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DESIGN FOR INDOOR AIR QUALITY: ADDRESSING THE GLOBAL ENVIRONMENTAL CONTEXT

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ABSTRACT

Historically, indoor air quality (IAQ) deteriorated because it was largely ignored as other issues were addressed. In spite of the currently increasing recognition of worldwide environmental deterioration, there is inadequate understanding and consideration of the impacts of building design, construction, operation, and demolition on the environment. This paper identifies and quantifies the magnitude of buildings' contributions to environmental problems based on life cycle inventory (LCI) data categories. It describes criteria used for and results of a process to identify and weight important environmental problems. The weightings it provides can inform choices among building alternatives with varying environmental impacts and may be useful in reconciling IAQ design goals with broader environmental concerns.

INTRODUCTION

Designing buildings to optimize indoor air quality may not address worldwide environmental concerns unless they are identified and considered in the design process. Failure to consider the broader environmental context while addressing indoor environmental concerns might lead to a repetition of the process that exacerbated indoor air quality deterioration during the 1960s and 1970s. Historically, indoor air quality deteriorated because it was largely ignored in favor of other issues. During the last 40 years or so, mechanical ventilation systems became the means primarily for meeting buildings' heating and cooling needs rather than for providing outdoor air ventilation. Energy conservation efforts reduced attention to outdoor air delivery. Variable air volume distribution systems produced significant shortfalls of outdoor air supply during terminal control box "pinch-down". Often this occurred when temperatures were warmest, pollutant source off-gassing rates highest, and occupant tolerance of indoor air pollutants lowest -- precisely the times when the most outdoor air was needed.

In the same period, the introduction of new building materials, consumer products, and equipment resulted in increased source strengths for indoor air contaminants. Materials made from composite wood and adhesives, from textiles, or from plastics replaced many more durable and more chemically stable traditional building materials. Consumer products such as household cleaners, personal hygiene products, and pesticides contributed to much higher indoor pollution levels. The problem was identified in the early 1970s but only recently became widely recognized.

Presently there is growing recognition of the causes and importance of environmental deterioration worldwide. World population has reached unprecedented levels and exponential growth rates (1). Current per capita consumption rates stress environmental resources and pollution sinks beyond their capacities. Stratospheric ozone depletion, global climate change, and biodiversity losses are grave global problems; local and regional environmental resource shortages are associated with famine and disease; and, biodiversity losses are occurring at dramatic rates (2). Local air, soil and water pollution, soil erosion, and acidification are widespread globally (3).

Buildings are significant environmental stressors (4). It appears essential that some combination of reductions in population growth, resource consumption, environmental pollution, and land encroachment be effectuated soon on a global scale (2, 3, 5).

Buildings contribute to environmental deterioration through processes of design, construction, operation, and demolition that fail to consider their larger environmental context. Indoor air quality control and other indoor environmental solutions must also take account of their impact on the total environment (4, 6). "Building Ecology" was defined in 1981 as the study of the inter-relationships between buildings, their occupants, and the larger environment. Building ecology is based on the methods used in the field of ecology, a sub-discipline of biology (6).

Understanding the larger context for building design and prioritizing environmental problems can lead to informed decisions that reconcile indoor air quality goals with broader environmental concerns. By applying sustainability criteria, specific, measurable targets can be established to evaluate alternative design or building environmental performance. Progress made in determining impacts of many building products and processes through life cycle inventories (of flows to and from the environment) can assist when there is a context for interpreting inventory data. That context requires the following: 1) a scoping analysis of buildings contributions to environmental problems to assess the potential for improvement through building-related decisions; 2) a uniform set of environmental problem definitions; 3) standardized methods for normalization of classified environmental impact inventory data; and, 4) weighting factors for environmental problems to be used in an overall scoring or ranking of building design or other alternatives. These methods plus reliable inventory data and impact analyses are necessary for scientifically reasonable decision making. This paper presents some recent work to address the first two and the last of these needs.

METHODS

Scoping building contributions to environmental problems

By quantifying buildings' contributions to environmental problems, the scope of those contributions can be understood in the context of other economy-wide contributions to the problems. Estimates of US buildings' share of contributions to environmental problems were made based on traditional life cycle assessment inventory categories. These categories include resource consumption, pollution generation, and encroachment (7-9). Comparison to estimates by others validated the estimates (10). Data from US government sources were used to estimate buildings' contributions. Where available, data were used that directly reported resource consumption or pollution emissions. Where such data were not available, market share or dollar value of production was used as a surrogate. Estimates were made of the ratio of economic value to material or product masses in order to translate economic data into material quantities. In general, where dollar values were used, an assumption was made that building products were twice as material intensive per dollar as other sources for the particular environmental burden. This assumption was made on a mass or volumetric basis because building materials are generally at least twice as massive or voluminous per dollar as other products (e.g., cars, furniture, appliances, clothing). Therefore, building materials were assumed to be twice as resource or pollution intensive per dollar as other product types. So, for example, if the economic market share of all building related sources of air pollutants were 10%, then it would have been assumed that 20% of all air pollutant emissions were building-related.

Defining environmental problems

Defining environmental problems of concern is an essential step in developing building performance evaluation methods. A literature review and analysis of major efforts resulted in a list of environmental problems. This list was based on published efforts to identify and prioritize environmental problems affecting ecological and human health. The review included studies done at the regional or national level in the United States (2, 3, 8-9, 11-14). and one comparison of international efforts to rank environmental risks (15).

Goals for the problem identification were that the list be 1) comprehensive (inclusive), 2) simply stated, 3) readily recognized by non-scientists and scientists alike, and, 4) consistent (i.e., the problems stated at a uniform level of detail and specificity). These goals were developed in part because it was assumed that the list would be used by many professionals and lay people in ranking or weighting exercises that might be part of building performance evaluations. Problem description and definitions were extracted from the literature and lists were compared. Explicit and implicit criteria for identifying environmental problems were taken from the reviewed studies and a set of overall criteria prepared. In addition to the four goals above, the following criteria were adopted to develop the final list.

1. There should be no mixing of sources, receptors and media within distinct problem topics.
2. The problems areas should be selected based on the potential types of environmental stress they cause, not based primarily on their physical / chemical properties.
3. The problems should have no considerable degree of redundancy for a single type of environmental stress.
4. The problems are formulated either in terms of processes/mechanisms or in terms of environmental effects. The preference is for processes / mechanism (9).

Candidate problem statement terminology was evaluated according to the criteria stated above. The list was reduced to the smallest number of problems that met the criteria. This was seen as important to simplify the ranking or weighting process.

Weighting environmental problem categories

A weighting scheme was developed to express the relative importance of various environmental problems. An elaborate procedure (including specific criteria) were developed from discussions in the literature (3, 7-9, 16-17). Additionally, the recent EcoIndicators weighting scheme proposal was reviewed and compared with our own(14). The first four criteria used for weighting were adapted from reference 12 and the fifth was added as follows:

1. THE SPATIAL SCALE OF THE IMPACT (Global, regional, local - large worse than small)
2. THE SEVERITY OF THE HAZARD (More toxic, dangerous, damaging being worse)
3. THE DEGREE OF EXPOSURE (Well-sequestered substances being of less concern than readily mobilized substances)
4. THE PENALTY FOR BEING WRONG (Longer remediation times of more concern)
5. THE STATUS OF THE AFFECTED SINKS (An already overburdened sink more critical than a less-burdened one. Sinks = receptors, environmental compartments)

Scoring was done by assigning one-hundred points for the maximum impact and other impacts were rated relative to the maximum. Scores on each of the criteria are averaged to determine the final weighting score for each environmental problem area. The potential contribution of buildings can be used to identify leverage points for applications.

RESULTS

Table 1. Buildings' contribution to total environmental burdens, US data (4)

RESOURCE USE	*% OF TOTAL*	*POLLUTION EMISSION*	*% OF TOTAL*
Raw materials	30	Atmospheric emissions	40
Energy use	42	Water effluents	20
Water use	25	Solid waste	25
Land (in SMSAs)	12	Other releases	13

Table 2. Building related environmental problems

ECOLOGICAL PROBLEMS	*HUMAN HEALTH PROBLEMS*
Top priority	***Building occupants***
Habitat destruction / deterioration (directly resulting in Biodiversity loss)	Indoor air pollution - radon
Global warming	Indoor air pollution - non-radon
Stratospheric ozone depletion	Accidents in buildings (electrical, fire, falls, etc.)
High priority	***Building workers***
Soil erosion	Building construction / demolition / material manufacturing, etc.
Depletion of freshwater resources	
Acid deposition	
Urban air pollution / smog	
Surface water pollution	
Soil and groundwater pollution	
Depletion of mineral reserves (esp. oil and some metals)	

Table 3. Weightings for ten environmental (ecological) problems

Environmental Problem Category	*Weighting*
Habitat destruction / deterioration (Biodiversity loss)	88
Global warming	80
Stratospheric ozone depletion	90
Soil erosion	19
Depletion of freshwater resources	12
Acid deposition	24
Urban air pollution / smog	26
Surface water pollution	25
Soil and groundwater pollution	35
Depletion of mineral reserves (esp. oil and some metals)	50

DISCUSSION

Clearly buildings' contributions to total environmental burdens have been shown to be substantial (see Table 1) not only in the US (4). This has also been shown to be true worldwide (10). A reasonably concise list of key environmental problems has been developed and a set of weightings proposed. These are important steps toward a comprehensive, systematic, reasonably scientific method for evaluating building environmental performance. The work presented here requires much further development and the participation of a diverse array of scientists and building professionals. The results of the work to date are preliminary, and it is likely that future efforts will produce different results.

In the absence of a weighting scheme, all environmental problems are treated as equal. Clearly they are not and should not be treated as such (2, 9, 11-17). Prior efforts to guide building environmental performance evaluation have not addressed the difficult issue of prioritizing environmental problems. They have adopted general goals and established scoring systems to guide decision-makers (18, 19). Worthy as they may be, these efforts lack the analytical basis necessary to guide defensible decisions among alternative building options. A weighting scheme (such as that presented here or in reference 14) can help ensure a decision process that will not suboptimize building environmental performance.

To develop tools specifically for application to building-related problems and decisions, the work presented here draws from relevant work occurring currently in the fields of life cycle assessment, life cycle impact analysis, industrial ecology, and risk assessment. It is hoped that this paper will stimulate critical discussion and ultimately development of reasonable, empirically-based methods for evaluating building environmental performance.

CONCLUSION

Previous efforts to address the impacts of buildings on the worldwide environment have not been based on a scientifically reasoned approach. This paper outlines some necessary components for such an approach. It describes development of some of the components that can provide useful guidance to those making building-related decisions. The indoor pollution problem grew due to unbalanced emphasis on narrow goals. By attending to indoor air quality in the context of the larger environment, it is hoped that building design can address both indoor and general environmental concerns simultaneously and systematically. Building ecology describes an approach to studying buildings' impacts on both the occupants and the larger environment that is essential to avoiding further exacerbation of worldwide environmental problems while addressing indoor air quality.

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