

Leveraging Social Media and IoT to Bootstrap Smart Environments

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Abstract As we move towards an era of Smart Environments, mixed technological and social solutions must be examined to continue to allow users some control over their environment. Realisations of Smart Environments such as Smart Cities and Smart Buildings bring the promise of an intelligently managed space that maximises the requirements of the user while minimising resources. Our approach is to create lightweight Cyber Physical Social Systems that aim to include building occupants within the control loop to allow them some control over their environment. 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 26%. We outline a use case for citizen actuation in the Energy Management domain, propose architecture (a Cyber-Physical Social System) built on previous work in Energy Management with Twitter integration, use of Complex Event Processing (CEP), and discuss future research in this domain.

1 Introduction

Realisations of Smart Environments such as Smart Cities and Smart Buildings bring the promise of an intelligently managed space that maximises the requirement of the users (e.g. citizen commute experience, building occupant comfort) while minimising

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resources required (e.g. transportation costs, energy costs, pollution, etc.). Smart Environments are often taken as the norm in research but in fact the majority of current environments have very little support for sensing or actuation and are far removed from being intelligent environments. The existence of Sensor Actuator Networks (SANs) is a key requirement for the delivery of Smart Environments; however retrofitting SANs into existing buildings is costly, disruptive in business situations, and a time consuming process with large scale rollouts being a medium to long-term vision. Deploying sensors in buildings is relatively cheap and time effective, sensors that measure energy usage can be a cost-effective way of monitoring cost in a building.

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” [27]. We envision by combining these already deployed sensors in buildings and through employing systems extensively utilised on the Social Web such as microblog services that the Social Web will act as an enabling layer, the “social glue” between the Cyber-Physical System (CPS), government agencies, and the community. Whether that community is a city, town, a group of interested citizens, or a group formed around a social object, these groups when connected through social connections or objects [40] can be envisaged as systems and as a whole as a System of Systems (SoS). In the near-term, we need an alternative approach if we are to realise Smart Environments. Our alternate approach builds on an Internet of Things (IOT) architecture, Linked Data, and Social Media and coupled with our key concept of citizen actuation to create a Cyber-Physical Social System (CPSS) to reduce energy costs and aims to keep humans “in the loop”. To test the concept of citizen actuation we conducted an experiment to examine if our hypothesis i.e. including citizen actuators in an energy management use case would help lower energy usage and during the test period energy usage was lowered by 26% on average.

2 Smart Environments

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 [38] or a small world where different kinds of smart device are continuously working to make inhabitants’ lives more comfortable [11] where a smart device is an electronic device, generally connected to the Internet or other networks through WiFi, 3G, or other protocols usually with a display and now commonly with touch or voice activated controls. As people, things, and the world gets more interconnected the vision of smart environments has moved into reality and the interlinking of these physical worlds as Weiser describes them allows for the creation of larger systems or System of Systems which integrates systems into complex systems that offer better functionality and performance than simply the sum of the constituent systems [28]. In the next two sections, we will examine two separate smart environments that, while different, encapsulate the challenges within this research area. We will then discuss the challenges in smart environments.

2.1 Smart Buildings

Defining what Smart Buildings are is inherently difficult as definitions rely on the concept of Building Automation Systems (BAS). BAS is an example of a control system that controls building elements or other systems such as electrical systems, fire, security, heating, and air conditioning. Snoonian states that for BAS to be effective, any automation system must enable all these mechanical and electrical systems to work from a single building control point [36]. The vision of a Smart Building is of one that optimises its internal environment for the comfort and usability of its 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 (e.g. internal lighting, temperature, room CO₂ levels, etc.) while minimising operational costs (e.g. 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. Sensors that measure energy usage can be a cost-effective way of monitoring energy costs 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.

2.2 Smart Cities

Caragliu et al believe a city to be smart when investments in human and social capital and traditional (transport) and modern Information and Communications Technology (ICT) infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance [9]. This is a very holistic view of a Smart City where services are integrated and humans are involved through participatory governance. Deploying urban sensor networks, while costly, is a realistic goal and some cities and countries are already investing heavily in smart energy grids, traffic monitoring sensors, weather stations, and parking

sensors to help manage the city. Research projects such as Smart Santander¹ are trying to realise the dream of a technologically smart city. While this technologically is a step forward it does not include any social data from inhabitants of the city. Concurrently there is also research looking at mobile social reporting applications that allow citizens to report on issues within their local environment [13] and IBM's Smarter Cities research aims to incorporate social elements.² In our research, we aim to allow people (building users or people living in an area) the opportunity to both report but also to be active in fixing the issues in their environment and this has led to the creation of the concept of citizen actuators.

2.3 Challenges

Integration of services and data from multiple sources from control systems (traffic, electrical, and emergency services), sensor networks, and social data is a serious challenge for large-scale smart environments. Interoperability between these systems is huge problem, aggregating data from proprietary software, legacy systems, and new systems can have a high cost. Linked Data discussed in Sect. 4 describes in detail an approach for data management by aggregating and linking heterogeneous data from various sources and transforming them to Linked Data. Sensor data can be represented in many formats like SensorML, Observations, and Measurements (OM) from the Open Geospatial Consortium (OGC), and more recently the W3C Semantic Sensor Network (SSN) ontology. The SSN ontology merges the concepts from SensorML (sensor focused), the OGC OM (observation focused), and system models. It develops a general representation of sensors and relies on upper-level ontologies to define the domain, and an operation model that describes the implementation of the measurement. The representation of a sensor in the ontology links together what it measures (the domain), the physical sensor (the grounding) and its functions and processing (the models) [10]. In this work, Linked Data principles were adhered to and play an important role in integrating data from over ten legacy systems, sensor data, and social data.

Improving energy performance, especially through changing the way an organisation operates, requires a number of practical steps, which will include the need for a systematic and holistic approach for information gathering and analysis. Creating a holistic view of energy information for an organisation is not a straightforward task; the complexities of real-world organisations mean they use energy in many different ways. Energy Intelligence platforms need to support four key requirements:

- Holistic energy consumption
- Multi-level energy analysis
- Business context Energy Consumption

¹ <http://www.smartsantander.eu/>

² http://www.ibm.com/smarterplanet/ie/en/smarter_cities/overview/index.html

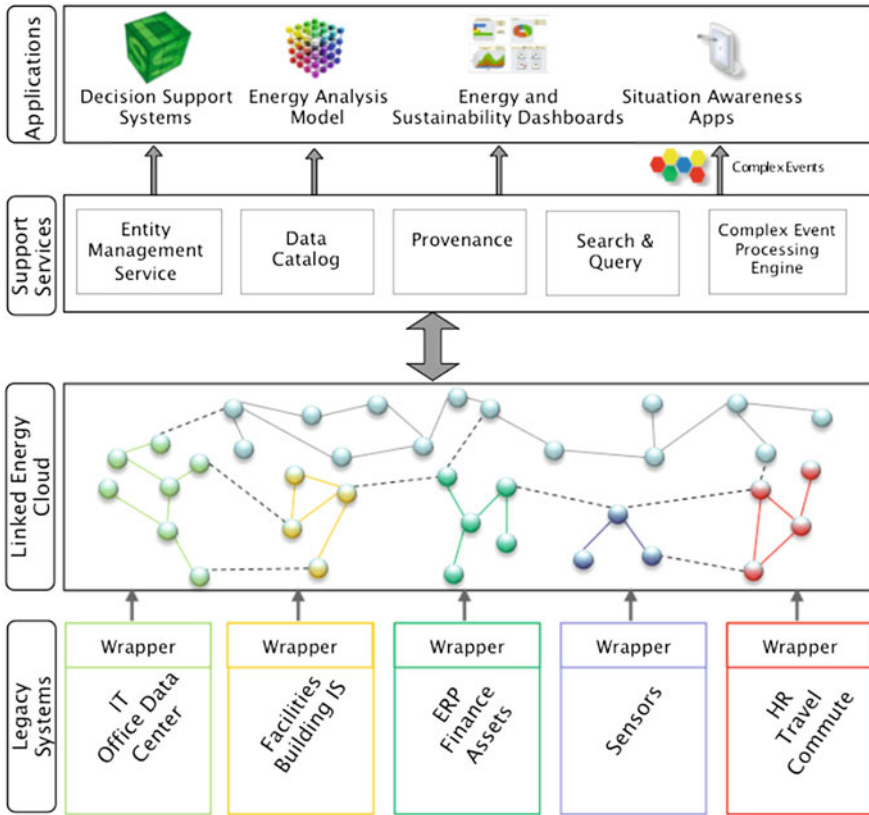


Fig. 1 Linked dataspace for energy intelligence

- Energy situational awareness

Implementation of these goals is described in [16] uses Linked Data to allow connection of multiple data sources including human resources systems, sensor networks, facility management, and finance systems to create a Linked Dataspace for Energy Intelligence as shown in Fig. 1. Our approach concentrated on energy situational awareness to allow building occupants to become actively involved in energy management and to play an important role in lowering energy consumption. A key element in improving building control systems in existing structures is installing SANs and while embedding sensors into an environment can be relatively cost-effective, the cost of installing actuation systems can be prohibitive (for example installing automated windows generally requires the replacement of the existing windows). In our experiment, we examined lowering energy usage within a building environment that had energy usage sensors but no form of automated actuation. Using IoT technologies and leveraging social media platforms we aim to bootstrap smart environments by developing light-weight CPSS that encourage (building or

environment) users to become part of the system. The concept of “bootstrapping” in computing originated with Engelbart describing bootstrapping systems where a system or a set of systems take in feedback from the output and feed it back in to improve the system [22]. Engelbart [21] saw the computer as a supportive device and envisaged explicit co-evolution of tool-systems and human-systems. We see this co-evolution as linking together the occupant and the existing control systems and aim to get closer to the “ideal system that links the building, systems within it and the occupants so they have some degree of personal control” [32].

3 The Rise of Social Media

We define Social Media as any web based service that acts as a means of interaction among people in which they create, share, and exchange information and ideas in online communities and networks. This definition is very close to Boyd et al.’s definition of social networks sites as web-based services that allow individuals to

1. construct a public or semi-public profile within a bounded system
2. articulate a list of other users with whom they share a connection
3. view and traverse their list of connections and those made by others within the system [3]

In this work, Social Media is used as a communication method using Twitter³ as the social channel. Twitter fits both the definition of Social Media and of Social Network Sites and Twitter while matching the characteristics of a social network it has been found to have similarities with news media [30]. Twitter was chosen due to its high use in the community chosen for the experiment described later. Other forms of communication were considered during the design process such as Facebook,⁴ internal email, and other social media platforms. Internal email was considered too formal a mode of communication as this email is used for college communication and research. Facebook’s communication mechanism did not have the directness needed beyond participant mentioning. Other networks did not have the user penetration in the participant community.

In the past ten years, we have seen the growth of online social networks and an explosion of user-generated content on the Web, in particular published from mobile devices. For example, a popular microblogging platform Twitter was founded in 2006 with an extremely fast growing user base with 175 million users⁵ by October 2010 and about 340m posts processed per day as of March 2012 with 140m active users.⁶ The ease of posting to services like Twitter while attaching data such as

³ <http://twitter.com/>

⁴ <https://www.facebook.com/>

⁵ <http://www.pcmag.com/article2/0,2817,2371826,00.asp>

⁶ <http://blog.twitter.com/2012/03/twitter-turns-six.html>

pictures, videos, and links significantly contributes to the growth in the volume of user-generated content.

In this work, it is a uni-directional communication between the building occupant and the system but in future work we would like to allow users to post photos issues or problems [7, 13] which would hopefully engage users more with the system. Social media platforms could also offer building-users the ability to view the energy consumption of the building and offer comment if the consumption is unexpectedly high through dashboards and social media platforms. Knowledge can also be shared by gauging people's experience with an environment and their reaction to changes to that environment.

3.1 Citizen Sensing

The concept of citizen sensing [25, 35] classed as opportunistic sensing where people report on issues or events in their surroundings and this information is then analysed to try to create insights into these events. In participatory sensing [8], the person "opts in" to send data concerning some task or request, for example eBird [37] (a real-time, online checklist program, eBird has revolutionized the way that the birding community reports and accesses information about birds⁷). In Sheth's citizen sensing, the people themselves can be seen as 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, or microblog posts [35]. Sheth 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" [35]. Citizen sensing and crowdsourcing have been applied to a large number of use cases as described in [29]. Research has examined concepts of a "sensor tweeting standard" and tweet metadata [15, 20] to embed structured metadata into Tweets. As discussed previously the goal of this work is to allow both citizen sensing and actuation in smart environments.

3.2 Citizen Actuation

This notion of "human in the loop" sensing has led to the creation of the concept of citizen actuation [14], where people can report on their surroundings but when these reports are combined with other data sources then actionable requests can be constructed and sent to users. While citizen sensors [33, 35] only sense and report on their surroundings, citizen actuators can sense and act. The concept of citizen actuation comes from the need to close the loop started by citizen's reporting about events in their surrounding environment. While citizen sensing examines collecting

⁷ <http://ebird.org/content/ebird/about/>

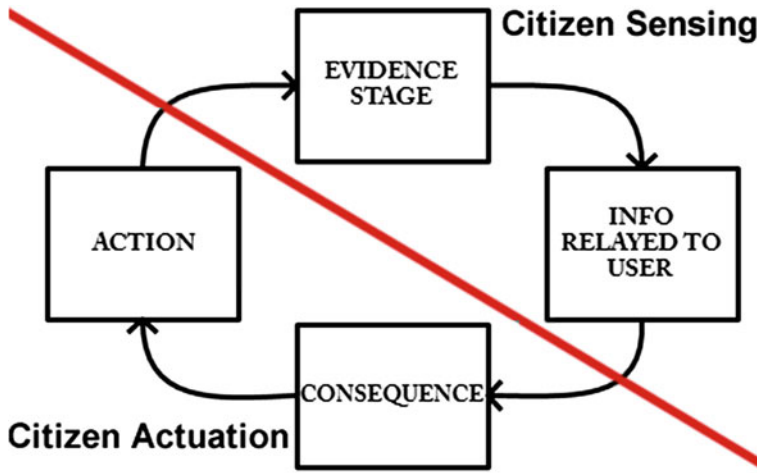


Fig. 2 Feedback loop diagram indicating where citizen sensing and citizen actuation occur

updates and extracting meaningful information, citizen actuation aims to make these reports an actionable item.

A good example of this is FixMyStreet, 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 (e.g. by collecting litter in their housing estate, painting over graffiti on walls etc.).

Figure 2 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. 2. 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 [24]. 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.

Feedback has been examined as a method of lowering energy consumption in multiple studies [7, 12, 23, 34]. These studies vary in success from zero reduction in energy consumption to some reporting a saving of 20%, usual reported savings are between 5 and 12% [23] in household studies. The feedback methods used range

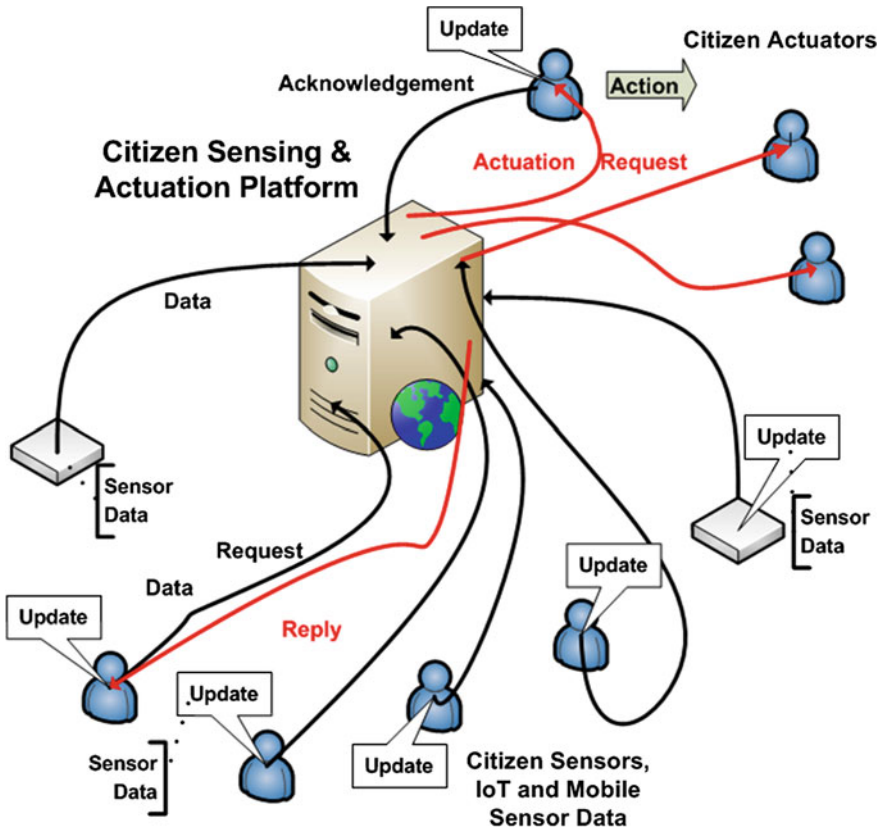


Fig. 3 Citizen actuators and citizen sensors within a cyber-physical social system

from feedback incorporated into an electricity bill to electronic feedback through a web interface or a smart meter. In designing our experiment discussed in Sect. 5 we examined the literature on feedback as our experiment can be seen as a kind of active or directed feedback using social media as the delivery channel and smart meters and similar devices can be seen as passive or undirected feedback. Our feedback can be described as active or directed as all the participants were individually messaged through social media.

Figure 3 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 acknowledgment; 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. 5. We define citizen actuation as the activation of a human being as the mechanism by which a control system acts upon the environment. In our use case of energy management in a building, we deploy citizen actuators to try to lower energy usage.

4 Linked Data

Sharing data between data stores using different versions, systems, and storage methods is inherently difficult. By integrating data from multiple sources, like social data, sensor data, human resources data, and building data using web standards we can both share and use this data in lightweight CPSSs. Web standards can simplify access to data and enable the sharing of large quantities of data on the Web. The Resource Description Framework (RDF)⁸ standard provides a common interoperable format and model for data linking and sharing on the Web. Linked Data is a best practice approach for exposing, sharing, and connecting data on the Web based upon W3C standards [2]. Linked Data has the following characteristics:

- Open: Linked Data is accessible through an unlimited variety of applications because it is expressed in open, non-proprietary formats.
- Modular: Linked Data can be combined (mashed-up) with any other pieces of Linked Data. No advance planning is required to integrate these data sources as long as they both use Linked Data standards.
- Scalable: It is easy to add and connect more Linked Data to existing Linked Data, even when the terms and definitions that are used change over time.

We propose that RDF and Linked Data provide an appropriate technology platform to enable the sharing of cross-domain information relevant to the operation of a building. We propose that as we move data to the cloud, Linked Data technology offers a viable medium for the sharing and reuse of data across silos. Whether it is the integration of multiple energy management systems, billing systems, building management systems, or spreadsheets, Linked Data offers a method of exposing, sharing, and connecting data in a manner that is reusable and not a one-off integration solution. Linked Data's characteristics that enable this sharing of cross domain data is derived from Linked Data publishing practices [1]:

- Use URIs as names for things: the use of Uniform Resource Identifiers (URI) (similar to URLs) to identify things such as a person, a place, a product, a organization, a building, a room, an event or even concepts such as risk exposure or net profit, simplifies reuse and integration of data.
- Use HTTP URIs so that people can look up those names: URIs are used to retrieve data about objects using standard web protocols. For a person this could be their

⁸ <http://www.w3.org/RDF/>

organization and job classification, for an event this may be its location, time, and attendance, for a product this may be its specification, availability, price, etc.

- When someone looks up a URI, provide useful information using the standards: when someone looks up (dereferences) a URI to retrieve data, they are provided with information using a standardized format. Ideally in Semantic Web standards such as RDF.
- Including links to other relevant URIs so that people can discover more things: retrieved data may link to other data sources, thus creating a data network e.g. data about a product may link to all the components it is made of, which may link to their supplier.

This integration of data from different sources allows integration of social data, IoT data, and building management data to be easily reused in building energy management. This linking of social data and sensor data has been proposed by Breslin et al. previously [4] and can be achieved by linking lightweight social data models like Semantically Interlinked Online Communities (SIOC) [5], Friend of a Friend (FOAF) [6], and Semantic Sensor Network (SSN) ontology [10].

5 Use Case

In order to study and visualise the effect of citizen actuators we chose to set up an experiment in the Digital Enterprise Research Institute.⁹ (DERI) part of National University of Ireland, Galway¹⁰ 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 located 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.

Individuals' seating location and unit membership details are stored in a graph database using RDF, a standard model for data interchange on the Web [19]. This information is stored as per Linked Data principles [1] and is stored with other data relevant to the Linked Energy Intelligence Dataspace [18] and Sustainable DERI Platform [17]. 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

⁹ <http://www.deri.ie/>

¹⁰ <http://www.nuigalway.ie/>

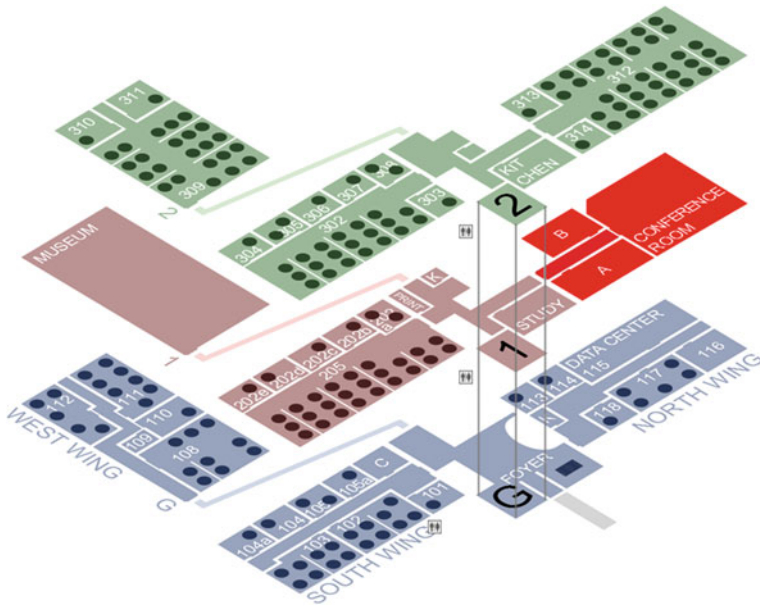


Fig. 4 DERI floorplan—meeting rooms highlighted in *red*

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 [10] 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 [26] 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 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

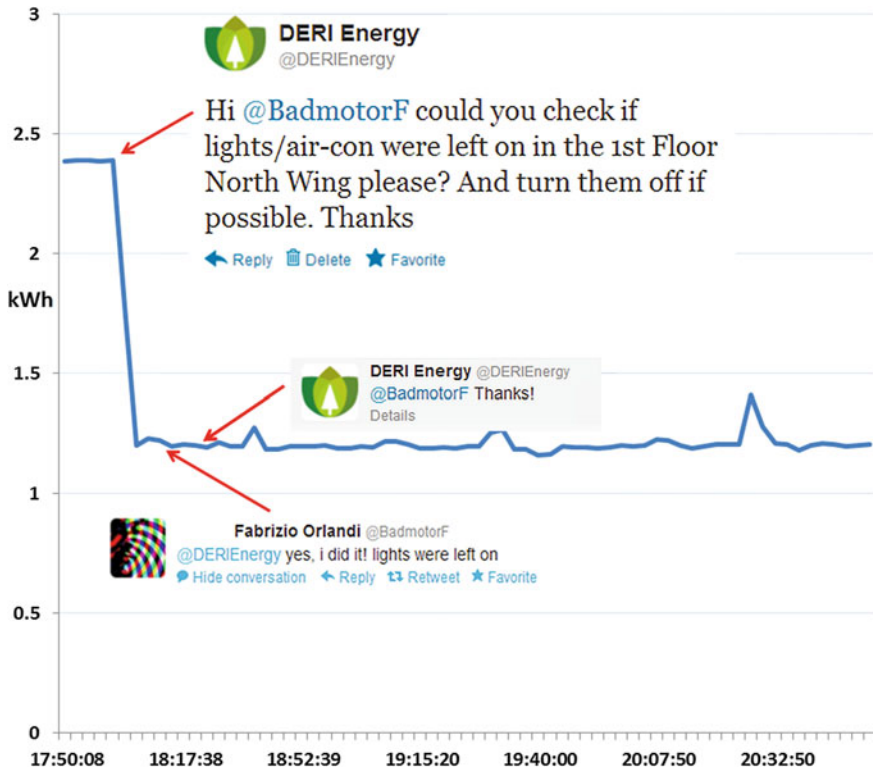


Fig. 5 Actuation request–request–acknowledgment and task completed–Thanks

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. Figure 5 displays an example of an actuation request, acknowledgment from a user, and the energy usage.

We designed an experiment that included citizen actuators in a Cyber-Physical Social System to test our hypothesis that citizen actuation could help to lower energy usage. For our experiment we collected data over a thirty two week period from November 2012 to August 2013. A control period of thirty-two weeks without any abnormal interference was chosen. 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 impossible to reconcile this data with data that included actuation requests because at weekends most (if not all) actuation requests would not be completed, as the users would not be on site. Fifteen volunteers were selected for the experiment and for each request; one volunteer was chosen at random to receive the request.

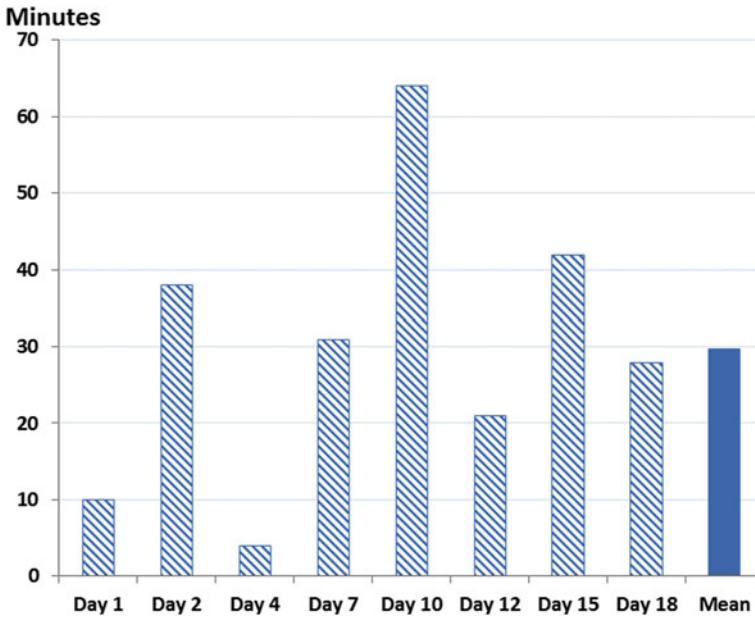


Fig. 6 Time taken for actuation to take place in minutes

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.

6 Results

The experiment ran from Monday to Friday over a four-week period (twenty working days excluding weekends). 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. Figure 6 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 when actuation requests were sent are marked with a* in Table 1, this table also displays the average energy usage in kilowatt hours¹¹ (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

¹¹ http://en.wikipedia.org/wiki/Kilowatt_hour

Table 1 Average kWh by day energy usage

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	1.93

*Denotes a day where Actuation took place. Avg Day is the daily average energy usage of the control period

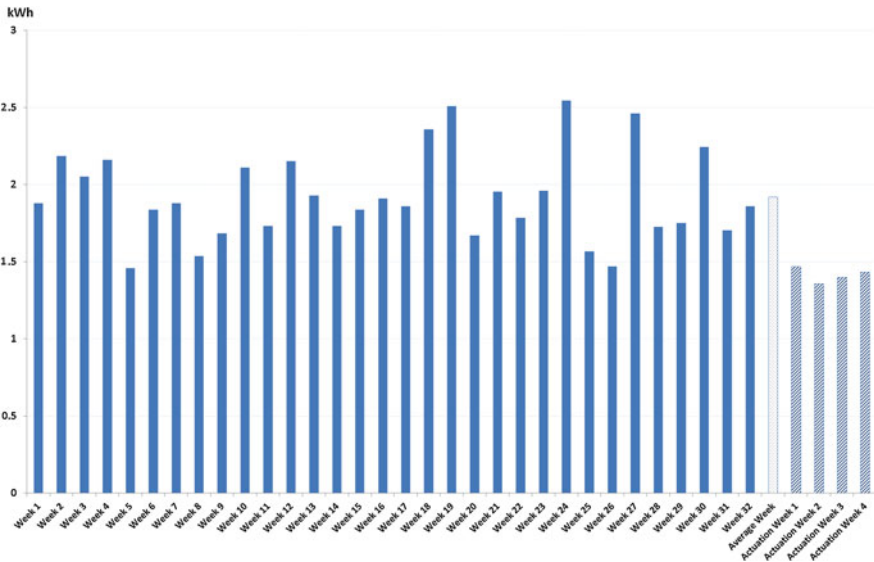


Fig. 7 Average weekly energy usage

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. 6. 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 Sect. 7.

Figure 7 shows the average energy usage (kWh) over each of the thirty-two weeks of the control period, the average of those thirty-two 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 0.503 kWh lower than the average of the thirty-two control weeks. Figure 8 displays the greater variance between the minimum and maximum energy usage during the control period, while the variance in the minimum and maximum

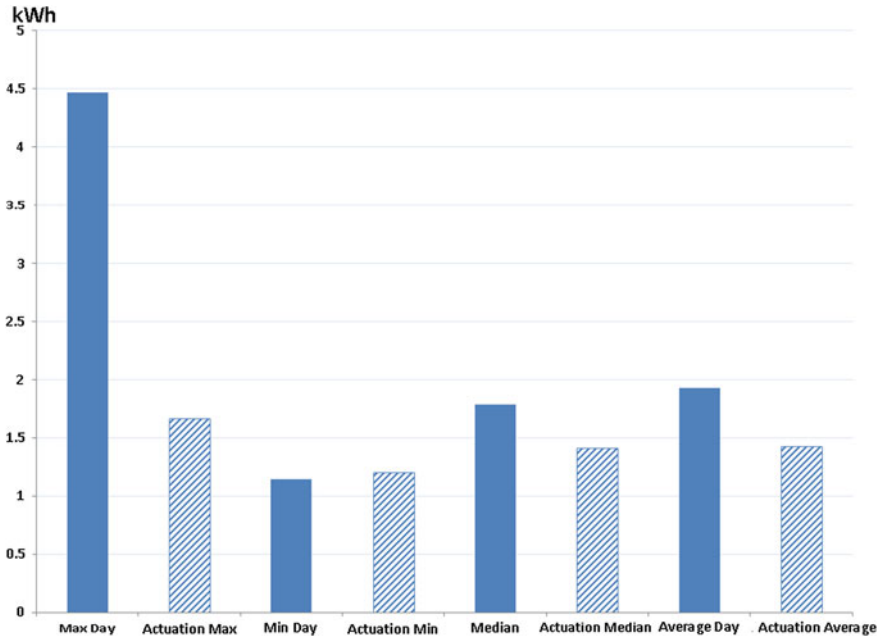


Fig. 8 Daily energy usage—average, max, min, median of control period and actuation period

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.

Figure 9 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. 5 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 0.503 kWh which when compared to the average energy used in the control weeks of 1.93 kWh; this equates to a decrease of energy usage by 26%. Each actuation week's energy usage was equal to or lower in value to the lowest control week apart from one 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 as the rooms are not in use. In the next section we will discuss these results and then we will discuss related future work.

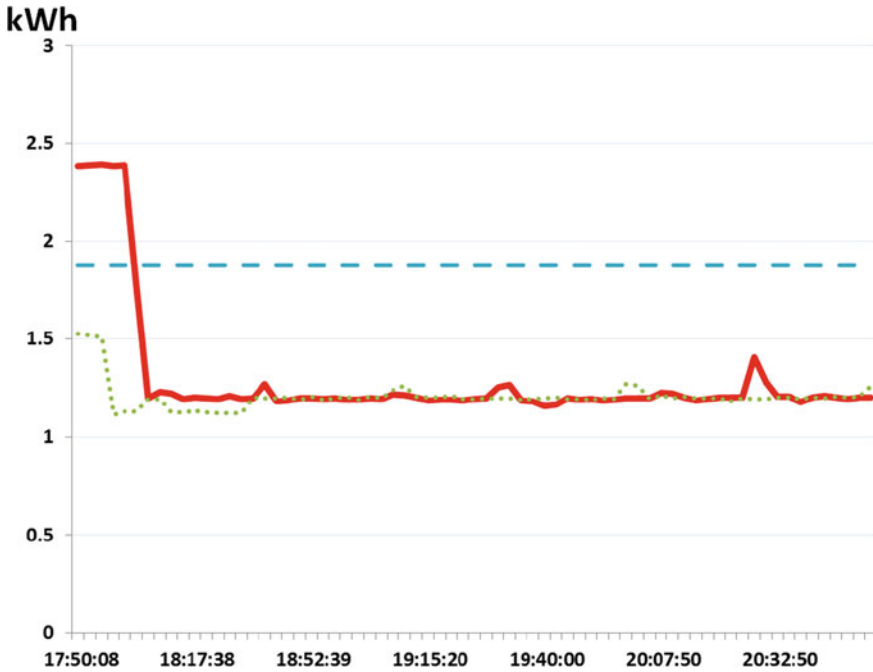


Fig. 9 Energy usage comparison—*dashed line* is average energy usage from control period, the *solid line* is energy usage with actuation, and the *dotted line* is a day when devices were turned off manually

7 Conclusion

Our initial hypothesis was that 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 from when citizen actuators were enabled would decrease significantly from the control period. By lowering the average energy usage by 0.503 kWh the hypothesis is confirmed. A 26% drop in energy usage is quite a considerable reduction and if transposed 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 [31].

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 26 % during the experimental period.

8 Future Work

Future work will examine a longitudinal study to reinforce the results shown in this chapter. 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 [39] 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 [15]. The integration of a reporting system to allow building occupants to post about issues in their environment is also being examined for future work. In separate but related work we have looked at implementing game elements in non-game applications (called Gamification) [13], this could also be examined to see if this can engage users in longer studies and improve gains. 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 Fitbit¹², Nike+¹³ 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 (e.g. the person with the lowest step count).

¹² <http://www.fitbit.com/>

¹³ <http://nikeplus.nike.com/plus/>

Furthermore, other interesting avenues of research would be creating formal models for Citizen Actuation and generalising the concept to other areas. This could lead to further examination of the cost of Smart Environments with actuation versus the cost of implementing CPSS to fulfil the needed actuation tasks. With generalisation of Citizen Actuation, the definition of Smart Environments could be redefined to include the symbiotic relationship between man and machine. As the Internet of Things is expanding to become the Internet of Everything (IoE), the human element has become included in the design of systems and as Cisco describe the IoE as the bringing together of people, process, data, and things to make networked connections more relevant and valuable.¹⁴ It is through taking advantage of both data from the Social Web and combining this with sensor data that the next generation of applications can be developed and researched.

References

1. Berners-Lee, T.: Linked Data-Design Issues. <http://www.w3.org/DesignIssues/LinkedData.html> (2006)
2. Bizer, C., Heath, T., Berners-Lee, T.: Linked data—the story so far. *Int. J. Semant. Web Inf. Syst.* **5**, 1–22 (2009). doi:10.4018/jswis.2009081901
3. Boyd, D., Ellison, N.B.: Social network sites: definition, history, and scholarship. *J. Comput. Mediated Commun.* **13**(1), 210–230 (2007)
4. Breslin, J., Decker, S., Hauswirth, M., Hynes, G., Le-Phuoc, D., Passant, A., Polleres, A., Rabsch, C., Reynolds, V.: Integrating social networks and sensor networks. In: *W3C Workshop on the Future of Social Networking*. Barcelona (2009)
5. Breslin, J.G., Harth, A., Bojars, U., Decker, S.: Towards semantically-interlinked online communities. In: *The Semantic Web: Research and Applications*, pp. 500–514. Springer, Berlin (2005)
6. Brickley, D., Miller, L.: FOAF vocabulary specification 0.98. Namespace document. <http://xmlns.com/foaf/spec/> (2010)
7. Bull, R., Irvine, K.N., Fleming, P., Rieser, M.: Are people the problem or the solution? A critical look at the rise of the smart/intelligent building and the role of ict enabled engagement. In: *European Council for an Energy Efficient Economy, ECEEE*. ECEEE, Toulon/Hyres, France (2013)
8. Campbell, A.T., Eisenman, S.B., Lane, N.D., Miluzzo, E., Peterson, R.A., Lu, H.L.H., Zheng, X.Z.X., Musolesi, M., Fodor, K., Ahn, G.S.A.G.S.: The rise of people-centric sensing. *IEEE Internet Comput.* **12**(4), 12–21 (2008). doi:10.1109/MIC.2008.90
9. Caragliu, A., Del Bo, C., Nijkamp, P.: Smart cities in Europe. *J. Urban Technol.* **18**(2), 65–82 (2011)
10. Compton, M., Barnaghi, P., Bermudez, L., García-Castro, R., Corcho, O., Cox, S., Graybeal, J., Hauswirth, M., Henson, C., Herzog, A., Huang, V., Janowicz, K., David Kelsey, W., Le Phuoc, D., Lefort, L., Leggieri, M., Neuhaus, H., Nikolov, A., Page, K., Passant, A., Sheth, A., Taylor, K.: The SSN Ontology of the W3C semantic sensor network incubator group. *Web Semant. Sci. Serv. Agents World Wide Web* **17**, 25–32 (2012). doi:10.1016/j.websem.2012.05.003
11. Cook, D., Das, S.: *Smart Environments: Technology, Protocols and Applications*. Wiley, London (2004)

¹⁴ <http://www.cisco.com/web/about/ac79/innov/IoE.html>

12. Costanza, E., Ramchurn, S.D., Jennings, N.R.: Understanding domestic energy consumption through interactive visualisation: a field study. In: Proceedings of the 2012 ACM Conference on Ubiquitous Computing, pp. 216–225. ACM, Pittsburgh, PA (2012)
13. Crowley, D.N., Corcoran, P., Young, K., Breslin, J.: Gamification of citizen sensing through mobile social reporting. In: IEEE International Games Innovation Conference 2012 (IGIC), pp. 1–5. Rochester, NY (2012)
14. Crowley, D.N., Curry, E., Breslin, J.G.: Closing the loop—from citizen sensing to citizen actuation. In: 7th IEEE International on Digital Ecosystems and Technologies. Menlo Park, CA (2013)
15. Crowley, D.N., Passant, A., Breslin, J.G.: Short paper: annotating microblog posts with sensor data for emergency reporting applications. In: 4th International Workshop on Semantic Sensor Networks 2011 (SSN11), pp. 84–89. Bonn, Germany (2011)
16. Curry, E.: System of systems information interoperability using a linked dataspace. In: IEEE 7th International Conference on System of Systems Engineering (SOSE 2012), pp. 101–106. Genova, Italy (2012)
17. Curry, E., Hasan, S., ul Hassan, U., Herstand, M., O’Riain, S.: An entity-centric approach to green information systems. In: Proceedings of the 19th European Conference on Information Systems (ECIS 2011). Helsinki, Finland (2011)
18. Curry, E., Hasan, S., O’Riain, S.: Enterprise energy management using a linked dataspace for energy intelligence. In: Second IFIP Conference on Sustainable Internet and ICT for Sustainability. Pisa, Italy (2012)
19. Curry, E., O’Donnell, J., Corry, E., Hasan, S., Keane, M., O’Riain, S.: Linking building data in the cloud: integrating cross-domain building data using linked data. *Adv. Eng. Inform.* **27**(2), 206–219 (2013)
20. Demirbas, M., Bayir, M.A., Akcora, C.G., Yilmaz, Y.S., Ferhatosmanoglu, H.: Crowd-sourced sensing and collaboration using twitter. In: IEEE International Symposium on a World of Wireless Mobile and Multimedia Networks (WoWMoM), pp. 1–9. IEEE, Sydney, Australia (2010)
21. Engelbart, D.C.: Toward augmenting the human intellect and boosting our collective IQ. *Commun. ACM* **38**(8), 30–32 (1995). doi:[10.1145/208344.208352](https://doi.org/10.1145/208344.208352)
22. Engelbart, D.C.: Augment, bootstrap communities, the Web: what next? In: CHI 98 Conference Summary on Human Factors in Computing Systems, CHI ’98, pp. 15–16. ACM, New York, NY, USA. doi:[10.1145/286498.286506](https://doi.org/10.1145/286498.286506) (1998)
23. Fischer, C.: Feedback on household electricity consumption: a tool for saving energy? *Energ. Effi.* **1**(1), 79–104 (2008)
24. Goetz, T.: Harnessing the power of feedback loops. http://www.wired.com/magazine/2011/06/ff_feedbackloop/all/1 (2011)
25. Goodchild, M.: Citizens as sensors: the world of volunteered geography. *GeoJournal* **69**(4), 1–15 (2007)
26. Hasan, S., Curry, E., Banduk, M., O’Riain, S.: 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), pp. 69–81. Bonn, Germany (2011)
27. Herring, M.: A sea of sensors. <http://www.economist.com/node/17388356> (2010)
28. Jamshidi, M.: System-of-systems engineering—a definition. In: IEEE International Conference on Systems, Man, and Cybernetics (SMC). Hawaii, USA (2005)
29. Boulos Kamel, M.N., Resch, B., Crowley, D.N., Breslin, J.G., Sohn, G., Burtner, R., Pike, W.A., Jezierski, E., Chuang, K.Y.S.: Crowdsourcing, citizen sensing and sensor web technologies for public and environmental health surveillance and crisis management: trends, OGC standards and application examples. *Int. J. Health Geographics* **10**(1), 67 (2011)
30. Kwak, H., Lee, C.: What is Twitter, a social network or a news media? In: Proceedings of the 19th International Conference on World Wide Web, WWW ’10, pp. 591–600. New York, NY (2010)

31. Lindenberg, S., Steg, L.: Normative, gain and hedonic goal frames guiding environmental behavior. *J. Soc. Issues* **63**(1), 117–137 (2007). doi:[10.1111/j.1540-4560.2007.00499.x](https://doi.org/10.1111/j.1540-4560.2007.00499.x)
32. Parsons, D.J., Chatterton, J.C., Clements-Croome, D., Elmualim, A., Darby, H., Yearly, T., Davies, G.: Carbon brainprint case study: intelligent buildings. Technical report, Centre for Environmental Risks and Futures. Cranfield University (2011)
33. Sakaki, T., Okazaki, M., Matsuo, Y.: Earthquake shakes twitter users: real-time event detection by social sensors. In: Proceedings of the 19th International Conference on World Wide Web. WWW'10, pp. 851–860. ACM, New York, NY (2010)
34. Shaw, D.: Smart, social energy: can software change our energy habits? <http://www.bbc.co.uk/news/technology-20173641>
35. Sheth, A.: Citizen sensing, social signals, and enriching human experience. *IEEE Internet Comput.* **13**(4), 87–92 (2009)
36. Snoonian, D.: Smart buildings. *IEEE Spectr.* **40**(8), 18–23 (2003)
37. Sullivan, B., Wood, C., Iliff, M., Bonney, R., Fink, D., Kelling, S.: eBird: a citizen-based bird observation network in the biological sciences. *Biol. Conserv.* **142**(10), 2282–2292 (2009)
38. Weiser, M., Gold, R., Brown, J.: The origins of ubiquitous computing research at PARC in the late 1980s. *IBM Syst. J.* **38**(4), 693–696 (1999)
39. Welsh, M.: Sensor networks for the sciences. *Commun. ACM* **53**(11), 36 (2010). doi:[10.1145/1839676.1839690](https://doi.org/10.1145/1839676.1839690)
40. Zengestrom, J.: 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)