The Safety and Health of Construction Workers on "Green" Projects:

A Systematic Review of the Literature and Green Construction Rating System Analysis

14 August 2013

Dr. Annie R. Pearce, Director

Sustainable Facilities & Infrastructure Lab

the MYERS-LAWSON SCHOOL of construction

Virginia Tech

Dr. Brian M. Kleiner, Director

the MYERS-LAWSON SCHOOL of construction

Virginia Tech

Executive Summary

With increasing interest in green construction technologies and methods, the number of green facilities being constructed in the U.S. is growing at a significant pace. Green facilities can be defined as *facilities that have net environmental benefits over their life-cycles compared to conventional construction, including benefits for occupants of their indoor environments as well as the natural environment*. These facilities offer a number of advertised and potential benefits to their owners and/or occupants, and environment, including a healthier indoor environment, increased resource efficiency and reduced operating costs, and overall lower impact on the natural environment. However, as green building becomes more common, a growing body of evidence and collective perception suggests that there may be unanticipated negative consequences of green projects in terms of worker health and safety during construction and post-construction (i.e., maintenance phase). The objective of Phase I of this project was to assemble and evaluate the evidence to draw conclusions about the exposure of workers to health and safety hazards in green projects, and to identify areas where additional investigation is warranted to evaluate the risks these types of projects may pose.

The goal of this investigation was to evaluate potential mechanisms that can be used to leverage growing trends in green construction to address occupational safety and health (OSH) risks associated with green projects. The objective of this study was to answer the following research questions as a step toward that end:

1) Is there evidence to support the assertion that green projects pose greater risks or new hazards to occupational safety and health?
2) What role(s) do rating systems play in the delivery of green projects?
3) Do existing rating systems explicitly address OSH?
4) Do existing rating systems indirectly encourage the use of technologies and practices that pose higher risk to workers involved with green buildings?
5) What are the ways in which rating systems can be leveraged to address OSH risks in green projects?

The first phase of the study focused on answering the first research question using a systematic analysis of the literature. A grounded theory analysis was undertaken to generate findings based on inferred relationships and patterns in the literature analysis. Key findings of the first phase of analysis include the following:

- Many hazards experienced in green projects are the same as hazards in conventional projects.
- Some green building features may be indiscernible from conventional features in evaluating OSH impacts.
- Some green projects incorporate innovations that ***reduce*** worker exposure to hazards.
- Some green projects incorporate innovations that ***increase*** worker exposure to hazards.
- Some green projects incorporate innovations that expose workers to known risks under *new conditions or constraints*.

- Some green projects pose *combinations of known hazards* that synergistically increase risk.
- There may be a perception of *increased* hazard with regard to some green products and technologies that leads to inaccurate diagnosis of incident causality.
- There may be a perception of *reduced* hazard with regard to some green products and technologies that leads to reduced use of safety measures and increases risk to workers.

Given the relatively recent emergence of the area and the quality and quantity of available documentation, further investigation was recommended to more formally evaluate these findings as hypotheses. Continued monitoring of OSH incidents on green projects was also recommended to provide a basis to efficiently respond to any presently unforeseen hazards that may emerge as the field of green construction continues to evolve.

Having assembled evidence to support the possibility of differences in risk between green and conventional construction, the second phase of the study focused on evaluating the role of green rating systems in influencing decisions leading to that differential risk, focusing specifically on research questions 2 – 5. It began with a comprehensive review of green construction rating systems available globally. Multiple sources in the literature were cross-referenced to identify green facility rating systems, which are focused on different types of construction, including buildings, residential construction, infrastructure, neighborhood development, and existing buildings/retrofit. A general level review was conducted of identified systems to evaluate overall scope of coverage and to identify whether OSH is explicitly addressed as a specific credit or within a specific credit category. Selected rating systems were then subjected to a more detailed review of associated technical guidance to determine whether they encourage the use of technologies and practices with higher OSH risk. Content and thematic analysis were applied to identify technologies and practices in the technical manuals used by practitioners to apply each rating system, and these technologies and practices were evaluated with respect to construction-related hazards identified in the literature or known to the research team as OSH subject matter experts. Finally, possible actions that could be taken to improve green building rating systems with regard to OSH risk were identified based on exemplars from existing rating systems, and recommendations are made regarding ways in which future versions of rating systems can evolve to better take into account both anticipated and unanticipated OSH risks resulting from green innovations in capital projects.

Phase II of the study found that rating systems are used in a variety of different ways at different phases of the project life-cycle, beyond their obvious purpose as a tool for third party certification of projects. From idea generation to marketing, rating systems can be employed from the very earliest stages of project planning to identify potential courses of action and determine what considerations are important for a project seeking to meet environmental performance or sustainability goals. They can also be used post hoc to market a completed project.

All rating systems evaluated in this study were found to address safety and health in at least some way, be it occupationally, with respect to building occupants, or with respect to the general public and society at large. Most rating systems evaluated in the study included one or more credits with direct relevance to OSH during the construction, operations and maintenance, or end of life-cycle phases of capital projects, and occupationally relevant safety and health issues were mentioned in multiple other credits throughout most rating systems as well. The range of issues addressed in existing rating systems is extensive and covers topics including healthy construction materials and products, avoidance of exposure to hazardous substances, life-cycle prevention through design (PtD) (sometimes called safety through design in other regions), working conditions during construction and maintenance, and organizational processes and plans.

At a detailed analysis level, a majority of best available technologies and strategies identified or advocated by rating system technical documentation had at least one possible impact on occupational safety and health during at least one life-cycle phase, be it positive, negative, or both. Using an energy source taxonomy (e.g., Kleiner 2013), types of hazards where possible negative impacts were identified more frequently than possible positive impacts included mechanical, electrical, temperature, gravity, and biological, due to trends such as increased use of the building envelope as a platform for additional technologies, increased potential for exposure to pathogens when using local alternative water systems, and increased material handling requirements. Overall, however, the number of potential positive impacts for green project Best Available Technologies and Strategies (BATS) was greater than the number of potential negative impacts. Further investigation is needed to determine whether the net *magnitude* of beneficial OSH impact is also greater.

Multiple possible mechanisms are possible to leverage green project rating systems to reduce risk and enhance OSH for capital projects. Approaches presently in use today include stand-alone supplements to green rating systems focused exclusively on construction safety and health, third party reference standards, credits devoted exclusively to OSH in existing rating systems, and OSH actions incorporated as part of credits developed for other purposes. Different approaches are appropriate based on the context of use of rating systems, but many opportunities exist to leverage rating systems as a way to address potential increases in OSH risk identified for green technologies and practices.

Introduction: Occupational Safety and Health on Green Projects

With increasing interest in green construction technologies and methods, the number of green facilities being constructed in the United States is growing at a significant pace. These green facilities offer a number of potential benefits to their owners, occupants, and the natural environment, including a healthier indoor environment, increased resource efficiency, reduced operating costs, and reduced negative impact on the natural environment. However, as green building becomes more common, a growing body of evidence suggests that there may be unanticipated negative consequences of green projects in terms of *worker* health and safety. For example, some green projects have been found to require:

- Extended work at height when installing and maintaining photovoltaics, air handling units, and skylights (Dewlaney et al. 2012; Fortunato et al. 2012; Gambatese et al. 2007; Rajendran et al. 2009)
- Additional exposure to confined spaces, congested work environments, and hazardous chemicals for infill development, brownfield redevelopment, and reuse of existing buildings (Gambatese & Tymvios 2012)
- Exposure to novel and unfamiliar work environments when installing and maintaining vegetated roofs, recycling and sorting materials, and interfacing with new building designs such as atria aimed at achieving energy efficiency and daylighting (Dewlaney et al. 2012).

Green building technologies and systems, in some circumstances, have also been found to combine or interact in unexpected ways that produce unwanted exposures and conditions that put workers at risk during later life-cycle phases. Examples include (Pearce et al. 2011):

- Accelerated corrosion and blockages of copper waste piping connected to waterless urinals due to concentration of salts in effluent (e.g., Gueverra 2010; Shapiro 2010)
- Increased incidence in opportunistic pathogens when tank-type hot water heaters are set at a lower temperature to save energy (Bagh et al. 2004; Mathys et al. 2008; Strickhouser & Edwards 2007; Strickhouser 2007)
- Increased bacterial growth and reduction in water quality in water supply lines due to reduced flow rate from conserving water fixtures (NRC 2006; Nguyen et al. 2008; Lin et al. 2006; Elfland et al. 2010; Elfland & Edwards 2008; EPA 2002).

Although green projects offer the potential for improved environmental performance, they are ultimately unsustainable if they compromise the health, safety, or quality of life of their constructors, their occupants, or the workers who operate and maintain them, not to mention an antithetical value-based approach. How can the construction industry develop increasingly more sustainable facilities while avoiding potential pitfalls that threaten the health, safety, and quality of life of the occupants and workers who use, operate, and maintain them?

Existing rating systems in the U.S. market such as the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED v. 3.0) or the Green Building Initiative's Green Globes, in their current form, do not presently appear to explicitly account for worker health and safety (Branche 2012, Gambatese 2009). Although more comprehensive social sustainability goals are known to be explicitly and formally considered in projects in some parts of the world such as the European Union (e.g., Pearce et al. 2012), the greatest focus of the green building movement has historically been on the well-being of the natural environment and eventual building occupants, not on workers whose job it is to design, construct, operate, maintain, and decommission or deconstruct built facilities. There is a need to better understand the potential occupational safety and health (OSH) risks associated with green projects and to formally incorporate mechanisms to address such risks as part of green project delivery and life-cycle management.

Goal and Research Questions

The goal of this investigation was to evaluate potential mechanisms that can be used to leverage growing trends in green construction to address OSH risks associated with green projects. The objective of this study was to answer the following research questions as a step toward that end:

1) Is there evidence to support the assertion that green projects pose greater risks or new hazards to occupational safety and health?
2) What role(s) do rating systems play in the delivery of green projects?
3) Do existing rating systems explicitly address OSH?
4) Do existing rating systems indirectly encourage the use of technologies and practices that pose higher risk to workers involved with green buildings?
5) What are the ways in which rating systems can be leveraged to address OSH risks in green projects?

Study Tasks

The current investigation was commissioned by the National Institute for Occupational Safety and Health (NIOSH) to be used for potential consultation with the World Health Organization (WHO). This two-phase study aimed to provide a starting point for improving the role of green rating systems in incentivizing improved OSH or worker well-being at various stages of the green building life-cycle. Specific tasks required in this project included:

1) Task 1 - Researchers will conduct a systematic review of scientific and other literature to illustrate the implications of safety and health on workers in green construction.
2) Task 2 – Researchers will examine green rating systems worldwide to identify credits with potential positive or negative impacts on construction worker safety and health.

These tasks correspond to the two major phases of the study, both of which are described in this report.

Report Overview

This report includes study methods, findings, and conclusions from both tasks undertaken in this project. The first part of the report describes steps taken to answer the first research question related to evidence that supports or refutes the assertion that green projects pose greater risks or new hazards to OSH compared to conventional projects. It contains the following sections:

The ***Phase I Background*** section provides a definition of the construct “green” that will be used throughout the report to distinguish the population of interest from conventional, non-green projects. It also presents and describes the challenges associated with "greenness" as an independent variable in this investigation as a point of departure for the study.

The ***Phase I Approach*** section describes the data collection and analysis methods used in the study to answer the research question. In this phase of the work, the focus was on literature analysis as a means to identify and evaluate evidence of the relationship between a project's "greenness" and its OSH risk.

The ***Phase I Findings*** section presents the results of the analysis, including eight hypotheses generated based on grounded theory analysis of the literature. Specific observations about the effect of project "greenness" on OSH are described and supported with evidence from the analyzed literature.

The ***Phase I Conclusions*** section presents interpretations of the findings in terms of the original research question and suggests next steps that should be taken in further investigation.

The primary outcome of Phase I is an analysis and interpretation of what is presently known about the effect of green projects on OSH over their life-cycle, which sets the stage for the investigation undertaken in Phase II to evaluate the role of rating systems and opportunities for using them to improve OSH in green projects. The second part of the report focuses on research questions 2 through 5, which deal with the influence of green project rating systems on OSH and potential mechanisms they may offer to influence OSH over a project's life-cycle. It contains the following sections:

The ***Phase II Background*** section provides an overview of existing green project rating systems worldwide, including the uses to which rating systems are put on capital projects, the major types of rating systems in use, and the scope and coverage of those systems.

The ***Phase II Approach*** section describes the data collection and analysis methods used in the second part of the study to answer the research questions. In this second phase of work, the focus was on document analysis as a means of identifying both explicit and implicit coverage of OSH-related issues within rating system checklists, guidelines, and technical manuals.

The ***Phase II Findings*** section presents the results of the analysis, including ways in which rating systems are presently used over the life -cycle of capital projects to achieve various ends, examples of occupational safety and health-related credits and mentions in existing rating systems, and specific practices endorsed or advocated by those rating systems that are likely to affect occupational safety and health in either a positive or negative way. Observations are also made about opportunities in the project life-cycle for rating systems to influence OSH and ways in which future versions of rating systems can evolve to better take into account both anticipated and unanticipated OSH risks resulting from green innovations in capital projects.

The ***Phase II Conclusions*** section presents interpretations of the findings in terms of the original research questions and suggests next steps that should be taken in further investigation and research to practice.

The primary outcome of Phase II is an analysis and interpretation of the ways in which OSH is influenced and addressed by existing green project rating systems, and identifies ways in which rating systems can evolve to positively influence OSH in future green projects.

Phase I:
Systematic Anaylsis of the Literature

Phase I Background: The Meaning of Green

Prior to beginning detailed analysis of the literature, the research team had to determine how to define the construct of "green" with regard to the built environment so that this key variable of the research could be evaluated. Although the overall study was focused largely on rating systems, many projects with green attributes have elected not to pursue formal certification. Rating systems are relatively new in the market with limited diffusion among projects, making certification irrelevant for much of the existing data and literature in the safety field. Moreover, existing safety and health data for construction does not typically include information about a project's certification under a green rating system, even if the project has been certified. In a sense, green has been a movement that has evolved independent of OSH considerations.

For these reasons, it was necessary to develop a more fundamental understanding of *green* as a construct so that it could be used to interpret and more uniformly analyze existing information and data from the occupational safety and health domain. This section of the report describes the operationalization of *green* as a construct, and discusses how measurement challenges for this construct were addressed in the design and implementation of the study.

What does it Mean to be *Green*?

The concept of green in the Architecture/Engineering/Construction (AEC) industry is becoming broadly accepted as part of efforts to reduce negative environmental impacts and natural resource depletion due to human activity. In particular, the construction industry has begun to emphasize the use of green building products and technologies and incorporate green goals and objectives as part of comprehensive green project delivery because of the growing public awareness of the industry's significant negative impact on both the natural environment and human health. Other important drivers include economic benefits of energy efficiency, increasing resiliency with regard to uncertain future energy prices and global conditions, and a variety of incentives have emerged to encourage energy efficiency in particular for these projects.

In the context of construction, many definitions of *green* have been proposed that address issues of environmental benefit and human health, examples of which are shown in Table 1. Common themes across definitions include environmental responsibility, resource efficiency, and reduction of negative impacts on human health.

Green facility projects have also been recognized in the literature as having other qualities that distinguish them from conventional projects, including:

- Tightly coupled designs and multifunction materials and systems (Riley et al. 2003; Rohracher 2001)
- Procurement of unusual products with limited sources (Klotz et al. 2007; Pulaski et al. 2003; Syphers et al. 2003)
- Existence of incentives and resources not available to other projects (Grosskopf & Kibert 2006; Pearce 2008; Rohracher 2001)
- Requirements for additional information and documentation (Lapinski et al. 2005, 2006; Pulaski et al. 2003)

- Greater involvement of later stakeholders in earlier project phases along with greater integration of their input (Cole 2000; Gil et al. 2000a; Matthews et al. 1996; Pulaski & Horman 2005; Pulaski et al. 2006; Reed & Gordon 2000; Rohracher 2001).

Table 1: Existing Definitions of Green Building/Construction (Pearce & Suh 2013)

Source	Definition
U.S. Environmental Protection Agency (EPA 2013)	"Green building is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort. Green buildings are also known as sustainable or high performance buildings."
U.S. Office of the Federal Environmental Executive (OFEE 2003)	"The practice of (1) increasing the efficiency with which buildings and their sites use energy, water, and materials, and (2) reducing building impacts on human health and the environment, through better siting, design, construction, operation, maintenance, and removal: the complete building life-cycle."
American Institute of Architects (AIA 2013)	"A green building incorporates design, construction, and maintenance practices that significantly reduce or eliminate the negative impact of the building on occupants and the environment."
Green Construction Market Outlook (McGraw-Hill 2008)	"[A building] built to LEED standards, an equivalent green building certification program, or one that incorporates numerous green building elements across five category areas: energy efficiency, water efficiency, resource efficiency, responsible site management and improved indoor air quality."
The Green Revolution (Yudelson 2008)	"A green building is a high-performance property that considers and reduces its impact on the environment and human health."

Similar issues are noted in the green OSH literature as having potential impacts on occupational safety and health, including (e.g., Oregon Solar 2006; EASHW 2013a; Dewlaney et al. 2012; NFPA 2010):

- Product unfamiliarity to installers, operators, and emergency responders
- Unfamiliarity with work context such as work at height for landscapers
- Additional exposure to work conditions while assembling documentation for certification or installing and maintaining performance monitoring equipment
- New companies entering the construction market to take advantage of subsidies and incentives
- Compressed project schedule and processes to meet incentive deadlines
- Inexperienced workers entering the workforce based on green jobs incentives or workforce shortages
- New types of construction such as wind turbines for which workforce experience is scarce.

Together, these factors mean that not only are the components of green buildings a source of novel hazards to workers, but the very nature of green projects can lead to more hazardous conditions as well.

The term "green" is often used interchangeably with "sustainable" or "high performance", although there are fundamental differences between these terms despite some overlapping scope (Figure 1). Among these terms, green is the most inclusive within the existing population of buildings, requiring only a net environmental benefit to qualify. The more stringent term "sustainable" has a specific definable meaning with respect to the built environment (Pearce & Vanegas 2002). Overall, sustainability includes a broader range of considerations and requirements needed to ensure system stability over time without depleting or damaging resource bases and ecosystems to ensure their ongoing viability (Table 2), whereas green focuses primarily on environmental impacts alone. In particular, social sustainability is an emerging term in the construction field that has been used to describe the impacts of projects on stakeholders throughout the facility life-cycle as well as indirect stakeholders in surrounding communities and the world at large. Key concepts addressed under the rubric of social sustainability include safety through design, social design, corporate social responsibility, and community involvement (Valdes-Vasquez & Klotz 2010).

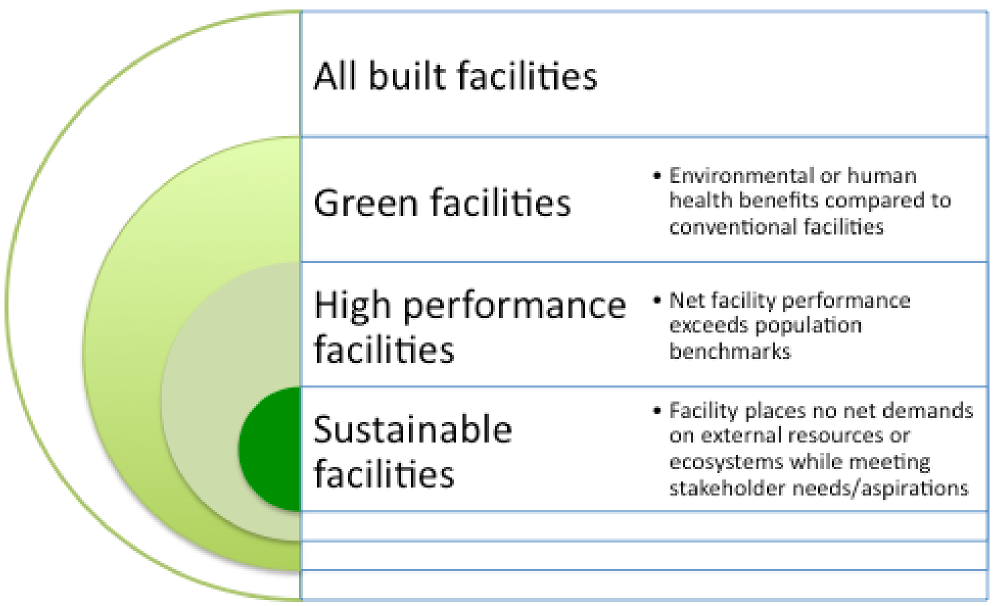

Figure 1: Comparison of Common Facility-related Descriptors

Table 2. Aspects of Facility Sustainability (Pearce et al. 2012)

Environmental Aspects	Social Aspects	Economic Aspects
• Protecting air, water, land ecosystems • Conserving natural resources (fossil fuels) • Preserving animal species and genetic diversity • Protecting the biosphere • Using renewable natural resources • Minimizing waste production or disposal • Minimizing CO^2 emissions and other pollutants • Maintaining essential ecological processes and life support systems • Pursuing active recycling • Maintaining integrity of environment • Preventing global warming	• Improving quality of life for individuals, and society as a whole • Alleviating poverty • Satisfying human needs • Incorporating cultural data into development • Optimizing social benefits • Improving health, comfort, and well-being • Having concern for inter-generational equity • Minimizing cultural disruption • Providing education services • Promoting harmony among human beings and between humanity and nature • Understanding the importance of social and cultural capital • Understanding multidisciplinary communities	• Improving economic growth • Reducing energy consumption and costs • Raising real income • Improving productivity • Lowering infrastructure costs • Decreasing environmental damage costs • Reducing water consumption and costs • Decreasing health costs • Decreasing absenteeism in organizations • Improving Return on Investments (ROI)

In this project, the primary focus is on green facilities instead of the more stringent descriptors such as sustainability, to provide the broadest possible perspective on this growing trend in the industry. For purposes of this investigation, a facility or technology is considered "green" if it has any of the following outcomes compared to a conventional facility or technology (Pearce & Suh 2013):

- Reduced negative impacts on or enhancements to natural ecosystems or their function
- Reduced depletion or enhanced recovery/generation/reuse of resources, including materials, energy, or water
- Reduced negative impacts on or enhancements to project stakeholders both current and future

Third party certification under a rating system was not used as a criterion due to the need to cast a wide net and accommodate existing OSH data and the expectation that individual products, technologies, and practices would be considered as part of the investigation. Ultimately, the most straightforward definition of green for this project is "having net environmental benefits compared to a conventional alternative." This includes benefits to eventual facility users and occupants in terms of a healthy indoor environment as well as benefits to the natural environment.

Why is Measuring *Greenness* Challenging?

Why is it challenging to draw conclusions about the impact of green facilities on occupational safety and health? The notion of green as studied in this investigation has multiple intrinsic and sometimes subjective qualities that make its measurement difficult as part of formal experimental work. As an independent variable, greenness should be objectively and reliably measurable as either a binary variable (i.e., green vs. not green) or as an ordinal or cardinal measure where projects, technologies, or practices can be compared to one another in terms of their greenness. The following subsections describe why measuring this variable is difficult, along with a discussion of how these challenges have been addressed in the investigation.

Green is relative

The construct of green is relative both with respect to peer technologies or practices and with respect to the conventional version of the thing itself. This means that as new technologies evolve and enter the marketplace, what is considered conventional will change over time, and what is considered green at one point may later become standard practice. At the technology scale, any product or process that has some environmental benefit over the status quo could correctly be denoted as "greener" than the standard product, be it greater resource efficiency, reduced impact on natural ecosystems, or improved human quality of life. "Green" does not imply any minimum level of performance, but instead implies only *better* performance than what is presently acceptable as a minimum or status quo.

In this study, the challenge of what is green vs. not green was addressed by considering the status quo point of comparison to be what is conventional at the point of time this study was undertaken. In general, due to ongoing evolution of products, what is standard today is at least as high performing as historical standards, and green products, technologies, and processes identifiable now as being green were also green over the nearly 30 years of data considered in this study.

Green is cumulative

From the standpoint of measurement, green should ultimately be a cumulative function of tradeoffs among environmental benefits compared to the status quo and across the whole life-cycle of a product or facility. In other words, a building, product, or process should not be considered green if it is very resource efficient in manufacture but uses considerably more resources than the status quo in operation. In their attempts to increase appeal for use in green projects, many product manufacturers have highlighted individual environmental benefits associated with their products as part of product information and advertising. In cases where one environmental benefit is offset by other environmental penalties, green marketing claims for these products are classified as "greenwash" (see box). In evaluating whether a project, technology, or process is green, environmental benefits should be carefully and explicitly balanced against environmental costs or penalties to determine the net benefits offered. A project, technology, or process should ultimately have a net environmental benefit compared to the status quo to be considered green.

In this study, the challenge of tradeoffs among potential environmental benefits was addressed with a heuristic (i.e., subject matter experience-based) approach, since detailed information about specific environmental costs and benefits was not available with historical data. As with relativity, the point of comparison to determine green was taken to be current practice, and facilities or technologies with likely net environmental benefit were included even in uncertain cases to maximize the potential information included in analysis.

Green on paper may not be the same as green in practice

While a building or technology denoted as green may be intended to have one or more environmental benefits during its life-cycle, those intended benefits may not always be realized in practice. For instance, recent studies of the energy performance of certified green buildings have called into question the efficacy of rating systems in achieving desired ends due to the huge variability in actual vs. predicted energy performance (Hughes 2012; Torcellini 2004; Turner 2006, 2008; Cotera 2011; Fowler & Rauch 2008; Newsham et al. 2009; Menezes 2011; Scofield 2009). Likewise, manufacturer claims of environmental benefits as part of marketing efforts may be technically correct but not be manifested in reality, such as a product made from a material that it is technically possible to recycle, but for which no recycling collection or processing facilities reasonably exist.

Identifying Greenwash

Greenwash has been defined as "the act of misleading consumers regarding the environmental practices of a company or the environmental benefits of a product or service." TerraChoice, a firm specializing in environmental marketing, has identified several common types of greenwash that they term the "Sins of Greenwashing":

- <u>Sin #1: Hidden trade-offs</u> – a claim based on a small number of environmental attributes without attention to other important environmental issues.
- <u>Sin #2: No proof</u> – a claim that cannot be supported with easily accessible data or reliable third-party certification.
- <u>Sin #3: Vagueness</u> – a claim that is so broad that its meaning is likely to be misunderstood by the consumer. "All-natural" is a good example – mercury and formaldehyde are naturally occurring but not necessarily green!
- <u>Sin #4: Irrelevance</u> – a claim that may be truthful but is unimportant for decision-making. "CFC-free" is a good example – CFCs are banned by law, so nearly all products are CFC-free.
- <u>Sin #5: Lesser of two evils</u> – a claim that may be true within the product category but which distracts the consumer from other negative product attributes. Organic cigarettes are a good example.
- <u>Sin #6: Fibbing</u> – a claim that is just plain false. Infrequent, but still a problem in some cases.
- <u>Sin #7: False labels</u> – a claim made using a made-up or fake eco-logo or claims of third-party endorsement where none exists.

Source: TerraChoice. (2009). *The Seven Sins of Greenwashing: Environmental Claims in Consumer Markets*. Available online at http://sinsofgreenwashing.org.

In this study, the challenge of what is green on paper vs. green in practice was addressed by the main focus of the literature itself. Almost all of the literature examined in this study was based on the construction phase of the project life-cycle, before a facility enters the operational phase. No data were available in the OSH literature on *actual* performance of the facilities in the data, so conclusions about facility or technology greenness had to be based on design without operational verification.

Green is context-specific

Combining the relative, cumulative properties of green means that what is green in one context may not be green in another – it depends both on the basis of comparison with others and also the net, overall performance of the facility in which the product or technology is used. With respect to built facilities, this means that whether or not a practice or technology is green depends on how it is employed within the facility to achieve overall environmental performance. Atria are one example of this idea – they have been used in buildings both conventional and green, with the focus on providing access to natural lighting for the activities occurring within the building. Atria may be used more frequently on projects with green performance objectives to improve indoor environmental quality and also reduce energy used for artificial lighting. However, they also pose hazards on conventional projects, such as the 1997 death of a carpenter in South Carolina who fell 120 feet from an unprotected floor edge while removing wooden forms (NIOSH In-house FACE Report 1997-08). Such incidents have been occurring since before the green construction movement became significant in the United States, which began largely in conjunction with residential green building rating systems originating in the early 1990's and commercial rating systems emerging later that decade.

In this study, the challenge of context specificity was addressed by capturing instances of distinct technologies and practices that are generally considered to be green, even though the projects on which they were employed were not green projects. These instances were used as part of hypothesis generation in the latter phases of analysis and used to compare whether hazards occurred on both green and non-green buildings using these technologies.

Green may or may not be innovative

While some technologies used to achieve green project objectives are novel, often green construction is achieved by new uses of *existing* technologies, or use of existing technologies by new types of workers. Therefore, some risks are associated with new technologies, means, and methods, but many risks in green construction may also be associated with new applications of existing technologies, means, and methods (such as landscaping and plant maintenance at height on green roofs); or new entry in the market of workers playing unfamiliar roles with existing technologies, means, and methods (such as electricians being required to work on pitched roofs to install photovoltaic systems).

Building green is often about adopting products or practices that are new or perceived as new by the adopting entity. As such, the population of green products overlaps the population of construction innovations and shares some attributes with these innovations in capital projects. Because these products and practices denoted as green are *also* unfamiliar to the stakeholders involved in implementing them, it may be difficult to tell whether differences in occupational safety and health are due to product *greenness* or merely due to their *unfamiliarity* to adopters. The innovativeness of many green technologies and practices presents a potential confound in attributing causality to the relationship between greenness and OSH. Addressing this confound was outside the scope of the present analysis and is a critical area for future research. On the positive side, however, observations about occupational safety and health of green products and practices in capital projects may also lend useful insights applicable to other types of innovations in the A/E/C industry, which is a fruitful area for further investigation.

Green may not always be evident to the observer, even "expert" observers

One of the easiest and least controversial ways to identify a green project is its certification under a third party rating system, and most scientific studies in the domain of OSH of green projects use this approach as their sampling frame. However, many green projects do not seek formal certification by a rating system, often due to additional first cost of certification. Focusing only on green projects that have achieved certification misses a key part of the population of green projects that may have different influences and attributes than certified projects. Given that current versions of rating systems generally do not require post-occupancy performance verification to achieve certification, it may also be possible that certified green projects do not perform as well as their conventional counterparts.

In addition, many technologies and practices that are part of a green strategy for a project may not be observable after construction, or are observable only through their impacts on overall building performance. For instance, green practices for sedimentation and erosion control during construction will not be visible after landscaping is in place. A high-albedo roof coating to reduce unwanted heat gain and subsequent cooling costs may not be visible from the ground, and energy-efficient heating, ventilation, and air conditioning (HVAC) equipment or insulation may be hidden in equipment rooms or behind interior walls, floors, and ceilings. This makes identifying and characterizing the whole population of green projects and their technologies very difficult, since green features must often be inferred from owner objectives, design documentation, construction practices, or other information.

In the FACE report review portion of this study, green features were identified based primarily on explicitly mentioned technologies in the reports. In other literature, classification of technologies or projects as green was based on either (a) the publication or source in which the document appeared (e.g., mention on buildinggreen.com web site or coverage in a blog dedicated to green building); (b) the heuristic ability of the research team to identify environmental benefits compared to conventional practice; or (c) classification by the document's author(s) based on criteria such as LEED certification.

In summary, many challenges exist with regard to measuring the variable of interest in this investigation: the greenness of facilities and their component technologies. There is a general consensus on the important variables constituting green with regard to built facilities, technologies, and practices. However, the broad temporal distribution of data over a range of nearly 30 years made it difficult to determine *how* green a particular technology might be, particularly since virtually none of the case reports or literature from the OSH domain includes any information about environmental benefits. Green building rating systems have only been used in the U.S. since the mid '90's, with the official launch of market leader LEED in 2000, so much of the time period covered by available OSH data precedes formal measurement of project environmental performance. When in doubt as to whether a facility, technology, or process was green, it was classified as green in the analysis to obtain the broadest perspective possible on potential effects of this variable on OSH. The next chapter describes the details of how data were collected and analyzed for this project, based on these broader design considerations.

Phase I Approach: Systematic Review of the Literature

To address the research questions posed earlier, the investigation was divided into two phases that focused on an environmental scan of current evidence from the literature and a detailed analysis of rating systems. This report focuses on Phase I, in which a systematic review of the literature was conducted to evaluate the evidence regarding the OSH impacts of green projects. A second companion report provides details on Phase II, which involved a systematic analysis of green project rating systems to determine their current use and future potential as a leverage point for improving OSH on green projects.

To address the challenges of evaluating the evidence regarding OSH impacts of green projects, this investigation focused on a comprehensive review of the literature pertaining to construction safety and green facilities. Extensive literature exists in both these domains individually, but the analysis conducted here focused on the overlap between them (Figure 2).

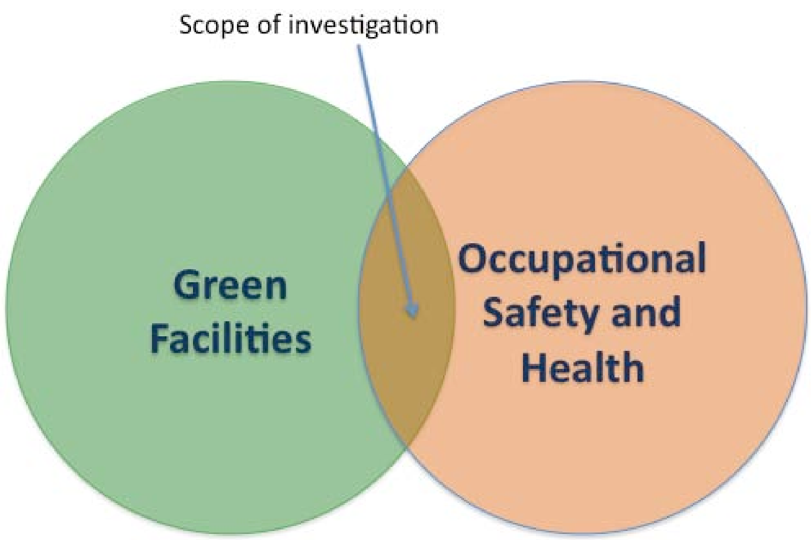

Figure 2: Scope of Investigation

Identification of Literature for Analysis

An environmental scan was conducted using a top-down approach, beginning with major search engines (Google and Google Scholar) and continuing using a snowball approach until identified sources such as web sites had been completely reviewed and referenced documents such as scholarly papers, reports, and other files had been downloaded and documented. Combinations of general search terms such as green/sustainable, construction/project, and safety/health were used to query broad search engines, including both web search engines and databases of scholarly literature such as the ASCE library, Engineering Village, and Google Scholar. Repositories of information specific to each domain that are independent of commercial interest, such as BuildingGreen.com in the green facilities domain, and the U.S. Department of Labor's web site in the OSH domain, were searched using keywords from the opposite domain to generate leads on anecdotal information and tap into blogs and other less formal sources of knowledge.

All sources were documented in a database that included fields for source information, scope of hazards discussed, and attributes of green facilities/projects that were involved, among others. The scan yielded four primary types of literature that were included in the database, including case-based evidence of actual incidents, scholarly studies focusing on incident rates associated with green technologies and projects, tools and resources developed for practitioners to address health and safety risks on green projects, and other anecdotal sources of information that could provide insight on the current state of practice and understanding.

Cases

Case-based evidence included formal incident reports from the Fatality Assessment and Control Evaluation (FACE) Program at the state and national level as well as newspaper reports, scholarly case studies, and mentions of specific incidents on web sites such as the U.S. Department of Labor's Green Jobs web site. For cases mentioned by multiple documents, the most scholarly source was used as a basis for analysis, although other sources were also documented. In reviewing FACE reports, title, summary, and description fields were scanned for mention of known green technologies or practices and included in the database if such mention was made. Primary focus was on reports classified as related to the Construction industry, with secondary focus on building-related incidents during other life-cycle phases such as maintenance, and incidents associated with green infrastructure such as wind turbines, geothermal facilities, waste recycling facilities, and composting facilities. Both the federal database (http://www2a.cdc.gov/NIOSH-FACE/) as well as individual state databases on the central cdc.gov web site and individual state sites were examined as noted in Table 1. A total of 3,279 records from FACE databases were reviewed for relevance to green projects, supplemented with additional information from other sources as available.

Studies

The scholarly literature yielded multiple studies examining incident rates on green projects and the perceptions of experts and project stakeholders on the differences in hazards between green and conventional projects. These sources included refereed journal and conference papers as well as accessible technical reports produced from academic research.

Tools and Resources

In some cases, hazards associated with green facilities, technologies, or processes are well understood enough that products can be developed to aid practitioners in their work. These types of literature included slide shows from professional meetings, guidebooks or workbooks, technical bulletins, training curricula, videos, and other items made publicly available with the aim of improving professional practice and reducing hazards on green projects. These items came primarily from government (federal or state) agencies, trade associations, and academic organizations.

Table 1: FACE Report Analysis

Source	Years	Total Records (# Reviewed)	# of Relevant Incidents
National OSHA In-house reports[1]	1982-2011	610 (257)	3
Active Partner States			
California[2]	1992 - 2012	228 (228)	14
Iowa[2]	1995 – 2012	1354 (1354)	5
Kentucky[3]	1999 - 2010	141 (141)	6
Massachusetts[3]	1990 – 2011	177(177)	26
Michigan[3]	2001 - 2011	143 (143)	4
New Jersey[3]	1990 – 2011	198 (198)	11
New York[3]	2002 - 2008	42 (42)	1
Oregon[3]	2003 – 2008	45 (45)	2
Washington[3]	1998 - 2010	23 (23)	1
Formerly Active States			
Alaska[3]	1991 - 2003	19 (19)	0
Colorado[3]	1989 – 1996	48(48)	1
Indiana[3]	1993 – 1997	14(14)	1
Maryland[3]	1994 – 1998	21(21)	1
Minnesota[3]	1992 – 2006	184 (184)	4
Missouri[3]	1992 – 2000	42 (42)	0
Nebraska[3]	1994 – 2006	77(77)	0
Ohio[3]	1999	3(3)	1
Oklahoma[3]	1997 – 2006	52(52)	2
Texas[3]	1998 – 2001	26(26)	1
West Virginia[3]	1997 – 2004	34(34)	0
Wisconsin[3]	1991 – 2005	106(106)	2
Wyoming[3]	1992 – 1995	45 (45)	1

[1] Only construction-coded records were comprehensively reviewed, supplemented by keyword search of other records to identify cases from other life-cycle phases including operations, maintenance, and demolition (http://www.cdc.gov/niosh/face/inhouse.html)

[2] Individual state databases reviewed; additional cases identified beyond NIOSH central database (http://www.cdc.gov/niosh/face/stateface.html)

[3] Only cases in the NIOSH central database were reviewed (http://www.cdc.gov/niosh/face/stateface.html)

Anecdotes

Other literature not falling under the previous categories was documented as anecdotal and captured for analysis as well, including web sites, blog and discussion group posts, and others. Social media and discussions among early adopters can be especially useful with emerging technologies or trends.

Analysis of Data

After relevant literature had been identified using the search strategies described in the previous section, the next step was to characterize the literature to determine coverage and draw conclusions about the relationship between green projects, technologies, and practices vs. occupational safety and health over the life-cycle of green facilities. A grounded theory approach was used to identify possible patterns in the data related to the relationship between project/technology greenness and occupational safety and health.

Grounded theory is an approach that originated in the social sciences and can be used to analyze bodies of data and derive theory and hypotheses inductively based on observed patterns and themes. In this study, each instance of literature in the four categories described earlier was treated as a data point or piece of evidence in which the relationship between a project's greenness (i.e., the independent variable) and occupational safety and health outcomes (i.e., the dependent variables) is exemplified. Due to the nature of the data and search strategies used, claims could not be made about the representativeness of the data to allow descriptive analysis or hypothesis testing (see *Limitations*). However, patterns and themes observed in the data could be used to generate hypotheses to be tested in future research.

In processing the data, the research team looked for both similarities and differences between green and non-green projects in terms of incidents, then stated hypotheses and searched for evidence to support or refute them. The hypotheses generated by this process are included as findings of the study and can serve as a point of departure for further research as well as an initial understanding of the relationships of interest.

Phase I Findings

Grounded theory was used in this research as a systematic approach to inductively generate hypotheses based on observed patterns, primarily from the case-based literature data. Patterns were identified and data were associated with those patterns as a point of departure for further research. Eight potential patterns emerged from the grounded theory analysis of the literature, as follows:

1) Many hazards experienced in green projects are the same as hazards in conventional projects.
2) Some green building features may be indiscernible from conventional features in evaluating OSH impacts.
3) Some green projects incorporate innovations that *reduce* worker exposure to hazards.
4) Some green projects incorporate innovations that *increase* worker exposure to hazards.
5) Some green projects incorporate innovations that expose workers to known risks under *new conditions or constraints*.
6) Some green projects pose *combinations of known hazards* that synergistically increase risk.
7) There may be a perception of *increased* hazard with regard to some green products and technologies that leads to inaccurate diagnosis of incident causality.
8) There may be a perception of *reduced* hazard with regard to some green products and technologies that leads to reduced use of safety measures and increases risk to workers.

The following subsections describe each pattern and provide examples of supporting evidence to substantiate it as a finding of the research.

Finding 1: Many hazards experienced in green projects are the same as hazards in conventional projects.

The first pattern observed in the case-based data was that the same hazards (e.g., trench collapse, falls through skylights, and others) occurred on both green and non-green projects and thus were not directly a function of the greenness of a particular project. Table 2 provides examples of this phenomenon for different hazards as supporting evidence from the case analysis.

Table 2: Examples of Similar Incidents from Green and Non-green Projects

Hazard/ Incident	Green	Not Green
Trench Collapse	Trench used for geothermal loops in energy efficient HVAC system *(USDOL Web site - "Green Job Hazards: Geo-thermal Energy.")*	Trench used for concrete footing for building *(NIOSH 2005-04)* Trench used for electric utility lines *(NIOSH 2003-07)*
Falls through Skylight	Fall through skylight on existing building where photovoltaic panels were being installed *(California 09CA003)*	Fall through skylight on existing warehouse undergoing roof repair *(California 11CA004)* Fall through skylight on existing building; worker servicing AC unit *(California 09CA007)*
Electrocution	Worker offloading excavator at wind turbine site contacts overhead power line *(USDOL Web site – "Green Job Hazards: Wind Energy")*	Laborer electrocuted after boom truck contacts overhead power line on conventional project *(NIOSH 2005-02)* Roofer's helper electrocuted when ladder platform hoist contacts a power line *(NIOSH 1992-24)*

A quote from the Tools/Resources literature further supports this finding with regard to solar photovoltaic systems, as follows (CA OFSM 2010, p. 29):

> *Many of the same hazards associated with PV technology are present at incidents where PV systems are not present. This is because they are general electrical hazards not specific to PV systems. Like other electrical systems, the components are only hazardous if the system is compromised or directly involved in fire or the protective coverings on the components are damaged.*

As in this example, the hazards posed by green products and technologies may in many cases be the same as or similar to hazards on projects where those products and technologies have not been used, although they may appear more frequently in green projects as discussed in Finding 4.

Finding 2: Some green building features may be indiscernible from conventional features in evaluating OSH impacts.

The qualities that make a product or technology green are not always apparent to the observer or installer, particularly if accompanying literature is not present or labeling is obscured. Moreover, some attributes of green products pertain to their impacts upstream or downstream of construction, such as recycled content in building materials or energy efficiency of an appliance, with no difference in the process or approach to handling that product in the field during or after installation. Many of these attributes are material properties of a product that do not affect the process of installation or maintenance of the product in any way. Table 3 provides examples of incidents from case data that may or may not have involved a green product; the greenness of the product was not considered to be an important factor for investigation and was not explicitly mentioned in the incident report.

Table 3: Incidents where Green Products or Technologies Might Have Been Used

Incident	Potential Green Feature
Worker struck by unsecured wooden truss after falling from scaffold *(NIOSH 2000-16)*	Wood truss may have been constructed from certified sustainably harvested wood
Carpenter dies after being struck by uncontrolled concrete bucket when crane tips over *(NIOSH 2000-12)*	Concrete being placed could have had post-industrial recycled content such as flyash or ground granulated blast furnace slab
Painter dies after falling from aerial platform *(NIOSH 1996-20)*	Paint could have had low or no VOC content
Welder dies after being struck by a three-ton steel roof truss *(NIOSH 1996-11)*	Nearly all steel contains recycled content, so roof truss likely contained recycled content
Sheet metal mechanic dies after falling 25 feet through roofing insulation *(NIOSH 1995-19)*	Insulation could have been high-performance or contain bio-based material/recycled content
Carpenter dies after falling 16 feet from roof while installing underlayment *(NIOSH 1995-09)*	Could have been underlayment for a high performance roof product

Finding 3: Some green projects incorporate innovations that ***reduce*** worker exposure to hazards

As noted in some of the scientific studies reviewed in this investigation, some innovations used on green projects tend to reduce risk to OSH by virtue of reducing maintenance requirements, minimizing landscape disturbance, and use of low-emitting products and equipment. Table 4 provides examples of incidents whose probability of occurrence would be lower on a green project, for the reasons noted.

Table 4: Examples of Incidents on Conventional Projects with **Lower** Probability of Occurrence on Green Projects

Incident	Likelihood of Occurrence on Green Projects
Chain Saw Operator Dies after being struck by Excavator Bucket During Site Clearing *(NIOSH 2004-07)*	Green projects seek to minimize landscape disturbance, reducing the need for site clearing, heavy equipment to move downed vegetation, and saw operators to process it.
Maintenance Supervisor Killed by Fall While Changing Light Bulb *(Michigan 10MI006)*	Longer-life, more energy efficient lamps such as LEDs used in green projects require less frequent changing.
Carpet Laborer Overcome by Carbon Monoxide Fumes *(Nebraska 04NE044)*	Use of alternative-power generators eliminates combustion fumes on some green project sites
Tub Refinisher Died Due to Methylene Chloride Exposure While Stripping a Bathtub *(Michigan 10MI013)*	Use of solvent-free or low-VOC chemicals reduces hazards from chemical exposure in green projects
Carpenter Dies after he Jumped/Lost Balance from An Unsecured Ladder that fell due to a wind gust during soffit repair *(Michigan 05MI051)*	Use of composite wood or recycled plastics for exterior construction can reduce the amount of time working at height to maintain exterior finishes

Finding 4: Some green projects incorporate innovations that ***increase*** worker exposure to hazards

In contrast to Finding 3, some innovations employed on green projects *increase* worker exposure to hazards, thus increasing OSH risk. Integration of building components to achieve greater performance and functionality of the building envelope is one trend in green design that poses multiple risks to occupational stakeholders. For instance, vegetated roofs, roof-mounted renewable energy systems, building-integrated photovoltaics, and other such technologies can greatly improve a project's environmental performance but pose additional risks to installers, maintainers, and emergency responders. Table 5 shows examples of incidents whose probability would be higher on a green project, for the reasons noted.

Table 5: Examples of Incidents on Conventional Projects with **Higher** Probability of Occurrence on Green Projects

Incident	**Likelihood of Occurrence on Green Projects**
Window washer falls approximately 60 feet off a swing stage scaffold when one of the electric hoists fails *(California 00CA003)*	Greater use of glazing to achieve natural daylighting and views requires additional maintenance to keep glass clean in green buildings
Maintenance worker replacing screens falls from ladder *(Iowa 2006IA069)*	Employing natural ventilation as an energy-efficient strategy to maintain indoor air quality requires additional operable windows and window screens in green building, necessitating additional work at height to maintain them
Worker was struck in knee by wrench while removing drill stem from geothermal well *(USDOL Web site - "Green Job Hazards: Geo-thermal Energy")*	Increased use of efficient geothermal heating and air conditioning systems requires additional earthwork in green projects, which can lead to excavation collapses and other drilling-related hazards
"Green" insulation suspected as cause of fatal fire *(Gouveia 2008)*	Two-part blown insulation products can create chemical exposure and flammability problems in confined spaces
Skid steer traps man underwater during pond construction *(Iowa 2005IA29)*	Greater use of on-site water retention features means more excavation and earthwork on some green projects, which can pose additional hazards to workers

Incident	Likelihood of Occurrence on Green Projects
Construction laborer dies in trench cave-in at oil tank removal site *(Massachusetts 97MA031)*	Remediation of brownfield sites is encouraged as a green building practice, but may expose workers to dangerous and unpredictable conditions
Carpenter dies when crushed beneath prefabricated modular roof panel *(Massachusetts 93MA011)*	Prefabrication and modularization are practices encouraged in green building for increased resource efficiency and reduced waste, but require workers to handle heavier and larger components that can cause strains or struck-by/caught-between incidents. Other heavier components may include high performance windows and large glazing assemblies for passive solar design, daylighting, and views.
Construction worker dies from heat stroke while installing sidewalks *(Minnesota 93MN00901)*	Providing alternative transportation amenities such as sidewalks is encouraged in green construction, requiring additional work in unfavorable outdoor conditions
School employees reported workplace illness after recent isocyanate foam installation (*USDOL Web site – "Green Job Hazards: Weather Insulating/Sealing")*	With additional focus on building air-tightness and controlled ventilation, workers may be exposed both to poorly ventilated conditions during construction and chemical exposure from certain types of insulating or sealing products.
Construction worker installing rain gutters dies after falling 13 feet from a scaffold *(Minnesota 96MN08501)*	Additional measures for harvesting and reusing rainwater in green buildings mean the possibility of additional work at height for installation and maintenance of collection systems, along with confined space work in rainwater tanks and the potential for pathogen exposure while working with treatment systems.

Multiple examples in the case-based literature support a claim of greater hazards in green projects and facilities. Whether such projects are ultimately safer or more hazardous than conventional projects cannot be determined from existing data, since the fewer examples to support Finding 3 were based on counterfactual statements that are not documented directly in the case-based literature. Additional investigation is required to draw valid conclusions about net benefits to safety, given the type of data available for analysis at present.

Finding 5: Some green projects incorporate innovations that expose workers to known risks under *new conditions or constraints*.

Some attributes of green projects have led to the use of innovations that place workers in unfamiliar conditions while working with technologies that would otherwise be familiar. Supporting examples are shown in Table 6.

Table 6: Examples of Incidents in which Workers may be Exposed to Otherwise Familiar Technology under Unfamiliar Circumstances

Incident	Likelihood of Occurrence on Green Projects
Carpenter dies in fall through wall opening in factory renovation site *(Massachusetts 97MA050-01)*	Adaptive reuse of existing buildings for new uses is encouraged as a green building practice, but may expose workers to dangerous and unpredictable conditions such as deteriorated building materials
DPW employee electrocuted attempting to read a water meter *(Michigan 03MI079)*	Greater use of meters, sensors, and controls for performance management requires additional work at height and in confined spaces during construction and ongoing operation; may also pose additional electrical hazards
Project Engineer dies in fall from roof while estimating materials for an energy efficient roof upgrade *(Massachusetts 97MA044-01)*	Improving energy efficiency of existing buildings requires additional time at height and in unpredictable building conditions to inspect, evaluate, insulate, and weather-seal building envelope
Flagger struck from behind and killed by a truck intruding into a highway construction work zone *(NIOSH 2000-02)*	To reduce environmental impacts of transportation, green facilities are often located in areas of higher development density where significant traffic management is necessary
Maintenance worker falls through skylight while attempting to sweep it clean with a broom whose handle breaks *(California 07CA007)*	Additional surfaces requiring transparency for proper operation may require maintenance personnel to work at height when they are unaccustomed to doing so

In addition to features of the project design itself, other conditions and constraints occurring as part of the delivery of green projects can also create unfamiliar conditions as discussed in the Background section of this report. These include compressed schedules to meet incentive deadlines, inexperienced workers entering the market to take advantage of new opportunities, and others.

Finding 6: Some green projects pose *combinations of known hazards* that synergistically increase risk.

Some trends in green facilities combine features in new ways to achieve new synergies, such as the trend toward using the building envelope as a palette for additional functions like power generation or landscaping. Along with functional synergies generated by these combinations, the hazards associated with each individual function can sometimes combine to pose hazards greater than the sum of their parts. Of particular note are systems associated with distributed rooftop renewable energy production, including wind microturbines, solar photovoltaics, and solar thermal installations. Table 7 provides examples of synergistic hazards mentioned in the literature that result from new combinations of known technologies.

Table 7: Examples of Synergistic Hazards Associated with Green Buildings identified in the Literature

Photovoltaic cells remain energized during daylight even when other elements of the system have been de-energized. This can pose electric shock hazards to rooftop workers that increase the likelihood of falls while working at height (e.g., NFPA 2010; Oregon Solar 2006).
Building-Integrated Photovoltaics (BIPVs) include photovoltaic cells as part of other building elements such as tiles or windows, making them a potential source of electric shock during installation to trades not familiar with working at height (EASHW 2013a).
Working at height to install roof-mounted power generating equipment coupled with increased roof openings for daylighting increases hazards associated with trips, slips, falls, and working at height along with electrical hazards and strains from carrying materials on roof surfaces (e.g., California 09CA003).
Increased focus on deconstruction and recovery of useful materials during demolition can increase fall hazards during material recovery on roofs and upper floors, along with cuts, abrasions, exposure to pathogens, and other hazards associated with demolition of existing buildings (e.g., California 00CA 003).

Finding 7: There may be a perception of *increased* hazard with regard to some green products and technologies that leads to inaccurate diagnosis of incident causality.

Several instances were observed in the case-based literature of initial misdiagnosis of the cause of an incident in which green technologies were involved, with the green technology being initially blamed for the incident but later found to not be the cause. This misdiagnosis was likely the result of perceived hazards associated with specific green technologies, namely photovoltaic arrays installed on buildings. Table 8 lists the examples identified in the case-based analysis to support this finding.

Table 8: Examples of Misdiagnosed Incident Causality with Green Technologies identified from the Literature

Firefighter received a non-life-threatening electrical shock during a residential content fire that was initially thought to be caused by the photovoltaic system but later determined to be caused by utility power (CA OSFM 2010).
A chimney fire was originally attributed to solar air heating panels mounted nearby, but later determined to have a different cause (CA OSFM 2010).

The existence of these misdiagnoses suggests that practitioner perceptions of risk may not be entirely accurate, particularly for innovative technologies and practices that are unfamiliar to them. The implications of this inaccuracy are discussed further in the Conclusions section.

Finding 8: There may be a perception of ***reduced*** hazard with regard to some green products and technologies that leads to reduced use of safety measures and increases risk to workers.

As noted in Finding 3, some green technologies and practices have the potential to reduce occupational hazards if implemented as part of green projects. However, it is possible that workers may respond to this perceived reduced hazard by reducing their use of safety measures and controls, sometimes to the extent that unexpected injuries or fatalities occur. One example was noted in the case-based literature to support this finding as shown in Table 9. However, the potential for greenwash in product labeling as well as general perceptions of green product safety to exacerbate and amplify safety risks is potentially significant and warrants further investigation. Accordingly, this finding was included even though only one supporting example was found.

Table 9: Example of Fatality involving Green Technologies in which Hazards were Underestimated

Technician using a "low odor" paint stripper was overcome by vapors; no ventilation or respiratory protection had been in use (Iowa 2012IA009)

In summary, eight key findings were derived from the literature analysis that suggest possible causal or correlational relationships between the greenness of a facility or its components and the occupational safety and health of its stakeholders. The next section of the report describes the conclusions that can be drawn from this analysis and its findings.

Phase I Conclusions, Limitations, and Future Research

Based on the specific findings identified by the literature analysis in this study, broader conclusions can be drawn about the current understanding of the relationship between OSH and green projects. This section describes those conclusions and observations, and presents limitations of the current study along with recommendations for future research.

Observations about Scientific Work in this Domain

The evidence assembled in this study, with few exceptions, was found to be focused at the component scale of green facilities (i.e., technology, process, product, sometimes organized around individual LEED credit) rather than facilities in their entirety. Only one scientific study reviewed (Rajendran et al. 2009) was conducted at the whole facility scale and not the component scale, specifically using Recordable Incident Rate (RIR) as a metric of safety for 74 LEED certified projects. This focus at the component scale, coupled with the case-based data from FACE reports and other sources, suggests that hazards are more likely to be understood at the component scale, not the whole building scale, by occupational stakeholders. Thus, although studies like Rajendran et al. (2009) characterize their findings in terms of LEED projects vs. non-LEED projects, the documented effects may be equally true for other non-green projects using the components causing the problems in the green buildings. Additionally, the findings of this study suggest that it may be quite difficult to draw conclusions about the net effect of a whole project's greenness on OSH, since some green innovations *increase* exposure to hazards (Finding 3), while other *decrease* exposure (Finding 4).

Scientific studies reviewed in this work used both case-based (Fortunato et al. 2012) and practitioner perceptions-based data (e.g., Dewlaney et al. 2012) to evaluate risk associated with green facility components. Of the two, perception-based data were used more prevalently. In general, perceptions-based data were described as being more practical to obtain than case-based data, both for logistical reasons as well as the relatively small population of green projects at the time of these studies. In light of the two findings of this study showing that perceptions about green technologies may be inaccurate, either (a) blamed as hazards when they were not the cause of incidents (Finding 7); or (b) assumed to be less hazardous than they actually were (Finding 8), there is a need to evaluate the accuracy of practitioner perceptions of risk in future research. A better understanding of the accuracy of practitioner perceptions can also contribute to more effective design of tools and resource for practitioner OSH, discussed next.

Observations about Tools and Resources in this Domain

There is a growing body of informational tools and resources that address OSH in green projects from a comparatively holistic perspective, although these tools are based on current knowledge of hazards in green facilities, and to a large degree they are focused on specific technologies and practices known from experience to pose hazards on green projects. To varying degrees, both holistic tools and component-focused tools present not only coverage of hazards at the component level over the facility life-cycle, but also provide content about unique qualities of green facility projects that make them different from conventional projects in terms of risk. For instance, the European Agency for Safety and

Health at Work (EASHW)'s recently released E-fact bulletin on OSH and Small-scale Energy Applications describes how industry trends such as immigrant workers and policy trends such as subsidies for renewable energy can contribute to work patterns that pose additional hazards to workers (EASHW 2013a). Consideration of these emergent system behaviors is important in identifying the most effective ways to improve the performance of a green project as a whole from an OSH standpoint.

As the green OSH domain continues to evolve beyond an individual component perspective, the tools provided to support effective decision making in practice will also need to evolve to recognize the unique aspects of green projects discussed in the Background section. Providing information about underlying causes of hazards helps to facilitate naturalistic decision making in unfamiliar situations (e.g., Lipshitz & Strauss 1997; Klein 1998). Resources and tools that take advantage of leverage points in the project delivery system and knowledge of the cognitive capabilities of practitioners are needed to address future hazards that may not have yet emerged in the relatively new practice of green construction. New understanding of the role of social media such as blogs and discussion boards can also help recognize future problems earlier when they first are noticed in the field rather than after multiple FACE reports have been filed and recognized as a trend at the level of state or federal regulatory and enforcement agencies.

Limitations of the Phase I Investigation and Future Research

One of the key limitations of Phase I was the representativeness of the case-based data evaluated in this research. In all but a few of the listings (e.g., State of Iowa), FACE reports have been developed only for *selected* incidents in focus areas of interest to the developing agency. Criteria for selecting FACE cases to report are not explicitly described in any of the case study databases, meaning that these data cannot be assumed to accurately represent the entire population of fatalities. Moreover, FACE reports are developed only for fatalities and do not cover the broad spectrum of reportable incidents that result in non-fatal harm, or the even broader range of "near misses" that occur in the workplace. Finally, the non-FACE cases included in the data for this research were largely assembled from work that had been developed around a particular technology or practice (e.g., solar installations; spray polyurethane foam), with cases deliberately selected to highlight risks of those technologies. Given the likely lack of representativeness of the whole population of actual or potential construction-related incidents, this study only produced potential hypotheses to be tested in future research and did not draw conclusions about prevalence of the identified patterns.

A second limitation in Phase I of the study was the operationalization of "green" for a data set inconsistent in its level of detail with regard to construction technologies and practices, and which consisted largely of incidents occurring before the advent and widespread use of third party green rating systems. Although there are methodological pitfalls in relying strictly on third party rating systems, most scientific studies in this domain (e.g., Dewlaney et al. 2012; Fortunato et al. 2012; Gambatese et al. 2009; and Rajendran et al. 2009) have used them, specifically LEED, as a common metric for project selection and characterization. Yet many green projects do not seek formal certification, and it is possible that the same factors driving the desire for formal third party recognition are mediating factors in the equation for health and safety outcomes. Future study of OSH in green projects must be coupled with understanding of the evolving field of green construction to ensure that methodological decisions lead to valid understanding that ultimately improves OSH on green projects.

In conclusion, additional investigation is warranted to further explore the relationships identified in this analysis between greenness and OSH. Based on the review of the literature overall, safety implications of some green technologies such as solar thermal and photovoltaic systems and spray foam insulation appear to be fairly well understood, and extensive tools and resources have been developed to support their safe implementation. However, new technologies continue to emerge as green goals for projects become more ambitious. Some technologies being increasingly employed are associated with the use of nano-materials in construction as well as on-site water recovery, treatment, and reuse. Concerns have been raised anecdotally that these systems may pose significant public and occupational health risks. For these and other innovations, systematic evaluation of potential risk is essential to meet occupational safety and health goals. The second phase of this study focuses on ways in which green building rating systems influence projects to affect the safety and health of their occupational stakeholders, and will focus in greater detail on technologies and practices encouraged by these systems that may not yet be well understood in terms of potential hazards.

Phase II:
Green Construction Rating System Analysis

Phase II Background: The Spectrum of Green Construction Rating Systems

The first broad-spectrum commercial green building rating system was developed and released in the United Kingdom in 1990. Since that time, a proliferation of systems has emerged worldwide (Figure 3), many having common ancestry with or evolving from the early rating systems deployed in the market. This may come as a surprise to Americans who tend to assume that innovation typically begins in the U.S.

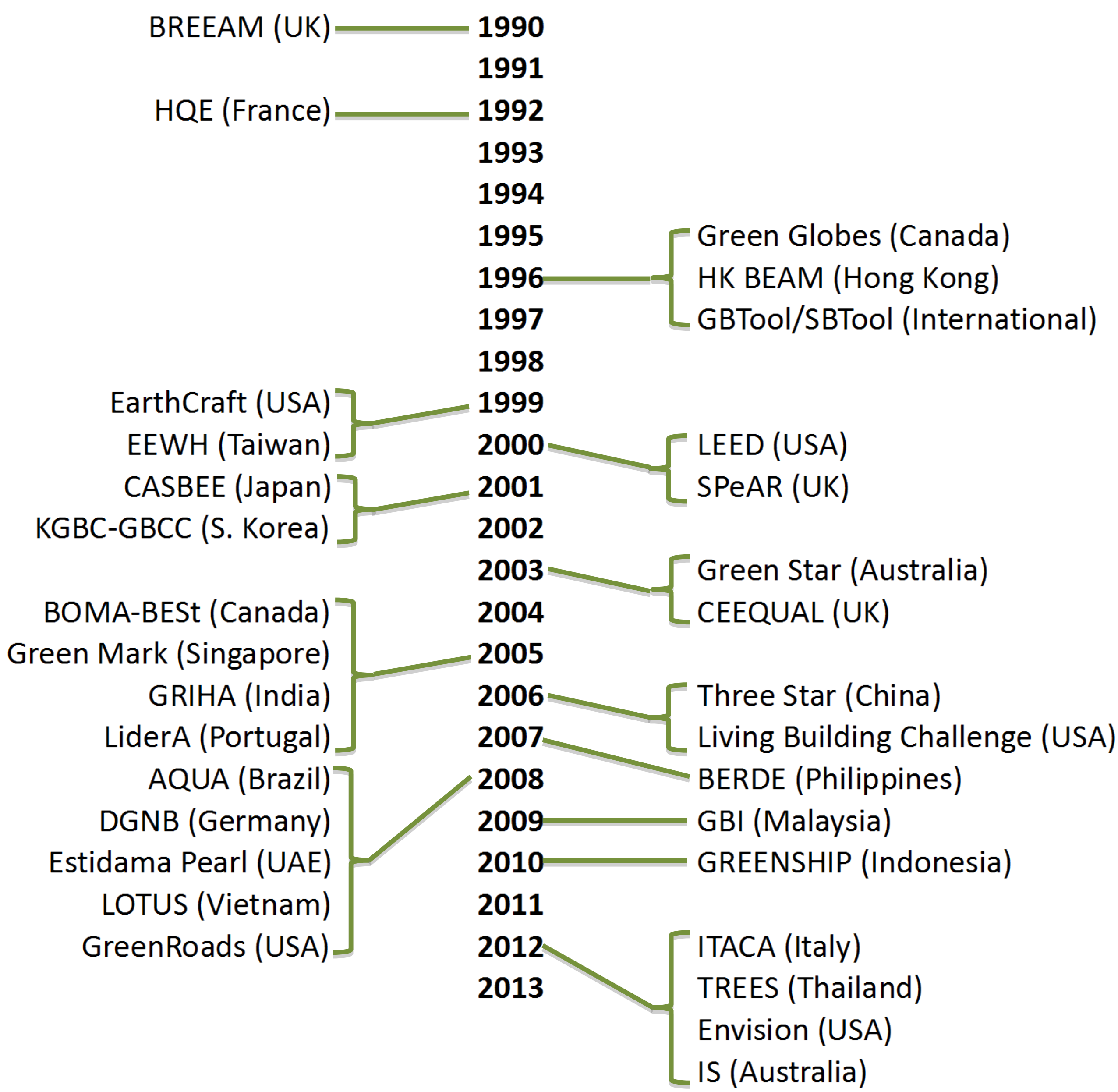

Figure 3: Release of Selected Major Green Building Rating Systems Worldwide

Scope and Customization of Rating System Coverage

Green project rating systems have been developed for both vertical and horizontal construction, ranging from single family houses and commercial buildings to bridges, highways, and canals. Many of the rating systems that initially focused on the individual building scale have begun to involve measures to evaluate the operations and maintenance of those buildings as well as their context as part of larger neighborhoods or communities. In addition to this broad range in project scale, some rating systems also have evolved into specific applications by project type to capture the unique attributes of particular building typologies. For instance, the Building Research Establishment Environmental Assessment Method (BREEAM) family of rating systems now contains special versions for courts, data centers, educational facilities, healthcare facilities, offices, retail, multifamily, and others. The data center version of the rating system, for example, focuses more on energy performance of these energy-intensive systems and less on indoor environmental quality since the majority of spaces in these buildings are not occupied by humans for significant periods of time. In this way, rating systems can be customized to different projects to better evaluate the traits most important for each particular project type.

Other approaches to customization include variable weighting schemes that allow users to adjust the relative importance of different issues considered in the rating. Current versions of the Leadership in Energy and Environmental Design (LEED) rating system in the United States allow customization through the use of Regional Priority Credits, where achieving certain credits obtains extra points based on what factors have been determined to be high priority in the geographic region where the project is located. For example, projects performing well on water efficiency may receive extra credit for high performance in parts of the country that are very dry and have limited water resources. Which credits are regional priorities were initially determined by local chapters of the U.S. Green Building Council (USGBC) whose members are most familiar with local issues, and they are applied to projects by zip code based on the project location.

Measurement Purposes and Approaches

There are a variety of purposes for measuring or assessing the sustainability of engineered systems (Pearce et al. 2000; Pearce et al. 2012). These include:

- <u>Baselining</u> – establishing an initial system state against which to calibrate future performance
- <u>Benchmarking</u> – providing a basis for comparison with competitors and identifying what is adoptable or adaptable as the state of the art in a given practice
- <u>Prioritization, decision support, or selection</u> – establishing a basis by which to allocate finite resources for implementation of one or more solutions with the objective of maximizing benefits
- <u>Surveillance</u> – monitoring, capturing evidence to support conformance with standards, compliance with policy, or progress being made toward improvement.

The ultimate use to which sustainability assessment is to be placed within the organizational context of application helps to guide the selection of an appropriate approach. Existing approaches to measure the sustainability of built facilities can be divided into three classes: (1) prescriptive approaches, (2) performance-based approaches, and (3) systems-based approaches, described in the following subsections.

Prescriptive Approaches to Measurement

Prescriptive tools consist of sets of recommended or best practices, and as measurement tools they are primarily point-based. A project could be evaluated using such a tool by allocating one or more points for each best practice that is implemented in the facility at the time of measurement. For example, early versions of the Leadership in Energy & Environmental Design (LEED) Green Building Rating tool (e.g., USGBC 1998) assigned a point for using specific technologies such as porous pavement. Porous pavement is an effective technology in many (but not all) circumstances for addressing the problem of urban storm water runoff, and as such is a recommended best practice for certain paved areas of facility systems. Later versions of the system (e.g., USGBC 2004; USGBC 2009) still rely on best practices with respect to specific technologies (e.g., Low VOC paints and carpets) for some of their credits, although other credits are now more performance-based (such as water and energy efficiency credits). Low VOC paints and carpets are actually somewhat of a hybrid between prescriptive and performance-based, since they allow multiple kinds of paints and/or carpets within the envelope of the low VOC criteria (a performance-based approach), but they still limit the points to instances where floors are covered with carpet (not other types of floor coverings) and walls are covered with paint (not other types of wall coverings).

Prescriptive measurement approaches have the strengths of simplicity and transparency to their users, allowing easy interpretation of what exactly is required to achieve a point, and straightforward verification of the action (did you do it or not?). However, they also suffer from several weaknesses. First, they are dependent upon extant technologies and best practices, which necessarily change over time due to improvements in state of the art and necessitate frequent updates of the rating system. While face valid, they can suffer from other forms of invalidity. Generalizability (i.e., external validity) to multiple types of facilities in different contexts is difficult to achieve with these tools; to be specific enough to be useful, they are limited in scope to the individual types of facilities and contexts for which they were developed. For example, the LEED New Construction tool is applicable primarily to new commercial or institutional construction in urban or suburban areas. In this type of context and for these facility types, using porous pavement and low VOC paints and carpets makes sense as a best practice. But what about adaptive reuse of existing facilities in urban areas, where pavement already exists that would not usually be replaced? In this situation, removing existing pavement and replacing it with porous pavement to obtain a point would involve significant additional impacts outside the typical scope of work (and perhaps is one of the reasons that porous pavement was removed as a potential point in later versions of the LEED system). What about facilities that contain no paved areas, such as certain residential facilities? From a runoff standpoint, having no paved areas is superior to having porous pavement, which is superior to using impervious pavement. Yet the prescriptive standard would essentially penalize the facility with no paved areas, since it does not meet the criterion as stated. What if the LEED system is being applied to a warehouse, where carpet is not typically used at all? Should project teams include a token amount of low VOC carpet for the sake of the point, even though they would not otherwise do so in a good warehouse design?

Optimizing the facility to maximize a rating score under a prescriptive rating system can result in suboptimization from a whole systems standpoint that could overwhelm the benefits realized from undertaking individual best practices (Bray & McCurray 2006). *What* *is green for one type of construction is not necessarily green for other kinds of construction*. Yet prescriptive standards for measuring project greenness offer an easily understood and easily measured way to encourage industry to adopt sustainability best practices (ibid.). The ethics and skills of the design team are the primary control to ensure that these systems do not encourage suboptimization in the project for the sake of points. A particular concern as evidenced in this report is in optimizing what is perceived as green if it compromises or suboptimizes safety to human beings. Prescriptive methods work well in situations where they are contextually adapted and applied, such as the proliferation of residential green building rating systems that have been developed locally in over 30 cities or regions around the United States (see NAHBRC 1999 and NREL 2002 for more detailed information about these programs).

Performance-Based Approaches to Measurement

Performance-based approaches to measurement and decision-making address some of the weaknesses of prescriptive tools and standards. Rather than specify a particular best practice or technology that might not be appropriate for all situations, performance-based tools assign points or otherwise denote compliance based on whether or not the solution meets or exceeds a threshold on some performance continuum representing the problem that a best practice is meant to address. For instance, a performance-based measurement system might allocate a point if the pavement used in the parking lot produces less than a certain amount of runoff for a storm event of a certain magnitude, or if the net runoff from the site is less than or equal to pre-development conditions. Newer versions of the LEED rating system have moved toward this type of standard for many credits, although there are still some prescriptive credits (e.g., site selection credits, among others). Performance-based measures specify an objective to be met by the pavement, not *which pavement* should be used to meet this objective. The designer or decision maker is free to choose a pavement type that is most appropriate in the context of the specific facility. As long as the pavement results in a condition that meets the objective, the point is obtained.

While performance-based measurement tools represent a significant improvement over prescriptive tools, they still encourage reductionist optimization of specific aspects of a built facility. As such, they fail to recognize that what is optimal from the perspective of a single problem (e.g., storm water runoff) might reduce the optimality of the system from a holistic standpoint (e.g., total resource consumption). How the problem is framed can also have a serious impact on the overall performance of the whole system. For example, if the measurement tool requires calculation of storm water runoff from the pavement system, the decision maker might never even consider the question of whether pavement is needed at all. Considering tradeoffs among objectives and designing for an optimal balance of points is left to the decision maker, and can be a serious challenge in all but the simplest of contexts.

Systems-Based Approaches to Measurement

Systems-based measurement tools represent the most comprehensive approach to measuring facility sustainability. Systems-based measurement is equivalent to performance-based measurement, but on the scale of *whole facility systems*, not individual building features. As such, systems-based measurement accounts for interactions and synergies among subsystems that comprise the facility system as a whole as well as between and among the human stakeholders who interact with them. An example of a system-level standard is to allocate credit if the whole facility system generates less than or equal to a certain quantity of storm water runoff for a storm event of a certain magnitude. For instance, current LEED credits dealing with storm water runoff take this approach in contrast to earlier approaches used in v.1.0. The scale of measurement is based on the response of the facility as a whole – runoff from the pavement system as well as other impermeable surfaces such as roofs could be captured by swales surrounding the parking area, or diverted into a settling basin for later use in groundwater recharge or irrigation, or any of a number of other strategies, as long as the combined effect meets the system-level requirement. What matters is the total impact of the whole facility system, which in the storm water example can be different than the mere sum of the impacts of the subsystems due to potential interactions among them.

The challenges associated with systems-based approaches to measurement are primarily associated with predictively understanding the synergistic effects of multiple subsystems acting in concert with one another and in obtaining commensurate and reliable data to conduct the analysis. Very few attributes of the built environment have been effectively modeled on this scale in ways that have been widely adopted by designers as a decision aid. Energy performance is one example – multiple modeling tools of whole building energy performance exist, and a growing number of designers either integrate this capability in-house or rely upon out-sourced expertise to incorporate it into design decisions. Yet the ability to concurrently optimize multiple facility attributes and easily compare implications and tradeoffs with respect to different design alternatives remains elusive. Approaches to concurrently optimizing multiple systems remain in their infancy and often rely on non-traditional modeling techniques such as genetic algorithms (e.g., Wang et al. 2005a, b; Gustafsson 2000). Similar approaches also have been applied in the horizontal facility domain using tools ranging from case-based reasoning to neural networks and Markov chains (e.g., Morcous 2005; Morcous & Lounis 2005a, b).

An interesting point to note is that while it is difficult to accurately *predict* future performance of a facility using a systems-based approach due to the difficulty of modeling complex systems interaction, it is considerably easier to *monitor* performance at a systems level for many project attributes using such an approach through the use of procurement information. By establishing a boundary around the facility system and tracking the flows of matter and energy across that boundary over time, a mass balance-type model can be constructed to model the *actual* performance of the system, thereby permitting inferences about the synergistic effects of the various sub-systems contained within the larger system. Pearce and Fischer (2001; see also Pearce 2008a, b) have developed and applied a protocol for systems-based sustainability analysis in the context of sustainable rehabilitation of historically significant structures that describes in detail the steps and assumptions involved in such an analysis.

Overall, **as levels of familiarity grow with green technology innovations, rating systems in general are evolving to be more performance-based and less prescriptive**. To use prescriptive systems requires increasing sophistication both among designers of green projects and also among those required to measure the outcomes of design. Table 10 compares these three approaches to measurement in terms of required information, validation, and outcomes (Pearce 2008c). The next section discusses the implications of this trend for evaluating the impacts of green rating systems on occupational safety and health.

Table 10: Comparison of Measurement Approaches (Pearce 2008c)

Approach	Information Required	Validation	Outcomes
Prescriptive	Information is needed about the presence or absence of specific observable design features.	A third party inspector typically visits the project to determine whether those features are included, OR the project team may document their inclusion via photographs, videos, or other means and provide this documentation for review by a third party.	If inspection occurs during construction before the system is "enclosed", discrepancies can be corrected before they are irreversible. Design features are typically generic from context to context and may represent significant over-design in order to succeed in the worst case scenario.
Performance-based	Information is needed about the ability of specific facility systems to meet or exceed specified performance thresholds under normal operating conditions.	Performance is typically either (a) observed post-construction through performance testing or during use; (b) predicted using simulation models; or (c) verified using design heuristics applicable to the particular system type and conditions being installed.	If validation is not undertaken until the whole system is completed and functioning, fixing performance failures may be costly and require taking the facility out of service. Validation occurring during design using simulation or heuristics may not correspond to actual facility performance when measured post hoc. Systems can be designed to better fit contextual requirements, thus reducing the penalties of over-design.
Systems-based	Information is needed about the inputs, outputs, sources, and sinks required to implement and operate the facility as a whole. This information may be derived from corresponding information at the subsystem scale.	Simulation or heuristic modeling is required to predict system flows based on design features. Verification of actual flows, sources, and sinks requires careful tracking during delivery and operation.	Problems with predicted performance may not be observable until it is too late to correct them without undoing previous efforts. Isolating and fixing the cause of discrepancies may be difficult. Balancing the impacts of many subsystems can result in whole system performance improvement.

Green Rating Systems and Occupational Safety and Health

For performance-based and systems-based rating systems, drawing ad hoc conclusions about net impact of credits on OSH is not desirable or possible since the desired performance can be achieved in different ways using different technologies and practices with different OSH implications on each project. Typically, as shown in Phase I analysis of Fatality Assessment and Control Evaluation (FACE) reports, incidents are documented in terms of specific actions a person was taking when injured, and/or particular technologies with which he or she was involved and interacting. Accordingly, for example, it is possible to say that skylights and atria represent higher risk for workers during construction, operations, and maintenance than solid roof surfaces. However, it cannot be claimed that every building containing an atrium or skylights is a green building, even if these technologies are frequently used to achieve green building goals such as daylighting and lighting energy use reduction. Lighting energy use reduction goals can be met equally well using other technologies with net neutral or even positive safety and health implications, such as the use of LED lamps with longer life-cycles that require less time working at height to perform maintenance functions. Which technologies are selected to achieve performance goals depends on the project design and delivery team carefully balancing many factors, of which OSH may be one. How, then, can we foresee what may be the OSH implications of the growing trend toward using green rating systems, both in the United States and worldwide, and how might those rating systems be most effectively used to forward the goal of greater safety and health for workers involved with green projects? The next section describes the approach taken in this study to evaluate the impact on OSH of green rating systems presently in use worldwide.

Phase II Approach: Analysis of Green Construction Rating Systems

The objectives of the second phase of study were to review the spectrum of green project rating systems in use worldwide, to evaluate their potential impact on occupational safety and health throughout the project life-cycle, and to develop recommendations for using rating systems to improve OSH on green projects. Four primary tasks were undertaken to answer the four remaining research questions, as follows:

- Identification and Characterization of Existing Rating Systems and Processes
- Comparison of Rating System Schemes and Documentation Keyword Search
- Detailed Review of Best Available Technologies and Strategies
- Development of Recommendations

The following subsections describe the research approach used in each task to answer the respective research questions.

Identification and Characterization of Existing Rating Systems and Processes

The first major task in Phase II was to identify and characterize the population of rating systems presently in use worldwide for green projects. Systems were identified both from popular online databases (e.g., Wikipedia's entry on "Green Building") as well as from the scholarly green building literature (e.g., Pearce et al. 2012). While the list of rating systems examined is not claimed to be exhaustive, it is representative of the major systems currently in use today at the commercial building scale or larger. The focus of the study was on "broad spectrum" rating systems addressing more than a single aspect of building performance. Accordingly, rating systems such as Energy Star and PassivHaus were not included in the analysis due to their singular focus on energy performance. Table 11 shows the list of rating systems identified in this task for further characterization in the study.

Rating systems developed and administered at the local level (e.g., City of Austin, TX; BuildItGreen of Denver, CO; etc.) were also not included in the study, since these local rating systems focus primarily on residential construction which is also covered by several national-level rating systems. In fact, national rating systems compete with these local systems in many instances, and may eventually supersede them as the real estate lending market seeks new ways to consistently evaluate the value added of a green home (Sanderford 2013). With their often prescriptive structure, however, local rating systems capture locally or regionally appropriate best practices (NAHBRC 1999; NREL 2002) that may not be part of performance-based national standards designed to be applicable to a broad range of climates and conditions. Further investigation of the differences among local rating systems is an area for additional inquiry in future research.

As part of classifying the rating systems by project type and scale, each system's documentation was also reviewed to identify process maps, flowcharts, or other indication of how that rating system is to be applied to the project delivery process. Most systems included an explicit description of the points in the project life-cycle where the critical rating tasks were intended to occur. These diagrams or descriptions were compiled and synthesized to answer the research question of what is the role of rating systems in achieving green projects.

Table 11: Rating Systems Addressed in this Study (shading indicates versions)

System	Country of Origin	Year Introduced	Commercial: New construction/Renov.	Commercial: Existing Building	Commercial: Operations/Performance	Commercial: Interiors	Homes: New construction/Renov.	Homes: Existing Building	Infrastructure	Neighborhood/Community
BREEAM	UK	1990	■	■			■	■		■
HQE	France	1992	■		■ *		■			
Green Globes	Canada	1996	■	■	■					
HK BEAM Plus	Hong Kong	1996	■	■		■	■			
SBTool	International	1996	■				■			
EarthCraft	USA	1999	■				■	■		■
EEWH	Taiwan	1999	■	■			■			■
LEED	USA	2000	■	■	■	■	■	■		■
SPeAR	UK	2000	■				■		■	■
CASBEE	Japan	2001	■	■			■			■
KGBC/GBCC	South Korea	2001	■				■			
Green Star	Australia	2003	■	■	■	■				■
CEEQUAL	UK	2003							■	
BOMA-BESt	Canada	2005		■						
Green Mark	Singapore	2005	■	■			■	■	■	■
GRIHA	India	2005	■				■			■
LiderA	Portugal	2005	■							■
Three Star	China	2006	■				■			
Living Building Challenge	USA	2006	■	■			■		■	■
BERDE	Philippines	2007	■		■					
AQUA	Brazil	2008	■	■						■
DGNB	Germany	2008	■				■			■
Estidama Pearl	UAE	2008	■				■			■
LOTUS	Vietnam	2008	■		■ *		■			
GreenRoads	USA	2008							■	
GBI	Malaysia	2009	■	■			■	■		■
GREENSHIP	Indonesia	2010	■	■		■	■			
ITACA	Italy	2012	■				■			
TREES	Thailand	2012	■							
Envision	USA	2012							■	
IS	Australia	2012							■	

* Under development

Comparison of Rating System Schemes and Documentation Keyword Search

After creating a database of existing rating systems at the project scale and classifying them by project type and scale, the next task was to identify the degree to which OSH is explicitly included as part of each system. This task not only addressed the research question of whether or not current rating systems address safety as part of their basic structure, but also provided a systematic basis for selecting a subset of rating systems to further investigate in the next task.

To accomplish a comparison of rating system schemes, each rating system was reviewed either at the checklist level if one was available, at the technical documentation level if no checklist was available, or based on other available literature if no original rating system documentation was available in English or could be parsed for translation using Google Translator, the most reliable method within budget. The "scheme" or structure of each rating system was extracted from the documentation in hierarchical form, generally following a "category--credit--point" hierarchy (e.g., "Site--Alternative Transportation--Alternative Refueling Stations" or "Indoor Environmental Quality--Low VOC Products--Paints and Sealants"). Not all rating systems had this level of detail available in public documentation, and many rating systems had more. At a minimum, the "category--credit" level of detail was captured in outline form in a spreadsheet for further comparison and analysis and was used as a basis for selecting specific rating systems on which to focus in later research tasks.

At the same time, technical guidance documentation for each rating system was searched using the keywords "health," "safety," "hazard," and "toxic" to identify instances in which these concepts had been explicitly mentioned in the rating system documentation. Instances of these terms were noted in a database and compiled to show (a) the topic with associated with each mention; and (b) the overall coverage of these topics for each rating system. Instances were classified into five possible categories, shown in Table 12.

Table 12: Classification of Safety/Health Instances in Technical Documentation

Category	Description
Workers: Credit	A credit exists whose primary focus is on occupational safety and health, or whose primary benefit is an increase in occupational safety or health
Workers: Mention	There is direct mention in the text of a safety or health impact (positive or negative) for workers
Building Occupants: Credit	A credit exists whose primary focus is on improving health and safety of building occupants, or whose primary benefit is an increase in occupant safety or health
Building Occupants: Mention	There is direct mention in the text of a safety or health impact (positive or negative) for building occupants
Public: Mention	There is mention or advocacy of some practice which is likely to have safety or health benefits for society at large

Detailed Review of Best Available Technologies and Strategies

After identifying ways in which each rating system made explicit mention of OSH-related topics, the next step was to evaluate ways in which rating systems *implicitly* might influence the decisions and practices of workers and cause either improvements in or degradation of OSH on green projects. This required a more detailed review of technical guidance documentation available for each rating system to determine what types of behaviors and practices were being advocated to achieve credits under each system.

Many of the credits reviewed in rating systems at the scheme or checklist level were performance-based and did not reference individual practices or technologies. More detailed analysis of technical guidance documents for key rating systems was necessary to provide the link to possible increases or decreases in OSH risk. For example, at the checklist level, an energy-related credit might be stated as "Increase energy performance of the building by 10% over the baseline building energy model." This way of communicating the minimum requirement for the credit allows the project team to determine specific technologies and practices such as atria for natural lighting or high efficiency fixtures that can be combined in the design to most effectively meet the requirement for each individual situation. However, the credit description for a performance-based credit does not typically provide information about specific technologies and practices, although it is at this level that OSH risk is affected overall. Therefore, additional analysis was necessary to map credit requirements against typical technologies and practices for which risk could be evaluated.

Based on the scheme comparison and analysis in the previous task, a subset of rating systems was purposively selected for additional detailed analysis at the practice or technology level. Table 13 shows the rating systems selected for this more detailed analysis. Rating systems were purposively selected to represent major market areas and demographics as well as each of the major families of rating systems, and were limited in scope to those systems used to rate commercial buildings.

Table 13: Rating Systems Selected for Content Analysis

BOMA-BESt (Canada)
CASBEE (Japan)
EarthCraft LC (USA)
Estidama Pearl (UAE)
GBCC (S. Korea)
GreenStar (Australia)
GRIHA (India)
Living Building Challenge (International)
LEED (USA)
Three Star (China)

Technical guidance documentation or manuals were available in English for each of the rating systems selected for this more detailed analysis, and these documents were the primary source of information regarding technologies and practices typically employed to achieve credit requirements. A content analysis approach was taken to analyze relevant guidance documents, in which the research team systematically parsed each manual and identified specific technologies and practices recommended or mentioned in the manual. Each technology or practice was entered into a database associated with the rating system. For rating systems with more than one particular building type or version available, the most recent version of the first scheme developed was selected for analysis (e.g., LEED NC; GreenStar for Offices), since this scheme was likely to have the longest history of evolution, experience, and improvement in use over time.

Over 2,100 individual Best Available Technologies and Strategies (BATS) were extracted from the ten rating systems selected for further analysis, representing approximately 30% of the total rating systems evaluated in the study. The specified BATS are not an exhaustive set of technologies and strategies that can be used to achieve green building certification under these rating systems, and they also may not include conventional building strategies that are combined in new ways to achieve higher performance. However, their explicit mention in technical reference material associated with rating system credits indicates that they can be used on some or all projects to achieve desired performance levels specified in the rating systems.

A random sample of 210 BATS (10%) from this total population was then evaluated in terms of the ten categories of construction hazards identified by Fleming (2009), each in comparison to the analogous conventional construction practice. Differential OSH impacts were identified, both positive and negative, based on instances reported in the literature reviewed in Phase I of the research and based on subject matter expertise of the research team. The outcome of this analysis was a set of differential OSH impacts associated with specific green building technologies and strategies to provide a basis for answering the fourth research question.

Development of Recommendations

After analyzing data extracted from rating system documentation, the last task involved identifying and evaluating possible courses of action that could be taken to improve occupational safety and health by leveraging green building rating systems. To complete this task, both exemplary and typical actions to explicitly include OSH in rating systems were identified and developed as a series of brief case studies.

Based on the ways in which OSH has been incorporated in the rating systems reviewed here, a model was developed of the multiple levels at which OSH can be incorporated into a general rating system credit/point structure. The overall context in which green project rating systems are typically employed also provides a basis for recommendations at a larger scale of analysis. The outcome of this task was a set of possible ways to use rating systems as a vehicle for improving OSH and reducing differential risk introduced by green technologies and strategies where such risk exists. The next section presents the findings from each of these tasks in terms of the research questions investigated in this study.

Phase II Findings: The Effects of Green Rating Systems on Occupational Safety and Health

The findings from this study are focused on ways in which green project rating systems are used in the project life-cycle and how they affect occupational safety and health. The following subsections present findings with regard to each of the major research questions in Phase 2 of the study:

- How rating systems are used in the project life-cycle
- Ways in which OSH topics are *explicitly* covered in existing rating systems
- Ways in which existing rating systems *implicitly* address OSH through recommendation of best practices
- Recommendations for using rating systems to influence project OSH.

Rating Systems in the Project Life-cycle

The first set of findings from review of rating system documentation includes ways in which rating systems are used throughout the project life-cycle to support and influence decision making about the project. Figure 4 shows the major phases of a project's life-cycle along with roles that can be played during each period as identified in the documentation of various rating systems.

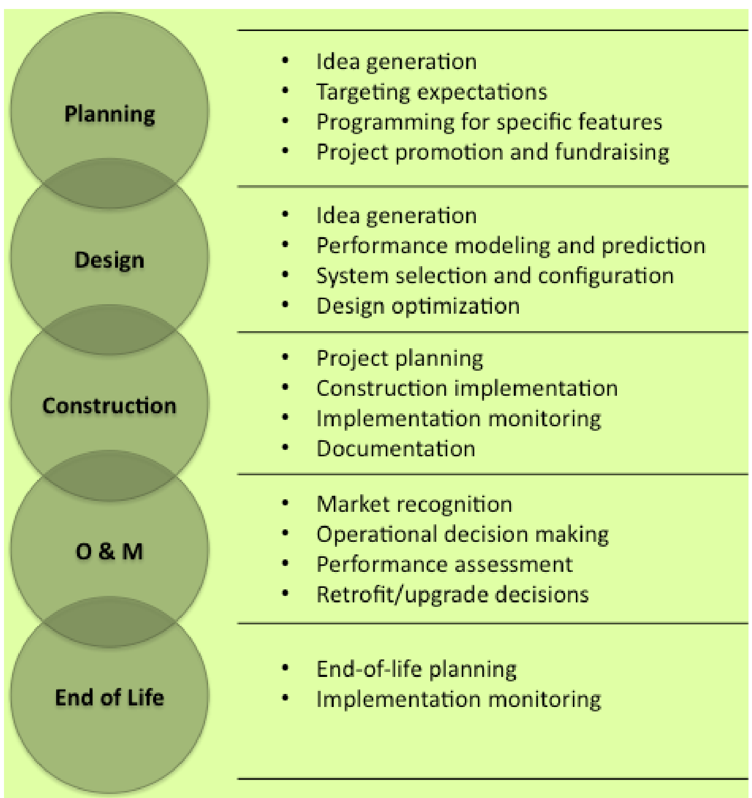

Figure 4: Roles of Rating Systems over the Project Life-cycle

Planning Roles

The planning phase of a project occurs at the beginning of the project life-cycle and is the stage in which a need for a project is identified and the scope and program of requirements for the project is defined. During this stage, specific functional needs and requirements are identified that the project will fulfill, and rough estimates of scope and cost are developed so that funding can be pursued for the project. The nature of the final design solution is not defined at this point, although the owner may identify specific functionalities or features desired in that final solution. Rating system checklists and documentation can be used for idea generation during this phase as a way to identify goals and desired features for the project.

At this stage of the life-cycle, green rating systems are most often used as a basis for goal setting and development and communication of expectations by the owner in preparing a program of requirements and building the project team. Many institutional policies requiring green building dictate only that a particular rating level be achieved, leaving the specific credits selected to reach the goal to be determined by the project team. However, if particular credits within the rating system are mandated for policy reasons or otherwise desired by the owner, actions necessary to achieve the credits may be defined and included specifically in the scope, particularly if these actions are expected to significantly impact the cost of the project. For example, if an owner strongly desires a feature such as a vegetated roof, that feature may be explicitly specified in the program and included as a separate budget item for planning purposes. After project goals and rating system targets have been established, those targets may be used for project promotion and fundraising as well.

Design Roles

The design phase of a project is the period in which a design solution that meets the owner's needs is developed and vetted. During design, the functional needs, objectives, and constraints identified in the planning phase are addressed in the development of a design solution that meets all requirements. In this phase, the project team may use a green building rating system for goal setting and idea generation. The rating system and accompanying documentation, along with the past experiences of the design and construction team, will also likely guide decisions about the types of simulation models that need to be built and the types of features, systems, and practices that can be incorporated into the project to achieve green goals and desired rating system outcomes. The team will iterate through the design process to develop increasingly detailed and refined solutions that provide the best possible performance within the envelope of cost and schedule feasibility.

Many credits in green project rating systems focus heavily on decisions made during the design phase, and the rating system itself serves as a yardstick of performance used by the design team to evaluate potential solutions. Performance- or systems-based rating systems will include credits that require evaluation of project performance using simulation models, and prescriptive credits will be evaluated based on the presence or absence of particular attributes or features within the design solution. During this phase, the team may also incorporate construction phase stakeholders to evaluate how design decisions may be implemented in the field, and what tradeoffs may exist between these two phases. The outcome of the design process is a project solution that can be built during the next phase, construction.

Construction Roles

In the construction phase, the design solution developed in the previous phase is brought to existence through the application of labor, materials, equipment, and other resources in the field. The construction phase is responsible for considerable environmental impacts, so rating systems are used during this phase to guide choices and decisions about material procurement, equipment selection, means and methods to use, and conditions and constraints to impose upon the construction process. Rating systems may provide performance criteria for objectives such as landfill waste diversion or minimization of site disturbance, or they may require processes such as commissioning, measurement and verification of system performance, or documentation of material sources and properties. In the project execution planning stage of construction, just as during design, rating systems can be used as a yardstick to evaluate various approaches to construction and help to optimize the design of the construction execution plan. They will often provide guidance as to what should be monitored and documented during this phase to allow evaluation after the project is complete and partially constructed systems can no longer be directly seen. The outcome of this phase is a finished, usable building or infrastructure system that can achieve the original design intent and meet the owner's needs.

Operations & Maintenance (O&M) Roles

The operations and maintenance phase of an average building's life-cycle represents a considerable share of its life-cycle environmental impacts, but those impacts are to a large degree determined by decisions made earlier in the project's life. Two types of rating systems have evolved to be applied during this phase of the project. The first is designed to follow after the use of a design/construction rating system for a facility certified during earlier life-cycle phases. These systems focus on improving the performance of the facility during operation and also on activities that specifically pertain to the operations phase, such as housekeeping. The other type of rating system applied during operations is designed for application to existing buildings that have not been previously certified or rated. This type of rating system can help to guide retrofit decisions to improve building performance in addition to improvements in general operations. With either approach, rating systems can be used to provide market recognition, assist in operational decision making and performance assessment, and guide decisions to renovate, upgrade, or otherwise adapt the building over time to better meet the owner's needs.

End of Life Roles

While most rating systems do not explicitly address end of life-cycle activities from the standpoint of the *existing* use of the facility, many do include credits such as managing demolition waste as part of the scope of project evaluation for a *new* facility replacing an old facility. A few rating systems have also begun to include credits for design for disassembly or reuse at the end of the project life-cycle, most notably Green Star Australia and Estidama Pearl. These credits encourage the project team to look far ahead at the project's expected service life during planning and design, and make choices to maximize flexibility and sustainability over time.

In summary, there are opportunities to make use of green rating systems for various purposes throughout a project's life-cycle, of which establishing a formal third party rating or certification is only one. It is important to note that in general, the use of rating systems is not obligatory unless it is mandated by the owner's organization or by policy in the area where the facility is located. For example, the U.S. General Services Administration has mandated that all of its new projects and major renovations achieve a LEED Gold rating or higher as part of its plan to meet federal environmental goals[1]. Likewise, public buildings in Singapore are mandated by law to achieve various levels of rating under the Green Mark system depending on their type and location[2]. However, even though use of rating systems is not generally mandatory for most projects, many projects have elected to make use of rating systems for the purposes discussed earlier, and these roles offer opportunities to change the ways in which OSH is considered in green projects.

Explicit Coverage of OSH Topics in Existing Rating Systems

The second set of findings targets the question of ways in which OSH is explicitly addressed in existing rating systems. To answer this question, a population of thirty-one rating systems was reviewed by searching for credits in each schema that were explicitly targeted toward OSH, and also by keyword searching of technical documentation to identify mention of OSH-related issues in the rating system. Instances were classified into categories based on *who* was addressed (Workers vs. building occupants vs. general public at large) and the degree of focus (whole credit vs. mention as part of a credit targeted for another purpose). Table 14 shows the types of mentions identified in each of the rating systems.

As shown in the table, *all* rating systems reviewed had at least some content pertaining to safety and health, and most systems had at least some mention, if not entire credits, dedicated to topics related to occupational safety and health at some point during the project life-cycle. The following subsections describe the specific topics identified in each category shown in the table.

---

[1] http://www.gsa.gov/sustainabledesign

[2] http://www.bca.gov.sg/Envsuslegislation/Environmental_sustainability_legislation.html

Table 14: Rating Systems and Levels at Which They Identify Safety and Health Issues

			Workers		Building occupants		Public
System	Range	Year Introduced	Credit	Mention	Credit	Mention	Mention
BREEAM	International	1990	x	x	x	x	x
HQE	International	1992	x	x	x	x	
Green Globes	Canada/US	1996	x	x	x	x	x
HK BEAM Plus	Hong Kong	1996	x	x	x	x	x
SBTool	International	1996	x		x		
EarthCraft	Southeastern US	1999	x		x	x	
EEWH	Taiwan	1999			x		
LEED 4.0	International	2000	x	x	x	x	x
SPeAR	International	2000	x		x		x
CASBEE	International	2001	x	x	x	x	
KGBC/GBCC	South Korea	2001			x	x	
Green Star	Australia, NZ, SA	2003	x	x	x	x	x
CEEQUAL	International	2003	x	x	x		x
BOMA-BESt	Canada/US	2005	x	x	x	x	
Green Mark	Singapore	2005		x	x	x	
GRIHA	India	2005	x	x	x		x
LiderA	Portugal	2005	x	x	x	x	
Three Star	China	2006	x	x	x	x	
Living Bldg Chal	International	2006	x		x	x	
BERDE	Philippines	2007	x	x	x	x	
AQUA	Brazil	2008	x	x	x	x	x
DGNB	International	2008		x	x	x	
Estidama Pearl	UAE	2008	x	x	x	x	x
LOTUS	Vietnam	2008	x	x		x	
GreenRoads	USA	2008	x	x	x	x	x
GBI	Malaysia	2009	x		x		
GREENSHIP	Indonesia	2010	x		x	x	x
ITACA	Italy	2012			x	x	x
TREES	Thailand	2012			x		
Envision	USA	2012	x	x	x	x	x
IS	Australia	2012	x		x		

Safety and Health Credits for Workers

Table 15 shows a clustered list of topics in which health and safety of workers were the primary focus of a credit and for which at least one specific point would be awarded under at least one rating system for a health- or safety-specific action related to a worker. Credits were clustered into six major categories, as follows:

- Healthy Construction Materials and Products
- Avoidance of Exposure to Hazardous Substances
- Life-cycle Prevention through Design (PtD)
- Working Conditions during Construction
- Working Conditions during Maintenance
- Organizational Processes and Plans

In this analysis, a worker is defined as a person involved with a building or project as a primary job responsibility, as opposed to a person who is merely an occupant or user of a built facility. Mentions of safety/health topics were included in this category if benefits to workers were explicitly mentioned in the credit documentation. Selected credits under this category are discussed further in the Recommendations section if they were determined by the research team to be exemplary in their coverage or approach of OSH topics.

Table 15: Safety and Health Credits for Workers

Healthy Construction Materials and Products

- Non-offgassing/low emitting
- Ability to resist bacteria or fungi
- Avoidance of mercury exposure
- Avoidance of exposure to toxins or radiation
- Non-polluting
- Red list avoidance
- Cleaning products - green
- Pavement - emissions reduction
- Material ingredients - content disclosure

Avoidance of Exposure to Hazardous Substances

- Hazards/contamination assessment/survey during technical site assessment
- Hazardous materials storage/management/disposal
- Hazardous chemicals management plan
- Polychlorinated Biphenyls (PCBs) - safe storage
- Material Safety Data Sheets (MSDS) - presence of
- Workplace Hazardous Materials Information System (WHMIS)
- Hazardous materials - purchasing policy
- Pest prevention technology - non-polluting
- Hazardous waste disposal – segregation/mgt
- Potable water – safe localized treatment
- Wastewater - safe localized treatment
- Water reuse – avoidance of exposure to hazards
- Furniture and medical furnishings off-gassing
- Brownfields/safe levels of subsurface contamination after remediation
- Waste management - hazardous/solid/recyclables
- Site remediation – soil, groundwater, and

Working Conditions during Construction

- Indoor Air Quality management during construction
- Lighting - appropriate levels/visual comfort
- Acoustics - control of noise during construction
- Operational safety equipment (e.g., eye wash stations)
- Dust control during construction
- Safety and security
- Thermal comfort
- Worker's amenities - safety and sanitation
- Community and user safety - during construction
- Protection from electromagnetic radiation
- Ventilation - appropriate/healthy/adequate outside air
- Avoidance of short term hazards during construction
- Safety, accessibility, and wayfinding during construction
- Equipment - emissions reduction

Working Conditions during Maintenance

- Legionella exposure/prevention
- Mold growth prevention
- Microbial contamination - prevention
- Exterior glass and walls – safe maintenance
- Air supply and vent holes – safe maintenance
- Lighting – safe maintenance of
- Fixtures in high places – safe maintenance of
- Maintainability
- Maintenance rooms - health of
- O&M Manuals - swimming pools to control TCE concentrations
- Swimming pools – maintenance to preserve water quality

surface water **Life-cycle Prevention through Design (PtD)** • Service life planning for safe operation • Life-cycle costing considering safe operation • Outlets – Placement to avoid electrical extension cord hazards • Water quality – use of compatible materials • Design for human/natural threats • Landscaping - reducing exposure to allergens and toxins • Site selection - careful use of contaminated sites • Structural elements - pre-forming voids for planting to reduce structural risk • Design for disassembly/deconstruction - inclusion of safety in brief • Crime prevention/environmental design - temporary construction	• Pests - Integrated Pest Management (IPM) • Maintenance - planned safe access for • Quality of ducted air **Organizational Processes and Plans** • Green training policies - preserve resources/conserve public health • Educational outreach - health/safety training meetings • Contractor - ISO 14001 certified • Contractor - ESH program/supervisor • Use of HACCP/ISO 22000 • Building life safety certification • Environmental site assessment • Integrative project planning and design • Material supply chain - ESH requirement • Construction health and safety policy/plan • Construction management plan - review by construction safety specialist • Health Impact Assessment • Health and Safety - going beyond regulations to consider all stakeholders • Noise Mitigation Plan • Safety audit • Labor standards • Responsible construction practices

OSH Mention in Other Credits

Table 16 shows clustered topic areas in which mention was made of safety or health impacts to workers, but which did not have enough significance within a rating system in which they were mentioned to warrant specific points or credits. The same clusters were used for these mentions as for credits in the previous section. Some overlap exists with the individual topics shown in Table 15, indicating different priorities across rating systems for health and safety topics. In other words, what is considered important enough to rate being a credit in one rating system is not necessarily considered important enough or even within scope at all in other rating systems.

Table 16: Occupational Safety and Health Mention in Other Credits

Healthy Construction Materials and Products

- Cleaning products - environmentally friendly
- Reused building elements - fire safety
- Materials register - health and safety file
- Use of local/regional materials
- Waste materials - reuse on site

Avoidance of Exposure to Hazardous Substances

- Asbestos - encapsulation
- Hazardous waste disposal - monitoring/management of
- Site contamination/brownfields - remediation before construction
- Alternative refrigerants - health impacts/hazards
- Cleaning chemicals - safe drainage for
- Pollutant source control
- Persistent, Bioaccumulative, and Toxic (PBT) substance source reduction
- Hazardous waste - reduction

Life-cycle Prevention through Design (PtD)

- OSH issues - included in design intent
- OSH issues - project planning for
- OSH issues - addressed in commissioning
- Site selection - hazard avoidance (disasters)
- Site selection - hazard avoidance (EMF radiation)
- Site selection - hazard avoidance (polluting sources)
- Air conditioners - provisions for safe replacement with more energy efficient models

Working Conditions during Construction

- Guest worker accommodation
- Light pollution
- Indoor Air Quality (IAQ)
- Noise levels
- Ventilation
- Existing buildings - safe reuse
- Considerate construction practices
- Waste management - construction
- Project traffic impact
- Construction nuisance - mud on roadways
- Construction nuisance - light pollution from night work
- Solid waste - landfill diversion
- Warm Mix Asphalt to replace Hot Mix
- Fossil fuel reduction

Working Conditions during Maintenance

- Ease of cleaning
- Elevated lighting fixtures - building features to allow safe maintenance
- Pollution control ponds/wet detention basins - control of deep water
- Pollution control ponds/wet detention basins - control of mosquito growth
- Pollution control ponds/wet detention basins - management of BOD to prevent water-borne disease
- Indoor Air Quality (IAQ)
- Noise levels
- Humidity control
- Alternative water systems - safe use
- Demolition - planning and supervision for safety
- Recyclables storage
- Risk from introduced animal species
- Water environment - safety issues with enhancement of
- Noxious weeds - safe disposal of
- Infiltration/evapotransporation levels - return to predevelopment levels
- Water use tracking

Organizational Processes and Plans

- Project team - including safety specialists
- Hazard assessment reporting
- Construction mgt system - safety included
- Design management - safety included
- O&M manuals - MSDS included
- O&M manuals - maintainability
- Maintenance management (cleaning and public health)
- Facility management - documentation
- Construction Environmental Mgt Plan
- Landscape/irrigation - plan including safety/environmental goals
- Site Maintenance Plan
- Exterior wall cladding systems - subcontractor site-specific safety plan
- Operations - operator training
- Sustainability Management System - address safety/health in
- Leadership
- Supply chain OSH requirement
- Lifecycle Assessment
- Environmental Management System
- Environmental training

Safety and Health Credits for Building Occupants

Table 17 lists topics in which health and safety of building occupants was the primary focus of a credit or point. Credits were clustered into six major categories, as follows:

- Healthy Construction Materials and Products
- Avoidance of Exposure to Hazardous Substances and Other Hazards
- Life-cycle Prevention through Design (PtD)
- Improved Indoor Environmental Quality (IEQ)
- Improved Outdoor Environmental Quality
- Organizational Processes and Plans

It should be noted that many of these actions could *also* conceivably benefit workers who spend time in facilities where they are used, although explicit mention was not always made of these benefits. For example, improved indoor air quality has potential health benefits for all building occupants including those responsible for building operational and maintenance, but in many cases these stakeholders were not called out separately in the documentation. If workers were mentioned explicitly, the topic would also be listed as a worker credit or mention in Tables 15 and/or 16.

Table 17: Non-Occupational Safety and Health Credits for Building Occupants

Healthy Construction Materials and Products

- Non-offgassing/low emitting
- Ability to resist bacteria or fungi
- Avoidance of mercury exposure
- Avoidance of exposure to toxins or radiation
- Non-polluting
- Red list avoidance
- Pest prevention technology - non-polluting
- Cleaning products - green
- Material ingredients - content disclosure
- New materials and technologies - consider implications of

Avoidance of Exposure to Hazardous Substances and Other Hazards

- Reduced electromagnetic radiation exposure
- Reduced hazardous materials exposure
- Mold growth prevention/reduced exposure to toxic spores
- Reduced Legionella exposure/prevention
- Biological pollutant control
- Improved fire safety
- Water reuse - on-site safety
- Wastewater - safe localized treatment
- Potable water – safe localized treatment
- Water quality - compatible materials
- Swimming pools – maintenance to preserve water quality
- Combustion equipment - safe
- Waste management and disposal - hazardous/solid/recyclables

Improved Indoor Environmental Quality (IEQ)

- Daylighting/natural light exposure
- Ventilation - appropriate/healthy/adequate outside air
- CO2 monitoring
- Acoustic wellness/performance
- Acoustics - control of indoor noise
- Thermal comfort/Thermohygrometric wellness
- Lighting - appropriate levels/visual comfort/quality
- Indoor Air Quality (IAQ) - management during construction
- Improved water quality
- IAQ flush out prior to occupancy
- Smoking/Environmental Tobacco Smoke (ETS) control
- Indoor pollutants - monitoring system
- Interior plants
- Views to outside
- Quality of ducted air

Improved Outdoor Environmental Quality

- Lighting - sufficient quality for security/safety while avoiding light pollution
- Safe access to building and walking areas (traffic and crime threats)
- Site selection - access to transit
- Site selection - surrounding density/diverse uses
- Landscaping - reduced exposure to allergens

- Integrated Pest Management (IPM)
- Hygiene of plumbing, drainage, and building amenities
- Furniture and medical furnishings off-gassing
- Brownfields - safe levels of subsurface contamination after remediation
- Site remediation – soil, groundwater, and surface water
- Tall buildings - safety risk during emergency egress
- Earthquake safety
- Community and user safety - during operations

Life-cycle Prevention through Design (PtD)

- Safety and security - planning for external threats
- Site selection – careful use of contaminated sites
- Site selection - hazard avoidance
- Site selection - certified neighborhood
- Floor load margin – increased safety margin
- Crime prevention/environmental design - attention to local character
- Elderly - design for special needs of
- Indoor pollutants - control/minimization of
- Maintainability
- Design for human/natural threats
- Safe refuge area
- Places of respite
- Accessibility and wayfinding
- Health and wellbeing - social networks and social vibrancy

and toxins

- Direct exterior access
- Transportation - user safety for all modes
- Bicycle and pedestrian facilities
- Active transport - contribution of project to
- Recreation - contribution of product to
- Community connectedness/cohesion - contribution of project to
- Civilized environment
- Biophilia/access to green space
- Traffic emissions reduction
- Quiet pavement

Organizational Processes and Plans

- Stakeholder participation
- Building user guide - covers safety issues
- Building users - room occupant survey
- Green training policies - preserve resources/conserve public health
- HACCP/ISO 22000
- Environmental site assessment
- Material supply chain - ESH requirement
- Health and Safety - going beyond regulations to consider all stakeholders
- Health and Safety plan
- Leadership and commitment
- Safety audit

Non-occupational Safety and Health Mention in Other Credits

Table 18 lists topics and issues from rating system documentation where mention was made of health or safety impacts to building occupants, but which did not have enough significance within the rating system in which they were mentioned to warrant specific points or credits. Issues were clustered into the same six categories as with non-occupational safety and health credits. As with workers, some overlap exists between this list and Table 8, indicating different priorities about the importance of these topics across different rating systems.

Table 18: Non-Occupational Safety and Health Mention in Other Credits

Healthy Construction Materials and Products

- Material selection - health impacts
- Low Volatile Organic Compounds (VOC)/formaldehyde-free
- Antibacterial materials in health care settings
- Lamps - low mercury
- Persistent, Bioaccumulative, and Toxic (PBT) substance source reduction
- Reused building elements - fire safety
- Use of local/regional materials

Avoidance of Exposure to Hazardous Substances and Other Hazards

- Improved fire safety
- Waste management, reduction, and disposal - hazardous/solid/recyclables
- Waste management - special provisions in healthcare facilities
- Recycling containers - risk at mental health facilities
- Noise emissions control
- Site contamination/brownfield remediation
- Clotheslines - ligature risk
- Cleaning chemicals - safe drainage for
- Combustion equipment - safety
- Power supply - cogeneration for safe production during disasters
- Wastewater - health impacts of on-site treatment
- Greywater reuse - health impacts
- Net-zero water - health/safety risks
- Water conservation - exceptions where there is risk of infection
- Hot water systems - Legionella-free
- Operable windows - health/safety risks
- Electrical grid - safe/reliable
- Flood risk minimization
- Reduced risk of fire/explosion/spills
- Reduced toxic chemical exposure

Life-cycle Prevention through Design (PtD)

- Safety and security
- Energy-saving elevators - tradeoffs in safety levels
- Existing buildings - safe reuse
- Site selection - hazard avoidance (disasters/adverse geology/steep slopes)
- Site selection - hazard avoidance (EMF radiation)
- Site selection - hazard avoidance (polluting sources)

Improved Indoor Environmental Quality (IEQ)

- Improved Indoor Air Quality (IAQ)
- Exhaust riser - per tenant
- Humidity control
- Ventilation health/rate
- Pollutant source control
- Indoor Air Quality (IAQ) - wet areas
- Indoor Air Quality (IAQ) - control during construction
- Smoking/Environmental Tobacco Smoke (ETS) control
- Air change effectiveness
- Daylight access/exposure
- Lighting - appropriate levels/visual comfort/high frequency ballasts
- Views (tradeoffs with barriers/safety measures)
- Noise levels - interior
- Improved water quality
- Thermal comfort

Improved Outdoor Environmental Quality

- Lighting - exterior security/nighttime safety/reduction of light pollution
- Walkway security/pedestrian access
- Bicycle facilities/parking - safety of
- Traffic safety
- Secure parking
- Non-vehicular transportation - safe access to
- Amenities - safe walking distance from
- Resources - conserving resources that support human health
- Heat island effects – reduction in
- Intelligent transportation system (ITS)
- Public space – safety/crime prevention

Organizational Processes and Plans

- Safety regulations - compliance with
- Maintenance management (cleaning and public health)
- Refrigerant monitoring
- Chemical Management and Minimization policy
- Pest reduction plan - management of toxins
- Hazard controls in place
- Indoor Air Quality (IAQ) - assessment
- Environmental Review Process
- Site Maintenance Plan
- Pavement Management Plan – include safety
- Lifecycle assessment
- Quality control plan

- OSH issues - project planning for
- Material selection - use that preserves materials for future safe use
- Healthy communities - design for
- Disasters - adaptation/mitigation of buildings for
- Disabled persons - access for
- Flood resistance
- Storm water cost analysis - consider health/safety
- Context-sensitive solutions
- Reduction in emergency services needed

Mention of Safety and Health Impacts at a Larger Scale

Several other instances were also observed in the rating system documentation analysis in which safety and/or health issues were mentioned, but no explicit link was established to direct facility stakeholders, either occupational or non-occupational. These instances pertained to benefits that might accrue to public health or safety in general at the community or global scale as a result of green project actions, or which might increase if green actions were *not* undertaken. Table 19 lists these topics and issues identified in the documentation of various rating systems, classified as benefits and risks at both the local neighborhood and global levels. Note that no mentions were found in the analysis that would increase risk at the global level as a result of green project rating system actions.

Table 19: Indirect Safety and Health Issues Identified

Neighborhood Benefits Resulting from Project	Neighborhood Risks Resulting from Project
• Local water resources - safeguarding • Car parking - provision of • Bicycling • PVC minimization • Contaminated sites/Brownfields - reclamation of • Reduced flood risk • Urban safety improvements • Heat island effects – reduction in • Pollution prevention plan • Runoff - flow control and quality improvement • Reduced road noise effects • Ecological connectivity to reduce risk of traffic incidents • Low Impact Development - health benefits • Site vegetation preservation • Noise and vibration reduction • Light pollution reduction • Air quality improvement	• Exterior landscaping - enhanced allergy risk • Greywater/blackwater systems – health impacts/risks • Green infrastructure - health impacts/risks • Water reuse - health impacts/risks • Air pollution during construction • Rapidly renewable materials - potential fire hazard **Global Benefits Resulting from Project** • Reduction in greenhouse gas emissions/Global Warming Potential (GWP) • Refrigerants - reduced ozone-depleting potential (ODP) • Material selection - locally manufactured to reduce transport impacts • Sensitive land - protection/development avoidance (flood plains) • Conflicting regulations and policies - address in plan • Site selection - greenfield preservation • Surface/groundwater contamination - prevention • Pavement reuse – resource conservation • Connection to place/natural environment • Biodiversity preservation

Other Mentions of Safety and Health in Rating System Documentation

In addition to mention of safety and health issues within the schema and credit descriptions for rating systems, some rating systems also mentioned safety and health in other parts of their documentation, generally in conjunction with the scope of the rating system itself. For example, the EarthCraft Light Commercial rating system explicitly *excluded* safety considerations from its scope, most likely for legal liability reasons, with the following language (EarthCraft LC Technical Guidelines, v. 1.0, p. iv):

> *Please note that the program participant is solely responsible for the project's design and construction. EarthCraft and its representatives are responsible only for verification of the completion of EarthCraft requirements and point items as set forth in the Technical Guidelines; such verification in no way constitutes a warranty as to the sufficiency, quality, preparation or comprehensiveness of the final design or for the construction of the Project in accordance with the approved final design. EarthCraft and its representatives*

> *shall not have control over, nor be responsible for, the construction means or methods, construction techniques, construction sequencing, or for safety precautions required of the Project.*

Likewise, the GreenMark Certification Standard 2012 also scopes out safety and health requirements already dealt with in other applicable laws, codes, and policies, as follows (p. 1):

> *This standard sets out the requirement for assessing the environmental performance of a building development. This Standard is not intended to abridge safety, health, environmental, or related requirements contained in other applicable laws, codes, or policies administered by relevant authorities.*

In contrast, the Sustainable Construction Safety and Health (SCSH) Rating System (Rajendran 2006) was developed *explicitly* with the intent to address the lack of coverage of OSH topics in then-current versions of the LEED Green Building Rating System. The SCSH Rating System is intended to be applied in conjunction with LEED, not displace it, although it could also be applied independently to a project that was not employing a green building rating system. Due to its exclusive focus on occupational safety and health, this rating system did not meet the screening criterion of being broad spectrum, and so it was not included as a separate system in the rating system analysis. However, it is examined in more detail in the Recommendations section of this report as an exemplar of how OSH could be more explicitly included as part of existing rating systems.

Additional Occupational Risks at the Credit/Point/Practice Level

The objective of the third main task in Phase II was to determine whether green rating systems encourage practices and processes that may affect occupational safety and health risks as a side effect to achieving improved environmental facility performance. The aim of this task was not to provide a comprehensive catalogue of green Best Available Technologies and Strategies (BATS), but instead to sample a population of practices generally associated with green projects in rating systems across multiple contexts and cultures. These practices could then be evaluated for their possible health and safety impacts compared to conventional practices. If a possible risk differential can be identified for practices mentioned or advocated by green rating systems, then these rating systems may have an impact on occupational safety and health, either positive or negative.

Comparison of BATS with Baseline Technologies

A random sample of ten percent of the approximately 2,100 BATS in the study population was selected to represent the population overall, and the research team reviewed each BATS to determine possible implications for OSH compared to conventional practice. Both positive and negative potential impacts were identified, and each BATS was classified as positive, negative, or neutral in terms of risk compared to conventional practice.

A majority of BATS in the sample were determined to have at least one possible OSH implication compared to conventional practice (148 out of 210), either positive, negative, or both. Approximately 40% of BATS affecting occupational safety and health would impact stakeholders during the Construction phase of the project, and approximately 60% would impact workers during Operations and Maintenance. Less than one percent (only one out of 210 BATS sampled) was determined to impact stakeholders at the End of Life-cycle phase, indicating that most rating systems have not yet begun to seriously focus on this phase of the project life-cycle. Table 20 shows examples of OSH impact descriptions compared to baseline technologies for BATS in the sample, to illustrate the type and range of impacts identified.

Table 20: Examples of OSH Impact Descriptions for Sampled BATS

Best Available Technology or Strategy (BATS)	Baseline	OSH implication compared to conventional practice
Non-potable makeup water for pool/spa	Utility-treated potable water	Potential exposure to pathogens
Low NOx emitting boilers	Conventional boiler	No change
Minimum thermal break for steel stud framing	Thermally-bridged walls	Lower likelihood of condensation leading to mold
Agri-products such as coconut, hemp, etc.	Synthetic products	Depends on what it displaces
Materials consumption management system	No materials management	Reduction of unwanted exposure to moisture and mold
Greywater recycling	Utility wastewater treatment	Potential exposure to pathogens
Non-toxic mold inhibitor applied to lumber	Conventional mold inhibitor	Reduced exposure to toxins
Dual function roof cladding (e.g., BIPVs; roof garden)	Conventional roof	Greater exposure to falls from work at height; electrocution
Use of eco-friendly material (Eco Mark, GR Mark)	Conventional, unlabeled materials	Reduced exposure to toxins for some labeling systems
Recycled content, recyclable materials	Conventional products	Varies by product
Bicycle route & parking available	No bicycle amenities	Mix of transportation modes may increase risk of accidents
Double-duct system (4 pipes for air-handling units)	Single-duct system	Improved indoor air quality/humidity management
Avoidance of pesticide and herbicide application	Prophylactic pesticide application	Reduced exposure to toxins
Flushing of supply lines in infrequently used washrooms	No flushing of lines	Improved water quality/reduction in pathogen exposure
Drift eliminators on cooling towers	Towers with no drift eliminators	Reduced exposure to pathogens (Legionella)
Hardened facades	Conventional facades	Reduced threat from explosions/natural disasters

Mapping of BATS to Construction Hazard Types

BATS were also mapped to the ten construction hazard types identified in the Fleming taxonomy of construction hazards (2009). Figure 5 shows the distribution of impacts according to this taxonomy, in terms of both positive and negative impacts for each category. As can be seen in the figure, the most impacted type of hazard across the sample was chemical hazards, including flammable vapors, reactive hazards, corrosives, toxic compounds, oxygen-deficient atmospheres, and others. The majority of BATS in this category *reduced* chemical hazards to workers (40 out of 64), primarily through substitution of materials with lower toxicity and use of practices to improve indoor air quality. However, some BATS in the sample potentially increased the level of chemical hazard as well, such as the use of alternative refrigerants with additional toxicity to humans, use of nanotechnology-based paints and coatings for thermal performance, or the use of roadbed materials containing ferrous slag.

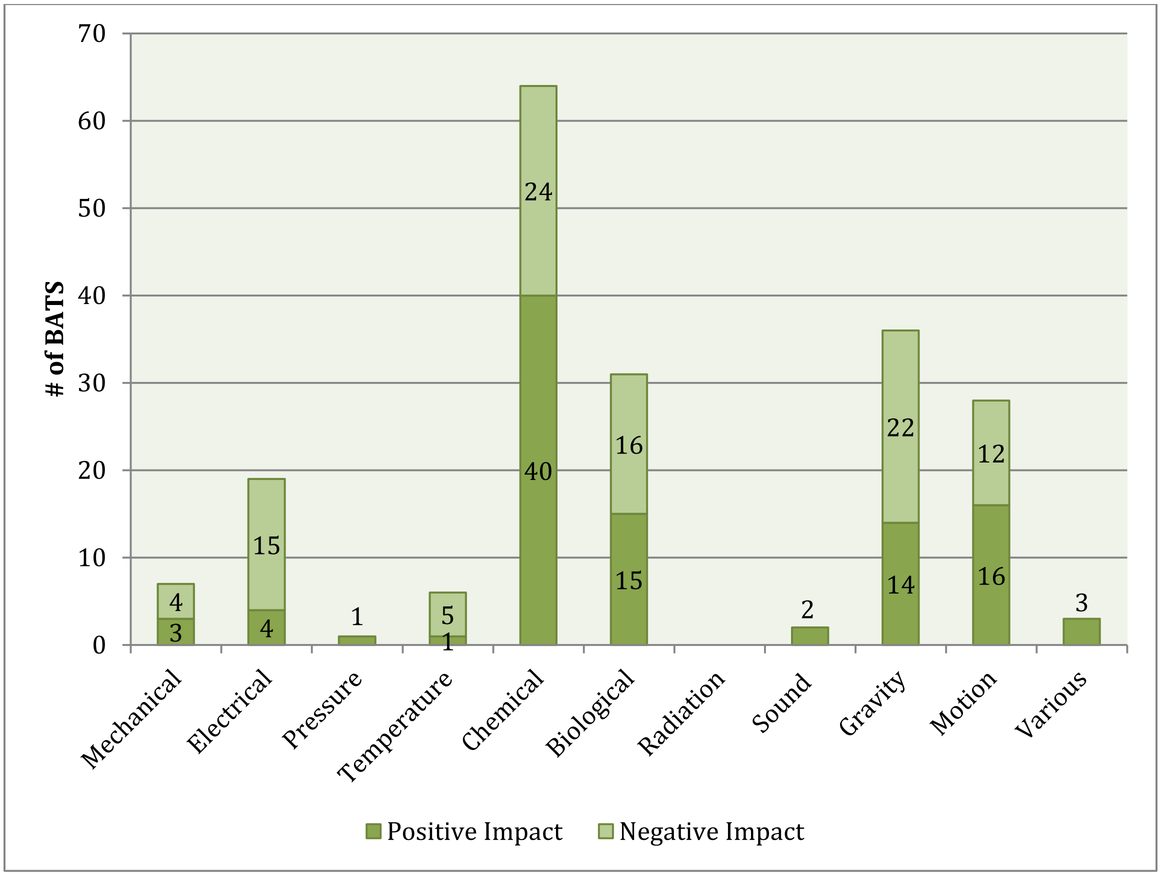

Figure 5: Distribution of Hazard Impacts across Sampled BATS

Overall, based strictly upon an item count, a higher number of BATS in the sample had positive impacts (86 out of 210) than negative impacts (77 out of 210) with regard to occupational safety and health during construction, operations/maintenance, and end of life-cycle phases. The level of analysis conducted in this study does not permit accurate comparison of the *magnitude* of impacts, so these proportions do not necessarily reflect overall net change in risk. However, they do suggest that there are both positive *and* negative OSH impacts associated with green technologies and strategies that must be considered in evaluating the overall impact of green rating systems on occupational safety and health.

Approximately half of the hazard categories in the typology had more BATS with negative impacts than with positive impacts, including mechanical, electrical, temperature, biological, and gravity hazards. A review of BATS in these categories suggests the following trends in green project technologies and strategies that may be responsible for differential risk in these areas:

- Many mechanical hazards can be explained by increased material handling requirements of green practices, such as hazards associated with separation, processing, and storage of recyclables and hazards associated with more frequent replacement or maintenance of certain products selected for their lower toxicity or environmental impacts.
- Increased electrical hazards most frequently stem from (a) greater use of sensors and controls to monitor building conditions and performance and make operational adjustments; and (b) increased use of on-site renewable energy and alternative fuel technologies such as fuel cells, photovoltaics, and others, which increase exposure of building stakeholders to electrical components that have historically been located away from the building as part of central utilities.
- Increased temperature hazards can be partially attributed to practices involving district or regional heating and cooling, where higher temperatures are needed to achieve desired temperatures at the building level.
- Increased biological hazards can be largely attributed to potential pathogen exposures associated with alternative water treatment and reuse practices such as greywater reuse, rainwater harvesting, low impact development strategies for treatment of storm water, and others. At the same time, multiple BATS were specifically addressed toward measures to reduce risk of Legionnaires' disease and mold growth, indicating an increased awareness of and attention to these problems.
- Increased gravity hazards seem to stem largely from the increased use of building envelope components as a platform for other functions such as renewable energy generation, green roofs, and daylighting. Each of these functions requires additional work at height during construction and/or operations and maintenance that increases exposure to potential fall risks.

In summary, while it is not possible to draw definitive conclusions about the net impact of green practices, technologies, and strategies on operational safety and health, multiple instances were identified of BATS that were likely to both *increase* and *decrease* OSH risk for stakeholders. This suggests a need for additional investigation to further determine both the nature of the risk involved and measures that can be employed to reduce it.

Recommendations for Using Rating Systems to Improve Occupational Safety and Health

The last task in the investigation focused on developing recommendations for ways in which rating systems can be used to improve occupational safety and health for stakeholders of capital projects by leveraging green building rating systems. To complete this task, both exemplary and typical actions to explicitly include OSH in rating systems were identified during the review of rating system documentation and developed as a series of brief case studies. These actions fall within four basic types of approaches, including:

- Stand-alone Safety and Health Tools
- Reference Codes and Standards
- Green Rating System Credits – OSH-Focused
- Green Rating System Credits – Incidental OSH Benefits

The following subsections describe each of these major approaches and present examples of each. The chapter concludes with an overview of strategic entry points for OSH in green project rating systems.

Stand-alone Safety and Health Rating Tools

The most straightforward approach to including OSH as part of a project's goals is to use a stand-alone tool focused specifically on the project's OSH performance. One tool, the ***Sustainable Construction Safety and Health (SCSH) Rating System***, was identified that has been developed for just that purpose. The SCSH Tool v.1.0 was developed by S. Rajendran (2006) with the intention of being a complement to existing green rating systems that focus primarily on ecological or environmental impacts. Organized into thirteen major safety and health categories, the system provides a means to rate projects based on relative importance given to the categories and degree of implementation of the elements in the categories. Twenty-five elements of fifty are prerequisites and must be implemented to some degree to receive a rating under the SCSH system. The system can be applied to all project types, either in conjunction with or independent of other green project rating systems. Its exclusive focus on safety and health mean that there is minimal overlap in topical coverage with most green rating systems (Table 21).

Table 21: Sustainable Construction Safety and Health (SCSH) Rating System

Project Team Selection • Constructor Selection • Subcontractor Selection • Designer Selection **Safety and Health in Contracts** • Safety and Health Requirements in Contracts • Safety and Health Hazard Identification in Drawings • Specification of Less Hazardous Materials **Safety and Health Professionals** • Competent Personnel for all High Hazard Tasks • Owner Safety Representative • Constructor Safety Representative • Subcontractor Safety Representative **Safety and Health Commitment** • Management Commitment to Safety and Health • Owner/Representative Commitment to Safety and Health **Safety and Health Planning** • Safety and Health during Conceptual Planning Phase • Constructability Review • Designing for Worker Safety and Health • Life-cycle Safety Design Review • Safety Checklist for Designers • Constructor Site Specific Safety Plan • Subcontractor Site Specific Safety Plan • Job Hazard Analysis • Pre-task Planning • Look Ahead Schedule • On and Off site Traffic Plan • Good Housekeeping Plan • Personnel Protection Equipment (PPE) Plan **Safety Resources** • Task-based Hazard Exposure Database **Drug and Alcohol Program** • Drug and Alcohol Testing Program	**Training and Education** • Safety Training for Designers • Safety Orientation for All Workers • Safety Training for All Field Supervisors • OSHA 10-hour Training for All Workers • Equipment Operators Skills and Training Assessment • Toolbox Meetings • Regular Safety Training for All Project Personnel • Constructor Mentors Subs to Improve Safety Performance **Accident Investigation and Reporting** • Accident and Near Miss Investigation • Accident and Near Miss Investigation with pre-task/JHA **Employee Involvement** • Employees Empowered with Stop Authority • Employee Safety Committee and Leadership Team **Safety Inspection** • Safety Inspections • Safety Violations Identified and Corrected **Safety Accountability and Performance Measurement** • Project Accountability and Responsibility • Supervisors Evaluated Based on Safety Performance • Safety Performance Evaluation using Safety Metrics • Contractor Evaluation Based on Safety Performance **Industrial Hygiene Practices** • Engineering Controls for Health Hazards • Hearing Protection Program • Respiratory Protection Program • Stretch and Flex Program • Ergonomic Task Analysis and Remediation

Reference Codes and Standards

A second approach to including OSH as part of a project's rating process is to reference a third party code or standard within the green project rating system with a focus on OSH that the project must meet. This requires adding a simple prescriptive credit in green rating systems to require that the project or stakeholders comply with the stand-alone requirement, as is the case in Singapore's Green Mark Rating System, which references the Green & Gracious Builder Scheme (Table 22) or the BREEAM system, which references the Considerate Constructors Scheme's Code of Considerate Practice (Table 23). The reference standard approach allows the green rating system and the externally-maintained standard or code to evolve independently in response to market evolution and changes in best practice, and is widely employed in many rating systems for other performance factors such as energy or water consumption.

Green and Gracious Builder Program

Launched in 2009 by the Singapore Building and Construction Authority, the Green and Gracious Builder Scheme is intended to raise the environmental consciousness and professionalism of builders and serve as a benchmark for construction corporate social responsibility. Companies can be evaluated according to scheme criteria and receive a rating of Star, Excellent, Merit, or Certified depending on their levels of achievement. The Green and Gracious Builder Scheme is a reference standard under the Green Mark rating system in Singapore. The primary focus of the scheme from a safety standpoint is on mitigating risks to the general public and neighbors of the project, not workers. However, there are also credits for workforce management that reward worker training, amenities, and other health and welfare-relevant activities.

Table 22: Green & Gracious Builder Scheme Criteria

Green Practices:	**Gracious Practices:**
• Company Policy • Materials (Reduce, Reuse, Recycle) • Energy • Environmental/Water • Housekeeping & Air Quality	• Company Policy • Accessibility • Public Safety • Noise & Vibration • Communications • Workforce Management

Considerate Constructors Scheme – Code of Considerate Practice

Developed in the UK in 1997, the Code of Considerate Practice is a voluntary standard against which companies can be evaluated either at the whole company or individual project site scales. The aim of the code is to improve the image of construction through enhancing the appearance of construction, respecting the communities in which it occurs, protecting the surrounding environment, securing everyone's safety, and caring for the workforce. It is open to construction companies and projects of all types and sizes in the UK. The code of practice is included as a reference standard for the MAN-02: Responsible Construction Practices credit in the BREEAM Rating System.

Table 23: Considerate Constructors Scheme: Code of Considerate Practice

Enhancing the Appearance – Constructors should ensure sites appear professional and well managed. • Ensuring that the external appearance of sites enhances the image of the industry • Being organized, clean, and tidy • Enhancing the appearance of facilities, stored materials, vehicles, and plant • Raising the image of the workforce by their appearance. **Respecting the Community** – Constructors should give utmost consideration to their impact on neighbors and the public. • Informing, respecting, and showing courtesy to those affected by the work • Minimizing the impact of deliveries, parking, and work on the public highway • Contributing to and supporting the local community and economy • Working to create a positive and enduring impression, and promoting the Code **Protecting the Environment** – Constructors should protect and enhance the environment. • Identifying, managing, and promoting environmental issues • Seeking sustainable solutions, and minimizing waste, carbon footprint, and resources • Minimizing the impact of vibration and air, light, and noise pollution • Protecting the ecology, the landscape, wildlife, vegetation, and water sources.	**Securing everyone's Safety** – Constructors should attain the highest levels of safety performance. • Having systems that care for the safety of the public, visitors, and the workforce • Minimizing security risks to neighbors • Having initiatives for continuous safety improvement • Embedding attitudes and behaviors that enhance safety performance. **Caring for the Workforce** – Constructors should provide a supportive and caring working environment. • Providing a workplace where everyone is respected, treated fairly, encouraged, and supported • Identifying personal development needs and promoting training • Caring for the health and wellbeing of the workforce • Providing and maintaining high standards of welfare.

Green Rating System Credits – OSH-Focused

A third way to incorporate OSH as part of green project rating system is to add new credits that are explicitly focused on OSH as their primary aim. As shown in the schema review of rating systems, there is precedent for this approach across nearly all of the existing rating systems. Table 24 shows several representative examples of this approach.

Ultimately, establishing new credits as part of existing rating systems can be very challenging and take considerable amounts of time. Many rating systems that are accredited by the American National Standards Institute (ANSI) require extensive consensus-based processes involving stakeholder groups who must agree on changes to the rating system and ways in which new credits should be documented and evaluated.

Thus, although this approach may seem straightforward, the level of effort required to establish a new credit is considerable.

Table 24: Examples of OSH-Focused Green Rating System Credits

System	Credit	Description
HQE	Target 7 - Maintenance and Durability of Environmental Performances	Rewards optimizing the building's design to simplify maintenance and increase safety in the servicing of building elements (Prevention through Design)
LEED v.4	MRc4 - Building product disclosure and optimization - material ingredients	Rewards disclosure of health impacts of products and component materials or OSH programs on the part of product manufacturers
Green Star	Mat-09 - Design for Disassembly	Rewards proactive documentation and planning for end of life-cycle, including safe disassembly
CEEQUAL	12.4.2 - Human environment, aesthetics, and employment	Design modified to take into account considerations for stakeholder health and safety, including operational staff
BOMA-BESt	4.5 - Workplace Hazardous Materials Information System	Requires information regarding workplace hazards to be present and accessible
GRIHA	RC-8 - Provide minimum level of sanitation/safety facilities for construction workers	Requires, among other things, provision of proper PPE, sanitation, and other accommodations for workers
BERDE	MN-RQ-2: Project Team	Requires including a safety consultant as part of the design team
LOTUS	MAN-2: Construction Stage	Requires a construction safety policy and plans

Green Rating System Credits – Incidental OSH Benefits

The fourth way to integrate OSH into green rating systems is by modifying existing credits with known hazards to include requirements that those hazards be addressed in some way in order to obtain those credits. In this approach, the primary benefit remains to achieve the original credit intent, but potential risks associated with that intent are concurrently mitigated. Table 25 shows selected examples of credits from existing rating systems that fall into this category.

Table 25: Examples of Green Rating System Credits with Incidental OSH Benefits

System	Credit	Description
Green Globes	3.5.9.1 - Envelope: Cladding - Exterior Wall Cladding Systems	Requires a subcontractor site-specific safety plan for wall construction subcontractors
Estidama Pearl	SM-1 - Non-Polluting Materials	Provides credit for using low toxicity materials defined by the EU Risk Phrases (Annex III of EU Directives 67/548/EEC)
BOMA-BESt	4.4 - Emissions: Hazardous Materials: Asbestos	Directs teams to properly encapsulate asbestos on projects where it occurs
CEEQUAL	10.2 - Construction transport, including nuisance and disruption	Requires accommodations to consider impacts of construction on traffic safety

Strategic Entry Points for OSH in Green Rating Systems

Given the multiple possible entry points for incorporating OSH into green rating systems, a key question is how to most effectively do so to achieve OSH goals for projects. Figure 6 shows a series of increasingly precise points in a project's existence where measurement and verification of goal achievement can occur, based on a synthesis of approaches observed in this research. The earliest step, mandating a specific practice to occur, corresponds to a prescriptive measurement approach which is straightforward to evaluate (did you do it, or didn't you), but whose outcomes may not be appropriate in every situation. An example of this approach might be to award credit for providing attachment points on roofs to reduce hazards for maintenance personnel working on roof-mounted systems. However, it might be the case that a particular building has no roof-mounted systems requiring regular maintenance. In that case, investments in attachment points might well be better spent on other safety improvements to achieve desired outcomes of that project.

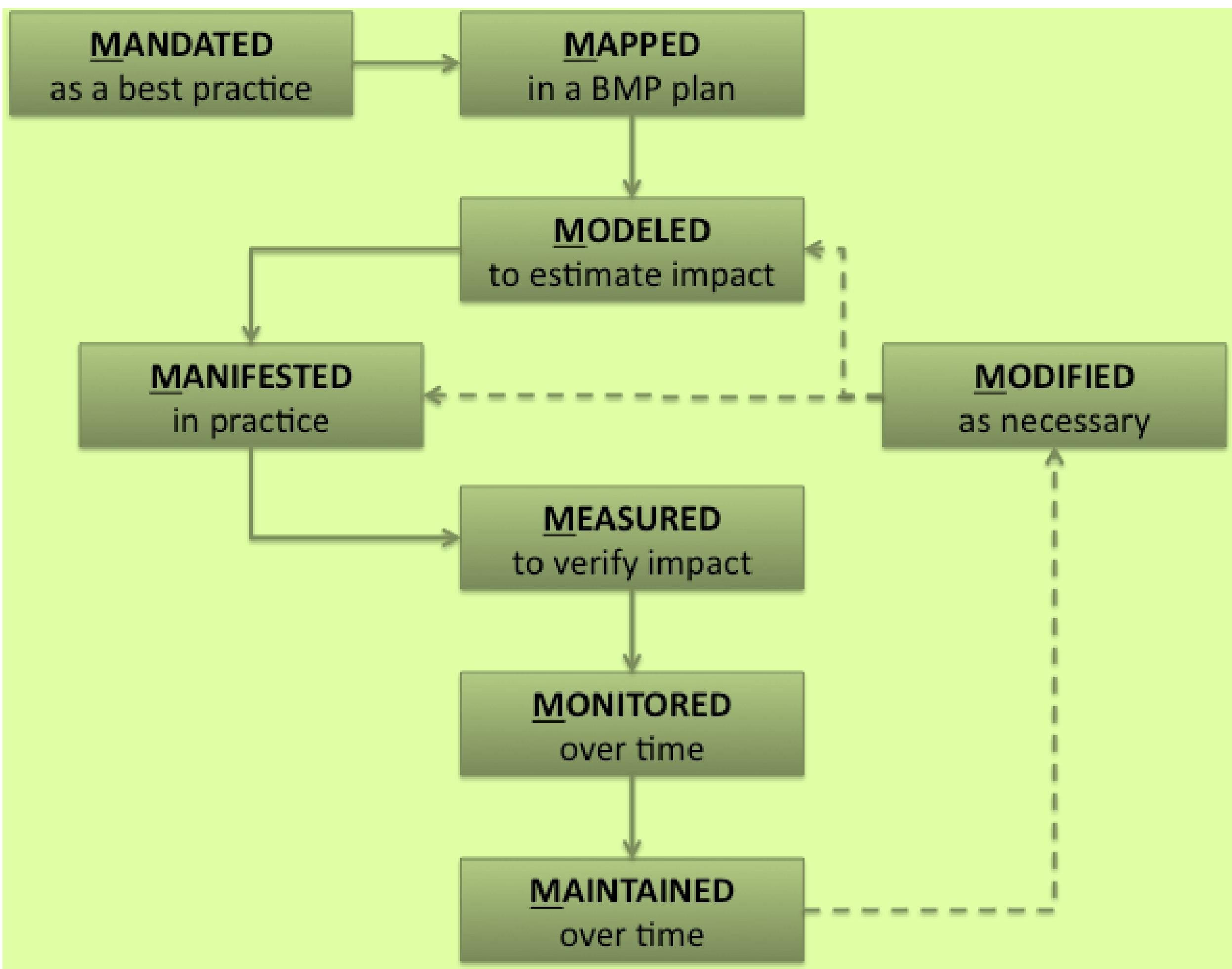

Figure 6: Strategic Entry Points for Influencing OSH in Green Projects

At the second level of depth, requiring a mapping of proposed best management practices (BMPs) for a project addresses the issue of project specificity by allowing the project team to determine which practices may work best in a particular project situation. This strategy involves developing a project-specific safety and health plan for a known hazard or for a project overall. The strengths of this approach lie in its measurability (the existence of a plan can easily be determined) and its ability to make use of the project team's expertise to determine the best solutions for the project. However, the existence of a plan is not necessarily proof of its implementation in practice, nor is it a guarantee of the desired outcomes the plan was developed to encourage. An example of this approach is a roof safety plan designed to address specific hazards associated with the roof of a particular project. The plan can initially be based on a generic template but should be customized by the project team to acknowledge and account for project-specific nuances.

The third level, modeling the project to estimate impacts of proposed actions, provides additional information that can contribute to more effective plan development that achieves desired OSH outcomes. This approach relies on the existence of modeling tools or methods with predictive capabilities, which may or may not be available. Modeling is a common requirement as a component of documentation for many green rating system credits, including energy and water performance, indoor air quality, lighting, acoustics, and other areas of performance. However, models to predict OSH outcomes, if they exist at all, are not well known in the green construction field and remain an area for future research.

The fourth level, manifesting desirable practices when implementing the project, is often documented in conjunction with mapping/planning to provide proof of implementation of plan provisions. Different rating systems require different types of proof of implementation, ranging from photographs to assertions by qualified personnel that actions have been properly completed. Given that many safety and health practices are not visually verifiable or measurable after the fact, concurrent documentation to verify proper implementation is a critical aspect to include as part of a credit requirement.

The fifth and sixth levels, measurement and monitoring of outcomes, is an approach employed to varying degrees across rating systems and topics within those systems. Increasingly, rating systems are beginning to require measurement of operational outcomes as a provision of maintaining certification, e.g., energy performance during building operations. This adds additional time and complexity to the rating process but is essential for performance-based measurement systems. It is being strongly driven by recent studies showing considerable disparity between modeled or predicted performance and actual performance, particularly for energy performance in green buildings (see Hughes 2011 for a recent overview). For occupational safety and health outcomes, waiting for incidents or injuries to happen to make a measurement determination is undesirable. Thus, this approach would be most useful in measuring and monitoring intermediate indicators that ultimately affect OSH in the long term, such as indoor air quality.

The seventh and eighth levels involve maintaining desired levels of performance and modifying as necessary to ensure those levels remain as desired. Increasingly, rating systems are evolving to include coverage of the operational phase of the facility life-cycle, which encourages these steps to be included as part of credit requirements. For example, continuous commissioning is gaining recognition as a way to make operational adjustments to ensure that buildings continue to perform as designed over time with respect to energy performance, water consumption, and indoor air quality. Similar approaches could be used to encourage ongoing management to achieve OSH goals.

Overall, different approaches to influencing OSH using green rating systems are appropriate for different types of risks and hazards. For industrial hygiene issues where long term exposures are required to cause problems, operational measurement and monitoring may be acceptable to identify problems and remediate them before they become a problem. However, for occupational safety hazards, waiting until incidents occur and can be measured is unacceptable if measures can be taken to prevent them. In these cases, mandates or mappings should be used to ensure that all appropriate measures are taken to prevent incidents. In addition, future research to develop better predictive models will be useful to most effectively allocate limited resources to achieve desired OSH goals.

Phase II Conclusions: Leveraging Green Rating Systems for Improved OSH

The growth of green rating systems is but one reflection of the significant industrial trend toward more environmentally and socially friendly projects now affecting the Architecture/Engineering/Construction industry. This trend is affecting the ways in which project stakeholders think about capital projects, in terms of:

- Larger scope and scale of issues considered as part of decision making
- Greater involvement by a broader set of stakeholders across the project life-cycle
- Internalization of factors previously externalized (e.g., concerns about life-cycle impacts of selected materials)

Some of these factors may help to reduce OSH risks on projects, including involvement of broader expertise (e.g. through Integrated Project Delivery) in developing design solutions and consideration of a larger scope of issues such as product toxicity and supply chain safety and health. Other factors, such as assumptions about product safety noted in Phase I of this study and building features commonly incorporated in green projects, may actually increase risk levels in green projects. However, with this "systems" perspective on capital projects comes significant opportunity to incorporate OSH considerations at the very earliest stages of project development, ultimately resulting in safer and healthier projects over their life-cycle. The purpose of this project was to explore how rating systems can play a role in achieving this end, starting with the question of how rating systems are used in the delivery of green projects. The bottom line is that OSH needs to be considered throughout the life-cycle, from planning and design through maintenance and end of cycle.

What role(s) do rating systems play in the delivery of green projects?

A review of thirty-one rating systems in use worldwide revealed a broad variety of ways in which rating systems are used to achieve project goals throughout the life-cycle. While early versions of rating systems focused primarily on design decisions and construction practices, newer versions of rating systems span a greater part of the facility life-cycle, including operations, maintenance, and end-of-life-cycle phases. In addition to being used for formal third-party rating and certification of green projects, rating systems can be used to generate ideas for improving project "greenness" or sustainability, to informally evaluate design decisions and alternatives, as a means of communicating and creating a common language among diverse project stakeholders, and as a way to communicate project attributes and achievements to the larger market.

Do existing rating systems explicitly address OSH?

All of the rating systems examined in this study addressed safety and health issues as part of their scope at some level. All of the rating systems reviewed had at least some explicit focus on the health and safety of project occupants/users, and most rating systems included provisions for safety and health of workers in various phases of the project life-cycle, either explicitly as a whole credit, or implicitly as a side benefit of other actions designed to increase project performance. That is not to say however, that all rating systems are informed by OSH professionals and include a level of detail that would satisfy such professionals. In this sense, green projects have the same challenges as conventional projects relative to OSH integration: they depend on owner, designer, engineer, contractor values and commitments to OSH.

The relative weighting or importance given to particular safety and health issues differed widely from rating system to rating system, as reflected in the topics covered by each system and the degree of focus on each issue. This may be due to:

- A particular issue being managed in another way in a given context such as via government regulation, and thus being scoped out of or omitted from consideration in the rating system (e.g., primary focus of the CEEQUAL rating system on environmental performance due to strong safety and health regulations in the UK)
- An issue being differentially significant in one context vs. another (e.g., design for disaster resistance being a focus of CASBEE in Japan, or design for flood prevention in Singapore's Green Mark system)
- An issue not having been considered during rating system development or determined not to be relevant by rating system developers (e.g., new credits being introduced in LEED 4.0 compared to LEED 3.0 based on new issues being recognized by rating system developers).

While some of the rating systems evaluated in this study have international range (e.g., BREEAM, LEED, Living Building Challenge, SBTool), others have been tailored for specific contexts and are thus able to focus more specifically on issues relevant to that context. For the one rating system where multiple versions were compared (LEED 3.0 vs. LEED 4.0), the level of safety and health coverage in the more recent version of the rating system was much greater than the earlier system, reflecting increased awareness of and importance ascribed to these issues. This awareness has been driven in large part by collaboration between NIOSH and USGBC in evaluating potential mechanisms to increase safety and health considerations in the newest version of the rating system. Since many of the national, context-specific systems are derived from or based on international systems such as LEED and BREEAM, hopefully best practices incorporated into new versions of these international systems will eventually propagate to country-specific rating systems as well.

Do existing rating systems indirectly encourage the use of technologies and practices that pose higher risk to workers involved with green buildings?

Based on a sample of Best Available Technologies and Strategies advocated by ten representative rating systems, green technologies and practices can have both a positive and negative impact on OSH risk for workers involved with green buildings. Specifically, several key trends in green projects may pose higher risks to workers, including:

- Increased material handling requirements throughout the life-cycle
- Greater use of electrical sensors and controls to monitor building conditions and make operational adjustments
- Greater use of on-site renewable energy and alternative fuel technologies
- Use of district heating and cooling requiring greater temperature ranges in occupational contexts
- Potential exposures to pathogens resulting from alternative water technologies such as on-site water treatment and storm water management facilities
- Increased use of building envelope components such as walls and roofs as platforms for other functions.

Some of these trends a shift in risk from outside the facility system to workers inside the system. For example, on-site wastewater treatment or power production shifts risks associated with these processes away from municipal utility providers and onto building maintenance personnel, who may or may not be properly equipped to manage and handle them. While such actions increase the overall sustainability and resilience of buildings and communities, they also increase the complexity and extent of requirements at the local scale.

Finally, while nearly all rating systems evaluated were observed to address OSH issues at some level, **none of the rating systems appeared to explicitly acknowledge that the technologies and practices being advocated might have negative tradeoffs for occupational safety and health**. The literature documenting these negative impacts is still in its infancy as reviewed in Phase I of this study. As it continues to evolve, hopefully these unwanted side effects of improving environmental performance will become more broadly recognized and addressed in green rating systems. The fact that green is a value consistent with human wellbeing presents an opportunity to make strides in this area.

What are the ways in which rating systems can be leveraged to address OSH risks in green projects?

Multiple approaches exist to better integrate OSH considerations as part of green rating systems, including as stand-alone rating systems, as third party reference standards, as new rating system credits, or within existing rating system credits. While each of these approaches has pros and cons, they can all be employed appropriately in different contexts to move toward improved OSH in green projects. Various mechanisms are available to guide the implementation of OSH actions in green projects, ranging from prescriptive mandates of best practices, to surveillance/mapping/planning, modeling, measuring, and other tactics, each of which is appropriate for different roles in the process.

In summary, green rating systems are becoming more extensive in scope and widespread to address the growing population of buildings seeking certification. As these systems continue to evolve, we need new ways to identify and address tradeoffs between environmental performance and human health and safety in terms of:

- Short vs. long term effects
- Local vs. global effects
- Internalized vs. externalized effects.

Significant opportunities exist to move from a prescriptive approach to a more performance- or systems-based approach to measurement and rating, and it is likely that rating systems will continue to evolve in this way over time. Better models are needed to predict, for particular project contexts, stakeholders, and requirements, how project decisions may influence health and safety of workers. With a larger systems-level perspective on both environmental and human health and safety, rating systems can ultimately contribute more effectively to the overarching goal of increasing societal sustainability.

A future project should be considered that leverages the knowledge gained by this NIOSH project to design and develop a universally adaptable, cross-culturally sensitive, systems-based measurement and evaluation process that countries can adopt to better attend to the social needs of occupational safety and health throughout the life-cycle of green building.

References

Ahn, Y. H., and Pearce, A. R. (2007). “Green Construction: Contractor Experiences, Expectations, and Perceptions.” *Journal of Green Building,* 2(3), 106-122.

AIA – American Institute of Architects. (2013). “Toolkit: Sustainability 2030.” <https://info.aia.org/toolkit2030/design/what-building-green.html>.

Bagh, L.K., Albrechtsen, H.J., Arvin, E., and Ovesen, K. (2004). “Distribution of Bacteria in a Domestic Hot Water System in a Danish Apartment Building,” *Water Res,* 38, 225-235.

Branche, C. M. (2012). “Making Green Jobs Safe: Integrating Occupational Safety and Health into Green and Sustainability.” *NORA Symposium Michigan Safety Conference, Grand Rapids, Michigan.* National Institute for Occupational Safety and Health (NIOSH). (April 17).

Bray, J., and McCurray, N. (2006). “Unintended Consequences: How the Use of LEED Can Inadvertently Fail to Benefit the Environment,” *Journal of Green Building,* 1(4), 152–165.

CA OSFM – California Office of the State Fire Marshall. (2010). *Fire Operations for Photovoltaic Emergencies*. http://osfm.fire.ca.gov/training/pdf/Photovoltaics/Fire%20Ops%20PV%20lo%20resl.pdf?bcsi_scan_53dc4632274cd1ca=0&bcsi_scan_filename=Fire%20Ops%20PV%20lo%20resl.pdf

Cole, R.J. (2000). “Cost and Value in Building Green.” Building Research & Information, 28(5/6), 304-309.

Cotera, P. (2011). “A Post-occupancy evaluation: To what degree do LEED certified buildings maintain their sustainable integrities over time?” http://etd.fcla.edu/UF/UFE0042961/cotera_p.pdf.

Dewlaney, K.S., Hallowell, M.R., and Fortunato, III, B.R. (2012). “Safety Risk Quantification for High Performance Sustainable Building Construction.” *Journal of Construction Engineering and Management,* 138(8), 964-971.

EASHW - European Agency for Safety and Health at Work. (2013a). "OSH and Small-Scale Solar Energy Applications." E-FACTS #68, EASHW, <https://osha.europa.eu/en/publications/e-facts/e-fact-68-osh-and-small-scale-solar-energy-applications>.

Elfland, C. and Edwards, M. (2008). “Managing and Resolving Lead Problems in Potable Water of New Construction.” *Proceedings, 2008 Water Quality Technologies Conference*, November.

Elfland, C., Scardina, P., and Edwards, M. (2010). “Lead Contaminated Potable Water from Brass Devices in New Buildings.” *AWWA National Conference*, Chicago, 2010.

EPA – U.S. Environmental Protection Agency. (2002). “Effects of Water Age on Distribution System Water Quality.” Distribution System Issue Paper. Office of Ground Water and Drinking Water. <http://www.epa.gov/safewater/disinfection/tcr/pdfs/whitepaper_tcr_waterdistribution.pdf>.

EPA – U.S. Environmental Protection Agency. (2013). “Definition of Green Building.” < http://www.epa.gov/greenbuilding/pubs/about.htm>.

Fleming, M. A. (2009). "Hazard Recognition Techniques." *By Design, ASSE,* 9(3), 15-18.

Fortunato, III., B. R., Hallowell, M. R., Behm, M., Dewlaney, K. (2012). “Identification of Safety Risks for High-Performance Sustainable Construction Projects.” *Journal of Construction Engineering and Management,* 138(4), 499-508.

Fowler, K., Rauch, E. (2008). Assessing Green Building Performance. A Post Occupancy Evaluation of 12 GSA Buildings.” http://www.gsa.gov/graphics/pbs/GSA_Assessing_Green_Full_Report.pdf.

Gambatese, J. A., Rajendran, S., and Behm, M. G. (2007). “Green Design & Construction: Understanding the Effects on Construction Worker Safety and Health.” *Professional Safety,* 52(5), 28-35.

Gambatese, J. (2009). “Don’t Leave Safety Out of Sustainability.” *ENR.* (November 18).

Gambatese, J., and Tymvios, N. (2012). “LEED Credits: How They Affect Construction Worker Safety.” *Professional Safety,* 42-52.

Gil, N., Tommelein, I.D., Kirkendall, B., and Ballard, G. (2000b). “Lean product-process development process to support contractor involvement during design.” Proceedings, ASCE 8th International Conference on Computing in Civil and Building Engineering, August 14-17, Stanford, CA, 1086-1093.

Gouveia, A. (2008). "'Green' insulation suspected as cause of fatal fire." *Cape Cod Times*, http://www.capecodonline.com/apps/pbcs.dll/article?AID=/20080520/NEWS/805200318/-1/rss01.

Grosskopf, K.R. and Kibert, C.J. (2006). “Developing market-based incentives for green building alternatives.” Journal of Green Building, 1(1), 141-147.

Gueverra, L. (2010). “Three Steps to Keeping Your Green Toilets Clean.” <http://www.greenbiz.com/news/2010/05/27/three-steps-keep-green-toilets-clean?page=0%2C0> (November 23, 2010).

Gustafsson, S. (2000). "Optimization and simulation of building energy systems." *Applied Thermal Engineering*, 20, 1731-1741.

Hughes, J. (2011). *Comparison of Large Scale Renewable Energy Projects for the United States Air Force.* M.S. Thesis, Department of Civil & Environmental Engineering, Virginia Tech, Blacksburg, VA.

Klein, G. (1998). *Sources of Power: How People Make Decisions.* MIT Press, Cambridge, MA.

Kleiner, B.M. (2013). *Mneumonic energy source system for hazard identification*. Construction Industry Institute Annual Conference, Orlando, Florida, July 30, 2013.

Klotz, L., Horman, M., and Bodenschatz, M. (2007). “A Lean Modeling Protocol for Evaluating Green Project Delivery.” Lean Construction Journal, 3(1), 1-18, April.

Lapinski, A., Horman, M., and Riley, D. (2005). “Delivering Sustainability: Lean Principles for Green Projects.” Proceedings, 2005 ASCE Construction Research Congress.

Lapinski, A.R., Horman, M.J., and Riley, D.R. (2006). “Lean Processes for Sustainable Project Delivery.” Journal of Construction Engineering and Management, 132(10), 1083-1091.

Lipshitz, R. and Strauss, O. (1997). “Coping with Uncertainty: A Naturalistic Decision Analysis.” *Organizational Behavior and Human Decision Processes,* 69(2), 149-163.

Liu, Z., Lin, Y.E., Stout, J.E., Hwang, C.C., Vidic, R.D. and Yu, V.L. (2006) “Effect of Flow Regimes on the Presence of Legionella within the Biofilm of a Model Plumbing System.” *Journal of Applied Microbiology*, 101(2), 437-442.

Mathys, W., Stanke, J., Harmuth, M., and Junge-Mathys, E. (2008). “Occurrence of Legionella in Hot Water Systems of Single-Family Residences in Suburbs of Two German Cities with Special Reference to Solar and District Heating.” *International Journal of Hygiene and Environmental Health*, 211(1-2), 179-185.

Matthews, J., Tyler, A., and Thorpe, A. (1996). “Pre-construction project partnering: developing the process.” Engineering, Construction and Architectural Management, 3(1/2), 117 – 131.

McGraw-Hill. (2008). *Green Construction Outlook Report.* McGraw-Hill Publishing, New York, NY.

Morcous, G. (2005) "Performance Prediction of Bridge Deck Systems Using Markov Chains", *Journal of Performance of Constructed Facilities.*

Morcous, G., and Lounis, Z. (2005a). "Maintenance optimization of infrastructure networks using genetic algorithms and Markovian models." *Automation in Construction,* 14(1), 129-142.

Morcous, G., and Lounis, Z. (2005b) "Prediction of Onset of Corrosion in Concrete Bridge Decks Using Neural Networks and Case-Based Reasoning", *Journal of Computer-Aided Civil and Infrastructure Engineering*, 20, 108-117.

NAHBRC – National Association of Home Builders Research Center. (1999). *A Guide to Developing Green Builder Programs.* NAHB Research Center, Upper Marlboro, MD.

NFPA – National Fire Protection Association. (2010). *Fire Fighter Safety and Emergency Response for Solar Power Systems*. http://www.nfpa.org/assets/files/pdf/research/fftacticssolarpower.pdf?bcsi_scan_53dc4632274cd1ca=0&bcsi_scan_filename=fftacticssolarpower.pdf

NREL – National Renewable Energy Laboratory. (2002). *Summary of Green Building Programs.* National Renewable Energy Laboratory, Golden, CO. http://www.nrel.gov/docs/fy02osti/32390.pdf (30 Jul 2013).

National Research Council (NRC). (2006) “Alternatives to Premise Plumbing.” *Drinking Water Distribution Systems: Assessing and Reducing Risk*. 8, 316-340.

Newsham, G., Mancini S., and Birt B. (2008). “Do LEED-certified Buildings Save Energy? Yes, but…” *Energy and Buildings*, 41(8), 897-905.

Nguyen, C., Edwards, M., DiGiano, F. and Elfland, C. (2008). “Resolving Water Quality Issues in Premise Plumbing Systems with Advanced Water Conservation Features. Blueprints for Sustainable Infrastructure,” *Proceedings, 3rd International Conference on Sustainability Engineering and Science*, Auckland, NZ.

OFEE. (2003). *The Federal Commitment to Green Building: Experiences and Expectations*, Office of the Federal Environmental Executive, Washington, DC.

Oregon Solar Energy Industries Association. (2006). *Solar Construction Safety.* <http://www.coshnetwork.org/sites/default/files/OSEIA_Solar_Safety_12-06.pdf> (June 18, 2013).

Pearce, A.R. (2008). "Sustainable Capital Projects: Leapfrogging the First Cost Barrier," *Civil Engineering and Environmental Systems*, 25(4), 291-301.

Pearce, A.R. (2008a). *Systems-Based Sustainability Analysis at the Installation Scale: Proof of Concept and Demonstration at Fort Belvoir.* National Defense Center for Environmental Excellence, Concurrent Technologies Corporation, Inc., Washington, DC.

Pearce, A.R. (2008b). "Sustainability at the Installation Scale: A Comparison of LEED-Based and Systems-Based Sustainability Assessment for Military Bases," *Proceedings of the International Conference on Sustainability Engineering and Science*, New Zealand Society for Sustainability Engineering and Science, Auckland, New Zealand, December 9-12, 2008.

Pearce, A.R. (2008c). "Measuring the Sustainability of Infrastructure Systems: An Innovation Diffusion Perspective," *Proceedings of the International Conference on Sustainability Engineering and Science*, New Zealand Society for Sustainability Engineering and Science, Auckland, New Zealand, December 9-12, 2008.

Pearce, A.R., Ahn, Y.H., and HanmiGlobal, Inc. (2012). *Sustainable Buildings and Infrastructure: Paths to the Future*. Taylor & Francis/Earthscan Publications, London, UK.

Pearce, A.R. and Fischer, C.L.J. (2001). Systems-Based Sustainability Analysis of Building 170, Ft. McPherson, Atlanta, GA. Summary analysis report to the Army Environmental Policy Institute, Atlanta, GA, May.

Pearce, A.R., Fischer, C.L.F., and Jones, S.J. (2000). *A Primer on Sustainable Facilities & Infrastructure.* Text prepared for continuing education public offering, February 6 and 9, Atlanta, GA.

Pearce, A.R., McCoy, A.P., Smith-Jackson, T., Edwards, M., Pruden, A., and Bagchi, R. (2011). "Designing a Sustainable Built Environment: A Hazards Analysis and Critical Control Points (HACCP) Approach." *Proceedings, CIB W099 Conference 2011: Prevention - Means to the End of Safety and Health Injuries, Illnesses, and Fatalities,* Washington, DC, August 24-26.

Pearce, A.R. and Suh, M.J. (2013). *Green Construction Technologies and Strategies in the United States.* Sustainable Facilities & Infrastructure Lab, Myers-Lawson School of Construction, Virginia Tech, Blacksburg, VA.

Pearce, A.R. and Vanegas, J.A. (2002). "Defining Sustainability for Built Environment Systems," *International Journal of Environmental Technology and Management*, 2(1), 94-113.

Pulaski, M.H. and Horman, M.J. (2005). "Organizing Constructability Knowledge for Design." Journal of Construction Engineering and Management, 131(8), 911-919.

Pulaski, M.H., Horman, M.J., and Riley, D.R. (2006). "Constructability Practices to Manage Sustainable Building Knowledge." Journal of Architectural Engineering, 12(2), 83-92.

Pulaski, M., Pohlman, T., Horman, M., and Riley, D. (2003). “Synergies between Sustainable Design and Construction at the Pentagon.” Proceedings, 2003 ASCE Construction Research Congress.

Rajendran, S. (2006). *Sustainable Construction Safety and Health (SCSH) Rating System, Version 1.0.* < http://sustainablesafetyandhealth.org/wp-content/uploads/SCSH-Rating-System-1.0.pdf> (August 2, 2013).

Rajendran, S., Gambatese, J. A., and Behm, M. G. (2009). “Impact of Green Building Design and Construction on Worker Safety and Health.” *Journal of Construction Engineering and Management,* 135(10), 1058-1066.

Reed, W.G. and Gordon, E.B. (2000). “Integrated design and building process: what research and methodologies are needed?” Building Research & Information, 28(5/6), 325-337.

Riley, D., Pexton, K., and Drilling, J. (2003). “Procurement of sustainable construction services in the United States: the contractor’s role in green building.” UNEP Industry and Environment, 26(2/3), 66-69.

Rohracher, H. (2001). “Managing the Technical Transition to Sustainable Construction of Buildings: A Socio-Technical Perspective.” Technology Analysis & Strategic Management, 13(1), 137-150.

Sanderford, A.R. (2013). “The Appraisal of High Performance Single Family Homes.” In *The Diffusion of Innovation Chasm for Green Housing*, Ph.D. Dissertation, School of Urban and Public Affairs, Virginia Tech, Blacksburg, VA.

Scofield, J. (2009). “Do LEED-certified buildings save energy? Not really…” http://www.oberlin.edu/physics/Scofield/pdf_files/eb-09.pdf .

Shapiro, S. (2010). “Stinky Situations: The Corrosive Case of Waterless Urinals.” *Green Building Law,* http://www.greenbuildinglawblog.com/2010/02/articles/codes-1/stinky-situationsthe-corrosive-case-of-waterless-urinals/.

Strickhouser, A. (2007). *Legionella pneumophila in Domestic Hot Water Systems: Evaluation of Detection Methods and Environmental Factors Affecting Survival*. M.S. Thesis, Virginia Tech, Blacksburg, VA.

Strickhouser, A. and Edwards, M. (2007). “Legionella pneumophila Re-growth in Domestic Water Heaters,” *2007 AWWA Annual Conference*, Toronto, Canada, June 24-June 28.

Syphers, G., Baum, M., Bouton, D., and Sullens, W. (2003). Managing the Cost of Green Buildings. State of California’s Sustainable Building Task Force, Sacramento, CA.

Torcellini, P.A., Deru, M., Griffith, B., Long, N., Pless, S., Judkoff, R., and Crawley, D.B. (2004). *Lessons Learned from Field Evaluation of Six High Performance Buildings*. NREL/CP-550-36290, National Renewable Energy Laboratory, Golden, CO.

Turner, C., and Frankel, M. (2008). *Energy Performance of LEED for New Construction Buildings.* New Buildings Institute. Vancouver, WA.

Turner, C. (2006). “LEED Building Performance in the Cascadia Region: A Post Occupancy Evaluation Report." http://cascadiagbc.org/resources/POE_REPORT_2006.pdf.

USGBC – United States Green Building Council. (1998). “Leadership in Energy and Environmental Design: The LEED Building Rating System.” 3rd Draft, http://www.usgbc.org.

USGBC – United States Green Building Council. (2004). “Leadership in Energy and Environmental Design – New Construction, v. 2.1”. http://www.usgbc.org.

USGBC – United States Green Building Council. (2009). *Green Building Design and Construction – LEED 2009 Reference Guide.* USGBC, Washington, DC.

Valdes-Vasquez, R. and Klotz, L. (2010). “Considering social dimensions of sustainability during construction project planning and design,” *Int. J. of Environmental, Cultural, Economic and Social Sustainability,* 6, 167-180.

Wang, W., Rivard, H., and Zmeureanu, R. (2005a). "An object-oriented framework for simulation-based green building design optimization with genetic algorithms." *Advanced Engineering Informatics*, 19, 5-23.

Wang, W., Zmeureanu, R., and Rivard, H. (2005b). "Applying multi-objective genetic algorithms in green building design optimization." *Building and Environment*, 40, 1512-1525.

Yudelson, J. (2008). *The Green Revolution*. Island Press, Washington, DC.