**To:** Department of Energy (DOE) Building Technologies Office

**From:** *Max Hayden Chiz*, BS EE, MBA, JD;

*Myron Katz*, PhD;

*Norman Witriol*, PhD;

*Richard M. Troy*, Founder and Chief Scientist, Science Tools;

*Cyndy Schmidt*, J.D.;

*Michael Holtz*, FAIA, NCARB, LEED AP, Principal and Co-Founder of LightLouver;

*Syed Adeel Ahmed*, PhD;

*V John White*, Executive Director, Center for Energy Efficiency and Renewable Technologies;

*Michael W. Tifft*, Former Director of Utilities for Council of New Orleans;

*Pres Kabacoff*, Executive Chairman of the Board, HRI Properties;

*Richard Dupont*, P.E., Dupont-LeCorgne Construction Consultants;

*Bill Badon,* Photography and Videography consultant;

*Gary Klein*, President of Klein and Associates; and

*Al Rich*, CEO, ACR Solar International;

on behalf of the ProRate Energy Team

**Subject:** Request for Information(RFI)DE-FOA-0002291, Draft Connected Communities Funding Opportunity Announcement (FOA)

# Introduction and Conceptual Overview

DOE currently envisions this project primarily from the perspective of control systems engineering. However, unless economic factors are explicitly accounted for, any research results will not be reliable or generalizable. These problems can be resolved by incorporating an *explicit* rate-design requirement into the FOA.

A time-of-use (TOU) rate-design is already an *implicit* requirement because occupants will be compensated for changing the timing of their energy use.[[1]](#footnote-2) Economic considerations are woven throughout the other requirements as well. For example, applicants are expected to “pilot new business models” and gather data regarding “financial costs and benefits”.

More importantly, as explained below, it is *provably* impossible to achieve DOE’s requirements without some sort of rate-design element. If this is handled haphazardly, the results of the research will fail to replicate or scale, and the data gathered will be unreliable and meaningless.

Therefore, the FOA must make this rate-design requirement *explicit*. Several organizations on the Teaming Partner List already have experience in this area and incorporating an explicit rate-design element will not significantly disrupt the plans of any teams that have already formed.

## Separating New Results from Existing Research

The FOA seeks to determine “how grid-interactive efficient buildings improve energy affordability, grid reliability and congestion, offer environmental benefits and enhanced grid services.” Without a rate-design requirement, this determination will not be possible.

The FOA already contemplates analyzing the interaction between energy efficiency and demand flexibility measures. Accounting for the interaction with rate-design should also be required.

Fifty years of research shows that consumers make large behavioral changes in response to TOU rates.[[2]](#footnote-3) These effects can be estimated econometrically,[[3]](#footnote-4) but they are so large[[4]](#footnote-5) that the effects DOE is interested in will not be statistically distinguishable. The only solution is to design a study that purposefully gathers information to take these effects into account.

Moreover, simply changing the rate-design can cause many of the same outcomes that DOE wants to achieve with grid-interactive efficient buildings (GIEB). Unless a study is designed to show how GIEBs add *additional* benefits, over and above what is already attainable via TOU rates, conducting the study would be pointless. If the study neglects rate-design issues entirely, no matter how promising the results may be, it will not be possible to say that the benefits it reports could not have been achieved faster, better, and cheaper, via rate-design.

The final FOA should make demonstrating a distinguishable improvement a mandatory requirement. As currently structured, one could argue that a reasonable response to the FOA would be to merely hire Johnson Controls or Siemens to manage the buildings using existing technology. Aggregators already achieve remarkable results for commercial customers.[[5]](#footnote-6) As a result of California Rule 24, they are doing the same for homes. The main reason aggregators rarely provide services in other parts of the country is because transactions costs are too high, and rate structures have not yet been adjusted to offer adequate customer incentives.

Nonetheless, a meaningful study must either achieve better results than what a commercial aggregator could currently achieve or demonstrate a new business model that eliminates barriers preventing them from providing those results to homes and commercial buildings on a national scale. In either case, a rate-design component is essential: benefits cannot be quantified in the absence of relevant data about reductions in customer bills and cost savings achievable for the utility system.

## Economic Theory Requires a Rate-design Element

Adding an explicit rate-design component will keep the research on track and confined to issues relevant to DOE’s mission. A research team unaware of the relevant economic theories and unprepared to account for them will be trying to navigate a desert without a map.

As a matter of textbook[[6]](#footnote-7) economics, it is mathematically impossible to conduct this study without at least an implied rate-design. These impossibility proofs[[7]](#footnote-8) are famous: Arrow’s Impossibility Theorem[[8]](#footnote-9), the Gibbart-Satterthwaite Theorem[[9]](#footnote-10), and similar results[[10]](#footnote-11), mean that it is generally impossible to collect truthful information about consumer preferences. Assuming that information could be collected, the preferences of individual consumers cannot be aggregated in a meaningful way. Even assuming they could be aggregated, the general algorithm for constrained resource allocation is NP-hard[[11]](#footnote-12) and thus intractable.

Achieving the goals of the FOA requires a special case scenario that does not suffer from these problems. Fortunately, if an economically reasonable rate-design is in place, none of these problems arise. Unfortunately, an arbitrary compensation mechanism will not satisfy that requirement. A documented rate-design avoids this distraction.

Without a rate-design, unless a research team is aware of these theories, the *best* result one could hope for would be that the study’s results reflect whatever preferences the designers inadvertently built into the system.[[12]](#footnote-13)

Therefore, in order to protect the integrity of the study’s results, DOE must require applicants to make rate-design an explicit, documented element of their study.

## Adding a Rate-design Requirement to the FOA

With existing rate structures, an electric grid suffers from a “tragedy of the commons”: when individual consumers act in their own best-interests, the combined result of everyone’s actions is not in the best interest of the electricity grid, nor of society as a whole. The textbook solution is to set prices equal to *long-run* marginal costs.[[13]](#footnote-14)

Using real-time rates and smart meters, customers can be *charged* for the marginal costs they create and *paid* for the marginal savings they produce.[[14]](#footnote-15) Both power (kW) and energy (kWh) can be accounted for. According to economic theory, this the only way to avoid cross-subsidies and align individual incentives with the needs of the grid.

Although a rate of this type has been pilot-ready since at least 2016,[[15]](#footnote-16) existing pilots have only explored limited versions of this idea. They either focus exclusively on the wholesale cost of electricity (kWh) or they incorporate modest demand charges or rebates, that are typically set much lower than the true cost[[16]](#footnote-17) of power (kW).

Applicants should be required to specify and document the rate-design they are using. Data should be gathered to determine how effectively that rate-design captures the true costs of the electrical grid and how effectively the design incentivizes the technology investments that are the subject of this FOA. The design should allow for a reasonable *net present value****[[17]](#footnote-18)*** calculation that can correctly gauge whether any particular combination of DERs can provide lifetime benefits that exceed their costs. This should be possible whether or not a particular DER was selected by that applicant and the determination should change depending on the particulars of any given installation. Without such a metric, it will not be possible to compare GIEB studies to one another.[[18]](#footnote-19)

Because existing TOU rates have been exhaustively studied, preferred applicants should propose rates that have not yet been piloted and that promise to achieve DOE’s goals of “pilot[ing] new business models” and gathering data regarding “financial costs and benefits”. A preferred applicant should also seek to gauge how accurately existing rate-designs have reflected economic realities.[[19]](#footnote-20)

Again, these are already implicit requirements of the proposed FOA, but requiring applicants to document their choices will avoid multiple distracting problems and provide substantial benefits.

## Benefits of Requiring a Rate-design Element

Financial and regulatory barriers are key limitations to the widespread adoption of GIEBs.[[20]](#footnote-21) Making rate-design an explicit component of this FOA provides an opportunity to familiarize state and local governments with these issues and to demonstrate the solutions by example. Once these ideas have been tried successfully in a few localities, widespread deployment will be substantially easier because the solution will cease to be theoretical. Making the rate-design considerations explicit and thoroughly documenting them will allow DOE to accelerate the widespread adoption of GIEBs.

Finally, having an explicit rate-design allows study authors to frame many important questions raised by the FOA. In the course of a multi-year study, the technological landscape will change. Such changes threaten to invalidate any research tied to particular technological configurations and related assumptions; costs and performance will have completely changed.[[21]](#footnote-22)

The systems being researched must be able to accommodate technologies and businesses that the designers have not contemplated. They must create a niche for technologies that do not yet exist. Proposed solutions must be totally agnostic to building type, condition, climate, DERs, and a variety of location specific conditions[[22]](#footnote-23) that will not be controllable outside of a research setting. They should also adequately reward older buildings for the larger savings they could produce.

Moreover, because demonstrating new business models is an explicit goal, technologies developed as part of this research need to be economically viable. The research should be valid even if a different set of technologies proves to be superior, and the systems designed need to work for more than a small handful of technologies.

Rate-design interacts with every element of this study. If we want to go from playing with toys to the widespread implementation of our solutions, we must understand how the technologies we are creating today will function in the world of tomorrow’s rate-design.[[23]](#footnote-24)

# Request for Information Questions

**Category 1:** Technical Requirements

***1.1.)*** *Will the proposed FOA requirements support demonstrations that explore the smart load controls and building design load reduction strategies (e.g. high performance envelope, shading, etc.) in combination with other DERs that provide the best options for demand flexibility to meet specific grid needs?*

It will not, unless an explicit requirement for a documented rate-design is added. That rate-design must incorporate a metric capable of providing a valid comparison between different GIEB studies.

***1.2.)*** *How can the FOA be designed to enable future scaling of connected communities beyond pilots?*

A significant benefit of including a rate-design requirement is that it would allow for the **immediate** scaling of the pilots. A system that works with a given rate-design could be commercially implemented in any jurisdiction that adopts a substantially similar rate-design.

***1.4.)*** *What should be the minimum square feet or number of buildings requirement for each project to demonstrate buildings can contribute as reliable grid resources? Is there a different way to require a minimum project size (e.g. load size)?*

The average home is between 1000 and 2000 square feet. A sample with 1000 homes would need to be at least 1 million square feet. This represents a lower limit for an adequate, heterogeneous sample.

***1.5.)*** *Is the requirement of including at least two DERs in addition to energy efficiency the right approach to exploring demand flexibility solutions to support grid needs, customer service, environmental and resiliency goals or other considerations and priorities?*

Two is too small a number. As noted above, DOE should be seeking demonstrations of the ability to handle heterogeneous combinations of multiple DERs, and that can readily adapt to accommodate DERs that do not yet exist.

*Should there be a minimum amount of demand flexibility resulting from the combined DERs? If yes what should it be and why?*

A reasonable baseline would be requiring 20% of homes in the pilot to be able to shift 90% of their demand outside of peak utility demand hours.

This result is already achievable with existing technology. The sole limitation is that existing rate-designs do not properly compensate people who make the investments necessary to achieve such results. As noted above, DOE should insist on proposals that improve on what is already possible.

The calculations are as follows:

For a 1000-square foot home with an AC unit in the top 40% in efficiency and insulation in the top half of our sample, a used Nisan Leaf could be used exclusively as a whole home battery[[24]](#footnote-25) to run the AC during peak hours. This leads to 20% of homes being capable of shifting 90%[[25]](#footnote-26) of their load.

*Should it be different for new and existing commercial and residential buildings; if yes how?*

Because an older building uses between two and ten times more energy per square foot and because buildings older than 10 years account for ~100 times the square footage of new ones, making an older building 20% more efficient produces far more savings than improving a new building by 50%. A properly designed rate would reward older homes commensurate with the savings they could provide.

The relevant metric is total energy savings. The age distribution of buildings included in the study should mirror the distribution of existing buildings. And it should focus technology and resources on older buildings because that is where the savings are.

***1.7.)*** *Are the required teams “composed of critical stakeholders representing grid resources/assets (e.g. utility), buildings owners/assets (e.g. home builder, building owner, developer, building manager), and researchers (e.g. national lab, university)” and suggested additional collaborators such as “relevant technology manufacturers and local governments” appropriate to meeting outcomes of the anticipated FOA? If not, are there other important partners that should be included?*

Renters and low-income households need to be specifically considered. Because low income households, landlords, and tenants are all critically important stakeholders, it is necessary to confirm that they consider the system to work. The homes these individuals live in are the oldest and least efficient. They are the homes where disruption due to installation would have the biggest impact and where affordability improvements would make the biggest difference to the occupants. These occupants are also the consumers least able to afford the time investment necessary to understand and properly use a complex system.

They are the litmus test of success. If a study cannot confirm that GIEBs work in that scenario, it cannot confirm that GIEBs work at all. Teams should directly involve such consumers in the design process to ensure that their needs are understood. Teams may wish to consider including a consumer advocate organization[[26]](#footnote-27) as a team member simply for the perspective and input they would bring.

***1.9.)*** *What technical communication (e.g. data access, data transport, network technologies, interoperability) requirements should be included for maximum project effectiveness and future scaling of the technologies? What cybersecurity and privacy requirements should be included?*

It must be possible for multiple aggregators using competing systems to operate on the same grid at the same time. Any technology that does not allow for this will not scale to a real-world scenario.

***1.10.)*** *Do any of the outlined criteria present limitations to emerging business models? Should other criteria be considered?*

A substantial benefit of a rate-design requirement is that it will avoid creating limitations for business models and technologies that DOE and the grant applicants are unaware of or that become available during the life of the study.

As discussed above, the important metric is not whether the system limits *currently* emerging business models, but whether it can accommodate multiple promising business models that emerge *after* the GIEB system is designed.

***1.11.)*** *Are there new or emerging technologies or strategies that support DER optimization that could leapfrog the outcomes of the anticipated FOA that should be incorporated into pilot design and implementation?*

Over 350 published evaluations have shown that time-of-use rates can produce substantial demand response benefits by themselves. The savings are even higher when time of use rates are paired with technology that already exists. The savings are 15% and 25% respectively.[[27]](#footnote-28)

Unless these results are incorporated as a starting point, the outcomes have *already* been leapfrogged before the FOA has been issued.

**Category 2:** Funding, Cost share, and Period of Performance

***2.1.)*** *Is the proposed DOE funding level per project (i.e. up to $7 million) reasonable to achieve the drafted FOA objectives? If not what would be more appropriate and why? Note that all demonstration projects must meet a minimum cost share requirement of 50%.*

A major benefit of including a rate-design requirement is that the effective amount of funding would be substantially higher. Existing businesses currently unaware of the FOA would be able to profit from the incentives provided by the rate-design.

Designing the project to accommodate this is the best way to ensure that the design will be able to accommodate future changes to the market.

Moreover, in order to see widespread adoption, demand response must be financed by the savings it generates. One desirable research approach would be to spend the entirety of the grant money implementing a state-of-the-art rate-design in several localities and to rely on the rate-design mechanism itself to finance the technologies provided by the various partners on the team. This would result in a dramatically larger sample and would allow for rapid, public adoption of successful GIEB designs and practices.

***2.2.)*** *Is a period of performance of 3-5 years reasonable? If not what is appropriate and why?*

A rate-design pilot would not take 3 years to implement and deploy using known technology. Data could be available after 18 months.

Extending the study to 5 years allows the researchers to explore how the system can accommodate the types of changes discussed above. It also provides assurance to anyone making a technological investment that they will be able to recoup their investment before the pilot program goes away.

**Category 4:** Other

***4.2.)*** *Is there any other feedback on the FOA goals, design, requirements, etc. you would like to provide?*

DOE should ensure that teams measure energy efficiency in a meaningful way.[[28]](#footnote-29)

Most building science researchers measure energy efficiency as energy service provided / kWh consumed. But this is misleading — it assumes that the electric system itself is uniformly efficient. It is not. During times of higher demand, both spinning reserves and transmission losses increase, lowering the efficiency of the conversion of primary energy to delivered electricity. The amount of energy put into the generator is the relevant factor. Primary energy consumed is highly correlated with wholesale price and that price can change by a large multiple over the course of a 24-hour period.[[29]](#footnote-30)

Failing to account for this leads to perverse results. A heat-pump water-heater consumes more kWh if it runs at night because it is heating water in a colder home. However, it uses less *primary energy* because the electricity it is consuming was more efficiently produced and transmitted at that time.

This mistake is harder to make if one is thinking about rate-design issues. Under a properly designed[[30]](#footnote-31) rate, GIEB strategies such as efficiency, generation, load shifting, load shedding, and load modulation all become cash-flows[[31]](#footnote-32), therefore a net present value calculation must incorporate primary energy conservation in order to compare the results of different GIEB studies.

1. One of the desired outcomes is, “perspective into the amount and duration that occupants are willing to change the timing of their energy use, and any necessary level of compensation.” [↑](#footnote-ref-2)
2. Ahmad Faruqui, Ryan Hledik, and Jennifer Palmer, Time-varying and Dynamic Rate Design, *Global Power Best Practice Series* (Regulatory Assistance Project and The Brattle Group July 2012). Available at: <https://www.raponline.org/wp-content/uploads/2016/05/rap-faruquihledikpalmer-timevaryingdynamicratedesign-2012-jul-23.pdf> [↑](#footnote-ref-3)
3. See, e.g., Faruqui et al. (2012), figures 2, 3, and 6. [↑](#footnote-ref-4)
4. In aggregate, previous TOU pilots have achieved a 15% reduction in peak demand without any enabling technology. If enabling technology is provided, peak demand is reduced by about 25%. These results were achieved despite the use of sub-optimal rate-designs. [↑](#footnote-ref-5)
5. .In 2013 Stem, an energy startup, partnered with the Mark Hopkins Hotel in San Francisco to install 108kW of battery storage to reduce the hotel’s demand by 20%. (See, e.g., <https://www.theatlantic.com/technology/archive/2013/11/the-100-000-battery-that-could-help-hotels-save-bundles-of-money/281194/>). See also, Garrett Fitzgerald, James Mandel, Jesse Morris, Hervé Touati, The Economics Of Battery Energy Storage (Rocky Mountain Institute 2015). [↑](#footnote-ref-6)
6. The standard reference, “MWG”, is Andreu Mas-Colell, Michael D. Whinston, and Jerry R. Green, *Microeconomic Theory,* Oxford (1995). [↑](#footnote-ref-7)
7. These proofs are widely known and will be cited here and explained informally because a mathematically formal explanation would require copying several hundred pages from a textbook. [↑](#footnote-ref-8)
8. MWG, Proposition 21.C.1, page 796. [↑](#footnote-ref-9)
9. MWG, Proposition 23.C. 3, page 874. [↑](#footnote-ref-10)
10. E.g., MWG, Proposition 22.D.3, page 837. [↑](#footnote-ref-11)
11. See, e.g., Itzhak Gilboa, Andrew Postlewaite, and David Schmeidler, The Complexity of the Consumer Problem and Mental Accounting (2010). [↑](#footnote-ref-12)
12. In the language of economics, the functions used by the control system will be “dictatorial” because they will not treat the preferences of all users equivalently or will impose value judgments made by the researchers and policy makers. [↑](#footnote-ref-13)
13. See, e.g., Hal Varian, *Intermediate Microeconomics* (5th ed. 1999) page 425. Long-run costs must be used because short-run costs will force the electrical utility to operate at a loss due to high fixed costs. This is obvious when one observes that wholesale energy prices are at most 30% of their costs while demand is at least 50%. Because fixed costs only exist in the short-run, this problem does not occur when using long-run marginal prices. In practice a three part tariff is used. A TOU energy charge is combined with a TOU demand charge and a fixed charge that pays for overhead expenses. [↑](#footnote-ref-14)
14. The specific implementation details are not explored here. Testimony from a recent rate-case in New Orleans discusses the specifics. See application of entergy new orleans, llc for a change in electric and gas rates pursuant to council resolutions r-15-194 and r-17-504 and for related relief, docket no. UD-18-07. See the testimony of Myron Katz, PhD on Feb 1, 2019 and April 25, 2019 as well his team’s response to ENO’s Interrogatory on Jun 1, 2019. These documents are available at https://ProRate.energy [↑](#footnote-ref-15)
15. See, various filings in the 2018 Entergy New Orleans Rate Case citing the 2015 Integrated Resource Planning docket. The original 2015 docket is not available via the web, but all the relevant information can be found in the 2018 rate case. To simplify matters, we have made the relevant documents available electronically via [https://clepenergy.org](https://clepenergy.org/). If the original documents are used, we recommend doing a keyword search for “CLEP”. [↑](#footnote-ref-16)
16. Demand charges for commercial customers average $120/kW-year. Residential demand charges in existing pilots are a small fraction of this price. Notably, commercial customers are typically *billed* $10/kW-month, but the true cost of demand varies throughout the year and within a given day. Billing issues aside, demand costs only truly exist during peak utility demand hours. [↑](#footnote-ref-17)
17. The 1985 NegaWatt metric, dollars spent per kWh saved, uses simple payback, but payback periods are often a misleading metric. Net present value takes the time-value of money into account and allows for the magnitude of the available savings to be meaningfully compared. [↑](#footnote-ref-18)
18. NegaWatts treats every kWh as having the same economic value and thus cannot be used for a study that incorporates load shifting. As discussed in the reply to question 4.2, at a minimum, a valid metric would reflect improvements in *primary energy* conservation. [↑](#footnote-ref-19)
19. For example, we were unable to determine the full rationale for the average commercial demand charge. An applicant capable of answering such a fundamental question via their research should be favored. [↑](#footnote-ref-20)
20. Lisa C Schwartz and Greg Leventis, Grid-Interactive Efficient Buildings: An Introduction for State and Local Governments (Lawrence Berkeley National Laboratory 2020). [↑](#footnote-ref-21)
21. The price of Tesla’s 10 kWh batteries dropped by 75% between 2016 and 2020. IceEnergy’s air conditioning technology had significant commercial promise, but the company filed for bankruptcy at the end of 2019. [↑](#footnote-ref-22)
22. For example, in New Orleans, land subsidence causes cracks around doors and windows that result in an order of magnitude more energy cost than any other source. This problem aside, because of the humidity, installing a more efficient AC unit and moisture retarding roofing will create a health risk to the build’s occupants if the installation does not also incorporate a mechanism to allow for moisture removal or evaporation. [↑](#footnote-ref-23)
23. By way of analogy, DOE’s “Sun Shot Initiative” sought to reduce the installation cost of solar panels to $1 per square foot. However, installation costs are not what matter to purchasers in the real world. They care about the rate of return, the payback period, and the net present value of any investment. We ultimately learned that the value proposition of a solar installation was dramatically enhanced by combining it with batteries. It is important to ask the right research questions. Simply demonstrating interesting technology does not mean that this technology will be useful. With an explicit rate-design element, we can ensure that the benefits provided by these new technologies are economically meaningful. [↑](#footnote-ref-24)
24. A whole home battery is a battery that can be charged in 4 hours and run the entire home off-grid for the next 20. See <https://www.buildingscienceinnovators.com/buildings-without-diapers.html>. [↑](#footnote-ref-25)
25. We recommend 90% instead of 100% to provide a margin of safety to accommodate other factors that may affect the load. [↑](#footnote-ref-26)
26. Prominent consumer advocates often oppose naive TOU rates because of their negative impacts on low-income individuals. A properly designed rate does not have these issues. See [https://www.pressherald.com/2016/10/02/maine-voices-electric-customers-cant-subsidize-solar/**,**](https://www.pressherald.com/2016/10/02/maine-voices-electric-customers-cant-subsidize-solar/) [https://www.energy.gov/sites/prod/files/2016/02/f29/Panel%202%20David%20Springe%2C%20Executive%20Director%2C%20National%20Association%20of%20State%20Utility%20Consumer\_0.pdf](https://www.energy.gov/sites/prod/files/2016/02/f29/Panel 2 David Springe%2C Executive Director%2C National Association of State Utility Consumer_0.pdf), and <https://www.utilitydive.com/news/inside-californias-rate-restructuring-plan-and-the-battle-for-fixed-charge/402117/>. [↑](#footnote-ref-27)
27. See footnotes 3 and 4 above. [↑](#footnote-ref-28)
28. In the course of our research, we have identified 19 ways of improving primary energy conservation that do not contribute to energy efficiency measured in kWh consumed. See <https://www.buildingscienceinnovators.com/primary-energy-conservation.html>. See also the DOE-funded National Standard Practices Manual project, <https://nationalefficiencyscreening.org/the-national-standard-practice-manual-for-ders/>. [↑](#footnote-ref-29)
29. While gathering price data to create out rate design simulator, we quickly found 10 days in 2018, concentrated in August, where MISO prices changed by a factor of 10. Regarding our simulator, see <https://www.buildingscienceinnovators.com/uploads/1/0/6/2/106256229/exhibit4-experiencingtheclep-dashboard-v3.pdf>. [↑](#footnote-ref-30)
30. Under *existing* rates, the listed strategies are often in conflict with one another. [↑](#footnote-ref-31)
31. These terms are explained in table 2, Monica Neukomm, Valerie Nubbe, and Robert Fares, Grid-Interactive Efficient Buildings Technical Report Series: Overview of Research Challenged and Gaps(DOE Office of Energy Efficiency and Renewable Energy December 2019). Available at <https://www1.eere.energy.gov/buildings/pdfs/75470.pdf> [↑](#footnote-ref-32)