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# Simple, timely and actionable feedback improves commercial office building performance

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**Abstract:**
This paper presents findings from a program adopted in a portfolio of Australian commercial office buildings in which an 'action-reflection' approach was applied to foster collaboration around energy performance 'feedback'. An automated energy diagnostic and visualisation system was developed to present simple, timely and actionable information to building operators and their managers. Automated short messages were emailed each morning describing (and illustrating) each building's energy use for the previous day relative to peer buildings and the model's prediction. Variations between actual and predicted impacts (in particular, energy use) pointed to learning opportunities that helped building managers identify and replicate 'better than expected' energy performance, and more efficiently respond to 'worse than expected' performance. Small teams of building managers from the same neighbourhood and other participants, including the researchers, were assembled on a fortnightly (and *ad hoc*) basis to evaluate results and share insights, thus contributing to the program's ongoing success.

**Keywords:** energy efficiency; commercial buildings; office buildings, building operators, energy performance data.

## Introduction

An analysis by Faruqui *et al.* (2010) found studies into the effect on consumer behaviour of various in-home energy feedback systems going back at least four decades "have consistently demonstrated that direct feedback motivates behaviour change, resulting in energy savings ranging up to 20 percent" (Faruqui, *et al.*, 2010). To-date, most of the research into the effect of informational feedback on energy consumption has been focussed on the residential sector, and in particular Home Energy Management Systems (HEMS). These generally take the form of energy monitors, also known as In-Home Displays (IHDs) – "intermediary products that can visualize, manage, and/or monitor the energy use of other products or whole households"(van Dam, Bakker, & van Hal, 2010).

While acknowledging there is still much to learn about the efficacy of HEMS, prescriptions for successful programs have tentatively been offered and broadly acknowledged in the literature (Darby, 2010; Department of Energy and Climate Change (DECC), 2009; Fischer, 2008). Fischer suggests that

> "Successful feedback has to capture the consumer's attention, to link specific actions to their effects and to activate various motives. If this is the case, then different

characteristics of the feedback itself become relevant, among them, its frequency, content, breakdown, presentation, inclusion of comparisons, and combination with additional information and other instruments."

(Fischer, 2008, p. 85).

Fischer found that, for householders, frequency of feedback is crucial. "It emerges that none of the 'less than monthly', and all but one of the 'daily or more' projects are among the best performing (as far as they can be compared)" (Fischer, 2008). Furthermore, information should be 'delivered' in a readily accessible form rather than simply being made 'available'. The UK government, citing experience in the USA and Sweden where only 2 to 4 per cent of customers choose to view smart meter data online, has confirmed its position that "a standalone display should be provided with the smart meter ... the provision of a display is important to securing the consumer benefits of smart metering, delivering real time information to consumers on their energy consumption in a readily accessible form" (DECC, 2009, p. 31).

Putting aside the obvious differences in scale and building technologies, there are important similarities between residential and commercial buildings: energy is used in both contexts to provide thermal comfort and indoor environment quality; the technical ability and motivation of the building operators significantly impact energy use; and the cost of energy is increasing.

The extent to which this knowledge about residential consumer interactions with energy monitoring and feedback systems can be transferred to commercial building typologies is uncertain, however. The authors of the chapter on residential and commercial buildings in the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report (AR4) noted that "the potential [greenhouse gas] reduction through non-technological options is rarely assessed and the potential leverage of policies over these is poorly understood" (Levine *et al.*, 2007, p. 389). As a consequence, that influential report, which surveyed 80 studies, did not assess the potential for emission reductions through behaviour-based options (either in residential or commercial buildings) such as the approach described in this paper.

The advent and worldwide growth of the 'green building' industry (USGBC, 2009) is associated with an increase in the technological complexity of modern commercial buildings. In part this can be attributed to the rising prevalence of rating systems. As Bordass *et al.* (2001) observe, more sophisticated technologies generally require greater levels of building management input in order to perform efficiently. More and higher technology without a commensurate increase in management input is risky and 'a hole that many buildings fall into'. While it has been found that there is little or no direct relationship between the comfort of occupants and the intensity of energy use, "good management of the procurement of a building and its subsequent operation can help to deliver simultaneous comfort, energy and organisational benefits" (Bordass, *et al.*, 2001).

In this paper we address the question: can the provision of simple, timely and actionable feedback to the operators of commercial office buildings improve building performance? We believe the question is timely given the recent emergence of a significant marketplace for facilities resource management (FRM) products and services which utilise detailed, near-real-time energy and resource data to optimise the operation of, typically, large commercial buildings (MacDonald & Bray, 2011). The marketplace for FRM solutions is heterogeneous and evolving rapidly despite a lack of scientific research into the efficacy of such approaches. This was indirectly acknowledged by the UK government in its response to the consultation on electricity and gas smart metering

> "In recognition of the different needs of the wide range of customers and premises in the non-domestic sector, the Government does not intend to require a real-time display device to be provided to electricity or gas consumers in this sector. As part of further preparatory work on the roll-out of smart meters, we will consider what data should be made available to these customers, and what requirements should be placed on licensees to provide such data"
>
> (DECC, 2009, p. 6)

It almost goes without saying that the operators of commercial office buildings are a diverse lot in terms of experience, education, technical proficiency and worldview. Standardised feedback must take these differences into account if it is to induce a consistent and proactive response. Fundamentally it must motivate. Fischer found that without a motivation to conserve, information about how well a building performs may even be counterproductive. For example, when comparative or historical feedback shows that consumption is relatively low (or has been dropping), it may signal that there is room to slacken off (Fischer, 2008).

Certain groups of people are more receptive to on-going performance feedback than others. These more intrinsically motivated people quickly develop new habits and exhibit larger savings in response to feedback on energy use (van Dam, *et al.*, 2010). In 2007 the British Government's Department for Environment, Food and Rural Affairs (DEFRA) surveyed public attitudes and behaviours toward the environment and found that, for the majority, "being 'green' is seen as the socially acceptable norm" (DEFRA, 2007, p. 2). They also found that many factors stood in the way of action and, in a subsequent analysis, produced a segmentation model that divides the public into seven clusters, each sharing a distinct set of attitudes and beliefs towards the environment, environmental issues and behaviours (DEFRA, 2008). DEFRA's model includes detailed profiles of each segment covering, for example, ecological worldview, socio-geo-demographics, lifestyle, attitudes towards behaviours and current behaviours, motivations and barriers, and knowledge and engagement. The clusters were found to vary across population groups and there was evidence that people's categorisation may change over time according to life stage and other individual circumstances (p. 8). The research suggests that building operators will respond differently to approaches aimed at focussing their attention on the environmental performance of buildings and it is necessary to adopt a targeted approach that is cognisant of each individual's mindset.

And then there is the challenge of maintaining interest. Van Dam *et al.* found that in general (domestic) feedback devices slowly drift into the background and that initial savings in electricity consumption are not sustained in the medium- to long-term (van Dam, *et al.*, 2010). While acknowledging a gap in the literature, they hypothesised that people may "simply lose interest". Faruqui *et al.* suggest that if consumers actually use and benefit from real-time, quantitative and qualitative information provided by feedback devices, then a change in behaviour is likely to be preserved. If, on the other hand, consumers simply treat the display as a physical reminder to conserve, many habituate and disregard it in the long run (Faruqui, *et al.*, 2010). This may also be a problem for approaches that are particularly novel or fashionable. Results of a study by Chen *et al.*, for example, which used a dynamically changing 'digital aquarium' to create a persuasive feedback model for inducing energy conservation behaviours in building users, indicated that "user fatigue is quite possibly a factor in the persuasion domain that would gradually reduce the effectiveness" (Chen *et al.*, 2012). However, there is also some evidence that displays can have an enduring impact even if only used for short periods, through investment in efficiency measures and changed habits (Darby, 2006; Fischer, 2008).

It is unreasonable to assume building operators will use feedback systems effectively, either over the short- or long-run, without an accompanying framework to induce action and reflection. This is emphasised by Darby who finds that feedback on consumption is necessary for energy savings, though "it is not always sufficient – sometimes people need help in interpreting their feedback and in deciding what courses of action to take – but without feedback it is impossible to learn effectively" (Darby, 2006, p. 17). Such findings point to a benefit in combining feedback technologies with formal collaboration frameworks. Such an approach, termed 'action learning' was developed and refined by Prof. Reginald Revans in the UK coal industry during the 1940's and 50's where pit managers were encouraged to meet together in small groups, to share their experiences and ask each other questions[1]. The approach was highly successful and Revans went on to refine the method into a formula:

$$\boldsymbol{L} = \boldsymbol{P} + \boldsymbol{Q}$$

Where: $\boldsymbol{L}$ is 'learning', $\boldsymbol{P}$ is 'programming' (or programmed knowledge, i.e. knowledge that is taught or read) and $\boldsymbol{Q}$ is questioning to create insight into what people see, hear or feel (Revans, 1980, 1997). Questioning involves the use of closed (e.g. what?), objective (e.g. how many?), open (e.g. why?) and relative (e.g. where?) questions.

The action-reflection approach adopted in this study and described in the following section, builds on Revans' model ($\boldsymbol{L} = \boldsymbol{P} + \boldsymbol{Q} + \boldsymbol{R}$) where $\boldsymbol{R}$ refers to 'reflection' (See Marquardt, 2004). Through background interviews with building managers and observations made prior to commencing the study, we noted how the effectiveness of measurement and monitoring frameworks hinge on how well information is interpreted, acted upon, and then refined through trial and error. The following model (fig. 1) developed by Kolb (1984) provides a theoretical basis and shows how the approach works.

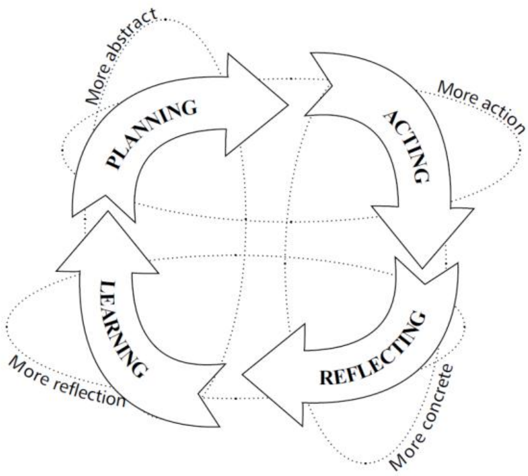


*Figure 1: Learning from experience.*
*(Source: Adapted by Serrat, 2008 from Kolb, 1984)*

[1] For a summary of the action learning approach, see Revans, 1997.

Put simply, the action-reflection approach is about solving problems and getting things done. Revans' showed that by assembling small groups of 5–8 peers (called an action learning set) and having them meet regularly for a day or half a day over at least 6 months to work collectively on a problem faced in ongoing practice, productivity increased by over 30% (Revans, 1980). An application of this approach in commercial buildings utilising near-real-time data is described in the following section.

While little research exists into the efficacy of energy feedback systems for operators of commercial buildings (presumably this is at least partly on account of the difficulty of gaining access to portfolios of operating buildings to conduct action research experiments), even less is known about the benefits (or otherwise) for occupant comfort. On-going research in Australian commercial buildings (Roussac, Steinfeld, & de Dear, 2011) points to an association between adjusting thermostat setpoints to reduce the temperature gradient between indoors and outdoors, energy savings and fewer complaints from building occupants. This association may arise on account of tighter building control. Piette *et al.* found that by introducing an information and diagnostic system, the operators of a large commercial office building were able to make "more effective use of the building control system, freeing up time to take care of other tenant needs. [Operators reported] observing significant improvements in building comfort, potentially improving tenant health and productivity" (Piette, Kinney, & Haves, 2001). That detailed case study looked at only one building, so inferences remain tentative. We are not aware of any studies to-date which attempt to explicitly link non-residential building energy and occupant comfort trends arising from the provision of near-real-time feedback. As Van Dam *et al.* concluded after their review of the literature relating to HEMS, "… a deeper understanding is needed that embraces social science, contextual factors, usability, and interaction design research" (van Dam, *et al.*, 2010). This need is even more pressing in the non-residential sector on account of the scale of the impacts, absence of research and rapid emergence of new FRM solutions – the majority of which seek to "optimise the operation of, typically, large commercial buildings" (MacDonald & Bray, 2011) in most cases without taking comfort data into account. The following sections describe a promising study that may, in time, contribute to more effective approaches for optimising the energy efficiency of non-residential buildings, which we define as a high level of internal environmental quality relative to the use of non-renewable resources.

## Method

Our study employs a purpose-built diagnostic and visualisation system that presents simple, timely and actionable building energy performance information to property supervisors, facilities managers and other stakeholders on a daily basis. The system, called *'Pulse'*, consists of two basic components: a data warehousing and processing platform; and a short messaging (email) tool. The design objective was to generate and convey feedback that would help building managers identify and replicate 'better than expected' energy performance, and more quickly and efficiently respond to 'worse than expected' performance. To ensure the system's feedback is meaningful and taken seriously by building operators, it creates a 'judgement' about the building's energy consumption, taking into account each day's weather conditions. This seasonal- and weather-adjustment is undertaken using multiple regression, by 'learning' from how each building's energy consumption historically varied with weather conditions to predict a future consumption. The feedback is also discussed within 'action learning groups' typically consisting of small teams (5-8 people focussed on 3-5 buildings) of building managers with direct operational responsibility for nearby buildings, a facilities manager (typically the property supervisors' boss) and energy experts who meet fortnightly and on an *ad hoc* basis to discuss recent performance and initiatives undertaken. The system has also been designed to support a web-based viewing tool (www.greenbuildingsalive.com/datatools/pulse/) which will assist building managers in tracking performance and present aggregated results to the public. The web platform was not in operation at the time of this study.

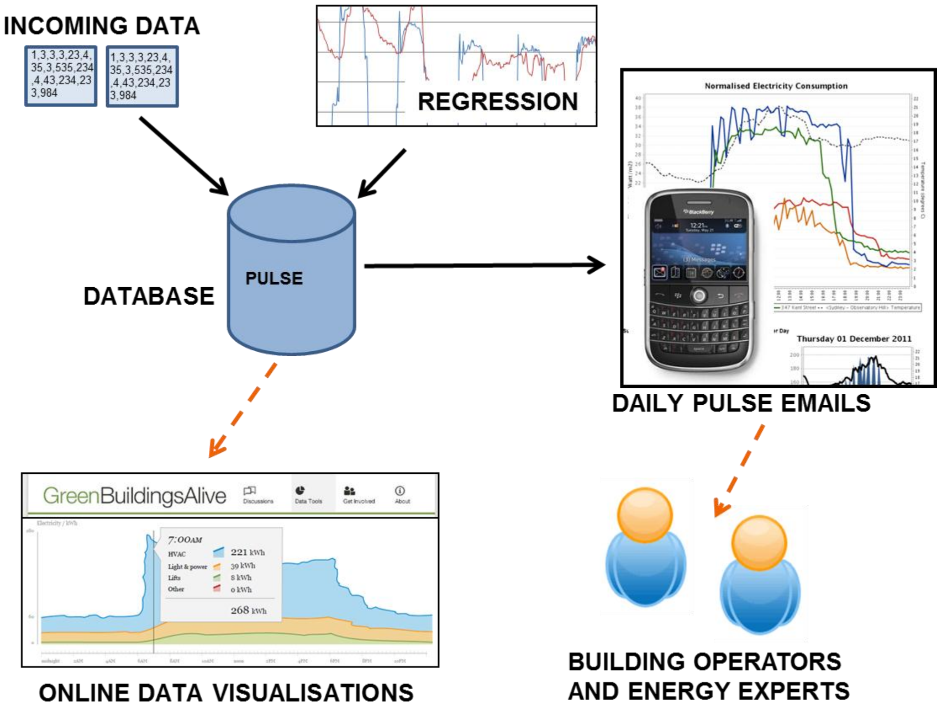


*Figure 2: Overview of 'Pulse' system architecture.*

The following broad description of the method used to generate the messages also explains the basis for our analysis of each building's performance in response to the feedback provided to the building operators.

1. Two years of 15-minute interval electricity and weather data was sourced for each building from the electricity network company's meter provider and the Bureau of Meteorology's nearest weather station.
2. Data was segmented to produce variables for multiple regression analysis. These variables include overnight average temperature and humidity, workday average temperature and humidity, and day of the week. To overcome a (typically insignificant) serial autocorrelation, a residual variable was estimated based on the workday average temperature. This variable was then used in the final regression analysis performed to determine each building's unique prediction equation. An element of expert judgement was used to exclude unusual days (weekends and public holidays were excluded, as were days with similar characteristics such as the period between Christmas and New Year) and narrow the period of focus to remove the effect of changes to building systems, occupancy etc. which may have confounded the analysis.
3. An automated data collection and analysis platform was developed to parse weather and energy data on a daily basis to produce messages. The platform houses detailed information about each building, including the predictive formulae which can be adjusted, as required, by an administrator.

A typical message adopts the following form:

> ***To:*** *operator@building.com.au*
> ***Subject:*** *123 Jones Street's electricity: good day yesterday*
>
> *Great news, yesterday 123 Jones Street used 13.1% less energy than expected. Nearby buildings used 6.0% less than expected. Over the past month 123 Jones Street has significantly beaten the prediction on 47% of occasions.*

Presented beneath that simple message is a series of graphs, including a sub-meter breakdown of yesterday's load profile and its closest 'like day' (the day within the past year where the model predicted electricity use would be most similar to the prediction for yesterday) and the building's profile overlaid against the others included in its 'action learning group'. The message and graphs were designed to present clearly on the building manager's smartphone, thus avoiding the effort required to logon to a PC.

One of Australia's largest institutional-grade office building portfolios was selected for the study. The portfolio is concentrated in the climatically diverse central business districts (CBDs) of Melbourne, Sydney and Brisbane. 'Pulse' was deployed at 31 buildings between 15 August and 22 December 2011 in the following order, with a pre-commencement meeting convened for each, followed by the regular fortnightly meeting. In all cases the evaluation is on-going.

15.08.11 — 3 buildings (Group A - Sydney)
12.09.11 — 4 buildings (Group B - Sydney)
17.10.11 — 4 buildings (Group C - North Sydney)
01.11.11 — 1 building (Group C - North Sydney)
07.11.11 — 5 buildings (Group D - Sydney (4) and Group C - North Sydney (1))
12.12.11 — 4 buildings (Group E - Melbourne)
22.12.11 — 10 buildings (Group F – Brisbane (8) and Group B – Sydney (2))

An important factor to note about the portfolio is its history of energy efficiency improvements. Between July 2004 and October 2011 the portfolio's intensity of electricity use for base-building services reduced by 30% (from 136 to 95 kWh/m$^2$.yr) and the intensity of natural gas use reduced by 49% (from 139 to 71 MJ/m$^2$.yr). This was taken to indicate that relatively few easily identifiable 'wins' would be available.

The portfolio is serviced by an independent web-based tenant helpdesk which administers occupant service requests and complaints. All communications are time-stamped and allocated a code (there are more than 50 codes) and a root cause once the issue has been addressed and 'closed out'. Building occupants were not advised about the introduction of the feedback system. It has been deemed too early to perform any analysis of helpdesk data, however the resource will be available for future reference.

Our analysis utilises the 'Pulse' feedback system's building-specific baseline model generated from the historical relationship between energy use and weather. This approach provides a robust basis for evaluating changes in building energy performance, and hence we do not believe a control or baseline sample would provide any additional insights. A similar approach will be adopted to evaluate the impact on comfort conditions, once sufficient data is available. A future iteration incorporating the use of IEQ data will likely adopt the baseline regression model approach described above.

**Results and discussion**

For this paper we limited our analysis to groups A and B, and the period from commencement at each building to 26 March, 2012 – approximately 7½ and 6½ months respectively. While it is acknowledged that this limits the statistical significance of our results, our data nonetheless offers useful insights that extend beyond many of the studies we have reviewed in the literature.

A noticeable difference in the mean ($\bar{x}$) and distribution of variances between recorded ("actual") electricity use and the model's prediction was observed at all buildings, as illustrated by the histograms in Figure 3, and in tables 1 and 2 below. In each case the distribution was normal prior to the introduction of the 'Pulse' feedback and the pattern of distribution was, more or less, maintained around the post-implementation mean. Group B - Building 1's (B1) variance distribution is more concentrated around the mean than the others, also indicated by its significantly lower standard deviation ($s$) in table 2, below. Building B1 is the only one in the sample to receive feedback based on 'whole building' electricity data, i.e. base building services *plus* tenant electricity use. In Australia, electricity supplying the tenants' light, power and supplementary air conditioning is typically metered separately and invisible to the building operator who (usually) has no control over it. The tenant load, which comprises approximately half the building total, is very stable and unresponsive to weather. It therefore had the effect of 'dulling' the feedback provided to the building manager by introducing a significant stabilising component and potentially also understating the reduction in the operator-controlled portion of the building's electricity use.

Tables 1 and 2 indicate that, in all cases, the feedback was associated with a reduction in electricity use, regardless of building age, size or technological sophistication. The mean reduction ($\Delta\bar{x}$) in actual electricity use versus the model's prediction indicates the magnitude of the observed improvement, noting that it may be conservative on account of the gradual improvement trend which was observed with both groups (figs 4 and 5).

*Table 1: Comparison of samples, pre- and post- introduction of the feedback system at Group A. $\Delta\bar{x}$ indicates the scale of the reduction in electricity consumption.*

| Group A | Building 1 | | Building 2 | | Building 3 | |
|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | Pre | Post |
| n (days) | 171 | 147 | 171 | 147 | 97 | 147 |
| $s$ | 0.09 | 0.07 | 0.06 | 0.06 | 0.07 | 0.06 |
| $\Delta\bar{x}$ | | -7.96% | | -3.77% | | -6.46% |

*Table 2: Comparison of Group B samples.*

| Group B | Building 1 | | Building 2 | | Building 3 | | Building 4 | |
|---|---|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| n (days) | 167 | 127 | 247 | 127 | 230 | 127 | 247 | 127 |
| $s$ | 0.01 | 0.02 | 0.10 | 0.08 | 0.10 | 0.10 | 0.10 | 0.07 |
| $\Delta\bar{x}$ | | -2.35% | | -6.66% | | -8.41% | | -1.63% |

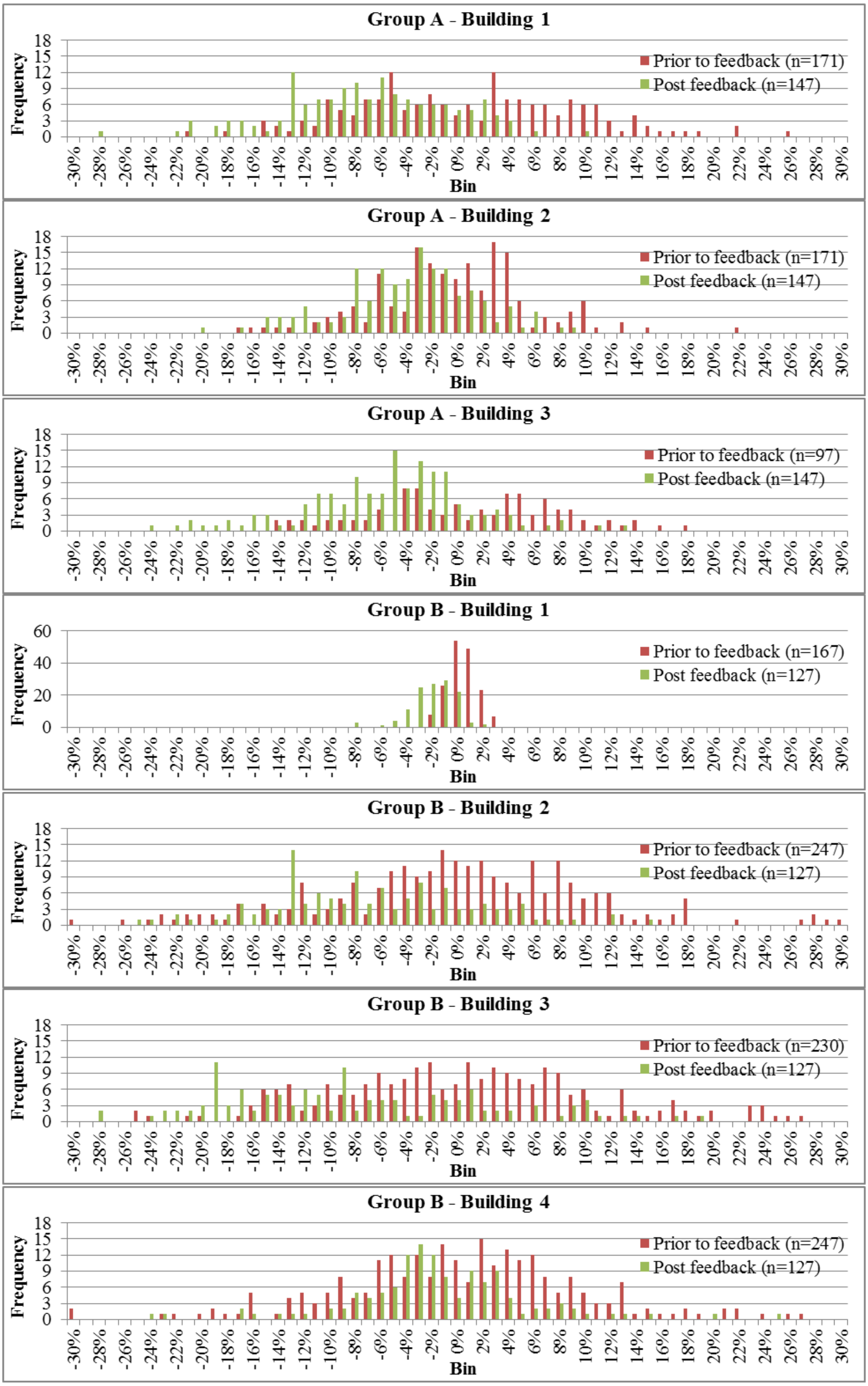


*Figure 3: Histograms showing percentage variance of 'actual' versus 'prediction'.*

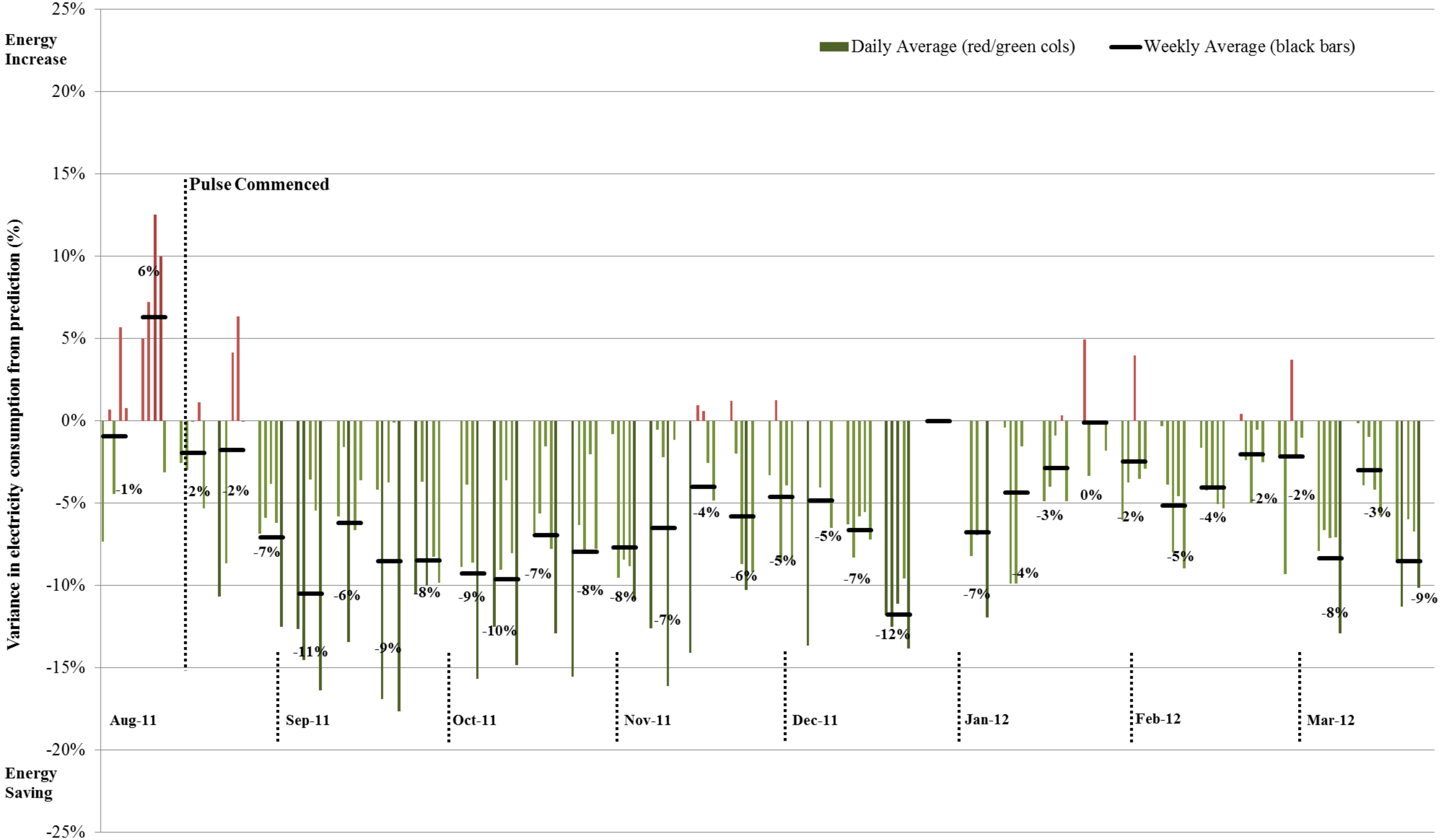


*Figure 4: Mean daily and weekly variance between actual and predicted electricity use for the three buildings in Group A, from two weeks prior to commencement.*

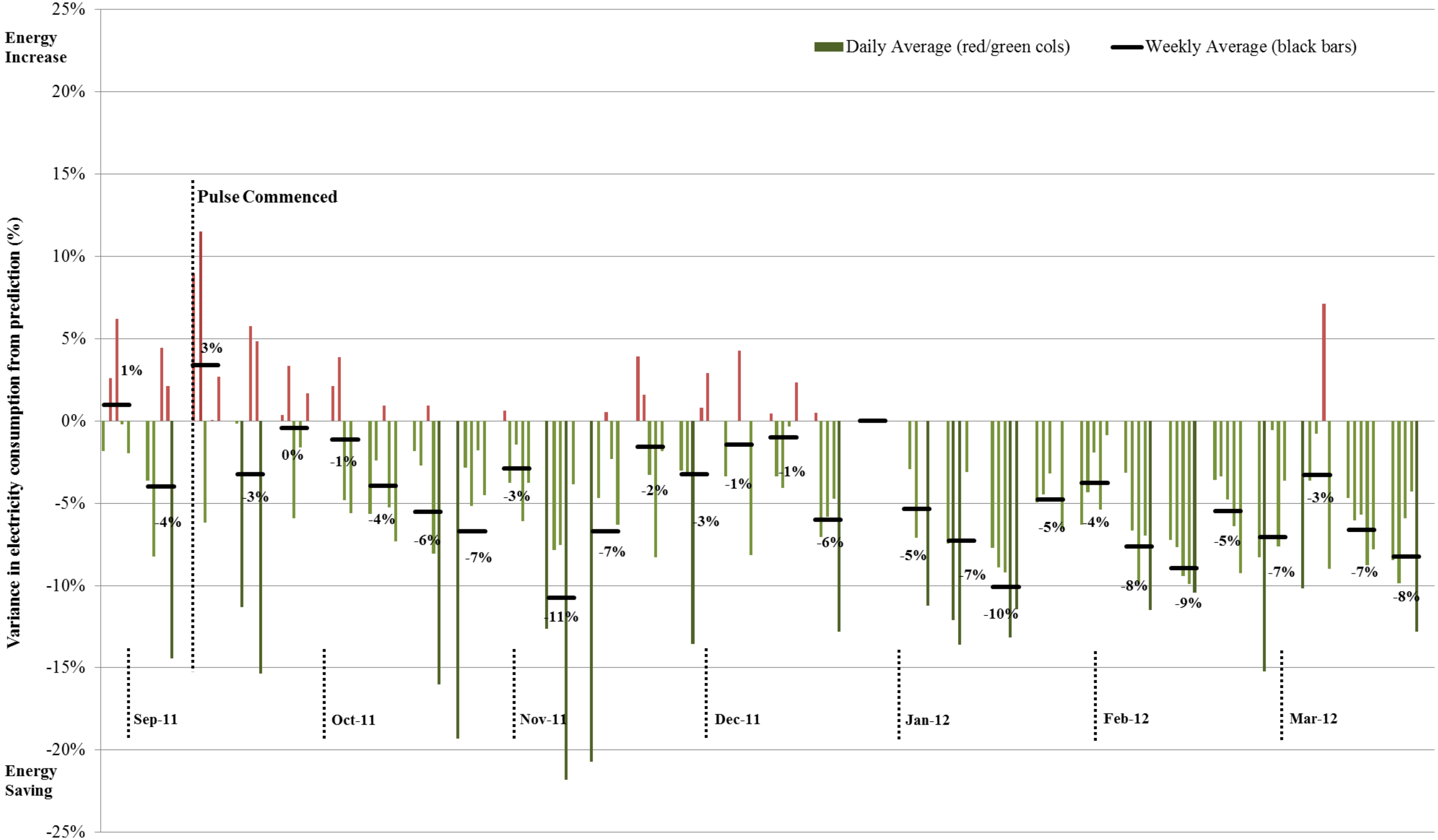


*Figure 5: Mean daily and weekly variance between actual and predicted electricity use for the four buildings in Group B, from two weeks prior to commencement.*

The summer holiday period between mid-December and mid-/late January in Australia is associated with erratic occupancy and also some disruption to the availability of the regular operations and technical services personnel. For those reasons we believe it is necessary to treat the December and January data with caution (although, for completeness, it has been included in all statistics and figures presented above).

Whilst we can say that a trend appears to be emerging, we cannot yet quantify it, nor say with certainty that the effect has been induced by the content of the feedback messages or the 'daily reminder' aspect, or something completely independent. Based on the observations of van Dam, Faruqui, *et al.* cited above, we anticipate this being resolved as the research goes on. We already have promising indications that the building operators are using the information to inform deliberate actions. Figure 6 illustrates what happened when space temperature setpoints, which had been set at 23°C±1.5, were reduced to 21.5°C±1.5 shortly after the introduction of 'Pulse'. On Monday 22 August, the first workday after the change, the building manager received his message saying "Great news, yesterday [Building A1] used 8.5% less energy than expected." He was very pleased and noted that there had been no negative feedback whatsoever from building occupants who, presumably, did not mind the change.

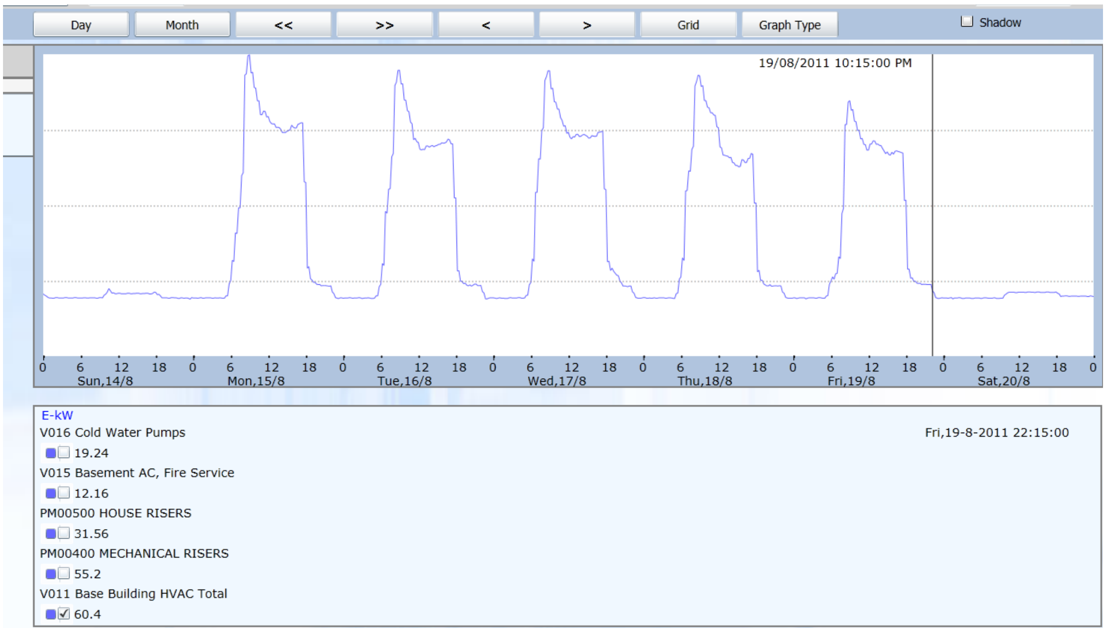


*Figure 6: Reduction in Heating, Ventilation and Air Conditioning (HVAC) sub-meter morning 'spike' at Building A1 indicating a reduction in space temperature setpoint reduced heating / cooling conflicts.*

Later that month the building manager increased the setpoint by 0.5°C (to 22°C±1.5) to delay the chiller start and balance heating/cooling demand. Note the weather warmed over the course of August. Figure 7 illustrates the building's energy use on 31 August compared to its closest 'like day' (Friday 26 August, 2011) and also the near-complete elimination of the 'spike' described above. The email containing the graph (fig. 7) opened with the message: "Great news, yesterday [Building A1] used 5.1% less energy than expected."

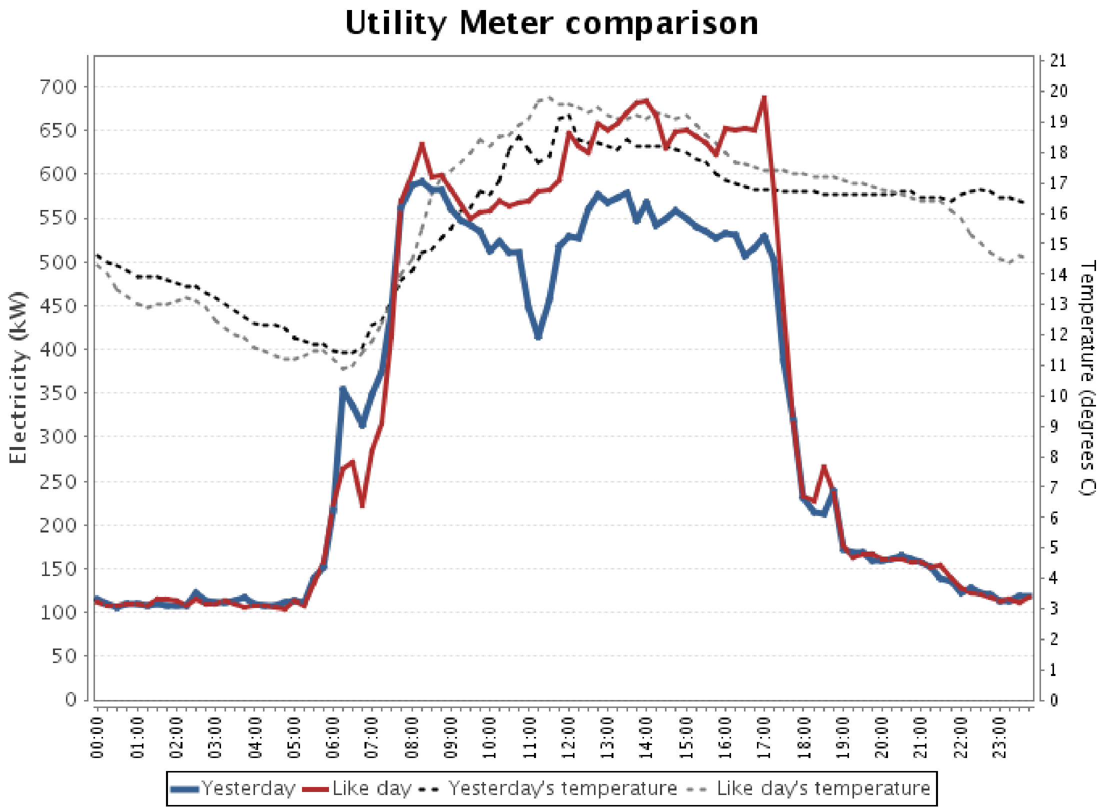


*Figure 7: Impact of fine-tuning temperature setpoints at Building A1, 31 Aug, 2011. (Graphic sourced from 'Pulse' message.)*

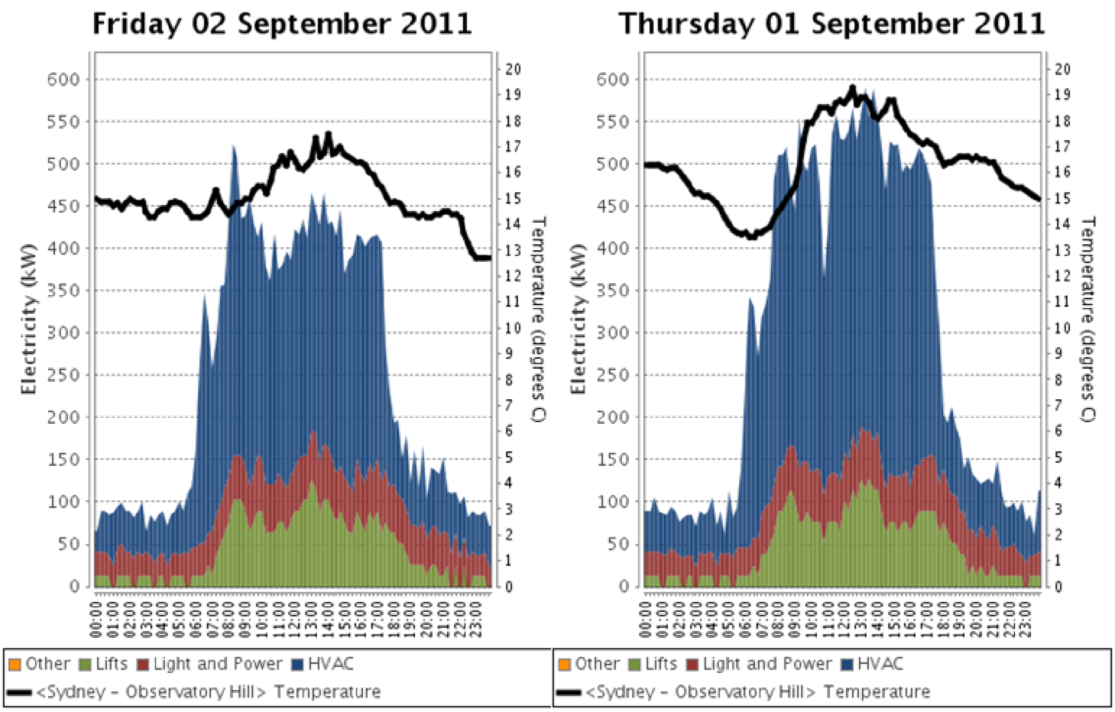


*Figure 8: Impact of annual chiller service at Building A1. Chillers were 'locked out' on Friday 2 Sept. and a 23% saving was reported with no 'too hot' complaints. (Graphic sourced from 'Pulse' message.)*

There have been other instances where "accidental" learning appears to have taken place. Figure 8, extracted from the message to the building manager at Building A1 on Monday 5 September ("Great news, yesterday [Building A1] used 22.9% less energy than expected.") prompted this reply: "[On] Thursday (1st Sept) chillers had annual service clean, chillers were locked out on Friday. 23% savings seen for Friday with no 'too hot' complaints." Had it not been for the feedback from 'Pulse', the building manager would not have had anything to alert him to the fact his chillers were disabled – again, there was no noticeable upswing in complaints from occupants! This prompted a rethink about the building's HVAC control strategy which is ongoing. In this case the 'like day' was the preceding day (Thursday 1$^{st}$ September – the day when the primary chiller was deliberately offline – which masked the impact on the 'like day' graph).

Feedback from the participants in the action learning groups has been consistently encouraging, and the comfortable team environment has been found to foster open discussion about experiences such as the three involving Building A1 mentioned above. Within a fortnight of commencing, the Group A building managers requested a change to the system allowing them to receive a daily graph overlaying each of their buildings so they could compare peer-building profiles on a daily basis. This change was introduced in October (prior to that their manager manually forwarded the requested graphic to each of them). Thus far we have not used the hierarchy engagement aspect of the tool because we are interested to understand the intrinsic motivational aspects prior to introducing extrinsic motivators. Given we are engaged in an action research methodology, we are obliged to listen and respond to the guidance of building managers who are directly accountable for their building's energy efficiency and performance. To-date they have expressed a preference for keeping the information feedback within their closed group of peers, however, given the encouraging trends it's difficult to see why most would not welcome broader engagement down the track.

As stated in the introduction, we believe building energy efficiency should be measured by the relationship between internal environmental quality and non-renewable resource use. As such, we are unable to observe improvements in energy efficiency without monitoring occupant comfort to a similar level of detail. The evidence we've observed from practice—where building managers are actively pursuing energy savings and treating direct occupant feedback, both through discussions with tenants and service requests logged with an online help portal, as a 'control' or 'check'—is encouraging insofar as occupant comfort appears not to have suffered as a consequence of a heightened focus on energy savings. This will need close monitoring, and accordingly we hope to measure, model and report occupant comfort conditions using a future version of 'Pulse'.

We noted earlier that there are similarities between domestic and commercial buildings; there also appear to be similarities between building HVAC systems and the occupants they service which may provide an additional explanation for the erratic variances between actual and predicted energy use indicated by figures 4 and 5 throughout late-spring and summer. Figure 9 shows a fairly neat (negative) correlation between the 8:45am ambient temperature and the clothing choices of people entering one of the Sydney buildings included in the study (Building D2). Until the apparent breakdown in the relationship from September 2011 onwards, that is! Sydney experienced an unseasonably cool spring and summer and this appears to have been reflected in the variability of clothing choices by office workers. We suspect the highly variable and unpredictable weather may also have made the task of setting building services more challenging than usual. We have not performed any analysis to test that possibility.

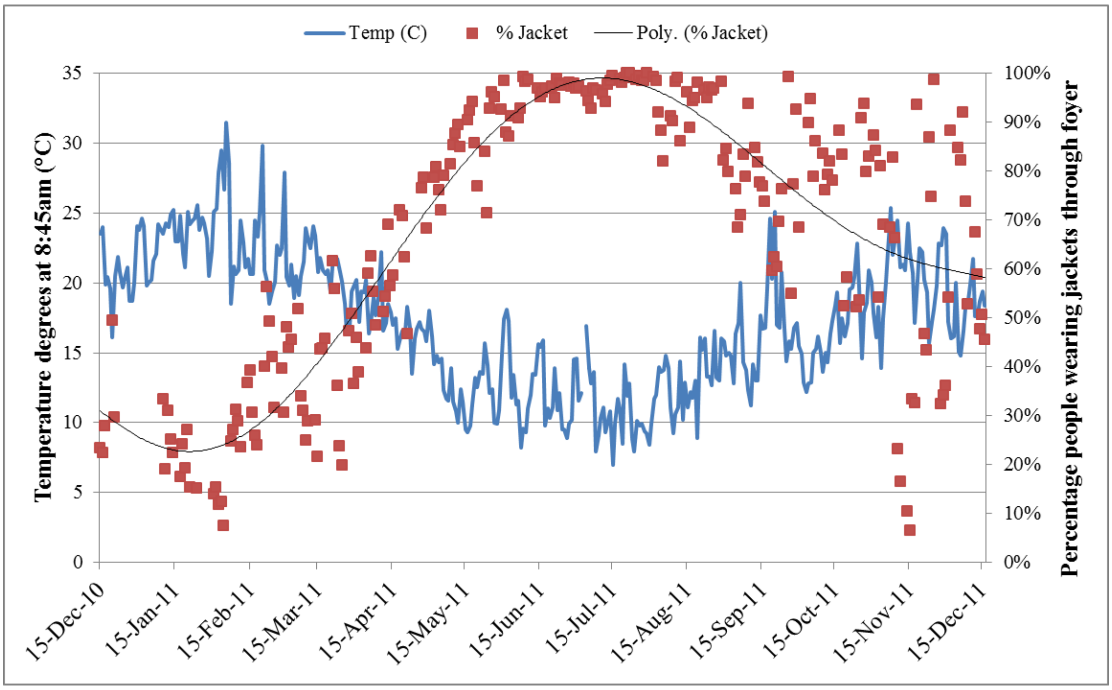


*Figure 9: Relationship between 8:45am outside air temperature and occupant clothing choices at a Sydney CBD office building (Group D).*

## Conclusion

Our study indicates that the performance of commercial office buildings can be improved by providing operations staff with simple, timely and actionable feedback. The feedback design, which incorporates elements associated with successful trials of energy monitoring systems in residential contexts, appears to have engaged building operators regardless of their level of experience, education, technical proficiency or worldview. Importantly, the results were achieved in a portfolio of buildings widely recognised for its pre-existing level of efficiency, and where significant operational improvement opportunities were not able to be anticipated.

We are mindful of evidence (from programs and case-studies focused on residential energy consumers) indicating potential 'fatigue' effects and are continuing the study to evaluate the efficacy of our method over the medium-term.


## Acknowledgement

We would like to thank and acknowledge the contribution of Jesse Steinfeld who has been actively engaged in all aspects of the project. We also gratefully acknowledge Investa Property Group and the Investa Sustainability Institute for financing the development of 'Pulse' and facilitating access to the properties and personnel for the purposes of conducting the research.


## References


Bordass, W., Leaman, A., & Ruyssevelt, P. (2001). Assessing building performance in use 5: conclusions and implications. *Building Research & Information, 29*(2), 144-157.

Chen, H.-M., Lin, C.-W., Hsieh, S.-H., Chao, H.-F., Chen, C.-S., Shiu, R.-S., et al. (2012). Persuasive feedback model for inducing energy conservation behaviors of building users based on interaction with a virtual object. *Energy and Buildings, 45*(1), 106–115.

Darby, S. (2006). *The effectiveness of feedback on energy consumption: A review for DEFRA of the literature on metering, billing and direct displays*. Oxford, UK: Environmental Change Institute, University of Oxford.

Darby, S. (2010). Smart metering: what potential for householder engagement? *Building Research & Information, 38*(5), 442-457.

DEFRA. (2007). *Survey of Public Attitudes and Behaviours toward the Environment: 2007*. London: Department for Environment, Food and Rural Affairs.

DEFRA. (2008). *A framework for pro-environmental behaviours*. London: Department for Environment, Food and Rural Affairs.

Department of Energy and Climate Change (DECC). (2009). *Towards a Smarter Future: Government Response to the Consultation on Electricity and Gas Smart Metering*. Retrieved from http://www.decc.gov.uk/publications/basket.aspx?FilePath=Consultations%5cSmart+Metering+for+Electricity+and+Gas%5c1_20091202094543_e_%40%40_ResponseElectricityGasConsultation.pdf&filetype=4#basket.

Faruqui, A., Sergici, S., & Sharif, A. (2010). The impact of informational feedback on energy consumption -- A survey of the experimental evidence. *Energy, 35*, 1598–1608.

Fischer, C. (2008). Feedback on household electricity consumption: a tool for saving energy? *Energy Efficiency, 1*(1), 79- 104.

Kolb, D. A. (1984). *Experiential Learning: Experience as the Source of Learning and Development*. Englewood Cliffs, N.J.: Prentice Hall.

Levine, M., Ürge-Vorsatz, D., Blok, K., Geng, L., Harvey, D., Lang, S., et al. (2007). Residential and commercial buildings. In B. Metz, O. R. Davidson, P. R. Bosch, R. Dave & L. A. Meyer (Eds.), *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK and New York, NY, USA: Cambridge University Press.

MacDonald, G. D., & Bray, D. (2011). *Facilities Resource Management Solutions: Emerging Tools Reshape Building Energy Management*: AltaTerra Research.

Marquardt, M. J. (2004). *Optimizing the Power of Action Learning: solving problems and building leaders in real time*. Palo Alto, CA: Davies-Black Publishing.

Piette, M. A., Kinney, S. K., & Haves, P. (2001). Analysis of an information monitoring and diagnostic system to improve building operations. *Energy and Buildings, 33*(8), 783-791.

Revans, R. W. (1980). *Action learning: new techniques for management*. London: Blond and Briggs.

Revans, R. W. (1997). Action Learning: Its Origins and Nature. In M. Pedler (Ed.), *Action learning in practice* (3rd ed., pp. 3-15). Aldershot, U.K.: Gower.

Roussac, A. C., Steinfeld, J., & de Dear, R. (2011). Revisiting summer setpoint strategies for conventional air conditioned office buildings. In S. Hayman, R. de Dear & W. Martens (Eds.), *From Principles to Practice in Architectural Science - 45th ANZAScA Conference* (pp. 8). Sydney: University of Sydney.

Serrat, O. (2008). Action Learning. Retrieved 12 June, 2011, from Asian Development Bank: http://www.adb.org/Documents/Information/Knowledge-Solutions/Action-Learning.pdf

U.S. Green Building Council. (2009). Green Building by the Numbers. Retrieved from www.usgbc.org/ShowFile.aspx?DocumentID=3340

van Dam, S. S., Bakker, C. A., & van Hal, J. D. M. (2010). Home energy monitors: impact over the medium-term. *Building Research & Information, 38*(5), 458-469.