Closing the Feedback Loop: A Systems Approach to Supporting Community-wide Behaviour Change in Non-domestic Buildings

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ABSTRACT

Energy consumption is notoriously invisible to building users. Communicating energy performance to users presents a significant opportunity to support behaviour change. Access to near real-time consumption data makes ubiquitous energy performance feedback systems a realistic possibility. Non-domestic building energy performance is a complicated issue, so providing simple, intelligible feedback can be difficult. Communicating what building users are supposed to do with the information is still more so. A true closed-loop feedback system must include both communication of information to users and a means for users to affect the building to which the information pertains.

This paper reports the design and use of a novel information system to facilitate a true feedback loop between a community of building stakeholders (users, energy professionals, researchers) and 25 pilot buildings. The buildings were equipped to communicate energy performance in near real time via a user-friendly ‘dashboard’ built on a sophisticated system of automated data capture, energy consumption modelling, predictive statistical analysis and visualisation. The ‘dashboard’ allowed casual users to access information easily via a simple happy/sad performance indicator whilst more “data-philic” users were able to click through to a data rich, easy-to-use interface. Users were also provided with access to a digital social platform enabling transparent discussion of energy performance with reference to the objective data.

Results show that the ‘dashboard’ and digital social platform components are each valuable in their own right but in combination they produced a system whereby users could identify and solve energy and water performance problems effectively and efficiently.

Introduction

Large public sector organizations are under constant pressure to reduce energy consumption in their building stock. Managing energy consumption across a large portfolio of buildings is a major challenge. Large scale capital investment in building fabric and energy systems is finite, takes time to roll out across hundreds of buildings and is only part of the solution. In many cases there are significant opportunities for energy saving by changing the energy consumption behavior of building occupants.

Energy systems in non-domestic buildings are far more complex and diverse than domestic equivalents. In addition, the target population for behavior change is not as well defined; there is a wider community of stakeholders with influence over building performance including energy managers, engineers and senior management.

Though it may be comprised of many individual changes, what is needed can be described as no less than a change in culture within the organisation. A change in how building users and the wider community of energy and building professionals view their collective responsibilities for the performance of the buildings they work with. By pooling their influence, the community should be able to take control of energy performance.

The scale of the challenge is matched by the scale of the opportunity. Large non-domestic buildings can have annual emissions equivalent to hundreds of domestic dwellings and large organisations such as municipalities and universities may control hundreds of large buildings. The direct emissions reduction potential is large. In addition to direct emissions there is an indirect impact, since public sector buildings are often open to the public and include education buildings such as schools there is an opportunity for a change in culture to have impact beyond the organization by setting an example for visitors to follow at home and at work.

This paper reports the design and use of a novel information system to facilitate a true feedback loop between a community of building stakeholders (users, energy professionals, researchers) and 25 pilot buildings. The buildings were from a municipality (20 buildings) and a university (5 buildings) in Leicester, a city in the East Midlands region of the UK.

Making energy visible

Energy consumption is notoriously invisible to building users (Burgess and Nye, 2008; Darby, 2006; Hargreaves et al., 2010). In non-domestic buildings the problem is exacerbated because the building users themselves are not directly responsible for covering the costs of energy consumption and can feel less responsible for its impact than in a domestic setting (Foster et al., 2012). Individual occupants in large buildings with perhaps hundreds of users can feel powerless to affect the consumption of the building as a whole.

There is a growing body of evidence supporting the use of feedback systems for supporting behavior change. Usually, studies of the use of feedback to increase energy efficiency concentrate on the domestic context (e.g. Darby, 2010; Fischer, 2008; Hargreaves et al., 2010) and feedback is usually used to describe a largely one way process where information about energy use is “fed back” to the user, who may or may not change their behaviour. In the small number of studies focused on feeding information about energy use in non-domestic buildings back to users, feedback is again often characterised as the provision of information to users (e.g. Coleman et al., 2013).

Communicating energy performance to users of non-domestic buildings presents a significant opportunity to support behaviour change and can be effective as a stand alone measure, particularly where the behavioural change necessary to affect the specific energy use is obvious, for instance the use of a personal computer, or turning off a personal desk light (Coleman et al., 2013; Mulville et al., 2014). More recently, the need to move beyond pure information provision has been highlighted (Bull et al., 2015), with researchers finding that non-domestic building user engagement is a key factor in increasing efficiency (Foster et al., 2012) alongside clear understanding of what difference their actions will make (Murtagh et al., 2013). It is clear that to achieve efficiencies in the challenging multi user non-domestic setting, pure information provision must be augmented. Encouraging a feedback loop between buildings and their occupants has great potential to make energy performance more visible and understood and to capture the enthusiasm and expertise of the wider community. This research explores the potential for such a feedback loop, where a novel method of providing (necessary) energy use information to users is augmented by providing the means for building users to query and affect that energy use, thus closing the feedback loop.

A proposed feedback system

In general, feedback is characterised by a loop of information passing as an output from a system back as an input to the same system. Information flows continuously around the feedback loop and acts to continually modify the chosen parameters of the system. With the correct control of reaction to feedback signals, a stable and desirable system state can be achieved.

It is usual to frame energy performance feedback in buildings as being centered on the individual building user whose actions impact on their building. Data are collected from the building and 'fed-back' to the user. The expectation is that with knowledge of the energy performance of their building, users can adjust their behavior and see the impact of the change, much like a driver viewing a speedometer in a car and adjusting speed accordingly. However, to take that analogy further, as the driver eases the pressure of their foot on the gas, they feel the car slowing, observe the speedometer measuring reduced speed and settle to a new state. If this satisfies the driver, no further action is taken, otherwise a further adjustment is made. As mentioned in the preceding section, this repeated loop of changing a parameter, re-observing data and measuring effects is often absent from energy feedback systems and studies thereof.

Applying this feedback principle to non-domestic buildings, since influence lies with the wider community of stakeholders, it is necessary to both provide concrete, objective information to the whole community and to support the community to make the best use of that information.

Existing feedback mechanisms

Typically in the public sector some information is already available to building users and involved in (ad-hoc) feedback loops. At a basic level, building users can simply observe their buildings for signs of energy performance issues. Occupants will very quickly notice if there is a disruption to the supply of energy services such as a boiler failure or power cut. A "maintenance helpdesk" telephone number and/or email address is often provided as a formal route for this information to pass to the professionals who maintain the systems. It is possible for these channels to be used to report less catastrophic issues with building control such as overheating or lighting left on during unoccupied periods. In this way, the wider community of stakeholders can work together to impact their buildings.

Being focused on building operation and maintenance, these formal channels are not capable of handling the more subtle behavioural issues. In some cases, a system of "environmental champions" exists to encourage more subtle behavior change. A small number of building users distributed across the organisation are allocated responsibility for environmental issues such as raising awareness of energy consumption behavior choices in their own department. These champions are involved in sustainability initiatives, usually led by a sustainability professional. They disseminate their findings to their respective departments and provide an important route for information to flow in the other direction from building users to the professionals.

For energy professionals, BEMS and AMR systems provide a major source of feedback from buildings, although the geographical dispersal and number of buildings in a portfolio often means the time between physical energy surveys can be long. Energy professionals have access to rich data flows covering electricity and gas consumption, internal and external temperatures and any number of measurements of the operation of HVAC systems and are equipped with the expertise and software to interrogate and interpret these data. They will use these systems to monitor and control the operation of HVAC systems, to identify and diagnose major problems and to monitor the impact of interventions.

General building users have no access to such detailed data and are not able to spend the time and effort necessary to study and interpret them. However, in some cases these data will be packaged into simple reports and disseminated (e.g. quarterly, possibly via the environmental champion network) to all staff. The organisation may also post such information publicly as part of environmental reporting systems, though this may be less frequent and less detailed.

A more recent trend is the use of web technology and social media. Organisations can maintain a website with regularly updated information about the various initiatives. Coupled with a comprehensive social media campaign this can reach building users whilst also allowing two-way communication and providing a positive, proactive public facing image for the organisation.

Designing a system to facilitate data flow

In order to fully capture the benefits of feedback, information flows between the buildings and the community of stakeholders must be improved. By definition, the stakeholders in total have absolute influence over energy consumption in the buildings and their behavior determines the energy performance directly. Changes to stakeholder behaviour should be reflected in the information which passes round the feedback loop and back to the stakeholder community.

Different stakeholders have access to different information sources and expertise, yet all stakeholders have influence over energy performance. Information must also pass freely within the community of stakeholders in order to optimise the impact of feedback. Figure 1 shows a simple schematic, where dashed lines indicate the restricted information flows from the building portfolio to members of the community and between stakeholders. Thus, the information has little impact on the majority of building users and building users are isolated from the feedback loop.

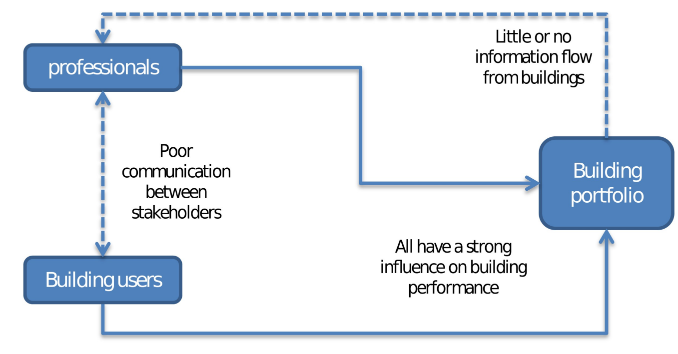

Figure 1: Information from buildings and communication between stakeholders limits feedback

Dashboard

The first information flow which we wish to encourage is that which flows from the building into the community of stakeholders. In existing systems, that flow of information is fragmented, restricted and incomplete. Energy professionals have access to detailed data but cannot easily share it with the rest of the community. It is safe to assume the non-expert has little interest in interpreting the complex data which is available. Simple quarterly reports provide good information but the low frequency with which they are provided does not allow for a true feedback loop to exist.A web-based energy dashboard system was developed (Stuart et al., 2013) to provide a near real-time source of objective information about the buildings in the study. The core of the dashboard is a half-hourly performance indicator (Stuart and Fleming, 2014). In brief, a consumption model was developed based on the standard variable base degree day (VBDD) model. This was applied to each of 336 half hourly slots in a week. A rolling baseline model was fitted to the most recent 52 complete weeks of data and half-hourly predictions of electricity, gas and water consumption were generated for the week of data under analysis. The indicator was calculated as the difference between baseline model prediction and the actual consumption expressed as a percentile of the residuals of the baseline model.

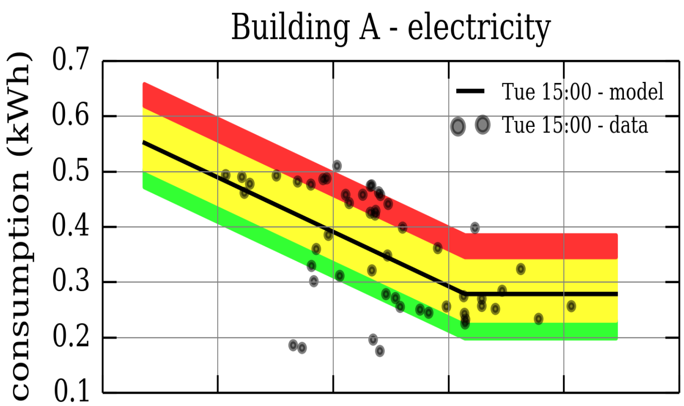

Figure 2: Consumption models were fitted to each half hour in the week

This performance indicator has many benefits for this application. In particular it produces a unit-less, context free number between 0 and 100. This allows indicators to be compared directly between buildings and between commodity types and even to be aggregated into single performance indicators across a population of buildings or commodities. It can also be visualised in many creative ways.

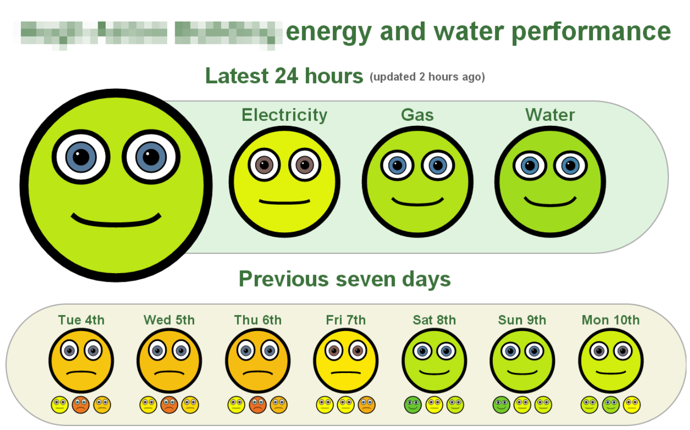

Figure 3: A screenshot of the simple energy performance visualisationIn this case the dashboard provided a very simple and easy-to-absorb visualisation of energy and water

performance composed of ‘smiley’ faces which appeared happy when the building performance was good and appeared sad when the building performance was poor. The dashboard was made publicly available on the web with no access restrictions and was updated every few hours as new data were collected and analysed. This basic dashboard was displayed on public screens within the buildings so building users would see them as they walked past the screen. Passive consumers of this service could determine how the building was performing at a glance.

For browser-based users there were three main pages. The home page showed a league table of all 25 buildings in the pilot. This introduced a gamification aspect to the dashboard. The performance indicator used was very sensitive to changes in building performance so buildings were constantly swapping positions and it was possible for any building to reach the top spot if even small savings were made.

Figure 3: A screenshot of the league table

The dashboard also provided a detailed visualisation for the more technical user. The predicted range of consumption generated by the consumption modelling system was presented as green, yellow and red coloured zones indicating good (10-25th percentile), neutral (25-75th percentile) and bad (75-90th percentile) consumption levels. These zones corresponded directly to the happy, neutral and sad faces and were presented alongside the actual consumption. Users could use this graphic to see which zone the actual consumption was in at any half hour in the last year. An interactive navigation bar was also provided showing the daily average indicator as a coloured band taking advantage of the possibility to aggregate the performance indicator over 48 half-hourly values.

Figure 4: A screenshot of the detailed view

The dashboard was designed to support all types of users. The league table was presented on the home page and users were required to click through in order to see the more detailed dashboard view for an individual building. A further click was required in order to see the more complex report.

Discussion forum

The second information flow which we wish to encourage is that which flows between members of the community of stakeholders. This flow of information is typically highly restricted and often ignored in existing systems, but is critical to a well-functioning feedback loop. Energy professionals and building users have access to very different information which may help the community as a whole understand how best to act. They also have very different influence over the energy performance of a building and over how the organization operates.

When information from the dashboard is made available to the community there may be only a small proportion of individuals who delve deeper and work to understand how the building is behaving. These individuals need to pass the information along to those individuals who understand the energy systems in detail and can diagnose a problem. The information should then pass to the individuals who can act on the information and affect change. Depending on the building and the problem, the individuals involved will be different. Some problems are solved with changes to control systems or maintenance, some can be fixed by changing the way in which building users work.

A web-based discussion forum (Discourse 2016) was deployed to facilitate communication between members of the stakeholder community. The Discourse software is a modern web-based forum software including features that make the system very easy and intuitive to use. The system was divided into categories so conversations could easily be filtered. This forum was in addition to existing maintenance helpdesk system and was occasionally used to raise issues that were subsequently added to the helpdesk system.

To ensure maximum use of the system it was made freely accessible to the public. There was no requirement to register or provide credentials in order to read the forum threads. In order to post a comment or start a thread it was necessary to register with the system. Newly registered users required the approval of moderators before they could post. The system allowed community members to engage in public discussions on subjects of their choice within the appropriate category.

The system was seeded with a number of discussions introducing the system and welcoming new users. Members of the project team including researchers and energy/sustainability professionals from the two organisations began by identifying issues using the dashboard system and promoting them through discussions.

Results: What happened?

The system was launched in January 2014 with a launch event including cakes and leaflets describing the system , which were taken to each building involved in the study to encourage building users to 'join the conversation'. Links to the websites were circulated and promoted at every opportunity.

Dashboard usage

Access to the system was monitored using google analytics. Information regarding the geographic location of each request was recorded. To avoid over reporting of usage due to fake traffic and traffic from non-users of the system, only requests originating in the city of Leicester were considered valid. Looking at sessions (users accessing one or more pages on the site from a unique device) the initial results showed a good interaction with the dashboard system.

In the first three months during the strongest period of promotion the site logged 1,471 sessions from the city of Leicester alone. After this initial pulse of interest the Leicester figures drop significantly to around 650 sessions per quarter and this level of interest was maintained for the remainder of the project (until December 2014). The total number of sessions originating in Leicester during the 12 month period of active promotion was 3,416. This is an average of over

65 sessions per week. Note that some of these would be associated with the automated public screens.

Beyond this point the promotion of the system stopped and the system was removed from public screens in the buildings. In the following 12 months (the calendar year of 2015) there were a total of 1,039 sessions originating in the city of Leicester, nearly 20 sessions per week spread more or less evenly across the year. Retention of active users is a critical issue and is covered in the discussion below. It is assumed that this drop is partly due to the public screens no longer needing to access the system and partly due to the decrease in active promotion.

A total of 976 individual users accessed the site, visiting an average of 5.1 pages per session with an average session duration of 5 minutes 27 seconds. Interestingly, the low number of users indicates many users visited the site multiple times. In fact, only 17% of sessions were from new users, 83% of sessions were from this core of active users returning to the site for more information.

Forum usage

Quantitative measures of activity in the forum system were also recorded. After 12 months the system had 57 registered users (7 of which were members of the project team). That is, 57 people had access to post content and all of these users were validated as being genuinely connected to one of the two organisations.

A total of 436 posts were recorded in 113 topics (conversations) over the year. Some topics included only a few posts and quickly ended. A few of the most popular topics grew steadily. There were seven topics with 10 or more posts and the largest topic included 48 individual posts with contributions from nine users.

The actual readership of the site is far larger. Since the site can be accessed without registering as a user. We also know that the most popular topic received 2,190 views and the top 35 topics received over 500 views each. Clearly there are substantial numbers of individuals reading the content. We can be fairly sure the total number of views was well in excess of the dashboard system. This may not be surprising as the content can often come up in google search results. Unfortunately the system was not configured to collect the same kind of usage data as the dashboard. As such the views could not be filtered by location so the figures are not directly comparable. However, they give an indication of the scale of interest in the system. Active readers are also likely to return to the same topic many times each time a new post is added so the numbers can be expected to be larger.

Secondly, the content of posts and the type of users generating that content were analysed. The majority of users in the system were from a technical background and of course had an interest in saving energy in buildings. Some discussions were of a general nature such as "what can I do to save energy?" or various links to online articles and events. The majority of the most popular topics tended to be about specific technical issues in specific buildings and include multiple direct references (and embedded links) to the dashboard system.

The example forum topic (conversation) shown in table 1 demonstrates the dynamic feedback achievable with the forum in combination with the energy dashboard.

Date	User	Summary of post
04/03/2014	User A (city)	Conversation initiated with a message passed on from a school indicating that a valve was faulty and causing problems with

Date	User	Summary of post
		the boiler timing.
10/03/2014	User B (city)	Noted that the boiler was turning on at 21:00. This information was taken from the energy dashboard and shared with the forum readers but directed at the school.
10/03/2014	User C (school)	Immediately signed up to the forum and reported that the problem was caused by the faulty valve. The valve had been fixed and the timer reset.
11/03/2014	User B (city)	Indicated that the timings were still wrong (now firing at 01:00).
17/03/2014	User C (school)	Indicated that they had been using the dashboard to experiment with the boiler settings.
19/03/2014	User B (city)	Reported that the timings were not right (in fact, heating was on constantly from 03:00 on the 18th March).
21/03/2014	User D (researcher)	Reiterated that timings were still not right with a link to the dashboard showing consumption for the period in question was constant.
26/03/2014	User B (city)	Indicated that experiments were ongoing.
26/03/2014	User C (school)	Explained that they had been experimenting with set-back temperatures and timings and had settled on a new configuration. Request for advice on "ideal" settings.
26/03/2014	User D (researcher)	Advice on optimal settings

Table 1: Example forum conversation in chronological order

The direct impact of changes to the timing of the heating system was a 52% reduction in weekly gas consumption. The average weekly consumption dropped from 16,198 kWh per week before the changes to 7,667 kWh per week after the changes. Figure 7 shows the average weekly consumption profiles from the four weeks before the changes and the four weeks after. These figures do not include the two-week period of experimentation. It should be understood that these figures are not corrected for weather conditions though it should be clear that the major impact on consumption was the timing of operation of the heating system including weekend operation.

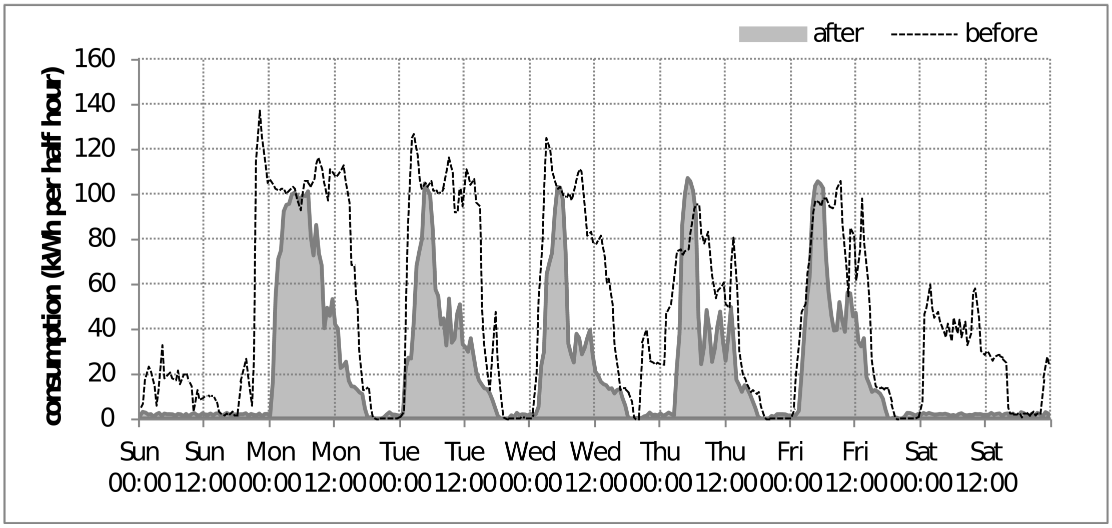

Figure 7: Average half-hourly consumption profiles before and after intervention

The conversation in the forum and actions are shown in graphical form in Figure 8. The conversation demonstrates continual feedback between the building, via the dashboard to the community. All contributors to the conversation were accessing the dashboard to see what was really going on in the building. The forum enabled an open conversation between these individuals based in three different buildings across the city. Users were able to publicise a problem to the community and interested parties were able to chip in with observations from the dashboard. Ultimately the forum allowed information, advice and encouragement to reach the individual with power to act. As they continually experimented with the building they were able to see the results and interpret them with the help of the community.

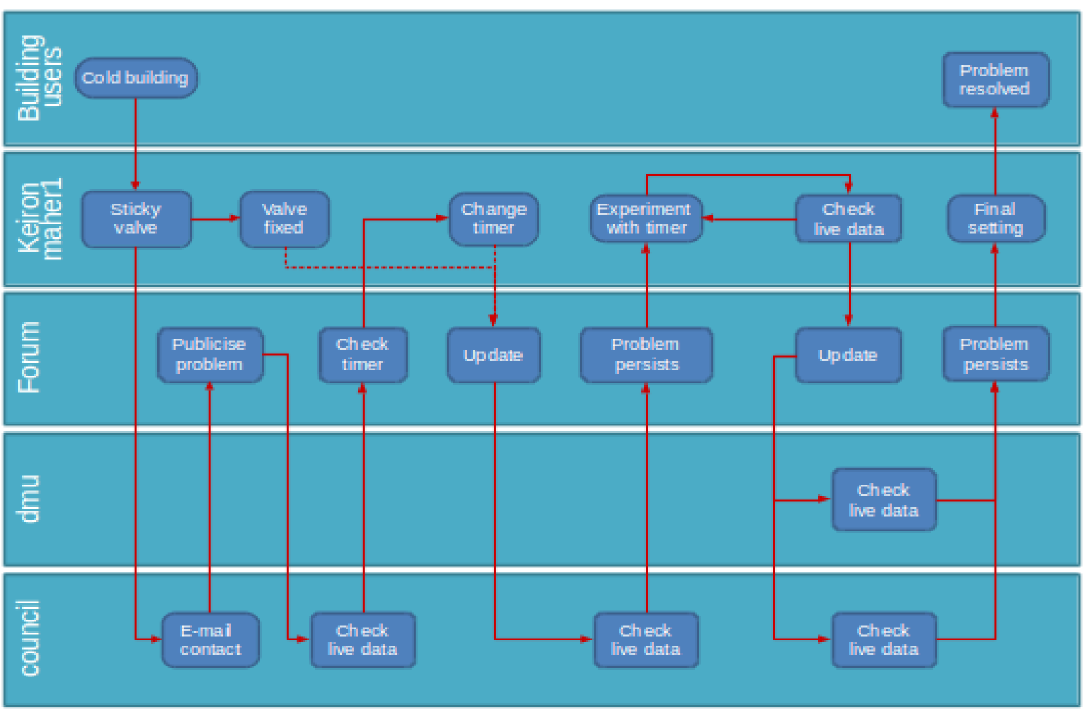

Figure 8: An example of feedback

Discussion – so what?

The forum software allowed stakeholders to access and elaborate on the information provided by the dashboard in a public discussion. This allowed all stakeholders (building users, managers and experts) to digest and interpret information on energy usage within buildings and to formulate considered plans to change behaviour in order to address examples where usage seemed excessive. This closed the feedback loop between stakeholders and buildings. In turn, actions could be taken by stakeholders and their effects observed, analysed and discussed. The examples presented show some evidence of this process occurring. This active, repeatable and repeated loop between stakeholders and building stands in contrast to the majority of previous research into energy feedback, where users receive information about their usage and record their reactions to it.

It is notable that the majority of communications on the forum originate from building energy managers or energy experts (including the present authors). This raises the question of how regular building users interact with the system. Firstly, although the forum communications are instigated by a relatively limited number of stakeholders, website logging shows that a far greater number of users accessed the forum and read the postings (so called “lurkers” in internet parlance). This means that observation of the forum and feedback loop was likely far wider than the group of actively posting users. In addition, the simple energy feedback visualisations were presented on large screens in a number of the pilot buildings. This has the effect of increasing visibility and, potentially, awareness of energy consumption even though and potentially encouraging energy saving behaviours which could not be directly measured.

Access data show that after an initial flurry of activity the system settled down to a consistent number of sessions per quarter. This dropped again after the project finished. Retention of active users is one of the biggest issues facing such systems. Users will return to the site if they gain a benefit from doing so. Different user groups will have different reasons to engage with such a system and much of the benefit is multiplied by maintaining a “critical mass” of users so the content remains fresh and relevant.

Conclusion and further work

Results show that the ‘dashboard’ and digital social platform components are each valuable in their own right but in combination they produced a system whereby users could identify and solve energy and water performance problems effectively and efficiently. There is evidence that stakeholders engaged with the tools designed within this research and that iterative use of the feedback loops facilitated improved the use of energy within the buildings. This research concludes that the use of a closed loop feedback system for non-domestic multi-user buildings can improve the energy efficiency of those buildings in day-to-day use.

Further work is needed to understand the relatively low number of forum postings initiated by non-expert building users and whether active participation from this group could be increased. Also, to understand how better to retain those users who do engage with the system. In addition, the application of the techniques to a wider range of non-domestic buildings and comparative study of success in those would be useful.

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