Chapter 83
A Framework to Explore Energy Saving Measures During Construction Phase

Abdol R. Chini and Sandeep Shrivastava

Abstract There has been a significant increase in interest and research in energy efficient buildings in recent years. In the construction phase of a building's life cycle, contractors provide resources and select the means and methods of construction. To make the construction phase less energy intensive, the contractor has to purchase the required resources from the jobsite proximity and select less energy-intensive resources to minimize the energy consumption. Sometimes, it might not be possible to analyze and practice energy-saving measures for the whole project due to time and budget constraints. Therefore, it would be helpful for a contractor to focus on the most energy-consuming activities and deploy energy-efficient procurement to reduce energy consumption of a particular project. This requires a tool to estimate energy required for procurement and installation of the building elements and to identify the most energy-intensive activities. This research focuses on developing a spreadsheet-based tool to estimate energy consumption during construction of a project. The proposed framework uses the project's bill of quantity, data related to materials transportation, and energy data for the required resources to estimate the probable energy consumption during construction. A case study was performed to demonstrate the application of the tool

Keywords Energy efficiency · Energy information system · Embodied energy · Materials transportation

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A. Chini (✉)
Rinker School of Building Construction, University of Florida, Gainesville P.O. Box 115703, USA
e-mail: chini@ufl.edu

S. Shrivastava
Department of Civil Engineering, Malaviya National Institute of Technology, Jaipur 302017, India

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83.1 Introduction

Building construction projects impose loads on the environment in various forms, namely depletion of resources and contamination of air, soil, and water. These loads are generated while various demands, such as materials and energy are met to construct the building. The construction industry uses more materials by weight than any other industry in the United States [1]. Moreover, the environmental impacts of building construction, partly caused by large consumption of energy, are imposed during the whole life cycle of a building [2, 3]. Energy consumed during the life cycle of a building may be divided into operational energy, embodied energy, and decommissioning energy [4–6]. Operational energy is required for heating, cooling, ventilation, lighting, equipment and appliances. Embodied energy is non-renewable energy required to initially produce a building and maintain it during its useful life. It includes energy used to acquire, process, manufacture the building materials, including any transportation related to these activities (indirect energy); energy used to transport building products to the site and construct the building (direct energy); and energy consumed to maintain, repair, restore, refurbish or replace materials, components or systems during the life of the building (recurring energy). Embodied energy is measured as a quantity of non-renewable energy per unit of building material, component or system. The embodied energy makes about 15-20% of the total energy consumption during building life cycle. However, the share of the embodied energy will become more significant when buildings become more energy efficient, as shown in Fig. 83.1 [5, 7].

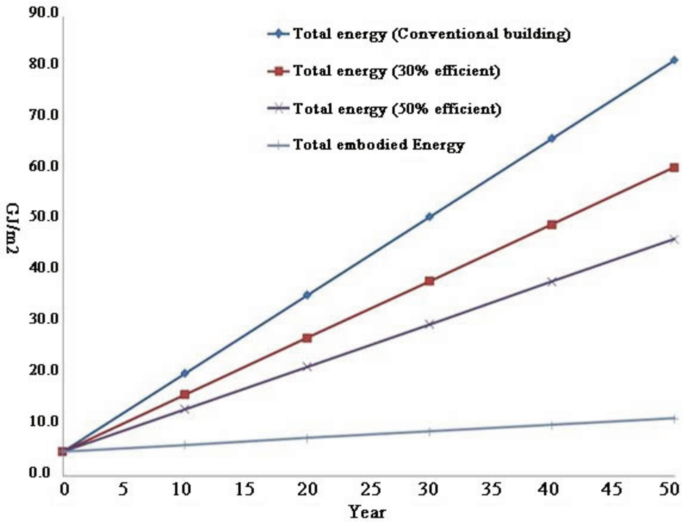

Fig. 83.1 Energy use in buildings - the changing relationship between embodied and operational energy

Among various phases of embodied energy, energy consumption during construction phase is less explored [8]. In the construction phase, contractors provide resources and select the means and methods of construction. To make the construction phase less energy intensive, the contractor has to purchase the required resources from the jobsite proximity and select less energy-intensive resources. This is possible if the contractor has access to an energy-profile of the project to identify which material procurement and/or installation consumes maximum energy. The contractor may then seek less energy -intensive alternatives that are available. This research focuses on developing a spreadsheet tool to estimate energy consumption during construction activities of a project.

83.2 Energy Estimation Tool

The construction phase of a building life cycle involves numerous activities such as construction of temporary structures, transportation and installation of building materials and components, site work, etc. These activities consume energy and affect the environment. When a construction project is started, the general contractor prepares a detailed estimate for the required materials, labor, and equipment. A bill of quantities (BOQ) that includes a list of materials as well as tasks required for the execution of the project is prepared. The framework for the proposed tool uses a project's bill of quantity and energy data related to transportation and assembly of building components to estimate energy consumption during construction. Resources required (materials, equipment, labor, etc.); their transportation modes, and their distances from the project site are assigned to each project activity (Fig. 83.2).

Fig. 83.2 Energy consuming tasks within jurisdiction of a contractor

For example, an estimation of the amount of energy consumed in transporting a material depends on the mode of transportation, energy consumption to transport one kg of material to one km distance, quantity of material required to finish the activity, and the distance of material manufacturing unit to the project site. In a construction process, an activity might include different materials transported from different distances using different transporting modes. The total sum of these energy requirements will be the energy required to transport the materials for that activity. The system calculates total energy required and arranges the activities of BOQ in a descending order to identify energy-intensive activities.

At the end of the estimation process, a report containing information about energy consumption of each activity and high energy-demanding activities is generated. This report can be utilized by the contractor to consider alternative solutions for energy-intensive resources and procurements for the project (Fig. 83.3).

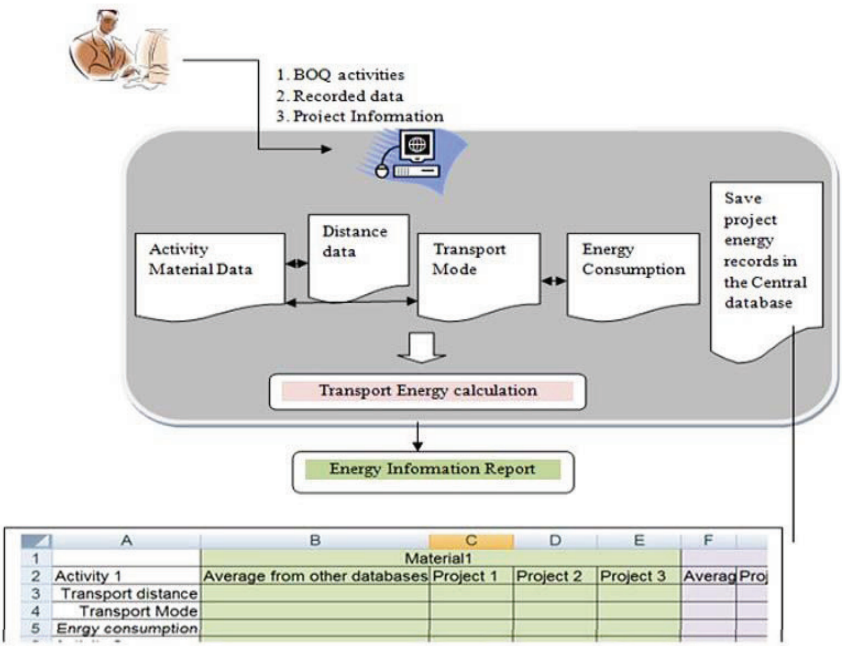

Fig. 83.3 The framework to estimate and record energy for material transportation

Many researchers have mentioned the lack of project-related energy and environment data to accurately assess energy consumption and environmental impacts [8, 9]. Currently, most of the work at this phase is performed by researchers using LCA application packages, which might use data on a national average. These data might be effective in getting an overall picture of the energy consumption, but may be less meaningful if a contractor wants to improve the supply chain at local level and for a specific project. In order to do so, the contractor needs a system that can estimate and record the relevant data to improve energy estimation for future projects.

The suggested framework can be extended to record the related data by adding one more sheet that saves energy data for construction activities of various projects. Fig. 83.3 shows the framework with a snippet of spreadsheet to record energy data.

The framework can be used to estimate energy consumption using reliable and local data for any activity. If such data is not available, national average data collected from various databases and available literature can be used. Once the required data is recorded for a few projects, energy consumption for a similar project could be estimated based on the recorded data.

83.3 Energy Information System Framework

An Energy Information System (EIS) framework was developed to assist contractors in estimating the energy demands of a project before it begins, and to record data to update the framework's databases.

The proposed framework utilizes the building project's Bill of Quantities (BOQ) sheet to estimate energy consumption during the construction. Project data needed are the building type, size, and duration of the project. In addition, the management set-up data, such as information about trailers, service vehicles, generators, and security lights are needed.

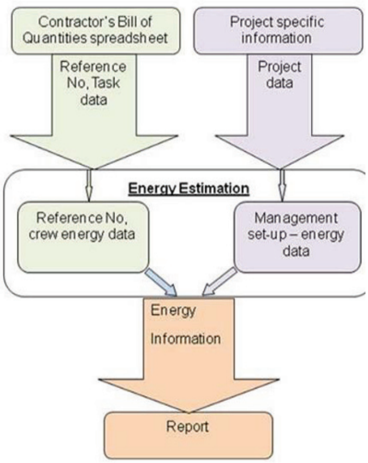

Fig. 83.4 Energy information system — internal divisions

Before a building construction project begins, the contractor or construction manager prepares a detailed estimate for materials, labor, and equipment required to finish the project. Almost all construction companies prepare a BOQ in a more or less similar format. Each row in a BOQ sheet contains a reference number (Construction Specification Institute master format number), task description, quantity, unit, cost per unit, and total cost of the task.

Fig. 83.4 shows the internal divisions of the framework. The framework is divided into two parts. One part handles data related to the building's dimensions and management set-up, and the other part handles the building's BOQ. The required energy for the management set-up and BOQ are estimated separately. The final report provides information about both of these estimates and the total energy consumption.

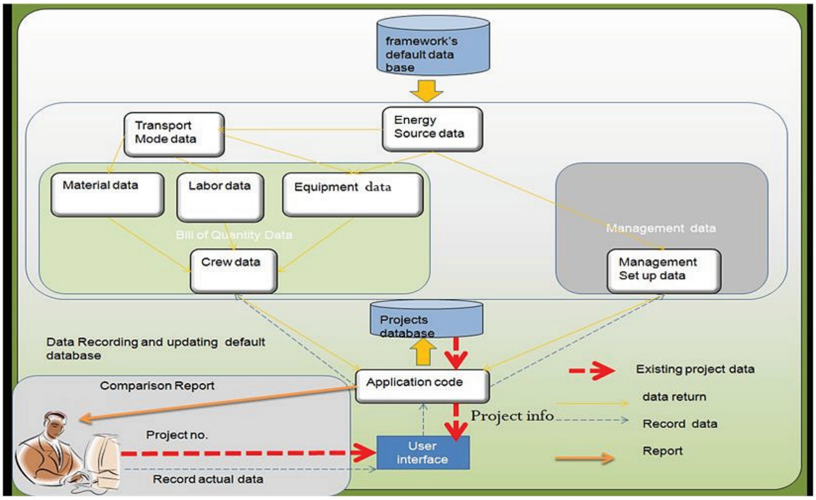

Fig. 83.5 Energy information system framework - estimation process

Fig. 83.5 shows a detailed diagram of the EIS framework used to estimate a project's energy consumption. The figure illustrates the relationships between various databases, and the processes that the framework follows to estimate energy consumption. The framework contains four main components:

- **User interface.** The user interface interacts with the user and asks for input to run the energy estimation process. The user provides a unique project number, project information, building information, management set-up data and the BOQ sheet. This information is saved into a project database against the unique project number.
- **Application code.** The application code interacts with the framework's internal databases. It takes information from the user and sends queries to the databases for data required to run the estimation process. The code makes a series of calculations and saves the results in the project's database against the project number.
- **Databases.** The required databases are shown in Fig. 83.5. Initially, these databases are developed based on the available information, but they are continuously updated based on the values recorded during the actual construction process.
- **Report.** Providing the project's unique number, a user can generate a report. The report contains information about the project's energy consumption and energy

use to provide insight into the energy demand of the project. It identifies the most energy intensive activities of a project so that the contractor can target those activities for reducing energy consumption.

It is important to note that the EIS framework can also be used to record the project's energy consumption. Fig. 83.5 illustrates the relationships between various databases and the processes that the framework follows to record data during the construction process.

83.4 Case Study

A three-story building case study was performed to demonstrate the use of the EIS tool. The goals of the case study were to demonstrate the use of the tool, address the challenges one may encounter in applying the tool, and check the accuracy of the model by comparing outcomes from estimated and recorded values.

The building was a steel-framed 4,514 sq m structure, with brick, metal panel, and exterior curtain wall. Construction started in July 2010 and finished in October 2011. The facility was planned to serve as a business incubator for new companies and products with an estimated cost of $10 million.

The contractor prepared a BOQ sheet, estimated the project cost, hired specialty contractors and subcontractors, and developed a project schedule. The EIS tool was used to estimate the building's probable energy consumption during construction. In addition, on-site energy consumption data for several activities were recorded. The energy consumption based on the recorded energy data was then compared to the estimated data.

83.4.1 Scope of the Study

Scope of the study was confined to the construction of structural components and included concrete, masonry, and structural steel activities. The activities under these divisions were further limited to those that were completed for the period of the study from November 2010 to July 2011. Table 83.1 shows the detailed descriptions of the activities and their quantities. Table 83.2 shows the total costs of the activities and those that were considered within the scope.

83.4.2 Energy Consumption Data

Since it was the first run of the EIS tool, the internal databases did not have the necessary data to estimate the project's energy consumption. Thus, the data for var-

Table 83.1 Activities within the scope of the study

Reference No	Descriptions	Quantity	Unit
33053404260	Building: tie beams	53.13	cu m
33053401220	Building: tie columns	70.26	cu m
33053403250	Building: slab on deck	3,034.4	sq m
33053404200	Building: walls	9.86	cu m
33053405001	Building: 100 mm slab on grade	1,572.5	sq m
33053405010	Building: 150 mm slab on grade	82.5	sq m
33053405020	Building: 200 mm slab on grade	20.8	sq m
33053407000	Building: metal pan stair fill	114.0	sq m
33105704260	Building: walls-elevator pit	11.85	cu m
35216160250	Lightweight insulating concrete at main roof	1,918.4	sq m
40516300250	Cell fill concrete	126.76	cu m
40519260060	Rebar	10.6	MT
42113133050	Brick veneer	1,420.8	sq m
42210141150	200 mm CMU	1,808.1	sq m
42210141250	300 mm CMU	103.7	sq m
51223770800	Structural steel construction area	4,927.9	sq m
53112352950	Roof deck	1,990.3	sq m
53113503450	Floor deck	3,034.4	sq m
54213300200	Steel tube beams at facade	44.81	m
55213500020	Aluminum railings	54.56	m
55213500500	Steel railings	51.21	m
55213500940	Metal pan stairs railings steel pipe	39.62	m

Table 83.2 Cost of the activities within the scope of the study

Division	BOQ cost	Cost under the scope
Concrete	$ 635,557	$ 323,844
Masonry	$ 312,920	$ 311,306
Metal	$ 866,480	$ 787,304

ious databases were entered into the EIS tool. This data was collected through R.S. Means Construction Cost Data, equipment manuals, and available literature.

The activities within the scope of the study were also observed on-site to collect data for verification of the EIS tool, and to update the databases. The project's contractor, subcontractors, equipment providers, equipment operators, fabricators, and material suppliers were approached for data collection. If any data could not be collected through these means, online resources were used to fill in the missing data.

83.4.3 Energy Consumption Data

Table 83.3 compares the energy consumption estimated by the EIS tool with those recorded on-site. The EIS tool estimated the total energy consumption for the targeted activities as 5,366 GJ, with an energy intensity of 1.18 GJ/sq m. A major portion of the type of energy consumed was in the form of fuels, such as diesel and gasoline. Only 9% of the consumed energy was from electricity. However, the use of electric and battery-operated equipment can increase a project's electricity demand.

Table 83.3 Output of the estimated and recorded energy consumption

Descriptions	Estimated values	Recorded values
Building construction energy intensity (GJ/sq m)	1.18	1.35
Total energy consumption (GJ)	5,366.62	6,081.28
Total BOQ energy (GJ)	4,867.79	5,654.86
Total Management setup energy (GJ)	497.84	426.42
Energy due to electricity demand (%)	9.28	5.03
Energy due to other fuel demand (%)	90.72	94.97

The total recorded energy consumption was 6081 GJ with an energy intensity of 1.35 GJ/sq m. The total recorded value increased by approximately 14% in comparison to the estimated value. The reasons behind this variation are changes in material transportation distances, equipment use, labor productivity, labor transportation distances, and equipment fuel consumption. It should be noted that as a whole this variation seems moderate, but at the activity level there might be activities with high variation (Table 83.4). The range of variation will improve if more data is collected on-site and recorded into the EIS tool. This supports the need for recording on-site data to create a more realistic database. As stated earlier, this was the first run of the EIS tool, and the data for the estimation was collected from various sources and a moderate variation was expected. Now, with the use of collected data in the EIS tool, a more accurate estimation can be made for a similar project in the future.

83.4.4 Recommendations to Improve Energy Efficiency

Table 83.5 and Fig. 83.6 present a comparative summary of the energy intensive activities within the scope of this study. They indicate that brick veneer construction was the most energy intensive activity because of high energy consumption in transportation of labor and material to the project site. The structural steel activity was the most energy-intensive activity in terms of equipment operation.

The recorded energy consumption in material transportation (3309 GJ) had the largest portion (72%) of the total energy consumption (4574 GJ). The bricks rec-

Table 83.4 Comparison of estimated and recorded energy consumption by activities (in GJ)

Specification	Software estimation	Recorded value	% change
Building: walls- elevator pit	6.39	7.20	13
Building: walls	4.83	4.66	4
Building: 100 mm slab	53.66	58.62	9
Building: 150 mm slab	3.91	3.95	1
300 mm CMU	50.84	43.30	15
200 mm CMU	615.33	565.30	8
Brick veneer	1,923.19	2,374.19	23
Cell fill concrete	88.31	102.37	16
Structural steel	1,304.14	1,634.64	25
Floor deck	239.44	205.40	14
Roof deck	155.13	126.78	18

Table 83.5 Estimated and recorded energy intensive items in the BOQ

Energy consumption	Office buiding-estimated BOQ items/activities	Total energy (GJ)	Office building-recorded BOQ items/activities	Total energy (GJ)
Labor transportation	Brick veneer	118	Brick veneer	192
	Structural steel	76	Structural steel	116
	200 mm CMU	55	200 mm CMU	49
Material transportation	Brick veneer	1,805	Brick veneer	1,925
	Structural steel	999	Structural steel	999
	200 mm CMU	560	200 mm CMU	385
Equipment operation	Structural steel	228	Structural steel	484
	Cell fill concrete	42	Brick veneer	258
	Building: slab on deck	15	200 mm CMU	132
Total Energy consumption	Brick veneer	1,924	Brick veneer	2,374
	Structural steel	1,304	Structural steel	1,635
	200 mm CMU	615	200 mm CMU	565

ommended by the architect were produced by a manufacturer 1,610 km away and transported to the site by trucks. One approach to reduce the transportation energy was to ask the architect to allow use of an alternative brick with similar performance that was available at a closer distance.

The second largest source of energy consumption was transportation of structural steel to the job site. The steel was purchased from two different locations, 652 km and 1,549 km away from the site. Nearly 44 Metric Tonnes (MT) of steel were ordered from the closer and the rest (131 MT) from the distant manufacturer. The cost of steel purchased from the closer manufacturer was 10% higher than that of the distant location. Fig. 83.7 shows the energy and cost distribution for the structural steel materials. It shows that additional costs may be incurred if energy reduction is desired. The structural steel cost (material and transportation) would have been $315,000 and energy consumption 1,170 GJ if all the steel were purchased from the distant location (1,549 km). However, the cost would have increased to $350,000 and energy consumption decreased to 503 GJ for purchase from the closer location

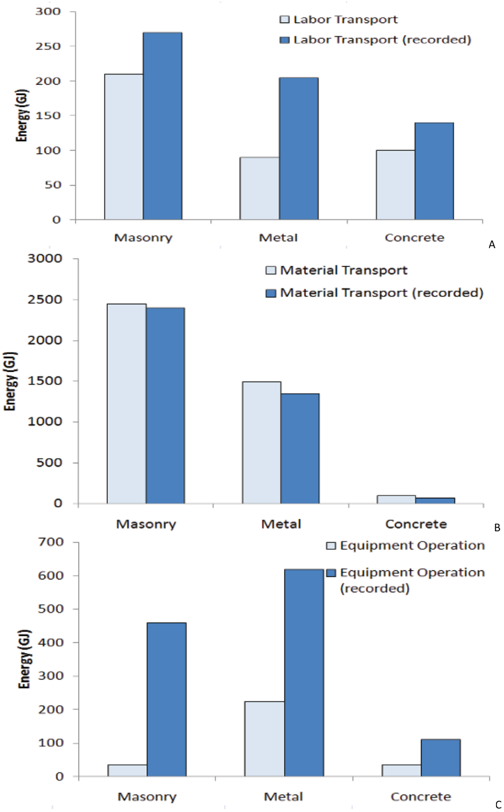

Fig. 83.6 Energy consumption comparison. A) Labor transport. B) Material transport. C) Equipment operation

(652 km). In this project, 25% of materials were purchased from the closer location and 75% from the distant location. This resulted in $328,000 material and transportation cost and energy consumption of 999 GJ.

When purchasing materials, contractors are looking for the least expensive option and may not be motivated to reduce energy consumption. However, the project owner may specify a maximum distance for material purchase or provide some incentive for purchasing materials from local vendors. The U.S. Green Building Council LEED rating system provides credit for materials that are purchased within an 800 km radius. At times, a lower cost might not be the only reason in the selection of manufacturers. Factors such as availability of material, production rate of a manufacturing unit, and specialty in manufacturing a particular item, and relations between parties may play a role in the selection process. In general, energy efficiency in procurement of resources should be given priority and required contractually.

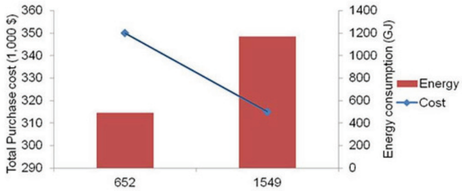

Fig. 83.7 Cost and energy distribution for the structural steel purchase

The construction of brick veneer was observed on-site and its energy consumption was recorded. A total of 192 GJ energy was consumed for transporting labor to and from the job site. The masons and their helpers were using their pick-up trucks for transportation, and the average distance from their homes to the job site was approximately 80 km. Moreover, most were coming from similar locations. One approach to reduce transportation energy for mason crew was to provide pooled transportation for them and forbid use of personal trucks in commuting to the project site.

83.5 Summary and Conclusion

In summary, contractors can play a major role in development of energy efficient means and methods to reduce energy consumption, i.e., carbon footprint, during the construction phase of a project. A spreadsheet-based framework was developed to estimate energy consumption of project activities during the construction phase. The proposed framework allows contractors to identify energy-intensive activities before construction starts and deploy energy-efficient procurement and installation methods to reduce energy consumption of a particular project. A case study was presented to demonstrate application of the framework for a building construction. Based on the energy consumption data, several recommendations were made for reducing energy consumption. The framework may also be used for collecting energy consumption data during construction for continuous update of the database and to increase its accuracy in estimating energy consumption for future projects.

The framework will be enhanced if it is integrated with a decision support system (DSS). The DSS should compare various energy-saving alternatives and their associated costs to identify a least expensive energy-saving measure on a project.

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