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Comparative Life Cycle Assessment of Precast Concrete Commercial Buildings
Executive Summary

1. Introduction

In 2013 PCI completed a "cradle-to-grave" life-cycle assessment (LCA) study relating to commercial buildings. In broadest terms, a cradle-to-grave LCA evaluates the environmental performance of a building over its entire "life cycle," which the study divides into Manufacturing, Construction, Maintenance, Operating Energy, and End-Of-Life stages.

This was a *comparative* study, examining the performance of precast concrete relative to alternative structural and envelope systems. While the scope of this study was limited to a "generic" mid-rise commercial building, the results are applicable toward improving the performance of precast concrete buildings generally.

The methodology employed in this study complied with international standards ISO 14040:2006 and ISO 14044:2006 for conducting life-cycle assessments.

2. Study Parameters

The basis of comparison chosen for the study was a five-story commercial office building that provides space for 130 people and meets minimum building and energy code requirements. The service life of the building was assumed to be 73 years, the median life for large commercial buildings according to published literature. In conformance with international standards for comparative studies, the same fundamental design parameters (dimensions, column spacing, etc.) were applied for all cases; the design of the comparison structure was not optimized for any of the structural and envelope systems evaluated.

The study evaluated 15 design cases consisting of 5 different building envelope systems combined with 3 different structural systems (Table 1). To consider different climate conditions, the 15 cases were modeled in four U.S. locations (Denver, Memphis, Miami, and Phoenix). The case using precast concrete for both the envelope and structural systems (designated "P-P") was defined as the baseline for comparison.

Table 1. Summary of Design Cases studied

Building Envelope System (and Designation)	Structural System (and Designation)		
	Steel (S)	Cast-In-Place Concrete (C)	Precast Concrete (P)
Curtain Wall (CW)	CW-S	CW-C	CW-P
Brick + Steel Stud (S)	S-S	S-C	S-P
Precast Concrete (P)	P-S	P-C	P-P
Insulated Precast Concrete (Pi)	Pi-S	Pi-C	Pi-P
Insulated Precast Concrete + Thin-Brick Veneer (Pib)*	Pib-S	Pib-C	Pib-P

**Thin-brick veneer is made of 13–16 mm (½-⅝ in.) thick bricks cast into the precast concrete panel*

In addition to the comparative study, a sensitivity analysis was conducted to determine the extent to which environmental impacts would be affected by using double tees instead of hollow-core planks for floors (see Appendix A).

3. General Results

The study yielded three important results:

- The environmental performance of buildings is dominated by the Operating Energy stage.
- The environmental performance of precast concrete buildings is competitive.
- The environmental performance of precast concrete buildings can be improved.

These outcomes are explained in more detail in the following sections.

4. The environmental performance of buildings is dominated by the Operating Energy stage

The Operating Energy stage—that is, the operating of the building over its lifetime—has the greatest overall impact on environmental performance. More than 90% of the impacts relating to global warming, acidification, respiratory effect, eutrophication, photochemical smog, and total primary energy occur in the Operating Energy stage. While the numbers vary somewhat among the four cities studied, in all cases at least 97% of the total primary energy (TPE) and 96% of the global warming potential (GWP) attributed to the building over its lifetime occurs in the Operating Energy stage.

The precast concrete structures industry, as a manufacturer / constructor, should be aware that as energy codes become more stringent and less-polluting sources of energy become widely available, Operating Energy stage impacts will decrease. Unless their impacts correspondingly decrease, the Manufacturing and Construction stages will represent an increasing percentage of the total impact.

5. The environmental performance of precast concrete buildings is competitive

This study confirmed a basic conclusion of most balanced LCA studies of commercial buildings, namely that there is presently not a significant difference in life-cycle impacts between steel, cast-in-place concrete, and precast concrete structural systems.

Concrete has received negative press due to energy use and carbon dioxide emissions associated with manufacturing portland cement. Systems that compete with concrete have capitalized on this to imply that concrete is a poor environmental choice. This mistaken idea has been embraced as true by many in the public, which can be problematic as codes, standards, and rating systems are influenced by public comment. The fact, as shown by this research, is that concrete buildings perform just as well as steel buildings in terms of environmental impacts.

Ten specific environmental impacts were evaluated for each of the 15 cases, in each of the four cities. To provide a simplified characterization for the purpose of this Summary, the discussion below focuses on the coefficient of variation (COV) of the results for the 15 building cases for each environmental impact. Fully detailed life-cycle impact assessment (LCIA) results are provided in the project report

5.1. Global warming potential, total primary energy, acidification, respiratory effects, eutrophication[1], photochemical smog, and solid waste impacts

Within a given city, the COV of results for the 15 building cases relating to global warming potential (GWP), total primary energy (TPE), acidification, respiratory effects, eutrophication, photochemical smog, and solid waste was 2% or less. This means that for a given climate, there is little difference among the building cases for these seven environmental impact categories.

5.2. Water use impact

Within a given city, the COV of results for the 15 building cases relating to water use was 14%. This means that for a given climate, there is a notable difference among the building cases for water use impact.

Water use in the Operating Energy stage is the same for all cases. However, buildings with steel structural systems (regardless of envelope system) have greater water use impact in the construction stage because they employ masonry elevator and stairwell walls, which embody significant water use.

5.3. Abiotic resource depletion

Abiotic resources are those that come from non-living, non-organic material such as land, fresh water, air, and metals. Within a given city, the COV of results for the 15 building cases relating to abiotic resource depletion was 36%. This means that for a given climate, there is a great difference among the building cases for abiotic resource depletion.

The majority of the abiotic resource depletion impact occurs in the Manufacturing and Construction stages. Regardless of city, the buildings with largest abiotic resource depletion impact were those with steel structural systems, due primarily to the use of steel decking for floors and roofs. Specifically, the Manufacturing stage abiotic resource depletion impact of just the floors and roofs for buildings with steel structural systems was greater than that for the *entire building* for concrete structural systems (cast-in-place or precast)

5.4. Ozone depletion

The COV of results for the 15 building cases relating to ozone depletion varied from 0 to 15%, depending on the city. This means that the difference among the building cases for ozone depletion depended on climate.

Most ozone depletion impact is from use of extruded polystyrene (XPS) insulation. Use of XPS in roofs, which is relatively consistent for all building cases, is the primary factor driving this impact. However, XPS is also used in concrete walls (both cast-in-place and precast), while it is generally not used with curtain wall and brick on steel stud walls. This means that in climates where wall insulation is used (for this study, all cities except Miami), the concrete-wall building cases had greater ozone depletion impacts. For Miami, there was essentially no difference among the building cases for ozone depletion

[1]The response of an ecosystem to the addition of artificial or natural substances (e.g. fertilizers, sewage) to an aquatic system.

6. The environmental performance of precast concrete buildings can be improved

In considering ways to reduce the environmental impacts of precast concrete buildings, each life-cycle stage should be examined. While the Manufacturing stage might seem to offer the only opportunity for improvement for precast producers, the fact is that refinements in building design, element detailing, plant facilities, manufacturing processes, and materials use can have positive effects in all stages.

In order to evaluate environmental impacts of precast concrete buildings, Manufacturing stage impacts for the constituent precast concrete elements (hollow-core slabs, wall panels, columns, beams, double tees) had to be evaluated. Unpacking this data revealed some differences among the various element types (about 6%). However, Manufacturing stage impacts for all precast concrete element types were driven by a few key factors.

- Portland cement. Portland cement use accounts for the majority of the impact in most environmental impact categories.
- Plant energy. Energy used in the fabrication process accounts for 23%–25% of the total primary energy (TPE) and 13%–14% of the global warming potential (GWP) for the Manufacturing stage.
- Plant material waste. 40% of the solid waste generated in the Manufacturing stage is associated with steel reinforcement and steel anchor plates; 44%–45% is associated with general plant operations.
- Other constituent materials. The extraction processes for fine and coarse aggregates are significant contributors to respiratory effects (21%–23% combined), due in part to particulate releases during quarrying. The manufacturing and handling of admixtures contribute to ozone depletion and primary energy use.

The identification of environmental "hot spots" for precast concrete production (energy, waste, recycling, water, and cement use) suggests ways to reduce the environmental impact of precast product manufacturing. This information is being used in the development of PCI's Sustainable Plant Program.

7. Conclusions

This study provided the precast concrete structures industry with a better understanding of the life-cycle environmental performance of precast concrete relative to alternative structural and envelope systems for mid-rise office buildings. While the scope of the study was limited, its key results will be broadly useful in improving the environmental performance of precast concrete buildings. In particular, specific areas were identified where precast concrete producers can reduce environmental impact.

APPENDIX A
Sensitivity Analysis for Precast Concrete Double Tee

Precast concrete double-tee elements, which are not generally used in office buildings but are commonly used in more heavily-loaded structures, are a possible alternative to precast concrete hollow-core planks for office building floors. Including double-tee construction in the LCA, however, would have been outside the international standard methodology, which requires that the model reflect construction practices in general use. It was therefore decided to examine double-tee construction with a sensitivity analysis.

To accomplish this, an additional scenario was studied: the baseline building (precast concrete for both envelope and structural system), located in Memphis, with double-tee construction substituting for beams and hollow-core planks in the floors. This scenario was designated "P-P-DT."

Overall, P-P-DT used about 25% less material (by mass, including steel reinforcement) than P-P but about the same amount as the cast-in-place concrete cases. The energy model was adjusted to account for the different quantity and distribution of thermal mass (the double-tee option has less mass, but larger surface area, than the hollow-core option). This resulted in a small decrease in heating energy (1.6%), cooling energy (0.5%), and fan energy (1.2%). However, the total difference was only 0.3%, or 8 GJ per year of operation.

Table A-1 shows the cradle-to-grave results for the double-tee option (P-P-DT) compared with the baseline building (P-P) located in Memphis. Because the majority of cradle-to-grave impacts are from the Operating Energy stage and the total difference in operating energy was only 0.3%, the relative differences are small (0%–2%) for all environmental impact categories

Table A-1. Cradle-to-Grave LCIA Results for P-P-DT Compared with Baseline Building P-P, Memphis

Impact Category	Units	Case P-P	Case P-P-DT	Percent Difference*
Global Warming	kg CO_2 eq.	45,841,119	45,488,593	0.8%
Acidification	H+ moles eq.	20,762,635	20,644,022	0.6%
Respiratory effects	kg PM2.5 eq.	95,746	95,004	0.8%
Eutrophication	kg N eq.	6,004	5,942	1.0%
Photochemical smog	kg NOx eq.	130,399	129,221	0.9%
Solid waste	kg	2,330,731	2,295,579	1.5%
Water use	m^3	28,720	28,303	1.5%
Abiotic resource depletion	kg Sb eq.	1.59	1.48	7.1%
Ozone depletion	CFC-11 eq.	3.77E+00	3.77E+00	0.0%
Total primary energy	MJ	813,644,683	809,072,266	0.6%

**Percent difference between the whole-building LCIA results of P-P-DT compared to P-P.*