

Embodied Energy and Historic Preservation: A Needed Reassessment

MIKE JACKSON

If more widely and comprehensively used, embodied-energy assessment can be a boon to preservation and sustainability advocates alike.

Introduction

The benefits of reusing historic and existing buildings versus those of constructing new buildings are frequently discussed in terms of economic, cultural, and design values. If those discussions are expanded to include environmental impact, one must also address the topic of embodied energy. Embodied energy is the sum of all the energy required to extract, process, deliver, and install the materials needed to construct a building. Embodied energy has received some attention in the green-design community but not nearly as much as operating-energy reduction.

It is important to take a look at previous efforts to use embodied energy as another basis for preservation. Preservationists will also benefit from exploring how embodied energy calculations could be used as a more quantitative method of measuring the overall environmental benefits of building renovation versus new construction.

Energy Use in Building Construction

The underlying research upon which almost all U.S. embodied-energy applications are based is the 1976 report entitled *Energy Use for Building Construction*. This pioneering effort is still the most thorough evaluation of the embodied energy of building materials to have been produced in the U.S. This material was developed for new buildings and was based upon construction-industry data from 1967.¹ The project was a collaboration between researchers at the University of Illinois at Urbana-Champaign and at Richard Stein Associates, Architects, of New York City.

The researchers investigated many, but not all, of the typical building materials of that time. An additional effort

was made to evaluate some typical building assemblies. One of the most useful aspects of the report is a summary of the typical embodied-energy values for various building types, presented in MBtu/sq. ft. (Table 1). This data can be used to quickly estimate the overall embodied energy of a typical building by use, based upon 1967 construction types.

There are a few caveats for using this information to compare the embodied energy of historic buildings to new ones, however. First, there is a strong likelihood that the overall building figures in the report underestimate the equivalent embodied energy of older buildings. This underestimation stems from two principal factors: older buildings often had more volume and greater amounts

Table 1. Embodied energy for new construction by building type

New Building Construction 1967 Input/Output 399 Level	Btu/sq. ft.
Residential - 1 family	702,047
Residential - 2-4 family	625,050
Residential - Garden apt	648,445
Residential - High rise	735,978
Residential - Alter and addn.	-
Hotel/Motel	1,128,655
Dormitories	1,430,724
Industrial buildings	972,551
Office buildings	1,641,748
Warehouses	558,432
Garages/Service stations	771,489
Stores/Restaurants	941,353
Religious buildings	1,257,766
Educational	1,386,046
Hospital buildings	1,722,200
Other non-farm buildings	1,449,216
a. Amusement, social and rec.	1,379,793
b. Misc. non-residential bldg	1,101,991
c. Laboratories	2,074,056
d. Libraries, museums, etc.	1,743,588
Farm residences	554,703
Farm service	149,071

Data from *Energy Use for Building Construction*.

Table 2. Embodied energy of typical construction materials

Material	Unit	Embodied energy (Btu/unit) – Before delivery to jobsite	Embodied energy (Btu/unit) – After delivery to jobsite	Material	Unit	Embodied energy (Btu/unit) – before delivery to jobsite	Embodied energy (Btu/unit) – after delivery to jobsite
Wood products				Facing tile and ceramic			
<i>Softwood</i>				Glazed brick			
Rough lumber	Board foot	5,229	7,661	Quarry tile	Square foot	46,589	51,031
Dressed lumber	Board foot	5,399	7,859	Ceramic mosaic tile, glazed	Square foot	62,682	68,660
<i>Hardwood</i>				Ceramic mosaic tile, unglazed	Square foot	58,081	63,619
Rough lumber	Board foot	6,744	9,816	Concrete block (8 by 8 by 16 inches)	Each	29,108	31,821
Dressed lumber	Board foot	6,633	9,655	Ready-mix concrete	Cubic yard	2,584,938	2,594,338
Wood shingles and shakes	Square foot	4,682	7,315	Quick lime	Ton	6,394,720	6,867,465
<i>Wood window units</i>				Hydrated lime	Ton	8,812,374	9,463,852
Double hung	Each	845,671	1,127,234	Dead burned dolomite	Ton	9,077,302	9,748,365
Awning and casement	Each	893,021	1,190,349	Gypsum building materials	Ton	6,189,370	6,970,088
Other	Each	1,373,150	1,830,335	Mineral-wool insulation			
<i>Wood doors</i>				Loose fiber	Ton	11,426,830	12,826,171
Panel type, interior and exterior	Each	654,851	872,881	Batts, blankets, and rolls (3½ inches thick)	Square foot	6,112	6,860
Flush type, hollow core	Each	259,952	346,502	Primary iron and steel			
Flush type, solid core	Each	893,696	1,191,182	Pig iron	Pound	7,075	7,444
<i>Veneer and plywood</i>				Carbon-steel sheet, hot rolled and enameled	Pound	15,965	16,803
Hardwood	Square foot	12,942	17,025	Carbon-steel sheet, galvanized	Pound	26,458	27,836
Softwood, interior	Square foot	3,790	4,986	<i>Hot-rolled bars and shapes</i>			
Softwood, exterior	Square foot	4,393	5,779	Carbon-steel	Pound	17,808	18,736
<i>Prefabricated structural wood members</i>				Carbon-steel reinforcing bars	Pound	14,888	15,664
Glued and laminated	Board foot	14,673	16,773	Alloy steel, plates and structural shapes	Pound	25,577	26,910
Paper products				Wire for prestressed concrete	Pound	42,423	44,633
Construction Paper	Pound	8,841	10,479	Carbon-steel nails and staples	Pound	32,331	34,016
Paint products				Steel wire, plain	Pound	29,635	31,179
Exterior oil paints and enamels	Gallon	413,066	488,528	Steel wire, galvanized	Pound	32,683	34,385
Exterior water base paints	Gallon	413,519	489,063	Concrete-reinforcing mesh (welded wire)	Pound	22,989	24,187
Interior oil base paints	Gallon	429,932	508,475	Carbon steel pipe	Pound	24,535	25,813
Interior water base paints	Gallon	369,519	437,025	<i>Stainless steel</i>			
Asphalt products				Sheets, hot rolled	Pound	76,814	80,816
Roofing asphalt	Pound	6,701	6,914	Sheets, cold rolled	Pound	131,449	138,298
Roll roofing, smooth surface	Square foot	7,514	7,753	Bars, hot rolled	Pound	25,577	26,910
Roll roofing, mineral surface	Square foot	10,673	11,012	Bars, cold finished	Pound	183,579	193,144
Standard strip shingles	Square foot	24,553	25,334	Wire	Pound	228,046	239,927
Asphalt-saturated felts	Pound	13,210	13,630	Fabricated metal products			
Tar-saturated felts	Pound	16,416	16,938	Fabricated structural steel	Pound	21,711	22,707
Glass products				Primary nonferrous metals			
Window glass, single strength	Square foot	11,895	13,659	<i>Aluminum</i>			
Window glass, double strength	Square foot	13,437	15,430	Plate	Pound	113,049	115,567
Plate glass, average (¾ inch)	Square foot	41,828	48,031	Sheet	Pound	94,596	95,943
Laminated plate, average	Square foot	185,058	212,504	Rolled bars and structural shapes	Pound	90,852	92,146
Stone and clay products				Screw machine products			
Portland cement	Barrel	1,526,498	1,528,126	Hex nuts, lag screws, and bolts, studs, and threaded rods	Pound	22,474	26,625
Brick (2¼ by 7½ inches)	Each	13,570	14,283	Rivets, ½ inch and over	Pound	14,640	17,344
Common and face	Each	24,306	25,582				

Data from *Energy Use for Building Construction*.

of materials. On the volume side of the equation, older buildings often had higher ceilings than those of the mid-twentieth century. On the materials side of the equation, older buildings used more massive masonry load-bearing walls rather than later masonry-veneer construction. For example, a typical school building of 1970 was a one-story structure made of concrete block with

brick veneer, metal-bar joists, and concrete floor slabs. A typical school from 1910 was a multistory structure with masonry load-bearing walls, terra-cotta tile floors, and wood roof framing. This same type of discrepancy will hold true for many older building types. No attempt was made to calculate the embodied energy of construction processes used in the original construction period.

Another concern with using data from 1967 is the potential change in the individual building-material values based upon newer, more efficient industrial processes. Both the steel and concrete industries have improved manufacturing efficiencies, which reduces the overall embodied energy of these materials. Since most historic buildings are made predominantly of masonry and

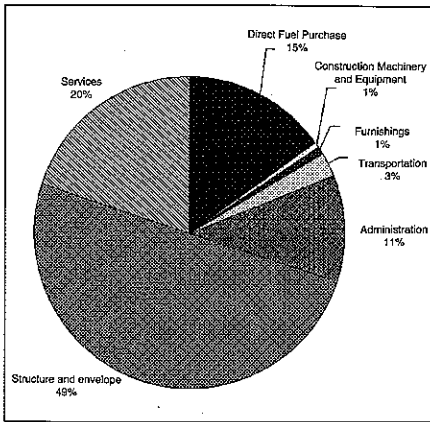


Fig. 1. Embodied energy of a building by category. Data from *Energy Use for Building Construction*.

wood, the error factor in this particular data is not critical. The data that is probably the least accurate today is the embodied energy of mechanical equipment. Boilers and furnaces installed in the last 25 years are far more efficient in both their physical make-up and their operation.

The materials that were surveyed in *Energy Use for Building Construction* include most of the typical materials of historic buildings, but there are a few notable exceptions (Table 2). Stone was not investigated. Unlike brick masonry or concrete, stone does not typically

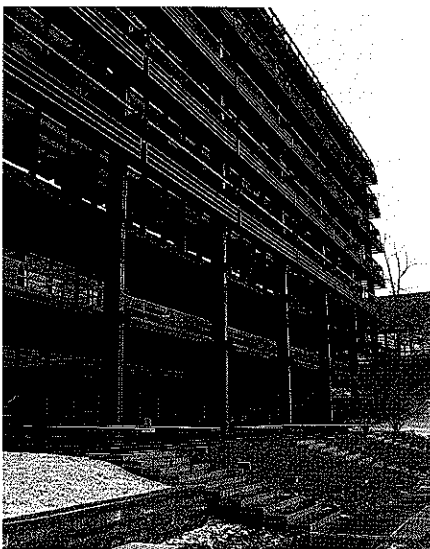


Fig. 2. John Deere Headquarters, Moline, Illinois, designed by Eero Saarinen, 1964. The typical embodied energy of an office building like this one is 1,641,798 Btu/sq. ft. Courtesy of the Illinois Historic Preservation Agency.

require any heating processes, just the mechanical energy to quarry, cut, shape, and deliver it. It should thus have a lower embodied energy than brick masonry or concrete, but determining how much less would require a detailed input-output study to follow the original protocols (a figure of 0.70 MJ/Kg for local stone was published in a Canadian study).² Plaster, another ubiquitous product in historic buildings, was not specifically investigated, but there are figures for gypsum and lime. Plaster can also be estimated to have an embodied-energy value somewhat close to that of concrete, since both materials contain a high degree of aggregate, which has a low embodied energy, and a relatively small percentage of binder (portland cement or lime), which have higher embodied energies.

A particularly interesting summary of how embodied energy was allocated in a building revealed that approximately 50 percent of the embodied energy is attributable to the manufacture of the basic architectural materials and components. Twenty percent can be allocated to mechanical, plumbing, electrical, and miscellaneous materials. The remaining 30 percent is divided among direct fuel purchases (15 percent); administration, such as wholesale and retail trade and miscellaneous business and professional services (11 percent); transport of materials (2.5 percent); furnishings (1 percent); and construction machinery and equipment (0.5 percent) (Fig. 1).³

Preservation Protocols and Embodied Energy

The publication of *Energy Use for Building Construction* was recognized by the Advisory Council on Historic Preservation (ACHP) as a new research tool that had the potential to support its mission

as the federal oversight organization for historic preservation. The ACHP commissioned an application study of the use of embodied energy and historic preservation, which was done by Booz, Allen and Hamilton in the late 1970s. The product of this effort was *Assessing the Energy Conservation Benefits of Historic Preservation: Methods and Examples*, which was produced by the ACHP in 1979 but not widely distributed. The application-study data was subsequently used in the 1981 National Trust publication entitled *New Energy from Old Buildings*. This book included several chapters on the topic of embodied energy, as well as other energy-conservation and retrofit strategies popular at that time, such as solar collectors.

Three different methodologies for measuring the embodied energy in historic buildings were developed in *Assessing the Energy Conservation Benefits of Historic Preservation*. These were classified as the concept model, the inventory model, and the survey model. The concept model can be characterized as a planning approach, in which various building types are given an embodied-energy value based upon the square footage (Figs. 2-4). It uses "a minimum of information to give a rough estimate of energy."⁴ As previously mentioned, the square-footage values are based upon those of typical new buildings constructed in the late 1960s, which means that the figures may vary greatly from that of a typical historic building. For the purposes of getting a "quick estimate," this is a useful tool, but it could represent a substantially lower value than would be obtained through the inventory model.

The inventory model requires an accurate accounting of the material used to create a building. This can be a fairly complicated task, particularly for buildings that do not have construction docu-

Table 3. Demolition energy for existing buildings, concept model

Construction Type	Small Building 5,000 – 15,000 sq. ft.	Medium Building 50 – 150,000 sq. ft.	Large Building 500,000 +
Light (wood frame)	3,100 Btu/sq. ft.	2,400 Btu/sq. ft.	2,100 Btu/sq. ft.
Medium (steel frame)	9,300 Btu/sq. ft.	7,200 Btu/sq. ft.	6,300 Btu/sq. ft.
Heavy (masonry, concrete)	15,500 Btu/sq. ft.	12,000 Btu/sq. ft.	10,500 Btu/sq. ft.

Data from *Assessing the Energy Conservation Benefits of Historic Preservation: Methods and Examples*.

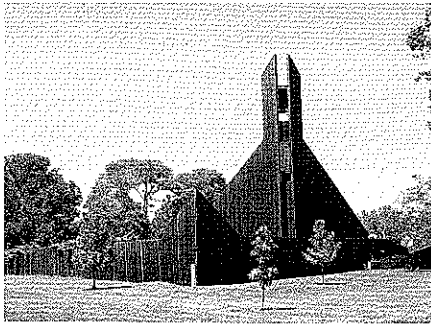


Fig. 3. Covenant Presbyterian Church, Danville, Illinois, designed by Ray D. Crites, 1967. The typical embodied energy of a religious building like this one is 1,257,766 Btu/sq. ft. Courtesy of the Illinois Historic Preservation Agency.

ments, but modern CAD programs are making this easier with their take-off tools that help calculate material quantities. In order to create a more accurate value but one that was not as complicated to calculate, the third assessment tool was developed — the survey model.

The survey model is based upon the assumption that most of the embodied energy in a building is contained in the bulk of the architectural materials. The seven primary materials are wood, paint, asphalt, glass, stone and clay, primary iron and steel, and primary nonferrous metals. In this method there is still some complexity to the quantity take offs, but limiting the range of materials to a few broad categories greatly simplifies this task. The seven categories of materials will equal 50 percent of the building's total embodied energy. Therefore, multiplying the total of the building's quantities for each of the seven quantities by two will give a figure for the overall embodied energy of the building. Using this model, a historic building with a great amount of masonry and metal framing might produce an overestimate of embodied energy. More detailed inventory studies of historic buildings are probably needed for better accuracy.

Demolition Energy

Evaluating the environmental benefits of renovating a building instead of demolishing it to construct a new building also raises the question of calculating the energy of building demolition (Table 3). Research and calculations for this topic were also developed in *Assessing the Energy Conservation Benefits of*

Historic Preservation. There is also the possibility of dismantling a building for salvage, which would recapture embodied energy.

Using Embodied Energy as a Basis for Eco-Decisions

The use of embodied-energy calculations as a basis for evaluating the relative environmental benefits of any building strategy, be it renovation or new construction, has merit, but it is particularly appropriate for historic buildings, which have relatively high embodied energies. The United States Green Building Council's LEED-NC 2.1 rating system — which addresses construction of new commercial buildings and major renovations — has a number of categories in which points are awarded to reduce the embodied energy of a building, although it is not stated as such.⁵ Using recycled materials, reused or salvaged materials, and regionally available materials (to reduce transportation costs) will earn points because of reduced embodied energy.

The relative environmental benefits if measured by reduced CO₂ are highly variable for various LEED categories. Transportation energy is approximately 2.5 percent of a building's total embodied energy, a relatively small percentage. LEED awards two points if 50 percent of a building's materials come from within 500 miles, with no accounting for the

delivery charges for the other 50 percent of the building. The LEED criteria are very generous in this regard, with small environmental benefit. At the other end of the equation, LEED 2.1 offers up to three points for reusing a building's structure, shell, and 50 percent of the interior. The reused embodied energy of these components could easily be 50 percent of the building's total embodied energy. If one compares the benefit of reusing a building versus the construction of an entirely new building, the embodied energy savings is even greater. What this evaluation suggests is that LEED 2.1 for new construction or major renovation drastically undervalues the true ecological benefit of building reuse.

Embodied-energy calculations could be used in other green-rating systems. The Vermont Builds Greener (VBG) scorecard uses housing size as a weighted measuring tool for new construction; larger houses receive fewer points than smaller houses in the overall assessment. Using a maximum embodied-energy figure rather than a size figure would allow for a more creative and environmentally sound building process. A straw-bale house might be able to be much larger than another kind of building system because of its reduced embodied energy and greater envelope efficiency. A renovated building may have a similar advantage over a new structure.

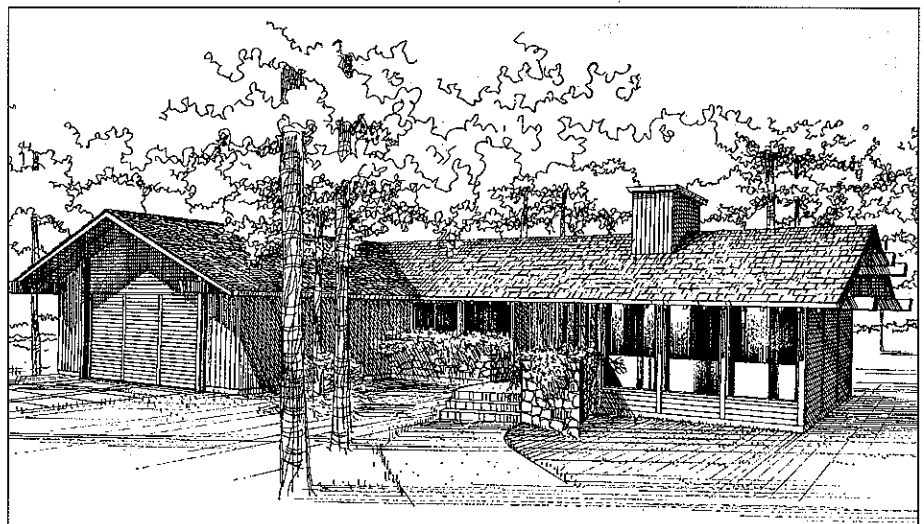


Fig. 4. Typical American ranch house, c. 1967, Anthony Rubano Collection, Illinois Historic Preservation Agency. The typical embodied energy of a single-family residence like this one is 702,047 Btu/sq. ft.



Fig. 5. The demolition of Normal High School, in Normal, Illinois, illustrates the volume of lost material that could have been saved if the building were reused. Courtesy of the Illinois Historic Preservation Agency.

Embodied Energy vs. Operating Energy

The relative value of the embodied energy and operating energy should be more fully investigated for historic structures.⁶ The ratio between total embodied energy and annual operating energy varies between 5:1 and 30:1.⁷ Historic buildings are more likely to be at the higher end of this ratio because of their use of durable, bulky materials and large volumes (Fig. 5). Most environmental-benefit studies focus on operating-efficiency improvements because they accrue over time. More long-term energy savings can be gained by improving the operational efficiency by 10 percent than by reducing the embodied energy by a similar amount. However, when the embodied energy is recaptured through building renovation, the equation is greatly altered.

Three case studies comparing embodied energy and operating energy help illustrate the relative value of renovating or demolishing and replacing a historic building (Table 4). A historic building that is slightly less energy efficient in its annual operating energy, but reuses 70 percent of its embodied energy, should be considered holistically. It can take more than 30 years before any cumulative energy savings is achieved when a building is demolished and replaced.

For preservationists the issue is one of evaluating embodied energy and operat-

ing energy in a true life-cycle comparison. It may be difficult to renovate a historic building and both achieve an Energy Star rating and meet preservation standards.⁸ However, it is feasible to renovate historic buildings and greatly improve their operating efficiency. New mechanical equipment is just as efficient in an old building as it is in a new building. The difference between the two situations usually is the relative efficiency of the building envelope.

Conclusion

Embodied energy deserves to be another factor in the equation of sustainable design, particularly for historic preservation. The historic built environment represents a huge resource that can be conserved and made efficient for the twenty-first-century challenge of fossil-fuel exhaustion. Preservation and design professionals will depend upon the research scientists to provide the data upon which to base embodied-energy decisions. Sustainability-rating tools are currently using the concept of embodied energy but in a manner that does not result in equitable quantification for historic buildings. The complete demoli-

tion and disposal of a historic building and all the embodied energy it represents is not measured in any of the popular green-building rating systems. Historic preservationists must help develop a better rating system that utilizes embodied energy more comprehensively. By combining preservation principles and the concept of embodied energy a stronger argument for the environmental benefits of building reuse can be made.

MIKE JACKSON, FAIA, is the chief architect of the Preservation Services Division of the Illinois Historic Preservation Agency. He holds degrees from the University of Illinois at Urbana-Champaign and Columbia University and is a visiting professor of architecture at the University of Illinois at Urbana-Champaign.

Acknowledgments

Thanks to Prof. Bruce Hannon, who was a principal researcher at the University of Illinois on the embodied-energy study, for his help while preparing this paper.

Notes

1. The principal research used to calculate embodied energy was the 1967 *Census of Manufacturers, Vols. I and II*, produced by the U.S. Dept. of Commerce, Bureau of the Census (Washington, D.C.: U.S. Government Printing Office, 1971).

Table 4. Life-cycle analysis comparing embodied energy and operating energy between reuse of an existing building and construction of a new building, illustrating the time it takes before a net energy savings is achieved

These three scenarios all point to the fact that reusing an existing building and making it more energy efficient results in an immediate savings of total energy use. If building new, no net savings of total energy are achieved until a future date that can be greater than the life expectancy of many new buildings.

Scenario 1: Do nothing to the existing building and build a new building. The existing building will remain and be used by a different user. The new building will be designed to meet Energy Star standards of operating efficiency.

- Embodied energy 1,200 MBtu/sq. ft. for the new building (mid-range value)
- Existing building operating energy at 70,000 Btu/sq. ft.
- New building operating energy at 35,000 Btu/sq. ft.

34.2 years before any life-cycle energy savings is achieved

Scenario 2: Demolish the existing building with partial salvage. Construct new office building to meet Energy Star standards.

- Embodied energy: 1,200 MBtu/sq. ft. (existing)
- Embodied energy: 1,200 MBtu/sq. ft. (new)
- Embodied energy: -400 MBtu/sq. ft. (salvage)
- Total embodied energy: 2,000 MBtu/sq. ft.
- New-building operating energy at 35,000 Btu/sq. ft.

57 years before any life-cycle energy savings is achieved

Scenario 3: Renovate existing building, improving its efficiency by 30 percent, although not meeting Energy Star performance standards. Construct new building to meet Energy Star Standards.

- Embodied energy: 400 MBtu (rehab)
- Operating energy: 50,000 Btu (rehab)
- Embodied energy: 1,200 MBtu/sq. ft. (new)
- Operating energy: 35,000 Btu/sq. ft. (new)

53.3 years before any life-cycle energy savings is achieved

2. There are several valuable international sources for embodied-energy values. Ted Kesik, "Measures of Sustainability: Embodied Energy," Canadian Architect, Architectural Science Forum, January 2002, http://www.canadianarchitect.com/asf/perspectives_sustainability/ measures_of_sustainability/measures_of_sustainability_embodied.htm (accessed November 1, 2005). George Baird, Andrew Alcorn, and Phil Haslam, "The Energy Embodied in Building Materials: Updated New Zealand Coefficients and Their Significance," *IPENZ Transactions* 24, no. 1 (1997): 46-54, <http://www.ipenz.org.nz/ipenz/publications/indexes/transaction/ transactions97/civil/7baird.pdf> (accessed November 16, 2005). Commonwealth of Australia Greenhouse Office and University of Technology-Sydney Institute for Sustainable Futures, "Technical Manual Section 3.1: Embodied Energy," Your Home: Design for Lifestyle and the Future, <http://www.greenhouse.gov.au/yourhome/technical/fs31.htm> (accessed November 16, 2005).
3. Energy Resource Group of the Center for Advanced Computation at the University of Illinois at Urbana-Champaign and Richard G. Stein & Associates, Architects, *Energy Use for Building Construction*, prepared for the U.S. Energy Research and Development Administration (New York: U.S. Dept. of Energy, 1976), 37.
4. Advisory Council on Historic Preservation, *Assessing the Energy Conservation Benefits of Historic Preservation* (Washington, D.C.: Advisory Council on Historic Preservation, 1979), 108.
5. The LEED system of sustainable building design is rapidly evolving. There are several different LEED rating tools, but the analysis in this report is based upon LEED-NC, which is for new construction and major renovation. There is also a LEED-EB for existing buildings. More information is available at www.usgbc.org.
6. The Athena Sustainable Materials Institute (<http://www.athenasmi.ca/>) has been developing environmental building-assessment tools that utilize life-cycle assessments and embodied-energy values. One particularly noteworthy study is "Renovating vs. Building New: The Environmental Merits" by Wayne Trusty, http://www.athenasmi.ca/publications/docs/OECD_paper.pdf (accessed October 20, 2005).
7. The U.S. Energy Information Administration's assessment reports are available at <http://www.eia.doe.gov/>. This report draws upon the data for energy use in commercial buildings from 1999, which can be viewed at <http://www.eia.doe.gov/emeu/cbecs/pdf/allce.pdf> (accessed October 20, 2005).
8. The Energy Star rating system was developed by the U.S. government to help consumers identify equipment that uses energy efficiently. The Energy Star homes program was developed to promote whole-house operating efficiency. However, historic and older homes are difficult to renovate and achieve Energy Star performance values. More information is available at <http://www.energystar.gov>.

A Look Back at the Embodied-Energy Study

Bruce Hannon was the team leader of the embodied-energy research at the University of Illinois in Urbana-Champaign that developed Energy Use for Building Construction in the 1970s. His reflections below provide insight into how this research evolved.

The idea of embodied energy first occurred to me in the late 1960s. As an engineer in the chemical industry and later in the company of energy-minded ecologists, I was well prepared for talk in 1970 by an industry representative on the virtues of throwaway beverage containers. I launched a study with my students of the total energy cost of the throwaway and the returnable containers that quickly became the basis for legislation in about a dozen states. These were heady times for a professor turning environmentalist.

The study was so laborious that I knew there had to be a better way to calculate embodied-energy cost. From the economists, we learned that such costs could be calculated by transforming the input-output matrices — the mathematical forms of who buys how much of what from whom — into energy terms. By 1972 I had assembled a small team of researchers at the University of Illinois' Center for Advanced Computation, and we made the first such calculations for every good and service provided by the U.S. economy, just in time for the 1973-74 energy embargo. Suddenly, we were very popular. Research money flowed easily, and we applied the calculations to everything from disposable diapers to the energy balance of foreign trade. We also made the same type of calculations to determine the embodied-labor by occupation for any good or service. By energy and labor cost of a unit of a good or service, we meant that we had calculated with very reasonable accuracy the entire amount of energy and of labor of every type that had to be extracted because of the existence of this unit. The form of the

calculation meant that all of the extracted energy and all of the labor hours were allocated, unambiguously and without double counting, to all of the economy's output, in detail. We pointed out the energy/labor tradeoff that ensues from a steep price rise in energy. The economy became more labor intensive for the first time, and labor productivity fell.

In the mid-1970s Richard Stein, a prominent New York architect, called and wanted to make the energy calculations for new buildings and for building remodeling. Together we produced several papers on the subject, including one in *Science* magazine. We were able to point to the energy cost of remodeling buildings as compared to building replacements. The interest in the rest of the architecture community was mild, and our research group moved on to other subjects.

Our efforts ended in 1982 with the cessation of federal research funding for energy-conservation research. Since that time I have been asked to provide updated calculations for other architects, but our little group was out of business. To my knowledge, no one has updated our architectural data, although the Department of Energy has continued to fund the formation of the basic energy matrices.

Certainly, there have been changes in the technologies that make the important components of buildings. Steel, concrete, glass, and so on and the total energy costs of building materials have changed as a consequence. Steel beams, for example, are now made with continuous casting, avoiding the billet reheating of earlier times. With new basic energy data and with the papers we had done in the 1970s, it would not be a daunting task to update the total energy-cost data for all the parts of the modern buildings. Until that time, the data we generated with Stein and his associates can serve as a guide in assessing the energy cost of architecture, including the energy embodied in existing buildings.

Bruce Hannon, Jubilee Professor
University of Illinois at Urbana-Champaign

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