead effect was significant only at very high baseline loadings. Specifically, to be considered successful, potential HATs had to meet all of the following criteria based on the one-year floor and sill models:

- The effect of interior strategy had to be significantly different for different HAT ratings and/or baseline dust lead loadings.
- The HAT rating had to be a significant predictor of one-year loadings. In addition, poor HAT ratings could not be significantly associated with lower one-year loadings than good HAT ratings.
- Interior strategy had to be a significant predictor of one-year loadings. In addition, lower strategy intensities could not result in lower one-year loadings than higher-level strategies.
- Higher baseline dust lead loadings could not be significantly associated with lower one-year dust lead loadings. If homes with higher baseline loadings tended to get higher level interventions, then this condition ensured that the intervention effect was not captured by the baseline dust effect.
- Exterior work could not result in significantly higher predicted one-year loadings for either HAT rating.
- Site/soil work could not result in significantly higher predicted one-year loadings for either HAT rating.

Potential HATs that did not meet the above criteria were not considered successful and were not further analyzed.

Step 3: Selection of the Most Useful HATs

The most useful HATs for identifying needed intervention intensity will be those that best identify differences between intervention strategy intensities. To select the most useful HATs, for surface type (i.e., floors or sills), HAT rating (i.e., good or poor), and dust lead loading quartile, the number of significant differences in predicted GM one-year dust lead loadings between pairs of strategy intensities was counted. To be included in the count, dust lead loading had to decrease by at least 20% from baseline to predicted one year post-intervention for one or both strategies. A total of 36 comparisons were made for each surface type. For each HAT, the counts of significant differences for floors and sills were then summed. The most useful HATs were identified as those with the highest total number of significant differences.

RESULTS

Summary of Dwelling Characteristics and Interventions

Data inclusion requirements were met by 1,417 dwellings in 898 buildings (109 dwellings from Alameda County, California; 80 Baltimore, Maryland; 43 Boston, Massachusetts; 30 California; 88 Chicago, Illinois; 92 Cleveland, Ohio; 106 Massachusetts; 190 Milwaukee, Wisconsin; 124 Minnesota; 193 New York City, New York; 110 Rhode Island; 128 Vermont; 124 Wisconsin; 0 New Jersey). Forty-two percent of the dwellings were built before 1910, 47% between 1910 and 1929, and the rest after 1929 but before 1978. Seventy percent of dwellings were rental properties. Single-family homes (e.g., single detached or row houses) comprised 32% of the 1,417 dwellings. The rest were multifamily buildings (average 2.2 dwellings per building), with 45% of dwellings in buildings with 2–4 units.

TABLE III. Percentage of Dwellings with Specified Deteriorations at Baseline, by Interior Strategy

Location	Variable	Strategy 02 (n = 170)	Strategy 03 (n = 267)	Strategy 04 (n = 271)	Strategy 05 (n = 709)	All Strategies (n = 1,417)
Exterior	Roof/Gutter/downspout or chimney	18	14	25	19	19
	Walls/siding	6	3	9	16	11
	Windows/doors	8	15	14	14	14
	Porch/steps	10	4	13	12	11
	Foundation	3	1	6	9	6
	Paint cond: Avg number non-intact exterior components per building side tested is ≥5	66	79	68	73	72
Interior	Wall/ceiling/door	9	19	23	27	23
	Floors	18	19	28	21	22
	Water damage	2	8	6	7	6
	Roof leak	3	4	8	8	7
	Paint cond: Avg number of non-intact interior paint per room is ≥2	45	48	72	70	63
	Paint cond: Percentage of rooms with non-intact window paint is ≥50%	74	57	83	90	81

Window lead abatement plus other treatments (Interior Strategy 05) was used to treat 50% (709) of the dwellings. Complete repainting (03) and complete repainting plus window treatments (04) were each used in 19% of the dwellings (267 and 271, respectively). Cleaning/spot painting (02) was used in 12% of the dwellings. Additional details on the interior strategies used by each grantee are available elsewhere.(14)

Sixty-eight percent of the dwellings were located in buildings where exterior work was done. The most common exterior strategy was complete paint stabilization and porch treatment (29%), followed by spot paint stabilization (12%); complete paint stabilization and porch/trim enclosure, stabilization or encapsulation (16%); and all LBP enclosed, encapsulated, or removed (10%). Complete exterior LBP removal was used in only 0.1% of the dwellings. No site/soil work was conducted at 84% of the buildings. Of the remaining 16%, 5% had soil covered with a temporary cover (e.g., mulch, stone); 7% had soil covered plus seeding and barrier installation (e.g., bushes, fencing); 2% had all of the above plus partial soil removal and sod planted; and 1% had complete soil removal or enclosure with asphalt or concrete.

Table III shows the percentages of dwellings with specified deteriorations at baseline. The three paint condition variables had the highest percentages of dwellings with deterioration: 72% for exterior, 63% for the interior, and 81% for windows. Water damage, roof leaks, and foundation deterioration were the least frequently observed deteriorations. At baseline, dwellings having higher-level strategies generally had more non-intact interior and non-intact window paint at baseline than dwellings having lower-level strategies, but clear patterns were not evident for other deterioration variables.

Descriptive statistics for dust lead loadings are shown in Table IV. Higher-level strategies tended to be applied to dwellings with higher baseline loadings. For all strategies, floor loadings declined from baseline to clearance and continued to decline somewhat through three years

TABLE IV. Geometric Mean Floor and Windowsill Dust Lead Loading ($\mu g/ft^2$) by Interior Strategy and Visit

Interior Strategy	Number of Units: Baseline to One-Year Data	Number of Units: Baseline to Three-Year Data	Floor GM (95% CI)[A]: Baseline	Floor GM: Clearance	Floor GM: One-Year	Floor GM: Three-Year	Windowsill GM (95% CI)[A]: Baseline	Windowsill GM: Clearance	Windowsill GM: One-Year	Windowsill GM: Three-Year
02	170	55	14 (11,17)	11 (9,14)	9 (7,12)	9 (6,12)	180 (137,235)	35 (29,42)	109 (82,144)	102 (58,178)
03	267	57	21 (18,24)	15 (13,18)	10 (9,12)	8 (6,11)	181 (150,219)	49 (43,56)	101 (84,120)	101 (63,162)
04	271	100	32 (27,38)	18 (16,20)	16 (14,19)	11 (8,14)	408 (323,516)	50 (43,57)	119 (98,144)	123 (91,166)
05	709	181	26 (23,29)	12 (11,14)	11 (10,12)	7 (6,9)	400 (350,456)	21 (19,23)	56 (50,63)	40 (33,49)
All	1,417	393	24 (22,26)	14 (13,14)	12 (11,12)	8 (7,9)	314 (286,345)	31 (29,33)	78 (72,85)	70 (59,82)

[A]CI = confidence interval.

post-intervention. Windowsill loadings declined substantially from baseline to clearance for all strategies. Sill loadings increased more from clearance to one year for lower-level strategies than for higher-level strategies (35 to 109 $\mu g/ft^2$ for cleaning/spot painting [02] and 21 to 56 $\mu g/ft^2$ for window lead abatement plus other treatments [05]). GM sill loadings were approximately the same from one year to three years post-intervention.

HAT Selection Results

Of the 117,232 potential HATs, 61,080 met the Step 1 sample size requirements and were modeled as specified in Step 2. Of those 61,080, 1,299 met the Step 2 criteria and were considered successful HATs. Applying Step 3 to these 1,299 HATs, the total number of significant differences between intervention strategies for the floor model ranged from 3 to 6 (average 3.8), while those for the sill model ranged from 13 to 20 (average 16.7). Considering both floor and sill models together, the total number of significant differences between strategies ranged from 16 to 24 (average 20.5). Protocols for the five HATs that had 24 significant differences between strategies are shown in Table V.

The top five HATs assign a dwelling a rating of poor if either the exterior or interior has the deteriorations specified in Table V. Although HATs were examined that rated a dwelling as poor only if both exterior and interior components were deteriorated, none of these HAT types had a large number of significant differences between intervention strategies. For example, in HAT 1 of Table V, a dwelling would be given a rating of poor if *either* of the following baseline conditions was present:

- Interior: The average number of non-intact interior painted components per room was ≥2, or
- Exterior: There was window/door deterioration and the average number of non-intact exterior painted surfaces was ≥5.

If neither of these conditions was present, then the dwelling received a good HAT rating.

Each of the top five HATs had the same total number of significant strategy differences. HAT Number 1 was selected as the tool of choice because it had 5 significant strategy differences on floors and 19 on sills, compared with the other four HATs, which had 4 significant differences on floors and 20 on sills. Significant differences were observed less frequently on floors than sills, so the floor differences were deemed more important. The regression model parameter estimates for the selected HAT are shown in Table VI. As with all the 1,299 successful HATs, for the selected HAT, site/soil work was not a significant predictor of one-year dust lead loadings for sills ($p = 0.424$) but was for floors ($p = 0.009$), while exterior

TABLE V. Top Five HAT Protocols

A building receives a HAT rating of poor if it has the listed deteriorations on the Exterior *or* Interior:		
HAT Number	**Exterior Deteriorations**	**Interior Deteriorations**
1	Both: • Windows/doors; and • Average non-intact exterior paint ≥5	Average number of non-intact interior painted surfaces per room ≥2
2	Windows/doors	Two or three of: • Water damage • Average number of non-intact interior painted surfaces per room ≥2 • Average percent rooms with non-intact window paint ≥50%
3	One or more of: • Windows/doors • Foundation	Two or three of: • Water damage • Average number of non-intact interior painted surfaces per room ≥2 • Average percent rooms with non-intact window paint ≥50%
4	Two or three of: • Windows/doors • Foundation • Average non-intact exterior paint ≥5	Both: • Average non-intact interior painted surfaces per room ≥2 • Average percent rooms with non-intact window paint ≥50%
5	Two or three of: • Windows/doors • Foundation • Average non-intact exterior paint ≥5	Two or more of: • Water damage • Average non-intact interior painted surfaces per room ≥2 • Average percent rooms with non-intact window paint ≥50%

Note: See Table I for exact phrasing of the deterioration terms.

TABLE VI. One Year Post-Intervention Regression Model Parameter Estimates for Selected HAT

			Floor Model (R^2 = 17%)			Windowsill Model (R^2 = 16%)		
Predictor	HAT Rating	Interior Strategy	Estimate	Std Error	p-Value	Estimate	Std Error	p-Value
Intercept	—	—	1.770	0.140	<0.001	3.295	0.228	<0.001
HAT * Interior Strategy	Good	02	−0.956	0.323	0.003	−1.660	0.502	0.001
	Good	03	−0.486	0.321	0.130	−0.131	0.517	0.800
	Good	04	−0.632	0.400	0.115	−1.544	0.620	0.013
	Good	05	−0.465	0.230	0.043	−0.591	0.424	0.163
	Poor	02	−0.900	0.367	0.014	−1.571	0.625	0.012
	Poor	03	−0.511	0.354	0.149	0.076	0.488	0.877
	Poor	04	−0.018	0.284	0.950	0.416	0.415	0.317
	Poor	05	0.000	—	—	0.000	—	—
Log(Baseline dust lead) * HAT * Interior Strategy	Good	02	0.490	0.110	<0.001	0.637	0.090	<0.001
	Good	03	0.346	0.096	<0.001	0.300	0.091	0.001
	Good	04	0.482	0.114	<0.001	0.501	0.106	<0.001
	Good	05	0.412	0.065	<0.001	0.249	0.063	<0.001
	Poor	02	0.610	0.105	<0.001	0.553	0.097	<0.001
	Poor	03	0.393	0.096	<0.001	0.248	0.078	0.002
	Poor	04	0.315	0.068	<0.001	0.203	0.055	<0.001
	Poor	05	0.214	0.046	<0.001	0.132	0.041	0.001
Log(baseline dust lead) * Exterior Work(1 = yes, 0 = no)*HAT	Good	—	−0.151	0.042	<0.001	−0.076	0.026	0.004
Log(baseline dust lead) * Exterior Work(1 = yes, 0 = no) * HAT	Poor	—	0.033	0.029	0.255	0.000	0.020	0.989
Log(baseline dust lead) * Site/soil work (1 = yes, 0 = no)	—	—	−0.074	0.028	0.009	0.014	0.018	0.424

Note: HAT 1 from Table V was selected as tool of choice.

work was a significant predictor of both sill and floor one-year loadings ($p = 0.004$ and $p < 0.001$, respectively).

DISCUSSION

The authors were concerned that the Step 3 HAT selection criteria could yield a HAT that identified anomalous strategy differences not seen with other HATs. This concern was addressed by examining how frequently the strategies found to be significantly different in the selected HAT were also significantly different in the larger pool of 1,299 successful Step 2 HATs. Approximately 60% of the strategy differences were consistent across all 1,299 HATs for both floors (3 out of 5) and sills (11 out of 19), indicating that anomalous strategy differences were not driving the HAT selection.

It would be simpler for the LHC practitioner if the recommended HAT used only an exterior assessment; however, none of the potential HATs that solely used exterior assessments met the Step 2 inclusion criteria. However, for the recommended HAT (HAT 1 from Table V), if unsatisfactory conditions are identified based on the exterior assessment, then the HAT rating is poor and interior assessment is unnecessary. The authors also examined HATs that classified a dwelling as being in poor condition only if both exterior and interior conditions were unsatisfactory, but none of those HATS were in the top five HATs. A 3-level HAT rating system of good, fair, and poor was examined, but none of these HATs met the Step 2 inclusion criteria.

The regression models directly use the overall HAT rating of good or poor and do not include all of the individual condition variables listed in Table I. An alternative approach would be to conduct an analysis to identify underlying factors behind the condition variables, use these factors in the regression equations instead of the HAT result, and use the resulting equations to create a HAT good/poor rule. However, this alternative approach is not feasible because the equations cannot be directly used in the field. Also, creation of the good/poor rule would require assumptions and manipulations that are not necessary with the simpler analysis approach used.

Factors Related to Interpretation of Findings

Exterior work was a significant predictor of one-year floor and sill dust lead loading when the HAT rating was good but not when it was poor. Loadings were 42% to 100% higher when exterior work was not conducted. When the HAT rating was poor, the effects of the poor dwelling condition may have overshadowed the effects of exterior work. Analysis of the effects of specific exterior strategies was not possible due to limited sample sizes within each strategy.

Site/soil work was a significant predictor of one-year dust lead loading on floors but not on sills, possibly because site/soil work influences the tracking of soil from the exterior to the interior, which influences floor but not sill loading. Analysis of the effects of specific site/soil strategies was not possible due to limited sample sizes within each strategy.

Interior strategy had greater effects on predicted one-year sill loading than on floor loading, while exterior work, site/soil work, and HAT rating had a greater effect on floor loadings than on sill loadings. These findings may be a logical result of the interior strategies being defined more by their specific treatments of windows than of the other dwelling components. Although data suggests that dwellings treated with more intensive window treatments also had more intensive treatments to other components, the strategy definitions did not require this protocol. Thus, it is reasonable that higher intensity interior strategies were more effective in reducing window loading than floor loading.

The Evaluation showed that, regardless of interior strategy, loadings on floors and sills decline or remain level 1 to 6 years after intervention,[(6)] while other previous studies have shown significant reductions from baseline to up to 3.5 years post-intervention.[(5,14–16)] Hence, it is reasonable to assume that these results are applicable to three years post-intervention and beyond. While GM loadings remain level from one year to three years post-intervention for all interior strategies, higher level strategies yielded greater percent reductions from baseline to one year post-intervention. These results may be due to (1) the amount of dust lead generated by deteriorating LBP or entering the house from the exterior being less than the amount of dust removed through routine housecleaning, (2) the depletion of exterior lead sources over time, or (3) an absence of newly deteriorated lead-based paint in the treated units. Although it would have been preferable to model loadings at three years post-intervention rather than at one year, sufficient data were not available. Three-year data was available only for 28% of the analysis dwellings because the Evaluation followed only a subset of dwellings to three years post-intervention.

CONCLUSION

National data from the HUD Evaluation were successfully used in regression models to identify a simple, easy-to-use housing assessment tool that can be used to predict intervention effectiveness for a range of intervention intensities and baseline dust lead loadings in occupied dwellings. Part II in this issue describes the field application of the selected HAT.

ACKNOWLEDGMENTS

The authors wish to thank the staff of the participating Lead Hazard Control grantees (Alameda County, California; Baltimore, Maryland; Boston, Massachusetts; California; Chicago, Illinois; Cleveland, Ohio; Milwaukee, Wisconsin; Massachusetts; Minnesota; New Jersey; New York City, New York; Rhode Island; Vermont; and Wisconsin) for their tireless efforts and dedication to making this project a success. The authors also want to acknowledge the guidance of Nick Farr and Ron Jones on this project.

The analysis and writing of this article were funded under Howard University Center for Urban Progress subcontract 633840-005442 of HUD Lead Technical Studies Grant No. DCHBC0001-03. The Evaluation by NCHH and the University of Cincinnati was supported by the U.S. Department of Housing and Urban Development (HUD) Grant Nos. MDLR005-94 and OHLPR0010-95 and by HUD grants to each of the individual LHC grantees.

The research reported in this article was conducted in accordance with national and international guidelines for the protection of human subjects. Each individual grantee collecting data obtained its own Institutional Review Board approval.

The conclusions reached are those of the authors and do not necessarily represent those of the sponsor.

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