INSTRUMENTED HOME ENERGY RATING AND COMMISSIONING

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Energy Systems Integration

What follows is the final report for the Instrumented Home Energy Rating and Commissioning project, Contract Number 500-98-033, conducted by the Energy Performance of Buildings Group, Environmental Energy Technologies Division of the Lawrence Berkeley National Laboratory. The report is entitled Instrumented Home Energy Rating and Commissioning. This project contributes to the PIER Building End-Use Energy Efficiency program.

For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200.

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Executive Summary

Introduction. Currently, houses do not perform optimally or even as many codes and forecasts predict, largely because they are field assembled and there is no consistent process to identify deficiencies or to correct them. Solving this problem in new and existing houses requires field performance evaluations using appropriate and agreed upon procedures. Many procedural elements to test the energy performance of energy-related components and systems of a home and to assess their impacts on health and safety already exist in a fragmented environment; some are ready now to integrate into a new process called residential commissioning.

Purpose. The purpose of this project is to develop and document residential commissioning procedures and to demonstrate the value that applying these procedures could provide in both new and existing California houses. We expect that this new information will lay the groundwork for a residential commissioning industry in California, which ultimately will increase the use of commissioning for California houses. In turn, we expect that the application of commissioning by people such as home energy raters, home inspectors, auditors, and weatherization contractors will improve or even optimize residential energy and indoor environmental performance, and will improve the energy cost/value of electricity for the state.

Project Objectives. The specific technical objectives for this project were to:

1. Define, assess, and articulate **metrics and diagnostics** ("yardsticks" and measurement techniques) for residential commissioning, with a focus on delineating them based upon their accuracy and usability in the field.
2. Provide information on the **potential benefits** of commissioning California houses using a whole-house approach, which recognizes that a house is a system of interacting components.
3. Develop programmatic **guidelines** for commissioning new and existing California houses.
4. Conduct **outreach efforts** to transfer project results, such as the residential commissioning guidelines, to industry stakeholders who will use the results of the work in program, code, standard, and technology development.

Project Outcomes: Based on the project objectives, the project has four primary outcomes:

Metrics & Diagnostics. We identified and described metrics for use in residential commissioning, along with a consolidated set of 24 practical diagnostics that the building industry can use now to evaluate them (Wray et al. 2002a). This set focuses on areas of particular concern where there are significant component and system interactions: envelope insulation quality, windows, airtightness, envelope moisture, HVAC fan and duct system airflows, duct leakage, cooling equipment charge, and combustion appliance backdrafting with spillage. We expect that a trained crew will need from 4 to 6 person-hours to commission a house, excluding any corrective adjustments and retrofits to the building and its systems. Most tests can be performed using an equipment package priced toward the lower end of the $6,000 and $15,000 equipment cost spectrum.

Potential Benefits. Simulations by Matson et al. (2002) of a set of hypothetical California houses indicate that the potential benefits from applying whole-house commissioning range from almost nothing in some well-engineered advanced new houses to substantial

savings in poorly-performing existing houses: as much as 70 to 80% savings in HVAC electricity and natural gas consumption, HVAC operating costs, and total HVAC fuel-related carbon emissions. Potential savings for typical houses are about 1/3 to 1/2 of the savings in the poorly performing houses.

In addition to these quantitative benefits, there is a broad spectrum of potential long-term qualitative benefits. Significant ones include more satisfied consumers, reduced callbacks and warranty costs for builders, improved abilities to enforce existing and future energy codes, greater confidence in predicting energy use, and greater assurance that energy efficiency reductions will actually occur.

Guidelines. We have produced a set of guidelines for developing a residential commissioning program that could be integrated with other building industry processes to achieve the benefits that we have identified. These guidelines provide specific recommendations about: how to structure the commissioning process, which diagnostics to use for each house component, and how to use them in a whole-house approach to commission new and existing houses. The guidelines are attached as Appendix I.

Outreach. Apart from our information dissemination to Project Advisory Committee (PAC) members and CEC staff over the course of the project, there have been substantial other activities to transfer project results to the building industry. Examples include: workshops to discuss the guidelines; presenting papers on residential commissioning topics; participating in related industry focus groups and standards development activities; and preparing a website (http://commissioning.lbl.gov/).

Conclusions. The primary outcomes from this project are the development of programmatic guidelines for residential commissioning and the analytical confirmation that there are significant potential benefits associated with commissioning California houses, particularly existing ones. In addition, we have made substantial advances in understanding the accuracy and usability of diagnostics for commissioning houses. In some cases, we have been able to work with equipment manufacturers to improve these aspects of their diagnostic tools. These outcomes provide a solid foundation on which to build a residential commissioning program in California. A concerted effort will be necessary to integrate such a program with existing building industry efforts and to demonstrate its use in the field, such that residential commissioning can ultimately improve house performance for consumers and the energy cost/value of electricity for the state.

Recommendations. Based on the project findings, our recommendations for further work are:

- Develop a practical diagnostic to evaluate the in-situ thermal conductance of envelope assemblies.
- Develop formal standards for assessing water damage and measuring the moisture content in building assemblies; for calibrating and using airflow diagnostic tools, such as those used to measure distribution system airflows at grilles or through the air-handler; and for superheat and subcooling tests of cooling equipment.
- Develop a method of assessing refrigerant charge in cool weather, and examine the utility of temporarily elevating indoor enthalpy in hot, dry weather, in order to extend the periods when the superheat method can be used to test cooling equipment.
- Assess the impact of wind effects, as well as envelope and duct leakage, on the accuracy and repeatability of duct leakage tests, including the new DeltaQ test. Related work is

currently underway with funding from the U.S. Department of Energy and would benefit from co-funding by the CEC.

- Further assess the accuracy and repeatability of methods that determine the potential for backdrafting and combustion gas spillage.
- Develop a simple and reliable test for furnace heat exchanger leakage. The norm for the current tracer gas test is poorly defined and may be unreliable for defining acceptable leakage levels of combustion gas products.
- Carry out field demonstrations to confirm that the benefits we have identified can be achieved by applying whole-house commissioning to new and existing California houses.
- Develop and implement a whole-house residential commissioning program for California that is integrated as much as possible with existing building industry processes.
- Continue collaborative work with the U.S. Department of Energy, industry organizations, and the private sector to transfer information to the building industry.

Benefits to California. We have identified several benefits that result directly from this study or that will accrue over time as necessary information and infrastructure develops further:

Electricity and gas consumption benefits. A principal benefit from commissioning houses is significant energy savings. For poorly-performing existing houses, we estimate that commissioning could achieve as much as 70 to 80% savings in HVAC electricity and natural gas consumption and HVAC operating costs; potential savings for typical houses are much less, but still significant (about 1/3 to 1/2 of these savings). It is difficult to extrapolate these savings over the entire state at this time, because the distribution of houses with problems is poorly defined. As the practice of commissioning grows, this activity will provide a statistical dataset that can be used to make such estimates.

Carbon emission benefits. Another significant benefit from residential commissioning is carbon emission savings resulting from reduced electricity and gas consumption. For poorly-performing existing houses, we estimate that commissioning could achieve as much as 80% reductions in total HVAC fuel-related carbon emissions. Like the energy savings described above, the potential carbon emission savings for typical houses are about 1/3 to 1/2 of the savings for the poorly-performing houses.

Durability, maintenance, and material replacement benefits. Through commissioning, we expect that the durability of building components will be improved and maintenance and material replacement activities and costs will be reduced. This translates into reduced use of natural resources and correspondingly, a lower embodied energy (the amount of energy required for manufacturing, construction, and deconstruction and waste reduction and decay) over the lifetime of the house.

Thermal comfort and indoor air quality benefits. Commissioning to reduce uncontrolled air infiltration, to provide appropriate ventilation capacity, and to achieve more consistent surface temperatures through better-installed insulation can help reduce moisture and comfort problems. It will also help ensure that the HVAC systems can deliver the expected amount of space conditioning capacity.

Economic benefits. The economy is a direct benefactor of the building improvements implemented in residential commissioning. Commissioning contributes to reduced energy

costs, which frees up increased funds for other purposes; expanded business opportunities; the development of new industries; increased jobs for California residents; and increased tax revenues.

Abstract

Currently, houses do not perform optimally or even as many codes and forecasts predict, largely because they are field assembled and there is no consistent process to identify deficiencies or to correct them. Solving this problem requires field performance evaluations using appropriate and agreed upon procedures in the form of a new process called residential commissioning. The purpose of this project is to develop and document these procedures and to demonstrate the value that applying them could provide in both new and existing California houses. This project has four specific objectives: to develop metrics and diagnostics for assessing house performance, to provide information on the potential benefits of commissioning using a whole-house approach, to develop programmatic guidelines for commissioning, and to conduct outreach efforts to transfer project results to industry stakeholders. The primary outcomes from this project are the development of residential commissioning guidelines and the analytical confirmation that there are significant potential benefits associated with commissioning California houses, particularly existing ones. In addition, we have made substantial advances in understanding the accuracy and usability of diagnostics for commissioning houses. In some cases, we have been able to work with equipment manufacturers to improve these aspects of their diagnostic tools. These outcomes provide a solid foundation on which to build a residential commissioning program in California. We expect that a concerted effort will be necessary to integrate such a program with existing building industry efforts and to demonstrate its use in the field.

Keywords: Buildings, HVAC, energy, metrics, diagnostics, commissioning, retrofits, benefits

1.0 Introduction

1.1 Background

California has one of the most advanced energy codes in the United States: Title 24 (CEC 1998). In spite of this, California houses still do not perform optimally, or even as many forecasts predict based on expectations of this code.

For example, Walker et al. (1998) found large variations in duct leakage of California houses, even between side-by-side houses with the same system design and installation crew. This has resulted in as much as factor of two variations in thermal distribution system efficiency for these houses. This and other studies (e.g., Jump et al. 1996) indicate that duct leakage testing and sealing can readily improve thermal distribution system efficiency and achieve a 25 to 30% reduction in installed cooling capacity and energy consumption.

As another example, consider that for at least 20 years the building industry has recognized the substantial impact of envelope airtightness on thermal loads, energy use, comfort, and indoor air quality. However, Walker et al. (1998) found 50% variances in airtightness for California houses with the same design and construction crews, within the same subdivision.

A substantial reason for these problems is that few houses are now built or retrofitted using formal design procedures, most are field assembled from a large number of components, and there is no consistent process to identify related energy and non-energy problems or to correct them. Solving the problems requires field performance evaluations of new and existing houses using appropriate and agreed upon procedures. Many procedural elements already exist in a fragmented environment; some are ready now to integrate into a new process called residential commissioning (Wray et al. 2000). California's Title 24 energy code already provides some commissioning elements for evaluating the energy performance of new houses.

The overall goal of this project is to develop and document residential commissioning procedures and to demonstrate the value that applying these procedures could provide in both new and existing houses. We expect that this new information will lay the groundwork for a residential commissioning industry in California, which ultimately will increase the use of commissioning for California houses. In turn, we expect that the application of commissioning by people such as home energy raters, home inspectors, auditors, and weatherization contractors will improve or even optimize residential energy and indoor environmental performance, and will contribute to improving the energy cost/value of electricity for the state.

This project contributes to the PIER program objective of improving the energy cost and value of California's electricity in three ways. One is by evaluating methods and developing guidelines for reliably identifying and correcting performance problems associated with deficiencies in interacting house components and systems. A second is to eliminate a barrier to performing residential commissioning by providing information on the value of performing residential commissioning services in California houses. A third is by conducting outreach activities to make building industry stakeholders aware of this newly developed information. We expect that the knowledge gained from this research will ultimately be used to develop a robust residential commissioning program in California that is integrated with existing building industry efforts and that can then be used to confirm the value of commissioning through field demonstrations.

1.2 Project Objectives

The specific technical objectives for this project are to:

1. Define, assess, and articulate metrics and diagnostics ("yardsticks" and measurement techniques) for residential commissioning, with a focus on delineating them based upon their accuracy and usability in the field.
2. Provide information on the potential benefits of commissioning California houses using a whole-house approach, which recognizes that a house is a system of interacting components.
3. Develop programmatic guidelines for commissioning new and existing California houses.
4. Conduct outreach efforts to transfer project results, such as the residential commissioning guidelines, to industry stakeholders who will use the results of the work in program, code, standard, and technology development.

1.3 Report Organization

This report presents our findings and recommendations that have resulted from investigating the practicality and value of commissioning residential buildings. Most of the work focuses on commissioning the energy performance of energy-related building components and systems rather than on indoor air quality and thermal comfort impacts, because energy-related diagnostics are currently much better developed for use in a process like residential commissioning.

In **Section 2 Project Approach**, we discuss the tasks that we undertook and our approach to the research to accomplish our objectives. In particular, we discuss changes to the field-testing procedures that we undertook and the need for diagnostic tool evaluations in those tests.

In **Section 3 Project Outcomes**, we present the key results from our investigations.

In **Section 4 Conclusions and Recommendations**, we present what we learned from the research and what we recommend for future activities.

Following the **Glossary** and **References**, there are three technical **Appendices**:

> "**Appendix I**. Guidelines for Residential Commissioning" provides a guide for industry stakeholders who are interested in developing whole-house residential commissioning programs. These stakeholders include managers of government and utility energy-efficiency programs, representatives of home performance contractor and home energy rater organizations, representatives of builder associations, executives of home inspection and quality home companies, and code official representatives.
>
> Until a program exists that requires specific aspects of commissioning, it is premature to include step-by step procedures in a comprehensive commissioning guide. As a result, this guide is not a test procedure, design, construction, installation specification, home inspection, operation and maintenance, or retrofit/repair manual. Many documents targeted specifically to individual areas in this list already exist, and this guide points to such existing references where appropriate. Even after the building industry develops and implements a commissioning program, it is probably better to leave such details to

these documents, which experts in each specific area can update over time within focused consensus processes that are coordinated with each other.

"**Appendix II**. Example Audit and Diagnostic Process" provides a flow chart to illustrate a possible sequence for carrying out tasks in the initial audit and diagnostic phase of the residential commissioning process. Supporting text in a table summarizes the commissioning tasks by describing what each task does, what test protocols could be used, what equipment is needed, how long each task takes, and the potential energy savings associated with carrying out each task.

"**Appendix III**. Example Commissioning Report" provides a sample report that could be used to document the audit and diagnostic findings from commissioning a house. The data included in the report are for an actual house in Concord, California, which has been retrofitted recently as part of a DOE demonstration of residential commissioning.

2.0 Project Approach

To achieve the project goals and objectives, the original project plan divided technical tasks into three groups that addressed multiple project objectives in some cases:

- Develop a commissioning process, metrics, and diagnostic approaches to evaluate and improve the energy and non-energy performance of new and existing California houses. A review of literature related to building commissioning was expected to provide information that could be used to select appropriate metrics and diagnostics. Where necessary, we anticipated that some adaptation or minor development of existing diagnostics might be needed to make them more practical for use in residential commissioning.
- Carry out a potentials study to assess the utility and accuracy of the selected metrics and diagnostics in field applications of the commissioning process and quantify the energy savings associated with using the recommended commissioning process. The first part of this effort was to involve field tests of the diagnostics to confirm that the commissioning process we recommended was practical and robust. The second part was to involve computer simulations that demonstrate the potential benefits of carrying out commissioning on various types of hypothetical houses located in various California climates.
- Prepare residential commissioning guidelines to describe the process and the metrics and diagnostics, and to provide guidance on when and how to use the diagnostics. In addition, to obtain feedback and fine-tune the guidelines, conduct outreach activities through workshops for the residential building industry in California.

As in any research effort, the results along the way also shaped the work. Based on input from the PAC and the PIER Buildings Program team, the project evolved. Changes included:

- Our focus shifted away from non-energy-related indoor air quality (IAQ) and thermal comfort diagnostics. At the conclusion of our literature review, it was clear that many well-developed diagnostics are already available to determine non-energy-related metrics. However, they tend to be complex, time consuming, and require expensive equipment or analyses and well-trained diagnosticians. Without selecting an appropriate diagnostic to target specific concerns or dissatisfaction of occupants, the cost of attempting to address the apparent myriad of possible comfort and IAQ problems is prohibitive. As a result, most diagnostics to assess IAQ and comfort tend to be impractical for residential commissioning at this time.
- Cofunding by the U.S. Department of Energy, as well as related efforts in projects for the California Institute for Energy Efficiency (CIEE) and Pacific Gas and Electric, allowed us to carry out more thorough tests of energy-related diagnostics in the laboratory and field, and to develop a better understanding of the accuracy and usability of these diagnostics (Wray et al. 2002a). The outcome was that many of these diagnostics (e.g., flow hoods) still needed significant development to be useful within a residential commissioning process.

  Consequently, we focused our field efforts within this project on further understanding and improving the accuracy and usability of the diagnostics rather than carrying out case studies of houses where the entire commissioning process might have been applied.

We also carried out more information dissemination than expected so that our findings would be documented in the archival literature.

Three technical appendices and Attachment I (Wray et al. 2000, Matson et al. 2002, and Wray et al. 2002a, see p. 25) describe our research efforts in detail.

3.0 Project Outcomes

This section presents the key results from our investigations, in the same order as the objectives.

Objective #1: Define, assess, and articulate metrics and diagnostics ("yardsticks" and measurement techniques) for residential commissioning, with a focus on delineating them based upon their accuracy and usability in the field.

> **Metrics & Diagnostics.** We identified and described metrics for use in residential commissioning, along with a consolidated set of 24 practical diagnostics that the building industry can use now to evaluate them (Wray et al. 2002a). This set focuses on existing diagnostics in areas of particular concern where there are significant component and system interactions: envelope insulation quality, windows, airtightness, envelope moisture, HVAC fan and duct system airflows, duct leakage, cooling equipment charge, and combustion appliance backdrafting with spillage.
>
> This assessment of metrics and diagnostics is based upon our recent literature review and annotated bibliography for this project (Wray et al. 2000), which facilitates access to 469 documents related to residential commissioning that have been published over the past 20 years. It is also based upon recent laboratory work and field studies in more than 100 houses by LBNL staff and others to evaluate the accuracy and usability of diagnostics. These studies concentrated on evaluating diagnostics in the following four areas: the DeltaQ duct leakage test, air-handler airflow tests, supply and return grille airflow tests, and refrigerant charge tests
>
> Individual equipment costs for the 24 practical diagnostics range from a few hundred dollars to many thousands of dollars; total equipment costs are expected to be between $6,000 and $15,000. The higher costs are associated with infrared thermography and state-of-the-art automated diagnostic systems. Most tests can be performed in one hour or less, using equipment priced toward the lower end of the cost spectrum. We expect that a trained crew will need from 4 to 6 person-hours to commission a house, excluding any corrective adjustments and retrofits to the building and its systems.
>
> The equipment prices listed here are based on data provided by manufacturers and distributors as of April 2001. These prices may change in the future as residential commissioning activities increase. Note that the total price for a diagnostic toolkit to carry out all tests is not the sum of each cost listed. In many cases, the equipment from one diagnostic can be used for other diagnostics, often with only slight modifications. An example is the envelope airtightness test and DeltaQ duct leakage test, where both tests use the same equipment (the DeltaQ test uses a blower door and a pressure measurement device to simultaneously determine envelope airtightness and duct leakage). Another example is using a fan-assisted flow meter to determine air-handler airflow and a fan-assisted flow hood to determine duct airflows. Both devices use a fan-assisted flow meter; the latter also has a flow capture hood.

Objective #2: Provide information on the potential benefits of commissioning California houses using a whole-house approach, which recognizes that a house is a system of interacting components.

> **Potential Benefits**. Based on simulations by Matson et al. (2002) of a set of hypothetical California houses, commissioning can result in better performing systems and houses. In turn, this will result in more efficient use of energy, carbon emission reductions, and improved occupant comfort. In particular, on the spot adjustments to houses ("tuning

and tweaking") can save a significant amount of HVAC-related energy (15 to 30% in existing houses, 10 to 20% in new conventional houses, and up to 8% in advanced energy efficiency houses). The process that we considered includes corrective measures that could be implemented together during construction or during a single site visit (e.g., air tightening, duct sealing, and refrigerant and air handler airflow corrections in a new or existing house). Taking advantage of additional, more complex opportunities (e.g., installing new windows in an existing house, replacing the heating and air conditioning system in a new or existing house) can result in additional HVAC-related energy savings (60 to 75% in existing houses, and 50 to 60% in new conventional houses).

Consequently, the potential benefits from applying whole-house commissioning range from almost nothing in some well-engineered advanced new houses to substantial savings in poorly-performing existing houses: as much as 80% savings in HVAC electricity consumption, 70% savings in HVAC natural gas consumption, 70% HVAC operating cost savings, and 80% reductions in total HVAC fuel-related carbon emissions. For typical houses, the potential savings are only about 1/3 to 1/2 of the savings in the poorly performing houses, because the typical houses have fewer opportunities for change. Field demonstrations are needed to confirm that these benefits can be achieved by applying whole-house commissioning to new and existing California houses.

The commissioning-related system and house performance improvements and energy savings translate to additional benefits throughout California and beyond. By applying commissioning principles to their work, the building community (builders and contractors) benefit from reduced callbacks and lower warranty costs. Home energy raters and home inspectors will have access to an expanded market sector. As the commissioning process rectifies construction defects and code problems, building code officials benefit from better compliance with codes. The utilities benefit from reduced peak demand, which can translate into lower energy acquisition costs. As houses perform closer to expectations, governmental bodies (e.g., the California Energy Commission and the Air Resources Board) benefit from greater assurance that actual energy consumption and carbon emissions are closer to the levels mandated in codes and standards, resulting in better achievement of state energy conservation and environmental goals. California residents' quality of life is improved through better indoor environmental comfort and lower energy bills. Lower energy bills free up money for residents to spend on other needs or goals, such as additional education and health and welfare. With an expansion of existing industries and the development of new commissioning-related industries, related jobs and tax revenues will increase, further increasing the quality of life for California.

Objective #3: Develop programmatic guidelines for commissioning new and existing California houses.

Guidelines. We have produced a set of guidelines (Appendix I) for developing a residential commissioning program that can be integrated with other building industry processes to achieve the benefits that we have identified. The guidelines contain three sections. The first section provides an overview of why commissioning is needed and why looking at the house as a system rather than as isolated components is an important element of commissioning. It then describes the characteristic elements of commissioning and how we envision the process would work. This section concludes with a discussion of cost barriers to commissioning and who might do the work.

The second section of the guide discusses the application of commissioning to new and existing houses. For each of these house types, we provide an example to illustrate whole-house commissioning and its benefits. In each example, we first describe the pre-commissioning state of the house, as could be defined by diagnostic testing. We then describe simple tuning and tweaking improvements to the houses, and then opportunities for further but more complex improvements, with the intent that all the changes could be verified using diagnostic tests.

We have subdivided the third section of the guide into four subsections, each of which discusses the commissioning of a specific house component: the building envelope, air distribution systems, cooling equipment, and combustion appliances. For each component, the relevant subsection discusses what is being commissioned, why testing is needed, applicable metrics, what tests are recommended, and how to choose a particular test from the recommended set. For each test, it also describes equipment needs, their relative cost, and their accuracy (as appropriate and where information is available). The subsection for each component ends with a list of available procedural references that the reader can consult for further information.

In terms of who should do the commissioning, it is important to note that there are several active new construction and home retrofit energy-efficiency programs within California, but few people are currently qualified to commission houses on a whole-house basis (Knight and Thomas 2000, Wirtshafter Associates 2000). Perhaps the best qualified at this time are home energy raters and building performance contractors, who typically have more building science training and a better understanding of the house-as-a-system concept than any other group. If these independent parties are used to commission houses, we envision that builders and perhaps subcontractors may still carry out some commissioning themselves throughout the construction process in preparation for the independent commissioning. However, careful integration of the building team and independent party commissioning with the construction process is important to avoid scheduling conflicts and unnecessary cost. Involving independent parties in the construction process has been problematic in the past (Pacific Consulting Services 2000). For whole-house residential commissioning programs to succeed, training, certification, accreditation, and commissioning management processes need to be developed and widely used. We anticipate that involving state agencies and building industry associations in the development of such processes is key.

Objective #4: Conduct outreach efforts to transfer project results, such as the residential commissioning guidelines, to industry stakeholders who will use the results of the work in program, code, standard, and technology development.

Outreach. Apart from our information dissemination to Project Advisory Committee (PAC) members and CEC staff at four technical review meetings over the course of the project, there have been substantial other activities to transfer project results to the building industry. Examples of these activities include:

- hosting a guidelines scoping workshop entitled "Defragmenting Your House: Guides for Residential Commissioning" at the ACEEE 2000 meeting (the objective of this workshop was to summarize work to date and to obtain industry input on a format for the commissioning guide, its technical level, and how commissioning can be integrated into existing building industry processes);

- presenting the draft guidelines to invited building industry stakeholders at a workshop to obtain feedback;
- presenting various papers on the concept of residential commissioning and on the accuracy and usability of diagnostic equipment (Wray and Sherman 2001; Walker et al. 2001; Siegel and Wray 2002; Wray et al. 2002b);
- participating in industry focus groups and standards development related to building commissioning (For example, the "Leadership in Energy and Environmental Design - Residential" (LEED-R) Green Building Rating System is being developed by the United States Green Building Council (USGBC). We have been participating in the development of this rating system to incorporate residential commissioning. In particular, we have submitted comments regarding suggested changes to elements of the draft LEED-R document related to performance verification. The revised draft document has incorporated most of our comments.);
- discussions with diagnostic equipment manufacturers about changes needed to improve accuracy and usability (some manufacturers have expressed a continued interest about participating in laboratory and field tests to further evaluate measurement techniques, with a view toward developing improved technologies for residential commissioning); and
- preparing a residential commissioning website hosted by LBNL (http://commissioning.lbl.gov/).

4.0 Conclusions and Recommendations

4.1 Conclusions

The primary outcomes from this project are the development of programmatic guidelines for residential commissioning and the analytical confirmation that there are significant potential benefits associated with commissioning California houses, particularly existing ones. In addition, we have made substantial advances in understanding the accuracy and usability of diagnostics for commissioning houses. In some cases, we have been able to work with equipment manufacturers to improve these aspects of their diagnostic tools. These outcomes provide a solid foundation on which to build a residential commissioning program in California. A concerted effort will be necessary to integrate such a program with existing building industry efforts and to demonstrate its use in the field, such that residential commissioning can ultimately improve house performance for consumers and the energy cost/value of electricity for the state.

4.2 Commercialization Potential

The output of this project is new knowledge about how to evaluate the energy performance of houses, about the usability and accuracy of specific diagnostic technologies both old and new, and about the value of applying commissioning to California houses. Apart from proposing a commissioning process, this project does not develop a particular technology, but it does provide a blueprint for the nascent commissioning industry that will improve end-use energy efficiency and will further develop improved diagnostic technologies.

In the near term, we expect that the results of this project will lower the implementation barriers for technologies and services already known. Our tools and evaluations give users confidence in the performance (or non-performance) of many housing components. In the medium term, we expect to see new kinds of services develop that would use the results of our project to facilitate a new kind of rating, auditing, or commissioning. In the long term, we expect to see innovative replacements for the lower performing equipment installed in the housing stock and more care taken in correct installation (and operation and maintenance) of envelope and HVAC systems. Industrialized construction, smart envelopes, and whole-building control may all factor into these designs.

We expect that commissioning could be integrated as part of California Title 24, which would potentially allow the energy budget of the integrated design to be increased, while at the same time lowering the actual energy usage of the building. Integrating commissioning with Title 24 will create a new value-added service that also has the indirect effect of lowering the value of products and installations that do not easily perform as expected and raising the value of those that meet or exceed their specifications. Commissioning would allow the market to more properly value different technologies and should have the effect of increasing the market presence/share of the good ones. Steps in this direction have already begun through the incorporation of additional performance testing requirements in the recent AB970 revisions to Title 24.

This project has benefited from over $400k of support from the Building Technologies office at the U.S. Department of Energy. DOE plans to continue supporting work in this area, including continued efforts to develop residential commissioning diagnostics, and best practice guidelines for retrofitting houses to address performance problems.

4.3 Recommendations

Based on our findings, our recommendations for further work are as follows, arranged in the same order as the three objectives:

Objective #1: Define, assess, and articulate metrics and diagnostics ("yardsticks" and measurement techniques) for residential commissioning, with a focus on delineating them based upon their accuracy and usability in the field.

> **Recommendation #1**: Develop a practical diagnostic to evaluate the in-situ thermal conductance of envelope assemblies.
>
> **Recommendation #2**: Develop formal standards for: assessing water damage and measuring the moisture content in building assemblies; calibrating and using airflow diagnostic tools, such as those used to measure distribution system airflows at grilles or through the air-handler; and superheat and subcooling tests of cooling equipment.
>
> **Recommendation #3**: Develop a method of assessing refrigerant charge in cool weather, and examine the utility of temporarily elevating indoor enthalpy in hot, dry weather, in order to extend the periods when the superheat method can be used to test cooling equipment.
>
> **Recommendation #4**: Assess the impact of wind effects, as well as envelope and duct leakage, on the accuracy and repeatability of duct leakage tests, including the new DeltaQ test. This work is currently underway with funding from the U.S. Department of Energy and would benefit from co-funding by the CEC.
>
> **Recommendation #5**: Further assess the accuracy and repeatability of methods that determine the potential for backdrafting and combustion gas spillage.
>
> **Recommendation #6**: Develop a simple and reliable test for furnace heat exchanger leakage. The norm for the current tracer gas test is poorly defined and may be unreliable for defining acceptable leakage levels of combustion gas products.

Objective #2: Provide information on the potential benefits of commissioning California houses using a whole-house approach, which recognizes that a house is a system of interacting components.

> **Recommendation #7**: Carry out field demonstrations to confirm that the benefits we have identified can be achieved by applying whole-house commissioning to new and existing California houses.

Objective #3: Develop programmatic guidelines for commissioning new and existing California houses.

> **Recommendation #8**: Develop and implement a whole-house residential commissioning program for California that is integrated as much as possible with existing building industry processes.

Objective #4: Conduct outreach efforts to transfer project results, such as the residential commissioning guidelines, to industry stakeholders who will use the results of the work in program, code, standard, and technology development.

> **Recommendation #9**: Continue collaborative work with the U.S. Department of Energy, industry organizations, and the private sector to transfer information to the building industry.

4.4 Benefits to California

We have identified the following benefits that result directly from this study or that will accrue over time as necessary information and infrastructure develops further:

Electricity and gas consumption benefits. One of the principal benefits from commissioning houses is significant energy savings. For poorly-performing existing houses, we estimate that commissioning could achieve as much as 80% savings in HVAC electricity consumption and 70% savings in HVAC natural gas consumption (70% HVAC operating cost savings); potential savings for typical houses are much less, but still significant (about 1/3 to 1/2 of these savings). It is difficult to extrapolate these savings over the entire state at this time, because the distribution of houses with problems remains poorly defined. As the practice of commissioning grows in California, data from such activities will provide a statistical profile that can be used to make such estimates.

Carbon emission benefits. Another significant benefit from residential commissioning is carbon emission savings resulting from reduced electricity and gas consumption. For poorly-performing existing houses, we estimate that commissioning could achieve as much as 80% reductions in total HVAC fuel-related carbon emissions. Like the energy saving described above, the potential carbon emission savings for typical houses are about 1/3 to 1/2 of these savings.

Durability, maintenance, material replacement, and house resale value benefits. Through commissioning, we expect that building envelope and equipment durability will be improved and maintenance and material replacement activities and costs will be reduced. In terms of the environment, this translates into a lower use of natural resources and correspondingly, a lower embodied energy (the amount of energy required for manufacturing, construction, and deconstruction and waste reduction and decay) over the lifetime of the house. Increased energy savings can increase house resale values (Nevin and Watson 1998).

Thermal comfort and indoor air quality benefits. Commissioning to reduce uncontrolled air infiltration, to provide appropriate ventilation capacity, and to achieve more consistent surface temperatures through better-installed insulation can help reduce moisture and comfort problems. It will also help ensure that the HVAC systems can deliver the expected amount of space conditioning capacity.

Economic benefits. The economy, within and beyond the State of California, is a direct benefactor of the building improvements implemented in residential commissioning. Commissioning contributes to reduced energy costs, which frees up increased funds for other purposes; expanded business opportunities; the development of new industries; increased jobs for California residents; and increased tax revenues.

5.0 Glossary

ACEEE	American Council for an Energy-Efficient Economy
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
CEC	California Energy Commission
CIEE	California Institute for Energy Efficiency
DOE	U.S. Department of Energy
HVAC	Heating, ventilating and air conditioning
IAQ	Indoor air quality
LBNL	Lawrence Berkeley National Laboratory
LEED-R	"Leadership in Energy and Environmental Design - Residential" - Green Building Rating System
PAC	Project Advisory Committee
PIER	Public Interest Energy Research
RD&D	Research, Development, and Demonstration
UC	University of California

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List of Attachments

This section lists the attachments to the final report of PIER Project Instrumented Home Energy Rating and Commissioning, Contract Number 500-98-033, conducted by Lawrence Berkeley National Laboratory. These attachments are part of report 500-04-012. To obtain copies of these attachments, or for more information on the PIER Program, please visit www.energy.ca.gov/pier/buildings or contact the Commission's Publications Unit at 916-654-5200.

Report Title	**Publication #**
Instrumented Home Energy Rating and Commissioning Technical Reports • *Residential Commissioning: A Review of Related Literature* • *Practical Diagnostics for Evaluating Residential Commissioning Metrics* • *Potential Benefits of Commissioning California Homes*	P500-04-012-A1

Appendix I. Guidelines for Residential Commissioning

Appendix II. Example Audit and Diagnostic Process

Appendix III. Example Commissioning Report