Can You Take the Heat?

A Cross-National Comparison of Thermal Comfort Strategies and Energy-Saving Field Experiments

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ABSTRACT

The typical U.S. household uses two to four times as much electricity per person as the typical Japanese household. Differences in space conditioning drive this disparity, in part. Several key differences are identified. Japanese homes have one-third the square footage, while heating and cooling strategies are more localized and more active.

In addition, cultural norms and expectations regarding thermal comfort play a key role. In Japan, the range of acceptable temperatures is wider than the U.S., and is higher in summer and lower in winter. The authors argue suggests that thermal comfort is more conditionally defined in Japan, relative to the season, social norms, and other factors, whereas it is a more fixed concept in the U.S.

Meanwhile, electricity use from air conditioning (AC) is now significant and rising in both countries. Researchers ran a pair of interventions to encourage passive cooling strategies and reduced AC use in an American community of zero energy buildings and a Japanese "smart home" community, both of which had identified AC use as an obstacle to reaching sustainability objectives. The interventions utilized behavioral levers such as commitments, goal setting, consumption feedback, reminders, and social norms. Both experiments induced modest increases in the use of passive cooling strategies. Japanese participants' electricity use from AC dropped by 7%, while American participants' remained unchanged. Cross-cultural comparisons of cooling strategies deepen our understanding of occupant behavior within the broader social context and indicate the "social potential" for energy conservation that could be tapped if alternatives to AC were viewed through that lens.

Introduction

Residential air conditioning (AC) is a significant and highly variable source of electricity use and peak demand across households and across countries (U.S. EIA 2009; ESRI 2014). As such, interventions large and small have aimed to reduce AC use while balancing the competing goals of energy conservation (and grid reliability) with human health and safety. Finding a way to do that successfully is particularly important in communities with zero energy buildings (ZEBs) which have an additional mandate to strike a balance between energy generation and consumption. To that end, the research team designed and implemented a pair of behavioral interventions to reduce AC usage at sustainable communities in the U.S. and Japan to understand how to stimulate behavior change that results in energy savings. The objectives were to identify promising levers for behavior change and extrapolate for the project's sponsor, Tokyo Gas Co., Ltd., recommendations for encouraging energy conservation among its customers. Systemic differences in the broad context in which occupants use their air conditioners are also considered.

Background

The E-Sogo Smart House is located in Yokohama, Japan, a city of 3.7 million people (Statistics Bureau 2015). By contrast, the West Village ZEB community is located in Davis, California, a city of only 66,000 (U.S. Census Bureau 2016). While Yokohama is a coastal city with hot, humid summers, Davis is located 22 miles inland in the relatively hot and dry California Central Valley. Thus, the climates of the two cities vary substantially. As Table 1 shows, although Davis and Yokohama experience similar average high temperatures at the height of summer, evening temperatures drop dramatically in Davis, while Yokohama nights remain warm and more humid. Thus, the geographic context of the two field experiments differs substantially, which is reflected in the difference between nighttime cooling strategies encouraged in the behavioral interventions.

Table 1. Average climatic conditions in August

	Davis, CA	Yokohama, Japan [3]
Average high temperature (°F)	93 [1]	87
Average low temperature(°F)	56 [1]	75
Humidity (%)	58 [2]	76

Sources: [1] NOAA. [2] WeatherSpark. [3] Japan Meteorological Agency.

On average, American households consume twice as much electricity as Japanese households (U.S. EIA 2009; Jyukankyo Research Institute 2013). This is likely the result of a combination of factors, including lower electricity prices (U.S. EIA, various years; Jyukankyo Research Institute 2013), larger homes (ANRE 2013; Statistics Japan 2013), and more energy-intensive technologies and usage, including air conditioning (U.S. EIA 2009; ESRI 2014), as well as social factors that are less readily observable (Wilhite and Lutzenhiser 1999).

Both field sites are designed to be sustainable apartment buildings, and zero-net energy in the case of West Village. The location and configuration of the buildings are intended to allow occupants to take advantage of natural ventilation to facilitate energy-efficient cooling in summer. However, many residents in both communities still rely heavily on AC, which was identified by building managers as a significant barrier to achieving sustainability goals (Noresco 2014; Mikami et al. 2014). In both communities, AC usage and electricity consumption from AC varied widely among residents. In West Village, the highest AC users consumed 3-4 times more than the median in the summer of 2013. Over the same period, the highest AC users in E-Sogo consumed nearly twice as much as the median. This heterogeneity in consumption was identified as an opportunity to save energy by encouraging reduced AC usage. The experiments on passive cooling, described herein, were among numerous programs and experiments that have been conducted to try to encourage energy conservation in both communities, although this was the first time such efforts were coordinated in parallel.

Although the field sites are somewhat distinct from typical Japanese and American residences, given the design emphasis on natural ventilation and explicit energy consumption targets (i.e., an amount less than or equal to the energy generated), the research findings may be relevant to more conventional communities. Most of the behaviors encouraged by the field experiments (e.g., opening windows, using fans, wearing lighter clothing) are low-energy cooling strategies that are feasible in many homes, regardless of their specific features.[1]

Field Experiments

Having identified air conditioner usage as a source of great variation in overall electricity consumption, through analysis of energy use data provided by community developers, it was determined that the field experiments should target energy conservation with respect to summertime cooling. Preparations for the experiments took place March through mid-July 2014. The field experiments were implemented in July and August 2014, and the resulting data was analyzed August through November 2014. The design and implementation of the studies were facilitated by various collaborators for each site. Given the significant differences in geographic and cultural context, residents' demographic characteristics, and household technology, the design of the interventions differed substantially between the two field experiments. However, common elements were incorporated, to the extent possible, to facilitate comparisons.

E-Sogo Smart House, Yokohama, Japan

Overview. The E-Sogo Smart House is an apartment building that Tokyo Gas built in March 2012 as a "smart home" demonstration project with a subsidy from the Japanese Government. It has 24 housing units, 22 of which are occupied by Tokyo Gas employees and their families,[2] while the other are reserved for demonstration purposes. Those invited to live at E-Sogo must grant permission to have their energy usage data monitored, and they are asked to cooperate with ongoing studies at E-Sogo, although participation is voluntary.

The E-Sogo apartment building was designed to be energy efficient, with an advanced thermal envelope and specialized doors and windows designed to capture breezes for natural ventilation and cooling. The E-Sogo apartment building also has a complex on-site energy generation and management system. End use equipment includes room ACs in the living rooms and bedrooms, as is now typical in Japanese homes. As mentioned earlier, AC usage and the resulting energy consumption varies widely among E-Sogo residents.

Methodology. Having identified AC usage as an opportunity for greater conservation, it was determined that the experiment would exclude households with very low (or no) energy use from AC. Thus the treatment group in the study is the 15 households (out of 22) with the highest energy use from AC, divided into two tiers: high and medium AC usage. The study compares the treatment group's behavior and energy use, before and after the intervention, to measure the effect of the energy-saving intervention.

The intervention consisted of pre- and post-intervention surveys, and a mid-intervention reminder. The study design leveraged several behavioral principles to encourage reductions in AC usage and utilization of passive cooling techniques including: social norms, commitments, reminders and an appeal to the intrinsic motivation to "save money, conserve energy and help fight global warming".

The pre-intervention survey had three key modules. The first module of questions identified baseline AC usage patterns, and the motivations and strategies driving them. It

[1] For a more in-depth discussion of the generalizability of this study, see the project report (Outcault, et al., 2015).
[2] This arrangement is not unusual. Tokyo Gas has many company-sponsored buildings in which employees live.

included questions that target how, when and why residents use their AC in the summer in various rooms within their apartment.

The second module contained a simple AC energy report illustrating the respondent's household energy consumption from AC, the average of their more conserving neighbors from the next tier down (i.e., medium AC usage for high users, and low AC usage for medium users), and the household's 10% reduction target.

In the third module of the survey, respondents were asked if they would be willing to commit to trying a range of energy saving techniques to reduce AC usage during the study period (July 30 to September 22) to achieve the 10% reduction target. Respondents were asked to report how often they typically utilize each of the 14 strategies listed in Table 2, and commit to use more frequently strategies of their choosing. Halfway through the intervention, the treatment group received reminders that highlighted the strategies participants had committed to trying for the study period.

At the conclusion of the study period, a post-intervention survey was implemented to measure the self-reported change in behavior (in terms of frequency of use of the 14 strategies) and estimates of energy use relative to the 10% reduction target. After completing the survey, respondents received another energy report that detailed how much the household reduced energy consumption from AC relative to: the previous year, the 10% target, and the average of all treatment group households. Participants were interviewed about their experience with the intervention and their approach to cooling in summer.

Intervention materials were created by the UC Davis Western Cooling Efficiency Center (WCEC) research team, with input from Tokyo Gas research staff. The latter also provided translation and logistical support by recruiting study participants and distributing surveys.

Data was collected via hardcopy surveys. All fifteen treatment group households completed pre-intervention surveys and eleven completed post-intervention surveys. Data was entered into a database and analyzed using Excel and STATA. AC energy use was sub-metered for all the apartments and provided to the research team by Tokyo Gas. Energy analysis was conducted using "R" statistical software.

Key Findings. Respondents' self-reported strategies, values, knowledge and habits regarding summertime cooling were assessed using baseline surveys. The survey revealed that even residents with relatively high AC usage actively manage their AC use. Shutting off ACs completely when leaving home was nearly universal. More than half (8 out of 15) said they did not use AC after going to bed. The median temperature setting respondents reported was 79°F when using the living room AC and 81°F when using the master bedroom AC. Furthermore, many respondents reported at least some use of the 14 AC conservation and alternative cooling strategies prior to the intervention. At Table 2 shows, each of the strategies was used by at least half of respondents at the baseline. Respondents also reported a considerable willingness to commit to increasing their use of the 14 strategies (only one abstained). On average, respondents committed to trying more frequently 6.7 out of 8 daytime strategies and 4.6 out of 6 nighttime strategies (11.3 out of 14, in total).

However, despite significant commitments, in the post-intervention survey most respondents reported little change in the frequency with which they used the 14 strategies. Only 5 of the 10 who completed the post-intervention survey increased the frequency of at least one passive cooling technique during the experiment. In the vast majority of cases, those who increased the frequency of use of particular strategies were the individuals who had committed to doing so, suggesting that the commitment device was somewhat effective. When asked about the barriers they faced to fulfilling their commitment, many noted the heat and humidity, particularly at night.

Table 2. Cooling strategies: Commitment, pre- and post-intervention prevalence

	Baseline survey		Post-intervention survey
	Use strategy (n=14)	Commit to increase (n=14)	Increased use (n=11)
Daytime strategies			
Closing windows and blinds as the outside temperature starts to rise in the morning.	79%	79%	10%*
Trying not to turn on the AC unless it is uncomfortably hot. Turning it off as soon as it cools down outside.	100%	100%	9%
Turning the AC off and turning on a fan	79%	71%	11%**
Cooling only rooms that are occupied and closing doors to rooms that are unoccupied	100%	71%	9%
Changing to lighter clothing	100%	100%	36%
Placing a cooling towel or pillow on the back of your neck	57%	57%	40%*
Running errands (at cool shops) during the hottest part of the day	79%	71%	18%
Using the AC's "Cool" setting instead of "Dry" setting.	86%	100%	27%
Nighttime strategies			
Running the AC for a short amount of time before bedtime, to dehumidify the air, with the door closed. Then shutting off the AC when going to bed.	79%	64%	0%
Turning the AC on when going to bed, but setting a timer to turn it off after a short amount of time.	86%	79%	0%*
Turning the AC off and turn on a fan	79%	71%	0%**
Using the AC's "Cool" setting instead of "Dry" setting.	86%	100%	9%
Placing a cooling towel or pillow on the back of your neck	50%	57%	20%*
Opening windows in the evening as soon as it becomes cooler outside than inside. Keeping the windows open all night.	79%	86%	18%

*n=10, **n=9

To evaluate energy savings from the intervention, we utilized the "retrofit isolation" approach in ASHRAE Guideline 14 (ASHRAE, 2014), which measures the energy use of a specific system during a baseline period, and again after an intervention is implemented. The raw savings were adjusted to account for factors such as differences in weather to yield the net effect of the intervention. Following this method, treatment group households, on average, saved 7% of the energy consumed from AC.[3]

Altogether, the effects of the intervention were positive, but modest and derived from a small population. Although many respondents committed to behavior changes, few achieved them, and the resulting total energy savings reflected that. Greater participant engagement with the study may have improved results.

West Village, Davis, California, United States

Overview. West Village is a mixed-use complex at the University of California-Davis in central, Northern CA. It currently houses 2000 students, faculty and staff in its residential apartments, as well as various UC Davis-affiliated offices (including the WCEC's) in its commercial space. Electricity (which powers all of the heating and cooling demands, among other things) is included in residential rents, and although there is an electricity quota, it is not enforced for a variety of reasons.

Although very hot during the day in summer, Davis experiences significant drops in temperatures during the evening (up to 40° F). To exploit that, West Village was designed to utilize passive cooling techniques through the positioning and shading of windows, and installation of ceiling fans in every room. However, AC usage remains high in many apartments.

Methodology. The West Village study utilizes pre-/post- comparisons of behavior, and pre-/post-, Treatment vs. Control group comparisons of energy use, to determine the effects of the intervention relative to the baseline, and across treatment groups. Eligibility for the study was limited to the 100 student households in which energy data monitoring devices were already installed (as part of a different research effort). Of those, 75 were randomly assigned to the treatment group, and 25 were assigned to the control group.

The intervention involved several components including distribution of an informational flyer, a pre-intervention survey, mid-intervention reminders and surveys, and a post-intervention survey. The study design leveraged several behavioral principles including reminders, commitment, and both extrinsic (e.g., small monetary gifts) and intrinsic (e.g., descriptions of environmental benefits) motivators. The surveys and other study materials were designed specifically for the West Village participants, and therefore were distinct from those used with Japanese research subjects.

The base level treatment was receipt of an informational flyer on how to use a three-step "natural" cooling approach by: 1) setting the thermostat to 80° F, 2) opening windows from 9 PM to 9 AM to capture cool night air, and 3) using ceiling fans to increase air circulation as needed. Flyers were hand-delivered to the 75 treatment group households along with a note requesting that residents mount them near their thermostat. This one-way mode of communication was utilized because prior studies had limited success engaging residents on an ongoing basis.[4] However, an attempt was made to engage residents further: all treatment group household members (n=210) received individual recruitment emails requesting they participate

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[3] The weighted average of energy savings among the treatment group was 3%, with lower AC users saving more energy than higher users. Individual households' savings ranged from 46% to -96%. The difference in savings between medium- and high-AC use groups is not statistically significant.

[4] Surveys were utilized as the primary mode of engagement with Japanese research subjects. The researchers expected a high degree of responsiveness given participants' standing agreement with Tokyo Gas.

in an online survey, for which a small incentive ($10) was offered. Based upon voluntary participation in the pre-intervention survey and control group assignment, there were essentially three tiers of participation within the treatment group and one control group, totaling 4 sub-groups, namely:

- Treatment group 1 - Received flyer, completed survey and commitment (n=11);
- Treatment group 2 - Received flyer, completed survey, did not commit (n=5);
- Treatment group 3 - Received flyer, did not complete survey or commitment (n=194);
- Control group (n=88).

The pre-intervention survey asked about respondents' knowledge, motivation, and use of AC and other cooling techniques, and requested respondents make a commitment to try the "natural" cooling techniques described on the flyer for the month of August. Those who agreed received weekly reminders by email and a request to complete a short online survey to report on their experience. Post-intervention surveys asked whether respondents engaged in alternative cooling strategies, how frequently, what the experience was like, and any challenges they faced.

Data was compiled by the survey software (Qualtrics), and cleaned and analyzed using Excel and STATA. AC energy use was sub-metered for all the apartments and provided to the research team by Noresco.[5] Energy analysis was conducted using "R" statistical software.

Key findings. In the pre-intervention survey, data was collected on respondents' use of AC and other cooling strategies, which illustrated the primacy of AC. The majority of respondents reported the highest acceptable temperature setting on the central AC was 76° F, although the range was 70-80° F. Most reported leaving their AC on during the night to stay cool, despite an average nighttime temperature of 55° F. As Table 3 shows, only one respondent left windows open at night and 7 were reportedly unaware of the notable drop in nighttime temperatures. Nearly two-thirds of respondents (n=11) committed to trying the 3-step "natural" cooling approach during the intervention period (August 2014), but only 7 who did so completed the post-intervention survey, 6 of whom reported having tried "natural" cooling.

Table 3. Summary of results

	% Respondents
Pre-intervention	
Opened windows at night	6% (1 of 16)
Unaware of nighttime temperature drop	44% (7 of 16)
Committed to try "natural" cooling	69% (11 of 16)
Post-intervention	
Tried "natural" cooling	55% (6 of 11)

Average temperatures were cooler during the intervention than at baseline, resulting in a decrease in energy consumption from AC among both Treatment and Control groups. We

[5] Noresco retains a contract to provide energy data monitoring for a subset of West Village apartments.

employed a difference-in-difference approach (Wooldridge 2006) to calculate the intervention's effect, but no statistically significant difference was found in total energy use from AC. We attribute this to three factors: minimal effect of the intervention, small sample size[6], and non-equivalent treatment and control groups despite randomization.[7]

Comparison of Key Findings

Both interventions had modest success in inducing respondents to more frequently use at least one passive cooling strategy. Four out of 7 West Village respondents reported doing so, while 4 others who committed to trying passive cooling did not respond to the post-intervention survey. Similarly, 5 out of 10 E-Sogo respondents increased the frequency of at least one passive cooling strategy, and 5 did not respond to the post-intervention survey. Given the small number of study participants who reported behavioral change, it is unsurprising that the energy savings from reduced AC usage was modest, 7% at E-Sogo and zero at West Village.

There are several key similarities among the study results. Both experiments suffered from low participant engagement. At West Village, survey response rates were low from the beginning, which we surmise is partly because students have little interest in energy conservation when they do not pay for electricity, which they furthermore perceive as renewable. At E-Sogo, despite midpoint reminders, numerous study participants reported that they had forgotten about the study. As our study was run in parallel with others, we suspect that residents may have suffered from study fatigue.

Participants from both sites noted barriers to adopting the cooling strategies promoted in the studies. They cited, for example, problems with natural ventilation (e.g., air quality, noise, privacy, safety) and obstacles to household/occupant coordination (e.g., different preferences, values, thermal comfort levels).

Those who did actively participate had relatively low energy consumption from AC at the baseline.[8] This type of self-selection bias – in which participation is higher among individuals who already display greater levels of the behavior being encouraged - is expected, and highlights the challenge of unlocking the potential energy savings from households with higher energy use. The small sample size limited the potential for other meaningful bivariate analyses to explore the relationships between cooling strategies, participant characteristics and energy savings.

There are also key differences between the studies, including participant demographics (i.e., college students versus families) and the broader context of the study locations. Geographic, climatic, and economic factors differ, as do housing characteristics, energy use and energy costs, although estimating the effect of these factors is beyond the scope of this research.[9] The behavior changes the experiments promoted also differed in familiarity and complexity (i.e., 14 individual strategies versus a single, 3-step strategy). At the baseline, use of the (site-specific) passive cooling techniques encouraged was relatively higher among E-Sogo respondents than West Village respondents.

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[6] Unfortunately, energy data was ultimately available for only 62 (46 Treatment and 16 Control) of the 100 households in our study, further reducing our sample size. To preserve statistical power, we draw comparisons between the control and treatment groups in aggregate, although we acknowledge this is not ideal.
[7] It was determined post hoc that the Treatment group's energy use from AC was significantly lower than the Control's at the baseline. This is likely a fluke explained by the small sample size, as random selection was utilized.
[8] A notable exception is the ultra-low AC users in E-Sogo who were excluded from the intervention.
[9] More can be read about the differences between the studies in the project report (Outcault et al. 2015).

Discussion

Although the interventions were designed to take into account local differences in the prevailing cooling strategies, they were founded on the same assumption: that participants would change their behavior "if only" they had more information and were made to care about the effect of their actions (Moezzi and Janda 2014). With this mindset, occupants get cast as the enemy to the "technical potential" for energy efficiency offered by the sustainable homes in which they live. In fact, the explicit impetus for this study was to identify ways to bring occupant behavior in line with the expectations of the community designers' models. Such a building-centric approach, ignores the needs, values, beliefs, preferences, and priorities of the humans who live there, beyond those that narrowly relate to energy use, its costs and consequences.

This approach has notable limitations as it largely ignores the broader social context, culture and expectations that shape individuals' decisions. Perhaps that explains, in part, the low rates of participation, responsiveness, and behavior change observed in the two studies. Recent scholarship urges a higher-level approach to capture the "social potential" for energy efficiency (Moezzi and Janda 2014). Although designing interventions that targeted social factors fell outside the scope of our work, we collected data throughout the studies that provide insight into how factors operating at this elevated level may contribute to the behaviors observed both before and during the interventions. What follows are several high level comparisons of the thermal comfort strategies utilized among our study participants, and their compatriots more broadly. Where possible, we provide supporting data from our study, or other sources, for the patterns we identify. The intention is merely to describe several factors that shape the "social potential" for energy conservation through reduced mechanical cooling, as the authors see it, each of which merit further research to document and identify how to capture such potential.

Scope

The scope of cooling strategies varies substantially between the U.S. and Japan. In the U.S., central AC is the dominant (and growing) cooling technology. In 2009, 63% of American homes had central AC (EIA 2013). With central AC systems, cooling is delivered in a uniform manner to an entire home. Energy use from this wide, building-level scope is exacerbated by the relatively large size of American homes, 750 sqft per person (US Census Bureau 2011) compared to 224 sqft per person in Japan (Statistics Japan 2013). As the median household size is virtually the same in both countries – nearly 2.6 people (Ibid, Ibid) – that equates to significantly larger homes in the U.S., and greater area to be cooled, as illustrated in Figure 1.

By contrast, the predominant source of mechanical cooling in Japanese homes is room ACs (i.e., mini-split heat pump systems), with indoor units for different rooms.[10] In 2009, 90% of households in Japan owned one or more room AC units (Statistics Japan 2014). Room ACs offer more localized, "task" cooling. As Figure 1 illustrates, Japanese room ACs target specific rooms, and even specific areas within rooms. Some newer technologies claim to detect occupants' precise location within a room and direct the cool air towards them.

[10] Room ACs in Japan provide both cooling and heating, although this paper addresses only their cooling functions.

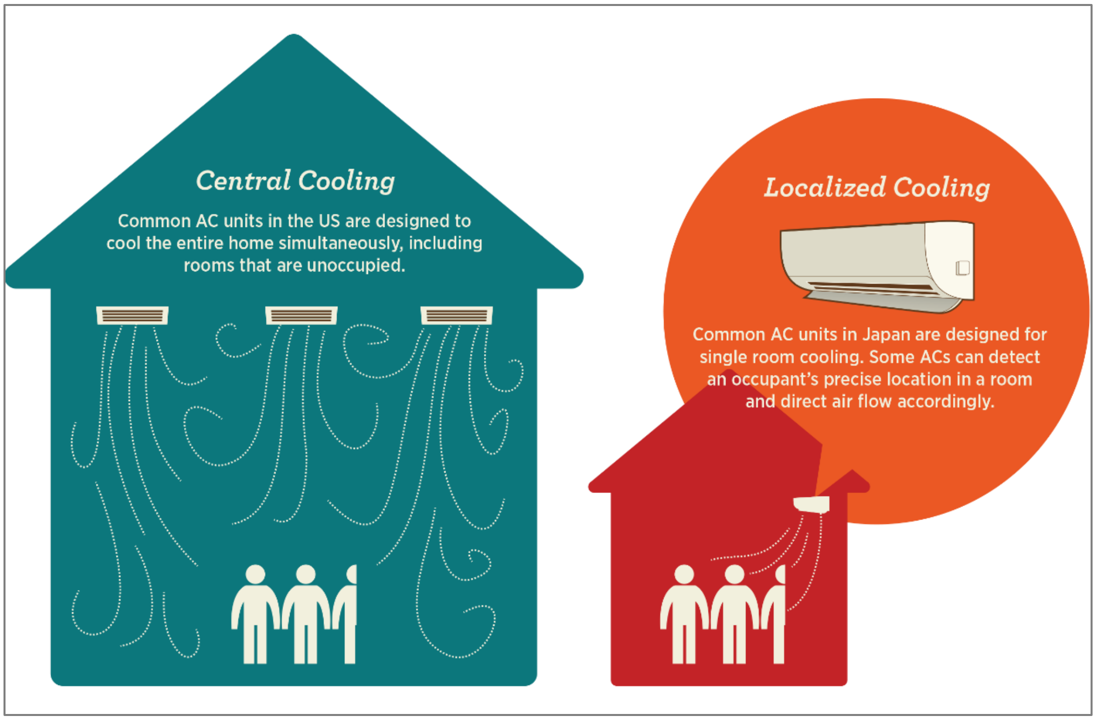

Figure 1. Graphical depiction of mechanical cooling approach in American vs. Japanese homes

Furthermore, Japanese, including study participants, often supplement cooling from room ACs with additional, highly targeted strategies including fans and personal cooling devices (e.g., cooling towels or pillows, specialized clothing), allowing occupants to achieve thermal comfort at relatively higher temperature settings than Americans (see survey results presented above).

Level of Engagement

Japanese employ cooling strategies that, in general, can be characterized by a higher level of engagement and activity. For example, occupants turn off room ACs as they exit a room or the house, as our baseline survey revealed. Furthermore, utilizing narrowly-targeted cooling technologies, such as fans and personal cooling devices, requires active engagement, sometimes multiple times each day. Wilhite et al. (1996) described similarly active management of space heating needs in Japan two decades ago, suggesting the Japanese have retained this approach and continue to apply it with new technologies.

By contrast, a very common American cooling strategy is the "set-it-and-forget-it" approach whereby a thermostat that controls a central AC is used in hold mode (Meier et al. 2012). Temperature setbacks that emulate the Japanese strategy can be achieved through programming, but there is evidence to suggest that few American residents have completed that one-time activity (Peffer et al., 2011). Thus, the typical American cooling strategy can be described as relatively passive. Air is cooled according to whether it is day or night, rather than closely tailored to the instantaneous needs of the occupants. Learning thermostats aim to provide more fine-tuned cooling, but do so with only minimal occupant engagement (Nest website).

Data from the respondents' surveys and interviews confirms this generalization. AC usage in Japan is a conscious choice. As one respondent stated: "I do not use air conditioners when it is not necessary to turn them on". E-Sogo residents also reported that they routinely turn off (or turn up) their AC when they leave the room (and the house), and close the doors to unoccupied rooms when cooling occupied rooms. Some respondents consider future occupancy in their strategy: "On a day when I am planning to go out, I never turn on the air conditioner in the living room." Others reported cooling strategies such as going up on the roof in the evening, avoiding the use of hair dryers, closing curtains to reduce solar gain, taking showers, drinking cold beverages, and going to the mall on hot days. By contrast, most respondents in the West Village survey reported rarely turning off their AC at night, despite sufficiently cool outdoor temperatures. As one respondents stated: "Why would I open my windows when I can use the AC to my heart's content and maintain a controlled temperature?" By contrast, one E-Sogo resident's assessment of the same cooling strategy was: "I just need to open the windows, so it's easy."

Comfort Assessment

Thermal comfort preferences differ substantially across individuals. As one Japanese respondent noted: "Air conditioner usage in my household was much more than the neighbors'…I am rather chubby but they are skinny husbands. Maybe because of that, air conditioner usage differs". Understanding these differences, one respondent noted the strategy in his household: "If one person is the only one who thinks it is very hot, instead of using the air conditioner we let her use the electric fans to cool herself." American study participants also noted different preferences between themselves and their roommates, but with the opposite result: the AC was used if *any single* occupant preferred it, rather than if all did.

This intra-group heterogeneity, however, masks an underlying difference in how Japanese and Americans tend to assess the acceptability of their comfort, which in turn drives differences in cooling strategies. Although previous studies have found no significant difference in thermal neutrality between Japanese and Americans (Tanabe & Kimura, 1994), there does appear to be a significant difference in their subjective tolerance for heat. As described further below, Japanese respondents in our study were more likely to tolerate what they considered to be high temperatures (and which were in fact warmer than the Americans' indoor conditions), whereas the Americans found discomfort unacceptable.

Relative or absolute comfort. This may be explained, in part, by differences in expectations, which affect subjective assessments of thermal comfort (see Brager and deDear, 1998). Prior studies have shown that thermal comfort assessments shift with the expectations set by changes in outdoor temperature over a season or the course of a day (Mishra and Ramgopal, 2013).

From the surveys and interviews with E-Sogo residents, it was apparent that many conceived of thermal comfort in conditional or relative terms. Their expectations about thermal comfort seemed to be influenced by the weather conditions, energy costs, environmental impact of AC use, and even self-conceptions of frugality, stoicism and personal responsibility, as this quote illustrates: "I tend to endure [discomfort] up until I reach the limit because my ancestors are…samurai. Endurance is something of beauty amongst the samurai. It is a cultural thing." Thus, respondents' prioritization of thermal comfort was typically weighed in relation to other values. Half reported being willing to tolerate higher indoor temperatures to save money or energy.

Our survey results showed that American respondents appeared to expect a certain *absolute* level of comfort, while Japanese respondents adjust their expectations (and demands) according to other relevant factors (e.g., energy cost, season). As Figure 2 below illustrates, West

Village residents were much more likely to report using their AC as much as they need to be comfortable, while E-Sogo residents were more likely to balance the desire for comfort with the desire to be frugal.

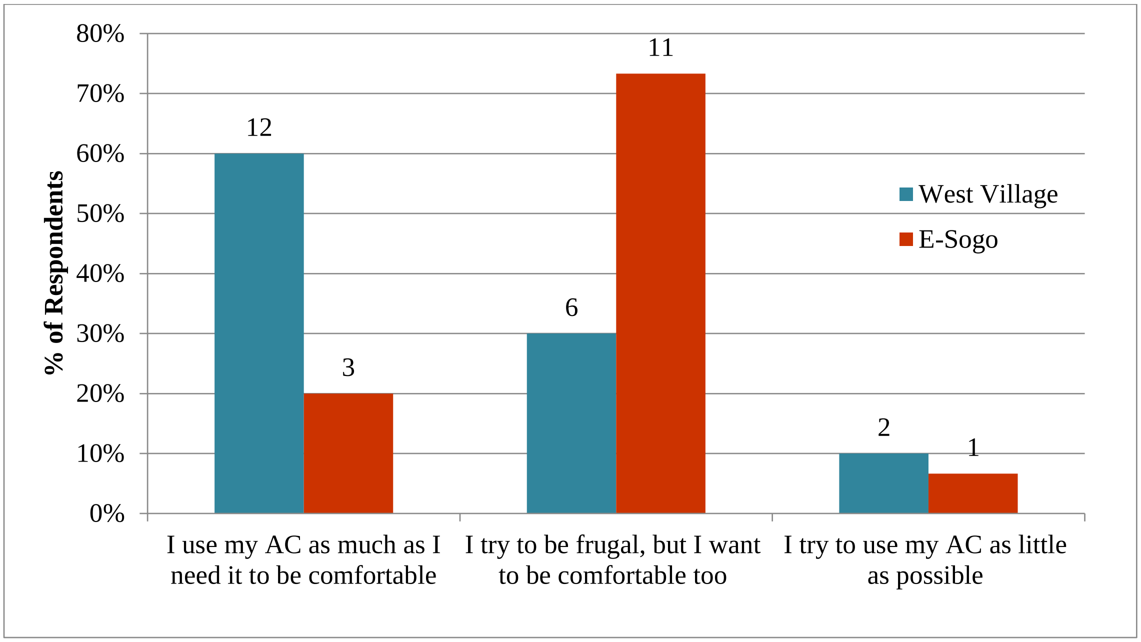

Figure 2. Prioritization of AC use

Social norms. The prevailing mindset of *relative* or *absolute* comfort, as a social norm, can significantly influence one's expectations of thermal comfort. Norms governing space conditioning can also influence expectations of thermal comfort. Secondary data shows that nearly 80% of U.S. households that regularly use central AC maintain daytime temperatures below 77 °F when someone is home (U.S. EIA 2013). Our survey results mirror this finding. On average, West Village respondents reported that the *highest acceptable* indoor air temperature in their apartment was 76 °F, By contrast, the median *actual* temperature setting on E-Sogo respondents' living room AC was 79°F, while occupied. Although not as high as the 82 °F recommended by the Japanese government to conserve energy and maintain system reliability during summer (TMG), this still represents a significant disparity.

Policies, both official and unofficial, regarding space conditioning equipment provide another perspective on social norms with respect to thermal comfort. In the U.S., there are strict policies on buildings' *capacity for* space conditioning (i.e., ASHRAE Standard 55). The authors posit that these policies communicate an endorsed range that serves as an anchor, and source of cognitive bias, for occupant decisions, thereby legitimating and further entrenching the norm. Japan does not have a comparable building code, so individual manufacturers of HVAC equipment set their own parameters, which may also reflect local norms. Figure 3 contrasts the seasonal thermal comfort ranges identified by ASHRAE and Kureseru, a Japanese manufacturer of indoor thermometers and "discomfort index meters" (Company website).

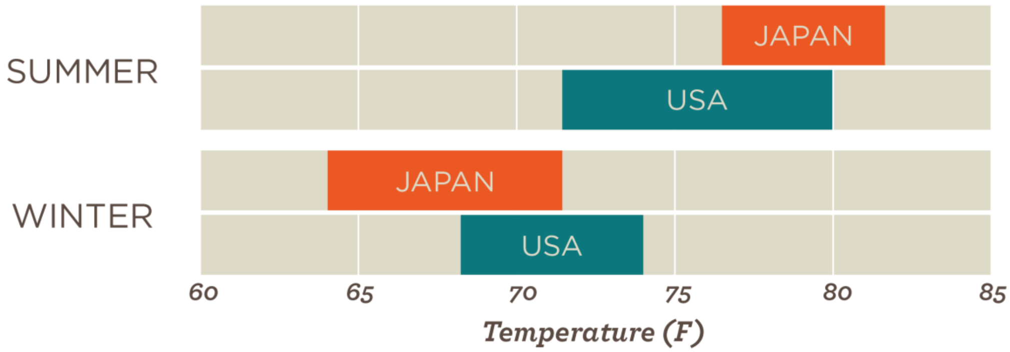

Figure 3. Industry's thermal comfort range

There are three key differences to note. The first is that the comfort ranges of the two seasons overlap in the U.S., suggesting a more absolute notion of thermal comfort, as mentioned earlier. The summer and winter ranges in Japan have a notable gap between them, suggesting Japanese expect (or at least accept) wider seasonal differences in thermal comfort. The second observation is that the overall thermal comfort range is much narrower in the U.S. than in Japan. Finally, the comfort range in the U.S. is relatively cooler in the summer and warmer in the winter, relative to Japan, which implies more aggressive cooling during the summer in the U.S., just as the data on AC use suggest.

Occupant control. The perception of control can improve one's assessment of thermal comfort, and in turn the acceptability of a given set of conditions. Numerous studies have demonstrated that occupants' control (or perceived control) over indoor conditions can also positively affect occupants' assessment of thermal comfort (Karjalainen 2009). The authors propose that the Japanese cooling strategy, with its emphasis on more active engagement, empowers occupants to control more variables to achieve thermal comfort. This subtle difference may have a powerful psychological effect, enabling the Japanese to align their behaviors, as well as expectations, to find relative comfort at slightly higher temperatures in summer.

Finally, as these patterns highlight, there is great value in conducting cross-cultural comparisons as they enable us to escape the limiting effects of local norms. By comparing the fundamental differences in attitudes about cooling, strategies for cooling, and the range of potential solutions, we confirm that such culturally-specific factors are indeed malleable, expanding the notion of what is possible or promising. For example, future interventions in Japan may benefit from de-emphasizing the highly granular, customized approach to personal cooling, the details of which can be easily forgotten and instead promote a single, integrated strategy that is both memorable and widely applicable. The government has taken this approach in the public arena by mandating cooling to 28 °C (82 °F) in all government buildings and promoting "Cool Biz" attire to cope with warm office temperatures. Perhaps a similar approach is merited for Japanese homes. By contrast, future interventions in the U.S. may find success by promoting the adoption of more active, personalized approaches to cooling, following the Japanese example. Such options could include promoting the creation of HVAC zones within homes, use of sensor-controlled fans, and personal spot-cooling devices. When understood from the perspective of the patterns described – i.e., the scope, level of engagement, and expectation and assessment of thermal comfort – it is clear that there are many ways to encourage conservation by unlocking the "social potential" for it.

Conclusion

Designing an intervention and effectively leveraging mechanisms for behavior change (e.g., commitment, reminders, social norms) requires a careful understanding of current behavior and its drivers. The cooling strategies of our American and Japanese research participants differed significantly in their scope, level of engagement, and expectation and assessment of thermal comfort. The behavior change each experiment promoted reflected those differences, urging a single, integrated approach in West Village and a portfolio of options in E-Sogo. In both study locales, modest changes in behavior (and energy savings) were reported, illustrating the potential for behavioral initiatives that educate, motivate, and remind consumers to try alternative cooling strategies and reduce AC use. However, the very small and non-representative sample sizes limit the generalizability of the study's findings. It does, however, illustrate that by identifying the dimensions on which cooling strategies differ – i.e., scope, level of engagement, and expectation and assessment of thermal comfort – we may unlock new avenues for energy savings.

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