

Designing live energy performance feedback for public buildings in Leicester

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Abstract

Buildings represent a huge potential for energy savings, in the UK buildings account for 45 % of energy consumption. Buildings owned and managed by the public sector make up more than 10 % of the EU building stock. In recent years there has been much interest in the use of feedback systems to encourage energy behaviour change but very little literature on the design of feedback systems in the non-domestic setting.

The EU “SMARTSPACES” project is developing ICT services using data generated from smart metering systems in public buildings at 11 pilot sites across Europe. The SMARTSPACES system being developed in the Leicester pilot site will provide users with a live, half-hourly comparison of energy (electricity and gas) performance across 20 public buildings.

A new indicator of energy performance is proposed. The indicator relates consumption for the current half-hour with the distribution of equivalent historical values. The indicator is robust and unambiguous, reflecting progress in energy saving activity, normalised to each building.

The context in which the indicator is presented is also described along with the wider project which is intended to support a change of organisational culture to an active, energy aware community of staff and visitors communicating with energy professionals in the context of ubiquitous building energy performance information.

Introduction

The SMARTSPACES project (SMARTSPACES 2012) is a three year (January 2012 to December 2014) EU-funded project focused on saving energy in Europe’s public buildings using information and communications technology. Pilot sites at eleven European cities are developing services around data generated from smart metering systems. The project includes more than 550 buildings in eight countries (France, Germany, Italy, the Netherlands, Serbia, Spain, Turkey and the UK).

The SMARTSPACES methodology is to develop both Energy Decision Support Services (EDSS) to help building users make informed energy decisions and Energy Management Services (EMS) to help control buildings (in some cases automatically). A unique solution is being developed at each pilot site and the project as a whole is developing a common template for these SMARTSPACES services. After one year the project is currently at the later stages of the development phase, and the services at each pilot site are beginning to take their final shape.

The SMARTSPACES project also includes a detailed evaluation of the impact each pilot site has on building users and how that translates into energy savings. Before and after the launch of the services a full year of energy monitoring will take place and a questionnaire will be delivered to building users. Changes in factors such as building users interpretation of messages about energy saving, their motivations, attitudes and perceptions of control over changing their energy use will be analysed to provide a detailed picture of **why** energy was or was not saved at each pilot site.

Leicester is the UK’s first Environment City. The SMARTSPACES pilot site at Leicester is made up of two partners. Leicester City Council (LCC) is a unitary local authority, providing fifteen buildings in which to pilot the services. De Mont-

fort University (DMU) is the technical partner and will also be piloting the services in five buildings. Pilot buildings include leisure centres, university buildings, offices, schools, community centres, libraries, a museum and a concert hall. Services are due to be launched in the autumn of 2013.

Both LCC and DMU already actively use advanced energy information systems. Leicester City Council was amongst the first local authorities in the UK to install large-scale half-hourly energy monitoring equipment (so-called 'intelligent metering') in 2001 (Stuart 2011). The LCC system now covers over 1,500 meter points in over 300 buildings. DMU installed a similar metering system (Energy Metering Technology 2008) in 2008. Both LCC and DMU have access to total electricity, gas and water consumption data for nearly all the buildings they control on a half-hourly basis. The systems have provided enormous benefits to energy management.

Data gathered through these systems have the potential to engage the general public, building users and decision makers, raising awareness of the issues surrounding building energy performance. However, the monitoring systems were installed as energy management tools and the data they generate have only been available in limited technical forms and to limited numbers of people via proprietary energy management analysis software (Energy Metering Technology 2008).

The Leicester project aims to use ICT to increase the transparency of these data. A web-based tool is being developed which uses sophisticated analysis to provide the information contained within these data in an intuitive, engaging manner. This tool is only part of the SMARTSPACES project which also includes 'softer' services such as user groups and awareness campaigns to be run alongside the feedback tool. The project is conceived as a 'grass roots' campaign to facilitate the autonomous action of groups of building users led by the more enthusiastic individuals. This paper describes the thinking behind the design of the tool and in particular the energy performance feedback system.

Energy feedback

Energy feedback is primarily useful because it makes energy 'more visible and more amenable to control' (Darby 2006). In non-domestic buildings there are many building users, consumption patterns are the sum of many smaller components. Non-domestic building users have less contextual information such as an appreciation of the normal pattern of consumption across the whole building or the normal energy bill than they might in the domestic case (Carrico and Riemer 2011).

Energy consumption is largely invisible to building users (Burgess and Nye 2008). If a space is comfortable and equipment is working then the effects of energy consumption are not obvious. Only the services provided by energy are visible, if they are removed (e.g. the space becomes uncomfortable or equipment fails) then a user will notice the impact immediately. The behaviour of building users has an important influence on energy consumption. Very often simple, low-cost or zero-cost changes to occupant behaviour can have a significant effect on building energy consumption. These so-called **low-hanging fruit** are a great opportunity for motivated building users to take meaningful, autonomous action to save energy.

Changing behaviour can reduce the energy required to provide a particular energy service. However, the amount of energy required to provide a particular service is unknown to the user of the service. Properly motivated building users with the appropriate knowledge can reduce energy consumption without impacting on the energy services they receive. However, without reliable information about the impact of their actions it is likely that their motivation to do so will be eroded. Energy feedback systems that provide timely, reliable and user-friendly information may play an important role in maintaining motivation in any behaviour change campaign.

Energy feedback systems can facilitate the timely assessment of energy saving interventions. Once an intervention is implemented, the ability to quickly assess its impact can be used to determine whether the intervention was successful or otherwise. With this information, effort made to implement unsuccessful interventions can be avoided in the future whilst successful interventions can be continued and replicated elsewhere. In this way, feedback systems can help to deliver more energy savings for less effort.

A successful feedback system sets up a feedback loop between building users and the building itself. The feedback loop is 'closed' by passing information back to the building users in such a way that it affects their behaviour. Since users' behaviour affects the building energy consumption, the information flows as a loop. A closed loop will enable building users to learn how changes in their behaviour influence the building. Thus building users who intend to save energy will be in a strong position to identify the most effective changes they can make to their day to day activities. An ideal feedback loop will provide immediate, detailed feedback.

Audience and primary use cases

The tool is designed for a variety of audiences, primarily building users. The main audiences are staff working in the building on a regular basis and visitors (i.e. the general public). The tool also includes technical elements designed for energy professionals, but in this paper the focus is on the public aspects of the tool directed towards the large numbers of staff and visitors.

The key public features of the tool are an energy performance feedback system and a discussion forum. The feedback system delivers reliable, objective information about the current status of each building. This information is provided in such a way as to be engaging, fun and easily absorbed for the casual user. More detailed information is also provided for diagnosing problems or investigating the effects of experimental interventions. The development of the feedback system is the main subject of this paper.

The discussion forum is intended to facilitate a dialogue between motivated building users. This is intended to be used to identify and debate the relative importance of potential opportunities for reducing energy wastage. It can also be used to coordinate experimental actions between building users. Importantly, the discussion forum can be used to discuss the impact of coordinated actions, to share best practice between buildings and to communicate with energy professionals who will also be encouraged to take part in discussions. The discussion forum is an integral part of the overall system as it facilitates a change in organisational culture to one where the more motivated build-

ing users actively engage in a systematic process of identifying and reducing wastage. It is hoped that these highly engaged users will act as peer educators, pass their extensive knowledge on to colleagues and coordinate collective action.

Building users will differ in the amount of time they are willing to spend using the tool and will have varying levels of energy literacy. This introduces a trade-off between ease of use and richness of information provision. The first design principle employed in the tool was to 'hide the detail'. The most visible pages of the application present user-friendly information about the status of the participating buildings. These top level reports are a part of the browser based application but will also be presented on public screens in the participating buildings. This is expected to be the primary means of accessing the system for a large proportion of users and also provide regular encouragement to revisit the browser based application. Users who want to see more detail for a building can select it and see a further, user-friendly building-specific report. For the intrepid user who needs more technical information, a further click is required to view a data-rich, diagnostic report.

The user-friendly reports are designed to be easy to absorb. This provides a high value reward (i.e. reliable information) for a low cost (i.e. easy to absorb at a glance). Most building users will only glance at the screens for a fraction of a second as they enter the building. At best a user may take a few seconds to look at such screens before moving on. It is critical that this is enough time to absorb the key message of 'how well this building is doing at the moment'.

Information, not data

Feedback systems rarely provide simple raw consumption figures. Indirect feedback where the data have been processed in some way, is more common (Darby 2006). Simple processing options include providing a historical comparison (i.e. comparison with historical consumption) or normative comparison (i.e. comparison with consumption from similar buildings). Other components often used in feedback systems include rewards and penalisation, where users can earn points for energy saving and be penalised for wasting energy and incentives for accumulating a certain number of points (Jain, Taylor et al. 2012).

To encourage behaviour change, energy saving behaviour should be reinforced and energy wastage attenuated. A historical comparison can be a useful proxy for savings and wastage. If consumption falls below the historical norm then savings can be said to have occurred. Conversely, wastage is indicated by an increase in consumption above historical norms. A historical comparison is used as the core measure of 'performance'.

It has been shown that individuals use their perceptions of peer norms as a standard against which to compare their own energy consumption behaviours (Schultz, Nolan et al. 2007). Thus, if building users are shown feedback that indicates that most people are saving energy, then there will be pressure to conform to this norm. Conversely, if users are shown feedback that indicates that most people are wasting energy, then there is a danger that users will lose interest in being amongst the perceived few who 'do their bit'.

An important role of the feedback system is to communicate a suitably tailored expression of social norms. Where

possible, users should be reminded that their peers are behaving responsibly. The tool achieves this by expressing the state of a building on the public screens in one of two ways. When performing poorly, a normative comparison is shown. When performing well, a historical comparison is shown. A normative comparison widens the norm to include all buildings and (hopefully) shows that other buildings are performing better, introducing an element of competition. A historic comparison supported by a message such as 'well done everyone, we're making great progress' indicates that the majority of users within the building in question are contributing to the good performance.

Consumption modelling

The feedback system is based on a historical comparison. To achieve the required level of information on a half-hourly basis requires a more sophisticated approach than a simple comparison of current consumption to that of the previous week or year. To generate a robust historical comparison it was necessary to construct a model of consumption that captures variation due to occupancy and outside air temperature.

In this case a 12-month rolling baseline period has been chosen as the basis for comparison. For each week of available data (Sunday to Saturday), the baseline period is defined as the 12-month period prior to the beginning of that week. Using a 'rolling' baseline like this means that the model of what is 'normal' for a building will adapt to persistent changes in consumption patterns over time.

Occupancy patterns in the participating buildings are highly predictable, following a strong weekly pattern. Occupancy peaks during the day on weekdays and is reduced during the weekends and overnight. Both electricity and gas consumption are affected by 'time of week' as a proxy measure of occupancy. The effect of 'time of week' can be captured by splitting the baseline data into 336 subsets, one for each half-hour in the week and fitting independent models to each subset. For example, one subset of data will include only data recorded at 14:00 on Friday afternoons; another will cover 05:30 on Sunday mornings. Each of these 336 subsets contains around 52 data points, one for each week in the baseline period.

A model of consumption that captures the effect of time of week can be created by simply fitting 336 independent models to the subsets. For example, the simplest possible model involves calculating the mean of each subset to provide an average consumption 'profile' with 336 values that simply repeats every week. Such a simple model is often suitable for establishing a baseline profile. However, when energy is used for heating the influence of outside air temperature cannot be ignored. In this case a three parameter heating model (Fels 1986) is fitted to each subset of data (and the corresponding half-hourly outside air temperature readings). In this way, the model prediction is dependent on both the outside air temperature and the 'time of week'.

In many cases, such as when a building is not being heated, energy consumption is expected to be independent of outside air temperature. To create a more parsimonious model the Bayesian Information Criterion is used as in (Stuart 2011) to choose for each half-hourly period whether to fit the simple average model or the more complex heating model. This pro-

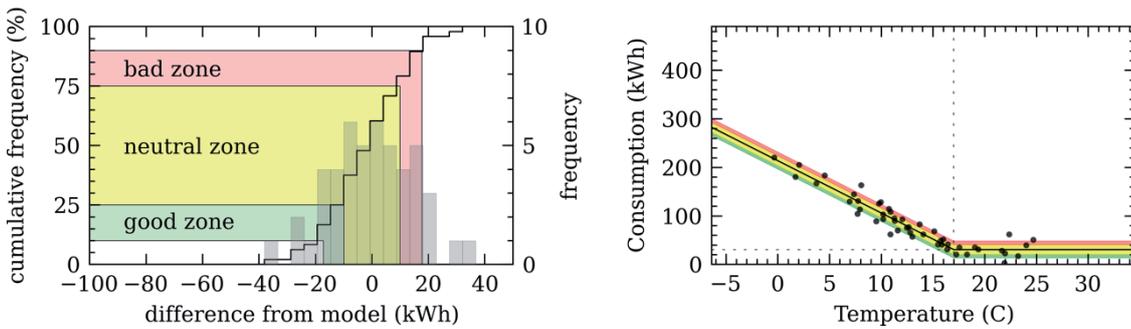


Figure 1. Derivation of consumption zones for subset of data relating to 11:00 on Fridays. A consumption model is fitted to the raw data (right) and model residuals (left) are used to generate the zones which are then added back onto the model prediction (right) to give an expected range for any given temperature.

vides a more sensible fit to the data and avoids the pathological effects of an over specified model.

To extend this (or any model) into a 'normal range', the model residuals (measured consumption minus modelled prediction) are calculated for each data point. From each of the 336 subsets, the 10th, 25th, 75th and 90th percentile values are then determined. These percentile values represent the variation around the model at each 'time of week' during the baseline period. This approach is used below to visualise the range of expected consumption as three zones surrounding the model prediction.

It can be said that only 10 % of historical data (at the equivalent time of week, in the baseline period) fell below the model by more than the 10th percentile and so this level can be considered as 'low' for the given building at the given time of week. Similarly, only 10 % fell above the model by more than the 90th percentile and this level can be considered very high. It follows that values between the 25th and 75th percentiles can be considered neutral and the intermediate regions, between the 90th and 75th, and between the 10th and 25th percentiles can be considered moderately high and low respectively.

Energy performance can be quantified at each half-hour by using the current consumption (and temperature) to generate a prediction from the model for the corresponding time of week. The prediction can then be converted to a residual (difference between consumption and prediction) and compared with the baseline residuals to determine a percentile score. Being a percentile value the indicator is provided on a normalised scale from 1 to 100, a value of 50 will always represent a value above and below which 50 % of equivalent historical consumption fell and thus will always represent a neutral level of consumption for that specific 'time of week'.

Designing the visualisation

As described above, the feedback system is organised in such a way that the engaging, user-friendly information is presented first and users are offered the opportunity to drill down into more detailed information if they wish to do so. The modelling approach described above explains how the data are converted into a half-hourly indicator. A major advantage of this percentile-based indicator is that it can be averaged over any period to produce an aggregate indicator for the period in question. This enables the detailed, half-hourly calculations to be pre-

sented in daily and weekly aggregated form. Converting these data into engaging visualisations is a critical step in closing the feedback loop.

DETAILED REPORT

Designing a detailed report from which simple diagnoses may be drawn by non-technical users requires a compromise between user-friendliness and sophistication. The report must show the current performance of the building and clearly indicate whether savings or wastage has occurred. For diagnosis it is important to know how much has occurred and when it happened.

A diagnostic report has been designed showing the latest week of data as a line chart. The data (blue line) are placed on a background showing the expected level of consumption as a shaded area. The shaded area is split into three "zones" representing normal (the middle band, in yellow), low (the lowest band, in green) and high consumption (the highest band, in red). The zones are bounded by the percentile data calculated above. As new data become available the report rolls to the left, always showing a full week of consumption.

The main diagnostic report shows one week of energy consumption against a shaded background indicating the zones defined by the model described above. Limiting the report to one week ensures users are always provided with a familiar baseline profile. With a little experience users can easily interpret the report by noting how the current consumption relates to this profile. An example is shown in Figure 2. Electricity consumption is low when the building is closed over the Christmas holidays and in the first few days of the year but the base load is still very high. The 'holiday switch-off' campaign has reduced electricity consumption below the normal weekend and overnight levels but the reduction has not been continued into the first weekend of the year and there is still a large base load to be investigated.

User-friendly reports

The detailed report requires time and experience to interpret and provides detailed information that many building users will never need. Two user-friendly reports have been designed to provide more immediate information with less need for interpretation. The reports both rely on converting an aggregate indicator which is a value between 1 and 100 into an engaging, emotionally appealing visualisation with a clear message.

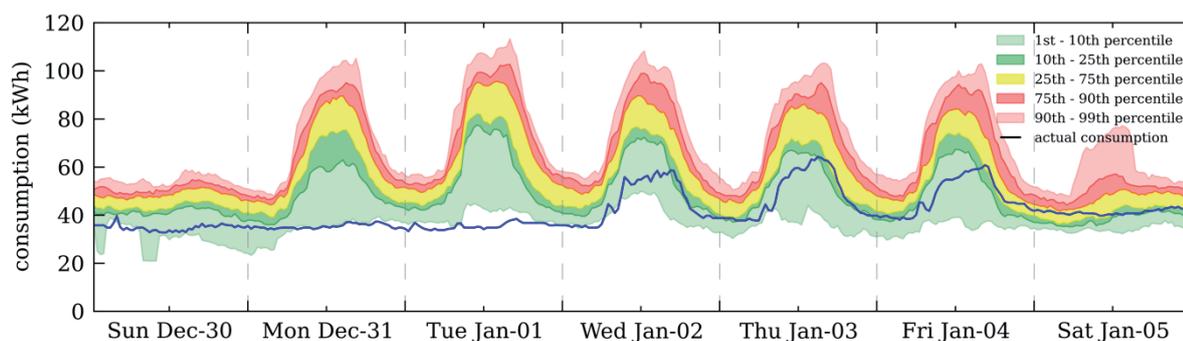


Figure 2. An example of the main diagnostic report as seen on Sunday Jan 6th (just after midnight).

To elicit an emotional reaction, the simplest approach is to present the user with a face expressing emotion. A simple face was designed to express the indicator as either a happy, neutral or sad expression. For each value between 1 and 100 the mouth changes from a smile to a frown and the colour ranges from green, through yellow to red. Other small changes also occur to the eye shape, iris position and pupil size. The benefit of this kind of visualisation is that it provides an unambiguous and immediate interpretation for the user. Low consumption is explicitly identified as “good” and high consumption as “bad”. Users are encouraged to avoid the sad faces and aim for the happy faces. The fine grained scale of the transition allows differences to be discerned between similar values of the indicator.

Historic comparison

The historic comparison provides a building-specific view of performance over time. The half-hourly indicators are averaged for each of the seven most recent complete days. This provides a single number between 1 and 100 for each of seven days ending on the latest complete day (i.e. yesterday). Each of the seven data points is converted into the corresponding image and arranged horizontally in a simple widget.

Normative comparison

The normative comparison provides a view of performance across multiple buildings as a league table. The half-hourly indicators for the last seven days are averaged to provide a single number between 1 and 100 for each building representing the current performance. The indicator for each building is converted into the corresponding image and arranged in order of performance with the best performing buildings on top.

Discussion

An energy feedback system has been designed to help building users to connect directly with live energy data. Making energy performance public information provides motivated building users with the information they need to effectively coordinate collective behaviour change actions. The efforts of building users who reduce their consumption will be reflected in this public information as either normative or historic comparisons depending on which indicates more clearly that energy savings are the norm.

The system relies on an energy performance indicator defined in terms of the change in energy consumption over time. Consumption is compared to baseline performance; improvement is expressed relative to the variability of historic data such that, if no change occurs, neutral feedback will be provided for 50% of half hourly values and the remaining 50% will be split evenly (i.e. 25% each) between positive and negative feedback. Changes in the consumption pattern will change this ratio. Even small reductions can lead to strong positive feedback if the historical pattern is consistent. The indicator can be averaged over longer periods to generate more stable values which reflect general performance of the building.

The indicator works well with the buildings tested so far but may not work well for all buildings. In cases where energy consumption patterns are not modelled effectively the indicator will show very wide variation and the indicator may not be a good measure of performance. In such cases an alternative model may be required.

The system also relies on a user-friendly visual scale to provide an engaging and immediate interpretation of performance. Daily and weekly indicators are publicised as historic comparisons and normative comparisons respectively. A simple emoticon scale is unambiguous and fun, perfect for communicating performance to the casual system user through public screens. Users who want to use the system for diagnosis have access to a detailed report. The underlying model is visualised as a weekly consumption profile showing the range of expected consumption, this adds diagnostic power to the detailed report.

Limitations of the available data present limiting factors on what is possible to achieve in this project. The main limitation is that for most buildings there is no sub-metering. That is, the data cover the entire building and so any feedback provided will relate to the entire building. A further limitation of the data is that they are not strictly ‘live’. Half-hourly data at LCC are only gathered into the system once a day; at DMU this happens every three hours.

These limitations are problematic as they reduce the usefulness of the available information. The time delay means that any building users that implement changes will have to wait a few hours or until the following day to see the impact of their actions. For the larger buildings, lack of sub-metering means the influence of worthwhile individual action may not be large enough to detect within the normal variation in consumption

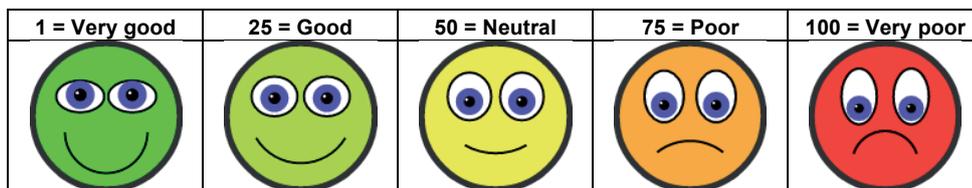


Figure 3. The indicator can be converted into a user-friendly scale.

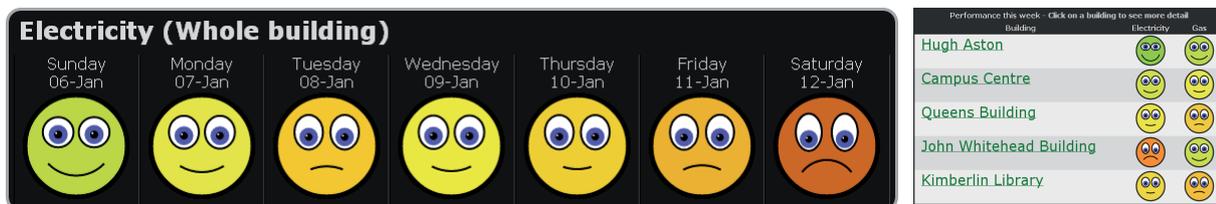


Figure 4. Historic and normative comparisons using the user-friendly scale.

of the building as a whole. Only collective action by groups of people will be large enough to make an obvious impact. However, the system will still provide a valuable service and improvements in the available data can easily feed into this provision.

The system encourages competition through the normative comparison. Buildings are competing, not to be the most efficient building but to be the most improved building. Competition is on a fair basis so large buildings can compete with small buildings. A one-off improvement may secure a good position for some months but the indicator will gradually fall back to neutral if nothing more is done. The top spots on the league table are achievable by any building and will only be held if continuous improvements are made.

The system encourages cooperation within each building through the historical comparison and the diagnostic report in combination with the discussion forum. Motivated building users can cooperate with energy professionals to identify the best opportunities and coordinate collective action by the wider population of building users. Temporary changes can be made to investigate their impact. Once wastage is identified and quantified the case for permanent change is made very strong.

The process of triaging all the potential interventions is expected to happen over many years, the feedback system will be a key component in driving continuous improvement and preventing the building from slipping back into poorer performance. Ultimately the aim is to facilitate a cultural change within an organisation towards a more 'distributed' form of energy management where building users take some collective responsibility for their energy use.

The system is still under development with a working version being tested with selected user groups from the participating buildings. The user groups are drawn from the environmental champion network and are expected to be more motivated and thus potentially influential users of the system. The system will

be launched in the autumn of 2013 and a full evaluation will be completed by the end of 2014.

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