

Quantifying the ‘human factor’ in office building energy efficiency: A mixed-method approach

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ABSTRACT: Greenhouse gas emissions from occupied Australian commercial office buildings can be reduced substantially. Accessible and cost-effective technologies and knowledge (know-how) are being widely adopted in the construction of new buildings and there is evidence that, on average, office buildings constructed since 2005 are performing with lower energy intensity than older buildings.

However, to achieve the sector’s potential for deeper and more sustained reductions in greenhouse gas emissions, research into the interaction between technology and the people that operate the buildings is required. This is especially the case for older buildings where accessible and cost-effective technologies and know-how that can abate greenhouse gas emissions have not, as yet, been widely adopted.

There is an urgent need to understand the role that human competency, values and interests play in determining the success of investments in technology and know-how and, indeed, the likelihood of investments being made at all. We need to ground this analysis in ‘real world’ operational data, rather than speculative models.

The paper proposes a mixed-method approach for defining and quantifying the extent to which operations staff and other key decision makers influence the energy efficiency of occupied Australian commercial office buildings, and presents preliminary findings.

Keywords: energy efficiency; commercial buildings; social theory; conceptual frameworks.

INTRODUCTION

The role that human competency, values and interests play in determining how much energy is used to operate Australian commercial office buildings needs to be better understood. Such factors influence the success of investments in equipment and people and, indeed, the likelihood of investments being made in the first place. Within the 60 page chapter on residential and commercial buildings in the Intergovernmental Panel on Climate Change’s (IPCC) Fourth Assessment Report (AR4), “the potential [greenhouse gas emission] reduction through non-technological options is not assessed” (Levine, *et al.*, 2007, p. 409).

We need analyses grounded in ‘real world’ operational data, rather than speculative models. Furthermore, in evaluating the potential for rapid improvements in energy efficiency, and the consequential reductions in greenhouse gas (GHG) emissions, the relationship between technologies and non-technological factors in bringing about these changes needs to be understood. This is especially the case for older air conditioned buildings where accessible and cost-effective technologies and know-how which can abate greenhouse gas emissions have not, as yet, been widely adopted. Technologies such as advanced metering, monitoring and control systems, efficient Heating, Ventilation and Air Conditioning (HVAC) systems, and on-site generation are being widely adopted in new buildings and there is evidence that, on average, office buildings constructed since 2005 are performing with lower energy intensity than older buildings. However, if the shortage of post-occupancy operational data verifying design projections is any indication, even these relatively advanced buildings may be failing to achieve their optimum operational performance.

A methodology is proposed that may give insights into the scale of the opportunity for GHG abatement through non-technological interventions (i.e. other than investments in energy efficiency or emission reduction technologies) within large air conditioned Australian commercial office buildings in general, and possibly other building types in other countries as well. Our preliminary analysis suggests that widely accepted estimates of the greenhouse gas emission reduction opportunity from occupied commercial office buildings may be conservative in the Australian context. A variety of audiences may therefore profit from the research objectives being met, including: policy makers, building owners and operators, manufacturers of technology, scientists and engineers.

1. CONTEXT

1.1. Energy use and greenhouse gas emissions from the built environment

The built environment accounts for in the order of 40 percent of greenhouse gas (GHG) emissions worldwide (United Nations Environment Programme, 2006). Of the 30-40 percent of final energy demand typically accounted for by the building sector in OECD countries, it is estimated that 33 percent is used in commercial buildings and 67 percent in residential (World Business Council for Sustainable Development, Undated).

Alarming, the World Business Council for Sustainable Development (WBCSD) has predicted that worldwide energy consumption for buildings will grow by 45 percent from 2002 to 2025 (World Business Council for Sustainable Development, Undated). This is broadly consistent with various scenarios modelled by the IPCC for its AR4 (Levine, *et al.*, 2007).

1.2. Australian commercial office buildings

While reliable statistics showing the trend in emissions intensity for the existing Australian office building stock are not available, a 2008 study for the Australian Sustainable Built Environment Council (ASBEC) suggested that commercial property sector emissions grow at an average annual rate of 2.1 percent and that the rate is linked to GDP growth (Centre for International Economics, 2008). This view is consistent with an Australian Bureau of Agriculture and Resource Economics (ABARE) projection that the rate of end use energy efficiency improvement will be maintained at 0.5 percent per year until 2030 for all fuels in non energy intensive sectors (Syed, Wilson, Sandu, Cuevas-Cubria, & Clarke, 2007). That is, sector emissions can be expected to grow at approximately the long-term GDP rate less 0.5 percent. According to ABARE, electricity production in Australia over the five years from 2002 to 2006 increased by 10 percent (Syed, *et al.*, 2007).

There is evidence that new office buildings are being constructed to be more energy efficient than buildings completed in the years immediately prior to the advent of the National Australian Built Environment Rating Scheme (NABERS) and the Green Building Council of Australia's Green Star rating scheme (Madew, 2009; Roussac, 2010). Given the introduction of more efficient modern stock into the Australian market through new construction, it is reasonable to assume, therefore, that much of the projected 0.5 percent annual improvement in the efficiency of Australia's office buildings can be attributed to the introduction of new stock rather than from improvements to the energy efficiency of buildings aged 10 years or older. It has been estimated that more than 80 percent, or almost 18 million square metres of Australian office accommodation, is more than 10 years old and thus predates the introduction of the NABERS and Green Star rating schemes (Davis Langdon, 2009). These buildings account for a substantial proportion of the sector's emissions and represent an opportunity to retrofit energy efficiency.

1.3. Potential for emission reductions

The scale of the opportunity is significant. According to a projection from the WBCSD, global GHG emissions could be reduced by 715 Mt per annum from a 1990 baseline by 2010 simply by improving the energy efficiency of buildings and appliances (WBCSD, Undated). This figure is approximately 25 percent more than the 597 Mt of GHG emissions reported from Australian sources in 2007 (National Greenhouse Gas Inventory, 2009).

Looking further ahead, the IPCC's AR4 estimated the economic potential for global greenhouse gas mitigation for different sectors (or 'wedges') as a function of carbon price in 2030 and came to the important conclusion that buildings present by far the largest opportunity for cost effective emissions reductions (Barker, *et al.*, 2007).

The IPCC's "mitigation of climate change" working group estimates the greenhouse gas emission reduction potential for the building stock in developed countries in 2020 (against 2010 start year) is within the following ranges:

- Economic (<US\$ 0/t.CO₂-e): 12% - 25% (i.e. from the perspective of society in general)
- Market: 15% - 37% (i.e. from the perspective of private consumers and companies)
- Technical: 21% - 54% (i.e. with no specific reference to costs, only to 'practical constraints')

(Barker, *et al.*, 2007)

If we conservatively assume that 30 percent of the world's final energy demand is accounted for by the building sector, drawing on the WBCSD (Undated) assertion that it accounts for 30 – 40 percent in OECD countries, and that 33 percent is used in commercial buildings, the opportunities look substantial. Of the approximately 28 Gt of annual GHG emissions from fossil fuel and other sources (Intergovernmental Panel on Climate Change, 2007), one tenth can be attributed to commercial, i.e. non-residential, buildings.

1.4. Potential from non-technological interventions is poorly understood

The summary of Working Group III's contribution to the IPCC's AR4 includes the following comments:

Our survey of the literature (80 studies) indicates that there is a global potential to reduce approximately 29% of the projected baseline emissions by 2020 cost-effectively in the residential and commercial [buildings] sectors, the highest among all sectors studied in this report (high agreement, much evidence).

Due to the limited number of demand-side end-use efficiency options considered by the studies, the omission of non-technological options and the often significant co-benefits, as well as the exclusion of advanced integrated highly efficiency [sic] buildings, the real potential is likely to be higher (high agreement, limited evidence).

(Levine, *et al.*, 2007, pp. 389-390)

While Levine *et al.* achieved *high agreement* and found *much evidence* to support the view that “over the whole building stock the largest portion of carbon savings by 2030 is in retrofitting existing buildings and replacing energy using equipment due to the slow turnover of the stock” (p. 389), there is clearly a lack of evidence to guide policy makers in addressing that opportunity via demand-side end-use efficiency options. Levine goes on to note that “the potential reduction through non-technological options is rarely assessed and the potential leverage of policies over these is poorly understood” (p. 389). If we consider the “substantial market barriers that need to be overcome” (p. 390), in order to more widely adopt “accessible and cost-effective technologies and know-how” (p. 406), clearly there is potential to contribute significantly to the body of knowledge in this field through action research.

One attempt to understand the potential for non-technological initiatives to influence the environmental performance of buildings has been made by the Low Energy High Rise (LEHR) project undertaken by The Warren Centre for Advanced Engineering at the University of Sydney (2009). The LEHR project surveyed 127 large commercial office buildings in Australia’s capital cities to identify factors that influence the buildings’ performance as measured by NABERS. The survey findings suggested that “there is potential for most buildings to achieve a 4 Star NABERS Energy base building rating with only limited recourse to major technical refurbishment, which corresponds to a performance improvement of approximately 30% for an average building” (Warren Centre, 2009, p. 9).” The report concluded: “The results indicate that there are a number of relatively clearly identifiable factors that can be shown specifically to correlate with improved performance. While it is specifically noted that correlation does not demonstrate causation, the results have been reviewed in this context and in all cases the proposed correlation would reasonably appear to be at least partially causal” (Warren Centre, p. 9).

1.5. Human factors are poorly understood

The chapter on residential and commercial buildings in Working Group III’s contribution to the IPCC’s AR4 also included this remark: “There is a broad array of accessible and cost-effective technologies and know-how that have not as yet been widely adopted, which can abate GHG emissions in buildings to a significant extent ... (*high agreement, much evidence*)” (Levine, *et al.*, 2007, p. 389). Why have they not been adopted? Levine *et al.* provides a summary of key barriers, yet omits discussion of the role human values and interests can play in determining the success of GHG mitigation measures in buildings.

This, perhaps, should not be surprising. The IPCC, the world’s foremost authority on climate change and comprised overwhelmingly of leading experts from the natural sciences, follows the Platonic tradition and gives greatest weight to analytical scientific knowledge (*episteme*) and technical knowledge or know-how (*techne*) drawn from the published scientific literature. This is appropriate for analysis of the problem’s cause; it is less effective in postulating solutions. For a solution, research must delve more deeply into the interaction between people and technology.

Bent Flyvbjerg has suggested a way forward. He points out that Aristotle discusses the three intellectual virtues, *episteme*, *techne*, and *phronesis* in arguing that natural and social science are and should be different ventures (Flyvbjerg, 2001, p. 3). *Phronesis* [Greek: φρόνησις] in Aristotle’s *The Nicomachean Ethics* is the virtue of practical thought, usually translated as ‘practical wisdom’, sometimes as ‘prudence’ (Wikipedia). Flyvbjerg brings focus to this long overlooked branch of the Aristotelian taxonomy of sciences, arguing that:

In their role as *phronesis*, the social sciences are strongest where the natural sciences are weakest: just as the social sciences have not contributed much to explanatory and predictive theory, neither have the natural sciences contributed to the reflexive analysis and discussion of values and interests, which is the prerequisite for an enlightened political, economic, and cultural development in any society, and which is at the core of *phronesis*.”

(Flyvbjerg, 2001, p. 3)

It is proposed here that a more thorough exploration of this third *practical* dimension may help us to identify and unlock emission reduction opportunities from buildings.

2. RESEARCH OBJECTIVES

The research has three broad objectives presented as an open-ended question with two associated hypotheses.

1. Why have accessible and cost-effective technologies and know-how which can abate GHG emissions not, as yet, been widely adopted in Australian commercial office buildings?
2. Technology investments are more effective for ‘fast tracking’ improvements to the energy efficiency of Australian commercial office buildings than approaches that focus on improving the ability and commitment of people associated with their operation [null hypothesis].
3. The ability and commitment of people associated with the operation of Australian commercial office buildings are important factors that determine whether technology investments are identified and made, and the extent to which a building meets its energy efficiency improvement potential [causal hypothesis].

3. METHODOLOGY

3.1. Methodological implications

According to the Property Council of Australia's (PCA) 2009 Office Market Report, there are 22 million square metres of commercial office accommodation in Australia (Property Council of Australia, 2009). The methodology is grounded on a single portfolio of large air conditioned office buildings in major Central Business Districts (CBD) that accounts for approximately five percent of the market. In some locations, such as Sydney's CBD, the owner has a major presence with a commercial interest in almost 10 percent of that CBD's entire stock; however it is well represented in all major CBD markets. The City of Sydney estimates that 60 percent of office accommodation in its jurisdiction is controlled by only twelve separate entities (Barone, 2009).

The portfolio operates under a common 'management platform' and yet the performance of its buildings ranges widely. This can be put down to the influence of building 'attributes' (such as façade systems, building management and control systems, plant and technologies) and varying levels of confidence, competency and motivation among the building operators. Through careful selection of cases, and by using precise and systematic action research interventions on multiple sites, the research aims to establish what effects these independent variables have on the dependent variables (energy use, greenhouse gas emissions) and also identify any confounding variables.

The portfolio's owner supports the research and has agreed to make human and financial resources available for the duration of the project to support the methodology. The study will only consider human subjects that are responsible for decisions that directly influence the procurement and operation of technologies associated with energy use in the buildings.

The mixed-method approach focussed on the interface between technology and non-technological factors has the following three components.

3.1.1. Quantitative data analysis to identify atypical or extreme cases

Atypical or extreme cases often reveal more information because they activate more actors and more basic mechanisms in the situation studied.

(Flyvbjerg, 2001, p. 78).

We regard a building's energy use intensity to be 'atypical' or 'extreme' if: 1) it is more than one standard deviation from the portfolio mean, or 2) the variance between recent and historical performance is more than one standard deviation from the portfolio mean.

The approach ranks buildings according to energy intensity using three scales:

- Electricity consumption normalised by floor area ($\text{kWh}/\text{m}^2.\text{yr}$)
- Electricity consumption normalised by floor area and weekly operating hours ($\text{kWh}/\text{m}^2.\text{weekly rated hrs.yr}$)
- NABERS Energy star rating

Changes to building performance over time are ranked according to the following four scales:

- Percentage change in $\text{kWh}/\text{m}^2.\text{yr}$ for the three years between Financial Year 2006-07 and 2009-10
- Percentage change in $\text{kWh}/\text{m}^2.\text{yr}$ for the year between Financial Year 2006-07 and 2007-08
- Percentage change in $\text{kWh}/\text{m}^2.\text{yr}$ for the year between Financial Year 2007-08 and 2008-09
- Percentage change in $\text{kWh}/\text{m}^2.\text{yr}$ for the year between Financial Year 2008-08 and 2009-10

3.1.2. Qualitative data analysis using an exploratory method

Such a method allows flexibility in procedure to pursue whatever promising opportunity arises for the identification of missing properties or variables. In order to maximise efficiency, a relatively small study population is observed intensively, and cases are selected on a purposive, non-random basis. Observational techniques are open-ended or intentionally unrefined.

(Mayer, 1980, p. 163).

Having identified extreme or deviant cases through a quantitative data analysis, a case-based qualitative analysis will then seek to uncover the stories behind the data.

- Specific technology investments and non-technological actions and interventions will be retrospectively identified through interviews with facilities managers that worked on the portfolio during the analysis period.
- Financial records containing evidence of return on investment (ROI) expectations and showing the timing and quantum of expenditure will be reviewed.

- The personal experiences of the staff operating the building, those directly involved and those in influential roles (e.g. fund managers), will be explored through open questioning.

These sources, combined with the principal researcher's own recollections drawn from an association with the portfolio that commenced in July 2004, provide valuable data and insights regarding the operation of the buildings.

3.1.3. Verification of conditions of causality using an explanatory method

Such a study yields a conclusion regarding the relative acceptability of the presumption of causality. One can infer causality only with respect to the cases observed and the variable controlled. ... the larger the study population and the greater the number of variables controlled, the greater the generalisability (sic) of the causal findings.

(Mayer, p. 164).

Action research will focus on the effect of changes to the buildings' technology and management 'know-how' over a period of time to identify and quantify the relationships between people and technology and the factors which influence them. Attempts will be made to replicate the successes observed in the 'atypical' or 'extreme' cases and correct the identified failures through specific targeted actions integrated into the buildings' operations.

Experiments aimed at building competency and improving motivation and confidence will be undertaken, for example by making building performance transparent to a wide audience of interested stakeholders.

Since a building's energy use varies with each day's prevailing weather conditions, climate adjusted performance models will be developed using historical energy and climate data to predict what each building's energy consumption may have been without the interventions. The variance between actual and predicted energy use is expected to provide an indication of causal relationships and help identify where operators are overcoming (or undermining) a building's latent potential

3.2. Sub-problems and organising principles

The research objectives go beyond seeking to understand how to reduce energy use from a select group of occupied commercial office buildings. It is hoped that the research will give insights into the scale of the opportunity for GHG abatement across Australian commercial office buildings in general, the potential to 'fast track' energy efficiency in buildings, and possibly the implications for other building types in other countries as well.

3.2.1. The first sub-problem

The first sub-problem is to identify what 'technologies' and 'know-how' are effective for abating GHG emissions and to gauge Australian commercial office buildings' energy performance potential. These may be established from reviewing the literature and analysing the relationship between building attributes and performance through a qualitative analysis of the portfolio data.

3.2.2. The second sub-problem

The second sub-problem is to identify what conditions (or circumstances) tend to be associated with the existence of the technologies and know-how identified by addressing the first sub-problem. This sub-problem can also be approached by reviewing the literature and studying relationships revealed in the case studies.

3.2.3. The third sub-problem

The third sub-problem is to establish a basis for comparing Australian commercial office buildings and their management regimes. This will require a clear definition of the "Australian commercial office building" typology and a detailed survey of a representative sample of buildings.

3.2.4. The fourth sub-problem

The fourth sub-problem is how to gauge competency and commitment. Relevant competencies and motivations may be identified, along with appropriate analysis techniques, by reviewing the literature, analysing selected cases and exploring through action research including via interviews. Competency in the context of an operating building may be understood as 'ability'; that is, being capable of making a building perform to its potential given its existing plant and equipment.

3.2.5. The fifth sub-problem

The fifth sub-problem is to identify the relationships between technologies, competencies and motivations so that the effect of these independent variables on the dependent variables (energy use, GHG emissions) is understood and any confounding variables can be identified. This may be accomplished through careful selection of cases and by using precise and systematic action research interventions on multiple sites.

3.2.6. Organising principle

Zeisel (1981) recommends using analogies as organising principles. One might be a symphony orchestra where: *fine instruments (technology) combine with highly skilled musicians (competency), who love playing music and practice a lot (commitment). All three must be present to achieve a world-class performance. Any two of the three in combination might produce an acceptable standard; one by itself, without the others, will be pretty woeful.*

4. PRELIMINARY OBSERVATIONS AND DISCUSSION

4.1. Data is suitable for identifying extreme or deviant cases

Preliminary findings from an analysis of energy efficiency actions undertaken in eleven of the portfolio's buildings were presented at the 43rd annual Australian and New Zealand Architectural Science Association (ANZAScA) conference in Launceston in November 2009 (Roussac, 2009). The buildings were selected to provide a pilot study to firm up the objectives and methodology presented in this paper. They are representative of the portfolio's mix of size, age, location and operating platform and, with a Net Lettable Area (NLA) of 298,000 m², represented approximately 1.4 percent of the Australian commercial office market. Buildings younger than ten years of age were excluded.

The pilot study found that the portfolio's available data is suitable for identifying extreme or deviant cases, both in relation to the selected portfolio (i.e. buildings with large/small reductions in energy use relative to the portfolio average) and the Australian commercial office market in general (i.e. buildings with large reductions relative to the market average).

The portfolio's owner commenced a program of investing in energy saving initiatives in 2003. In all cases this began with installation of sub-metering systems for electricity and natural gas. Business cases for capital investments, training programs, staff incentives and the like were subsequently identified through analysis of sub-meter data.

It is acknowledged that the reduction in the portfolio's energy use is not typical of the market (29 percent reduction from 2004 to 2008) in general and it could be argued that buildings within the portfolio are therefore not 'representative'. However, it is not necessary that the portfolio's energy performance and management approaches be typical of the broader market, only that the buildings themselves are of a commercial office building typology that makes them comparable. An approach to this challenge is proposed in the description of the third subproblem (3.2.3).

4.2. Potential for qualitative exploratory analysis

As Mayer and Greenwood have noted in *Design of social policy research*, if a researcher is seeking to identify a property of a phenomenon which is the subject of policy making, "i.e., to discover a policy variable missing in the conceptual framework, the method required is exploratory" (Mayer, pp. 158-159). The research proposed here, which seeks to address the gap identified by the IPCC (i.e., to have accessible and cost-effective technologies and know-how more widely adopted in buildings to abate GHG emissions), clearly has that objective.

The buildings' energy use intensities range widely despite a common management platform. Each of the seven measures described above (at 3.1.1.) has produced a distribution similar to that shown below in Figure 1. By allocating a score to each building that falls more than one standard deviation from the portfolio mean (+7 for the furthest positive outlier, +6 for the second furthest etc. and the opposite for negative outliers) we are able to consolidate the outcomes of the various tests to identify buildings that are most likely to yield interesting findings from a detailed qualitative analysis using an exploratory method.

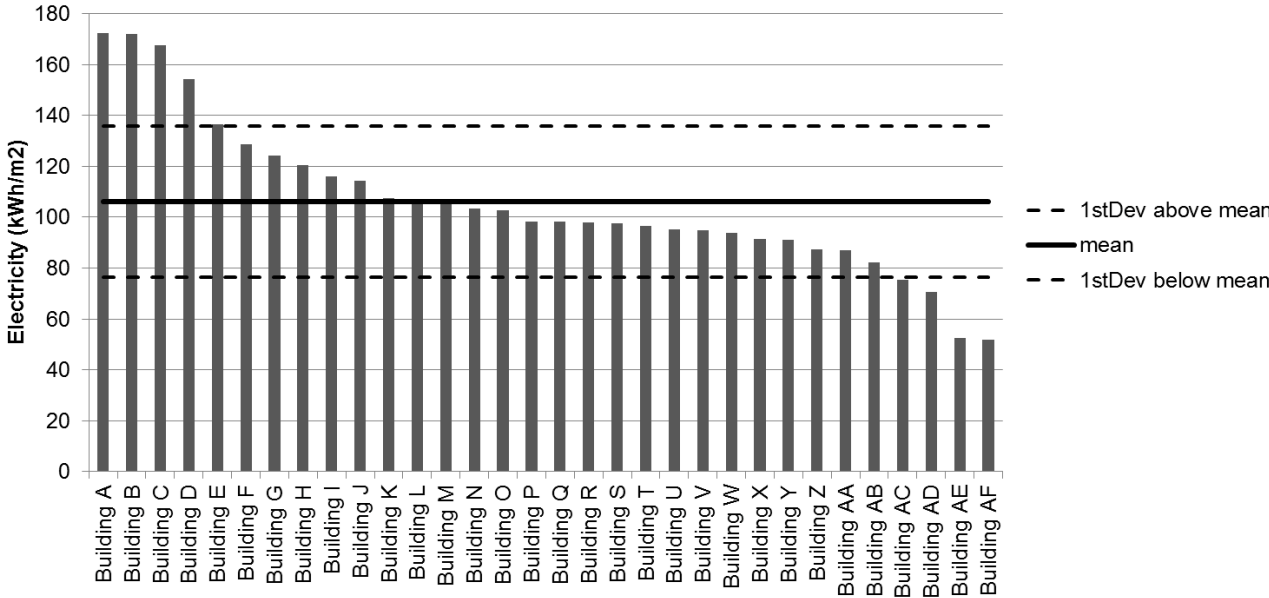


Figure 1: Normalised base-building electricity consumption (2009-10)

To allow detailed comparison of management effectiveness under steady state conditions, a climate adjusted performance model is being developed for each building using historical energy and climate data to predict daily energy consumption. Since HVAC energy requirements vary with prevailing weather conditions, the output of the regression model is a formula which infers the relationship of HVAC consumption to climate variables (temperature and humidity). The researchers may then attempt to explain performance that is 'better' or 'worse' than expected.

4.3. Building blocks for action research

As discussed above, a quantitative analysis of the portfolio's extensive database will identify promising cases for detailed exploratory analysis. Case studies may reveal properties or variables which have contributed to large/small reductions in energy use relative to the portfolio and the Australian commercial office market in general. It is unlikely, however, that by themselves these retrospective analyses will satisfactorily answer the research question or offer anything more than speculative support for the causal hypothesis.

Action research focussing on the effect of changes to the buildings' technology and management "know-how" over a period of time may help in identifying and quantifying the relationships between people and technology and the factors which influence them. The approach of further analysing and testing findings from the case-based qualitative analysis draws on Zeisel's framework (1981) which suggests that "making visible the implications of the data leads to improved hypotheses, further data gathering, and so on until the problem is sufficiently redefined and a tenable solution is found" (p. 18).

The first prototype of a publicly accessible web-based data visualisation platform is now complete. A snapshot is presented at Figure 2 below (Investa Property Group, 2010). It facilitates analysis and also, by its nature, supports research on the effect of performance disclosure on the motivation and confidence of building managers. Greater transparency is expected to advantage those associated with well performing buildings and draw attention to poorer performance. It is recognised that people can be *motivated* by a variety of things: e.g., by competitiveness, recognition, money, fear, concern for the environment, etc.

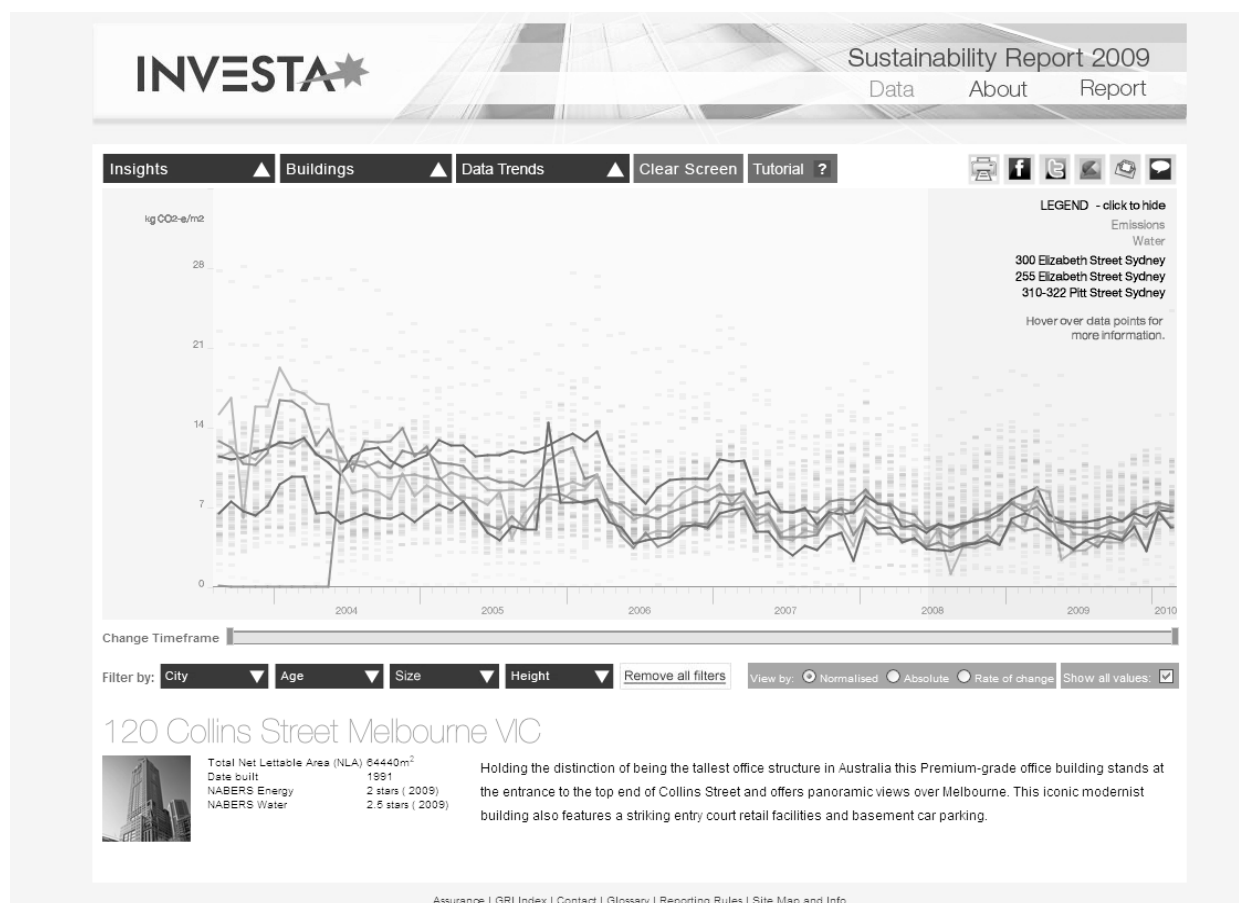


Figure 2: Snapshot of the Investa 2009 Sustainability Report

Blanchard and Hersey suggest people are most effective when they combine high levels of competence and commitment. Competence is the knowledge and skills an individual brings to a goal or task, whereas commitment is a combination of an individual's motivation and confidence on that goal or task. If either motivation or confidence is low or lacking, commitment as a whole is considered low (Blanchard & Hersey, 1969).

The relationship between 'fear' (one potential reaction) and 'persuasion' (the desirable consequence of a focus on transparency) is complex and there are likely to be a variety of individual responses (Block, 1999). For example, a survey of property supervisors (site based building operators) and their immediate superiors (off-site facilities managers) upon their first exposure to the online data visualisation prototype (Fig. 2) revealed strong support for the initiative; however, facilities managers on average were more supportive and less wary about the initiative than their subordinates. According to Block, "[f]urther investigation of the interaction of fear and the various personality and message variables will help us better understand the nature of the fear-persuasion relationship" (Block, 1999, pp. 243-244).

The same will likely be true of other primary motivators and the investigation of these is forming part of a literature review. For example, Ryan and Deci suggest that everyone has a need for competence, autonomy and relatedness irrespective of their degree of self awareness or cultural context (see Wadley, 2010). These factors will regularly coincide with secure, high-level self-esteem which may lead to greater commitment and overall effectiveness.

CONCLUSION

Popper in *The Logic of Scientific Discovery* requires that a system's "logical form shall be such that it can be singled out, by means of empirical tests, in a negative sense: *it must be possible for an empirical scientific system to be refuted by experience*" (emphasis in original) (1972, p. 42). In addressing research objectives such as those put forward in this paper, Flyvbjerg (2001) has suggested that "the case study is ideal for generalising using the type of test which Karl Popper called "falsification"" (p. 76). It is therefore expected that the open-ended question and associated hypothesis can be thoroughly addressed by considering a range of cases using precise and systematic procedures and controlling for a wide variety of variables (see Mayer, 1980). A data visualisation tool will greatly assist in evaluating action research interventions in real time.

A mixed-method study focusing on the 'human factor' in operating existing commercial office buildings will suggest the potential to 'fast track' energy efficiency. There is an indication that widely accepted estimates of the greenhouse gas emission reduction opportunity from such buildings may be conservative in the Australian context.

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