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Raising the AC temperature in the tropics, one degree at a time

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ABSTRACT

In tropical countries, air conditioners (ACs) account for a significant fraction of energy consumption. We conduct a randomized control trial to examine how people can best be induced to raise their AC temperature by 2 °C over time, to reduce energy consumption. Subjects were randomly assigned to (1) raise the AC temperature gradually, by 1 °C in period 1 and an additional 1 °C in period 2; (2) increase the temperature by 2 °C in one go during period 2; or (3) a no-incentive control condition. We find that raising AC temperatures gradually worked better in achieving higher AC temperatures during the intervention and post-intervention periods. Energy consumption data confirmed that these higher AC temperatures translated into energy savings. Our findings demonstrate the effectiveness of gradual targets to initiate and sustain behavioral change in energy conservation and other related domains.

1. Introduction

In tropical countries, air conditioners (ACs) are a major source of energy consumption and CO_2 emissions (International Energy Agency (IEA), 2018; Shah et al., 2015). For instance, in Singapore, air conditioning accounts for nearly one quarter of household energy consumption (National Environmental Agency (NEA), 2017). Globally, the number of ACs in use is expected to increase fivefold by 2050 (International Energy Agency (IEA), 2018; Shah et al., 2015; Davis and Gertler, 2015). Such an exponential increase will exacerbate global warming, so finding practical ways to reduce energy consumption by ACs is important (IPCC, 2014; Peters et al., 2013). One solution is to raise the temperature at which people set their ACs (Gardner and Stern, 2008).

Recognizing this, governments in Singapore and Japan are encouraging households and workplaces to increase the AC temperature to 25 °C and 28 °C, respectively (National Environmental Agency (NEA), 2018; Ministry of the Environment, 2006), while authorities in India and Spain have prescribed higher AC temperature settings (Press Information Bureau (PIB), 2018; Bloomberg, 2022). Yet despite these directives, our understanding of how best to motivate people to raise their AC temperature is still nascent. Our paper examines how financial incentives and AC temperature targets can be structured to induce this specific behavioral change.

In particular, our paper employs a three-arm randomized control trial (RCT) that compares two incentive schedules, both with an ultimate target of encouraging people to raise their AC temperatures by 2 °C. We introduce monetary incentives along with temperature targets either gradually (GT) or abruptly (AT), along with a control condition (CC). Our unique institutional context, which will be described in more detail below, coupled with the use of temperature sensors, allows us to track subjects' AC temperatures accurately and attribute any observed behavioral change to the effect of the given incentives on the individual participant.

We first measured all subjects' AC temperatures over a 7-day baseline period and obtained each subject's lowest AC temperature recorded over this period. We call this temperature the baseline minimum. After this, we randomized subjects into one of the three arms in the RCT.

Subjects in the control condition (CC) were given neither AC temperature targets nor daily monetary incentives throughout the study.

Subjects in the gradual treatment (GT) were incentivized to increase the AC temperature across two periods. In period 1, they were given $1 each day their daily minimum temperature (DMT), which is the lowest temperature recorded in a given day, was 1 °C higher than their baseline minimum. In period 2, they received $2 each day their DMT was 2 °C higher than their baseline minimum. This brought the total increase to 2 °C relative to their baseline temperature, albeit in a gradual manner over the two periods.

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In the abrupt treatment (AT), subjects were incentivized to increase the AC temperature only in period 2. In period 1, they were given neither a temperature target nor a monetary incentive. In period 2, they received $2 each day their DMT was 2 °C higher than their baseline minimum. This was identical to the intervention given to GT subjects in period 2.

The rationale for comparing GT versus AT is as follows: If participants can be financially incentivized to abruptly raise their AC temperature by 2 °C over a relatively short period, then policymakers can simply induce people to do so. However, two parallel theories suggest that asking people to increase AC temperatures gradually would be more effective, despite a longer intervention duration.

Based on the literature on heat exposure, GT participants would have been more acclimatized to a higher temperature compared to AT subjects at the end of period 1, so the acclimation to the 2 °C target increase in period 2 would be relatively easier (Hanna and Tait, 2015; Périard et al., 2015). As such, in period 2, subjects who have been exposed regularly to a 1 °C increase in AC temperature should feel less thermal discomfort with the 2 °C increase from baseline, compared to subjects who had not acclimatized to a higher temperature before. This heat acclimation perspective leads to the same prediction as habit formation theory (Pollak, 1970; Becker and Murphy, 1988; Becker, 1992), which is that once people initiate a behavioral change, the marginal cost of improving on that behavior becomes lower. In our context, given that GT subjects have already adjusted AC temperatures to a little higher than usual, another small increase to reach the ultimate target is less painful than if they were asked to reach that same target immediately. Hence, both theories suggest that GT participants should achieve higher AC temperatures in period 2 and in the post-intervention, compared to CC and AT subjects.

Past research has demonstrated that financial incentives can motivate people to shift energy demand to off-peak hours or lower overall household energy usage (McClelland and Cook, 1980; Bradley et al., 2016; Faruqui and Sergici, 2010; Joskow and Wolfram, 2012; Ito, 2014; Ito et al., 2018). Beyond monetary incentives, research has shown that social comparisons, energy conservation goals, feedback on energy consumption, and information on pricing and externalities can also encourage energy conservation behavior (Ito et al., 2018; Jessoe and Rapson, 2014; Allcott and Rogers, 2014; Allcott, 2011; Brülisauer et al., 2020; Tiefenbeck et al., 2018; Asensio and Delmas, 2015; McCalley and Midden, 2002). However, most existing studies focus on incentivizing subjects to reduce total energy consumption. Given that it is difficult for subjects to know the amount that each of their appliances contribute to their total energy consumption, appliance-specific energy usage goals and incentives could tap new energy savings (Brülisauer et al., 2020; Tiefenbeck et al., 2018). Here we focus exclusively on AC usage, which contributes a significant and growing amount to worldwide energy consumption and global warming (Peters et al., 2013).

Our aim is to drive a reduction in AC energy consumption by incentivizing subjects to increase their AC temperature. Raising AC temperatures is a promising way to reduce energy consumption because subjects can easily track and change their AC temperature in real time using their thermostat. While some existing studies did include setting a higher AC temperature in the energy-saving tips provided to participants (Allcott and Rogers, 2014; Brülisauer et al., 2020), subjects' room temperatures were not measured. One exception is Brown et al., who focus on reducing energy usage in an office environment (Brown et al., 2013). However, the authors are interested in reducing energy usage from heating by lowering the default thermostat temperature in cold climates. Further, unlike Brown et al., our study aims to raise AC temperatures of subjects by providing explicit AC temperature targets and financial incentives. In addition, we are also able to quantify the effect of raising AC temperatures on kWh energy consumption.

Finally, we contribute to the literature on behavioral change (Charness and Gneezy, 2009; Volpp et al., 2008; Volpp et al., 2009; Acland and Levy, 2015; Loewenstein et al., 2016). Since raising AC temperatures can lead to energy savings, it is important to determine the best way to achieve this goal. This paper uses an RCT to examine if reaching a 2 °C AC temperature increase is best achieved by asking people to increase temperatures gradually, albeit over a longer period, or to raise temperatures immediately. We are not aware of any work in the energy conservation and related domains that has examined the role of such gradual versus abrupt behavioral targets.

2. Empirical setting and study design

2.1. Empirical setting

A total of 191 students at the National University of Singapore (NUS) participated in our study. All subjects resided in one of three residential dormitories on campus; the three dormitories were all located within a 500-m radius. Each subject lived alone in a single dorm room with its own AC unit. The AC unit comes with a remote control, which was used to turn the AC on or off, or to adjust the AC temperature (in 0.1 °C intervals). Since subjects did not have any roommates, they were the only people who controlled their AC unit. We installed a temperature sensor in each room to measure the temperature every 10 min in 0.1 °C intervals (Supplementary Fig. 1).[1] Daily minimum temperature (DMT), captured by the sensor, was our main dependent variable and formed the basis for the temperature targets in GT and AT. The DMT corresponds to the lowest temperature recorded in a subject's room on any given day. On the days when the AC was switched on, the air temperatures in the small dorm rooms (<10 square meters) converge to the AC temperature set within minutes, and so the DMT corresponds to the lowest AC temperature set that day. See 'Explanation of our chosen temperature measures' in the supplementary materials for additional details.

Per university's policy, each subject pre-purchased AC credits to use the AC, at a rate of $0.25 for each hour of AC usage. Credits could be added at any time through a website or by visiting a terminal within the dormitory compound. The university charges students only for the duration of AC usage and not the AC temperature set. Therefore, besides the financial incentives provided in GT and AT, there was no other economic motive for subjects to increase the AC temperature. Outside of AC credits, participants did not pay for electricity or other utilities in their dorm rooms.

2.2. Experimental design and procedure

The experimental design is described in Fig. 1. The study was divided into four periods: (1) baseline period, (2) intervention period 1, (3) intervention period 2, and (4) the post-intervention period.

Before the start of the study, we visited each subject's room to distribute the baseline period instructions and install the temperature sensor.[2] At this time, we also asked all subjects to fill out a survey detailing their baseline AC use. Results of the survey are shown in Supplementary Table 6, with findings indicating that AC use before the intervention began was very similar across subjects in all experimental conditions.

During the baseline period (first seven days of the study), all subjects

[1] The sensors used were Rotronic HL-1D sensors with an accuracy of +/− 0.3 °C. All sensors were placed on top of the subjects' dorm issued armoires, which were all situated in the same place in the rooms and were out of the direct airflow of the AC unit. We taped the sensors down, being careful not to obstruct any vital temperature measurement parts of the sensors, to ensure they would not move during the duration of the study. Subjects were also instructed not to touch the sensors during the study. We tested the sensors' sensitivity to changes in AC temperature and found they adjusted to temperature changes accurately within a few minutes. Periodic checks of the sensors confirmed their functioning and reliability throughout the study duration.

[2] Scripts of all instructions can be found in the supplementary materials.

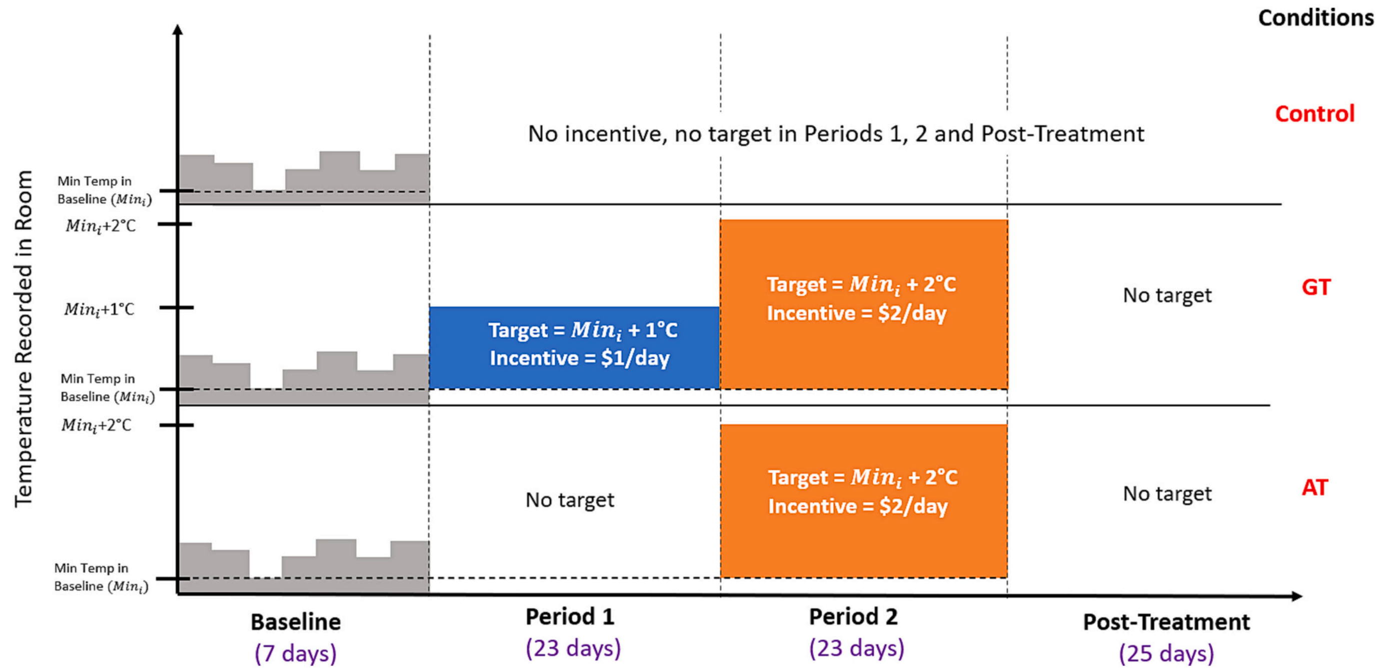


Fig. 1. Experimental conditions, temperature targets and monetary incentives. Subscript "i" (e.g., Min_i) denotes a subject.

were given neither a temperature target nor a financial incentive. We obtained each subject's single lowest temperature setting, as recorded by the sensor, during all the days when the AC was on during the 7-day baseline period. This temperature formed the baseline minimum. See 'Explanation of our chosen temperature measures' in the supplementary materials for additional details on why we incentivized the subjects to increase their AC temperature relative to their baseline minimum. The minima did not vary across the three conditions (see Supplementary Table 1 and Supplementary Fig. 2).

At the end of the baseline period, we visited all subjects' rooms within a span of two consecutive days to obtain the baseline minimum temperature from the sensor (specified in 0.1 °C intervals) and explain the instructions for period 1. Subjects were asked whether they had turned on the AC at least once during the baseline period. Five of the 191 subjects did not switch on their ACs during the baseline period and so were excluded from the study. The remaining 186 subjects were randomly assigned to the GT, AT or CC condition.[3] Subjects in all conditions were given a handout discussing the benefits of increasing the AC temperature (see 'Handout on the importance of energy conservation' in the supplementary materials). Subject randomization and attrition are shown in Supplementary Fig. 3.

There were 47 subjects in CC, 74 subjects in GT, and 65 subjects in AT. The targets and incentives used during the intervention and post-intervention periods are described in Fig. 1.[4] Note that periods 1 and 2 were each 23 days long, which, based on the literature, is enough time for people to acclimate to a higher temperature (Robinson et al., 1943; Flouris et al., 2014; Périard et al., 2021).

At the end of period 1, we visited subjects' rooms within a span of two consecutive days to give instructions for period 2 and ensure that the temperature sensors were working properly. Once period 2 was complete, we e-mailed subjects to tell them that, while there were no more temperature targets or incentives, the sensors would continue tracking the temperature in their rooms for another 25 days. We e-mailed instructions for the post-intervention period, rather than delivered them in-person as we did for other sets of instructions, because the instructions were very straightforward (no temperature targets and no monetary incentives).[5]

At the start of each period, subjects were told their individual temperature targets and daily incentive amounts (if any). Instructions for each period were printed on differently colored paper, making it easier for subjects to keep track of the changes from one period to another. Twice a week, we sent reminders about the temperature targets and incentives to subjects in GT and AT. Researchers were available at any time to answer questions or address concerns that subjects may have had.

At the end of the post-intervention period, we visited the subjects' rooms to collect the temperature sensors and disburse a $60 fixed payment to all subjects for participating. We explained to subjects in GT and AT that they could collect their incentive payments two weeks later, after we confirmed whether they met their temperature targets for each day and tallied the individual earnings. The experiment was approved by the Institutional Review Board (IRB) at NUS, and we obtained written informed consent from all participants. See Supplementary Fig. 4 for a

[3] The randomization was done in the following manner. We had a total of 100 balls. Out of these, 25 balls were assigned to CC. The remaining 75 balls were split between the two treatments: GT (38 balls) and AT (37 balls). Since we had a limited number of subjects, we designed the study to collect more data from the treatment conditions so that we could better detect differences between the GT and AT treatments across various periods. For each of the 186 subjects, we picked a ball randomly (sampling with replacement) and the subject was assigned to the corresponding condition.

[4] There was a possibility that the outside temperature was lower than some temperature targets, resulting in subjects not being able to meet their targets despite their best efforts. However, this occurred only on 2 out of 78 days. Both days were in period 2 and affected only 3 and 7 subjects on the first and the second days, respectively. During these occurrences, those subjects were given the incentive payment for that day.

[5] Upon receiving instructions for the post-intervention period, subjects were given 24 h to complete an online survey where they were asked to confirm that: 1) they had read the instructions in full, 2) they understood there were no temperature targets or incentives during the post-intervention period, and 3) they should contact a member of the research team immediately if they had any questions or needed clarification. If subjects did not complete the survey within 24 h, a member of the research team contacted them to ensure that they did so promptly.

study timeline and Supplementary Table 1 for participant characteristics, baseline temperatures and AC credit balances.

2.3. AC usage and temperature measures

At the end of the post-intervention period, we obtained participants' energy consumption data from the power company that tracks students' AC usage. The power company provided data on 1) daily AC energy consumption (in kWh) for each subject's AC unit, and 2) each subject's daily AC credit balance (calculated at the beginning of each day), for the intervention and post-intervention periods. By looking at the data on energy consumption along with credits consumed, we could determine whether subjects turned on their ACs at least once on each day of the study. The energy consumption data was also used to calculate the energy savings arising from our intervention (see Table 3).

To capture the daily outside temperature for the duration of the study, we placed sensors in 14 dorm rooms that were not equipped with ACs (Supplementary Fig. 5). Over the course of the study, the outside temperature increased slightly, from an average of 27.99 °C in the baseline period to an average of 29.15 °C in the post-intervention period. The average daily minimum temperature recorded in non-AC rooms did not go below 26.6 °C (80 °F). Thus, even during the coolest part of the day, the outside temperature was typically much higher than subjects' AC temperatures (average of the baseline minimum temperatures was 24.3 °C).

2.4. Hypotheses

This study aims to test three hypotheses:

1. In period 1, DMT will be higher in GT than in CC and AT.
2. In period 2, DMT will be higher in GT than in AT, even though both treatments had identical targets and incentives.
3. In the post-intervention period, DMT will be higher in GT than in CC and AT.

3. Results

Before testing the hypotheses using regression analyses, we describe the summary statistics and key empirical patterns.

3.1. AC switch-on rate

We first checked for differences in the daily AC switch-on rate, which records whether a subject switched on the AC at least once on any given day. We focus on this because subjects could increase the DMT in two ways: 1) switch off the AC or 2) increase the AC temperature. We observe no differences in the AC switch-on rate across conditions in each of the four periods (see Fig. 2 and Supplementary Table 2). This suggests that if there are temperature differences across conditions, they are not attributable to differences in AC switch-on rates.

3.2. Average DMT across conditions

Fig. 3a compares the average DMT between GT and CC, and Fig. 3b compares the average DMT between GT and AT (see Table 2 for the 95% confidence intervals), whenever the AC is turned on. There are no significant differences in the baseline period DMTs across conditions.

Fig. 3a-b show that DMT was generally higher in GT than in CC and AT in periods 1, 2 and the post-intervention period. In period 1, average DMT in GT was 25.80 °C, which is higher than AT (25.37 °C) and CC (25.36 °C). This suggests the incentives are effective in nudging subjects to increase their AC temperatures. In period 2, average DMT in GT was 26.43 °C, which is again higher than AT (26.19 °C) and CC (25.75 °C). This supports the hypothesis that gradual targets are more effective than abrupt targets. In the post-intervention period, a higher average DMT in GT (26.18 °C) was maintained compared to AT (25.94 °C) and CC

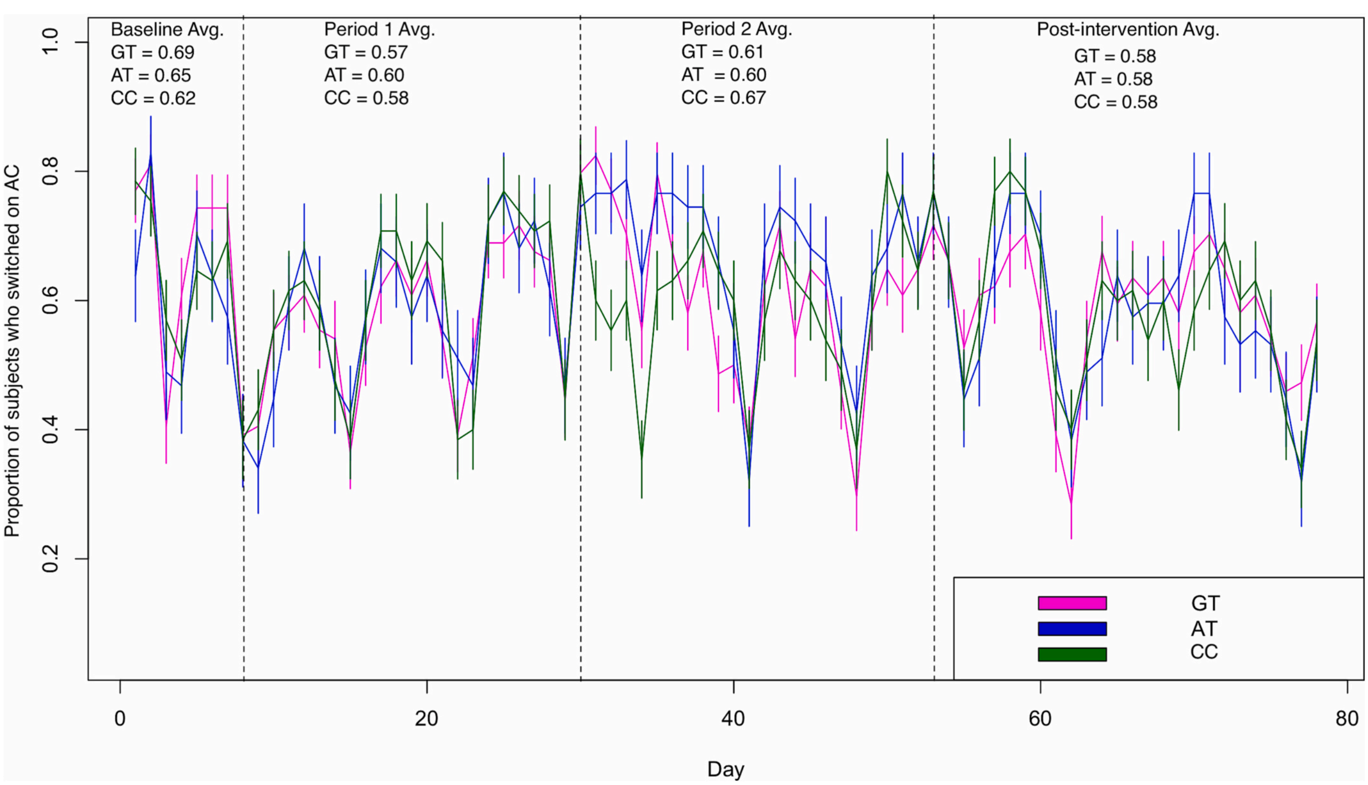


Fig. 2. Daily AC switch-on rate. The AC switch-on rate averages around 60% because subjects were primarily Singaporeans, who usually return home during weekends. The troughs in the figure correspond to the weekends. Standard error bars are shown.

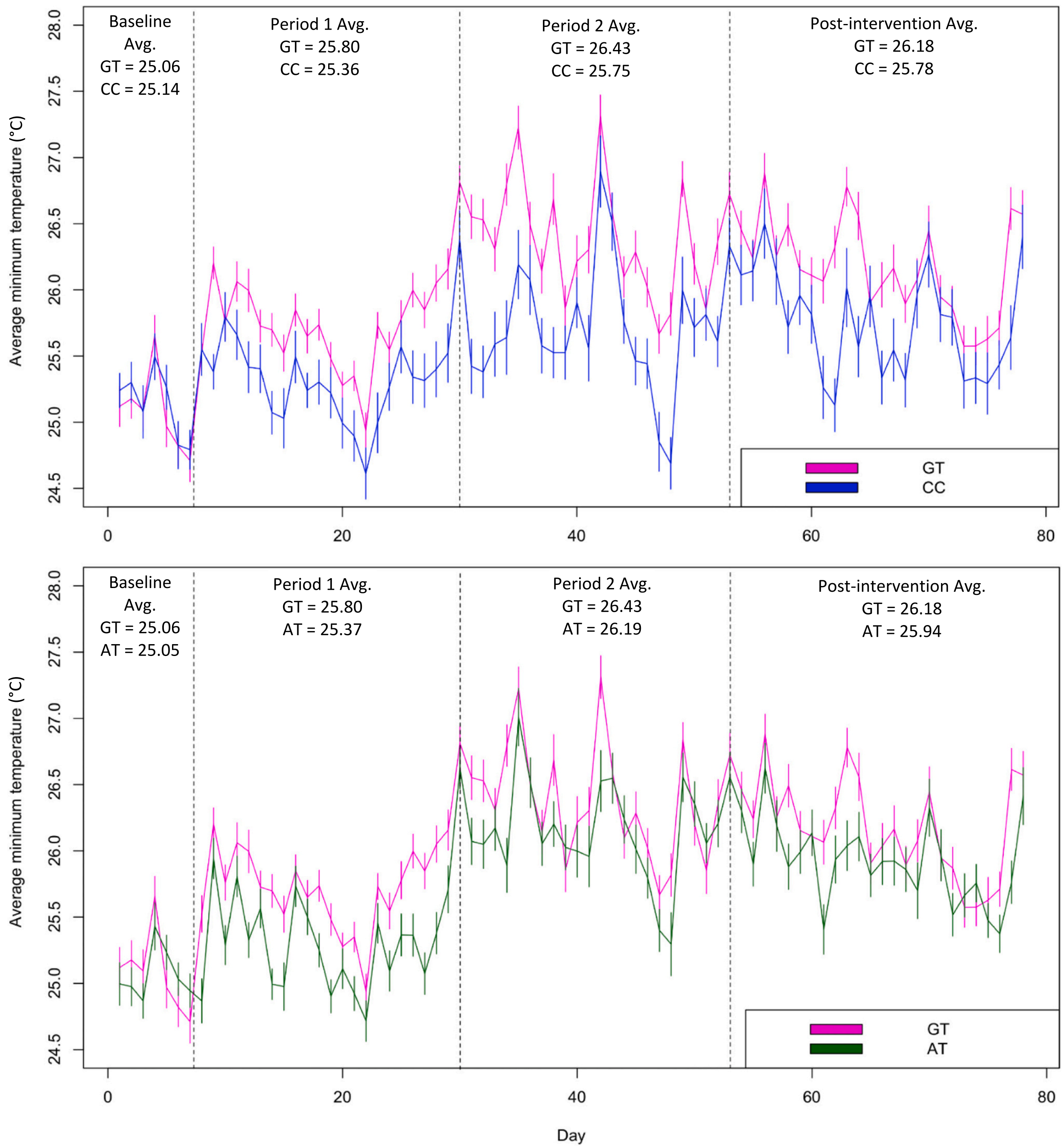


Fig. 3. a-b Average DMT when the AC is on in each condition across subjects. Standard error bars are shown.

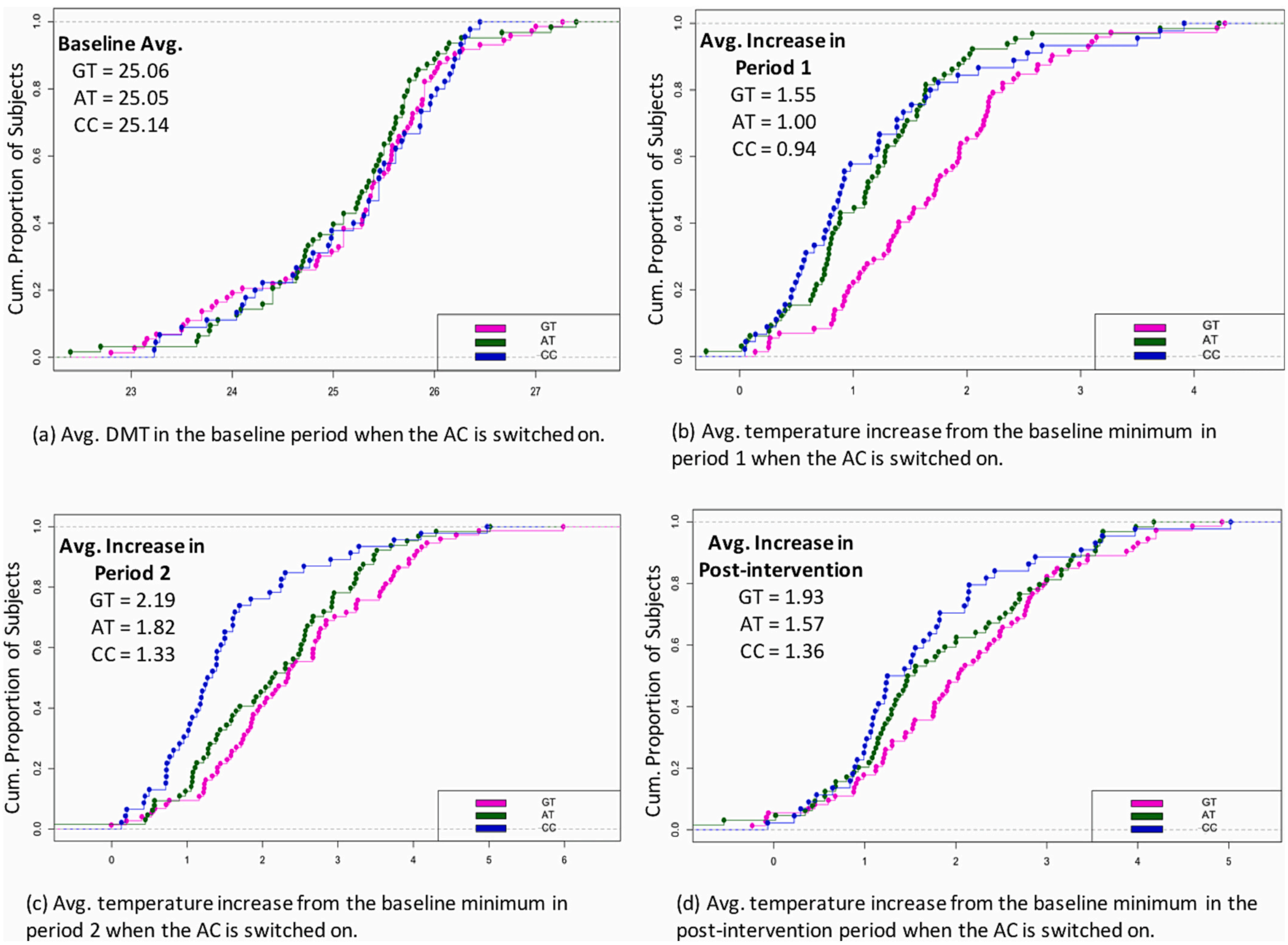
(25.78 °C). The effect size (Cohen's d) calculations for the between condition temperature differences are reported in Supplementary Table 3.

3.3. Distribution of change in temperature for each subject across conditions

Fig. 4a-d plot the cumulative distribution functions (CDFs) of subjects' average DMTs, with each dot representing one subject. In the baseline period (Fig. 4a) the CDFs overlap, indicating that the distribution of average DMT is similar across conditions.

Fig. 4b-d plot the CDFs of the *change* in subjects' DMT relative to their baseline minimums. These plots also reveal the proportion of subjects that achieved the +1 °C target (in period 1) and the +2 °C target (in period 2).

In period 1 (Fig. 4b), the CDF for GT consistently lies below the CDFs for AT and CC. This suggests that a higher proportion of subjects in GT raised the AC temperature by 1 °C compared to AT and CC. In period 2 (Fig. 4c), the CDF for GT mostly lies below that of AT, even though both conditions had the same temperature target (+2 °C) and the same incentive ($2 per day when target was met). This is consistent with our hypothesis and shows that a greater proportion of subjects in GT increased the AC temperature by 2 °C, compared to AT. The same pattern persists during the post-intervention period (Fig. 4d).



(a) Avg. DMT in the baseline period when the AC is switched on.

(b) Avg. temperature increase from the baseline minimum in period 1 when the AC is switched on.

(c) Avg. temperature increase from the baseline minimum in period 2 when the AC is switched on.

(d) Avg. temperature increase from the baseline minimum in the post-intervention period when the AC is switched on.

Fig. 4. a-d CDFs. a. DMT in the baseline period when the AC is switched on. b. Increase from baseline minimum in period 1 when the AC is switched on. c. Increase from baseline minimum in period 2 when the AC is switched on. d. Increase from baseline minimum in the post-intervention period when the AC is switched on.

3.4. Regression analysis

We now formally test the hypotheses using ordinary least squares (OLS) regressions. We exploit the panel structure of our data by regressing subjects' DMTs on 1) the treatment variables (GT is the base category and AT and CC are dummy variables); 2) temporal dynamics (daily outside temperature, AC credits purchased up to day *t*-1); and 3) the control variables which capture subject-specific, time-invariant fixed effects (dormitory, gender, baseline AC energy consumption, baseline minimum temperature).

Our rationale for including the control variables is as follows. First, while the average daily temperature in Singapore was consistently between 27.0 °C and 30.0 °C during the RCT, fluctuations in the outside temperature may affect the temperature inside the subjects' rooms, and in turn the AC temperatures they choose to set. Second, we control for AC credits purchased up to day *t*-1 as it influences how long the subject can switch the AC on, on day *t*,which could affect how cool the subject's room was. Third, while all three dorms are close in geographical proximity, differences in building layout and sun exposure may affect temperatures inside each dorm, and so we control for which dorm the subject resides in. Next, there is some research that suggests that gender may play a role in sensitivity to temperatures (Kingma and van Marken Lichtenbelt, 2015; Karjalainen, 2007; Beshir and Ramsey, 1981), so we control for participant gender. We also include baseline AC energy consumption to account for pre-intervention individual differences in the duration and preference of AC usage. Most importantly, we control for each subject's baseline minimum temperature as this likely influences the AC temperature the individual is able to be accustomed to.

In our regressions, we also include the interaction of the treatment condition and"AC off" (the default category is "AC on") to ensure that the treatment variable coefficients capture differences in subjects' DMTs across conditions only when the AC is turned on. Standard errors are clustered at the subject-level to account for potential within-subject correlation. We use GT as the reference condition to more easily compare whether AC temperatures are higher in GT compared to CC and AT.

The regression estimates are presented period-by-period in Table 1, with Supplementary Tables 4 and 5 showing the replicated results with limited and no control variables. A summary of the regression adjusted DMTs along with their 95% confidence intervals is shown in Table 2. In period 1, GT subjects had DMTs 0.483 °C and 0.453 °C higher than those of AT and CC subjects, respectively (both p's $=$ 0.000). Hence the financial incentive for attaining the 1 °C target in GT was effective in raising AC temperatures. In period 2, GT subjects had DMTs 0.732 °C higher than CC ($p = 0.000$) and, more importantly, 0.335 °C higher than AT ($p = 0.035$). Since GT and AT subjects were given identical targets and incentives in period 2, this higher temperature in GT suggests that gradual targets may make it easier for people to adapt to temperature increases. This is consistent with our hypothesis. In the post-intervention period, GT subjects maintained a DMT 0.406 °C higher than CC ($p =$ 0.006) and 0.308 °C higher than AT ($p = 0.041$). Despite DMTs in AT being higher than those in CC in period 2 ($p = 0.028$), AT subjects did

Table 1
OLS estimation showing treatment effect by period.

	Dependent variable = Daily minimum temperature (°C)		
	Period 1 (1)	Period 2 (2)	Post-intervention period (3)
CC	−0.453***	−0.732***	−0.406**
	(0.113)	(0.159)	(0.146)
AT	−0.483***	−0.335*	−0.308*
	(0.105)	(0.158)	(0.150)
Dorm 2	0.264***	0.172	0.160
	(0.073)	(0.124)	(0.107)
Dorm 3	−0.199	−0.292*	−0.335*
	(0.105)	(0.144)	(0.136)
Male	−0.173*	−0.092	−0.071
	(0.069)	(0.106)	(0.092)
Baseline Min. (°C)	0.350***	0.307***	0.228***
	(0.047)	(0.062)	(0.047)
Outside temperature (°C) on day t	0.589***	0.461***	0.573***
	(0.038)	(0.037)	(0.054)
Baseline energy consumption (kWh)	−0.248***	−0.428***	−0.226
	(0.073)	(0.118)	(0.155)
AC credits purchased until day t-1	−0.002	−0.005*	−0.007*
	(0.002)	(0.002)	(0.003)
AC off	1.153***	1.002***	1.463***
	(0.097)	(0.112)	(0.128)
CC X AC off	0.298	0.696***	0.410*
	(0.157)	(0.206)	(0.193)
AT X AC off	0.394**	0.518***	0.142
	(0.145)	(0.175)	(0.185)
Constant	25.818***	26.550***	26.273***
	(0.085)	(0.127)	(0.127)
Observations	4278	4278	4573
R^2	0.504	0.431	0.459
Adjusted R^2	0.503	0.429	0.458
Residual Std. Error	0.946 (df = 4265)	1.194 (df = 4265)	1.176 (df = 4560)
F Statistic	361.745*** (df = 12; 4265)	268.921*** (df = 12; 4265)	322.850*** (df = 12; 4560)

Standard errors (clustered at the subject level) are shown in parentheses. Reference categories are GT, dorm 1, female subject and AC on. Daily outside temperature, baseline minimum temperature, baseline AC energy consumption, and credits purchased until day *t*-1 are mean-centered. There is no difference in DMT between conditions in the baseline period. Our main results do not qualitatively change when we include weekend and day fixed effects.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.005$.

not maintain a higher temperature than CC subjects, post-intervention ($p = 0.550$). Overall, these results support our hypotheses and suggest the effectiveness of gradual targets in initiating and sustaining energy conservation behaviors.

Note that, an alternative approach is to use the Heckman selection model, which accounts for the possibility that subjects' DMTs are related to their AC switch-on decisions. The Heckman model results are qualitatively similar to the OLS findings (see 'Robustness check: Heckman selection model' in the supplementary materials).

3.5. Analysis of energy consumption data

While we show that GT led to higher AC temperatures, it is also useful to confirm if this translated into lower energy consumption. To evaluate this, we used data on the subjects' daily AC energy consumption (in kWh) from the power company. Recall that, because subjects pay only for the duration of AC use via the advanced purchase of AC credits at $0.25 per hour of use, there are no additional monetary savings in the form of lower energy bills if they raise their AC temperatures. However, because actual AC energy consumption is a function of both the duration of AC use (primary component) and the AC temperature set

Table 2
| Daily minimum AC temperature (°C) when AC is switched on (mean and 95% confidence interval) by condition.

	CC	GT	AT
Baseline Period			
Mean DMT (°C), Unadjusted	25.14	25.06	25.05
95% CI	24.83–25.45	24.8–25.32	24.84–25.28
Mean DMT (°C), Regression-adjusted	25.24	25.21	25.15
95% CI	25.07–25.41	25.08–25.34	25.00–25.29
Period 1			
Mean DMT (°C), Unadjusted	25.36	25.80*,††	25.37††
95% CI	25.05–25.67	25.57–26.03	25.15–25.59
Mean DMT (°C), Regression-adjusted	25.43	25.89***,†††	25.40†††
95% CI	25.25–25.61	25.76–26.01	25.25–25.56
Period 2			
Mean DMT (°C), Unadjusted	25.75	26.43***	26.19
95% CI	25.39–26.12	26.15–26.71	25.88–26.5
Mean DMT (°C), Regression-adjusted	25.85	26.59***,†	26.25*,†
95% CI	25.61–26.09	26.41–26.77	26.00–26.5
Post-intervention			
Mean DMT (°C), Unadjusted	25.78	26.18	25.94
95% CI	25.42–26.13	25.91–26.44	25.67–26.20
Mean DMT (°C), Regression-adjusted	25.90	26.31**,†	26.00†
95% CI	25.67–26.12	26.13–26.48	25.76–26.23

We indicate whether CC differs from each treatment condition (AT and GT) using *, **, *** to represent $p < 0.05$, $p < 0.01$, and $p < 0.005$, respectively, for each treatment condition's comparison with CC. We indicate whether the treatment conditions (AT and GT) differ from one another using †, ††, ††† to represent $p < 0.05$, $p < 0.01$, and $p < 0.005$, respectively, for each treatment condition's comparison with the other treatment (AT or GT).

(secondary component), we should observe energy savings if the increase in AC temperature is sufficiently large. In Table 3, we check for this by regressing subjects' daily AC energy consumption (in kWh) whenever the AC is turned on, on dummy variables for CC and AT (GT is the reference category). We evaluate periods 1 and 2 separately. Unfortunately, we are unable to perform a proper comparison of energy consumption across the conditions in the post-intervention period as it coincided with the end of the academic semester, and some participants wanted to finish using their expiring AC credits. A more detailed explanation of why we do not examine the post-intervention period is provided in the supplementary materials (see 'Energy consumption data during the post-intervention period').

In Table 3, we find that period 1 AC energy consumption was lower in GT compared to AT ($p = 0.008$) and CC ($p = 0.004$). Similarly, in period 2, energy consumption was also lower in GT than AT ($p = 0.001$) and CC ($p = 0.011$). In absolute terms, during period 2, GT subjects used an average of 0.027 kWh (or 15.4%) less AC energy per day compared to CC subjects, and 0.030 kWh (or 17.2%) less than AT subjects.

4. Discussion

To address climate change, policymakers are encouraging investments in green technologies and the adoption of environmentally friendly behaviors (Gillingham et al., 2006; Sorrell, 2015; European Commission, 2019; Sovacool, 2014). In countries with tropical climates, one continuing challenge is the increase in AC usage as household incomes rise, leading to greater energy consumption. Since most electricity in these countries is generated by fossil fuels (World Bank, 2019), CO_2 emissions will increase. Therefore, raising the AC temperature by as little as 2 °C can help reduce energy consumption and CO_2 emissions.

Table 3
OLS estimation showing effect of treatment on AC energy consumption by period.

	Dependent variable = Daily energy consumption (kWh) | AC turned on	
	Period 1 (1)	Period 2 (2)
CC	0.031***	0.027*
	(0.011)	(0.010)
AT	0.024**	0.030***
	(0.009)	(0.008)
Dorm 2	0.014	0.004
	(0.008)	(0.008)
Dorm 3	0.017	0.009
	(0.011)	(0.016)
Male	0.007	0.010
	(0.008)	(0.008)
Outside temperature (°C) on day t	0.018***	0.011*
	(0.004)	(0.005)
Baseline energy consumption (kWh)	0.129***	0.111***
	(0.006)	(0.008)
AC credits purchased until day t-1	0.0004	0.001***
	(0.0002)	(0.0001)
Constant	0.107***	0.120***
	(0.008)	(0.009)
Observations	2052	2298
R^2	0.412	0.366
Adjusted R^2	0.409	0.364
Residual Std. Error	0.106	0.110
	(df = 2043)	(df = 2289)
F Statistic	178.770***	165.383***
	(df = 8; 2043)	(df = 8; 2289)

Standard errors (clustered at the subject-level) are shown in parentheses. Reference categories are GT, dorm 1 and female subject. Daily outside temperature, baseline minimum temperature, baseline AC energy consumption, and credits purchased until day *t*-1 are mean-centered. There is no difference in energy consumption between conditions in the baseline period.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.005$.

We incentivized subjects to increase their AC temperatures 2 °C above status quo, via gradual versus abrupt temperature targets over two periods. In period 2, GT subjects were more successful than AT subjects in raising and maintaining higher AC temperatures, even though both conditions had identical temperature targets and financial incentives. The higher AC temperatures in GT led to lower energy consumption. In the post-intervention period, the GT subjects continued to maintain a higher AC temperature than CC subjects. On the other hand, AT subjects did not maintain a higher AC temperature than those in CC. Therefore, gradual targets are more effective for driving sustained behavioral change.

We demonstrate that increasing AC temperatures can be a promising way to achieve energy savings, especially in tropical climates. We find that AC temperature is amenable to behavioral change, and policymakers can use monetary incentives to nudge subjects to adapt to a higher AC temperature. Our findings may carry broader implications. For example, coupling financial incentives with gradual targets may also induce behavioral change when encouraging people to lose weight, exercise more, and smoke less (Charness and Gneezy, 2009; Volpp et al., 2008; Volpp et al., 2009; Acland and Levy, 2015; Loewenstein et al., 2016).

We conclude with several observations and caveats. First, to accelerate adaptation to a higher temperature, subjects should be used to turning on their ACs regularly. Our results are particularly relevant for tropical climates like that of Singapore where most people use the AC daily. Further, in 2021, 94.8% of the Singapore population lived in either a public housing block or a condominium, and this degree of apartment dwelling is consistent with other large Asian cities.[6] Consequently, the small dormitory rooms in our RCT are quite similar to the bedrooms in a typical housing unit in Singapore and many cities in Asia, where each small bedroom comes with its own AC unit and remote control (instead of having central air conditioning for the entire apartment). Thus, the findings in our study should generalize to these living environments.

Second, in our study, subjects were offered money to raise their AC temperature. This is effectively a measure of subjects' willingness to accept (WTA) compensation for higher temperatures.[7] Practically, we might expect policymakers to charge a higher price or impose a tax for setting a lower AC temperature, which would instead depend on subjects' willingness to pay (WTP) for lower temperatures. We know that WTA is generally higher than WTP (Brown and Gregory, 1999; Kahneman et al., 1991). However, we find that price elasticity computed using the energy data (Mean = −0.14, 95% CI = [−0.20,-0.09]) is consistent with the actual short run price elasticity of Singapore electricity demand data (which ranges from −0.35 to −0.09) for the past 30 years (Phoumin and Kimura, 2014).[8] Therefore, we believe our intervention might have had a similar effect if subjects were instead forced to pay for setting a lower AC temperature.

Third, we observed that the outside temperature increased across periods (see Supplementary Fig. 5), which we controlled for in our analyses. We speculate that if outside temperatures were cooler across periods, it would be easier for subjects to raise their AC temperatures and reach their targets, so that the effect sizes in our study would be larger.[9] However, it is possible that if the outside temperature increase across periods had been larger than we observed, subjects might have had a harder time increasing their AC temperature and treatment effects might have been more modest. Fourth, while all the subjects in our study lived alone, in households with multiple occupants there may be conflicting temperature preferences which make changing the AC temperature more difficult. In this case, greater financial incentives and/or smaller initial targets may need to be offered to induce behavioral change.

Fifth, in our study context, participants could have turned on ceiling fans in their room instead of the AC. Unfortunately, our data does not capture the energy consumption associated with this possibility. However, research has shown that indoor fans consume up to 30 times less electricity than AC units (Malik et al., 2022), and so we would still expect substantial energy savings even if subjects were substituting fan use for AC usage. Sixth, our subjects did not save energy costs by increasing the AC temperature since they were only charged when the AC was turned on, regardless of the temperature they set. However, in reality, there would be an additional financial incentive for people to set higher AC temperatures, as they would enjoy lower energy bills.

Seventh, in scaling our results to actual households, policymakers must weigh the short-term costs of financial incentives alongside the long-term benefits of using less energy and generating fewer CO_2 emissions due to environmentally friendly behavioral change

[6] https://www.singstat.gov.sg/find-data/search-by-theme/households/households/latest-data.
[7] We compute WTA using the change in GT subjects' (AT subjects') AC temperature and energy consumption from the baseline to period 1 (period 2), compared to the C condition. The WTA compensation for higher AC temperatures is, on average, 0.55 °C per $1, and this translated to an average energy savings of 0.015 kWh per $1.
[8] See 'Computation of price elasticity' in the supplementary materials for details.
[9] To check if the treatment effects varied based on the outside temperature, we ran a regression with an interaction between outside temperature and condition. We found that none of the interaction terms were significant.

(Borenstein and Bushnell, 2018). Eighth, the subjects in our study were students who likely have only a modest income from working part-time or through student loans or family transfers. Given this, the $1 and $2 daily monetary payments in the intervention periods seemed to be a large enough financial incentive to induce behavioral change. This might not be the case for those earning a higher income. Relatedly, we cannot rule out the possibility that our study had salience effects that made our subjects more responsive to the daily monetary payments than they might have otherwise been.

Finally, lasting behavioral change is difficult to induce in almost any setting (Wood and Neal, 2016). While our research finds that people who received gradual incentives and targets were able to maintain a higher AC temperature in the post-intervention period than those with abrupt incentives and targets, we cannot definitively say that this difference persisted beyond our study period. Future research should therefore continue to evaluate the long-term effects of inducing environmentally friendly behaviors using financial incentives, especially among diverse demographic groups who have been found to have varying marginal utilities of comfort (Reiss and White, 2005).

Author contributions

All authors contributed equally to the different stages of the project.

Declaration of Competing Interest

The authors declare no competing interests.

Data availability

The data supporting the findings of this study are available from the corresponding author upon request.

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Appendix A. Supplementary data

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