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Mind the Gap: Predicted vs. Actual Performance of Green Buildings

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Figure 1: Melbourne's Council House 2 (CH2), a 6-star Green Star rated building with a post-occupancy evaluation to back up its design rating.
(Image: Wikimedia Commons)

ABSTRACT

This paper reviews the major North American and Australian sustainability rating tools to determine how they measure building energy performance. It then reviews the major building energy simulation software packages. The paper then details some of the literature surrounding predicted vs. actual energy performance in green buildings, and concludes with an argument for a more performance-orientated ratings regime.

Introduction

Over the past decade, the mainstream green building movement has become dominated by green building councils. Established by property owners, construction companies, architects, engineers and other allied building sector professionals, these organisations have developed sustainability rating tools to help guide, assess and benchmark the design of green buildings.

Superior performance in regard to the reduction in energy use and greenhouse gas emissions over standard buildings is a major requirement of these tools. However, many of the tools allow projects to be hailed as successes before they are completed and their actual performance is known. Inevitably, some are found wanting.

As this paper's review of North American and Australian design-focused sustainability rating tools shows, there is no requirement for a building's predicted energy performance to be maintained or verified against its actual performance for it to retain a rating. For example, the Canada Green Building Council's LEED building rating system awards optional credit points for the measurement and verification of a building's actual energy performance. But as of June 2010, only one quarter of the 156 Canadian LEED New Construction (NC) certified projects were awarded points for achieving this credit (CaGBC 2010). Furthermore, when a project is awarded this credit there is no penalty if it should fail to deliver on its predicted energy performance.

If unchecked, this state of affairs will almost certainly erode public confidence in the green building industry. To prevent that from occurring, the industry needs to take stock of its current tools and processes, to better hold building owners and designers to account, and to head off accusations of greenwashing.*

Rating Tools

Around the world, a growing number of rating tools are being used to measure and rank the environmental performance of buildings. Energy use plays a significant role in many of these tools. The following is a survey of the tools in use in North America and Australia.

LEED-NC (United States)

The United States Green Building Council (USGBC; www.usgbc.org) currently has a suite of LEED rating tools that cover different project types and phases, from design and construction to operation. The primary design-focused rating tool for new buildings is LEED 2009 for New Construction and Major Renovations (LEED-NC). This tool has three options for demonstrating compliance with the minimum energy requirements:

Option 1 involves whole-of-building energy modelling to show performance relative to a baseline building performance rating under the building energy standard ANSI/ASHRAE/IESNA 90.1-2007.

Option 2 requires designing the building in compliance with one of the applicable ASHRAE Advanced Energy Design Guides. This option is limited to offices and retail spaces under 20,000 sq ft (1,860 m2) or warehouses less than 50,000 sq ft (4,650 m2).

Option 3 is to demonstrate compliance with the Advanced Buildings Core Performance Guide. This option is limited to buildings under 100,000 sq ft (9,280 m2). Health care, laboratory and warehouse buildings are unable to use this option.

In addition to achieving the minimum energy performance requirements projects are able to awarded credit points if they can demonstrate improved predicted energy performance under the Credit EA1: Optimize Energy Performance. In the case of projects using the ASHRAE/IESNA 90.1-2007 methodology, up to 19 credit points are available.

A prerequisite of LEED-NC certification is that building energy systems are inspected during commissioning to verify that they are installed and calibrated to perform as designed.

In 2009, USGBC introduced a requirement for certification that projects must agree to provide actual whole building energy use data to USGBC for a period of 5 years after completion. USGBC proposes to use the data to improve the LEED system but does not require projects that do not perform as predicted to take corrective measures to improve their actual energy performance.

LEED-EB (United States)

In addition to LEED-NC, the USGBC also has the LEED for Existing Buildings: Operation and Maintenance (LEED-EB) rating tool. This also allows existing buildings to become LEED certified. Once a building is certified under LEED-EB it must be recertified at least every five years to retain the currency of its certification. Unlike the design-focused LEED rating tools, the energy performance credits of LEED-EB are based on a building's actual energy consumption, using at least 12 months of utility bills. USGBC encourages buildings certified under LEED-NC to seek re-certification under LEED-EB but currently this is not mandatory. The Energy Star rating tool (refer below) or one of the other specified calculation methods is used to confirm compliance. If Energy Star (see below) is

*'Some Buildings Not Living Up to Green Label', *New York Times*, 30 August 2009 (www.nytimes.com/2009/08/31/science/earth/31leed.html)

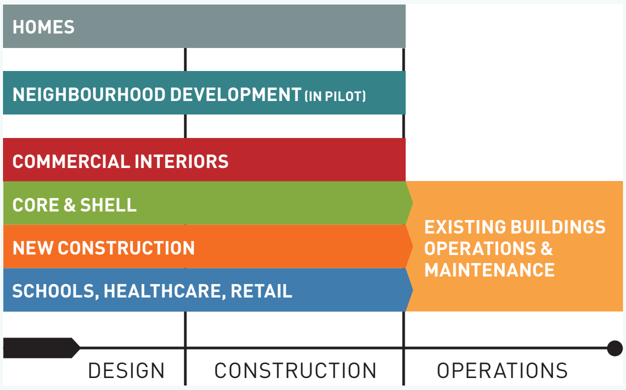

Figure 2: USGBC LEED rating tools (Source: USGBC, 2010)

used, an energy performance rating of at least 69 must be achieved for a building to be certified. Interestingly, that score of 69 means that a LEED-EB certified building is not necessarily an Energy Star building.

Energy Star for Buildings (United States)

The Energy Star program (www.energystar.gov), developed by the US Environmental Protection Agency and US Department of Energy, was introduced in 1992 to promote and identify energy-efficient products. It has now has over 50 different categories, with Energy Star Buildings (ES-B) being added in 1995. In 1999, ES-B was extended to commercial buildings and now covers a wide range of building types. ES-B is a voluntary program and uses information about a building including actual energy usage, usually in the form of utility bills, to rank the building's energy performance against those of similar types of buildings within the United States. Based on this information a score between 1 and 100 is determined. A building is eligible for an Energy Star if it achieves a score of at least 75 and the results are verified by a Professional Engineer or a Registered Architect. As the score is effectively a ranking, a score of 75 places a building within the top 25 per cent of energy efficient buildings of a similar type.

Energy Star also offers a Designed to Earn the Energy Star (DEES) label, which means that means that a building has been assessed as being designed to achieve an Energy Star rating of at least 75. Energy Star also has a tool called Target Finder with enables architects and engineers to determine the predicted energy performance that must be achieved if the project is to qualify for a DEES.

LEED Canada Rating Tools

The Canada Green Building Council (CaGBC; www.cagbc.org) released its first LEED rating tool, LEED Canada NC-1.0, in 2004. The tool was based upon USGBC's LEED for New Construction rating tool but adapted for Canada's climate and building requirements. The current version of the rating tool for new buildings is LEED Canada for New Construction and Major Renovations 2009 (LEED Canada NC 2009). The energy performance requirements are contained in the Energy and Atmosphere (EA) category of the tool. As a prerequisite for a building to be certified under LEED Canada NC 2009 it must be designed to achieve a minimum predicted energy performance.

There are a number of different options for demonstrating compliance with the minimum performance requirements including designing the building in accordance with the applicable ASHRAE Advanced Energy Guides. Another option is to demonstrate a 23 per cent cost improvement in design energy performance relative to a reference building that is designed to comply with Canada's Model National Energy Code for Buildings 1997 (MNECB). Alternatively the building can be designed to achieve a 10 per cent improvement in design energy cost relative to a reference building designed to ANSI/ASHRAE/IESNA 90.1-2007. In both cases the predicted energy performance is determined using whole-of-building computer modelling.

The credit EA 1: Optimize Energy Performance awards points for improvement of the predicted energy performance above the requirements of EA Prerequisite 2. However, for both the prerequisite and EA Credit 1 there is no requirement for verification of the predicted performance once the building is operational. Under EA Credit 5: Measurement and Verification, 3 credit points are awarded developing a monitoring and verification plan for a project that runs for at least one year after completion of the project. Achieving this credit is optional, and while there is a requirement for developing a corrective action plan there are no penalties if a project does not perform as designed.

CaGBC also have a rating tool for existing buildings, LEED Canada for Existing Buildings: Operations and Maintenance 2009, which is based on the USGBC rating tool, LEED-EB. The minimum energy performance requirements and assessment methodologies are virtually identical to those of LEED-EB except that that the Canadian tool specifically mentions that building eligible to be assessed using Energy Star do not require an official Energy Star label.

EnerGuide (Canada)

Canada has developed an energy use rating system called EnerGuide and it shows the overall and relative performance of various products including appliances, vehicles, heating and cooling equipment (http://oee.nrcan.gc.ca/energuide/home.cfm). There is also an EnerGuide rating system for new and existing houses which gives a ranking out of 100 based on a range of criteria including overall energy performance. Since 2006, Natural Resources Canada (NRCan) has been developing a Commercial and Industrial Building system based largely on the US Energy Star system. Piloting of the rating scheme has been undertaken on over 300 buildings across Canada with the full scheme scheduled to be launched in 2012 or 2013 (NRCan 2009).

Green Star Rating Tools (Australia)

The Green Building Council of Australia (GBCA; www.gbca.org.au) developed the Green Star sustainability rating systems using LEED and the British rating sustainability system, Building Research Establishment's Environmental Assessment Method (BREEAM) as the guiding models. Since the first Green Star tool was released in 2003, GBCA have expanded the system into a suite of rating tools that cover a range of different project types. The energy performance of projects is assessed under the Energy category and achieving a minimum predicted energy performance requirement (Credit ENE) is one of the preconditions of a project becoming Green Star certified.

Green Star Office Design V3 (Green Star Office) is the rating tool currently used to assess the design of new commercial office projects. The minimum energy performance requirement for this tool is based on a project's predicted greenhouse gas emissions from its energy consumption not exceeding 110 $kgCO_2/m^2$/annum (GBCA1 2010). The predicted energy consumption is determined by computer modelling using the NABERS Energy Guide to Building Energy Estimation (refer below). The estimated energy consumption including the fuel types used are then converted into estimated greenhouse gas emissions using either the Green Star Energy Calculator or using the NABERS system. It is worth noting that unlike LEED-NC, the energy performance for Green Star Office is for the base building only and not the whole building.

Up to 20 points are awarded under Greenhouse Gas Emissions (Credit ENE-1) for reduced energy related greenhouse gas (i.e. improved energy performance) above the minimum requirement. While further credit points are offered for installing sub metering (ENE-2) and peak load reduction equipment (ENE-5), there is no requirement for a building's actual energy performance to be reviewed and compared back to its predicted performance.

Shortly after releasing the first version of Green Star Office Design, GBCA released a pilot tool for existing buildings, Green Star – Office Existing Building. This pilot tool which allowed use of a 'Predicted Energy Potential Method' using computer simulation as an alternative to energy performance assessment using NABERS. However, in August 2010 GBCA (GBCA2 2010) announced that it would not be continuing with the current version of the pilot tool and would be exploring a new approach to addressing existing buildings. It was expected that it would be at least six months before a new pilot tool is released.

NABERS Energy (Australia)

The National Australian Built Environment Rating Scheme (NABERS; www.nabers.com.au) is used to rate the operational performance of buildings in a number of areas including energy and water consumption. Currently NABERS covers offices, homes, hotels and large retail facilities, and it is proposed to be expanded to include hospitals, schools and data centres (DECCW 2010). The energy rating component of NABERS was first released in 1998 as Australian Building Greenhouse Rating (ABGR) and was renamed as NABERS Energy in May 2008.

In the case of office buildings, their energy performance is based on their annual energy related greenhouse gas emissions. NABERS Energy can be used to rate whole buildings, base building and/or tenancies. Information including utility bills from the previous 12 months of operation, floor area, hours of operation, number of occupants and fuel sources is used to determine a star rating. A maximum of 5 stars can be awarded with 2 stars representing average building performance. While it is possible to self assess the performance of an office using a tool on the NABERS website, an official rating can only be obtained through the use of an accredited NABERS assessor.

Buildings being designed can also qualify for a NABERS Energy star rating if the building owner enters into NABERS Commitment Agreement. This binds the owner to achieving an agreed rating once the building is operational. The agreed rating is based on computer modelling using the NABERS Energy Guide to Building Energy Estimation. If the agreed rating is not achieved the owner commits to undertaking an 12-month building review with the NABERS administering body to improve the energy performance of the building.

In mid 2010, the Australian Government made it a mandatory requirement that the energy efficiency of commercial offices over 2,000 m2 had to be disclosed at the time of their sale or lease. Commercial Building Disclosure (www.cbd.gov.au) as the program is known, applies across Australia and uses NABERS Energy as the system by which the energy efficiency of a office building or space is determined.

Transnational Ventures

In early 2009 representatives of the USGBC, BREEAM and GBCA signed a memorandum of understanding to develop a common system of measuring and reporting

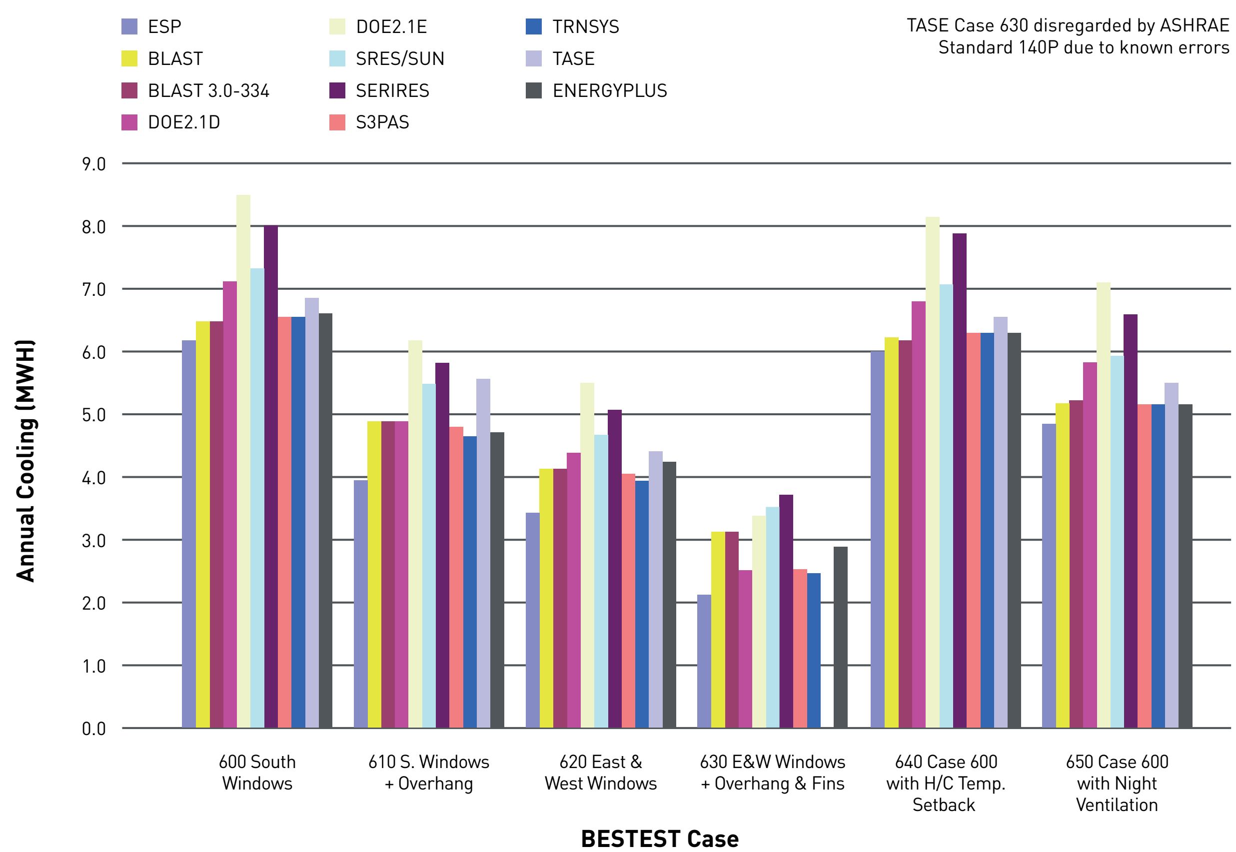

Figure 3: BESTEST results for a range of energy simulation programs
(Source: Witte et al. 2001)

building energy use and greenhouse gas emissions. However, further information on the proposed system has not been made publicly available to date.

At the United Nations Climate Change Conference 2009 (COP15) held in Copenhagen, the United Nations Environment Programme – Sustainable Buildings and Climate Initiative (UNEP-SBCI) released a report (UNEP-SBCI 2009) on its work on developing a common system to measure the energy use and carbon emissions from buildings. Known as the Common Carbon Metric the system aims to allow buildings from across world to measure, report and benchmark their relative energy use performance. UNEP-SBCI is currently developing a methodology to measure performance and plans to pilot the methodology across a range of project types and countries throughout 2010 and 2011.

Building Energy Simulation Software

Building energy simulation software is commonly used by mechanical engineers, architects and other building professionals to predict the energy performance of buildings and help size air conditioning and other building plant. This software takes large amounts of information about the building, its location, construction, operating schedules and prevailing weather and processes it to give a prediction of how the building will perform when it has been built.

A review of the US Department of Energy's Building Energy Software Tools Directory (www.eere.energy.gov) showed that it has information on over 340 different software programs for "evaluating energy efficiency, renewable energy, and sustainability in buildings". While not all of these programs are used for whole-of-building energy modelling, a large number of them are and each has their own different characteristics and capabilities.

A report released in 2006 (Crawley et. al. 2006) reviewed 20 of the most widely building energy simulation programs including:

- DOE 2.1E
- Energy 10
- eQUEST
- BLAST
- ECOTECT

The report determined that users may be limiting themselves by relying on only one program and that it may be better to use a range of programs depending on what stage of the design process the modelling is carried out.

In order to standardise software and give users confidence in the results of the many different simulation programs, the International Energy Agency (IEA) developed the Building Energy Simulation TEST (BESTEST) protocols. BESTEST is used by many building codes and rating tools as one of the acceptance criteria that a simulation program must pass in order to be approved for use. The protocols include testing new and updated versions of software to determine how they perform modelling a standardised fictional building with a varying of features such as different overhangs, windows and building fabric. The results are then reviewed and compared with results of other modelling programs and if they fall within an acceptable range, the program is deemed to have passed. The range can be up to +/-20 percent. Figure 3 shows the range of results for some commonly used programs.

As well as problems inherent to particular programs, building energy simulation programs also suffer from the same issue as all other computer programs in that the results are only as good as the information that is entered into the program (i.e. 'garbage in garbage out').

The prevailing weather used for the modelling is one area that can lead to differences between predicted and actual energy use. While many of the programs use hourly weather data for a whole year to increase the accuracy of their calculations, the data itself may not be that accurate. In the case of the Canada, the weather data commonly used is Canadian Weather for Energy Calculations (CWEC) which has hourly weather data for 72 locations across Canada. The weather data is based on weather information collected from 1953 to 1995. Two possible reasons for inaccuracies come to mind. The first is that prevailing climatic conditions can change significantly within short distances; consequently the nearest location for which data is available may not represent a building's actual prevailing weather conditions. The second is that while the data is based on over 40 years of records it may now be less accurate due to the impact of global warming on climate.

The person undertaking the modelling can also affect the results of the simulation. Personal experience by the author has shown that different people modelling the same building with the same simulation program can achieve widely different results. This is particularly the case if the users are inexperienced or unfamiliar with the features of a program.

In addition to all of the above, the actual construction of the building may vary from what have been modelled.

How Green Certified Buildings are Performing

There are an increasing number of studies and reports that have prepared on the performance of green buildings, with many of those reports focusing on actual energy use compared to predicted use. This section is a review of some of these reports to see what they have found and to determine whether there any lessons that can be learned.

Lessons Learned from Case Studies of Six High-Performance Buildings

The Buildings and Thermal Systems Centre at NREL www.nrel.gov/buildings studied six green buildings in detail to review their performance, understand what lessons could be learned and establish a set of best-practice guidelines (Torcellini et al. 2006). One of the major drivers of the study was to help the US Department of Energy achieve its goal of developing the knowledge and technology to deliver (Commercial) Zero Energy Buildings by 2025. The report is highly detailed and presents many useful and insightful findings. In regard to predicted verses actual energy use the report found that all six buildings used more energy than predicted. Some of the reasons given for this disparity were:

- controls and energy saving systems not working together properly
- daylighting strategies didn't deliver expected energy savings
- installed insulation was less effective than the modelled insulation
- appliance and other plug loads were higher than expected
- the occupants didn't use the building and energy saving equipment as predicted

Despite the difference between predicted and actual performance the report found that the buildings that set the most aggressive energy targets delivered the best results. The report also recommended that energy use monitoring and feedback to the building operators is essential to ensure than design energy use goals are achieved.

EcoSmart Building Performance Evaluation Report

The EcoSmart Foundation, a Vancouver based not-for-profit organisation, carried out detailed assessments of the performance of six unnamed green building projects in Canada (EcoSmart 2006). The assessments were undertaken in 2006 and utilised an evaluation protocol developed by Stantec Consulting.

Building A involved the refit of the top three floors of an existing 13-storey building. The report found that while no energy modelling took place before the refit, the building as a whole used 30 percent less energy than the average. However, as no sub metering was installed it could not be determined whether the energy performance was due to the refit, management practices or the design of the original building. Building B was found to use much more energy than predicted but it still used eight percent less than average buildings of its type. Reasons given were; longer than predicted operating hours, excessive amounts of outside air being introduced into the building and poor communication between the design team and building operators.

Energy modelling for Building C indicated that it would use 60 percent less than the MNECB however the actual performance of the building could not be assessed as no records were taken from the analogue meters installed in the building. It was a similar case for Building D which had high performance goals which could not be verified as no monitoring or metering equipment was installed.

Building E was found to use much more energy than predicted but still about 40 percent less than the average for its location and building type. The reasons given for the difference between predicted and actual performance were changed hours of operation, greater than predicted loads from computers and issues with equipment and plant.

Building F used much more energy than predicted but less than a comparable adjacent building. Much longer actual operating hours than predicted was given as the reason for the difference.

The Energy Performance of LEED Buildings

In 2007 the USGBC commissioned the New Buildings Institute (www.newbuildings.org), to undertake an extensive study and evaluation of the energy performance of 121 buildings certified under LEED for New Construction. The final report, released in 2008, found that 30 percent of the buildings performed better than predicted, 25 percent of buildings worse than predicted and high-energy-use buildings such as laboratories were using up to 100 percent more energy than predicted. Encouragingly they did find that, on average, LEED-certified buildings were 25 to 30 per cent more efficient than buildings that were not certified. The authors concluded that there needs to be better systems and protocols put in place to monitor, verify, and encourage improvement in both actual and simulated energy performance.

Australian Building Codes Board: Class 5 Benchmarking

In 2004, Dr Paul Bannister of Exergy Australia prepared a report (Bannister 2004) to assist the Australian Building Codes Board (ABCB) in its deliberations on setting minimum energy targets for inclusion in the

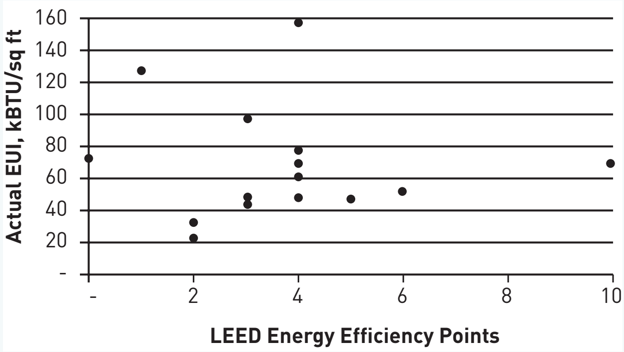

Figure 4: Comparisons of theoretical and actual building performance

(Source: Bannister 2006)

2006 version of the Building Code of Australia (BCA). One section of the report deals with the relationship between predicted and actual energy performance by comparing the energy performance results of 66 actual building against two theoretical buildings modelled with a variety of energy saving features and equipment. The report found that for average-to-well designed buildings, the simulated performance was always better than actual performance. Further on in the report it deals with the setting of energy performance benchmarks and describes the advantages and disadvantages of absolute and relative performance benchmarking. The energy performance provisions (Part J) of BCA 2006 were released with both absolute and relative energy performance benchmarks. However, the absolute benchmark provisions were removed in 2008 and verification of energy performance under the BCA is now undertaken only using relative benchmarks.

Why Good Buildings Go Bad While Some Are Just Born That Way

This report (Bannister 2006) focuses on the reasons why buildings don't achieve their predicted energy performance and what can be done to correct this. The report determined that some of the primary reasons for the gap in performance are:

- HVAC controls not being programmed or working properly
- lack of commissioning
- too much complexity in building services and controls
- poor construction and installation
- poor quality equipment
- use of net leases where tenants are not responsible for paying the utility bills

A Comparative Study of Building Energy Performance Assessment between LEED, BREEAM and Green Star

Integrated Environmental Solutions, the developers of IESVE - a building performance and energy simulation program, published a report in 2009 (Roderick et al. 2009) that assessed the predicted energy performance of a single case study building using the energy performance assessment methods of LEED-NC V2.2, BREEAM Offices 2008 and Green Star Office Design V3. The report found that the predicted energy performance of the case study building varied significantly between the different assessment methods. In the case of LEED, the building failed to achieve the required minimum predicted energy performance and therefore would not be eligible for LEED certification. When assessed using the Green Star methodology the building achieved 11 out of the 20 possible credit points for energy performance. The primary reason for this disparity is that LEED requires the whole building energy performance to be modelled while Green Star assesses base building performance. The report concludes that energy ratings are highly dependant on the assessment methodology used and that further work is required to allow comparison of buildings assessed under the different rating tools.

Conclusions & Recommendations

It is apparent from the case study review that there is a need for the ongoing measurement of buildings' energy use, without which it is impossible to know how a building is performing. Detailed monitoring of different areas and equipment is to be preferred, but even rudimentary metering is better than none.

Users and operators of a building must be involved in its design. This will reduce the incidence of faulty operating assumptions and help ensure the building is operated the way it was designed to. A building's systems also need to be made as simple and robust as possible, to ensure its ease of operation and maintenance.

Building owners and operators need better incentives – such as time-limited certification or biennial recertification – to maintain and operate their building to its performance goals. Further, it should be a precondition of certification that a building's predicted and actual energy performance are compared through detailed building monitoring.

It is vital that the sustainability rating tools continue to be developed and refined, particularly in the area of energy use. Real performance information, together with the reasons for any deviation, must be given to the building owner, operator, designers and relevant green building rating organisation.

Finally, design-focused rating tools should be better aligned with the actual energy-use rating tools, such as Energy Star and NABERS Energy, so that, for instance, a Green Star Office certified project would have to enter into a NABERS Commitment Agreement.

With these steps, we can begin to close the gap between the predicted and actual energy performance of green buildings. Without them, fresh charges of greenwashing by the building sector are bound to emerge.*

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