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Energy efficiency retrofits for U.S. housing: Removing the bottlenecks☆,☆☆

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ABSTRACT

U.S. housing accounted for over 22% of the country's total primary energy consumption in 2009, which equated to more than $2000 per household and $229 billion in aggregate expenditure. It appears that these amounts could be reduced substantially, with benefits to both household budgets and the environment's well-being. This paper's goal is to evaluate the alternative mechanisms that could expedite energy efficiency retrofits for U.S. housing.
We begin by evaluating the evidence that significant improvements in the energy efficiency of existing U.S. housing are feasible, both technologically and financially. We compare the relatively optimistic positions taken in McKinsey and Company (2009a,b), EPRI (2009), and Harcourt, Brown, and Carey (2011) versus the less optimistic appraisal in Allcott and Greenstone (2012). We conclude that significant energy savings do appear to be both technologically and financially feasible.
The remainder of the paper considers the bottlenecks that hamper energy-saving investments for the residential sector. We focus on imperfect information and loan market failures as the two key factors. We evaluate the state of the art with respect to scoring and assessment tools for energy-saving investments and the On-Bill, PACE, and Solar programs to facilitate secured loans. The discussion concludes with a series of proposals to overcome the bottlenecks.

1. Introduction

In 2009, U.S. residences accounted for over 22% of the country's total primary energy consumption, which equated to more than $2000 per household and $229 billion in aggregate expenditure.[1] Energy use rises with the age of the home, with homes built after 2000 using 40% less energy than homes built before 1950. Energy efficiency in many older homes could improve significantly with upgrades to the structure or new appliances, but many homeowners have not yet made these investments.

This paper addresses the apparent failure of U.S. property owners to carry out energy-saving investments in the presence of financially productive technologies by analyzing the impediments to improving residential energy efficiency, assessing potential gains to households and the economy, and evaluating policy approaches to increasing residential energy efficiency investments.[2] We focus on the failure to retrofit existing homes since older homes are significantly less efficient than newly constructed homes. Furthermore, given the low rate at which U.S. homes are removed from the existing stock, these older units will continue to waste energy for decades to come unless they are retrofitted. The paper's goal is then to evaluate alternative mechanisms that could expedite energy efficiency retrofits for U.S. housing.

We begin in Sections 2 and 3 by evaluating the evidence that significant improvements in the energy efficiency of existing U.S. housing are feasible, both technologically and financially. With this basis, Section 4 of the paper discusses how property owners, and other stake holders in the retrofit process, can obtain expert advice to allow informed choices in carrying out energy-saving investments. We focus on the usability and accuracy of computer-based audit "tools" that allow property owners to evaluate the benefits from various energy-saving investments.

Section 5 of the paper considers the financial impediments to carrying out energy-saving investments. We focus on two widely discussed programs, namely On-Bill plans available from participating public utilities and Property Assessed Clean Energy (PACE) plans available from participating local governments. We also consider other loan instruments that could be used to finance energy-saving investments.

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[1] Source: Energy Information Administration (2012).

[2] It is worth noting that this is not a new question; see Jaffee (1984) for an early study of the factors that create energy-saving investments in new homes.

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Section 6 concludes with our evaluation of the available policies and other actions that could encourage energy efficiency. Some proposals are intended directly to remove informational and financial obstacles, whereas others are intended to “nudge” households to action, for example, by allowing the investment activity to be carried out in conjunction with trigger events.

2. Residential energy use and potential benefits of energy saving investments

Statistics compiled by the U.S. Department of Energy (2012) on home energy use and energy-saving investments underline the potential for energy savings:

- Almost three-quarters of residential energy goes for space and water heating and space cooling, with the remainder primarily used by electronic appliances; see Table 1.
- Homes built between 2000 and 2009 used 15% less energy per square foot than homes built in the 1980s, and 40% less energy than homes built before 1950. However, these gains in efficiency have been partially offset because the new homes are larger; see Table 2 for further details.
- The energy consumption per household in multi-family buildings with five or more units is less than half that of detached single-family homes. On the other hand, on a square-foot basis, single-family homes are more efficient, because they are on average about twice the size of multi-family units; see Table 3.
- The energy efficiency of U.S. residences overall appears to be substantially less than that of comparable buildings in Western Europe and other developed countries, after controlling for such factors as climate, GDP, and population.[3] This suggests that practical technology does exist to improve the energy efficiency of U.S. residences, although part of this difference could also be due to the behavioral response of European residents to higher energy prices.

These facts raise a key question: why have the investments to achieve these energy savings not already been carried out? Carrying out an energy-efficiency upgrade generally requires two fundamental steps. The first step is to acquire the necessary information to recognize the overall economic feasibility and viability of energy-saving investments and to select the specific investments and contractors. The second step is to acquire the financial resources, normally a loan, to cover the capital costs of the investments. A bottleneck at either step can very well doom the entire project, since taking no action, or postponing action is often an available option for property owners.

3. The potential benefits of energy-saving investments

In a widely discussed study, McKinsey and Company (2009a)—*Unlocking Energy Efficiency in the U.S. Economy*—evaluates the availability of “NPV-positive” energy-saving investments for the U.S. economy, including residential real estate, for a twelve year period running from 2008 to 2020.[4] For the residential sector alone, the study projects that a present value of $229 billion in upfront investment costs would yield a present value of $395 billion in savings. By 2020, energy use in the residential sector would be reduced by 28% relative to a “business as usual” (BAU) benchmark.[5] The savings and investment costs translate into an internal return on investment (IRR) of over 19%.[6] The McKinsey report further identifies the most important residential energy-saving investments, which include sealing ducts, insulating basements/attics, upgrading heating equipment, and adding programmable thermostats. These investments deliver the highest IRRs with the exception of the upgrading of heating equipment. The McKinsey report also evaluates the factors that have inhibited these investments and recommends actions that would expedite the investments. We consider these factors and recommendations below.

Table 1
2010 residential energy by end-use.
Source: U.S. Energy Information Administration (2012).

Space heating	44.7%
Water heating	16.4%
Space cooling	9.2%
Electronics/computers	6.2%
Lighting	5.9%
Refrigeration	3.9%
Cooking	3.7%
Washers/dryers	3.3%
Other	6.7%
	100.0%

The Electric Power Research Institute (EPRI, 2009) carried out its own assessment of potential U.S. energy efficiency over the period 2010 to 2030. The EPRI and McKinsey studies both use the U.S. Energy Information Administration's (2008) Annual Energy Outlook to compute the benchmark forecast of U.S. electricity consumption to 2020, and they both apply a “bottom-up” methodology to compute the potential savings. While the EPRI study focuses only on electricity consumption, it still provides a useful comparison for validating the McKinsey methodology. The EPRI study does estimate a significantly lower potential of 473 terawatt-hours (TWh) in energy savings by 2020, compared to the McKinsey estimate of 1080 TWh. However, McKinsey and Company (2009b) provides a useful bridge between the two studies that accounts for the variance based on differences in the aggregate scope and technologies considered.

Table 4 shows the key differences between the EPRI and McKinsey studies. The largest factor is that McKinsey included: a wider range of public infrastructure investments (street lights, water distribution and treatment, etc.); more electronic controls and small appliances, larger building shell measures; and a wider range of industrial processes. The next factor is that McKinsey allows new technology to be deployed as soon as it becomes a positive net present value investment, whereas EPRI introduces the new technology on a slower time schedule. The third factor is that EPRI applies a “frozen technology” standard, whereas McKinsey uses data from the EIA's National Energy Modeling System to factor in anticipated increases in productivity and decreases in costs. The final factor is that EPRI uses a lower discount rate (5% versus 7% for McKinsey) and lower energy rates, which lead to higher EPRI savings estimates. In our opinion, the EPRI study provides a useful and successful robustness check for the McKinsey method and conclusions. It should be noted, however, that both the EPRI study and the McKinsey report were published in 2009, at a time when energy prices were historically high. The future trajectory of energy prices will evidently play a critical role in the incentive structure and regulatory response to energy efficiency related issues. Lower (higher) future energy prices would generate lesser (greater) push for energy efficiency investments. Indeed, several articles emphasize the vulnerability of point-in-time saving estimates to lower energy prices (Palmer et al., 2012, Gillingham et al., 2006, 2009).

[3] The International Energy Agency, IEA (2004, 2008), provides comparisons of residential energy use in the U.S. and Europe corrected for climate and measured per unit of GDP or per capita. McKinsey and Company (2007) shows similar data. Ries et al. (2009) compare energy use in the U.S., Australia, and the European Union. The ACEEE (2012) report ranks the U.S. only slightly behind the European Union in building efficiency, but this includes commercial buildings and “national efforts” on which the U.S. scores relatively well.

[4] Allcott and Greenstone (2012) provide citations to studies they consider predecessors to McKinsey and Company (2009a).

[5] The BAU benchmark is based on the Energy Information Administration's National Energy Modeling System and Annual Energy Outlook 2008.

[6] To compute the IRR, we first translated the $395 billion present value of savings into an equivalent constant annual flow of $49.7 billion based on the 12 year horizon and McKinsey's assumed 7% discount rate. The IRR is then computed based on the $229 billion present value of the investment and the $49.7 billion annual savings.

Table 2
Delivered energy, by vintage of residence, as of 2009.
Source: EIA (2012), 2009 RECS Preliminary Consumption and Expenditure Tables.

Year built	Per square foot (thousand Btu)	Per household (million Btu)	Per household member (million Btu)	Total # of housing units (millions)
Before 1940	51.7	110.2	45.6	14.4
1940 to 1949	52.0	96.8	36.4	5.2
1950 to 1959	52.6	97.1	38.1	13.5
1960 to 1969	50.2	87.9	35.8	13.3
1970 to 1979	46.9	79.0	31.2	18.3
1980 to 1989	43.5	77.0	30.7	17.0
1990 to 1999	39.8	87.7	33.0	16.4
2000 to 2009	37.1	91.4	32.4	15.6

Table 3
Delivered energy, by building type, as of 2009.
Source: EIA (2012), 2009 RECS Preliminary Consumption and Expenditure Tables.

Building type	Per square foot (thousand Btu)	Per household (million Btu)	Per household member (million Btu)	Total # of housing units (millions)
Single family	42.8	103.6	37.7	78.6
Detached	42.6	105.7	38.0	71.8
Attached	46.0	81.3	33.0	6.7
Multi-family	60.1	55.9	27.2	28.1
2 to 4 units	69.2	76.1	32.8	9
5+ units	54.6	46.4	4.0	19.1
Mobile homes	62.4	67.8	25.8	6.9

Significant research has also focused on the potential for energy-saving investments within the state of California. California has received special attention due to its large share of U.S. energy consumption, as well as the variety of innovative energy-saving initiatives created by California governments at all levels. The most detailed study, conducted by Harcourt, Brown, and Carey (HBC, 2011) under the sponsorship of the California Public Utilities Commission, analyzes the potential for energy-saving investments in California, concluding that a typical energy efficiency retrofit would achieve energy reductions of 20 to 25% in single family homes at investment costs ranging from $7200 to $15,000 per home. The HBC results for California appear generally consistent with the McKinsey and Company (2009a) study for the U.S. as a whole. A larger part of the HBC study is then focused on explaining why such productive investments have not been carried out, a topic to which we return below; see also Bamberger (2012) for policies to expedite energy efficiency investments in California.

In contrast to the above studies, Allcott and Greenstone (2012), in a recent survey paper, provide a less optimistic appraisal for the effectiveness of energy saving investments, concluding "it is difficult to substantiate claims of a pervasive Energy Efficiency Gap." They are particularly dismissive of "the massive potential savings calculated in engineering analyses such as McKinsey & Co." Their key complaint is that studies in support of energy savings, such as from the Weatherization Assistance Program and public utility programs, exaggerate the benefits because they fail to consider "unobserved factors." Their paper examines a few different possible causes of the energy gap and finds no measurable evidence of a large gap. They conclude that where savings exist, they are smaller than calculated through engineering studies. They add that heterogeneity in consumers and circumstances dictates that policies should be targeted to situations where the greatest gains are likely (Allcott and Greenstone, 2012, p. 5).

Gillingham and Palmer (2013) emphasize the breadth of factors that contribute to the ambiguity of evaluating the energy gap. They present arguments that engineering estimates may be overoptimistic as the result of hidden costs, heterogeneous customer situations, imperfect investment installation and maintenance, and the impact of risk and uncertainty on the decision (related to large fixed investments in a world with fluctuating energy prices). They also note that, beyond information and credit access barriers, behavioral anomalies may create suboptimal energy efficiency investments, thus creating potential benefits for a "nudging" approach to mitigate the behavioral factors.

A main conclusion of these works is that policy actions are constrained because we still have a limited understanding of how the behavioral responses of individual homeowners affect their energy efficiency decisions. In contrast, in our opinion (and as documented in the following sections), informational obstacles and credit access barriers are clearly evident as *observable market failures* that inhibit energy-saving investments. Mitigating these market failures thus provides a critical next step for effective public policy.[7] Nevertheless, we agree with Allcott and Greenstone that the appropriate policy will depend on the form of the market failure, and we consider their views on this topic in the following sections.

Table 4
Comparison of McKinsey and Company (2009a) and EPRI (2009) studies.
Source: McKinsey and Company (2009b). TWh = terawatt hours.

Factor of comparison	McKinsey increment in energy savings
McKinsey allows greater scope of end-uses of energy	490 TWh
McKinsey allows accelerated deployment of new technology	180 TWh
McKinsey assumes advances in technology over time	60 TWh
EPRI uses lower discount rate and energy retail rates	−120 TWh
Total	610 TWh

4. Informational obstacles to energy-saving investments in residential properties

Information is an essential input to implement an energy-saving investment if the property owner is to recognize and select productive

[7] Nadel and Langer (2012) also provide a critique of the Allcott and Greenstone (2012) paper, although based on a different set of factors.

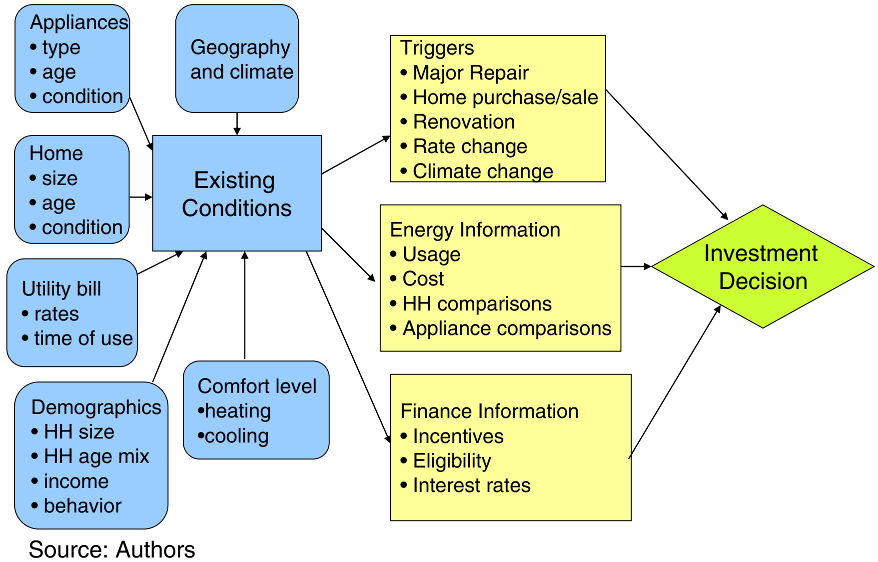


Fig. 1. Residential energy efficiency investment decision process.

investments. Information is equally important in the financing stage, since lenders will generally require evidence that the investment is productive. Significant informational issues arise in choosing energy-saving investments because the production function through which homes generate housing services can be remarkably complex and opaque to most property owners. In particular, as shown earlier in Table 1, significant energy use arises in at least three different home systems: (1) heating, ventilation, and air conditioning (HVAC), (2) sealing and insulation, and (3) electric appliances. These systems also interact, so the impact on the final energy bill and home comfort will generally not be the sum of the parts. For example, an investment in an improved HVAC system would likely reduce the return to improved sealing and insulation, and vice versa. Furthermore, there could be tradeoffs between lower energy costs and home comfort. Thus, an effective energy-saving investment plan should consider all major systems simultaneously.

Property owners, of course, do have on-the-spot mechanisms to change the home comfort level and energy bill. For example, lowering the thermostat to reduce winter heating will dependably achieve a lower energy bill, albeit with a cooler and potentially less comfortable home temperature. However, when it comes to changing the main operating systems through energy-saving investments, most property owners have little if any experience. While they can reasonably anticipate that the energy bill will fall if they improve the insulation or upgrade to energy-efficient appliances, they will generally not know if the benefits are worth the investment cost.

The typical property owner will thus require expert advice if she is to carry out energy-saving investments that are both technologically and financially efficient. Fig. 1 shows the major components of the decision-making process. High energy costs are an immediate trigger to motivate energy-saving investments. Home structure/design, geography and climate, as well as idiosyncratic behavioral household characteristics (including desired comfort level), then determine the appropriate investments. Since the very process of considering the alternatives and committing to a specific action may be unpleasant and create disutility, further triggers may still be needed before the energy-saving investment is made.

4.1. Energy efficiency, audit tools and the property owner

A variety of tools have been developed over the past decade to help the property owner sort through the decision-making complexities of energy-saving investments. Tools can be separated into two broad categories: *scoring* (e.g., ranking tools such as the EPA Home Energy Yardstick), and *assessments* of potential savings (e.g., audit tools to determine potential upgrade savings). Scoring is particularly valuable for recognizing if there is a potential gain from action. Assessment tools, on the other hand, allow property owners to evaluate alternative energy-saving investment savings and costs.

Table 5 provides an illustrative list of tools. Studies by Kim et al. (2009) and Sentech, Inc. (2010), in combination, identify and categorize 60 different building energy analysis tools, 22 of which are designed primarily for single family residences. The level of sophistication and required inputs of these tools vary substantially. The great majority distinguish among areas by climate, while other required information varies from very basic (for four of the tools) to highly detailed data input (for five tools). Some models allow the user to choose the level of data detail. Fewer than half of the models make use of existing information on energy use in the home (from utility bills, for example). Several models provide a score or rating, and the majority provide some recommendations for action.

With this abundant choice of tools, a property owner may suffer not so much from too little information on potential benefits of retrofitting as from a confusing array of information options. Our next step is to clarify how these tools work at different levels by describing in more detail a representative sample of energy audit tools, illustrating the ease or complexity of use, information inputs, and outputs. We then turn to the issue of accuracy and reliability—is this information truly useful to the property owner in making an energy efficiency investment decision, and how does accuracy affect the decision process?

4.2. User paths for audit tools

As described above, a property owner (or in some cases a renter) may pursue one of three paths to gain information on home energy efficiency and retrofit options. First, the property owner may directly access a tool (most often on-line, but computer software and hard-copy check sheets are also available). Second, the property owner may use tools provided by a utility company. Third, the property owner may go directly to a contractor, who in many cases will use an audit tool to provide more information as well as a cost estimate. These three paths are not mutually exclusive. In addition, the tools are not necessarily exclusively the product of a single entity. Often a strong set of engineering measures will be paired with a web or wireless application interface developed independently to make a product usable for individuals, utilities, or contractors; see Mills and Mathew (2012). We

Table 5
Examples of residential energy efficiency tools.
Source: Authors from Kim et al. (2009), Sentech, Inc. (2010), and individual tool websites.

Tool	Organization	For whom	Data required	Scoring/benchmark	Assessment/recommendations	Review source
Energy Star Home Energy Yardstick	U.S. EPA and DOE	Home-owner	Basic	Yes	Limited	SEEC
Home Energy Saver (HES)[a]	Lawrence Berkeley National Lab	Home-owner	Basic to detailed	Yes	Detailed alternatives and savings	Both
National Energy Audit Tool (NEAT)	Oak Ridge National Laboratory	Results aimed at state agencies, utilities	Medium	No	Detailed alternatives and savings. Focus on weatherization	Both
REM/Rate	Architectural Energy Corporation (2012)	Auditors, other organizations required to use HERS	Basic to detailed	Yes	Advice on specific features; mortgage report, appraisal addendum	Both
Targeted Retrofit Energy Analysis Tool (TREAT)	Performance Systems Development	Auditors, utilities, state and local agencies	Detailed	No	Detailed alternatives and savings based on HERS framework.	Both
Home Energy Efficiency Survey	Southern California Edison (2012)	SCE customers	Basic	Yes	Limited; with energy saving tips tailored to household	SEEC

[a] Also available in a professional form (HESPro) for contractors.

describe examples of how tools along each of these paths are used and what may be learned from them.

4.2.1. Path 1: Tools for the individual property owner (engagement tools)

Many tools are freely available from publicly supported sources and require no specialized knowledge. The range of required inputs varies widely, as does the tool output. The two examples described here represent the two ends of the spectrum.

4.2.1.1. EPA yardstick. The EPA yardstick is one of the simplest and most accessible of the energy efficiency on-line tools, ranking individual household energy use taking into account square footage and location.[8] Input for the model includes energy/fuel type, fuel usage, geographic location (zip code), house square footage, and number of occupants; see Fig. 2. The initial results include a "yardstick" that compares the home's energy use to the average home (with 5 out of 10 being the average home). The results also provide simple "what if" scenarios, showing how the yardstick changes with different types of appliances. To go further, users are referred to "home energy professionals."

4.2.1.2. Home Energy Saver (HES). Home Energy Saver (HES) is a website-based, interactive tool developed by the Lawrence Berkeley National Laboratory. LBNL has also created a more detailed assessment tool for professionals (HESPro) as well as the Home Energy Scoring Tool available on the U.S. Department of Energy (DOE) (2012) website, for asset rating.[9] HES is based on a physics/engineering/energy simulation model that allows the user to input home parameters at differing levels of detail.[10] Parameter inputs include home location (for climate), home structure (size, insulation, heating and cooling, age, occupants), and micro-foundations (windows, lighting, appliances, thermostat). With the stepwise interactive structure, the user can choose to expand the input details and refine the results. Wherever the user has not included actual house and appliance characteristics, the system enters default values based on aggregate assumptions. Tool output includes:

a) Estimated energy cost,
b) The potential savings of upgrades (including reductions in CO_2 emissions),
c) The cost to carry out the upgrades,[11]
d) Payback times and return on investment for recommended upgrades.

[8] The yardstick is accessed at: https://www.energystar.gov/index.cfm?fuseaction=HOME_ENERGY_YARDSTICK.showGetStarted.

[9] See Bourassa et al. (2012) for a full description of the Home Energy Scoring Tool. The tool can be found at http://homeenergyscore.lbl.gov.

[10] An alternative approach would be to build the model from parameters based on regression analysis that looks at utility bills as a function of building attributes, appliance features and usage, climate, household demographics, and behavioral elements.

[11] Retrofit costs, including labor/installation costs, are largely derived from the National Residential Efficiency Measures Database; see http://www.nrel.gov/ap/retrofits/measures.cfm?gId=5&ctId=30http://www1.eere.energy.gov/calculators/homes.html.

The on-line program is relatively easy to use. At any point, the user can ask for a calculation, which provides estimates of upgrade costs and savings (Fig. 3).

4.2.2. Path 2: Customer engagement tools through utility companies

Given the high costs of building new generation plants, utilities may have a strong incentive to help their ratepayers reduce the demand, although the magnitude of this incentive may be increased or diminished by regulatory policies that affect financial prospects of utilities (see Chu and Sappington, 2012 for a discussion of the regulatory role). Many utilities have histories of offering energy assessments to property owners and partnering with public sector programs to offer property owners incentives to invest in energy efficiency upgrades. Companies may offer web sites with information on specific upgrades as well as interactive web portals or tools that encourage the property owner or resident to begin exploring possible ways of reducing energy use.

As an example, San Diego Gas and Electric Company (SDG&E, a part of Sempra) makes a Home Energy Survey available to its customers. The customer logs in and provides house details on square footage, major energy using appliances, home age, and primary heating fuel; see Sempra (2012). The site produces a report that includes an overall estimate of energy use based on internal-to-the-company records of energy use at the address, as well as a scoring in comparison with like properties. The site also allows the customer to choose energy efficiency actions and provides the savings from those actions, but without estimates of the costs to undertake those investments (see Fig. 4).

The SDG&E site is comprehensive, addressing energy use, improvements, and carbon emissions. Many utilities take less comprehensive approaches. For example, Pacific Gas and Electric (PG&E) provides links to an appliance calculator, a carbon footprint calculator, and a general site describing ways to save energy. Much of PG&E's consumer engagement relates to action plans (for example, setting an energy reduction goal, reducing the temperature of water used in the clothes washer, etc.) Tool output is provided for many different individual options, rather than for a consolidated plan of action.

4.2.3. Path 3: Tools for contractors

Certification is a primary distinguishing feature of tools for contractors. For example, the state of California certifies energy audit tools, with the state entity CalCERTS effectively acting as a gatekeeper.[12] The California Energy Commission has developed the Home Energy Rating System (HERS) to rate homes in California; see http://www.energy.ca.gov/HERS. Other tools based on different HERS standards are in use

[12] See https://www.calcerts.com/About_Us.cfm. In addition, through CalCERTS, the state has developed its own software.

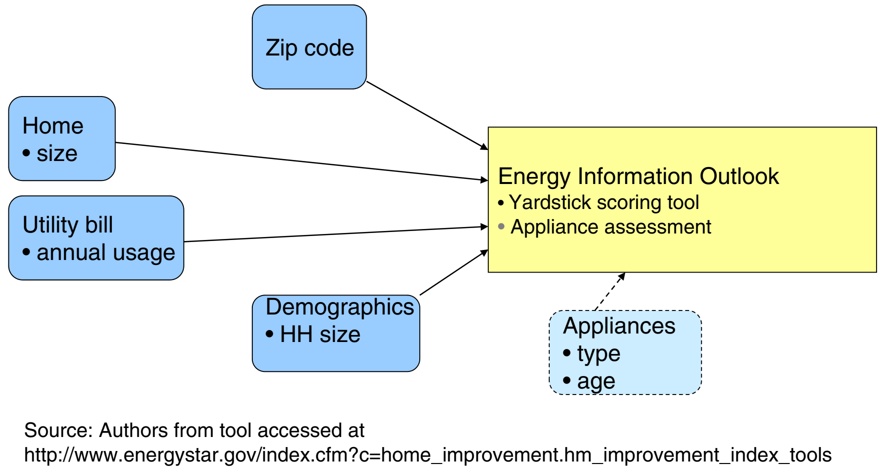


Fig. 2. EPA Home Energy Yardstick.

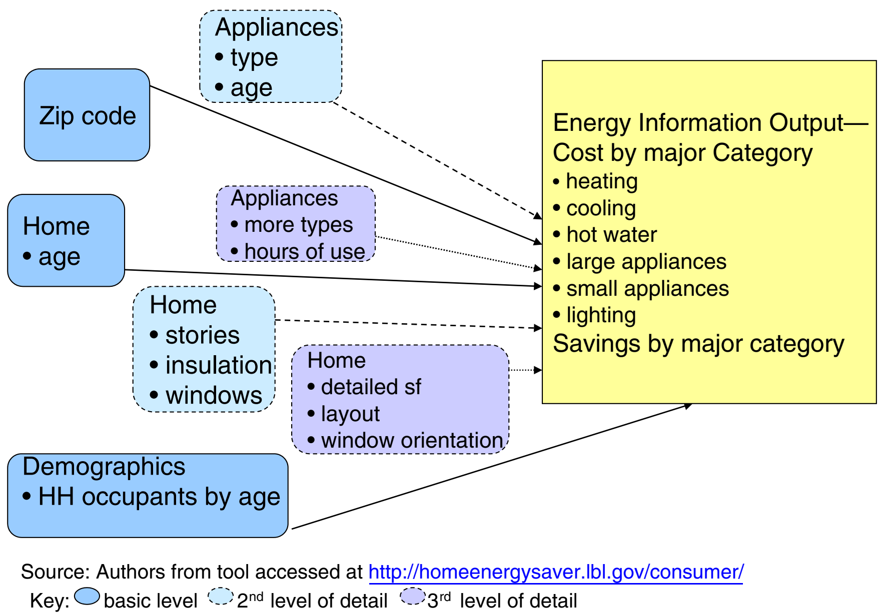


Fig. 3. Home Energy Saver (HES).

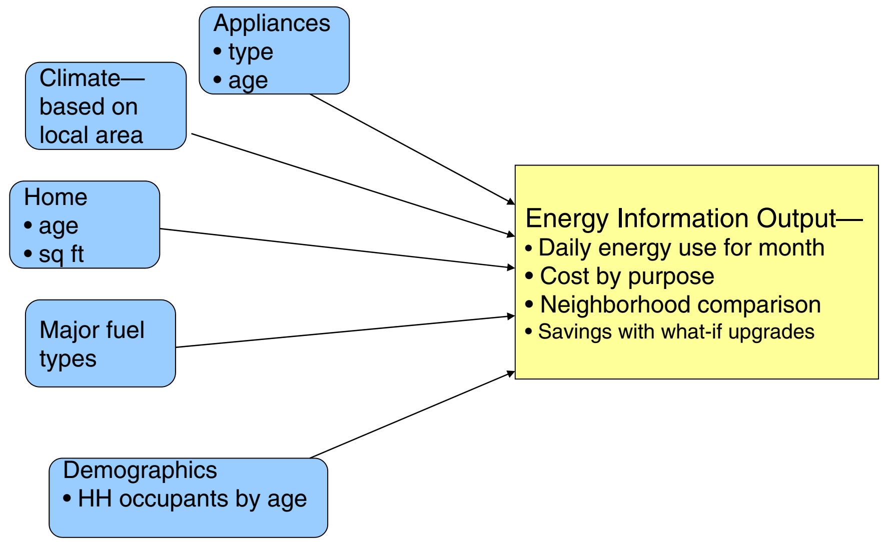
throughout the country. In addition, DOE approves specific tools for assessments related to weatherization programs; see Oakridge National Laboratory, 2012. Furthermore, tool providers may require that users have certified builder qualifications before providing access to the tool.

We now describe two tools designed for contractors, namely TREAT and CakeSystems. TREAT is a DOE approved plan which was reviewed by both SEEC and Sentech and has an accessible description on the web. CakeSystems is designed to require less complex inputs, and its underlying energy model, SIMPLE, has been identified in studies discussed later in this paper as having a high level of accuracy.

4.2.3.1. TREAT. The Targeted Retrofit Energy Analysis Tool (TREAT) is a computer software package that is promoted as "the only energy audit software approved by the DOE for all residential housing types—including multifamily;" see PSD Consulting, 2012. There is a cost of several hundred dollars to purchase the software, but there are no training or licensing requirements, and training modules are provided. Specialized measurement equipment is needed to fully implement the tool. Model inputs are summarized in Fig. 5. Applying baseline customer and building information, the model will estimate energy use, but it is also possible to reconcile the results with actual usage data. If the user selects the specific improvements to be assessed, the model will then produce a report of proposed energy efficiency improvements and payback period.

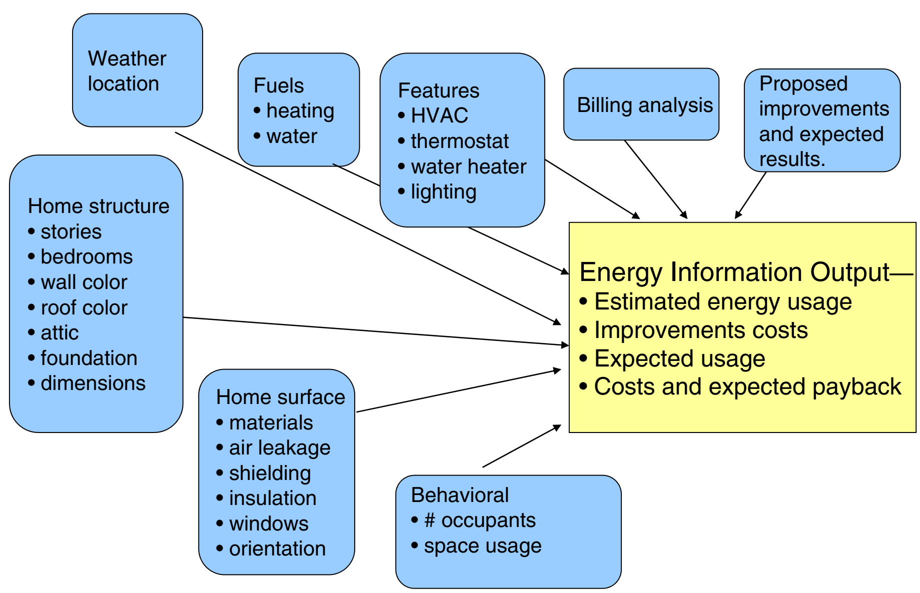
4.2.3.2. CakeSystems. CakeSystems (earlier known as the Energy Performance Score software platform or EPS) is based on the SIMPLE algorithms that were developed by a nationally recognized energy expert, Michael Blasnik, in conjunction with Earth Advantage Institute in Oregon. Detailed documentation of the tool is not available, but according to the company material, "SIMPLE is a heat loss model utilizing best practices for considerations such as modeling duct loss regain and air infiltration […] trued up using empirical data."[13] The CakeSystems tool is now used primarily in partnerships between a utility company and individual contractors to assess the potential for energy efficiency improvements in the home.

[13] From printed material provided by Andrew Healy of CakeSystems.



Source: Authors from tool accessed at http://www.sdge.com/residential

Fig. 4. San Diego Gas & Electric.



Source: Authors from http://www.psdconsulting.com/sites/www.psdconsulting.com/files/emodules/Intro%20to%20TREAT/Intro%20to%20TREAT.html

Fig. 5. TREAT.

CakeSystems consists of three modules, which can be used either as a full service package or individually; see CakeSystems, 2012. The core audit module (used for energy assessment in the home) requires CakeSystems training which is available only to users with building science credentials such as BPI certification. Inputs require data ranging from simple information on appliance and fuel types to measurement of air leakage, which requires specialized equipment used by trained personnel. The tool uses no occupant behavior inputs. See Fig. 6.

Each potential problem area is noted and rated on a scale from very poor to excellent. The software user can enter potential improvement measures (for example, existing incandescent light bulbs where compact florescent light (CFL) bulbs would be an option—see gray box in diagram) and can select the best mix of improvements from a list of recommendations, based on the auditor's professional judgment. The final report provides estimated energy savings (in kWh and dollars) and reduction in carbon output and compares results to a scale showing the state's average and goals.

CakeSystems has two other modules. The HOME Portal is an interface designed to guide the homeowner, step-by-step, through the audit-to-retrofit process. The portal is customized to meet the goals of the service provider (for example, introducing the homeowner to energy efficiency programs offered by a utility company, or linking the homeowner to an engagement tool and/or a contractor). The final module, the Proposal Generator, allows home performance contractors to present the specific cost and expected savings of different upgrade packages.

4.2.4. Impact of audit tools

A survey of energy auditors (Palmer et al., 2013) found that audits were used by a very small share of the market at the time of the study, perhaps between one and five percent. Company respondents

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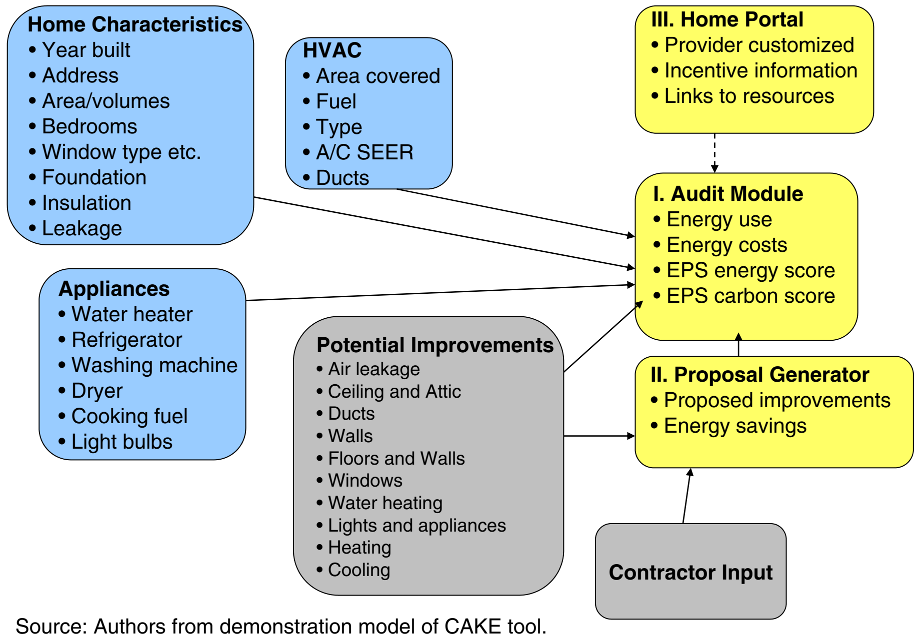

Fig. 6. CakeSystems.

felt that the majority of households did not know about the existence of audits or did not understand what an audit could provide. For many, the cost of an audit was a barrier to getting the information, and for those who paid for the audit, costs were an important factor in determining which retrofits would be implemented.

4.2.5. Potential stumbling blocks

The paths described here and the tools within them can be influential in leading homeowners to energy retrofits. However, at least three issues arise once a proposal is in hand. First, we must ask if the tools are dependable. Is the information generated reliable enough for the property owner to make a retrofit decision and for a lender to choose to provide financing? Second, once a set of changes is identified, the property owner or renter may then need to take action in multiple directions, because the saving actions (new appliances, home structural changes, household equipment) generally cannot be accomplished by one provider. Third, due to the idiosyncratic features of individual homes and/or occupants, the effectiveness of any particular energy efficiency investment may vary widely, even among apparently similar homes. Behavioral elements embedded in the tool can significantly reduce the variance, but also may make the results less generally applicable as a way of estimating advantages from a type of improvement.

In the next section, we review the debate concerning tool accuracy and discuss our reasons for relying on the HES tool for our analysis.

4.3. Review of the accuracy and reliability of energy audit tools

The accuracy, internal consistency, and reliability of these energy audit tools are critical if they are to be useful in the decision-making and financing steps for energy-saving investments.[14] However, given the range and complexity of the tools on offer, and many confounding behavioral, idiosyncratic, household responses, it is not a trivial task to compare them or evaluate their accuracy.

The tools all apply simulation software models based on energy physics and engineering relationships. The more advanced tools have detailed interactive components that help gauge behavioral issues, as well as allowing more detailed technical inputs. Behavioral elements include the temperature setting for the heating and cooling equipment, computer and appliance use, etc. Detailed technical inputs include parameters such as the efficiency metrics of HVAC systems and appliances and the effectiveness of insulation and sealing.

The level of complexity in terms of detailed, customized, inputs and outputs varies with model purpose. Models built for designers are much more complex and focus particularly on structural elements, while the Lawrence Berkeley National Laboratory's (LBNL) (2012) Home Energy Saver (HES), designed for homeowner use, allows alternative levels of input detail, for both technical data and behavioral factors. Models built for energy audits by contractors are not necessarily more complex than homeowner-oriented models (in fact some have a simpler underlying design), but may require specialized equipment to make more accurate measures of factors such as air flow through the house.

We reviewed the accuracy and credibility of the energy audit tools and models based on several factors. The literature (e.g., Earth Advantage Institute and Conservation Services Group, 2009; Sentech, Inc., 2010; Polly et al., 2011a) defines predictive accuracy in terms of the ex-ante energy consumption predictions of these tools relative to actual utility bill data.[15] The models generate energy bill predictions based on technical and behavioral user inputs, default assumptions in case of missing inputs, climatic assumptions based on location, and costs from various databases. The predictive accuracy is therefore a function of the accuracy of all these individual elements. The models also generate retrofit costs and corresponding savings. Therefore, predictive accuracy involves both the ex-ante bill prediction, as well as the savings generated between pre- and post-retrofit bills.

We also take into account whether the model is transparent in terms of displaying its internal structure, its default assumptions, and the path from input to outputs. It is also important to give weight to responsiveness and revisions based on new data, identified bugs, and user

[14] The importance of transparency and accuracy in figuring out the component costs of individual end-uses in a utility bill is nicely illustrated by Brown (2001). As she argues, “For example, residential consumers get a monthly electricity bill that provides no breakdown of individual end-uses. This is analogous to shopping in a supermarket that has no product prices; if you get only a total bill at the checkout counter, you have no idea what individual items cost. Supermarkets, of course, have copious price labeling; household utility bills, in contrast, do not.”

[15] An alternative criterion would judge model accuracy in terms of the predicted change in usage from a retrofit relative to the actual change. For this measure to be operational, a control for the behavioral responses of the residents would be necessary.

complaints. The range and reliability of data sources is yet another element that will have a bearing on accuracy. Our evaluation also relies on assessments by peer reviewers with greater engineering background than we have, and on interviews and conversations with energy professionals to gauge the credibility and predictive accuracy of these models.

Several studies have analyzed the predictive accuracy of tools. Earth Advantage Institute and Conservation Services Group (2009) reviewed the accuracy and reliability of a range of models using a metric similar to the "miles per gallon" measure for cars, to compare energy efficiency among homes for a standard usage pattern. With that objective in mind, they reviewed over 100 software models, and selected four, two based on Home Energy Saver (demanding two different levels of inputs—HES-Mid and HES-Full, which they refer to as the "most complete level of HES"), a model which they call "SIMPLE" (later developed into the EPS Auditor Pro), and REM/Rate, a widely used HERS (Home Energy Rating System) accredited model. The results are summarized in Table 6.

The developers of the HES model contested the methodology of the Earth Advantage study and the accuracy of its results (Mills and Parker, 2012). Parker et al. (2012), in a paper discussing accuracy of the HES model, identify some of the hazards of comparisons across models, including reliance on default settings rather than known conditions, inconsistent weather normalization methods, and reliance on absolute values of errors and average outcomes. Their comparison of the results of a single assessment model over different locations and using different degrees of detailed inputs reached quite a different conclusion from Earth Advantage Institute and Conservation Services Group, 2009. While Earth Advantage concluded that simpler models are as accurate as more expensive, complex ones, Parker et al. find in comparing predicted and actual savings, that greater detail produces greater accuracy, and that the "value" of this accuracy compared to the time required to create the more detailed result depends on the purpose of the evaluation.

The Sentech study cited in Section 4.1 reviews several tools that evaluate single-family residential buildings. The primary conclusion of this study is that, "no one tool fully captures all the characteristics currently thought to be important to a national home performance assessment program: low cost, universal availability, ease of use with reasonable input requirements, conformance to a universally accepted accuracy standard, and the ability to generate improvement recommendations and associated costs."

While Polly et al. (2011a) do not review tools individually, they develop a methodology for improving the accuracy of simulation tools through improved data collection procedures, simulation protocols (default assumptions), and testing procedures. They note that there is a perception that tools over-predict, due to faulty inputs and software deficiencies (as well as complex interactive elements in an individual house), but also because behavioral responses are probably underestimated. Relying on categories developed by Judkoff and Neymark (2006) and Berry and Gettings (1998), Polly et al. (2011a) identify the following groups where errors and inaccuracies can creep in: a) Structural Inputs, b) Occupant Behavioral Inputs, c) Geographic Inputs, and d) Software and Coding Errors.

The predictive accuracy issue and comparability of tools is also analyzed by Holladay (2012) in a meta-review. The study notes that the inaccuracies of these models may relate to incomplete information concerning idiosyncratic behavior (the missing variable in the models) of households/consumers. The author also references five studies that found that the measured savings from retrofit work equal 50% to 70% of predicted savings.

The jury is still out concerning model accuracy, but the facts are much clearer on other attributes such as accessibility, the transparency of the model structure, and updating. The EPS Auditor Pro (now CakeSystems, described in Section 4.2), for example, is accessible only by certified BPI analysts who then need to complete a multistage training program that includes a 5-hour online class, a 3-hour Webinar, and a final exam. Many models have other barriers in terms of user-friendliness, accessibility, transparency, and required equipment. This is why many of the major recent policy-oriented studies rely on the HES tool created by LBNL, which the McKinsey and Company (2009a) Report rates positively on those attributes.

The LBNL HES model has the advantage that it is well calibrated in terms of engineering data and is continuously updated. It also has options to add data on behavioral aspects, such as the detailed temperature settings of the thermostat. Furthermore, the LBNL model is quite transparent—the inputs are documented and easily available on the web, as are all their data sources and methodology. It is also completely transparent in an operational sense, i.e., the user receives detailed savings estimates based on precise inputs, allowing users to evaluate alternative assumptions. In view of these attributes, we use the HES tool in the next section where we carry out a NPV ranking and benchmarking exercise of individual retrofit elements.

Overall, it is clear that much more remains to be done to improve the accuracy of these tools. Since a significant source of inaccuracy may be behavioral/idiosyncratic factors that are very difficult to calibrate, it is also necessary to carry out randomized controlled experiments and surveys of households, both those carrying out retrofits and those that are not. The need for greater efforts in this direction is being increasingly recognized. For example, Polly et al. (2011b) note "efforts continue at NREL (National Renewable Energy Laboratory, 2012) to assess and improve the accuracy of analysis tools by developing new and improved models and validating software predictions against measured data." They go on to say, "Energy use and savings predictions in this and future studies should be compared to measured use and savings from laboratory tests, field tests, and pre- and post-retrofit utility bill analysis."

4.4. NPV ranking and benchmarking exercise

We now employ the HESPro model to rank the productivity of individual energy retrofit elements. To conduct this exercise, five cities were chosen from around the country—San Francisco, Denver, Houston, Miami and Boston. Since HESPro works on zip codes, we chose a representative zip code with a sizeable resident population from each urban area. We chose the Quick Input format of the HESPro tool since it provides default inputs for a "typical house", including the year of construction and whether it has an air conditioner.[16] However, as shown in Table 7, we overrode the defaults to standardize certain housing characteristics across the cities, including size/dimensions, occupancy, and year of construction. The HESPro model then calculated the annual energy consumption for our standardized house in each of the cities, measured in kilowatt hours (Electricity), therms (Gas), and dollar amounts.

Table 6
Energy performance score report 2009, total energy (MBtu) for 190 homes.
Source: Earth Advantage Institute and Conservation Services Group (2009, Table 3.5).

	REM/rate	SIMPLE	HES-Mid	HES-Full
Mean actual use	101	101	101	101
Mean predicted use	133	84	157	119
Mean error	32	−17	48	18
Mean absolute error	37	27	75	28
Median absolute error	31	21	66	23
Mean absolute percent error	43.7%	25.1%	96.6%	33.4%
Median absolute percent error	31.1%	24.0%	73.8%	21.8%
Percent of homes with accurate prediction (less than +/−25%)	43.2%	51.6%	19.5%	53.7%
Percent of homes with large error in prediction (larger than =/−50%)	31.6%	7.9%	60.5%	21.6%

Note: absolute signifying no distinction between +ve error or −ve error.

[16] For example, the default year of construction in San Francisco is 1968, whereas in Miami it is 1975.

Table 7
Standardized housing and energy characteristics across cities.

Characteristic	Standardized assumption
Year built	1968
Number of adults 14–64	2
Number of children, 6–13	1
Stories in structure	1
Square footage	1800
Dimensions	72 ft by 36 ft
Foundation type	Slab on grade
Roof insulation	R-0
Ceiling insulation	R-11
Attic type	Unconditioned attic
Wall insulation	Don't know/no
Thermal distribution	Insulated ducts
Windows	Double pane clear aluminum
Water heater	40 gal/natural gas
Heating equipment	Central gas
Boiler pipe insulation	None
Cooling equipment	Central AC
Refrigerator	1
Clothes washer	Yes

The model also generates upgrade recommendations and calculates yearly savings and costs for each specific retrofit. The costs are calculated on the basis of two types of upgrades. For the case of purchasing appliances, the savings/returns calculations are based on the marginal cost of an efficient appliance over and above the cost of an inefficient one. This method will underestimate the actual cost when an appliance has many more years of useful life. On the other hand, when an upgrade does not involve replacing an existing feature, for example sealing ducts and air leaks, or insulating the attic or walls, the total cost of the retrofit is calculated.

Using the model's cost estimates and annual energy savings for individual retrofit measures, we generated a ranking of savings–cost ratios across the five cities (see Fig. 7A to E).[17] In addition to identifying the retrofit measures with the highest returns, the results also serve as a robustness check on the internal consistency of the model. The investments with the highest returns are similar across the country and include installing and using programmable thermostats, compact fluorescent lights (CFLs) in high-use fixtures, and Energy Star appliances.

There are of course climatic variations. Reducing air leakage through improved sealing and insulation has particularly high returns in colder climates, such as Boston and Denver, whereas a "cool roof" is viable in Miami and Houston. [18] In colder climes with significant heating requirements, the latter in fact delivers a penalty. For example, in a standardized Boston home, a programmable thermostat generates annual savings of $364 for an additional cost of just $85, reducing duct sealing leakage to 6% delivers a sizeable yearly savings of $468 for a total cost of $890, but a cool roof delivers negative savings of $25 for an additional cost of $186. In Miami, however, a cool roof for the same cost generates positive savings of $74 annually.

Table 8 shows costs and yearly savings for selected energy efficiency upgrades for the five cities. While the costs are assumed to be the same across cities in this model, the savings differ by climate related usage. Looking at savings relative to total costs, it is evident that there are significant opportunities in these upgrades. New appliances and improved sealing and insulation, however, involve sizeable expenditures, so financing availability and costs could become a significant factor. Our next section deals with this potential barrier.

[17] We use a savings–cost ratio as a simple indicator of the financial viability and relative speed at which the homeowner would recoup costs. This was calculated by the authors. The HES model provides measures of payback time and return on investment, but those require additional assumptions. As a comparative measure and a simple heuristic, we chose the ratio approach.

[18] A cool roof has high solar reflectance thereby reducing heat transfer to a building. At the same time it has high thermal emittance, i.e., it radiates absorbed energy.

4.5. Benchmarking solar photovoltaic systems

Solar photovoltaic (PV) systems are currently the predominant way of providing renewable energy to both residential and commercial property owners in the U.S. A successfully installed Solar PV system will produce electricity (kWh) and re-sell it to a utility ($/kWh) that provides local electrical distribution at specified rates. Customers have a variety of methods to pay for the large up-front costs of purchasing and installing a Solar PV renewable energy system. Two key differences between the energy retrofit markets described in the preceding sections and the Solar PV market are that the energy production (in kWh) for each PV module can be measured exactly and the cost of installation can be much more uniformly measured and priced for consumers. The availability of standardized metrics in the Solar PV market versus the lack of such metrics in the rest of the energy retrofit market has created important differences in their relative market success.

5. Financing energy-saving investments

Given the 19% annual IRR on residential energy-saving investments estimated by the McKinsey and Company (2009a) study discussed earlier, it might seem that financing would generally not impede projects, as long as the annual borrowing costs were below that high level.[19] However, there are at least five reasons why financing terms may still impede energy-saving investments[20]:

1) Property owners with weak credit records may have no access to loan markets at all.
2) Non-interest rate loan terms, such as short maturities, may be unacceptable to borrowers.
3) McKinsey's 19% IRR is an average over all residential projects, so a significant percentage of the available projects will have lower IRRs and thus will require financing costs below, possibly well below, 19% if they were to proceed.
4) Property owners are likely to be risk averse in evaluating energy-saving investments, and would thus require borrowing costs below the IRR before they will make the investment. "Ambiguity aversion"—reflecting uncertainty over the distribution of project returns—would require a still lower borrowing rate.
5) Property owners face a large number of "transaction costs," including the time and expense to find and monitor contractors and arrange the financing. The interest cost of borrowing must be low enough to offset these costs.

It is thus plausible that borrowing costs in the single-digit range will be essential if property owners are to carry out a significant volume of energy-saving investments. Putting aside government subsidized loans, borrowing rates this low can generally be achieved only with *secured loans*, or with special loan contracts that allow the property owner to make a *highly credible commitment to repay the loan*.

The immediate question is thus how to finance energy-saving investments with secured loans or with comparable loan contract features. For newly constructed homes, the financing of energy-saving investments is generally not a problem because the costs of such investments are embedded in the home purchase price and thus are automatically included in the mortgage amount. The FHA and VA also offer

[19] This assumes that funding is available for the same maturity as the energy-saving benefits and that the time pattern of the loan payments and savings are compatible.

[20] This is not to say that providing adequate financing mechanisms would immediately and necessarily create the full range of energy-saving residential investments, such as proposed in McKinsey and Company (2009a), to be carried out. As we have indicated in the previous section, a wide range of informational issues also have to be solved. The limitations of financing as "the" solution to expedite energy-saving investments are discussed more fully in Borgeson et al. (2012).

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special programs for Energy Efficient Mortgages (EEMs) that allow large qualifying payment-to-income ratios on homes that are certified as energy-efficient through a program such as Energy Star. Table 2, discussed earlier, confirms that new homes have steadily incorporated more effective energy-saving technologies over time.

In contrast, the mortgage market is not this accommodating to owners of older existing homes. It is possible to refinance an existing mortgage and add the energy-saving investment cost to the loan balance in the fashion of a cash-out refinancing. However, this requires that the property appraisal reflects the value of the investment or that the property owner otherwise has sufficient excess equity in the home to meet the standards for a larger mortgage. Furthermore, significant fixed transaction costs are associated with mortgage refinancings, so refinancing solely for the purpose of funding an energy-saving investment is unlikely to be economic. To be sure, savvy property owners may find opportunities to carry out energy-saving investments at the same time they are refinancing a mortgage due to falling interest rates. In addition, Fannie Mae now offers an Energy Improvement Mortgage that allows the costs of certified energy-saving investments to be included in a new mortgage at the time of an existing home purchase. Nevertheless, in the absence of government subsidies, it appears that first-lien mortgages will not be a dependable source of funding for the large number of existing homes that require energy-saving retrofits. Brown (2009) and Fuller (2009) both come to a similar conclusion.

Home equity loans or other forms of second mortgages provide another instrument through which property owners may use a secured mortgage to fund energy-saving investments. Indeed, such loans provide the funding for many types of home improvement projects. However, the interest rates on such loans will necessarily be higher than on primary mortgages, reflecting the junior status of the second lien. The borrowing rate will be higher still for property owners with less than sterling credit ratings, assuming the loan is available at all. Finally, property owners must have sufficient equity—property value in excess of the first mortgage balance—for lenders to consider a second mortgage loan. Indeed, this is a requirement on the new FHA 2nd mortgage program, called PowerSaver, which is in the midst of a two-year trial. Overall, given the current state of depressed house prices in the United States, it appears that 2nd mortgage programs also will not soon be a dependable source of funding energy-saving investments.

Fortunately, these limitations of standard mortgage instruments—either as first or second liens—have been well recognized, and a variety of new loan mechanisms have been developed to fund energy-saving investments. To various extents, they also deal with some of the underlying theoretical issues in economics and finance mentioned above—such as credit rationing, the heterogeneity of credit constrained borrowers, the risk averse nature of most borrowers, the difficulty of scaling-up, and high transaction costs, all of which result in higher borrowing rates and hence much lower investments in energy efficiency projects. In broad categories, the new loan mechanisms are *energy purchase contracts*, *on-utility-bill loans*, and *on-property-tax-bill loans*. We now discuss these in turn.

5.1. Energy purchase contracts

Energy purchase contracts have the common feature that a third party generally makes the investment decision and covers the capital costs. The property owner then compensates the third party, the form of this compensation differentiating the various plans.[21] Energy purchase contracts, however, have the drawback that they must reach a sufficient size to be cost effective, which has limited their current use; see Fuller (2009). Solar installations are one area to date in which such contracts have been applied in homes; see Section 5.4 below.

[21] See Larsen et al. (2012) for a full discussion of energy purchase contracts and of the energy service companies that provide them.

5.2. On-utility-bill financing and repayment plans

On-utility-bill (hereafter just On-Bill) plans come in two basic varieties. On-Bill *financing plans* require the public utility itself to provide the capital for the loan financing. On-Bill *repayment plans* raise the capital for loan financing from third parties, although the utility still collects the loan payments. In both cases, the key feature is that the property owner commits to make payments on a loan for an energy-saving investment in tandem with the standard utility bill payments for energy.[22] Partial payments may be prorated across the loan and energy components, and the utility may commit to apply its standard collection methods, including turning off the power if the property owner should become sufficiently delinquent. If the property is sold, the loan payment obligation generally transfers to the new owner, although there may be options for the seller to prepay the full loan at that time. Overall, On-Bill plans are a significant step forward in allowing the property owner to make a credible commitment to repay the loan.

A particularly attractive feature of On-Bill plans is the potential for *bill neutrality*, meaning that the total utility bill remains the same or falls because the reduction in energy costs equals or exceeds the loan payments. Bill neutrality cannot be guaranteed, however, because property residents may well opt for a more comfortable environment, for example by maintaining the home at a cooler level during a hot summer due to the more efficient system. This "rebound" factor is sometimes considered a negative dimension of energy-saving investments, but this is incorrect. When the cost of any good falls, consumers always have the choice of distributing the cost savings over all of their consumption expenditures (the "income effect" in microeconomic theory) and/or consuming more of the particular good (the "substitution effect" in microeconomic theory). The substitution effect—keeping a home more comfortable when the cost of doing so has fallen—is properly considered a benefit of the success of the energy-saving investment.

There are, of course, potential pitfalls to On-Bill payment plans, three of which are:

- The penalty of turning off a household's power if it defaults on its loan may be considered too harsh. State consumer protection laws may not allow it, and in any case utility companies and public utility commission may be reluctant to receive the adverse publicity.
- The transfer of the repayment obligation to a new owner upon sale of a property may also face legal impediments. The plans must therefore be carefully crafted in this regard.
- Public utility funding for On-Bill programs is limited, and greater use of these repayment plans will be essential if the concept is going to reach a significant scale.

The Environmental Defense Fund (EDF) has become a major advocate of On-Bill repayment plans as a means to substitute private capital for public-utility funding. Copithorne and Fine (2011), from EDF point out further advantages of On-Bill repayment plans including the potential to provide:

a) longer term loans, thus better matching the life of the energy-saving in investment;
b) relatively low interest rates, assuming the experience of low default rates continues;
c) customization for individual multifamily units, thus avoiding the split incentive problem.

[22] In some states, it may be important to state the payments as part of an energy tariff, and not explicitly as loan payments, for otherwise the utility might become subject to restrictive regulations as a lender.

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5.3. PACE plans

Property Assessed Clean Energy (PACE) plans provide an alternative mechanism through which the property owner can make a credible commitment to repay the loan. The key here is that the loan payment obligations become part of the property tax bill, and the property owner commits to make the loan payments in tandem with the standard property taxes. Partial payments may be prorated across the loan and tax components, and the municipality may commit to apply its standard collection methods, including foreclosure on the property if the owner becomes sufficiently delinquent; see Zimring and Fuller (2010) for other options if payments become delinquent. If the property is sold, the loan payment obligation transfers to the new owner, although there may be options for the seller to prepay the full loan at that time; see Coughlin et al. (2010) for a more complete discussion of transferring PACE assessments.

PACE plans are created by a local government unit—typically a county or municipality—which sets the detailed terms and conditions and provides the initial capital for the loans. All PACE plans include requirements to ensure that the expected present value of the savings exceeds the present value cost of the energy-saving investments. Under this condition, the investment is productive and it would be expected that

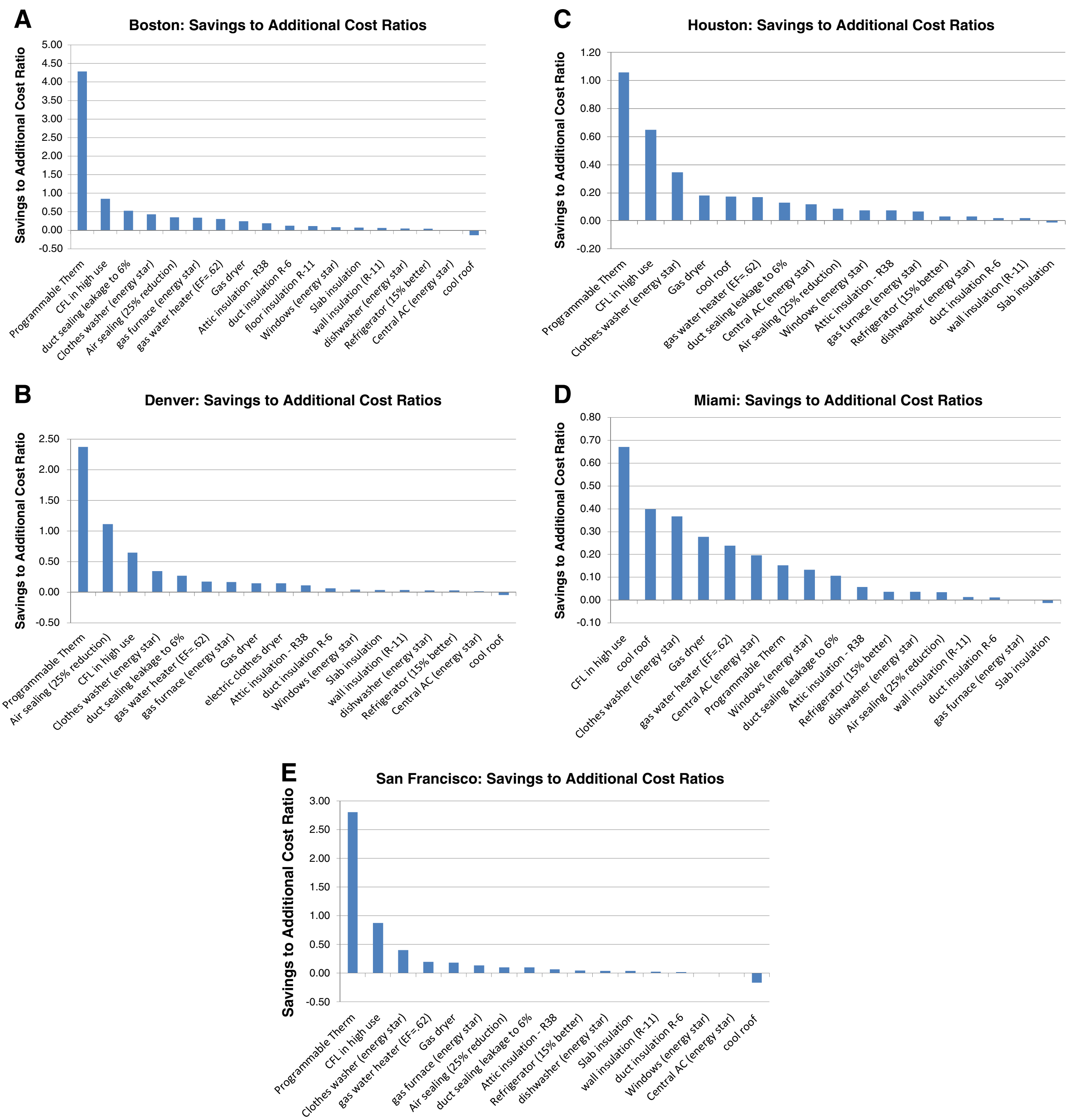

Fig. 7. A. Boston: Savings to additional cost ratios. B. Denver: Savings to additional cost ratios. C. Houston: Savings to additional cost ratios. D. Miami: Savings to additional cost ratios. E. San Francisco: Savings to additional cost ratios.

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Table 8
Costs and savings (in $) from selected energy efficiency upgrades.

		Clothes washer[a]	Gas water heater[a]	Gas dryer[a]	Air sealing[b]	Duct sealing[c]
	Assumed Cost =>	90	180	340	850	890
Boston	Yearly savings	39	55	83	299	468
	Savings/cost	0.43	0.31	0.24	0.35	0.53
Denver	Yearly savings	31	31	50	125	240
	Savings/cost	0.34	0.17	0.15	0.15	0.27
Houston	Yearly savings	31	30	62	74	115
	Savings/cost	0.34	0.17	0.18	0.09	0.13
Miami	Yearly savings	33	43	94	29	95
	Savings/cost	0.37	0.24	0.28	0.03	0.11
San Francisco	Yearly savings	36	35	63	87	87
	Savings/cost	0.40	0.19	0.19	0.10	0.10

[a] Implies switching to energy star clothes washer, premium efficiency water heater, or to a gas dryer from electric dryer.
[b] Air sealing involves reduction in air leakage of 25%; costs are total, not additional.
[c] Duct sealing involves reducing leakage to 6% of total air flow; costs are total, not additional.

the property value would rise by at least as much as the loan balance. Furthermore, loan payments could be organized so that the energy savings equal or exceed the loan payment obligation, a version of bill neutrality. This should provide alignment of the interests of all the involved stakeholders:

1) Property owners have every incentive to ensure that the benefits exceed the costs as they make the investment and take on the obligation to repay the loan.
2) Sponsoring local governments will recognize that PACE obligations are parallel with their own property tax receipts, and for this reason PACE programs generally impose requirements to ensure the investments are productive.[23]
3) PACE loan payments will generally be sold by the municipality to third-party investors. These investors must expect the investments to be productive and the loans to be repaid. This force will become even more active if programs such as WHEEL succeed in securitizing PACE loans; see National Association for State Energy Officials (2012).

In summary, the incentives of the three participants in a PACE program are fully aligned to insure the projects are productive and the loans will be repaid.

PACE plans can be applied to either residential or commercial property. By 2010, a number of PACE programs, both commercial and residential, had started and appeared to be successful on first look. However, in a Directive of February 28, 2011, the Federal Housing Finance Agency (FHFA) directed Fannie Mae and Freddie Mac (hereafter the Government Sponsored Enterprises, GSEs) "not to purchase mortgages affected by first-lien PACE obligations." This reiterated an earlier FHFA Statement of July 6, 2010 directing the GSEs to "limit their exposure to financial risks associated with first-lien PACE programs." The FHFA concern was that a PACE lien has priority over a first-mortgage lien, and in the case of a foreclosure initiated by a GSE, it was possible that the GSE recovery would be reduced by the amount of the PACE lien. On this basis, the FHFA concluded that the PACE programs present a significant risk to the safety and soundness of the GSEs.

Not surprisingly, legal objections were filed against the FHFA policy. As a result, the FHFA reopened the discussion period and offered three alternative means of mitigating the financial risks that it believes PACE programs pose for the GSEs.[24] Alternatives 1 and 2 impose conditions that effectively require that PACE loans be risk-free, an underwriting standard the FHFA and GSEs obviously do not follow in their main business of providing guarantees against mortgage defaults. Enacting these alternatives would effectively prohibit PACE programs. Alternative 3 is more feasible and the comments of a number of existing PACE programs indicate they believe they could operate within the requirements of this alternative. Key features of Alternative 3 include[25]:

- The property owner is current on the mortgage and has suffered not more than one instance of mortgage payment delinquency over the past three years.
- The PACE investment is validated in an audit or feasibility study performed by a certificated contractor under a program such as HERS (see discussion above), which confirms that the total energy and water cost savings are expected to exceed the total investment cost.
- The total amount of PACE assessments for a property shall not exceed 10% of the appraised property value and the property owner shall have equity in the property of not less than 15% of the appraised value.
- The maximum term of the PACE assessment shall be no longer than the expected useful life of the PACE improvements.

At this writing, we are waiting for the FHFA decision.

As an innovative program for energy-saving loans, there is no doubt that PACE programs will evolve into more productive forms, and the GSEs and FHFA can play an important and constructive role in encouraging such improvements. Perhaps most importantly, by allowing PACE loans to be made on properties with GSE-guaranteed mortgages, more data will become available and research can investigate the specific conditions that could be included within PACE programs to ensure that the loans are as productive as possible.

5.4. Financing mechanisms for Solar PV

Solar PVs are a distinct subset of energy efficiency investments, both operationally and in terms of their financing. A solar installation is not a replacement; it is a new installation and it has standardized metrics in terms of the costs per square foot for equipment and installation, and how much electricity the installation will generate. The three most common mechanisms used to finance Solar PV systems are cash payments, Solar Power Purchase Agreements (PPA), and Solar Leases. Solar PPAs and Solar Leases are especially popular financing mechanisms because Solar PV systems allow for clearly measureable relative costs and

[23] The need to require productive investments is also reinforced by local government concern that the ratings on their municipal bonds could fall were the rating agencies and bond investors to come to believe that the PACE programs were raising the likelihood of a municipal bond default.
[24] The three FHFA alternatives are provided in Federal Housing Finance Agency (2012). The discussion in the remainder of this section is based on Jaffee (2012), a comment offered to the FHFA concerning their proposal and alternatives.
[25] The full details of the FHFA Alternative 3 cover almost a full page of the Federal Register and include 29 separate paragraphs and sub-paragraphs.
[26] See, Bloomberg New Energy Finance — Ted Hesser, Senior Market Analyst, Presentation on Renewable Energy.

benefits to the consumer as well as metrics that allow for a measureable return to investors. PPAs and Solar Leases are usually combined with the Federal Renewable Energy Investment Tax Credit (ITC) program, and have thus provided a key source of funding for the rapid growth of the Solar PV system market over the past several years.[26]

Cash payment is made by the property owner to the solar installation company to pay for the purchase and installation of a Solar PV system. The property owner becomes the owner of the Solar PV system and thus is eligible for receiving all Federal (30%), state (up to 20%), utility, and other local solar grants (1–10%). In this structure, the property owner owns and maintains the Solar PV system via independent solar contracting companies who are paid on an "as needed" basis.

The *Solar Power Purchase Agreement* (*PPA*) is an unsecured agreement to purchase the electrical power produced from an installed Solar PV system on an individual property. With a PPA, the price per kWh that the customer pays is set in a negotiated 5–20 year agreement upfront. The PPA often allows the customer to purchase the system after five years and includes a locked in "spread" between the current and contracted utility rates. This measure determines the amount that the customer will pay the solar finance company per kWh produced.

The Solar Lease is an unsecured lease agreement used by property owners to use a Solar PV system to reduce their electricity costs for a term of five to twenty years. The periodic payment of the lease is a fixed amount that is negotiated between the finance/installation company and the property owner. This payment is fixed for at least five of the ten to twenty year term of the lease and may include escalations for inflation increases, as well as fixed-term step-up payments over the Solar Lease term. The amount of energy savings to the customer is often guaranteed as a form of security for the customer engaging in a long term Solar Lease. Upon expiration of a solar lease, the customer has three basic options: renew the Solar Lease period; upgrade to a new Solar PV system with a new lease; or remove the Solar PV system from the property and return it to the solar finance company.

In both non-cash financing cases, the financing company agrees to maintain and often monitor the installed PV system. Since these mechanisms have full recourse to the customer, they require a FICO score of 700 or greater. The options upon property transfer during a Solar Lease or PPA are: 1) Pay the remaining amount owed on the lease or PPA; 2) Pay to physically move the PV system to a new property and continue the lease or PPA obligations according to the original lease with possible adjustments based on the location of new property; 3) Negotiate to have the new property owner assume the existing obligations under the current PPA or Solar Lease.[27]

Despite the long term financial obligations for customers, non-cash methods are currently the most widely accepted methods for financing the cost of purchasing and installing a renewable energy Solar PV system. In California, 72.4% of all new PV installations from Jan–May 2012 were paid via a third party financial mechanism such as a Solar PPA or Solar Lease, up from 45.6% during the same period in 2011.[28] These financial products are scalable, measureable, and thus available for securitization.

The key difference between energy retrofits and Solar PV is that the cost parameters for the latter are clearly delineated and the benefits, in the form of electricity generation. In short, two key impediments which are present in retrofits—incomplete information and heterogeneity—are absent. On the issue of financing, it may also be the ability to reduce both risk and transaction costs to the homeowner by funneling costs and savings through the solar provider that clinches the deal.

5.4.1. The role of federal tax credits

The federal government has extended the solar investment tax credit (ITC) which allows for a 30% tax credit in the form of a tax rebate once a Solar PV system has been installed on a roof. It previously was limited to $2000 per home, but that cap was lifted in 2009 and the term of the bill was extended to 2016. Solar investments also receive an accelerated depreciation tax benefit. Private equity funds create pools of the tax benefits, which are now also being securitized. Currently, ITC subsidy funds are needed to make these projects work for both the end consumer (property owner) and the various entities along the Solar PV delivery chain.

Since the tax credit investor's equity in the PV project goes to zero over the thirty-year tax credit agreement, the risks for tax credit investors associated with investing in these funds lie in two main categories: collateral risk and ownership risk. Collateral risk arises if the lien associated with funding the Solar PV system goes into default, so that the equity status of the investor is lost along with the tax credit. Ownership risk is associated with a five year recapture period when tax credits can be recaptured if the investor is deemed to lack sufficient ownership in the PV system.

Low Income Housing Tax Credit (LIHTC) investors are also a major source of Solar ITC funding. The credit is based on a simultaneous 30% equity investment with a thirty-year depletion model similar to the ten-year LIHTC depletion model for low-income housing credits. The remaining 70% of the project must be funded from sources that commonly include homeowner equity, bank loans, local government credits, and credits from the solar manufacturers and installers.

5.4.2. Makers Depreciation funds

Makers Depreciation funds are an additional income tax reduction tool created by the 2008 federal financial relief package and sold by solar financing companies to finance their projects.[29] The depreciation credits for the installed solar system are sold to profitable businesses looking to reduce income tax exposure, often the same ITC investors. It is believed that Makers Depreciation represents the third largest source of equity financing (23%) for a new PV project after the Federal (ITC) portion (30%) and working capital requirements of the finance and/or installation company (approximately 28%.)

5.4.3. Secured mortgage liens

Secured mortgage liens provide the same potential for funding solar investments as other energy-saving investments. The methodology for secured financing for Solar PV is that a lender willing and able to acknowledge the value of the cost reducing improvements of an energy retrofit through an increased appraised value or increased disposable income will allow the borrower to service the additional debt. Unfortunately, as discussed above, secured mortgage liens—both first and second liens—remain more a future hope than a current reality, despite the greater ease of measuring Solar PV costs and benefits.

5.5. Summary of financing mechanisms

Given the relatively large size and long duration of benefits from energy-saving investments, it is understandable that accessible financing is a necessary condition to carry out these investments on a large scale. Since the investments are intrinsically connected to a home, lenders could treat the associated loans as secured credits. Lenders have been slow, however, to create such secured "energy mortgages", although some pilot programs are in process. As a result, alternative mechanisms have been developed to obtain financing through public utilities (on-utility-bill financing) or through local governments (Property Accessed Clean Energy, PACE). Unfortunately, the public utility

[26] See, Bloomberg New Energy Finance — Ted Hesser, Senior Market Analyst, Presentation on Renewable Energy.

[27] Industry Interview — Chris Pawlik, Co-Founder of Energy-Producing Retail Realty, Inc. www.eprsquared.com.

[28] Database of State Incentives for Renewables and Efficiency — http://www.dsireusa.org/incentives/homeowner.cfm?state=CA&re=1&ee=1.

[29] Greentech Media Article on Solar Strong program, available at: https://www.greentechmedia.com/articles/read/solarcitys-solarstrong-to-move-more-bank-money-into-military-housing/.

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mechanism has faced both contract design and utility funding limitations, while the PACE programs currently face stiff resistance from Fannie Mae and Freddie Mac.

The provision of financing for Solar PV has been more successful, and thus provides a useful case study. Two key components appear responsible for the success of Solar PV: (1) clear metrics for the costs and benefits of a solar investment; (2) government tax benefits that have allowed the industry to reach an effective scale. A key result is that most solar installations are funded through third parties connected directly or indirectly with the installation. Unfortunately, government tax benefits for general energy-saving investments do not appear to be on the horizon. Thus, in line with the discussion in Section 4 of this paper, clear metrics for the costs and benefits of general energy-saving investments remains a critical first step to improve the mechanisms available for their funding.

6. Summary and conclusions

In this paper, we review the possible market failures that could create the large under-investment in productive energy-saving projects documented in McKinsey and Company (2009a).[30] We focus on two major categories: imperfect information and loan market inefficiency. Imperfect information is a plausible bottleneck for energy-saving investments because the production function that generates the costs and benefits of housing services is intrinsically complex and no doubt opaque to most property owners. Given the high costs to acquire the necessary information, it is not surprising that productive energy-saving investments are not carried out.

Regarding loan markets, it would appear that financially productive investments embedded in real estate structures should serve as collateral for secured loans, and the loans should thereby receive appropriately low interest rates. In practice, however, private market lenders generally do not consider energy-saving investments to be collateral for a secured loan, and property owners of existing residential properties generally face relatively high borrowing costs to finance energy-saving investments. Thus, the loan market failure is also fundamentally informational, in that lenders appear unconvinced that the investments will dependably increase house values.

A primary conclusion of this paper is that the informational imperfections relating to energy-saving investments are sufficiently severe to deter the investments for both demand and supply reasons. On the demand side, the information imperfections may plausibly and significantly limit the effective demand of property owners to carry out such investments. On the supply side, imperfections may severely limit access to secured loans to finance the investments that property owners do desire to carry out. Given the potential for information imperfections to deter energy-saving investments, the key remaining question concerns possible policy solutions for these market failures.

As emphasized in the text of this paper, computer-based tools that either score the relative efficiency of a home or assess the productivity of alternative energy-saving investments have a great potential to resolve the current informational imperfections. Unfortunately, this potential has not been realized to date. This can be seen first from the limited success of the existing tools in promoting energy-saving investments, and second from our analysis which reveals significant and continuing shortfalls in both tool accuracy and accessibility. Nevertheless, we believe that such tools have the potential to eliminate a significant part of the current informational imperfections. We are thus strong advocates for the continuing development of these tools. Government funding is a key element of this development because it encourages transparency, an important aspect of tool credibility. Furthermore, in order for the models to better anticipate the actual behavior of residents and property owners, we advocate expanding surveys and randomized controlled experiments.

We believe that the development of reliable tools to evaluate the productivity of energy-saving investments will also provide significant benefits in promoting access to secured loans to fund these investments. As discussed in the text, the loan market innovations of On-Bill financing and repayment programs and PACE programs have significant potential to expand loan market access for borrowers making energy-saving investments. The relative success of Solar PV installations appears related in part to the availability of clear metrics to evaluate the costs and benefits.

While improved tools are clearly part of the answer, a number of issues remain. The heterogeneity of customers means that a multiplicity of tools may be appropriate, so that the various groups of individuals, contractors, and investors can choose the most useful tool to make their investment decisions. As Palmer et al. (2012, 2013) point out, while both informational and financing issues are clearly important, little data exist to identify the specific participants in various programs and their behavioral idiosyncrasies, or to make comparisons between participants and control groups of non-adopters and non-participants.

Although we expect the forthcoming development of improved assessment tools and loan market mechanisms will substantially mitigate the bottlenecks that currently deter energy-saving investments, we also recognize that the option to take no action may also contribute to an important part of the observed inertia. It is interesting in this context that there is an expanding recognition that consumers, over many economic decisions, continue to operate in a sub-optimal fashion in the absence of behavioral forces that "nudge" them to action; see Thaler and Sunstein (2008). The relevance is that the motivation to carry out energy-saving investments may be substantially enhanced at certain key decision points.

For example, the failure of a heating or cooling system or a water heater requires immediate action, creating a strong nudge to make the energy-saving investment. The success of the Energy Star ratings for appliances and HVAC units, from the U.S. Environmental Protection Agency (2012), illustrates the benefit of such "nudge" programs. Home sales may also create the nudge to carry out energy-saving investments, since homeowners commonly carry out a variety of home repairs at the time of sale, including repairs required by local governments for certification at the time of sale. The sale event might also provide opportunity for disclosures about energy usage in a standardized format that will help homebuyers make more informed decisions. For a more complete discussion of the potential to nudge action, see Bamberger (2012). There may also be an entrepreneurial opportunity for third-party businesses to realize scale by providing an integrated service that combines a trusted brand and financing access, similar to the existing programs for solar installations.

In closing, we note that there may be an important but distinct role for government subsidies in expediting energy-saving investments. Here we agree with Allcott and Greenstone (2012) that subsidies are the proper instrument to mitigate the negative externalities of energy use that arise from, say, environmental pollution. However, for the informational and loan market failures that are the focus of this paper, the first-best solution is to fix the problems directly. In that spirit, we believe the actions proposed here to mitigate directly the recognized bottlenecks are the proper path for expanding the volume of energy-saving investments.

[30] To be clear, we focus in this study on the failure of private agents to carry out apparently productive investments. Energy-saving investments may also be motivated by the negative externalities of energy-based environmental pollution, but that issue is beyond the scope of this paper.

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