COST PERFORMANCE OF ENERGY EFFICIENCY MEASURES IN RESIDENTIAL RETROFIT PROJECTS

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ABSTRACT

To date, few experiments have attempted to apply lean principles within the residential energy retrofit sector. This research focuses on factors that influence the setting of target costs in residential energy retrofit assessments. A case-study-based cost-performance model is presented. The model is centered on savings/investment ratios and describes the variability of upgrade costs and their relationships with community size; house characteristics; site constraints; project site complexity; labor and materials: and the production operations design of installation procedures. The cost model for the community studied indicates that savings/investment ratios increase and per-unit costs decrease as the number of housing units to be retrofitted increases. The project is estimated to achieve approximately 50% per-unit cost savings from the initial baseline of a single home estimate. Significant labour cost savings are achieved by completing more attics in one day and/or by increasing the production rate of the installation crews. Per-unit overhead costs are cut significantly as the scope of the project expands. Based on this cost performance model, the study proposes a set of target cost planning principles to support energy efficiency retrofit decisions by facility managers of centrally-managed housing communities.

KEYWORDS

Energy efficiency measures, cost modeling, home energy assessments, target cost planning, residential energy retrofits.

INTRODUCTION

Energy efficiency has recently received increased interest in the residential building sector as a result of rising energy costs, environmental quality demands, and the potential for the sector to contribute to a sustainable local economy in communities.

This research paper addresses the issue of cost performance in energy efficiency upgrade delivery systems. In particular, the research is concerned with how community scale energy assessments and upgrades can provide favourable economies of scale when compared to single-home retrofits.

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Existing energy assessment and upgrade programs primarily employ a house-by-house approach. The single-bid per project model is the dominant paradigm used in contracting energy upgrades, and economies of scale are generally not considered. In private retail markets, homeowners lack the collective purchasing and management capabilities needed to commission contractor installations at a community scale.

Specialty contractors are often best positioned to deliver large-volume projects and achieve economies of scale in their operations design, resource allocation and total product and service costs.

This research tests the proposition that delivery systems centred on community-based upgrades can provide value in savings/investment ratios and in improved payback period performance over the traditional single-house project bid package model. The study focuses on a large, centrally managed housing community that has opportunity to take advantage of community-scale upgrades.

A home performance contractor's approach to a 201 home community case study is used to demonstrate the principle variables driving economies of scale in the upgrade delivery system.

A cost-performance model is presented based on analysis of a selected energy efficiency measure (EEM) package – specifically, attic air sealing and insulation. The model examines the factors that influence the change in per-unit project costs based on the relationships between house characteristics and constraints; project site complexity; labor and materials; batch sizes of housing units; and the production operations design of the upgrade contractor. The predicted results show that 50% per-unit savings can be achieved over the initial baseline of a single home by retrofitting all 201units as a single project using a single contractor.

Cost control tools are equally important for project management and this research outlines future research to develop target cost control tools based on this cost performance template. The study proposes a set of target cost planning principles to support community facility managers' energy efficiency retrofit decisions.

PRODUCTION CHALLENGES IN ENERGY EFFICIENCY RETROFITS

ENERGY EFFICIENCY VALUE CHAIN MAP

Through a series of process phases, householders are engaged in the marketplace; an energy assessment is carried out; house and householder conditions are characterized; energy solutions are prescribed; and upgrades are installed by a range of service providers.

Figure 1 illustrates the range of process variability in home energy efficiency delivery systems and the multiple paths available to service providers. From a process design and performance perspective, upgrade contractors seek to minimize process waste and maximize the potential to install cost effective energy efficiency measures. General contractors may leverage energy assessment procedures to add value to their existing construction services. Whole home energy performance contractors may tailor a full service of assessment procedures or a more limited assessment based on their market evaluation and householder profiling.

The purpose of this process map is to distinguish the primary service delivery contractors in home energy efficiency. These process maps highlight the fact that delivery providers offer varying degree of process services depending on the operating market conditions.

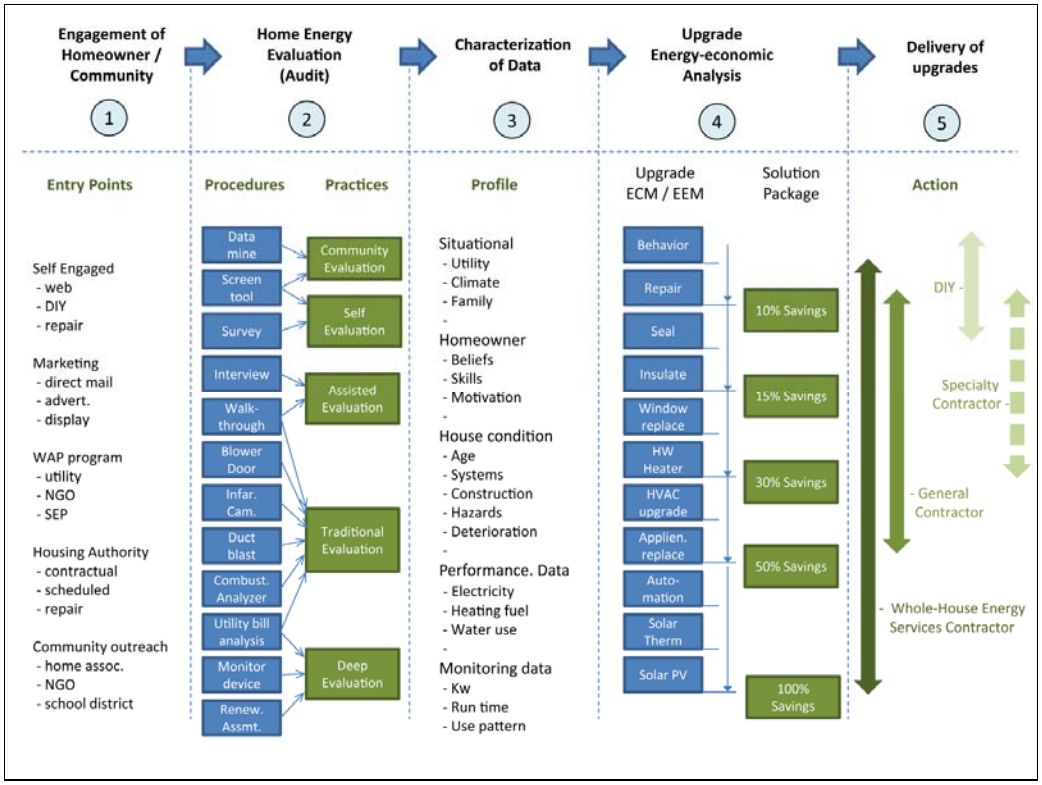

Figure 1: Residential Home Energy Value Chain Map (Riley et al. 2012)

RESEARCH STUDY

In energy retrofit projects, front-end planning methods often employ unrealistic assumptions about the true costs of audits and upgrade installations, and which in turn can inflate the predicted energy savings. Energy efficiency program assessors may find that energy savings are overestimated in the program planning and design phase of the energy efficiency delivery process.

Having accurate cost data allows energy modellers and assessors to predict savings/investment ratios; it bolsters the ability of homeowners and facilities management to make informed decisions; and it allows upgrade contractors to provide efficient and reliable services. A well-defined cost estimate can also provide reliability and the means to control and assure upgrade installation and performance to program designers and program evaluators.

Within the cost spectrum of understanding energy savings are the performance of the upgrade measure(s); materials specification; and workmanship and installation quality. The costs of upgrades are particularly important when modeling the design of prescriptive lists (upgrades) for communities. Costs can vary significantly for an upgrade in a particular community based on product materials and skilled labor availability.

Tommelein, Ballard, and Lee (2011) have developed target value design methods applied to commercial buildings, based on Ballard's (2008) research. This research establishes a target-cost-setting framework for upgrading residential homes. The focus on residential energy retrofits is warranted given the unique construction operations associated with residential energy retrofit projects.

The research presented here addresses the following questions:

1. What economies of scale can be observed through the targeted deployment of energy efficiency measures (EEMs) in a centrally-managed housing community?
2. What are the effective community characterization techniques that support large-scale, cost-effective upgrade adoption in communities with similar housing stock? How are these techniques specific to home performance contractors?
3. What operational efficiencies can be expected to be achieved through lean, community-scale delivery of packaged upgrades in communities that have similar housing stock?
4. What are the dependent variables that influence economies of scale in a specialty contractor delivery system for a community-scale project?
5. Communities with operational and financial constraints may require phased upgrades over time. How can cost-performance models support targeted upgrade solutions for such communities?

A case study research method was utilized to answer the above set of research questions. The energy assessment and upgrade procedures employed by a home performance contractor in a 201-unit retirement community case study were used to formalize the energy assessment and cost-modelling methodology, and to demonstrate the relationships of the principle variables driving economies of scale in the delivery system.

PROJECT PLANNING AND FEASIBILITY OF ENERGY RETROFIT PROJECTS

Figure 2 illustrates a typical process flow of an energy retrofit feasibility study. The owner of a housing community typically hires an energy services provider to perform an energy assessment. The contractor moves through a set of appraisal activities and a sample of homes representative of the housing stock is selected for further assessment. Based on the site energy assessment, an EEM package is prescribed as a solution set, and contractors are engaged to provide price quotes for upgrade installation.

Through a series of planning activities, owners and facilities management decide on a scope of works, and a contract is developed for a retrofit project. Through these phases a series of iterative cost modelling informs the planning process. This cost modeling process warrants further study to understand how cost performance models of EEM solutions are developed. Information flows across these organizational boundaries can breakdown at various process handoffs. Reliability in assessment methods for existing building systems adds to the complexity of developing high quality cost performance models within reasonable planning costs.

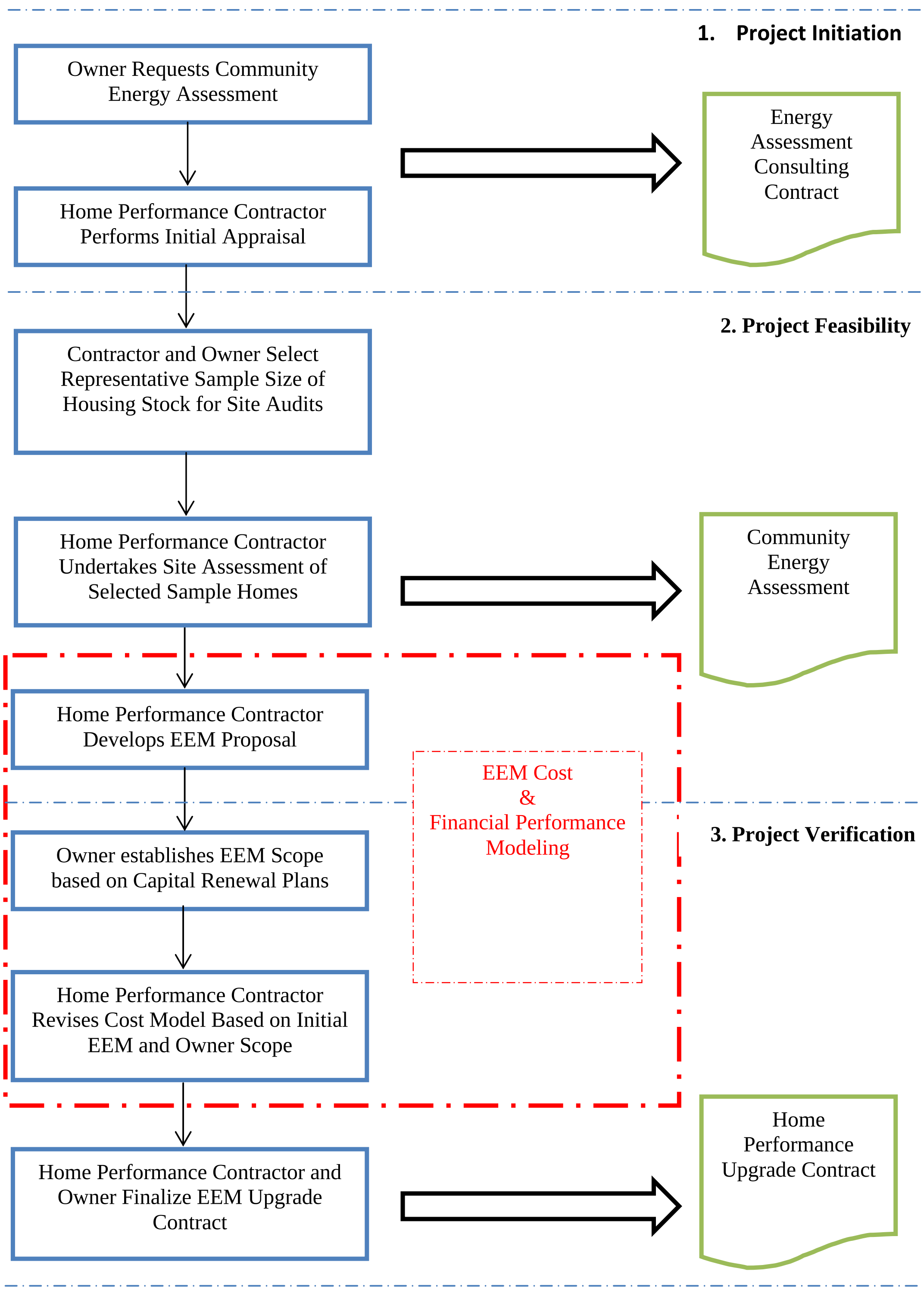

Figure 2: Typical Energy Improvement Retrofit Process

INTEGRATED COST MODELLING PERSPECTIVE

Figure 3 illustrates a holistic cost modeling framework comprised of 4 primary perspectives-- the auditor assessment; the upgrade contractor; the project owner; and facilities operations. Auditor assessments have a primary focus on EEM and energy costs, and on the reliable specification of EEMs and prediction of their corresponding savings. The upgrade contractor is primarily focused on cost modeling the EEM retrofit work specifications. The project owner is focused on the financial performance of the energy retrofit; specifically, with project costs; predicted energy savings; and the availability of manageable financing. The facilities operations perspective is focused primarily on operational and maintenance efficiency. An ideal integrated energy retrofit cost model would support all of these views over the course of a project's life cycle.

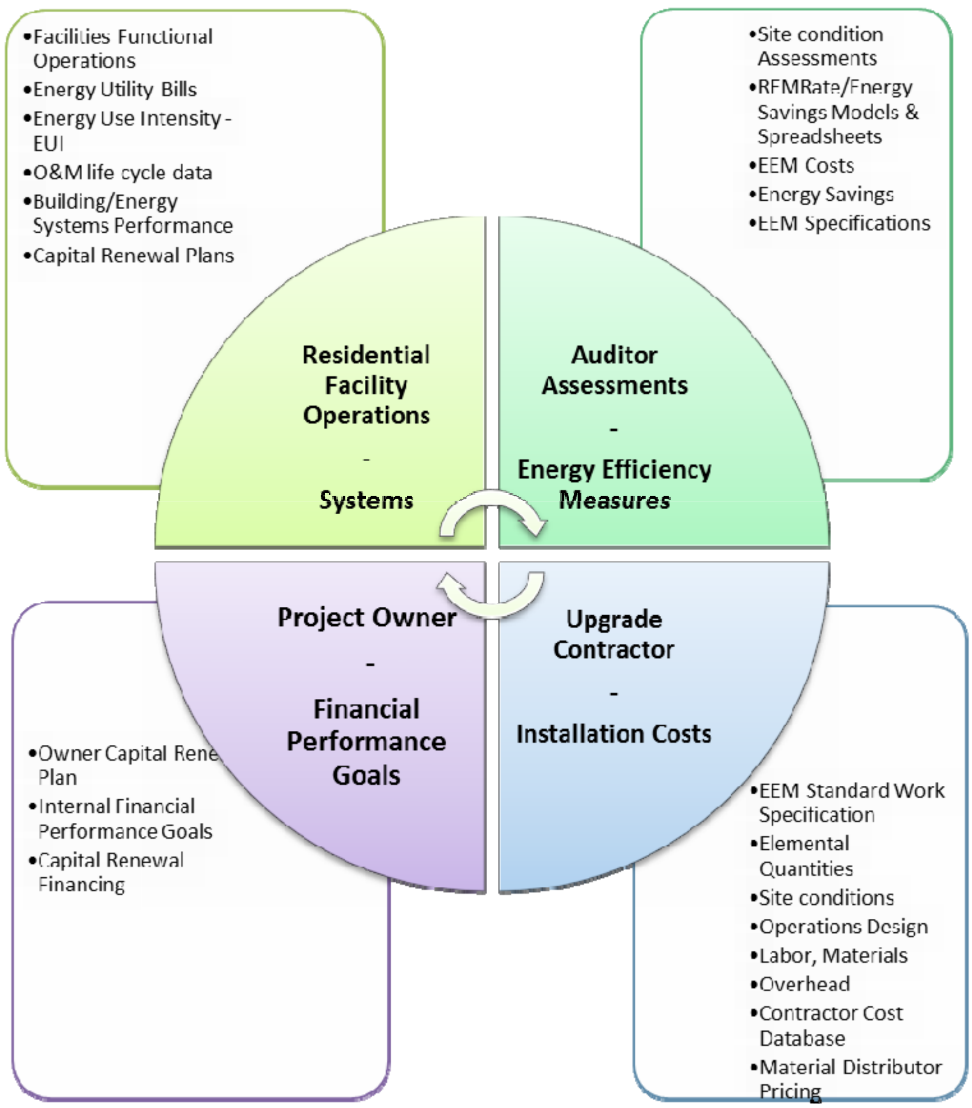

Figure 3: Integrated Cost Modeling Perspective

CASE STUDY RESULTS – COMMUNITY SCALE ENERGY ASSESSMENT

The research focuses on contractual delivery structures that have the capacity to provide energy efficiency services at community scale. This research reports on a home performance contractor and one EEM retrofit package (air sealing and insulation), and on cost performance for single and multiple jobs.

Figure 4 illustrates the 201-unit housing community evaluated in the study. The figure illustrates the variability at the house level that may be seen within a single planned community's housing stock. (See Whelton et al. 2012 for a detailed examination of the case study).

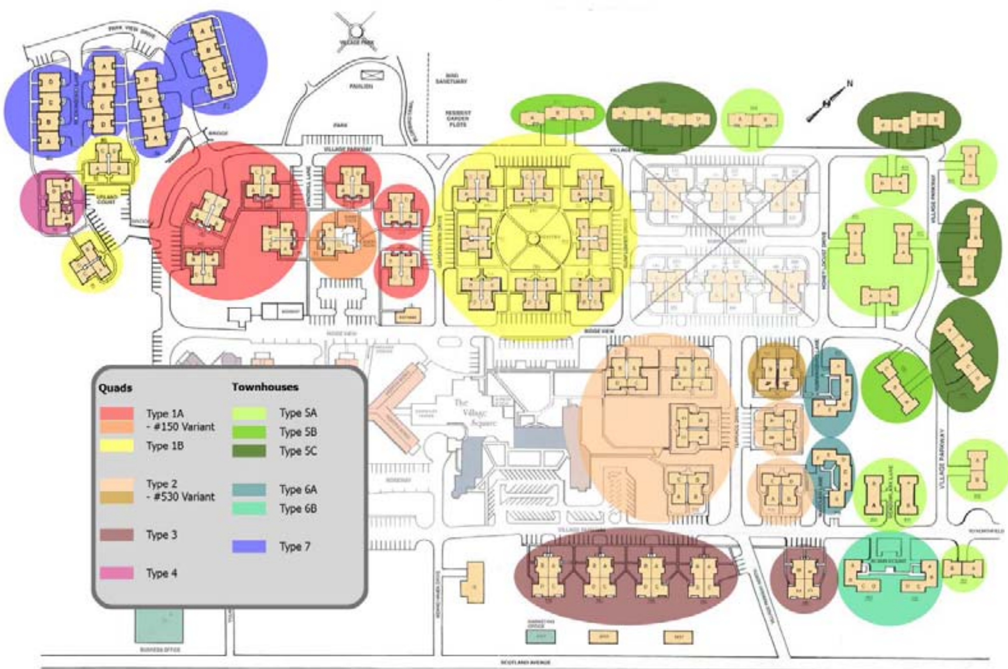

Figure 4: Housing stock characterized by floor plan

PROJECT COST PERFORMANCE

A set of cost performance models were developed using a range of project scales. Estimates were generated by the home performance contractor using their internal cost estimating system. Costs for retrofitting between 1 attic and 201 attics were estimated. The cost performance model is representative of this community; i.e., it is specific to this particular housing stock, homeowner profile, existing conditions, upgrade solutions, and home performance contractor capabilities. EEM cost modeling was only performed for the attic air sealing and insulation measure. A whole home bundle of EEMs would yield a different cost performance model than the model shown in

. Further extensive cost modeling is required to complete the full package of energy efficiency measures and is beyond the scope of this research project.

Figure 5 displays the facility owner's cost per square foot for performing attic air sealing and insulation within this community at multiple scales. Low, average, and high values from the National Energy Efficiency Measures Database are displayed on the graph to show how this project compares with national cost data benchmarks.

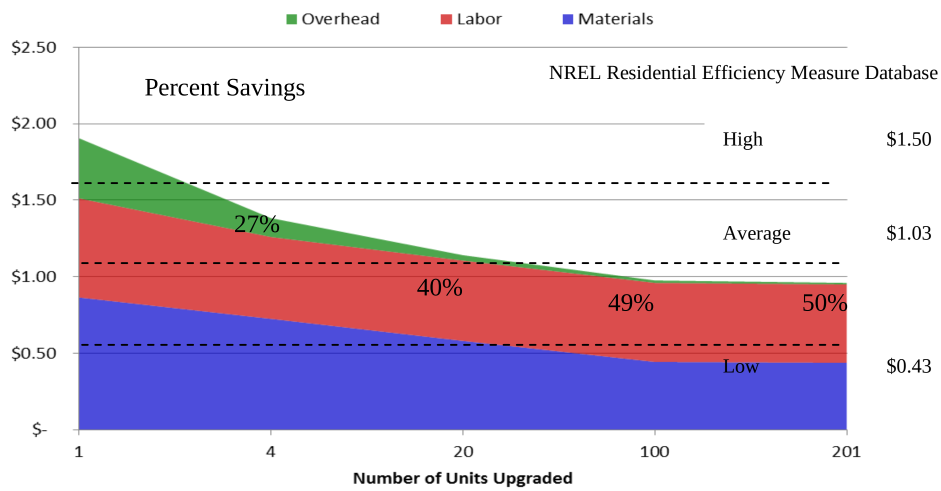

Figure 5: Total cost estimate curves ($/ft^2)

Figure 6 depicts projected gains in savings-investment ratio performance and illustrates the decrease in per-unit-area air sealing and insulation costs as more units are retrofitted.

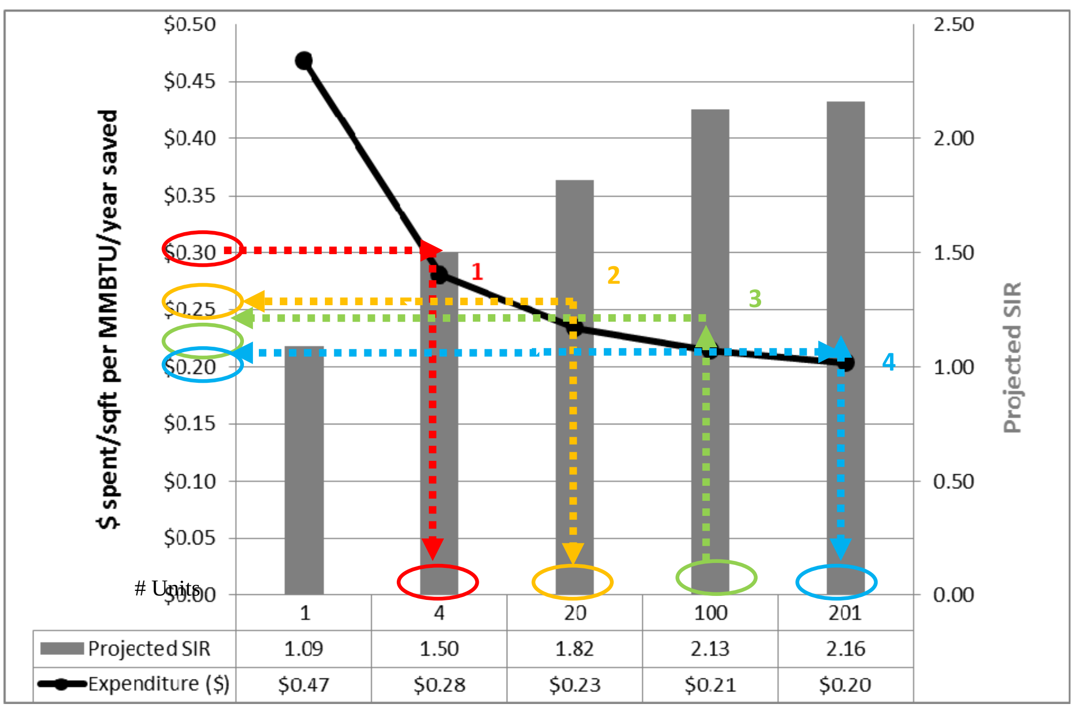

Figure 6: Projected range of savings-investment ratios and cost intensity per achieved energy savings for air sealing and insulation measures

TARGET PLANNING PRINCIPLES FOR ENERGY RETROFITS

The cost performance chart in Figure 6 is a proposed support tool for owner decision making engaged in energy retrofit investment decisions. Specific examples of planning scenarios are given in Table 1. Figure 6 illustrates the potential target mapping (of these scenarios) to a set of cost performance models in order to set target planning objectives and to test feasibility of community scale solutions.

Table 1: Potential energy planning scenarios

Scenario 1: Identification of number of units to retrofit based on targeting a cost indicator value. Principle: An owner targets a cost indicator value and identifies the number of units to retrofit for a selected EEM type. Hypothetical Example: A financial officer specifies a cost performance level based on benchmark indicators and "insulation upgrades" are selected and a number of units to upgrade.
Scenario 2: Identification of the scope of a retrofit based on a desired EEM type and a cost indicator value. Principle: An owner targets a specific EEM and identifies the number of units to retrofit and associated cost indicator value. Hypothetical Example: A facilities manager targets attic air sealing and insulation upgrades based on tax incentives and a capital budget plan, and subsequently identifies the maximum number of units for potential retrofit.
Scenario 3: Identification of an EEM or EEM package based on a targeted number of units available for retrofit based on operational functions. Principle: An owner targets a set number of units to retrofit based on operations availability and identifies a specific EEM and associated cost indicator value. Hypothetical Example: A facilities maintenance manager identifies that a number of units will become vacant over the course of an operating year and identifies HVAC upgrades for capital budget planning.
Scenario 4: Identification of the scope of a retrofit based on targeted EEM end-of-life specifications. Principle: An owner targets a specific EEM type and identifies the number of units to retrofit and associated cost indicator value. Hypothetical Example: A facilities operator examines the operating life cycle data of the building systems and identifies high priority upgrades that are near end of life and require capital budgeting.

CONCLUSIONS

This case study established that an upgrade contractor can realize savings through coordinated economies of scale when performing community-scale retrofits, as opposed to performing the retrofits as if they were single, one-off projects. The case study investigated a specific EEM package- the air sealing and insulation of attics. Adopting a single work package for all units is estimated to provide approximately 50% per-unit savings over the initial baseline of a single home estimate.

The cost modeling results accounted for site conditions (community and house characterization) and upgrade operations design- i.e. the construction means and

methods of the contractor. Subsequent to this research process and new information, the partner home performance contractor re-evaluated their procurement and operations processes by increasing the scale of their solutions packages to take advantage of material pricing and scheduling efficiencies.
Economies of scale can be realized in:

- Bulk discounts on materials, particularly spray foam used for air sealing;
- Increased labor productivity due to improved workflow design and optimized crew size;
- Improved travel, setup and clean-up times achieved by performing more insulation jobs at a single site; and
- Program management overhead associated with managing the project.

The impacts of upgrade cost variability on savings-investment ratios in the energy modelling phase were notable. Community-scale pricing for upgrades may provide value to multi-unit residential community owners and operators and may make larger scale upgrades more attractive. Facility owners and operators can also benefit from more reliable cost solution packages when planning energy retrofits.

The cost performance model can by expanded by modelling a full solution package of EEMs and charting of cost saving curves for all EEMs implemented for this particular community.

Future research proposes to track upgrade installation and monitor the actual internal cost performance of contractor operations with the predicted costs. This study can form the basis for improving the reliability of cost projections. A longitudinal study to track the upgrade process and variability in site conditions and contractor operations can provide more reliable actual data for comparison with the estimated cost models.

Finally, the research seeks to further examine the emerging target cost planning principles from this case study and to develop more reliable energy assessment methods through the testing of these techniques.

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