Energy Economics 74 (2018) 582–591

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneeco

The effect of behavioural interventions on energy conservation in naturally ventilated offices☆

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ARTICLE INFO

Article history:
Received 12 October 2017
Received in revised form 2 July 2018
Accepted 5 July 2018
Available online xxxx

JEL classification:
Q2
Q4
Q29
Q41

Keywords:
Behavioural intervention
Window opening
Energy conservation
Carbon emission reduction
Naturally ventilated office

ABSTRACT

This paper investigates the effects of behavioural interventions on energy conservation in naturally ventilated offices. Our aim is to inform building managers, environmental consultants, and social scientists on the effectiveness of low-cost, easy-to-implement interventions aimed at reducing energy waste and carbon emissions in a setting where individuals do not have direct financial gain and have low awareness of the environmental impact of their actions. The interventions consist of three types of emails with different information content aimed at encouraging recipients not to leave the windows of their office open overnight or during weekends. Our results show that these interventions are effective in promoting energy savings, as the percentage of windows left open by treated occupants is typically halved compared to a control group. We find that the impact of the treatment is stronger when we provide specific information about the energy waste of the building where the email recipients work or when we show them how their behaviour differs from that of their peers. Moreover, our results show that positive behavioural changes are still observed a few weeks after the interventions are terminated, thus suggesting that such interventions do not act only as temporary "cues" which are easily forgotten by recipients.

1. Introduction

Market-based policies to reduce greenhouse gas emissions such as carbon cap-and-trade programs or subsidies to renewable energies have proved to be very effective.[1] However, the political resistance to the use of some of these approaches (as in the case of the market for trading carbon emissions in the US) and the financial cost involved in sustaining them (as in the case of the subsidies for solar and wind energy) have pushed in recent years, academics and policy makers to shift their attention to alternative low-cost, non-price-based energy conservation programs (see Allcott and Mullainhatan (2010) and Dietz et al. (2009) among others).

A large body of ongoing research on consumption feedback, appeals to environmental protection, and social comparisons has shown that behavioural interventions can be cost-effective in encouraging households to conserve energy (Abrahamse et al. (2005); Allcott and Mullainhatan (2010)). For instance, in an influential study based on data from a randomized experiment involving thousands of US households, Allcott (2011) finds that Home-Energy-Report letters comparing the electricity bill of residential customers to that of their neighbours induce a 2% reduction in energy consumption.

Building upon these findings, the aim of this paper is to evaluate the effectiveness of a simple energy conservation intervention in the context of naturally ventilated office buildings, namely to remind participants to close the windows before leaving the office. Non-domestic buildings in UK are responsible for one quarter of the total emissions attributed to residential and non-residential buildings (which together represents around 18% of UK's CO_2 emissions) but, whereas emissions from residential buildings have gradually decreased over the last

☆ We would like to thank Beatrice Avanzini for her excellent research assistance and seminar participants at the University of Southampton for useful comments. This work was supported by the Engineering and Physical Sciences Research Council, UK [EP/L024608/1].
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[1] According to the figures published by the EU, the EU Emission Trading System (ETS) has reduced greenhouse gases emitted by installations covered by the system by around 5% in the period 2013–2015. The EU estimates that in 2020, emissions from sectors covered by the system will be 21% lower than in 2005 (see https://ec.europa.eu/clima/policies/ets_en).

https://doi.org/10.1016/j.eneco.2018.07.008
0140-9883/

decade, emissions from non-domestic buildings have increased by 6% in the period 2007–2015 (Committee on Climate Change, 2016). This trend could be reversed if occupants were using building systems and controls more effectively. Several studies (Leaman and Bordass (2001) and Clements-Croome (2006), among others) have shown that people favour office spaces where they can interact with the facade to regulate their indoor environment. But this ability to individually change the internal environmental conditions does bear a risk of compromising the energy performance of the building as occupants are often oblivious to the necessity of minimizing energy use, especially in the absence of any direct costs as employees do not pay for the energy bills.

Behavioural interventions aimed at promoting energy conservation, such the OPOWER program studied by Allcott (2011), while non-price-based, do imply a financial gain for the subjects. It can be argued that the impact of social norms and pro-environment feedback may not be equally effective in a context where people receive no direct financial benefits. The findings from the literature on the impact of behavioural interventions in non-domestic buildings suggest that eco-feedback can be effective in encouraging energy conservation even in the absence of direct financial gains for participants.[2] However, existing studies on energy conservation in the workplace are scant; the effectiveness of the interventions is almost always measured in terms of aggregate electricity usage at the building level. In addition, little is known about the long-term effects of these interventions as employees' behaviour is generally not monitored over longer periods.[3]

Insights from psychology literature suggest that promoting behavioural change is more effective when the behaviour to be changed is carefully selected, interventions are well-tuned and not too costly to implement and feedback makes salient the relationship between one's action and a given outcome (Abrahamse et al., 2005; Steg and Vlek, 2009). In this respect, Carrico and Riemer (2011) note that "*feedback that is removed from the specific behaviour, either temporally or in unit of analysis (i.e. aggregated across many behaviours and/or individuals) will not provide the type of information that allows an individual to gauge whether his or her actions are having the desired effect*". Building upon these findings, the key contribution of our research is to investigate the effectiveness of environment appeals and social norms in the workplace in a setting where (*a*) the intervention refers to a single task, simple and easy to implement (i.e. close the window of your office), (*b*) feedback is at individual level and delivered at relatively high frequency (two emails a week) and (*c*) the link between the behaviour to be changed and the impact on energy consumption is less obvious.[4] Moreover, as we monitor the behaviour of our subjects from two to seven weeks after the interventions have been discontinued, our study can shed light on the "medium-term" effects of our energy conservation program.

Our approach builds on a multi-disciplinary project (Bourikas et al., 2016), and it involved the development of a bespoke software system to monitor the status of windows starting from photos of the façade and which allowed the semi-automatic dispatch of emails (sent twice a week) to the individual in control of the windows, based on each window's status. Three types of intervention were defined around these emails, and they were designed based on insights from psychology science on the importance of moral obligations and social norms on behaviour (Steg and Vlek, 2009). The first intervention involved a generic email informing recipients about the problem of energy waste due to windows being left open overnight. The second intervention involved a feedback email informing recipients about the average number of windows left open *in their building*. Finally, the third intervention involved an email based on social norms, which informed recipients about how many times they have left their office window open *compared to others* in their building. Our interest in comparing these three options is to examine whether tailored information specific to the working environment of the recipients and social norms, which have been found to be potent behavioural drivers in experimental settings (Cialdini and Goldstein, 2004), are confirmed to be a more powerful motivator of prosocial behaviour than a simple appeal to energy conservation also in a real context where subjects do not have direct financial gains. The three interventions were compared to a baseline period, before the interventions started, and to the performance of a group of participants who had their windows monitored, but did not receive any emails.

The results, detailed in Section 4, indicate that the interventions are effective in encouraging energy conservation and that the impact of the treatment is stronger when feedback and normative comparisons are included. We also found some evidence that our interventions may facilitate the formation of an energy conservation culture as the positive effects of the intervention are still observed some weeks after the interventions are terminated. Back-of-the envelope calculations suggest that these types of intervention have the potential to lead to annual savings of more than £40,000 over a bill of £3.5 million on gas alone for an institution such as the University of Southampton.[5]

The rest of this paper is organized as follows. Section 2 reviews the existing literature on non-price interventions. Section 3 first explains the type and timing of the interventions and then provides information about the variables used in the empirical analysis. Section 4 details the empirical specification used to investigate the effects of the interventions and the results obtained. Section 5 concludes.

2. Literature review

This study sits in between different strands of literature. Research in economics and psychology has mainly focused on the effects of behavioural interventions on energy conservation in a domestic setting. The resulting literature has shown that social norms including feedback, energy conservation tips, or household energy reports comparing their energy usage to that of neighbours, can have substantial effects on reducing energy consumption, at least in the short-term (Allcott and Mullainathan, 2010 among others). Allcott and Rogers (2014) show that if interventions are sustained over time, individuals build a "capital stock" which eventually allows altered behaviours to become natural ones and thus to persist over time.[6] The study by Asensio and Delmas (2015) compares the efficacy of price and non-price interventions. The authors find that providing feedback of the negative effects of energy use on the environment and human-health (e.g. pollution or child asthma) outperform monetary incentives to drive energy conservation.

Arguably, the extent to which information affects behaviour depends on the precision of the feedback provided. Nolan et al. (2008) find that messages notifying how neighbours engage with energy conservation are more effective in spurring behavioural changes than those encouraging standard appeals to the environment. Agarwal et al. (2017) also confirms that peers' comparisons have substantial influence on consumers' behaviour. They find that school children nudging their families to conform to efficient energy habits are an effective way of organizing "voluntary commitments" resulting in a 1.8% drop in household energy use. These simple experiments show how social norms

[2] See the papers by Carrico and Riemer (2011), Gulbinas and Taylor (2014) and Dixon et al. (2015) discussed in the literature review.

[3] As noted by Abrahamse et al. (2005), most studies do not monitor energy usage after interventions have been discontinued and, consequently, it is difficult to know whether "*behavioural changes were maintained and whether new (energy-saving) habits were formed, or whether energy use returned to baseline levels*".

[4] In a survey we conducted one year before the beginning of this study, we found that the vast majority of the respondents did not associate wasting heat with energy waste (Bourikas et al., 2016). Abrahamse et al. (2005) note that "*educational campaigns may especially be advisable when people are unaware of energy use and environmental problems*".

[5] University of Southampton (UoS) Carbon management Plan, 2011

[6] In a study on the effects of construction activities on residential electricity consumption, Agarwal et al. (2016) find evidence of persistent increase in electricity usage trigger by a temporary negative environmental externality.

affect people's decision-making; conformity is more likely to occur once peer behaviour is presented. Although most studies proved the efficacy of non-price interventions, Costa and Kahn (2013) point out that a major pitfall resulting from this type of mediations is a "rebound effect", that is a possible increase in usage when consumers are told to be under-consuming energy compared to their neighbours.

A limited number of studies have investigated the effectiveness of behavioural intervention on energy conservation in non-residential buildings. Masoso and Grobler (2010), in a study of commercial buildings in Botswana and South Africa, find that 56% of energy usage occurs during non-working hours mainly because occupants leave lights and equipment on at the end of the day. Because occupants do not bear the financial cost of energy, price intervention would be ineffective in shifting individuals' consumption towards more energy-efficient outcomes, thus making behavioural intervention more relevant. On this matter, Gulbinas and Taylor (2014) find that providing energy-use information of colleagues within an organization can result in greater energy savings than individual feedback and Dixon et al. (2015) find that comparative feedback within a university reduces energy consumption by 6.5%. Similarly, Carrico and Riemer (2011) estimate that group-level feedback and peer education resulted in respectively, 7% and 4% reduction in the energy used in a workplace.

While all the studies above focus on electricity consumption, it is reasonable to assume that similar results would be obtained in other contexts, such as water usage and space heating. Cialdini et al. (2008), in a study on towel reuse among hotel guests, find that appeals stating that the majority of hotel guests reuse towels proved a more effective intervention than a general appeal to the environment. Ferraro et al. (2011) show that technical advice alone does not encourage water conservation, but it is effective when the former is combined with social comparisons. Likewise, Brown et al. (2013) find that reducing the default option of thermostat by 1 °C is an effective way to combat excess heating.

In essence, previous studies show that non-price interventions not only spur behavioural changes stimulated by peers' attitudes, conformity, feeling of guilt and responsibility but they also help filling in the gaps when the lack of knowledge itself is the driving force of resources overuse.

3. Data and variables

3.1. Building and offices

Five naturally ventilated (i.e space heating, natural ventilation, no cooling) office buildings at the University of Southampton were monitored during the 2016/2017 heating season with a bespoke camera based system that identifies the status "open/close" of the windows (for more information we refer to the companion paper by Bourikas et al., 2016). Based on the camera analysis status, emails were automatically sent to the office occupants who were in control of the identified windows. The emails aimed at drawing the occupants' attention to the problem of poor window management.

The five studied buildings include a combination of individual offices, shared office space and some small lecture/meeting rooms (not included in the interventions). They have top-pivot windows that can be manually operated by occupants and they are all connected to the University district heating scheme. The heating system is a high temperature hot water distribution (>65 °C) that runs along the outer wall of the buildings with radiators in the offices to distribute the heat in the space. Originally the radiators were boxed in panels and heat in offices was managed with flaps on the box that would allow air to flow or to close it. The only thing that has really changed since 1960's is that these flaps no longer work and there is no way to isolate the heating system of individual offices. Inaccessible and ineffective heating control in the offices exacerbates poor window behaviour as occupants feel that their only option to reduce excess overheating is to open a window.

Table 1
Offices in the treated and untreated group and occupancy number profile.

Part A			Part B	
Building	Treated	Untreated	Occupancy	Offices
1	53	27	1	111
2 & 3	35	23	2	26
4	13	6	3	33
5	–	28	>3	15
Total offices	101	84	Total offices	185

Building 1 was built in 1975. It has a square floor plan with an internal courtyard. Participants were randomly distributed across all the 4 sides of the building and they all had access to windows looking outwards onto the building surroundings and not to the courtyard. This building had the largest number of participants with 80 offices monitored. Buildings 2 & 3 were both built in the 1960's and they have similar construction properties to Building 1. Their main facades have a Southeast-Northwest orientation, the windows are steel framed with single glazing and fitted with internal venetian blinds. Buildings 2 & 3 are part of the same phase of the intervention (i.e. receive the same emails simultaneously) and the results are combined in the analysis. In these buildings there was a total of 58 offices monitored. Building 4 was also built in the 1960's and it has similar characteristics to the rest of the studied buildings. However, there is a big difference to the floor plan layout because a large part is used for labs and views to some parts of the facade are blocked by vegetation. In Building 4 there were 19 offices monitored with 33 participants in the intervention. Lastly, Building 5 was built in the 1960 and it also has steel framed single glazed windows. In this building there were 28 offices monitored.

To comply with ethic rules, all participants in the study consented to have the status of their windows monitored. Treated units are the occupants that also agreed to receive our email interventions.[7] To increase participation rate, we repeatedly visited the occupants of the selected buildings in order to distribute/collect ethics forms and answer enquiries. The decision of taking part in the study and, in addition, agreeing to receive an email notification was often taken after this short meeting and it can reasonably assumed to be orthogonal to the inclination to close the windows before leaving the office, which is the behavioural change we aimed to affect. Indeed, the analysis of the status of the windows during the pre-intervention period shows that on average the probability of leaving a window open is not statistically different between participants that agreed to receive emails (i.e. treated units) and the participants that only agreed to have their windows monitored (i.e. untreated units).

Part A of Table 1 shows that the sample used in the empirical analysis of the intervention results includes 185 offices. Occupants of 101 of these offices are part of the treated group.[8] For each office we have 64 observations: 20 observations during the pre-intervention phase (corresponding to the working days from Friday 29th of September to Thursday 27th of October 2016), 37 observations during the intervention period (working days from Friday 28th of October to Monday 19th of December 2016 included) and 7 observations for January 2017. Part B of Table 1 shows that 111 of the 185 offices were

[7] A thorough ethics assessment was undertaken prior to any work and researchers had visited the occupants of these buildings several weeks before starting monitoring the façade in order to distribute participant information sheets, discuss any concerns and enroll the office occupants to the study. The participant information sheet had generic information about the aims of the study and the activities to be undertaken. All the participants have provided written consent for having the windows' status monitored and/or receiving the intervention emails.

[8] In case of a shared space, an office is part of the treated group only if respectively, all the occupants have agreed to have their windows monitored and at least one of the occupants has also agreed to be contacted by email.

Fig. 1. Pictures of the monitored building facades at the University of Southampton.

occupied by one individual, 26 were shared between two people, 33 were shared by more than two persons (these spaces are typically occupied by PhD students or administration staff) and finally 15 were public shared spaces, including visitors' room, and small meeting/teaching rooms. In addition, we note that the windows in 68 of the 185 offices are always closed (39 offices in the treated group and 29 offices in the untreated group) while none of the offices was found to have their windows always open during our study.

Given that the number of untreated control units is lower than the number of treated units, we construct three control groups with the same number of offices as the treated groups (e.g. 53 control offices for the 53 treated offices in Building 1) by sampling (with repetition) from the pool of 84 untreated units located in any of the buildings (including Building 5). More precisely, for each treated office i, we select a control office j that closely matches the number of the times the windows of office i have been left open in the pre-intervention period (see Section 3.3 below for statistical evidence on the quality of the match).[9]

3.2. Behavioural intervention

Our behavioural intervention consists of sending one of three different types of emails to participants that agreed to be contacted by our team.[10] Guided by insights from behavioural science, we drafted three emails with different information content with the aim of motivating receivers to save energy by closing the office windows when the heating system is on operation.

The first email, which we will refer to as *General Mail* (*GM*), informed the recipients about the problem of energy waste due to windows being left open overnight in non-residential buildings, and its implication for the environment and the energy bill paid by the institution where they work. The second and the third emails also appealed to the environment and economic benefits of closing the windows but included additional specific information more relevant to the recipients. The second email, which we refer to as *Local Mail* (*LM*), gave the occupants feedback on the average number of windows left open in the building they work. The third email, which we refer to as *Personalised Mail* (*PM*), tried to appeal to social norms by informing the recipients on how many times they have left their office window open compared to other occupants of the same building. A copy of these emails is shown in Fig. 2.

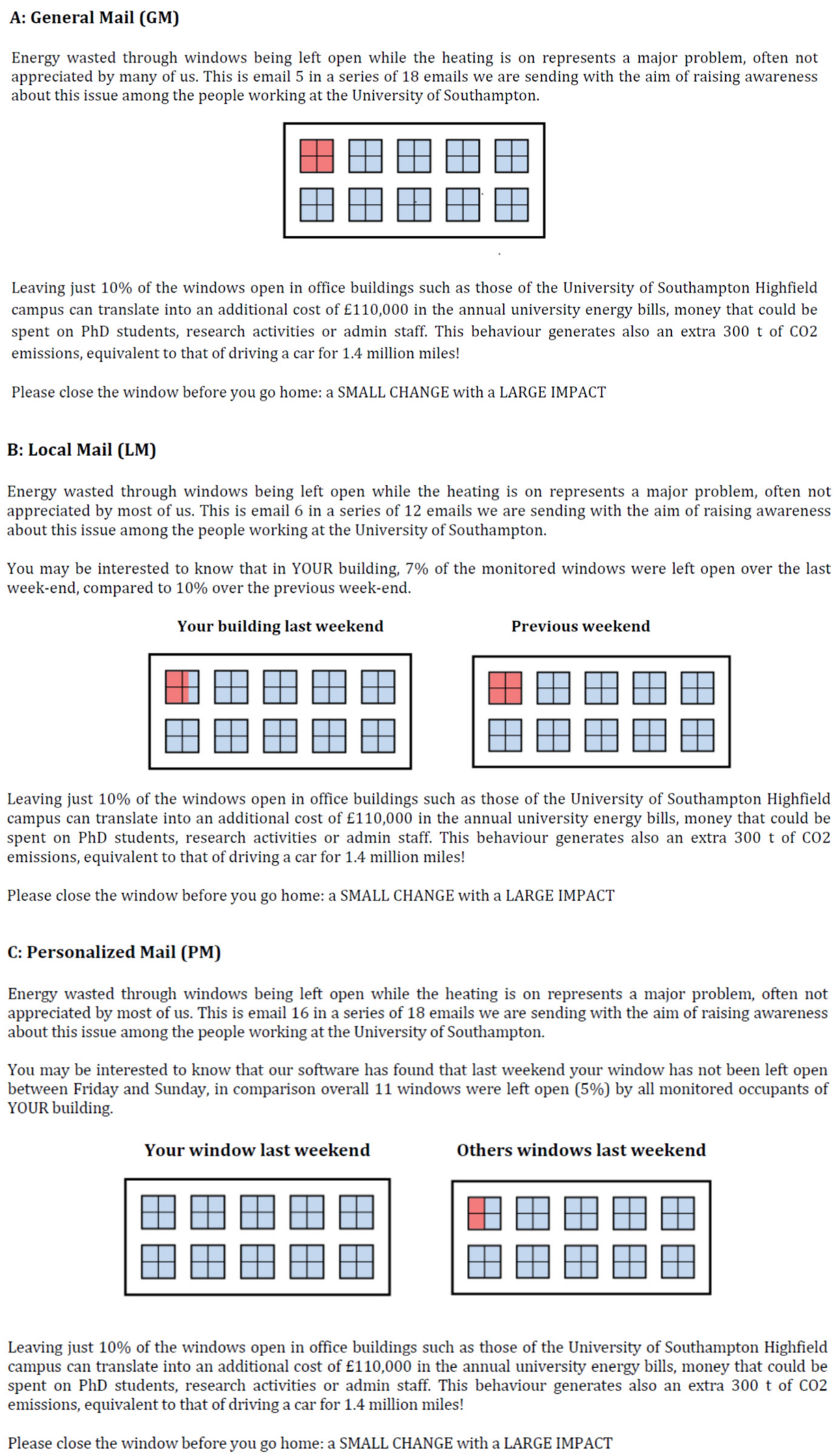
These three emails aim to pull at different motivational strings. All the emails appeal to the environmental motivation by informing the participants of the importance of closing the windows for the reduction of heat waste and consequent greenhouse gas emissions. The LM aims at assessing whether behavioural interventions are more effective when describing the behaviour of a group with whom the participants share similar characteristics and that they can relate to (see Goldstein et al. (2008) among others). This is achieved by replacing the somehow abstract problem of energy waste in non-residential buildings with precise information on the number of windows left open in the building where recipients work. Finally, the PM tries to evaluate the effectiveness of social comparison in the absence of financial incentives by appealing to feelings of guilt (reward) for individuals that behave worse (better) than their colleagues.

Responses to an online questionnaire which we sent in September 2015 to a random sample of people that work in office buildings in the UK (see the companion paper by Bourikas et al. (2016) for full details), show that the vast majority of the respondents did not associate wasting heat behaviour with energy waste.[11] This is also the case for individuals that considered themselves as highly motivated towards environmental protection. The fact that people seem more inclined to save electricity but not heat suggests that informing and reminding people about the negative effect of poor window management can have a substantial impact on energy conservation in a non-domestic building.

[9] Using the same number of treated and control units increases the precision of the estimates, in particular for building 4 where the number of monitored offices is particularly small. All but two of the treated units are matched to an untreated unit which left the windows open exactly the same number of times during the pre-intervention period. For the two treated units for which we could not find a "perfect" match, we selected an untreated unit with the closest number of windows left open. Our approach is similar in principle with the methodology proposed by Abadie et al. (2010), which has been extensively used in settings where the number of untreated control units is small and therefore they may not provide by themselves a perfect comparison for the treatment group.

[10] All emails were sent from a purposively created university account. Participants could send their emails to this mail account if they needed information or if they wanted to be removed from the study. Only 4 participants asked to be removed from the mailing list. We do not know whether the emails were read. On this point, we note that if similar interventions were deployed in other institutions, we would expect some participants to open and read emails and other disregard them. In that respect, there are no reasons to believe that the attitude of our subjects is different from the attitude we may encounter in another working environment. By selecting only the people that read all the emails, we would over-estimate the impact of our intervention.

[11] Out of the 91 valid questionnaire responses, >70% of the respondents considered "leaving the lights on" a wasteful behaviour but <30% had the same view about "leaving the windows open". The responses showed that the reasons for closing a window are mainly due to environmental influences (e.g. temperature, rain, noise) while energy seems to be a weak driver in this respect.



A: General Mail (GM)

Energy wasted through windows being left open while the heating is on represents a major problem, often not appreciated by many of us. This is email 5 in a series of 18 emails we are sending with the aim of raising awareness about this issue among the people working at the University of Southampton.

Leaving just 10% of the windows open in office buildings such as those of the University of Southampton Highfield campus can translate into an additional cost of £110,000 in the annual university energy bills, money that could be spent on PhD students, research activities or admin staff. This behaviour generates also an extra 300 t of CO2 emissions, equivalent to that of driving a car for 1.4 million miles!

Please close the window before you go home: a SMALL CHANGE with a LARGE IMPACT

B: Local Mail (LM)

Energy wasted through windows being left open while the heating is on represents a major problem, often not appreciated by most of us. This is email 6 in a series of 12 emails we are sending with the aim of raising awareness about this issue among the people working at the University of Southampton.

You may be interested to know that in YOUR building, 7% of the monitored windows were left open over the last week-end, compared to 10% over the previous week-end.

Your building last weekend **Previous weekend**

Leaving just 10% of the windows open in office buildings such as those of the University of Southampton Highfield campus can translate into an additional cost of £110,000 in the annual university energy bills, money that could be spent on PhD students, research activities or admin staff. This behaviour generates also an extra 300 t of CO2 emissions, equivalent to that of driving a car for 1.4 million miles!

Please close the window before you go home: a SMALL CHANGE with a LARGE IMPACT

C: Personalized Mail (PM)

Energy wasted through windows being left open while the heating is on represents a major problem, often not appreciated by most of us. This is email 16 in a series of 18 emails we are sending with the aim of raising awareness about this issue among the people working at the University of Southampton.

You may be interested to know that our software has found that last weekend your window has not been left open between Friday and Sunday, in comparison overall 11 windows were left open (5%) by all monitored occupants of YOUR building.

Your window last weekend **Others windows last weekend**

Leaving just 10% of the windows open in office buildings such as those of the University of Southampton Highfield campus can translate into an additional cost of £110,000 in the annual university energy bills, money that could be spent on PhD students, research activities or admin staff. This behaviour generates also an extra 300 t of CO2 emissions, equivalent to that of driving a car for 1.4 million miles!

Please close the window before you go home: a SMALL CHANGE with a LARGE IMPACT

Fig. 2. Samples of intervention emails.

To this aim, all of the three emails we sent to the participants contained a general appeal to the problem of energy waste and contained the same stylized picture of a building to avoid bias in the way the information is conveyed. In the case of a GM, the picture always had one of ten windows coloured in red to represent the average percentage of windows left open overnight (see Fig. 2A).

Besides raising awareness about the environment and financial impact (for the University of Southampton) of leaving windows open, the LM also reported specific information about the percentage of windows left open in the building where each recipient works and whether this percentage was higher or lower compared to what had been observed in the previous period: "You may be interested to know that in YOUR building, 7% of the monitored windows were left open over the last weekend, compared to 10% over the previous weekend." We use the same stylized image of a building using a red colour to represent the percentages of windows left open (see Fig. 2B). With this second type of email, we sought to assess whether there is a stronger drive to energy conservation if the problem of energy waste is presented in a context that is relevant to the recipients and, at the same time, participants are informed about the progress (or lack of it) of the intervention over time. Note that emails sent out on Fridays (respectively, Mondays) reported information on the status of the windows for the nights from Monday to Thursday (respectively, for the weekend).

Our third email reported information about the behaviour of each recipient compared to the other occupants of the same building: "You may be interested to know that our software has found that last weekend your window has not been left open between Friday and Sunday, in comparison overall 11 windows were left open (5%) by all monitored occupants of YOUR building." (see Fig. 2C). This PM tries to strike the chord of personal reward (or shame) when people learn that they are doing better (worse) than their peers as far as this specific energy conservation program is concerned.

The different phases of our behavioural intervention are shown in Fig. 3. The state of the buildings' windows was monitored during working days from Friday 30th of September 2016 until Thursday 12th of January 2017, excluding 12 days during the Christmas break (from Tuesday 20th of December 2016 to Monday 2nd of January).[12] On Friday 28th of October, occupants in the treated group started receiving two emails a week, every Friday at 15:00 and every Monday at 10:00. For instance, occupants of Building 1 were sent six GM, followed by six LMs and four PMs. We also monitored the state of the windows for seven working days in the first half of January 2017 in order to evaluate the persistence of the impact of the interventions. Note that the notation used in the legend of Fig. 3 to describe the different phases of our study (i.e. PRE, GM, LM, PM and POST) will be used also in the regression model of Section 4.

As mentioned in the Introduction, this intervention configuration enabled our team to investigate whether tailored information specific to the working environment of the recipients and social norms are a more powerful motivator of prosocial behaviour than a simple appeal to energy conservation for environmental protection. At the same time, the follow-up monitoring of the windows after interventions are terminated made it possible to assess whether pro-environmental habits are short-lived or tend to be maintained over the following weeks.[13] Following Allcott and Rogers (2014), an intervention can be considered as a way to provide either information or a "cue". In the first case, as the intervention is repeated, people gradually develop new habits that generates persistent changes in outcomes. Accordingly, we would expect to find that the numbers of windows left open in January is still lower for the treated group than the control and also that the energy conservation attitude is stronger for participants that have been exposed to the intervention for a longer period. Alternatively, if the treatment acts as a temporary "cue" that reminds occupants to close the windows when leaving the office, the behaviour of the treated people is likely to converge quickly to that of the control group as the recipients forget about the message once the intervention has been discontinued.

3.3. Windows status

Our unit of observation is an office, not a window. The reason for this is that if any of the windows are left open overnight energy is wasted and it is then reasonable to assume that our intervention has a positive effect only when occupants close all the windows under their control. Accordingly, an office is classified as "open" (respectively, "closed") overnight if our system detects that at least one of its windows (none of its windows) is open at around 18:00 pm on that day and it is still open at around 08:00 am the following day. The status of an office is observed five days a week, from Monday to Friday. The "open/close" status for the weekends is defined using the information on Friday evening and the following Monday morning. We acknowledge that our approach may lead to a wrong classification if, for instance, occupants arrive in their office (and interact with their windows) before we check the status of the window. However, we do not think that this represents a major problem because both academic and administrative staff typically start working around 9 am, as in most UK universities and companies. More importantly, there is no reason to believe that the intervention and control groups are affected in different ways by this type of measurement error.

To detect the status of a window, photographs of the facades were taken and analysed by the bespoke software mentioned above. The detailed window detection methodology and technical specifications of the system and its function are described in a previous publication (Bourikas et al. (2016)). While the software is designed to automatically detect the status of windows, the data used for the interventions reported in this paper was manually verified by the researchers, not only to avoid inaccuracies, but also to collect a so-called ground-truth dataset needed to calibrate the automatic detection processes.

To have a preliminary understanding of how the facade interaction evolves over time, Fig. 4 shows the percentage of offices left open for treated units (red line) and control units (blue line) for the three different treatment schedules separately and ALL together. The vertical lines indicate the beginning of an intervention. As in Fig. 3, we use orange, yellow and red to indicate that occupants in the treated groups are sent respectively, a GM, a LM or a PM (for ALL, we use a black line as the intervention varies across buildings). As mentioned in Section 3.1 above, control units have been selected by sampling (with repetition) from any of the 84 untreated offices (including those located in Building 5) so that each treated unit is matched to the untreated unit that shows a very similar behaviour during the pre-intervention period.

The vertical lines indicate the beginning of an intervention. As in Fig. 3, we use orange, yellow and red to indicate that occupants in the treated groups are sent respectively, a GM, a LM or a PM (for ALL, we use a black line as the intervention varies across buildings). Visual inspection of the four panels suggests that treated and control groups indeed share very similar patterns during the pre-intervention period. Moreover, *t*-tests on the equality of means during the pre-intervention fail to reject the null hypothesis that the percentage of windows left open in treated and control groups are the same for the three sets of buildings individually and all together.[14]

The top-right picture of Fig. 4 shows a significant departure between the two lines after the beginning of the intervention on the 28th of October 2016. The red line (intervention group) lies beneath the blue line (control group) for most of the following days, including those in January 2017. Looking at all the buildings, we find that a similar pattern is evident in Building 1 and in Buildings 2 & 3. Finally, the pattern in Building 4 is more difficult to interpret because the percentage of "open-windows" offices in the treated and control groups is subject to large variations over time. This is not surprising if we consider that the number of offices monitored in Building 4 is small.

[12] Friday 16th of December was the last day of teaching before the Christmas break.

[13] We assume that January can be used to assess whether effects are short-lived because, for Buildings 2 & 3 and Building 4, the intervention ends several days before the New Year and, more importantly, Christmas holidays give the opportunity to all occupants to disconnect from their working environment and forget about our messages.

[14] The *p*-value of the two-tail tests of the null hypothesis that the difference in means is zero vs the alternative hypothesis that the difference in means is different than zero is 0.9 or higher for all the four cases reported in Figure 1.

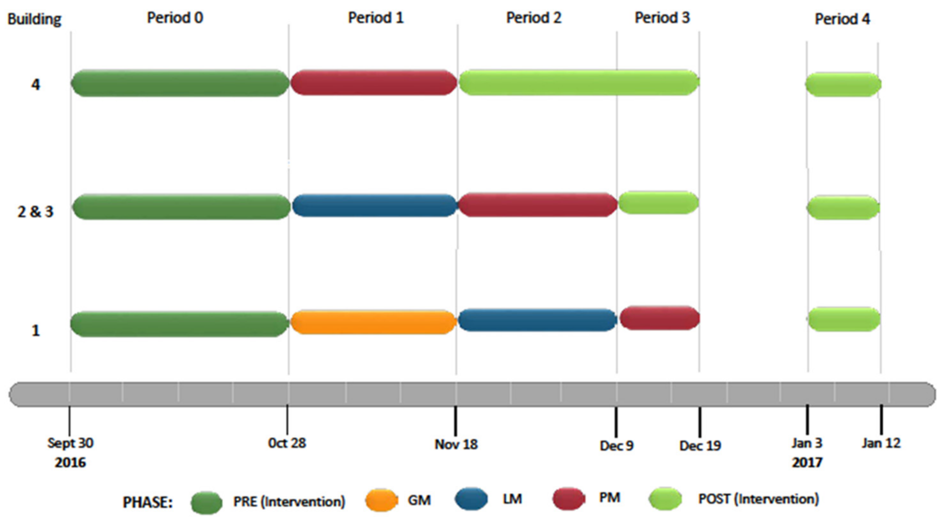


Fig. 3. Timing of interventions across the buildings in our study.

4. Econometric specification and results

To assess the impact of our behavioural interventions on the percentage of office with windows left open overnights, we use the following regression model:

$$W_{i,t} = \sum_j \alpha_j P_j + \sum_j \beta_j P_j T + \boldsymbol{X}\boldsymbol{\delta} + u_{i,t} \tag{1}$$

where $W_{i,\,t}$ indicates the percentage of office with open windows in Building i on the night of day t and Greek letters are coefficients to be estimated. The variable P_j refers to one of the five phases of the program as shown in Fig. 3, with $j = \{\text{PRE, GM, LM, PM, POST}\}$, and T is an indicator for the treatment group. Accordingly, the coefficients α_j measure the percentage of windows left open during phase j in the control group while coefficients β_j indicate whether the percentage of open windows is higher or lower in the treated group.[15] If our behavioural interventions are effective in encouraging energy savings behaviour, we expect the coefficients β_j (excluding β_{PRE}) to take statistically significant negative values. As different types of intervention are implemented across buildings, the functional form of specifation (1) is also different for the three sets of buildings. For instance, for Building 4, we can only estimate three α_j (namely, α_{PRE}, $\alpha_{PM}$and α_{POST}) and three β_j (namely, β_{PRE}, $\beta_{PM}$and β_{POST}) while all five α_j and β_j can be estimated for Building 1.

Specification (1) is estimated using ordinary least-square (OLS) regression, with robust standard errors. Estimated coefficients for the three sets of buildings are reported in Table 2. Whereas the number of observations is the same across the three specifications, recall that the number of treated and control units used to compute the percentage of windows open at each point in time is higher in Building 1 than the other buildings. As explained above, the α coefficients capture the evolution of the windows left open over time in the control group. For instance, for Building 1, around 14% of the windows in the control group are left open during the pre-intervention period. This percentage increases to 21% during the GM phase (which, in the case of Building 1, corresponds to the days from the 28th of October to the 18th of November) and then it constantly decreases over the following weeks until we observe a 8% of open windows in the post-intervention period (which corresponds to the 7 observations of January 2017).

[15] Our time-phase dummies P capture any "exogenous" event that can affect a change in behaviour of all subjects over time, for instance changes in weather (e.g. a drop in the temperature) that make people more likely to close their windows.

A number of interesting findings emerge from the estimates of the β coefficients. First, the estimates of β_{PRE} are very close to zero and not statistically significant for all the three buildings, which confirms that the behaviour of treated and control units are (almost) identical during the pre-intervention period. Second, all the estimates of β_{GM}, β_{LM} and β_{PM} are negative and statistically significant, thus giving strong support to the idea that there is a substantial reduction in the numbers of windows left open in the treated group compared to the control group during the intervention period. Third, the fact that the estimates of β_{POST} are also negative suggests that the impact of our interventions continues after the intervention have stopped. Particularly interesting is the coefficient of β_{POST} for Building 1, which refers to the January data. Christmas holidays represent an important break from the work environment during which treated occupants are likely to forget about the intervention. Accordingly, if the treatment acts only as "cue" that draws the attention to energy waste but does not create a permanent "capital stock", we should not find any difference in the percentage of "open-windows" office in January. Starting from a base-line of 7% of windows left open in the control group, we observe a reduction for the treated group to 4.9% of windows left open. These numbers show that some of the pro-environmental behavioural changes observed during the intervention period are maintained after we stop sending out mails, thus suggesting that our interventions may have facilitated the formation of new (energy-saving) habits.

In order to test whether there are significant differences among our three types of emails, Table 3 shows how the effectiveness of our interventions changes from one phase to the following one, together with the p-value of a non-linear Walt test for the null hypothesis that the change is not statistically different from zero. To compute the "incremental" effects of our interventions, we need to take into account the percentage of open windows in the control group during the different phases of our study. For instance, the first value in Column (1) is computed using the α and β coefficients in Table 2 as follows:

$$\frac{\beta_{GM}}{\alpha_{GM}} - \frac{\beta_{PRE}}{\alpha_{PRE}} = \frac{-0.088}{0.207} - \frac{-0.00}{0.137} = -0.424$$

The numbers reported in column (1) suggest that the percentage of windows left open in the treated group is substantially lower compared to the control group across all the buildings, with an aggregate reduction of around 40% in Building 2 & 3, 50% in Building 4 and 70% in Building 1. Considering that the number of treated units in Building 1 is more than the other buildings, we can assume that a reduction of 50% in the number of windows left open can be

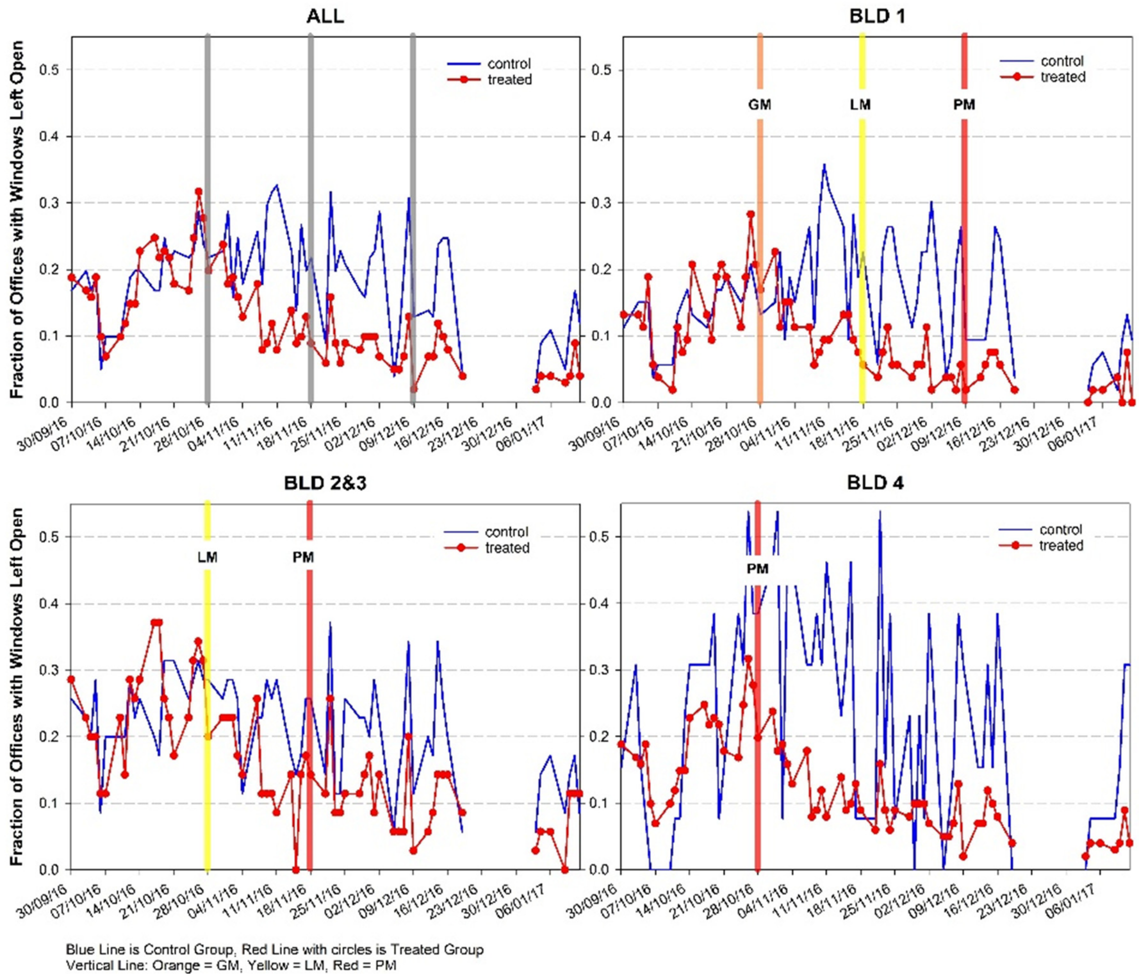


Fig. 4. Number of the windows left open in treated and control group.

easily reached by interventions similar to those we have implemented in this study.

Our results show that the impact of LM is stronger than GM for treated offices in Building 1, while we cannot reject the null hypothesis that the impact of LM is the same as the impact of PM for both Building 1 and Building 2 & 3. These confirm previous findings that feedback about relative performance may be helpful in promoting pro-environmental behaviour when important or relevant others are used as reference group (Abrahamse et al., 2005). At the same time, the fact that LM and PM are not statistically different suggests that the feeling of competition and social comparison that is evoked by PM seems to be equally effective in promotive virtuous behaviour than the social pressure that may be installed by PM. Finally, the fact that there are no statistical differences between the "LM" and "POST" shows that the pro-environmental behaviour observed during the intervention period does not fade after interventions are terminated, even in the case of a relative short treatment as the one applied to offices in Building 4.

To sum up, the results presented in Tables 2 and 3 show that: (i) All our interventions are effective in encouraging energy savings. (ii) Providing precise information about energy waste in the environment where the occupants work (LM) or comparing the behaviour of recipients to their peers (PM) provides greater incentives to reduce energy waste than a generic appeal (GM) to the environmental and financial benefits of closing the windows. (iii) We find positive effects even after the interventions are discontinued. This suggests that our treatments do not only act as a temporary "cue" that is easily forgotten but they may contribute to the creation of pro-environmental habits. In terms of magnitude, we find that the percentage of windows left open has generally halved.

The numbers above can be used to calculate the financial savings and environmental benefits of our interventions. Obviously this calculation needs to be treated with caution given the small scale of our interventions. In our previous work we show that leaving windows open during out-of-work hours at the buildings used in this study can account for around 10% of the annual heating load (Bourikas et al. 2016). If this estimation were to be generalized to the total number of university buildings, the 10% of the total heating energy use (estimated average total of 212kWh/m^2 from DEC data, 10% of the total is ~21 kWh/m^2) can be translated into an additional cost of £85,000 per year for heating and an additional 285 tCO_2 emissions due to the heating use increase,[16] equivalent emissions to driving a medium sized car for 1.3 million miles. Therefore, implementing an intervention that can halve the number of windows left open would translate into cost avoidance of £43,000 per year from the heating bills and a reduction of 142 tCO_2 in the associated emissions. This represents fairly big

[16] Note that this estimate is based on the case of the University of Southampton Highfield campus where heating is provided by a combined heat and power (CHP) generation system. In the business as usual case of using condensing gas boilers with an efficiency of 90%, the extra cost would be £21,000 per year more than the CHP case (£105,000 in the gas boiler case compared with £84,000 in the CHP case) and the increase in emissions would be 6 tCO_2 less than the CHP case (277tCO_2 increase in emissions from the condensing boilers compared with 283tCO_2 increase in the case of a CHP system). That shows that in the current financial environment the CHP systems may offer cost avoidance opportunities but the carbon emissions are comparable with the "traditional" heating systems.

Table 2
Impact of email interventions on percentage of windows left "open".

Variable	Coefficient	Bld 1	Bld 2 & 3	Bld 4
		(1)	(2)	(3)
T_{PRE}	α_{PRE}	0.139***	0.244***	0.212***
		(0.01)	(0.01)	(0.03)
T_{GM}	α_{GM}	0.208***	–	–
		(0.02)		
T_{LM}	α_{LM}	0.190***	0.234***	–
		(0.02)	(0.01)	
T_{PM}	α_{PM}	0.140***	0.211***	0.349***
		(0.03)	(0.02)	(0.04)
T_{POST}	α_{PS}	0.070***	0.157***	0.183***
		(0.02)	(0.02)	(0.03)
$T_{PRE}^{*}I$	β_{PRE}	−0.000	0.003	−0.000
		(0.02)	(0.02)	(0.04)
$T_{GM}^{*}I$	β_{GM}	−0.088***	–	–
		(0.02)		
$T_{LM}^{*}I$	β_{LM}	−0.135***	−0.078***	–
		(0.02)	(0.02)	
$T_{PM}^{*}I$	β_{PM}	−0.092***	−0.090***	−0.174***
		(0.03)	(0.03)	(0.04)
$T_{POST}^{*}I$	β_{PS}	−0.049***	−0.073***	−0.090***
		(0.02)	(0.02)	(0.03)
Obs		128	128	128
R-squared		0.851	0.9	0.733

Robust standard error in parenthesis ***$p < 0.01$, **$p < 0.05$,*$p < 0.10$.

savings considering that our intervention is easy and not expensive to implement.

5. Conclusions

According to figures published by the UK Committee on Climate Change (2016), emissions in non-domestic buildings have increase by 6% in the period 2007–2015. The report suggests that "*the current policy framework is not generating sustained emission reductions and that a transformational change is needed for non-residential buildings to make the necessary contribution to meeting future carbon budgets*." One of the main barriers to reducing energy consumption and carbon emissions while delivering thermal comfort in the working environment is the unpredictable behaviour of the occupants. Numerous studies show that users prefer buildings with facades with which they can interact to fully serviced offices with sealed windows. However, the ability to change the internal environmental conditions does bear a risk of compromising the energy performance of the building. This is true in particular in an office environment, because there are no financial incentives for the occupant to operate the façade in the same energy efficient manner as they would do in their own home. In addition, because appliances and machines are often shared by multiple employees, incentives for saving energy may be greatly diminished as users may feel that the problem is out of their control (Carrico and Riemer, 2011).

This paper investigates the effects of behavioural interventions in office buildings with the aim of informing building designers, managers, energy consultants and social scientists on the effectiveness of a low-cost, easy-to-implement interventions aimed at reducing energy waste and the consequent carbon emissions in a context where individuals do not have direct financial gains. The interventions consist of three types of emails with different information content ranging from a generic environmental appeal to person specific feedback. Our results show that these interventions are effective in promoting energy savings in office buildings. We also find that the impact of the treatment is stronger when the recipients are given information about an environment they can identify with or when their behaviour is compared to that of their peers. Our study confirms that social norms are potent drivers not only in experimental settings, where norm salience can be easily prioritized (Cialdini and Goldstein, 2004), but also in a real working environment. This study shows that improved energy-saving behaviour is still observed some weeks after the interventions are discontinued. This result seems to contradict the idea that treatments simply act as temporary "cues" which are easily forgotten by recipients. An important contribution of future works on energy conservation would be to monitor the effects of interventions over longer periods of time to understand whether such interventions can effectively create permanent pro-environmental habits.

A number of factors discussed in the economics and psychology literature can explain the effectiveness of our intervention. First, promotive behavioural change is more effective when people are unaware that their behaviour can significantly contribute to environmental problems (Abrahamse et al., 2005). In a survey we conducted one year before the beginning of this study, we found that the vast majority of the respondents did not associate "open" windows with wider energy waste, an information deficit that our intervention could easily address. Second, interventions are known to be more effective when they are easy-to-implement and well-tuned to change relevant behaviour (Steg and Vlek, 2009), which is clearly the case for our request to close the window. Thirdly, our emails provide highly personalized and specific information to the participants and previous studies have found that tailored information produces greater reduction in energy usage compared to aggregate feedback (Abrahamse et al., 2005).

Our results suggest that there is a clear economic incentive for the organizations to implement a simple intervention such as the one we implement here. Our calculations suggest that an institution like the University of Southampton can reduce the energy bill by more than £40,000 per year by implementing a conservation program that costs a fraction of this amount. In this respect, the fact that we still find a positive, but lower impact over time suggests that it may be advisable to have an intense information campaign at the beginning of the heating season to facilitate the formation of energy conservation habits, and reduce (but not discontinue) interventions after this has happened.

One important concern is whether our findings can be generalized to other working environments. Although most of our occupants have a higher educational level than the population at large, it should be noted that our intervention is very easy to understand and to implement. Moreover, there are good reasons to believe that the social effects of behavioural interventions can be greater than those observed in this and other studies as eco-friendly habits can be handed down to future building occupants and transferred to other spaces in an everlasting, virtuous cycle. Investigating how people develop these habits and the extent to which these can generate positive spillovers will be a very interesting direction for future research.

Table 3
Incremental effects of email interventions across study buildings.

From	To	% change[a]	p-Value[b]
Phase j	Phase $j+1$	(1)	(2)
Building 1			
PRE	GM	−0.424	0.006
GM	LM	−0.284	0.003
LM	PM	0.054	0.622
PM	POST	−0.038	0.837
Building 2 & 3			
PRE	LM	−0.345	0.005
LM	PM	−0.09	0.472
PM	POST	−0.044	0.754
Building 4			
PRE	PM	−0.499	0.026
PM	POST	0.007	0.961

[a] Computed as the difference of the ratio (β_j/α_j) over two consecutive phases using coefficients in Table 2. e.g. $(-0.088/0.207) - (-0.00/0.137) = -0.424$.
[b] *p*-Value of a non-linear Walt test of the null hypothesis that the ratio (β_j/α_j) is the same over two consecutive phases.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2018.07.008.

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