Beyond Data in the Smart City:

Repurposing Existing Campus IoT

A case study using existing Internet of Things (IoT) infrastructure to create a campus-scale "living laboratory" that promotes energy savings and environmental sustainability reveals challenges and opportunities in developing smart cities and buildings.

Oliver Bates and Adrian Friday
Lancaster University

The Internet of Things (IoT) is often portrayed as key to opening the door to smart cities, heralding a "smart future" facilitated by technology that joins together systems to provide better control of resources. Improving such control can increase efficiency, reduce waste and energy use, and lower greenhouse gas emissions from public services and infrastructures.[1] Sensors that provide data about city life can encourage "a single view of the truth,"[2] understood using big data analytics and decision support systems, revolutionizing how cities operate and are managed. However, in these systems, the energy requirements of people can be overlooked, with qualitative and nuanced views of how energy supports practice, business, and everyday life falling by the wayside.

Irrespective of the confidence we place in some of these grandiose claims, there is little question that data and analytics have been catalysts for revolution in other domains and are worthy of exploration in terms of how they might help cities more effectively manage their resources. Here, we offer some lessons based on our own relatively modest case study of creating a software platform to help make our campus "smart." This is part of a broad and ambitious initiative to transform Lancaster University into a living laboratory for sustainability.

Our case study focuses on an early step in this process: integrating data from the existing energy and building management systems to enable integrated analysis and optimization. This process has helped us identify several opportunities for innovating with regard to energy and sustainability while also highlighting challenges that threatened the project's viability. Our work draws attention to gaps in knowledge in this type of research in terms of how to assess emerging ethical concerns and better identify and understand the everyday needs of the people who live, work, or study at the campus. Our goal here is to share the challenges we experienced to help other smart city technologists.

Multibuilding campuses commonly span both academic and industrial institutions, resulting in densely populated areas in which people conduct a multitude of day-to-day practices. The resources and infrastructures provided by such campuses are implicated in these practices and are directly linked to the bottom line of not only the campus itself but also the city in which it resides. IoT developers will face similar technical and organizational barriers involving integrating complex financial or institutional constraints and priorities. We reflect on why creating this platform has been more challenging than we first thought and present a set of lessons learned and opportunities for the community. We hope that drawing attention to these issues will start an important dialogue among practitioners and researchers in academic and nonacademic settings alike.

Published by the IEEE CS ■ 1536-1268/17/$33.00

Energy Information System Case Study

Energy data is our starting point: by making data about energy and building use on campus available more widely to a variety of stakeholders, we aim to bring new ideas and innovation to address the challenges of sustainability and to strategically inform operational decision making. Our platform integrates various data sources relating to energy demand and building use. Our logic for this is simple: our campus infrastructure isn't optimized, so if we can demonstrate energy savings (a substantial cost to the institution), then we can build confidence and stakeholder buy-in for the platform and the wider sustainability project.

The campus is in many ways a city in microcosm. Lancaster University comprises over 288 buildings, which include offices, lecture halls, laboratories, small business incubators, a theater, a library, a sports center, shops, and residences. There are 13,300 students, of which over 7,000 live on campus during term time. There are 2,350 employees and numerous visitors and service delivery personnel. The campus consumes over 80,000,000 kWh energy per year across 360,000 m, costing in the region of £4 million annually. Solely in energy terms, the associated CO externality is over 19,000 tons annually.

We need to make the campus infrastructure available in a controlled way so that we can better understand and optimize campus' systems performance, identify waste and targets for energy savings and infrastructural improvements, and bring innovative solutions and analysis to bear. The campus electricity, gas, water, heating, and cooling is overseen by a building management system (BMS) with more than 100 controllers—one or two buildings per controller, with more than 5,000 attached sensors—and an energy monitoring system that captures the consumption of electricity, water, and gas using just over 900 sensors. The systems and infrastructures used to manage and monitor buildings and energy on campus are proprietary, with access to the raw data (such as data about energy consumption and the heating of buildings) accessible only via dedicated software.

To bring together energy and building performance data with the other data sources for the first time, we created a central data hub called the Energy Information System (EIS). This EIS will be key to properly evaluating the campus estate and any energy-saving interventions. We successfully integrated the following data sources:

- *Building management systems*—the BMSs control the heating, cooling, and ventilation on campus and provide related data. They also provide a large range of telemetry data for the combined heat and power (CHP) generator, the boiler room, and internal and external building temperatures.
- *Energy monitoring system*—the EMS controllers let us get data from attached sensors that aggregate readings from the energy monitoring subsystems used to understand the energy consumption and flow across campus. The EMS covers electricity, gas, and water flow.
- *Wind turbine*—the performance of the wind turbine is measured every 10 minutes and reports the wind direction and speed, blade rotation speed, and power (kW) and energy (kWh) produced.
- *Campus timetabling and room booking*—this data source provides all room booking events (meeting rooms and lecture halls but not offices), including class timetables.
- *Local meteorological data*—a local meteorological office-grade weather station provides the ambient temperature, relative humidity, wind speed and wind energy (10-minute averages), and minutes of sun each day.

Data-Driven Insights

Figure 1 shows energy use for four buildings overlaid for one calendar week in 2015. As you can see, the daily rhythms of energy use climb slowly as the week progresses but also return to a substantial baseline energy load overnight. The EIS lets us drill down below this top-level view to further explore what composes these loads.

Unlocking Data for Stakeholders

We make EIS data available in raw format (CSV, API) via a Comprehensive Knowledge Archive Network (CKAN; https://ckan.org) server. However, despite fast initial progress, this proved complex at the entire campus level, as we discuss later. We formed steering and user groups to help us refine the platform to meet key stakeholder needs.

Understanding Day-to-Day Life

The data exposed via EIS has enabled the interrogation of how, when, and why energy is used on campus (compare the patterns of consumption in Figure 1 and of heating input and temperature in Figure 2). Early results indicate that the granular data provides a limited representation of the complex configurations of people, technology, labs, offices, and living spaces implicated in practices. The results also indicate that more nuanced and detailed enquiries reveal important sociotechnical perspectives, which data-driven perspectives can overlook.

Opportunities

There are several straightforward ways in which data from our EIS is already helping researchers work with facilities managers at Lancaster University.

Providing Strategic Oversight

By providing a view of energy demand and consumption through business intelligence tools, we're engaging university management and revealing some of the complexity of why energy and building systems on campus perform in certain ways.

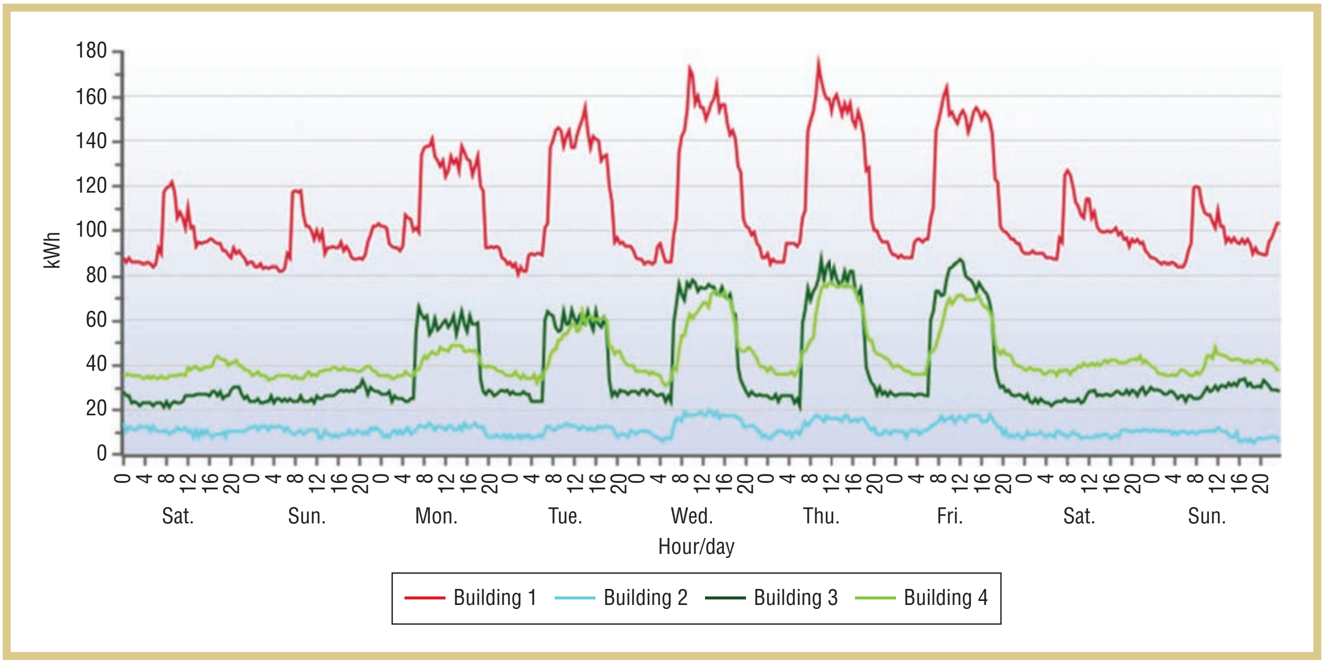

Figure 1. Top-level energy use for four buildings on campus. Weekdays clearly exhibit higher peaks than weekends. Substantially different baseline loads are also obvious, but the load is not normalized by building size or occupancy.

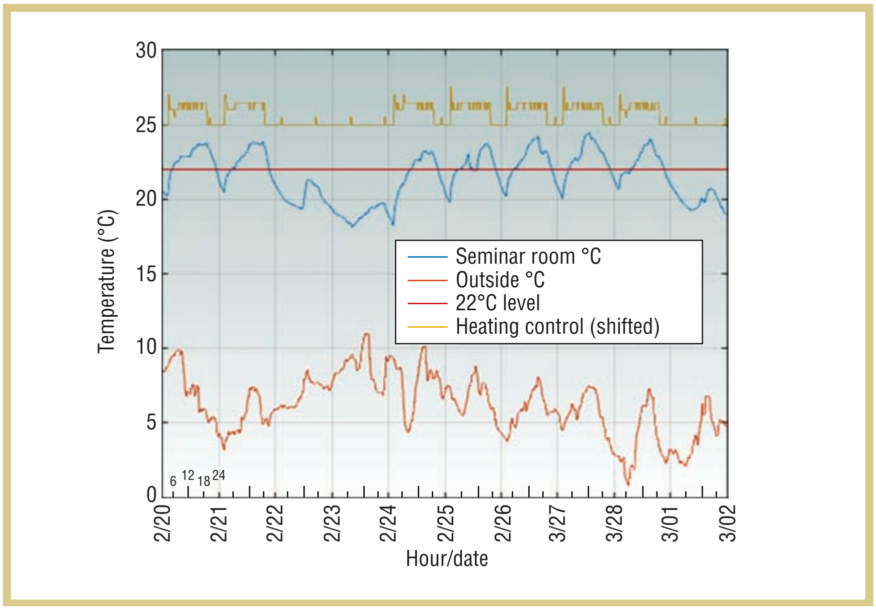

Figure 2. Temperature and heating input to a seminar room from historical data used to create a new control schedule to avoid overheating and to use heating only during occupied hours.

Optimizing Heating Systems

We can also help reduce wasted energy from overheated buildings. Figure 2 shows that the indoor temperature in this specific building is above a nominal 22°C level from approximately 5 a.m. until after 9 p.m. Assuming a "normal" temperature range of 19–22°C, we can reduce the temperature by at least 2°C for most of the day. We can also turn the heating on one hour later and turn it off three hours earlier to maintain this temperature from 6 a.m. until 6 p.m., reducing the heating period by four hours.

Although this snapshot is certainly not representative of the entire estate, it represents a potential 25 percent reduction in heat input to this space. Additional savings are also anticipated, assuming we can heat or cool spaces only when they're in use or change expectations regarding indoor comfort.[3]

Conducting Live Experiments

Perhaps the most exciting potential of the platform is its ability to conduct—and measure the effects of—experiments designed to reduce energy impacts at a small city scale. In the past, it has been difficult to measure the effects of our interventions due to our limited access to infrastructural sensors.[3–5] We're currently engaged in a project with university facilities to explore room-level heating control for an entire building.

Making Sense of the (Smart) City

The living laboratory lets us integrate experimental energy supply-and-demand technologies. It also presents a great opportunity to understand peoples' role in the city and how this relates to energy and emissions. From an interdisciplinary perspective, it's important to more clearly understand the implications of smart cities and living labs on those who live, work, and study in them.

We echo calls for better contextualization of the day-to-day lives of citizens in the smart city to help understand how people integrate and acknowledge the smart city environment[6] alongside how the smart city affects changes in everyday practices and routines of citizens[7] (though some might argue that it shouldn't!). We hope our research can help explain how smart city technologies can be domesticated into everyday life.[8]

Challenges

Despite aligning with university sustainability priorities and enjoying considerable support from influential decision makers around the university, creating this platform has been challenging, precisely because it cross-cuts the organization and many stakeholders. We now discuss the challenges relevant to researchers and smart city developers, especially those operating at a similar scale and context.

Data Granularity and User Requirements Mismatch

The stakeholder requirements for temporal and spatial data aren't fixed. There's a tension between the ambition of some researchers and the data that we can make available given the underlying systems' limitations. For example, researchers might want a room-level breakdown of energy consumption, which might be a finer resolution than the system can or is likely to provide.

Similarly, a standard metering interval for energy data is 30 minutes, which is considerably coarser than what's required for typical nonintrusive load monitoring and state-of-the-art energy disaggregation systems.[9] We need to be able to cope with different nonhomogeneous sampling intervals across hardware but offer uniform aggregate views as a basis for comparison. Our user requirements continue to co-evolve with our campus community and estate. We plan to offer cleaned, resampled, and raw disaggregated datasets via our data portal.

Complexity and Missing Metadata

Even at the campus scale, you can't underestimate the complexity of organizing the data and data sources into meaningful hierarchies and understanding the context for intelligible use. Meters connect at different points in both electrical and spatial terms. A meter might include a particular circuit (say, lighting), or it might be one of multiple meters relating to the same physical space. BMSs evolve over time and grow organically with the evolution of buildings.[10] This digital-physical mapping typically exists outside of the existing system—sometimes in digital form but sometimes as the "tacit knowledge" of operational staff. This needs to be captured, encoded, and brought into the system.

System Age and Complexity

Unlike our previous research deployments,[3,4] which were deployed at one time using homogeneous hardware and software, the campus environment has evolved over decades. The management infrastructure reflects this evolution, and there are many types of equipment manufacturer and technology. This is particularly true of the BMS, where different versions of the same manufacturers' hardware and other hardware entirely are found in buildings constructed during different eras. A large portion of the work on our platform has gone into "unlocking" these potential data sources and developing software to manage important data from these devices.

Security and Critical Infrastructure

There is currently a gray area when it comes to security concerns and identifying who is prepared to "own" the problem should the smart infrastructure misbehave intentionally or unintentionally. Our platform requires that traditionally closed infrastructures—such as energy metering systems, BMSs, weather stations, and telemetry from boiler houses and wind turbines—are made open to our system. This naturally raises fears and concerns about security, not only for our system but also in terms of the wider access to critical infrastructure and potential for new attack vectors. There are also concerns about data sensitivity, given the finer grained sensing as well as the existence of commercially sublet premises on campus.

We have found that decisions around the security of IoT and its data extend beyond the remit of existing well-defined security policies and decision-making processes. Sometimes, security and the maintenance of the infrastructure are in tension. Usernames and passwords are the gateway to the underlying sensing and actuation that controls the energy flows and building systems on campus. In a modern age, where hard-to-crack passwords are almost taken for granted, we forget that secure passwords and encryption can complicate fault finding across large and physically distributed critical energy infrastructure during emergencies, especially when external companies and contractors are involved.

Understanding the Meaning behind the Data

Figure 1 illustrates how energy consumption data, on its own, is insufficient to make decisions for a department or building. As one of the larger energy users on campus, it would be tempting to target Building 1 with a number of standard energy-based interventions to "change the behavior" of its occupants. In reality, making energy reductions isn't that simple (consider Yolande Strengers' questioning of whether we should design for the "Resource Man"[11]). The dynamics of a building such as Building 1 are completely different from any of the others shown in Figure 1.

Building 1 is a large and complex mixed-use building; it contains a lot of energy-intensive equipment specific to ongoing research in environmental sciences and biology, which requires close (and energy intensive) environmental control. To some extent, energy is science, and changing the infrastructure to save energy could impact scientific findings. Accurately capturing this kind of consequence is essential to informing the design of energy and sustainability policies and technologies for the people—and the practices that go on—inside specific buildings. We advocate qualitative observational and ethnographic fieldwork to develop these understandings and inform intervention design. Smart city platforms thus must capture, and make available, this kind of qualitative metadata alongside the data to ensure these understandings aren't lost.

Responsibility

A particular challenge for our project has been identifying who should be responsible for running and maintaining the project, given that the goals crosscut the institution and thus budgets. Until we can demonstrate a substantial return on investment (reductions), it will be difficult to find the necessary resources to conduct wide-reaching and cross-cutting sustainability projects of this kind (which are not directly the core responsibility of any single decision structure for teaching or research).

Given the technical challenges of the various hurdles for accessing data, changing infrastructure, and developing software, the project needs a champion who has a broad perspective of the entire system and who will push for the system regardless of his or her domain or own specific interest. The problem lies in other parties (researchers or investors) having other, more pressing concerns in their day-to-day roles; until the system is complete (and it might always be developing and growing), stakeholders will find it difficult to understand how the system benefits them. The system needs a champion who can talk to a diverse audience. The longevity of this project currently resides with invested individuals across the organization—such as the researcher and energy manager. Consequently, identifying these motivated stakeholders is essential to the project's success.

Ethics

It's far from clear to what extent we're allowed to conduct living laboratory experiments that affect the expectations and established norms of campus life. We don't anticipate requiring ethics process approval as long as we optimize the existing estate without discomfiting campus users (for example, by only turning off the heat for a space that's considered unused). A traditional study involving human subjects requires disclosing the study to potential participants and explicitly having them opt in. How can this process scale to entire buildings or sections of a campus? What happens if certain participants opt out, yet the effects of changes to participants around them bleed through and affect them? We don't yet have answers to these questions.

In a living lab, we might well face an ethical dilemma: to what extent are we engaging participants in the goals of the study, and to what extent are they being experimented upon? So-called "natural field experiments," in which participants are unaware that they are taking part in an experiment, provide potentially powerful evidence that energy savings can be made in real domains, without self-selection biases. These kinds of experiments are more common in certain disciplines, where fundamental ethical principles of minimizing harm to participants are considered sufficient, but in many countries and disciplines, that would require making adjustments to ethical approval processes and codes of practice.

Sustaining a Smarter Campus

Looking forward, as the campus expands and new technology is retrofitted to replace existing systems, there will be challenges around the integration of new and different solutions for the EMS and BMSs. For integration into the EIS, continued support will be required from the university to ensure successful expansion and maintenance of the platform.

Reflection and Lessons Learned

Our project has been more difficult than we anticipated. We remain optimistic about the potential benefits and hope to provide centralized data storage and access, as well as new data to inform policy and energy-related decisions and new opportunities for building applications and tools that can save resources and possibly improve research. These benefits should not be small by any means, but it's crucial to reflect on the current state of the project and its potential limitations.

Danger of Grasping Low-Hanging Fruit

Pragmatically, it's expedient to focus on gaining value from existing infrastructure. Our proposed system presents "low-hanging fruit" opportunities for ICT and computing (for example, opportunities to expose and explore energy in day-to-day life, develop applications for data visualization and decision support, connect existing systems, and close the automation loops of existing BMSs). From our experience, it's important to first identify areas (buildings, infrastructures, and so on) that might look interesting to inform further investigation.

Questions remain about energy demand and whether quantitative data and systems such as the EIS are sufficient to inform decision making. Where data is used as a lens for understanding a problem, it's easy (given the scale of the new resource) to ignore the limitations of what's being represented or even misrepresented along with information and context that's not being captured quantitatively. The temptation might be to increase the levels of monitoring (disaggregated sensing, finer granularity data, appliance-level monitoring, and so on) or to pair data sources with qualitative accounts (for example, methods or approaches to understand practices).

Although these might seem like natural avenues forward, the reality is that new technology might not play well with existing systems. In addition, campus-scale deployments of IoT for sensing and control require considerable investment, and sociological-based qualitative studies or ethnographic explorations of the campus might struggle to capture the full diversity. Although these are all attractive in smaller scales on campus (student cooking practices,[4] for example), the reality is that these solutions don't scale well due to deployment and maintenance costs. The worth of this kind of study comes in developing new understandings of how a campus is implicated in practices, and how these understandings can help in the (co)design of a smart and sustainable campus.

The Data Tells You Only One Story

Data tells you one story about energy consumption,[1] but more often than not, energy is not linked to why or how it's being consumed. There's a need to understand the system to reform it. We should be encouraging data-aware design[12] over data-driven design to promote a fuller understanding of the implications, limitations, and boundaries of the data we collect. To do this, it's important to capture the complexity of the system and its use through multiple lenses (such as through systems thinking[13] or sustainability[14] lenses), and not just with an increase in the levels and granularity at which we perform sensing.

One way of doing this is by working with citizens and stakeholders (employees, researchers, security personnel, businesses, hotels, campus residents, and so on) to understand their requirements to better inform and contextualize the data in the EIS. We need to incorporate nuanced qualitative understandings of the everyday lives of (at least a subset of) these citizens and stakeholders[4] when the data is exposed (though business analytics, in applications, or in aggregated data, for example).

The Link between Energy and Practices

Primary qualitative data has highlighted that it is important to understand the roles of people and technology and to understand the spaces in which people study, live, and work. This understanding is important to the successful integration of smart technologies in areas where technology can't currently be used to capture and comprehend human complexity and variations. At this stage, we have struggled to make the case to management and other data-driven practitioners that we must incorporate the role of social rhythms and variations in practices to promote a sustainable campus (a related discussion appears elsewhere[15]).

Repurposing and Retrofitting IoT

IoT offers the potential to exploit existing infrastructure for the smart city. It's worth pausing to question whether the technology already present is good enough for the job. Questions over data granularity come back to industry standards (for example, 30-minute aggregate energy meter readings for the EMS) versus the (potentially infinite) requirements of researchers. For several stakeholders (such as managers and some statisticians), the current granularity of data is good enough (30-minute bins). However, looking forward, with the expectations of subsecond live data that the smart grid and storage techniques might rely on (such as data at 100 Hz granularity), will we need finer/higher granularity than what IoT promises?

One case for retrofitting is the inconsistent disaggregation due to a variety of differently aged meters and manufacturers being used throughout the EMS. The aggregation and representation of the data provided is dependent on subsystems, the age of building, and the age of the technology, all of which have been affected by changes in standards over the years. The inability to obtain higher granularity data might be a barrier for some researchers, including those who wish to investigate applications for the smart grid and micro generation. Retrofitting new technology across the campus is an option, but not one that will happen overnight.

Interdisciplinary Co-Creations

Although computing can deal with large amounts of data and operationalize energy-related interventions and control elements in the smart city/campus, it has its limitations. When it comes to the smart city, there is a serious need to understand how the smart city affects the everyday lives of its citizens.

Requirements and implications of the smart city can be more deeply understood by turning to other fields of expertise—fields that are more classically trained in understanding humans and their interactions with technologies (ethnographers and designers, for example) and in understanding the dynamics and planning of cities (building managers, office managers, and civil engineers, for example). Experts in energy, energy systems, and environmental systems will also be important (such as scientists, engineers, and energy managers). By engaging these experts to help make informed decisions about designs for the smart city, we will be better equipped to understand the nontechnical limitations when it comes to designing for city, campus, and energy systems. By leveraging this expertise, we can develop an understanding of energy supply and demand and co-create a smart campus for all citizens and stakeholders.

Challenging the Rhetoric of Energy Waste

It's key to acknowledge that energy is science, energy is business, and energy is tuition. Energy is required to run the campus and the services it provides. Simply put, it doesn't always make sense for the institution to have aggressive reduction-centric goals and expectations around the consumption of energy. From the engagement with a variety of stakeholders (the manager, building manager, researchers, lecturers, and businesses), the answers to the question of whether energy is actually being wasted seem more complex than those provided by analysis of quantitative data provided by the EIS.

Although we agree that inefficiencies should be addressed (such as not lighting or heating buildings not in use), it's crucial to recognize that energy is the core resource that makes practically everything that happens on campus possible, including aiding the increase of the institution's impact in terms of economic value, contributions to academia, and education. With this in mind, given the context and complexity of a university and its core business, it perhaps doesn't make sense to create policies that assume we can simply limit the energy consumption of existing equipment, technologies, or buildings. Rather, from an energy viewpoint, smarter cities and campuses should be looking more toward curtailing redundant activities, continually updating zero-carbon and renewable energy solutions, and reshaping the core activities and infrastructures.[7] In this way, the living laboratory has a key role to play.

A fundamental question for smart cities is to what extent they can challenge the norms and routines for those living and working in them to promote sustainability. For example, changing the temperature maintained in buildings and revising heating schedules might be interpreted as withholding heat from employees or as a loss of benefit. It might even bring complaints or result in fears about compliance with health and safety expectations or with organizational norms and policies. But if we're constrained to anything that is possible "as long as it goes unnoticed or doesn't change existing practice," then we'll never create a truly sustainable smart city.

the AUTHORS

Oliver Bates is a researcher at the School of Computing and Communications, Lancaster, UK. His research interests include the environmental impacts of domestic ICT and IoT, data demand in social practices, greenhouse gas emissions of student cooking methods, adaptive thermal comfort, environmental public policy, and using IoT to understand campus energy patterns. Currently, he is working with data science techniques and IoT to promote more sustainable freight logistics. Bates has a PhD in computer science from Lancaster University, UK. Contact him at o.bates@lancaster.ac.uk.

Adrian Friday is a professor in computing and sustainability at the School of Computing and Communications, Lancaster, UK. His research interests focus on the use of ubiquitous computing systems for the empirical study and reduction of energy and greenhouse gas impacts of everyday life. In particular, he is working on projects related to fine-grained accounting for energy use in the home; new algorithms for achieving thermal comfort; systems for promoting more sustainable food shopping, advancing sustainable transport infrastructure maintenance, and promoting more sustainable freight logistics. Friday has a PhD in computer science from Lancaster University, UK. Contact him at a.friday@lancaster.ac.uk.

REFERENCES

1. V. Olgyay, "Connecting Buildings Helps Fight Climate Change," *GreenBiz*, 11 Dec. 2015; www.greenbiz.com/article/connecting-buildings-helps-fight-climate-change.
2. C. Harrison, "Building a Resilient Planet," IBM, Jan. 2013; www.redbooks.ibm.com/redpapers/pdfs/redp4978.pdf.
3. A.K. Clear et al., "Understanding Adaptive Thermal Comfort: New Directions for Ubicomp," *Proc. 2013 ACM Int'l Joint Conf. Pervasive and Ubiquitous Computing*, 2013, pp. 113–122.
4. O. Bates et al., "Accounting for Energy-Reliant Services within Everyday Life at Home," *Proc. Int'l Conf. Pervasive Computing*, 2012, pp. 107–124.
5. A. Clear et al., "Catch My Drift? Achieving Comfort More Sustainably in Conventionally Heated Buildings," *Proc. 2014 Conf. Designing Interactive Systems*, 2014, pp. 1015–1024.
6. V. Thomas et al., "Where's Wally? In Search of Citizen Perspectives on the Smart City," *Sustainability*, vol. 8, no. 3, 2016, p. 207.
7. E. Shove, M. Pantzar, and M. Watson, *The Dynamics of Social Practice: Everyday Life and How It Changes*, Sage Publications, 2012.
8. T. Berker, M. Hartmann, and Y. Punie, *Domestication of Media and Technology*, McGraw-Hill Education, 2005.
9. S. Gupta, M.S. Reynolds, and S.N. Patel, "Electrisense: Single-Point Sensing Using EMI for Electrical Event Detection and Classification in the Home," *Proc. 12th ACM Int'l Conf. Ubiquitous Computing*, 2010, pp. 139–148.
10. T. Rodden and S. Benford, "The Evolution of Buildings and Implications for the Design of Ubiquitous Domestic Environments," *Proc. SIGCHI Conf. Human Factors in Computing Systems*, 2003, pp. 9–16.
11. Y. Strengers, "Smart Energy in Everyday Life: Are You Designing for Resource Man?" *Interactions*, vol. 21, no. 4, 2014, pp. 24–31.
12. E.F. Churchill, "From Data Divination to Data-Aware Design," *Interactions*, vol. 19, no. 5, 2012, pp. 10–13.
13. S. Easterbrook, "From Computational Thinking to Systems Thinking," *Proc. 2nd Int'l Conf. ICT for Sustainability* (ICT4S), 2014; www.cs.toronto.edu/~sme/papers/2014/Easterbrook-ICT4S-2014.pdf.
14. S. Mann, *Sustainable Lens: A Visual Guide*, CreateSpace, 2011.
15. J. Pierce et al., "Introduction to the Special Issue on Practice-Oriented Approaches to Sustainable HCI," *ACM Trans. Computer-Human Interaction* (TOCHI), vol. 20, no. 4, 2013, p. 20.