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Developing Energy Conservation Measure Assembly Costs for Rapid Integrated Retrofit Feasibility

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Abstract: Cost estimating for energy retrofit projects typically carries high margins and large contingency due to high degrees of risk, particularly unforeseen conditions and variability in return on energy investments. Abundant literature is available on the risks a contractor faces to stay within a fixed price for new construction, however, retrofit projects offer a unique side of the industry due to the level of definition of the existing conditions. While typical early design estimates for a new capital facility focus on high level project and system based decisions, retrofit projects have sufficient detail to focus on more detailed considerations for defining the "problem" from the outset. This paper addresses the issue of risk in applying an assemblies based estimating approach for energy retrofits, with special attention direction towards identifying heuristic means for linking costs for individual energy conservation measures to observable data in existing buildings to identify and reduce risk. The paper presents the method used for example energy conservation measures embedded in an ongoing energy audit and retrofit feasibility tool, with comparison of costing with actual project costs from case study energy retrofit projects to demonstrate the value of the process. The paper will conclude with outcomes for the case studies along with future directions for refining the costing methodology.

1. Introduction and Background

Cost estimating for construction processes is not an exact science. An accurate estimate not only considers data from cost databases, historic information, and personal experience of the team, but also leverages detailed projections of the new, undefined design variables for the project in question. In addition, an estimate includes consideration of quantities, productivity, means and methods, market conditions, and unforeseen conditions. Regardless, the accuracy of any given estimate varies based on the information available and the time spent planning and developing the cost estimate (Gould, 2005). Typically, the project cost estimating process starts with an order of magnitude or square foot estimate, and proceeds toward a unit price or detailed estimate as a project's design progresses (RS Means, 2011). An accurate estimate is vitally important to the success management of owner financial risk. The result of poorly assembled estimates, or ill assumptions, is overextended budgets and potentially project failures.

When moving from new construction cost estimating to renovation and retrofit projects, the estimating process benefits from the detailed information already available about the constructed building. While typical conceptual or order of magnitude estimates are assumed to be +/- 20%, well thought out conceptual estimates are projected to be within 10% and retrofit projects offer opportunities for greater detail in information and planning at this early stage of a project (Levy, 2007). However, in order to provide a relatively accurate estimate, risk needs to be properly identified and allocated, which minimizes any unforeseen costs.

Risk on new energy focused construction projects are contained and controllable mostly due to site investigations, fully developed design, and constructability analysis. Risk, as it relates to energy retrofit projects, are susceptible to larger contingencies because energy conservation measures (ECM) are driven by current conditions, such as building age, mechanical/electrical system degradation, and building schedule variability.. Since each energy retrofit project is unique, the energy conservation measures feasible for a given project are evaluated individually (Desai et al, 2012). As a result, they can be executed independently, which has the potential to carry a larger contingency due to the lack of detail relative to the unforeseen conditions. An energy retrofit project poses the threat of uncertainty and missed opportunity but within the veil of seeming predictability. The assessment of a current condition can impact the execution or can discourage potential implementation of an energy conservation measure. As defined by Kubba (2010), the contingency value is an indicator of the level of project development and typically, the less defined a project, the higher the contingency value.

In energy retrofit projects, an energy audit should be performed on behalf of the owner. The information gathered from the audit is required to assemble financial information to evaluate the feasibility of a variety of ECMs (Shapiro, 2009). Inherent to this process is costing of the initial construction, including associated contingency for risks (Coulter et al, 2012). Following an energy audit, an estimate can be assembled for each individual ECM. Often, broader approaches to evaluating a long list of ECM's is hindered by the time involved in individually evaluating energy savings and the financial implications (Desai et al, 2012). Therefore, satisficed measure energy savings and costing is developed for a building owner to make an "informed" decision. Unfortunately, the labor intensive audit process coupled with a costing phase lacking specificity, prevents any way to rapidly assemble reliable costs for energy conservation measures, sufficient for properly considering deeper retrofit opportunities.

2. Objectives and Scope

The evaluation of energy conservation measure costs is a component of a larger research project to develop a Level I energy audit tool for field data collection and ECM evaluation to better inform owners at an early stage of the feasibility of an energy retrofit. The Energy Audit Tool is targeted to produce rapid and reliable energy conservation measure cost evaluations to quickly provide feedback financial feedback to owners. The focus of this paper is to present the process used to develop assembly estimates for pre-defined ECM scopes, to rapidly develop the first costs of construction and support future work for optimizing packages and investment approaches.

The goal of this study is to:

- Demonstrate the process used to develop assembly costs for feasibility of energy retrofit system scopes,
- Validate the process for developing the energy conservation measure cost data through heuristic rules for linking existing facility data to assembly cost estimates, and
- Use case study data to validate the process by checking example heuristic rule values for a case study project.

Based on the data collected for building parameters, such as square footage or air supply flow rate, the feasibility tool will have the capabilities to reflect costs for individual ECMs as well as ECM packages. The purpose of the tool for feasibility analysis is to rapidly study and align packaging of ECM costs to allow building owner's the opportunity to analyze different scenarios based on goals and expectations, specifically focused to properly align ECM implementations to reduce the overall risk with deeper or greater ECM implementation. Before packaging of ECM's can be considered, the individual costs, and areas of potential work breakdown overlap, need to be identified within the scope of considered ECM's. The process for developing the ECM costs will be presented, followed by a case study; a cost analysis of completed projects will be compared to costs outcomes for the case study project.

3. Research Methodology

The research process for developing and validating energy conservation measure costs, shown in Figure 1, included three steps. First, the scoping and initial costs were identified for the pre-developed ECM list, based on traditional detailed estimating techniques. Second, semi-structured interviews were performed with industry experts, each with more than 15 years of experience in assessing energy retrofit projects. Based on the approaches, constraints, and heuristic rules that were identified from these experts were used to refine the structure of the costs for project applications. A case study was used to evaluate sample developed costs approaches. A case study project was identified which matched certain, not all, of the ECM's under consideration. The heuristic rules were applied to the input parameters from the audit report, and the cost outcomes were compared for direct construction costs.

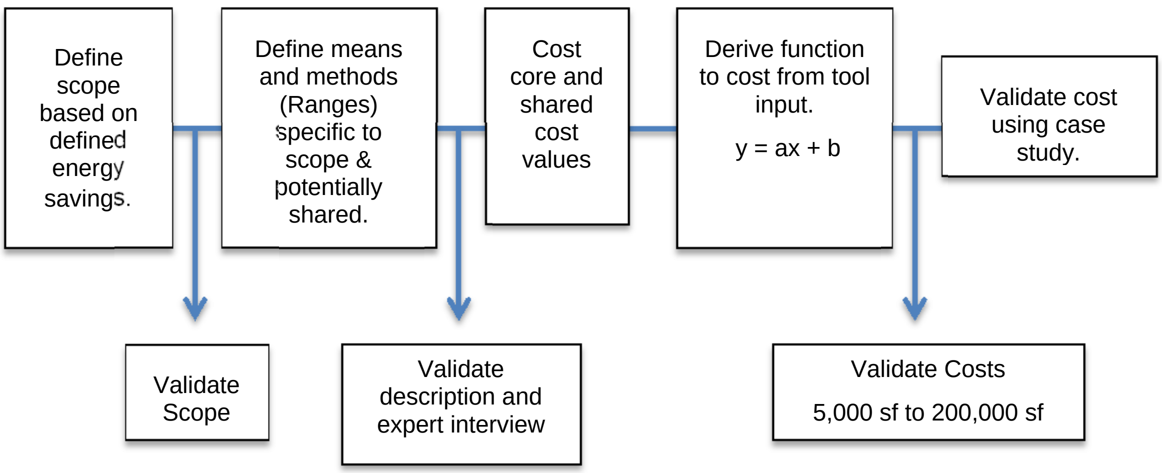

Figure 1: ECM Cost Development Process.

A pre-defined list of 38 energy conservation measures has been identified for use in the energy audit tool simulation engine (Desai et al, 2012). Development of the cost for each ECM relied heavily on defining the construction scope based upon the energy savings goal. The development of the analytical engine has been under way for several years to rapidly assess the energy savings potential. The construction scope is directly related to how the energy conservation measure was defined in the energy audit tool. Aligning these two pieces in the development was essential to be able to capture a reliable initial cost. The scope definition focused on establishing levels of system, sub-system, and component requirements directly correlated with the energy simulation scope levels. Direct and indirect construction activities were identified, along with the trade and means options for installation, these definitions were reviewed with the engineer who developed the simulation engine to validate the alignment with the simulated energy savings.

3.1 Expert interviews

Initially, the audit tool was somewhat limited with building parameter inputs, namely gross square footage and annual source energy usage; therefore all costs were developed to be created as a square foot price. The focus of the interviews was to address this approach in the analysis process, because using square foot metrics at this level of detail increased the level of risk in the financial evaluation. Interviews were conducted with energy engineers having 15 years, or more, of experience in engineering, energy audits, and retrofit estimating. Unstructured interviews were used to engage the experts in discussions of costing the full array of energy conservation measures. The discussion leveraged hypothetical buildings to encourage the interviewee to expound upon how they would determine the system sizing and costs considerations. After having them explain their costing approach for the energy conservation scopes, the construction processes, equipment, material, and manpower were identified to execute each ECM successfully. Each ECM was re-evaluated to identify the input metric(s) suitable to assure accurate costing. The application of heuristic strategies, identified from the relationships the experts expounded in the interviews, played a key role in defining the costing methodology. The heuristic strategies were based upon past experiences, rules of thumb developed based on code requirements, or the successful execution of a past projects.

3.2 Case study cost validation

A case study of a past energy retrofit is presented to validate the process by testing sample unit prices embedded in the energy audit tool. A case study was selected to pilot two ECM costing approaches on one facility, where the appropriate input data was available to evaluate the cost outcomes against the costs developed by the industry team. The two ECM's constitute two different systems and types of input parameters to test the process for each of these approaches. The focus is not simply validating the cost, though that is considered as one means to demonstrate reliability of the cost data. The validation is performed to compare the different heuristic links identified from the interviews and test which of the relationships best supports developing the assembly costs in retrofit projects. The audit tool is focused on small to medium size buildings ranging anywhere from 5,000 to 300,000 gross square feet (464.5 m^2 – 27,870.9 m^2). The selected facility is 312, 451 SF, so while slightly outside the targeted range, the influence of the additional 4% is not expected to be significant.

3.3 Developing ECM Costs

In order to establish consistency in the interview data collection process, hypothetical building parameters were used to solicit cost development information from the experts. A 100,000 SF, 5-Story office building was used as the basis of the ECM analysis for the expert interview scopes. This allows the researcher the ability for whole system ECM unit prices to be represented and translated back to input parameters by system, such as a square foot of a given system or a different metric like volume of airflow, using the heuristic guidelines from the interviews. The interviewees were asked to verbally walk through the process of assumptions for the hypothetical building, which allowed them to move past generalities be specific in the traits they were using to associate the specific costs to identify the heuristic links.   While Square foot unit measurements may be quite appropriate for certain ECMs; for example, the replacement of interior lighting with a new lighting system would be based on the interior building area being retrofit, they do not represent the most reliable approach to costing for each ECM. When building area is not appropriate, or requires substantial assumptions about system sizing, more specific system units were sought, such as airflow or heat load for mechanical systems. By applying the hypothetical building parameters to a defined construction scopes for each ECM, the heuristic relationships can be determined, and the detailed costing methodology was developed and translated back to this metric.

3.4 Example Individual ECM Heuristic Rule Development

As noted, developing initial costs for each of the systems was performed using unstructured interviews with industry experts. The focus of these interviews was not the detailed costs they applied, but to capture the heuristic approaches they used when evaluating the scale and cost of systems. By having the experts discuss the driving system parameters or cite rule of thumb calculations they were using in practice, it was possible to delve into the underlying relationships which influence the costs in each of the approaches. To illustrate the process, two sample ECM's are presented:

3.4.1 Interior Area (Daylighting Sensors)

Daylight Sensor ECM: Artificial lighting energy use can be reduced by leveraging daylight through windows to dim and switch off electric lights automatically in response to the presence of daylight measured by installed daylight sensors.

$$Initial\ Square\ Foot\ Cost\ = \frac{Demolition\ Cost\ + New\ System\ Labor\ and\ Material}{Gross\ Building\ Area}$$

Based on the unstructured interview, the following content was developed: For the hypothetical building (100 ft x 200 ft, 5 stories) offices are assumed around the entire perimeter (600 LF of windows), with an assumed depth of 15ft into the building from daylight, thus giving a Day-Lit area of 45,000 sf. The Day-Lit area is calculated as follows:

$$Day\ Lit\ Area\ = Number\ of\ floors \times Perimeter\ of\ building \times Assumed\ Day\ lit\ Depth$$

Having a Day-Lit Area, an assumed office size can be determined. In order to tie the office size to the day-lit depth, a 15 ft deep office is assumed. An average office size of 180 sf and a depth of 15 ft, calculates a 12-foot x 15-foot office. This assumed office size was used to calculate the number of offices, by dividing the Day-Lit Area (Equation #) the assumed office square footage. A total number of offices is calculated to be 250 ea (Equation #). The number of office calculation is as follows:

$$Number\ day\ lit\ offices\ = \frac{Total\ Day\ lit\ Area}{Assumed\ Office\ Area}$$

It was assumed, by the experts, that each office will receive one dimmable ballast, or 250 total for the project, and one photoelectric sensor to control 600 SF of Day-Lit Area, requiring 75 sensor zones throughout the building. The approximate price to install the dimmable ballasts and photo sensors for the hypothetical building was approximated to $60,000, with a cost of $1.33/sf of Day-Lit Area.

3.4.2 System sizing (Boilers)

Condensing Boiler ECM: A condensing boiler utilizes the latent heat of water produced from the burning of fuel, in addition to the standard sensible heat to increase its efficiency.

$$Initial\ Square\ Foot\ Cost\ = \frac{Boiler\ Material\ and\ Labor\ Cost\ + Demo\ Cost\ + Controls\ Cost}{Gross\ Building\ Area}$$

Based on the unstructured interviews an assumed boiler size was necessary. When considering the size of the boiler that will be required for the hypothetical building parameters of a 100,000 SF office building, it was determined that an assumed size of 970 MBh boiler was appropriate. Since RS Means Boiler costing information is limited, assuming 5 ea 194 MBh boilers, provides the proper MBh for the hypothetical building. The RS Means installed boiler unit price ia $8,051 to install 1 ea 194 MBh boiler. Multiplying the unit price by 5 ea, gives a total cost of $40,255. Dividing $40,255 by 100,000 SF establishes the cost of $0.40/SF for an installed condensing boiler.

4. Aggregated Costs

The costs of the energy conservation measures specifically exclude design costs, overhead and profit, and related soft costs. The future work of this research is to explore the potential benefit in retrofit assessment of properly aligning and assessing risks in retrofit scopes as it relates to unforeseen and service specific costs, along with contingency strategies. For this reason, these costs were excluded from the individual system costs and are considered in the packaging of costs but not included in this study.

4.1 Case study comparison of costs for actual retrofits ECM Analysis

Selection of an applicable audit to serve as a case study is required to properly analyze and align the costing developed for each ECM. Understanding the audited buildings existing conditions aids in the determination to confirm similar scopes are being evaluated. Reviewing the recommended ECMs from the case study energy audit and comparing them to the defined construction scopes from costing development assures the proper evaluation. Once individual ECMs with one of the identified approaches were recognized for evaluation, the quantified metrics from the case study were used to evaluate the accuracy of the system costs using the comparative approaches of cost on a building area and ECM specific approach. If the accuracy exceeds 10%, reconfirming scoping and unit prices align may need to be considered. If scoping and unit prices check out, the defined heuristic methodology may be incorrect.

5. Overview of Case study

A Level 2 energy audit on the 911 Federal Building located in Portland, OR was used for the case study. The building is 312,451 gross square feet (29,027.6 m^2), has nine stories above ground plus three levels below. Above ground the building dimensions are approximately 50 feet wide by 500 feet long. The mechanical, electrical, and plumbing systems are a mix of old and new equipment due to an interim retrofit. The most pressing need for replacement is the building automation system and major HVAC components for the heating and cooling plants. The ECMs that were recommended in the case study were based upon the model findings from eQuest energy modeling software.

5.1 Daylighting Energy Conservation Measure Case Study Comparison

Daylighting conservation was suggested within the scope of the audit report and presents the opportunity to study the approach taken for the Daylighting ECM Cost Methodology.

Table 1: Summary comparison of Case study Daylight costs to developed costs.

	Case Study	ECM Cost (SF)	ECM Cost (Assembly)
Unit Costs	N/A	$0.647 / GSF	$ 181.46/ Perimeter office + $ 198.66/ Photosensor
Core Cost	$108,952	$202,185	$121,872
Demolition Cost	Included Above	Included Above	Included Above
Control Cost	$17,629	Included Above	Included Above
Total ECM Cost	$126,581	$202,185	$121,872
Percent Accuracy		59.73%	3.79%

Daylighting Assembly Cost:

When determining the cost of the installation of daylighting controls, calculating the day-lit area and number of ballasts to be retrofit will drive the actual construction cost. It is estimated the case study has a day-lit area of 117,450 sf (approximately 653 perimeter offices with 17 daylighting sensors needed). The calculated total cost of the Daylighting ECM is $121,872 as shown in Table 1.

Exceeding the goal of an accuracy percentage of 10% for the building area calculation is clearly a problem. The comparison of case study and the developed ECM cost revealed more detail about the variability issues associated with this particular ECM approach in the material and labor cost, in particular the labor involved will vary the most depending on the type and access available to replace the existing lighting ballasts. The use of the more detailed information aligned with the future ECM clearly allowed more accurately aligned costs to be compiled.

5.2 Condensing Boiler Energy Conservation Measure Case Study Comparison

Table 2: Summary comparison of Case study Condensing Boiler costs to developed costs.

	Case Study	ECM Cost (SF)	ECM Cost (Assembly)
Unit Costs	N/A	$0.40 / GSF	$41.50 / MBh
Boiler and Piping Cost	$176,525	$124,981	$254,478
Demolition Cost	$18,164	Included	Included
Control Cost	$45,000	Included	Included
Total ECM Cost	$239,689	$124,981	$254,478
Percent Difference from Case Study		62.9%	5.99%

The existing building's heating system leverages a boiler, and the replacement of the existing boiler with a more efficiency set of condensing boilers was included in the case study.

Using both the gross building area and heating capacity approaches presented previously, the same assumptions were used to develop the system costs summarized in Table 2. The base study costs carry separate line items for the boiler install, demolition, and controls work needed to properly install the new condensing boilers. Initial costing approaches used square footage to estimate a total price, which was found that an acceptable accuracy was unable to be produced. The method of using MBh to estimate a total price was found to be inside 10% of the case study cost. When considering the size of the boiler that will be required for the hypothetical building parameters of a 100,000 sf office building, it was determined that an assumption of 5 ea 194 MBh boilers was appropriate. Using MBh as the driving building parameter for costing, the total capacity of boilers can be determined by dividing the size of the new boiler from case study of 6,132 MBh into the MBh cost.

Both ECM approaches show relatively simple means of capturing data about the existing building and developed heuristic assumptions which allow cost alignment at a feasibility level inside 10% of the case study building costs. The key outcome is not the cost accuracy itself, but the ability to develop heuristic rules to apply to retrofit costing which allow for the capture of assembly level of detail estimating accuracy using limited data easily collectible during a typical energy audit process. In addition, but positioning the ECM costs to align with the driving system performance measures, such as Day-Lit area and Boiler capacity, the costs can be easily revised and re-aligned to supported the design process as the detail of the new systems are developed.

6. Conclusions

This paper presented a method to generate retrofit assembly construction costs for Energy Conservation Measure rapid first cost generation. Expert interviews were used to identify heuristic rules for associating system sizing and costs scope estimating assumptions, which were piloted for sample assembled ECM's using a case study project. As energy retrofits gain popularity to combat rising energy costs, commercial buildings will be continue to be analyzed for inefficiencies. Since, the process of assessing energy retrofit projects is variable; the use of these methods begins to offer consistent means of evaluation of the initial cost implications for retrofit projects which can more easily feed into integrated design processes and as reasonable values for aligning initial cost estimates. Energy Audits will be instrumental in properly assembling recommended ECMs for a building owner. If distinct building parameters are known relatively early in the audit process, a rapid feasibility analysis can be assembled with greater reliability for the final cost. The heuristic rules tested demonstrate a reliable process which, for the costs piloted was within 10% accuracy of the case study project.

As this research progresses, the accuracy of all of the ECM's will continue to be validated using actual construction cost data. In addition, the focus on further cost development and validation will allow the audit tool to be useful for making high-level feasibility decisions. Once validation of accuracy for all ECM's approaches is achieved, the tool will be moved forward for identifying opportunities to leverage work breakdown structure approaches to reduce demolition and unforeseen conditions risk by identifying overlapping scopes and strategies for coupling ECM packages.

7. Future work

Continued validation of costing will continue. Analysis of costing against similar building types with different sizes and functions will be performed to validate costing. The ECM costs will continue to be evaluated and evolved using the goal of achieving accuracy within 10% of actual costs.

New energy audits will be performed on multiple buildings in the Philadelphia region. Full audits using the audit tool and associated costing of ECM's will be performed in parallel with a series of traditional audits, with the buildings followed through retrofit to compare assessment and final cost accuracy.

Further research will explore the synergistic benefits to initial cost possible through selective shared risk of certain ECM scopes. Shared cost between multiple ECMs will be identified, in an attempt to reduce contingency and risk carried on each ECM. ECM packages will be defined with goals of providing the "biggest bang for your buck." Based on the pre-construction information, system, subsystem, and component packages will be assembled.

Additional ECMs, which are not included in the audit tool, will be evaluated with goals of future ECM content expansion for the audit tool. If particular ECMs are deemed valuable to include, they will be evaluated using the same ECM cost development process.

8. Limitations

Currently the ECM development is primarily focused on commercial office buildings. Inaccuracies in costs between different building types may be possible. Certain ECMs are being evaluated; any ECM that is not included will have to be evaluated individually. Executed energy audits that are being used as case studies require certain assumptions to be made. Inaccuracies due to invalid assumptions may exist. Unit prices for all ECMs will have to be updated each year to reflect cost changes in RS Means.

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