

INTEGRATING INDOOR AIR QUALITY CONSIDERATIONS INTO MATERIALS LIFE CYCLE ASSESSMENT

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ABSTRACT

Buildings design professionals and their clients are increasingly interested in the environmental performance of their designs. So-called "life cycle assessments" (LCAs) have been done on some building materials. Most LCA practitioners have either ignored indoor air quality (IAQ) or stated that integration of IAQ into LCA practice is either impractical or infeasible. A "building ecology" approach to design, construction, and operation of buildings demands inclusion of IAQ in LCAs of building materials and products. Three methods for the integration of IAQ into LCA are described and compared. These methods include three different ways to assess chemical emissions from building materials and the impacts of these emissions on IAQ. The results show that data and health-based criteria are needed to advance the practice. Evaluation of IAQ in LCAs is no more complex than many tasks already routinely performed by LCA practitioners.

INTRODUCTION

Many interests and issues compete for professional building designers' attention and priorities. Among these indoor air quality and "sustainable design" increasingly have been considered in recent years [1]. While neither of these has gained widespread acceptance and use in the building design professions to date, they are both being used at a rapidly growing rate in the United States and certain parts of Europe. The tools available to designers include several directly using or derived from life cycle assessment (LCA).

A few so-called LCAs have been done on building materials [2-6]. The purpose of these assessments is to improve the overall environmental performance of buildings by selecting products and materials that have less harmful impacts on the environment through the consumption of resources and production of pollution required for their production, installation and use in buildings. The cradle-to-grave analysis used in LCAs includes not only extraction and processing of raw materials but also the final disposal of the materials at end-of-life. The results of LCAs are usually presented either as comparisons of several alternative candidate products or materials or as a series of LCA environmental performance scores for one or more candidate products or materials.

Most LCA practitioners have either ignored indoor air quality (IAQ) or have actually stated that integration of IAQ into LCA practice is either impractical or infeasible [7]. Their assertion hinges around their perception of the relative availability of data and the complexity of its analysis for general environmental impacts and for IAQ impacts [7]. Generally LCA practitioners have not been involved in IAQ research or professional practice and, therefore, they lack awareness of the methods and practices available to evaluate or compare products' IAQ performance. At the same time, IAQ researchers and practitioners have not been involved in the preparation of LCAs on building materials.

A "building ecology" approach to design, construction, and operation of "healthy" buildings requires broad considerations including the cradle-to-grave implications of product selection in terms of resources consumed, pollution released, and land encroachment. It also requires consideration of the impacts on humans both in the production of the materials and their incorporation into buildings and also of the impacts on building occupants through, among other things, indoor air quality effects [8]. If building materials are selected that have low impacts on the external environment but that are either unhealthy or unpleasant for building occupants, these materials are impractical and unacceptable, and they will not be used in buildings. Therefore, indoor air quality must be assessed and the results must be integrated in LCAs on building materials.

IAQ is neither more complex nor is it characterized by data that are any less available than data on the materials' impacts on the general environment. Therefore, the integration of IAQ into LCA is proposed and the proposed approach is described. Application of this approach will require explicit decision-maker judgments regarding the relative importance of human and non-human impacts. Such judgments are implicitly made even when they are not overtly considered or even acknowledged, as is normally the case, i.e., to include IAQ concerns explicitly is an implicit decision that IAQ is not important. The required judgments can be made in a systematic and consistent fashion that enables the decision-maker and other concerned parties to determine the acceptability of the values used and the impact of their application on the decision process and its outcome [1]. These value judgments will not be addressed here but are important components of the ultimate total life cycle assessment process and its application in building design decision-making.

METHODS

Various approaches to developing an IAQ profile for a product that can be integrated into life cycle assessments are described. These same methods can be applied for product IAQ evaluations without regard to their inclusion in LCAs. Data needs, availability and quality are considered important criteria for selection of methods. These approaches were developed by the author and have been applied in various building design projects to assist architects in product selection.

The following criteria have been used to evaluate the alternative methods:

- Accuracy; Are the results accurate and reliable?
- Health-Based Results; Are the results directly related to health impacts?
- Data Availability; Are the necessary data readily available and reliable?
- Time Required to Perform Analysis: How much effort and time is required by the designer to perform this type of analysis?
- Communication of Results: Can the results be easily communicated and are they likely to be easily understood by the users?

RESULTS

The results include description of the three methods used in various projects and the comparison using the criteria described above.

Method A: IAQ Concentration Calculation and Assessment

The first method is the theoretically complete and comprehensive IAQ assessment, referred to here as Method A. It involves acquisition of data on emissions from a product or material as the material will be used in a projected building design. Product specific data are obtained either from manufacturers or suppliers who have tested their products or from tests requested by the designer or building owner. These data are used to calculate indoor air concentrations of chemicals of concern attributable to the candidate product over the life of the building [9-10]. These concentrations can be compared to a reference value, for example, 1/40 the TLV or MAK value, as suggested by Nielsen et al [11-13]. The ratio of the calculated concentrations to the reference value can then be plotted alongside the typical LCA plots of other inventory items (e.g., greenhouse gas emissions, energy consumption, toxic chemical emissions, etc.) [14-16].

Method A requires determination or estimation of emission profiles from installation through the end of the product service life. It will also require assessment of any emissions related to the cleaning, maintenance, surface protection or renewal (such as paint, wax, or sealant application), periodic replacement during the life of the building, and removal at the end of service life.

Method B: Potential Emissions "Indicators"

Method B involves calculations based on simple, reasonably accessible and reliable data on product contents. As for emission rates in Method A, estimates may also be acceptable in Method B where accurate data are not available. For wet products or thin films, these data include the total mass of the chemical compounds of concern in the product and the vapor pressures for these chemicals. For dry products with thickness >1 mm, the diffusion coefficient should also be determined for the chemicals of concern and for the product being evaluated. These data are used in a simple calculation to derive a dimensionless number that can be used to compare alternative products.

Since designers are generally choosing from available products for a particular application, the relative potential emissions can be used for a first order estimate of IAQ impacts. If differences are not large (e.g., > factor of 2) in the emissions of chemicals being compared, then the IAQ impacts can be considered similar. The actual values can be plotted and displayed as relative potential life cycle emissions, concentrations, or exposures. This will allow display of the IAQ potential emissions along with the display of the emissions data used in the typical presentation of LCA results. These results are usually presented as histograms or bar charts showing the relative environmental impacts of the compared alternatives on one or more environmental criteria, e.g., energy consumption, solid waste, toxic air pollutants, etc.

Method C: TVOC Concentration Calculation

Method C involves obtaining emissions data for TVOC values only and using them to develop estimated concentrations and life cycle exposures as in Method A. These estimates are then compared. The projected or estimated TVOC concentrations can be compared for each alternative product. A ratio of each product's calculated result to the lowest calculated result can produce a simple reduction of the data to a value that can be easily understood by

non-indoor air quality specialists. Alternatively, the life cycle concentration and human exposure values can be used directly in the comparison.

DISCUSSION

Because each method has advantages and disadvantages, it is useful to compare them in a table to see them side-by-side. Table 1 summarizes this comparison.

Table 1. Advantages and Disadvantages of the Three Methods

	Method A: IAQ Concentration Calculation and Assessment	Method B: Potential Emissions "Indicators"	Method C: TVOC Concentration Calculation
Accuracy	Moderate to High	Moderate	Low to Moderate
Health-Based Results	Yes	No	Imprecise, potentially inaccurate
Data Availability	Low	High	Moderate
Time Required to Perform Analysis	Large	Small	Moderate
Communication of Results	Difficult	Difficult	Moderate

Method A has the advantage of being the most accurate method to develop an IAQ profile of a building material or product. This method compares calculated concentrations to a health-based reference concentration, thus enabling decision-makers to assess the potential for undesirable impacts of the emissions. The disadvantages of Method A include the high data intensity, the low data reliability, and the difficulty or impossibility of acquiring all necessary data. Generic product emissions data may be available, for example, for other products of the same class or type, but data for the specific products being evaluated may be lacking. Since designers actually choose from among different brands of similar products, product-specific data unavailability could be a major barrier to use of this method.

Method B has advantages because data are generally far more readily available, except when manufacturers refuse to divulge the chemical contents of their products. This does occur and can be a serious obstacle. In general, the trend is toward more disclosure as companies compete to be regarded as "environmentally-friendly." The disadvantage of this method compared to Method A is that the potential impacts of the chemical emissions reported as TVOC cannot be related directly to health-based standards. Bornehag et al concluded that there is no scientific basis for stating whether TVOC can be used as indicator of VOC health effects [17]. However, TVOC emissions can be compared relative to each other as semi-quantitative estimates of potential emissions.

Method C has the advantage that TVOC data are more readily available than detailed chemical data. However, TVOC values cannot be used as a surrogate for health effects. Therefore, Method C also has the disadvantage of not providing results that can be related directly to impacts. The recent European Community TVOC guideline, if adopted and used widely, would be considerably more detailed than any TVOC data used to date [18].

Surface Protection, Maintenance and Cleaning Products

Many materials require periodic surface treatments and cleaning in order to perform well. For example, many flooring products require lacquer and wax applications to protect their material surface and improve its appearance. The total life cycle emissions from such products can easily exceed those from the material to which they are applied. The emissions from such products that are routinely used with a given material or product should be included in analysis of IAQ for use in LCA. They should just as well be used in building material selection processes based solely on IAQ.

CONCLUSION

Based on the comparison of the three methods, it is unclear whether one will always be more practical, useful and reliable than the others. In general, we favor Method B as more frequently being feasible and providing a result that has an order of accuracy as good as or better than many indicators used for life cycle assessment practice. It is also worth pointing out that these three methods can be used for product IAQ assessments whether or not LCA is being conducted. A life cycle perspective can also improve the evaluation of material emissions on indoor air quality.

Further work needs to be done to refine these methods and develop the data that will make them more practical and reliable. This is also the case for most factors in typical life cycle assessments and should not be considered a barrier to inclusion of indoor air quality in life cycle assessment practice. Design firms wishing to offer services as "green" or "sustainable" designers should adopt the practice of incorporating IAQ into their standard services for clients with low environmental impacts as an important criterion for their buildings.

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