Solar PV and Energy Efficiency in Residential Building Codes

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Abstract

The Energy Rating Index (ERI) in the 2015 International Energy Conservation Code (IECC) introduced the question of whether renewable energy could be a way to comply with the building energy code. Following the passing of a compromise proposal in the 2018 IECC that credited renewable energy but limited its ability to take the place of building envelope measures, the debate over renewable energy's role in the code shifted to state-level adoption hearings. Renewable energy—primarily solar photovoltaics (PV)—and energy efficiency each provide value in the form of reduced greenhouse gas emissions and peak demand, as well as more resilient homes during disasters. Another key metric is cost effectiveness. For cities in climate zones 2–6, this study shows that energy efficiency upgrades in new homes are on average more cost effective than installing rooftop solar photovoltaic panels. Using the 2006 IECC as a baseline, typical homeowners would save $4 to $32 each month from energy-efficient codes or standards, while an equivalent amount of solar energy generation would cost them up to $14 per month. These values do not consider energy efficiency or renewable incentives or tax credits, or renewable energy credits.

Introduction

The national model minimum energy code for homes in many states, the International Energy Conservation Code (IECC) is designed to ensure that builders construct cost-effective and energy-efficient homes.[1] It sets guidelines and requirements primarily for the design of energy-efficient building envelopes and mechanical and lighting systems. This helps maximize comfort and safety for homeowners while minimizing their energy bills and improving affordability. This holds true both for the national model code and for any amended version adopted at the state level.

Renewable energy is a relative newcomer to building energy codes. Its role and the way that it interacts with existing energy efficiency code provisions are still unclear. Recent changes have allowed builders to install a limited amount of renewable energy technology such as solar photovoltaic (PV) panels to help comply with the codes.

We undertook this study to help inform how states choose to adopt and amend efficiency and renewable energy measures in building energy codes. Both energy efficiency and solar PV have advantages for homeowners. Both are key to a clean energy future with lower emissions of a variety of pollutants including greenhouse gases. However we are concerned that using onsite PV to achieve compliance with model energy codes could result in buildings with reduced envelope efficiency and no additional carbon reductions. This outcome would be at odds with policymakers' increasing support for greenhouse gas reduction policies and pathways to zero energy use.

A second concern is the cost effectiveness of solar PV compared to that of energy efficiency. Builders (and sometimes future homeowners) make many design decisions during the construction of a new home. They are often trying to strike a balance among aesthetics, comfort, and cost. Whereas they typically prioritize up-front costs, they should also consider long-term cost savings.

The goal of this white paper is to provide technical and economic guidance to energy code policymakers on these subjects. We begin by briefly comparing the nonenergy and nonfinancial benefits of energy efficiency and solar installations—that is, the advantages to homeowners beyond cost savings. Then we move to a quantitative comparison of the cost of achieving a particular level of energy efficiency and the equivalent level of rooftop solar generation.

Recent Renewable and Efficiency Trends in the IECC

EFFICIENCY LEADS THE WAY

Prior to 2015, the IECC included only energy efficiency provisions. Some of the largest efficiency gains occurred in back-to-back editions in 2009 and 2012, which together achieved 32% energy savings compared to the 2006 IECC (Mendon, Lucas, and Goel 2013). Provisions included increased building envelope tightness, mandatory duct testing, high-efficacy lighting requirements, HVAC controls, and improved insulation and fenestration

[1] The IECC is managed by the International Code Council (ICC). To see your state's residential code, refer to DOE's State Adoption database at www.energycodes.gov/status-state-energy-code-adoption.

requirements (DOE 2010, 2011). The code regulated minimum energy conservation requirements and paid minimal attention to energy generation.

RENEWABLE ENERGY ENTERS THE PICTURE

Although the 2015 IECC included few efficiency gains compared to 2012, it introduced the Energy Rating Index (ERI) as an optional compliance path. This path provides a target score in a range of 0 to 100, where 100 represents the 2006 IECC and 0 represents a zero-energy building. IECC section 406, which describes the ERI path, was based on the home's total energy use and did not explicitly mention renewable energy.

However the ERI path was modeled after the Residential Energy Services Network (RESNET) Home Energy Rating System (HERS), which gives credit for onsite generation and hence allows renewables to be traded off for efficiency. Some people interpreted the ERI's connection to HERS as suggesting that onsite renewable generation could be used in place of efficiency measures to meet the ERI targets—such as installing solar PV panels instead of a higher R-value of insulation. Others determined renewables should not be part of the ERI. For example, Texas, an early adopter of the 2015 IECC, explicitly prohibited the use of renewable energy for energy code compliance under the ERI path.

The debate on renewables in the energy codes took place in the context of other code changes and an evolving business landscape. The 2015 IECC also incorporated a "solar-ready provisions" appendix, which provided guidelines for installing solar-ready interconnections for future PV installation. Although it was not mandatory, jurisdictions could use it if they decided to mandate solar-ready home construction.

In addition, leading up to 2015, the solar industry had changed. For instance, on the residential side, solar panels dropped from more than $7 per watt in 2010 to a little over $4 per watt (Feldman, Ebers, and Margolis 2019).[2] Perhaps more importantly, between 2012 and 2017, the popularity of leasing (and power purchase agreements) grew to the point where third-party ownership of solar panels was larger than the customer-owned market share (Munsell 2018).[3] In these arrangements, a third party pays the up-front cost for the solar panels, which is paid back by the homeowner over time. The third party also typically receives any tax and other incentives. Using these third-party-owned panels as a method to achieve compliance could allow homebuilders to save substantial up-front cost when building the home, but the homeowner would pay the cost (with interest) over time.

FINDING COMPROMISE

Between the development of the 2015 and 2018 IECCs, stakeholders in the energy efficiency and renewable energy industries debated how to bring onsite renewable generation into the code as a compliance measure without compromising the efficiency gains achieved since 2009.

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[2] These prices include fairly generous federal tax incentives, which are due to expire in a few years.

[3] In 2017, customer-owned solar retook the lead for dominant market share over third-party-owned solar (Munsell 2018).

In 2016, the Department of Energy (DOE) released a position statement on the topic; it praised both efficiency and renewable energy, "both of which are vital to achieving national energy and emission reduction goals." However the department ultimately concluded that it did "not support unlimited trade-offs for renewables" since energy savings "represented in the 2015 IECC are cost effective to consumers" (DOE 2016). In other words, DOE supported allowing renewable energy in the energy codes, but not when it weakened cost-effective efficiency measures.

For the 2018 IECC, a compromise proposal set a limit (or a backstop) so that buildings that comply with the ERI path using renewable energy still must be built to a minimum 2015 IECC thermal envelope (prescriptive path). This means that a home could have somewhat less-efficient lighting, HVAC, water heating equipment, or appliances,[4] but the building envelope—which is crucial to the long-term efficiency and comfort of the home—must meet a minimum level of efficiency.[5] Stakeholders that often have different code priorities, including the Leading Builders of America, the Energy Efficient Codes Coalition, and the North American Insulation Manufacturer's Association came together to support the proposal (Alliance to Save Energy 2016).

STATE-LEVEL CODE DEBATES

However the 2018 IECC compromise did not completely settle the debate. Although the national model code was set, the state-level adoption conversation was just ramping up. Proponents of renewable trade-offs in the ERI path often attend state-level code adoption hearings and advocate for overturning the compromise proposal by removing the building envelope backstop, thus allowing unlimited trade-offs for renewables. As a result, insulation levels and other efficiency measures may be reduced in states that allow unlimited trade-offs for renewables.

Nonfinancial and Nonenergy Benefits

GREENHOUSE GAS EMISSIONS AND AIR POLLUTION

Many states, cities, and jurisdictions are setting goals to reduce greenhouse gas emissions. Both energy efficiency measures and rooftop solar reduce reliance on electricity from power plants, which contributes to reducing these emissions. In addition, using less grid electricity reduces harmful air pollution—including nitrogen oxides, sulfur oxides, and particulate matter—and benefits human health.

COMMITMENT SIGNALING

Rooftop solar PV panels have one advantage that is often unacknowledged: they can serve as a signal of belief. Homeowners who install rooftop solar panels overtly display their commitment to using renewable energy. In contrast, efficiency measures such as insulation and efficient water heaters are out of sight in walls and closets. The obvious presence of

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[4] The ERI path allows homebuilders to consider a broader set of end uses than the IECC prescriptive path. See Appendix A for more information on IECC compliance paths.

[5] In exchange for the solar PV backstop, the compromise proposal relaxed the stringency of the ERI values in the 2018 IECC.

rooftop solar can lead neighboring homeowners to take similar steps toward clean energy use. However, if the panels are being used only to meet the minimum energy code, homeowners may not be getting the environmental benefits they are seeking.

RESILIENCE

A well-insulated home loses heat (and allows heat to enter a home) at a more gradual rate than a poorly insulated home. As a result, residents in well-insulated houses may be able to remain in place longer during power outages. Solar PV panels may also provide a homeowner with resiliency benefits, primarily when paired with battery storage. Depending on the configuration of the solar system and on local utility requirements, a homeowner may be able to store energy generated from their solar panels in batteries and use it as backup storage during power outages and emergency events.

PEAK DEMAND REDUCTION

Energy efficiency reduces the homeowner's weather-related energy consumption, which reduces both strain on the grid and peak pricing charges to the consumer.[6] It also helps keep utility rates lower than they would be otherwise. Solar power can have a similar effect in areas where the solar generation is coincident with peak loads on the electricity grid.[7] However some areas in the country have days and hours of the year when there is surplus renewable energy generation; during those times, additional onsite solar generation is of reduced benefit, if any, to the grid or the environment. In addition, in California, where solar penetration is high relative to the overall demands on the system, rooftop solar can actually *increase* strain on the grid when the sun sets and consumers switch from solar power to conventional grid power around the same time and non-solar generation must quickly ramp-up to meet the rising demand.

COMFORT AND HEALTH

One advantage of energy efficiency is its ability to improve the comfort and health of the home occupants. Building envelope code provisions such as air sealing, high-efficiency windows, and slab edge insulation can reduce drafts and make temperatures more even throughout the home, as well as help prevent mold, mildew, fungal growth, and dust mites. Further, efficient two-speed and variable-capacity HVAC systems use controls to meet the desired temperature more precisely than single-speed systems, which are either off or operating at 100% capacity. Solar power does not offer home occupants these comfort and health benefits.

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[6] Demand charges and time-of-use rates are common for commercial and industrial customers; however they are still relatively rare for residential customers. Some organizations advocate for residential peak demand pricing, which can be enabled by installing smart meters (Alliance to Save Energy 2018).

[7] To be coincident with solar generation, peak demand must typically fall between 12–4 pm. However even modest solar generation peak demand more commonly falls later in the day (e.g., 5–6 pm), when solar output is diminishing. Geographical location (e.g., differences between load shape and weather) is also a factor (Darghouth et al. 2017).

Cost Effectiveness

The following analysis compares the cost effectiveness of energy efficiency measures in newly constructed homes, as stipulated in various residential energy codes and standards, versus installing rooftop solar panels that would provide the same energy savings. Various cities and jurisdictions adopt different code levels, and it is important to evaluate a variety. For this study, we chose the 2009 IECC, 2012 IECC, 2015 IECC, and ENERGY STAR Certified New Homes version 3.1.[8] We framed the savings in terms of monthly costs (or savings) to a homeowner as a 30-year investment (the period typically covered by a home mortgage).

Although the current debate focuses on the IECC ERI performance path, we did not calculate energy savings based on a particular ERI score. Instead, we evaluated the minimum amount of energy saved by the prescriptive requirements over a 2006 IECC baseline, since there are well-documented costs and savings for the prescriptive path in each code cycle. In addition, for rooftop solar PV, we evaluate the average purchase cost of a rooftop solar PV system. For both efficiency and PV, we do not consider variables such as federal tax credits, utility or state incentives, or different forms of financing, which can change quickly. Thus, while the results may not represent the specific impacts for specific homeowners who have access to incentives and tax credits today, they show the total cost of achieving comparable energy savings through new home efficiency and rooftop solar.

What follows is a summary of the methodology of our cost-effectiveness comparison. We present additional details in Appendix A.

CALCULATIONS

Energy Efficiency Measures

In each climate zone, houses built to various codes and standards must meet energy efficiency requirements that are estimated to save a certain amount of energy[9] over and above a stipulated baseline. Efficiency measures in houses built to the 2009 IECC code in St. Louis,[10] for example, are estimated to save 1,230 kilowatt-hours (kWh) more electricity each year than the measures in houses built to the 2006 code. In this study, we used the 2006 code as our baseline for the electricity savings mandated by successive iterations of the code in 2009, 2012, and 2015. Thus, for example, compared to houses built to the 2006 code, those

[8] ENERGY STAR for Homes v3.1 is estimated to save 19–25% in total energy costs over the 2012 IECC (EPA 2016). The 2018 IECC was not included in the analysis because DOE has not published the energy savings determination. The 2012 and 2015 IECC are relatively similar in terms of costs and energy savings, but we included both in the analysis because both are widely adopted codes.

[9] For this study, we considered only electrical energy savings; we did not consider other fuel types such as natural gas or fuel oil. The codes and standards thus will save more overall energy and energy costs than indicated here.

[10] We use St. Louis as an example throughout the study because it represents an average US city: its climate zone, 4A, is defined as mixed humid, meaning that it is neither very hot (like Tampa) nor predominately cold (like Burlington). In addition, it has an average electricity cost, relatively high solar output, and relatively low cost for solar panel installation.

built to the 2012 code would save 3,491 kWh more electricity on average each year while those built to the 2015 code would save 3,518 kWh.

We based our calculations on DOE determinations that use EnergyPlus simulations to estimate the energy use in an average single-family home for each version of the code for each state. Then, to determine each code's energy savings, we calculated the difference between the 2006 IECC energy use and the later version of the IECC or ENERGY STAR for homes.[11]

See tables 1 and 2 below for the detailed results of these calculations and the ones that follow.

To translate the annual energy savings into monthly bill savings, we multiplied the energy savings by the 2018 local average electricity cost and divided by 12. For example, St. Louis electricity prices average $0.1125/kWh (EIA 2019); for houses built to the 2009 code, the savings over 2006 levels would amount to $12 per month.

For each IECC code, DOE also estimates the up-front cost of the energy efficiency measures necessary to achieve the increased energy savings over the previous code for each state. For houses built in St. Louis to the 2009 code, the efficiency measures necessary to save the additional 1,230 kWh/year would cost $666.[12] Measures such as improved duct sealing and more-efficient windows and lighting account for this increased cost. DOE also identifies this cost differential for the 2012 and 2015 codes. For St. Louis, it amounts to $2,901 for 2012 over 2006, and $2,936 for 2015 over 2006.

Like DOE, we amortized these costs over 30 years at a 5% interest rate (Taylor, Mendon, and Fernandez 2015). For houses built in St. Louis to the 2009 code, the $666 up-front cost of the additional efficiency measures translates to an additional cost of $4 per month, and so on.

Finally, to derive net monthly homeowner savings, we subtracted the amortized cost of the efficiency improvements from the monthly energy bill savings. For St. Louis houses built to the 2009 code, these net savings amounted to $8 per month, and so on.

We also calculated the increased energy and cost savings over the 2006 baseline for houses built to ENERGY STAR 3.1 for Homes. Appendix A offers details of our methodology with regard to these requirements.

Rooftop Solar

Next, we calculated the net monthly homeowner savings generated by a rooftop solar installation that achieves equivalent savings and compared these with the monthly savings from energy efficiency. In other words, we sought to answer a key question: What would be

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[11] See Appendix A for more details.

[12] This represents the total cost to achieve electricity and natural gas savings. We were unable to separate out costs that contributed only to natural gas savings.

the net impact on the monthly spending of a homeowner who chose to install rooftop solar to achieve the energy and cost savings stipulated in our various codes and standards?[13]

Solar generation capacity varies throughout the country depending on the average amount of sunlight available. It is often expressed as the number of kWh produced per watt of the solar array.

Solar arrays in St. Louis typically produce 1.373 kWh/W each year, according to the National Renewable Energy Laboratory (NREL) PVWatts Database.[14] We divided the increased energy savings mandated by the various codes and standards by this number to determine the size of the solar array required to achieve them. For example, 896 watts of solar panels would be required to generate the increased additional savings of the 2009 code.

The cost of an array (including equipment and installation) also varies across the country; in Missouri, the average cost is $3.00/W according to the website SolarReviews.[15] This cost represents a homeowner purchasing and owning the solar PV system, rather than a third-party ownership arrangement like a lease or power purchase agreement.[16] We multiplied this cost by the required additional wattage to determine the up-front cost of generating the various codes and standards savings increases. Here is the overall equation:

$$Increased\ solar\ cost = \frac{Increased\ energy\ savings\ from\ codes\ (kWh)}{Array\ capacity\ (\frac{kWh}{Watt})} \times Array\ cost\ (\frac{\$}{Watt})$$

Applying this equation, we found that in St. Louis the cost would be $2,687 for a solar array that achieves the same electricity bill savings as the 2009 IECC. Amortized over 30 years at 5%, this would cost the owner $14 per month.

Finally, we subtracted this amount from the monthly bill savings to determine the net monthly cost of the array. For example, as with energy efficiency, the increased monthly bill savings for the 2009 code amount to $12. But since the amortized cost of the upgraded array is $14, the homeowner ends up paying an additional $2 per month.

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[13] We examined only the solar equal to the energy savings of the energy efficiency measures. With or without efficiency, additional solar can be added to meet more of a home's load, but we do not include this additional solar in our analysis.

[14] PVWatts uses hourly meteorological year data from NREL's National Solar Radiation Database to estimate solar output; it assumes a residential fixed rooftop mount with 14% system losses (default), 20˚ tilt (default), 180˚ azimuth (default), and 96% inverter efficiency (default) (NREL 2019b).

[15] SolarReviews maintains a database of solar power system prices from approximately 500 US solar companies. For the states in this analysis, PV system costs ranged from $3.00/W–$3.43/W (SolarReviews 2019), which is lower than the US average cost of $4.25/W for small PV systems (i.e., 2.5kW–10kW) found in a different study (Feldman, Ebers, and Margolis 2019).

[16] We discuss the relative cost of mortgage and lease financing below.

RESULTS

St. Louis

Table 1 compares the monthly net homeowner costs for energy efficiency and solar.

Table 1. Monthly net homeowner savings and costs in St. Louis from code/standard compliance compared to 2006 IECC

	Savings		Energy efficiency costs		Solar costs	
Code/standard	Energy savings (kWh)	Energy cost savings	Amortized up-front cost	Net cost	Amortized up-front cost	Net cost
IECC 2009	102	$12	$4	($8)	$14	$2
IECC 2012	291	$33	$16	($17)	$41	$8
IECC 2015	293	$33	$16	($17)	$41	$8
ENERGY STAR 3.1	469	$53	$22	($31)	$66	$13

Sources: IECC electricity savings: code impacts spreadsheet (provided by PNNL). ENERGY STAR v3.1 electricity savings: costs and savings tables (provided by EPA contractor). IECC 2009 and 2012 incremental costs: Mendon, Lucas, and Goel 2013. IECC 2015 incremental costs: Mendon et al. 2015. ENERGY STAR v3.1 incremental costs: costs and savings tables (provided by EPA contractor). Solar cost: SolarReviews 2019. Cost estimates adjusted to 2018$ using Federal Reserve Implicit Price Deflator. Methodology for amortized costs: Taylor, Mendon, and Fernandez 2015.

In St. Louis, energy efficiency upgrades in new homes are on average more cost effective than installing rooftop solar PV panels. For instance, the average home built to the 2015 IECC saves an estimated 3,518 kWh over the 2006 IECC each year, saving St. Louis homeowners about $33 each month. These efficiency upgrades, such as improved insulation and high-efficiency lighting, cost about $16 per month. To achieve an equivalent level of energy bill savings by generating energy through rooftop solar panels, the cost would be about $41 a month—more than double the cost of efficiency. In monthly terms, energy efficiency *saves* the average homeowner in St. Louis $17 net of financing costs, while equivalent solar generation *adds* a net cost of $8.

National

We performed the same calculation for cities in climate zones 2–6. Table 2 shows the results.

Table 2. Amortized residential monthly costs to consumers over 2006 IECC: energy efficiency (EE) and rooftop solar PV

	Tampa (2A)		Fort Worth (3A)		St. Louis (4A)		Indianapolis (5A)		Burlington (6B)	
Code/standard	EE	Solar	EE	Solar	EE	Solar	EE	Solar	EE	Solar
IECC 2009	($11)	$4	($10)	$4	($8)	$2	($4)	$2	($6)	$0
IECC 2012	($13)	$7	($15)	$9	($17)	$8	($9)	$5	($8)	$1
IECC 2015	($13)	$7	($15)	$9	($17)	$8	($9)	$5	($8)	$1
ENERGY STAR 3.1	($28)	$11	($32)	$14	($31)	$13	($21)	$9	($25)	$1

Energy efficiency values include only electricity savings. Cost estimates adjusted to 2018$ using Federal Reserve Implicit Price Deflator. Methodology for amortized costs: Taylor, Mendon, and Fernandez 2015.

Across the board, we found results similar to St. Louis: Energy efficiency is more cost effective for consumers than rooftop solar generation. In our study, energy efficiency saves consumers $4–32 per month, while solar generation actually adds a payment of up to $14 per month. We found that efficiency has the greatest advantage in Tampa, Ft. Worth, and St. Louis. Since our methodology takes only electricity savings into account, and since states with high heating energy use—such as Vermont and Indiana—tend to use more natural gas, it makes sense that they have smaller potential for electricity savings than states like Florida, Texas, and Missouri. Even despite favorable solar conditions in states like Florida and Texas,[17] it can still be difficult to replicate the cost-effective savings from energy efficiency in building codes.

What happens when a homebuilder installs a leased solar PV system?

Solar can be used to help meet the minimum ERI efficiency score in states without a building envelope backstop. If the homebuilder decides to install a leased system, the homeowner will have to sign a long-term agreement and pay for it on a monthly basis. If the homeowner cannot make the payments, and the solar panels are removed, the house would then fall out of minimum compliance. Currently, there is no way for a code official to know if a solar PV system has been removed. Even if there were a way to know, enforcement may not be possible and the cost of retrofitting a home to bring it back into compliance, such as by adding more insulation, is often prohibitively expensive, especially for a homeowner who could not afford to pay for the panels.

FACTORS NOT CONSIDERED IN THE ANALYSIS

It is important to underscore that our calculations did not consider factors such as the following:

- Leasing/financing
- Power purchase agreements
- Utility, local, and state incentive programs
- Solar Renewable Energy Certificates (SRECs)
- Federal solar and energy efficiency tax credits
- Interest tax deduction
- Natural gas savings from efficiency measures
- Changing costs

These variables could potentially reduce or increase the up-front or ongoing cost of solar PV systems and efficient new homes for the owners. If they purchase a solar PV system within the next few years, a federal investment tax credit allows them to deduct a portion of the total cost of the system from their federal taxes, starting at 30%. In 2020, this is reduced to 26% of the system's total cost and in 2021 it drops to 22%. After that, the credit for residential rooftop solar panels is eliminated, and only a 10% credit for commercial systems remains (EnergySage 2019). Additionally, utilities, states, and local jurisdictions may offer incentive programs for energy efficiency or solar, such as in the form of mail-in rebates, sales tax exemption, or special financing options.

[17] Solar panels in Fort Worth, Texas, and Tampa, Florida, are estimated to produce roughly 25% more energy than solar panels in Burlington, Vermont (NREL 2019b).

Third-party-ownership options such as leasing and power purchase agreements can also reduce up-front costs, although these options are usually more expensive to the homeowner in the long run.[18] Typically, the third-party installer takes advantage of incentives such as the solar tax credit—money that would normally go to the homeowner. In addition, payments can escalate by as much as 3% per year (Solar Power Rocks 2019), which means that after 20 years, homeowner payments could be as much as 75% higher than when they started. One case study published by Bloomberg revealed that a 20-year lease agreement would cost a total of approximately $24,000, whereas if the homeowner purchased the system with the tax credit, it would have cost only about $13,000. Even without the tax credit, the system would cost only $18,000 in cash (Deprez 2019).

Homeowners in a handful of states, including Massachusetts and Ohio, can sell the environmental attributes associated with the power generated by their rooftop system through the SRECs system.[19] Although the earnings can be significant, they again go to third-party owners for leased systems.

The availability of these incentives, programs, and financing schemes changes frequently. For this study, we relied on SolarReview's most updated data on the true cost of solar PV systems. In addition, our calculations did not include incentives that some utilities and states provide for beyond-code efficiency measures in new homes (e.g., those found in ENERGY STAR v 3.1).

Our calculations also did not consider measure life. When comparing equipment longevity, building envelope measures typically last the longest. A PV panel's average lifespan is 25–40 years (NREL 2019c), and the panel's electricity output degrades an average of 0.5–1% each year (NREL 2019a). Further, a PV system's central inverter typically lasts only about 10–15 years (Richardson 2019). On the other hand, the building thermal envelope, including insulation and windows, often lasts for the entire lifetime of the house, which is generally 50 years or longer.[20] Other efficiency measures may have shorter lifetimes, however. For instance, the median lifespan of a central air conditioner is 15–20 years (DOE 2019a).

RESULTS OF OTHER STUDIES

Our findings are supported by similar studies. One showed that homes meeting the DOE Zero Energy Ready Home program threshold had a simple payback of less than 12 years, whereas zero energy homes with solar PV generally did not reach this threshold (Petersen, Gartman, and Corvidae 2019).[21] Another study, conducted by the Florida Solar Energy

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[18] Homeowners with leased systems typically pay a fixed cost per month, while homeowners with power purchase agreements typically pay a rate per kWh of solar generation for a fixed period of time. The costs for both methods typically increase each year (Solar Power Rocks 2019).

[19] A list of states in the SREC market can be found at www.srectrade.com/srec_markets/.

[20] According to Residential Energy Consumption Survey data, nearly 40% of existing US homes are at least 50 years old (EIA 2018), which shows that US housing stock lasts a long time.

[21] The DOE Zero Energy Ready Home has substantially more stringent requirements than the ENERGY STAR v3.1, including more stringent insulation, fenestration, and HVAC requirements, in addition to requirements about water use and indoor air quality (DOE 2019b).

Center for the Natural Resources Defense Council, concluded that the most cost-effective way to meet the 2015 IECC was via the prescriptive or the ERI path using only energy efficiency. Complying using solar PV is cost effective, but less so than energy efficiency (Fairey 2016).

Conclusions and Next Steps

We conclude that, across the board, energy efficiency is the most cost-effective option in new home construction to achieve the levels of efficiency associated with minimal energy code compliance. Whereas homeowners would *save* $4–32 each month from efficiency, they would have to *pay* up to $14 each month for the installation of solar panels to obtain the same energy savings as the energy-efficient upgrades (not counting various incentives or financing).

We recommend that policymakers take these findings into account when adopting codes, and that they prioritize upgrades such as energy-efficient insulation, windows, lighting, HVAC, and water heating. Ideally, states will adopt building codes with strong energy efficiency requirements and adopt complementary policies that encourage rooftop solar PV in addition to efficiency, not in place of it.

At the same time, factors outside the scope of this study (e.g., incentives and tax credits) could reduce solar costs to the homeowner, resulting in monthly savings paid for by taxpayers. It is also true that the retail cost of rooftop solar is decreasing each year. However, even considering these factors, rooftop PV systems do not necessarily translate into savings for homeowners. We suggest a more detailed study that reveals the circumstances (geographies, incentive regimes, and so on) in which it might be cost effective to install solar PV over particular energy efficiency measures. The states and the energy efficiency and solar communities would all benefit from this deeper analysis.

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Appendix A. Methodology Details

MEASURE LIFE

For the sake of simplicity and an equivalent comparison, we disregarded measure life. Water heaters, insulation, lights, and solar panels all have different life expectancies; however for this study we followed a simplified version of *DOE's Methodology for Evaluating Cost-Effectiveness of Residential Energy Code Changes*, which amortizes the first cost over 30 years at a 5% interest rate. DOE determined that the average homeowner pays his or her mortgage over a 30-year term, and Freddie Mac shows that the average real interest rate is approximately 5%. DOE also includes metrics such as replacement cost and residual value, which we did not include in our calculation (Taylor, Mendon, and Fernandez 2015).

IECC

Currently there are three strategies to comply with the IECC:

- *Prescriptive path*. This method prescribes mandatory minimum requirements for homes in each climate zone, such as window U-factor, insulation R-value, and duct leakage. This method allows little flexibility for homebuilders.
- *Performance path*. The more flexible performance path allows builders to design houses to their specifications, as long as the houses are modeled to use less energy than an equivalent home built using the prescriptive path.
- *Energy Ratings Index (ERI) performance path*. Introduced in 2015, this path is similar to the performance path, but it requires builders to meet a mandatory maximum score between 0 and 100 (with lower scores being more energy efficient) using the HERS index or a similar rating. As described in the main text, this path introduced the potential for solar trade-offs.

In addition, all three paths must meet mandatory provisions.

When determining the energy use of each code edition, DOE evaluates the prescriptive path. It uses EnergyPlus models to determine the energy savings for all 50 states. To determine incremental costs, DOE uses studies and databases on existing costs, such as RSMeans and industry reports. It is then easy to determine the energy savings compared to the previous version(s) of the code. For instance, in the cities we evaluated, homes built to the 2009 IECC use from 750 kWh to 1,900 kWh less energy than under the 2006 code, and the 2012 IECC saves even more energy.

DOE also estimates the incremental costs between each code.[22] For example, in the cities we evaluated for this study, the increased cost of the 2009 IECC over the 2006 IECC ranged

[22] DOE commissions a rigorous and well-documented "determination" of cost effectiveness for each IECC version. The Environmental Protection Agency followed a similar methodology when evaluating the cost effectiveness of ENERGY STAR v3.1, and we were able to make adjustments to better align with the IECC determinations.

from $590–1,400 (adjusted to 2018$, and depending on climate zone and a locational cost factor) (Mendon, Lucas, and Goel 2013).

We decided to consider only electricity savings for this study.[23] However DOE determinations aggregate electricity, natural gas, and fuel oil savings. Using information we obtained from the Pacific Northwest National Laboratory (PNNL),[24] we were able to separate the average electricity, natural gas, and fuel oil energy savings in their estimates for each code for each state.

ENERGY STAR

Calculations for ENERGY STAR v3.1 differed slightly from those for the IECC. The IECC energy savings methodology accounts only for lighting, water heating, and HVAC energy savings, while the ENERGY STAR savings also account for appliances. To make the values more consistent with each other, we discounted the energy savings from appliances.[25] Similarly, we separated electricity from natural gas savings with the help of the analysts who conducted the cost-effectiveness study for ENERGY STAR v3.1. ENERGY STAR also uses an improvement factor that accounts for average home convective losses and HVAC commissioning. Because the PNNL does not include this in its calculations, we discounted the improvement factor, resulting in a more conservative estimate. However we did not adjust the costs since we were unable to separate which upgrades contributed to electricity savings versus natural gas.

In addition, ENERGY STAR divides housing into two types—electric and gas—where the former uses an electric air-source heat pump/electric water heater and the latter uses a gas furnace/electric air conditioner/gas water heater. To simplify our final results, we calculated the costs and energy savings for both types of homes and then combined them, according to estimated shares of heating systems from the IECC determinations. For instance, in the West North Central census division (where St. Louis is located), homes are estimated to be about 40% electric heat pump, 57% gas heating, and 3% electric furnace.

See Appendix B for a summary of the assumptions, costs, and savings we used in this report.

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[23] This gives a fairer and simpler comparison of kWh of electricity saved through codes/standards to kWh generated through solar rooftop PV panels.

[24] PNNL is the national laboratory that completed the determination for DOE.

[25] ENERGY STAR groups together lighting and appliance (L&A) data; using 2015 EIA Residential Energy Consumption Survey data, we were able to determine that in the average home, lighting represents about 34% of the L&A total.

Appendix B. Detailed Results

City	Tampa		Fort Worth		St. Louis		Indianapolis		Burlington	
Assumptions										
Climate zone	2A		3A		4A		5A		6B	
Electricity price ($/kWh)	$0.1159		$0.1140		$0.1125		$0.1203		$0.1797	
Annual solar production (kWh/W)	1.540		1.497		1.373		1.329		1.208	
Average rooftop solar cost ($/W)	$3.36		$3.33		$3.00		$2.99		$3.43	
Monthly kWh savings over 2006										
IECC 2009	159		148		102		76		63	
IECC 2012	270		301		291		192		157	
IECC 2015	273		305		293		194		157	
ENERGY STAR v3.1	447		525		551		542		549	
Monthly $ savings over 2006										
IECC 2009	$18		$17		$12		$9		$11	
IECC 2012	$31		$34		$33		$23		$28	
IECC 2015	$32		$35		$33		$23		$28	
ENERGY STAR v3.1	$56		$56		$53		$43		$53	
Up-front costs ($2018)										
	EE	Solar	EE	Solar	EE	Solar	EE	Solar	EE	Solar
IECC 2009	$1,410	$4,172	$1,335	$3,944	$666	$2,687	$980	$2,058	$923	$5,220
IECC 2012	$3,361	$7,075	$3,666	$8,034	$2,901	$7,628	$2,687	$5,193	$3,777	$15,913
IECC 2015	$3,392	$7,146	$3,695	$8,133	$2,936	$7,686	$2,721	$5,225	$3,809	$16,031
ENERGY STAR v3.1	$4,440	$11,627	$4,517	$13,127	$4,027	$12,291	$4,055	$9,609	$5,183	$10,046
Monthly amortized upfront costs over 30 years ($2018)										
IECC 2009	$8	$22	$7	$21	$4	$14	$5	$11	$5	$11
IECC 2012	$18	$38	$20	$43	$16	$41	$14	$28	$20	$29
IECC 2015	$18	$38	$20	$44	$16	$41	$15	$28	$20	$29
ENERGY STAR v3.1	$24	$62	$24	$70	$22	$66	$22	$52	$28	$54
Net monthly costs over 30 years ($2018)										
IECC 2009	($11)	$4	($10)	$4	($8)	$2	($4)	$2	($6)	$0
IECC 2012	($13)	$7	($15)	$9	($17)	$8	($9)	$5	($8)	$1
IECC 2015	($13)	$7	($15)	$9	($17)	$8	($9)	$5	($8)	$1
ENERGY STAR v3.1	($28)	$11	($32)	$14	($31)	$13	($21)	$9	($25)	$1

Cost estimates adjusted to 2018$ using the Federal Reserve Implicit Price Deflator. *Sources:* Electricity price: EIA 2019. Solar production: NREL 2019b. Solar cost: SolarReviews 2019. IECC electricity savings: code impacts spreadsheet (provided by PNNL). ENERGY STAR v3.1 electricity savings: costs and savings tables provided by EPA contractor. IECC 2009 and 2012 incremental costs: Mendon, Lucas, and Goel 2013. IECC 2015 incremental costs: Mendon et al. 2015. ENERGY STAR v3.1 incremental costs: costs and savings tables provided by EPA contractor. Methodology for amortized costs: Taylor, Mendon, and Fernandez 2015.