Designation: E1991 – 05

Standard Guide for Environmental Life Cycle Assessment (LCA) of Building Materials/Products[1]

This standard is issued under the fixed designation E1991; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

This is a general guide for the application of environmental Life Cycle Assessment (LCA) as a tool for evaluating the environmental aspects of materials/products, processes, and services produced and used in buildings and the built environment. This guide does not include, necessarily, all of the environmental features and impacts of the complete building life cycle, but focuses on those issues directly related to building materials/products and those elements of the building's environmental performance affected by these materials/products. Fig. 1 illustrates the total life cycle of a building. Fig. 2 is an example of the relationship between the life cycle processes of building materials/products and the total life cycle of a building and illustrates how these product/material life cycle processes merge with the total building life cycle. Fig. 3 illustrates an example of the life cycle of a building construction material within the context of the total building life cycle.

1. Scope

1.1 This guide covers a common framework and set of principles for potential users, such as product manufacturers, environmental analysts, consultants, architects, and the building industry in general. It describes a framework for life cycle inventory analysis, and describes various options and aspects of Impact Assessment and Interpretation.

1.2 The complexity and level of detail of an LCA will vary greatly depending on the material/product or system studied, the purpose and use of the study, the intended users of the study, and the resources committed to complete the study. The level of detail can range from generic to material/product specific.

1.3 This guide does not describe in detail the actual techniques for performing a LCA.

1.4 LCA is an emerging methodology, which is still evolving. This guide will present its concepts and major features. It should enable the user to better understand LCA and its application to building materials/products, and help to identify sources of additional information and guidance. LCA is only one of many tools designed to aid in environmental evaluation and decision making.

1.5 The component phases of LCA, including goal definition and scoping, inventory, impact assessment, interpretation, and the various methodologies used in these phases are in various stages of development. Consequently, the results of an LCA must be understood in the context of their completeness and accuracy and must be applied appropriately. LCA does not necessarily proceed as a linear process through these phases but is conducted in an iterative fashion.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E631 Terminology of Building Constructions

E1765 Practice for Applying Analytical Hierarchy Process (AHP) to Multiattribute Decision Analysis of Investments Related to Buildings and Building Systems

[1] This specification is under the jurisdiction of ASTM Committee E60 on Sustainability and is the direct responsibility of Subcommittee E60.01 on Buildings and Construction.

Current edition approved July 1, 2005. Published July 2005. Originally approved in 1998. Last previous edition approved in 2004 as E1991 – 98 (2004). DOI: 10.1520/E1991-05.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

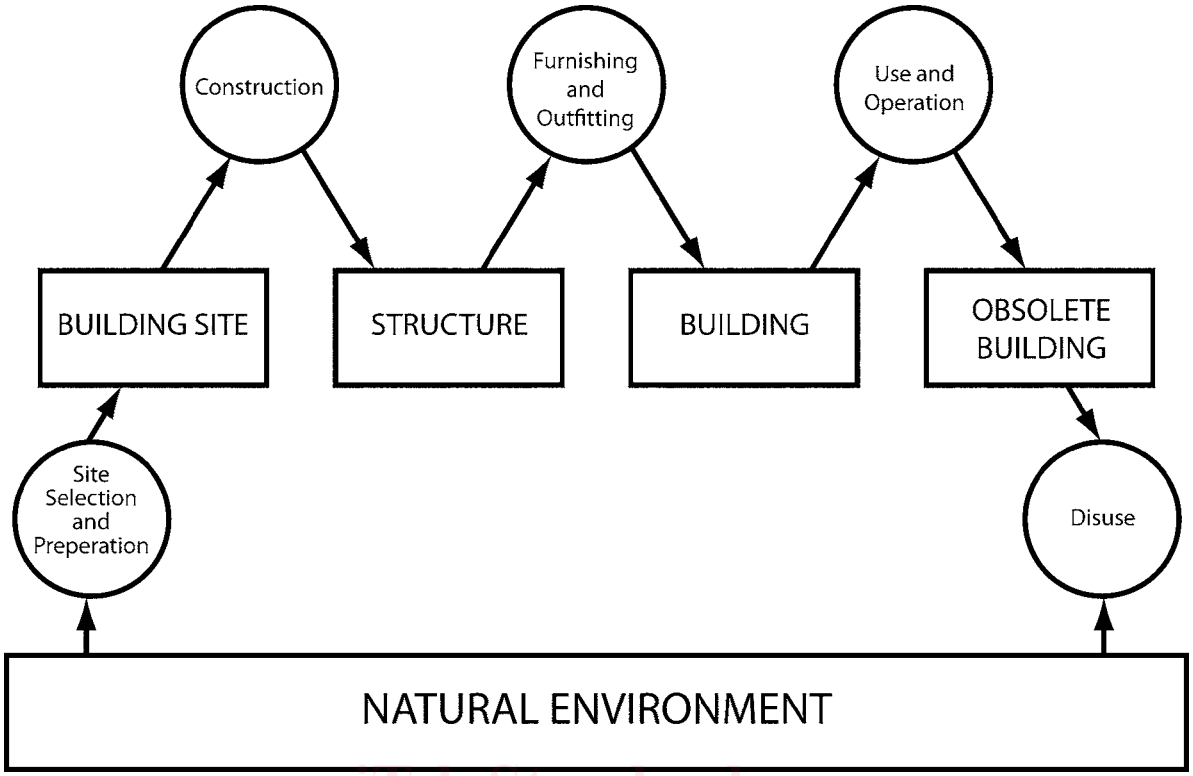

FIG. 1 Total Life Cycle of a Building

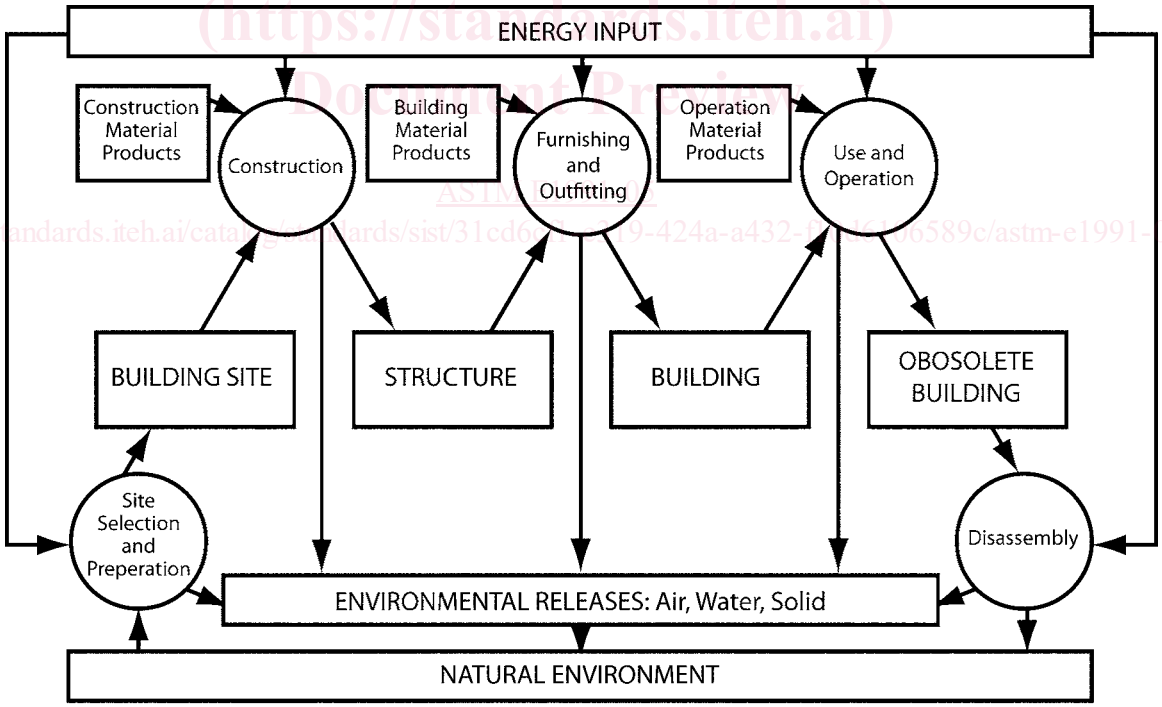

FIG. 2 Flow of Building Materials/Products into Building Life Cycle

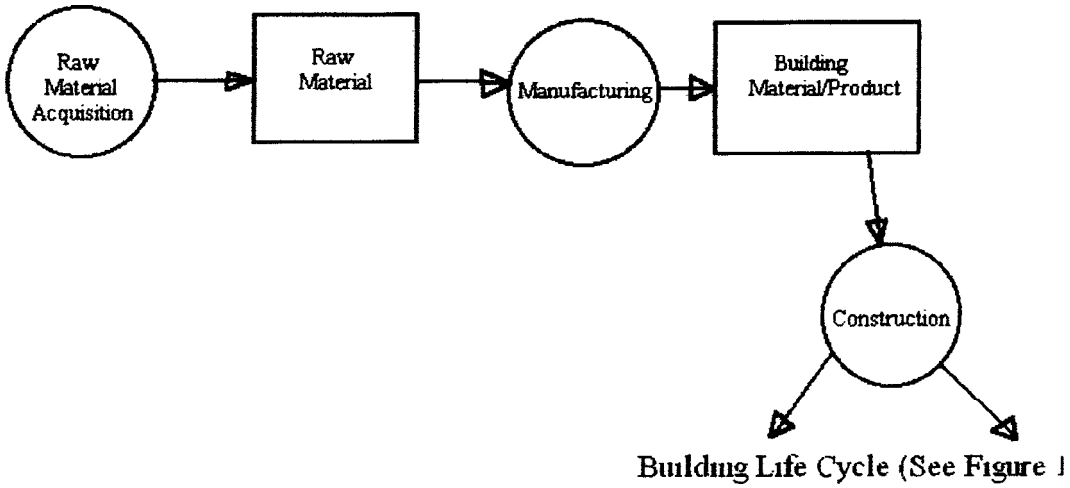

FIG. 3 Example of Building Material/Product Segment of Total Building Life Cycle

E2114 Terminology for Sustainability Relative to the Performance of Buildings

2.2 *Other Standards:*

ISO 14040 Environmental Management—Life Cycle Assessment—Principles and Framework[3]

3. Terminology

3.1 *Definitions:*

3.1.1 For terms related to building construction, refer to Terminology E631. Some of these terms are reprinted here for ease of use.

3.1.1.1 *building, n— (1)* A shelter comprising a partially or totally enclosed space, erected by means of a planned process of forming and combining materials; *v—(2)* The act or process of constructing.

(a) apartment building—a building containing more than two dwelling units not intended for individual unit ownership.

(b) condominium—an apartment building, group of townhouses, or single dwellings in which each dwelling units is individually owned and each owner holds an interest in common areas. Also commonly used to denote an individual unit.

(c) house—a building intended in its entirety as a dwelling.

(d) manufactured building—a structure wholly or substantially made in a manufacturing plant for installation or assembly at the building site.

3.1.2 For terms related to sustainability relative to the performance of buildings, refer to Terminology E2114. Some of these terms are reprinted here for ease of use.

3.1.2.1 *life-cycle assessment (LCA), n*—a method of evaluating a product by reviewing the ecological impact over the life of the product.

Discussion—At each stage, the product and its components are evaluated based upon materials and energy consumed, and the pollution and waste produced. Life stages include extraction of raw materials, processing and fabrication, transportation, installation, use and maintenance, and reuse/recycling/disposal. ISO 14040 defines LCA as the compilation and evaluation of the inputs, outputs, and the potential environment impacts of a product system throughout its life cycle from which pollutants are discharged; any single identifiable source of pollution.

3.2 *Descriptions of Terms Specific to This Standard:*

3.2.1 *building material/product, n*—a manufactured or produced unit or component that goes into any of the building life cycle processes. In the text of this guide, this term is used in a broad context and is meant to include fundamental construction material, for example, stone, as well as manufactured products, such as, windows, roofing, HVAC, and electrical systems, interior furnishings, maintenance products, and so forth, used throughout the total building life cycle.

3.2.2 *deconstruction*—disassembly of buildings to recover materials

3.2.3 *energy input, n*—all forms of energy necessary for the accomplishment of the particular building life cycle process under consideration.

3.2.4 *environmental releases, n*—all air, water, and solid emissions, which are given off by the building life cycle process under consideration that return to the natural environment.

3.2.5 *furnishing and outfitting, n*—the complete series of activities and actions that begins with a building structure and results in a completed building.

3.2.6 *interior furnishings, n*—those temporary and semipermanent systems and components, which generally are required for the normal utilization of the building for its intended purpose including decorative components.

[3] Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, http://www.iso.ch.

3.2.7 *obsolete building, n*—a building that has reached the end of its useful life.

3.2.8 *raw material, n*—those components and ingredients that enter into the manufacturing process of the particular building material/product under consideration.

3.2.9 *raw material acquisition, n*—the processes by which natural resources are taken from the natural environment, including subsequent processing, to produce raw materials for the manufacture of the particular building material/product under consideration.

3.2.10 *sponsor, n*—the individual or individuals who have initiated and funded the LCA.

3.2.11 *stakeholder, n*—an individual or collection of individuals who have some substantial interest or concern in the building, its materials/products, or its life cycle processes; or, whose environment is or will be influenced by the building and its life cycle.

3.2.12 *use and operation, n*—the complete and ongoing series of activities and actions that occur and are required during the life of a building from the point of occupancy to the point where the building is obsolete and is about to be disassembled.

4. Summary of Guide

4.1 LCA is a tool for identifying, assessing, and interpreting the environmental aspects, such as, material, natural resource, and energy use; environmental releases and other burdens of a product, process, or activity. A typical LCA can be thought of as consisting of four phases: goal definition and scoping, inventory analysis, impact assessment, and interpretation (**1-7**).

4.2 Defining a clear and unambiguous goal or purpose of the LCA is essential at the outset. Doing so will assist in imposing boundaries on the study and will help to establish the scope of the effort. Identification of the target audience also is important to establishing the scope. Depending on the goal and purpose of the LCA, other parts of the process may involve identifying the relevant stakeholders throughout the life cycle, ranking the degree to which the various stakeholders interests will be accommodated in decision making processes, and identifying stakeholder priorities regarding the various potential impacts possible throughout the life cycle.

4.3 The inventory analysis will comprise a process analysis of the Life Cycle of the subject of the LCA, in this case the building material/product. Fig. 1 illustrates the life cycle of a building. Fig. 2 illustrates how the life cycle of a building material/product merges with the life cycle of the building. This analysis of the life cycle process then is followed by a compilation of the relevant inputs and outputs of the processes making up the total system. The depth of this analysis will be consistent with the goal, scope, and intended use of the study (**1**, **2**, **3**, **5**, **6**, **7**).

4.4 Impact assessment will consist of an evaluation of the potential environmental impacts of the inputs and outputs of the total system. The general categories of environmental impacts to be considered may include resource use, human health, and ecological consequences. (**1**, **4**).

4.5 Interpretation of the results of the inventory analysis and the impact assessment must be made in relation to the goal and intended use of the LCA.

4.6 The application of the LCA concept to decision making processes for the reduction of the environmental consequences of a building, and its materials/products is an iterative process and generally will involve the examination of a variety of options. Because this takes into consideration impacts on all environmental media and examines the entire material/product life cycle, LCA provides the user with an opportunity to achieve actual reduction in environmental impact and not a shift of impact from one medium to another, from one geographical area to another, or from one part of the life cycle to another.

4.7 This guide provides general guidance for initiating the performance of a LCA for buildings and building materials/products and illustrates some of the potential benefits derived from its use.

5. Significance and Use

5.1 LCA in its broadest context is a holistic, comprehensive concept with many potential applications. Currently, there are numerous organizations, from both the public and private sectors, such as the Society of Environmental Toxicologists and Chemists (SETAC), ISO, many national standards organizations, universities, private companies, consulting groups, and so forth, working in the area of environmental LCA. Each group has its own specific set of objectives and requirements. This guide includes the elements of LCA on which general consensus has been reached and incorporates them into a guide tailored to buildings and building materials/products.

5.2 This guide provides general guidance for the practice of conducting LCA on building materials/products for the purpose of making decisions and choices.

5.2.1 Those who specify or select materials for use in buildings will benefit from the guidance provided here in that it will provide a means of incorporating environmental considerations into their decision-making processes.

5.2.2 Those who develop, manufacture, and market building materials/products will benefit from the guidance provided here in that it will enable them to more objectively assess the environmental implications of new products, designs, and processes; evaluate existing products, designs, and processes; and compare other product and process alternatives.

5.2.3 This guide offers guidance that can be helpful in minimizing the subjectivity often associated with environmental decision making and will foster more consistent, more complete assessments and decisions regarding the environmental aspects of building materials/products. Even with this guidance, results may vary greatly.

5.2.4 See Appendix X1 for some specific examples of the potential applications or uses of LCA as suggested in this guide. Application and use can have either an internal or external focus. An internal application is intended primarily for the use of the sponsor and focuses on some internal aspect, material, or process over which the sponsor has primary

control and influence. In this case, the sponsor is the exclusive audience. An external application is intended either primarily or secondarily for use by some stakeholder external to the sponsor. In this case, the sponsor and one or more external stakeholders are the audience for the LCA. A critical review by knowledgeable expects should be done for all external applications of an LCA.

5.2.5 In the application of LCA to building materials/products, the environmental information developed by the LCA often will be only part of a series of issues and factors to be considered in a more complex decision making process. In the building industry decisions generally will depend on more than an assessment of environmental impact. Other factors and considerations, such as economics, material/product performance and function, aesthetics, availability, timing, and so forth, almost always will intervene. The decision making process must accommodate these factors. Procedures exist, which will be useful in this process (see Practice E1765 and Ref **8**).

5.2.6 It should be recognized that in conducting an LCA on building materials/products there are certain considerations that differentiate it from an LCA on nondurable consumer products, such as:

5.2.6.1 Durability of alternative materials/products for a given application may vary significantly,

5.2.6.2 Building use patterns can change during the life of the materials/products,

5.2.6.3 Environmental effects during the use stage can dominate the total environmental impact,

5.2.6.4 Building site and location can affect the environmental profile,

5.2.6.5 Materials/products often are incorporated into assemblies with other materials/products and must be considered in the context of those assemblies and their environmental implications, and

5.2.6.6 Environmental impacts may depend on how materials/products are used and maintained.

6. Procedure

6.1 The following section describes in more detail the content and components of an LCA as it relates to building materials/products. The information contained herein is not intended to be exhaustive. Rather, it is intended to provide an overview and assist the user in deciding how to undertake an LCA and how the results might be applied.

6.1.1 There are four major phases in conducting an LCA. They are goal definition and scoping, inventory analysis, impact assessment, and interpretation. In the context of this guide, the application of a complete LCA will involve the application of these four phases to a series of building and building material/product options and choices for the purpose of decision making (see Fig. 4).

6.1.2 The four phases will be discussed here as a methodology for the evaluation of a single material, product, or activity. When evaluating alternate materials/products, alternate process options, or when making comparative assertions, it is essential that the LCAs of each of the options be conducted in a thorough, consistent, and comparable manner so that comparisons are valid.

6.2 *Goal Definition and Scoping:*

6.2.1 The purpose, goal, or intended use of the LCA must be defined clearly and unambiguously prior to proceeding. This provides the project/problem definition, enables the setting of boundary conditions for the analysis, and establishes the objectives of the study.

6.2.2 The purpose, goal, and intended use also will determine the level of detail and the depth of the Life Cycle process analysis required.

6.2.3 Data quality targets also will be set. It must be realized that achieving these data quality targets may not always be possible. The available data and the quality of those data will depend upon many things, such as source, completeness, precision, and so forth. As data are collected throughout the study, it is important to record a measure of data quality.

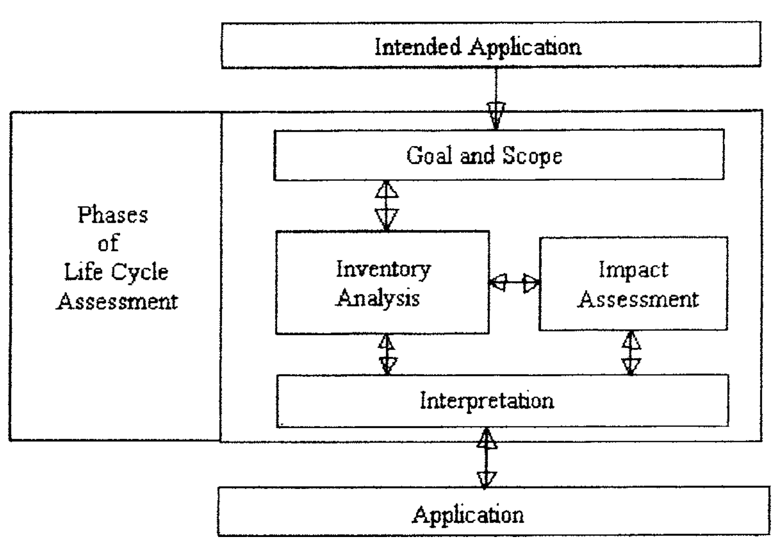

FIG. 4 Outline of LCA for Building Materials/Products

6.2.4 The target audience of the study should be identified. The target audience is the principal audience for whom the results of the study are intended. The target audience may be internal to the entity sponsoring the study, or the study may be intended for use by the sponsor with some audience external to the sponsor. Often, it is the case that there are several target audiences to be considered. This is particularly the case for a building since it has an extended lifetime and since it interfaces with many stakeholders.

6.2.5 It is important in setting the goal and scope to identify not only the target audience but also all of the relevant stakeholders who will have some stake in the total environmental impact of the building and its materials/products. The stakeholders can be of several different types. For example, the sponsor of the LCA is a stakeholder and certainly a target audience. Those affected by the environmental impacts throughout the life cycle also are stakeholders, and depending on the purpose of the LCA, some also may be part of the target audience. Also, it may be important for the decision maker (user of the LCA) to establish the degree to which stakeholder's values and views have been considered and accommodated in the decision making process.

6.2.6 At the goal definition and scoping stage, the LCA is specifically designed and planned with the intended use, audience, and stakeholders in mind. Consequently, a study designed to provide product or process improvement may be unsuitable for use in marketing or educating the public.

6.3 *Defining the Scope:*

6.3.1 In defining the scope of a study, the following issues should be considered and clearly described: the function of the material/product system under consideration; the functional unit; the system boundaries; temporal features and time scales; geographic and locational aspects; the extent, type, and methodology of impact assessment processes to be used; data and data quality requirements; known assumptions and limitations; and, methods to be used to evaluate the significance of differences revealed in the inventory and impact assessment.

6.3.2 The "functional unit" is a descriptor or measure of the service or function performed by the material/product system under consideration. The purpose of defining the functional unit for an LCA study is to permit comparison of equivalent items or services (functions). The functional unit is to provide a means of comparing different materials/products or designs for a given function. For items to be functionally equivalent, they must be able to meet a defined need (function) within specified use, performance, and time parameters.

6.3.2.1 The functional unit for an interior wall paint or finish may be defined as effective coverage of and performance on a given area of interior wall surface for a specified time period. Then, depending on the properties and performance of the paint or finish options, this unit will be defined further in terms of a specific number of gallons or some other quantity in units more common to the material under consideration. In general, a comparison on a gallon for gallon basis may not necessarily be valid. For example, one paint may require different numbers of applications than the alternative to achieve the desired performance.

6.3.2.2 The functional unit for a floor covering could be defined as a specific area of coverage of the subfloor meeting specified use and performance characteristics, installation requirements, aesthetic qualities, and maintenance properties, for a given period of time. Durability and lifetime of the material, recyclability, impact on indoor air quality, cost, and so forth, are important factors to be considered.

6.3.2.3 Definition of the functional unit can sometimes be complex in the case of building materials, particularly when several different options of very different design are under consideration; however, it is necessary to define clearly some equivalency in order to fairly compare the options. The functional unit for building materials may involve several specific functions simultaneously and will include an accounting for the expected life of the material. The functional unit must be quantifiable, measurable, and definable in terms of some unit characteristic of the material or design. Accurately and completely defining the functional unit is very important in ensuring equivalency in comparing options, alternatives, and in making comparative assertions.

6.3.3 The system boundaries are determined by the goals and objectives of the LCA. These boundaries are defined more specifically by which operations, processes, and subsystems are included and by which inputs and outputs are included in the study. When availability of data affects the system boundaries it should be so recorded.

6.3.4 The life cycle of a building material/product involves considerations of durability and expected life span. The scope should define clearly the anticipated life of the material and time frame over which the system is being studied. Likewise, environmental impacts can be time dependent and the system should account for such temporal features.

6.3.5 The scope of the study should take into account geographical and locational considerations that can have an effect on the impacts of the system. Environmental impacts can be very dependent upon location and geography. Some impacts can be of global scale and some only of local scale.

6.4 *Data Quality:*

6.4.1 Data quality assessment is a systematic approach to measuring the suitability of the data for its intended purpose. The quality of the data used in an LCA in large measure determines the degree of confidence the user will have in the ultimate results of the LCA and the decisions that result. Data quality is a representation of the reliability of the individual data and in the data set as a whole.

6.4.2 Data quality goals are specifications of the required quality of the data based on a set of data quality indicators. The goals and objectives of the LCA can assist in establishing minimum data quality goals. The data quality achieved may to some degree be dependent on the level of effort allocated to the study which will be a function of the purpose, budgetary and time constraints, and data availability. Inability to meet the data quality goals may require modification of the goals and scope of the LCA.

6.4.3 Data quality indicators are quantitative or qualitative measures of the credibility of the data. Data quality indicators should address such things as precision, accuracy,