Achieving the Green Dream: Predicted vs. Actual

Greenhouse Gas Performance in Green Star-certified office buildings

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Green Building Council of Australia

The Green Building Council of Australia (GBCA) is a member-based, not-for-profit organisation established in 2002 to develop a sustainable property industry in Australia, and drive the adoption of green building practices through market-based solutions.

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Abstract

The main objective of this study is to verify how predictive energy modelling applied to the design of Green Star rated buildings, translated into greenhouse gas performance in operations. Specifically, the analysis compared modelled and actual greenhouse gas performance of 70 Green Star certified office buildings.

The findings include evidence indicating that 57% of Green Star certified office buildings have achieved their modelled greenhouse gas performance, including 17% that have performed better than predicted. An additional 26% achieved actual greenhouse gas performance that may match their modelled targets if certain operational practices are implemented. These results do not seem to support the commonly accepted idea that predicted energy performance does not translate to actual operational performance.

Additionally, potable water operational performance was analysed for 48.5% of the sample (34 of the 70 Green Star certified buildings). The results indicate that typically, as greenhouse gas efficiency increases in these buildings, so does potable water performance. This suggests that high potable water performance does not appear to have been achieved to the detriment of energy efficiency.

The research in this report was presented at the AIRAH "Achieving the Green Dream" conference in September 2012.

1. Introduction

The GBCA has assisted industry stakeholders in developing a common language for the design and construction of green buildings in Australia, through its Green Star environmental rating system for buildings. First launched in 2003, Green Star takes a holistic approach to the environmental performance of the design and construction of buildings by addressing the following topics in its nine categories: Management, Indoor Environment Quality, Energy, Transport, Water, Materials, Land Use and Ecology, Emissions and Innovation. The Green Star rating system is now being expanded to incorporate existing buildings in operation, with the development of Green Star - Performance. This new Green Star rating tool will address the holistic operational performance of existing buildings, covering all nine Green Star categories mentioned above.

The research piece presented in this paper has focused on the Energy category of a group of 70 Green Star – Office certified projects (see '2.2 Sample Population'). More specifically, the analysis has collected data from the 'Greenhouse Gas Emissions' credit within the Energy category from these 70 Green Star – Office certified projects. The data collected from the 'Greenhouse Gas Emissions' credit is the result of computer generated energy modelling, carried out by the individual project teams involved in the design and construction of the buildings within the sample.

The output from the energy model is a predicted annual figure of the base building's total energy consumption, converted to greenhouse gas equivalent terminology. This is typically expressed in kilograms of carbon dioxide equivalent per metre square per annum (kgCO2-e/m2/annum), which is known as 'normalised emissions' in Green Star. The predicted 'normalised emissions' are then expressed in predicted NABERS Energy stars.

NABERS is a national government program managed by the Office of Environment and Heritage New South Wales. NABERS Energy provides a star rating to a building that represents its actual operational performance, using 12 months of measured performance information, such as electricity and gas bills. The program compares the performance of a building to benchmarks that represent the performance of other similar buildings in the same location. These benchmarks are known as 'benchmarking factors' and are unitless. 'Benchmarking factors' were called 'normalised emissions' in the NABERS program until July 2010 (NABERS n.d.1).

2. Methodology

The aim of this data analysis is to verify how computer generated energy modelling used in the 70 Green Star certified office buildings in the sample, translates into greenhouse gas performance in operations. Some more specific objectives are:

- Collect predicted and actual performance data in a single database, which brings together modelled 'normalised emissions', predicted NABERS Energy results (GBCA n.d.), actual 'benchmarking factors' and actual NABERS Energy star ratings (NABERS n.d.2);

- Compare predicted to actual greenhouse gas performance, analysing how accurately modelled greenhouse gas figures translate into actual NABERS Energy results; and

- Compare predicted to actual greenhouse gas performance, analysing how accurately modelled 'normalised emissions' translate into actual 'benchmarking factors'. The output from modelling reports for Green Star certification utilises the term 'normalised emissions' to describe predicted normalised greenhouse gas emissions, and it provides a pathway to using the NABERS Energy methodology (GBCA 2011).

In addition to the main objectives above, an analysis between the relationship of actual greenhouse gas performance (NABERS Energy) and actual potable water performance (NABERS Water) of these Green Star-rated buildings has also been carried out.

2.2 Sample Population

The population of interest for this study is composed of all Green Star office buildings that also have a valid NABERS Energy certificate up until 30 June 2012. The population that is accessible to this study consists of all Green Star - Office certified projects (Design and As Built, v1, v2 and v3) that met the following criteria:

1. Predicted greenhouse gas performance is available from Green Star certification records in two formats: predicted 'normalised emissions' in kgCO2-e/m2/annum and related predicted NABERS Energy stars; and

2. Actual greenhouse gas performance is available from the NABERS Energy database in two formats: 'benchmarking factor' and actual NABERS Energy stars, both without GreenPower.

It was important to exclude the effect of GreenPower (GreenPower n.d.) for the purposes of this analysis, since the modelling methodology used in predicting the greenhouse gas performance of Green Star - Office Design/As Built projects does not allow for operational solutions (such as the purchase of GreenPower to reduce the environmental impacts of greenhouse gas emissions).

All analysed figures correspond to data available according to the criteria above. Green Star certified buildings that did not have actual greenhouse gas figures available by 30 June 2012 were not included in the analysis, which resulted in a final sample size of 70 buildings.

The results show that for the buildings analysed, the modelled outputs had a mean of 4.9 NABERS Energy stars and achieved a mean actual performance of 4.5 NABERS Energy stars (minimum and maximum values were 4.0 and 6.0 for predicted performance, and 0.0 and 5.5 for actual performance). In terms of greenhouse gas emissions, the average 'normalised emissions' were 69 kgCO2-e/m2/annum.

Green Star – Office certified buildings	Sample size	Modelled Mean	Actual Mean
Valid NABERS Energy Certificates	70	4.9 Stars	4.5 Stars

Table 1 - Sample summary

Half of the projects in the sample were rated with the 'Green Star – Office As Built' rating tool (50%) while the other half was rated with the 'Green Star – Office Design' rating tool. Where projects were rated with both 'Green Star – Office Design' and 'Green Star – Office As Built', only the data from the 'As Built' rating was considered. The sample population included projects from all states and territories; ACT (7), NSW (19), NT (1), QLD (12), SA (7), TAS (2), VIC (17) and WA (5).

2.3 Initial Assumptions to be Rejected or Confirmed

The following statements are commonly accepted assumptions that are addressed by this report:

1. Modelled greenhouse gas performance of Green Star certified buildings does not relate to actual greenhouse gas performance in operations.

2. Increased levels of greenhouse gas efficiency in buildings are only achievable to the detriment of potable water performance.

The data analysed in this research was used to either reject or confirm these assumptions.

2.4 Analyses Groups

Four main groups of analyses were carried out in this study. The following points below describe each analysis type and the related buildings considered:

1. Whole Sample: comparison between predicted and actual NABERS Energy results;

2. Whole Sample: comparison between predicted normalised emissions (kgCO2-e/m2/annum) and actual benchmarking factor;

3. Part Sample 1: buildings that have not achieved predicted NABERS Energy target were analysed to verify how close they were to the predicted target, comparing results between predicted normalised emissions and benchmarking factor;

4. Part Sample 2: buildings that have an actual NABERS Water rating available: comparison between actual greenhouse gas and potable water performance.

Once again, for all NABERS Energy analysis, the results without GreenPower and without 'externally supplied recycled water' were considered.

3. Findings of analyses

3.1 Predicted vs. Actual NABERS Energy results

The first analysis compared predicted to actual NABERS Energy results, specifically the difference between the modelled and actual results for each Green Star - Office Design / As Built certified project within the sample population.

It was found that the majority of buildings perform as predicted or better (57%), obtaining the same or a higher NABERS Energy rating than predicted by the computer model. The group of buildings that perform as predicted has been labelled 'Achieved Prediction', while the group of projects that do not perform as well as predicted are called 'Have Not Achieved Prediction', as shown in Figure 1.

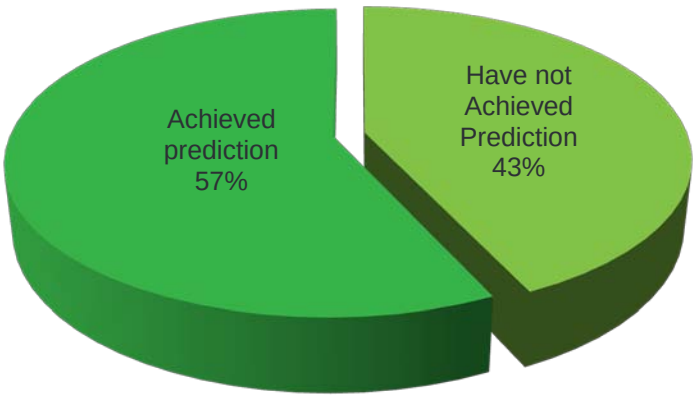


Figure 1 - Predicted vs. Actual NABERS Energy rating

In general terms a positive relationship between modelled and actual greenhouse gas performance was found, as Figure 2 illustrates.

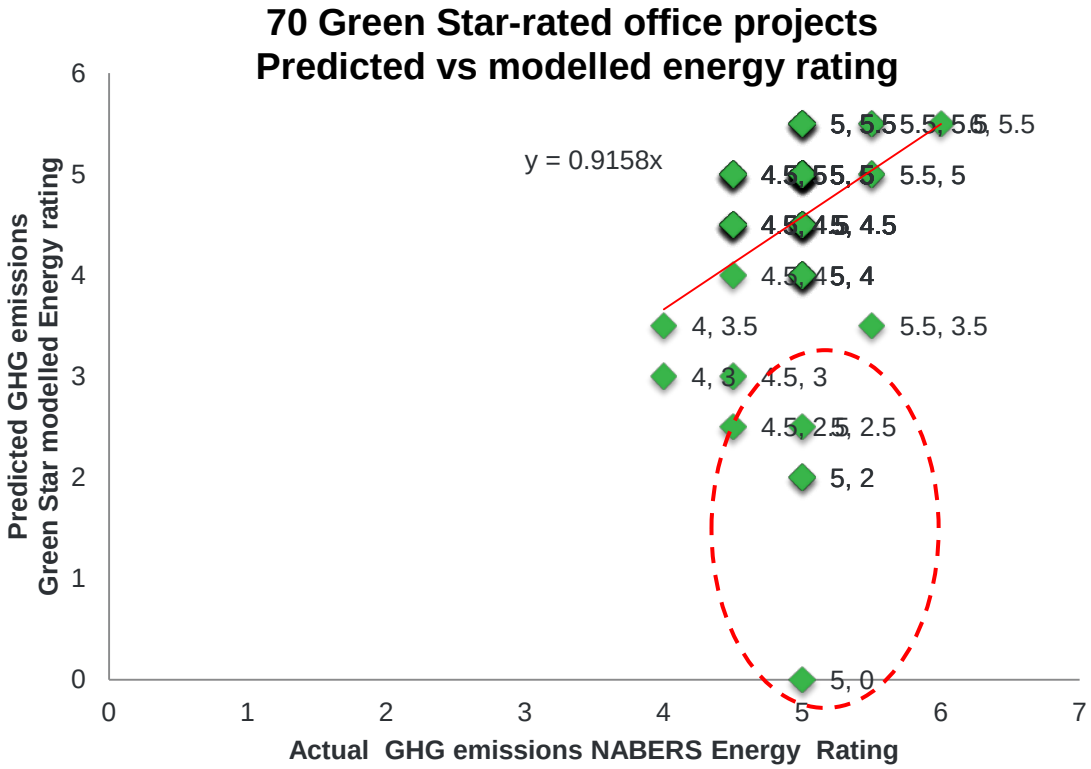


Figure 2 - Scatter Plot analysis - Predicted versus Actual NABERS Energy rating

The scatter plot analysis demonstrates that, due to the positive relationship observed, as modelled NABERS Energy scores increase, actual NABERS Energy scores also increase.

There are a few individual buildings however, that do not follow this trend. These buildings are shown circled below the 'line of best fit', where the actual greenhouse gas performance is considerably lower than the predicted greenhouse gas performance. Section '3.3 - Have not Achieved Prediction group' presents detailed results for this group.

It can also be inferred from the scatter plot analysis, that since the slope of the trend line is significantly non-zero and it sharply rises from left to right, there is probably a positive relationship between the dependent (observations) and the independent variable (regressor). Although it has been demonstrated that a positive relationship exists, it has not been possible to test the strength of this relationship accurately (r-squared). This is due either to the size of the sample as a whole or to the ratio of observations to regressor being too low.

The modelled performance data was tested as the independent variable (y-axis, regressor) and the actual performance data as the dependent variable (x-axis, observations). The dependent variable is the event studied and expected to change whenever the independent variable is altered.

Predicted NABERS Energy	Actual NABERS Energy									
	0.0	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	Total
4.0				1	1					2
4.5			1	1		1	7	6		16
5.0	1	2	1			7	10	19	6	46
5.5					1			2	2	5
6.0									1	1
Total	1	2	2	2	2	8	17	27	9	70

Table 2 - Predicted vs. Actual NABERS Energy rating

3.2 'Achieved Prediction' group

While 57% of all projects achieve their greenhouse gas target, closer analysis indicates that this includes 28 projects (40% of total) that perform just as predicted; this means that the modelled NABERS Energy results match the actual NABERS Energy results exactly. Notably, 12 buildings (17% of total) performed better than their modelled greenhouse gas target, meaning their actual NABERS Energy results are higher than the computer model predicted.

Interestingly, 10 projects (14% of total) perform as predicted in NABERS Energy stars, but have not achieved an exact match in 'benchmarking factor' terms. This is because as NABERS Energy scores above 5.0 stars increase in 25% increments (NABERS n.d.3), where a building is modelled in Green Star at 5.0 stars + 20% NABERS Energy and it achieves its target, the official NABERS Energy rating would still be 5.0 stars (5.5 stars would be at 5.0 stars + an additional 25% reduction). Figure 3 illustrates these results.

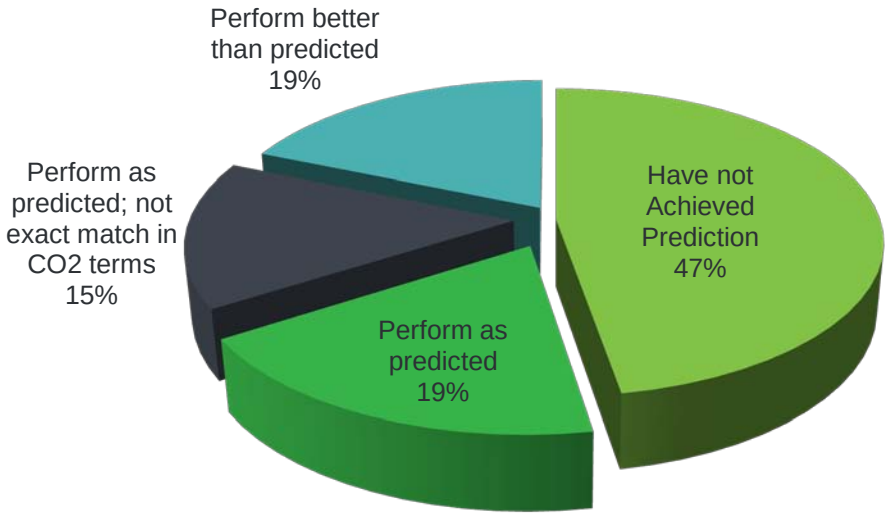


Figure 3 - 'Achieved Prediction' group

A closer look at the group of buildings that perform better than predicted (17%), reveals that they all exceed their modelled target by the same amount - 0.5 NABERS Energy star.

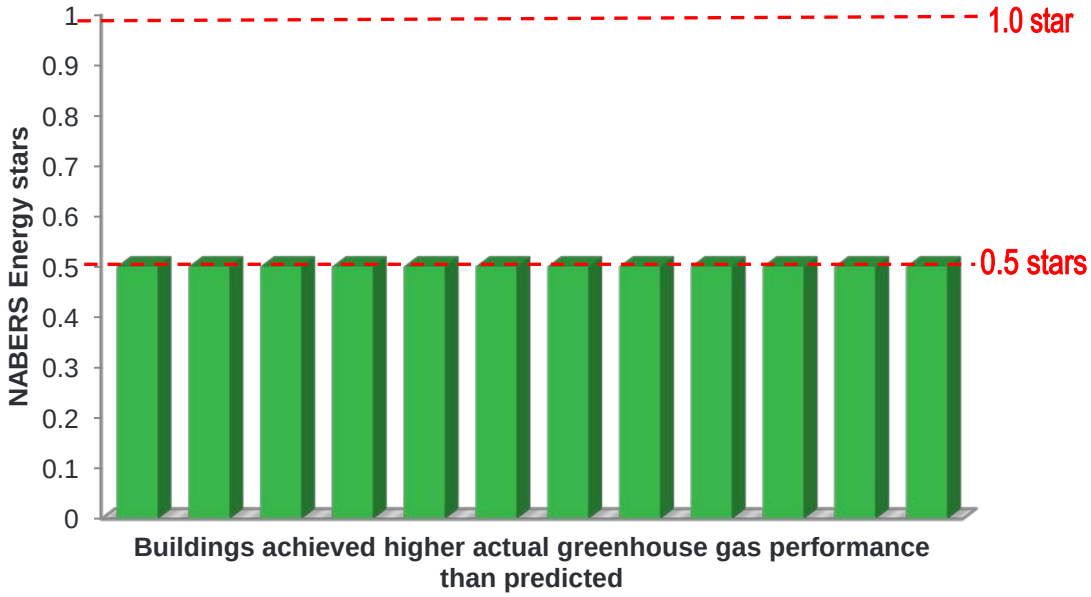


Figure 4 - Overachievers: exceeding their predicted NABERS Energy results

3.3 'Have Not Achieved Prediction' group

Thirty (30) buildings (43% of total) have not achieved the predicted greenhouse gas performance target. However, a comparison between modelled and actual normalised emissions (kgCO2-e/m2/annum) demonstrates that 8 of the 30 buildings are within half a star (0.5) of the modelled NABERS Energy result. An additional 10 buildings are within one star (0.51 to 1.0 star) of the predicted greenhouse gas performance, when compared to the actual NABERS Energy result.

The majority of buildings in this group, 18 buildings (26% of total), missed the predicted target by 1.0 NABERS Energy stars or less. The remaining 12 buildings (17% of total) underperform by more than 1.0 NABERS Energy stars. Figure 5 illustrates these results.

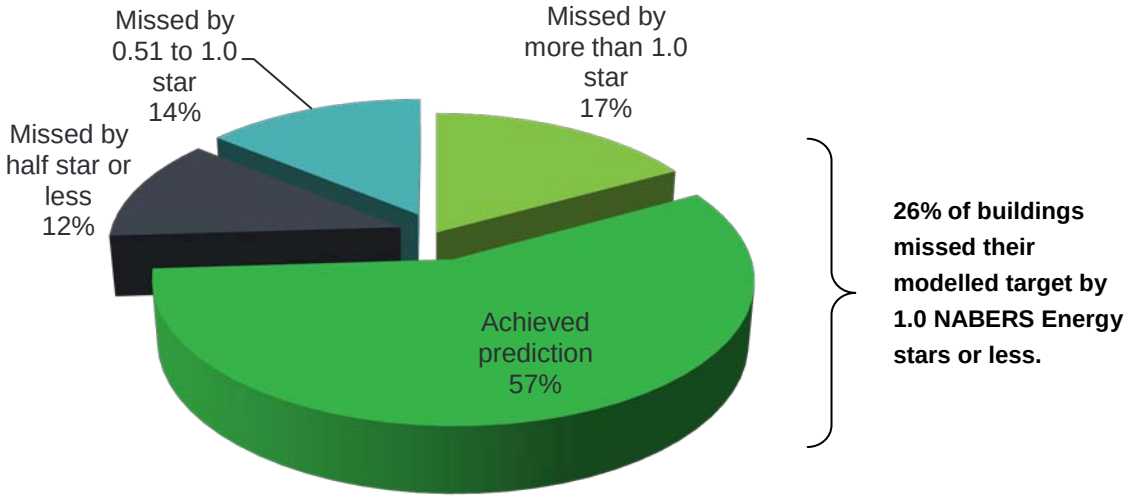


Figure 5 - Buildings within 1.0 NABERS Energy stars of predicted performance

Further analysis was carried out to identify how close these 'underperforming' buildings were to achieving modelled performance, as illustrated in Figure 6. A comparison between predicted 'normalised emissions' (kgCO2-e/m2/annum) and actual 'benchmarking factors' for all buildings that have not achieved the predicted NABERS Energy star level was done.

As 'benchmarking factors' vary per state/territory in NABERS Energy (NABERS 2010), the data presented in Figure 6 has been standardised to illustrate national results. Specifically, the standardisation was calculated by using each state/territory's 0.5 NABERS Energy 'benchmarking factor' increment to compare it to the difference between the predicted 'normalised emissions' and the actual 'benchmarking factor' achieved.

For example, the 0.5 star NABERS Energy 'benchmarking factor' increment in NSW is 16 (NABERS 2010). Therefore, where a building located in NSW misses the predicted greenhouse gas target by 18, the standardised NABERS Energy figure used in the comparison in Figure 6 would be 0.56 stars [(18*0.5)/16]. This is not an official NABERS Energy result, but rather a way in which these results can be compared for the purposes of this analysis.

The results of the analysis below indicate that most of the buildings (60%) that have not achieved predicted 'normalised emissions' targets, are within 1.0 NABERS Energy star of their predicted greenhouse gas performance. Conversely, 17% of the total sample of Green Star buildings has missed their predicted 'normalised emissions' target by more than 1.0 NABERS Energy star as shown below in Figure 6.

This gap of 1.0-star NABERS Energy or less is a very telling figure, particularly when taking into consideration independent research carried out by the University of Sydney's Warren Centre for Advanced Engineering. The Warren Centre's Low Energy High Rise Building (LEHR) Research Study results (Warren Centre 2009), indicated that greenhouse gas performance improvements can be achieved by managing buildings better and educating facilities managers about energy efficiency.

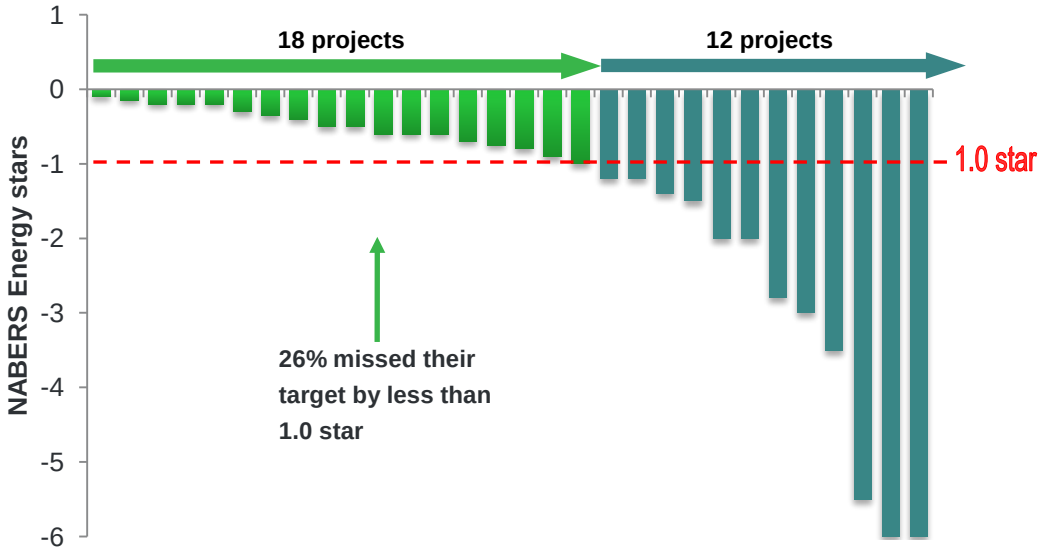


Figure 6 - Difference between predicted 'normalised emissions' and actual 'benchmarking factor', represented in NABERS Energy stars equivalent.

The Warren Centre's report concluded that building management and the level of energy efficiency education of building managers can strongly affect NABERS Energy rating results. Specifically, gains of 1.3 stars were realised where the building manager reported a higher level of energy efficiency knowledge, while gains of 0.9 stars were found when building, asset and portfolio manager all felt able to affect efficiency (Warren Centre 2009).

Based on the outcomes from the LEHR Study Report, Figure 7 illustrates the results to the same 'Predicted vs. Actual' analysis, this time setting the gap to 1.3 stars. In this second scenario 20 of the 30 underperforming buildings are within 1.3 stars of their predicted NABERS Energy rating, hence, less than 15% of the projects fall short by more than 1.3 stars. This is very positive considering the Warren Centre's findings; if several management and operation aspects have the potential to improve a building's performance by as much as 1.3 NABERS Energy stars, a significant proportion (two-thirds) of these underperforming buildings could achieve their energy target by improving management and operational practices.

Figure 7 - Difference between predicted 'normalised emissions' and actual

In summary, more than half of the sample achieved their predicted target (57%) and an additional 26% of projects are within 1.0 NABERS Energy star of their predicted greenhouse gas performance. Therefore, 83% of all Green Star projects analysed achieved their modelled greenhouse gas performance or are within 1.0 stars of their predicted NABERS Energy rating. Seventeen percent (17%) of the total sample did not achieve their predicted goal by more than 1.0 NABERS Energy stars.

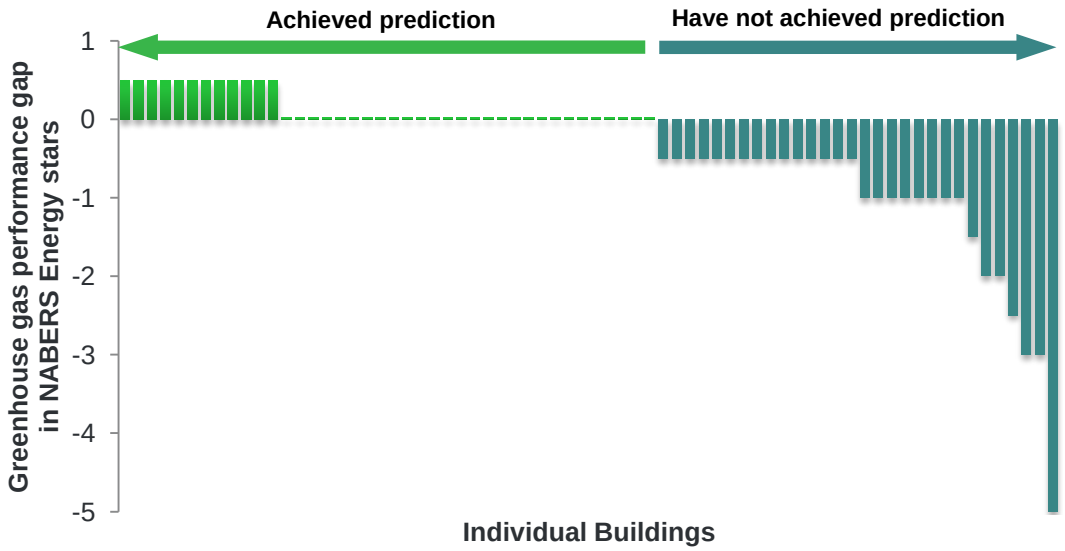


Figure 8 - Difference between predicted 'normalised emissions' and actual 'benchmarking factor', represented in NABERS Energy stars equivalent (all buildings)

3.4 Relationship between NABERS Energy and NABERS Water results

Almost half (34 of 70) of the Green Star certified office buildings in the sample had a valid NABERS Water rating available, in addition to a valid NABERS Energy rating. For these projects, an analysis of the relationship between actual greenhouse gas performance (NABERS Energy) and actual potable water performance (NABERS Water) was carried out. This analysis resulted in encouraging results, with Green Star certified office buildings achieving an average (mean) of 4.2-star NABERS Water rating, with all but one building achieving at least a 3.0-star NABERS Water result.

Green Star – Office certified buildings	Sample size	Modeled Mean	Actual Mean
Valid NABERS Energy Certificates	70	4.9 Stars	4.5 Stars
Valid NABERS Water Certificates	34	N/A	4.2 Stars

Table 3 - Sample summary

In addition to that, a mean sample t-test was conducted to test whether the average NABERS Water results obtained by Green Star certified buildings (4.2 stars) differs significantly from the average NABERS Water results for all office buildings of 3.0 stars (NABERS n.d.4). The mean sample t-test demonstrated that the NABERS Water mean for Green Star certified buildings is significantly higher in statistical terms, with a 99% confidence (t=8.256, sig. (2-tailed)=0.00).

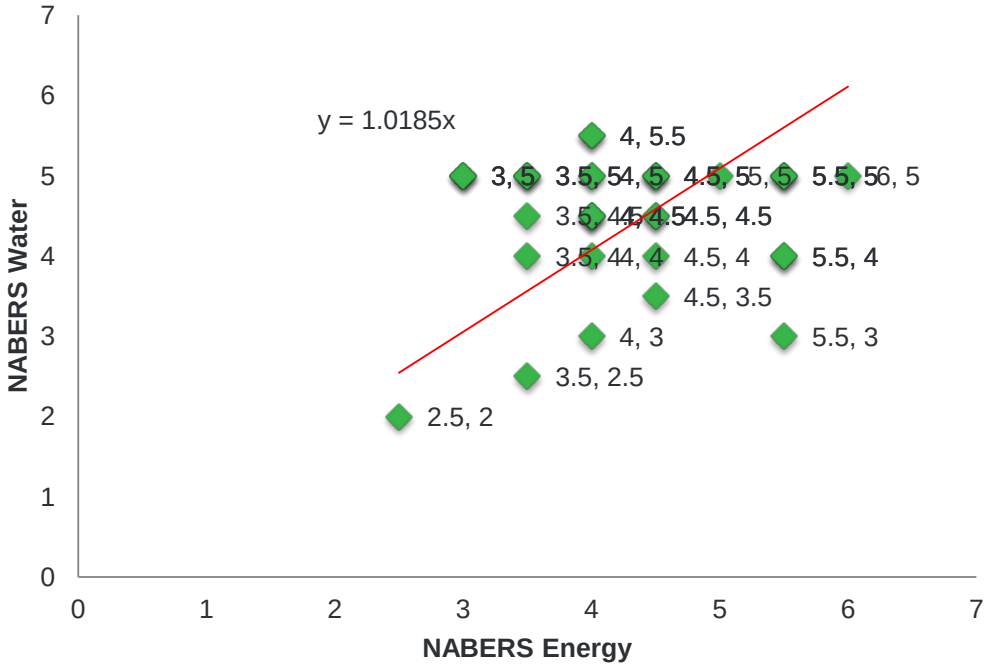
The analysis of the relationship between energy and water efficiency indicates that, the majority of Green Star certified buildings that have achieved above average greenhouse gas performance (4.0 NABERS Energy and above) have also achieved above average potable water performance (3.5 NABERS Water and above).

However, while most Green Star certified buildings have achieved above average actual performance in energy and in water, there does not seem to be a clear relationship between the numerical results. This means that a 5.0-star NABERS Energy result does not necessarily yield a 5.0-star NABERS Water result within the sample analysed.

NAB Water Ratings	NABERS Energy								
	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	Total
2.5	1								1
3.0							3		3
3.5		1			1	1	3		6
4.0			1		1	3	2	2	9
4.5				1	1	2	3		7
5.0							1		1
5.5			1		2		3		6
6.0							1		1
Total	1	1	2	1	5	6	16	2	34

Table 4 - Relationship between NABERS Energy and NABERS Water ratings for sample

When cross-referencing the results of actual greenhouse gas performance with actual potable water performance results, a positive relationship was found as Figure 9 illustrates. This is true where NABERS Water results are the independent variable and NABERS Energy results are the dependent variables (i.e. observed results) and vice-versa, as shown in Figures 9 and 10. The scatter plot analysis demonstrates that, due to the positive relationship observed, as actual NABERS Energy scores increase actual NABERS Water scores also increase.



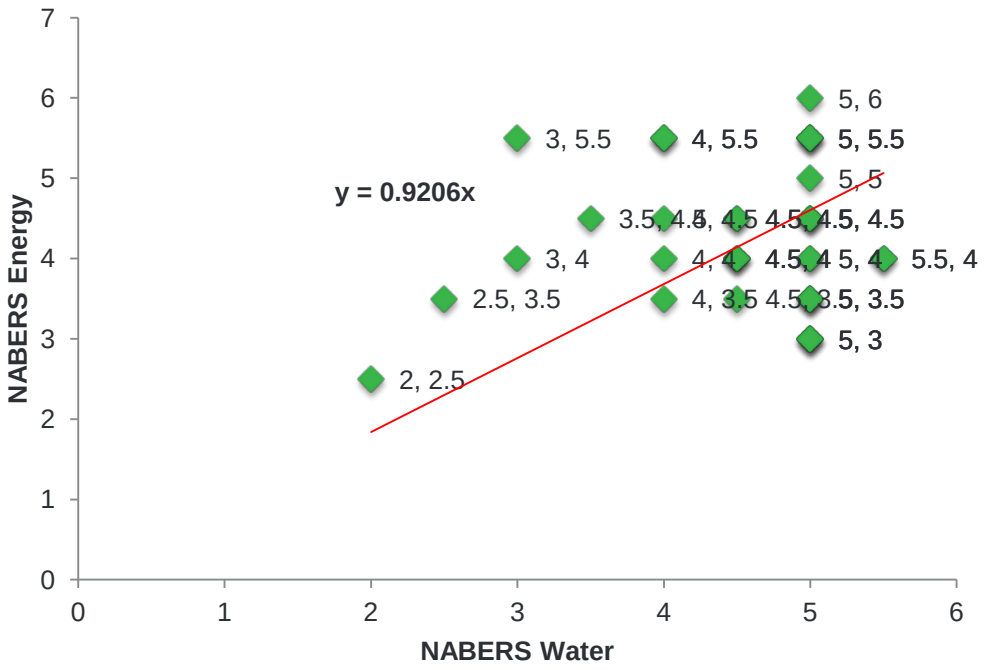


Figure 10 - Scatter plot analysis: NABERS Energy vs. NABERS Water

4. Conclusions

A. The majority of Green Star certified buildings (83%) that have a valid NABERS Energy result, achieved their modelled 'Greenhouse Gas Credit' performance (57%) or are within 1.0 star of their predicted NABERS Energy rating (26%).

B. Within the 43% of buildings that do not achieve their greenhouse gas performance, nearly two-thirds (18 out of 30) miss their predicted target by 1.0 NABERS Energy star or less. This group of buildings is likely to achieve their modelled performance with improved management and operational practices.

C. There is a positive relationship between modelled and actual greenhouse gas performance, meaning as modelled performance increases, so does actual performance.

D. The conclusions outlined in A., B. and C. do not support the initial assumption that 'modelled greenhouse gas performance does not relate to actual greenhouse gas performance in operations'.

E. There is a positive relationship between actual NABERS Energy results and actual NABERS Water results. This is true regardless of which measure is used as the independent variable, meaning as NABERS Energy rating results increase, so do NABERS Water rating results.

F. The conclusions outlined in E. do not support the initial assumption that 'increased levels of greenhouse gas efficiency in buildings are only achievable to the detriment of potable water performance'.

5. Acknowledgments

We would like to acknowledge the support and contributions of building owners, project teams and all other professionals involved in Green Star certified projects over the years.

We would also like to acknowledge the National Administrators of the NABERS program for making the NABERS Energy and NABERS Water results used in this analysis publically available on their website

We would like to thank the GBCA and its senior management for encouraging and supporting the research into the topics presented in this report.

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7. Appendix

The following is a list of all the data used to produce this report. Any information that could be used to identify individual buildings has been removed to maintain the anonymity of the data.

#	Green Star - Office rating	V.*	Green Star rating achieved	Predicted Greenhouse Gas Emissions (kgCO2-e/m2/annum)	Predicted NABERS Energy results (stars)	Actual NABERS Energy results (no GreenPower)	Actual 'benchmarking factor' (formerly normalised emissions)	Actual NABERS Water results (without ESRW*)
1	Design	1	5	88	4.5	4.5	77	NP
2	Design	2	5	76	5	4	94	5.5
3	Design	2	5	58	5	4.5	81	NP
4	As Built	1	4	88	4.5	5	68	NP
5	As Built	2	4	123	4.5	4.5	112	4
6	As Built	2	4	62	5	4.5	69	4
7	Design	2	5	52	5.0 + 20%	5.5	NA	4
8	Design	2	4	69	5	4.5	82	4
9	Design	2	4	70	5	4.5	75	4.5
10	As Built	2	5	100	4.5	4.5	107	NP
11	As Built	2	6	52	5.0 + 20%	4.5	79	NP
12	Design	2	4	71	5	5	67	NP
13	Design	2	5	71	4.5	5	57	3.5
14	As Built	2	6	38	5.0 + 40%	5	62	5
15	Design	2	5	56	5.0 + 40%	5	64	3.5
16	Design	2	5	73	5	2.5	268	NP
17	Design	2	4	87	4	3.5	109	4.5

18	Design	1	6	78	5.0 + 20%	5	165	6
19	Design	2	4	112	4.5	5	100	4.5
20	Design	2	5	63	5	2	225	NP
21	Design	2	6	44	5.0 + 40%	5.5	NA	NP
22	As Built	2	5	55	5.0 + 20%	5	62	5.5
23	Design	2	4	61	5	5.5	NA	4
24	Design	2	4	58	5.0 + 20%	5	73	4
25	Design	2	6	42	5.0 + 40%	3.5	95	NP
26	As Built	2	5	58	5.0 + 20%	4	94	4
27	Design	2	4	56	5.0 + 20%	5.5	NA	NP
28	Design	2	5	98	5	4.5	109	NP
29	Design	2	5	110	4.5	4.5	109	4.5
30	Design	2	4	101	4	3	179	5.5
31	As Built	2	5	57	5.0 + 20%	5	44	NP
32	Design	2	5	64	5	5	65	NP
33	As Built	2	5	64	5	5	69	4.5
34	As Built	2	5	97	4.5	5	97	5.5
35	As Built	2	5	53	5.0 + 20%	5	73	NP
36	Design	2	4	73	4.5	4	91	NP
37	As Built	2	6	25	5.0 + 60%	5.5	NA	NP
38	Design	2	4	81	4.5	5	71	5.5
39	As Built	2	5	59	5.0 + 20%	5.5	NA	NP
40	Design	2	4	69	4.5	4.5	61	NP

41	As Built	2	4	64	5	0	215	NP
42	Design	2	4	67	5	4	85	NP
43	As Built	2	4	71	5	4.5	87	NP
44	As Built	2	5	58	5.0 + 20%	5	70	NP
45	Design	2	4	58	5	4.5	79	NP
46	As Built	2	5	90	5.0 + 20%	5.5	NA	NP
47	As Built	3	5	35	5.0 + 20%	4	94	5.5
48	As Built	2	5	40	4.5	3	174	4
49	Design	2	5	71	5	2	305	2.5
50	As Built	2	5	98	5	4	128	4.5
51	Design	3	5	21	5	5.5	NA	NP
52	As Built	2	5	47	5.0 + 20%	5	71	3
53	As Built	2	5	56	5.0 + 20%	5	68	3
54	As Built	1	5	57	5.0 + 20%	4.5	80	3.5
55	As Built	2	5	110	4.5	5	97	NP
56	As Built	2	5	69	5	4.5	80	NP
57	As Built	2	5	54	5.0 + 20%	5	59	3.5
58	As Built	2	6	61	5.0 + 40%	5.5	NA	NP
59	As Built	2	4	69	5	5	69	NP
60	As Built	2	4	74	4.5	4.5	87	NP
61	As Built	2	5	98	5	4	141	NP
62	Design	3	5	74	5	4	124	3.5
63	As Built	2	4	76	5.0 + 20%	5	44	NP

64	Design	2	5	57	5	5	69	NP
65	Design	2	5	61	5	5	67	3
66	Design	1	4.5	87	4.5	4.5	81	NP
67	As Built	2	5	63	5	5	68	4
68	Design	2	2.5	84	4.5	2.5	118	3.5
69	As Built	3	5	71	5	5	63	NP
70	As Built	2	5	79	5.0 + 20%	5	101	4.5

Legend

V. – Green Star - Office rating tool version.

ESRW – Externally supplied recycled water.

NA – 'Not applicable': there is no 'benchmarking factor' provided by the NABERS program beyond 5.0 stars. Ratings are calculated based on a 25% improvement over the 5.0 star 'benchmarking factor' for each 0.5 star increment above 5.0 stars.

NP – 'Nor pursued': this is to indicate that a particular building has not pursued a NABERS Water rating, therefore no result is available.