

Closing the Loop - From Citizen Sensing to Citizen Actuation

David N. Crowley*[†]

Digital Enterprise Research Institute*
School of Engineering and Informatics
National University of Ireland, Galway
Galway, Ireland

Email: firstname.lastname@deri.org

Edward Curry*

Digital Enterprise Research Institute*
School of Engineering and Informatics
National University of Ireland, Galway
Galway, Ireland

Email: firstname.lastname@deri.org

John G. Breslin*[†]

Electrical & Electronic Engineering[†]
School of Engineering and Informatics
National University of Ireland, Galway
Galway, Ireland

Email: firstname.lastname@nuigalway.ie

Abstract—“Human-in-the-loop” sensing or citizen sensing as a method for collecting, analysing, and mining information about events is becoming more mainstream. In this work, we aim to utilise the concept of citizen sensors but also introduce the theory of citizen actuation. Citizen sensors observe, report, and collect data – we propose by supporting these citizen sensors with methods to affect their surroundings we enable them to become citizen actuators. We outline a use case for citizen actuation in the Energy Management domain, propose an architecture (a Cyber-Physical Social System) built on previous work in Energy Management with Twitter integration, use of Complex Event Processing (CEP), and perform an experiment to test this theory. We motivate the need for citizen actuation in Building Management Systems due to the high cost of actuation systems. We define the concept of citizen actuation and outline an experiment that shows a reduction in average energy usage of 24%. The experiment supports the concept of citizen actuation to improve energy usage within the experimental environment and we discuss future research directions in this area.

I. INTRODUCTION

Realisations of smart environments such as Smart Cities and Smart Buildings bring the promise of an intelligently managed space that maximise the requirement of users (i.e. citizen commute time, building occupant comfort) while minimising the resources required (i.e. transportation costs, energy costs, pollution, etc.). Smart environments are physical worlds that are interwoven with sensors, actuators, displays and computational elements, embedded seamlessly into everyday objects and connected through a continuous network [1]. The existence of sensors and actuators are a key requirement for the delivery of smart environments, however installing these capabilities is expensive, and a time consuming process with large scale rollouts being a medium to long-term vision. In the near-term, we need an alternative approach if we are to realise Smart Environments.

The Economist in 2010 in relation to the Internet of Things (IoT) said, “Everything will become a sensor – and humans may be the best of all” [2]. This leads to a view of sensors as being ubiquitous and embedded in our everyday environment through our mobile devices and our built environments. This in turn has led to the notion of “human in the loop” sensing and the fields of citizen science and citizen journalism. In turn collecting, analysing, and mining useful information from these citizen reports has led to the creation of the concept of citizens as sensors. Research in this field has included using Twitter as

an earthquake sensor [3] and people tracking bird sightings [4], crowdsourced applications built on User Generated Content (UGC) have exploded in recent years. Applications have also used this content to aid in crisis situations like Ushahidi¹, or in reporting local issues like FixMyStreet².

The contributions of this paper can be summarised as proposing and defining the concept of citizen actuation. We conduct an experiment to examine if our hypothesis that including citizen actuators in an energy management use case would help lower power usage and lower costs. This experiment outlines the design of a Cyber-Physical Social System [5] to test our hypothesis. The paper has the following layout, initially we discuss the concept of citizen sensing. The following section defines citizen actuation how it can supplement citizen sensing and aid in the development of a feedback loop. Then we describe the motivation for this work and experiment in a building management context. After describing our citizen actuation experiment, we display and discuss the results from this experiment. Finally, we discuss our conclusions and future work.

II. CITIZENS AS SENSORS

Citizen sensors are humans posting reports on the Web about events in their surroundings often-through mobile devices or through other Web 2.0 services. Goodchild discusses citizen sensing in the field of Volunteered Geographic Information (VGI) and sees citizens as a network of human sensors with over “6 billion components, each an intelligent synthesiser and interpreter of local information. One can see VGI as an effective use of this network, enabled by Web 2.0 and the technology of broadband communication” [6]. Sheth describes these networks as citizen-sensor networks where an “interconnected network of people who actively observe, report, collect analyze, and disseminate information via text, audio, or video messages” [7]. The author defines the role of these citizen sensors as “humans as citizens on the ubiquitous Web, acting as sensors and sharing their observations and views using mobile devices and Web 2.0 services” [7]. In Sheth’s citizen sensing, the people themselves are acting in a similar manner to physical sensors, but what is being sensed must typically be derived from the texts of their status updates, photo captions

¹<http://www.ushahidi.com/>

²<http://www.fixmystreet.com/>

or microposts. Citizen sensing and crowdsourcing has been applied to a large number of use cases as described in [8].

These events reported on by citizen sensors can be used to describe a model where events are “the basic unit for organizing data and for user interaction” [9]. Jain [10] defines this event driven model as a “human-centered computing system that will give users a compelling experience by combining quality content, carefully planned data organization and access mechanisms”. These events can lead to ad-hoc spontaneous networks that are not necessarily socially interlinked but are connected where such events are described in spatial, thematic, and temporal terms. Events defined by time, space, and location create a link between events and objects where the people involved in an event are linked by object-centred sociality. Shared objects link the spontaneous networks that exist around events. Zengestrom in fact states that “social networks consist of people who are connected by a shared object” [11]. In this case, the shared object is the citizen actuators’ shared environment and more specifically their place of work.

III. CITIZEN ACTUATION

The concept of citizen actuation comes from the need to close the loop started by citizens reporting about events in their surrounding environment. While citizen sensing examines collecting updates and extracting meaningful information, citizen actuation aims to make these reports an actionable item. Citizen sensors [3], [4], [7] in general only sense and report on their surroundings while citizen actuators can sense and act. A

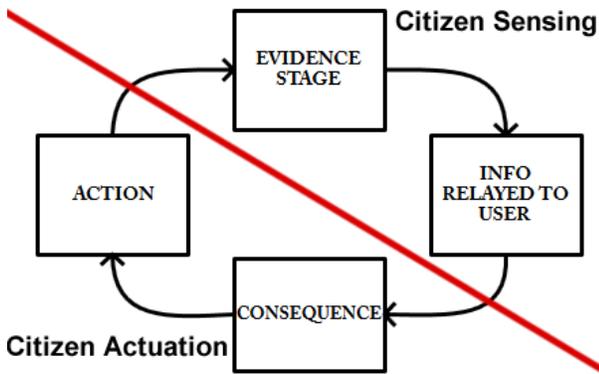


Fig. 1. Feedback loop diagram indicating where citizen sensing and citizen actuation occur

good example of this is FixMyStreet as mentioned previously, this application allows users to report (sense) issues with their locality, and this report is referred to the corresponding local government body. With citizen actuation (depending on the issue reported), the local people that reported the issue could fix the problem (i.e. by collecting litter in their housing estate, painting over graffiti on walls etc.). Fig. 1 displays how the citizen sensing and citizen actuation elements take place and how in conjunction they form a feedback loop. We define citizen actuation as the activation of a human being as the mechanism by which a control system acts upon the environment. Control systems often incorporate feedback loops, a feedback loop can be visualised as in Fig. 1. Feedback loops can be split into four stages, the data acquisition or evidence stage is the first. This

stage collects the data and processes it for presenting to the user. The second stage relays the information to the user with richer context. This can be through visual representations like graphs, signs, or even warnings. A good example of this is a speed sign that measures a car’s current speed displaying it to the driver in comparison to the speed limit. The third stage is consequence, which shows the gain from what the user has reported. The final stage is action, where the user completes an action or makes a choice then this action/choice has a reaction and the feedback loop can restart [12]. By encouraging citizen sensors to interact with their environment, we aim to allow for the creation of a feedback loop where people’s actions will feed back into the loop.

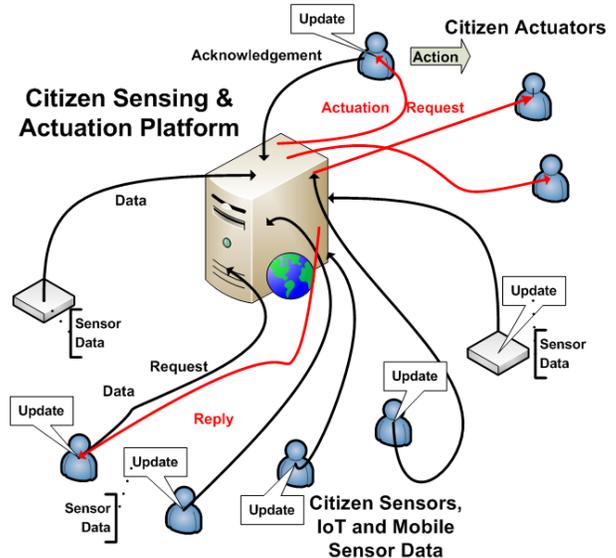


Fig. 2. Citizen Actuators & Citizen Sensors within a Cyber-Physical Social System

Fig. 2 shows a Cyber-Physical Social System including how updates flow from citizen sensors, IoT objects, and mobile sensor data. These updates may contain sensor data, aggregated sensor data from multiple sensors or sensor stations, or citizen sensor updates with or without annotated sensor data attached. Updates are posted to a citizen sensing and actuation platform (evidence stage of the feedback loop) that processes or aggregates and displays them to the users for the information relay stage of the feedback loop. The user then can choose to complete an action or in the case of our specific system send an actuation request to the user. The system then waits for an acknowledgement; if received it returns to the evidence stage of the feedback loop, and replies to the user with thanks. This citizen actuation request and response flow is shown in Fig. 3.

IV. EXPERIMENT

In order to test the concept of citizen actuation we designed an experiment to track energy usage in a designated area in an office-based environment. This experiment ran over a four-week period following a control period of fourteen-weeks.

A. Motivation

The vision of a Smart Building is of one that optimises its internal environment for the comfort and usability of its

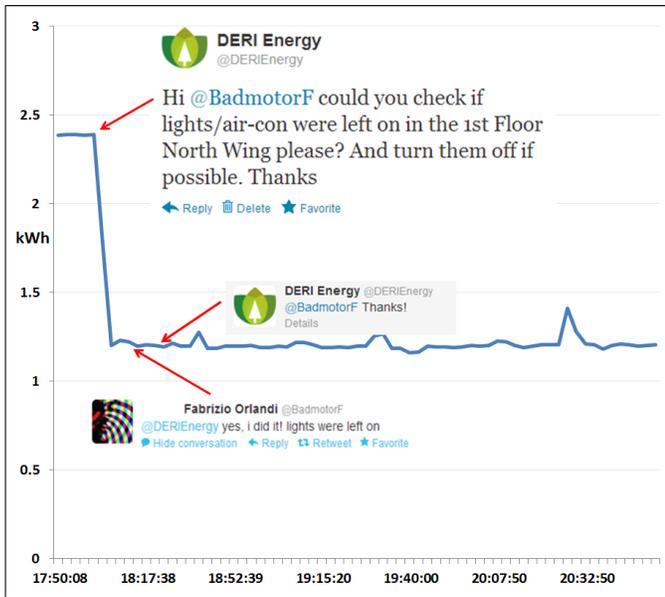


Fig. 3. Actuation Request - Request - Acknowledgment and Task Completed - Thanks

occupants while minimising the resources required to run and maintain the building. Within the context of a smart office building the objective would be to optimise the operation of the building to provide the ideal working conditions to increase staff productivity (i.e. internal lighting, temperature, room CO₂ levels, etc.) while minimising operational costs (i.e. energy consumption, water consumption, CO₂ emission etc.). The heart of a Smart Building is the Building Management System (BMS) and the Building Automation System (BAS) that provide advanced capabilities for the control and management of the building.

These systems rely heavily on the use of sensors and actuation to monitor and control operations (air-conditioning, ventilation, heating, lighting, etc.) within a building. While deploying sensors in buildings is relatively cheap and time effective, and sensors that measure energy usage can be a cost-effective way of monitoring cost in a building. The cost of full management systems is often prohibitive for Small and Medium Enterprises (SMEs) as retrofitting existing buildings is costly and can disrupt business. While BMS and BAS systems are becoming more popular within new building construction, most buildings are not currently equipped with sophisticated building management or building automation systems. The opportunity to reduce energy consumption in these buildings will require the retrofit of such systems at significant cost and time. An alternative lower-cost solution is needed; we believe that citizen actuation can offer this benefit without the need for high-cost installation of building automation equipment.

B. Experiment Setting

In order to study and visualise the effect of citizen actuators we chose to set up an experiment in the Digital Enterprise Research Institute (DERI). DERI is a research institute with about 130 members divided into research streams, research units, and administrative staff. DERI consists of about 20 organisational units. Generally, unit members are co-located

in offices, wings, or floors. For this experiment, we selected one area the North wing on the First Floor as highlighted in Fig. 4 to monitor energy usage patterns and to build a model of energy usage over time. This wing of the building was selected as it contains two smaller meeting rooms and one larger conference room and these rooms are principally used in normal business hours (9am to 6pm). In our experiment, we examined the data from 6pm to 9pm, as this would allow us to track energy usage out of office hours and model energy usage to detect abnormal usage.

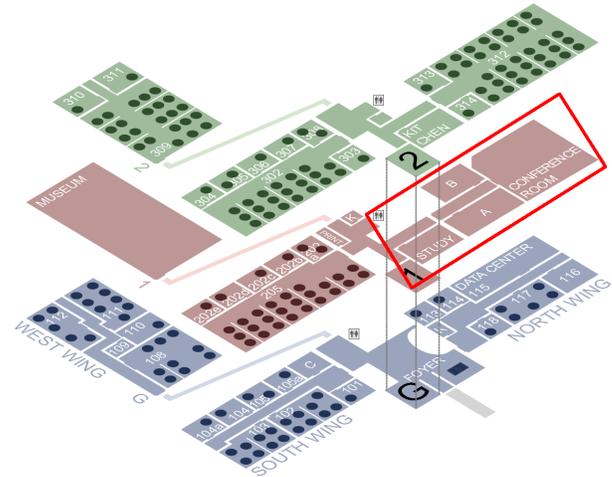


Fig. 4. DERI Floorplan - meeting rooms highlighted in red

C. Experimental Setup

Individuals' seating location and unit membership details are stored in a graph database using the Resource Description Framework (RDF)³ a standard model for data interchange on the Web [13]. This information is stored as per Linked Data principles [14] and is stored with other data relevant to the Linked Energy Intelligence Dataspace [15] and Sustainable DERI Platform [16]. Using this Linked Data representation of members' seating location and the booking schedule for the meeting rooms and conference room, we can both analyse when the meeting rooms are not in use and which individual is normally in close proximity. By modelling energy usage and data on room usage, abnormal usage outside of times when meetings are not scheduled can be monitored. A Complex Event Processing (CEP) system can then be used to process real-time information streams (energy usage sensors) to detect situations of interest (abnormal energy usage) with the use of event patterns. When a pattern is matched, a new higher-level event is generated and can be utilised in further processing, be visualised in a dashboard or sent to other processing tools. By utilising the Semantic Sensor Network ontology [17] to represent the sensors and sensor readings, the readings can be implemented with Linked Data principles in mind and this information can be used by a CEP engine.

For this experiment, a CEP engine as described in [18] detected abnormal energy usage from sensor data as set by a threshold from modelling energy usage over time. This combined with temporal data and information from the room

³<http://www.w3.org/RDF/>

management system allows the system to process the data and create a higher level event, in this case the event can be described as abnormal energy use for both the time of day and room status (booked for a meeting or not). This event then sends a Twitter message to an appropriate user to request the user to check on the issue. This is what we have called the actuation request. Twitter was used due to its available API and relevant heavy usage within the institute. Other platforms were investigated for usage but none had the same usage or availability on devices. Twitter is also highly suited to this experiment because of its ease of posting and lack of barriers to entry. The request took this form:

Hi @username could you check if lights/air-con were left on in the 1st Floor North Wing please? And turn them off if possible. Thanks

The CEP engine then waits for a response from the user and if the user completes the request and replies to the system then the system checks the energy usage and replies to the user with thanks. Fig. 3 displays an example of an actuation request, acknowledgement from a user, and the energy usage.

D. Data Collection

For our experiment, we collected data over a fourteen-week period in November, December 2012, and January, February, March 2013 (discarding holiday days). This fourteen-week period was chosen as our control period/baseline without any citizen actuation requests – this period was chosen as it included the start/end of months to try to cancel any abnormal usage events out; events like project meetings, proposal deadlines, or end of financial reporting periods when meeting rooms would be more heavily used. Weekend data was removed from the experiment, as it would be have been impossible to reconcile this data with data that included actuation requests because at weekends most actuation requests would not be completed, as the users would not be on site. For our experimental data four weeks were used, again we discarded weekends so this data includes twenty days. Fifteen volunteers were selected for the

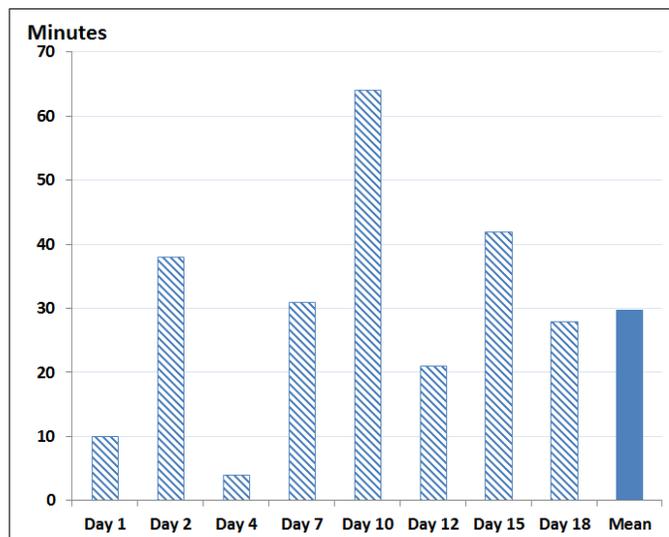


Fig. 5. Time Taken for Actuation to Take Place in Minutes

experiment and for each request; one volunteer was chosen

at random to receive the request. Overall, seven volunteers were sent requests over the four-week period used for the experiment and in total eight actuation requests were sent. In the next section, we will display and discuss the results from the experiment.

V. RESULTS

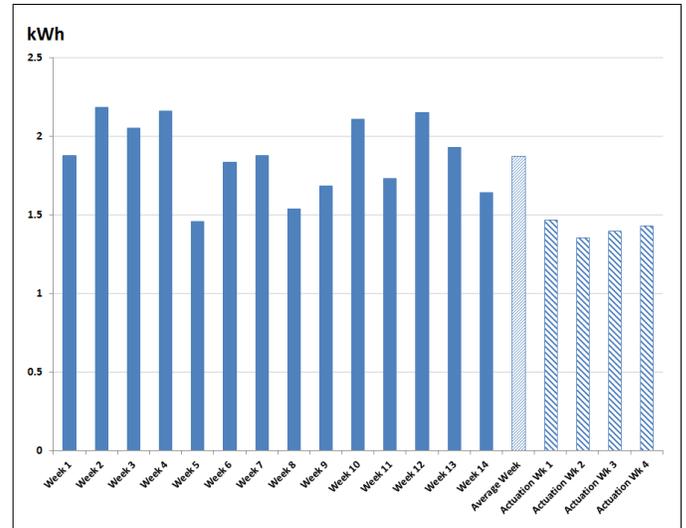


Fig. 6. Average Weekly Energy Usage

The experiment ran from Monday to Friday over a four-week period (twenty working days). During the twenty-day experimental period, eight actuation requests were sent to seven randomly chosen volunteers and in each case, the volunteer completed the requested action. Fig. 5 shows the time to complete the actuation request but does not show data for the days when no actuation request was sent. Actuation requests were sent on eight days and actuation was completed on each of those eight days. These days marked with a * in Table I along with the average energy usage in kilowatt hours⁴ (kWh). The time taken for the actuation to take place varies greatly from a minimum of five minutes to a maximum of sixty-four minutes. From this data, days with actuation have higher averages than days without actuation, this is due to the fact that days with actuation have some time period with higher energy usage than days without actuation (days where everything has been turned off). However, when compared to the average of the control period these days have lower energy consumption. The average time between request and acknowledgment was just under thirty minutes (29.75) as shown in Fig. 5. In this experiment, re-routing of the request was not implemented as a decision was made to only examine the data and chance of success when one request was issued. The success rate was 100% in this experiment when only one request was sent. This will be discussed further in the Conclusion section.

Fig. 6 shows the average energy usage (kWh) over each of the fourteen weeks of the control period, the average of those fourteen weeks and the average energy usage (kWh) in the four weeks with actuation. The actuation weeks' energy usage is lower than all but one of the control weeks (week 5) and the actuation weeks' average usage is 0.4474 kWh lower

⁴http://en.wikipedia.org/wiki/Kilowatt_hour

than the average of the fourteen control weeks. Fig. 7 displays the greater variance between the minimum and maximum energy usage during the control period, while the minimum and maximum of the actuation period is far smaller. On actuated days, the usage could be in part high (before the actuation) but overall the usage would be low (after the actuation) so the minimum and maximum usage would be much closer to the average usage. The difference between the minimum and maximum could also be lessened by lowering the time between the actuation request and the person completing the action.

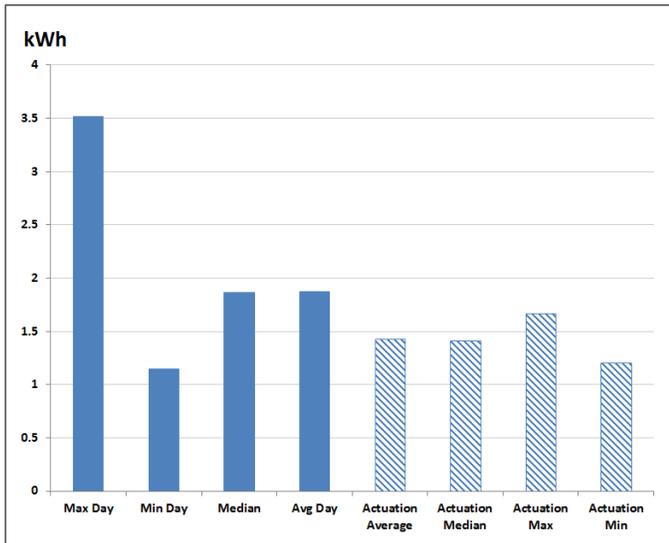


Fig. 7. Daily Energy Usage - Average, Max, Min, Median of control period and actuation period

Fig. 8 shows energy usage of three days, the dotted line represents a sample day taken when every device was turned off manually and checked periodically to get a low baseline for energy usage (this was done before the control period). The dashed line shows the average daily usage from the control period. The solid line shows the actuation day graph from Fig. 3 that shows the energy usage before and after the actuation took place.

Overall, the results show that the energy usage on average declined compared to the control weeks during the weeks that had active participation (experimental weeks) from users which were the weeks these users received actuation requests and completed the actions of turning off electrical components. This saving on average was 0.4474 kWh which when compared to the average energy used in the control weeks of 1.875 kWh; this equates to a decrease of energy usage by 23.86%. Each actuation week's energy usage was equal to or lower in value to the lowest control week (which compared to the other control weeks is considerably lower). This is quite a large drop in energy usage during a time when energy usage should be generally lower. In the next section we will discuss these results and then we will discuss related future work.

VI. CONCLUSION

Our initial hypothesis was that by enabling citizen actuators to interact with their environment in an energy management use-case would help lower power usage and lower costs. This hypothesis would be supported if the energy usage data

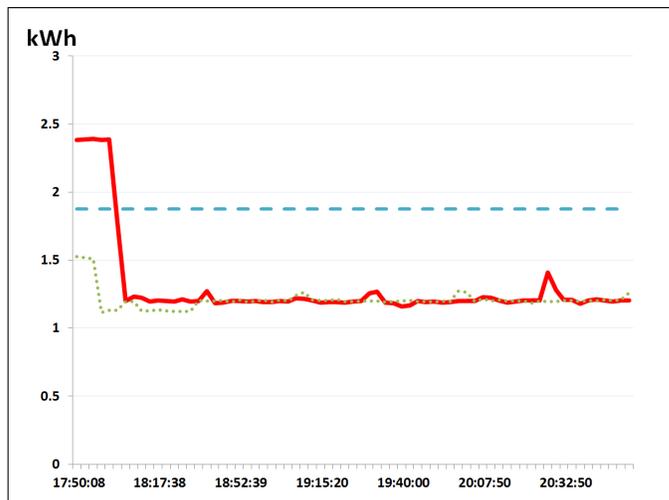


Fig. 8. Energy Usage Comparison - Dashed line is average energy usage from control period, the solid line is energy usage with actuation, and the dotted line is a day when devices were turned off manually

from when citizen actuators were enabled would decrease significantly from the control period. By lowering the average energy usage by 0.4474 kWh the hypothesis is confirmed. A 23.86% drop in energy usage is quite a considerable reduction and if transpose this to financial savings over a year the benefit would be significant. Further research would be needed to show if this is possible in our experimental setup on an institute level or in a larger enterprise environment. Furthermore, other factors that could have been integrated into this experiment, like better education for users or signage encouraging people to turn off electrical apparatus, which has proved successful in other social studies [19].

In this experiment, the actuation request success rate is 100% which may or not always be achievable as people in an enterprise could be travelling/on holidays or not checking their social media accounts. This is why routing and rerouting of requests is an important aspect of future work in this area. Deciding which person is the most likely (according to some optimisation criteria) to complete the request is an interesting question. In an enterprise this criteria could include availability of the person accessed from an internal calendar system. The selection process of citizen actuator, routing, and rerouting of the actuation request could improve the time taken to complete the action requested and would have a beneficial effect on energy conservation in our use case. This could improve the gains in energy conservation by speeding up the time from sending the actuation request to the time the action is completed. There is quite a substantial gain to be made in this area as the completion time in our experiment was just under thirty minutes and this could be lowered considerably. This study examined the hypothesis that introducing citizen actuation, as a component of an energy usage system would enable energy conservation in a research institute environment. The empirical results confirmed the hypothesis and show that an average reduction in energy usage by 23.86% during the experimental period.

TABLE I. AVERAGE KWH BY DAY ENERGY USAGE (* DENOTES A DAY WHERE ACTUATION TOOK PLACE). AVG DAY IS THE DAILY AVERAGE ENERGY USAGE OF THE CONTROL PERIOD

Day	Day 1*	Day 2*	Day 3	Day 4*	Day 5	Day 6	Day 7*	Day 8	Day 9	Day 10*
kWh	1.5359	1.5727	1.2344	1.5984	1.4041	1.2059	1.6658	1.2031	1.3067	1.6484
Day	Day 12*	Day 13	Day 14	Day 15*	Day 16	Day 17	Day 18*	Day 19	Day 20	Avg Day
kWh	1.5901	1.2934	1.2540	1.5731	1.2854	1.4013	1.6251	1.4393	1.4205	1.8749

VII. FUTURE WORK

Future work will examine a longitudinal study to reinforce the results shown in this paper. We would like to broaden the experimental setup to include a larger area in the DERI building or in multiple buildings and widen the participation to a much larger group. In addition to using energy usage sensors the goal would be to widen the scope of the research with the inclusion of other sensors like motion, light, or heat would also create a clearer picture of energy usage and occupancy. Welsh [20] describes issues with sensor networks for scientific experiment especially in creating dense networks especially in built up areas or pre-built buildings so in addition to stationary sensors the presence of mobile device sensors could be utilised to improve the data gained drawing on previous work in [21].

Routing of requests to users that best fit to the requirement of the task is another area of future work – where the initial user to receive the actuation request is chosen by examining multiple selection criteria and if this user does not complete the action then the task will be rerouted to the next most suitable candidate. The choosing of the best candidate might also include other features such as data collected on personal fitness tracking devices/services like Fitbit⁵, Nike+⁶, or mobile phone applications. Fitness and wellness of employees is a concern for enterprise and a person’s step count for that day could be taken into account as one of the criteria for choosing the best fit for the task (i.e. the person with the lowest step count). In separate but related work we have looked at implementing game elements in non-game applications (called Gamification) [22], this could also be examined to see if this can engage users in longer studies and improve gains.

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REFERENCES

- [1] M. Weiser, R. Gold, and J. Brown, “The origins of ubiquitous computing research at PARC in the late 1980s,” *IBM systems journal*, vol. 38, no. 4, pp. 693–696, 1999.
- [2] M. Herring, “A sea of sensors,” <http://www.economist.com/node/17388356>, Nov. 2010.
- [3] T. Sakaki, M. Okazaki, and Y. Matsuo, “Earthquake shakes twitter users: real-time event detection by social sensors,” in *Proceedings of the 19th international conference on World wide web*. ACM, 2010, pp. 851–860.
- [4] B. Sullivan, C. Wood, M. Iliff, R. Bonney, D. Fink, and S. Kelling, “eBird: A citizen-based bird observation network in the biological sciences,” *Biological Conservation*, vol. 142, no. 10, pp. 2282–2292, 2009.
- [5] F.-Y. Wang, “The emergence of intelligent enterprises: From cps to cps,” *Intelligent Systems, IEEE*, vol. 25, no. 4, pp. 85–88, 2010.
- [6] M. Goodchild, “Citizens as sensors: the world of volunteered geography,” *GeoJournal*, vol. 69, no. 4, pp. 1–15, 2007.
- [7] A. Sheth, “Citizen sensing, social signals, and enriching human experience,” *Internet Computing, IEEE*, vol. 13, no. 4, pp. 87–92, Jul. 2009.
- [8] M. N. Kamel Boulos, B. Resch, D. N. Crowley, J. G. Breslin, G. Sohn, R. Burtner, W. A. Pike, E. Jezierski, and K.-Y. S. Chuang, “Crowd-sourcing, citizen sensing and sensor seb technologies for public and environmental health surveillance and crisis management: trends, OGC standards and application examples,” *International Journal of Health Geographics*, vol. 10, no. 1, p. 67, Dec. 2011.
- [9] U. Westermann and R. Jain, “Events in Multimedia Electronic Chronicles (E-Chronicles),” *International Journal on Semantic Web and International Journal on Semantic Web and Information Systems*, vol. 2, no. 2, pp. 1–23, 2006.
- [10] R. Jain, “EventWeb: Developing a Human-Centered Computing System,” *Computer*, vol. 41, no. 2, pp. 42–50, Feb. 2008.
- [11] J. Zengestrom, “Why some social network services work and others don’t - Or: the case for object-centered sociality,” <http://www.zengestrom.com/blog/2005/04/why-some-social-network-services-work-and-others-dont-or-the-case-for-object-centered-sociality.html>, 2005.
- [12] T. Goetz, “Harnessing the Power of Feedback Loops,” http://www.wired.com/magazine/2011/06/ff_feedbackloop/all/1, 2011.
- [13] E. Curry, J. ODonnell, E. Corry, S. Hasan, M. Keane, and S. O’Riain, “Linking building data in the cloud: Integrating cross-domain building data using linked data,” *Advanced Engineering Informatics*, vol. 27, no. 2, pp. 206–219, 2013.
- [14] T. Berners-Lee, “Linked Data-Design Issues,” <http://www.w3.org/DesignIssues/LinkedData.html>, 2006.
- [15] E. Curry, S. Hasan, and S. O’ Riain, “Enterprise energy management using a linked dataspace for energy intelligence,” in *Second IFIP Conference on Sustainable Internet and ICT for Sustainability*, 2012.
- [16] E. Curry, S. Hasan, U. ul Hassan, M. Herstand, and S. O’Riain, “An Entity-Centric Approach To Green Information Systems,” in *Proceedings of the 19th European Conference on Information Systems (ECIS 2011)*, Helsinki, Finland, 2011.
- [17] M. Compton, P. Barnaghi, L. Bermudez, R. García-Castro, O. Corcho, S. Cox, J. Graybeal, M. Hauswirth, C. Henson, A. Herzog, V. Huang, K. Janowicz, W. David Kelsey, D. Le Phuoc, L. Lefort, M. Leggieri, H. Neuhaus, A. Nikolov, K. Page, A. Passant, A. Sheth, and K. Taylor, “The SSN ontology of the W3C semantic sensor network incubator group,” *Web Semantics: Science, Services and Agents on the World Wide Web*, Jun. 2012.
- [18] S. Hasan, E. Curry, M. Banduk, and S. O’Riain, “Toward Situation Awareness for the Semantic Sensor Web: Complex Event Processing with Dynamic Linked Data Enrichment,” in *4th International Workshop on Semantic Sensor Networks 2011 (SSN11)*, Bonn, Germany, 2011, pp. 69–81.
- [19] S. Lindenberg and L. Steg, “Normative, Gain and Hedonic Goal Frames Guiding Environmental Behavior,” *Journal of Social Issues*, vol. 63, no. 1, pp. 117–137, Mar. 2007.
- [20] M. Welsh, “Sensor networks for the sciences,” *Communications of the ACM*, vol. 53, no. 11, p. 36, Nov. 2010.
- [21] D. N. Crowley, A. Passant, and J. G. Breslin, “Short Paper: Annotating Microblog Posts with Sensor Data for Emergency Reporting Applications,” in *4th International Workshop on Semantic Sensor Networks 2011 (SSN11)*, Bonn, 2011, pp. 84–89.
- [22] D. N. Crowley, P. Corcoran, K. Young, and J. Breslin, “Gamification of Citizen Sensing through Mobile Social Reporting,” in *IEEE International Games Innovation Conference 2012 (IGIC)*, 2012, pp. 1–5.

⁵<http://www.fitbit.com/>

⁶<http://nikeplus.nike.com/plus/>