Testing Spillovers in Resource Conservation: Evidence from a Natural Field Experiment*

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Abstract

This paper studies the potential for behavioral interventions aimed at promoting resource conservation within one domain to induce spillovers in another. Through a large-scale natural field experiment involving around 2,000 residents, we assess the direct and spillover effects of real-time feedback and social comparisons on water and energy consumption. Three interventions were implemented: two targeting shower use and one targeting air-conditioning use. We document a significant reduction in shower use attributable to both water-saving interventions, but no direct effects on air-conditioning use from the energy-saving intervention. For spillovers, we precisely estimated null effects on air-conditioning use arising from the water-saving interventions, and vice versa.

Keywords: Spillovers, field experiment, resource conservation

JEL Codes: C93, D12, Q50

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1 Introduction

A wide range of behavioral interventions, such as feedback provision, social comparisons, and moral suasion, have been deployed in urban settings to influence consumer behaviors and promote resource conservation (Allcott, 2011; Allcott and Rogers, 2014; Ayres et al., 2013; Ferraro et al., 2011; Ferraro and Price, 2013; Di Cosmo and O'Hora, 2017; Ito et al., 2018). Significant efforts have been made to identify the direct conservation effects of these interventions within their targeted domains, such as evaluating the impact of home energy reports on energy use or real-time feedback on shower water use. Yet, a crucial question remains largely unexplored: Can interventions targeted at one resource domain lead to spillover effects on non-targeted behaviors in another domain? Understanding these spillover effects is vital not only for designing comprehensive conservation strategies but also for assessing the welfare implications and cost-effectiveness of behavioral interventions.

Various mechanisms have been proposed to explain the existence of behavioral spillovers, each offering competing predictions (see e.g., Dolan and Galizzi, 2015). On one hand, positive spillovers could emerge from priming effects, self-identity considerations or a preference for consistency, wherein individuals are inclined to exhibit pro-environmental behaviors in the non-targeted domain after doing so in the targeted domain (Whitmarsh and O'Neill, 2010; Van der Werff et al., 2014). On the other hand, negative spillovers might result from a sense of moral entitlement after individuals have performed well in the targeted domain, leading them to perform worse in the non-targeted domain (Merritt et al., 2010; Miller and Effron, 2010). In addition, negative spillovers might stem from limited attention, whereby attention is diverted from the non-targeted domain when individuals are nudged to focus on the targeted behavior (Trachtmann, 2023; Altmann et al., 2022; Koch et al., 2024).

The recent economics literature has begun to investigate the direction and magnitude of behavioral spillovers in the context of resource conservation. Nonetheless, the findings have been mixed and inconclusive. Tiefenbeck et al. (2013) documented an increase in energy consumption in response to weekly feedback on water consumption, consistent with moral licensing. In contrast, Jessoe et al. (2021) reported positive spillovers in energy use during summertime, and Carlsson et al. (2021) found reductions in energy consumption only among water-efficient households from their respective interventions aimed at reducing water use. Additionally, Goetz et al. (2024) observed no impact on electricity consumption from their hot water saving intervention, though they reported positive spillovers on room heating. It is worth noting that these previous studies used designs that provide periodic feedback and social comparisons about the target behavior, which may have limited the potential for spillover effects due to their more modest direct conservation effects.

This paper investigates behavioral spillovers in resource conservation by examining two key domains of consumption behavior: shower use and air conditioning use, both of which constitute a significant portion of water and energy consumption, respectively. Central to our investigation is the deployment of a new class of digital technologies for sustainability, specifically through the provision of real-time feedback enabled by the Internet of Things. In our study, smart shower heads were employed to provide users with instantaneous feedback on their water usage. This approach has demonstrated greater efficacy in promoting resource conservation compared to traditional interventions based on social comparisons and moral suasion (Tiefenbeck et al., 2018; Fang et al., 2023; Goette et al., 2021a), raising the potential for larger spillover effects. Furthermore, these real-time digital interventions tap into a new behavioral mechanism—limited attention—thereby creating the scope for attentional spillovers in addition to moral licensing (Medina, 2021; Altmann et al., 2022; Trachtmann, 2023; Koch et al., 2024).

We conducted a large-scale field experiment with around 2,000 residents across four university residences, implementing three interventions: two targeting shower use and one targeting air conditioning use. Specifically, we targeted shower use through real-time feedback and social comparison interventions, and examined the spillover effects on air conditioning use. Additionally, we targeted air conditioning use with social comparisons and assessed the spillover effects on shower use. This design allows us to investigate cross-domain spillover effects from water use behavior to energy use and conversely, energy use behavior to water use, contrasting with existing literature that considers only the former. Importantly, our large sample size enables us to perform a precise and definitive test for spillover effects from these two forms of feedback, and to explore the underlying mechanisms, i.e., moral licensing and attentional spillovers. In addition, this study qualifies as a natural field experiment since the residents were unaware of their involvement, as our interventions were embedded within a broader university-led resource conservation initiative (Harrison and List, 2004). Together, our findings offer valuable insights into the complexities of fostering resource conservation efforts, highlighting both the potential and limits of digital technologies for urban sustainability.

2 Design and Hypotheses

The field experiment, involving approximately 2,000 residents across four residential colleges at NUS University Town, Singapore, was conducted from August 9, 2021 to December 4, 2021. Two classes of behavioral interventions—real-time feedback and social comparisons—were employed to assess the direct and spillover effects on residents' resource use behaviors. We pre-registered our design and analysis plan on AsPredicted (#76362).

2.1 Experimental Design

Our experimental design, presented in Figure 1, encompasses six experimental conditions which feature a mix of interventions: real-time feedback for shower usage (RTF), social comparison for shower usage (SC-S), and social comparison for air conditioning usage (SC-A). Each intervention is described as follows:

RTF intervention: Residents receive real-time feedback on their water usage during showers. Within each shower facility, a smart shower head equipped with built-in LEDs is programmed to provide immediate feedback on water consumption through color changes.

At the start of a shower, the smart shower head displays a green light, which changes color sequentially to yellow, orange, and then red as water usage increases. If water consumption exceeds 24 litres, the shower head signals this with a blinking red light. The color change thresholds are clearly explained to the residents via an informative poster displayed prominently in the assigned shower facility.

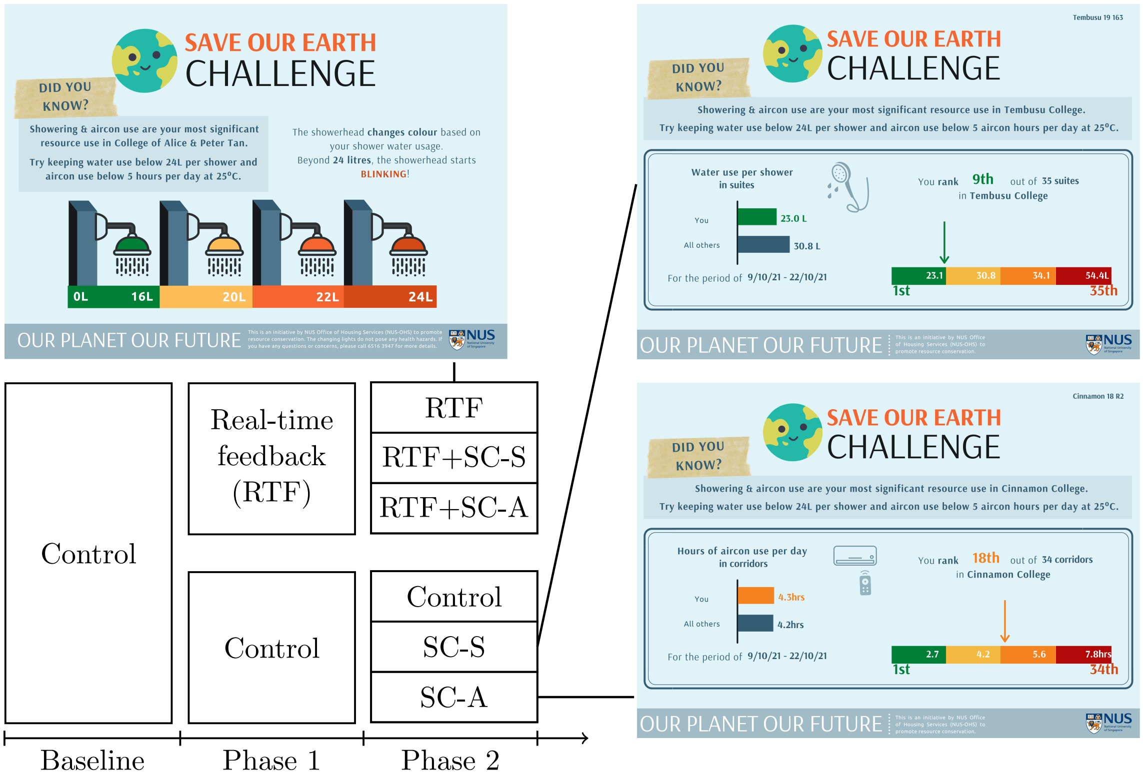
SC-S intervention: Residents receive comparative feedback on their average shower water usage. Specifically, residents are informed of their average water consumption over the preceding two weeks, juxtaposed against the average consumption of their peers within the same residential college and room type (reference group). In addition, individuals are ranked based on their water usage, from 1 (indicating the lowest use) to a maximum of 37 (indicating the highest use). These ranks are divided into four quartiles, each denoted by a color: green (lowest quartile), followed by yellow, orange, and red (highest quartile). This information is clearly conveyed through a detailed poster displayed prominently in the assigned shower facility.

SC-A intervention: Mirroring the SC-S intervention, residents receive comparative feedback on their average daily air conditioning usage. The structure is identical except that the information is focused on air conditioning usage and the rankings range from 1 (for the lowest usage) to 41 (for the highest) instead.

These interventions were rolled out in phases. Initially, the baseline phase involved no interventions, which allows us to confirm balance of treatment across our experimental conditions (see Table A1 in the Appendix). In phase 1, half of the residents served as the control with no interventions, while the other half received the RTF intervention. In phase 2, the social comparison interventions were introduced across both groups. Specifically, within the control (RTF) group from phase 1, one-third were subjected to the SC-S intervention, another third to the SC-A intervention, and the remaining third continued without any intervention (with only RTF intervention).

In particular, each residential college offers two accommodation options: single corridor

Figure 1: Overview of the experimental design



Notes: The figure outlines our experimental design, where 'SC-S' represents social comparison for shower usage, and 'SC-A' represents social comparison for air conditioning usage. The RTF intervention features a poster (top left) that explains the color changes of the shower head as water usage increases. The SC-S intervention features a poster (top right) that compares average shower water usage with that of peers in the same reference group. Similarly, the SC-A intervention features a poster (bottom right) that compares average air conditioning usage with that of peers in the same reference group. For examples of each poster type across all six experimental conditions, refer to Figure A2.

rooms and apartment suites. On each floor, residents in single corridor rooms use a common bathroom, while those in apartment suites use a private bathroom shared with other suite occupants (see Figure A1 for details). Given this layout, our unit of randomization is thus at the bathroom level, with each bathroom equipped with 2 to 3 shower facilities that receive the same set of interventions.

2.2 Hypotheses

We discuss two primary mechanisms underlying spillover effects—attentional spillovers and moral licensing—that we can test with our tailored interventions. Within this context, we present a series of hypotheses pertaining to our interventions.

2.2.1 Attentional Spillovers

The first mechanism, attentional spillovers, relates to the literature on inattention in decision-making (Gabaix, 2014, 2019). This mechanism posits that interventions targeting behavior in one domain might inadvertently affect the individual's attention to behaviors in other domains, thereby leading to unintended side effects. Nafziger (2020) formalizes a framework for understanding spillover effects stemming from interventions that increase the individual's attention to a specific factor, or in our case, the targeted domain. The nature and direction of spillover effects on the non-targeted domain hinges on whether the two domains are attentional substitutes, complements, or independent.

To test this mechanism, our experimental design incorporates real-time feedback for shower usage (RTF) as an attentional intervention. Recall in the RTF intervention, the smart shower head uses a color-changing light (green, yellow, orange, and red) to signal water usage, with a blinking red light indicating excess usage. This feedback mechanism is designed to draw the subject's attention to their showering behavior by salience.

In the case of attentional substitutes, our intervention might lead to negative spillover effects in the non-targeted domain. Specifically, RTF could direct attention towards showering, inadvertently diverting attention away from other domains, like air conditioning usage. This mechanism is supported by findings from Trachtmann (2023), who observed that attentional intervention, in the form of messages, promoting one healthy behavior (meal-logging) reduced completion rates in another behavior (meditation), and vice versa. Additionally, Medina (2021) found that reminders for upcoming credit card payments led to increased overdraft fees in checking accounts, and Altmann et al. (2022) documented negative cognitive spillovers impacting decision quality in areas not targeted by their attentional intervention. This leads us to the following hypothesis:

Hypothesis 1A: ***Water and energy usage as attentional substitutes.*** *The RTF intervention reduces shower water usage (target behavior), but leads to an increase in air conditioning usage (non-target behavior) due to negative spillovers.*

On the other hand, in the case of attentional complements, our intervention may not only steer attention towards showering but also increase attention on air conditioning usage, since both domains are closely related and pertain to resource conservation behaviors. This would align with the findings of Simonov et al. (2023), who documented positive attentional spillovers from engaging news articles to adjacent advertisements on the same page in an online setting.[1] This leads us to propose a competing hypothesis for our treatment:

Hypothesis 1B: ***Water and energy usage as attentional complements.*** *The RTF intervention reduces shower water usage (target behavior), but also leads to a decrease in air conditioning usage due to positive spillovers.*

2.2.2 Moral licensing

The theory of moral licensing posits that past instances of morally commendable actions can confer a sense of 'moral credits,' leading individuals to feel justified in subsequently engaging in morally questionable actions (Merritt et al., 2010; Miller and Effron, 2010). This phenomenon has garnered empirical support across various domains, including racism (Effron et al., 2009), consumer choice (Khan and Dhar, 2006), health behaviors (Chiou et al., 2011), and charitable donations (Meijers et al., 2015), with an extensive review by Blanken et al. (2015). Apart from operating within the same domain, moral licensing can also

[1]Beyond purely attentional factors, positive spillovers may also arise from an information effect, wherein individuals process the information provided to them and become more aware of their resource use patterns, leading to spillovers in other domains. Barløse et al. (2024) provide evidence supporting this mechanism in the context of promoting healthier food choices.

occur across unrelated domains. For example, within the context of resource consumption, engaging in pro-environmental actions in one area might lead to increased wastefulness in another, exemplifying moral licensing. A study closely related to our paper is by Tiefenbeck et al. (2013), who found suggestive evidence of moral licensing across domains. The authors found that residents who received weekly feedback on their water consumption reduced their water usage, but concurrently exhibited an increase in their energy consumption.

In our experimental design, we test moral licensing through our social comparison treatments: SC-S for shower usage and SC-A for air conditioning usage. Residents assigned to these treatments receive information about their average shower or air conditioning consumption, with their performance ranked against their peers. They are further categorized into one of four quartiles, with green indicating the lowest resource consumption, and red the highest, based on their consumption patterns over the preceding two weeks.

Consider a scenario with the SC-S treatment where an individual learns she has lower shower water consumption compared to her peers based on her ranking. This knowledge could lead to moral licensing in two ways. Firstly, the individual might perceive their positive action as a 'license' to increase shower water usage in subsequent weeks, exhibiting within-domain moral licensing. Secondly, the individual might extend this 'license' to less responsible behavior in other domains, such as increased air conditioning usage, indicative of cross-domain moral licensing. We thus examine the effects of our social comparison treatments (SC-S and SC-A) on residents' subsequent resource usage, in relation to their performance rankings. We hypothesize that in the presence of moral licensing, our SC-S and SC-A treatments have differential average treatment effects (ATE) on subjects based on their relative performance. Specifically, we arrive at the following hypotheses:

Hypothesis 2: ***Moral licensing within the target domain.*** *In the SC-S (SC-A) intervention, subjects who are ranked higher, indicating lower resource usage, exhibit a smaller ATE on subsequent shower (air conditioning) usage within the targeted domain.*

Hypothesis 3: ***Moral licensing across domains.*** *In the SC-S (SC-A) intervention, subjects who are ranked higher, indicating lower resource usage, exhibit a negative ATE on air conditioning (shower) usage within the non-targeted domain.*

2.3 Outcomes of Interest

To study resource use behaviors, our analysis centers on two primary outcome variables: shower water usage and air conditioning energy usage. We focus on these measures as they constitute the most substantial portions of overall water and energy consumption among residents. Data on shower water usage were collected using the HYDRAO smart shower heads, while data on air conditioning energy usage were obtained from Power Automation, which manages the air conditioning metering systems in the residential colleges.

In line with existing literature, we differentiate between two dimensions for each resource type. For shower usage, the intensive margin is defined by the average volume of water used per shower, whereas the extensive margin refers to the daily frequency of showers per shower head. For air conditioning usage, we consider the total daily usage, while the extensive margin assesses whether the air conditioner was used on a given day.

Extensive evidence demonstrates that showering behavior is highly responsive to behavioral interventions, particularly the use of real-time feedback in promoting water conservation (Tiefenbeck et al., 2018; Agarwal et al., 2022b; Goette et al., 2021a; Fang et al., 2023). In contrast, the evidence on responses to interventions targeting air conditioning behavior are more mixed. Goette et al. (2021b) observed that social comparison intervention might have an effect on specific subgroups, whereas Tiefenbeck et al. (2013) documented that weekly water feedback intervention might have influenced energy consumption patterns, likely driven by increased air conditioning usage. In this regard, our study aims to synthesize these disparate strands of evidence by examining the impact of similar interventions on both shower water and air conditioning energy usage within the same experimental setting.

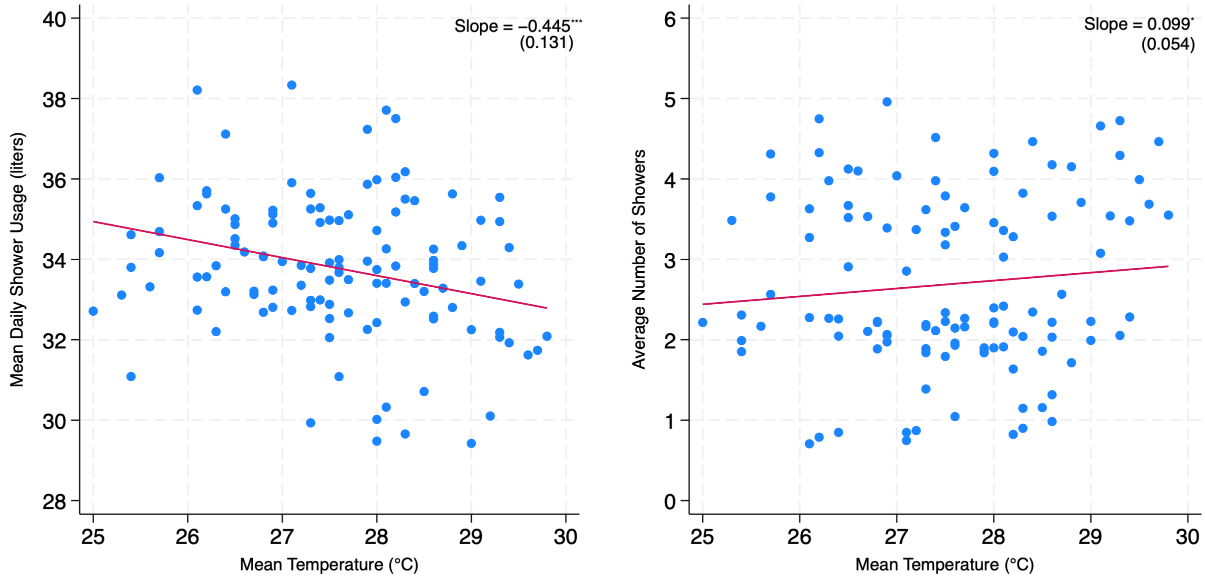
2.4 Responsiveness of Resource Usage to External Influences

An important starting point is to assess whether showering and air conditioning usage are responsive to external influences. In our context, both behaviors exhibit strong sensitivity to local weather temperatures, suggesting that residents are capable of adjusting their resource consumption in meaningful ways. Establishing this baseline responsiveness is critical as it allows us to interpret the direct and spillover effects of our behavioral interventions in a setting where individuals have the capacity to adjust their behavior. This mirrors the logic of Myers and Souza (2020), who show that students responded to a simple email reminder to lower thermostats before leaving for the winter break, demonstrating that participants were both attentive and able to act, even though their main social comparison-based intervention yielded null effects.

Figure 2 shows that daily shower usage decreases with the average daily temperature (Panel A), albeit with a marginally significant increase in the average daily number of showers (Panel B). Specifically, a 1°C increase in temperature results in a reduction of 0.4 litres in shower water usage on average. Conversely, Figure 3 shows that daily air conditioning usage among residents increases with the average daily temperature, and this pattern is significant for overall air conditioning use and the extensive margin. In particular, a 1°C increase in temperature translates into an additional 0.2 hours of air conditioning usage and a 2.6% increase in the share of residents using air conditioning on that day.[2] The key takeaway is that behaviors related to both shower water and air conditioning usage are highly responsive to external factors, in particular, temperature fluctuations. This observation provides the impetus for investigating whether popular behavioral interventions like real-time feedback and social comparison can effectively influence these behaviors, both within

[2] Consistent with our findings, Salvo (2018) documents that in Singapore, higher-income households tend to increase their electricity demand, primarily through adopting and using air conditioning more extensively, in response to higher temperatures. Relatedly, Zhang et al. (2022) provide causal evidence that extreme weather conditions (i.e., days where mean temperature exceeds 32°C) result in a marked increase in electricity consumption in China. This increase is attributed to the households increasing their air conditioning usage for heat relief.

Figure 2: Shower water usage and mean temperature



(a) Intensive margin

(b) Extensive margin

Notes. The figure shows the relationship between daily showering use and mean temperature in Singapore, with the left panel showing the intensive margin and the right panel showing the extensive margin. Each observation is a day of the sample period between 10 August 2021 to 4 December 2021.

and across domains.

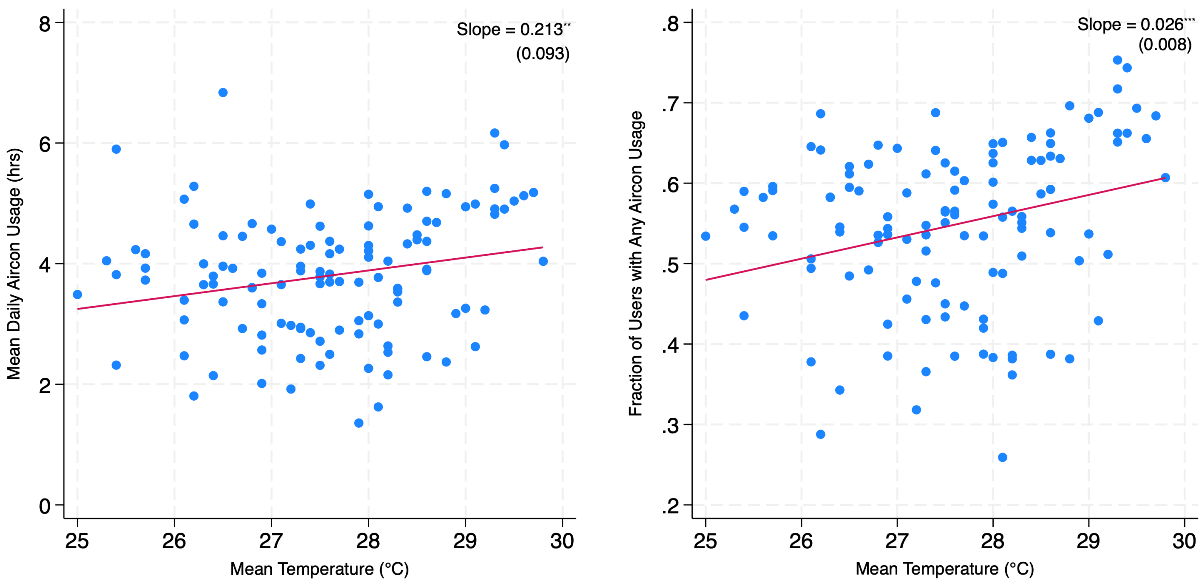
3 Results

3.1 Estimation Strategy

We estimate the average treatment effects (ATE) of being assigned to real-time feedback (RTF) and/or social comparisons (SC-S for shower usage or SC-A for aircon usage) using a difference-in-differences regression model of the form:

$$\begin{aligned} y_{it} = \alpha_i + \lambda_t + \beta_1 \mathrm{RTF}_{it} + \beta_2 \text{SC-S}_{it} + \beta_3 \text{SC-A}_{it} \\ + \beta_4 \left(\text{SC-S}_{it} \times \mathrm{RTF}_{it} \right) + \beta_5 \left(\text{SC-A}_{it} \times \mathrm{RTF}_{it} \right) + \epsilon_{ith} \end{aligned} \tag{1}$$

Figure 3: Air conditioning usage and mean temperature



(a) Overall air conditioning use

(b) Extensive margin

Notes. The figure shows the relationship between daily air conditioning use and mean temperature in Singapore, with the left panel showing the intensive margin and the right panel showing the extensive margin. Each observation is a day of the sample period between 10 August 2021 to 4 December 2021.

where y_{it} denotes the outcome variable, either water use per shower for device i on day t, or total aircon use for room i on day t. α_i is the device or room fixed effect and λ_t is the day fixed effect. RTF_{it}, SC-S_{it}, and SC-A_{it} are indicators of device or room i receiving the respective treatment on day t. ϵ_{it} is the random error term clustered at the bathroom level, which is the unit of randomization.

3.2 Impact on Targeted Behavior

Table 1 reports the effects of our interventions on conservation behavior in the targeted domain. To begin, we examine how the RTF and SC-S treatments impact shower water usage, and how the SC-A treatment affects air conditioning usage. When implemented in isolation, the RTF and SC-S treatments led to significant reductions in shower water usage by 15% and 3%, respectively, from baseline levels. These effects are consistent with estimates from prior studies (Tiefenbeck et al., 2018; Agarwal et al., 2022b; Goette et al., 2021a; Fang et al., 2023; Andor et al., 2023). Interestingly, combining RTF and SC-S did not enhance conservation effects in the shower beyond those achieved by RTF alone, which contrasts with the findings of Andor et al. (2023). However, the SC-A treatment did not significantly influence daily air conditioning usage, which aligns with findings from Goette et al. (2021b). The null effect on air conditioning usage is precisely estimated, and we can rule out a minimum effect size as low as 12 minutes of air conditioning usage with our large sample. Importantly, the differing outcomes between the SC-S and SC-A treatments suggest that the lack of response for air conditioning usage was not due to inattentiveness to the social information, as the subjects clearly responded to the SC-S treatment by reducing their shower usage.

Table 1: ATE of real-time feedback and social comparison

Dependent variable:	Water use per shower (litres)		Aircon use per day (hours)	
	(1)	(2)	(3)	(4)
Real-Time Feedback (RTF)	–5.490***	–5.959***	0.012	0.073
	(0.478)	(0.501)	(0.111)	(0.111)
Social Comparison for Shower (SC-S)	–1.211**	–2.014***	–0.021	0.096
	(0.597)	(0.696)	(0.111)	(0.139)
Social Comparison for Aircon (SC-A)	–0.340	–1.159	–0.090	–0.010
	(0.679)	(0.929)	(0.143)	(0.170)
SC-S × RTF		1.708**		–0.233
		(0.743)		(0.175)
SC-A × RTF		1.592		–0.159
		(0.994)		(0.243)
Constant	35.686***	35.855***	3.805***	3.788***
	(0.187)	(0.200)	(0.038)	(0.036)
Device/Bathroom FEs	✓	✓	✓	✓
Date FEs	✓	✓	✓	✓
R^2	0.227	0.227	0.471	0.471
Observations	153,882	153,882	147,376	147,376

Notes. OLS estimates with device/room and day fixed effects. Standard errors are clustered at the bathroom level.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

3.3 Impact on Non-Targeted Behavior

We explore the potential spillover effects of our interventions by assessing their impact on conservation behavior in the non-targeted domain. Specifically, we examine the effect of the RTF and SC-S treatments on air conditioning usage, and vice versa, the effect of the SC-A treatment on shower water usage. Returning to Table 1, our findings reveal that while our attentional RTF intervention leads to a significant reduction in shower water usage (i.e., a strong first-stage), it does not lead to any spillover effects on air conditioning usage. Notably, we are able to reject an effect size as low as 12 minutes of air conditioning usage with our large sample. Therefore, we conclude that water and energy consumption do not serve as attentional substitutes nor complements within our experimental setting. We summarize our results as follows:

Result 1: ***No evidence of attentional spillovers.*** *The RTF intervention reduces shower water usage (target behavior), but does not impact air conditioning usage (non-target behavior), on average.*

A similar pattern is observed with the SC-S treatment; it has no significant effect on air conditioning usage, despite a modest but significant effect on shower water usage. Thus, our findings align with those of Goetz et al. (2024), who also report no spillover effects on energy consumption from their hot water intervention. Additionally, for the SC-A treatment, the lack of a direct effect on air conditioning usage appears to preclude any indirect spillover effects on shower water usage.

Next, we examine the presence of moral licensing within and across domains by conducting a heterogeneity analysis based on performance rankings in shower and air conditioning usage. Recall that in both our SC-S and SC-A treatments, residents receive a ranking based on their usage of water and air conditioning, respectively, and are informed of which quartile they fall under through our color-coded system. Table 2 displays the ATEs of our interventions, where the regression specification is augmented with interaction terms by performance rankings. To ease interpretation, we normalize the performance rankings for both shower and air conditioning usage to percentiles on a scale ranging from -50 to 50. We inlcude these as interaction terms SC-S $\times$ Percentile$_{Shower}$ and SC-A $\times$ Percentile$_{Aircon}$, respectively, in our regression equations. Thus, the interpretation of the main effects of treatments are the impact of the respective interventions on bathrooms at the 50th percentile of the displayed ranking.[3]

In column (1), we observe a robust and significant interaction effect for the SC-S treatment by performance rankings, with a point estimate of 0.064 ($p = 0.007$). This result indicates that at baseline usage levels, the median resident exhibits an average reduction in shower water usage of -1.323 litres ($p = 0.034$). Notably, a positive estimate on the interaction term is consistent with the presence of moral licensing within the showering domain. Specifically, residents at the first quartile (25th percentile) exhibits a more pronounced conservation effect, reducing water usage by -2.919 litres, compared to their counterparts at the top quartile (75th percentile), who showed a slight increase of 0.273 litres, if anything. This difference in treatment effects is highly significant ($p = 0.007$), consistent with the interpretation that residents who learned they had performed better than their neighbors through the SC-S treatment may have felt as though they had earned a moral license, and thus did not respond to the SC-S treatment in phase 2.[4] Conversely, column (2) reveals no significant interaction effect for the SC-A treatment by performance rankings, suggesting that moral licensing does not operate within the air conditioning domain.

Finally, to test for moral licensing across domains, we examine the point estimates of SC-A $\times$ Percentile$_{Aircon}$ in column (1) and analogously, SC-S $\times$ Percentile$_{Shower}$ in column (2). Again, a positive estimate would indicate moral licensing across domains, whereby residents

[3] We also include an interaction effect between a bathroom's percentile ranking and phase 2 to account for possible dynamics correlated with percentiles (e.g., regression to the mean). The percentile rankings of the control group identify these coefficients.

[4] Aligning with our results, Agarwal et al. (2022a) find heterogeneous effects of (nationwide) peer comparison on residential water consumption using a quasi-experimental design: households with below-median baseline consumption increased their water usage post-treatment, while those above the median decreased theirs.

who have performed well relative to their peers in one domain (say showering), might exhibit weaker conservation effect in the other domain (air conditioning usage). Notwithstanding, both point estimates are not significant and do not support the hypothesized channel.

Taken together, we summarize our results as follows:

Result 2a: ***Evidence of moral licensing is found within the showering domain but not the air conditioning domain.*** *Within the showering domain, there is significant heterogeneity in treatment effects of the SC-S treatment by performance rankings that is directionally consistent with moral licensing. Such heterogeneity is not observed within the air conditioning domain, suggesting the absence of moral licensing.*

Result 2b: ***No evidence of moral licensing across domains.*** *There is no significant heterogeneity in treatment effects by performance rankings across domains.*

4 Discussion

A considerable challenge in identifying behavioral spillovers in resource consumption stems from the confounding influence of many appliances (e.g., dishwasher, washing machine, etc.) that simultaneously utilize both water and energy, referred to as "mechanical complementarities." Jessoe et al. (2021) make the first attempt to isolate the spillover effects of their social norms intervention by bounding the extent of mechanical complementarities with simulated electricity usage data, finding small reductions in summertime energy use. Notwithstanding, their methodology relies on strong assumptions regarding appliance use and ownership patterns, and thus the estimated spillover effects can only be viewed as an approximation at best. By contrast, our study circumvents this issue by directly measuring water usage in the showers and energy usage from air conditioning, rather than relying on aggregate data for water and energy usage. Therefore, we can definitively rule out mechanical complemen-

Table 2: ATE by percentile rankings

Dependent variable:	Water use per shower (litres)	Aircon use per day (hrs)
	(1)	(2)
Real-Time Feedback (RTF)	–5.261***	–0.068
	(0.549)	(0.106)
Social Comparison for Shower (SC-S)	–1.323**	–0.046
	(0.597)	(0.106)
Social Comparison for Aircon (SC-A)	–0.222	–0.115
	(0.693)	(0.128)
RTF × $\text{Percentile}_{Shower}$	–0.029	0.006*
	(0.021)	(0.003)
SC-S × $\text{Percentile}_{Shower}$	0.064***	–0.009*
	(0.023)	(0.004)
SC-A × $\text{Percentile}_{Aircon}$	0.018	0.004
	(0.019)	(0.005)
Phase 2 × $\text{Percentile}_{Shower}$	–0.036**	0.006**
	(0.017)	(0.003)
Phase 2 × $\text{Percentile}_{Aircon}$	–0.011	0.001
	(0.009)	(0.003)
Constant	35.522***	3.834***
	(0.204)	(0.036)
Device/Bathroom FEs	✓	✓
Date FEs	✓	✓
R^2	0.220	0.472
Observations	140,168	144,888

Notes. OLS estimates with device/room and day fixed effects. Standard errors are clustered at the bathroom level.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

tarities in our setting, providing a clean test of spillover effects that arise solely from shifts in behavior.

We designed our field experiment to test two main mechanisms that underlie spillover effects—attentional spillovers and moral licensing—with our real-time feedback and social comparison interventions. For the former mechanism, the potential for attentional spillovers in resource conservation is particularly relevant in today's context, where consumers frequently receive real-time feedback on a wide array of behaviors via the Internet of Things, suggesting the possibility of spillovers to non-targeted domains due to limited attention (Trachtmann, 2023; Altmann et al., 2022; Koch et al., 2024). With our RTF treatment, we documented significant conservation effects, achieving a 15% reduction from baseline levels within the showering domain. However, we found no evidence of attentional spillovers on the non-targeted domain, with tightly estimated null effects on air conditioning use. Notably, our findings highlight a key difference between real-time feedback and reminders as nudges to influence human behaviors. While reminders have been shown to produce negative spillover effects on other actions (Koch et al., 2024; Medina, 2021), our use of real-time feedback to target shower water use resulted in no such spillovers on air conditioning use. This suggests that real-time feedback may be a more effective intervention on the targeted behavior without unintended negative consequences in the non-targeted domain, which is a novel finding in the literature.

Turning to the latter mechanism, our social comparison treatments (SC-S and SC-A) enable us to investigate moral licensing both within and across domains. Our analysis reveals significant heterogeneity by performance rankings within the showering domain, which is consistent with moral licensing within the same domain. Residents who were informed through the SC-S treatment that they had performed relatively well exhibited weaker conservation effects subsequently, suggestive of a sense of having earned a moral license due to their initial better relative performance. However, we do not find the same treatment heterogeneity within the air conditioning domain. Additionally, we do not find evidence of moral licensing across domains in our setting.

Finally, identifying spillovers in resource conservation is imperative to performing a comprehensive welfare analysis of these widely-used behavioral interventions (Allcott and Kessler, 2019; Jessoe et al., 2021). Without accounting for these spillover effects (if any), assessments of the cost-effectiveness of these interventions may be significantly skewed. Thus, our study contributes to a more complete and nuanced understanding of how interventions in one resource domain may influence behaviors in another non-targeted domain, offering crucial insights for policymakers to design more effective and holistic resource conservation strategies in urban environments. Overall, showering behavior is directly affected by both our RTF and SC-S treatments, yet no spillover effects on shower water use were observed from the SC-A treatment. In contrast, air conditioning use appears to be harder to influence, despite being highly responsive to local weather temperatures. We do not find any significant direct or spillover effects on air conditioning use, even though residents were primed to reduce their consumption throughout the intervention. Future studies could explore other interventions that might more effectively influence air conditioning use, and investigate the presence of spillover effects in other resource domains beyond showering and air conditioning use.

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Appendix

A Supplemental analyses and material

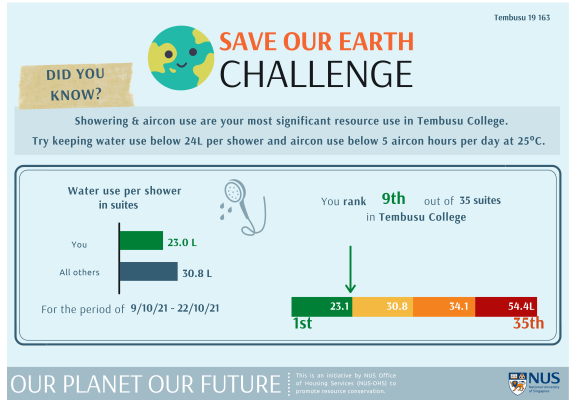
A.1 Background information on the field experiment

Figure A1: Layout of the residential college

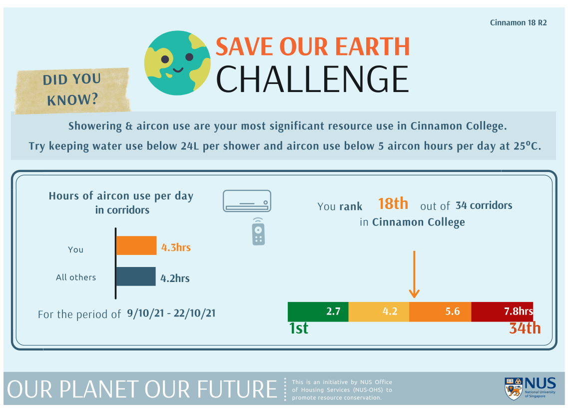
Notes. The figure displays a representative floor plan of the residential colleges, illustrating that each floor contains two types of bathrooms: the common bathroom, marked in orange, and the apartment (suite) bathroom, marked in blue. The unit of randomization is at the bathroom level. See `https://uci.nus.edu.sg/ohs/future-residents/undergraduates/utown/room-types/` for further details.

Figure A2: Sample poster by experimental condition

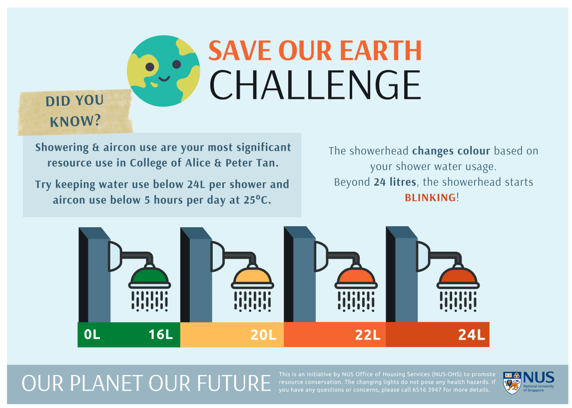
(a) Control



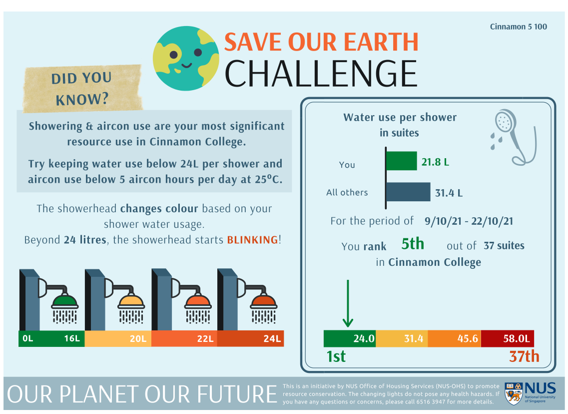
(b) SC-S



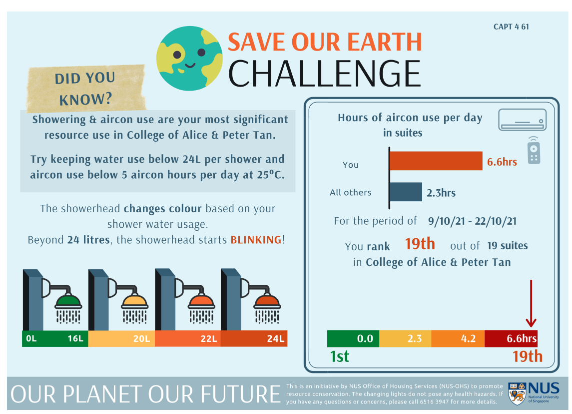
(c) SC-A



(d) RTF



(e) RTF + SC-S



(f) RTF + SC-A

Notes. A specific type of poster was displayed in each shower facility based on the assigned experimental condition. Since the interventions were rolled out in two phases, the posters from phase 1 (either Control or RTF) were replaced with new, corresponding posters (featuring social comparison of either shower or air conditioning usage) upon transitioning to phase 2 of the experiment.

Figure A3: The RTF intervention

(a) Below 14L (b) 14L to 20L (c) 20L to 22L (d) 22L to 24L

Notes. At the start of each shower event, the smart shower head displays a green light, and remains so for water use up to 14 liters. With increasing water use, the shower head changes color sequentially to yellow, orange, and then red at the pre-determined levels. Beyond 24 liters, the shower head signals this with a blinking red light.

A.2 Randomization checks

Table A1 presents the mean baseline characteristics for bathrooms and bedrooms across our six experimental conditions. The two main observables, i.e., baseline shower water usage and air conditioning usage, are comparable across all conditions, with no statistically significant differences.

Table A1: Sample and balance

	Experimental Condition						
	Control (1)	SC-S (2)	SC-A (3)	RTF (4)	RTF+SC-S (5)	RTF+SC-A (6)	p-value (7)
Shower water usage (L)	38.32	36.25	37.25	40.72	36.21	34.68	0.281
Aircon usage (hr)	3.62	3.67	3.73	3.67	3.43	3.55	0.963
Share of suites	0.51	0.58	0.51	0.47	0.54	0.51	0.867
Floor	10.51	12.70	11.14	10.60	10.41	10.15	0.019
Bathrooms	106	73	69	91	71	71	-
Bedrooms	192	231	219	212	220	202	-

Notes. Each p-value is from an F-test of joint significance in an OLS regression of the variable on treatment group dummies.

A.3 Treatment effects on the extensive margin

This appendix provides evidence against residents responding to any of the interventions on the extensive margin. Table A2 illustrates that the number of showers and the fraction of users using air conditioning each day do not vary across experimental conditions.

Table A2: ATE of real-time feedback and social comparison (extensive margin)

Dependent variable:	Number of showers per day		Fraction using aircon each day	
	(1)	(2)	(3)	(4)
Real-Time Feedback (RTF)	0.225	0.304	0.003	0.005
	(0.226)	(0.222)	(0.013)	(0.014)
Social Comparison for Shower (SC-S)	–0.287	–0.160	0.005	0.010
	(0.204)	(0.264)	(0.013)	(0.016)
Social Comparison for Aircon (SC-A)	–0.292	–0.108	–0.002	–0.001
	(0.237)	(0.318)	(0.014)	(0.018)
SC-S × RTF		–0.267		–0.010
		(0.314)		(0.020)
SC-A × RTF		–0.370		–0.003
		(0.393)		(0.023)
Constant	2.647***	2.625***	0.548***	0.547***
	(0.068)	(0.067)	(0.004)	(0.004)
Device/Bathroom FEs	✓	✓	✓	✓
Date FEs	✓	✓	✓	✓
R^2	0.343	0.343	0.435	0.435
Observations	57,953	57,953	147,376	147,376

Notes. OLS estimates with device/room and day fixed effects. Standard errors are clustered at the bathroom level.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

A.4 Details on the performance ranking measure

As detailed in the paper, each residential college features two types of bathrooms: common bathrooms and apartment suite bathrooms. The type of bathroom residents use depends on their accommodation type. Consequently, we can rank each bathroom by comparing the average shower water usage and air-conditioning usage of its residents against those of other bathrooms. In particular, we make the comparison within the same residential college and bathroom type. For example, Tembusu College has 34 corridor bathrooms and 41 suite bathrooms. The ranking of a bathroom (e.g., 5th out of 34 corridor bathrooms) is then converted into a percentile, ranging from 0 to 100. To ease interpretation in our regression analyses, we normalize these percentiles to a scale from -50 to 50, where a value of 0 indicates the median usage. These measures are denoted by $\text{Percentile}_{Shower}$ and $\text{Percentile}_{Aircon}$ for shower water usage and air conditioning usage, respectively, in Table 2.