RESEM: AN EVALUATION TOOL FOR ENERGY RETROFITS IN INSTITUTIONAL BUILDINGS†

by

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ABSTRACT

Lawrence Berkeley Laboratory is developing a PC-based computer tool, the Retrofit Energy Savings Estimation Model (RESEM) which can provide high-quality estimates of energy savings, based on actual pre- and post-retrofit utility bills. Designed to be used by state and regional energy office **staff who** have little energy modeling expertise and access to only limited information regarding a building and its retrofits, RESEM hides much of its sophistication behind a simple, intuitive interface. Descriptions of the development of RESEM and of its characteristics provide an overview of an interesting and instructive exercise in the careful packaging of an ASHRAE-based energy estimation model into a robust, generalized tool that accomplishes a complete retrofit savings analysis of a building without demanding extensive engineering expertise on the part of the user. We describe software design goals and approaches developed for: 1) providing a rational interface and maximal self-containment; 2) development of building prototypes and parameter defaults based on minimal information from the user; 3) a concise and efficient way of describing retrofits; 4) the calibration of the building description and its simulated performance against utility bills; and 5) the allocation of energy savings among multiple retrofits, together with cost-effectiveness estimates. Future needs and capabilities to respond to them are also discussed.

INTRODUCTION

The U.S. Department of Energy (DOE) Institutional Conservation Program (ICP) Office has managed a legislatively mandated federal matching-grants program for energy conservation retrofits in not-for-profit elementary and secondary schools, colleges and universities, and hospitals since 1979. The ICP Program is implemented through state energy offices *via* DOE regional offices. The Energy Conservation Measure (ECM) grants, which are used to carry out engineering audits and for the design, purchase, and installation of retrofit measures, have been awarded in annual proposal/evaluation cycles, and have provided support for approximately 70,000 ECMs in 28,000 buildings through 1987. The total federal expenditures have been slightly greater than $700 million through that time. Grants are available only for buildings constructed prior to April 20, 1977.

All proposals submitted by institutions are evaluated by state energy offices based on infor-

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mation in detailed technical engineering audits of the buildings that provide estimates of the costs, savings, and cost effectiveness of the proposed retrofits. A 1987 evaluation of the ICP program [1]* made aggregate savings estimates due to ICP-funded ECMs. These estimates were based on the savings calculations completed as part of the engineering audits for the individual buildings. However, the ICP program also desired the capability to evaluate in more detail the energy savings of individual buildings for which utility consumption data was also available, and to relate the savings estimates directly to the metered consumption.

We discuss in this paper some details of the design and implementation of the PC-based Retrofit Energy Savings Evaluation Method (RESEM), which is under development to satisfy ICP needs. The LBL project has as its objective the development, demonstration, and documentation of a building-specific retrofit savings model. The need for this model was dictated by LBL observations of variations in the technical quality of ICP engineering audits, and thus uncertainties in the related savings estimates produced by them [2]. In order to improve the quality of aggregate estimates, a building-specific savings estimation model was needed which would provide accurate savings estimates for ECM retrofits, both singly and in combination. To enhance credibility, it was important that the model be able to utilize actual pre- and post-retrofit consumption data as a benchmark. In the longer term, it was also anticipated that the model could be useful as a tool for the evaluation and improvement of the technical audit procedures used in grant evaluations.

DESIGN CONSIDERATIONS

A number of design considerations for RESEM arose out of technical, programmatic, and user considerations, and influenced its design and implementation. Some of the more important of these considerations, which most significantly affected the design and implementation approaches used in RESEM, include (1) the conceptual and technical complexity of the of the savings analysis process; (2) typical levels of quality and completeness of data available on which to base the analyses; (3) the decentralized nature of the field offices which would carry primary responsibility for the analyses; and (4) user expertise levels and computer hardware typically available in the field offices.

The retrofit analysis process is described in detail in the following section; this process defines the technical analysis capabilities needed in RESEM. Subsequent sections describe design approaches used in RESEM to satisfy the defined needs and anticipated future development activities.

Energy Savings Evaluation Process

The central issue in estimating energy savings due to ECM installations is the attribution of differences in pre- and post-retrofit consumption among the many possible causes. As a result, the overall process of determining the energy savings and cost effectiveness of the ECM retrofits is conceptually complex and technically demanding. The sequence of steps includes:

- The pre-retrofit building has to be described in enough detail for an energy simulation. Since the available information is often limited, it is necessary to provide the user with reasonable assumptions, both for engineering details and for the overall building design itself.
- The pre-retrofit building description has to be appropriately adjusted so that the simulated energy use agrees with measured utility data. A systematic "reconciliation" process needs to be developed to accomplish this, and actual weather data corresponding to the location of the building and the time period of the utility bills is needed for the energy simulation.
- Weather normalization is accomplished by simulating the reconciled pre-retrofit building with appropriate long-term average

* Figures in brackets refer to citations in the References Section of this paper.

weather for the site.

- The ratio of the *simulated* building energy performances for actual and long-term weather is then used to correct the *measured* utility data to a long term average. This result is used as the pre-retrofit basis for determining savings.

- Next, the post-retrofit building description is determined by applying the ECMs and other retrofit changes as modifications to the pre-retrofit configuration.

- Reconciliation, weather normalization, and utility bill adjustment processes like those described above are carried out for the post retrofit building, subject to maintaining consistency with the known ECMs and other changes.

- The long-term average overall pre-post change in building energy use is determined.

- Simulation is used to separate ECM savings from other pre-post changes.

- If desired, individual ECM savings are separated out from each other.

- Individual ECM energy savings and cost effectiveness are determined.

The complexity of this process implies the need for a fast, comprehensive energy analysis tool at its core, together with an internal control structure and interface that combine to relieve the user of as much of the burden of detail as possible, while allowing access to analysis details when needed.

RESEM DESIGN FEATURES

In order to decentralize ECM savings analyses to state and regional offices, RESEM was designed to run on currently available, "upper-end" PCs, which are the commonly available hardware in the field offices. RESEM has to run fast enough that the session time for an interactive analysis consists mostly of the time the user needs to collect, organize, and input data. The analysis calculations thus were constrained to only very modest waiting times, and had to be significantly less than typical "batch processing" turnaround times on central mainframes. RESEM had to be a self-contained and complete software package, needing no additional software routines for operation. Because of its specialized analysis capabilities, it could not be an extension of, or a "macro package" to be used with existing PC spreadsheet or data base software. RESEM had to contain almost all supporting information necessary for a building analysis, except that specific information about the building itself provided by the user as input during an analysis session. Other generalized approaches that were part of our design philosophy included the use of existing algorithms or software wherever possible, and a highly structured approach that allowed for compartmentalized development and testing. Selected specific capabilities are discussed in detail below.

User Interface

Because of typical levels of user expertise, an interface had to be designed that was as simple and clear as possible, and yet provided access to the full range of analysis capabilities that is needed for complex situations that might arise in some analyses. Interaction with the program had to give the user a feeling of reliability, *i.e.*, that it is easy to get the right answer, and difficult to get the wrong one. The design of the interface was considerably aided by interaction with and feedback from early users in a testing program.

Much has been written about good interactive user interface design. We focussed on a limited number of simply designed screens and menus that provide a consistent visual interface by being used over again for as many different circumstances as possible. Also, hardware typically available in field offices led us to a keyboard and character based interface. To minimize our own development efforts, we used third-party software that gave us dynamic on-line help and data error and range-checking capabilities that provided immediate feedback to the user. We also chose to use a dynamic screen approach that pops up and removes small subscreens as necessary, while retaining already displayed screens. This approach visually approaches a windows concept and is very effective in providing the user with constant visual context information about their status and progress through the analysis process. Such an approach also minimizes the inconvenience and confusion that can occur in an intrinsically hierarchical process by making it quick and easy to traverse the hierarchy with visual cues. At a higher level, the internal logic behind the interface contains real-time diagnostic messages to help the user recover from abnormal contingencies that might arise during the analysis, as well as status messages to keep the user informed at all times about the status of progress through the analysis process. Additionally, we designed the internal screen control to provide or disallow selective access to screen fields and menu choices as a very effective adjunct to guiding the user correctly through the analysis process. The interface makes reliance on written documentation largely unnecessary.

RESEM user-selectable reports include verification summaries of all inputs, and analysis results including pre-and post-retrofit energy use broken out by end-use and fuel type, retrofit savings for each ECM, and economic measures of ECM performance, based on fuel costs. No graphical output is available at this time.

Energy Analysis Module

RESEM is complex and sophisticated enough in its energy modeling to explicitly reflect the influence of a wide range of design, operation, and weather parameters encountered in ICP buildings. The energy calculations are carried out with an accuracy consistent with (1) the levels information available and (2) analysis speed requirements. The energy analysis module is able to explicitly deal with the full range of ECMs allowed under the ICP program.

The energy analysis approach used is based on the ASHRAE modified bin method [3], modified to use monthly bins and to simulate complete HVAC systems and plant equipment performance at each bin condition. To the maximum degree possible, the energy estimation model developed for RESEM is based on existing, public domain methods and algorithms [4,5]. However, all code has been designed and rewritten in order to provide maximum speed consistent with accuracy requirements. This minimizes development and validation efforts and provides a finished model with the greatest credibility. Building energy consumption results are broken down into a matrix of components by both fuel type and end use. This breakdown facilitates both the billing-data reconciliation process and the allocation of savings to specific ECMs, described below. HVAC fan system and plant equipment sizing capabilities are also provided.

In the one major exception to self-containment, a separate weather data processor has been developed that operates independently of RESEM. This weather processor uses hourly NOAA weather data for input (both actual-year data and typical years in TRY and TMY formats) and provides as output the bin data necessary for RESEM simulations. The weather processor is based on existing processors designed for use with detailed hourly energy analysis programs such as DOE-2, but is designed, like RESEM, to operate on PCs. Thus, it is well suited to use in either a centralized approach, or out in the field offices. The latter approach is especally feasible because the NOAA hourly weather data is now available on floppy disks.

Building and Engineering Defaults

RESEM must be able to base its analysis and resulting savings estimates on information typically available to ICP state, regional, or headquarters staff, namely building location, the audit report, pre- and post-retrofit utility bills, and other grant information such as actual retrofit costs. Because the available information can at times be limited, we have developed a method for defining not only all engineering defaults that might be necessary to provide specific parameters for simulation (*e.g.*, typical operating parameters for a Variable Volume HVAC system), but also complete prototypical building descriptions. This approach makes the user's job easier, since no extra technical information has to be gathered from other sources. Currently, the RESEM default building generator will produce prototypical building descriptions for major institutional building types (elementary and secondary schools and hospitals). The building descriptions are then customized based on their size and age.

Utility Data Reconciliation

The basic premise underlying the reconciliation process is that the actual billing history of the building represents the most reliable starting point for determining "real" savings resulting from ECM installation. RESEM uses a specially developed method to accomplish this reconciliation that yields a "calibrated" modification of the building input description, which in turn reproduces the actual billed consumption. This method is based on a set of rules for bringing building simulation descriptions into alignment with measured consumption in a systematic way [6]. These rules and procedures were developed during a detailed re-analysis of a selected set of ICP engineering audit reports [2]. The rules, while relatively simple, are an example of knowledge-based rules, based on the expertise and experience of their developers in conjunction with their observations during the audit analysis process. The reconciliation method can be reduced to a relatively simple set of building description modification rules that selectively change certain aspects of the building description based on the nature of the differences between the simulated performance and the measured data. These rules can be iteratively applied until the desired quality of agreement is reached. This iterative method is the most computation-intensive part of the RESEM analysis, and drives the speed requirements for the energy analysis module. The reconciliation is done for both the pre- and post-retrofit building configurations.

ECM Descriptions

The ICP program predefined 74 ECM types, which were used in evaluating proposals and tracking the types of retrofits that were installed. The ICP data base contains complete information on the types and costs of all of the ECMs that were installed as a consequence of ICP grants. This data can be accessed by field offices and used as part of the RESEM analysis process. The RESEM approach to describing the post-retrofit building is to use a description of each ECM to sequentially modify a copy of the pre-retrofit building description until all ECMs have been accounted for. To facilitate the description of these ECMs as modifications of the pre-retrofit building, we have developed a dynamic menu-and-subscreen approach that allows the user to quickly select each ECM by type. RESEM then develops a modification to the building description either based on pre-defined assumptions for the particular ECM type (*i.e.* all the windows experience a double glazing retrofit), or the user can specify additional details for the retrofit, if desired. Input screens for selecting each ECM type allow as detailed a description of the ECM as necessary to accurately reflect the design changes from the pre-retrofitted building to the post-retrofitted building. For user convenience, an inventory of applied ECMs is listed for the user. This "push-button" ECM description approach greatly facilitates the RESEM analysis. Since the non-ECM retrofit changes are conceptually analogous to ECMs, they are treated as another lumped category as part of this overall procedure.

Savings Allocation

We are currently developing an allocation method that estimates the effects of each individual ECM in producing the total observed energy savings. To the degree allowed by the comprehensiveness of the energy simulation model, we would like this ECM savings allocation method to take into account the interactive effects that can can occur when multiple-ECM combinations are installed. While it is recognized that there are some instances in which it is not possible in principle to disaggregate total savings to multiple causes, it is possible to use methods that yield disaggregations that are meaningful in the specific context of this application, namely relative cost effectiveness. Two approaches that are being explored in detail are (1) a proportional fractions allocation, based on the individual effects of each of the separate ECMs or changes, and (2) a cost-effectiveness-ordered priority approach, based on cumulative marginal effects of each ECM or change, applied in the order of their cost effectiveness.

FUTURE DEVELOPMENT

As experience is gained and additional user needs are identified, it is anticipated that a number of enhancements will be developed for the single-building oriented version of RESEM. Additionally, subsequent phases of RESEM development will provide major new analysis capabilities that involve the accumulation and subsequent analysis of many individual-building analyses. This will require the design and implementation of a data base structure to hold individual RESEM analysis results. The design will be flexible enough that individual data bases can be maintained in state and regional offices that can be arbitrarily combined into larger aggregates in any way desired. Second, a tool will be designed to access the data base and provide a "Performance Profile" for energy consumption and savings in any individual building and compares it to corresponding average data for the entire class of similar buildings that have been analyzed by RESEM and are in the data base. Third, an aggregation capability is also planned that would access the RESEM results data base and determine total savings realized over a given time period for any desired range of geographical regions and subregions, different building types, or different retrofit types or classes. Finally, the comprehensiveness of the energy analysis modules at the core of RESEM would lend themselves well to development of an engineering audit tool that is specially oriented toward the needs of ICP in the grant evaluation process.

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