

Triumph of the Tweakers: Engaged Homeowners Optimizing Air Conditioning Energy Use

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ABSTRACT

We are addicted to gadgets. Got a problem? Install a doodad! There are two problems with this approach: doodads are expensive, and they are seldom transformational. Unless they completely solve a problem on their own, they leave the problem only partly solved and at the same time fail to provide users with the ability, motivation, or triggers necessary to solve the problem. For example, while some residents have a “set it and forget it” relationship with their thermostat, “tweakers” want to use their thermostat as a tool to help them to find their own balance between energy and comfort. When these residents are empowered to control their own home’s energy use, they become engaged with daily weather cycles and better understand their home, creating a spillover effect on other energy using behaviors.

This paper will discuss research into the effectiveness of low-cost means of optimizing residential air-conditioning, using a behavioral lens. It will describe modeling and field studies that estimate the impacts, throughout California. Using a simple programmable thermostat and the right information and motivation, it is possible to dramatically reduce or eliminate on-peak cooling.

Several things could help to support this optimization, such as development of supportive thermostat capabilities, more compelling rate structures, program mechanisms to ensure engaged recipients, research on the potential in different climates, and research on residents’ desires to reduce energy use and what range of conditions they would be willing to choose to achieve those reductions. Given the potential benefits, policymakers, technology providers, behaviorists, and technology researchers should put effort into developing solutions for user-optimized cooling strategies.

Introduction

Engineers love to develop products to help users reduce their energy use transparently—without requiring any interaction by the user. They assume most users don’t want to be bothered by having to interact, and that users will fail to optimize operation if we leave it to them. This neglects evidence that many users want to be in control, to find their own delicate balance between energy use and comfort, and to incorporate it into their lifestyles and their overall commitment to reducing the threats of climate change. There are a range of user-optimized control strategies that could be quite effective, if incorporated in conjunction with education, motivational engagement, and technical support mechanisms.

User-optimized cooling strategies include using thermostats to implement pre-cooling, using ceiling fans to cope with discomfort before opting to turn on air conditioning, opening windows at night or when it is cooler outside, and using window fans to get nighttime ventilation cooling.

User-Optimized Cooling Strategies

Some of the primary user-optimized cooling strategies include:

- **Pre-Cooling.** A home is cooled to a lower than usual temperature during the hours just preceding the typical utility peak period, and then allowed to “float” through the peak period with lower or even zero energy used for cooling during the peak period. This can be done while maintaining the home temperature at acceptable comfort levels. This is typically envisioned to be accomplished by smart thermostats, but it can also be implemented by a programmable thermostat with user-optimization.
- **Nighttime Ventilation Cooling.** In many climates, outside air at night is much cooler than inside, and can be brought in to reduce temperatures overnight, ideally pre-cooling enough to offset the need for mechanical cooling later in the day.
- **Ceiling fans and other coping mechanisms.** In addition to these techniques, occupants who are committed to avoiding air conditioning energy use can utilize a range of coping mechanisms to get through times when it is warm, rather than resort to turning on the air conditioner. The primary mechanism is the use of ceiling or desk fans, but it can include other things such as reducing clothing levels, limiting activities that increase metabolism, and personal cooling, such as hand fans, wet cloths, and ice packs.

Figure 1 shows an example of the use of all these strategies. The data show measured conditions in a home in Davis CA, on a typical summer day in 2021, with a committed and knowledgeable homeowner [disclosure: the homeowner was the author, and this example is provided as a proof of concept]. A simple thermostat program was used with a cooling setpoint of 83°F at all times throughout the day, except a “pre-cooling” period of noon-4pm, when it was 75°F. Ceiling fans were the first choice when conditions were beginning to become uncomfortable. Although is not shown in this figure, anytime conditions became quite uncomfortable, the air-conditioner was manually turned on (by reducing the cooling setpoint temporarily). All windows in the home were routinely manually opened in the evening as soon as the outdoor air was cooler than the indoor air, and a window fan was operated during sleeping hours. Upon waking, the window fan was turned off and the windows were closed.

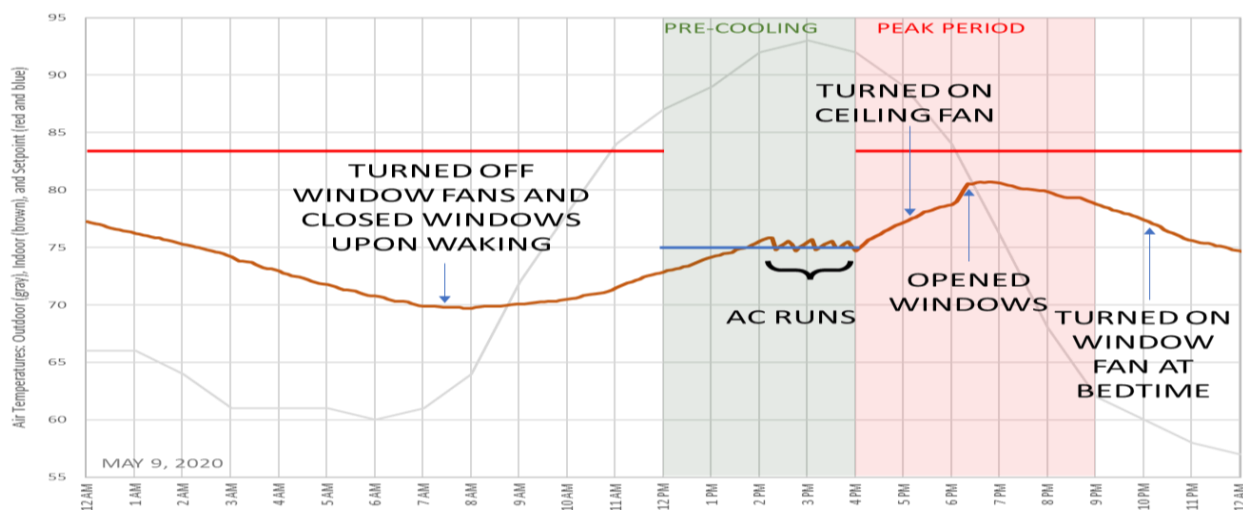


Figure 1. Operation of User-Optimized Natural Cooling Strategies. This chart shows one day of operation, with temperatures (set points are red and blue, outdoor air is gray, and indoor air is brown).

Smart Control vs. User-Optimized Control

There is a natural tendency to want to implement these kinds of strategies with ever smarter automatic controls. However, the track record for smart thermostats is not encouraging.

Starting in 1995, ENERGY STAR began promoting programmable thermostats as a means of reducing space conditioning energy use. Estimates of savings impact suggested programmable thermostats could reduce heating and cooling bills by 10-30 percent, based on simple simulations (Malinick, Wilairat, et al. 2012). The analysis typically assumed that without programmable thermostats, users maintained a constant setpoint, and that with programmable thermostats, a regular setback program would be used.

It has been found that neither of these assumptions is necessarily accurate (Meier 2011) (Meier, Aragon, et al. 2000). The projected savings were not materializing, and the ENERGY STAR programmable thermostat program was suspended in 2009. A new program was established in 2016, to certify Connected Thermostat products.

Smart thermostats are not without their troubles either, however. Outcalt et al (2014) found that user experience with a smart thermostat was generally not favorable. Six out of the ten users surveyed were “mostly unsure” that the smart thermostat did what they wanted it to do (only one reported the same concerns about their prior programmable thermostat), and four reported being “completely unsure.” In open-ended comments, at least half mentioned things like “the thermostat seems to have a mind of its own”; “it does not do what I want it to do” or “it turns on and off at will.” One asked “how can the thermostat be put back into mode where it operates like a normal thermostat?”

A recent evaluation of California utility smart-thermostat incentive programs found that realized savings were much lower than expected, and that electric savings from smart thermostats provided through direct install mechanisms were 40% lower than those provided with end-user rebates (CPUC 2021). This indicates that the way thermostats are deployed can influence their effectiveness, and that motivated users can use them more effectively.

Given the concerns that programmable thermostats do not provide reliable savings, and usability issues with smart thermostats, there must be a more reliable way to control HVAC systems in single family homes.

Evidence for User-Optimized Cooling Strategies

Several separate studies, conducted over the past decade, have provided clues to the potential for promoting user-optimized cooling strategies. It should be noted that many of these studies are from California, and Davis specifically. Davis is a best-case location for nighttime-ventilation cooling: although daytime temperatures are quite high, nighttime temperatures are much lower: 91°F average daytime high in August, and 55°F average nighttime lows. These consistently low nighttime temperatures are possible because of cool offshore breezes that flow up the San Joaquin Delta every evening. While these strategies might not make sense in all climates and for all types of users, there may be sufficient interest from environmentally minded “early adopters” to justify providing solutions, with the promise of likely adoption by a broader range of the population once demonstrated. The successes achieved by these early adopters can readily be infused into the broader population gradually. As concerns over climate change intensify and consequences are felt more broadly, more and more people may find that they would be willing to take a bigger role in the operation of their energy-using systems, even if this results in less-optimal comfort or requires some effort. Solutions need to be made available.

The sections that follow provide evidence from a range of different studies we conducted and provide evidence that there could be benefits from providing more opportunities for user control. These include:

- modeling to support a potential building code credit for pre-cooling,
- field measurements of pre-cooling and automated nighttime ventilation (NTV),
- analysis of behavioral interventions designed to promote use of ceiling fans and windows before mechanical cooling,
- attempts to propose technology support for these behaviors.

While not all the studies that follow were successful, the evidence provided here can provide motivation to come up with better solutions to support users, and better methods for encouraging their use.

Modeled Potential

Analyses of the Potential for Pre-Cooling Strategies

In 2021, Energy + Environmental Economics conducted an analysis of the potential of pre-cooling as part of an investigation of strategies for Zero Net Energy homes, which also included batteries and renewables (Wei et al, 2021). They concluded that HVAC pre-cooling can be thought of as an alternative to batteries, although it is much less reliable and much less expensive. They modeled the reduction in cooling energy for many different scenarios, in each of California's 16 climate zones. The scenarios included one hypothetical scenario that assumed perfect hindsight (or a perfect forecast) of outdoor conditions, in order to provide just enough pre-cooling for each day's temperature profile. The other scenarios used different temperature settings and schedules for pre-cooling. Their analysis showed that pre-cooling can provide substantial savings, especially with perfect hindsight or a perfect temperature forecast. However, a review of their results suggests that a priori selection of a single setting for a particular climate zone can have almost as much savings, and in fact selecting the best single setting across climate zones can have nearly the same savings. Although perfect optimization has greater savings, it is much more complicated and requires a connected thermostat and may require allowing someone else to select settings for a given day. Their findings suggest that not much is lost by implementing a simple and consistent program. Any benefits in acceptability of user-control may outweigh the sub-optimal technical savings

Following on to their findings, as part of the Statewide Utility Codes and Standards Program, we analyzed the savings from a potential pre-cooling compliance credit for Title 24 (CASE 2020). The analysis included modeling the performance of two prototype single-family homes (2100 sqft and 2700 sqft), using a standard thermostat schedule that is used for other Title 24 analysis and a set of alternative schedules that were identical to the baseline except for a lower setpoint during some number of pre-cooling hours and a higher setpoint during peak periods.

The primary metric for cost effectiveness for Title 24 is "Time-Dependent Valuation" (TDV) savings: a time varying energy consumption metric calculated by multiplying the hourly site energy use by a TDV multiplier, which varies by hour of the year. TDV is designed to value energy savings at peak periods more highly than off-peak periods (Energy + Environmental Economics, 2016).

Table 1 shows the results of the analysis done for the code proposal, which found that while TDV savings in most climate zones were favorable, there was a minor energy penalty in some climates: mostly in off-peak periods, due to loss of some of the stored “coolth” throughout the day, and potential for overcooling. It was determined that in most climate zones, the best setting was to pre-cool the home to 75°F from noon to 4pm, and to let it float to as high as 83°F from 4pm to 9pm. The Codes and Standards Enhancement (CASE) team recommended allowing this credit only in Climate Zones 9-15, where TDV savings were positive and kWh penalties were only moderate.

Table 1: Results of Title 24 modeling of pre-cooling for a 2,100 square foot prototype single-family home.

Climate zone	Energy savings (%-TDV)	Energy penalty (%-kWh)	Cost savings under different rate scenarios:			
			PG&E TOU		All on-peak	
			(%)	(\$/yr)	(%)	(\$/yr)
9	3%	2%	-1.7%	(\$26)	15.1%	\$231
10	4%	2%	-1.2%	(\$20)	20.0%	\$327
11	8%	1%	1.1%	\$24	33.6%	\$743
12	1%	1%	-1.1%	(\$20)	8.1%	\$127
13	12%	1%	1.4%	\$30	37.1%	\$850
14	5%	1%	0.4%	\$9	31.9%	\$688
15	13%	1%	2.7%	\$67	50.9%	\$1,758

Source: CASE 2020.

Pre-cooling can provide are significant TDV energy savings, although it comes with a small energy use penalty, so this measure would not be advisable on a purely energy-reduction basis. Time-of-use (TOU) rates should mimic the TDV benefits of reducing cooling energy use during peak periods. However, estimated bill savings were minor—or negative—using current TOU rates, because these rates are not “peaky” enough to encourage load shifting. The “All on-peak” rate scenario in Table 1 is a hypothetical extreme case where electricity is free at off peak times, and during on-peak times it is quite expensive (\$1.33/kWh during the summer peak period, just enough to make the rate revenue-neutral for a flat load curve). In this scenario, energy costs could be reduced by 8% - 51%, which should be big enough to get people’s attention.

Pre-cooling can provide grid load-shape benefits, although energy savings are not expected. It is also not expected to lower energy bills, even under current TOU rates. Since it requires user control and possibly inconvenience or discomfort, there needs to be more motivation in the form of a more favorable rate structure or other extrinsic motivators, such as appeals to concern for the environment or utility grid stability.

Field Measurements from Manual Pre-Cooling

Measurements in Home in Davis California

Figure 2 shows the results of the user-optimized cooling strategy described in Figure 1. It shows the total number of hours of active cooling that took place during each hour of the day for each month, over the course of the summer of 2021, as recorded by the smart thermostat. Pre-

cooling hours are shown in blue, on-peak cooling is shown in red, and any other off-peak hours of cooling are shown in yellow.

This chart shows that most cooling did take place during the pre-cooling hours of noon to 4pm. However, there were a considerable number of hours of peak cooling, due to manually turning on the air conditioner to reduce discomfort. It should be noted that most of the cooling that took place during the pre-cooling period would have taken place during the peak period if no pre-cooling had been implemented.

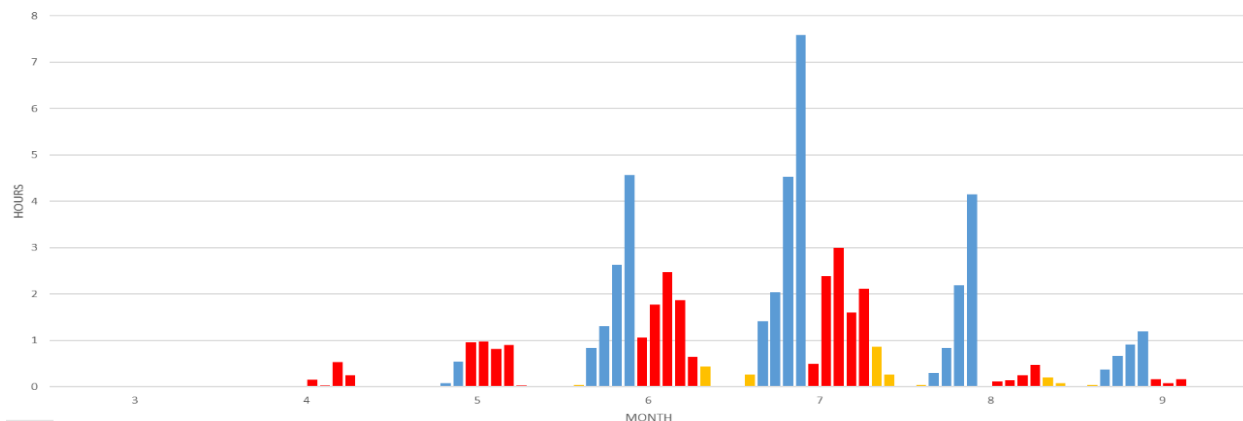


Figure 2. Results of one season of pre-cooling, ceiling fans, window operation, and window fans. Measured at the Author's home. This shows the number of hours of cooling over the summer of 2021 by month, including pre-cooling hours in blue, peak cooling hours in red, and other off-peak hours in gold.

Low-Capacity HVAC Field Demonstration

As part of a demonstration of the effectiveness of lower-capacity HVAC systems in Southern California in 2021, a brief study was conducted in two homes, to investigate the effectiveness of pre-cooling with these smaller (less-oversized) systems (Biswas, in press). One concern that people may have about a lower-capacity system is that if a homeowner were to implement a simple daytime set-back during the summer and return home after work to a very hot house (on the order of $>83^{\circ}\text{F}$), they may be unable to recover to a comfortable temperature in a reasonable amount of time. It was hypothesized that pre-cooling could obviate the need for oversizing equipment to provide this kind of rapid and substantial temperature reduction.

In this limited test, researchers remotely-controlled each home's thermostat for a week. The thermostat setpoint schedules imposed were:

- A relatively low temperature from noon to 4pm—varied by researchers each day, in the range $72\text{--}76^{\circ}\text{F}$
- 80°F (or higher) from 4pm to 9pm
- Any “comfortable” temperature from 9pm to noon on the following day

Homeowners were advised about alternate ways to achieve comfort should the home overheat, including turning on ceiling or desk fans or opening windows if outside conditions were favorable, while explicitly being encouraged to turn up the air conditioner temporarily at any time during the peak period if needed to achieve comfort. Temperature setpoints (from schedule and temporary overrides), interior and exterior temperatures, and air conditioner operation were monitored throughout the week, as a continuation of the already implemented monitoring.

During the tests, several problems emerged. While the project team was able to readily modify the temperature schedules at each site remotely, neither the researchers nor the homeowners were aware that the thermostats were configured with smart thermostat optimization routines that changed the setpoints that had been selected, so that the test settings did not persist from day to day. Also, prior to the pre-cooling tests, the sites were using less energy than usual for cooling, while during the test periods ambient temperatures were not excessive, so it is likely that little cooling would have been required anyway. For these reasons, and because a sample of two homes is not enough to draw strong conclusions, these results cannot be generalized. However, despite these problems, the results did indicate that the homes were successful in shifting cooling loads to the period before the peak period. The results do suggest that automatic pre-cooling on mild days may increase energy use unnecessarily. Higher pre-cooling setpoints resulted in lower overall energy use, although at one site, the higher pre-cooling setpoint resulted in more on-peak and total energy use. The homeowners had no complaints about the testing, but it should be considered that they did not seek out pre-cooling, so they were less motivated to take actions to make it more successful. These findings suggest that more research should be conducted into optimization of pre-cooling, under different conditions and with a larger and representative sample.

Nighttime Ventilation Cooling Field Demonstration

NTV cooling can be considered as an alternative to the strategies described here. NTV has been successfully implemented as an efficiency boost for conventional air-conditioning—automatically bringing in outside air whenever it is cooler than inside air, before closing the outside air damper when air conditioning must be provided (Springer et al, 2004). However, it can also be installed *in lieu of* installing an air conditioner, and as an automated alternative to a whole-house fan or window/fan operation. It does have several advantages over user-optimized cooling, in that it provides filtered air (a benefit in wildfire country) and can provide security and noise benefits. However, it is much more expensive. Also, although its operation is automated, it is not as easy for homeowners to understand.

As part of a California Energy Commission study, Frontier Energy and Sonoma Clean Power (SCP) conducted a 10-site field trial of using NTV in homes without cooling, in the relatively mild Sonoma County region (Hendron et al, in press). NTV systems were installed in ten homes, consisting of a damper box that is installed in the attic between the existing heating forced-air unit inlet and the return air grille, and an added outdoor air vent and duct. Controls on the damper box are provided by the manufacturer based on input from an outdoor air sensor, and the existing thermostat is used to control the operation of the furnace fan which brings in outside air during favorable times. The systems were installed during July and November of 2020, and the cooling season of 2021 is the primary performance dataset.

Sites that were technically suitable (relatively small, to accommodate the limited size economizer box; no central cooling; central heating system with forced-air unit in the attic) were considered for inclusion, and a questionnaire was conducted of potential participants to ascertain the likelihood that they would consider installing air conditioning at some point. The ideal participant would not have air conditioning currently but would be likely to consider it at some point in the future. The impact of the retrofit, then would be seen in their decreased likelihood to install air conditioning in the future. In a survey completed before and after the demonstration, respondents were presented with a series of scenarios, and they reported how likely it would be that that scenario would convince them to install air conditioning. The scenarios fell into a set of

categories: financial issues (e.g., if you suddenly had more money), comfort issues (e.g., if the climate changed, resulting in more very hot days), and other issues (e.g., if friends or neighbors added central air conditioning).

Table 2 shows the results of the survey before and after the demonstration. Two sites remained firmly in the position that they were not likely to install AC, and most hypothetical changes would not sway them. One home reported that they were less likely to install AC than before the study and one reported that they were more likely than before to install AC. Two sites actually did install AC over the course of the study.

Table 2. Survey of Nighttime Ventilation demonstration participants, indicating their assessment, before and after the study, of their likelihood of installing air conditioning in the future under various scenarios.

Site	Before	After	Notes
42	Considering Installing	<i>Actually Installed AC</i>	Installed AC. They had a baby and ventilation was not able to keep the house cool enough.
43	Somewhat Likely to Install	Somewhat Likely to Install	Now somewhat likely to install AC, but not more than before.
44	Somewhat Likely to Install	Somewhat Likely to Install	Occupant is waiting until it's time to replace heating system as they would like to move to a heat pump system for both heating and cooling.
45	Very Unlikely to Install	Very Unlikely to Install	Now very unlikely to install AC, but not less than before.
46	Very Unlikely to Install	No Survey	No Post Survey
47	No Survey	No Survey	No Pre or Post Survey
48	Somewhat Unlikely to Install	<i>Actually Installed AC</i>	Installed AC. They were unlikely to install it, but their heating system died and they wanted a heat pump. They do not expect to use cooling.
49	Considering Installing	Somewhat Unlikely to Install	Now somewhat unlikely to install AC, and even less than before.
50	Somewhat Unlikely to Install	No Survey	No Post Survey
51	Somewhat Unlikely to Install	Somewhat Likely	Now somewhat likely to install AC, and much more likely than before. They had a child who was sensitive to heat.

It is notable that two households had babies over the course of the study. One chose to add AC because of that, and the other reported that they are now somewhat likely to install AC after reporting previously that they were somewhat unlikely. It is also notable that the other home that installed AC did it because their heating system died and they wanted to replace it with a heat pump (although they reported that they don't plan to use the AC much). Another home reported that when it is time to replace their heating system, they will replace it with a heat pump, and are therefore somewhat likely to install AC.

Other changes that led to an increased reported likelihood of installing AC someday included increases in outdoor temperatures due to climate changes and increased incidence of

smokey air. The homes that signed up for the demonstration were presumably more interested than average in pursuing improved comfort, and it is possible that other homes that were not initially interested would remain uninterested in installing AC.

Table 2 shows that on average, the fan operation consumed about 295 kWh over the course of the summer. When compared to a hypothetical home simulated with air conditioning, energy consumed for cooling was reduced by 46%, leading to a whole-home energy reduction of about 4%. The benefits are more striking when looking at energy consumed during peak hours of 4-9pm: these homes reduced on-peak energy for cooling by 93% and whole home energy by a considerable 15%. Bills would be reduced by about 5% under flat rates and 7% under TOU rates.

Table 2: Performance and Financial Metrics and Results of NTV Demonstration

Metric	Average Results
Peak Fan Watt Draw	400 W
Fan Energy Use	295 kWh/summer
Energy Savings	46% of cooling 4% of whole home
On-Peak Energy Savings	93% of cooling 15% of whole home
Bill Savings	\$94 with flat rates (5%) \$129 with TOU rates (7%)

Most of the homeowners reported being satisfied with their NTV system. However, it should be acknowledged that the systems are somewhat expensive (about \$1000 for the equipment and \$3400 for installation during the study, although mature market prices may be somewhat lower). This is much less than an air conditioner would cost, but more than one might expect for a “passive” device. The homeowners received this system at no cost, and this may have influenced their satisfaction with it.

Behavioral Interventions to Encourage Natural Cooling

Behavioral Study in Student Housing

There is an implicit assumption that everyone wants to be at 72°F at all times (personal communication with HVAC manufacturer). We have conditioned people to expect that they should find efficiency measures that are transparent, and never cause any discomfort or inconvenience, and actually save them money. The days of such easy solutions may be numbered, and we must start considering how we will answer people when they do start asking for deeper energy savings. This expectation is often cultural. For example, in a study sponsored by Tokyo Gas Company, we investigated behavioral interventions that can be used to promote user-optimized cooling strategies (Outcault et al 2015). Behavioral interventions were implemented in low-energy housing complexes in Yokohama, Japan and in Davis, California, during the summer of 2014.

We found, as shown in Figure 3, that the American residents we surveyed strongly preferred using their air-conditioning when they need it to be comfortable, while Japanese residents were seeking a balance between energy use/cost and comfort. In interviews with

Japanese housewives, we found that to them “uncomfortable” and “unacceptable” are two very different things, while in the US we tend to believe that if we are not comfortable, something is wrong. One enlightening interviewee in Japan indicated that she felt quite sorry for Americans, when she was informed that they cannot tolerate uncomfortable temperatures.

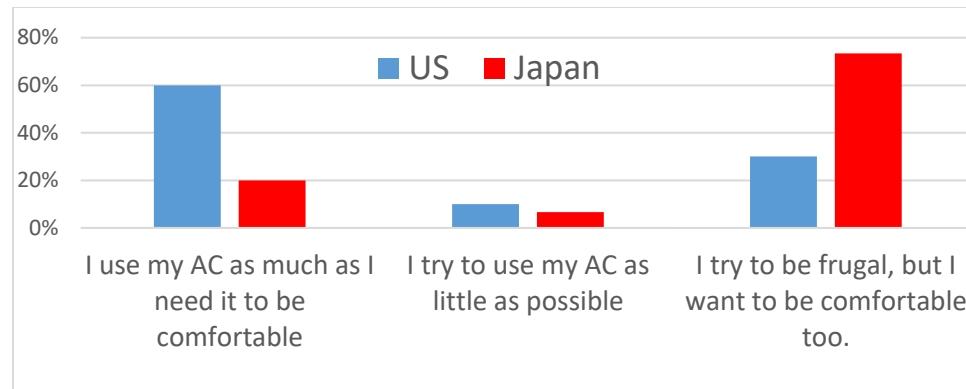


Figure 3. Impressions from residents in two low-energy housing complexes, in the U.S. and in Japan. *Source:* Outcault et al. 2015.

In conjunction with that study in Japan, we also studied a mixed-use Zero Net Energy complex at the University of California, Davis, housing 2000 students, faculty, and staff. Apartments are spacious, modern, and high-end, and electricity is included in rents (all units are all-electric). Housing units were designed to utilize user-optimized cooling strategies, through the oppositional positioning of windows to promote cross-breezes, and installation of ceiling fans in every room. After recruiting participants from among the student residents, a variety of targeted interventions were implemented in different ways for a control group and several different treatment groups.

- Since some individuals have a limited attention span, some residents were asked to mount informational laminated flyers in a highly visible place, near their thermostats to provide relevant information at an appropriate time and nudge individuals towards the desired outcome. These described “natural” cooling as a combination of use of ceiling fans and opening windows before resorting to use of air conditioning. Providing well-placed and well-timed reminders can help to overcome that behavioral barrier. Furthermore, the laminated flyers came with double-sided tape attached to the back to facilitate easy of mounting, to overcome procrastination.
- Some residents received a survey and were asked to make a commitment to try this “natural” cooling for a month, and subsequent communications reminded them of that commitment.
- Mid-intervention reminder emails were intended to overcome the common barrier of limited attention.
- To motivate behavioral change, small monetary gifts (extrinsic motivators) were offered for participating in the surveys, while intrinsic motivation was stimulated by stressing the environmental benefits of the utilizing passive cooling techniques. The laminated flyers urged respondents to reduce air conditioner use and save energy for the benefit of a “Happy Planet,” and to “Do it for your Mother (Earth).”

- To make the environmental benefits more concrete, the mid-intervention survey gave respondents feedback on their efforts, by reporting on their energy use. It did so by providing an example of an activity with equivalent energy saving potential (e.g., riding a bike instead of driving to the local grocery store).

At the beginning of the study, 12 out of 18 respondents reported using their air conditioner as much as needed to stay comfortable. 12 out of 16 reported they did not like feeling hot. The highest acceptable temperature setting on the central air conditioner was reported to be between 70°F and 80°F, with the majority reporting 76°F. 9 out of 16 respondents said they never left their window open at night while only 1 respondent said they left their window open most nights during the week. Most respondents reported leaving their air conditioner on during the night to stay cool, and most left their air conditioner on for 4 or more nights a week. In the initial survey, 13 out of 16 respondents indicated an interest in trying “natural” cooling strategies. When asked to commit to trying “natural” cooling strategies for a month, 11 out of 16 survey respondents reported a willingness to try.

The impact such actions had on energy usage from air conditioning units, relative to control apartments, were also measured (i.e., with a pre/post, treatment control analysis), although the small sample size made it impossible to draw conclusions. The primary assessment of the impact of the intervention was based upon the self-reported frequency of user-optimized cooling strategies utilized before and after the intervention. By the end of the study, 6 out of the 7 who took the post-intervention survey had tried using some of the “natural” cooling strategies over the month. 5 out of 7 respondents had opened their windows at night, although only a few nights per week for most respondents. 3 respondents did report an increase relative to before the intervention. 3 out of 7 respondents had used their ceiling fans more often to stay cool.

Despite a very high-touch study designed to give occupants every opportunity to decide to implement user-optimized cooling strategies, the response rate was low, and the impact was minimal. It is also difficult to generalize on the findings from this study due to the unique population studied (college students during a summer month), the fact that the residents did not have to pay for air-conditioning energy, and that many reported a belief that living in a Zero Net Energy community with plentiful renewable energy sources meant that they did not need to conserve. These factors removed some potentially important motivators. Students are a transient population, and probably less invested in the operation of their housing units.

None of the efforts to influence and motivate these students were terribly effective, however the interventions attempted can provide a guide for recommended interventions for future efforts to influence these behaviors. For example, the results may suggest that students would have to be targeted in some other way, and other types of populations may be easier to influence. Low-income homeowners who struggle to pay energy bills, for example, may be more open to finding novel tradeoffs between maximum comfort and lower bills. Environmentally concerned residents may also be influenced since they are often more amenable to modifying their behavior or tolerating discomfort and inconvenience to achieve an environmental goal.

Community Based Behavioral Interventions

The findings of several of the studies noted above suggest that carefully designed behavioral interventions are needed to encourage user-optimized cooling strategies. Community-Based Social Marketing (CBSM) provides several well-tested techniques for motivating certain behaviors, including commitments, prompts, norms, communication, and

incentives (Mckenzie-Mohr, 2011). Cool Davis is a non-profit community-based organization with a mission to help the city of Davis, California achieve its climate action goals through engagement with the community. Through their many campaigns, they utilize CBSM techniques to influence home energy use behaviors, in addition to purchasing, food, water, and solid waste. One of their campaigns focuses on reducing HVAC energy use in homes throughout the community. While most of the recent effort is going into workshops and communications designed to encourage homeowners to “Make a Plan” to replace their HVAC system with all-electric appliances, they would be remiss if they did not focus first on taking advantage of the local climate effects and encourage homeowners to do whatever they can to take advantage of user-optimized cooling strategies. As part of that effort, they have developed a series of videos designed to educate homeowners on why off-peak cooling is important, and how to implement user-optimized cooling strategies, with simple step-by-step instructions, for example, on how to use a conventional programmable thermostat for pre-cooling (Cool Davis 2021a and Cool Davis 2021b). These videos have been well received in the community and have been viewed over 500 times. As a college town in a very environmentally active region, Davis residents are educated and aware, although they often do not know how to implement these strategies. Cool Davis intends to follow up on these videos and ascertain what influence they have had on occupant behaviors.

Technology Support for Behavior

Development of a Compliance option for Pre-Cooling in California Building Code

After the modeled potential analysis described above was complete, the California CASE team developed code requirements for a compliance option for pre-cooling for the 2022 version of Title 24 (CASE 2021), based on load flexibility rather than energy savings. When it goes into effect, it will provide a credit that allows builders to implement fewer demand flexibility measures in exchange for adding pre-cooling capabilities. The credit is limited to Climate Zones 9-15 where savings were most significant. The compliance software calculates the credit using a setpoint schedule that implements pre-cooling to 75°F from 12-4pm and eliminates on-peak cooling by increasing the setpoint to 83. All TDV savings are derated to 30% of the modeled value in calculating the credit, due to its “occupant dependent nature.”

Although specific details are not included in the code requirements, the CASE team recommended that thermostats have functionality that will help to support pre-cooling. This set of functionalities will help users to implement pre-cooling effectively.

- **Dedicated pre-cooling mode.** With a simple gesture, initiate a pre-cooling schedule using the selected pre-cooling and peak times and setpoints.
- **Default Schedule Programming.** For example, providing named schedules for pre-cooling and peak-periods.
- **Temporary Override.** Provide a temporary override that is simple to initiate, and not likely to be confused with a permanent override. It should be limited to 72 hours at a time.
- **Usability Considerations.** The thermostat user interface should make it easy to program the pre-cooling schedule correctly, difficult to inadvertently change the pre-cooling schedule or permanently override the pre-cooling strategy, and easy to temporarily override the pre-cooling and peak period modes, for a limited amount of time. It should provide a clear indication to the user that the pre-cooling or peak period mode is in effect.

- **Verification.** Installing contractors should verify that a pre-cooling schedule is implemented upon turning the building over to the occupants (ideally one that they have discussed with the new owners) and leave behind educational materials. Ideally, future versions of the code would require verification of these settings by a third-party: a new check included in a set of other verifications that are already required.

As part of the CASE process, a survey was done by Evergreen Economics (2020) to assess the market response to pre-cooling (among other grid-integration measures).

The pre-cooling section of the survey began by defining pre-cooling:

“Pre-cooling your home means using a thermostat to automatically cool your house a little extra, say 4 degrees below your normal setpoint, from noon to 5 p.m., followed by having the AC off from 5 p.m. to 9 p.m., which could result in the home being extra warm, say 4 degrees above your normal setpoint”.

When offered a hypothetical incentive to implement pre-cooling, 79 percent of the 502 survey respondents indicated that they were somewhat to extremely likely to participate in a program that would offer them \$30 per summer month to pre-cool their home, and when the incentive was doubled, that went up by 9 percentage points. However, when they were asked how likely they would be to override pre-cooling settings, 58% reported that they would be somewhat, very, or extremely likely to override it under normal circumstances. Quite a few (78%) indicated that they would be likely to override it on days when it was not convenient (such as when company was coming over), and a very large number (90%) reported that would be likely to override it on very warm days. These results seem to indicate that even if they were provided with the ability to pre-cool their homes, it is likely that it would not be effective, particularly when it is most needed on warm days. However, again the motivation of the users must be considered. These respondents were asked what they would do if they had the ability, but those who CHOOSE to have the ability can be expected to be much more likely to take advantage of it. It is also interesting to note that over half of respondents who indicated that they would not participate were concerned about loss of control of their own living environment, service disruptions that require manual override, and intrusion on privacy. This indicates that user-optimized cooling strategies may be more effective than externally-implemented strategies.

Other Technical Supports

In addition to the thermostat characteristics proposed to help support the use of thermostats for pre-cooling, there are a number of strategies that could go even further in accommodating users’ desires to control their energy use and comfort.

- With many residential customers being moved to TOU rates (many not voluntarily), and the sensitivity and anxiety that that can cause, customers may be eagerly looking for a solution to control costs. They may be looking for a simple and transparent solution that will not either overwhelm them with complexity or take their control. Since pre-cooling can be a complicated concept, thermostats could use terminology such as “low-cost cooling” rather than “pre-cooling” to select opting into or out of pre-cooling.
- This simple mechanism could also be a part of a critical peak program. After receiving a simple notification (as simple as text alerting occupant to critical peak events the following day), a user could use a single gesture (e.g., push a “Low Cost Cooling” button) to opt into pre-cooling the following day. This can be done currently manually,

although it requires the user to change the programming, which can be confusing and error-prone, causing users not to bother.

- Provide users with information about the outside temperature, so they know when it is safe to open windows, and to let them know how long it may be before it is cool enough to open windows. Users may find that they can “tough it out” for a half hour or so, even if they would not choose to do so for the whole afternoon.
- Thermostats and supporting apps could provide feedback on how well user-optimized cooling strategies are working: this can provide information to improve their optimization, and also motivation to keep it up.
- While a single pre-cooling setting can generally be an improvement over normal operation, one that is fine tuned to a particular climate and even to a particular home would provide even more savings. It could be possible for thermostats to have an “optimization routine,” in which, during setup, the home is heated or cooled, and then the time it takes to float back to a neutral temperature could be used to identify a thermally-optimal setting. This would still have all the user-optimized advantages, since the user would still have the ability to opt in or out and to temporarily invoke or override settings at any time.

Conclusions

While many occupants may prefer to “set it and forget it” and let a smart thermostat figure out and implement optimized control of their home’s comfort systems for them, there are other types of occupants who prefer to be in control of their systems, and to find their own balance between energy costs and comfort. Many of these individuals are currently getting the most out of their programmable thermostats and implementing optimized cooling strategies manually. However, if we understand the motivations of these individuals, and what these strategies might consist of, we can provide technical solutions, as well as education and motivation to support them in their efforts.

This paper showed evidence that user-optimized cooling strategies can be effective, based on modeling and field measurements. Encouraging and supporting their use, however, will require several things:

- development of technical solutions such as thermostat capabilities that provide information and control mechanisms that allow users to be in control of their conditions,
- utility rate structures that provide a stronger signal to encourage load shifting,
- community-based engagement efforts to provide the education and motivation at the household level,
- exploration of different program modalities to ensure that recipients of measures (such as smart thermostats) are fully engaged with the program and committed to using the technologies effectively, rather than simply inheriting a technology that they neither understand nor really want,
- more research on the potential for improvements (in terms of energy use and occupant satisfaction) in different climates, and
- more research on residents’ desires to reduce energy use, and what range of conditions they would be willing to choose to achieve those reductions, under different circumstances—research investigating a broader range of conditions with larger and more representative samples.

While these strategies might not make sense in all climates and for all types of users, there may be sufficient interest from environmentally-minded “early adopters” to justify providing solutions, with the promise of likely adoption by a broader range of the population once demonstrated. The successes achieved by these early-adopters can readily be infused into the broader population gradually. As concerns over climate change intensify and consequences are felt more broadly, more and more people may find that they would be willing to take a bigger role in the operation of their energy-using systems, even if this results in less-optimal comfort or requires some effort. Solutions need to be made available.

It is understood that user-optimized cooling strategies may be less reliable than automatic controls in some ways. Without proper technical support, motivation, and education, we might not be able to count on people to implement these strategies consistently, vigilantly, or effectively. On the other hand, occupants invested in implementing their own control would be less likely to override demand limiting efforts than if they are imposed by the utility. Also, if provided with the support they need, occupants given control of their energy-consuming systems might find that gaining effective control in one area spills over into tackling control of other areas, such as lighting or water consumption. Given the potential benefits, policymakers, technology providers, behaviorists, and technology researchers should put effort into developing solutions for user-optimized cooling strategies.

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