RESEARCH

ENVIRONMENTAL RELATIVE BURDEN INDEX: A STREAMLINED LIFE CYCLE ASSESSMENT METHOD FOR FACILITIES POLLUTION PREVENTION

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ABSTRACT

This paper describes a new semi-quantitative streamlined life cycle assessment (SLCA) method, the Environmental Relative Burden Index (ERBI), for describing and ranking the relative environmental burdens associated with facility operations and maintenance options. The long-range goal is for this ERBI method to serve as a pollution-prevention decision support tool for facilities managers, when faced with competing operations and maintenance alternatives. The specific application presented in this paper evaluates asbestos-containing materials (ACM) and lead-based paint (LBP) management options in public school facilities. The ERBI methodology is adapted from previous streamlined semi-quantitative LCA methodologies and is described in detail. The ERBI is then employed to evaluate the relative environmental impacts of six management strategies for these hazardous building materials: management in-situ, encapsulation/containment, and full abatement/disposal, for both ACM and LBP. SLCA goal definition, system boundaries, ERBI matrix, and overall ERBI Ratings (RERB) for each material management strategy are presented. The ERBI can be a useful tool in prioritizing building maintenance alternatives, especially in cases where detailed quantitative data are unavailable.

KEYWORDS

Life Cycle Assessment, buildings, maintenance, environmental hazards, Environmental Relative Burden Index (ERBI)

INTRODUCTION

Life-cycle Assessment and Construction

Life cycle assessment (LCA) is a methodology for evaluating the environmental impacts associated with products and processes of human-developed systems. This approach has been applied to "products" of the construction industry: buildings and civil infrastructure (Erlandsson and Borg, 2003). LCA accounts for all phases of a product life cycle, from "cradle" to

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“grave” (Ortiz et al, 2009). An LCA process typically involves four distinct phases: definition of goals and scope, inventory creation, impact assessment, and results interpretation. In the first phase, the purpose, audience, and system boundaries are established. The second phase, creation of a life cycle inventory, involves the definition of functional units of the system in question and identification of mass and energy flow patterns within the bounded system defined in phase one. In the third phase, the life cycle impact assessment, estimates of impacts and resources are modeled and characterized. The end result of the process is an aggregated indicator result, or results, which can be used to make comparisons and prioritizations.

There are two basic approaches to LCA: problem-oriented (mid-points) and damage-oriented (end-points). The problem-oriented approach evaluates global impacts such as climate change, acidification, and ozone creation (Ortiz et al, 2009). Whereas, the damage-oriented approach classifies material and energy flows into various environmental themes, modeling damage of each theme. Therefore, the work described in this paper has developed a damage-oriented approach which can be employed to evaluate the potential impacts to indoor environments, ambient air pollution, and ground water contamination, resulting from various management options for school building components containing asbestos and lead.

Streamlined LCA (SLCA)

By the 1990’s, the LCA had become a standard framework for thinking about relationships between human industrial activities and environmental impacts (Vigon et al, 1992). In practice, however, several limitations became evident, including data availability, data accuracy, allocation problems, and extrapolation of nonlinear processes (Kisch et al, 1992). By the mid-1990’s, several authors had suggested that life cycle assessments for complex products and systems were associated with prohibitively high cost, data requirement, and uncertainty to be useful to decision-makers and practitioners in industry and streamlining methods were developed (Todd 1995; White and Shapiro 1993; Owens 1995).

The Society of Environmental Toxicology and Chemistry (SETAC) created a workgroup entitled Streamlining LCA in 1994. The report of that workgroup outlined several approaches to LCA streamlining (Todd and Curran, 1999). Setting system boundaries to restrict inclusion of either “upstream” or “downstream” lifecycle stages is one suggested approach. The authors suggest that this is necessarily done in any LCA methodology, even the most exhaustive full LCA. The LCA approach typically includes all four stages of a product or process life cycle: raw material acquisition, manufacturing, use/reuse/maintenance, and recycle/waste management. In a more streamlined LCA approach, system boundaries can be set to examine, for example, just the “use/maintenance” and “recycle/waste” portions of the entire lifecycle. A second streamlining approach outlined in the report involves limiting the scope of environmental burdens included in the review. A final solution for streamlining the LCA methodology involved the simplification of the data collection associated with the LCA inventory. A full, quantitative, LCA will include data on mass and energy transfer associated with all product components and processes. The SETAC workgroup suggested that semi-quantitative and qualitative data can yield adequate outputs to inform decision-making and ranking of environmental burdens.

Also in the mid-1990’s, the United States Environmental Protection Agency (US EPA) established a cooperative agreement with the Research Triangle Institute to develop and demonstrate streamlined life cycle approaches for a broad range of applications (Weitz et al, 1996). Several approaches to streamlining were suggested, including: 1) a narrowing of system boundaries, 2) focusing on environmental burdens of greatest impact, and 3) using more readily-available data, including qualitative (Weitz et al, 1996).

Graedel (1996) published the development of an SLCA method: the Environmentally Responsible Product Assessment (ERPA). This SLCA method employed standardized rating scales and checklists, completed by subject-matter-expert assessors. The rating results were used to populate weighted-factor matrices of product lifecycle stages and environmental burdens. The ERPA method has been evaluated in subsequent studies and has been found to provide comparable information to that obtained from a fully quantitative LCA (Hunt et al, 1998). In a comparison of multiple SLCA methods, the ERPA was found to provide more information that could be used in product or process re-design (Lee et al, 2003). The ERPA was found to generate more information about toxic environmental burdens than would a full LCA (Hochschorner and Finnveden, 2003).

Since the environmental burdens of toxic pollutants are of particular interest in the present study, the ERPA method was chosen and modified for the stated analysis of ACM and LBP pollution-prevention management alternatives. In the ERPA method, five product lifecycle stages and five environmental impacts comprise the dimensions of a 5 x 5 matrix. Each element of the matrix is evaluated on a rating scale of 0 to 4, with 0 meaning "very high impact" and 4 indicating "no impact". The result is a semi-quantitative overall rating for each product, as the sum of the matrix element values: the Environmentally Responsible Product Rating (ERPR) (eq 1).

$$R_{ERP} = \sum i \sum j \, Mij \qquad (1)$$

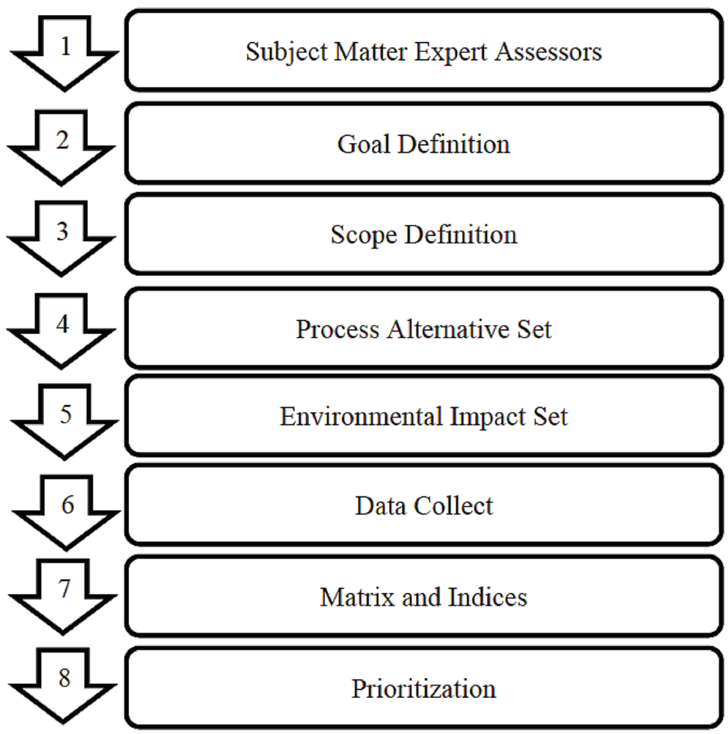
Because there are 25 cells, each with a maximum value of 4, a total maximum R_{ERP} rating of 100 can be obtained for each product. Therefore, in the ERPA method, lower R_{ERP} ratings indicate greater environmental burdens, and higher R_{ERP} ratings indicate lessor burdens.

Environmental Relative Burden Index (ERBI)

The streamlined LCA methodology described in the present paper, the Environmental Relative Burden Index, is adapted from the ERPA, with substantial modification. First, whereas the ERPA is employed to describe the burdens associated with the entire lifecycle of a *single product*, the ERBI is a system that can be employed to compare/rank-order the environmental burdens of *several competing alternatives/decisions* in the lifecycle of a product. This tool is designed to enable the comparison of relative burdens and assist selection of process alternatives with the minimal impacts. Matrix dimensions are "process alternatives" in the rows and "environmental impacts" in the columns. The ERBI does not necessarily need to include all lifecycle phases, but can be streamlined according to the system boundaries established during the scope definition phase of this SLCA method. A second modification of the original ERPA method involves the rating scale employed. While the ERBI also employs a five-point rating scale, the anchors are reversed. In the ERBI rating system, 0 indicates "no impact" and 4 represents "severe impact". Each process alternative (row) has a total environmental impact rating, which is termed the Environmental Relative Burden Index (R_{ERB}). Then, the R_{ERB} for all process alternatives can be compared and rank-ordered, to determine pollution prevention prioritization and to aid decision making. The ERBI methodology is described in detail, below.

The work described in this paper was performed in two phases: 1) the development of the Environmental Relative Burden Index (ERBI) standardized methodology, and 2) an application of the ERBI methodology specific to asbestos and lead-based paint maintenance management in public schools. This section presents a detailed description of the generalized ERBI methodology and a description of the methods of the applied study. The generalized ERBI methodology is depicted graphically (Figure 1) and described in detail in the sections that follow. This methodology involves eight distinct steps: 1) creation of a team of subject matter expert assessors, 2) goal definition, 3) life cycle boundary scoping, 4) definition of the maintenance management process alternatives to be evaluated and prioritized, 5) definition of a set of environmental impacts associated with the problem in consideration, 6) collection of data to be employed in computation of the ERBI, 7) creation of the ERBI matrix and indices, and 8) ranking of indices for prioritization of alternatives.

FIGURE 1: The Environmental Relative Burden Index Methodology.



Step 1: Subject Matter Expert Assessors

This methodology relies on rating scores from subject matter expert (SME) in the technical domain of the problem being considered. Since this method was developed for use in situations where objective quantitative data are missing, this SME rating will serve as the data for calculation of the ERBI. It is essential that the SME assessors have the technical knowledge of process alternatives and environmental impacts associated with the problem.

Step 2: Goal Definition

Goal definition is the phase of the LCA process that defines the purpose of analysis, including: the problem, the environmental need, and how life cycle environmental impacts factor into the decision-making process. In this phase, the following items must be determined: the type of information that is needed to add value to the decision-making process, how accurate the results must be to add value, and how the results should be interpreted and displayed in order to be meaningful and usable.

Step 3: Scope Definition

In the scope definition phase of an LCA, bounds are set on the product or process of interest, establishing which aspects of the life cycle are to be included in the assessment. The life cycle of a product begins with the removal of raw materials and energy sources from the earth. During the manufacturing stage, raw materials are transformed into a product and the product is delivered to the consumer. The manufacturing stage consists of three steps: materials manufacture, product fabrication, and filling/packaging/distribution. The following stage involves the consumer's actual use, reuse, and maintenance of the product. Once the product is distributed to the consumer, all activities associated with the useful life of the product are included in this stage; including energy demands and environmental wastes from both product storage and consumption. The product or material may need to be reconditioned, repaired or serviced so that it will maintain its performance. When the consumer no longer needs the product, the product will be recycled or discarded. The recycle/waste management stage includes the energy requirements and environmental wastes associated with disposition of the product or material.

Step 4: Process Alternatives Set

The ERBI methodology has been developed as a tool to aid in the prioritization of building maintenance needs and management alternatives to address those needs. Therefore, the methodology includes a step in which the SME assessors define the alternative management approaches or strategies.

Step 5: Environmental Impacts Set

As in classical LCA, environmental impacts are a key consideration in ERBI. As this methodology is intended for use in building maintenance management scenarios, the environmental impacts to be considered in this step would include: building energy, equipment energy, impacts associated with new building materials, impacts associated with removal and disposal of existing materials, transportation impacts, construction equipment impacts, among others.

Step 6: Data Collection

In this step of the ERBI, the SME assessor ranks and ratings of the maintenance alternatives and environmental impacts are gathered. The SME assessors should use the following scale to rate the environmental impacts associated with the various maintenance alternatives: 0 = no impact, 1 = slight impact, 2 = some impact, 3 = moderate impact, 4 = severe impact.

Step 7: Matrix and Indices

The ERBI matrix should contain all items from the process alternatives set in the left-hand column and all items from the environmental impacts set across the top row. Mean SME rating environmental impact per process alternative scores will populate the matrix. The mean environmental impact scores are then summed to produce the ERBI index (R_{ERB}) for each process alternative.

Step 8: Prioritization

The R_{ERB} for the process alternatives can then be rank-ordered, with the highest index indicating the process alternative with the greatest overall environmental impact and the process alternative with the lowest index indicating the process alternative with the least overall environmental impact. This ranking can be employed by building maintenance managers to prioritize various, competing alternatives for maintaining a facility.

METHODS

In order to illustrate how the ERBI can be used to prioritize maintenance management alternatives, an experimental field study was performed to implement the ERBI methodology in the case of public school system maintenance of asbestos-containing materials (ACM) and lead-based paint (LBP) materials. Three public school systems were selected for this field study. All are located in counties of rural, Southwestern Virginia. These school systems have a median facility age of 52 years. All three systems have buildings which contain ACM and LBP, in various states of maintenance and condition. Surveys of these materials and building inspection data and drawings were used in the study. A focus group of subject-matter-experts (SME) were presented with the field case information and instructed to engage in the following steps of the ERBI process: 2) goal definition, 3) scope definition, 4) development of a set of alternatives for maintenance, 5) development of a set of environmental impacts associated with the materials and maintenance alternatives, 6) assignments of ratings and rankings to the items in the maintenance alternatives and environmental impacts sets. An ERBI matrix and indices were then generated by the investigator and a prioritization ranking was produced.

Ten subject-matter-experts provided input into the development of the ERBI for management alternatives for ACM and LBP in public schools. All were industrial hygienists certified in comprehensive practice by the American Board of Industrial Hygiene (ABIH), with additional credentials as asbestos management planners and lead-paint risk assessors. The SME group was trained on the use of the ERBI methodology and provided input into the development of the LCA Goal and Scope Definition through participation in a focus group discussion. The SME participants provided input into the development of the ERPA matrix, through assignment of ratings to environmental impacts per maintenance process alternative. The focus group discussion was video recorded. Transcripts of the discussion were analyzed using Content Analysis methods. The results of the Content Analysis were used to develop the LCA Goal Definition and LCA Scope Definition, as described in the following section.

RESULTS

LCA Goal Definition

In this section, the environmental problem of asbestos and lead paint materials in public schools is defined and described. And, the goals developed by the SME panel in step 2 of the ERBI are presented. In this phase, the SME panel defined the problem, the environmental need, and how life cycle environmental impacts factor into the decision-making process.

The public school infrastructure, like all sectors of the national civil infrastructure, is aging and at risk of deterioration (ASCE, 2009). Managing those aspects of the infrastructure which pose a risk to the health of the human occupants is of critical importance, since children are one of our most important resources for future national prosperity. The built environment can have significant impacts on occupant health. Some contaminants, such as asbestos, lead, and VOCs arise directly from building materials. The Environmental Protection Agency (EPA) has recognized the importance of controlling public school indoor environmental hazards, through establishment of its Healthy School Environments information dissemination program for public school systems (EPA, 2000). According to the EPA, more than 53 million children spend a significant portion of their days in 135,000 public and private school buildings (EPA, 2000). Many of these buildings are old, in poor condition, and may contain environmental conditions that inhibit learning and pose increased risks to health (EPA, 2000). According to the U.S. Department of Education National Center for Educational Statistics (NCES) report, *Condition of America's Public School Facilities*, approximately one-quarter of the nation's schools, housing 11 million children, require extensive repair (NCES, 2000). Nearly 40 percent of the schools reported unsatisfactory environmental conditions (NCES, 2000). Given the constrained financial resources facing our national educational system, school decision makers are in need of systematic methods of evaluating risks associated with facility condition and prioritizing maintenance activities.

Asbestos is a fibrous mineral that was widely used as a constituent of building materials in schools constructed between 1940 and the 1980's. Asbestos was commonly used in insulation, soundproofing, and finishing materials, such as: floor tile, ceiling tile, cement pipe, corrugated-paper pipe wrap, acoustical insulation, and thermal system insulation. According to the EPA, asbestos-containing-materials (ACM) are present in approximately 107,000 of the nation's 135,000 schools and have a typical service life of 30 years (EPA, 2000). The average public school facility age is 51 years (ASCE, 2009). Therefore, the EPA projects an increasingly pressing risk of ACM deterioration. When ACM deteriorates, microscopic fibers are released into the air and pose a health hazard through inhalation or ingestion. Through inhalation, these fibers have been associated with mesothelioma, lung cancer, and asbestos, a fibrotic lung disease (ACGIH, 2007). Through ingestion, they are associated with malignancy of the gastrointestinal tract. The latency period between fiber exposure and disease onset is 10 to 30 years; thus, exposure to asbestos early in childhood is associated with incidence of disease in early adulthood. The potential for ACM to release fibers depends primarily on its condition. If the material surface deteriorates and is capable of crumbling under contact stress, then it is considered to be "friable" and at risk of releasing air contaminant fibers. In 1987, the EPA issued the Asbestos-containing Materials in Schools Rule under the authority of the Asbestos Hazard Emergency Response Act (AHERA) enacted by the United States Congress (EPA, 2001). This rule requires school districts to conduct periodic facility inspections to identify ACM and assess material condition. School systems are also required to develop plans for maintenance and management of these materials. Across the nation, school system compliance with the EPA rule has been variable. In July 1991, the EPA released the results of a study of AHERA effectiveness (EPA, 2000). The study concluded that some elements of school asbestos programs were not being effectively implemented. Asbestos fiber releases and student exposures were ongoing. For example, in 1999, the District of Columbia Public School system experienced major asbestos fiber releases that resulted in remediation costs totally five million dollars and temporary closure of 55 of the 175 school facilities (EPA, 2000).

Lead, known to cause impaired intellectual development, blood dyscrasias, peripheral neuropathy, and kidney dysfunction, was a common constituent of paints until the Consumer Product Safety Commission ban of 1978 (ACGIH, 2001). Children under the age of six are particularly vulnerable to the central nervous system effects of lead, with even low-level environmental exposure affecting intellectual development and lifetime achievement (ACGIH, 2001). Studies have found that childhood exposure to lead contributes to the development of attention-deficit/hyperactivity disorder. Exposure is associated with increased rates of reading disability, diminished vocabulary, and poor performance in high school. Also, lead exposure increases the risk for antisocial and delinquent behavior (ACGIH, 2001). There is no demonstrated safe concentration of lead in blood and adverse health effects can occur at very low blood lead levels (ACGIH, 2001). Lead hazards within the school environment may be an important contributor to exposure. The best indication of the current state of lead-based paint hazards within the public school infrastructure comes from a comprehensive evaluation conducted by the state of California (Levin et al, 2008). In 1992, California passed the Lead-Safe Schools Protection Act. Following approval of this legislation, the California Department of Health Services conducted a study to determine the prevalence of lead and lead hazards in the state's public elementary schools, including elementary school buildings that house day care centers and preschools. Ninety percent of all schools surveyed had lead-containing paint. All pre-1980 schools and 45 percent of schools built between 1980 and 1995 had lead-containing paint. Thirty-seven percent of all public elementary schools surveyed in California had both lead-containing paint and some deterioration of paint. Thirty-two percent of these schools had lead-based paint and some deterioration (Levin et al, 2008. The term "lead-containing paint" refers to paint containing any detectable level of lead. "Lead-based" paint refers to paint containing at least 5,000 parts per million of lead. Most of the California schools built before 1940 had lead-containing paint and some deterioration, compared with only 3 percent of the schools built between 1980 and 1995.

The SME team for the project arrived at a set of goals for the ERBI. Table I lists the goals that have been developed for the current study, in order to assess the environmental impact of ACM and LBP in public school facilities, under differing management alternatives.

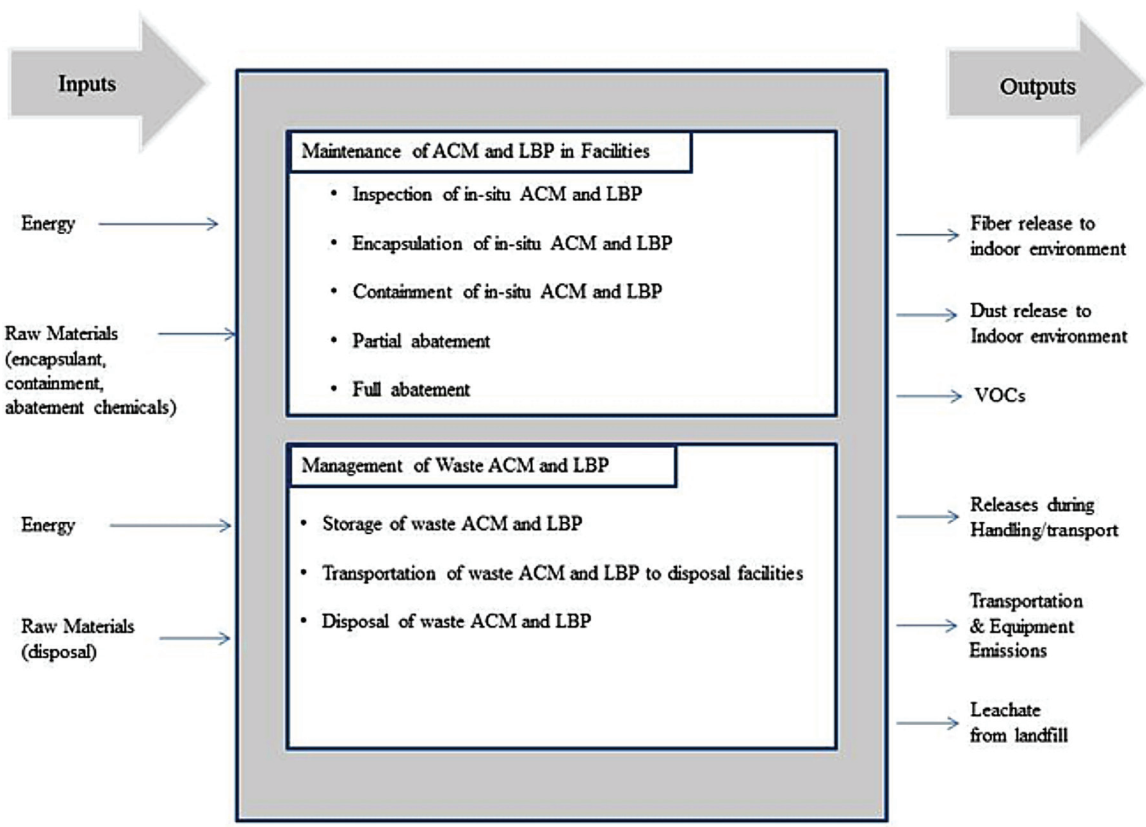
TABLE 1. LCA Goals.

Goal #	Goal Question
1	What are the environmental impacts associated with maintaining ACM and LBP, without management, in-situ, in public schools?
2	What are the environmental impacts associated with the encapsulation/containment management alternative for ACM and LBP?
4	What are the environmental impacts associated with the partial or full abatement management alternatives for ACM and LBP?
5	Which management alternatives have the lowest life cycle costs?
6	Which management alternatives have the lowest overall environmental impacts, when considering both indoor and global environments?

LCA Scope Definition

In this section, the scope definition of the SME panel is described and presented. The LCA approach typically includes all four stages of a product or process life cycle: raw material acquisition, manufacturing, use/reuse/maintenance, and recycle/waste management. However, in the present study, the scope was necessarily reduced, since these building materials are already manufactured and installed in school facilities. Therefore, the SME group discussed appropriate bounds to place on the LCA scope. In the case of public school building components containing asbestos and lead, the life cycle phases of consideration are use/reuse/maintenance and recycle/waste management. Since these products were installed in the public school infrastructure in the past, earlier phases of the life cycle are not applicable. An analysis of the current public school infrastructure building component situation has yielded the system boundary definition depicted in Figure 2.

FIGURE 2: System Boundary



Process Alternatives Set

For both ACM and LBP, the maintenance alternatives range from a non-action alternative to a full-scale abatement, removal and disposal of the materials. In between those two extremes are options for sealing, encapsulating, containing, or otherwise reducing the hazard while leaving the material in place. These various maintenance alternatives have varying and differing associated environmental impacts. The SME assessors developed the following set of maintenance alternatives available to public school facility managers: no action, encapsulation or containment of material, full abatement of material. The 'no action' alternative would indicate that school facility managers would leave the materials in-situ and not take any steps to control deterioration. The 'encapsulation/containment' alternative involves activities such as applying paint or polyurethane coatings, building containment structures, or constructing new layers of materials to cover the ACM or LBP. An example of this last activity would be construction of a drop-ceiling to hide ACM acoustical material on an existing ceiling.

Environmental Impact Set

Once the process alternatives set had been developed by the SME team, categories of environmental impacts were discussed and decided upon. These included: the release of hazardous dust or fibers in the indoor environment, the release of semi-volatile or volatile-organic compounds in the indoor air, the release of hazardous dust or fiber into the outdoor environment during material transport and disposal, raw material impacts, energy use, and ground water contamination.

ERBI Matrix

Each SME assigned a score to each cell of the ERBI matrix. Mean scores from all 10 SME's were included in the ERBI matrix provided, below (Table II). These mean scores were summed to arrive at the Total Rebindices listed in the far right-hand column of the matrix.

TABLE 2. Environmental Relative Burden Index Matrix.

Assessment of Materials Maintenance and Disposal Alternatives							
Material Maintenance Alternative	Environmental Impact (mean ERB rating score) (n = 10 raters)						
	A	B	C	D	E	F	Total R_{ERB}
No action ACM	3.8	0	2.6	0	0	0.8	7.2
No action LBP	3.1	0	3.5	0	0	1.6	8.2
Encapsulation/Containment ACM	0.3	1.6	0	2.4	1.5	0.1	5.9
Encapsulation/Containment LBP	0.8	1.2	0.5	1.6	1.7	0.2	6.0
Abatement ACM	1.5	1.7	1.3	1.9	2.1	1	9.5
Abatement LBP	1.8	2.6	1.2	1.3	1.9	1.8	10.6

Impact Rating Scale:
0 = No, 1 = Slight, 2 = Some, 3 = Moderate, 4 = Severe Impact

Environmental Impacts:
A: Indoor Fiber/Dust Release
B: Indoor SVOC/VOC Release
C: Outdoor Fiber/Dust Release during Transportation, Handling, Disposal or Treatment
D: Raw Material Use
E. Energy Use
F. Groundwater Leachates

Prioritization

Based on the RERB scores, the ACM and LBP maintenance management alternatives available to public school facilities managers have the following rank-order, in terms of descending overall environmental impact: full abatement of LBP, full abatement of ACM, no action LBP, no action ACM, encapsulation/containment LBP, encapsulation/containment ACM. Therefore, facility managers could use this ranking to aid their decision-making regarding management of these hazardous building materials and the ERBI would indicate that encapsulation/containment is the lowest-environmental-impact alternative available. The SME team reviewed this finding and general consensus of the discussion supported the rank-order.

CONCLUSION

This paper describes a new streamlined LCA method designed specifically to enable relative ranking and prioritization of maintenance alternatives based on their environmental impacts, for cases when quantitative inputs are not available. The method uses the assessment of Subject Matter Experts for assignment of relative impact rankings for environmental impacts. The ERBI was tested in the case of maintenance management of asbestos-containing materials and lead-based paint in rural public school systems. A set of maintenance alternatives and a set of environmental impacts was were developed by the SME panel. ERBI indices were computed and a prioritization ranking was produced. This study demonstrates the effectiveness of the ERBI for ranking of relative risks associated with various maintenance alternatives. For both ACM and LBP, the maintenance alternatives range from a non-action alternative to a full-scale abatement, removal and disposal of the materials. In between those two extremes are options for sealing, encapsulating, containing, or otherwise reducing the hazard while leaving the material in place. These various maintenance alternatives have varying and differing associated environmental impacts, for both the indoor and outdoor environments. Taking no action to maintain the condition of ACM or LBP could lead to release of asbestos fibers and lead dust in the indoor school environments. While, full abatement and disposal of materials can lead to impacts on the outdoor environment. Intermediate maintenance alternatives can be associated with environmental impacts such as volatile organic compound release to the indoor environment. This method allowed for consideration of all maintenance alternatives and their associated impacts and allowed for a clear ranking of those, from lowest to greatest impact.

Contribution: This LCA process aims to provide decision-makers with a tool for assessing the various environmental impacts associated with ACM and LBP building material management. The methodology presented in this paper can provide a useful tool for assessing environmental impacts in problems where quantitative data are not available and for prioritizing competing process alternatives in terms of their total environmental impacts.

DISCUSSION

As with the bulk of the national civil infrastructure, the public school infrastructure is at risk of deterioration and in need of systematic condition management. The American Society of Civil Engineers (ASCE) states in its 2009 Infrastructure Report Card that there has been no comprehensive assessment of the condition of the public school facilities in more than a decade (ASCE, 2009). Spending on the nation's schools grew from $17 billion in 1998, to a peak of $29 billion in 2004, only to drop by 2007, to $20.28 billion. The National Education

Association estimates the cost to renovate the school infrastructure to acceptable condition to be $322 billion. The most recent comprehensive evaluations of the public school condition were performed in the late 1990's. In 1996, the United States General Accounting Office (GAO) reported on the condition of the national public school infrastructure and estimated that $112 billion is required to repair or upgrade America's multibillion dollar investment in facilities to good overall condition (U.S. GAO, 1996). Approximately fourteen million students, distributed nationwide, are required to attend the one-third of schools that have inadequate environmental conditions. According to a 2000 report of the National Center for Education Statistics (NCES), three-quarters of schools reported having facilities that were in fair or poor condition. Eleven million students were enrolled in schools reporting inadequate environmental conditions. While federal regulations require public education facilities to manage environmental health hazards, such as asbestos, funding the compliance with these mandates is the responsibility of local governments. Forty-two percent of schools reported the need to perform control measures for asbestos-containing materials and twenty-nine percent for lead-based paint. These maintenance conditions varied by concentration of poverty: schools with the highest concentration of poverty were more likely to report poor environmental conditions. Schools reporting poor facility conditions tended to be located in urban centers and rural regions (U.S. GAO, 1996).

Managing those aspects of the infrastructure which pose a risk to the health of the human occupants is of critical importance, since children are one of our most important resources for future national prosperity. Given the constrained financial resources facing our national educational system, school decision makers are in need of systematic methods of evaluating risks associated with facility condition and prioritizing maintenance activities.

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