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Grenoble Applied Economic Laboratory
Consumption – Energy - Innovation

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Demand response in the workplace: a field experiment*

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To increase the share of intermittent renewable energy in our production mix, occupants of buildings can be called upon to lower, anticipate or postpone their consumption according to the network balance. This article presents a small-scale field experiment aimed at introducing demand response in the workplace. We test the impact of load-shedding signals assorted with incentives on energy consumption of workers in the tertiary sector. Two incentive schemes are tested: a honorary contest and a monetary tournament. The results show a reduction in workers' power demand during the load-shedding periods when the incentives are based on the honorary contest. At the opposite, the monetary tournament where workers could win money according to their behavior seems to have had no impact. The results also suggest that few workers can be responsible for a large part of energy consumption while the building is partially automatically controlled.

Keywords : flexibility, load-shedding signal, working place, living lab.

1 Introduction

Energy planning programs highlight the importance of diversifying energy mixes, promoting the penetration of renewable energies.¹ The increasing introduction of intermittent energy and the multiplicity and diffuse distribution of these production sites lead to problems of energy source elasticity at the neighborhood level. Proposing and analyzing a scenario of a 100% renewable mix across France by 2050, the ADEME report suggests that the power demand flexibility of buildings could help to manage the network balance of the peak demand ([Artelys *et al.*, 2016](#)). The main flexibility tools of the electrical system to ensure the balance of supply and demand are related to storage and demand management. Storage capacity seems however unlikely to fully compensate

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¹See for instance the PPE Program (multi-year energy program) in France, <https://www.ecologique-solidaire.gouv.fr/programmations-pluriannuelles-lenergie-ppe>.

for supply volatility (Giulietti *et al.*, 2019). The viability of a future green power market depends critically on a number of innovative ways to increase demand elasticity. Dynamic electricity pricing is expected to become more widespread and depends on power demand (kW) whereas it is currently based on the amount of energy (kWh). The introduction of automated systems for energy flexibility offers many advantages to meet the challenge. Nevertheless, completely replacing the decisions of the actors is not the solution, because satisfying individual objectives remains a real challenge, and their disengagement a certain cause of failure of the technical solutions implemented. Demand response programs that may influence consumers towards more flexibility by willfully agreeing to decrease their energy use in response to demand response programs are seen as central in this context (Palensky and Dietrich, 2011) and to present obvious advantages (U.S. Department of Energy, 2006).

It therefore appears important to test whether consumers are able to adapt their energy use and evaluate the extent of their flexibility. Some field experiments testing demand response of households have already been conducted and found that households decrease their energy consumption at home in response to incentives (Faruqui and Sergici, 2010; Ito *et al.*, 2018; Wolak, 2011). For a deeper analysis of incentive effects at home, Bradley *et al.* (2016) use pilot trials to compare alternative financial incentives in relation to the barriers consumers encounter to change their energy use. Another area where energy consumption is at least as important as at home is at the workplace.

However, evidence on workers' demand response in the workplace is still very scarce. The current study thus proposes a small-scale field experiment aimed at evaluating the potential for flexibility of workers in the tertiary sector through their choice for erasing consumption over time.² Two types of demand management exist, depending on whether it is carried out directly on equipment (direct load control), or by the workers themselves via demand response programs (indirect load control) based on load-shedding signals or advisory services. We focus on the impact of load-shedding signals and related incentives on workers' energy use in a building with some devices that are automatically controlled. Our study then provides original results regarding the remaining impact of some incentive policy on human behavior and flexibility at work in an automatically controlled environment, that is intended to develop.

The experiment tests the effect of load-shedding signals for erasing consumption of workers on specific time slots of their working day coupled with incentives: a *honorary contest* or a *monetary tournament*. It took place in a University building with participants being either researchers or technical or administrative staff. The experiment lasted for four months including observation periods without signals nor incentives and two treatment periods with load-shedding signals coupled first with the honorary contest and then with the monetary tournament. On working days when participants were asked to erase their electricity consumption, they were notified by load-shedding signal in the morning indicating the erasure time slot of the day. During this period of time, the participants were instructed to keep their energy use to a minimum. The equipment available was standard for tertiary offices with a computer and its screen, as well as a LED desk lamp. We used a system of communicating sensors allowing real-time data collection. For either type of incentives, the prize was determined by the sum of efforts in energy consumption erasing of the participants to the experiment: the lower the energy consumption on the specified time slots, the higher the prize. In the honorary contest, the winner, i.e. the participant with the lowest energy consumption during the time slots of load-shedding, chose the NGO to whom the prize would be given and her name was publicly broadcast on the screens of the building at the end of the experiment. In the monetary tournament, 50% of the prize was given to the winner and the other 50% went to the other participants. These two types of incentives contrast efforts for social reward and efforts for monetary reward. Both are incentives that have been shown to increase effort: the former calls for self- and social-image motivation (Batson, 1998; Bénabou and Tirole, 2006) – named hereafter *social incentives* – whereas the latter applies the basic principle of economic incentives (Gibbons, 1997; Prendergast, 1999) – named hereafter *private incentives*.

Efforts to save energy in the workplace are characterized by the principal-agent problem because

²France was the first European country to allow consumers to make the most of their load-shedding by using a load-shedding operator without having to obtain the prior agreement of their supplier. A payback mechanism is set up from the erasure operator to the supplier in return for the energy transfer.

the person consuming the energy is not the one who pays for it. As such, it can be difficult to motivate employees to make an energy conservation effort: as while the cost of effort (changing behavior by erasing energy use during specific time slots) is immediate, the direct monetary benefits are rarely passed on to employees, or are distant (reductions in environmental impact) (Kollock, 1998; Platt, 1973). Therefore, it is recommended that demand response signals should be coupled with incentives to change behavior (Jain *et al.*, 2015).³ The honorary contest and the monetary tournament provide such incentives to reduce energy consumption.

Some experiments have explored the effect of social and private incentives on overall energy consumption in the workplace. For instance, Handgraaf *et al.* (2013) show that Social rewards have a greater effect on encouraging energy conservation in the workplace than monetary rewards alone, in particular when feedback is made public rather than private. Other interventions in the workplace have looked at the effect of social comparisons of employees' consumption in relation to colleagues (Murtagh *et al.*, 2013; Ornaghi *et al.*, 2018) and nearby commercial buildings (Charlier *et al.*, 2020) or of changing thermostat defaults on behaviour (Brown *et al.*, 2013). To the best of the authors knowledge, only one paper has explored energy consumption flexibility or demand response in the workplace. Focusing on the consumption of desk lamps, Ida *et al.* (2019) compare employees participation and effort in a demand response program implemented over six peak consumption days. The authors find that while participation in the program is greater if employees are defaulted into the program, greater electricity savings can be achieved using an opt-in performance based incentive. Our study provides additional and complementary evidence about energy load-shedding at the workplace. In this research we indeed investigate the relative effectiveness of incentive mechanisms in terms of employee responsiveness to load-shedding signals, as well as their impacts over time. In particular, this analysis should enable us to assess the capacity for indirect flexibility in a tertiary building. Finally, this experiment has enabled us to design and validate a technological solution for the deployment of such mechanisms, ranging from occupant interaction systems to automatic data processing.

The current paper is organized as follows. Section 2 presents the field experiment, Section 3 provides the data analysis and Section 4 concludes.

2 Field experiment

The field experiment took place in offices of the tertiary sector where we measure the participants' energy consumption and test whether load-shedding signals coupled with social or private incentives change their energy consumption on specific time slots. We first present the working environment and energy consumption, then we detail the experimental design and the incentives and finally, we describe the experimental procedure.

2.1 Working environment and energy consumption

Building The setting for the experiment is a University building showcase for smart energy management as part of the eco-district the Presqu'île in Grenoble (INP, 2018).⁴ The G2ELab's Predis-MHI platform has been designed and developed since 2008 to monitor energy use in real-life situations (Dang *et al.*, 2013). Since 2016, version 2 of Predis-MHI is within the GreEn-ER building and is

³Jain *et al.* (2015) also suggest that high rewards that are uncertain are more likely to reduce energy consumption rather than low certain rewards. In our experiment, one participant receives a higher prize than other ones based on a competitive scheme between the participants. The incentives we use then correspond to high uncertain rewards.

⁴The objective of such eco-districts is to reduce the environmental impact of groups of buildings through the integration of renewable energy sources and the improvement of energy efficiency (Debizet *et al.*, 2016). The latter can be achieved through the optimisation of automated responses to inputs such as daylight availability or exterior temperatures, and less emphasis is placed on the role of the individual. In a review of 15 European eco-districts, Menanteau and Blanchard (2014) find that less importance is given to the behavioural dimension in order to meet energy performance objectives with only two eco-districts allowing for the use of incentives to encourage behavioural changes.

positioned as a living lab in which it is possible to experiment and innovate in connection with the occupants (Delinchant *et al.*, 2016). This 23,000m² building accommodates about 2,000 people, mainly students, but also technical and administrative staff and researchers. The consumption in 2018 was 120kWhEP/m². The share of electricity consumption is preponderant (75%) because only the heating and part of the domestic hot water (kitchen of the university restaurant) are not of electrical origin. Only researchers and technical and administrative staff were eligible to participate in the experiment.

Energy consumption Participants work with a standard equipment available in a "typical" office: a computer and its screen, as well as a LED desk lamp. Such a configuration consumes from 20W to 80W depending on the computer models and the work done (office automation, numerical simulation...).⁵ Our experiment requires the measurement of consumption at the workstation. To do so, it was necessary to deploy a secondary network of sensors.⁶ A system of communicating sensors allowing real-time data collection was preferred to a non-communicating solution. Indeed, as the study period spanned four months, it was deemed necessary to have regular feedback. The communicating sensor selected was the Fibaro WallplugTM. It transmits power up to 2500W on a resistive load, with a sending period that can be configured according to a duration or a power variation. We have configured it to transmit the measured power if it varies from 0.1 W. It also transmits the count of the consumed energy. The transmission is carried out by radio frequency in Z-WaveTM (868MHz). The range of this protocol is limited to a few tens of meters, so it was necessary to repeat the signal to a gateway connected to the Ethernet network of the building. The Fibaro WallplugTM offers this repeater function and therefore allows a good coverage in the building. It is connected between the equipment to be measured and a 230V socket.

A meshed infrastructure has then been set up, both for data transfer and backup. In order to cover the entire building, a Z-Wave/Ethernet gateway was placed on each floor in the form of a Raspberry Pi nanocomputer. The backup system is based on an open source Jeedom software layer installed on each Raspberry Pi. A Jeelink plugin allows us to link the Raspberry Pi computers together, thus allowing us to set up redundant data backup on each floor on all the nanocomputers. Figure 1 schematizes the network of sensors.

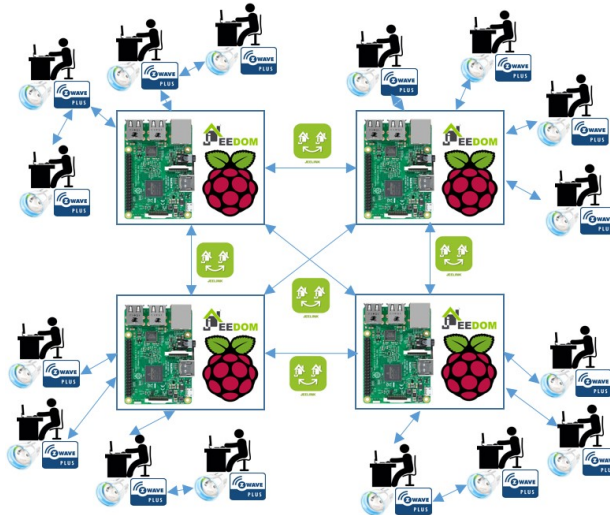


Figure 1: Sensors network

We register energy consumption for each participant with the Jeelink plugin that is individually

⁵The load-shedding potential for 200 offices has been evaluated at 8000W, which remains very low at the scale of the building. Therefore, this study focuses more particularly on the load-shedding methodology than on load-shedding itself.

⁶Despite 1500 sensors in the building, including 300 electrical sensors, individual data per workstation were only available in the Predis-MHI zone, and not for the whole building.

installed. The data report energy consumption for each 15 minutes period for the whole working day.

2.2 Experimental design

Sample Researchers and technical and administrative staff were eligible to participate in the experiment. The number of potential participants was evaluated at 200. The participation rate was 13% with 26 participants enrolled. Those who responded are administrative (11), technical (4), doctoral students (7) and researchers (4). We observe a low response rate for participating in the experiment. One explanation we can put forward may come from our observation of the energy consumption of employees, which they may see as monitoring of their productivity. A second explanation may come from the fact that asking employees not to consume energy could be felt as a hindrance to their productivity.

Treatments We conduct two treatments in a within-subjects design. All participants to the experiment were subject to the two successive treatments. This method allows to observe the impact of the two treatments on the whole sample of the participants.⁷ In both treatments the participants receive a load-shedding signal coupled with incentives to erasing their energy consumption on specific time slots of their working day. Participants were notified with text messages on their phones on the morning of the day of the load-shedding period indicating when they were asked to erase their electricity consumption. During this period of time, participants were instructed to keep their usage (computer and its screen, and a LED desk lamp) to a minimum. Load-shedding periods are either a 45-minutes period during lunch break, or three 15-minutes periods spread over the day. Clearing consumption for 45 minutes during the lunch break allowed us to minimize disruption to the work of employees while exploiting a source of flexibility. The other 15-minute periods could happen during the day as their shorter length would have a smaller impact on the employee work.

The two treatments differ by the type of incentives that are implemented: first, the participants engage in a *honorary contest* (treatment C) and then play a *monetary tournament* (treatment T). Both incentives are based on competition between employees where the size of the prize pool depends on the effort of all participants (see Gershkov *et al.* (2009) for theoretical framework and Bos *et al.* (2016) for direct application). The prize is proportional to energy consumption of all participants to the experiment during the load-shedding time periods: it increases as the energy consumption of the participants decreases to zero during the load-shedding periods of the work day. Specifically, the prize pool is between €0 and €300. It equals €300 if all participants have energy consumption equal to zero during the load-shedding periods, i.e. make the maximum possible effort. If it is higher than zero, the total energy consumption of all participants on all load-shedding periods will be compared to a threshold of energy consumption calculated with optimal modelling.⁸ In both treatments, the winner is the participant with the lowest energy consumption during load-shedding periods. The two treatments are as follows:

- **Treatment C:** in the honorary contest, the winner chooses an environmental NGO to whom the prize pool will be given. She will also see her name publicly broadcast on the screens in the lobby of the building at the end of the experiment. It was indicated that she was the person making the highest effort to participate to the inclusion of renewable energy.
- **Treatment T:** in the monetary tournament, the winner receives %50 of the prize pool and the other participants share the other %50, that makes %50/($n - 1$) of the prize pool for each one (with n being the number of participants).

⁷The within-subjects design is particularly adapted when the size of the sample is limited. We can identify overall effects although this method prevents a proper comparison of the two treatments, because they are not implemented in strict similarity of time.

⁸From previous observations, we calculated that the usual consumption during 7h30 would be a consumption of 365Wh per worker. Thus, if all the participants in the experiment consume 365Wh during the 7h30 of the load-shedding time, the prize is 0. If the consumption is below, the prize P is given proportionally by $P = \frac{x*300}{365*26}$, with x being the sum of the consumption of all the participants during the load-shedding time.

	Treatment C	Treatment T
	Honorary contest	Monetary tournament
<i>45 minutes load-shedding period</i>		
Tuesday - 12:00	October, 9	December, 11
Thursday - 13:00	October, 18	December, 20
Friday - 12:15	November, 9	January, 11
Monday - 13:00	November, 12	January, 14
<i>15 minutes load-shedding period</i>		
Thursday - 11:45/14:15/16:00	October, 11	December, 13
Friday - 10:15/14:00/15:30	October, 12	December, 14
Tuesday - 11:15/14:15/15:30	October, 16	December, 18
Tuesday - 10:15/11:15/14:00	November, 6	January, 8
Thursday - 10:00/11:00/15:15	November, 8	January, 10
Friday - 11:15/14:15/15:30	November, 16	January, 18

Table 1: Date and hour of load-shedding periods in treatments C and T

The two competition incentives are based on two different types of motivation (Bénabou and Tirole, 2006). The honorary contest provides social incentives and appeal to self- and social- image as well as intrinsic motivation which occurs when individuals are internally motivated to do something because it brings them pleasure, moral satisfaction or otherwise. The monetary tournament gives private incentives to increase extrinsic motivation which occurs when external factors such as the environment, remuneration and working conditions intervene. We suppose that energy consumption will be lower during the load-shedding time periods of the two treatments rather than energy consumption in time periods without load-shedding signals and incentives. Our field experiment tests for this hypothesis.

Timing The experiment consists in the two treatments with Treatment C first and Treatment T second lengthening from October 2, 2018 and January, 25, 2019. Each treatment is composed of three phases: (i) first, an observation phase where energy consumption is registered for each participant: from October, 2 to 7 in Treatment C and from December, 3 to 9 in Treatment T; (ii) second, the use of load-shedding signals and incentives (honorary contest in Treatment C and monetary tournament in Treatment T): from October, 8 to November 18 in Treatment C and from December, 10 to January, 10 in Treatment T, with a two weeks break with no load-shedding periods after two weeks of incentives due to school holidays; (iii) third, a second observation phase: from November, 19 to December 2 in Treatment C and from January, 21 to January, 25 in Treatment T. Each treatment included one week of observations, two weeks with load-shedding signals and incentives, two weeks break, two weeks with load-shedding signals and incentives, and finally one week (Treatment T) or two weeks (Treatment C) of observations. No load-shedding period was planned during holidays.

In total, each treatment consisted in four working days with 45 minutes load-shedding periods during lunch and six working days with three times 15 minutes erasure periods during the day between 10:00 and 16:15, for each treatment. The working days with load-shedding periods are on the same week days and at the same time in both treatments. Table 1 summarizes the date and time of load-shedding periods asked to the participants during treatments C and T. We indicate the length of the load-shedding period, the day of the week, the beginning of the load-shedding period and the date.

2.3 Experimental Procedures

We recruited participants by sending emails to the technical and administrative staff and the researchers who have their office in the building. Employees interested to participating in the experiment sent us an email to register. Before the start of the experiment, the participants had to make

an appointment to install the sensors and sign the consent documents to participate in the experiment. They were aware that they could quit the experiment at any moment. A test of each piece of equipment was conducted in order to control for the calibration and the good communication of the sensors. To ensure anonymity of data, each sensor had a randomly generated identifier whose association with the personnel identification was encrypted in a unique file that was guaranteed by one person.

One week before the beginning of the treatment, the participants received by email the instructions of the treatment, with essentially how the diffusion of load-shedding signals is made and how the incentives are set up (how the prize pool is calculated, how the competition winner is determined, and how much participants – or NGO in treatment C – receive). Before sending the instructions for treatment T, we asked the participants whether they wanted to continue the experiment or to stop. 6 participants decided to stop after treatment C. To avoid that the results of the honorary contest pollute behavior in the monetary tournament, the winner in treatment C and in treatment T were revealed at the same time at the end of the experiment.

The prize pool was about €150 in treatment C calculating from a consumption of 4747,6Wh and was given to an environmental NGO. Considering the absent of prize, no winner was announced in treatment T. because the overall consumption greatly exceeded the 365 Watts hour per participant calculated for the load shedding time.⁹ We now present the results of the experiment.

3 Results

3.1 Sample and observations

In total, 26 employees registered to participate in our experiment. Due to unexpected moving, we dropped six employees from our database as their energy consumption remained very low at any period of time meaning that the office was not occupied.¹⁰ This led us with 20 participants in *treatment C*. Six participants decided to stop the experiment after *treatment C* and two participants moved for professional reasons and did not participate in *treatment T*.¹¹ We thus observed 12 participants in *treatment T*.

For data analysis, we consider as observations only days where the worker was at her office: we drop data for working days with a consumption below 80Wh, which corresponds to the minimum possible consumption of three hours a day. We also do not analyze neither data during school holidays because an important number of employees are also in holidays in this period, nor data for the week-ends as these periods are not representative of standard week days.¹² To ease the reader lecture, we present energy consumption as workers' power demand in Watts.

3.2 Individual data investigation

Figure 2 presents the consumption of all the workers during the whole period of the experiment. Every bar represents a working day and every colour represents a participant's power demand during this day. The two large blanks (end of October and end of December-beginning of January) correspond to the weeks of school holidays. Week-ends are also indicated with blanks. We observe higher power demand in December and January rather than in October and November and this difference seems mainly driven by the behavior of few participants.

⁹The consumption of one participant during 7h30 was estimated to be of 365watts hour. The consumption in the treatment T was of 7960,7Wh, representing an average consumption of 442,25Wh.

¹⁰The six employees identified as X14, X16, X17, X21, X23, and X26 were having a total power demand below 1008W during the whole experiment, meaning that they were almost never present.

¹¹The employees identified as X1, X2, X6, X14, X15, and X25 wanted to stop after treatment C and the employees identified as X7 and X19 left their office.

¹²The consumption of the day was indeed for most cases below our threshold of 80Wh during school holidays.

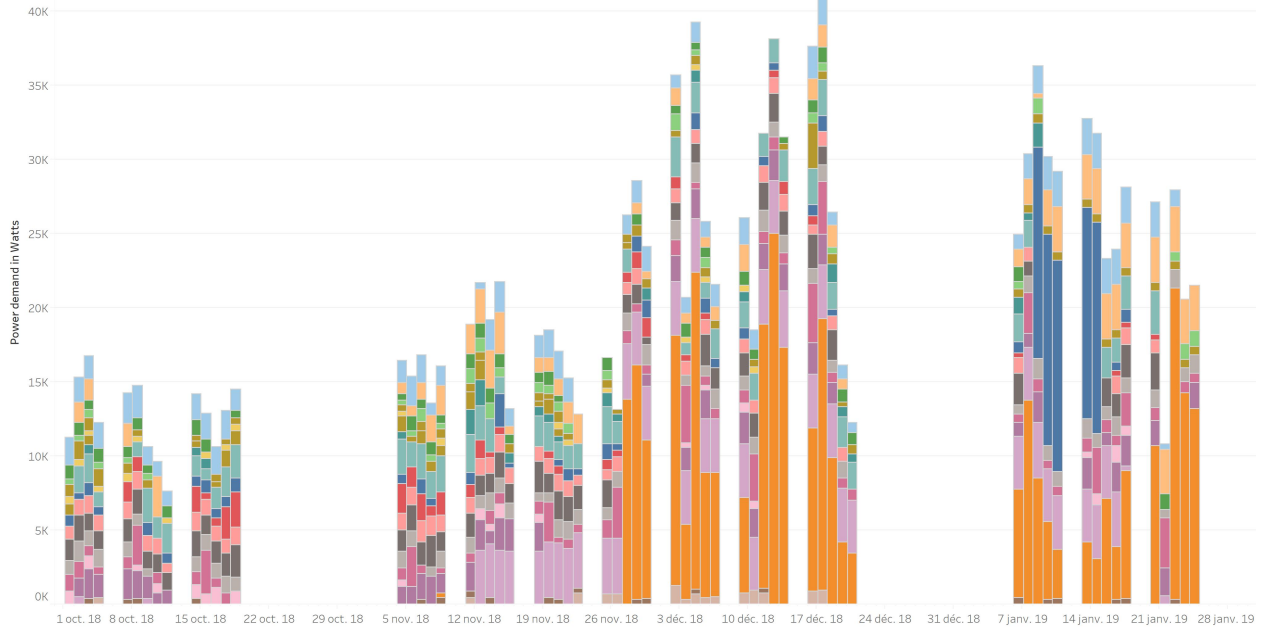


Figure 2: Total power demand per day in watts

A further investigation of the data gives Table 2 that presents, for each treatment, differentiating load-shedding from no load-shedding periods, each participant's average power demand for 15 minutes intervals as well as standard deviation and number of observations. The table emphasizes important heterogeneity in energy consumption behaviors. More specifically, it shows that three participants, X10, X22, X24 (respectively in dark blue, light pink and orange in figure 2), were exhibiting the highest average power demand and were responsible for 56,6% of the consumption during treatment T.¹³ The most extreme energy consumption path is observed for participant X24 who has an average power demand of 287.75 in treatment C and 283,76 in treatment T, which is around 9 times the "usual" average of other participants in treatment T (i.e. excluding participants identified as X22 and X10 in treatment T). Participant X22 presents an extreme behavior as well with an average power demand of 91.08 in treatment C and 93.94 in treatment T. Participant X10 has extreme consumption in treatment T with a power demand of 128.77 but not in treatment C where her power demand is of 22.28. For further analyses we thus exclude participants X24 and X22 for both treatments and X10 for treatment T.

¹³Such a high power demand by these participants may be due to the use of an individual electrical heater. Indeed, during the experiment we were informed that it was very cold in the building during winter in some offices and some workers brought individual electrical heater to warm their offices.

	No load-shedding Period			Load-shedding Period		
	Mean	Sd	Obs. (/1230)	Mean	Sd	Obs. (/30)
<i>Treatment C</i>						
X1	44.35	24.40	1052	45.65	23.57	27
X2	41.41	28.39	738	46.26	28.00	18
X3	22.14	13.32	911	17.69	14.12	24
X4	16.21	14.71	707	9.59	12.98	12
X5	17.10	19.62	953	15.35	11.97	18
X6	11.48	8.61	524	4.51	7.09	15
X7	20.98	18.21	563	16.98	15.00	12
X8	22.05	24.33	459	22.06	24.54	9
X9	50.18	33.96	1017	50.59	33.54	27
X10	22.28	35.11	845	7.95	12.26	18
X11	30.29	30.02	807	35.71	25.07	21
X12	29.58	11.29	1157	30.22	9.91	30
X13	42.02	26.57	1157	46.44	22.72	30
X15	27.93	25.70	1055	21.54	15.32	24
X18	31.03	26.38	986	43.96	31.95	21
X19	20.39	19.69	458	15.81	22.75	9
X20	43.91	27.13	696	27.64	26.34	24
X22	91.08	34.62	573	102.40	0.00	3
X24	287.75	484.66	141	34.93	3.40	3
X25	10.44	6.41	459	5.80	7.80	9
X26	16.74	17.85	177	0.60	0.00	3
<i>Treatment T</i>						
X1	45.46	25.10	876	58.94	17.18	24
X2	57.04	32.50	843	63.28	25.36	21
X3	22.54	14.29	456	8.59	13.07	12
X4	20.69	14.39	393	14.80	0.00	3
X5	18.18	34.36	873	20.48	24.40	27
X6	10.74	8.66	177	0.60	0.00	3
X8	24.71	23.17	282	36.61	17.47	6
X9	53.95	32.99	735	53.45	27.26	21
X10	128.77	174.21	594	214.18	198.95	18
X11	14.61	15.61	351	7.88	14.50	9
X12	26.89	10.88	627	29.90	8.78	21
X13	48.91	30.70	630	43.93	31.93	18
X15	29.83	26.10	1014	27.21	24.71	30
X18	39.93	37.35	1014	46.38	42.90	30
X20	48.74	23.98	771	56.85	18.89	21
X22	93.94	29.40	942	93.53	31.51	30
X24	283.76	472.78	981	707.84	616.47	27
X25	9.79	5.94	279	7.24	6.49	9
X26	20.71	17.89	354	6.14	13.58	6

Note: Participants' numbers in bold are workers who participated in treatment C but stopped afterwards and did not participate in treatment T.

Table 2: Individual power demand for load-shedding and no load-shedding periods, by treatment

3.3 Treatment effects

Additionally to the heterogeneity of energy consumption behaviors, table 2 also shows that several participants have a lower power demand during load-shedding periods rather than during no load-shedding periods in treatment C. In treatment T, among participants registered in this treatment, some also have a lower energy consumption during load-shedding periods, but the number is lower than in treatment C (7 participants in treatment C against 2 participants in treatment T). Incentives for load-shedding periods given through the honorary contest (treatment C) or the monetary tournament (treatment T) then change behaviors. We now investigate the aggregate effect of each type of incentives on power demand of the participants.

Figures 3a. and 3b. present the average power demand depending on whether load-shedding periods were during lunch time or during working time. We separate load-shedding from no load-shedding periods and separate treatments. Every color represents the power demand of a participant. We observe a decrease in power demand during the load-shedding periods for both lunch time and working time in treatment C and only during lunch time for treatment T.

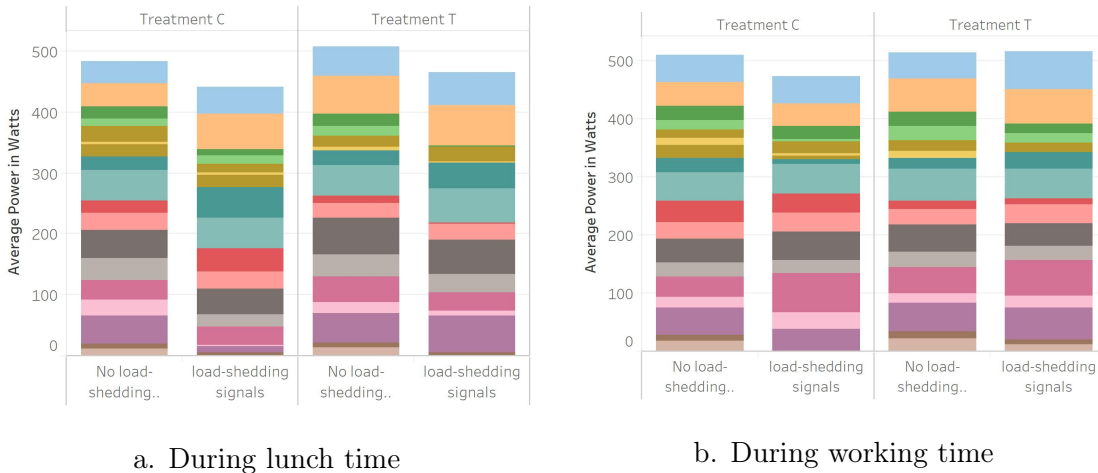


Figure 3: Average power demand by treatment each 15 minutes

To deepen our analysis, we conduct a linear regression to explain individual power demand for each 15 minutes time interval depending on whether it is a load-shedding period or not and controlling for the month, the day of the week, the hour of the day and for individual characteristics using a dummy for each participant.¹⁴ Table 3 presents the results of the OLS estimations.

The regressions confirm that the incentives based on the honorary contest (treatment C) lower power demand during load-shedding periods. We find a significant decrease in power demand about 3.2 Watts during the load-shedding periods in treatment C. Incentives based on the monetary tournament (treatment T) do not significantly affect behavior. Hence, in treatment C, the power demand decreases by 8.5% as compared to the 38.576 average power demand.

As mentioned when analyzing individual data, these results hide a wide range of behaviors regarding the reaction to load-shedding signals. We indeed observe that no subject was able to successfully react to all load-shedding signals (see Figures 4.1 and 4.1 in Appendix presenting, for both treatments C and T, each participant's power demand for every load-shedding signals relatively to their average power demand when there is no load-shedding signal). In treatment C, the most successful participant, identified as X10, was able to decrease her power demand during the 6 days of load-shedding signals over the 6 days she was in the office. Including this participant, 4 participants have a high success rate of 75% of decrease in power demand during load-shedding periods (X6, X10, X15, X20). In addition, 8 participants have a ratio of success in reaction to load-shedding signals ranging from 40 % to 75%. 2 participants have under-performed during load-shedding periods with

¹⁴We pool all the observations instead of conducting a panel analysis because this allows us to consider only days where the worker was present. For robustness checks, we also conducted the estimations with a classic panel analysis that lead to similar qualitative results.

Table 3: OLS regression of the power demand in watts for each 15 minutes interval

	<i>Dependent variable: Power demand in watts</i>	
	Treatment C	Treatment T
Load-shedding Period	-3.214** (1.299)	-1.337 (2.164)
Monday	0.647 (0.617)	7.483*** (1.047)
Tuesday	1.801*** (0.615)	11.335*** (1.126)
Wednesday	-1.600*** (0.612)	0.965 (1.130)
Friday	-2.167*** (0.630)	2.281** (1.149)
November	-0.034 (0.405)	
December		0.992 (0.725)
Constant	38.576*** (1.002)	2.661 (1.907)
Control for each participant		
Control for each hour of the day		
Observations	14,892	6,300
R ²	0.211	0.237
Adjusted R ²	0.209	0.234
Residual Std. Error	23.647 (df = 14860)	27.219 (df = 6276)
F Statistic	127.815*** (df = 31; 14860)	84.603*** (df = 23; 6276)

Note:

*p<0.1; **p<0.05; ***p<0.01

a score below 40% of decrease in power demand. In treatment T, there is no significant impact of load-shedding signals on behavior and a specific analysis of each participant's behavior for every load-shedding periods is not informative. Instead, we discuss the behavior of participant X24, as she accounts for 40% of the power demand during treatment T (see the orange color in Figure 2). Figure 6 in Appendix shows the consumption of this participant during each load-shedding period in treatments C and T. We notice that the Figure starts at the eighth load-shedding period, meaning that nobody was present before. The power demand of load-shedding signals 17 and 18 is surprising as the power demand only rises during the load-shedding period. One can interpret this as a will to consume during the load-shedding period instead of erasing herself. As the prize pool was a function of the energy consumption of everybody, the behavior of X24 prevents any participant to win a positive reward from her behavior.

4 Conclusion and Policy Implications

In this article we show the scientific interest of studying flexibility by integrating users in the control loop. Indirect control by occupants is an important issue in diffuse flexibility, deployed on a large scale. On the one hand, the costs of equipment, installation and maintenance are considerably reduced as compared to an automatic control system, and the potential for flexibility is extended to non controllable equipment. On the other hand, it is important to understand the incentive mechanisms that maximize the effectiveness of flexibility.

We have studied the effectiveness of two types of incentives: a honorary contest and a monetary tournament, among a population of workers in the GreEn-Er tertiary building. Real-time monitoring was implemented with centralized and redundant reporting of anonymous data. These data were processed and then automatically analyzed in order to produce indicators defining the winners of the two treatments and indicators allowing us to analyze the efficiency in terms of energy consumption of the proposed mechanisms. The results show that workers were able to react to load-shedding signals by lowering their power demand when the honorary contest incentives were set up. Therefore, incentives lead to flexibility of workers, provided that they respond to incentives. Indeed, the monetary tournament instead did not lead to a change in behaviors during the load-shedding periods.

Our study has some limitations. We first note that the external validity of our study is weak due to the limited number of participants and then the results must be taken with caution. Nevertheless, we prove that flexibility is possible among workers in the tertiary sector even with a limited control of workers on the devices when incentives are correctly chosen. Our study thus suggests further research in this area with larger scale experiments and wider tests various incentives, monetary or non-monetary (based on moral or social motivations). Second, we faced the inherent difficulty to satisfy the heterogeneity of preferences with automated systems like in new building such as GreEn-ER building. During the experiment we were informed that it was very cold in the building during winter for some offices and some workers brought individual electrical heater to warm their offices. This was a source of discontent for the employees and disagreement with the building manager. This illustrates the need to account for the differences in human preferences in the design of automated system.

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4.1 Appendix

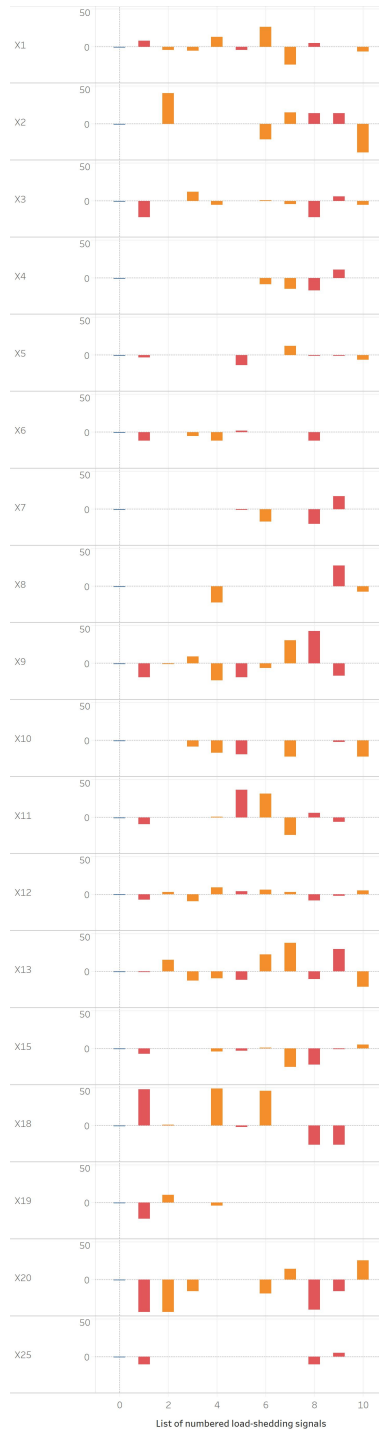


Figure 4: Power demand differences for each load-shedding signals between average power demand for *treatment C*.

In vertical, there are each participants (X1,...,X24). In horizontal, the number from 0 to 10 represents the numbered load-shedding signals in *treatment C*. The load-shedding time "0" is the average power demand when there is no load-shedding signal measured each 15' minutes and is taken as a bases to calculate the differences of power demand with each load-shedding signals. The color orange represents the average power demand when there is load-shedding signal during the day and the color red is during lunch. A missing number represents the absence of the participant in a day where load-shedding signals were sent. Let's take an example : for the participant X1, for the first day of load-shedding signals, the average power demand of the 45' minutes load-shedding during lunch is superior to the average power demand during no load-shedding signal.

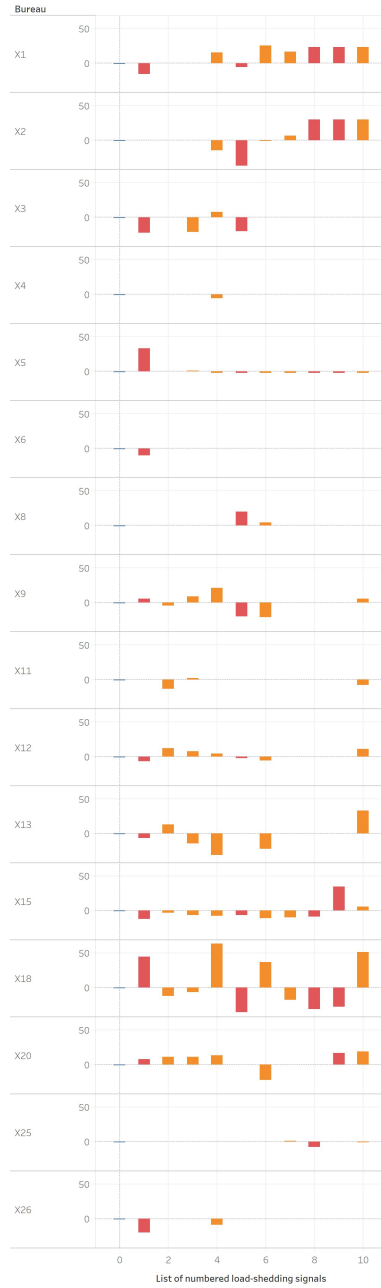


Figure 5: Power demand differences for each load-shedding signals between average power demand for *treatment T*.

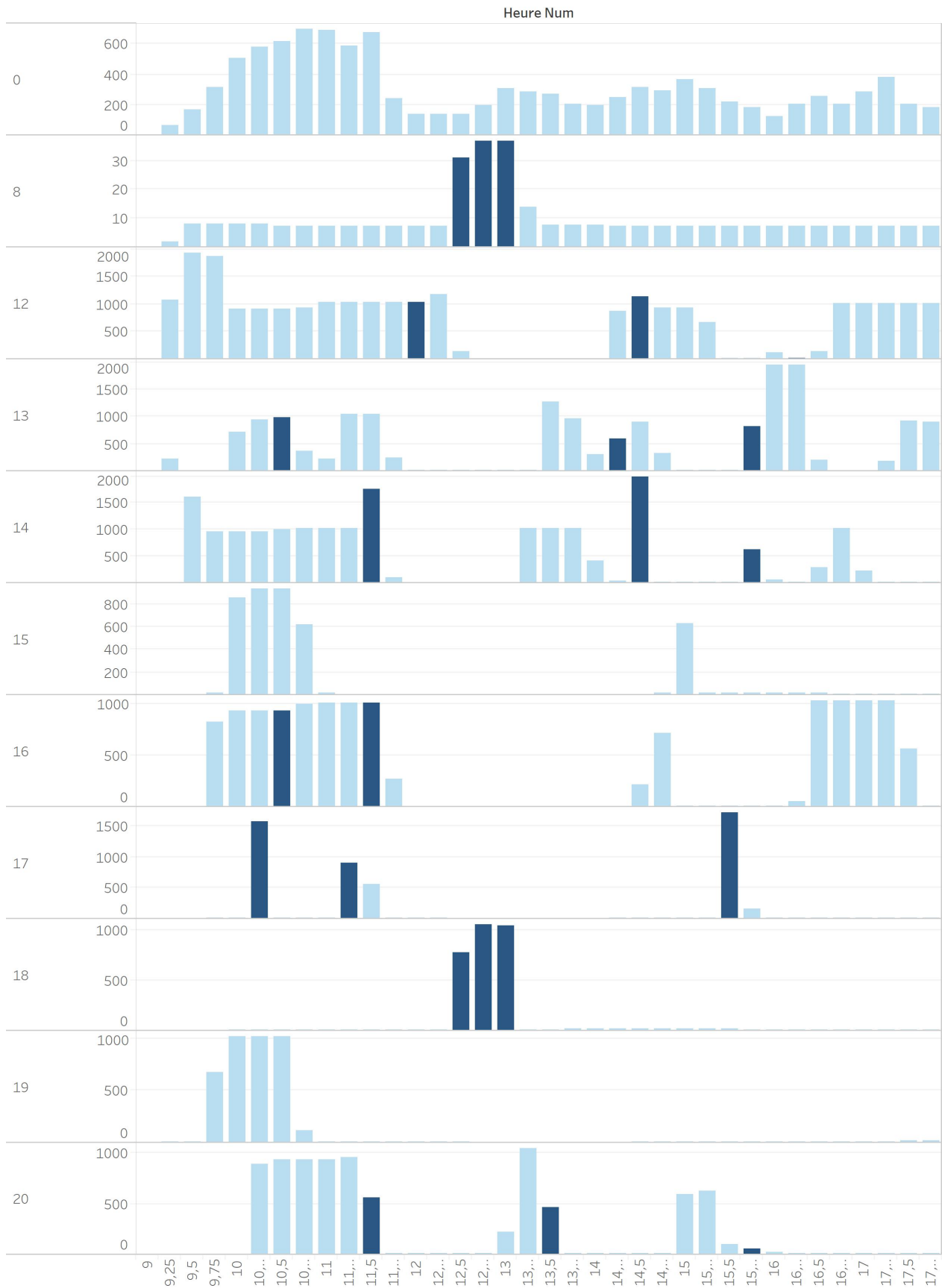


Figure 6: Average power demand measured each 15 minutes for each days with a load-shedding signal (20 days in total). The load shedding time "0" is the average power demand when there is no load-shedding signal. A missing number represents day when a load-shedding signal was sent but the participant was absent, i.e. with a consumption below 80W. In dark blue, the time of the load shedding.