Energy Research and Development Division

FINAL PROJECT REPORT

Advanced Residential Energy and Behavior Analysis Project

Appendix A – Extended Executive Summary
EXECUTIVE SUMMARY

Introduction

California’s climate change goals call for reductions in energy-related greenhouse gas emissions (GHG) far beyond anything attempted by previous energy efficiency efforts. Achieving these goals requires direct attention to how people actually use energy, in sharp contrast to the traditional emphasis on improving technology in isolation from users. To date, there has been no broad systematic view that captures the importance, complexity, and variability of human energy use behavior. To accomplish deep GHG reductions and address a range of new adaptation and resilience goals, it is critical to shift focus toward energy uses and energy users with a new kind and depth of attention.

The Advanced Residential Energy and Behavior Analysis (AREBA) research project examined the state of knowledge related to California’s household uses of energy and technology. The team asked, “Where are the people?” and “How are they characterized?” in California residential energy policy models, analytic approaches, and databases. The AREBA team also assessed current energy use practices. Based on this information, the team developed new conceptual and applied models that integrated energy users and use behavior with traditional device-centered factors. The models were used to investigate a series of key issues related to contemporary climate change and energy policy concerns. The result is an improved social science-informed and quantitatively grounded view of California residential energy use. The AREBA team’s empirical findings open new possibilities for improved residential energy analysis, more effective energy efficiency and climate change policy development and applications, and better buildings.

Project Purpose

The primary purpose of the AREBA project was to develop a more comprehensive view of California residential energy uses and energy users than is generally found in energy efficiency policies and programs. The more comprehensive view is particularly important in a world facing rapid environmental, technological, and social change, where legacy approaches may not adequately serve new purposes and urgencies.

The research was developed to respond to the needs and interests of California stakeholders, including ratepayers, the Energy Commission and its development plans (including those for EPIC 2014-2017 and PIER Natural Gas Research), utilities, researchers, and others. The main technical objectives of the project were to:

- Assess the current state of knowledge about people in residential energy use, covering models, theories, vocabularies, assumptions, data, and other representations.
- Characterize variability in residential sector energy use, identify patterns and forms of this variability, and demonstrate why and how continued attention to understanding and using this variability is critical for developing deeper policies, programs, and research and for crafting more realistic goals.
• Provide new models, frameworks, and practical recommendations to better account for people in residential energy use, supporting improvement of California forecasting, planning, evaluation, energy models, built infrastructure, and energy technologies.

• Offer empirical illustrations and tests of how these new models, frameworks, and recommendations can be applied to current energy policy problems – particularly the reduction of greenhouse gas emissions and energy use, as well as considering non-energy aspects of energy use, energy efficiency, and climate change policy.

• Support the transition from policies that center on energy efficiency *per se* to those targeting the broader challenges of climate change: very ambitious goals for absolute GHG emissions reductions, as well as the need to explicitly consider dimensions beyond just energy.

**Project Results**

The research was organized into two main phases. First, posing the basic question “Where are the people?”, the project examined conventional models, tools, perspectives, arguments, and protocols for assessing and changing residential energy use in California. The work also highlighted the problems and traditions that have limited attention to people as energy users and conservers in research and policy. Second, the project developed, demonstrated, and applied alternative representations of people and their activities in ways that could substantially improve the results of energy research, programs, and policies. Analysis covered both fundamentals and many of the most current residential energy policy efforts.

The Executive Summary key findings are organized into four central topic areas that parallel the major substantive sections of the report. These are: [1] Laying the Groundwork and Exploring Variability of Demand, [2] Current Policy Landscape, [3] Next Generation Models, and [4] Applied Studies from a New Vantage Point.¹

¹ In order to provide a concise and accessible summary, this structure merges the contents of Parts I and II of the main body of the report. It also brings key points from the conclusions and recommendations chapters (Part VI) into the discussions of each of the substantive topic areas, rather than setting them apart as a separate discussion. For readers interested in the details of analysis, a series of published scientific articles, conference proceedings, presentations, and working papers from the research are included in a separate Appendix document.
Laying the Groundwork and Exploring Variability of Demand

This section of the report provides an orienting perspective and factual foundation for the subsequent reporting of analysis and findings.

A. Setting the Stage (Chapters 1-3)

The opening discussions provide background and context for the research. They consider the basic problem of how to understand people (persons, consumers, customers, households, end-users), in the larger picture of California residential energy demand. These chapters assess how people fit into current policy, efficiency programs, data collection, modeling and analysis, and research practices, and argues that new approaches are needed. Key concepts and terms are defined and placed in historical context. Macro-scale residential energy use patterns in California are presented and important features of energy end-uses, fuels, and trends are discussed.

B. Variability of Energy Use and Energy Users (Chapters 4-5)

A basic challenge to representing people as energy users is accounting for the tremendous amount of variability in energy use. The complexity of the interactions among people and technologies shape energy use across and within households and over time.

Key Findings:

- Energy use is dynamic in the short term. It changes with the seasons and is constantly evolving over time as people, technologies, and environments themselves change. Locations of consumption are dispersed and the uses of energy are diffuse. Segments of the population may behave very differently from one another, and for any particular end-use, a high percentage of total energy consumption may be concentrated in a small group. For example, among natural gas-using California households, the 10 percent most-consumptive households consume nearly one-fourth of residential sector use. For electricity, the top 25 percent most-consumptive households account for nearly 50 percent of residential electricity use.

- In addition to the variability of total energy consumption, details of how this energy is used, as well as energy savings potential — opportunities, ability, and willingness to reduce energy consumption — vary widely across the population. In general there is very large savings potential for some households, while for others, programs, policies, and more efficient technologies may offer little or no savings benefits.

- Energy use variability has consequences for energy systems, but it has largely been ignored in most energy efficiency analyses, other than those oriented to peak electricity demand. Instead, people are generally represented by assumed average or typical behaviors. This has led to a tendency to assume that there really are average users, to design policies for these averages, and to ignore contrary evidence. Large savings potentials may remain overlooked because consumption and savings estimates based on assumed averages may be quite wrong.
• Data on household energy use are difficult to collect at sufficient granularity to enable precise policy and technology design. These data require careful analysis beyond what is normally done, and rarely support simple cause and effect interpretations of the relationships between technology and energy consumption.

Recommendations:
• Invest in improved data collection and methods. Develop new methods to identify and leverage real-world variability in energy use. Better knowledge about variability will improve modeling and analysis of energy use and conservation. The investment will lead to more successful policy, program, and technology design. Specific policy examples are provided in the report.

• Support critically needed research on how energy policies, technologies, and homes are working in practice. Improved understanding of real-world behavior, and the limitations and failures of seemingly reasonable assumptions and schemes in current use, is vital for updating energy efficiency policy to serve climate change goals and the diversity of modern California.

• Adopt a broader policy perspective that considers dimensions of energy and buildings beyond simply “energy input” and “services output,” and better accommodates the many different ways that there are of inhabiting homes. Embracing variety and variability in energy use and energy use practices opens the door to better recognizing and accommodating a broader set of “degrees of freedom” in energy use, and to identifying and encouraging practices that lead to more sustainable energy use. This both brings people front and center into the policy equation and helps shift the focus from energy efficiency per se to the policy goals and environmental challenges of climate change.


This section of the report considers how people and energy are formally characterized in current policy analysis and policy discussions. Identified are key issues in measurement, data quality, and data access that affect the practice, quality, and results of policymaking.

A. Models and Legacies: California’s Ecosystem of Models (Chapters 6, 9)
Models—from the conceptual/mental models to the formal policy models—offer tools to examine the world and analyze its workings, while they also constrain understanding. Models are powerful lenses, as well as blinders that can make it difficult to think about and understand new or different relationships between factors, variables, and possible outcomes. The answer to the question “Where are the people?” in these models has tended to result from the complex policy processes and organizational networks that have created the models and put them to use to help address policy problems. However as policy processes, organizational networks, and aspirations reach further, these limitations are ripe for reconsideration.
California energy policy and planning draw on a set of well-developed legacy models, data sources, and routines. The Energy Commission’s California energy forecast model, for example, is among the most sophisticated anywhere. The research team examined the ability of California’s “ecosystem of models” to accommodate improved representations of people in energy use. The team provided an overview of the current state of affairs and recommendations for developing improvements to the modeling that supports California energy policies.

Key Findings:

- As a first step, the research team created a detailed map of many of the applied models, intermediate models and analyses, source data, and relationships among these components at play in California energy policy. This map provides a solid basis for understanding current modeling processes and organizational and institutional relationships, and for considering improvements that can both serve and encourage changes in policy, energy use, data availability, analytical capabilities, and knowledge.

- Current models, which were originally developed for a variety of limited purposes, provide partial views not necessarily adapted to contemporary problems or evidence. They may do some things quite well, but they are also sometimes stretched beyond their limits in terms of how output is interpreted and used and to which situations they apply. There is relatively little ability to recognize what is misleading or what is being missed in these situations. Instead, outputs may often be accepted at face value. Though these outputs have effects (e.g., on utility programs), the research team also notes that modeling results are not necessarily closely linked to policy deliberations given real-world political and institutional factors.

- Current energy analysis and modeling largely excludes people and behavior and in this sense does not necessarily sync with reality. Modeling is shaped by well-developed regulatory logics and organizational arrangements, intentionally and unintentionally limiting consideration of people and behavior. Derived from a technology-centered paradigm, the models’ fundamental assumptions are not critically examined, and bypass important questions, such as how well assumptions about use reflect reality.

- Statistical models routinely relied upon in energy analysis to support policy decisions are chronically plagued by large errors. Along with uncertainties in measurement, and the dynamism of the underlying phenomena, the techniques in common use limit how much can be known about energy use (and how it varies and changes) with much confidence. The technical sophistication of the work renders it opaque to non-specialists and often shields methods, assumptions, and results from close scrutiny.

Recommendations:

- Improve models to better inform policy. To reach climate change policy goals, the energy efficiency industry should strive for better modeling, acknowledgement of uncertainties, and an improved ability to identify risks and to cope with the
unknowability of how the future will develop. Models can be improved by bringing in new source data, adding new models or new intermediate analyses, adding perspectives from other disciplines, and linking models in new or different ways – along with reviewing and reconsidering the various purposes and consequences of those models. At the same time, it will be necessary to develop a better understanding of how research and modeling affect planning and policies, as well as how they do not.

- Pursue a more detailed understanding of real-world residential energy use as a foundation for improved modeling. This would include better data on household energy use behaviors (accompanied by metered energy use data), explicit strategies to accommodate energy demand variety and variability (such as through analysis that tests performance under a variety of conditions), improved acquisition and application of qualitative data, and a better understanding of how people think about, learn about, and co-evolve with technological and other changes with respect to home energy use.

- Adopt stress tests of analytic methods used for model inputs (e.g., Conditional Demand Analysis or CDA) to determine their sensitivities to assumptions about behavioral variation and change. Include assessment of overall model performance under a variety of changing social and environmental conditions.

- Evaluate the ability of conventional models to address climate change uncertainties. Invest in developing models with better capacities to generate and compare scenarios and outcomes that include people, variability, and dynamic interactions. Assess how well current demand modeling approaches support the need to understand and predict uncertain change in large-scale systems under new stresses from climate change. This work can be conducted in coordination with climate change and GHG emissions scenario modeling work, such as that currently being conducted at the Energy Commission.

- Launch a research initiative to create a “simulation sandbox” in which Energy Commission staff, staff from other state agencies, academic researchers, and others can examine hypothetical effects and interactions of various technological and social factors and risks together. Even with uncertainty about variables, inputs, and relationships, this analytic approach would help thinking about all factors involved. It can also give some guidance to policy deliberations, as California and the Energy Commission enter uncharted waters related to changes in climate, technology, and society. This effort could also address detailed data needs and possible repairs to stumbling blocks and gaps in current processes.

**B. What and How You Measure Matters a Lot (Chapter 7)**

Planning, research, and regulatory energy analyses use a variety of statistical methods, analytical assumptions, and metrics to express and compare energy consumption. The AREBA team reviewed common methods and metrics, focusing on key statistical techniques, e.g., for end-use specific Unit Energy Consumption (UEC) estimates (annual energy use per unit of
energy-using device or energy end-use, generally averaged over a group of households) and weather normalization.

Key Findings:

- “Standard” estimates of Unit Energy Consumption for California residential energy uses can vary greatly. For example, differences between the 2003 and 2009 California Residential Appliance Saturation Survey (RASS) average UEC estimates exceed 30 percent for natural gas space heating, electric heating, and electric cooling – which is more than seems plausible for the short time period between the two sampling points. There is also very little end-use metering data available to help validate statistically derived UEC estimates.

- The Conditional Demand Analysis (CDA) statistical method that is commonly used to produce Unit Energy Consumption end-use estimates for various appliances and systems is based on survey, billing, and weather data. CDA has a number of statistical weaknesses. Furthermore, unmeasured social and behavioral characteristics of energy use mean that UECs can be misleading for individual households.

- Evaluation protocols use billing analysis methods that separate electric and gas bills into weather and non-weather driven components. Codified “weather-adjustment” methods use fairly simple statistical processes. But the methods fail to jointly consider Heating Degree Days and Cooling Degree Days, which could improve the accuracy of estimates for weather-sensitive energy uses. Also buried in conventional weather-adjustment techniques are energy user responses to weather conditions that have not been systematically considered.

- The building stocks, appliance saturations, and UECs used in modeling are point estimates. On their own, they do not take variability and uncertainty into account. The use of summary measures is unavoidable, but their fictive character is rarely acknowledged. Rather such estimates of central tendency are often treated as real representations of individual technologies and behaviors, without considering variability, uncertainty, or the foundational assumptions under which the original estimates were constructed, which may often not hold true in real situations.

- Planning, research, and regulatory energy analyses use a variety of metrics to express and compare energy consumption. These metrics are often accepted at face value. The AREBA team reviewed general characteristics of common metrics, focusing on the information they contain and omit, especially as to how people and social values are (and are not) reflected in those metrics.

- The metrics commonly used to express energy use and energy efficiency (such as energy use per square foot) influence interpretations, conclusions, and directions in policy, research, and technology development. Using different metrics can lead to very different policy choices or directions. The underlying dynamics of demand are often subsumed within coarse physical variables, such as amount of floor space in a residence, or (in the
best case) numbers of bodies in a dwelling. Although a very wide variety of persons, activities, and spatial configurations may contribute to energy demands, they are invisible by definition because of the metrics chosen. This, in turn, reinforces overly narrow frames for problem definition and provides limited information on which to base solutions. In some cases, solutions based on such framing could even encourage higher demand.

• The research team compared two possible ways to measure a home’s energy efficiency as operated, energy use per square foot, and energy use per person, using the California RASS data. The second metric incorporates people explicitly, while the first does not. The correlation between these two metrics was low. This contrast hints at a number of higher-level questions about residential energy use that are outside the normal realm of energy efficiency, e.g., the nature of homes, framing expectations about comfort, and what is meant by “efficiency.”

• Focusing too narrowly on improving technological efficiency (the target of most metrics), rather than overall energy savings, could result in higher consumption—working counter to the formal policy goals of reducing energy use and emissions.

Recommendations:

• Be more explicit about accounting for and expressing uncertainties. For example, develop forecasting models with practical ways to express uncertainty in UECs and other estimates. While expressing uncertainty is difficult, progress here can help identify policy risks as well as research and evaluation needs. This will also require new debates about and practices for reacting to uncertainty, once it is acknowledged.

• Promote statistical collaborations that help improve legacy analytical approaches. For example, by working together, commission staff and academic researchers could improve Conditional Demand Analysis (e.g., using Ridge, LASSO, and Liu estimators) to produce UECs through the application of advanced modeling/statistical techniques that are widely published in the scientific literatures but have not been implemented in policy and research practice.

• Improve the use of weather data in assessing energy use. Jointly considering Heating Degree Days and Cooling Degree Days, for instance, would provide a more accurate analysis of energy end-use and of relationships between energy use and weather patterns. Behavioral interactions with weather conditions and technologies (e.g., thermostat management practices) should also be included to provide more realistic and complete representations of dynamism in weather effects.

• Use multiple metrics to improve how energy use is characterized. When defining and assessing energy use and energy efficiency, using of multiple metrics would help avoid
overly narrow perspectives on what is “efficient” or desirable. The metrics in use should also be scrutinized for what important aspects of “the problem” that they do not capture (e.g., total energy use in the case of intensity metrics, such as energy use per floor area), for possible missed assumptions, unintended consequences, and overlooked elements in complex systems, and for how well the values that are buried in quantitative expressions capture policy intents.

C. The Information You Have (and Don’t Have) Matters (Chapter 8)

The types of answers that can be generated to support energy efficiency policy depend on how problems are defined, what data are or can be collected, and the kinds of evidence or arguments that are considered scientifically defensible. High-quality research on residential energy consumption relies fundamentally on high-quality data that combine building, technology, behavior/practice/lifestyle, energy use, and environmental information. Without the application of these data, model-based representations can be quite wrong – overlooking the differences between assumed and actual conditions, assumed and actual technological performance, assumed and actual behaviors, and the interactions and feedbacks among conditions, technologies, and people.

Key Findings:

- A household’s energy use is not primarily a stable physical system with fairly fixed demands, but rather the result of an evolving set of social practices, things, and conditions. So all analysis with these data (including technology-centered analysis) turns out to be “back-of-the-envelope” analysis. These uncertainties are rarely acknowledged. If people are not adequately integrated into data collection schemes and analytical conventions, then they will remain relatively invisible, and seen as relatively passive energy “end users.”

- Research projects, including the one reported here, often encounter the problem that some already-collected data cannot be made available by utilities or government agencies. Even where provisions for sharing data with researchers exist, there are often problems in execution. There is confusion about access to utility data and access to utility customers for voluntary survey data collection. When data can be accessed, they frequently come with legal limitations that prevent collection of additional data from the same households to fill in gaps. Until policy uncertainty (around data access, customer privacy, and the proprietary vs. public status of billing data) that currently plagues the regulated utility environment is solved, these data will not exist, and data quality will remain unnecessarily weak relative to what policy and research aspire to address.

- The team identified many energy-relevant databases but found that the data are hardly usable for better answering questions about people in energy use. Sources that look closely into one aspect of energy use (e.g., lighting energy use, building stocks,
consumer opinions) rarely consider other aspects. Meaningfully merging data collected at different times, geographies, and levels of aggregation is difficult to do with any degree of confidence.

- Since energy policy and modeling are currently not oriented to taking variability and diversity into account, there has not been much impetus to collect and assemble high-quality data that provides a more granular and dynamic picture of actual energy use and energy conditions in households.

**Recommendations:**

- Advance efforts to improve access to utility customer data. Formal protocols may be needed to facilitate access while protecting both customers and utilities.

- Support improved data collection, including efforts that combine data about people with data on technical conditions and actual energy use. The latter could be devised in coordination with existing efforts (such as the California RASS) to incorporate more detailed qualitative information about people, including more on-site data collection to supplement remotely-collected data. The resulting combination of data could be used to detect and quantify relationships amongst people, technologies, and energy use in the residential sector as a system, to help shape policy and research policies. Longitudinal data and improved data collection instruments and protocols would support improved understanding and modeling.

- Develop strategies to bring social sciences into energy and climate change policy and programs. The Energy Commission and other policy agencies can help open up the potential contributions of social sciences to energy and climate change policy in the state. Besides collecting better data about people as energy users, as noted above, leadership is needed to find ways that policy, programs, visions, and plans can better accommodate social sciences-based evidence and arguments. Contributions could take a number of forms – from supporting combinations of qualitative analyses and more quantitative exploratory modeling, to sustained dialogues among groups of experts (e.g., policymakers, social scientists, and engineers) that might otherwise rarely talk to each other. Even uncertain findings can provide “clues” that suggest areas that need attention.

In this section of the report, the team critically examines what is known about people and energy through an extensive examination of the academic and applied literatures on residential energy demand. A better integrated, more inclusive, and otherwise improved conceptual model of residential energy demand is proposed to serve as a heuristic (conceptual orientation) for how to approach questions about people in energy use going forward.

A. The Knowledge Base is Broad but Depth and Agreement are Limited (Chapters 10-11)

The research team reviewed 30 years of residential energy efficiency research from a variety of disciplines and applied policy fields. The review helps to build on existing knowledge about people and energy by better understanding how problems have been formulated and what is known or relatively unknown. It also highlights how existing and new research might be better used for coordinating research, policy, and results.

Key Findings:

- The knowledge base on energy efficiency is broad, but the empirical backing behind many common arguments (whether by professional energy efficiency experts or academic researchers) is weak and may often be more symbolic than evidence-based. For example, price elasticity is often the only way that people's behavior is acknowledged in many formulations of energy use – in particular, the assumption that energy use across a group will automatically decrease if prices increase. This attention to price elasticity is not accompanied by much understanding of the human actions that are mechanisms of elasticity, nor of changing historical conditions, the equity implications of price changes, or the relatively inelastic nature of demand. Aggregate effects that are communicated as smoothly correlated with an “external” price (or other) change may, in fact, be statistical artifacts that are resulting from strikingly different behaviors by population subgroups. For example, reactions to electricity price spikes can range from abrupt cessation of air conditioning in some segments and to stubborn disregard for price in favor of comfort or habit in others. Summarizing highly varied responses in a single price elasticity is not only misleading, it can lead to overlooking opportunities for better-targeted policies in favor of simple price increases.

- Historically the energy efficiency field has targeted improved technical efficiency, largely excluding the actions and reactions of people. The failures caused by this exclusion are reflected in a large vocabulary of “problems” or mismatches, such as the design-performance gap, rebound effect, calibration factors, or “miscellaneous” energy use. Integrated attention to these questions is often lacking.

- Accessing and using the extensive literature on energy use is a challenge. Much of the formal knowledge base is spread among scientific journals in different disciplines that policy agencies often cannot access directly, and accessible reviews of the literature are not common. Findings from evaluation studies may not be published at all or in any detail. Some of the potentially most valuable knowledge about energy use (e.g., from
field technicians or energy auditors) is never documented or discussed, falling into the realm of tacit knowledge or lay theories that cannot be mined for insights (Lutzenhiser et al. 2009). More importantly, the overall large knowledge base, when accessible, is also scattered and fragmented, both among siloed academic disciplines and among separate regulatory processes.

- Multidisciplinary approaches seem obviously needed, but they haven’t been well developed. There is a lack of a unifying perspective, which is also to say there is a lack of a productive conversation among academic disciplines and among professionals trained in different disciplines – let alone conversations between academics and professionals working in and consulting for government agencies and private sector energy companies. Venues for engaging in such multidisciplinary conversations are scarce.

Recommendations:

- Promote cross-discipline collaborations. For the energy efficiency field to transition to the problems posed by climate change, productive collaborations across disciplines and arenas (e.g., policy development, implementation, applied research, theoretical research) are required. Because energy use is so basic to nearly everything that people do, results of research, programs, and other developments should be assessed from a variety of disciplinary perspectives and at a number of different levels.

- Create venues for conversations to produce a more comprehensive framework for accounting for people in energy use, in contrast to a focus on technology and economics in isolation from human activity. This should include improving the accessibility of the literature, increasing the availability of findings from prior research distilled in a practical way, and improving communications among all parties.

- Develop a more integrated perspective built on stronger theoretical foundations. Because this has not been achieved over a number of decades, it may seem to be a utopian prescription, but it is attainable. Conversations about energy demands, energy system problems, and energy futures informed by something like the heuristic model proposed in the report can support broader understandings of challenges and potential policy approaches.

B. New Models of Systems and Practices (Chapter 12)

Building upon several decades of scientific and applied policy research and model building in the United States and elsewhere, the AREBA report sketches a heuristic model (a tool for thinking more coherently). The model focuses on social systems of residential demand organized on a variety of scales – from micro-behavioral interactions of people and technologies in the home, to the larger social and technical networks in which any household functions as one of millions of local nodes.
Key Findings:

- The report presents a heuristic model of “where the people are” in residential energy use in two stages. The first stage builds upon conventional perspectives about physical relationships between the dwelling, its system, and the environment. The second stage expands this model in space, time, and social organization in order to take into account the interconnections of the household and the house within the larger human, technical, and natural systems.

- The heuristic model also accommodates a systems perspective. The system perspective promotes attending to feedback and interactions among various elements of the system and recognizing multiple levels of system structure and of analysis.

Recommendations:

- Adopt a heuristic model to inform public policy. The heuristic model of embedded systems synthesized by the AREBA team should be applied and tested in a variety of policy contexts and concerning a variety of specific questions related to residential energy demand and GHG emissions and reduction potentials. The data necessary to support a full-blown, multi-systems modeling of California residential demand are not readily available. But that does not eliminate the need to improve how energy use is modeled. Starting with a broadly conceived heuristic model can aid critical thinking in a number of ways that can guide iterative improvements in models and data collection efforts. For example, by identifying a fuller range of social factors involved in the creating and sustaining demand, a wider array of questions (a variety of which are proposed in the report) can be posed to help inform public policy than are ordinarily considered by conventional device-oriented perspectives.

- Use such a heuristic model to help create and assess “what if” scenarios that can be used to think through and otherwise assess possibilities that do not lend themselves to deterministic modeling.

- Foster broader conversations among policymakers, researchers, evaluators, and practitioners, as well as across disciplines. This should include discussions about data needs and limitations, and the development of revised ideas about the nature of evidence and its reliability, to synchronize with the proposed grounded, but less rigid, model of energy use.

[4] Studies from a New Vantage Point

This section of the report presents the results from specific studies on major topics in residential energy efficiency pertinent to California. As argued in the summary above, conventional methods, vocabularies, metrics, and data resources may hide a good deal of what is most important to improve. Therefore, much work remains to be done especially in light of climate
change and climate change policy goals. A new approach or new set of questions embracing the central role of people in residential energy use can offer guidance on the energy and environmental problems with which the Energy Commission and other California policy agencies are currently grappling. The remainder of this section sketches results for these applied studies from the new vantage point expressed in the critiques and in the heuristic model described above.

A. How Much Does Behavior Matter? (Chapters 13-14)

The AREBA research team undertook a number of studies examining the level and nature of behavioral variability in California residential energy use. The team considered the implications of this variability (as well as the common glossing-over of this variability) in various energy efficiency policies and industry practices.

Key Findings:

- Using a combination of building energy simulation modeling and data on behavior, the research team constructed an analytic model made up of four major elements distilled from the strengths of various disciplinary views found in the literature and the heuristic model of residential demand. These are: the physical dwelling unit (Building), environmental conditions (Environment), building systems and energized devices (Technology), and household actions and behaviors (Activity). The resulting “BETA” model was used to estimate the influence of behavior in comparison to the other elements under a variety of conditions common in California. In relative terms, the social/behavioral (“A” elements) in the BETA model are clearly as large as the physical and technological effects. Also, the various components are correlated with each other (e.g., there are interactions between what people do and the efficiency of the technology they have), so that changes in buildings and equipment are not necessarily neutral across the population. These changes are not only targeted differently at different groups of energy users, they affect these groups in different ways.

- The wide variation in end-use demand underscores that one-size-fits-all technologies or efficiency prescriptions are unlikely to provide an adequate recipe for policy and program effectiveness or equity. Rather, deep attention to recognizing variability in use and conditions, as well as to the wide variety of ways any “energy service” can be rendered (e.g., how heat is provided in a home), can help expand the scope for energy savings and emissions reductions potentials. This more realistic stance can open the possibility of a new version of efficiency that explicitly recognizes energy users’ realities and concerns, with greater energy savings and a better, more salient, portfolio of non-energy benefits and costs.

- Statistical modeling of the Energy Commission’s Residential Appliance Saturation Survey (RASS) data underscored the fact that simple truisms may not be true. For example, the expectation that income should be an important determinate of energy demand. When income is considered alongside a host of physical, technological, and social variables that
are also associated with demand, only the highest incomes are seen to have strong effects on overall demand (emissions, in this case).

- Overlooked ethnic and cultural characteristics may be important for understanding the differing living conditions, preferences, values, and opportunities for different consumer segments. A deeper knowledge of these dimensions could improve energy efficiency intervention targeting and help to avoid unintended equity problems (e.g., offering products, services, information, and/or subsidies that are inappropriate and not useful).

- Self-reported household-level “typical” heating thermostat settings in California households vary widely. Using building energy simulation modeling, the research team estimated natural gas use for the most commonly reported thermostat-setting profiles and compared these to estimates using Title 24’s residential heating set point schedules. Average estimated heating use across the tested profiles was close to that for the Title 24 schedule. However, they were much higher for some thermostat-setting profiles and much lower for others.

- Many homes in California frequently turn their heating systems off in the heating season. For example, according to the California 2009 RASS data, 42% of single-family households typically turn their heating systems OFF periodically for a number of hours or even entire days during the heating season. But this possibility seems rarely acknowledged and creates simulation challenges. It also suggests that there is a great deal of leeway in “livable” temperatures, which both technology design and program design would do well to heed.

- Current Title 24 assumptions for heating use may be far from optimal given actual practices observed in the real world. The variety of thermostat setting practices in real homes, the sensitivity of residential efficiency definitions to these assumptions of “normality,” and feedback between home design and energy use challenge many of the assumptions. A similar conclusion follows for other end-uses, such as domestic hot water and “miscellaneous” technologies.

- Based on survey data, measured data on hot water draws, and recent literature, the research team investigated the variability of domestic hot water use patterns in California households and analyzed strategies for reducing hot water energy use. Hot water use accounts for approximately 40% of California household natural gas use, on par with space heating consumption. Although the 80/20 rule-of-thumb (80 percent of the use occurs in 20 percent of the draws) appears to roughly apply in hot water consumption, it might be naïve to conclude that hot water use reduction may be easily targeted and achieved. Households and their behaviors and routines are integral to this demand, and these remain understudied and very poorly understood. This is surprising given the status of residential hot water heating as one of the primary end-uses of natural gas in California and the escalation of water and the water-energy nexus as central resource issues.
Recommendations:

- Develop more realistic energy analysis models to reflect real-world conditions. The BETA model results underscore the importance of acknowledging the variability and major effects of what people do as a central contributor in shaping energy use. Independent improvement of technological factors under assumed “typical” behavior and conditions may in reality be much less effective than assumed. This is particularly important for residential end-uses such as heating, cooling, and hot water use. Modelers, forecasters and other energy analysts should therefore seriously revisit and critically assess conventional assumptions made about “normalcy,” particularly where averages are used as proxies for highly diverse real-world variations in behavior and energy demands.

- Improve quality by including realistic residential energy use behavior and demand patterns. Continued work needs to be undertaken on statistical modeling and data analysis of household energy use, especially with the better quality data that include more realistic and nuanced specifications.

- When addressing means of reducing hot water use in California residences, consider a fuller realm of hot water use behaviors and routines, how these behaviors and routines are shaped (e.g., by technology), and means for change.

B. Retrofits of Existing Dwellings (Chapter 15)

California and the Energy Commission have long histories with policies and programs designed to upgrade the energy performance of existing homes. Assembly Bill 758 initiated a process of analysis, planning, and policy development, in which the Energy Commission is tasked with crafting a statewide initiative to achieve ambitious goals for widespread housing energy upgrades (CEC 2012).

The AREBA project assessed various questions about home energy audits, remote assessments, simulation models, and residential energy efficiency upgrades, drawing from two high-quality home energy assessment programs: an on-site audit program in Seattle and a program providing web-based remote assessments to households in Alameda County, California.

Data included homeowner surveys of retrofit decision-making and upgrade choice, energy use behavior patterns, results from energy audits, building performance testing (and post-retrofit retesting), auditor interviews, home energy reports, and electricity and natural gas billing records (pre- and post-retrofit).

Key Findings:

- Household behavior is poorly characterized even in otherwise sophisticated building energy performance and audit models. Applying an asset approach – which uses assumed averages or assumed typical values for behavioral inputs – can yield
misleading conclusions and retrofit recommendations when applied to individual households. However such output is often offered as “customized” advice. Adding self-reported behaviors from a 10- to 15-minute survey to home energy audit models can improve how well the models represent actual energy use and can provide a basis for offering more specific and effective upgrade design guidance. This kind of more personalized approach can also open the door to productive conversations about household behavior. The asset approach also may not yield the benefits theorized for real estate markets – i.e., distinguishing “good” energy-wise/environment-wise houses from others and thus driving market transformation.

- Home energy audit models that reflect the operation of any individual home can better track actual home energy use and may reduce the differences between predicted and achieved upgrade energy savings. Interval meter data and historic utility bills can also provide behavioral information and other means for modeling homes as inhabited and operated. Interval meter data analysis can also complement site audit strengths by bounding savings estimates or by serving as a triage or screening step.

- Multi-family and rental units in general have been relatively neglected in the realm of home energy audits. Operational home energy assessments can offer behavior change analysis, idle mode reduction, and the possibility of various other energy saving actions that may be relevant to multi-family property owners, to renters and tenants, and to owner-occupants. This larger set of actions may also offer households greater total energy savings potential.

- To maximize potential impacts, home energy assessment should be about much more than delivering technical upgrade advice and dollar savings estimates to participating households. Rather, they can be closely tied to the energy-related problems and questions that people already perceive in their homes and to delivering a motivating experience rather than just a technical assessment. For example, analysis of open-ended survey responses provided by home energy audit recipients suggested that more tangible, visual, and even tactile elements could be very motivating to homeowners. In particular, audit recipients commented on being intrigued by infrared imaging (thermography) that dramatically shows the temperatures of the exterior or interior surface of the building, as well as by blower door testing. Also, expert energy auditors who have the ability and leeway to tailor technical advice may be able to better address homeowners’ specific and contextual needs, wants, and circumstances. Auditors who can assess the non-energy impacts and implications of upgrade and conservation recommendations may add greatly to the more standardized print-out elements of typical audits. The idle mode power draw provided by the StopWaste remote analysis appeared to trigger similar interest and action by households.

- The quality of audit and upgrade advice, and the quality of interaction between homeowners, contractors and other supply chain actors is not well understood. Both areas are susceptible to wishful thinking by retrofit advocates and seem fraught with
problems, such as overlooking behavioral savings, missing opportunities for less-extensive upgrades, or demonstrating substantial bias toward wealthier households.
Recommendations:

- In developing and implementing home energy audit programs, work on reframing the “energy problem” so it has greater salience for the problems and questions that households already perceive that they have, rather than trying to get households to perceive new problems that they may not have or focusing narrowly on increasing participation rates.

- Create home energy audit programs that directly address behavior. Behavior can be cast as a negotiable component of energy use and weighed alongside major technological changes. There appears to be latent interest in high-quality customized energy advice that reflects the details of how a household occupies their home and what they are interested in changing. This contrasts with typical “check-list” of behavioral conservation recommendations and can address ways to make energy use in the home work better (e.g., comfort, stress, ease of use), rather than focusing just on piecewise energy use reductions.

- Evaluate audit and building simulation for behavioral sensitivities and errors. Open up the inner workings of common models to wider scrutiny and discussion.

- Investigate and debate the practical application of home energy modeling and analysis in real-world contexts. Continue to develop operational energy analysis and building simulation approaches for providing energy use information and energy saving guidance to occupants (e.g., using calibration methods).

- Improve methods for assessing a household’s water heating energy use. Even the ability to provide a rough or bounding estimate of water heating energy use would be a useful improvement beyond current operational approaches.

- Verify and improve home energy and upgrade advice by grounding more extensively in empirical data. For example, projected savings estimates can be compared to historical energy use for a given household, and studies can analyze actual savings from upgrades as compared to modeled savings over a period of several years. These measured results are a key to improving modeling and can reign in exuberant savings expectations.

- Build on the more engaging and compelling elements of home energy assessment. This includes activating the inherent appeal of visible diagnostic testing, such as infrared photography, customized and contextual audit results, and personal interactions with expert and enthusiastic auditors. Analytic and modeling improvements alone, without being accompanied by more attention to what is inherently interesting to the people who will end up writing the checks and/or altering their energy use activities, are unlikely to overcome low uptake of energy upgrades.

- Investigate why some households do not participate in home energy audits. The vast majority of households are non-participants in home energy audits and retrofits. If home energy audits are to be successfully expanded, there is a need to better understand the circumstances and expectations of households who do not participate in these programs as well as those who do but do not follow up on recommendations.
C. New Construction Codes (Chapter 17)

Since 1978, the California Energy Code (Title 24, Part 6 of the California Code of Regulations) has required that new residential construction incorporate certain energy efficiency levels, especially for space heating, space cooling, water heating, and lighting. Changes in the code over 35 years have increased the efficiency bar, with the most recent iteration supporting the construction of Zero Net Energy homes (discussed as a special case of new construction below). However, there has scarcely been assessment of how much these codes contribute to actual changes in residential energy use and GHG emissions.

Key Findings:

- High-quality sources of longitudinal energy consumption data to investigate policy effects do not exist. But it is well established that over the past fifty years, the sizes of new California single-family homes have increased dramatically. This would be expected to increase energy consumption. At the same time, increasingly stringent energy codes would have had a restraining influence on growth in demand (and emissions). Based on data from a cross-sectional sample of California homes (the RASS 2009 data set), analysis of household energy use by the year the home was originally built was conducted. Not unexpectedly, it shows average energy use per household trending somewhat higher in newer homes, similar to the result for space conditioning energy use reported by the Energy Commission (Brook et al. 2012). However, the picture is more complicated when specific energy forms (e.g., electricity versus natural gas) are considered independently, and the data do not allow parsing out the interplay of competing pressures to either increase or slow the growth of demand.

- The fact that newer houses, on average, are bigger, is itself not a simple contributor to the pattern noted in the previous bullet. From a physical perspective, larger houses should also have somewhat lower energy use per square foot than smaller houses, even if they could be expected to have higher energy use overall. So the research team conducted an analysis of energy use per square foot over combinations of house vintage category and house size category, for homes in the RASS 2009 data set with natural gas heating. Although the data are not granular enough for high certainty or ideal comparisons, an interesting picture emerges. For example, for every house size category, average energy use per square foot for homes built 2001-2008, is actually lower than for any of the earlier vintage ranges. However, for other vintage categories, energy use per square foot was often found to be on par, or higher, in newer homes than pre-1970 units of similar size. Again, making sense of these results is not straightforward. In addition to gross floor area, other energy-relevant features of newer housing are not captured in the available data (e.g., the addition of two-story atriums, central air conditioning as the norm, and the dense packing of dwellings in new subdivisions) – that is, the houses and their amenities are not completely comparable across vintages. Also, there may be differences in the behaviors of households living in newer dwellings (e.g., how those persons interact with buildings, HVAC systems, and appliances), which could also help
explain consumption differences. So the results should not be interpreted as meaning that energy efficiency codes have not saved energy. As noted throughout the report, the conventional framing of problems and selection of variables mean that many potentially salient factors are measured only crudely, if at all, in current data sources. This is very important, because regardless of surmised causes, a number of important understudied issues may affect the savings realized from changes in building codes, appliance standards, energy pricing policies, etc. The lack of high-quality and broadly focused longitudinal data limits researchers’ and other analysts’ efforts to provide policymakers with an adequate understanding of the dynamics of the systems involved.

Recommendations:

- Conduct further analysis, collect more detailed data, collect longitudinal data, and continue tracking new home energy use and its evolution over time. These efforts will improve understanding as to why energy use has not declined as much as expected, be it about house size and amenities, occupant behavior, efficiency characteristics that do not work as well as expected or deteriorate over time, or something else. The results could be used to improve codes and savings estimates. More generally, this policy analysis approach is an example of a type of broader, empirically-based mode of evaluation that can not only improve savings estimates but more importantly, can lead to better energy policy, program, and technology design.

- Perform stress tests of efficiency codes and building simulation models under various realistic assumptions about occupancy and occupant behaviors in models. Use results to help shape efficiency design that takes better account of variability, in contrast to designs that are oriented to a point estimate.

- Assess how homebuyers actually buy homes and develop a better understanding of the dynamics of the broad socio-technical systems involved in the design, construction, and retailing of new housing. Such research can identify how consumer preferences are shaped (e.g., where do increasing house sizes “come from”?), how innovation (or non-innovation) takes place in the industry, the dynamics of code compliance, and the role of codes and standards in real-world markets. It can also offer answers as to how new home markets connect the macro economy to the individual household consumer.

D. Energy Savings from Behavior Change (Chapter 16)

The California Public Utilities Commission has mandated the use of consumer behavior change initiatives in residential energy efficiency program portfolios (CPUC 2014), and various researchers have argued that a “behavioral wedge” of savings potential should be considered in climate stabilization policies. A key question about behavior change proposals is how they should address the wide variability of total and end-use level energy use and the differential impacts of any behavior change depending on the situation. The AREBA research team
conducted two analyses to explore the importance of energy use in the context of distributions of behavior when considering energy savings from behavior change.

Key Findings:

- The research team used a combination of data sources and modeling techniques to explore the emissions impacts of changes in household-level behavior. The results showed, somewhat unsurprisingly, that if the highest-consuming households had thermostat-setting practices similar to those for the lowest users, their energy demands and GHG emissions from energy use would be much lower. This underscores the importance of looking at combinations of usage practices and technical efficiency, especially where absolute emissions reduction is a goal.

- Based on modeling of household-level behavior changes, a second analysis examined possible aggregate behavioral energy savings from more modest shifts in energy use patterns and practices. Segmenting the California residential sector by climate zones, housing types, and dwelling sizes, the analysis used empirical data on consumption within those segments to pose the question: How much savings would be possible if each quartile (highest-consuming 25 percent, next lower 25 percent, etc.) exhibited the energy use levels of those households in the next lower quartile? The results showed that savings would vary across the state and by housing characteristics, but within each segment savings potentials were observed and some were very large (e.g., 40-50 percent).

Recommendations:

- When developing behavior change programs, take account of the variability across households, in contrast to an “everybody do everything” approach. Energy savings potential varies widely across actions and households. Behavior change programs would benefit from working with these differences, both at a program level and from the household perspective where there are real impacts and costs of behavior change.

- Foster additional household-level research to understand real-world human energy users and the complex systems in which they are embedded. Macro-level analyses as seen above tell an important part of the story, but considerable research remains to be done to better understand distributions, consumption patterns, lifestyles, and specific energy-using practices. Information on the who, what, and when of household energy usage can help move beyond the relatively superficial view of instilling “correct” behavior in isolation to one that views energy behavior in context.

E. Changes in Natural Gas Use over Time (Chapter 17)

Natural gas consumption has been a major focus of the AREBA research in terms of direct residential gas usage (primarily for heating space and water) and electricity generated through
natural gas combustion. The continued widespread use of natural gas represents an important source of GHG emissions and is, therefore, an important object of policy intervention. Knowledge of the actual dynamics of gas consumption, however, is limited. Future forecasts are hampered by knowledge limitations and by puzzling patterns of change over time in natural gas demand trends.

Detailed retrospective studies of residential natural gas use are rare. So the AREBA team undertook an examination of observed changes in California residential natural gas use, drawing together explanatory data from several sources.

Key Findings:

- Direct natural gas consumption in California households has declined tremendously over the past four decades. Per household, average natural gas consumption in 2010 was less than half of that in 1967. Per capita, average direct household natural gas use declined by 40 percent between 1980 and 2012. Improved equipment and building efficiency could explain much of the decline. But other changes may have also contributed substantially, such as shifted portfolios of natural gas end-uses within homes, warmer heating seasons, and demographic changes. In fact, over the past 25 years, natural gas use per capita has declined at a similar pace in the United States as a whole. The explanations behind the U.S. and California declines may be quite different, but the comparison speaks against automatically arguing that California energy policies are primarily responsible for the observed reduction.

- The demographic and behavioral dimensions of past changes in natural gas usage are poorly understood. Demand forecasts and long-range plans, including the development of climate change scenarios, may benefit from more directly considering the details of past changes and the uncertainties inherent in predicting system-wide change – beyond just matters of predictive accuracy.

- The natural gas trend analysis also underscores that energy use changes in the past are not directly controlled by policy (e.g., housing preferences and social standards, emerging energy uses, changes in household composition and size). Changes in the future will likely have a similar character.

Recommendations:

- Conduct research to try to better explain (to the extent possible) the decline in natural gas usage, taking care not to automatically attribute it to efficiency policies. More complete understandings of the scope and nature of past changes can make forecasting efforts and future policies more effective, while acknowledging inherent uncertainties. Efficiency policies can obviously have major direct and indirect effects. However, there are many moving parts in the evolution of home energy use, and systematic investigation into what these are can help hone energy codes, evaluation methods, and the ability to detect problems and unintended consequences.
• Continue and expand careful parsing of past changes in energy use more generally (with respect to end-uses, technologies, and changing lifestyles). Though data are limited, this work can help reveal the structure of energy use. Insights can be interpreted with respect to their implications for policy effectiveness and forecasting, especially for questions about what changes are under the direct control of current policies and what changes are not, and for feedback and dynamic interactions among the elements that shape energy use.

F. New Technologies: Zero Net Energy and Rooftop PV (Chapter 18)

With ambitious climate change policy goals, California seems poised for a transition to a very new way of thinking about housing and a new, bold approach to refashioning cities, suburbs, and towns. Zero Net Energy (ZNE) construction and the diffusion of rooftop solar photovoltaics (PV) are likely important building blocks in thoughtfully navigating that transition. However, there are many systems issues that may come along quietly with technology-centered goals. The AREBA research team investigated topics in two major emerging energy technologies: Zero Net Energy dwellings and rooftop PV.

Key Findings:

• With large enough PV generation capacity (sufficient “real estate” on the rooftop), ZNE homes will likely “work” for even the most consumptive occupants. But there is no guarantee of an efficient integration of ZNE in the built environment or that ZNE homes will reduce energy use or emissions as much as projected. Building for this level of high consumption will result in some dwellings being vastly overpowered in terms of individual household needs. There are unknown consequences for how this excess capacity might influence energy use and unclear benefits relative to other potential configurations of generation.

• Current attention to ZNE homes largely misses some important questions about how these homes perform for occupants with respect to expected energy savings. Even if ZNE performance is easily achieved in theory, research on low-energy homes in Europe have pointed to topics that fall outside the scope of this theoretical performance, including: (a) how occupants experience these buildings in terms of satisfaction, comfort, and home use; (b) responses to on-site supply and energy cost changes, including the possibility that occupants use more energy services than they would have with conventional electricity supply; (c) how occupants of ZNE homes will learn how to use new systems and what adaptations they make to their behaviors or the home; (d) implications of this occupant learning and adaptation for house and technology design; (e) indoor air quality.

• Interviews with installers of residential rooftop PV systems helped paint a picture of just how different PV and energy efficiency may be perceived by potential adopters. While PV is a large investment, it can do things that energy efficiency cannot do. For example, potentially eliminating monthly energy bills, relatively “plug and play” installation
rather than complex or multi-step energy efficiency improvements, changes in relationship with the utility, and visual signals to neighbors in a way that interior efficiency upgrades cannot provide. Though rooftop PV and energy efficiency can complement each other, it is also plausible that promoting PV could discourage energy efficiency investments or behavioral energy conservation, just as households with low energy use are often not considered good candidates for cost-effective rooftop PV.
Recommendations:

- Invest in learning how occupants use, modify, judge, and react to the ZNE homes they purchase and occupy. For ZNE goals to be effective at both a system level and for consumers, there needs to be a much better understanding of how energy is used, how energy might be modified across the entire spectrum of household energy users and uses, and how new technologies might bring unexpected changes in how occupants energy use. This type of research can help develop much more effective designs, technology applications, standards, and other forms of policy support.

- Focus empirical research on how innovative energy efficiency features are used, overridden, or otherwise adapted in next-generation housing, and how households adjust to the evolving energy systems in their homes. Because energy efficiency affects not just energy use but the entire built environment, related aspects, such as indoor air quality and climate change resilience, need be considered as well.

- Conduct research examining how efficiency and energy use behaviors evolve in the presence of PV. For example, to what extent do efficiency and PV “compete” with each other, and to what extent does the presence of PV change how and when households use energy? What are the implications for GHG emissions reductions, systems planning, policy development, programs, equity, utility tariffs, and technology design?

- Include people – as energy consumers, technology purchasers, and adapters (not just “adopters”) – in energy research. Understanding people as technology users will also be critical for development/demonstration agendas. New technological solutions are an important part of climate change agendas, and technologies should take users explicitly into account and provide improvements that have palpable household as well as social benefits.

- As long as policy seeks to reconfigure the built environment, it will also reconfigure social and institutional environments. Thus, it would make a good deal of sense for policy and analysis to explore some older but still quite innovative technologies, such as passive (and people-involved as opposed to fully automated) heating and cooling options and lower-impact lifestyles in general. It would be useful to ask how prevalent these lower-impact lifestyles are and how they might be accommodated in future development of new buildings and technologies. The alternative to enforcing more “average” solutions or more “smart” buildings and systems that often fail to meet their promises can be more people-centered planning, analysis, and design – possibly supporting improvements that are more localized or specific to context.

Project Benefits

The AREBA project has pushed forward the frontiers of addressing where and how people figure in residential energy use, and in so doing, it identified a series of potential improvements to current practice in residential energy use research, demand analysis, modeling, energy
policy, and the overall concept of energy use in home. The implications of these project findings depend on how they are used. Thus, the biggest follow-on benefits of the project will arise as treatments of people and energy are further developed and applied by policy agencies, researchers, technology developers, others in the energy efficiency industry, and the climate action community.

Clearly there are potential benefits to innovation in the design of program offerings, communicating more effectively, segmenting customer subpopulations appropriately, and better targeting of policies, such as household-level customization in the case of home energy upgrade advice. The range of applications to the efficiency problem is likely even broader. Determining applications and priorities of a more refined and effective “behavioral” mandate will require a more transparent discussion of existing program designs, methods, data, and organizational practices. It will also require combining the efforts of all parties involved. This means drawing upon efficiency industry experience, regulatory agency system knowledge, Energy Commission expertise and tools, and university innovation in analysis, design, and technique. It will also require the active engagement of local government, the non-profit sector, and innovative firms.

The most important participants, who are easily forgotten, are the actual real-world energy users. These users have an enormous stake in what all the other actors produce. The world created by that production is one the users will have to occupy and manage in the future. The implications go far beyond the size of the energy bill or whether or not policy goals are achieved. So their concerns about indoor environmental conditions, building quality, technology performance, comfort, landscape, safety, and community – all intimately connected to energy flows and efficiency initiatives – need to be given priority consideration. Progress can be made in at least three ways:

First, by providing a more integrated approach for seeing people in energy use and by highlighting some shortcomings in conventional industry practices, the project helps build beyond technology-centric approaches that are not suited to the current set of energy and climate problems. It also identifies problems in data collection, data access, knowledge sharing, and legacy limitations that curtail policy and research progress, as well as potential pathways to move beyond these problems, improve California’s ecosystems of energy models and to foster collaborative conversation among disciplines and within and between institutions. These improvements in turn can foster higher-quality creative analysis and improved results.

Second, deeper attention to individuals, the multi-dimensionality of energy use and the built environment, and the human elements of energy use and change means that persons as real-world energy users will be less likely to be “washed out” in average policies. This will require more focus on empirical results and particular segments and situations, as well as to the non-energy costs and benefits of home energy use. This will yield greater opportunities for more local perspectives and more local participation in research and policy development. This contrasts the current pattern of top-down deployment, which can be particularly ineffective when localities are increasingly responsible for the policies and processes that mitigate and adapt to climate change and as they experience the local impacts of climate change.
Third, the AREBA project offers specific results designed to support improved cornerstone residential energy policies in the state, including home energy upgrades for existing homes, residential new construction codes, Zero Net Energy construction, and behavioral energy savings potential. Undertaking these improvements would help better target the best opportunities for improvements, reduce the possibility of policies that may be ineffective or harmful, and increase the likelihood of effective policy impacts and outcomes.