



# LIFE CYCLE COST ANALYSIS OF NON-RESIDENTIAL BUILDINGS

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## Executive Summary

The goals of this report are to clarify the differences between Life Cycle Cost Analysis (LCCA) and Life Cycle Assessment (LCA), summarize what is known about the life cycle costs of non-residential wood construction, compare the life cycle costs of wood structures to those of other materials, and review processes for conducting life cycle cost analyses on structural systems or whole buildings. Summaries of LCCA resources are also provided.

Among the findings of this report are:

- Published life cycle cost analysis information for commercial buildings is sparse, particularly for wooden structures.
- LCCA is required for federal buildings.
- Life cycle environmental costs (impacts) are not considered in LCCA in current practice, indicating a clear difference between LCA and LCCA as currently structured.
- Current indices of the useful lives of various products allocate lower useful lives to wood than other materials without clear basis for any of the chosen values.
- Despite a pervasive perception that the useful life of wood structures is lower than buildings of other materials – there is no meaningful relationship between the type of structural material and average service life.
- The combined lack of LCCA research on wood use in construction and the common availability of what appear to be non-research based estimates of useful lives of materials can create an unwarranted bias against the use of wood in structures.
- Development of definitive, research-based information on durability/longevity of wood structural and non-structural elements used in various building applications is needed.

## Background

Life cycle cost analysis (LCCA) as applied to buildings, sometimes also referred to as *value engineering* or *life cycle costing*, involves accounting for all costs related to construction, operation, maintenance, and disposal at the end of the useful life of a structure. The purpose is to provide a basis for selection of the most cost-effective design alternative over a particular time frame, taking into account anticipated future costs as well as initial costs of construction. LCCA is particularly suitable for the evaluation of building design alternatives that satisfy a required level of building performance, especially when investment, operating, maintenance, and repair costs differ, and/or when alternative designs may have different expected service lives.

Life cycle costing has long been used in the United States for evaluation of design alternatives in highway and bridge construction. However, application to design of buildings in general is much more recent, led by requirements of the federal government, several states, and a number of educational institutions.

Despite the similarity in the acronyms LCCA and LCA, there is no relationship between techniques currently used in *life cycle cost analysis* and *life cycle assessment*. In LCCA, the focus is entirely on factors that result in bottom-line financial performance. Environmental costs, such as those linked to emissions associated with building materials or building operations (greenhouse gases, or emissions that contribute to smog formation, acidification, eutrophication, or human health impacts) are currently not considered in life cycle costing. LCA examines a full range of inputs, emissions, effluents, and wastes that may or may not directly impact financial performance of a particular project, but which have implications for broader societal costs as well as the local, regional, and global environment.

### **LCCA in Building Design**

Life cycle costing was developed by the Department of Defense (DOD). Requirements for consideration of life cycle costs in government projects began with a mid-1960s study by the Logistics Management Institute for the Assistant Secretary of Defense for Installations and Logistics. This led to a series of guidelines for DOD procurement, and then to DOD Directive 5000.1 in 1971 that established requirements for life cycle costing for all major defense systems acquisitions. In 1978, Congress passed the National Energy Conservation Policy Act that requires every new federal building to be life cycle cost effective<sup>1</sup> (Dhillon 1989). Today, all federal agencies are required to use life cycle cost analysis in project evaluation.

LCCA is described in documents supporting the Federal Energy Management Program as particularly suitable for the evaluation of building design alternatives that satisfy a required level of building performance, but that may have different initial investment costs; different operating, maintenance, and repair costs; and possibly different service lives (Fuller and Petersen 1995). As noted in an LCCA user guide published by King County, Washington (King County 2011), in addition to direct costs of a building such as costs of construction, energy costs, building renewal and replacement, and operation and maintenance costs, LCCA can also take into account indirect costs such as staff salaries, staff productivity, lost construction time, fire insurance, lost revenues due to downtime, and other costs that are not directly related to the costs of a building. Notably, and consistent with generally-accepted principles for conducting LCCA, there is no mention of environmental costs in the King County list, or in any other LCCA related literature published by federal or state agencies or the construction industry.

In 1974, Florida became the first state to formally adopt requirements for life cycle costing in state funded projects (Dhillon 1989). Subsequently, other states began requiring or encouraging LCCA in the planning, design, and construction of state buildings, including Alabama, Alaska, Arkansas, Maryland, New Mexico, North Carolina, Texas, and Wisconsin. The State of Wisconsin, for example, has life cycle costing requirements for the design and location of any state building project including new

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<sup>1</sup> The term "life cycle cost-effective" when applied to a building component, innovation, or design feature refers to a situation in which estimated savings exceed estimated costs of the building component, innovation, or design feature over the lifespan of the feature under consideration.

major buildings, structures, major remodeling, or building additions; in this case, cost analysis requirements encompass all aspects of structures, including structural and non-structural building materials (State of Wisconsin 1997). Florida also takes a comprehensive approach to LCCA, but requires such analyses only for state-funded educational facilities. The majority of states have LCCA requirements for evaluation of design alternatives in highway and bridge construction.

Several universities require LCCA as part of project design; examples include Clarion University of Pennsylvania, Harvard University, Stanford University, the University of Florida, Florida State University, and the University of Arkansas. Several of these – Clarion, Harvard and Stanford – have developed their own guidelines for conducting an LCCA.

A study that examined the use of life cycle costing in the U.S. (Nornes 2005) surveyed architects, engineers, and consultants in the State of Colorado. The greatest use was in conjunction with LEED projects; 38% reported having used life cycle costing as part of LEED projects, with lesser use when not building to LEED specifications. Of all respondents, reported use of life cycle cost evaluations ranged from public (51% of respondents), institutional (35%), commercial (31%), renovation (13%), and residential (7%) projects<sup>2</sup>. Application of life cycle costing to consideration of foundations and structural elements of buildings, however, was reported as rare, with the number of respondents always, sometimes, and seldom evaluating structural elements reported at 5, 15, and 36 percent of respondents, respectively.

### **LCCA and LCA – Fundamental Differences**

As noted previously, the focus and intent of LCCA are fundamentally different than in LCA, and there is no relationship between the techniques used in performing them. As explained by Norris (2001), *"In nearly all private industry applications of LCA, the decision making situations which LCA addresses must also eventually take the economic consequences of alternative products or product designs into account. However, neither the internal nor external economic aspects of the decisions are within the scope of developed LCA methodology, nor are they properly addressed by existing LCA tools. This traditional separation of life cycle environmental assessment from economic analysis has limited the influence and relevance of LCA for decision making, and left uncharacterized the important relationships and trade-offs between the economic and life cycle environmental performance of alternative product design decision scenarios."* Table 1, also developed by Norris, identifies the critical aspects of LCA and LCCA and how they differ. It is important to recognize that consumption of things such as energy and water, both of which have environmental impacts, are included in LCCA, a reality that seems to blur the differences between LCA and LCCA; however, only the direct costs of consumption are considered in LCCA.

Norris notes that tools were developed in the late 1990s to integrate LCA and LCCA, including "Total Cost Assessment (TCA)" methodology that resulted from a collaborative

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<sup>2</sup> Numbers add to more than 100% because multiple responses by a single respondent were allowed in the survey.

effort of ten multinational companies and the American Institute of Chemical Engineers, Center for Waste Reduction Technologies (Beaver 2000, CWRT 1999). Another tool, the "PT Laser" Systems Dynamics Model, was developed by Norris' company Sylvatica, in 1995 and has been used by various companies, universities, and the USEPA.

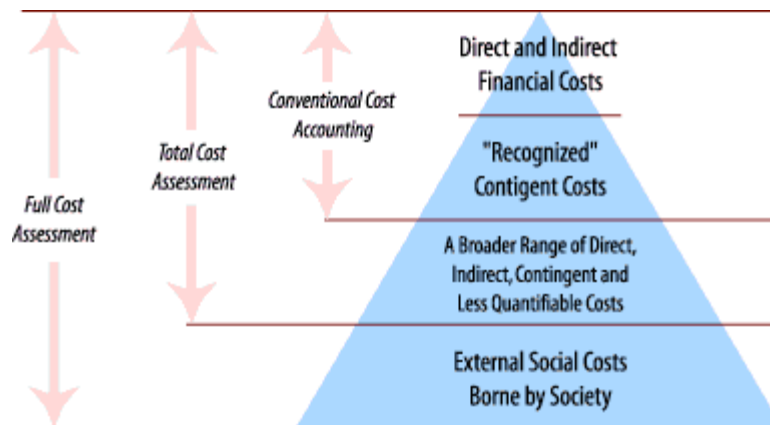
Table 1  
Critical Aspects of LCA and LCCA and How They Differ

Tool/Method	Life Cycle Assessment (LCA)	Life Cycle Cost Analysis (LCCA)
Objective	Compare relative environmental performance of alternative product systems for meeting the same end-use function, from a broad, societal perspective	Determine cost-effectiveness of alternative investments and business decisions, from the perspective of an economic decision maker such as a manufacturing firm or a consumer
Activity scope of the addressed "life cycle"	Supply chain of processes supporting usage phase; entire physical usage	Activities directly causing costs or benefits to the decision maker during the economic life of the investment as a result of the investment
Flows considered	Pollutants, resources, and inter-process flows of materials and energy	Direct costs and benefits to decision maker
Units for tracking flows	Physical and energy units	Monetary units (e.g. dollars)
Time treatment and scope	Timing ignored; all causally linked flows, and some other impacts, collapsed in time and valued equally regardless of timing	Timing is critical. Present valuing (discounting) of costs and benefits. Specific time horizon scope, outside of which costs and benefits are ignored

Source: Norris (2001)

A search of TCA in contemporary applications revealed that the current methodology still does not include full consideration of societal costs linked to raw material procurement or manufacturing emissions. As noted by the International Institute for Sustainable Development (2013) TCA is viewed as simply one tool within the broader field of environmental accounting that differs from conventional approaches by considering a broader range of costs that are particularly applicable to pollution prevention. It is noted, however, that "TCA has a more narrow focus than full cost assessment or life cycle analysis, because it may exclude external social costs for which a company is not legally accountable or financially liable" (Figure 1). In addition, references to TCA within the USEPA have largely disappeared from current usage, though the term "dynamic systems modeling" does still appear in recent reports.

Figure 1  
The Relationship Between Total Cost Assessment (TCA) and Other Approaches to Environmental Accounting



Source: International Institute for Sustainable Development (2013)  
([http://www.iisd.org/business/tools/systems\\_tca.asp](http://www.iisd.org/business/tools/systems_tca.asp))

Highton (2012) provides an interesting commentary on the relationship between LCA and LCCA, suggesting that there is a greater relationship than commonly acknowledged. The author points out that life cycle costing, by including costs of energy, water, and materials used in construction, repair, and maintenance through the life of a project, an automatic linkage is created to environmental impacts, providing incentives for reducing them. She notes that incentives are magnified when governments use pricing mechanisms, including taxes, as tools for increasing costs of basic resources, and that these too are borne largely by resource and manufacturing centers which then pass these on to consumers.

It now appears that consideration of social costs has gained attention within the DOD, with thought being given to perhaps moving beyond life cycle costing to broader consideration of environmental impacts. A recent presentation by the Deputy Under Secretary of Defense for Installations and Environment (Yaroschak 2012), in which references were made to inclusion in LCCA of societal costs linked to emissions and other wastes, may signal potential for change in procurement practices within the military.

## Life cycle Cost Comparisons of Non-Residential Buildings

### Published Reports

Few life cycle cost comparisons of buildings have been published. The number of published reports involving wood construction is even fewer.

One study of building envelope systems, including consideration of materials manufacturing, building construction, and building operation found large differences in life cycle costs linked to selection of building materials and the level of thermal insulation (Lucuik and Meil 2004). In this case, costs considered included not only direct costs associated with construction, maintenance, and operating energy, but also costs



to society in terms of human health and environmental impacts that are not commonly considered in project evaluation. A hypothetical two-story, 2300 m<sup>2</sup> building in Toronto, Ontario was as a basis for modeling over a 20-year life, and all model output was compared to a 92mm (3.6 inch) steel stud wall system with glass fiber batt insulation within the studs (Steel 1). This system was compared with various wall designs and insulation levels for buildings constructed of wood, steel, and concrete (Table 2); costs associated with the baseline system (Steel 1) were set to zero, with differences in life cycle costs associated with all other systems shown in Table 3. The least-cost systems identified in this analysis were both wood-based (Wood 1 and Wood 2); the lowest cost system is of standard wood 2x6 design. Use of high levels of exterior insulation with steel systems also yielded relatively low life cycle costs (Steel 2 and 3). The 20-year life precluded consideration of maintenance and replacement issues and cost consequences at the end of building life.

Table 2  
Alternative Wall Designs Considered by Lucuik and Meil (2004)

<b>Wood-based wall systems</b>		
<b>Wood 1</b>	<b>Wood 2</b>	<b>Wood 3</b>
12 mm gypsum board	12 mm gypsum board	12 mm gypsum board
6 mil polyethylene	6 mil polyethylene	6 mil polyethylene
2x4 wood studs@ 406 mm o.c.	2x6 wood studs@ 406 mm o.c.	2x4 wood studs@ 406 mm o.c.
glass fiber batts within studs	glass fiber batts within studs	glass fiber batts within studs
12 mm plywood sheathing	12 mm plywood sheathing	2x4 wood studs @406mm o.c. (staggered)
15# asphaltic building paper	15# asphaltic building paper	glass fiber batts within studs
vented 20 mm airspace	vented 20 mm airspace	12 mm plywood sheathing
100 mm brick	100 mm brick	15# asphaltic building paper
		vented 20 mm airspace
		100 mm brick
<b>Steel-based wall systems</b>		
<b>Steel 1</b>	<b>Steel 2</b>	<b>Steel 3</b>
12 mm gypsum board	12 mm gypsum board	12 mm gypsum board
6 mil polyethylene	6 mil polyethylene	6 mil polyethylene
92 mm steel studs@ 406 mm o.c.	150 mm steel studs@ 406 mm o.c.	150 mm steel studs@ 406 mm o.c.
glass fiber batts within studs	glass fiber batts within studs	glass fiber batts within studs
12 mm gypsum board sheathing	25 mm EPS type III sheathing	75 mm EPS type III sheathing
15# asphaltic building paper	15# asphaltic building paper	15# asphaltic building paper
vented 20 mm airspace	vented 20 mm airspace	vented 20 mm airspace
100 mm brick	100 mm brick	100 mm brick
<b>Concrete/Masonry-based wall systems</b>		
<b>Concrete 1</b>	<b>Concrete 2</b>	<b>Concrete 3</b>
12 mm gypsum board	12 mm gypsum board	12 mm gypsum board
6 mil polyethylene	6 mil polyethylene	6 mil polyethylene
12 mm air space with wood strapping @ 600 mm o.c.	2x4 wood studs@ 406 mm o.c.	2x4 wood studs@ 406 mm o.c.
200 mm concrete block	glass fiber batts within studs	glass fiber batts within studs
15# asphaltic building paper	200 mm concrete block	200 mm concrete block
vented 20 mm airspace	25mm EPS type III sheathing	75mm EPS type III sheathing
100 mm brick	15# asphaltic building paper	15# asphaltic building paper
	vented 20 mm airspace	vented 20 mm airspace
	100 mm brick	100 mm brick

Source: Lucuik and Meil (2004)

**Table 3**  
**Direct and Indirect Cost Comparison Across Wall Envelope Systems**

Wall Envelope System	Total Direct Cost in C2003\$	Total Indirect Cost in C2003\$ (for 20-year period)	Total Full Cost in C2003\$
Concrete 1	25,564	19,397	44,961
Steel 1	0	0	0
Wood 1	-3,758	-5,928	-9,685
Concrete 2	11,092	-176	10,916
Steel 2	-4,040	-3,768	-7,808
Wood 2	-4,714	-7,365	-12,079
Concrete 3	13,514	-549	12,965
Steel 3	-3,828	-4,612	-8,441
Wood 3	3,506	-7,945	-4,439

Source: Lucuik and Meil (2004)

Another study of wood vs. steel and concrete commercial buildings (Cole and Kernan 1996a,b) provides insights into an important segment of life cycle costs, though what was reported was limited to energy use linked to construction, maintenance and repair, and building.

In the Cole and Kernan study, total life cycle energy use was examined in a 4,620 m<sup>2</sup> (50,000,ft<sup>2</sup>) three-story, generic office building for alternative wood, steel and concrete structural systems, with and without underground parking. Detailed estimates were made of the initial embodied energy and recurring embodied energy (and the costs of this energy) associated with maintenance and repair, and operating energy. Operating energy requirements were assumed to be the same for all building types, based on designing to an equivalent energy standard. Over a 50-year building life, and for both of two geographic locations considered, the wood building was found to have lower energy use in construction (i.e. lower embodied energy), and lower energy use for maintenance and repair. Unfortunately, no costs other than direct costs of energy were considered.

Because of the lack of published LCCA studies involving wood commercial buildings, several studies involving other types of structures were examined and are reported herein. The most comprehensive life cycle cost evaluation of wood vs. other structures was commissioned by the DOD (NAHB Research Center 2004). In this study, estimates of the life cycle costs of barracks constructed with masonry and steel framing at Fort Detrick, Maryland were compared with life cycle costs of barracks constructed with light wood-frame construction at Fort George G. Meade, Maryland. For each barracks, the authors estimated initial capital costs and salvage values, as well as maintenance, preventive maintenance, and capital improvements over a 40-year time frame. The findings were highly favorable to wood construction. Overall, the life cycle costs of the wood-frame barracks were found to be about 40 percent lower than those of the masonry and steel barracks on a per square foot basis. The present value of initial construction costs was found to be about 37 percent lower in wood-frame construction, while the present value of the maintenance, preventive maintenance, and capital



improvements was about 55 percent lower in wood-frame construction. The authors of the report noted that considerable differences existed between the two facilities that may have affected the outcome. The Fort Meade wood-frame barracks were about three times the total square feet of the Fort Detrick barracks, which may have afforded some economies of scale in construction and maintenance on a per square foot basis. Additionally, the Fort Detrick masonry and steel barracks were constructed five years prior to the Fort Meade barracks, resulting in capital improvements required earlier in the facility's life cycle.

Subsequent to the US Army evaluation, the US Government Accountability Office (GAO) examined costs of building materials and methods when developing or acquiring new permanent facilities (US GAO 2010). Findings of this study highlight the lack of published life cycle cost information for various building types and also point to negative bias regarding perceived durability of wood structures. GAO reviewed selected project information and determined that the Army appears to have achieved some savings in selected construction projects by expanding the use of wood materials and modular construction methods for some of its facilities, but found little quantitative data on whether the use of these materials and methods would result in savings over the long term compared to the traditional use of steel, concrete, and masonry materials and on-site building methods. The GAO pointed out that without long-term or life cycle analyses that consider not only initial construction costs but also possible differences in facility service lives and annual operating and maintenance costs between the construction alternatives, it is not clear that the Army's expanded use of wood materials and modular building methods will achieve their intended purpose of reduced facility costs over the long term. Notably, the Navy and the Air Force reportedly expressed general disagreement with the Army's view that wood construction would result in savings, believing that the use of wood materials and modular construction will result in facilities with shorter service lives and higher life cycle costs. However, GAO found that none of the services had analyses to support their views, and that without additional study and analysis, DOD could not know whether military construction program guidance needs to be changed to ensure that facilities are constructed with materials and methods that meet needs at the lowest cost over the long term.

A fourth study that has gained some notoriety since publication (Ochsendorf 2011) was conducted by the Massachusetts Institute of Technology Concrete Sustainability Hub. In what is advertised in a talking points document regarding building life cycle cost analysis (MIT 2012), three types of buildings were described:

- o Wood and concrete two-story single-family homes (2,400 sf)
- o Wood and concrete four-story multifamily buildings (34,000 sf)
- o Steel and concrete 12-story commercial buildings (500,000 sf)

Reported results included the following findings:

- With respect to both single and multi-family homes, tightly constructed code-compliant wood structures were found to have lower embodied global warming potential, but higher consumption of energy for heating and cooling, and overall greater energy costs and similarly greater global warming potential (GWP).

- Life cycle costs of single and multi-family homes, as determined through LCCA in which only energy costs, and not costs of maintenance, societal costs of emissions, or other factors, were considered, were found to be lower for insulated concrete form (ICF) structures than for those constructed of wood.
- Wood was not considered when evaluating the 12-story commercial buildings.

This study, like several other recent studies commissioned by the Portland Cement Association, chose for comparison a wood structure with minimal insulation and a highly insulated concrete structure – ICF. It is no surprise that energy use over the life cycle of the building was found to be higher for the minimally insulated wood structure. Had comparison been made of embodied and operating energy of buildings with equivalent energy performance levels, results would have shown – consistent with a number of other life cycle assessments of similar structures – much lower embodied energy for the wood structure and very similar operating energy requirements.

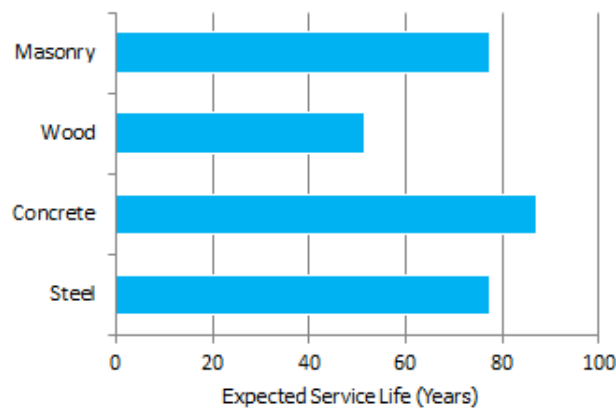
With respect to life cycle costing, although in this study LCCA did not include consideration of costs related to emissions, the finding that wood structures are associated with similar or greater GWP than ICF structures would mean that costs of wood structures, based on the MIT study, would also be higher if a carbon tax were in existence. However, because MIT modeling shows an early GWP advantage of wood that is only gradually overcome through assumed thermal performance advantages of ICF construction, wood structures would likely show lower life cycle costs in comparison to ICF since all LCCA calculations involve discounted cash flow of expenditures over the life of a building to present value.

### Ongoing Comparisons

Regardless of the scarcity of published LCCA studies involving different types of buildings, such comparisons take place on an almost daily basis across North America. While guidance for the conduct of LCCA provided by ISO, ASTM, and various agencies of the federal government do not specify useful life estimates for various construction materials (but also do not prevent practitioners from assuming unequal lives for various components), independent sources and some state governments and state agencies do. Where estimated useful lives are specified for various types of materials, in virtually all cases lower useful lives are assigned to wood than to other materials, despite a lack of evidence of a scientific basis for useful life estimates.

The use of lower useful service life estimates for wood in comparison to other materials appears to be reinforced by a pervasive view of wood inferiority among many in the building industry. A survey of 683 architects, structural engineers, builders, and developers in the U.S. and Canada (Gaston et al. 2001) regarding building durability revealed that non-residential wood buildings were, on average, expected to last for far shorter periods than buildings constructed of other materials (Figure 2).

**Figure 2**  
**Average Expected Service Life for Non-Residential Buildings –**  
**A Survey of 683 Architects, Structural Engineers, Builders, and**  
**Developers in the U.S. and Canada**



Source: Gaston et al. (2001).

Examples of estimated life tables for building components are provided below, with information from the Departments of Administration of North Carolina (Table 4) and Wisconsin (Table 5), and from the website Costmodeling.com (Table 6). In regard to lifespans for structures, the DOD United Facilities Criteria – General Building Requirements specify a life of 25 years or greater for permanent structures ([http://www.wbdg.org/ccb/DOD/UFC/ufc\\_1\\_200\\_01.pdf](http://www.wbdg.org/ccb/DOD/UFC/ufc_1_200_01.pdf)). Criteria for High Performance and Sustainable Buildings specify that a maximum life of 40 years be assumed in any LCCA analysis. ([http://www.wbdg.org/ccb/DOD/UFC/ufc\\_1\\_200\\_02.pdf](http://www.wbdg.org/ccb/DOD/UFC/ufc_1_200_02.pdf)). DOD does not have any guidelines that specify assumed useful lives of various building materials and components.

**Table 4**  
**Estimated Useful Lives of Building Components in Life cycle Cost Analyses**  
**for State Facilities in North Carolina**

<u>Component</u>	<u>Economic Life (years)</u>
<b>GENERAL CONSTRUCTION (DIVS. 2-14)</b>	
Foundations	30(+)
Substructure	30 (masonry), 20 (wood)
Superstructure	30 (masonry), 20 (wood)
Exterior Closure	30 (masonry), 20 (wood or metal)
Roofing	shingles 12-20
	built-up 17
	single-ply 20 (other than EPDM)
	EPDM single-ply 10-12
Interior Construction	10

Source: North Carolina Department of Administration. 2001. Life Cycle Cost Analysis for State Facilities. State Construction Office. ([www.nc-sco.com/documents/guidelines/lcca/LCCA%20Manual.doc](http://www.nc-sco.com/documents/guidelines/lcca/LCCA%20Manual.doc))

**Table 5**  
**Typical Useful Lives of Building Systems and Components Used in**  
**Life Cycle Costing for State Building Products in Wisconsin**

<u>Building Enclosure</u>	<u>Useful Life (Years)</u>
Concrete Framing System:	
- Masonry Exterior	45-60
- Metal Clad	40-50
Steel Framing System:	
- Masonry Exterior	40-50
- Metal Clad	40-50
Wood Framing System:	
- Metal Clad	35-45
- Wood Siding	35-60

State of Wisconsin. 1997. Guidelines for Life Cycle Costing on State Building Projects. Department of Administration, Division of Facilities Development. ([www.doa.state.wi.us/docs\\_view2.asp?docid=101](http://www.doa.state.wi.us/docs_view2.asp?docid=101))

**Table 6**  
**Typical Life Expectancy of Building Components as Estimated by Costmodeling.com**

<u>Element</u>	<u>Component Name</u>	<u>Typical Life Expectancy (Years)</u>
Frame	Steel frame	83
	Concrete frame	81
	Timber frame	69
	Laminated timber frame	65
	Space frame	73
Upper Floors	Profiled steel and reinforced concrete floor	71
	Precast concrete slab	78
	Timber joists	90
	Softwood decking to timber joists	71
	Chipboard decking to timber joists	51

Costmodeling.com. Typical life expectancy of building components. [n.d.]  
(<http://www.costmodelling.com/downloads/BuildingComponentLifeExpectancy.pdf>)

Some of the information regarding useful life estimates of wood building components that is in common use appears to stem from a 2007 report by the National Association of Home Builders and Bank of America that provides estimates of life expectancy of home components. Unfortunately, reported information leaves considerable room for interpretation. For instance, the following information is taken verbatim from the project report:

#### Engineered Lumber

Floor and roof trusses and laminated strand lumber are expected to last a lifetime, while engineered trim and laminated veneer lumber are expected to last 30 and 30+ years, respectively.

#### Framing and Other Structural Systems

Framing and structural systems have extended longevities: poured-concrete systems, timber frame houses and structural insulated panels will all last a lifetime.

### Panels

Hardboard panels and softwood panels are expected to last 30 years, while oriented strand board has a life expectancy of 25-30 years, and flooring underlayment should last about 25 years. Wall panels are expected to last a lifetime, and plywood and particleboard have a life expectancy of about 60 years.

This information can be easily interpreted to mean that OSB and softwood plywood sheathing will last no longer than 25-30 years and that laminated veneer lumber when used as headers or other structural elements will last as little as 30 years. Long term experience with these materials in North American construction would suggest that these estimates are unrealistically short.

Additional information regarding estimated useful lives of building components can be found in information published by the National Institute of Building Sciences (2000), the National Research Council (LaCasse and Vanier 1999), industry publications ([Dell'Isola and Kirk 2003](#)), and the State of Florida (Florida Department of Energy 2010, Kibert et al. 2010). The two publications cited above for the State of Florida contain tables of life cycle costs of various building materials and components. However, for columns, beams, floors, roofs, exterior walls, and exterior wall coverings only steel and concrete are considered; there is no mention of wood products except for flooring, doors, cabinets, and base trim. The Athena Sustainable Materials Institute (2002) also has published information regarding typical maintenance, repair, and replacement needs for building components; this report lists averages in tabular form as to average cycles for repainting, re-caulking, re-pointing, and replacement of various types of exterior walls, curtain walls, siding, windows, roofs, and gypsum.

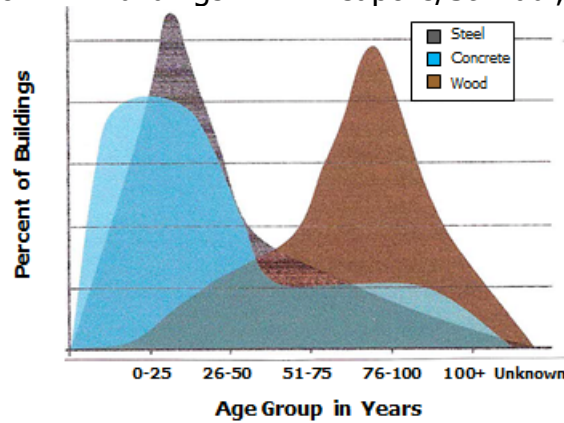
Given the ready availability of the kind of information cited above and its use in LCCA in practice, it may make little difference that research-based data regarding the useful lives of various construction materials and building systems is not available. Instead, it appears that on a daily basis architects and engineers are conducting evaluations of their own, using the data that is available, with the result that each calculation serves to reinforce a perception that wood materials are not as durable, and therefore not as cost effective, as alternative building materials.

### **Research Findings Regarding Building Durability and Construction Material**

Only one definitive study of building durability by primary type of material used in construction has been conducted; this involved an examination of building demolition records for the Minneapolis/St. Paul metropolitan area for the years 2000-2003 (Athena Institute 2004). The age at demolition of 227 buildings (which included both residential and commercial structures) for which there were public records is shown in Figure 3.

While the ages of demolition for concrete and steel structures were as long as 100 years+, the majority of these buildings reached the end of their useful lives at about 25-30 years of age. The wood structures were, on average, far older at the time of demolition. Interestingly, upon delving into the reasons for demolition, it was found that about 60% of structures were removed as part of area redevelopment initiatives,

Figure 3  
Demolition of 227 Buildings in Minneapolis/St. Paul, 2000-2003

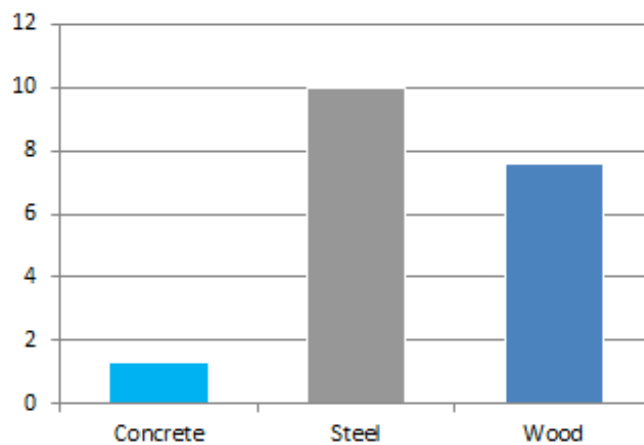


Source: Athena Institute (2004)

because the buildings no longer fit the needs of the owner or tenant, due to changing land values, or because of socially undesirable use or inability to economically bring a building up to code. Less than one-third were demolished because of physical condition and less than 7 percent as a result of fire damage. Of buildings demolished due to fire damage, the greatest percent were of steel construction (Figure 4).

The fact that more of the steel and concrete buildings depicted in Figure 3 were commercial/industrial structures, and thus more subject to code changes and redevelopment factors explains much of the difference in longevity between these buildings and wood structures.

Figure 4  
Percent of Each Building Type Demolished Because of Fire Damage

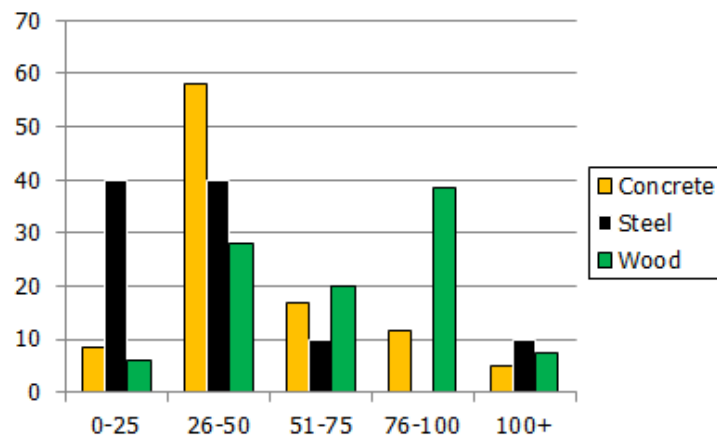


Source: Athena Institute (2004)

Of the 227 buildings for which demolition records were available, 94 were non-residential with the principal construction material identified; 51 percent were concrete, 29 percent wood, 10 percent steel, 1 percent aluminum, and the rest various combinations of concrete, steel, and wood. In this case the most common age at demolition was 25-50 years. Again, the longevity of wood structures at age of demolition compared favorably to structures constructed of other materials (Figure 5).



Figure 5  
Distribution of 94 Non-Residential Buildings by Structural Material and Age at Demolition



Source: Athena Institute (2004)

Examination of the data from Minneapolis/St. Paul led to the conclusion that despite a pervasive perception that the useful life of wood structures is lower than other buildings, no meaningful relationship exists between the type of structural material and average service life. It is worth noting that most buildings in this study were demolished for reasons that had nothing to do with the physical state of the structural systems.

### LCCA Guidance

Sources of information regarding proper methodology for the conduct of LCCA include standards-setting organizations, and government bodies – particularly the US federal government. A summary of guidance documents is contained in Appendix A.

### Centers of Excellence in LCCA

Because LCCA, beyond evaluation of energy-related components of buildings, is seldom practiced in the United States, there appears to be a lack of research organizations within the country that could be considered “Centers of Excellence” for the conduct of LCCA in the context of buildings and building materials. Some of these are identified in Appendix B.

### Bottom Line

Among the findings of this study are that:

- Published life cycle cost analysis information for commercial (non-residential) buildings is sparse, and such information for wooden structures is not widely available in current literature.

- LCCA is required as part of the design process for federal buildings, for building projects undertaken or financed by state governments in several states, and for building projects undertaken by a number of educational institutions.
- Life cycle environmental costs are not considered in any current life cycle costing requirements or standard practices, indicating a clear difference between LCA and LCCA as currently structured.
- There are a number of lists of estimated useful lives of building components in common use and virtually all of these assign lower useful lives to wood than to other materials but do not provide any basis for their chosen values.
- Recent research indicates that despite a pervasive perception that the useful life of wood structures is lower than for buildings of other materials, no meaningful relationship exists between the type of structural material and average service life.
- The combined effect of a lack of solid LCCA research on wood use in construction, and the common availability of what appear to be non-research-based estimates of useful lives of various materials that are prejudicial to wood, creates an unwarranted bias against the use of wood in structures.
- Development of definitive, research-based information on durability/longevity of wood structural and non-structural elements used in various building applications is needed.

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## **Appendix A**

### **Sources of LCCA Guidance**

#### LCCA Guidance and Standards Setting Organizations

Within the United States, the most authoritative source of information regarding the conduct of LCCA is the American Society of Testing and Materials (ASTM). The principal document is ASTM Standard E 917 – *Practice for Measuring Life Cycle Costs of Buildings and Building Systems*. The ASTM E-917 or the NIST Building Life Cycle Cost Program (which is ASTM compliant) offer the best available guidance for the conduct of LCCA.

Nine additional ASTM standards provide guidance in LCCA, with these concentrating on identification, calculation, and reporting of costs and cost recovery:

- E964 *Practice for Measuring Benefit-to-Cost and Savings-to-Investment Ratios for Buildings and Building Systems*
- E1057 *Practice for Measuring Internal Rate and Adjusted Internal Rate of Return for Investment in Buildings and Building Systems*
- E1074 *Practice for Measuring Net Benefits for Investments for Investments in Buildings and Building Systems*
- E1121 *Practice for Measuring Payback for Investments in Buildings and Building Systems*
- E1185 *Standard Guide for Selecting Economic Methods for Evaluating Investments in Buildings and Building Systems*
- E 1699-00 – *Performing Value Analysis (VA) for Buildings and Building Systems*
- E 1765-02 – *Applying the Analytical Hierarchy Process (AHP) to Multiattribute Decision Analysis of Investments Related to Buildings and Building Systems*
- E 1804-02 – *Performing and Reporting Cost Analysis During the Design Phase of a Project*
- E 1946-02 – *Measuring Cost Risk of Buildings and Building Systems*

The International Organization for Standardization (ISO) also provides guidance for the conduct of LCCA through its document:

- ISO Standard 15686-5: *Buildings and constructed assets – service life planning: part 5, life cycle costing.*



## LCCA Guidance and the US Federal Government

As noted previously, the use of life cycle costing has been a mandate of the federal government since the late 1970s, with energy the primary focus, then and now, of LCCA within federal agencies. The military services, in particular have embraced LCCA.

In view of the fact that the US federal government considers LCCA almost exclusively in the context of energy-saving investments, this is not the best source of guidance for the conduct of LCCA in the holistic design of structures. Nonetheless, considerable information is available through the Federal Energy Management Program and through the National Institute for Standards and Technology (NIST). Key documents are the following:

Federal Energy Management Program. 2013. Life Cycle Cost Analysis for Sustainable Buildings.

(<http://www1.eere.energy.gov/femp/program/lifecycle.html>)

Fuller, Sieglinde. 2010. Life-Cycle Cost Analysis (LCCA). National Institute of Standards and Technology. (<http://www.wbdg.org/resources/lcca.php>)

National Institute of Standards and Technology. 1999. The NIST "Building Life Cycle Cost" Program, NISTIR 5185-2.

([http://www.eere.energy.gov/femp/information/download\\_blcc.cfm](http://www.eere.energy.gov/femp/information/download_blcc.cfm))

Life cycle analysis information related to buildings and building components can be found at:

National Institute of Standards and Technology. 2011. Building for Environmental and Economic Sustainability (BEES).

(<http://www.bfrl.nist.gov/oae/software/bees/>)

This is an authoritative source of information, though far from complete, for a wide range of building materials. Information regarding assemblies is not included in the BEES database.

Other important information includes:

Fuller, Sieglinde 2005. Guidance on Life-Cycle Cost Analysis Required by Executive Order 13123. National Institute of Standards and Technology, for U.S. Department of Energy.

([http://www1.eere.energy.gov/femp/pdfs/lcc\\_guide\\_05.pdf](http://www1.eere.energy.gov/femp/pdfs/lcc_guide_05.pdf))

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([http://www.nist.gov/customcf/get\\_pdf.cfm?pub\\_id=907459](http://www.nist.gov/customcf/get_pdf.cfm?pub_id=907459))

General information about the use of life cycle costing in federal government construction projects can be found in publications of the General Services Administration (GSA), the US Department of Agriculture-USFS, and of the military services (US General Services Administration 2012, US Marine Corps 2010, US Navy 2010).

## **Appendix B**

### **Centers of Excellence in LCCA**

Universities that are involved in LCCA research are focused on its application in the design and construction of highways and bridges. In this regard, there are several universities that stand out:

- Carnegie Mellon University – Department of Mechanical Engineering
- University of California at Berkeley – Institute of Transportation Studies
- University of Michigan, Center for Sustainable Systems
- University of Minnesota – Industrial Ecology Laboratory
- Rutgers University – Department of Civil and Environmental Engineering

The foremost organization in the United States for LCA and LCCA research and guidance is not a government entity or a university, but instead a small private company – Sylvatica Life Cycle Research and Consulting (<http://www.sylvatica.com/>) that works globally on the development and practice of LCA and LCCA. Several articles by the firm's founder and principal, Greg Norris, are cited in this report.

There are organizations outside of the US that qualify as Centers of Excellence in LCCA. Areas of considerable activity include the UK, Australia, and Sweden. Of particular note are the following organizations:

- The Building Research Establishment (BRE) – UK (David Richardson)
- The School of Construction and Property Management, Salford University, Great Manchester, UK (G. Aouad)
- Curtin University of Technology, Department of Civil Engineering, Perth, Australia (A. Whythe)
- Queensland University of Technology, Brisbane, Australia (Matt Noor)
- Department of Civil, Mining, and Environmental Engineering, Luleå University, Luleå, Sweden (J. Schade, L. Stehn)

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