TESTING THE EFFECTS OF WINDOW REHABILITATION ON LEAD DUST LEVELS: A CASE STUDY

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF URBAN AND REGIONAL PLANNING

Urban and Regional Planning

2012

ABSTRACT

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Lead dust poses a significant health hazard for children, and windows in pre-1978 dwellings are an important source of lead contamination. Earlier research finds that window replacement is among the most effective methods for home lead-dust control. However, these studies did not focus specifically on lead-hazard remediation resulting from the rehabilitation of original windows, and historic preservation guidelines discourage window replacement. This case study adds to the body of research on this issue by testing the effects of three window rehabilitation intensities—low, medium, and high—on dust lead loadings in four wood windows. The findings suggest that high-intensity window rehabilitation—defined as removing lead-based paint from friction and impact surfaces, repainting those surfaces, and using lead-safe work practices—yields short-term (one year) dust lead loadings comparable to those resulting from window replacement as documented by a prominent national study. Low- and medium-intensity rehabilitation were somewhat less effective, but they still reduced lead dust to acceptable levels under current federal guidelines. The findings suggest that high-intensity window rehabilitation may be a safe alternative to window replacement. They further indicate that if lower-intensity treatments were combined with simple, periodic cleanings, they would also be effective for making windows lead safe. Large-scale, long-term research is needed to test these findings. If window rehabilitation can be shown to provide lead-safety results comparable to window replacement, it will prove beneficial for property owners, planners, contractors, historic district commissioners, and others who live in or work with low-income and historic housing.

ACKNOWLEDGMENTS

The author extends her profound gratitude to the following individuals, whose assistance and advice were critical to the successful completion of this study.

- **Nancy Finegood** of the Michigan Historic Preservation Network, who graciously allowed her residence to be used as the test site for the window rehabilitation and follow-up lead tests over the course of more than one year.
- **Lorri Sipes** of Wood Window Repair in Ann Arbor, Michigan and **Jim Turner** of Turner Restoration in Detroit, Michigan, who provided invaluable training and assistance in the window rehabilitation work at no charge. Their generous contribution of time and knowledge is deeply appreciated.
- **Steve Smith** of the Michigan Department of Community Health, who traveled to the test site many times over the course of the study period to take dust-wipe samples and return the samples to the laboratory at MDCH for testing, and **Cheryl Lariviere** of MDCH, who provided important information on MDCH's dust-wipe testing methodology as well as additional data from dust-wipe tests that fell below the laboratory's reporting limit.
- **Patricia Machemer, Ph.D.**, **April Allen, Ph.D.**, and **John Schweitzer, Ph.D.**, of Michigan State University, who served on the faculty advisory committee. Their careful review of the study design and report drafts, their constructive criticism, and their insightful recommendations were essential for ensuring the quality and relevance of this study.

- **Jonathan Wilson** of the National Center for Healthy Housing, **Ellen Thackeray** of Michigan Historic Preservation Network, and historic preservation contractor **Steve Stier**, who provided important advice during the early stages of the study design.

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- BLL: Blood lead level
- DLL: Dust lead loadings
- EPA: U.S. Environmental Protection Agency
- HEPA: High efficiency particulate air
- HUD: U.S. Department of Housing and Urban Development
- MDCH: Michigan Department of Community Health
- $\mu g/ft^2$: Micrograms per square foot
- NCHH: National Center for Healthy Housing
- TSP: Trisodium phosphate
- UCDEH: University of Cincinnati Department of Environmental Health

INTRODUCTION

Current literature indicates that wood windows are a significant source of lead-dust contamination in homes built before 1978 (mainly because of the release of lead dust due to the friction and impacts caused by their opening and closing) and that window replacement, coupled with lead-safe work practices, is the most effective way to reduce that risk. However, window replacement is discouraged by the Secretary of the Interior's Standards for Rehabilitation of historic buildings due to the negative impact of window replacement on historic character, and no previous studies have tested the lead-reduction effects that could result from specific window rehabilitation approaches that comply with the Secretary's Standards. To balance lead-safety needs with the demand to preserve the integrity of historic buildings, further research is needed to test the effectiveness of window-rehabilitation methods that retain original windows while eliminating lead-based paint hazards.

This pilot case study hypothesizes that the removal of lead-based paint from friction/impact surfaces alone, along with painting of friction surfaces and new application of primer and paint on nonfriction surfaces with deteriorated paint, can result in a reduction of lead-dust levels similar to that achieved by window replacement. The hypothesis will be tested through the rehabilitation of four windows at three levels of intensity designed to replicate (1) a routine, low-intensity maintenance by the homeowner, (2) a medium-intensity rehabilitation designed to improve the functionality of the window, and (3) a full-scale, high-intensity rehabilitation such as a window-rehabilitation specialist might perform. The study hypothesizes that the high-intensity rehabilitation will result in a lead-dust reduction comparable to that achieved by window replacement; the medium-intensity rehabilitation will be less effective than window replacement and may even increase lead dust levels due to the exposure of traces of lead-based paint to friction; and the low-intensity rehabilitation will be associated with a short-term reduction of lead dust within federally accepted guidelines but will show an increase in lead dust levels over time.

If these alternatives can be performed effectively, they will prove useful and beneficial for property owners, planners, contractors, historic district commissioners, and others who live in or work with low-income and historic housing.

LITERATURE REVIEW

INTRODUCTION

Lead poisoning is a known health hazard among U.S. children, particularly those living in older housing. Original windows in residences built before 1978 present an important risk factor for lead-dust contamination because they were frequently coated with lead-based paint and their frequent opening and closing causes friction that can release lead-paint dust. The U.S. Department of the Interior (1992), the National Trust for Historic Preservation (2012), and historic preservation advocates nationwide recognize the importance of maintaining original windows in historic housing; however, there is considerable pressure to replace them—often with new windows of incongruous design and synthetic materials that damage historic integrity.

One of the reasons given for window replacement is that it reduces the risk of lead-dust contamination by removing components that might release lead dust into the home or environment due to the abrasion or deterioration of lead-based paint. Another is that replacement windows increase energy efficiency. Given the average whole-house window-replacement cost of $7,000-$20,000 or more (Consumers Union, 2012), window manufacturers have a significant incentive to convince homeowners and landlords that their old wooden windows need to be replaced, and window replacement is big business. Despite widespread factory closures and layoffs in the window industry as well as a decline in sales resulting from the recent rollback of federal energy efficiency tax credits, each of the top seven American window manufacturers still generated over $1 billion in annual sales in 2012 (Swanson, 2012).

Meanwhile, the federal government's Energy Star program strongly advocates window replacement. The Energy Star website promises that Energy Star replacement windows will help consumers reduce greenhouse gases from power plants, reduce energy bills, get rid of cold drafts, and protect from sunlight. The site offers estimated energy savings resulting from replacement of original windows with Energy Star windows (for example, $372 per year for replacing single-pane windows and $160 when replacing double-pane windows in the Great Lakes region) but does not specify whether these savings are greater than those afforded by retrofits that retain the original windows (Energy Star, 2009). In addition, in 2009 and 2010, the Energy Star program offered a $1,500 tax credit toward the replacement of old windows with Energy Star-rated new windows (Energy Star, 2010).

There are a complexity of issues surrounding residential lead paint abatement in relation to the repair or replacement of windows in historic housing. Literature addresses this complexity, and has been centered around:

- The risks and sources of childhood lead exposure.
- The advantages of window replacement for lead-dust remediation.
- The energy efficiency and cost effectiveness of window rehabilitation and replacement.
- The importance of windows for preserving the integrity of historic buildings.
- An overview of federal lead-remediation guidelines.
- A selection of techniques available for the removal of lead-based paint.

The literature review found several articles (HUD, 1999a; NCHH & UCDEH, 2004; Jacobs and Nevin, 2006; Wilson et al., 2006; Dixon et al., 2012) indicating that window replacement is more effective than the rehabilitation of original windows as a means of reducing lead-dust contamination, but the existing literature aggregates numerous different techniques for lead remediation in existing windows and does not compare their effectiveness individually. Two studies (James, Shapiro, Flanders, and Hemenway, 1996; Klems, 2002) were found documenting the effectiveness of properly installed storm windows for achieving energy efficiency comparable to that found in replacement windows. Several studies (Mielke, Powell, Shah, Gonzales, and Mielke, 2001; Mielke et al., 2001; Scholtz et al, 2002; NCHH & UCDEH, 2004; O'Bright, 1986; Rich et al., 2002; Yiin et al., 2002; Tohn et al., 2000) document the effectiveness of individual lead-control techniques, but these techniques were studied in isolation and not applied specifically to windows. Further research is needed to demonstrate specific, viable window-replacement alternatives that effectively eliminate lead-based paint hazards but respect the historic integrity of original windows.

CHILDHOOD LEAD EXPOSURE AND HISTORIC HOUSING

The health risks of childhood lead exposure are well documented. Lead attacks the central nervous system and is especially dangerous to fetuses, infants, and children; however, it is also hazardous to adults. Fetal lead exposure is associated with premature birth, low birth weight, and impaired cognitive development. In children, heavy lead exposure can lead to anemia, brain damage, colic, kidney damage, muscle weakness, and death. Health risks from lower levels of exposure are less severe, and recovery is likely once the contamination source is removed;

however, long-term cognitive and behavioral impairment may still occur as a result (Agency for Toxic Substances and Disease Registry, 2007).

The principal sources of lead contamination in America during the twentieth century were lead-based paint and leaded gasoline (Agency for Toxic Substances and Disease Registry, 2007). Lead was used in gasoline from the early 1920s until it was phased out between 1973 and 1996 (U.S. EPA, 1996), and the use of lead in paint was banned in 1978 (U.S. Consumer Product Safety Commission, 1978). In a nationally representative random sample of U.S. houses, Jacobs et al. (2002) found that lead hazards were five to eight times more prevalent in houses built before 1960 than in houses built from 1960 to 1978. Given that the Criteria for Evaluation of the National Register of Historic Places do not typically allow for the historic designation of properties under 50 years old (U.S. Department of the Interior, 2004), it may be inferred that most historic buildings present a lead-paint hazard (Park and Hicks, 2007).

Even in older houses, however, most surfaces do not carry lead-based paint. Jacobs et al. (2002) found that housing built after 1960 had lead paint on 0-2% of interior surfaces and 0-12% of exterior surfaces; housing built between 1940 and 1960 had lead paint on 2-7% of interior surfaces and 16-37% of exterior surfaces; and pre-1940 housing had lead paint on 7-22% of interior surfaces and 24-41 % of exterior surfaces. Unfortunately, this study found that the interior surfaces most likely to carry lead-based paint were also those most at risk of friction, impact, and other forms of deterioration: windows and doors. (A later study by Dixon, Wilson, and Galke (2007) found a strong correlation between window friction/impact and increased lead dust levels.) The study found lead hazards to be most prevalent in houses with severely deteriorated lead paint; only one-third of houses with lead paint in good condition presented lead-dust hazards, compared to two-thirds of those with severely deteriorated lead paint.

A study by Clark et al. (2002) underscores the danger posed by the prevalence of lead-based paint on windows; this study found that window sills were 36 times more likely to show teeth marks than other surfaces of dwellings participating in the Lead Hazard Control Grant Program funded by the U.S. Department of Housing and Urban Development (HUD). This should not come as a surprise, given that windowsills often project from walls and tend to be accessible to young children.

THE BENEFITS OF WINDOW REPLACEMENT FOR LEAD REMEDIATION

Several studies indicate that window replacement is more effective than most forms of lead remediation involving the retention of original windows. These are discussed below.

HUD's National Lead Paint Survey (1990) found that while home exteriors were the most prevalent lead-dust source overall, windowsills and window troughs were the most prevalent source of lead dust inside the home. This finding would later be corroborated by the National Center for Healthy Housing (NCHH) and the University of Cincinnati Department of Environmental Health (UCDEH) (2004), discussed in greater detail below. Another study by HUD (1999a) found that lead-contaminated houses where windows had been replaced exhibited significantly lower post-intervention lead levels than did houses where the windows had simply undergone "window work" and/or paint stabilization. However, the study's definition of “window work” (i.e., repair) did not specify the form of repair; rather, it only differentiated “window work” with paint stabilization from paint stabilization alone (HUD, 1999a).

Jacobs and Nevin (2006) developed a forecast for 1990-2010 of residential lead-paint hazards and lead poisoning in children. The study combined blood-lead data from the National Health and Nutrition Examination Survey and other sources with datasets from the American Housing Survey, the Residential Energy Consumption Survey, and HUD’s National Lead Paint Survey that described trends in housing demolition, rehabilitation, lead-paint prevalence, and window replacement. This paper updated the model through 2010 and suggested that window replacement was largely responsible for a significant reduction in lead poisoning between 1990 and 2000. To continue this reduction through 2010, the authors recommended that a window-replacement policy be instituted. They suggested that such a policy would also contribute to greater home energy efficiency, which in turn would help reduce greenhouse gas emissions and increase the affordability of housing (due to reduced home heating costs).

A study by Nevin, Jacobs, Berg, and Cohen (2008) assigned a dollar value to lead remediation incorporating window replacement. Building upon earlier studies documenting the negative impacts of childhood lead exposure on brain development, educational attainment, and lifetime income as well as the monetary value of increased lifetime earnings resulting from avoiding childhood lead exposure, the researchers sought to quantify the benefits of lead remediation. Specifically, they examined remediation achieved through lead-safe window replacement, defined by the authors as replacement of all single-pane windows with high-efficiency Energy Star windows; paint stabilization; specialized cleaning to remove lead-contaminated dust after the repair; and clearance testing to confirm the absence of lead dust hazards. The study used child lead exposure data from the National Health and Nutrition Examination Surveys of 1999-2000 and data from the 1999-2000 National Survey of Lead and Allergens in Housing on the prevalence and type of lead paint hazards by age of housing to calculate the benefits of lead abatement. These benefits included figures for the monetary value of reduced preschool blood lead; higher lifetime earnings (as a result of lack of brain damage due to lack of lead exposure); other health benefits (lower health care costs, reduced mental retardation, reduced attention deficit-hyperactivity disorder, reduced crime and other antisocial behavior); energy savings; and market-value benefits. In total, Nevin et al. estimated that lead-safe window replacement would yield at least $67 billion in monetary benefits.

A large-scale evaluation of the HUD Lead-Based Paint Hazard Control Grant Program, which implemented lead-remediation work in low-income households at 14 grantee sites nationwide (NCHH & UCDEH, 2004), found that houses whose windows had been replaced exhibited lower lead-dust levels at three years post-intervention than did those which had undergone partial window treatments. The study defined "partial window treatments" as any combination of window jamb liners; sash replacement; paint removal from sashes, windowsills, and/or window troughs; or "other treatments." Category 5, "full window abatement," was defined as window replacement or window paint removal. Different interventions were grouped on a scale of intensity from two[1] to seven:

- *2: Cleaning Only/Spot Painting (median cost $430)*

[1] Category #1, no intervention at all, is not applicable because the grant only paid for interventions in categories 2 through 7 and the evaluation did not include a control group.

- *3: Full Paint Stabilization (median cost $4,930)*
- *4: Partial Window Treatments (median cost $6,120)*
- *5: Full Window Abatement (median cost $6,800)*
- *6: Full Lead Abatement (median cost $9,570)*
- *7: Full Lead Removal (median cost $4,110)* (NCHH & UCDEH, 2004, page ES-3)

A follow-up study by Wilson et al. (2006) tested a subset of households from four of the HUD grantee sites at six years post-intervention and found that lead dust continued to decrease or remain stable in both low-intensity (e.g., cleaning, partial paint stabilization, capping, etc.) and medium-intensity (e.g., cleaning, full paint stabilization, window treatment or replacement) interventions. However, lead-dust levels were significantly lower in households where windows had been replaced or where the lead paint on friction surfaces had been removed than in households that had only undergone paint stabilization. This suggests that the removal of paint from friction surfaces alone, used together with paint stabilization and other lower-intensity techniques, could offer an effective means of lead remediation that would allow for the retention of the original windows.

Another study by the National Center for Healthy Housing (Dixon et al., 2012) examined a smaller subset of 189 houses from the same four HUD grantee sites studied by Wilson et al. (2006), twelve years after the original intervention—the longest-range study yet conducted. The results corroborated the previous studies, which suggest that window replacement provides superior lead remediation. However, like the previous studies, this study did not differentiate among different intensities or methods of window rehabilitation. Instead, it arranged the subject houses in three categories—"all replacement" (all windows replaced), "partial replacement," (at least four, but not all, windows replaced), and "no replacement" (no more than three windows replaced). Of the houses in the "no replacement" category, only 64% had any work done on their windows (defined by the authors as partial sash replacement, paint stripping, repainting, and repair). In other words, this study aggregated data from windows that underwent a full rehabilitation and those which had no window work done at all in the same category. Furthermore, houses that underwent no window rehabilitation at all comprised more than one-third of the sample in the "no replacement" category. Therefore, while this study clearly demonstrates that window replacement is more effective than *non-replacement* in general, it does not adequately compare window replacement with specific methods or intensities of window rehabilitation.

While the studies above provide compelling indications that window replacement is among the most effective lead-hazard remediation methods, they aggregate window paint removal with other forms of rehabilitation (or no rehabilitation at all) and do not clearly differentiate among specific window rehabilitation approaches. To accurately assess the effects of window rehabilitation *per se* on lead dust in the home, further research is needed.

ENERGY EFFICIENCY AND COST EFFECTIVENESS OF REPAIRED AND REPLACED WINDOWS

While the main focus of this research project is the relationship between window rehabilitation/replacement and lead dust, several of the authors cited above have claimed that window replacement offers other significant benefits—especially energy efficiency and, as a result, cost savings. For example, Jacobs and Nevin (2006) suggested that a federal window-replacement policy would contribute to greater home energy efficiency, which would in turn help reduce greenhouse gas emissions and increase the affordability of housing due to reduced home heating costs. However, the following studies indicate that window replacement may not be the only viable option; in fact, certain methods involving the retention of original windows may be as effective as window replacement for achieving energy efficiency. Furthermore, whole-house window replacement can be very expensive. According to Consumers Union (2012), whole-house window replacement for an average house costs $7,000-$20,000 (or more if the installation requires custom-sized windows), and it can take nearly two decades for replacement windows to pay for themselves. HUD (1999a) estimated that at then-current energy rates, it would take 30 years for replacement windows to recoup 85 to 95 percent of the cost of installation.

While documented statistics on the costs of window rehabilitation approaches that comply with the Secretary of the Interior's Standards for Rehabilitation are lacking, anecdotes from rehabilitation specialists indicate that the cost is likely to vary considerably based on individual window condition, the labor costs charged by individual artisans, and the average costs of rehabilitation work in different parts of the country. As noted in promotional literature from Turner Restoration, a rehabilitation specialist who participated in this study, "Those selling vinyl windows may be able to give you a quote over the phone because they sell standard windows. In your historic home, there is nothing standard." (Turner Restoration LLC, n.d., para. 3.) According to John Leeke, a window restoration specialist with over 40 years of experience, "The cost of repair/rehab varies greatly with the experience and labor cost of the worker. A professional window specialist keeps track of time and materials costs and will accurately estimate the rehab costs. A do-it-yourselfer does not have to pay for labor" (Leeke, 2011, para. 4). Limited anecdotal information suggests that window rehabilitation can be less expensive than window replacement; for example, an architect for the Division of State History of the State of Utah said that he received quotes averaging $12,000 to replace the windows in his 1916 home with new, energy-efficient wood windows. In the end, he opted to have his windows refinished, weatherized, and equipped with storm windows at a cost of $5,000—less than half the cost of window replacement (State of Utah, Division of State History, 2012). More research is needed to compare the costs of window rehabilitation against the costs of window replacement. However, the literature indicates window replacement does not necessarily confer a clear energy efficiency advantage, as shown below.

James, Shapiro, Flanders, and Hemenway (1996) compared the energy efficiency of repaired historic windows with that of replaced windows through a field test of 151 windows in Vermont. First, the study documented first-year energy costs associated with windows pre- and post-intervention. Sixty-four of these windows were in original condition, and eighty-seven had been upgraded in various ways (ranging from sealing and weatherstripping of the original windows to complete window replacement). The authors used fan pressurization to estimate air leakage, then used the results to estimate whole-building infiltration rates during the heating season. The results for the 64 original windows were used to develop models for typical, tight and loose original-condition windows, and the annual energy-cost estimates for these windows became the frame of reference for calculating the estimated first-year energy cost savings resulting from the upgrades. The study found that energy cost savings were very similar across the different upgrades and that the level of energy efficiency was much more dependent on the quality and care of installation than on the type of upgrade. Based on this information, the authors concluded that window-replacement decisions should be made using criteria other than energy efficiency, such as historic integrity, ease of use and maintenance, lead risk, and the comfort of the occupants.

Klems (2002), working from the assumption that most existing windows in the United States are single-glazed, double-hung windows and that the cost of replacing all of them would be prohibitive, sought to compare the thermal efficiency of three different retrofit configurations that retained the single-glazed windows but improved their efficiency. In a test facility allowing the author to control for variables like temperature, wind speed, and wind direction, the author installed a control window—a new, single-hung vinyl window with low-emissivity (low-e), argon-filled sealed-insulating glazing and a weatherstripped frame. Next to the control window, the author installed a single-glazed wooden double-hung window with air leakage (intended to represent a typical candidate for retrofits) to which he applied three different storms in succession: a low-e exterior storm, an uncoated exterior storm, and a low-e interior storm. Because the wood window was leaky, pre-intervention tests revealed a rate of heat loss double that of the control window. The study found that the performance of the wood window when equipped with low-e storm windows was very similar to that of the control window, even though the wood window leaked and was not weatherstripped. The uncoated exterior storm performed better than the wood window alone but less well than the low-e storm or the control window.

Campagna and Frey (2008) documented the growing awareness of the role that historic preservation can play in the U.S. Green Building Council's influential Leadership in Energy and Environmental Design (LEED) certification system, which awards points to buildings that meet its stringent energy-efficiency standards. The article offered several case studies of historic rehabilitation projects that have achieved LEED certification. One of these, the Lincoln Cottage Visitors Education Center restored by the National Trust for Historic Preservation, was expected to exceed minimum energy-efficiency requirements for LEED certification by ten percent; the authors noted that the project's "meticulously restored windows" (Campagna and Frey, 2008, page 24) contributed to the building's energy efficiency with the help of brass weatherstripping. According to the authors, this case suggests that green building and historic preservation are not necessarily incompatible and can even be mutually reinforcing.

THE IMPORTANCE OF WINDOWS IN HISTORIC PRESERVATION

From the federal level to the local level, historic preservation advocates assert that the replacement of lead-contaminated windows is frequently unnecessary and has the potential to severely compromise the integrity of a historic building. The replacement of historic windows in usable or reparable condition is actively discouraged by the Standards for Rehabilitation of the Secretary of the Interior. The most pertinent of these include Standards 2, 5, and 6:

> *The historic character of a property will be retained and preserved. The removal of distinctive materials or alteration of features, spaces, and spatial relationships that characterize a property will be avoided.* (U.S. Department of the Interior, 1992, par. 2)
>
> *Distinctive materials, features, finishes, and construction techniques or examples of craftsmanship that characterize a property will be preserved.* (ibid., par. 5)

> *Deteriorated historic features will be repaired rather than replaced. Where the severity of deterioration requires replacement of a distinctive feature, the new feature will match the old in design, color, texture, and, where possible, materials. Replacement of missing features will be substantiated by documentary and physical evidence.* (ibid., par. 6)

In a discussion of the implications of the Standards for specific aspects of historic buildings, the Secretary of the Interior specifically recommends that original windows be identified, retained, and preserved, as they constitute an important part of a building's historic character (U.S. Department of the Interior, 1992). Chapter 18 of the HUD *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing* (2007) notes the potential conflicts of normal lead remediation techniques with the needs of historic housing, including such issues as the removal of historically significant features and finishes, the destruction of evidence of craftsmanship, the loss of paint chronology or evidence of previous finishes, and the loss of architectural integrity.

Myers (1981), in a National Park Service preservation brief offering guidelines for the rehabilitation of historic wood windows, recommended that original windows be retained wherever possible, noting that many windows are replaced due to lack of awareness of how to properly evaluate, repair, and weatherize them. He stated that windows should be considered significant if they were original to a building, reflected the intent of the building's original design, exemplified period or regional building practices or styles, indicated changes made to a building during important events or periods of time, or showed excellence in design or craftsmanship. Myers also noted that properly maintained and repaired windows have very long usable lives and also contribute to the historical authenticity of the buildings in which they are housed.

The replacement of historic windows is also discouraged by advocacy groups like the National Trust for Historic Preservation, which provides a great deal of information and resources on rehabilitating original windows, including guidelines on when repair or replacement is warranted, types of residential windows, a map of window-rehabilitation contractors, a schedule of workshops and trainings, and links to additional resources (National Trust for Historic Preservation, 2012). In addition, numerous preservation organizations around the country have added historic wood windows to their “most endangered” lists—normally reserved for specific individual buildings, not a wholesale category like windows—due to the intense push by the window industry and the federal Energy Star program to get homeowners and landlords to replace their historic windows. These include Worcester, MA (Preservation Worcester, 2010); Chicago, IL (Preservation Chicago, 2009); and the states of Alabama (Alabama Historical Commission, 2010), Indiana (Indiana Landmarks, 2009), and Kentucky (Preservation Kentucky, 2011). This statement by Preservation Chicago, however slanted, sums up the dilemma:

> *Everybody wants to save money on their heating bills, and we’ve all been told that replacing those old wood windows is the best way to do that. But the fact is, traditional wood double-hung windows are more cost and energy efficient, more durable, easier to maintain and simply more attractive than most any replacement window on the market. … The multi-million dollar replacement window lobby has convinced the general public that it is in their interest to pay more for an inferior version of something they already own. This explains why residential and commercial buildings all across Chicagoland are sprouting new vinyl and aluminum replacement windows. And why thousands of wood windows are being relegated to landfills. This neither conforms to the green movement, nor does it present a money-smart solution in these challenging economic times* (Preservation Chicago, 2009, page 1).

Window replacement is also discouraged or prohibited by local historic districts, which typically follow the Standards for Rehabilitation of the Secretary of the Interior (Electronic Code of Federal Regulations, 1986). The issue is not just one of aesthetics or of historic authenticity. As noted by Sedovic and Gotthelf (2005) in an essay for the Association for Preservation Technology, the loss of historic windows may incur a host of disadvantages, including a loss of the "embodied energy" from their original manufacture and installation; increased environmental costs including the need to dispose of old windows in landfills and transport new ones; difficulty or impossibility of maintenance (given that most vinyl windows cannot be repaired when they fail); and shorter life (as manufacturers' warranties for new vinyl windows typically pale in comparison to the usable life of wood windows, which can last a century or more when properly cared for). The same paper cautions that window manufacturers often overstate the energy efficiency of their windows, that similar energy efficiency can be achieved through restored windows fitted with weatherstripping or weatherseals, and that high-quality replacement windows can cost as much as three times the price of rehabilitation of original windows.

GUIDELINES AND TESTS OF LEAD-PAINT REMEDIATION TECHNIQUES

Lead-remediation guidelines. Several resources offer guidelines for lead-paint remediation specific to historic housing, including techniques for remediation in historic windows. Title X of the Housing and Community Development Act of 1992, the Residential Lead-Based Paint Hazard Reduction Act, offers a list of definitions relating to lead-paint remediation that may be useful for understanding different techniques and categories of intervention. Some of these definitions include the following:

(1) Abatement. *The term "abatement" means any set of measures designed to permanently eliminate lead-based paint hazards in accordance with standards established by appropriate Federal agencies. Such term includes --*

> *(A) the removal of lead-based paint and lead-contaminated dust, the permanent containment or encapsulation of lead-based paint, the replacement of lead-painted surfaces or fixtures, and the removal or covering of lead contaminated soil; and*
>
> *(B) all preparation, cleanup, disposal, and postabatement clearance testing activities associated with such measures.*

(2) Accessible surface. *The term "accessible surface" means an interior or exterior surface painted with lead-based paint that is accessible for a young child to mouth or chew.*

(5) Deteriorated paint. *The term "deteriorated paint" means any interior or exterior paint that is peeling, chipping, chalking or cracking or any paint located on an interior or exterior surface or fixture that is damaged or deteriorated.*

(10) Friction surface. *The term "friction surface" means an interior or exterior surface that is subject to abrasion or friction, including certain window, floor, and stair surfaces.*

(11) Impact surface. *The term "impact surface" means an interior or exterior surface that is subject to damage by repeated impacts, for example, certain parts of door frames.*

(13) Interim controls. *The term "interim controls" means a set of measures designed to reduce temporarily human exposure or likely exposure to lead-based paint hazards, including specialized cleaning, repairs, maintenance, painting, temporary containment, ongoing monitoring of lead-based paint hazards or potential hazards, and the establishment and operation of management and resident education programs.*

(14) Lead-based paint. *The term "lead-based paint" means paint or other surface coatings that contain lead in excess of limits established under section 302(c) of the Lead-Based Paint Poisoning Prevention Act.*

(15) Lead-based paint hazard. *The term "lead-based paint hazard" means any condition that causes exposure to lead from lead- contaminated dust, lead-contaminated soil, lead-contaminated paint that is deteriorated or present in accessible surfaces, friction surfaces, or impact surfaces that would result in adverse human health effects as established by the appropriate Federal agency.*

> ***(16) Lead-contaminated dust.*** *The term "lead-contaminated dust" means surface dust in residential dwellings that contains an area or mass concentration of lead in excess of levels determined by the appropriate Federal agency to pose a threat of adverse health effects in pregnant women or young children.* (Residential Lead-Based Paint Hazard Reduction Act, 1992)

The evaluation of the HUD Lead-Based Paint Hazard Control Grant Program provided examples of forms of intervention that fit within these definitions. The distinction between permanent and interim controls was of particular importance. They noted that HUD defined abatements—i.e., "permanent" interventions—as those which were expected to last a minimum of 20 years. Examples included complete paint removal, the removal of building components (e.g., windows or parts of windows), and the total enclosure of surfaces (e.g., covering wooden clapboard with vinyl siding). Interim controls also eliminated lead-paint hazards, but their effects were not expected to last 20 years. Examples of interim controls included wet scraping, sanding, and repainting; friction and impact reduction (e.g., through jamb liners); and cleaning (NCHH & UCDEH, 2004).

The HUD *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing* (2007) offered detailed information on how to identify and control residential lead-based paint hazards. This included everything from risk assessment and monitoring to resident and worksite preparation, hazardous waste disposal, interim controls, abatement, encapsulation, routine maintenance, and more. Chapter 18 of the *Guidelines* offered more specific recommendations on which methods to use and which to avoid during lead-paint remediation in historic housing. Issues of concern could include not just architectural features (e.g., wooden windows) but also paint and other surface coverings, which might provide chronological indications of previous decorative schemes and therefore merit retention depending on the value of the historic resource.

The chapter recommended that the intensity of the intervention be defined by the level of historic significance of the structure and that all interventions strive to retain historic appearance and building materials to the fullest extent possible; that records and original paint samples (in the event of paint removal) be kept to guide maintenance and rehabilitation work in the future; and that the danger of lead exposure be assessed for individual housing components to determine the necessary intervention level. The chapter also recommended that special consideration be given to hazard-control methods that did not eliminate significant features and finishes, remove significant historic materials, utilize harsh chemicals or abrasives that damage historic materials, or enclose historic features (as with vinyl siding). Where paint removal was necessary, recommended methods included the wet sanding of deteriorated paint, mechanical sanding using sanders attached to high-efficiency particulate air (HEPA) filters, low-temperature heat guns, chemical strippers other than methylene chloride, and offsite stripping of paint.

A preservation brief by Park and Hicks (2007) offered further guidelines on appropriate lead-remediation methods for historic resources. For example, when replacement of an important feature or finish was needed, they recommended that the replacement match the original in "design, detail, color, texture, and, in most cases, material" (ibid., page 4). In addition, the authors presented a hierarchy of priorities to guide the decision to repair or replace a given feature:

- *Highly significant features and finishes that should always be protected and preserved;*
- *Significant features and finishes that should be carefully repaired or, if necessary, replaced in-kind or to match all visual qualities; and*
- *Non-significant or altered areas where removal, rigid enclosure, or replacement could occur.* (ibid., page 4)

The authors recommended a three-step process to determine a course of action for lead remediation. First, the historical significance and architectural character of the building should be identified. Next, a lead-hazard risk assessment should be conducted. Finally, lead-hazard control options should be evaluated in light of the three historic preservation priorities listed above. The authors stressed that it was always preferable to select methods that only removed *deteriorating* paint or which involve selective repair rather than wholesale replacement of historic features and finishes.

While these remediation measures may be more appropriate for protecting historic resources, HUD's guidelines and the Parks and Hicks preservation brief did not establish the extent to which they were effective for mitigating lead contamination risk by comparison to measures known to compromise historic integrity. The studies below may shed some light on this issue, as they evaluate the results of several specific lead-remediation techniques.

Unprotected power sanding. HUD (2007) recommended the use of power sanding for lead-paint removal only when the sander was fitted with a HEPA filter. The following case study shows why. Jacobs, Mielke, and Pavur (2003) documented the multiple costs incurred for lead remediation following the use of unprotected power sanding to remove lead-based paint from wooden siding on a house in New Orleans. At a cost of $15,600, a family hired a professional contractor to strip the siding on a 75-year-old house. No lead testing was carried out prior to starting work. The contractor used power sanding to remove paint for six weeks without collecting the resulting dust or safeguarding the interior or exterior of the house. Shortly before the completion of sanding, the family's dog died, exhibiting an elevated blood lead level (BLL).

After their veterinarian raised the alarm, the family screened their three children, who were immediately hospitalized due to high BLLs. The original contractor then abandoned the project, and the family hired a lead remediation contractor to finish the job properly. The study documented a formidable array of expenses, including the hiring of a replacement painter, numerous decontamination efforts, and medical bills for the children. The total estimated cost was $195,693, which did not include other costs such as the family's labor, the decreased market value of the house, the potential for chronic poor health and decreased lifelong earnings among the family's children, the cost of insurance litigation, the payment of $13,866 to the original painter, and the emotional stress endured by the family. Not surprisingly, none of the guidelines in this literature review advocate unprotected power sanding.

Dry scraping. HUD (2007) has advocated against dry scraping, saying that it releases too much airborne lead dust and that a scraper attached to a HEPA vacuum is more effective. However, one case study found favorable results from dry scraping by hand. Mielke, Powell, Shah, Gonzales, and Mielke (2001) compared the levels of contamination by lead and several other toxic metals resulting from two exterior home paint removal projects in New Orleans. One, the background study, was the project summarized above in Jacobs et al. (2003). The other project, conducted by a nearby family who knew of the power-sanding incident and wanted to remove their lead-based paint safely, involved hand scraping of dry paint. During this process, the family allowed the authors to document the effects of the process on household lead levels through blood-lead tests, paint-chip tests, estimates of metals removed based on the weight of paint scraped from the house, and surface-wipe samples in the interior of the house. To expand the focus of the study, the authors also took exterior paint samples from 31 houses in New

Orleans to document quantities of lead and several other toxic metals. Overall, the study found the lead-dust levels in and around the scraped house to be relatively low both before and during the scraping work and before cleanup. Localized areas of lead dust accumulation were discovered in entryways and quickly addressed by the family through mopping and other measures. After cleanup, lead-dust levels were lower than they had been prior to the start of the project. The children's blood tests also indicated low BLLs. The authors also used the exterior paint sample tests, calculated against the weight of the paint scraped from the house (41 kilograms, or about one-half of the total paint on the house), to estimate the amounts of heavy metals that would have escaped into the environment had the house been power-sanded. This estimate included approximately 7.4 kilograms of lead, in addition to measurable quantities of several other toxic metals. The authors concluded that the scraping and collection of lead-based paint was relatively safe and did not add significant amounts of lead dust to the interior or exterior of a house.

Wet scraping. Many sources (NCHH & UCDEH 2004, HUD 2007, Tohn et al. 2000, HUD 1999a) have advocated wet scraping over dry scraping, as it reduces the release of dust particles into the air. HUD (2007) recommended the continuous misting of the scraping surface to prevent dust release along with the use of damp rags to gather the smallest dust particles and a dropcloth to collect paint chips. However, Mielke et al. (2001) noted that the contractor in the case study above first attempted wet scraping but found that the scraped paint "became an unmanageable mess of wet paint chips that stuck to the plastic sheeting [and] was difficult to gather into a single container" (Mielke et al., 2001, page 974). The contractor found dry scraping much less difficult and was able to gather the resulting paint chips with ease; based on post-intervention tests, the authors concluded that the process was effective. However, the knowledge of the power-sanding incident plus the constant monitoring by the study authors may have caused the family to take higher-than-normal cleanliness and safety precautions. Further research would be needed to test the general effectiveness of dry scraping for mitigating lead hazards.

Wet sanding. HUD (2007) recommended the use of wet sanding over dry sanding, noting that it should mainly be used for the removal of deteriorated paint and that caution should be exercised to prevent excessive abrasion of historic features and finishes. Depending on the surface sanded, wet sanding could be accomplished through the use of wet/dry sandpaper (for smooth finishes) or sanding blocks, i.e., sponges dipped in aluminum oxide grit (for rougher surfaces). In a two-year study of the blood lead levels of twelve residential and commercial painters, Scholtz et al. (2002) corroborated this recommendation, finding that painters who employed wet sanding exhibited very low BLLs. Meanwhile, painters who used dry manual sanding and painters who used uncontrolled power sanding exhibited blood lead levels above the Occupational Safety and Health Administration's limits for permissible exposure.

Window jamb liners and paint encapsulation. The evaluation of the HUD Lead-Based Paint Hazard Control Grant Program (NCHH & UCDEH, 2004, also discussed under "Benefits of Window Replacement" above) found that window jamb liners, a measure used to eliminate window friction that could deteriorate lead paint and result in lead-dust contamination, had a very high failure rate of 17 percent at six months and 46 percent at three years post-installation. More than one-half of the failures were attributed to poor installation. This finding suggests that jamb liners—whether properly installed or not—are inadequate to address the risk of lead-dust contamination when original windows are retained. The study also suggested that paint encapsulation was not more effective than paint stabilization at mitigating lead risk, as encapsulants exhibited failure rates similar to those of paint stabilization. The study authors cautioned, however, that more research was needed because the encapsulation sample was much smaller than the paint-stabilization sample.

Low-temperature heat guns. HUD (2007) and U.S. EPA (2010) have recommended the use of heat guns as an effective means of lead-paint removal with the caveat that the temperature must not exceed 1,100°F, as heat guns have been known to ignite wooden structures (Tremblay, 2009; Peters, 2010). The chapter of HUD (2007) relating to historic structures also recommended heat guns but was more conservative in its temperature guidelines, recommending that heat guns not exceed 450°F and that scraping be done with a round-edged scraper to prevent damage to wood surfaces beneath the paint. In addition to helping prevent fires, low temperatures also help to prevent the release of lead particles into the air; Scholtz et al. (2002) found that painters using low-temperature heat guns exhibited very low BLLs. O'Bright (1986) provided a case study of the effective use of heat guns for removing lead paint from a historic structure. The Harry S. Truman National Historic Site, an ornate Victorian house, was suffering widespread and severe exterior-paint failure. Given the condition of the paint, it was decided that most painted surfaces would be cleared to bare wood and repainted. To assess the potential safety of heat-based paint removal methods, portions of siding were removed in order to ascertain the flammability of materials beneath the walls. The heat guns were set at the lowest heat setting (500°F) and adjusted to higher temperatures as necessary for paint that was thicker or more difficult to remove. Strict fire precautions were observed, especially the training of workers not to keep the heat guns in one spot for too long or to raise the temperature unnecessarily. One member of the crew was designated as a fire-safety inspector to ensure compliance. Fire extinguishers were kept within reach of every work station where heat guns were used, additional smoke detectors were installed, and heat-gun work was concluded before the end of the workday so that workers could be present in the event that a slow-burning fire broke out inside the walls. To protect against lead contamination, workers wore lead respirators and separate clothing used only for stripping paint. Paint was collected on disposable drop cloths, windows and doors were kept closed, and workers were not permitted to enter the house. As a result of the paint removal, the house was left with a smooth surface that readily accepted new coats of paint. Although lead-safe work practices were observed, the author did not specify whether lead-dust levels were tested before or after the work.

Lead-paint dust removal. Most lead-remediation procedures involve the release of some amount of lead-paint dust. The literature documents several tests of the safety and efficacy of different techniques for removing lead dust from the worksite. Rich et al. (2002) sought to compare two recommended lead-particle removers—HEPA filter vacuums and trisodium phosphate (TSP) detergent—against other dust-removal methods employed in 127 New Jersey houses. The study found varying results from the use of different techniques in different locations, including windowsills, window troughs, and hard floors. Based on the inconsistency among treatment results, the authors recommended the use of low-phosphate detergents and non-HEPA vacuums—which are more affordable and easier to obtain—for the removal of lead-paint dust.

Some surfaces can also support dangerous accumulations of lead dust during intervention, especially fabric surfaces like carpet and upholstery. In the same 127 houses documented in the study above, Yiin et al. (2002) compared the results from HEPA and non-HEPA vacuuming on carpets and upholstery. They found non-HEPA vacuuming to be nearly as effective as HEPA vacuuming but found the overall effectiveness of one-time vacuuming to be limited on both upholstery and carpets. Thus, they recommended frequent carpet and upholstery cleaning over one-time cleanings. Finally, Tohn et al. (2000) tested the lead-dust levels on walls and ceilings in 22 residential units following lead-hazard control intervention through the removal or repair of windows, combined with paint stabilization. The study found statistically significant increases in lead-dust loadings on both walls and ceilings; however, this increase only reached dangerous levels on walls. Therefore, the authors concluded that current HUD recommendations to clean walls were strongly supported and that the study did not provide sufficient justification to alter HUD's current recommendation to clean ceilings as well.

IMPLICATIONS OF THE LITERATURE

As demonstrated clearly by the literature, the risks of childhood lead poisoning—especially by lead-based paint—are very real. To ensure that historic buildings can be safely inhabited by families with children, it is imperative that lead-dust hazards be mitigated through proper remediation procedures. Window replacement is a viable way to address this risk and can also improve energy efficiency. However, window replacement also damages architectural and historical integrity, wastes durable and reparable resources, and requires a large up-front investment that is slow to pay for itself and unaffordable for lower-income households.

Replacement windows also do not necessarily confer superior energy efficiency, as the literature documents effective methods for creating comparable energy efficiency in original windows.

A large body of research indicates that window replacement is generally more effective than lead-remediation treatments involving the retention of original windows; however, the existing literature aggregates the alternative methods into broad categories and does not directly compare among specific rehabilitation approaches. The literature demonstrates several tools and techniques that are effective for the safe removal of lead-based paint; however, few of these studies address windows directly. More research is needed to test the effectiveness of specific window-rehabilitation approaches that work in accordance with the Secretary's Standards for Rehabilitation and federal lead safety guidelines but also have the potential to present effective, affordable alternatives to window replacement. These could include such methods as the removal of paint from friction surfaces alone; the selective covering, stabilization, or removal of deteriorated paint; and the complete stripping and recoating of all friction and impact surfaces.

RESEARCH METHODOLOGY

RESEARCH QUESTIONS

The objective of this case study was to test the effectiveness over time of a selection of window-rehabilitation approaches which, based on the literature, appeared to have potential for making original wood windows lead-safe. A further objective was to inform larger-scale, longer-term research on the same topic. The study was designed to answer the following research questions:

- Over the course of 12 months, how do window lead-dust levels change:
    1. When lead-based paint is removed from friction/impact surfaces but those surfaces are not painted afterward?
    2. When lead-based paint is removed from friction/impact surfaces and those surfaces are then painted?
    3. When lead-based paint is not removed from friction/impact surfaces, but areas with deteriorated lead-based paint are scraped and painted?

HYPOTHESIS

This study hypothesized that the removal of lead-based paint from friction/impact surfaces alone, combined with painting of friction surfaces and new application of primer and paint on nonfriction surfaces with deteriorated paint, would result in a reduction of lead-dust levels similar to that achieved by window replacement. Further hypotheses included the following:

- Friction surfaces where lead paint is removed but which are not repainted (e.g., jambs) will be at higher risk for lead-dust contamination because the friction surfaces are not painted after stripping and traces of lead-based paint could remain on the surface of the wood; however, because most visible paint is removed and the surface is treated with linseed oil, lead-dust levels may still fit within federally accepted guidelines.
- Friction surfaces where lead paint is removed and which are repainted will pose the lowest risk of lead-dust contamination over time.
- Friction surfaces of windows where lead paint is not removed or altered will be at higher long-term risk for lead-dust contamination; however, if surfaces (e.g., the trough or sill) with visibly deteriorated paint are scraped and repainted, these windows may exhibit lead levels within federally accepted guidelines during the study period.

CASE STUDY DESIGN AND COMPLETION OF WORK

To answer the research questions, the following case study design was devised. Case-study design elements are shown in italics, followed by a concise description of the actual work, which took place from July 2011 to December 2012. More detailed information on the study site, rehabilitation work, timeline, and dust-wipe testing methodology is provided in the following appendices:

- Description of the case study site and the test windows: Appendix A.
- Description of the rehabilitation work and timeline: Appendix B.
- Description of the dust-wipe testing methodology: Appendix C.

1. Secure Test Site

Secure access to a pre-1978 home with at least three original windows at risk of lead-dust contamination. The test site was a 1912 house in Eaton Rapids, Michigan, with four lead-contaminated windows that were accessible for rehabilitation.

2. Seek Accurate Lead Testing Service

Secure assistance by a lead-testing specialist with the ability to provide accurate analysis of the dust-wipe samples. An official from the Michigan Department of Community Health (MDCH) visited the test site to perform dust-wipe tests before, during, immediately after, and at six-month intervals following the rehabilitation. The dust-wipe samples were analyzed at MDCH's nationally accredited laboratory (U.S. Environmental Protection Agency, 2012).

3. Conduct Baseline Dust-Wipe Tests

Conduct baseline dust-wipe tests of trough, sill, floor, and room entry for each test window to determine whether a lead-dust contamination risk is present. Prior to the start of work, the MDCH official took dust-wipe samples at the test site to ascertain that a lead hazard was present and set a baseline for future work. All four windows presented a lead hazard and, therefore, were ideal candidates for the study.

4. Obtain Training and Assistance from Window Rehabilitation Specialists

Seek training and assistance from one or more window rehabilitation specialists to provide training and guidance in window rehabilitation. Two window rehabilitation specialists provided training and assistance in window disassembly and reassembly, paint removal, wood repair and protection, and reglazing.

5. Rehabilitate Windows

Rehabilitate at least three windows using three rehabilitation intensities, in accordance with the three research questions above. Specifically:

- ***Medium intensity rehabilitation:*** *Strip paint from friction surfaces and trough. Treat friction surfaces with boiled linseed oil and mineral spirits only.*[2] *Wet sand, prime and paint trough and sill only. Clean worksite with trisodium phosphate (TSP) solution and HEPA vacuum.* Two windows (Windows A and B), located next to one another on the south side of the house and facing the front porch, received medium-intensity rehabilitation. The window rehabilitation specialist and the researcher worked together to complete this work in one day. The window sash and stops were removed and stripped of paint on the front porch.
- ***High intensity rehabilitation:*** *Remove sash for offsite rehabilitation. Strip all friction surfaces, trough, and sill. Seal friction surfaces with linseed oil and (if feasible) primer. Wet sand, prime and paint sash, trough, and sill. Clean worksite with trisodium phosphate (TSP) solution and HEPA vacuum.* One window (Window C), located on the west side of the house in the same room as Windows A and B, received high-intensity rehabilitation. For this work, the researcher took the sash to the shop of the second rehabilitation specialist to be stripped of paint and reglazed. Next, the researcher took the sash home to let the glazing putty cure

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[2] One of the window rehabilitation specialists participating in this study indicated that a blend of boiled linseed oil and mineral spirits was often used to protect unsealed wood surfaces. Gallagher and Kline (1977) corroborated this point, noting that boiled linseed oil, blended with mineral spirits as a solvent, was useful as a penetrating sealant for porous materials like wood and concrete because of its ability to polymerize (harden) both on and beneath the surface to which it was applied.

and then apply primer and paint. Finally, the researcher completely stripped and repainted the stops, jamb, trough, and sill.

- ***Low intensity rehabilitation:*** *Thoroughly clean trough and sill. Wet scrape, prime and paint trough and sill. Clean worksite with TSP solution and HEPA vacuum.* One window (Window D), located on the second floor and facing south, received low-intensity rehabilitation. The researcher, working alone, removed only the deteriorated paint on the trough, sill, and sash with a carbide scraper, followed by moistened sanding blocks. Next, these surfaces were primed and painted.

6. Conduct Post-Rehabilitation Dust-Wipe Tests

After rehabilitation is complete, but immediately before the final cleaning, conduct post-rehabilitation dust-wipe tests to determine whether the rehabilitation work itself caused elevated lead-dust levels. After all four windows had been rehabilitated and prior to the final cleaning, the MDCH official returned to perform dust-wipe tests.

7. Final Cleaning of Worksite

In an attempt to isolate the potential causes of lead contamination to the windows themselves and control for contamination resulting from the rehabilitation, clean the worksite with TSP and a HEPA vacuum after rehabilitation work is complete. Following the post-rehabilitation dust-wipe test, the researcher vacuumed all surfaces, then wiped them with a rag soaked in TSP solution. The paint-removal techniques had generated little dust, and the researcher had kept a vacuum on hand to periodically remove paint chips and dust during the course of the rehabilitation, so very little debris was visible at the time of the final cleaning.

8. Conduct Post-Cleaning Dust-Wipe Tests

Immediately after the final cleaning, conduct a post-cleaning dust-wipe test to ascertain the effect of the cleaning on lead-dust levels and set a post-cleaning baseline. The MDCH official returned the day after the final cleaning to perform dust-wipe tests on all window troughs, sills, and adjacent floor surfaces. In addition, floor dust-wipe samples were taken immediately inside and outside the main entry to the house, which gave onto the living room where windows A, B, and C were located.

9. Conduct Follow-Up Dust-Wipe Tests

At six-month intervals over the next 12 months, conduct follow-up dust-wipe tests to document the accumulation of lead dust over time. The MDCH official returned six months and 12 months after the final cleaning to perform follow-up tests.

10. Analysis and Reporting

Analyze lead-test results over time against window-rehabilitation techniques used, compare results with window-replacement findings from previous research (NCHH & UCDEH, 2004), report on results, and recommend further avenues of research. Data analysis commenced immediately after the completion of the final dust-wipe test and was completed in December 2012. The researcher analyzed the changes in lead dust content over time, then compared the findings with the mean lead dust content for window replacement in a national study (NCHH & UCDEH, 2004).

FRAME OF REFERENCE FOR INTERPRETING THE FINDINGS

This case study used lead-safety criteria developed by the U.S. Environmental Protection Agency (EPA, 2001) and adopted by HUD (2004) as its frame of reference for interpreting the findings. EPA's standards for dust lead loadings (DLL), which are measured in micrograms per square foot ($\mu g/ft^2$) included the following:

- Lead risk assessment and reevaluation: Floors 40 $\mu g/ft^2$, sills 250 $\mu g/ft^2$
- Lead clearance (post-intervention): Floors 40 $\mu g/ft^2$, sills 250 $\mu g/ft^2$, troughs 400 $\mu g/ft^2$

It should be noted that the above criteria do not include an assessment and reevaluation standard for window troughs. HUD and EPA included only a *clearance* standard (i.e., immediately post-intervention) for troughs "as a way of ensuring that window troughs are cleaned and/or treated during hazard reduction work" (HUD, 1999b, page 50182) when window rehabilitation work is carried out. According to HUD, this criterion is not applied to lead risk assessment because almost all window troughs exhibit elevated DLL prior to intervention, because it is easier to take wipe samples from sills, and because troughs may be more likely to contain lead dust from sources outside a building. In justifying its decision, HUD also cited Lanphear et al. (1995), who found a strong correlation between DLL on sills and DLL on troughs. In keeping with this lack of a standard for follow-up tests, Wilson et al. (2006) and Dixon et al. (2012) collected post-clearance trough data but did not report them. Dixon et al. stated that this was "due to limited space and the fact that hazard standards do not apply to troughs" (Dixon, 2012, page 4).

This case study applied HUD and EPA's more rigorous clearance standard to all data throughout the study, rather than clearance data alone. This was done in order to provide a more complete picture of the effects of window rehabilitation on DLL, particularly for a window component which—as the next section will show—is prone to significant lead dust contamination both before and after rehabilitation.

FINDINGS

The following section presents the findings from the pre-, post-, and follow-up dust-wipe tests of the four windows. In addition, a rough comparison is made between the case study findings and those of a national study of the effects of window replacement on lead dust contamination.

The full dust-wipe test results are shown in Table 1 on the next page.

Table 1: Dust-Wipe Test Results, 7/29/11 to 8/31/12

	Test Area	7/29/11 Pre-rehab (µg/ft^2)	8/29/11 Post-rehab, pre-final clean (µg/ft^2)	8/31/11 Post-final clean (µg/ft^2)	2/27/12 First follow-up (µg/ft^2)	8/31/12 Second follow-up (µg/ft^2)	Cumulative post-clean DLL (µg/ft^2)***	Net % decline in DLL
Window A (medium intensity rehab)	Trough	560	9.2	1.9	100	74.2	174.2	68.9%
	Sill	21	1.9	0.5	24.2	8.9	33.1	-57.6%
	Floor*	3.4	3.9	1.8	1.6	1.3	2.9	14.7%
Window B (medium intensity rehab)	Trough	850	4.4	3.7	80	120.2	200.2	76.4%
	Sill	18	3.1	1.8	13	5.4	18.4	-2.2%
	Floor*	0.85	3.9	1.8	1.6	1.3	2.9	-241.2%
Window C (high intensity rehab)	Trough	2800	5.1	-0.1	140	35.1	175.1	93.7%
	Sill	81	0.35	0.8	4.9	2.6	7.5	90.7%
	Floor	1.1	0.36	0.6	0.98	0.4	1.38	-25.5%
Window D (low intensity rehab)	Trough	980	-0.24	0.2	65	60.6	125.6	87.2%
	Sill	15	3.3	1.5	7.6	3.6	11.2	25.3%
	Floor	0.56	0.7	0.2	0.96	0.4	1.36	-142.9%
Inside entry	Floor	NA**	12	7.7	11	3.5	14.5	-20.8%
Outside entry	Porch	NA**	76	15	36	30.5	66.5	12.5%

*Because windows A and B were next to each other, samples were taken from one 12" square space of floor, about 6 inches from the wall, between the two windows in all but the first test. For the first test, samples were taken in front of both A and B.

**No samples were taken from the inside entryway of the house or the outside entryway (front porch) prior to the start of work. This was a mistake by the researcher.

***These square-footage calculations were made by the researcher because, for the final round of tests only, MDCH submitted data in the form of micrograms of dust lead per sample and actual square footage rather than µg/ft^2. For the previous rounds of tests, MDCH had provided the data in the form of µg/ft^2.

DUST-WIPE TEST RESULTS

As shown in Table 1, pre-intervention DLL was most significant in the window troughs, with lower DLL on windowsills and the lowest DLL on interior floors. The sills had readable DLLs prior to rehabilitation, but these were well below the HUD lead safety threshold; for all tests thereafter, lead dust was below MDCH's lead-dust reporting limit of 20 $\mu g/ft^2$ on all sills except the sill of Window A, which registered a DLL of 24.2 $\mu g/ft^2$ at the second post-cleaning dust-wipe test. All surfaces except the outside entry (front porch) were virtually free of lead dust after the work was completed and immediately after the final cleaning.

Table 1 shows net percentage *increases* in DLL for the sills of Windows A and B and the floors of Windows B, C, and D. However, for all of these surfaces except the sill of Window A, the actual DLL was below 20 $\mu g/ft^2$ during the entire study period, and the floor DLLs were below 10 $\mu g/ft^2$.

Net Effect on DLL

To test the accumulation of lead dust over time, the homeowner was asked not to clean the window troughs or sills during the study period; therefore, the readings for the year following the rehabilitation represent all lead dust that gathered on those surfaces. For the four troughs, the cumulative DLLs after 12 months showed net declines ranging from 68.9% (window A) to 93.7% (window C). The significant net effect of the rehabilitation and cleaning is shown in Figure 1 on the next page.

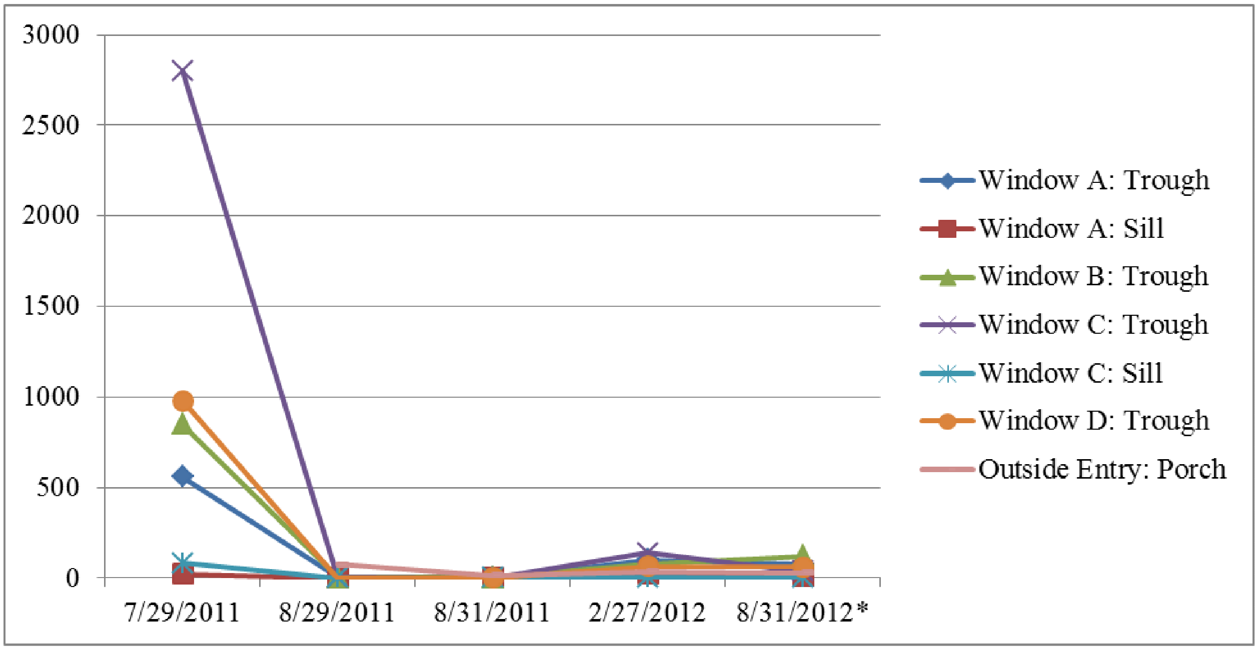

Figure 1: Net decline in DLL over the complete study period. To make the chart more readable, test areas that were below 20 µg/ft^2 throughout the study are not shown. Due to the relative similarity in post-rehabilitation, post-cleaning DLLs, data labels are not included. For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this thesis.

Post-Rehabilitation Increase in DLL

Despite this strong decline relative to pre-rehabilitation DLL, trough DLLs were already fast approaching the HUD (2004) *clearance* threshold within a year after the intervention; the front porch and all four window troughs exhibited DLLs above 20 µg/ft^2 at both the six-month and the twelve-month marks. However, the DLL for window troughs A, C, and D was lower at twelve months than it was at six months. The only exception was the trough of Window B, which exhibited a nearly linear increase in DLL during the year after final cleaning.

Cumulatively, the DLLs of troughs A, B, and C reached roughly half the HUD clearance standard for troughs, which is 400 µg/ft^2 (HUD, 2004). The cumulative trough DLL for

Window D, which received the least intensive rehabilitation, was slightly over one-quarter of the HUD clearance threshold. The sill of Window A was the only sill to show a post-rehabilitation DLL over 20 µg/ft^2. The front porch also exhibited low but readable DLLs. The post-rehabilitation, post-cleaning increase in DLL is shown in Figure 2, below.

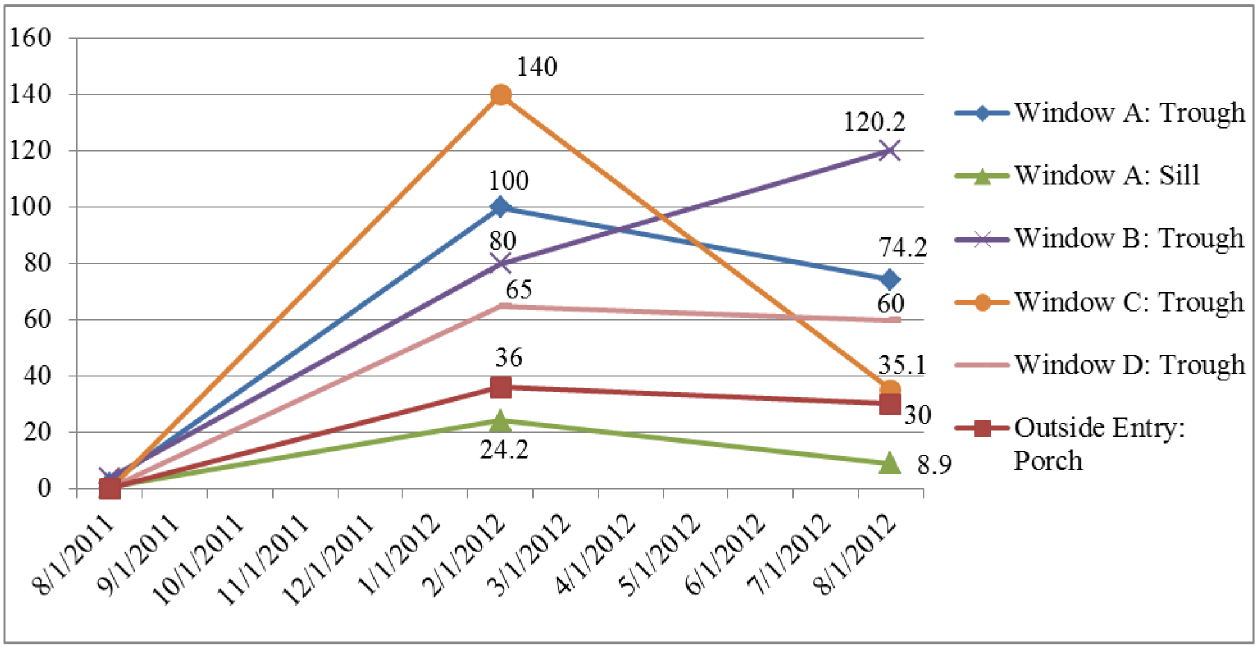

Figure 2: Increase in DLLs after rehabilitation and cleaning. To make the chart more readable, this chart shows only the test areas that presented DLLs above 20 µg/ft^2 during the post-cleaning period.

COMPARISON WITH WINDOW-REPLACEMENT RESULTS FROM OTHER RESEARCH

To weigh the lead-reduction findings from this case study against those from window replacement, the case-study findings were compared with the findings from NCHH & UCDEH (2004), which tested the effects of window replacement against other modes of rehabilitation for a national sample of houses receiving lead-hazard interventions funded by HUD. As noted in the literature review, that study grouped participating dwellings into six categories: cleaning only/spot painting; full paint stabilization; partial window treatments; full window abatement; full lead abatement; and full lead removal. To provide an approximate comparison, the mean case study DLLs were compared with the arithmetic mean DLLs for dwellings in the "full window abatement" category of HUD lead hazard control grant recipients.

Comparison by Mean DLL

Table 2, below, compares mean trough, sill, and floor DLLs prior to and one year after intervention for the case study and the NCHH & UCDEH study.

Table 2: Comparison of Mean Pre- and Post-Intervention DLL for Rehabilitated and Replacement Windows

	Study	Before (µg/ft^2)	1 Year (µg/ft^2)	% Decline
Trough	Case Study (n=1)	1,297.5	168.8**	87.0%
	NCHH & UCDEH 2004 (n=675)*	5,881	266	95.5%
Sill	Case Study (n=1)	33.8	17.6**	48.0%
	NCHH & UCDEH 2004 (n=675)*	685	53	92.3%
Floor	Case Study (n=1)	1.5	2.1**	-44.5%
	NCHH & UCDEH 2004 (n=675)*	50	15	70.0%

*Source: NCHH & UCDEH, 2004, pp. 8-26.
**For the case study, MDCH sampled the entire test surface area (e.g., the entire windowsill surface) at each testing. For NCHH & UCDEH, testers alternated between one half of the surface and the other half at each six-month post-test interval. To control for this difference, the researcher combined case-study values from the six-month and the one-year dust-wipe samples.

As shown in Table 2, the mean percent decline in trough DLL was significant in both studies but more pronounced in the NCHH & UCDEH study. However, the mean trough, sill, and floor DLL *values* from the case study were lower than the corresponding mean DLLs resulting from window replacement in the NCHH & UCDEH study. As noted in the previous section, case-study floor DLLs increased slightly (under 1 µg/ft^2) from before rehabilitation to one year after.

Comparison by Rehabilitation Intensity

To test the effectiveness of the individual rehabilitation intensities vis-à-vis window replacement, the data were disaggregated by rehabilitation intensity and compared with the window-replacement findings described by NCHH & UCDEH. This comparison is shown in Table 3.

Table 3: Pre- and Post-Intervention DLL of Rehabilitated and Replacement Windows, Disaggregated by Rehabilitation Intensity

		Site	Before ($\mu g/ft^2$)	1 Year ($\mu g/ft^2$)	% Decline
Case Study**	Window A: medium intensity (n=1)	Trough	560	174.2	68.9%
		Sill	21	33.1	-57.6%
		Floor*	3.4	2.9	14.7%
	Window B: medium intensity (n=1)	Trough	850	200.2	76.4%
		Sill	18	18.4	-2.2%
		Floor*	0.85	2.9	-241.2%
	Window C: high intensity (n=1)	Trough	2800	175.1	93.7%
		Sill	81	7.5	90.7%
		Floor	1.1	1.38	-25.5%
	Window D: low intensity (n=1)	Trough	980	125.6	87.2%
		Sill	15	11.2	25.3%
		Floor	0.56	1.36	-142.9%
NCHH/ UCDEH 2004 ***	5: Window replacement (n=675)	Trough	5,881	266	95.5%
		Sill	685	53	92.3%
		Floor	50	15	70.0%

*Because windows A and B were next to each other, dust wipe samples were taken from a single 12" square space of floor, about 6 inches from the wall, between the two windows in all but the first test. For the first test, samples were taken in front of both A and B.

**For the case study, MDCH sampled the entire test surface area (e.g., the entire windowsill surface) at each testing. For NCHH & UCDEH, testers alternated between one half of the surface and the other half at each six-month post-test interval. To control for this difference, the researcher combined case-study values from the six-month and the one-year dust-wipe samples.

***Source: NCHH & UCDEH, 2004, p. 8-26.

As shown in Table 3, the rehabilitation of Windows A, B, and D yielded net declines in trough DLL of 68.9%, 76.4%, and 87.2%, respectively, after one year. This is less pronounced than the percent decline achieved by window replacement (95.5%). The high-intensity rehabilitation of Window C registered a net decline of 93.7%, less than two percentage points lower than the result yielded by window replacement.

DISCUSSION

This section discusses the meaning and implications of the findings. First, three key observations are presented. Second, the findings are interpreted vis-à-vis the hypotheses. Third, the validity of the findings is established. Fourth, the implications of the findings for future research are discussed. Finally, overall conclusions from the research are offered.

KEY OBSERVATIONS

All Three Rehabilitation Intensities Increased Lead Safety

For all surfaces that presented high pre-rehabilitation DLLs, the rehabilitation work resulted in a significant net decline in DLL one year after rehabilitation. All four windows (i.e., all three rehabilitation intensities) presented lead-dust hazards prior to rehabilitation and were well within HUD and EPA's clearance guidelines for lead safety one year after the rehabilitation. This indicates that the rehabilitation work was successful in making the windows lead-safe in the year following the completion of work. Because all four windows presented negligible DLLs after rehabilitation and after the final cleaning, the clearance findings are consistent with earlier research on the effectiveness of techniques that help avoid the release of lead dust in the home (i.e., heat guns, wet scraping and sanding by hand, and careful cleaning with filtered vacuums and detergent-soaked cloths)—even when used by a novice.

The floors of three windows and the sills of two windows registered net increases in floor DLL after one year. However, all of these surfaces presented low DLLs prior to the work, and the actual amounts of the increases were negligible except in the sill of Window A. Furthermore, even the sill of Window A presented a DLL well below federal guidelines.

High-Intensity Rehabilitation Yielded Results Comparable to Window Replacement

The decline in DLL for Window C (high-intensity rehabilitation) was nearly equal to the net decline achieved by window replacement as documented by NCHH & UCDEH (2004). This suggests that high-intensity rehabilitation yields one-year lead-safety results comparable to those achieved by window replacement. The implication of this finding is that high-intensity window rehabilitation may be indicated as a viable substitute for window replacement.

Medium- and Low-Intensity Rehabilitation are Less Effective

The reduction in DLL was least pronounced for Windows A and B (medium intensity), which did not have friction surfaces recoated after rehabilitation, and for Window D (low intensity), which did not undergo extensive removal of lead-based paint. This indicates that medium- and low-intensity rehabilitation are less effective than window replacement for making windows lead safe. However, as noted above, all three of these windows were still within HUD guidelines one year after rehabilitation. This is especially true if one applies HUD's less rigorous risk-assessment and follow-up standard rather than its clearance standard, as was done by Wilson et al. (2006) and Dixon et al. (2012). Furthermore, because these rehabilitations removed deteriorated paint and left the sills and troughs with smooth surfaces, they should be easy to clean. Because the mean one-year accumulation of trough lead dust amounted to less than one-half of HUD's clearance threshold, it seems likely that these periodic cleanings would be highly effective for controlling the lead hazard. All three rehabilitation intensities left the treated windows with surfaces that were smooth, free of deteriorated paint, and easy to clean.

COMPARING CASE STUDY FINDINGS WITH HYPOTHESES

As noted in the Methodology section, this study hypothesized that the removal of lead-based paint from friction/impact surfaces alone, combined with painting of friction surfaces and new application of primer and paint on nonfriction surfaces with deteriorated paint, would result in a reduction of lead-dust levels similar to that achieved by window replacement. The primary and secondary hypotheses are evaluated against the findings below.

Primary Hypothesis

Overall, the data suggest that the primary hypothesis is correct. All four windows were well within HUD's safety guidelines one year after treatment, and the one-year mean case study DLLs for troughs and windows were lower than those achieved by window replacement.

Window C, in particular, exemplifies the conditions laid out in the primary hypothesis. All of Window C's friction/impact surfaces and nonfriction surfaces with deteriorated paint were stripped and repainted. This work yielded a one-year percentage reduction in trough and sill DLL that was very similar to the mean reduction percentages achieved by window replacement over a one-year period, as documented by NCHH (2004). The one-year trough DLL for Window C (175.1 $\mu g/ft^2$) was lower than the mean one-year DLL for window replacement (266 $\mu g/ft^2$). However, it is possible that the latter DLL was a function of the much higher average level of lead contamination in the windows documented by NCHH.

Secondary Hypothesis 1: Friction Surfaces Stripped but Not Repainted

The findings support the hypothesis that friction surfaces which are stripped but not repainted will pose a greater risk for lead-dust contamination. The friction surfaces of the sash and jambs of Windows A and B (medium-intensity rehabilitation) were stripped but not repainted; upon reinstallation of the sash, traces of old paint were still visible in cracks and other recessed areas in the wood. This may explain why the one-year DLLs for the troughs of Windows A and B were comparable to or higher than that of Window C, and why the net percentage reduction in trough DLL (68.9% for Window A and 76.4% for Window B) was less pronounced than that of Window C (93.7%). It may also explain the near-linear increase in post-rehabilitation DLL for the trough of Window B, which was the only surface to present such a pattern and which also showed the highest cumulative post-rehabilitation DLL of all four windows. Furthermore, Windows A and B were the only two windows to show a net increase in sill DLL. It seems likely that the opening and closing of the windows released exposed paint chips or tiny wood fragments, impregnated with the lead-based paint that had covered them for decades. Because they were not recoated, these fragments were released when friction was applied.

The medium-intensity rehabilitation presented another notable issue. The front porch floor presented DLLs above 30 $\mu g/ft^2$ at three points in the study—after rehabilitation, at six months, and at 12 months. The rehabilitation of sash A and B took place on the front porch, and the porch columns and ceiling showed peeling paint. Due to an oversight by the researcher, the porch was not tested prior to rehabilitation, but it is reasonable to expect that the rehabilitation work on the porch and/or the peeling paint from the columns and ceiling might have contributed to the DLLs there, helping account for the reading of 76 $\mu g/ft^2$ before the final cleaning.

Because the DLL in the front entryway remained low throughout the study, it is unlikely that this work resulted in lead dust being tracked into the house; however, it would still be advisable to carry out medium- or high-intensity rehabilitation work in an offsite location if possible.

Secondary Hypothesis 2: Friction Surfaces Stripped and Repainted

This hypothesis is similar to the primary hypothesis but adds that friction surfaces which are stripped and repainted will pose the lowest long-term risk of lead-dust contamination. As such, it applies primarily to Window C (high-intensity rehabilitation). The data do not provide a conclusive answer to this hypothesis. Although Window C exhibited the highest percent decline in trough and sill DLL of the four windows (which indicates that high-intensity rehabilitation yields the most dramatic effect in terms of DLL reduction), its actual one-year cumulative DLL (175.1 $\mu g/ft^2$) was very close to the mean DLL for all four windows (168.8 $\mu g/ft^2$); in other words, the post-rehabilitation lead contamination for Window C was not significantly better or worse than it was for the other three windows. It is possible that longer-term studies might reveal more conclusive findings in this regard.

Secondary Hypothesis 3: Deteriorated Paint Scraped and Recoated

This hypothesis applies to Window D (low-intensity rehabilitation), which only received a scraping and recoating of areas with deteriorated paint. The data support this hypothesis. Although the sills, troughs, and floors of all four windows were within federal lead-safety parameters during the study period, Window D exhibited the lowest one-year cumulative trough DLL. This indicates that the low-intensity rehabilitation was effective at eliminating the lead hazard, at least in the short term. This observation is consistent with NCHH & UCDEH (2004), which found that the lowest-intensity rehabilitation methods yielded the lowest short-term DLLs but then became less safe over time. Because most of the lead-based paint is still present on the friction surfaces of Window A, it may experience higher long-term DLLs as the paint deteriorates over the next several years.

VALIDITY OF THE FINDINGS

The findings from this case study are far from definitive. They represent only three rehabilitation intensities, tested on a tiny subset of windows in a single house for just over one year. The bulk of the rehabilitation work was carried out by the author of this paper—a student whose only training in the craft of window rehabilitation was received in the context of this study. The results might have been different if all work had been carried out by a window rehabilitation specialist. It is also possible that the low DLLs for the four windows resulted from the fact that the researcher was working with the specific intent of reducing lead-dust contamination and cleaned the site more thoroughly than the average contractor, homeowner, or renter might have done.

The comparison between the case-study findings and those from NCHH & UCDEH (2004) also has several important caveats. The first and most obvious is that NCHH & UCDEH tested 675 dwellings, while this case study tested just one dwelling. Second, the NCHH & UCDEH data represent whole-house interventions, while the case study represents just a few windows in one house. Finally, the pre-rehabilitation DLLs of the four test windows, while certainly hazardous according to federal guidelines, were lower than the average pre-intervention DLLs of the replacement windows in NCHH & UCDEH. The case-study results might have been different if the baseline DLLs had been as high as those documented by NCHH & UCDEH.

Because of the caveats described above, it is important that these findings be tested further with a larger-scale, longer-term study. On the other hand, several factors help to reinforce the accuracy of the study; these are listed below.

- The dust-wipe samples were taken by a state official and analyzed by a nationally accredited laboratory.
- Aside from the post-rehabilitation test and the first post-cleaning test, in which all DLLs were negligible, every window exhibited a descending pattern of DLL at each sampling event, from highest (troughs) to lowest (floors). This is consistent with NCHH & UCDEH (2004), which found the same DLL pattern in their national study.
- The trough DLL for windows A, C, and D was lower at twelve months than at six months. This observation is consistent with NCHH & UCDEH (2004), which found that regardless of treatment method, average DLL underwent sharp increases during the six months following the completion of work, then gradually decreased thereafter.
- It is likely that all post-rehabilitation lead dust was generated through friction and impact from the windows themselves, for the following reasons:
    - All test surfaces presented extremely low clearance DLLs, so it is unlikely that post-rehabilitation DLLs were significantly influenced by residual dust from the rehabilitation itself.

- The entryway registered DLLs well below 20 µg/ft^2 during both follow-up tests, so it is unlikely that the post-rehabilitation window DLLs were the result of lead dust being tracked in from the front porch or the street.
- There were no nearby industrial facilities or obvious major renovations of nearby houses, so it is unlikely that the lead dust originated outside the house.
- There was no obvious deteriorated paint on the walls, ceiling, or floors in the rooms tested, so it is unlikely that the lead dust originated in these areas.

IMPLICATIONS FOR FUTURE RESEARCH

Large-scale, multiyear research is needed to test the validity of these findings and control for potential differences in individual windows, dwellings, inhabitants, rehabilitation techniques, and rehabilitation workers. There are nearly as many variables as there are windows; every one of the four windows in this study presented distinctive conditions and characteristics. This case study suggests several possible approaches for a large-scale, longitudinal study of window rehabilitation techniques. Such a study would probably be most feasible in the context of a publicly funded lead-remediation or historic rehabilitation program. Possible approaches could include the following:

- Comparing the lead-reduction effects of a specified set of window rehabilitation intensities for a large number of dwellings (e.g., 100 or more) over a period of at least three years and preferably six years or more (NCHH, 2004; Wilson et al., 2006; Dixon et al., 2012). Such a study should incorporate comparison groups of dwellings that have had most or all windows replaced and dwellings that have not undergone any rehabilitation. Mean pre-intervention DLLs in the rehabilitated windows and the comparison-group windows should be comparable.

- Gathering national and regional data on the costs of specific window rehabilitation intensities as well as window replacement. This information could be gathered in the context of the hypothetical study described above.
- Gathering data on the long-term effects gained from the cleaning of rehabilitated friction surfaces at differing intervals (e.g., monthly, bimonthly, quarterly, etc.) following rehabilitation.

CONCLUSIONS

The existing literature establishes that lead poses a clear threat to children's health, and because of the time period during which lead paint was in common use, much of America's historic housing is likely to contain lead paint. Therefore, this is a critically important issue for historic district commissioners, planners, and other officials who are charged with the management of housing built before 1978—to say nothing of the property owners, contractors, renters, and especially children who are in direct contact with this housing. Previous literature finds window replacement to be more effective at lead remediation than most alternatives, but window replacement is often unacceptable from a historic-preservation or cost-effectiveness perspective, and several studies show that window rehabilitation can achieve similar energy efficiency results. Furthermore, window-replacement alternatives have not been disaggregated sufficiently in previous research to clearly establish whether some approaches are more effective at lead-dust remediation than others.

The findings from this case study suggest that window rehabilitation may be a safe and effective alternative to window replacement, provided that lead-safe work practices are observed throughout the rehabilitation process. If this is true, then lead-safe window rehabilitation can be recommended for any original wood window that is capable of repair. The findings further suggest that less intense window rehabilitation methods also provide effective results when they are followed by periodic cleanings. Low-intensity rehabilitation, followed by periodic cleaning, could be indicated in cases where the property owner or public agency has insufficient resources to carry out a high-intensity rehabilitation or window replacement, or in cases where the property is of such historic importance that intensive paint removal is not desirable. A low-intensity rehabilitation like the one conducted for Window D would be simple enough for a homeowner or renter to carry out quickly, safely, and affordably with supplies available from a hardware store.

Above all, the findings suggest that it is not necessary to sacrifice historical integrity to make windows lead safe. In addition to helping safeguard children from lead poisoning, these solutions bring the added benefits of maintaining historic character, preventing the waste of usable windows, lightening the burden on landfills, and potentially yielding cost savings for property owners and public agencies. Furthermore, if window rehabilitation can achieve lead-remediation effects comparable to those achieved by window replacement, then the implications of earlier studies on the impacts of window replacement will also apply to lead-safe window rehabilitation—e.g., the significant monetary benefits estimated by Nevin, Jacobs, Berg, and Cohen (2008).

It is hoped that the findings from this pilot study will inform a much larger body of research that conclusively demonstrates the most effective approaches for making windows safe for children while retaining the historic character, aesthetic appeal, and longevity of original wood windows.

APPENDICES

APPENDIX A: WINDOW AND ROOM CHARACTERISTICS OF TEST HOUSE

Figure 3: Window A before rehabilitation. The front porch, where sash A and B were rehabilitated, is visible through the window. The relatively good condition of the inside trim was typical of all four windows. All photos by the author.

The study site was a house in Eaton Rapids, Michigan with four original windows that were accessible for rehabilitation and follow-up tests. The house used for this study was located in a quiet residential neighborhood, approximately one mile from downtown Eaton Rapids. Most of the surrounding houses appeared to be of roughly the same age as the test house, suggesting moderate potential for lead-dust contamination originating outside the test house; however, none of these houses presented obvious signs of deteriorated paint, and there were no obvious major exterior renovations taking place in the immediate vicinity. There were no industrial land uses or major highways in the area.

All four test windows were double hung wood windows with white paint on the inside trim, sills, and sash, and brown paint on the troughs and jambs. All four windows appeared to be original to the house. The sash and trim presented multiple layers of paint (white, yellow, and green), with the innermost layer being varnish. All windows were fitted with aluminum-framed exterior screen windows that appeared to date to the 1950s or 1960s. None of the windows appeared to have ever been equipped with sash weights, pulleys, or ropes, probably due to their relatively small size. All four windows presented deteriorating paint, especially in the troughs and to a lesser degree in the jambs.

The homeowner indicated that she often opened the test windows to regulate the temperature of the house and let in fresh air. She said that she vacuumed the carpeted floors in the test rooms regularly but never cleaned the sills or troughs.

Figure 4: Window B before rehabilitation. Close-up photo showing fair to poor condition of trough and jamb typical of all four windows.

The windows and the rooms in which they were located are described in greater detail below, including the condition of the windows prior to the start of rehabilitation work. For a more detailed description and condition of all four windows, the living room entry, and the front porch, please see Table 5 in Appendix A.

Front Porch and Entryway

The entry door was located at the center front of the house, leading onto the porch. The porch floor had been replaced sometime in the last 25 years approximately; the rest of the porch appeared to be original. The ceiling and columns of the porch presented peeling paint. The area just inside the doorway consisted of approximately 16 square feet of parquet wood flooring in good condition. The front door gave onto the living room.

Living Room

This was the room where the first three windows (A, B, and C) were located. Except for the parquet flooring in the front entryway, this room contained wall-to-wall carpet. The walls were covered with white paint in very good condition.

Windows A and B (Medium-Intensity Rehabilitation)

Windows A and B were south-facing windows in the first-floor living room, immediately to the right of the front door, located next to one another and looking onto the front porch. The inside trim and sills were in good condition (Fig. 3). The troughs were very dirty, with paint chips, peeling paint, and dust (Fig. 4). The jambs presented moderate peeling paint as well as scrape marks from the movement of the sash, which possibly accounted for some of the dust and dirt in the trough. Neither of these windows was painted shut, but both were difficult to open.

Figure 5: Window D before rehabilitation. Close-up of lower sash chewed by dog. Roof of front porch is in background.

Window C (High-Intensity Rehabilitation)

Window C was located in the first-floor living room, looking west onto the driveway. Of the four windows, the paint on the sill, trough, and jamb of Window C was in the worst condition. The trim was in good condition, but the sill showed signs of mild rot and/or water damage; although the paint had not peeled, the wood exhibited a raised grain and felt slightly soft to the touch after the paint was removed. The trough was extremely dirty, with peeling paint, paint chips, heavy dirt, dead insects, and mildly deteriorated wood. Like Windows A and B, Window C was difficult to open and showed paint deterioration at the friction surface where the sash met the jamb.

Upstairs Bedroom

This was the room where Window D was located. It contained clean wall-to-wall carpet, and the walls were covered with white paint in good condition.

Window D (Low-Intensity Rehabilitation)

Window D was a south-facing window in the second-floor bedroom, looking out onto the roof of the front porch. The trim of the window presented white paint in good condition. This window exhibited a different form of paint deterioration than the others: the sash had been chewed by the homeowner's dog. The lower edge of the sash showed notable paint loss and splintered wood (see Fig. 5); however, there were no obvious loose paint chips on the sill or the floor. The paint on the trough and jamb was more deteriorated than that of A and B but better than that of C, with considerable peeling paint, paint chips, dirt, and dead insects. Of the four windows, this one was the easiest to open and close because the original stops that held the sash in place had been replaced with narrower stops.

An inventory of the window and room characteristics of the test house is provided in Table 4 on the next page.

Table 4: Inventory of Window and Room Characteristics of Test House						
Name	**Window A "living room side A"**	**Window B "living room side AB"**	**Window C "Living Room Side B"**	**Window D "2nd floor bedroom side A"**	**Main Entry (Living Room)**	**Main Entry (Front Porch)**
General						
Description—General	Double hung wood window. Left side of two windows situated to the right of front door of house. Aluminum storm window. Fastens with spring bolts; not equipped for sash weight/pulley.	Double hung wood window. Sits immediately to right of Window A. Aluminum storm window. Fastens with spring bolts; not equipped for sash weight/pulley.	Perpendicular to Windows A and B. Double hung wood window. Aluminum storm window. Fastens with spring bolts; not equipped for sash weight/ pulley.	Upstairs window in attic bedroom; looks out over front porch. Double hung wood window. Aluminum storm window. Fastens with spring bolts; not equipped for sash weight/ pulley.	Front entryway just inside living room. Consists of approximately 50 square feet of wood parquet flooring.	Porch outside front door. Floor appears to be recently installed (last 10-20 years) wood flooring. Porch columns and ceiling appear to be original to house.
Condition—General	Fair. Window opens with difficulty. Paint on window frame (not tested) in good condition. Sill, trough, floor condition described below.	Fair. Window opens with difficulty. Paint on window frame (not tested) in good condition. Sill, trough, floor condition described below.	Fair to poor. Window opens with great difficulty. Paint on window frame (not tested) in good condition. Sill, trough, floor condition described below.	Fair. Retrofitted (narrower stops installed) to make easier to open. Lower sash was chewed by homeowner's dog and thus has exposed wood and paint chips.	Good. Scuffed, but no notable dust or paint chips.	Porch columns and ceiling have peeling paint; otherwise in good condition. Porch floor is in good condition. No paint chips visible on floor.
Orientation	South	South	West	South	South	South

Table 4 (Cont'd)						
Sill						
Surface Type	Wood with at least 4 layers of coatings (white, yellow, green; original coat varnish).	Wood with at least 4 layers of coatings (white, yellow, green; original coat varnish).	Wood with at least 4 layers of coatings (white, yellow, green; original coat varnish).	Wood with at least 4 layers of coatings (white, yellow, green; original coat varnish).	NA	NA
Dust-wipe test Area	Entire surface	Entire surface	Entire surface	Entire surface	NA	NA
Condition of Test Area	Good. Small amount of peeling/flaking	Good. Small amount of peeling/flaking	Fair. Some peeling paint. Also signs of mild rot from the inside out; wood feels somewhat soft; raised grain.	Fair. No peeling or decay, but sill was chewed by dog.	NA	NA
Trough						
Surface Type	Brown painted wood	Brown painted wood	Brown painted wood	Brown painted wood	NA	NA
Dust-wipe test Area	Entire surface	Entire surface	Entire surface	Entire surface	NA	NA
Condition of Test Area	Fair. Paint somewhat deteriorated. Very dusty/dirty. Paint chips visible.	Fair. Paint somewhat deteriorated. Very dusty/dirty. Paint chips visible.	Poor. Paint very deteriorated. Very dusty, dirty. Many large paint chips visible. Minor cracking, rot of wood.	Poor. Paint very deteriorated, peeling. Very dusty/dirty. Paint chips visible.	NA	NA

Table 4 (Cont'd)						
Floor						
Surface Type	Carpet	Carpet	Carpet	Carpet	Wood parquet flooring, varnished (polyurethane?)	Treated boards (pine?)
Dust-wipe test Area	12"x12" square 6" from wall at center front of windows 1 and 2	12"x12" square 6" from wall at center front of window	12"x12" square 6" from wall at center front of window	12"x12" square 6" from wall at center front of window	Center of parquet floor, 12" square 12" from front door	
Condition of Test Area	Very good/like new. Cleaned June 2011.	Very good/like new. Cleaned June 2011.	Very good/like new. Cleaned June 2011.	Very good. Cleaned June 2011.	Good, scuffed, no notable dust or paint chips	Good, somewhat dusty, no notable paint chips

APPENDIX B: COMPLETION OF REHABILITATION WORK AND DUST-WIPE TESTS

Figure 6: Windows A and B after rehabilitation. Note paint removed from stops and jambs.

The window rehabilitation took place in August and September 2011, and the dust-wipe tests took place between July 2011 and August 2012. The representative of MDCH visited the house on July 25, 2011 to perform baseline dust-wipe tests and return the samples to the laboratory at MDCH. The troughs of all four windows exhibited DLLs that exceeded federal lead-safety guidelines (see Table 1 in the Findings section), demonstrating that the windows were excellent candidates for the case study.

Repair Renovation and Paint (RRP)-certified[3] window rehabilitation professionals from Turner Restoration (Detroit, MI) and Wood Window Repair (Ann Arbor, MI) agreed to provide the researcher with direct assistance and training, pro bono, to rehabilitate the four windows.

[3] Window rehabilitation professionals often do not carry lead *abatement* certification; however, they typically carry the RRP certification, which provides training in lead-safe work practices and authorizes them to remove lead paint for pay if the intent is to "Repair or Renovate" the windows. Therefore, this study is not testing lead abatement *per se*, but the potential reduction in lead dust content as an incidental benefit of window rehabilitation. (personal communication from RRP-certified window rehabilitation specialist, August 8, 2011)

The rehabilitation process for the four windows is described in greater detail below. Throughout this process, cleanliness was maintained through periodic gathering and vacuuming of paint fragments and dust. Following the rehabilitation of each window, the researcher thoroughly cleaned the worksite using a Miele canister vacuum equipped with a HEPA filter, followed by rags moistened with TSP solution purchased at a hardware store. During indoor paint removal via low-temperature heat gun, the researcher wore a chemical respirator and thick gloves for safety. Whenever she left the worksite, she removed her gloves and shoes and left them at the worksite.

Figure 7: Left: Trough of Window C before rehabilitation. Right: Same trough after rehabilitation and before reinstallation of sash and stops.

Windows A and B: Medium-Intensity Rehabilitation

The goal of the rehabilitation of Windows A and B was to remove paint from the friction surfaces only, but not to paint those surfaces afterward. These were the first two windows to undergo rehabilitation. Turner Restoration and the researcher carried out the work together. This was the researcher's first window-rehabilitation experience, so Turner Restoration provided important training that the researcher went on to utilize for rehabilitating the other two windows. First, a dropcloth was spread on the worksite and fastened to the wall with removable tape. The sash and stops were removed from the frames and relocated to the front porch, where paint was removed from the friction surfaces only (i.e., those surfaces that undergo friction with the jamb during opening and closing). The troughs and the friction surfaces of the sash, stops, and jamb were stripped of most paint using a heat plate (similar to a heat gun but with a broader application area) and a scraper. Additional paint on the friction surfaces was removed with sanding blocks after the surfaces were moistened with water from a spray bottle to impede the spread of lead dust. Despite these efforts, traces of paint were still visible in recessed areas of the wood that were difficult to access. The friction surfaces were rubbed with a rag soaked in a combination of linseed oil and mineral spirits. The sash and stops were reinstalled in the frames without repainting. The troughs were primed and painted for aesthetic reasons and to provide a smooth, cleanable surface. This rehabilitation took approximately 18 person-hours to complete (i.e., eight hours in which Turner Restoration and the researcher worked concurrently plus two hours in which the researcher worked alone to prime and paint the troughs).

Window C: High-Intensity Rehabilitation

The goal of this rehabilitation was to remove lead paint from all surfaces, then recoat those surfaces. This was the third window to undergo rehabilitation. Because it was the most deteriorated of the four, this window was chosen for a very

Figure 8: Sash of Window C after stripping, reglazing, priming, and painting and before reinstallation.

intensive rehabilitation, including removal of the sash and stops offsite for paint removal and reglazing. The researcher performed the bulk of the rehabilitation, including all onsite work and most offsite work. A dropcloth was spread on the worksite and fastened to the wall with removable tape. The sash and stops were removed for offsite rehabilitation. All exposed surfaces of the jambs and trim were completely stripped of paint (with the exception of paint in deep crevices) using a heat gun and carbide scraper. Next, the surfaces were moistened with water from a spray bottle and sanded with sanding blocks. The jambs and trim were then primed and painted. The sash were taken to Wood Window Repair, whose proprietor taught the researcher several useful techniques for paint removal and reglazing. The researcher removed all visible paint (with the exception of traces of paint in deep crevices) using heat guns and a heat plate as well as sanding blocks. The old caulk and glazier's points were removed using scrapers. The glass was cleaned, returned to the sash, and secured with new caulk and glazier's points. Next, the researcher took the sash home to let the caulk cure, then prime and paint the sash; the friction surfaces were treated with linseed oil and mineral spirits and then painted with a very thin coat of primer. At the same location, the researcher stripped, sanded, primed, and painted the stops. Once the primer and paint had cured, the sash and stops were reinstalled at the test site. Due to the intensity of the work and the inexperience of the researcher, this rehabilitation took approximately 45 hours to complete.

Window D: Low-Intensity Rehabilitation

The goal of this rehabilitation was to remove paint only from those areas where the paint was deteriorated, without any disassembly of the window components. A dropcloth was spread at the worksite and fastened to the wall with removable tape. The trough, the sill, and the damaged lower rail of the sash were cleaned of loose paint chips and dirt. Next, these surfaces were moistened with water from a spray bottle, and additional deteriorated paint was removed using a carbide scraper. Finally, these surfaces were primed and painted. As shown above in Figure 7, the jamb did not present deteriorated paint and thus was not scraped or recoated. This rehabilitation work took approximately 2.5 hours.

At the conclusion of the onsite rehabilitation work but before the final cleaning, the MDCH official visited again to perform dust-wipe tests. The purpose of this visit was to indicate whether the work itself had released additional lead dust. Lead dust was negligible for all four windows (see Table 1), indicating that the researcher's use of heat guns, wet scraping and sanding, and periodic cleanup had been effective in controlling the release of lead dust during the rehabilitation work. Next, the researcher carried out a final cleaning of the worksite using TSP solution and a HEPA vacuum. Following the final cleaning, MDCH performed another dust-wipe test. Again, the DLL was negligible (Table 1), establishing that any subsequent positive DLLs were probably not the result of residual dust from the rehabilitation work.

Study Timeline

Due to the intensity of the work and the time spent in learning the craft of window rehabilitation, negotiating the schedules of the rehabilitation specialists, and performing the labor-intensive rehabilitation of Window C, the actual rehabilitation work took one month longer than projected; however, the rest of the study was carried out as expected and without significant challenges. The timeline—including projected and actual times—is shown below in Table 5.

Table 5: Study Timeline		
Task	**Projected**	**Actual**
■ Secure test location (1912 home with 4 original wood windows that were accessible for rehabilitation and follow-up tests for duration of study).	Spring-summer 2011	Completed 7/15/11
■ Perform dust-wipe tests on windows to confirm that they exceed federally accepted lead dust levels on trough, sill, and/or floor.	June-July 2011	Completed 7/25/11
■ Perform window rehabilitation.	August 2011	All onsite rehab 8/28/11; offsite sash rehab 9/29/11
■ Perform lead assessment immediately after rehabilitation and before final cleaning (to test whether rehabilitation caused elevated lead dust levels).	August 2011	Completed 8/29/11
■ Perform lead assessment immediately after final cleaning to set a post-rehabilitation baseline lead level.	August 2011	Completed 8/31/11
■ Perform lead assessment 6 months after rehabilitation.	February 2012	Completed 2/27/12
■ Perform lead assessment 12 months after rehabilitation.	August 2012	Completed 8/31/12

APPENDIX C: DUST-WIPE TESTING METHODOLOGY

To assess the effects of the rehabilitation work on lead-dust contamination, dust-wipe samples were taken by a representative of the Michigan Department of Community Health (MDCH) in accordance with steps 3, 6, and 8 of the study design. The lead testing facilities at MDCH are accredited by the U.S. Environmental Protection Agency's National Lead Laboratory Accreditation Program (U.S. EPA, 2012). Before the rehabilitation, after the rehabilitation, after the final cleaning, and at six-month intervals for one year after the final cleaning, the MDCH official took dust-wipe samples from three test areas (trough, sill, and floor) at each of the four windows. In addition, floor dust-wipe samples were taken immediately inside and outside the main entry to the house, which gave onto the living room where windows A, B, and C were located.

The samples were taken using Ghost Wipes, a moistened wipe that is used for the sampling of metal deposits on surfaces (SKC, 2011) preferred by HUD (2004). For each test, the MDCH official measured the surface area to be tested (e.g., the total surface of the windowsill or trough) to allow for calculating the DLL per square foot. Next, he rubbed the full test area with a Ghost Wipe and added each wipe to a container that was labeled to identify the sample. For the floor tests, the official took samples from 12-inch square areas six inches in front of the window to be tested, in the center of the parquet floor at the entry to the living room, and approximately two feet beyond the door of the front porch.

Once the samples were returned to the laboratory at MDCH, they were dissolved in acid, and the resulting solution was analyzed using an inductively coupled plasma atomic emission spectrophotometer. The results were uploaded to Starlims, an online program that analyzes the raw data from the samples and develops an automated report that can be submitted to the end user. These reports were generated and sent to the researcher and the homeowner after each round of dust-wipe tests. For purposes of reporting, MDCH initially provided data only for surfaces that presented DLLs exceeding the laboratory's reporting limit of 20 $\mu g/ft^2$. Because this figure is well below HUD and EPA's minimum lead safety threshold of 40 $\mu g/ft^2$ for floors (EPA, 2001; HUD, 2004), the dust-wipe tests ensured an accurate assessment of the extent to which the rehabilitation complied with federal lead-safety guidelines (Michigan Department of Community Health, 2012). However, in the interest of making a thorough comparison between case-study DLLs and DLLs resulting from window replacement in an earlier study, the researcher requested that MDCH provide actual values for all surfaces tested. Therefore, the data in the Findings section and in Appendix D represent actual values reported by MDCH.

APPENDIX D: RAW DATA FROM DUST-WIPE TESTS

This appendix contains the raw data from the dust-wipe tests conducted by the Michigan Department of Community Health on the four test windows. The Sample ID is the unique identifier used by MDCH to set each sample apart.

Table 6: Raw Data from Dust-Wipe Test of July 29, 2011					
#	***Sample ID***	***Component***	***Location***	***Results***	***Ug/ft^2***
1	AF14173	Trough	Living room side A	*positive*	560
2	AF14174	Sill	Living room side A		21
3	AF14175	Trough	Living room side AB	*positive*	850
4	AF14176	Sill	Living room side AB		18
5	AF14177	Floor	Living room side A		3.4
6	AF14178	Floor	Living room side AB		0.85
7	AF14179	Trough	Living room side B	*positive*	2800
8	AF14180	Sill	Living room side B		81
9	AF14181	Floor	Living room side B		1.1
10	AF14182	Trough	2nd flr bedroom side A	*positive*	980
11	AF14183	Sill	2nd flr bedroom side A		15
12	AF14184	Floor	2nd flr bedroom side A		0.56

Table 7: Raw Data from Dust-Wipe Test of August 29, 2011					
#	***Sample ID***	***Component***	***Location***	***Results***	***Ug/ft^2***
1	AF21123	Trough	Living room side A		9.2
2	AF21124	Sill	Living room side AB		3.1
3	AF21125	Sill	Living room side A		1.9
4	AF21126	Trough	Living room side AB		4.4
5	AF21127	Floor	Living room side A		3.9
6	AF21128	Trough	Living room side B		5.1
7	AF21129	Sill	Living room side B		0.35
8	AF21130	Floor	Living room side B		0.36
9	AF21131	Trough	2nd flr bedroom side A		-0.24
10	AF21132	Sill	2nd flr bedroom side A		3.3
11	AF21133	Floor	2nd flr bedroom side A		0.7
12	AF21134	Floor	Entry side A		12
13	AF21135	Porch floor	Front porch	*positive*	76

Table 8: Raw Data from Dust-Wipe Test of August 31, 2011					
#	*Sample ID*	*Component*	*Location*	*Results*	*Ug/ft^2*
1	AF21136	Trough	Living room side A		1.9
2	AF21137	Sill	Living room side A		0.5
3	AF21138	Trough	Living room side AB		3.7
4	AF21139	Sill	Living room side AB		1.8
5	AF21140	Floor	Living room side A		1.8
6	AF21141	Floor	Entry side A		7.7
7	AF21142	Trough	Living room side B		-0.056
8	AF21143	Sill	Living room side B		0.83
9	AF21144	Floor	Living room side B		0.58
10	AF21145	Floor	2nd flr bedroom side A		0.23
11	AF21146	Trough	2nd flr bedroom side A		1.5
12	AF21147	Sill	2nd flr bedroom side A		-0.2
13	AF21148	Porch floor	Front porch		15

Table 9: Raw Data from Dust-Wipe Test of February 27, 2012					
#	*Sample ID*	*Component*	*Location*	*Results*	*Ug/ft^2*
1	AF41920	Trough	Living room side A		100
2	AF41921	Sill	Living room side A		24.2
3	AF41922	Trough	Living room side AB		80
4	AF41923	Sill	Living room side AB		13
5	AF41924	Floor	Living room side A		1.6
6	AF41925	Floor	Entry side A		11
7	AF41926	Trough	Living room side B		140
8	AF41927	Sill	Living room side B		4.9
9	AF41928	Floor	Living room side B		0.98
10	AF41929	Porch floor	Front porch		36
11	AF41930	Trough	2nd flr bedroom side A		65
12	AF41931	Sill	2nd flr bedroom side A		7.6
13	AF41932	Floor	2nd flr bedroom side A		0.96

Table 10: Raw Data from Dust-Wipe Test of August 31, 2012					
#	***Sample ID***	***Component***	***Location***	***Results***	***Ug/ft^{2*}***
1	TM12-500205	Floor	Entry Side A		3.5
2	TM12-500206	Floor	Living Room Side A		1.3
3	TM12-500207	Trough	Living room side A		74.2
4	TM12-500208	Sill	Living room side A		8.9
5	TM12-500209	Trough	Living room side AB		120.2
6	TM12-500210	Sill	Living room side AB		5.4
7	TM12-500211	Floor	Living Room Side B		0.4
8	TM12-500212	Sill	Living room side B		2.6
9	TM12-500213	Trough	Living room side B		35.1
10	TM12-500214	Floor	2nd flr bedroom side A		0.4
11	TM12-500215	Sill	2nd flr bedroom side A		3.6
12	TM12-500216	Trough	2nd flr bedroom side A		60.6
13	TM12-500217	Porch floor	Front porch		30.5

*This final set of square-footage calculations was made by the researcher because, for the final round of dust-wipe tests only, MDCH submitted machine values in the form of micrograms of lead and actual square footage. For the previous rounds of tests, MDCH had provided the machine values in the form of micrograms of dust lead per square foot.

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