

Help! I Can't Set the Clock on my Microwave Oven and Now I Need to Program My Heat Pumps, Batteries, Solar Panels, and Electric Vehicle Charger to save the Planet?!

*Dave Intner, Randall Higa, Jerine Ahmed, Southern California Edison
Maziar Shirakh
Carol Yin, Yinsight, Inc.*

ABSTRACT

The operation of appliances in a home became significantly more complex when 7-day set-back programmable thermostats replaced the simple round analog thermostats. Like the blinking “12:00” on the microwave oven’s clock, many thermostats are not programmed and are consequently used as on-off switches. The consequences are deemed to be minor and result in an ignored increase in energy bills with some sacrifice in comfort. As we look to a future with more all-electric homes to mitigate climate change with heat pump (HP) heating/cooling systems, HP water heaters, photovoltaic (PV) solar panels, batteries, and electric vehicle chargers, the control requirements are substantially more complex. In this scenario, the unintended consequences of non-optimized operations are significant. Heat pumps, PV panels, and batteries can appreciably reduce energy bills, grid impacts and greenhouse gas (GHG) emissions if controlled optimally in accordance with time-of-use rates, GHG emissions data, building loads, PV output, grid congestion, predicted weather conditions, etc. On the other hand, these same electric appliances with a lack of proper controls programming will result in very different, negative impacts. This paper will examine the magnitude of the opportunities and challenges that may occur with the proliferation of electric end-uses based upon how they are controlled. Impacts will be considered from the perspective of utility customers, utilities, home builders, appliance manufacturers, and installers. Potential solutions to simplify and optimize the operation of electric appliances as a harmonized system may include greater levels of automation, pre-programming, updated price signals, and outreach and education.

Introduction

While the obsolescence of videocassette recorders has saved many of us from ever having to learn to program the devices correctly, that is not a viable long-term strategy as we enter a world that is even more connected than ever. It is likely that at this moment, many of us still have devices in our homes that may be set in a manner different than what the manufacturer intended. Thankfully, most manufacturers have by now realized that consumers do not necessarily want every single device to double as a clock, and we see a greater trend towards internet connected devices that can automatically populate some location-specific information such as local time.

While the consequences of incorrectly setting VCRs and microwave ovens may only be a mildly reproachful blinking “12:00” or having to manually turn equipment on and off, suboptimal settings on today’s devices could have more costly or even counterproductive consequences.

One looming set of questions that underlies this whole discussion is, “What are we optimizing for?” and “Who decides?” Do we optimize for customer comfort? Energy reduction? Greenhouse gas emissions reductions? Mitigate climate change? These objectives in some cases may be incompatible; we will return to these questions at the end of this paper.

This paper addresses the human factors and user experience dimensions of this complex equation, and the role of the utilities, home builders and trade allies in facilitating a smooth adoption experience for the customer that also supports grid operations.

Building controls have long been recognized as key to optimizing use of individual energy efficiency measures (Rogers and Junga 2017). Discussion on controls have spanned the continuum from “connected” technologies that simply allow the user to control a device through an app, such as a connected garage door opener that can be operated through a smartphone app, to intelligent control systems that utilize learning algorithms and two-way communication across communities (DOE 2021a). In 2021, The U.S Department of Energy (DOE) threw down a \$61 million gauntlet, challenging communities and market actors to develop grid-connected pilot communities that will provide energy savings, reduce carbon emissions, and reduce grid costs, while maintaining comfort for building occupants (DOE 2021b). A recent NREL market assessment of existing connected communities found that the benefits of using control technologies may have multiple payoffs including a revenue stream from grid services and better lifecycle costs than for individual buildings alone (Olgyay et al. 2020). This would present a potentially attractive proposition for utility program portfolios that may be facing decreasing cost effectiveness.

Consequences of a poor user experience

Manufacturers that rely on users to program equipment correctly may be faced with wide ranging consequences if the user has difficulty doing so. Worldwide, businesses spent an estimated \$4.43 billion on managing customer loyalty in 2021, and the number one reason why US consumers would lose trust in brands is using a faulty product (Guttmann 2022). In this context, the consequences of a poor user experience potentially have lifelong ramifications beyond merely ceasing to use the product. For the retailer, customer returns are a rising cost, with estimates ranging from 10.6% to 16.6% in recent years (Repko 2022). Conceivably, customer dissatisfaction with their product could result in their abandonment of an entire “ecosystem” of devices, e.g. Google Home/Nest vs Amazon Alexa vs Apple, and switching to a competitor’s ecosystem.

Damage to the user system. Although poorly operated controls are unlikely to have catastrophic adverse consequences to the equipment itself, due to manufacturer safeties and overrides programmed in to prevent such occurrences, there is potential for poor operation to lead to system degradation or early equipment failure. One example which warrants further study is the frequency of battery charging. Estimates vary as to the potential of daily charge and discharge cycles to reduce the anticipated service life of the battery (Bhagavathy et al 2021) although the battery chemistry, temperature, rate of charge/ discharge, and duration of charging event all appear to be potentially significant factors.

Stress to the grid. Poor controls can have devastating impacts on the electrical grid. Utilities have devoted many resources to ensuring that they can provide power during peak periods to ensure power quality and reliability to customers. Some key tools that utilities continue to rely upon are demand side management systems, where customers voluntarily reduce or cease energy use during peak periods.

Many utilities offer residential customers the opportunity to enroll in a demand response (DR) program where, in return for an incentive or bill discount, customers allow the installation of a device that can turn off or cycle their HVAC system for a period of time (ranging from 15 minutes to a few hours) during demand response emergencies. As these events historically occurred during the hottest parts of the day that coincide with business hours, many customers do not notice the demand response events. However, with the increase of solar generation in California, the residential demand response events have been called between late afternoon into the evening. A 2019 market assessment by Smart Electric Power Alliance (SEPA) found that utilities were moving away from AC switch control programs because customer participation in such programs was decreasing. However, thermostat programs are popular and expected to expand, with the Bring Your Own Thermostat business model becoming the industry standard for utility thermostat programs. (SEPA 2019).

Private industry has proposed several innovative solutions for customer-side demand response management systems (DRMS) that have the capability of forecasting demand response events, triggering events based on locational marginal prices, and controlling load reduction within a non-residential customer's facilities. However, utilities have yet to widely adopt these systems due to a number of control issues.

Utilities decide to call events based on several factors, and usually only after consultation with customer account representatives about the possible impact of events on the customers' operations. Utilities must also decide which program to utilize for dispatching the demand response event, taking into consideration the costs and impacts of the different programs. It is difficult to trust such decisions to algorithms within DRMS. It is correspondingly difficult for DRMS manufacturers to develop and test algorithms that would be sufficient for utility DR needs, with the real risk of having their code become obsolete during the intervening years of development.

Part of the utilities' concerns with dispatching DR events is that the grid may not be able to handle the inrush current when thousands of AC units are turned back on after an event ends. If enough AC units in the same circuit are shut down under a low voltage situation, the inrush current could bring down that circuit and result in rolling blackouts across the grid. With careful control and sequencing of DR events and monitoring of grid conditions, utilities can maintain a stable grid that can tolerate some abuse, but the potential for the "perfect storm" of adverse conditions can be exacerbated by poorly controlled devices.

Environmental costs. There are significant costs of embedded energy involved in the mining of rare materials and the manufacture and transport of these goods, as well as costs of environmental waste from discarded plastic packaging and incorrect disposal of electronic waste and of any environmental clean-ups necessitated by leakage of toxic materials. These considerations can be ameliorated by greater interoperability. Proponents of a common communications protocol use that basis to give competitors a solid reason for collaborating on

increasing device interoperability. Better yet would be to ensure that customers have a good experience.

Implications for regulators, legislators, and policy makers

In addition to the concerns above, poorly controlled devices have implications for regulators, legislators, and other policy makers. As stewards of ratepayer dollars, policy makers and utilities must work together to address equity issues in the adoption of high-efficiency technology. Ratepayers fund energy efficiency programs under strict cost effectiveness requirements, and a poorly controlled device not only has immediate costs to the users, but also to the ratepayers whose dollars will have ended up wasted. A recent report from UC Berkeley found that Californians pay two to three times more for electricity than it costs to provide in order to fund public-benefit programs that are addressing California's non-energy needs (Next10, 2021). This poses a particular burden on the mid- and lower-income ratepayers (the latter do not include low-income customers who participate in rate assistance programs).

If equipment or measures that have been incentivized with ratepayer dollars are not performing as designed due to poor control, this impedes California's progress towards everything from its ambitious carbon emissions reductions goals to its energy equity and infrastructure planning goals.

Is “plug and play” the holy grail?

There are several options for setting controls, each with different implications and challenges. Yes, of course, everyone wants “plug and play” but the devil is in the individual differences. One option for setting controls is to set devices to “zero” and rely on documentation to guide users to select the most appropriate ones or themselves. Perhaps unsurprisingly, the downfalls of this approach are multitudinous, and few manufacturers select this option.

A second option is for the manufacturer to set the controls according to aggregated historical customer usage patterns that they have gathered from their existing customer base. Many manufacturers and software developers strive to explain their purpose and offer customers a choice in whether or not to send usage data back; many others don't. But fortunately, the industry standard seems to include privacy policies in which customers are asked if they are willing to share their usage data in order to improve the product or improve the user's experience. It's important in these cases to make the clear how a customer can opt out of these processes.

It's critical to recognize that any aggregated historical customer usage data may be biased, particularly if early adopters of a new technology tend to have higher incomes and greater access to infrastructure necessary for program participation (including wifi or broadband internet access), as has been the case for adoption of photovoltaic rooftop systems. The California Solar Initiative (CSI) was a 10-year long effort with more than \$2.1 billion budget with a goal to establish a self-sustaining customer solar market. A recently completed evaluation of the CSI found that while the program largely achieved its goals, solar adoption in less affluent areas initially lagged adoption in more affluent areas: While households with a median income greater than \$100,000 constituted approximately 23% of California's population, these homes were disproportionately represented in the CSI participant population, constituting 45% of all

residential PV installations in 2007. As households with lower median incomes increased participation, the percentage of >\$100,000 households that participated declined to less than 30% by 2016 (Verdant Associates, 2021).

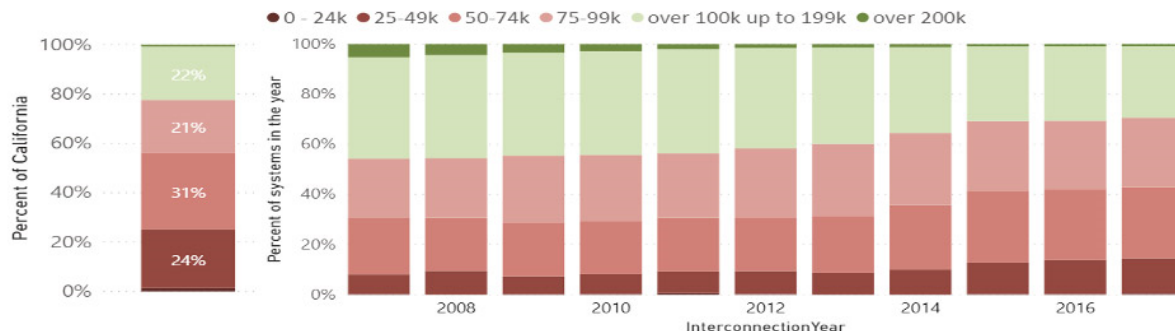


Figure 1. Solar installations by household median income. <https://verdantassoc.com/wp-content/uploads/solar-adoption-graph.jpg>

Manufacturers that rely on data gathered during early years of adoption need to keep in mind that those data may be reflecting a non-representative customer segment, and should they use that data may have been basing production and marketing forecasts on those data. Manufacturers and utilities may need to be vigilant to understand the early adopters' financial means and characteristics in general in order to understand the most effective incentive structures and program delivery mechanisms for the mass market and the disadvantaged communities.

There are certainly many ways in which manufacturers and developers have minimized bias. Rather than averaging across their aggregated data, they can (if the data are available) develop more than one customer profile, using common demographic information such as household size, home size, vintage, comfort preferences, etc. Within these profiles, manufacturers can offer a more appropriate set of default control settings.

Beneficial defaults. Many, if not most, customers are likely to retain the default settings in a piece of equipment, therefore manufacturers can and should set control defaults in a way that encourages a certain outcome, such as energy or GHG reductions. For example, HP water heaters could be shipped in a default mode that might not be most economical to operate. These outcomes need to be balanced against customer needs and comfort, because settings that don't align with customer preferences will likely be bypassed or unused. Manufacturers also will look at ways to reduce customer complaints and therefore set defaults to minimize comfort issues. However, there is no guarantee that customers will continue to use those defaults. For example, the television industry has developed a standard practice of including a "retail" or "store" setting, otherwise fondly known as "torch" or "blowtorch" setting. This energy intensive setting is used in retail showrooms, where TVs are competing for the shoppers' attention with the brightest, sharpest, highest contrast displays, in showrooms that are often harshly lit. Once purchased, however, the "torch" setting is too energy intensive and too bright for most home television rooms, and the consumer must change that setting. Upon startup, many televisions today guide users through their options, one of which might be a "home" setting. The home setting may be too dim or desaturated for consumer preferences but may be provided so that the TV qualifies for California Title 20 code or for an Energy Star rating (Wilcox, 2021). The consumer might be

happy with other presets; many manufacturers offer separate settings for sports, or cinema. Or, the consumer is left to their own tweaking of brightness, contrast, and other settings. The availability of an energy efficient, but unused default, somewhat undermines the intent of appliance codes.

Nudging. There are indirect ways in which manufacturers can influence customer choices of settings. In the behavioral sciences, the concept of choice architecture and “nudging” gained prominence in the late 2000s. The foundations of choice architecture come from psychology and behavioral economics studies showing that customers’ choices are influenced by their choice options. Nudges are those interventions that can change a chooser’s behavior without changing their freedom of choices and without changing any financial considerations.

There are numerous fascinating relevant findings in this area, including the perseverance of “default” settings in customer choices (i.e., many people go along with the defaults), and choice overload (i.e., too many choices lead to decision-making paralysis). The seminal study, also known as “the jam study,” was one showing that a supermarket display with 24 different kinds of jams sold fewer jars than a display with only 6 different kinds (Iyengar and Lepper, 2000). Another study found that even medical professionals are subject to cognitive biases, and that in situations where choice complexity is increased, the chooser may default to the standard practice. However, there has been some difficulty replicating that study and some evidence that choice overload is not a robust effect (Scheibehenne, Grifeneder, and Todd, 2010). Others have suggested that the paralysis may stem from information overload rather than choice overload.

Would decision-making become easier if more information or other assistance is provided? A recent meta-analysis of research on choice architecture compared the effectiveness of three types of decision-making interventions. In “*decision information*” interventions, the chooser is provided with more easily accessible information that might help their choice. One successful energy efficiency program in that category is the home energy report that provides homeowners with information about the social norms of energy use, information that has been shown to influence behavior, and information that may not be readily available to the user. In “*decision structure*” interventions, structuring an organ donation program wherein the informed consent form indicates “opted in” as a default results in more participants than a form that does not. In “*decision assistance*” interventions, customers may be asked to make a commitment to reducing energy use and be reminded of that commitment come time to purchase an appliance. A particularly interesting set of findings suggest that translating a product’s attributes into their energy efficiency impact could remind consumers to value energy efficiency if they already held energy efficiency values (Ungemach, et al., 2017). The meta-analysis found that all such “nudges” have only a small to medium effect, and that “*decision structure*” interventions outperform “*decision information*” or “*decision assistance*” interventions (Mertens, et al., 2021). These findings have implications for manufacturers who design default settings for controls and suggests that providing customers with information about the implications of their energy use may only have a limited effectiveness. Manufacturers, code developers, and program designers may have greater effectiveness by utilizing decision structure interventions.

Sub-optimal automation and/or documentation. In the Table 1 below from a heat pump water heater manual, a thermostat’s different modes and their “efficiency” versus “recovery” (i.e., and

thus comfort) rates is summarized for the user. This is an example of an information-assistance intervention. This is laudable in that it seeks to help the customer make an “authentic choice”¹ that would strike their desired balance between energy use and comfort. The keen-eyed reader may notice that the water heater seems to also have an electric resistance strip, which would explain why there is an “Energy Saver” mode that has “Very High” efficiency and “Fast” recovery. In a case such as this, the mode of operation that some would consider less efficient than heat pumps alone seems to be presented as the more attractive balance between which raises the question of what the manufacturer means by “Efficiency”.

Table 1. Summary of user settings from a heat pump water heater manual

Mode	Efficiency	Recovery
Electric	Very Low	Fast
Heat Pump	High	Very Slow
High Demand	Low	Very Fast
Energy Saver	Very High	Fast
Vacation	Very High	None

This speaks to the importance of having instruction manuals and technical documentation that is comprehensible to the average consumer. In some situations, the information be simplified to the point that they de-emphasize information that is important for California’s energy savings and GHG reduction objectives, for which ratepayers paid. Often these situations are not known until an energy efficiency program evaluator finds an unexpected spike in energy use.

While there are no easy answers for situations where defaults are not programmed or incorrectly programmed for the purpose of energy efficiency, we note that in Europe the default setting for hybrid HPWHs is the heat pump alone setting, and the lessons from HPWH deployment in Europe may be useful for California. Further, it may be useful for utilities to continue communicating evaluation findings to manufacturers.

“Intelligent” algorithms for control. Many devices today utilize algorithms to determine control settings. These algorithms can be rule-based or can have learning capabilities, and they can utilize data that are entered by the customer. The Nest Learning Thermostat learns the customer’s preferred setpoints over the course of several days, and then programs a schedule based upon that data. Anecdotally, there are some complaints that the algorithm weights exceptions to the setpoints too heavily, so that a single hotter or cooler day may end up affecting settings for days afterwards. Honeywell has a smart response feature that learns how long a room takes to reach a particular temperature, and then factors that time into the programmed schedule so that the HVAC system turns on earlier in order to achieve the desired temperature at the specified time. False positives caused by ambulatory pets may increase energy use inadvertently. And, as anyone who has ever been plunged into darkness in an otherwise empty office (or worse, in a restroom) knows, these sensors can be tricky to properly locate and calibrate.

Customers may also be expecting too much from “intelligent” devices: a recent evaluation was conducted on the effectiveness of a pilot that provided smart thermostats to help

¹ The authors thank Henry Richardson of WattTime for early formative discussions about this topic.

California's low-income customers transition to time-of-use (TOU) rates². The study found that while smart thermostats successfully enabled low-income customers to improve comfort, increase awareness of TOU rates, and have more control, they did not reduce peak nor daily energy usage, compared to the control group. The evaluators hypothesized that the control group without smart thermostats may have decided simply not to use their HVAC system at certain periods to reduce energy costs. The evaluators also hypothesized that the treatment group may have relied solely on the smart thermostat's default settings to control their usage during the highest TOU rate periods (Evergreen Economics, 2020)

Utility-assisted automation. The final option we discuss for setting controls is utility-assisted automation, in which periodic signals are sent to customer equipment. Depending on the program, customers can opt out, or choose not to participate in specific events. For residential customers, California investor-owned utilities offer demand programs that directly control customer equipment. These include programs that turn off or cycle AC switches, or temporarily adjust their smart thermostat's settings. Through third party vendors, the California utilities also allow residential customers to participate in capacity bidding programs, where the events are called by the utility with day ahead notice. While these programs do offer participation incentives, they also require the customer to give up some level of comfort to respond to events.

The interconnected future

As the market gains more experience with control technologies and addresses some of the interoperability and security challenges we discussed above, there will arise a need to control across multiple systems, not just the individual HVAC or television systems.

There are several prerequisites that need to be resolved before we are ready to conduct research into this area. But even assuming perfect interoperability of controls, even if systems are secure against cyber attacks, and all manuals are clear, there has been little to no discussion of the need to optimize all these systems together. For example, in what circumstances should a resident use solar to precool the home, versus using a battery storage system to charge their electric vehicle? Should there be a different initial setting for a heat pump in a home with multiple controlled devices, versus a home with none? How should these initial settings be changed, and using what algorithm/data? This is a needed area of research.

There will be a more urgent need to answer the set of question we raised in the introduction: "What are we optimizing for?" Should the settings in a massively interconnected home (or community of homes), be optimized for cost? For GHG reductions? We suggest that the DOE pilots on grid-connected communities may be forced to address such questions earlier than the rest of the market, and that those pilots may be able to provide valuable lessons learned. We also suggest that manufacturers provide a default setting that is initially optimized for GHG emissions reduction, so long as that default is not, say for the sake of argument, an arbitrary 20%

² The evaluators report that near the end of the pilot period, the thermostat manufacturer notified the utilities that they had inadvertently not included the expected eco plus mode that had been expected to help customers shift usage away from the periods with the highest TOU rates; subsequently the eco plus functionality was pushed to only 69% of the treatment group participants, due to connectivity problems. The evaluators said this manufacturing error may have impacted the findings due to a decreased sample size and shortened test period.

more costly in terms of energy rates than for the lowest cost scenario. This will vary by regional grid mix- so a reasonable national average may be needed, or the ability to customize (manually or geo-locating) a preset by region.

These considerations will be greatly aided by regulatory policies that align utility prices and tariffs with greenhouse gas emissions. Steps have already been taken towards that direction: The California Energy Commission recently updated their code compliance metrics to include the use of time dependent long term source energy, which acknowledges the differently hourly costs of source energy and indicates the marginal emission rates for every hour of the year. In addition, the source energy metric will be updated to represent the marginal emission rates for each future cycle of standards considering changes to the grid as a result of environmental policies such as SB 100, which establishes the goal for zero emissions from the grid by 2045 (California Energy Commission, 2020).

Grid-Harmonized Batteries

Battery storage technologies are expected to play a key role in the reduction in GHG emissions, and in the interconnected future. Currently, standalone batteries pose an additional cost to the homeowner, and are usually used for backup within the home, and not designed to support grid operations. But batteries may resolve many of the control problems described earlier by optimizing the charge and discharge periods to reduce the building's operating costs as well as reducing GHG emissions. The energy savings and GHG benefits can be further enhanced when the battery storage systems are paired with onsite PV systems.

Battery Storage Communication and Control Capabilities Requirements. When batteries are paired with onsite or community solar PV systems, and properly grid harmonized, they are capable of load shifting strategies that can reduce the energy cost of the building while also very significantly reducing the GHG emissions from the building. In fact, among load shifting strategies, grid harmonized battery storage systems by far offer the largest cost and emission saving potentials as indicated in Table 2 below. However, like other demand response measures, the batteries must have certain capabilities and proper control strategies to save cost and reduce emissions; a poorly controlled battery, or batteries that are permanently left in backup mode, can indeed result in higher building energy cost and emissions compared to a building with no battery storage system, even if the building already has a PV system. In addition, as battery technologies mature in parallel with electric vehicle technologies, batteries in EVs are expected to play a role in grid stability, if only because the time window in which the EVs are charged could greatly harm or greatly aid grid operations and GHG reduction effectiveness.

To ensure these cost and emission benefits are realized, California's Building Energy Efficiency Standards (Title 24) developed Reference Joint Appendix 12 (California Energy Commission, 2021), which specifies communication requirements and control strategies that are designed to make these benefits possible. This primarily applies to new construction, but as manufacturers begin complying with JA12, we can expect this to become the norm for all battery installations. Here is a summary of these requirements:

General Requirements:

- For applicable buildings that require PV systems, battery storage systems in California must be certified to the California Energy Commission to meet all JA12 requirements; the following is a link to the JA12 compliant battery storage systems certified to the Energy Commission by the manufacturers:
<https://solarequipment.energy.ca.gov/Home/EnergyStorage>
- Usable capacity of at least 5 kWh
- Energy capacity retention of 70 percent of nameplate capacity after 4,000 cycles covered by a warranty, or 70 percent of nameplate capacity under a 10-year warranty
- The battery storage system must have the capability of being remotely programmed to change the charge and discharge periods and program modes by the utilities, third party aggregators, or manufacturers
- The battery storage system must perform a system check within 10 calendar days before the onset of summer and winter TOU schedules to ensure that the batteries are not permanently left in the backup mode

Control Strategies. To ensure that battery storage systems are grid harmonized and can benefit the building occupants and the environment, at the time of installation, the battery storage system must be installed to meet one of the following control strategies. The battery storage system also must have the capability to remotely switch to the other control strategies:

- Basic Control - Allow charging only from an on-site photovoltaic system when the photovoltaic system production is greater than the on-site electrical load and discharge only when the photovoltaic system production is less than the on-site electrical load
- Time-of-Use (TOU) Control - Allow charging only from an on-site photovoltaic system and must begin discharging during the highest priced TOU hours of the day
- Advanced Demand Flexibility Control - The battery storage system must be programmed by default as Basic Control or TOU control as described above, and the capability to change the charging and discharging periods in response to signals from the local utility or a third-party aggregator
- JA12 also allows development of a future control strategy that optimizes around minimizing GHG emissions from the building, whether the battery storage system is paired with solar resources (onsite PV systems or community solar resources) or is installed as a standalone system.

Table 2 below indicates the magnitude of energy cost saving and emission saving benefits of a 14-kWh battery storage system that operates in the TOU control mode, compared to precooling and heat pump water heater demand response strategies. In short, if a battery is controlled properly and paired with renewable sources such as PVs, they may be our best options for significant GHG emission reductions, compared to other demand response options.

Table 2. California-specific cost and GHG benefits of various demand response measures

CZ12-Sacramento, 2,700 sf prototype, Furnace with HPWH						
	2022 Standard Design	Pre- cooling	HPWH DR	14 kWh Battery - TOU Control	TOU Battery Control & Pre- cooling	TOU Battery Control & HPWH DR
EDR Scores (TDV Based)	32.9	31.1	32.6	20.8	18.9	20.4
CO2 Emissions, kg/yr	2,189	2,178	2,171	1,707	1,711	1,687
EDR Change Relative to Standard design		1.8	0.3	12.1	14.0	12.5
CO2 Change Relative to Standard design		11.0	18.0	482.0	478.0	502.0

The Energy Design Rating (EDR) scores is a Time dependent Valuation (TDV) related metric which represents the building energy costs. As can be seen in Table 2 the energy cost and emission savings of properly controlled battery storage system are several times larger (1.8 EDR benefit and 11 kg/yr GHG benefit for Pre-cooling, 0.3 EDR benefit and 18 kg/yr GHG for HPWH DR, and 12.1 EDR benefit and 482 kg/yr GHG benefit for TOU Battery Control) than precooling and heat pump water heater demand response strategies. This is true in large part because a grid harmonized battery storage system has the capability to load shift the entire electrical load of the building, including air conditioning, supply air fan power, Indoor Air Quality (IAQ) supply fan load, water heating, plug loads, and indoor and outdoor lighting loads. Precooling on the other hand, can only shift part of one load – the summer cooling load, while heat pump demand response measure can only load shift part of water heating load.

As indicated in the recent SGIP report, an improperly designed and controlled battery storage system can actually result in increased GHG emissions from the building (Maloney, 2018). Therefore, to achieve the maximum GHG and cost saving benefits, it is paramount that the battery storage systems are grid harmonized as specified in JA12 or similar specifications.

Battery Storage System Cost Effectiveness. The first costs and the cost effectiveness of battery storage systems remain a challenge. For residential buildings in California, unpaired (standalone storage systems not paired with onsite PV systems) battery storage systems are not cost effective under the current NEM compensation provisions. However, when battery storage systems are paired with an onsite PV system that generate enough electricity to offset the annual electrical usage of the building, the cost effectiveness improves drastically. Table 3 below indicates that if the first cost of battery storage systems decreases by 20 to 30 percent, which is probably achievable in the next few years, battery storage systems will be cost effective in half of California climate zones, and on the cusp of cost effectiveness in several other climate zones.

These calculations assume that these 2,700 square feet, newly constructed buildings already have a NEM compliant PV system – around 4 kW - that generates enough electricity to displace the annual kWh usage of the building; therefore, the cost effectiveness benefit cost ratios shown below are for battery storage system only (not accounting for PV benefits), when under Time-Of-Use control:

Table 3. Battery storage benefit to cost by climate zone and control strategy

14 kWh	Battery Cost
Initial Install	\$ 8,500.00
Replacement	-
30 Year Total	\$ 8,500.00

Battery storage system cost effectiveness can further be improved under each (or a combination) of the following possible scenarios:

- Future NEM tariffs increase the cost difference between highest peak TOU period, and mid and low peak periods
- Electricity costs increase more than forecast due to escalated inflation or other factors
- Cost of battery storage systems decrease due to mass production and technological improvements

This data also indicates that TOU control for battery storage systems provides far more cost savings benefits than the Basic control, nearly doubling the benefit/cost ratios in some climate zones, highlighting the fact that proper controls and timing of charge and discharge periods are essential for realizing the anticipated cost and GHG benefits.

CZ	Benefit-to-Cost Ratio	
	NEM Compliant PV	
	Basic Control	TOU Control
01	0.6	1.2
02	1.0	1.5
03	0.7	1.4
04	0.7	0.9
05	0.8	1.5
06	0.8	1.0
07	0.8	1.2
08	0.8	0.6
09	0.6	0.7
10	0.6	0.7
11	0.7	1.1
12	1.0	1.2
13	0.7	1.1
14	0.9	1.0
15	0.4	0.5
16	0.6	1.0

Table 4 summarizes TDV (cost) and GHG benefits of various control strategies, when a 14-kWh battery storage system is installed in a 2700 square feet, newly constructed building equipped with a 4-kW PV system, located in CZ12:

Table 4. Impact of different control strategies on cost and GHG reduction

2700 square feet, CZ12, 4 kW PV System					
		Basecase		Savings Relative to Basecase	
		TDV (Cost)	CO2 Emmissions, kg/yr	TDV (Cost)	CO2 Emmissions, kg/yr
No Battery Storage	Basecase	71.67	2,197	NA	NA
14 kWh Battery Storage	Basic Control	44.48	1,700	27.19	497
	TOU Control	39.51	1,645	32.16	552
	Advanced DR Control	35.37	1,697	36.3	500

Interestingly, while the Advanced DR control strategy saves TDV (cost) relative to the TOU control strategy (39.51 vs 35.37), the CO2 emissions increases (1,645 vs 1,697). This point to the problem of price signals not being entirely aligned with the GHG signals.

Other Battery storage challenges. Battery storage technologies are a necessary part of our interconnected future and have the promise of obviating many of the control issues related to grid stability. However, it's critical to acknowledge that significant challenges remain before battery storage systems can become a common tool for achieving GHG and other environmental benefits. For example, the industry and the regulators must address environmental impact of batteries such as embodied carbon as well as end of life disposal, recycling, and recovery issues. Fortunately, the industry and the regulators are aware of these issues and are calling for solutions to these challenges. In 2021, the California Energy Commission has launched a key initiative to investigate embodied carbon in building materials and their role in building decarbonization. Other technologies are promising but likewise still emerging; while redox flow batteries offer several advantages over lithium ion for utility scale storage applications, they are still not yet cost-competitive with other energy storage technologies.

Further studies and solutions are needed to address the issue of controls complexity that will impact technology adoption, user health and comfort, and the achievement of California's energy efficiency goals. Battery storage systems must be interconnected with utility services in a safe manner. Utilities can provide standard interconnection procedures as recommended operating modes. Utilities and regulators should also examine what policy frameworks would be necessary to ensure that battery storage is adopted equitably across California households. Regulators must also create tariffs that better align cost reductions with environmental benefits.

Other challenges. We want to briefly acknowledge some of the numerous issues related to controls programming that are not within the scope of this paper: One long-standing challenge is the lack of a common communications protocol across manufacturers and the repeated attempts to resolve that challenge. However, the new Matter collaborative seeks to address the common language issue. Matter is an open-source communications standard with the Connectivity Standards Alliance (CSA) acting as the certifying body. With the backing of big players such as Apple, Google, Amazon and Samsung, as well as a 400-member alliance, this market-led solution to the long-standing communication barrier is both exciting and promising.

Also out of scope are thornier problems concerning cyber security and "surveillance capitalism". Neither of these two issues are addressed in this paper, but we note that most federal agencies and private sector entities have ongoing efforts to address cybersecurity threats. The DOE has a specific responsibility "to improve security and resilience in the energy sector" and engages with the building industry to anticipate and prevent cyber security breaches (Reeve et al. 2020). The Internet of Things (IoT) already offers hackers a way to amass resources of thousands of connected devices to issue a denial-of-service attack on another target, steal data, or disrupt operations (Diaz 2020).

On the surveillance capitalism front, Apple's recent blocking of third-party cookies that track users across different websites from its Safari web browsers in March of 2020 may prove to be a watershed event. This may signal a change in the available supply of customer data for those firms whose business model depends on it; this may lead to a decline of in the number of those firms, or it may drive them to other avenues for collecting such data.

Summary and Recommendations

Customers are faced with a myriad of control options and demands, creating complexity that impacts not only their experience with a product, but also potentially impacting the energy efficiency and GHG reduction benefits for which ratepayer and others' resources have been spent. While certain emerging technologies such as home battery storage systems may offer greater and easier control and may obviate many of the problems of controls complexity, there are inequities in access to emerging technologies that need to be addressed. Battery deployment will take time and not be universal. Thus, the issue of controls complexity for appliances will continue to have implications for manufacturers, vendors, utilities, and policy makers. The ultimate choice must be the customer's, but there are tools to help the customer make a choice that balances their comfort with environmental benefits. These tools must be accessible to customers in a way that they can understand from a layperson's perspective. The complexity of controls is likely to expand exponentially as we approach a massively interconnected future. We must begin to gain a better understanding of the interactions, benefits, and costs, of utilizing multiple control systems within the home.

Manufacturers should utilize or continue to utilize user experience experts and social scientists who can test and monitor whether customers find products and product documentation easy to use and clear. Manufacturers should continue to utilize devices that streamline the choice of control settings, such as "setup wizards" to minimize any possible choice overload upon the consumer. Consumers should be given clear information to support their decisions on controls settings; social scientists should be brought in to test for intended or unintended biases in choice architecture of the settings. Regulators and legislators should align or continue to align tariffs and rate plans to support GHG emissions reductions and should address the financial burden associated with funding non-energy programs upon the middle- and lower-income ratepayers. Utility and third-party energy efficiency program implementers should include information about GHG reduction potential associated with the interventions being proposed, to provide consumers with an alternative framework for valuing their decisions.

Finally, the foundation of the most grid interactive, greenest home will still need to be the most energy efficient home possible. As we gain more understanding about the embedded costs in the manufacture, transport, and installation of new measures such as battery storage systems, the energy efficient home will be necessary to decrease the overall size of the GHG footprint that must be mitigated by additional technologies.

References

- Bhagavathy, S. M., H. Budnitz, T. Schwanen, M. McCulloch. 2021. Impact of Charging Rates on Electric Vehicle Battery Life, *Findings*, March. <https://doi.org/10.32866/001c.21459>.
- California Energy Commission. 2020. *Time Dependent Valuation of Energy for Developing Building Efficiency Standards: 2022 Time Dependent Valuation (TDV) and Source Energy Metric Data Sources and Inputs*. 2022 Energy Code Update Rulemaking Docket Log, Docket 19-BSTD-03. Docketed Date 6/5/2020. <https://efiling.energy.ca.gov/GetDocument.aspx?tn=233345&DocumentContentId=65837>

- California Energy Commission. 2021. *Final Express Terms for the Proposed Revisions to the 2022 Energy Code Reference Appendices*. 2022 Energy Code Update Rulemaking Docket Log, Docket 21-BSTD-01. Docketed Date 11/23/2021.
<https://efiling.energy.ca.gov/GetDocument.aspx?tn=240699&DocumentContentId=74055>
- Department of Energy. 2021a. “Meet Doe's Newest Connected Communities of Grid-Interactive Efficient Buildings.” Department of Energy, October 13, 2021.
<https://www.energy.gov/eere/buildings/articles/meet-does-newest-connected-communities-grid-interactive-efficient-buildings>.
- Department of Energy. 2021b. “DOE Invests \$61 Million for Smart Buildings that Accelerate Renewable Energy Adoption and Grid Resilience.” Department of Energy, October 13, 2021.
<https://www.energy.gov/articles/doe-invests-61-million-smart-buildings-accelerate-renewable-energy-adoption-and-grid>.
- Diaz, 2020. “Internet of Things and Distributed Denial of Service as Risk Factors in Information Security”. In T. F. Heston, & S. Ray (Eds.), *Bioethics in Medicine and Society*. IntechOpen.
<https://doi.org/10.5772/intechopen.94516>
- Evergreen Economics. 2020. “Evaluation of the California Statewide Smart Thermostat Time of Use Pilot.” March 31, 2020.
http://calmac.org/publications/PCT_TOU_Evaluation_Report_Final_033120.pdf
- Guttmann, A. 2022. “Loyalty programs – statistics & facts”. Statista.com, March 14.
<https://www.statista.com/topics/7986/loyalty-programs-in-the-us/#dossierKeyfigures>.
- Iyengar, S. S., & Lepper, M. R. 2000. When choice is demotivating: Can one desire too much of a good thing? *Journal of Personality and Social Psychology*, 79(6), 995–1006.
<https://doi.org/10.1037/0022-3514.79.6.995>
- Maloney, P. 2018. “California PUC unveils proposed fix to storage incentive program, quantifying GHG reductions”. *Utility Dive*, Sept 18.
<https://www.utilitydive.com/news/california-puc-unveils-proposed-fix-to-storage-incentive-program-quantify/532573/>
- Mertens, S., M. Herberz, U. J. J. Hahnel, T. Brosch. 2021. The effectiveness of nudging: A meta-analysis of choice architecture interventions across behavioral domains. *Proceedings of the National Academy of Sciences*, 119, No. 1. <https://doi.org/10.1073/pnas.2107346118>
- Munroe, R. 2011. How Standards Proliferate. United States.
<https://imgs.xkcd.com/comics/standards.png>
- Next 10. (2021). Designing Electricity Rates for An Equitable Energy Transition.
<https://www.next10.org/publications/electricity-rates>

- Olgyay, V., S. Coan, B. Webster, and W. Livingood. 2020. *Connected Communities: A Multi-Building Energy Management Approach*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5500-75528. <https://www.nrel.gov/docs/fy20osti/75528.pdf>.
- Reeve, H., S. N. G. Gourisetti, P. McKenzie, J. Hagerman, A. Nicholls, M. Mylrea, P. Erlich, G. Fink, D. Vrabie, C. Glantz, R. Underhill. 2020. *Challenges and Opportunities to Secure Buildings from Cyber Threats*. <https://www.energy.gov/sites/default/files/2021-04/bto-pnnl-29813-securing-buildings-cyber-threats-040821.pdf>
- Repko, M. 2022. “A more than \$761 billion dilemma: Retailers’ returns jump as online sales grow.” CNBC.com, January 25. <https://www.cnbc.com/2022/01/25/retailers-average-return-rate-jumps-to-16point6percent-as-online-sales-grow-.html>
- Rogers, E., and E. Junga. 2017. *Using Intelligent Efficiency to Collect and Analyze Nonenergy Benefits Information*. Washington, DC: ACEEE. <https://www.aceee.org/research-report/iel701>)
- Scheibehenne, B., R. Greifeneder, P. M. Todd. 2010. Can There Ever Be Too Many Options? A Meta-Analytic Review of Choice Overload. *Journal of Consumer Research*, Volume 37, Issue 3, October 2010, Pages 409–425, <https://doi.org/10.1086/651235>
- Smart Electric Power Alliance. 2019. “2019 Utility Demand Response Market Snapshot”. Smart Electric Power Alliance, September 2019. <https://sepapower.org/resource/2019-utility-demand-response-market-snapshot/thank-you/>)
- Ungemach, C., A. R. Camilleri, E. J. Johnson, R. P. Larrick, E. U. Weber. 2017. Translated Attributes as Choice Architecture: Aligning Objectives and Choices Through Decision Signposts. *Management Science*. March 23, 2017. <https://doi.org/10.1287/mnsc.2016.2703>
- Verdant Associates, LLC. 2021. “California Solar Initiative (CSI) Final Impact Evaluation”. January 28, 2021. http://www.calmac.org/%5C/publications/CSI_Evaluation_Report-2.pdf
- Wilcox, J. K. 2021. “TV Settings That Deliver the Ultimate Picture Quality”. *Consumer Reports*, March 22, 2021. <https://www.consumerreports.org/tvs/tv-settings-for-the-ultimate-picture-quality-tv-calibration-a3400045646/>