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## **The success of greenhouse gas mitigation in existing Australian office buildings**

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# **The success of greenhouse gas mitigation in existing Australian office buildings**

## **Abstract**

Frequent site energy consumption auditing is a potential strategy to mitigate greenhouse gas emissions from existing buildings. Such a strategy has been practiced in Australia for nearly 15 years and this paper documents the effect of repetitive audits on measured site energy consumption. Using a self-constructed database of over 3,500 audited disclosures representing over 800 unique office buildings, empirical models demonstrate that measured site energy consumption declines, on average, over the first five re-certification periods. The results also suggest a market average post-certification equilibrium in Australia of approximately 430 MJ/m<sup>2</sup>/year (120 kWh/m<sup>2</sup>/year) within approximately 6 years, if all else – including green management strategy – is held constant. Since greenhouse gas emissions from buildings in Australia are highly correlated with site energy consumption, such a result is comparable to meeting 50-year greenhouse gas mitigation targets reliant on the implementation of existing technologies, suggesting that repetitive auditing is successful at motivating owners to invest in existing energy efficiency technologies.

## **Keywords**

climate policy; commercial offices; energy performance; environmental targets; investment incentives; market mechanisms

## **Introduction**

Greenhouse gas mitigation in urban environments is sensitive to energy consumption in existing buildings because many existing buildings pre-date the earliest forms of energy efficiency regulation in statutory building codes, and they last a long time. Building stock replacement rates in developed countries range from 0.66% to 3% per year (United Nations Environment Programme, 2007; Holness, 2008; Jowsey and Grant, 2009; Eichholtz, Kok, and Quigley, 2010), meaning that a complete transition to current building code energy performance standards could take somewhere between 30 and 130 years if the potential to retrofit existing buildings is ignored<sup>1</sup>. As such, simulations of greenhouse gas emissions for an entire building stock conclude that existing buildings have a

disproportionate effect on the total (Coffey et al., 2009; Seo and Foliente, 2011; Kohler and Hassler 2012).

In light of the importance of existing buildings to urban greenhouse gas mitigation, the framework of intervention in property markets needs reconsideration because energy efficiency, a popular strategy for greenhouse gas mitigation, requires attention to design and to user behaviour. Green building assessment traditionally began as a means to segment the market for new construction (Crawley and Aho, 1999) and assess compliance with various statutes, policies and standards designed to promote building thermal efficiency (Cole, 1999; Simons, Choi, and Simons, 2009; Kontokosta, 2011). In both these cases, the property industry has generally been interested in dissociating the environmental performance potential of design with the observed performance in-use. But scholars writing in this journal have long recognised the interdependency of design and user behaviour in regard to environmentally beneficial outcomes, particularly energy efficiency and greenhouse gas mitigation (Bordass, Leaman, and Ruysevelt, 2001; Schweber and Leiringer, 2012). By implication, successful urban greenhouse gas mitigation policies must implement socio-technical solutions that optimise design and usability.

One potential policy is building energy performance disclosure, which has caught the attention of policymakers seeking to mitigate greenhouse gas emissions in existing buildings. The policy problem is that, with the exception of major redevelopment activities, existing buildings are not typically subject to revisions of building codes. Market uptake of voluntary energy consumption disclosure schemes has opened up the intervention of mandatory disclosure as a potential solution to the problem (Kontokosta, 2013). In 2010, the federal Australian government became the first to mandate measured energy consumption disclosure via the Building Energy Efficiency Disclosure [BEED] Act<sup>2</sup>. Similar measured performance rating disclosure laws have been enacted at the local and state level in the United States using the Energy Star methodology (Kontokosta, 2013; Hsu, 2014).

Will a mandate to disclose measured energy performance have an effect on operational energy consumption from the existing building stock? This paper examines the outcome of repetitive

participation in building energy consumption disclosure in the absence of any further intervention (such as a cap on allowable consumption). It is the first study to model the progress of building energy consumption outcomes purely as a result of repetitive participation in a measured performance disclosure scheme. Using a self-constructed database of nearly every NABERS [National Australian Built Environment Rating Scheme] Energy certificate issued between 1999 and 2013 in Australia, this paper describes how quantitative models find a positive relationship between depth of participation (number of re-certifications) in the disclosure scheme and measured energy consumption savings.

## Literature Review

The objective of rating tools is to create product differentiation and thereby encourage private sector innovation. In a paper on the general practice of using ratings to segment markets, Chatterji and Toffel (2010) argue that firms will adapt their practices in order to improve external ratings, particularly if the market perceives them to be rated poorly. Fuerst and McAllister (2011) and Kontokosta (2013, p. 35) apply this general theory of behaviour change through differentiation to the real estate sector, with the latter arguing that, “the potential for energy disclosure policies to shift market awareness of building energy efficiency is substantial”. By increasing market awareness and enabling differentiation, rating systems create a market for energy efficient buildings. As evidence of this market, Warren-Myers (2012) reviews a wide range of literature arguing that building energy efficiency creates value in real estate, leading to theories that energy efficiency is positively associated with measures of building value<sup>3</sup>.

Borck and Coglianese (2009) review the general environmental management literature on product differentiation and produce a helpful framework to understand the outcome as measured by environmental performance metrics. The effectiveness of environmental differentiation is defined as follows:

$$Effectiveness = \frac{Number\ of}{Participants} \times \frac{Effect}{per\ Participant} + \frac{Spillover}{Effect} \quad (1)$$

where “effect per participant” measures the average environmental performance outcome for the

market segment that participates in a rating scheme. For building energy consumption, effect per participant can be measured by the quantity of energy saved as a result of participating in a disclosure scheme. The “spillover effect” represents the influence of participants on the behaviour of non-participants, such as the development of new energy efficient technologies by participants that diffuse throughout the entire sector. Spillover effects can vary depending on the context of the intervention, the accounting framework adopted, and on the assumptions of the researcher. These choices are complex and therefore this paper will only consider the direct effect of intervention<sup>4</sup>.

The literature implicitly assumes that energy efficient buildings are the outcome of a robust certification process (for examples, see Miller, Spivey, and Florance, 2008; Eichholtz et al., 2010; Fuerst and McAllister, 2011). Using the formula above, the implication is that the participation rate in a certification scheme determines the effectiveness of a voluntary certification programme. Hence Fuerst (2009) and Eichholtz, Kok, and Quigley (2013) attribute increasing participation in voluntary green building assessments as evidence of their effectiveness in mitigating energy-related greenhouse gas emissions emitted by the building sector.

The argument that participation is the critical metric has spawned interest in the determinants of voluntary participation. Kok, McGraw, and Quigley (2012) and Fuerst, Kontokosta, and McAllister (2014) argue that higher incomes and traditional indicators of a “healthy” property market (i.e. low vacancy rates and high capital values) are positively associated with the local adoption of energy efficient technologies. Kok et al. (2012) also argue that energy prices influence the diffusion of buildings certified as energy efficient while Fuerst et al. (2014) find only limited support that public policies promoting certification (not mandating) affect adoption.

However, knowing how to affect participation rates is only useful if effect per participant is non-zero. The mechanism that leads to the possibility of zero effect per participant is the widespread use of asset ratings, which simulate potential performance as opposed to measuring actual performance. Asset ratings are preferred by architects, engineers, and consultants in the property development sector because their objective is to isolate the effect of decisions made in design by excluding variation

caused by human factors in building operation and management. Unsurprisingly, as evidence of the potential gap between building design and usability, there are many detailed case studies of individual buildings that underperform expectations for energy efficiency once human factors are introduced (for examples, see Bordass et al., 2001; Scofield, 2002; Gabe, 2008).

But is this underperformance systematic? Two studies of green-certified buildings in the United States argue that, while variance at the individual building level is high, certified green buildings are more energy efficient than comparable uncertified buildings on average (Fowler, Rauch, Henderson, and Kora, 2011; Turner and Frankel, 2008). Data on energy consumption from the Turner and Frankel study has been subjected to additional statistical analyses, one of which confirms the original conclusion (Newsham, Mancini, and Birt, 2009) while the other finds evidence of systematic underperformance in large buildings (Scofield, 2009). Oates and Sullivan (2012) gathered data from 19 office buildings in Arizona, finding that all but one building underperformed its asset rating and 15 buildings underperformed the baseline code specification for energy efficiency.

These three studies are largely the extent of empirical knowledge on the systematic effect of green building certifications on measured building energy consumption. Data availability is one reason for this lack of research; one of the studies reports that very few green buildings actually measure energy consumption post-occupancy (Oates and Sullivan, 2012). All three assess the impact of a rating system designed for new construction, leaving no empirical evidence in regard to the effect of existing building interventions. Additionally, while the causal path between green building certification and energy efficiency is strong (Newsham et al. 2009), it is not guaranteed, since building owners can qualify for LEED [Leadership in Energy and Environmental Design] certification in the United States and similar new construction green building schemes elsewhere with minimal investment in energy efficiency because of the elective nature of that certification process.

A knowledge gap that may be responsible for the lack of study into the effect of interventions on existing building energy consumption is the absence of benchmark data. Newsham et al. (2009) uses a five-year old survey of commercial building energy consumption across the United States to

statistically extract the most comparable non-certified building for each LEED building in the Turner and Frankel (2008) dataset. Both Turner and Frankel (2008) and Oates and Sullivan (2012) attempt to compare a simulated asset rating with post-occupancy measured performance, but discuss how the simulated asset ratings are not meant to measure total consumption<sup>5</sup>. This journal recently devoted a special issue looking at the challenge of measuring, understanding, and improving energy performance in existing non-residential buildings (Isaacs and Steadman 2014).

To fill the gap in understanding regarding existing building intervention, this study contributes the first model of a shift in energy consumption outcomes purely as a result of repetitive energy performance disclosure schemes in existing non-domestic buildings. In markets where there is a strong relationship between energy consumption and greenhouse gas emissions, such as Australian cities that predominantly consume electricity in non-domestic buildings, energy consumption acts as an effective proxy for greenhouse gas emissions. This study also addresses the lack of benchmark data by showing how the implementation of repetitive performance disclosure creates a more unbiased benchmark: prior audit results from the same property.

The core research task is estimation of an effect per building as a result of participation in NABERS Energy, the Australian site energy consumption and greenhouse gas emission disclosure scheme. Because NABERS Energy certification must be renewed annually with a fresh third-party site energy consumption audit, hundreds of buildings across Australia have undergone repetitive certification. The question of calculating the effect on site energy consumption per building will be answered with a set of statistical models examining site energy consumption as a function the depth of participation in NABERS Energy (measured as the number of certificates obtained by a particular building).

The next section briefly examines the NABERS Energy assessment system for readers unfamiliar with its use in Australia. This is followed by discussion of data collection, the methodology used to construct the quantitative models and the estimation of these models.

## **NABERS Energy**

The NABERS Energy scheme was developed by the New South Wales state government and has been



used across Australia since 1999 for building owners choosing to advertise their energy performance credentials. Prior to 2008, NABERS Energy was branded as the Australian Building Greenhouse Rating [ABGR], but no change in the underlying audit methodology has occurred<sup>6</sup>. Third-party auditors assess 12 months of site energy consumption and produce a rating from 0 to 6 stars based on greenhouse gas emissions resulting from that measured site energy consumption.<sup>7</sup> Star ratings are calibrated regionally such that a 2.5-star rating is assigned to a building with average greenhouse gas emissions from site energy consumption in each metropolitan area. Certificates are freely available via the programme website (<http://www.nabers.gov.au>). To control for vacancy rates, the effective size of the building being rated is reduced by a pro-rata calculation of occupancy for the year being audited. Readers interested in a thorough description of the NABERS Energy auditing process are encouraged to consult the Department of Environment Climate Change and Water NSW (2010).

The boundaries of the site energy consumption audit are typically “Base Building” services, which exclude tenant power consumption (computers and plug-in appliances). Included in the Base Building rating are common area lighting, space conditioning, hot water production, and all common area power consumption. By design, Base Building ratings conveniently mimic the boundaries of energy and greenhouse gas costs paid by the party liable for operating expenses in an office lease contract.

Owners wishing to improve NABERS Energy ratings have three options: invest in on-site operational energy efficiency, purchase Green Power offsets for electricity consumption, or fuel-switch to maintain site energy consumption while reducing source greenhouse gas emissions. This paper measures the first option – investment in on-site operational efficiency – which is the most common approach. Green Power is a national Australian scheme administered by the federal government that allows an electricity consumer to pay a rate premium for electricity that goes to renewable energy producers in exchange for certification that the consumer’s electricity was generated by zero-emission renewable energy<sup>8</sup>. When an owner elects to purchase Green Power to improve his NABERS Energy rating, the certificate includes star ratings with and without the Green Power purchase. Because Green Power offsets must be excluded from mandatory disclosure under the BEED Act, it is not a common option.

Fuel switching is also rare. The correlation from first to final certification of the ratio of greenhouse gases per unit of site energy is above 0.9, which most likely reflects minor variability in electricity production. In Australia, electricity is the source energy used for nearly 85% of total commercial building energy demand (Department of Climate Change and Energy Efficiency, 2012).

## **Data**

Information on building energy consumption is extracted directly from a comprehensive collection of ABGR and NABERS certificates gathered by the author over the past 14 years. All publicly available certificates using the Base Building scope described above have been obtained from the certification agency via the internet since the commencement of ABGR in 1999 up until April 2012. Additional NABERS Energy certificates issued between April 2012 and the end of October 2013 were obtained for buildings complying with BEED Act disclosure regulations from the regulator's website (<http://www.cbd.gov.au>). Thus, the full NABERS Energy dataset spans nearly all certifications between August 1999 and October 2013.

Multiple certificates for the same building with the same expiry date are removed to eliminate duplicates, with the chosen certificate having the highest NABERS ID Number (a proxy for the issue date). A small number of certificates (71) are removed owing to missing data that clearly identifies the certified building. In total, the cleaned dataset contains 3,661 unique NABERS Energy certificates. The certificates are then organised in issue sequence for each individual building in the database based on ascending NABERS ID numbers. Table 1 shows there are 1,153 unique buildings in the energy dataset, with 818 having been certified at least twice.

[Insert Table 1 here]

## **ENERGY CONSUMPTION and GREENHOUSE GAS EMISSIONS**

To describe environmental performance data captured in an audit, each certificate includes a disclosure of overall building energy use intensity [EUI] in MJ/m<sup>2</sup>/year that is unaffected by Green Power offsets. The only accounting adjustment is that energy sourced from on-site zero-emission sources are excluded from the disclosed EUI. To ensure valid comparisons, energy performance in

this study is measured using this raw consumption data. EUI has been consistently produced on every certificate using a static methodology. Star ratings are calibrated separately for each Australian city and thus unsuitable for comparison across regions.

Despite greenhouse gas mitigation being a key objective for investment in operational building energy efficiency, emission figures from NABERS Energy certificates are not used in this study. Early NABERS Energy certificates only report emissions that take Green Power offsets into account, leading to a number of “zero-emission” buildings. Later certificates switch between different greenhouse gas accounting protocols. This leads to the discard of many valid certificates in an attempt to compare data only within the same accounting framework. Finally, over 14 years, greenhouse gas accounting has been very dynamic; even if accounting scopes were consistent, conversion factors between the raw data and greenhouse gas emissions are unknown and have varied over time. The non-disclosure of energy fuel sources for each building further complicates the ability to compare greenhouse gas emission totals. Thus, it would be difficult to differentiate trends in NABERS Energy-reported greenhouse gas emissions between operational management and accounting changes. As indicated earlier, EUI is highly correlated with greenhouse gas emissions in Australia.

However, it is possible to measure the effect of the Green Power offset purchasing decision on operational efficiency. All building owners electing to purchase over 1% of their electricity via the Green Power scheme in every NABERS re-certification are identified using a binary variable. This variable will enable the model to differentiate whether Green Power offsets act as a substitute or complement to operational energy efficiency.

## **GREEN MANAGEMENT STRATEGY**

A second binary variable identifies “green owners”, which will be defined as building owners that are explicitly differentiating their assets as green or sustainable in the commercial real estate market. In the establishment of a benchmark rating system measuring the depth of green strategy present in global real estate investment firms, Bauer, Eichholtz, Kok, and Quigley (2011) rated three Australian-based firms – Stockland, GPT and the Commonwealth Property Office Fund – as three of the top five

“Global Environmental Leaders” for publicly listed property companies. In addition, GPT and a fourth Australian-based firm, Investa, were identified as the top two Global Environmental Leaders for private property holding companies. Buildings owned by these four firms are considered to have “green owners”.

## **LOCATION**

The process of assigning NABERS certificates to an individual building makes it possible to generate variables based on location. In particular, Australian four-digit postcodes convey two useful pieces of data. One is the state or territory each building is located in. This is important because Australia has three distinct levels of government – federal, state, and local – and certain states, including New South Wales, the Australian Capital Territory, Western Australia, and Victoria, were early supporters of NABERS Energy. Hence, the particular state location can proxy fixed state effects, such as local government policies and climate, that may influence the decision to pursue operational resource efficiency.

The second useful variable that can be generated from a postcode is whether or not a building is located in a capital city central business district [CBD]. Office markets in a CBD offer prospective tenants greater choice than smaller provincial or suburban centres. Competition between owners may lead to greater investment in resource efficiency in major cities as part of an asset positioning strategy. Postcodes are used to identify buildings located in each capital city CBD: 800 for Darwin, 2000 for Sydney, 2601 for Canberra, 3000 for Melbourne, 4000 for Brisbane, 5000 for Adelaide, 6000 for Perth and 7000 for Hobart.

## **BUILDING SIZE**

The existing literature identified that building energy consumption, when normalised by building area, may be affected by building size (Scofield, 2009). The net lettable area [NLA] of each multi-certified office building was obtained from property reports and owner disclosures. A consistent measure of net lettable area could not be obtained for 12 of the 818 multi-certified buildings, so these 12 are omitted from further analysis<sup>9</sup>.

## OTHER CHARACTERISTICS

Data on other hedonic characteristics of all the buildings in this dataset, such as building age, was not available on a consistently measured scale for all buildings and is therefore omitted from the analysis in this paper to avoid further omissions of observed buildings. To give readers a brief illustration of building age distributions in NABERS Energy-certified buildings, the author has excellent data on building age in one market, central Sydney, which contributes 119 of the 818 multi-certified office buildings to the dataset. In 2012, these 119 buildings have an average age of 27.7 years (median of 24), with a range between 3 and 76 years and standard deviation of 16.2 years. Anecdotal evidence gathered by the author suggests similar distributions in other cities. Buildings are not eligible for NABERS Energy certification until they have been in operation for 24 months.

## Descriptive Statistics

Table 2 provides a descriptive overview of the entire energy dataset with analysis by number of certificates obtained. To ensure sufficient sample sizes, the number of multiple certificates is capped at eight. This means that 31 buildings with more than eight NABERS Energy certificates are not analysed beyond their eighth certificate. Note that the aggregate column on the far right only includes multi-certified buildings; the column of buildings with only one NABERS Energy certification is excluded from the totals.

[Insert Table 2 here]

The descriptive statistics suggest that repetitive participation in NABERS Energy is associated with a measurable improvement in building energy efficiency on average. Mean energy consumption indicators decrease between a building's initial certification and its final certification. Population variance also decreases from initial certification to final certification. A key variable of interest, change in energy consumption, shows a clear trend of increasing energy savings over time and a decrease in variance. Boxplots in Figure 1 demonstrate the reduction in energy consumption and variance, particularly the reduction of outliers, as the number of certifications increase. These

boxplots also suggest that after five certifications, mean energy consumption begins to stabilise while variance continues to decrease. The robustness of these observations will be subjected to further tests.

Besides change in consumption, four variables are also associated with the number of certifications.

As would be expected, the number of certificates earned is related to the year a building first sought an assessment; early adopters are the only buildings with the highest numbers of certifications.

Second, the percentage of buildings managed by green owners increases as the number of re-certifications increase. Unsurprisingly, this means green owners are likely to be early adopters of NABERS. Finally, there are also positive associations between building NLA, the percentage of buildings in a CBD, and the number of certifications.

[Insert Figure 1 here]

Table 3 presents the correlation matrix between these related variables. The strongest correlation is between the year of entry into NABERS and the number of certificates. There are cross-correlations between green ownership, building size and the number of certificates. Green owners begin NABERS certification early and are likely to own large properties. Hence the interpretation of the green owner variable needs caution because it could be measuring green strategy as intended, or it could represent unmeasured characteristics of large institutional property owners, such as greater access to capital or the involvement of professional property managers. In this study, number of certifications (depth of participation) is the key variable of interest, so the exact interpretation of the green owner variable is not important.

The strong correlation between year of certification and number of certificates, however, does lead to a potential interpretation problem. The improvement as depth of participation increases seen in Figure 1 could be an artefact of fixed time effects. To control for fixed time effects, it is necessary to fix the number of certificates. Figure 2 demonstrates that if change in EUI is captured at every intermediate certification, central tendencies and variance follow a similar pattern as if change in EUI is only captured at the final certification (Figure 1).

[Insert Table 3 here]

[Insert Figure 2 here]

Although time between certificates is not uniform, it is often slightly more than a year. Looking at Table 2, the median number of days between certificates is typically around 400 days, indicating that most buildings are recertified soon after an existing certificate expires. Nevertheless, it will be necessary for a multivariate test to control for variation in the number of days between certifications because the average time between certification ( $\mu=518$  days) is much higher than the median, indicating a number of buildings with multiple years between certificates.

Tables 4 and 5 present the results of *t*-tests indicating the statistical significance of the decline in energy consumption over time seen in the Figure 4 boxplot. For the marginal effect of re-certification (Table 4), each additional certificate produces a consistent 5 to 7% reduction in energy use intensity on average. After the sixth certificate, the marginal decline is not statistically significant at conventional levels. One interesting observation is the similarity in final energy consumption between the 6th period of re-certification (sequence 6 to 7) and the 7th period of re-certification (sequence 7 to 8). The market appears to settle on a limit in average office building energy use intensity of approximately 430 MJ/m<sup>2</sup>/year (120 kWh/m<sup>2</sup>/year).

[Insert Table 4 and Table 5 here]

The cumulative tests (Table 4) shed some light on why eight-certificate buildings take longer to reach this equilibrium. Mean initial consumption rises as the depth of participation increases. This leads to two potential interpretations: late adopters may be more energy efficient at the time of NABERS entry as a result of spillover effects or a subsample bias could be responsible for inflating the average benchmark EUI in early adopters.

## **Multivariate Model Specification**

Multivariate regressions are run to include other exogenous variables – location, capacity for

improvement, and willingness to purchase Green Power offsets – in order to test the robustness of the descriptive statistics above.

Consider building  $j$ , in which EUI has been observed in the dataset from period  $s=1$ , the initial benchmark certificate, to period  $s=\max_j$ , representing the most recent, re-certification for building  $j$ . Subtracting the energy consumption benchmark from the energy consumption of the most recent re-certification gives the total change in EUI,  $\Delta P_j$ , which will be the dependent variable:

$$P_{j(s=\max)} - P_{j(s=1)} = \Delta P_j \quad (2)$$

$P_{j(s=\max)}$  would be an equivalent choice for the dependent variable in the multivariate model. In regard to the variable of interest – depth of involvement in NABERS Energy – the two approaches will give identical independent variable coefficients because  $\Delta P_j$  is a linear transformation of  $P_{j(s=\max)}$ . But in regard to the overall model, the two approaches model slightly different outcomes. Modelling  $P_{j(s=\max)}$  is less interesting than  $\Delta P_j$  because  $P_{j(s=1)}$  and  $P_{j(s=\max)}$  are highly correlated (coefficient = 0.737), so while the overall explanatory power of the model will be high when  $P_{j(s=1)}$  is inserted as an independent variable, much of the explanation is due to the uninteresting correlation between initial and final energy consumption. What is more interesting is how strongly one can explain the change in energy consumption using a variety of independent control variables in addition to the depth of NABERS Energy certification. Hence  $\Delta P_j$  is chosen as the dependent variable.

The model takes the form:

$$\Delta P_j = \alpha + \beta_1 \mathbf{LOC}_j + \beta_2 \mathbf{NLA}_j + \beta_3 \mathbf{CAP}_j + \beta_4 \mathbf{OWN}_j + \beta_5 \mathbf{AVGDAYS}_j + \beta_6 \mathbf{CERT}_j + \epsilon_j \quad (3)$$

where  $\alpha$  is an intercept,  $\beta$  is an estimated coefficient, and  $\epsilon$  represents stochastic error. These three variables are estimated with ordinary least squares regression using the observed dataset of 806 multi-certified buildings. Each independent variable or vector variable (the latter indicated by bold typeface) in the observed dataset measures:



**LOC<sub>j</sub>**= Fixed effects associated with the location of building *j*

**NLA<sub>j</sub>**= Size of building *j* (net lettable area)

**CAP<sub>j</sub>**= Capacity for building *j* to improve its energy performance

**OWN<sub>j</sub>**= Fixed characteristics associated with the owner of building *j*

**AVGDAYS<sub>j</sub>**= Average days between certificates for building *j*

**CERT<sub>j</sub>**= Depth of participation by building *j* in NABERS Energy (number of certificates)

A list of all variables contained within each independent vector variable is shown in Table 6. Note that the year of certification is not included in this model because of its high correlation with the variable of interest. Later, a test is run to assess the impact of omitting this variable.

[Insert Table 6 here]

The independent variable of interest is the depth of NABERS Energy participation, measured using a flexible functional form in the vector variable **CERT<sub>j</sub>**. Number of certificates obtained proxies the depth of participation. Since diminishing returns to performance outcomes are expected as the number of re-certification periods *s* increases, the vector variable includes a series of binary variables measuring depth of participation. If a building has obtained *s* certificates, then it assumes a value of one for the *s*-certificate variable and zero for the remaining **CERT<sub>j</sub>** variables. Note that interpretation of this specification is similar to cumulative univariate *t*-test – the coefficient of each variable measures the cumulative influence of *s* certifications, not the marginal influence. The 2-certificate variable is omitted from all specifications as a reference category.

The capacity for improvement, **CAP<sub>j</sub>**, is a critical control variable given the use of an initial certificate to benchmark energy performance. The best variable to estimate capacity to improve is this initial EUI benchmark ( $P_{j_{s=1}}$ ). An alternative measure for capacity to improve, the star rating from the initial NABERS certificate, was considered but the continuous distribution of initial EUI was found to better differentiate potential than the categorical measure of initial star ratings. All else equal, buildings with high initial EUI are expected to improve more than those with low initial EUI. Another reason to include this variable is to relax the assumption that an initial NABERS certificate is acceptable as a pre-intervention benchmark. Buildings with low initial EUI are more likely to have invested in

operational energy efficiency prior to certification, so including this variable allows the model to control for this.

In  $OWN_j$ , green ownership will be assessed as an interaction between the green owner binary variable and the variable for improvement capacity. The interacted variable allows for a difference in building energy improvement potential between green and non-green owners. It can be interpreted as the excess energy savings that a green owner will pursue beyond that which a normal owner would pursue having accounted for what both groups would pursue given an initial energy consumption benchmark. The alternate specification where green ownership is only included as a binary variable does not produce as good of a fit to the observed data.

## Test for Fixed Time Effects

High correlation between year of the benchmark NABERS Energy certificate and the number of total NABERS Energy certificates obtained by each building means that year of entry cannot be reliably controlled for in the specified model because of concerns with collinearity. But there is a chance that the depth of participation variable is acting as an instrument for fixed time effects. To test for the influence of fixed time effects, three additional models will be run that fix the number of certificates earned. Fixed time effects become the variables of interest in these models.

Models with the number of re-certifications fixed are constructed using a similar approach as described in the previous section, with  $\Delta P_j$  as the dependent variable. However, instead of measuring  $\Delta P_j$  using  $P_{j(s=max)}$  for each building  $j$ , these models will measure  $\Delta P_j$  at the fixed period  $u$  of NABERS Energy certification:

$$P_{j(s=u)} - P_{j(s=1)} = \Delta P_{j(s=u)} \text{ for } u = 2,3,4 \quad (4)$$

Additional models are not run for the fifth through eighth certificates because of diminished sample sizes.

Each model investigating fixed time effects follows the general specification similar to Equation 3:

$$\Delta P_{j(s=u)} = \alpha + \beta_1 \mathbf{LOC}_j + \beta_2 \mathbf{AST}_j + \beta_3 \mathbf{CAP}_j + \beta_4 \mathbf{OWN}_j + \beta_5 \mathbf{TIME}_j + \epsilon_j \quad (5)$$

Ordinary least squares regression is used to estimate the intercept, coefficients and stochastic error.

The control variables  $\mathbf{LOC}_j$ ,  $\mathbf{AST}_j$ ,  $\mathbf{CAP}_j$ , and  $\mathbf{OWN}_j$  are identical to those described in the first multivariate model.

Table 7 lists the variables included in the new vector variable,  $\mathbf{TIME}_j$ . The vector includes the variable representing the average number of days between certifications and a set of binary variables measuring fixed time effects. The variable representing the average number of days between certificates now measures the average number of days between certificates from the initial benchmark to the certificate issued in period  $u$  (the fixed re-certification period used to calculate the dependent variable in each model). For the year of initial certification, a small number of benchmark observations in 2002 and earlier mean that the variable for 2003 includes all 1999 through 2002 start dates. At the other end, each model groups the final two years together because of a low number of observations in the final year. The variable representing the earliest adopters commencing certification between 1999 and 2003 is excluded from the model as the reference time effect.

[Insert Table 7 here]

## Results

The estimation of the multivariate model (Equation 3) is presented in Table 8. The dependent variable, change in EUI, is negative if a building reduces its energy consumption, so the significant negative coefficient as the number of certificates increase reveals a strong association between depth of participation in NABERS Energy and energy efficiency outcomes.

[Insert Table 8 here]

The  $t$ -test and model results are in good agreement, with the multivariate model showing a slightly lower reduction in energy consumption as a function of participation depth. Figure 3 compares the two<sup>10</sup>. The one notable deviation from agreement begins at the sixth certificate. The Multivariate model specification shows little change in energy savings after the sixth certificate while the

univariate trend continues to show a decrease in energy consumption. This divergence suggests that the multivariate model is better able to attribute any additional increase in energy savings past the sixth certificate to other factors besides participation in NABERS Energy, such as green ownership characteristics. The multivariate curve supports the conclusion that post-certification equilibrium is reached approximately five to six years after a building enters NABERS Energy.

[Insert Figure 3]

The control variables in Table 8 confirm a number of expected outcomes. A building with higher initial EUI is likely to experience higher energy savings. The interaction between green ownership and initial EUI reveals that buildings with a green management strategy are successful in reducing energy consumption beyond the model's expectation for an average owner. Buildings with owners that purchase Green Power regularly have significantly more energy consumption reductions in all specifications. This observation suggests that Green Power offsets are used to complement operational energy efficiency, not substitute for it.

The locational controls in this model reveal that, in nearly all cases, operational energy efficiency outcomes are not significantly influenced by unobserved factors unique to a building's location, such as local policies, interstate economic differentiation, or climate. Suburban Queensland appears to be one exception that could perhaps be understood through a unique economic boom occurring in the state at the time of this study. During this period, vacancy rates in suburban Brisbane office space were unusually low (1 to 2%), so high demand for suburban buildings means there was little scope for tenants to demand energy conservation and likewise, little need for owners and developers to invest in energy efficiency.

The only other control variable that has an effect on change in energy consumption is the average number of days between certificates. But it is in an unusual direction; buildings with more time between certificates reduce energy consumption less than buildings with fewer days between certificates. This suggests that the variable may be acting as an instrument for future expectations; owners committed to undertake regular NABERS Energy audits are more concerned with energy

efficiency than owners that certify infrequently. Hence it can be concluded that expectations of future audits are an important component of building energy efficiency.

There are some potential missing variables in the multivariate model. Data availability limits the scope of independent variables measured systematically for the entire population. The author has run multivariate models on subsamples of the data that include average hours of occupation, building service quality ratings (Premium, A, B, and C-grade), and building age. The only variables that added any further value to the model were lower building service quality ratings (B- and C-grades) and building age. Low service quality was associated with less interest in energy efficiency relative to high service quality. This supports the literature arguing that energy efficiency is a “luxury good” (Fuerst et al. 2014). The coefficient for building age in these subsamples is negative, suggesting that older buildings are more likely to improve energy consumption than newer buildings. Much of this age effect is likely captured in the variable for the capacity to improve (initial EUI). What the addition of an age variable likely contributes is the fact that older buildings are more likely to be scheduled for major renovations and there is usually a wider scope for investment in energy efficiency in these cases (e.g. replacing an entire mechanical conditioning system).

The model explains just over one-third of variability in energy efficiency improvements. Keeping in mind that energy savings are not automatically correlated with investment – many buildings with large investments in energy efficiency fail to perform efficiently in practice (Newsham et al., 2009) – the explanatory power of this model is comparable to estimations of factors that influence the construction of new energy efficient buildings (Kok, McGraw, and Quigley, 2012; Fuerst et al., 2014).

However, there is a concern that number of certificates is measuring a fixed time effect as opposed to depth of participation. This concern was tested using the fixed time effects model specified in Equation 5. Table 9 summarises the fixed time effect results from the models where the number of certification periods is fixed. At the time of a building’s second certificate there are weakly significant fixed time effects in 2006, 2011 and 2012-13, as measured in reference to the earliest adopters.

Buildings commencing NABERS Energy certification in these years are statistically more likely to have greater reductions in energy consumption at the time of a building's second certificate. But once these buildings obtain a third or fourth certificate, there are no longer significant fixed time effects. Hence it can be concluded that number of certificates is a good proxy for depth of participation and is not likely to be an instrument for omitted time effects.

[Insert Table 9]

## **Conclusions**

The results of this study point to a consistent relationship between depth of NABERS Energy participation and operational energy efficiency outcomes in Australian office buildings. Initially, the more NABERS Energy audits undertaken by a building owner, the more operational energy conserved on average, all else being equal. However, after the sixth audit, owners appear to reach an apparent post-intervention equilibrium energy consumption intensity, which, for the Australian sample in this study, measures approximately 430 MJ/m<sup>2</sup>/year (120 kWh/m<sup>2</sup>/year) on average for core building services<sup>11</sup>. Multivariate analysis revealed some differentiation within the population; owners with green asset management strategies obtain marginally higher levels of energy efficiency, as do owners purchasing Green Power offsets regularly. This latter observation suggests Green Power offsets are a complement, not a substitute, to operational energy efficiency. Location is generally unimportant in relation to operational energy conservation, although energy efficiency does not appear to be a concern in a booming property market defined by a scarcity of supply, such as the Brisbane suburban market during the period of this study.

Additional tests were needed to establish the robustness of the relationship between depth of certification and energy savings because of high correlation between the year a building commences NABERS Energy certification and the depth of its participation. Fixed time effects are weakly important at the second NABERS Energy audit, but these fixed time effects disappear as the buildings undergo further certification.

There is another possible explanation for the relationship between depth of participation and energy efficiency that has little to do with private investment: the possibility that rising vacancy rates during the global financial crisis are responsible for the energy consumption improvements observed in this study. The fixed time effect test provides some evidence against this possibility: the global financial crisis, which began in 2008, is notably absent from the time effects. Furthermore, the guidelines for NABERS Energy auditors (Department of Environment Climate Change and Water NSW, 2010), specify that vacant space is to be excluded from the denominator of any area-normalised metric such as EUI. The author has no evidence auditors are systematically failing to adhere to these standards, thus vacancy is not likely affecting these results.

For building owners and tenants, this study reinforces the effectiveness of integration between behaviour and design in building energy management or greenhouse gas emission outcomes. One direct implication is that owners and tenants may face increased scrutiny in regard to energy management practices if policymakers decide to mandate regular energy or greenhouse gas emission audits. This increased oversight could encourage owner-tenant partnerships for energy management, such as the inclusion of so-called “green lease” clauses that specify the responsibilities of each party in meeting energy or greenhouse gas emission targets.

For policymakers, the results of this study add clarity in regard to outcome expectations of using repetitive auditing of energy consumption as an operational component of a market-based regulation. Nearly all buildings in this dataset are privately owned, so there is strong evidence that repetitive disclosure motivates the private sector to invest in operational energy efficiency. It is also possible to conclude, using the control variable representing time between certifications, that expectations of future auditing play an important role in motivating owners to manage energy efficiency and maintain high performance.

Finally, the overall justification for the introduction of NABERS Energy is greenhouse gas mitigation. How effective has NABERS Energy been at mitigating greenhouse gas emissions in Australia? Policy targets are nearly always stated as a percentage reduction relative to an annual benchmark; for

example, Australia's federal government has committed to an unconditional 5% reduction on greenhouse gas emissions measured in the year 2000 by the year 2020. How does the intervention of NABERS contribute? Depending on how one accounts for outliers, potential sub-population bias and spillover effects, pre-NABERS Energy consumption averaged between 580 and 626 MJ/m<sup>2</sup>/year (161 to 174 kWh/m<sup>2</sup>/year) for the entire building stock in this study (Table 5). It was then observed in the *t*-tests that six NABERS Energy audits or more delivered an average stock consumption of 430 MJ/m<sup>2</sup>/year (120 kWh/m<sup>2</sup>/year), meaning a reduction in greenhouse gas emissions from base building services somewhere between 26 and 32%. The multivariate model attributes some of the reduction to green asset management strategies potentially unrelated to the presence of NABERS Energy, so it is best to use the asymptote around an average energy reduction of 120 MJ/m<sup>2</sup>/year (33 kWh/m<sup>2</sup>/year) observed in Figure 3. Using this, NABERS Energy audits can be held responsible for approximately 20% of the observed decline in building energy consumption. Further work on this project is assessing whether the motivation to participate – voluntarily or under mandate – affects these results.

This conclusion integrates well with the findings of Pacala and Socolow (2004), who argued that deployment of existing technology could reduce greenhouse gas emissions from energy consumption in the built environment by 25% relative to 2004 global emissions. The reductions seen in this study indicate that NABERS Energy, as implemented in Australia, may be an effective tool for introducing these existing technologies to the market more rapidly. Pacala and Socolow (2004) proposed a 50-year timeframe for their 25% reduction; if the conclusion in this study is accurate, then stronger targets are likely to be achievable within a 50-year timeframe.

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<sup>1</sup> This statement refers to the performance standards of current statutory building codes. A change to the high-performance expectations of most voluntary green building assessment tools would take much longer. Kok, Miller, and Morris (2012) estimate that only 10% of new construction in the United States has sought certification under its LEED assessment system.

<sup>2</sup> BEED applies to office buildings greater than 2,000 square metres and the required energy disclosure is a NABERS Energy certificate (discussed in detail later). The NABERS Energy rating from the certificate must be displayed prominently on any advertisement for lease or sale. The European Union mandates building performance ratings for existing buildings, but these have all been based on simulated, not measured, performance. European governments are now considering the introduction of "Direct Energy Certificates", which would be based on measured consumption and thus be comparable with Energy Star in the United States and NABERS Energy in Australia (Fuerst et al. 2013).

<sup>3</sup> The statement "energy efficiency is positively associated with measures of asset value", means that reduced energy consumption (i.e. increased energy efficiency) is associated with increased measures of asset value. An equivalent statement would be that nominal energy consumption is *negatively* associated with asset value.

<sup>4</sup> As Borck and Coglianese (2009) report in their review, little is known about the existence or size of spillover effects. In the buildings sector, Simcoe and Toffel (2013) find evidence of a spillover effect resulting from government procurement policies that have nudged private building producers to adopt LEED construction standards as a "de facto" construction standard for non-government projects. However, their conclusion comes with a number of caveats typical of studies looking for spillover effects, namely the possibility of reverse causation (i.e. environmentally conscious municipalities are the ones most likely to develop green procurement policies). An extreme example of spillover effects is the use of voluntary standards as mandates in public policy (Simons et al., 2009, Kontokosta, 2011).

<sup>5</sup> Asset ratings ignore behavioural energy demand, such as plug loads (computers and other devices that tenants plug into a wall socket), so a researcher receiving total energy consumption data post-occupancy must estimate

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how much of that energy is consumed by the services included in an asset rating. This introduces the potential for significant bias and error.

<sup>6</sup> Some minor adjustments have been made, such as increasing the top star rating to 6 from 5, but these have not affected the core assessment methodology or the audit process.

<sup>7</sup> For clarity, a NABERS Energy audit only measures site energy directly. The process to calculate star ratings involves estimating greenhouse gas emissions from site energy consumption at the source (i.e. including generation and transmission losses for electricity). This paper predominantly uses the site energy audit result to define “operational energy” because it is the most consistent and not subject to accounting protocol variations. Audit results indicating the fuel mix are not made public. Since purchased electricity is the dominant fuel in Australia, the site energy audit is a good proxy for greenhouse gas emissions in this study.

<sup>8</sup> This Green Power purchasing scheme is the only greenhouse gas emission offset scheme recognised by NABERS Energy. As such, the terms “Green Power purchasing” and “Green Power offsets” are used interchangeably in this paper. Other forms of greenhouse gas emission offsets, such as re-forestation credits, will not improve a NABERS Energy rating.

<sup>9</sup> To test whether the omission of these 12 buildings biases the results, all the statistical models in this paper have also been run with all 818 buildings, omitting building size as a variable when necessary. No changes to these results occur, most likely because the models in this paper find that building size is not a factor in energy efficiency outcomes in Australia.

<sup>10</sup> Using the data in Table 5, the expected value of the change in energy consumption from each t-test for each recertification period  $s$  is calculated as such:

$$E(\Delta P_s) = e^{\ln(P_1)} \left( \frac{E(\ln P_s)}{E(\ln P_1)} - 1 \right)$$

A further adjustment is to modify  $E(\Delta P_s)$  so it is relative to the second certificate because the equation above calculates the expected change relative to the initial benchmark certificate. Thus, each value of  $E(\Delta P_s)$  for  $s > 2$  is reduced by  $E(\Delta P_2)$ .

<sup>11</sup> Note that the Base Building scope of NABERS Energy used in this study only measures core asset services. See the Data section for more detail on what energy sources are included.

**Table 1. Number of unique buildings by number of certificates obtained.**

<b>Number of Certificates</b>	<b>Number of Unique Buildings</b>
<b>1</b>	335
<b>2</b>	242
<b>3</b>	192
<b>4</b>	106
<b>5</b>	72
<b>6</b>	75
<b>7</b>	63
<b>8</b>	37
<b>9</b>	20
<b>10</b>	9
<b>11</b>	2
<b>Any</b>	<b>1,153</b>

**Table 2. Descriptive statistics. Mean (Standard Deviation) unless otherwise indicated.**

	<b>Number of NABERS Energy certifications</b>								<b>Total Multi- Certified</b>
	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>	
N	84 <sup>D</sup>	235	189	104	72	75	63	68	<b>806</b>
Initial EUI (MJ/m <sup>2</sup> /yr)	669 (516)	639 (337)	660 (401)	577 (228)	553 (182)	642 (189)	618 (186)	643 (140)	<b>627 (299)</b>
Initial Star Rating <sup>A</sup>	2.66 (1.61)	2.65 (1.56)	2.67 (1.56)	2.83 (1.48)	2.88 (1.35)	2.59 (1.13)	2.69 (1.20)	2.43 (1.10)	<b>2.68 (1.44)</b>
Final EUI (MJ/m <sup>2</sup> /yr)	n/a	597 (291)	600 (377)	470 (185)	436 (151)	436 (126)	421 (114)	440 (115)	<b>526 (273)</b>
Final Star Rating <sup>A</sup>	n/a	2.87 (1.60)	3.06 (1.61)	3.66 (1.22)	3.94 (0.91)	3.97 (0.97)	4.17 (0.71)	3.96 (0.75)	<b>3.40 (1.43)</b>
Change in EUI (MJ/m <sup>2</sup> /yr)	n/a	-42 (220)	-60 (221)	-107 (173)	-117 (180)	-207 (188)	-197 (177)	-203 (132)	<b>-102 (209)</b>
Net Lettable Area (m <sup>2</sup> )	6,983 (5,696)	10,560 (10,854)	14,097 (12,976)	15,655 (13,715)	16,309 (13,045)	20,757 (13,736)	19,523 (16,265)	23,595 (19,272)	<b>15,310 <sup>H</sup> (14,081)</b>
% Purchasing Green Power <sup>B</sup>	n/a	6.6%	8.3%	12.2%	13.9%	34.7%	14.3%	16.1%	<b>12.3%</b>
% in CBD	38.2%	40.5%	48.4%	53.8%	45.8%	64.0%	61.9%	72.1%	<b>51.0%</b>
% with Green Owner <sup>C</sup>	0.0%	7.4%	7.8%	16.0%	22.2%	28.0%	46.0%	54.4%	<b>18.7%</b>
Avg. Days between Cert.	n/a	599 (483)	509 (272)	467 (219)	501 (180)	493 (144)	450 (79)	441 (99)	<b>518 (319)</b>
Median Days between Cert.	n/a	420	407	389	432	454	433	407	<b>418</b>
Median Year of 1 <sup>st</sup> Cert.	2011	2011	2010	2009	2008	2006	2006	2004	<b>2009</b>

<sup>A</sup> Star ratings exclude Green Power offsets

<sup>B</sup> Binary variable for a building offsetting at least 1% of its energy through the Green Power scheme in every re-certification.

<sup>C</sup> Binary variable equalling 1 for a building owned by Stockland, GPT, Commonwealth Property, or Investa.

<sup>D</sup> Accurate measures of NLA for the 1-certificate properties were not pursued aggressively, hence the small sample.

**Table 3. Correlation matrix for selected variables. N=806.**

	Change in EUI	Building NLA	Green Owner	Num. of Cert.	Located in CBD	Year of First Cert.	Initial EUI
Change in EUI	1.000						
Building NLA	-0.113*	1.000					
Green Owner	-0.134*	0.256*	1.000				
Num. of certificates	-0.298*	0.335*	0.380*	1.000			
Located in CBD	-0.109*	0.336*	0.115*	0.189*	1.000		
Year of first cert.	0.200*	-0.264*	-0.274*	-0.749*	-0.213*	1.000	1.000
Initial EUI	-0.467*	-0.085*	-0.076*	-0.029	0.025	0.020	

\*  $p$ -values less than 0.05

**Table 4. Univariate results describing the marginal effect on performance from each additional re-certification**

Sequence $s$ to $s+1$	Mean $\ln(P_s)^A$ [Std. Error]	Mean $\ln(P_{s+1})^A$ [Std. Error]	$t$ -value	Probability	N
1 to 2	6.36 [0.014]	6.30 [0.014]	2.805	0.0051	806
2 to 3	6.31 [0.016]	6.24 [0.016]	2.902	0.0038	571
3 to 4	6.23 [0.017]	6.15 [0.016]	3.114	0.0019	382
4 to 5	6.18 [0.018]	6.13 [0.017]	2.205	0.0279	278
5 to 6	6.16 [0.018]	6.09 [0.019]	2.784	0.0056	206
6 to 7	6.11 [0.024]	6.06 [0.023]	1.462	0.1449	131
7 to 8	6.11 [0.032]	6.06 [0.031]	1.326	0.1872	68

<sup>A</sup>  $P_s$  is used to abbreviate building energy consumption at the initial time step  $s$ , while  $P_{s+1}$  is used to represent the secondary time step  $s+1$ . Units for figures in these columns are  $\ln(\text{MJ}/\text{m}^2/\text{yr})$

**Table 5. Univariate results describing the cumulative effect on performance from additional re-certification.**

Sequence 1 to $s$	Mean $\ln(P_1)^A$ [Std. Error]	Mean $\ln(P_s)^A$ [Std. Error]	$t$ -value	Probability	N
1 to 2	6.36 [0.014]	6.30 [0.014]	2.805	0.0051	806
1 to 3	6.36 [0.016]	6.24 [0.016]	5.312	$1.30 \times 10^{-7}$	571
1 to 4	6.35 [0.016]	6.15 [0.016]	8.687	$2.22 \times 10^{-17}$	382
1 to 5	6.38 [0.018]	6.13 [0.017]	10.343	$4.88 \times 10^{-23}$	278
1 to 6	6.42 [0.019]	6.09 [0.019]	12.498	$1.37 \times 10^{-30}$	206
1 to 7	6.41 [0.022]	6.06 [0.023]	10.885	$5.55 \times 10^{-23}$	131
1 to 8	6.44 [0.026]	6.06 [0.031]	9.722	$3.10 \times 10^{-17}$	68

<sup>A</sup>  $P_s$  is used to abbreviate building energy consumption at the initial time step  $s$ , while  $P_{s+1}$  is used to represent the secondary time step  $s+1$ . Units for figures in these columns are  $\ln(\text{MJ}/\text{m}^2/\text{yr})$

**Table 6. Independent variables**

<i>LOC<sub>j</sub></i>	<i>AST<sub>j</sub></i>	<i>CAP<sub>j</sub></i>	<i>OWN<sub>j</sub></i>	<i>AVGDAYS<sub>j</sub></i>	<i>CERT<sub>j</sub></i>
State=ACT (reference)	Asset NLA (Nat. Log. m <sup>2</sup> )	Initial EUI (MJ/m <sup>2</sup> /yr)	Green Power (1=yes)	Avg. days between certificates	2 certificates (reference cat.)
State=NSW (1=yes)			Green Owner (1=yes)*Initial EUI	(Natural Log. days)	3 certificates (1=yes)
State=QLD (1=yes)					4 certificates (1=yes)
State=SA (1=yes)					5 certificates (1=yes)
State=VIC (1=yes)					6 certificates (1=yes)
State=WA (1=yes)					7 certificates (1=yes)
State=Other (1=yes)					8 certificates (1=yes)
CBD=Canberra (1=yes)					
CBD=Sydney (1=yes)					
CBD=Brisbane (1=yes)					
CBD=Melbourne (1=yes)					
CBD=Adelaide (1=yes)					
CBD=Other (1=yes)					

**Table 7. Variables included in *TIME<sub>j</sub>*.**

<i>TIME<sub>j</sub></i>
Avg. days between certs. (Natural Log. days)
Start 1999-2003 (reference variable)
Start 2004 (1=yes)
Start 2005 (1=yes)
Start 2006 (1=yes)
Start 2007 (1=yes)
Start 2008 (1=yes)
Start 2009 (1=yes)
Start 2010 (1=yes) <sup>A</sup>
Start 2011 (1=yes) <sup>A</sup>
Start 2012-2013 (1=yes) <sup>A</sup>

<sup>A</sup> Groups for recent years change in the models investigating performance at the third and fourth certificates. In the third-certificate model, 2011 and 2012 are combined; no buildings commence in 2013. In the four certificate model, 2010 and 2011 are combined; no buildings commence in 2012.

**Table 8. Regression estimation of Equation 3. Standard error in brackets.**

<b>Depth of Participation</b>	
Two Certificates	<i>Reference</i>
Three Certificates	-2.64 (17.01)
Four Certificates	-77.61 (20.7) ***
Five Certificates	-87.62 (23.62) ***
Six Certificates	-126.26 (24.53) ***
Seven Certificates	-126.59 (26.18) ***
Eight Certificates	-115.60 (26.13) ***
<b>Building Location</b>	
State ACT	<i>Reference</i>
State NSW	-2.44 (30.27)
State QLD	92.25 (37.2) **
State SA	-0.3 (81.39)
State VIC	42.75 (34.11)
State WA	-39.69 (48.46)
State Other	-71.09 (75.73)
CBD Canberra	17.24 (40.76)
CBD Sydney	-8.82 (19.91)
CBD Brisbane	-64.85 (32.34) **
CBD Adelaide	-45.81 (82.46)
CBD Melbourne	-12.02 (28.37)
CBD Perth	26.65 (47.03)
CBD Other	37.73 (94.90)
<b>Building Characteristics</b>	
Nat. Log. Building NLA	-9.73 (9.17)
<b>Capacity to Improve</b>	
Initial EUI	-0.345 (0.021) ***
<b>Owner Characteristics</b>	
Green Power Purchased	-46.25 (18.99) **
Green Owner*Initial EUI	-0.075 (0.028) ***
Avg. Days Between Certs. (Nat. Log.)	31.24 (14.87) **
Intercept ( $\alpha$ )	69.34 (127.92)
N	<b>806</b>
R-squared	<b>0.365</b>
Adj. R-squared	<b>0.345</b>

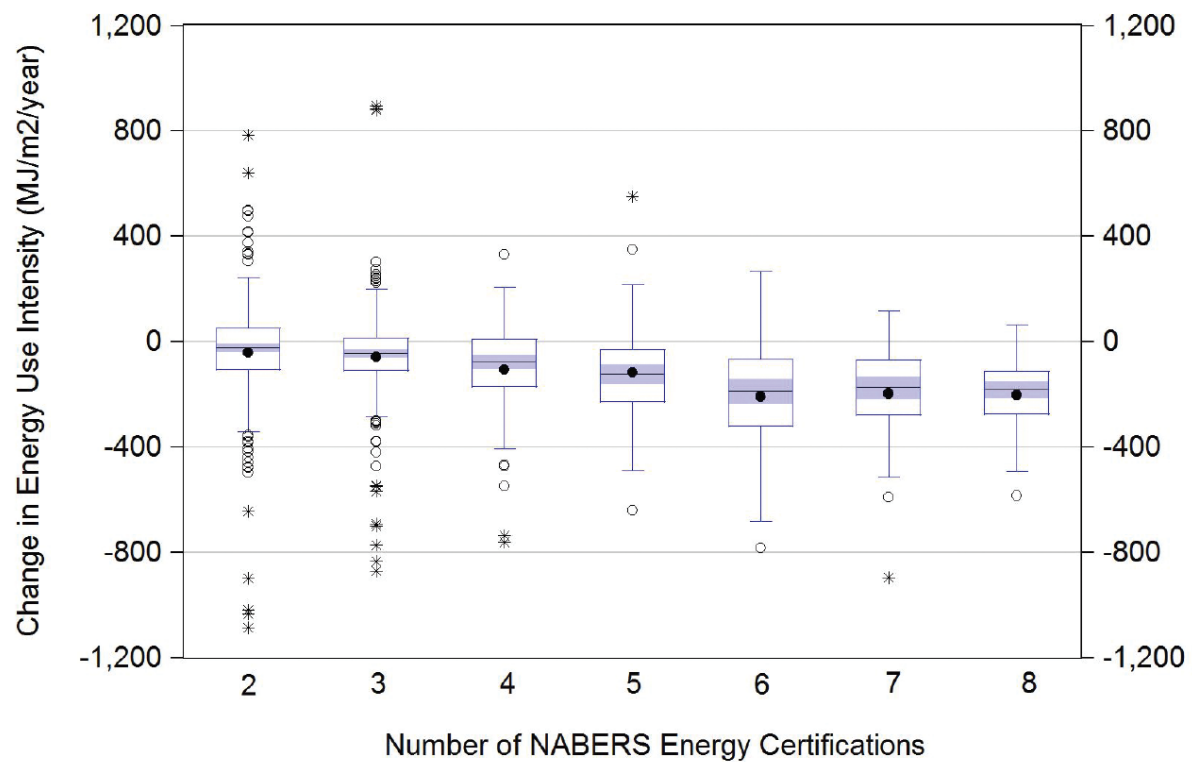
\*, \*\* and \*\*\* indicate  $p$  values less than 0.10, 0.05, and 0.01 respectively.

**Table 9. Results of the tests for fixed time effects (Equations 4 and 5).**

	2 <sup>nd</sup> Certificate	3 <sup>rd</sup> Certificate	4 <sup>th</sup> Certificate
Benchmark 1999-2003	<i>Reference</i>	<i>Reference</i>	<i>Reference</i>
Benchmark 2004	-28.42 (38.85)	-11.42 (37.77)	-9.08 (32.57)
Benchmark 2005	-40.90 (34.11)	-22.53 (32.43)	-39.47 (28.82)
Benchmark 2006	-59.30 (31.32) *	-21.86 (31.45)	-19.76 (28.65)
Benchmark 2007	-40.04 (35.29)	-30.09 (36.24)	-28.32 (33.62)
Benchmark 2008	-52.67 (39.56)	17.38 (41.72)	21.80 (37.29)
Benchmark 2009	-20.89 (33.96)	12.84 (36.60)	-24.00 (35.50)
Benchmark 2010	-16.90 (31.28)	-11.35 (35.89)	-29.45 (38.87)
Benchmark 2011	-84.09 (33.38) **	14.76 (41.40)	n/a
Benchmark 2012-2013	-61.27 (37.13) *	n/a	n/a
Locational controls	<i>Included</i>	<i>Included</i>	<i>Included</i>
Initial EUI	-0.202 (0.023) ***	-0.250 (0.026) ***	-0.511 (0.039) ***
Owner/Building Characteristics	<i>Included</i>	<i>Included</i>	<i>Included</i>
<b>Adj. R-Squared</b>	<b>0.109</b>	<b>0.173</b>	<b>0.343</b>

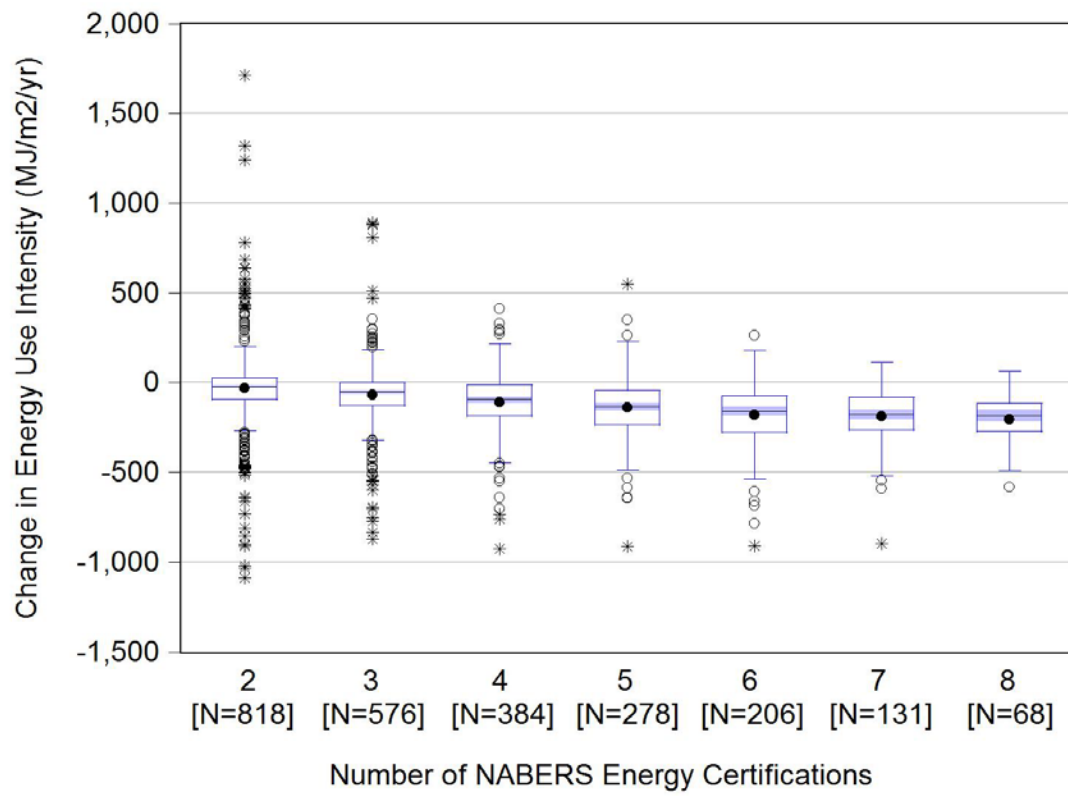
\*, \*\* and \*\*\* indicate  $p$  values less than 0.10, 0.05, and 0.01 respectively.

## Figures



**Figure 1. Boxplots of the relationship between number of certifications per building and change in EUI between first and last certification. N=806.**





**Figure 2. Boxplots of the relationship between number of certifications per building and change in EUI at every intermediate re-certification.**

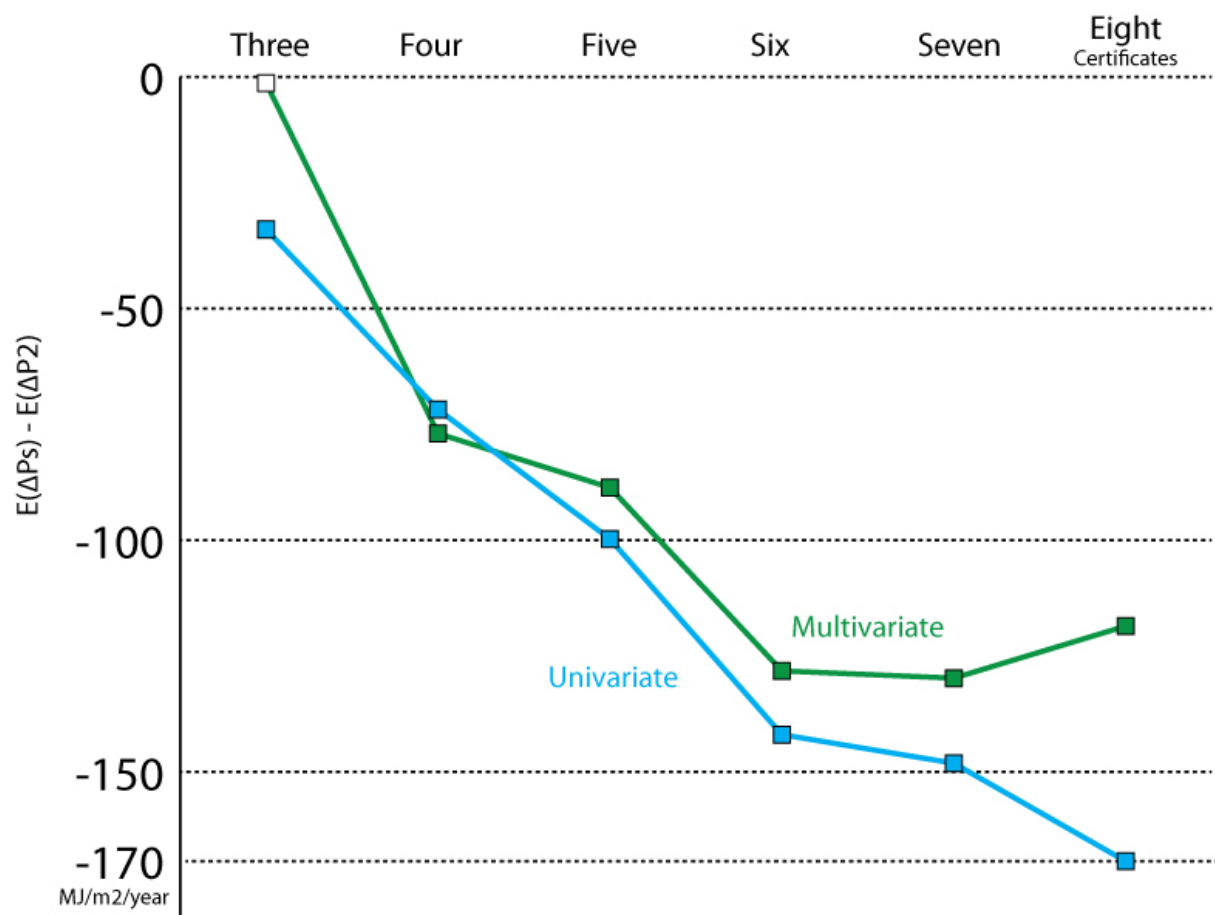


Figure 3. Comparison between  $t$ -test and multivariate results.