FINAL REPORT

GREEN BUILDINGS IN THE US AND CHINA: BRIDGING THE ENERGY PERFORMANCE GAP

DONALD BREN SCHOOL OF ENVIRONMENTAL SCIENCE & MANAGEMENT
UNIVERSITY OF CALIFORNIA, SANTA BARBARA

A 2012 GROUP PROJECT

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The Group Project is required of all students in the Master's of Environmental Science and Management (MESM) Program. It is a three-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

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Sarah Anderson, Advisor

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CONTENTS

ABSTRACT

The necessity for buildings designed to be environmentally responsible and resource efficient has never been higher. Globally, the built environment accounts for 39% of anthropogenic greenhouse gas emissions. As the world develops strategies to address climate change and rising energy demand, the United States and China, which account for 40% of greenhouse gas emissions, will play key roles. This study was created in collaboration with students at the Nanjing University School of the Environment in China to analyze the performance of buildings designed to be energy efficient in both countries. Operational energy demand data indicates green buildings are not meeting energy performance predictions. This failure to achieve predicted performance is commonly referred to as the performance gap. A systematic tool called Post-Occupancy Evaluation was customized for selected case studies to identify causes of the gap and inform recommendations about how it can be reduced in the future. Case-studies include green buildings on UCSB's main campus and in the Eco-Zone of Suzhou Industrial Park in Suzhou, Jiangsu Province, China. Results identify large system issues, such as heating system failures and management policies regarding computer data protection, as substantial factors contributing to the performance gap. Procedures developed in this research will enable building managers to pin-point problems and design effective solutions to help ensure buildings perform according to their credentials, thereby reducing the contribution of GHG emissions from the building sector.

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LIST OF ACRONYMS

ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers
BREEAM: Building Research Establishment Environmental Assessment Method
CBE: UC Berkeley Center for the Built Environment
CDIAC: Carbon Dioxide Information Analysis Center
DHW: domestic hot water
DOE: US Department of Energy
EBOM: Existing Buildings: Operations & Maintenance
EIP: Eco-Industrial Parks
EMO: energy management opportunities
EPC: Environmental Performance Criteria
EUI: energy use intensity
GHG: greenhouse gas
Labs21: Laboratories for the 21st Century
LEED: Leadership in Energy and Environmental Design
MSRB: Marine Science Research Building
POE: Post-Occupancy Evaluation
PROBE: Post-occupancy Review of Buildings and their Engineering
SCV: San Clemente Village
SIP: Suzhou Industrial Park
SRB: Students Resource Building
UCSB: University of California Santa Barbara
USGBC: US Green Building Council

EXECUTIVE SUMMARY

The growing awareness and necessity for buildings designed to be environmentally responsible and resource efficient has never been higher. As the world develops strategies to address climate change and rising energy demand, the built environment is a key sector to address. Specifically, emissions from the United States and China account for near 40% of total anthropogenic greenhouse gas (GHG) emissions (CDIAC 2009). There is no prospect of making significant progress in addressing climate change without finding ways for these two countries to cooperate in efforts to reduce emissions and stabilize atmospheric GHG concentrations. This study was created in collaboration with students at the Nanjing University School of the Environment in China to analyze the performance of buildings designed to be energy efficient in both countries. Empirical data indicates that buildings do not meet energy performance predictions once they are in use. The discrepancy between predicted and actual energy consumption in buildings is commonly referred to as the performance gap.

Although numerous reasons for inaccurate models exist, more research is needed to understand the impact of occupant behavior on energy performance. This study demonstrates how data obtained from Post-Occupancy Evaluation (POE) can be used to identify causes of the performance gap, and ultimately how the gap can be reduced in the future. Case studies assess four buildings at the UC Santa Barbara (UCSB) main campus and four one in the Eco-Zone of Suzhou Industrial Park in Suzhou, China. Initially, we establish the size of the performance gap for each building then use occupant surveys, walkthrough audits, and interviews with building managers and maintenance personnel to administer POE.

The performance gap exists in all four buildings at UCSB. Actual performance indicates energy consumption as high as 180% of predicted. Results from the POE pinpoint that occupant behaviors contribute limitedly to the performance gap; however, large system issues including management policies, lack of auditing, construction quality, and modeling flaws form the major parts of the gap. This research seeks to share POE findings with building modelers to improve prediction accuracy and create recommendations for building managers in both countries to actively engage occupants and maintenance personnel to maximize efficiency. These recommendations include utilization of our customized POE decision-tree by building managers and third-party consultants to efficiently identify causes of the performance gap.

INTRODUCTION

In the US and China, there are many factors contributing to climate change, but none bigger than energy consumption of the building sector. According to a report issued by the Carbon Dioxide Information Analysis Center (CDIAC) for the United Nations, the countries accounted for over 41% of annual CO2 emissions (2009). While intergovernmental negotiations aimed at strengthening global climate change agreements deteriorate, there is a growing movement of bottom up efforts to deal with GHG emissions at the local and regional levels. Initiatives of this sort identify the roots of the problem and develop strategies to tackle them. As a result, green buildings are now a major focus of attention both in China and the US.

With buildings responsible for one-third of global CO2 emissions, it is commonly agreed upon that combating climate change will inevitably rely on reducing energy consumption of buildings (Urge-Vorsatz et al., 2007). The concept of green building establishes environmentally responsible and resource efficient practices for the construction and operation of buildings. For the purposes of this research a green building is defined in the US as a building recognized by the United States Green Building Council (USGBC) as certified under the Leadership in Energy and Environmental Design (LEED) rating system. The USGBC reports buildings account for roughly 40% of CO_2 emissions in the US and this figure is even higher in increasingly populated cities (2010).

Cities and buildings are dominating the emissions profile within China's rapidly emerging economy. Chinese residents are migrating to cities at a rate the world has never seen before. The population in urban zones is expected to double from its 2000 level by 2030 and more than 2 billion square meters of buildings have been constructed annually in China since 2000 (Toth et al., 2003). GHG emissions from buildings in China are currently estimated at 25% of the country's total and this figure is expected to increase to 35% by 2020 (Long, 2005). The Chinese government recognizes the problem and is actively requiring Three Star certification for new buildings. Three Star is a rating system based on LEED and will define a green building in China in this report.

These figures indicate why low carbon development is now a major focus of attention both in China and in the US. This is especially evident in California and Jiangsu Province, which have entered into a cooperative agreement designed to encourage communication and collaboration in this realm. Our research contributes to this effort by engaging in applied research and analysis on a collaborative basis. The project is designed to contribute to international efforts aimed at assessing and reducing the gap between how a green building is predicted to perform and how it actually performs in terms of energy efficiency, the performance gap. LEED requires energy modeling to demonstrate energy efficient performance. This is demonstrated by comparing the predicted energy performance of the modeled design versus the energy intensity of a similarly modeled code-compliant building. In addition to its function for third-party verification systems like LEED, energy modeling is becoming increasingly a standard to meet basic governmental building codes. In California's Title 24 building code, compliance is demonstrated in a similar manner to LEED.

While LEED is effectively driving energy efficient design, there are growing concerns about the method of awarding energy performance based on simulation models. Researchers for the international engineering conglomerate AECOM acknowledge that "with the increasing demand for more energy efficient buildings, the construction industry is faced with the challenge to ensure that the energy efficiency predicted during the design is realized once a building is in use. There is, however, significant evidence to suggest that buildings are not performing as well as expected and initiatives such as PROBE (Post-occupancy Review of Buildings and their Engineering) and

CarbonBuzz aim to illustrate the extent of this so called 'Performance Gap'" (Menezes 2011). This gap needs to be reduced to ensure the credibility of LEED and other green building standards. More importantly, green buildings will not contribute to the overall global goal to "decarbonize the built environment over the next 30-40 years," if design predictions are not closer to reality (Oreszczyn and Lowe 2010).

OBJECTIVES

1. Identify the performance gap by utilizing available energy data to calculate predicted versus actual energy consumption in the selected green buildings in Santa Barbara, CA and Suzhou, China.
2. Develop and administer a Post-Occupancy Evaluation of UCSB campus buildings and SIP Eco-Zone green buildings to test hypotheses regarding causes of the gap.
3. Investigate and identify primary factors contributing to the performance gap in each individual building.
4. Collaborate with Nanjing University to compare and contrast results between American and Chinese green building performance.
5. Provide conclusions and recommendations for stakeholders to reduce the performance gap.
6. Provide overall conclusions on the green building industry and the greater worldwide issue of the performance gap. Determine the future role of the industry in reducing energy demand.

LITERATURE REVIEW

ENERGY CONSUMPTION IN THE BUILDING SECTOR

In 2008, the United States consumed 20% of total world energy ranking just ahead of China at 17%. The US building industry alone accounted for 40% of energy consumption, far exceeding other sectors (DOE, 2010). Accordingly, the building sector accounts for nearly 40% of total domestic CO2 emissions (USGBC, 2012). Figure 1 illustrates world and US energy consumption proportions.

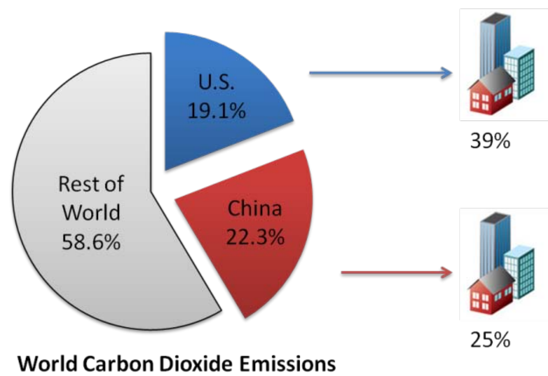


Figure 1: Energy consumption in US building sector

Analysts predict China will become the largest energy consumer in the world within the next 25 years. By 2035, China is projected to consume 70% more energy than the US (IEA, 2011). The portion of energy consumption attributed to the Chinese building sector totaled 19% in 1996 and increased to 23% in 2008 (Long, 2005). Today, it continues to rise and current projections place the building industry near 35% by 2020 (Chhabara, 2009). Similarly, the Chinese building sector accounts for 25% of total carbon emissions (Long, 2005).

A trend that promises to decrease the impact of buildings is the tremendous growth in certified green building construction within the next decade. Certified green building space is estimated to increase to 53 billion square feet globally by 2020, approximately a 780% increase from 6 billion in 2010 (Pike Research Group, 2010). About 80% of this space will be commercial buildings certified under the Leadership in Energy and Environmental Design (LEED) rating system in the United States and the Building Research Establishment Environmental Assessment Method (BREEAM) in Europe.

In addition to the US and Europe, rapid economic development in China and India indicates substantial growth in Asia's green building market. Certified green building space in Asia is expected to reach 5 billion square feet by 2015, a tenfold increase from 2010. In addition, LEED is predicted to remain the single largest certification system, covering approximately 22 billion square feet around the world by 2020, and representing over 40% of all green-certified space (Pike Research Group, 2010). Considering the growing influence and popularity of LEED, we define US green buildings as LEED-certified buildings in this study. As for our case studies in China, green buildings are certified by LEED and a localized system, the Three Star Rating System.

LEED AND THREE-STAR RATING SYSTEMS

A variety of green building rating systems exist worldwide as guidelines to standardize the design, construction and evaluation of green buildings. Both the United States and China have established systematic tools for green building assessment. This project focuses on LEED certification for green buildings which "provides independent, third party verification that a building or community was designed and built using strategies aimed at achieving high performance" (USGBC, 2012). LEED was created to provide a national standard in the US in 2000 and has expanded its influence around the world. In 2006, China introduced its first national green building standard, known as the Three Star Rating System. Table 1 outlines basic differences between LEED and Three Star. Unlike LEED, the Three Star System was initiated by the national government and operated by both national and local governments. In the implementation process, the government plays a more critical role for Three Star System than LEED. In addition, LEED, which has a longer history, measures more rating categories in a more systematic way than Three Star. Another difference is that Three Star issues two kinds of labels: Design Label and Operation Label. The former is issued right after the construction phase, while the latter is issued one year after occupancy. This one-year of performance verification ensures a more accurate assessment of the real performance of the buildings.

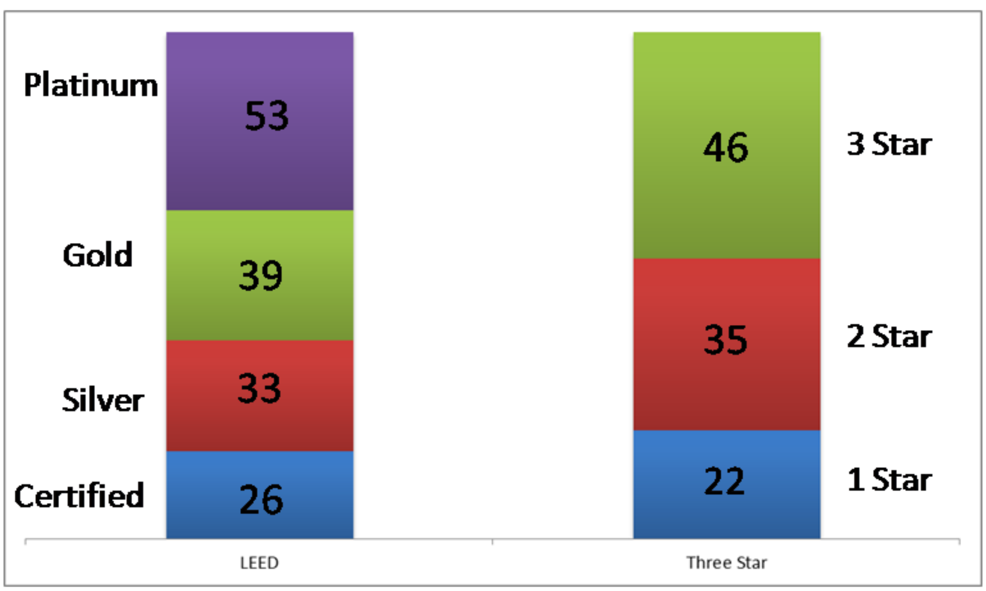
History	USGBC (United States Green Building Council), 2000	MOHURD (Ministry of Housing and Urban-Rural Development), 2006
Organization Operation	Non-governmental	Governmental
Rating time	For new construction: immediately after completion	One year after occupancy
Application	Worldwide	China only
Categories	New Construction, Existing Building, Commercial Interior, Core & Shell, School, Retail, Healthcare, Homes, Neighborhood Development	Public (including commercial, hotel, and governmental-owned buildings) and Residential

Table 1: Comparison of LEED and Three Star Rating System

As a credit based system, LEED New Construction (NC) Version 2.2 offers a rating scale that is 69 points in total. Each project needs to satisfy all prerequisites and earn a minimum number of points to be certified into different levels (USGBC, 2012). The credits are distributed into six categories, with no minimum points limitation for each category. In other words, a building does not need to be highly energy efficient to be certified green if it can earn high scores in other categories.

In China, the “Evaluation Standard for Green Buildings” is the legal title for the Three Star green building rating system. It was initiated under the context of China’s efforts to build a resource saving and environmentally friendly society (MOHURD, 2006). It earned the name “Three Star” from the three levels of certification: three stars are the highest label earned versus one star is the lowest. One- and two-star certifications are processed by the local Green Building Label Management Office (GBLMO), while the three-star label requires certification by the national GBLMO (MOHURD, 2006).

Similar to LEED, the Three Star rating scales are divided into three categories: “Control Items” as prerequisites, “General Items” as credits, and “Preference Items” as bonus points that are more difficult to acquire. Each level of certification requires the prerequisite points as well as a minimum number of credits. Table 2 provides a comparison of the credit distribution between the two systems, which indicates that the two systems have similar rating structures. This is partially due to the fact that USGBC previously consulted with the Chinese MOHURD in developing Three Star. One difference is that LEED does not allocate credits on operations and maintenance while Three Star does. On the other hand, Three Star does not account for innovation while LEED does. Levels of certification of the two systems are listed in Graph 1. For both of these two systems, a minimum total point is needed in order to gain relevant levels of certificaton. However, no minimum point is required for each rating category for these two systems as well, which indicates that buildings do not necessarily need to consume less energy in order to be a LEED or Three Star building.



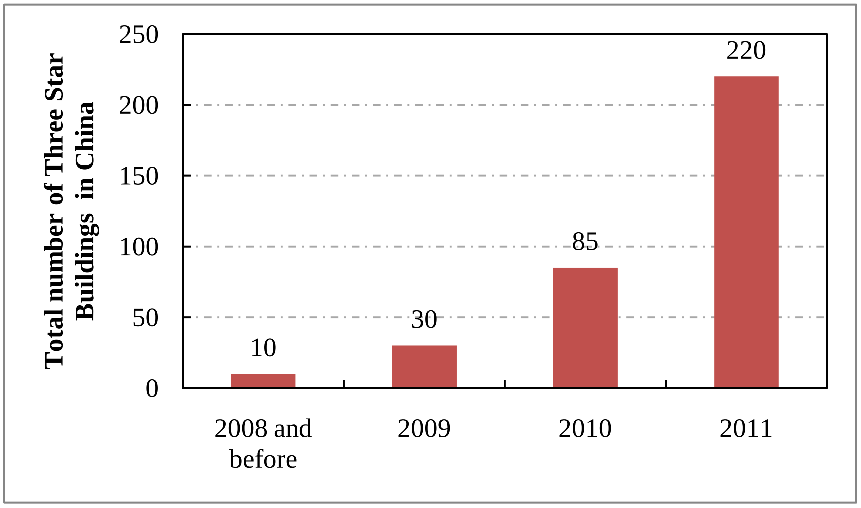
Graph 1: LEED and Three Star Certification Levels (Source: USGBC, 2010 and MOHURD, 2012)

Category	LEED NC 2.2	Three Star
Sustainable Site	14+1	9
Water Efficiency	5	7
Energy & Atmosphere	17+3	14
Materials & Resources	13+1	10
Indoor Environmental Quality	15+2	9
Operations & Maintenance	N/A	8
Innovation	5	N/A
Total	69	57

Table 2: LEED and Three Star Credit Distributions

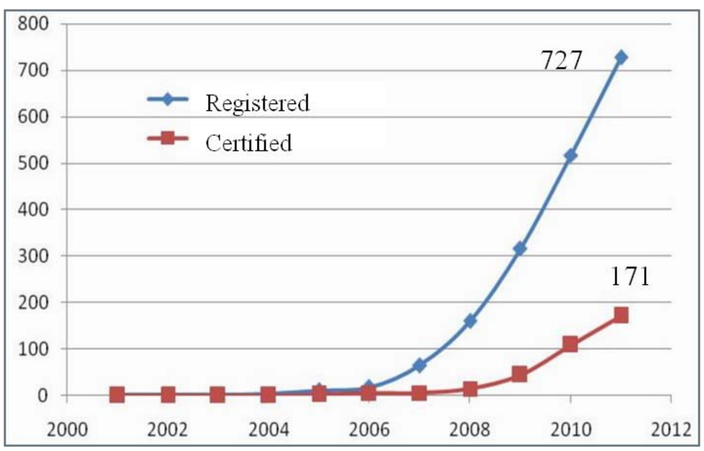
GREEN BUILDINGS IN CHINA

China currently has the largest construction volume in the world of new buildings completed annually (Chmutina, 2010). During the next 20 years, China will build 40 billion square feet and up to 50,000 new skyscrapers (McKinsey Global Institute, 2008). If trends continue as shown in Graph 2, increasing numbers of these buildings will be certified under Three Star.



Graph 2: Three-Star Green Buildings in China (Source: MOHURD, 2012)

In addition, the volume of LEED certification in China is increasing. According to USGBC, 727 green buildings have been submitted for LEED certification (2012). Currently, 171 green buildings have successfully been awarded certification totaling approximately 407 million square feet. Graph 3 illustrates near-exponential growth of LEED certification in China that parallels the growth in Three Star illustrated in Graph 2. As a result, China boasts the second largest portfolio of LEED buildings behind the US both in total amount and total area. Currently, 80% of new buildings in China are categorized as high-energy buildings (Chmutina, 2010).



Graph 3: LEED programs in China

When pursuing Three-star, building developers in China apply for two certifications: one during the design phase and one a year after the building is constructed and occupied. The standards and certification process are promoted and implemented by the Construction Council. All building-related data is also submitted to the central government. Many other top-down state-level policies, laws, regulations and incentives are established to propel the green building movement. However, researchers conclude that compared to green building codes and standards in other countries, Three Star is "less stringent, rather narrow in scope and lacks a strong regulatory framework" (Yao et al., 2005). It is complicated to implement large policies or laws in different areas, given China's poor record of enforcement in provinces. Therefore, sustained growth in green building construction requires more local and public efforts (Yong et al., 2003; Liu, 2011).

THE PERFORMANCE GAP

Researchers define the "performance gap" as the discrepancy between predicted energy efficiency during design and actual performance later realized in the life of the building. Industry experts assert that "what has been largely absent from the debate, to date, has been comprehensive and high-quality empirical evidence on the actual performance of low-energy [buildings], on the difficulties faced by designers and builders of such [buildings], and on where and how these difficulties have been overcome. Where information is available, it indicates that energy use is higher than design predictions" (Oreszczyn et al, 2009). Several studies around the world utilizing energy audits yield similar results. Interestingly, the availability of energy performance data is limited due to lack of post-occupancy monitoring (Bordass et al, 2004). Building designers are therefore uninformed of energy consumption discrepancies and the same problems may persist. Moreover, for green building policymakers this translates into a credibility gap and hinders efforts for green buildings policy.

As awareness of the discrepancy between predicted and actual performance grows, more programs are being launched to standardize the measurement of this gap. Governments and third-party verification bodies that seek to promote low-carbon buildings are mindful of the credibility risk and seek to respond proactively. In the United Kingdom, the Royal Institute of British Architects and the Chartered Building Services Engineers launched CarbonBuzz, an anonymous platform to share and analyze building energy consumption. Similarly in the US, the USGBC's Building Performance Partnership program serves as a data-collection venue for tracking, benchmarking, and analyzing building performance information. The Commercial Buildings Energy Consumption Survey (CBECS) is a sample survey that collects information on the stock of US commercial buildings, their energy-related building characteristics, and their energy consumption and expenditures. This information is used by the US Department of Energy (DOE) EnergyStar Portfolio Manager program to develop performance benchmarks for buildings with similar features. While the programs differ slightly due to international complexities, they each seek to gather data that can be used to systematically measure performance in the future.

It is important to analyze and limit the performance gap to help designers and managers generate relevant modification plans to ensure the gap is reduced in the future. Simulation modeling is expected to continue being the best available tool to predict future energy consumption based at the design phase. It provides information to systematically and quantitatively compare strategies to reduce energy consumption through the design phase of construction. When used properly, it allows the design team to prioritize investment in the strategies that will maximize energy efficiency. Moreover, the modeling results are the basis for the evaluation of a building's performance. For instance, LEED requires energy use modeling to demonstrate energy efficient performance, which is demonstrated by comparing the predicted energy performance of the modeled design versus the energy intensity of a similarly modeled code-compliant building. In addition, energy modeling is becoming increasingly standard to meet basic governmental building codes. In California's Title 24 building code, compliance is demonstrated in a similar manner to LEED. Therefore, using the modeling results to compare with the actual energy consumption can provide building managers with the right direction of enhancing energy performance of green buildings.

PREDICTIVE ENERGY MODELING

Building energy simulation may encompass the whole building or smaller, selected components of a building. For the purpose of this report, we will only discuss whole building energy simulation and refer to it as predictive energy modeling. Whole building energy simulation aims to predict energy use intensity (EUI) of a building by assessing all of the building components working in conjunction with each other over the course of one year by computer-based tools. This is a complex process that incorporates years of studies conducted by physicists refining algorithms that represent millions of interactions between a building's own systems and its surrounding environment. The process is built into modeling software that integrates the mathematical relationships between building components and simplifies the interface for the modeler.

A building's energy performance is predicted by building thermal performance calculations. There are two purposes for conducting a thermal performance analysis: to size and select mechanical equipment and to predict annual energy consumption. In recent years, with increased pressure on the building sector to reduce energy use and greenhouse gas emissions, energy analysis tools are being applied much more often. These tools are computer-based and can vary greatly in sophistication and accuracy, however functionally they will all follow the steps represented in the flowchart in Figure 2 below.

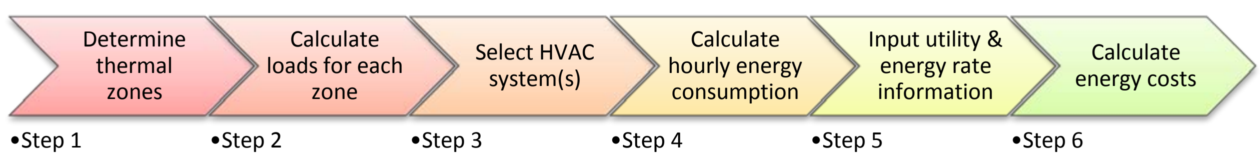


Figure2: Model flowchart

Source: Paradis 2011

PERFORMANCE GAP CAUSES

Many factors can contribute to the performance gap. One of the reasons that the modeling results have not represented the actual building energy usage is the fundamental errors or inadequacies embedded in the equations and assumptions, which may lead to inaccuracies in the predictions. We refer to this kind of causal factor as *modeling flaws*. In addition, the energy performance of a building is affected by the quality of its construction as well as the maintenance of the mechanical equipment. Lack of adequate built quality and maintenance is considered as *commissioning issues* in this report. Moreover, current simulation tools do not accurately model the impact of *occupants and management* on the energy performance of buildings (Menezes et al, 2011), which may also be a contributor to the increased energy usage of buildings. The following sections describe these causes in greater detail.

MODELING FLAWS

It is easy to conclude that no energy model can capture the moving parts and interactions in a building over the course of a year. Therefore, it is often said that the existence of the performance gap must simply be the result of models' inability to capture everything. However, Menezes et al discovered, "results from the PROBE (Post-occupancy Review of Buildings and their Engineering) studies suggest that such discrepancies transcend the expected shortcomings of current modeling programs; being a result of poor assumptions, as well as lack of monitoring following construction" (2011). From the modeling perspective, there are three major sources of inaccuracies: modeler assumptions, data quality, and software limitations.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and California Building Code Title 24 requirements are designed to standardize the modeling process so assumptions are limited, but the opportunity for human error is still plenty. Several inadequate assumptions may result in the performance gap.

- Occupancy schedules: It is at the modeler's discretion to select the number of occupants and their schedules. According to experienced modelers, a common practice is to simply count the number of chairs the architect draws into the building's conceptual design. However, the actual number of occupants after the building is in operation can be very different from the modelers' assumption. Either underestimation or overestimation of occupancy schedules can result in the inaccuracy of the modeling results. Determining the number of occupants can often prove difficult but is highly related to energy use. When possible, modelers should identify the intended use of the space through comprehensive investigation and interviews.

- Receptacle load: ASHRAE and Title 24 specify a generic receptacle load based on square footage for the code-compliant building. This is not critically assessed in most circumstances, but our observations show that additional appliances may be a contributor to the increased energy consumption in some buildings.

- Adequate building operation: Extensive literature assessing occupant engagement in buildings indicates users may not operate windows as the design intended. If the significant energy savings assumed from natural ventilation is to be achieved, a thorough training program must be incorporated. We included this assumption in our post-occupancy survey; however, the results show that the actual operation of windows is in accordance with the designed intention for our sample buildings.

Although the PROBE studies reveal shortcomings of current modeling programs are only part of the performance gap, they still need to be addressed. A comprehensive study conducted by Raslan et al at the University College of London confirmed drastic variability among government accredited energy modeling software for the same project (2009). They reveal, "for the majority of advanced energy simulation tools, the significant range of disagreement in their respective methods for calculating basic building physics has resulted in significant predictive differences between their results" (Raslan et al 2009). Some dynamic software tools are more sophisticated than others and can incorporate unique features explicitly.

OCCUPANT BEHAVIOR AND MANAGEMENT POLICY

A portion of the performance gap can be attributed to building occupants, as they operate green buildings on a daily basis and have direct influence on their performance. According to Guerra et al, the occupancy characteristics account for 4.2% of the variation in energy consumption ; however, this number is suggested to be higher due to the inherent relationships between dwelling types, heating, mechanical ventilation and air conditioning (HVAC) systems, and the occupants.

The thermal simulation of occupied buildings requires assumptions to be made about the behavior of the occupants, including the use of building controls such as windows, blinds, heaters, doors, lighting devices, and thermostats. The assumptions are based on best practices or experiments instead of actual behavior, hence having limited applicability when used to predict the behavior of buildings (Nicol, 2001). In this project, we hypothesized that occupants' control over windows, blinds, lights and doors do not meet predictions. An occupant behavior survey was conducted to test the hypothesis. However, the survey results from the sample buildings do not support the hypothesis.

Mahdavi et al (2009) introduced a relationship between the lighting conditions in offices and the probability that the occupants would switch on the lights. We hypothesized that the use of artificial lights when the natural light luminance level in the room is sufficient would increase the energy consumption. Walkthrough data proved that this kind of excessive lighting is a problem for our sample buildings. However, according to further analysis on the predictive models, excessive lighting only contributes limitedly to the overall performance gap.

The occupant's level of environmental awareness may also play a decisive role in the magnitude of the performance gap. A study by Steinberg et al (2009) states, "occupants need to be educated and trained on behaviors that will ensure the success of the green building." One of the probable causes of this mismatch between actual and predicted building use is that information on green building benefits and operation might be overwhelming to their occupants (Steinberg et al, 2009). Accordingly, we made a hypothesis that the level of green building mentalities is in correlation with the size of the performance gap. However, survey results show that this is not the case. Occupants only contributed a small portion to the overall gap.

Besides the individuals, the building management system may also affect the buildings performance. Facilities or buildings managers are in charge of the central plant equipment, accounting for a great portion of the energy consumption, especially in highly automated buildings like our case studies (Menezes et al, 2011). It is their responsibility to interact directly with individual occupants and make sure the proper function of the buildings. Therefore, buildings performance can vary significantly under different management strategies. To investigate the influence of management, we conducted several interviews with the buildings managers and facilities managers and staffs, as well as collected response from the occupants. Results show that management policies can be a factor contributing to the gap.

COMMISSIONING

Building commissioning is a systematic and documented process of ensuring that the owner's operational needs are met, building systems perform efficiently, and building operators are properly trained (Washington Department of Enterprise Services). It can be viewed as a quality-assurance process that increases the likelihood of a building meeting its specifications. LEED Operations & Maintenance standard identifies building commissioning and energy audits as a tool for verifying and optimizing energy performance as well as planning to achieve energy savings. Lack or delay of commissioning may lead to the improper use of the buildings, and therefore causing the performance gap.

Campus building commissioning, especially for UCSB, is expected to be done through installation of sub-meters to track electricity, stream, hot water, chilled water and natural gas use (NAM, 2008). In order to assess the relationship between building commissioning and the performance gap, we reviewed the commissioning documentations and interviewed the facilities staffs of our sample buildings. Results show that the frequency and efficiency of building commissioning contribute to the gap significantly for some buildings.

POST-OCCUPANCY EVALUATION (POE)

The major recognized way to analyze the performance gap is POE, which is defined as "the process of evaluating buildings in a systematic and rigorous manner after they have been built and occupied for some time" (Preiser and Vischer 2005). From the management perspective, POE is defined as "a diagnostic tool and system which allows facility managers to identify and evaluate critical aspects of building performance systematically."

A great number of POE approaches and techniques are available around the world, differing in scales, types and parameters. Appendix A summarizes several common POE methods as well as their availability. Three basic approaches we have chosen are occupant behavior surveys, walkthroughs, and interviews.

Occupant behavior survey is a main approach of evaluating occupants' influence on building performance. The target behaviors to be assessed include reducing heat, water, or electricity consumption. In this study, we focus on heat and electricity related behaviors. Questionnaires were formed using single choice questions, multiple choice questions and open-ended questions. The survey can qualitatively reveal occupants' influence on building energy consumption.

Walkthroughs be conducted based either on observations or informal discussions with occupants to indicate how space is performing. Due to time constraints, we conducted the walkthrough mainly through observations with only little involvement of the occupants. Our checklist is derived from the "Observation Evaluation Sheet" by HEFCE (2006) with modifications based on the features of our sample buildings.

Interviews with individuals can be an effective way in getting specific and detailed information on particular problems. We conducted interviews with facilities managers and buildings managers of all the sample buildings as well as several building professionals. Our targeted area focuses on buildings management policies and commissioning strategies.

CASE STUDY SELECTION

UNIVERSITY OF CALIFORNIA

Efficient energy use and resource sustainability are critical components of policy in the University of California. In 2009, the "Policy on Sustainable Practices" issued by President Mark Yudof outlines recommendations for future University operations to develop environmental stewardship, increase environmental awareness, and reduce dependence on non-renewable energy sources (UC Regents, 2009). Section I provides scope and direction for Green Building Design policy.

All new building projects in the UC system are required to outperform California Energy Code (Title 24) energy-efficiency standards by at least 20%. In addition, all new buildings need to meet the minimum standard certification of the current LEED-NC Silver rating version. Laboratory facilities will also be subject to the Laboratories for the 21^{st} Century (Labs21) Environmental Performance Criteria (EPC). By meeting green building criteria and goals across the UC system, sustainability practices will provide means to "stabilize campus budgets, increase environmental awareness, reduce environmental consequences of University activities, and provide educational leadership for the 21^{st} century" (UC Regents, 2009).

UC SANTA BARBARA CAMPUS

UCSB is located on a bluff overlooking the Pacific Ocean, occupying just over 1000 acres. It represents a good possibility for assessing energy performance in green buildings due to the following reasons:

<u>Climate</u>: temperate climate in Santa Barbara is relatively easy to incorporate in building design. Likewise, all buildings and occupants have very similar needs in terms of lighting, insulation and ventilation.

<u>Building variety</u>: the UCSB campus has a wide array of building types, including residential, commercial and laboratories, representing most LEED categories.

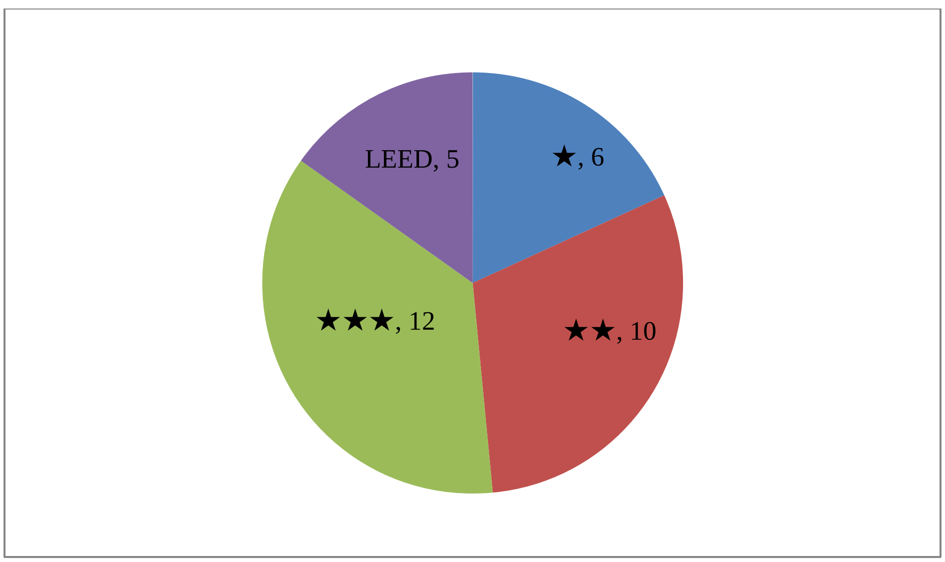
<u>Management</u>: all buildings are managed under the same principles (policy and budget). Activities related to building maintenance and commissioning are equal across buildings, with a central authority in charge of them (UCSB Facilities).

Those reasons allow for using study findings as a "best-case scenario". This takes into consideration physical, economical, political and demographic aspects that make the UCSB campus an ideal case study for green building energy performance. The four buildings selected for the case study are described in greater detail in Appendix B. They were chosen because they represent each building type that exists on the UCSB campus: commercial office, laboratory and residential.

SUZHOU INDUSTRIAL PARK

To stimulate economic development, the Chinese government introduced a new concept for industrial parks termed Eco-Industrial Parks (EIPs) to enforce environmental protection. Suzhou Industrial Park (SIP) in the city of Suzhou is among the first established. SIP is located in the southeast of Jiangsu Province near the east coast of China. The city has a history of co-development between the Chinese and Singapore governments. Today, the local government of SIP and its environmental sustainability efforts ranks first in the nation for energy conservation and emissions reduction in China. SIP is a case study for several other low-carbon development projects in the Jiangsu Province. Today, SIP continues to strive for international competitiveness to attract high-tech firms to the industrial park and enhance social, economic, and environmental development.

SIP has a strong commitment to green buildings. It has its own policy and management rules to evaluate green buildings in SIP, and encourages projects to be green buildings by providing awards to them. Currently, SIP has 28 Three Star green buildings, accounting for 47% of Jiangsu Province and 13% of national level (MOHURD, 2012). There are nearly 30 green building projects totaling more than 3.9 million square meters (MOHURD, 2012) of building area. In addition, 19 parcels have been planned, designed, and awaiting construction in accordance with two-star and three-star standard, including residential, commercial, financial, and high-tech land. Furthermore, LEED certification is also common in SIP with five buildings currently certified. Graph 4 illustrates the proportion of certifications for green buildings in SIP.



Graph 4: Green Buildings in SIP

Case studies for SIP were primarily chosen based on available similarities to chosen UCSB buildings. Selected buildings include parallel range of uses, variance in certification levels, and variety of occupants as illustrated in Table 3.

Name	Type	Certification	Construction Time	Construction area	Ownership
Sino-Singapore Eco-Tech R&D Service	Office Building	★★ Operation	Finished and operated on Nov. 4th, 2007	77, 220	Private
Suzhou Industrial Park Youth Center	Public Center	★ Operation	Operated on May, 2009	35,026	Government
Suzhou Langshi Residential Building	Residential	★★★ Design	Started to open on Dec. 2007	189,000	Private
Plantronics Office Building	Office building	LEED Silver	Operated at 4/25, 2006	6,000	Private

Table 3: Green Buildings selected in SIP

METHODS

CALCULATING THE PERFORMANCE GAP

Necessary data to calculate the energy performance gap is related to predictive energy models and utility bills. All data was obtained from the UCSB Facilities Department.

Predictive energy models are required by LEED as part of the certification process. Usually it includes a “standard” and “proposed” scenario. In the case of California, the “standard” scenario refers to Title 24 (state building requirement), which does not include efficiency measures and acts as a performance baseline. The “proposed” scenario is basically Title 24 requirements with energy efficiency measures included in the building design. For both cases, data is presented in terms of electricity (kWh), natural gas (therms or cf) and chilled water (ton-hrs or kWh), depending on the categories used by the modeler.

Ideally, buildings would be sub-metered so that data is available for each system installed in a building, but this is not the case in UCSB. Utility bills include total monthly energy usage for every building. This is usually separated into electricity (kWh) and natural gas (therms). An important consideration for actual energy is the period over which it was measured. There might be annual variations due to weather or occupancy intensity that would skew data.

Total building area is also required for performance gap calculations. This data is also found in predictive energy model reports. Building characteristics and data used to calculate the energy performance gap in UCSB buildings are included in Table 4.

			Building			
			Bren	MSRB	SCV	SRB
Area		**sq ft**	84,896.00	51,052.00	320,710.00	68,413.00
Baseline energy consumption (Title 24)	**Natural Gas**	**therms**	31,205.00	14,253.00	81,984.05	4,802.00
	Electricity	**kWh**	1,294,693.00	1,339,584.00	18,031.24	582,977.00
Actual energy consumption	**Data period**		1/2008 - 12/2008	4/2009 - 3/2010	7/2010 - 7/2011	1/2009 - 12/2009
	Natural Gas	**cf**	2,394,904.05		6,065,600.00	
		therms		10,087.66		17,337.00
	Electricity	**kWh**	1,279,899.17	1,096,344.37	1,602,000.00	631,720.00
	Chilled water	**ton-hrs**	100,797.72	112,617.63		
		kBtu				939.34
Predicted energy consumption	**Natural Gas**	**therms**	23,756.00	8,541.00	40,654.36	2,704.00
	Electricity	**kWh**	999,729.00	1,261,529.00	12,293.13	508,526.00

Table 4 – Building characteristics and data

PERFORMANCE GAP CALCULATIONS

The energy performance gap was calculated for each building by using the following general formula:

Energy performance gap = actual energy use – predicted energy use

The predictive energy models produce an energy intensity value of kBtu/square feet and will either list it as "site energy" or "source energy". Source energy represents the total amount of raw fuel that is required to operate the building. It accounts for all transmission, delivery, and production losses, thereby representing a complete assessment of energy consumed from a building. When comparing to utility bills, predictive models illustrate what the anticipated building energy consumption actually is after the inefficiency losses from the transmission and delivery. This decision prevents bias as a result of a building's proximity to the power grid substation or due to differences in the efficiencies of transmission lines to individual buildings.

For the actual usage, the method of calculating EUI varies across the four case study buildings due to differences in the utility bill formats. Ultimately the goal is to convert all energy consumption to kBtu. For example, data provided by UCSB Facilities for the Marine Science Research Building (MSRB) lists monthly meter readings for Main Electrical Total Consumption (kWh), Building Chilled Water Consumption (ton-hrs), and Natural Gas Consumption (therms). These values are aggregated and converted into kBtu to represent total annual energy usage. All unit conversion factors were all taken from the DOE Energy Star website.

The gap was calculated in terms of EUI with units of kBtu/sq ft. The US DOE defines EUI as the energy use of a building relative to its size. Using EUI allows standardized comparison of all building types. For the UCSB case study site EUI values from predictive modeling reports were compared to annual utility bills for each building.

POST-OCCUPANCY EVALUATION

SURVEY

Occupants can affect the building energy consumption by influencing the internal conditions as well as controlling over various energy appliances that are considered as "unregulated loads". Guerra et al. (2009) suggested that the occupancy characteristics account for 4.2% of the variation in energy consumption; however, this number is suggested to be higher due to the inherent relationships between dwelling types, heating, mechanical ventilation and air conditioning (HVAC) systems, and the occupants. To assess the occupants' influence on the buildings performance, this project integrated an occupant behavior survey in the post-occupancy evaluation across the four targeted buildings.

According to Gill et al. in 2010, building occupant behavior is defined as the aggregated response of a person resulting as a consequence of complex interactions between internal and external factors. These factors may include emotional, moral, habitual, contextual, attitudinal, social, normative, and control factors. This project focused on the behaviors that specifically have an effect on energy consumptions, including heating system, lighting system, appliances usage, and environmental mentalities.

SAMPLING AND DATA COLLECTION

The survey was administered to occupants of the four UCSB buildings from November 2011 to January 2012. Targeted population was defined as people to whom a workspace is assigned in the targeted building. Both paper surveys and on-line surveys were used. A $100 Apple Store Gift Card was offered as an incentive.

Paper surveys (Appendix C) were distributed among occupants that have a fixed office or cubicle. Each occupant was assigned a unique track number to identify non-respondents and contact them to boost response rate. Confidentiality was maintained and identifying information was destroyed after collection.

Online surveys (Appendix C) were distributed among master's students at Bren Hall and San Clemente Village (SCV) residents. The online distribution was chosen because of the relatively larger population size, and the effective email list. The master's students were chosen because that their behaviors were expected to have a considerable influence the performance of Bren Hall, particularly with energy usage in the lecture rooms, computer labs, and common rooms. The survey distribution among the four buildings is listed in Table 5.

	Data Collection	Sample Size	Respondents
Bren Office Occupants	Paper survey	160	80
Bren Master's Students	On-line survey	178	105
MSRB Office Occupants	Paper survey	76	35
SRB Office Occupants	Paper survey	Approx. 150	58
San Clemente Residents	On-line survey	965	144

Table 5 Sampling and Data Collection

DATA PROCESSING

The response rates for each building are listed below in Table 6.

Building	Survey response rate
Bren (Offices)	50.0%
Bren (Master’s)	59.0%
MSRB	46.1%
SRB	38.7%
SCV	14.9%

Table 6: Response rates.

The response rate for SCV is relatively low, at 14.9%. An acceptable average response rate in academic studies is 48.4% with a standard deviation of 20.1% (Baruch, 1999). Hence, the responses can be considered as representative except for SCV.

The paper survey data were entered into Excel spreadsheet, and relevant analysis was manipulated through Excel and R statistical tool. The on-line survey data was downloaded from the Surveymonkey, and processed through Excel and R.

For questions that contain open-ended choices or choices that indicate, “If you have other options, please specify,” a post-coding process was performed under the guidelines described in the *Survey Research Handbook* (Alreck et al). The new answers were grouped into several categories, and new codes would be given to the new categories. The new categories were all inclusive so every original value was included, and also mutually exclusive so there would be no double counting.

WALKTHROUGHS

An energy audit is defined as "the verification, monitoring and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency and an action plan to reduce energy consumption" (Bureau of Energy Efficiency, 2012). Energy audits are a key tool for a systematic approach to energy management. Researchers can pinpoint where and how energy inefficiencies are located and identify malfunctions. After that, improvements and recommendations of energy management opportunities (EMO) can be identified and provided (Electrical & Mechanical Services Department, 2007). EMO can have a very broad range, including energy-saving technologies, energy commissioning improvements, and occupant education improvements.

Walkthroughs are a simple, easy, and inexpensive method to asses energy audits in green buildings. Following established methods for building walkthrough audits, we created our own walkthrough methods and procedures to administer inspections (Appendix D).

The process considers site inspection, auditors majorly conduct a site inspection of a building's energy system. More comprehensive audit includes detailed audits, like occupant surveys, detailed calculations of energy use, assessment of all equipment and operational systems, computer simulations. Following Figure 3 describes procedures of a typical walkthrough inspection for one building.

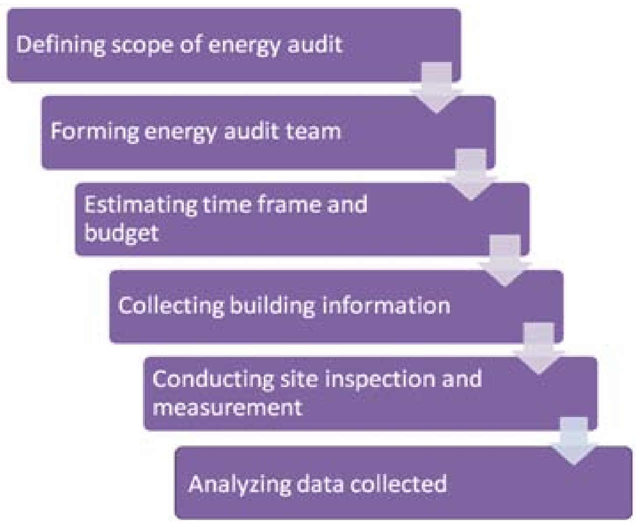


Figure 3: Procedures of a typical walkthrough inspection for one building

Source: Electrical & Mechanical Services Department. Guidelines on Energy Audit. 2007.

RECEPTACLE LOADS

The walkthrough checklist requires number of energy-demanding equipment to determine average receptacle load, as office equipment and other plug-loads consumes very large proportion of energy in buildings (EIA, 2007; ECOS, 2011). The variety and complexity of different plug-loads creates a challenge to quantify the energy-demand devices and further improve energy efficiency of use (Peters et al 2010). In final data processing, we estimate energy consumption of receptacle loads based on our assumptions and specifically quantify computers to calculate improvement potentials.

Laboratories in Bren and MSRB

Nearly half the working space of Bren and MSRB is laboratories. Energy consumption is large for laboratories, and often more than three or four times of the rate of offices with a square feet base (Hopkinson et al. 2011). Ventilation, space and water heating, plug-load lab equipment, and lighting are big energy sinks in laboratories (Hopkinson et al. 2011). Typically, ventilation consumes around 50% of the total energy in labs (Hopkinson et al.

2011; Mathew et al. 2012), equipment consumes around 25% and lighting consumes about 10% (Hopkinson et al. 2011). However, much less attention is drawn from the public for energy efficiency of labs than commercial buildings. In addition, due to the variety of laboratories and equipment, and highly expertise-oriented, it is very hard to model and measure the energy consumption and efficiency. Therefore, we only measured energy-related management and occupancy behaviors in the laboratories in Bren and MSRB.

INTERVIEWS

Interviews supplement surveys and building walk-throughs by gathering information and data from people who are responsible for the managing and overseeing building performance. Primarily, interviews were held with building managers (for all four buildings) and laboratory managers (for buildings with labs: Bren and MSRB), since they are knowledgeable on issues that other building occupants (staff, students, faculty) are not aware of. The main focus of the interviews revolves around the following themes, which will aid understanding why each building performs in the manner they do and what can be done to improve such situation:

- Energy performance
- Building commissioning and maintenance activities
- Occupant behavior and building use

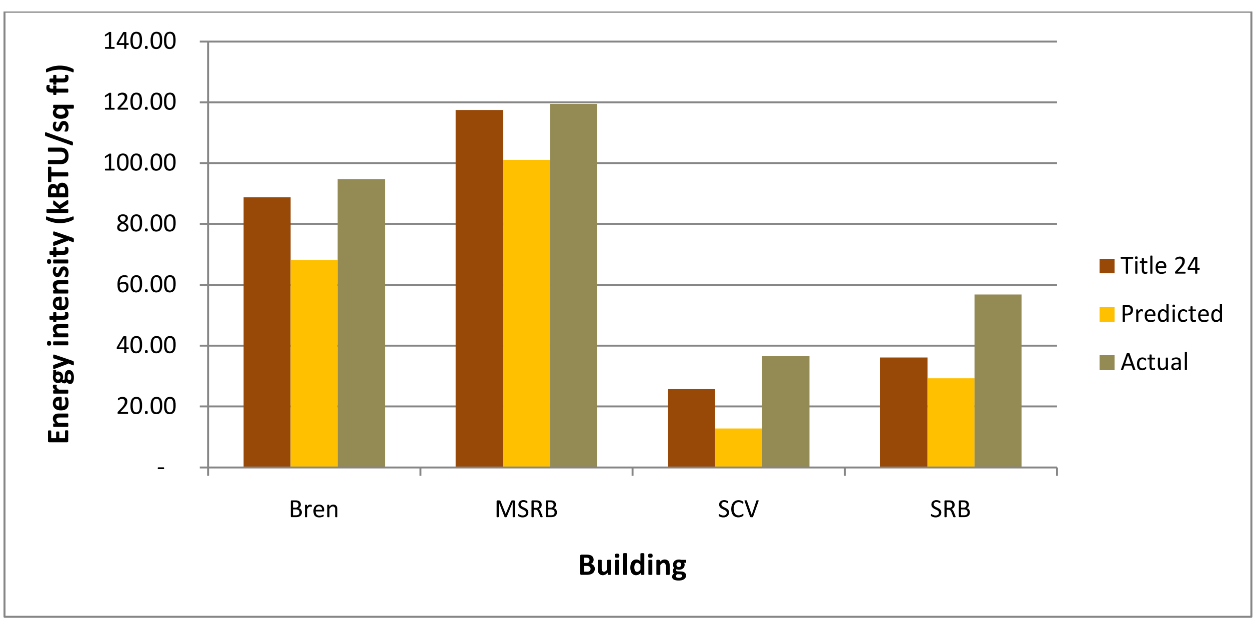
Questions for both building and laboratory managers, as well as guidelines for the process can be found in Appendix E. Unlike surveys, these questions are used as a guide by interviewers and were not necessarily read word by word to develop an open-ended conversation.

RESULTS/DISCUSSION

PERFORMANCE GAP - UCSB

The performance gap results (Table 7 and Graph 5) show that all UCSB buildings included in this study are underperforming in terms of energy use. UCSB green buildings are using more energy than predicted by the model. When compared to code compliant Title 24 baselines (California's Energy Efficiency Standards for Residential and Nonresidential Buildings), all the studied buildings have a higher actual energy use (Graph 5). According to the calculations, the quantified performance gap accounts for between 18.27% (MSRB) and 185.04% (SCV) of predicted energy use. Interestingly, there is a clear trend between energy intensity and the magnitude of the performance gap: the latter decreases as energy intensity increases. MSRB has the largest actual energy use intensity and the smallest gap; SCV is the opposite situation.

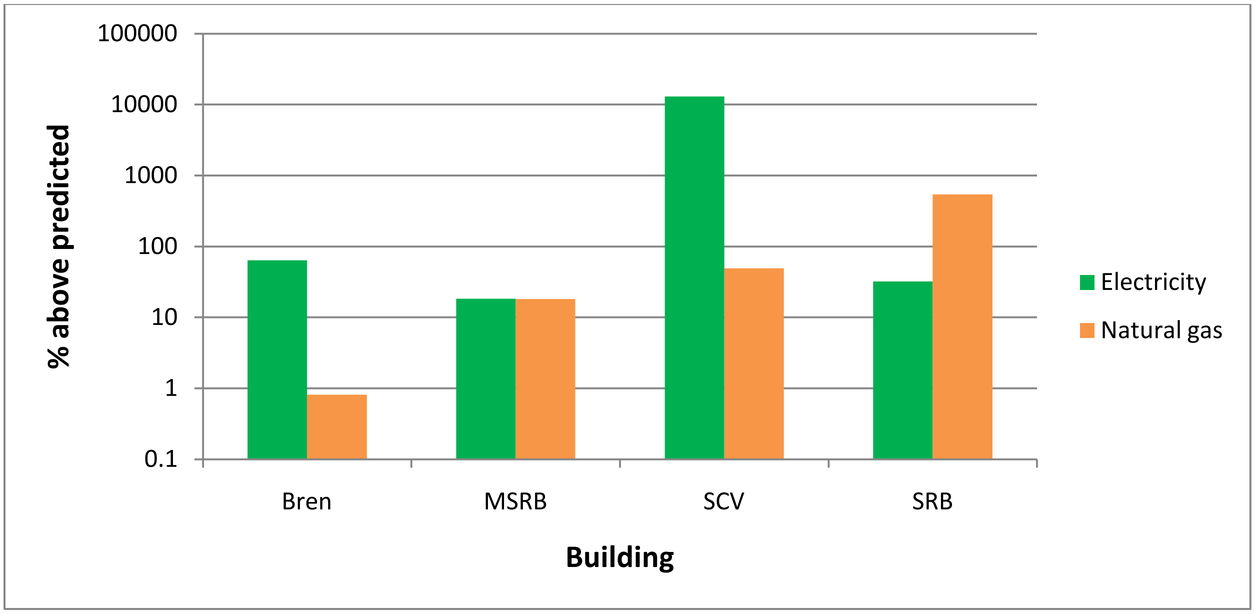
Graph 6 shows the contribution of electricity and natural gas use to the performance gap. There are huge variations across four buildings, which could represent some causes of the gap. This would be discussed in detail later. Bren's natural gas use is very similar the modeled value (0.81% higher), portraying a good prediction in the use of natural gas powered equipment. In this case, the major driver of the gap is electricity use, possibly due to receptacle loads. MSRB increased equally electricity and natural gas use, representing a well-spread increase in building use. In SCV, excess electricity use was estimated at 12,931.67%, largely related to the fact that the model for living areas only accounts for heating (space and water) and space heating, disregarding indoor lighting and receptacle load. An important observation is that LEED modeling requirements for residential buildings do not include those loads, thus underestimating energy use. SRB shows a substantial increase in natural gas use, contributing to most of their performance gap.



Graph 5 -Building EUI

		Building			
		Bren	**MSRB**	**SCV**	**SRB**
Total (kBtu)	**Title 24**	7,537,992.52	5,995,960.61	8,259,927.27	2,469,317.52
	Actual	8,040,944.88	6,100,904.55	11,707,526.40	3,890,067.98
	Predicted	5,786,675.35	5,158,436.95	4,107,379.70	2,005,490.71
EUI (kBtu/sq ft)	**Title 24**	88.79	117.45	25.76	36.09
	Actual	94.72	119.50	36.51	56.86
	Predicted	68.16	101.04	12.81	29.31
Excess energy use (%)	**Natural gas**	0.81	18.11	49.20	541.16
	Electricity	63.47	18.29	12,931.67	32.02
	Total	38.96	18.27	185.04	93.97

Table 7 - Performance gap results



Graph 6 - Electricity and natural gas

PERFORMANCE GAP COSTS

Energy performance models are used as budgeting tools for building mangers. Monthly and yearly energy usage could be estimated from them, representing a concept similar to miles per gallon in cars. In this respect, the performance gap affects financial planning. This study uses rates of $0.11/kWh and $1.07/therm from UCSB utility providers Southern California Edison and Socal Gas (ARUP, 2005). Costs associated with the performance gap are presented in Table 8.

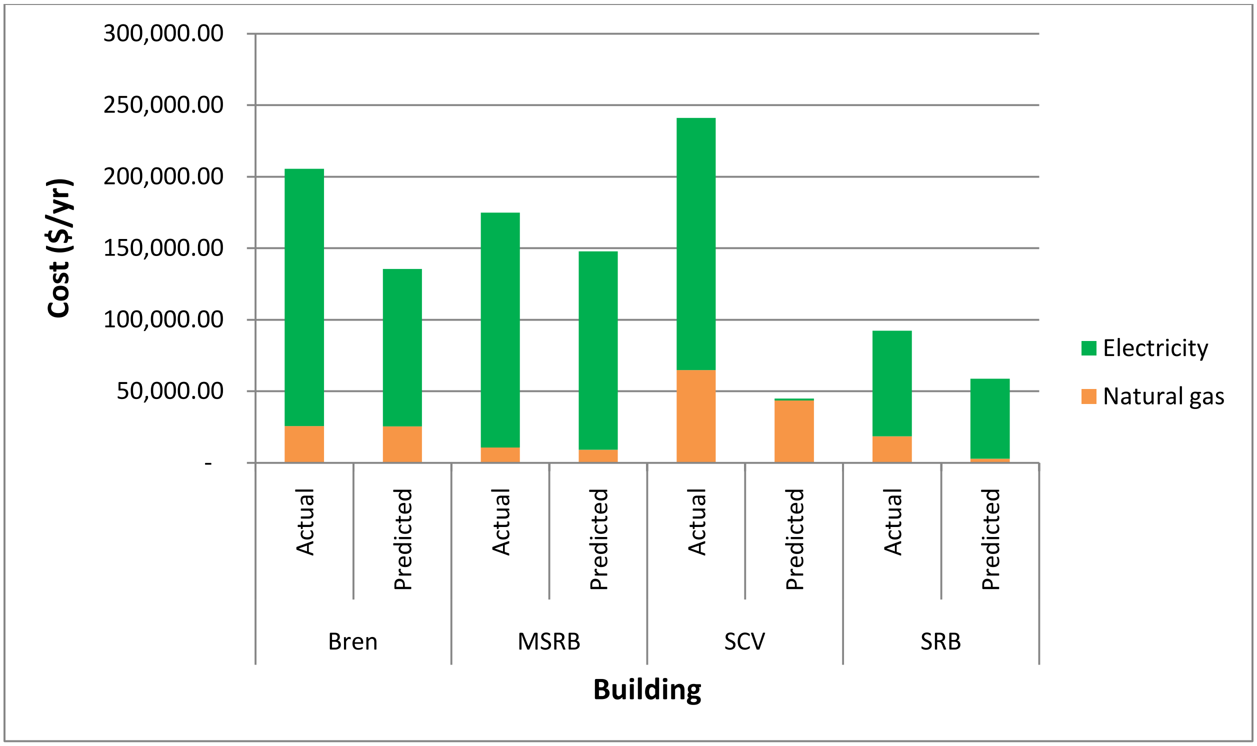
The performance gap in monetary terms brings more tangible significance to managers and building occupants. From this data it is clear that energy costs are driven by electricity (Graph 7), as its increase has a larger incidence in total energy cost than that of natural gas. This is mainly due to the current cost of natural gas being significantly lower than the cost of electricity.

SCV is the building most affected by the performance gap, both in relative and absolute terms (437.59% increase with a cost of $196,269.52/year). This is related to SCV being significantly larger than the other buildings. However, when analyzed on a per sq ft basis, Bren has the highest increase in energy cost ($0.82/sq ft). Compared to Title 24 baseline, all buildings have higher energy costs than estimated.

The performance gap accounts for large sums of money that could be used otherwise for the benefit of the building and its occupants. On a state University campus operating on ever-tightening budgets, reducing costs from inefficiencies is vital.   At the best performing building, yearly excess energy costs are approximately $27,000, which could be used for building commissioning. Commissioning activities have costs estimated between $0.61/sq ft and $1.22/ft (NAM, 2008).

		Building			
		Bren	**MSRB**	**SCV**	**SRB**
Total ($)	**Title 24**	175,805.58	162,604.95	89,706.37	69,265.61
	Actual	205,398.91	174,947.67	241,121.92	92,399.39
	Predicted	135,389.11	147,907.06	44,852.40	58,831.14
Relative ($/sq ft)	**Title 24**	2.07	3.19	0.28	1.01
	Actual	2.42	3.43	0.75	1.35
	Predicted	1.59	2.90	0.14	0.86
Excess cost above predicted	**%**	51.71	18.28	437.59	57.06
	$/yr	70,009.80	27,040.61	196,269.52	33,568.25
	$/sq ft	0.82	0.53	0.61	0.49

Table 8 - Performance gap costs



Graph 7 - Actual and predicted energy cost

LIMITATIONS AND ASSUMPTIONS

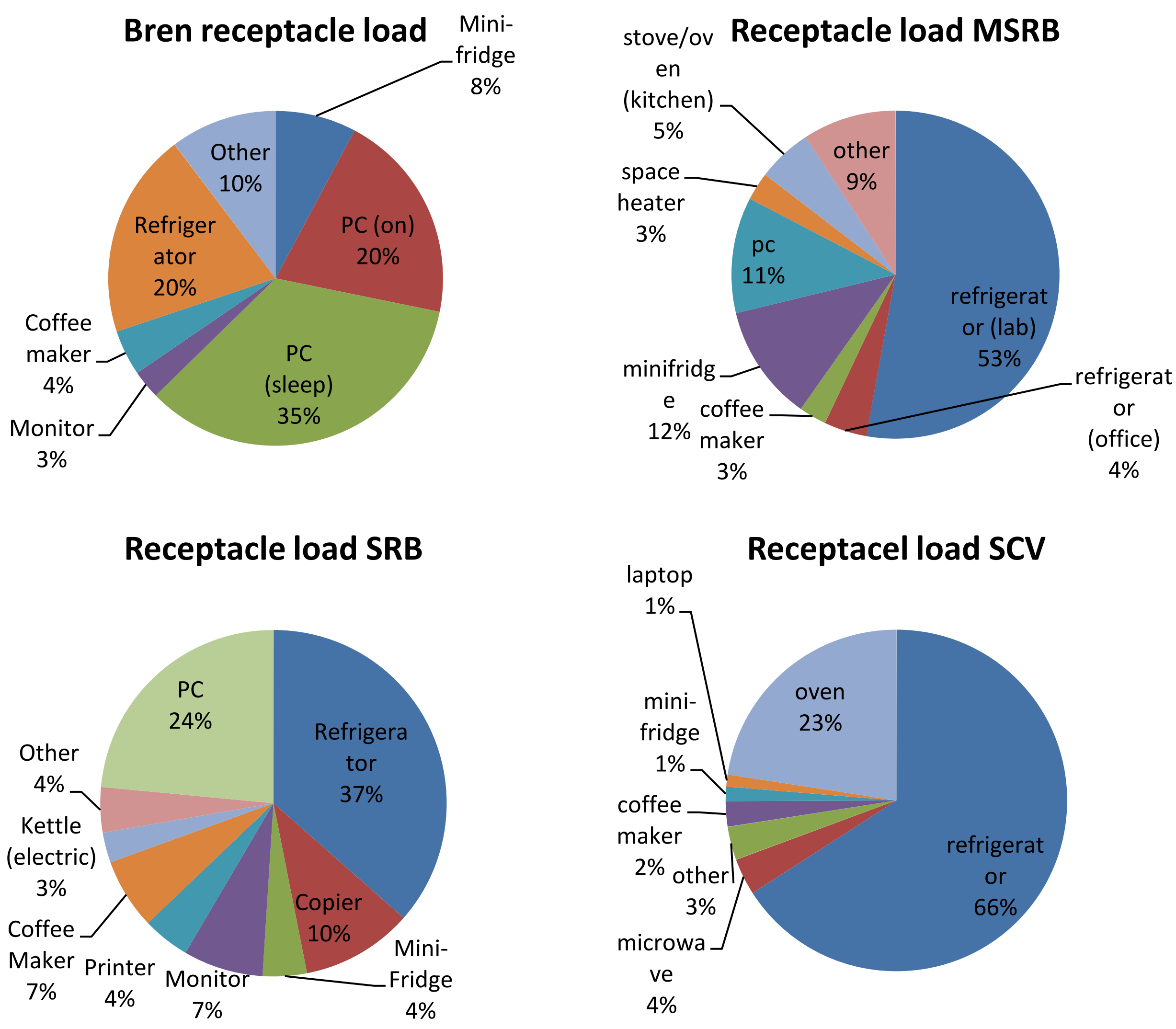
As discussed in prior sections of this report, building energy performance modeling cannot be expected to precisely represent reality. Therefore, using modeling results to quantify the performance gap may result in its over or underestimation, depending on model inputs. Occupant related inputs (schedule, behavior) are very difficult to predict and account for most model inaccuracies.

On the other hand, data for calculating actual energy use was only available for a short period. Therefore it may not be representative of a normal year, thus generating further inaccuracies. For instance, SCV has varying yearly occupancy, and as such will have different yearly energy intensity. Similar situations may occur at MSRB and Bren, where scientific research may require varying levels of technological involvement which will affect energy use. Meteorological conditions also influence energy use, although this seems to be of smaller significance given that climate has not drastically changed in the last 10 years during which each of the building's models were completed.

Inputs used for calculating the performance gap represent the best available data and assumed to be representative of a normal year. Longer, more comprehensive studies of green buildings should account for the limitations and assumptions stated before and include them in their methodological framework.

RECEPTACLE LOADS

As discussed earlier, an important portion of the energy performance gap is due to inaccuracies in model assumptions. A major assumption is the receptacle load of a building. It is very difficult for modelers to correctly estimate the number and type of electric devices that occupants bring into buildings. Analyzing differences between the predicted and actual receptacle load in buildings will shed light on occupant behavior and the guidance level they had when occupying the building. After counting receptacle loads during walkthroughs of four case buildings, estimation of receptacle loads for each building is presented below.



Graph 8: Receptacle load in UCSB buildings

Across all four buildings (Graph 8), refrigerators represent the largest portion of the receptacle load (between 28% and 66%). These include those located in laboratories and kitchens, and mini-fridges in offices. The two major sources of receptacle load are related to office equipment (PCs, monitor, printer, copier) and cooking (microwave, coffee maker and refrigerators). Coffee makers and mini-fridges in offices are very common (around 20% of the rooms observed with one coffee maker and/or fridges) and represent a significant portion ranging from 11% to 15% of the performance gap. This shows issues with building design, namely access to kitchen areas.

Although occupants directly influence the energy consumption of these devices, building managers also affect such behavior. Throughout buildings, internal policies and system design drive the performance gap to different degrees. In the case of Bren, occupants are not allowed to turn off their computers (35% of current receptacle load) due to software update schedules. Other buildings have overrun thermostat and lighting controls, preventing occupants from manipulating them and potentially preventing them from reducing energy usage.

Due to lack of documentation it is not possible to compare these results to model assumptions and gauge the degree to which modelers considered these use patterns. However, this information is used later in this document to deal with specific issues affecting each building's energy performance and designing strategies aimed at reducing such inefficiencies.

LIMITATIONS AND ASSUMPTIONS

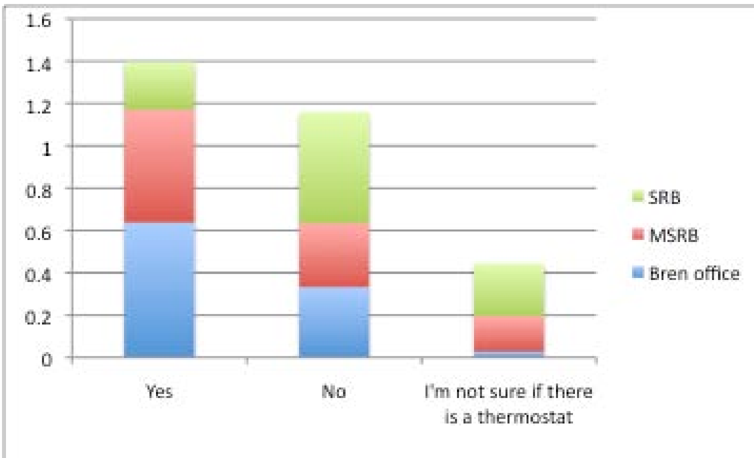
Modeling limitations on receptacle loads are the same as the ones described in the previous section. In the same manner, the actual energy use of receptacle loads was estimated by using data collected during walk-throughs in conjunction with estimated device power from several sources. All devices were assumed to be equal across buildings. Obtaining specific data for every electric device in all buildings would have been a very time and resource intensive task, which was not possible within our project constraints. The estimate of electric devices per building is similarly inaccurate. These were calculated from a sample of rooms, assuming that all other rooms with similar characteristics would have the same devices.

PRELIMINARY POE RESULTS

Results from surveys administered at the four buildings have been integrated into our analysis and compared to each other. In addition, our colleagues from Nanjing University had distributed a similar survey in a commercial building in China. Comparisons between the US occupants and Chinese occupants had been made on some of the comparable questions. The main findings are listed below.

1. Lack of occupant education regarding building operation and use exists.

- For thermostat use, 61% of the office-building occupants in UCSB reported that there is no information available in the workplace; 18.6% were not sure if there is a thermostat.
- For lighting systems, 81.6% reported that there is no information on the functioning of lighting systems in their workplace.
- Thermostat settings. Graph 9 shows the percentage of occupants who have or have not changed the thermostat settings in their workplace. In total, 38.1% of occupants have never changed the thermostat settings; and the chi-square test shows that the proportion in SRB is significantly more than that in other two buildings. (X-squared = 22.6238, df = 4, p-value = 0.00015).

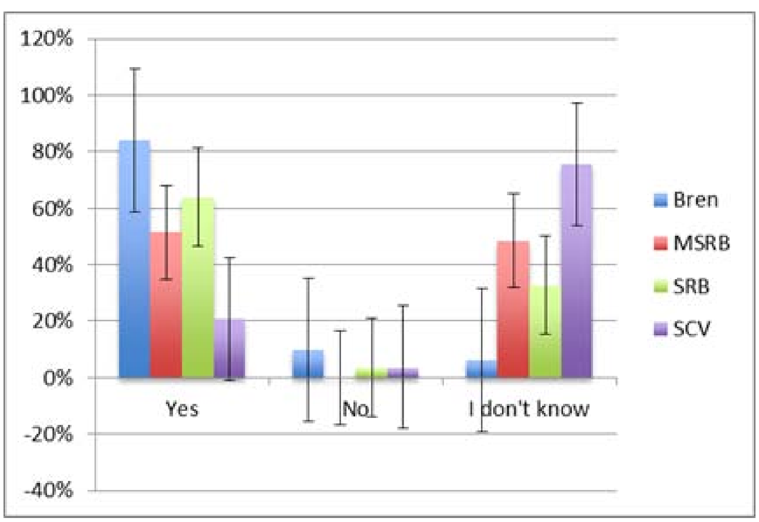


Graph 9: Have you ever changed the thermostat settings in your workplace?

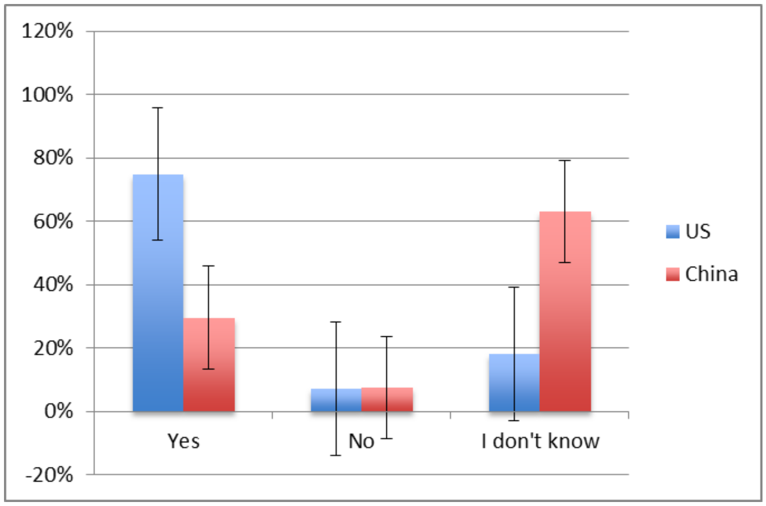
The lack of information on the proper use of thermostat settings and lighting systems is a common problem among the three office buildings, which may lead to incomplete or inadequate usage of the building facilities. In particular, 52.5% SRB occupants have never changed their thermostats, which calls for a need to better inform the occupants of appropriate building control.

2. Green building mentality varies among buildings.

When asked the question "Is your building LEED certified?", there was variations among buildings both in the US, and between the US and China (as is shown in Graph 10 and Graph 11). For UCSB buildings, Bren occupants have the highest green building mentalities, while SCV occupants have the lowest. The results are significantly different (X-squared = 157.8466, df = 6, p-value < 2.2e-16). Moreover, the sampled US occupants are expected to have a higher awareness than the sampled Chinese occupants. (X-squared = 95.9716, df = 2, p-value < 2.2e-16). However, according to the performance gap data, the level of green building mentality does not necessarily correlate with the size of the performance gap. For instance, the Bren occupants have higher mentality than MSRB occupants, however, MSRB has a smaller performance gap than Bren. The Chinese occupants have a lower green building mentality than the US occupants, however, the performance gap is potentially much lower than the US.



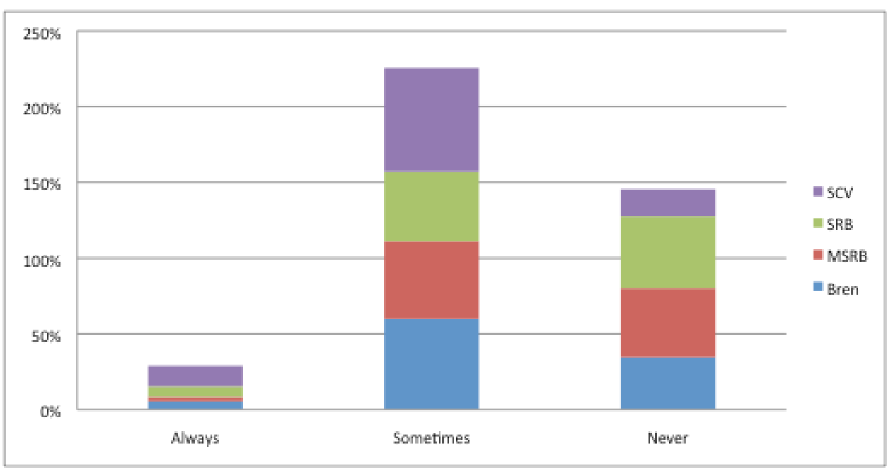
Graph 10: Is your building LEED?



Graph 11: Is your building LEED? (US and China)

3. The energy efficiency awareness of green buildings needs to be improved.

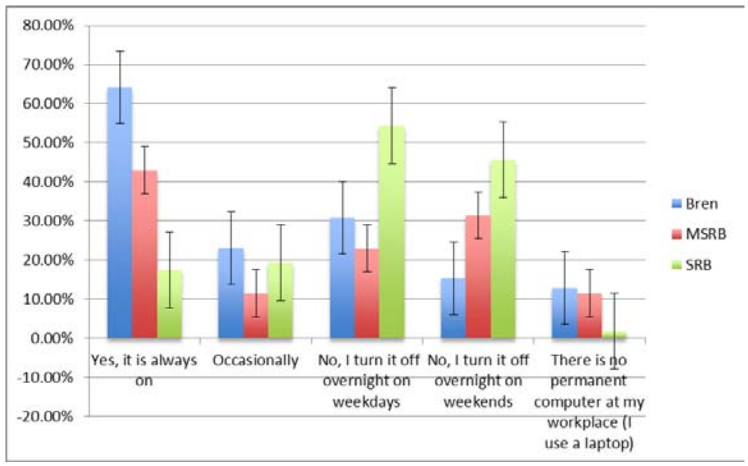
- The not-in-use plug-ins was recognized as a major issue through the survey results (shown in Graph 12). Only 7.3% on average would always unplug electrical devices when they are not in use.



Graph 12: Do you unplug electrical devices when they are not in use?

- Computer receptacle load is an issue for some buildings. As is shown in Graph 13, the number of overnight computers in Bren is significantly larger than MSRB and SRB (X-squared = 71.2144, df = 8, p-value = 2.815e-12). This also relates to the computer management policy at the Bren School, which creates barriers for reducing energy consumption. Some comments from occupants in the surveys said that they think not turning off the computers could cause more energy use while technology facilities generally control the computers and sometimes update or fix them so that they would not like occupants to turn off personally.

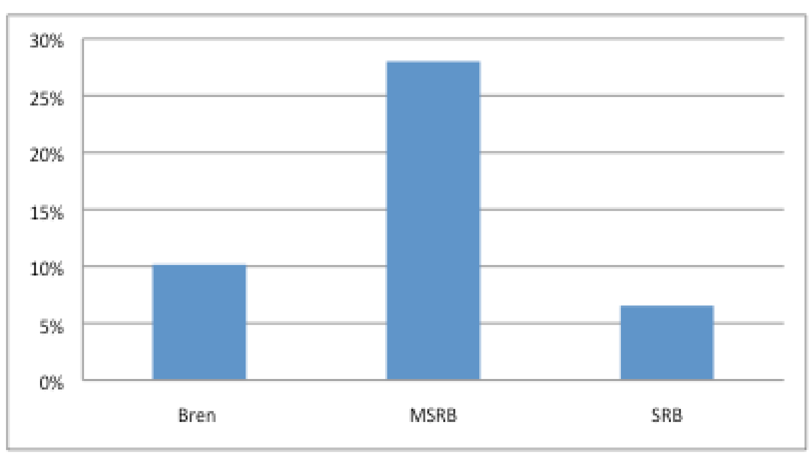
- One point worth-noting is that 73.4% of the Chinese building occupants turn off their computers after work, which is much higher than the UCSB average.



Graph 13: Do you leave your computers on overnight?

4. Occupant behavior needs to be adjusted to reduce unnecessary day lighting.

One of the major reasons for turning on the lights even when natural light is sufficient is to prevent glare. This, in particular is an issue for MSRB. As is shown in Graph 14, the proportion of day lighting to prevent glare in MSRB is about 28%. This also raises the issue of matching the interior arrangement with the orientation of the room to prevent glare and reduce day lighting.



Graph 14: Proportion of turning on the lights to prevent glare

5. Green building occupants operate the buildings well in several ways.
Based on our survey results, we also found that green-building occupants operate building features correctly.

- Windows open/close: Reasons for opening windows include air circulation (45%), cooling the room (47%), and warming the room (8%). This is in accordance with the design goals for the operable windows in the Southern California area buildings where there is no air conditioning.
- Blinds operation: According to our results, a large proportion of people, about 49% use their blinds depending on their comfort level. No abnormal trend was found.
- Turning off lights in unoccupied rooms: Our results show that 67.3% occupants would turn off the lights in an unoccupied room. The statistics were similar among the three office buildings (X-squared=0.3587, df=2, p-value=0.8358).

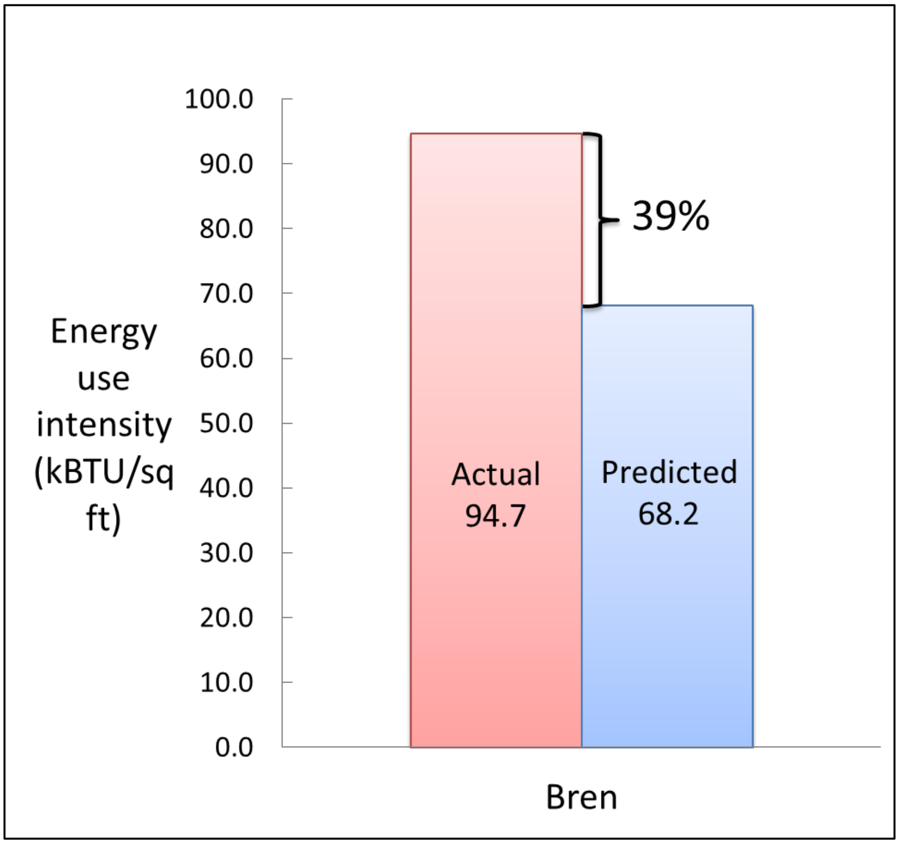
The survey results can qualitatively evaluate occupants' influence on the energy consumption of green buildings. It has been illustrated above that to some extent, green building occupants have been operating the buildings in the way that they were designed; however, there is also great potential that inadequate occupant behaviors may increase the discrepancy between modeled energy performance and the actual energy consumption. Different buildings have various behavioral patterns regarding to occupancy, and further research is needed for the quantification of the contribution of occupancy to the total energy consumption in each building.

PERFORMANCE GAP DRIVERS

MANAGEMENT PROBLEM

STUDY: BREN HALL

In 2002, Bren Hall became the first laboratory building in the United States to receive a LEED Platinum certification by the USGBC. In 2009, Bren Hall became the first building to receive LEED Platinum certification for the second time under the Existing Building (EB) award. As the oldest building among the case studies in this project, we hypothesized a high EUI of Bren Hall based on deterioration of mechanical systems over time. An additional challenge within the performance gap analysis is restrictions and limitations within older energy modeling software utilized when the building was being designed in the early 2000s. Also, Bren Hall houses a highly efficient water chiller that supplies chilled water to a campus-wide distribution system. Utility meter data is normalized for this system.



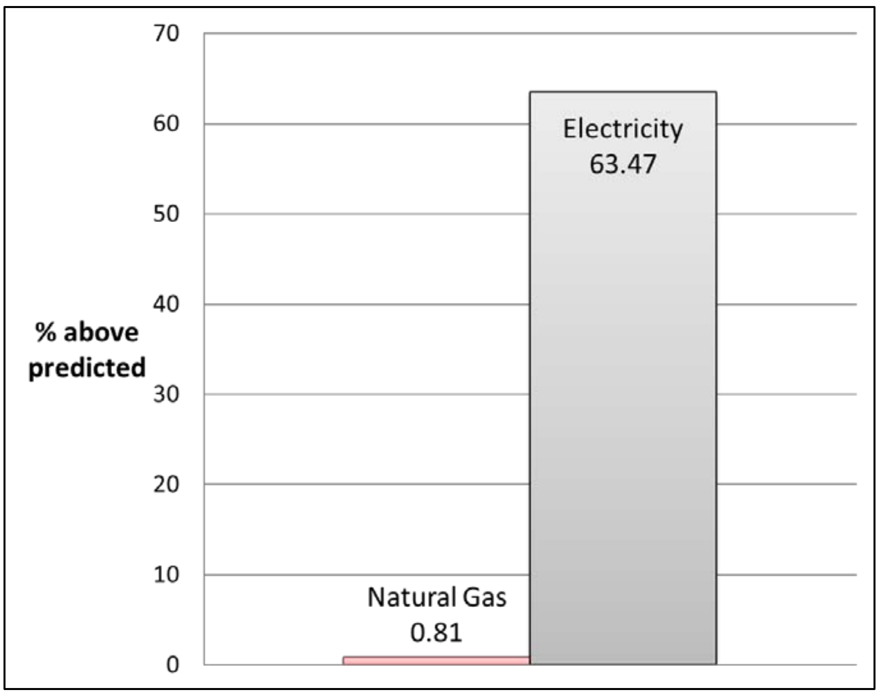
Graph 15: Performance gap at Bren Hall

Bren Hall's EUI is 39% above its predicted modeling baseline (Graph 15). Bren ranks second among the four buildings at UCSB behind the other laboratory building, MSRB. In order to compare actual performance versus predicted at the time of design, POE data and a more in-depth analysis of the performance gap is necessary. Upon receiving the second LEED Platinum certification under the Existing Buildings designation, Bren Hall placed in the

99th percentile for commercial buildings of similar size and type. This report analyzes excess electricity load as a driver of the gap due to building managerial problems.

ELECTRICITY

The electricity load is much higher than anticipated and specifically, computer energy consumption is the biggest driver. Bren Hall is a unique structure in that it is a combination of laboratory, classrooms, offices and meeting rooms. A building of this type is difficult to model due to the dynamic nature of room use and occupancy schedule. The modeling report prepared in 2000 does not provide a detailed expected energy load for individual categories. The only breakdown available is electricity and natural gas. Graph 16 illustrates actual natural gas usage is very near to predicted consumption levels (<1%). However, actual electricity consumption is 63% above predicted. Thus, this allows us to narrow our focus when interpreting the results of the POE.

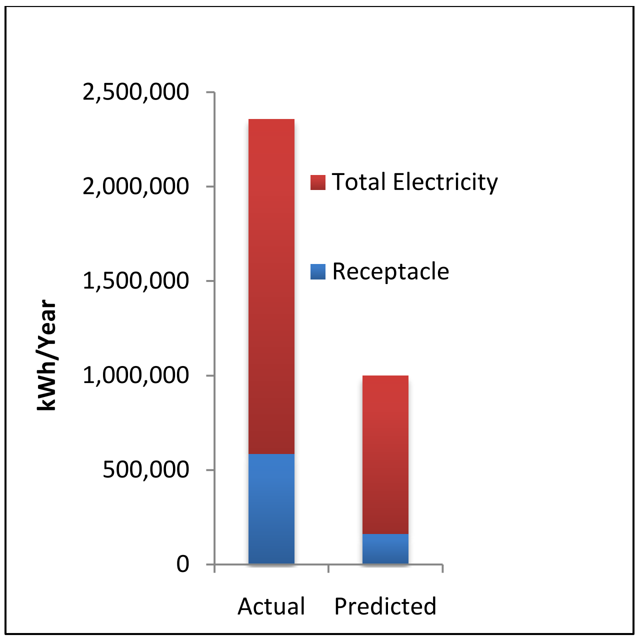


Graph 16: Natural gas and electricity use in Bren Hall

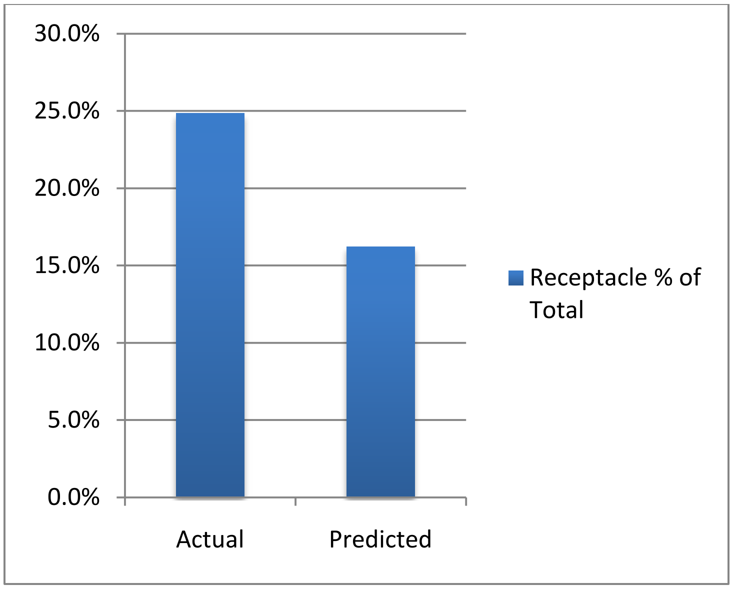
The building is not equipped with sub-metering to quantify electricity consumption of individual systems or devices such as lighting, receptacles, and chilled water. However, the POE identified numbers of plugged-in devices which can be compared to the model to calculate the portion of the performance gap attributable to receptacle load. The POE also includes statistical significant findings related to lighting behaviors and management so this allows for qualitative hypotheses that contribute to the analysis. Figure demonstrates an obvious result: There is a severe miscalculation from the predictive energy model for electricity load. After comparing the POE findings to the receptacle load calculation, it is evident this was either underestimated in the model or another factor is driving receptacle load higher than it should be.

RECEPTACLE LOAD

As stated above, the predictive energy modeling report provided for Bren Hall was very basic and difficult to extract specific modeling assumptions. POE indicated plug-loads are an area for further investigation. Bren Hall predictive model references 2000 California Title 24 default values for plug-loads at 1.5W/sq ft. To compare this to actual values for receptacle load we took the data from Appendix F, which was gathered from counting devices in Bren Hall and applied it to the 1.5W/sq ft default. To calculate actual receptacle load based on total number of devices counted, a recent study by the UC Berkeley Center for the Built Environment (CBE) was referenced to apply average hours/day and days/year values for each device (Appendix F). The total average for hours/day and days per year and applied it to 1.5W/sq ft results in the predictive model value for receptacle load in kWh/year. Graphs 17 and 18 below display the resulting comparisons.



Graph 17: Receptacle load and total electricity



Graph 18: Receptacle load percentage of total electricity

Receptacle load was predicted to be 16% of the total electricity consumption but instead is 25%. This finding allows us to conclude that receptacle load is indeed a significant driver of the performance gap.

POE IDENTIFIES MANAGEMENT PROBLEM

It was observed during the building walkthroughs that every computer in the building was on all the time. In addition, volunteered information from survey participants indicated occupants electricity consumption from computers has great potential for reduction. This included offices, labs, computer labs and study rooms. Cumulative survey results revealed 64% of occupants acknowledge their computer is always on. The building manager stated that the Bren IT department does not allow building occupants to shut down computers. We then interviewed Bren IT manager, to learn the reasoning behind this policy.

The Bren School Computer Resource Committee collectively sets policy related to computers. All computers are remotely controlled to maximize energy conservation without compromising management services including security updates, virus scans, and inventory monitoring. The first priority of the computing committee is to minimize the risk of massive data loss (Simpson, 2012). When computers are not in use, the monitor shuts down and the PC tower operates in a low-energy "sleep" operating state. All computers remain powered on for off-hours management. There are several software packages that would enable computers to operate in a "deeper sleep" operating state, and therefore conserve more energy. It would enable computers to shut down and reboot remotely when management needs to access them. With computers identified as a significant contributor to the performance gap, a similar software package could be an investment for serious consideration for the university in the future.

COMPUTER LOAD

Combining the data from the analysis of receptacle load and the POE results indicating computers to be an issue, we investigated predicted computer consumption versus actual. Using Appendix F enables a comparison between the assumptions the modeler made about computer consumption and actual consumption observed. When the modeler used 2000 Title 24 default values for receptacle load, the DOE2 drivers behind the modeling software would account for computers being on or off per the occupancy schedule. Referencing default values from the CBE report, computers average demand is 90W (Goins, 2011). Based on the occupancy schedule for Bren assumed in the predictive model, the predicted computer contribution to annual energy consumption is as follows (Table 9):

PCs at Bren	Watts	Total Energy (W)	Hrs/Day	Days/Year	kWh/yr
454.4	90	40,927	8	200	65,483

Table 9: Predicted computer contribution to annual energy consumption

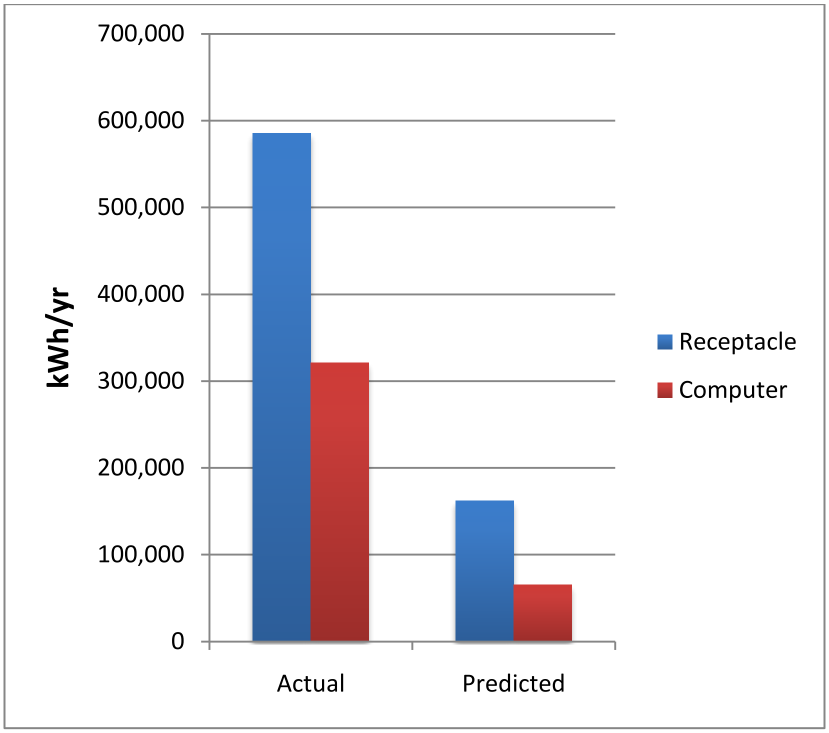
Now, comparing this to the computer consumption we observed from the POE and interview with the Bren IT manager, the actual computer consumption is as follows (Table 10):

	Number	Watts	Total Energy (W)	Hrs/Day	Days/Year	kWh/yr
PCs On	454.4	90	40,927	8	365	119,507
PCs in Sleep Mode	454.4	76	34,561	16	365	201,834
					Total	321,341

Table 10: Bren actual PC electricity consumption

Actual computer consumption values were measured using a P3 International Kill-a-Watt electricity usage device. 20 PCs in Bren Hall were sampled over a 10-minute timeframe while in use and while in sleep mode. The watt values listed above represent the average of the sample.

Actual computer consumption at Bren Hall is 491% higher than was predicted. It was predicted to be 40% of the total receptacle load but instead is 55% (Graph 19). While the reasoning behind the Bren IT computer policy is appropriate, it is still an important exercise to quantify the size of the performance gap specifically related to computer load. The increased computer load equates to 255,858 kWh, $28,144, and 94 tons of CO_2e annually.



Graph 19: Computer and receptacle load

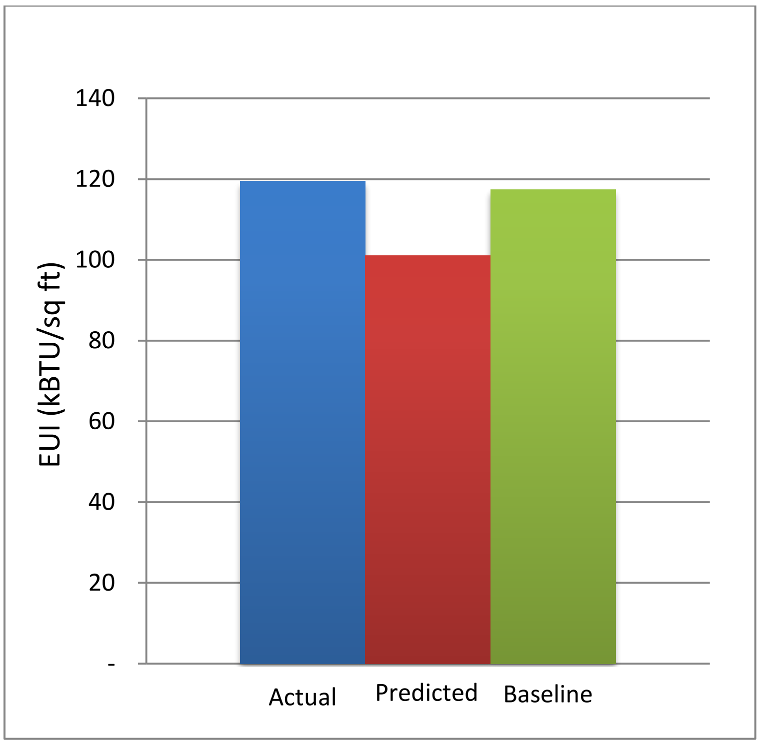
CONCLUSION

The results of the performance gap analysis and POE for Bren Hall reveal electricity consumption as a primary driver due to several managerial issues. Upon investigating what is driving the electricity performance gap, the POE helped establish receptacle load, and specifically computers are the largest cause. POE also rejected the hypothesis that building occupants drive excess electricity consumption. Interviews revealed that Bren Hall IT policy is to never turn off computers. An initial tool to solve the problem without changing their policy includes software to limit consumption during non-use. The computing department managers were unable to provide an estimate of capital costs to install and implementing a software platform to reduce the computer receptacle load. A cost-benefit analysis would be useful in the future to determine possible long-term energy savings for the university given the magnitude of the gap. Perhaps the results could stimulate a reconsideration of the University's policy with individual departments.

CONSTRUCTION QUALITY AND COMMISSIONING

STUDY: MARINE SCIENCE RESEARCH BUILDING (MSRB)

The MSRB followed the example of its neighbor, Bren Hall, and incorporated sustainable features into the building design. Like Bren, MSRB is a mixed-use laboratory building. It was awarded LEED Certified for New Construction when it opened in 2006. In 2010, it was awarded LEED Gold for Existing Buildings demonstrating improved performance from when it opened. LEED category in which there is marked improvement is Energy & Atmosphere – Optimize Energy Performance credit. According to UCSB LEED Project Manager, campus building engineers were able to further reduce energy by 44% (Sager, 2012). Furthermore, MSRB is the best performing building of all UCSB case studies. EUI is 18% above predicted and less than 1% above the modeled baseline building (Graph 20). The performance gap is based on predicted performance from a simulation model performed after the design phase and actual performance in 2009.



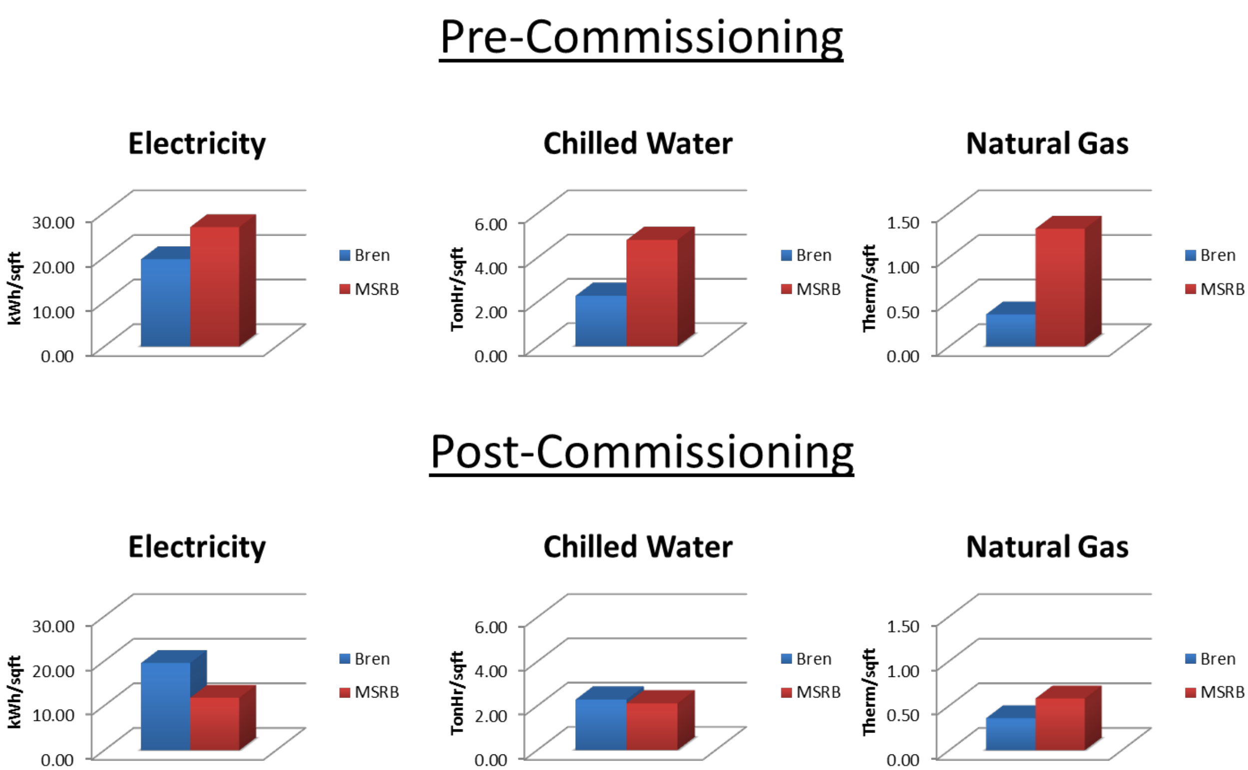
Graph 20: MSRB performance gap

A commissioning exercise performed by UCSB facilities helped the building improve energy efficiency during that time frame so this reduced what would have been a larger performance gap. Literature on the performance gap indicates lack of commissioning is often a significant contributor so this example provides an interesting case for analysis. A further investigation into the commissioning reveals a link to findings from the MSRB POE.

POE IDENTIFIES COMMISSIONING PROBLEM

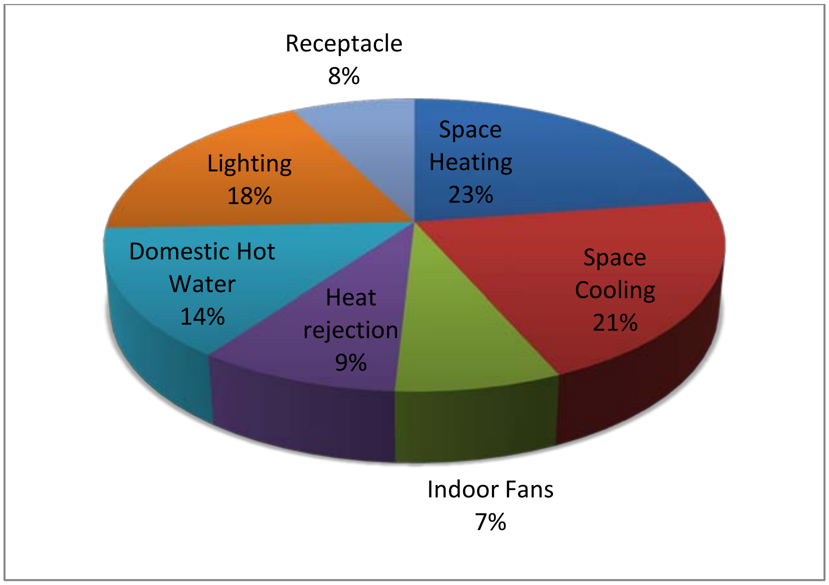
MSRB is similar to its neighbor, Bren Hall, in that they are a combination of laboratory, classrooms, offices and meeting rooms. When Bren Hall was certified as LEED Platinum for Existing Buildings in 2010, it was measured as performing in the 99th percentile for a baseline building of the same size and use. This makes Bren one of the most efficient laboratory buildings in the world in terms of EUI. When MSRB achieved LEED Certification in 2006, it only achieved 6 of possible 17 points in the Energy & Atmosphere (EA) category. Specific to the Optimization of Energy Performance credit, it was awarded 3 points for the predictive simulation model demonstrating 15% EUI compared to baseline. Also within the EA category, it achieved the point available for Measurement & Verification, which rewards designers for applying metering systems to track energy. Because of this metering system, UCSB Facilities were able to identify MSRB was not performing as it should. With the same location, orientation, activity and construction as Bren Hall, UCSB Facilities felt there was opportunity to improve MSRB's energy performance. So in 2007, a team of mechanical engineers at UCSB Facilities initiated a commissioning project to identify causes of energy inefficiency, implement solutions, and verify results.

Using the same utility data we used for the performance gap analysis, the commissioning team identified MSRB was significantly underperforming compared to Bren in all three reported meter readings: kWh/sq ft for main electricity, therms/sq ft for natural gas consumption, and ton hrs/sq ft for chilled water cooling (Dewey 2007). The team commenced to address all three issues but we will only investigate the natural gas discrepancy because it is the largest disparity and related to information we gathered from the POE (Graph 21).

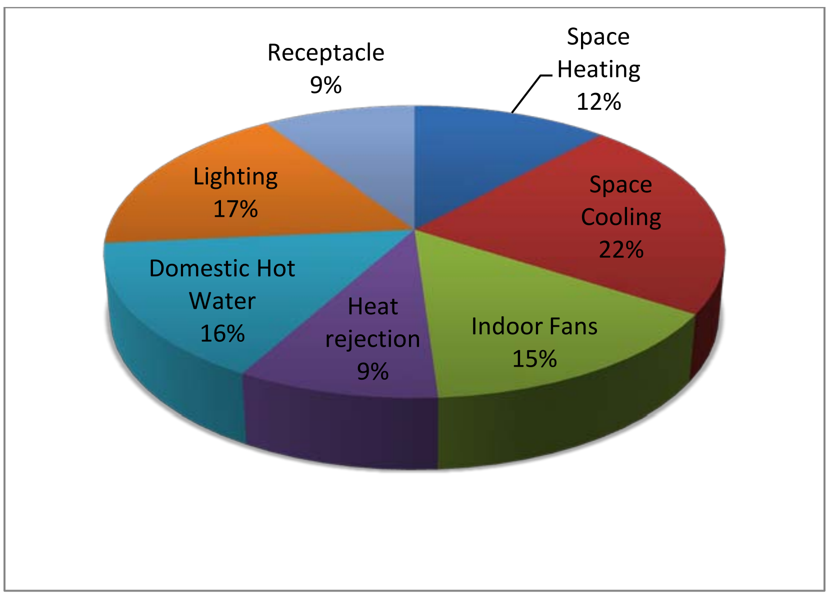


Graph 21: Commissioning results at MSRB

In 2006 (the year data is from) MSRB was consuming almost 4x the amount of natural gas as Bren. The energy model for MSRB predicted space heating in MSRB would be about half the modeled baseline building. As Graph 21 demonstrates, MSRB's predicted performance compared to baseline was using less natural gas for space heating but more electricity for indoor fans. For natural gas to be that much greater than Bren when it was predicted to use half the amount a baseline building would use is a signal of system malfunction.



Graph 22: MSRB Baseline load breakdown



Graph 23: MSRB predicted load breakdown

Upon investigation into causes of natural gas overconsumption, the team discovered a few very simple mistakes were having a major effect. 50% of reheat valves were wired wrong and a chilled water valve on the air-handling unit was stuck open (Dewey 2007). With both of these problems occurring simultaneously, the building was heating and cooling at the same time. A prerequisite to achieving any level of LEED Certification is a commissioning process that includes verification that all HVAC systems are installed and calibrated per design specifications. The reheat valves being wired wrong should have been discovered during the commissioning event performed in 2006.

The faulty systems were addressed and the results have shown a drastic reduction in natural gas consumption. The commissioning team reported in 2008, a year after they fixed the valves, the annual natural gas therms/ square feet had gone from 1.32 to 0.24, which is lower than Bren. This resulted in a $60,300 annual savings for natural gas. Our actual data for 2009 shows natural gas consumption efficiency has improved even more to 0.17 therms/square feet.

CONCLUSION: COMMISSIONING

MRRB demonstrates the positive effects commissioning can have on building energy performance. The observed performance gap we are analyzing would be much greater without the efforts of the UCSB Facilities team in 2007. Combining the solutions the commissioning team implemented to address electricity and chilled water inefficiencies, the commissioning event will save the following annually (Table 11):

	Before	After	Total	$	CO_2e
Annual kWh/sqft	26.76	15.6	678,930 kWh	$74,682	248.49
Annual Chilled Water TonHr/sqft	4.8	1.2	770,038 kWh	$84,704	281.83
Annual Gas Therms/sqft	1.32	0.24	65,703 therms	$70,302	347.9
			Total	$229,689	878.22

Table 11: Commissioning savings

Although the heating system appears to now be running to its optimum efficiency for energy reduction, there was an indication from the POE that it may not be providing occupants with optimum comfort. During the walkthrough it was observed 47% of perimeter offices had personal electric space heaters plugged-in and ready for use. This seemed to be high given the Santa Barbara climate and a building heating system designed to deliver heat to all offices to maintain a comfortable room temperature. Upon bringing this to the attention of the building manager in the interview, it was learned that the MSI department paid for space heaters for occupants that often complained of being cold.

In an interview with the Energy Efficiency Manager at UCSB Facilities, he stated that is generally their policy to not allow occupants to control thermostats when possible because it often leads to inefficiencies. But as demonstrated at MSRB, people and departments value comfort over efficiency. For this research project it was not possible to quantify the amount of electricity used by the 34 electric space heaters in MSRB offices. We only observed usage in the winter and could not extrapolate hourly and weekly usage for other seasons required to quantify contribution of space heaters to annual energy and emission values. However, if we make some basic assumptions on usage rates in the winter combined with the energy consumption value of each space heater (known from testing with Kill-a-Watt measurements), we can estimate a minimum energy consumption value (Table 12).

Device	Number	W	Total Energy (W)	Hrs/Day	Days/Yr	kWh/Yr	CO_2e/Yr
Space Heater	34	500	17,000	8	100	13,600	4.98

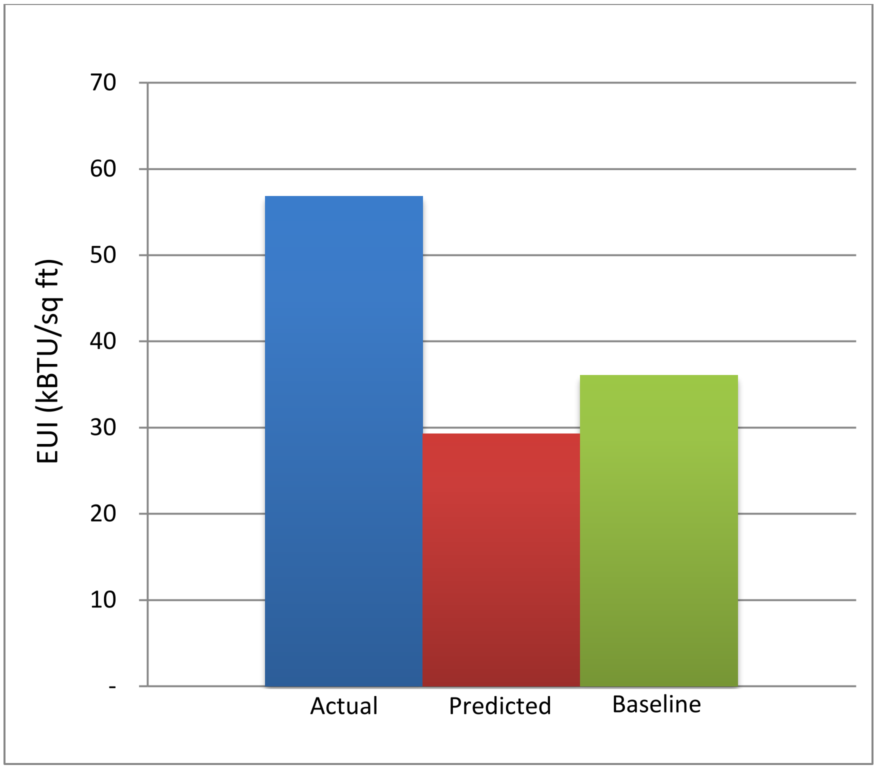
Table 12: Space heater energy consumption

This equates to 0.9% of actual electricity consumption and slightly less than $1,500 annually. We are raising this as a comfort problem that is causing electricity consumption to increase. However, we do acknowledge that if this were to be addressed, it would result in the heating system likely working harder than it is currently, which would increase natural gas usage. Replacing electricity consumption with natural gas consumption would save money (natural gas is cheaper) and emissions (natural gas creates less emissions based on SCE's energy portfolio).

CONSTRUCTION QUALITY

STUDY: STUDENT RESOURCE BUILDING (SRB)

The predictive simulation model for SRB was the most detailed and complete among the UCSB case studies. ARUP engineers provided specific information about lighting power densities, occupancy schedules and breakdowns of data used to calculate energy consumption reductions in all applicable systems. This allowed for a more thorough analysis to identify causes of the performance gap. Combining the information in the ARUP report with the results derived from the POE, we identified multiple sources for the performance gap. After extrapolating the size of each source's contribution to the performance gap the results indicate consumption of natural gas for space heating and domestic hot water to be the greatest contributor.



Graph 24: SRB Performance gap

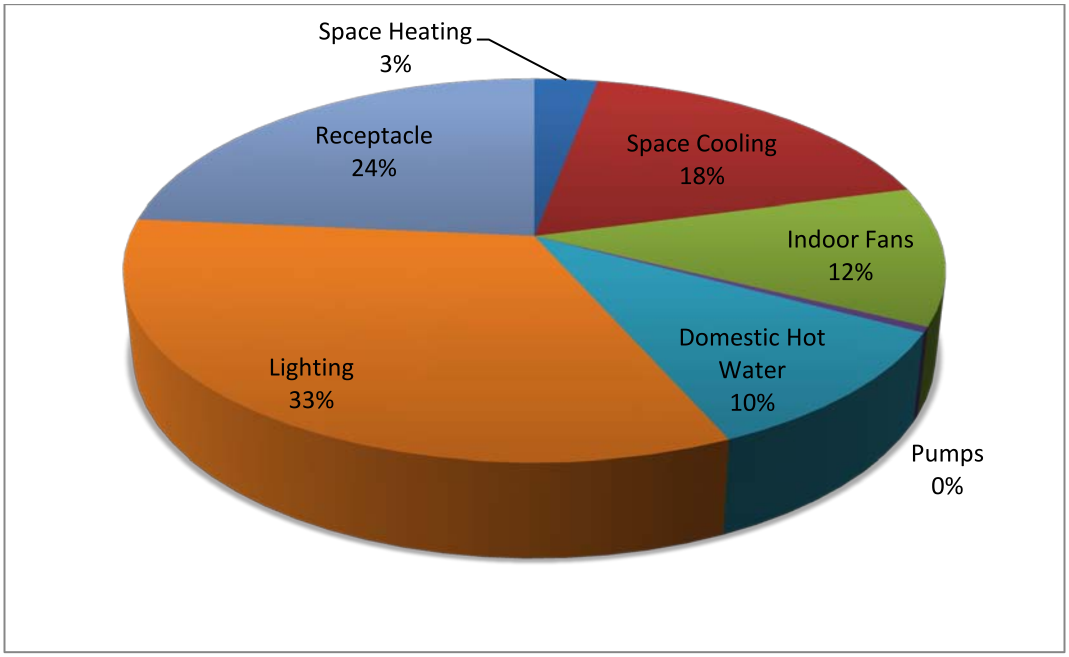
As Graph 24 represents, the actual performance of SRB is almost twice as much as the predictive model and substantially above the modeled baseline building. SRB is the worst performing building in terms of predicted vs actual in the UCSB case study. This was a surprising result given building modelers should utilized most complete information in terms of occupancy schedule and room use out of the four case-study buildings.

NATURAL GAS

SRB uses natural gas for space heating and domestic hot water (DHW). DHW is service water used for domestic purposes including cooking, restrooms and showers. SRB uses a 75 gallon Lochinvar gas-fired hot water heater to provide DHW. This heater is equipped to provide 80,000 Btuh (British Thermal Unit hours) with a recovery efficiency of 84%.

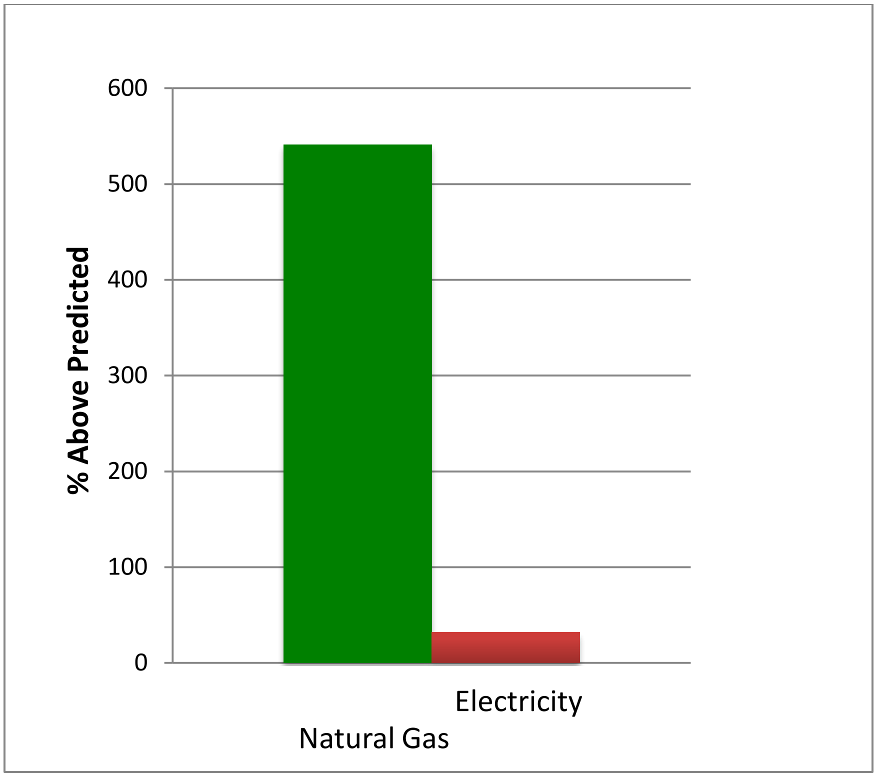
Space heating is distributed to building zones via one Raypak Boiler size 2070 MBH input capacity. Hot water is generated from natural gas and delivered by efficient hot water pumps through variable speed hot water loop through coils and perimeter wall convectors. Exterior offices and rooms are designed to be heated through convection via a radiator heating system. The Children Center and main ground floor atrium are designed to be heated by a radiant floor heating system. The entire system is considered best practice in energy efficiency because it is not using fans to distribute heated air.

The simulation model for SRB predicted an extremely efficient heating system. Compared to the baseline modeled building, SRB was predicted to use 76% less natural gas for space heating. Predicted breakdown of energy load indicates space heating should only be 3% of total energy and DHW 10% for a total of 13% of total energy used by the building generated from natural gas (Graph 25).



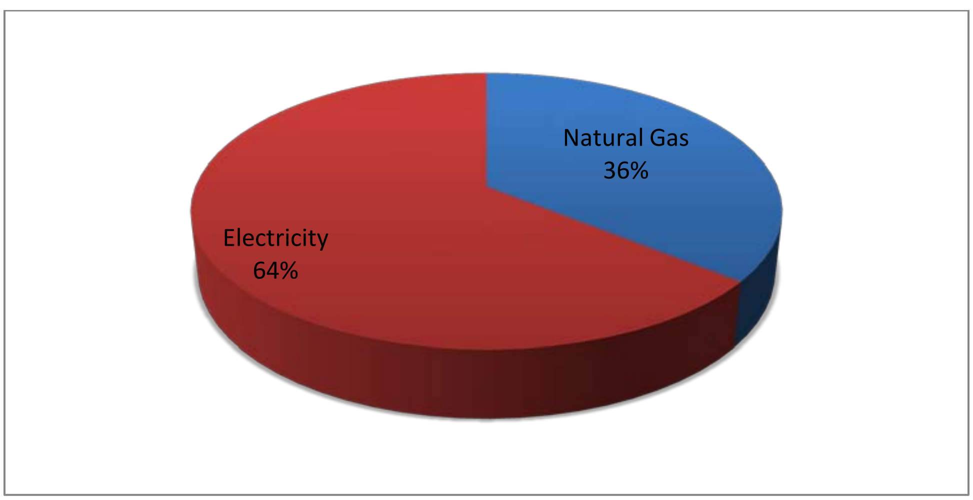
Graph 25: SRB Predicted Load Breakdown

An analysis of actual performance shows the building is using much more natural gas than anticipated. The building is not equipped with sub-metering to identify how much natural gas is being consumed for space heating and DHW individually but our POE will allow us to make informed assumptions. Simply displaying the performance gap for natural gas and electricity demonstrates a staggering result. When breaking down predicted vs actual for the two energy sources individually, Figure 3 shows a gross inaccuracy for natural gas.



Graph 26: Electricity and natural gas

Instead of 13% of total building energy consumption, natural gas is accounting for 36% (Graph 27). It is difficult to determine whether the predictive model grossly underestimated space heating and DHW, the building is not operating properly, or a combination of both. The POE provides important data to identify the cause.



Graph 27: SRB actual load breakdown

POE IDENTIFIES CONSTRUCTION QUALITY PROBLEM

An analysis comparing data from the survey, walkthrough and building manager for the SRB was conducted to identify commonalities and potential sources for energy inefficiencies.

The performance gap analysis indicated a major discrepancy with natural gas consumption. The survey and walkthrough portion of the POE indicated electricity from lighting could be a major contributor. A quantitative analysis shows this is not the case. The remaining portion of the POE is the building manager interview.

SRB's building manager system is unique on the UCSB campus. Because the building is owned and operated by the students with many autonomous organizations inhabiting it, there is no overarching body to act as management. Thus, building occupants in various leadership positions form a committee that acts as the building manager. For an interview on building functions related to energy and occupant behavior we were directed to the Assistant Director of New Student Orientation. The interview revealed many interesting findings related to energy performance (See Building Manager Summary above) but she had one piece of information that was particularly relevant when analyzing with the performance gap breakdown. She described issues with the building's radiant heating flooring system. When the building was first opened in 2007, the main floor of the atrium continuously cracked and UCSB Facilities spent the first year replacing floor tiles constantly. At first, facilities personnel attributed the problem to geotechnical settling, but after persistent issues, the University decided to hire a third-party consultant to analyze the problem. According to her, the consultant determined the radiant heating flooring system was not installed properly and the whole system would need to be replaced. The University has since made the decision to not utilize the radiant heating floor system. It would be too costly to retile the floor with the appropriate material or reinstall the heating system so the system remains dormant.

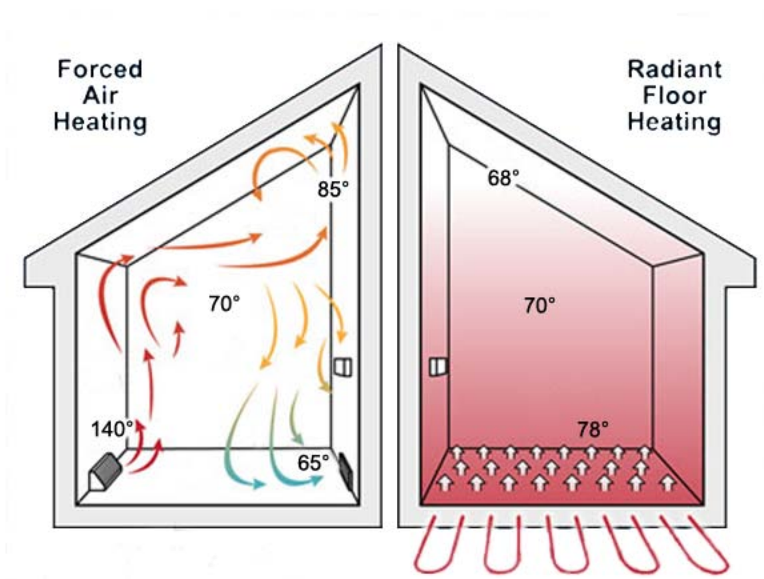


Figure 4: SRB heating

SRB's design incorporated a radiant heating flooring system in the first floor atrium and Children's Center. This heat is designed to keep first floor occupants comfortable and transfer heat to the interior spaces in floors above through radiation, conduction and convection. It is intended to save energy by utilizing low amounts of natural gas to heat panels beneath the floor then transfer that heat through conduction via high thermal mass of concrete and the natural property of heat to rise through an open cavity (atrium). This is efficient compared to a baseline building because it doesn't require electric motors to drive fans that distribute forced air to the building zones (Figure 4). With this system out of commission, the process of heating the building is different than was anticipated when it was modeled.

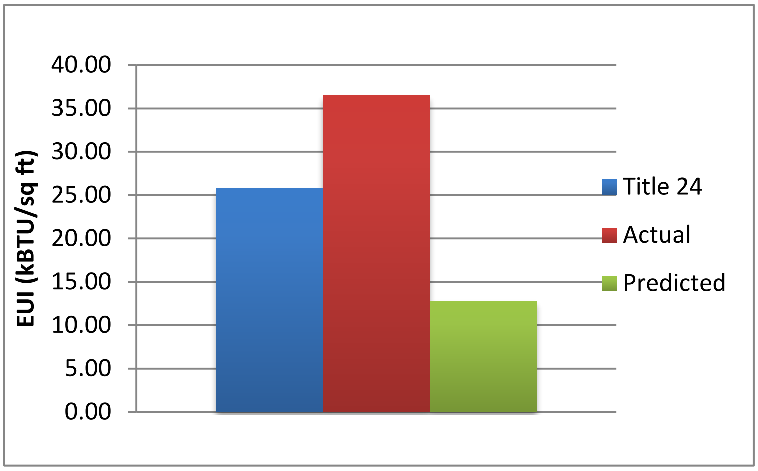
CONCLUSION

The story of the radiant heating floor system represents a combination of management and built quality. It is challenging to quantify without sub-metering but the heating system is not operating at optimal efficiency without the radiant heating floor system. It is possible the grossly elevated consumption of natural gas is due to the perimeter radiator heating units overworking to keep the building at its thermostat set point for comfort. The building manager also indicated the building management committee decided to purchase two space heaters from the miscellaneous fund the student groups contribute to for employees working on the first floor of the atrium. Space heaters consume a relatively large amount of electricity. Although this research is not analyzing built quality, we are able to identify when it is the primary cause of the performance gap through the process of elimination from the POE. The heating system was not installed properly and now management at the facilities level is neglecting to address it due to capital costs. It is not a commissioning issue because the entire heating system would have been commissioned according to USGBC standards before Certificate of Occupancy. The commissioning agent (CxA) could not have determined the floor tiles would be compromised. His or her role is to analyze if the mechanical systems are operating as designed and calibrated to work together.

MODELLING INACCURACIES

STUDY: SAN CLEMENTE VILLAGE (SCV)

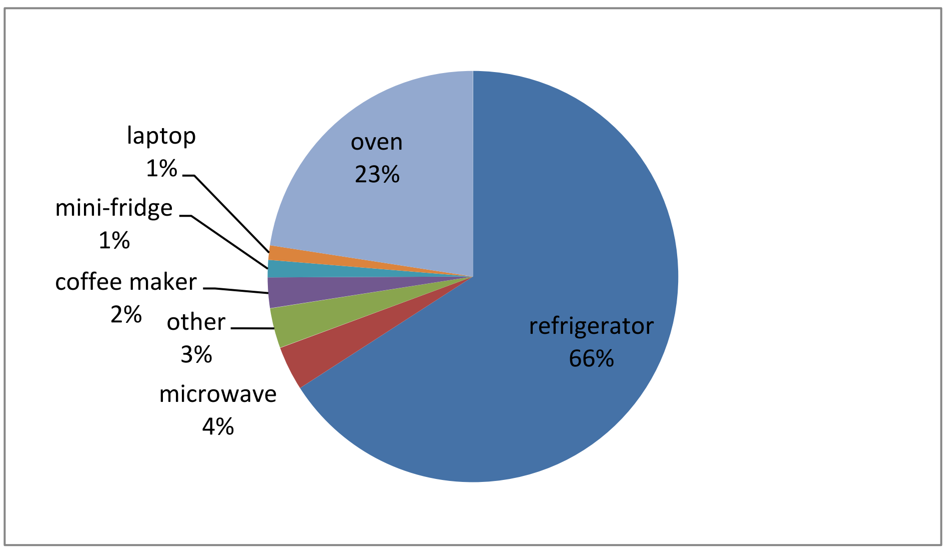
The San Clemente Village, which was intended for graduate students housing, opened in July 2008, and earned LEED Gold one year later. It was one of the largest LEED-Gold projects in the country at 384,000 square feet in total. It is the only residential building sampled in our research. SCV is a relatively new LEED building compared to our other samples. The building has been performing exceptionally well in maintenance and malfunction reporting system, according to the answers from occupant surveys. However, Graph 27 shows that the actual EUI is much higher than both the predicted results and the baseline data (185% and 41.7% higher respectively). In fact, SCV reflects the largest performance gap among our case studies. The excessive energy use mainly resides in electricity, which is 12,931.67% higher than the predictive results. Our post-occupancy evaluation indicates that the additional receptacle loads is the drivers for this discrepancy.



Graph 27: Performance Gap SCV

RECEPTACLE LOAD

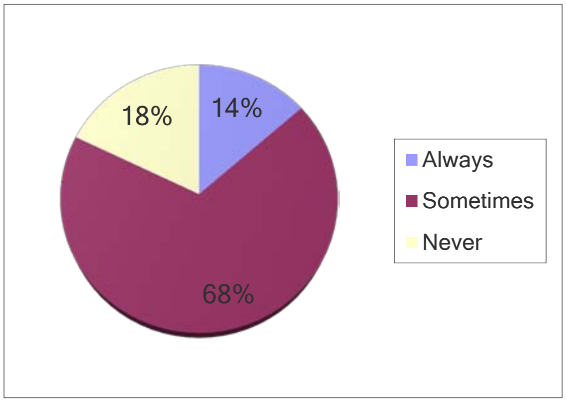
Based on our current knowledge, the predictive model does not take into account the receptacle loads and lighting for energy consumption calculation. However, our POE observations indicate that a considerable amount of additional devices that were brought in by the occupants can contribute greatly to the electricity usage. Graph 28 shows a breakdown of the receptacle loads.



Graph 28: Receptacle loads SCV

The POE approach also quantified the energy usage of receptacle loads, which is 5,465,129 kwh/yr. This is significant because it accounts for 46.7% of the actual yearly energy consupmtion of SCV.

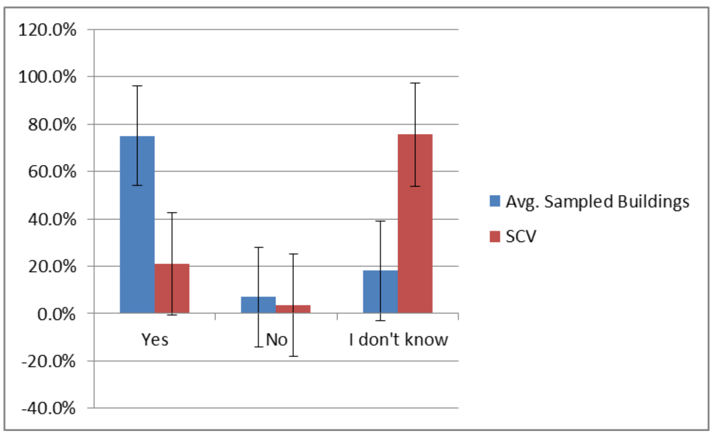
In addition, according to the Building Manager of SCV, the unused plug-ins is a common problem among the occupants, and consumes considerable unnecessary energy. This is also supported by our survey results. As is shown is Graph 29, only 14% occupants reported that they would always unplug electric devices when they are not in use.



Graph 29: Do you unplug electrical devices when they are not in? (SCV)

CONCLUSIONS

According to the occupant behavior survey, SCV occupants tend to have a poorer understanding of the green building concept than the average sampled occupants. As is shown in Graph 30, the portion of occupants who do not know if their building is LEED or not in SCV is much higher than the average (75.5% answered "I don't know", Appendix G).



Graph 30: Is your building LEED? (San Clemente VS. Average)

According to the Building Manager, the San Clemente Village is now in the process of applying for the LEED for Existing Buildings: Operations & Maintenance (EBOM). As a result, the building management team has been making efforts on more intensive commissioning plans as well as occupant education programs. The energy consumption is expected to be reduced in the near future.

PERFORMANCE GAP

Energy bills and survey data are available for the Sino-Singapore Eco-Science Hub building. The Eco-Science Hub was constructed in 2007, received the two-star green building design label in 2008, and successfully gained the continued operation label in 2010. It has four sub-buildings consisting of residences and commercial spaces currently at 60% occupancy as of January 2012. Currently, there are 46 companies totaling 500 employees in all buildings.

The Table 13 below contains electricity consumption figures of the four sub-buildings within Eco-Science Hub.

Building name		**Sino-Singapore Eco-Science Hub**				**Total**
Sub-building		A	B	C	D	
Area (square feet)		250,325.5	105,023.47	108,241.88	156,012.12	619,602.97
Floor	Ground	14	4	4	6	-
	Under ground	1	1	1	1	-
Operation time		September, 2008				
Occupancy rate		60%-70%				
Electricity consumption (KBTU)	2009	3,114,800.38	1,306,807.11	1,346,853.79	1,941,258.92	7,709,720.20
	2010	3,319,481.07	1,392,680.41	1,435,358.65	2,068,823.51	8,216,343.65
	2011	3,660,437.40	1,535,727.83	1,582,789.71	2,281,320.12	9,060,275.05

Table 13: Sino-Singapore Eco-Science Hub buildings

Therefore, energy intensity of the buildings are 12.44 kBtu/sf, 13.26 kBtu/sf, and 14.62 kBtu/sf in the years between 2009 and 2011.

Ideally, for the cases selected in SIP, energy modeling and energy utility bill data should be accessible to calculate the energy performance gap. Additionally, as stated in the literature review, all green building data has to be submitted to the government, which keeps it as a secret, such as national statistics. Due to this lack of transparency, it is very difficult to access modeling data from the design phase of all green buildings in SIP.
To allow for a comparison, actual EUI from green buildings in SIP were compared with EUI form similar green buildings in the UCSB campus. Since EUI is normalized by area, it allows comparison between buildings of different size. In this manner, the predicted EUI for the Student Resource Building (23.36 kBtu/sq ft) was selected as a reference because it has a similar use and falls within the same building category as the Sino-Singapore Eco-Science Hub. According to such comparison, the Sino-Singapore Eco-Hub is performing 42% better than predicted, at only 13.44 kBtu/sq ft.

At first sight this is a surprising outcome. However, certain points need to be clarified for a better understanding of such performance. The sub-buildings in the Eco-Hub are not fully occupied, with occupancy ratios between 60-70%. In addition, the calculations for the actual energy use did not include the natural gas consumption data. Since SIP is in the south part of China, buildings do not use the centralized heat supply except during the winter. Therefore, even if natural gas consumption was included, overall energy consumption is still below that of buildings in UCSB and other LEED buildings in the US

According to Beijing A registered architect continuing education "green building" compulsory curriculum (BRAMC, 2012), average energy consumption per square feet or per capita of buildings in China is lower than that in developed countries. People in China work and live in more centralized high buildings than in lower and disperse buildings in the US, and their comfort requirements are lower. Such variations account for differences in indoor temperature, heat supply period and air circulation.

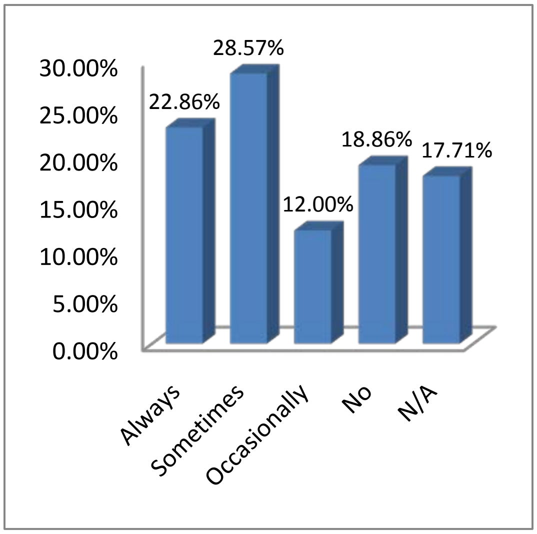
POE RESULTS: OCCUPANT BEHAVIOR

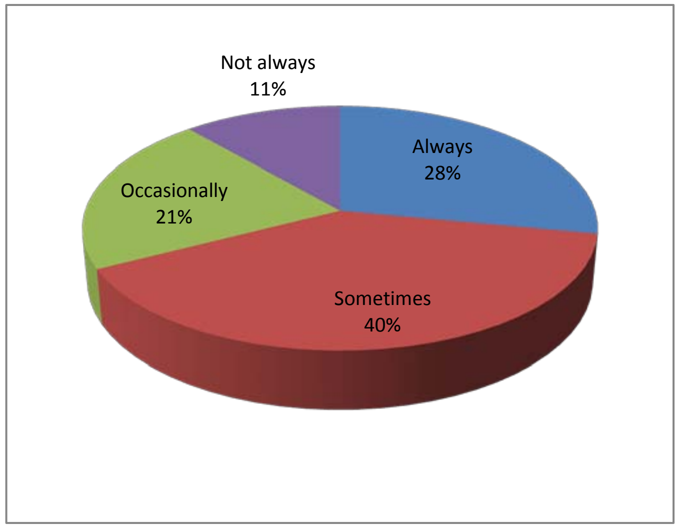
Our colleagues at Nanjing University administered a survey similar to the one fielded in UCSB, after careful language translation. Surveys were delivered and returned during December 26th to 31th, 2011. Researchers at Nanjing University sent out 204 surveys to 22 companies in building A, B, C and D, including 10 electronic surveys. From these, 181 questionnaires were returned, representing an 89% recovery rate. Among those recovered, only 4 were incomplete or repeated, leaving 177 useful surveys. Approximately 40% of surveyed occupants were employees. Results reveal that better occupant behaviors and practices in China could be reasons why their green buildings consume less energy than in other countries.

Regarding to computer use, 73.14% of the occupants always turn off their computers before leaving the office, and another 17.14% of the occupants turn them off most of the time. This is significantly higher than results for UCSB, were computers are mostly left on all the time.

Another reason is occupancy schedules. In China, working hours are 7-9 per day with usually no overtime during the nights and weekends. Compared to occupants in the UCSB case studies, these patterns result in less total working hours and energy consumption.

The following Graphs 31 and 32 show occupant energy saving mentality and behaviors in the Sino-Singapore building. More than a half of them always or sometimes consider energy savings.





Graph 31: Would you tend to adjust blinds/curtains to reduce electric lights usage?

Graph 32: Do you usually consider energy saving when using energy-demand equipment?

ISSUE: DATA TRANSPARENCY

Obtaining energy modeling data was a difficult process. Firstly, building managers stressed that all the data was submitted to the government and confidential within the company. Nanjing University attempted to acquire data from the Chinese government, but failed to do so. Finally, it turned out that there was no energy modeling data compiled with the green building documentation. This leads to believe that the certification process is not as transparent as it claims to be. A similar situation happens with utility bills, reducing the quality of research to be conducted in China.

Doing research in SIP is also full of obstacles. Residential buildings cannot be accessed to conduct surveys or walkthroughs. Even with permission from SIP facilities management, the majority of companies refused researchers to field surveys or conduct walkthroughs. They claimed this distracted employees from their work. In China's state-level system, all the energy and water consumption data required for certification should be submitted to the government, but since they are kept secret there is no way of verifying this actually occurred. The certification process is hindered by lack of transparency to the public who cannot freely access building documentation. Therefore, there is a huge improvement opportunity in increasing data transparency in all the processes of measuring and verifying green building performance in China.

CONCLUSIONS

The main conclusion from this research is that the performance gap exists. From the UCSB case studies, it ranges between 18% and 185%. This is unfortunate, as a building's predicted energy use could be used as a miles per gallon label for buildings, allowing occupants to know how their building should perform and its operating costs.

Another main conclusion from this research is that there is no smoking gun driving the performance gap across all buildings. However, there are four main sources that affect it in varying degrees:

- Predictive energy modeling: LEED and Title 24 employ models to certify green buildings. If these models consistently show less predicted energy than actual, it threatens the credibility of LEED and state building regulations (like Title 24) as a tool to reduce energy consumption. We observed consistent underestimations for occupancy schedules, lighting densities and receptacle loads in each case study. The model completed for the San Clemente villages is clear example of this issue, as it did not include large energy sinks (receptacle loads in apartments). Having better models also facilitates identification of problems associated with building performance.

- Occupants: Although occupants contribute to the gap, results show that larger systematic issues related to management, built quality and commissioning drive the gap. Buildings at UCSB are relatively new so occupants control of energy systems is reduced compared to older buildings. Additionally, survey results show that building features influenced by occupants (windows and lights) are operated according to design specifications. Even when occupants adapt and implement their own strategies (such as the use of space heaters in the Marine Science Research Building) to maintain comfort, this did not result in a significant portion of the gap.

- Management: Some management policies are designed to prioritize system function and appliance lifespan, neglecting effects on energy performance. In the case of Bren Hall, the policy to leave computers on constantly led to an increase of 491% energy use when compared to predicted levels.

- Construction and commissioning: Built quality is a recurring source of the performance gap, which may be identified by commissioning exercises. However, commissioning exercises are rarely conducted In the UCSB case studies, excessive use of natural gas in the Student Resource Building could have been avoided with commissioning exercises. Similarly, sub metering should be included in all buildings (although it represents a high cost) as it helps easily identifying performance issues.

RECOMMENDATIONS

There is no one-size-fits-all approach to reducing the energy performance gap, as it involves multiple stakeholders. For these reasons, a bottom-up approach is most appropriate for addressing the performance gap. Building managers can prioritize cost-effective and simple measures, while working on more complex issues (amending policy and improving predictive energy models) that will yield further improvements in the long term.

As stated in the previous section, building data shows two main results from this project: there is a performance gap and there is no smoking gun driving it across all case studies. Due to this, a traditional POE approach (survey all occupants, walk-through the complete building) is not a resource efficient procedure to identify drivers of the gap. As in the case of SRB, a traditional POE approach would not have led to discovering that the natural gas excess use was due to management decisions regarding the radiant heat floor operation. Instead managers should first narrow the search for the main causes of the performance gap in a particular building. The following decision tree (Figure 5) provides building managers, consultants, government employees and policy makers with a tool to serve as guidance for evaluating and reducing the performance gap. It is intended to be simple to use, with low data requirements that will not compromise the outcome quality, allowing its periodical execution

The decision tree is a tool used to evaluate building performance, identify sources of inefficiencies and propose solutions to reduce the performance gap. Following are a few guidelines to help implement it:

- Managers should first strive to understand building systems, specifically what energy type they use and what proportion of it can be allocated to the building (some systems provide services for more than one building).
- Energy demand data can be obtained from utility bills. Sub metered data shows how different systems consume energy, but even more coarse data can point to the source of the gap.
- The threshold for the size of the gap above which managers should engage in attempts to reduce is equal to the gap in the best performing UCSB building, the Marine Research Science Building. As the performance gap literature expands, this threshold should be revisited.
- Surveys and walkthroughs need not be as extensive as the examples that abound in the academic literature. It is possible that even one open-ended question could be enough to identify issues. In the case of walkthroughs, managers should start by visiting only a handful of rooms, with selection based on the system identified as driving the gap.
- It is up to the building manager's discretion to stop following the decision tree when repeatedly following same set path without getting to a stop. Some issues will need a bigger understanding of buildings and will not be solved by employing this decision tree.
- The decision tree is intended to identify large systematic issues affecting the performance gap. Smaller issues may not be identified and should be dealt with differently.

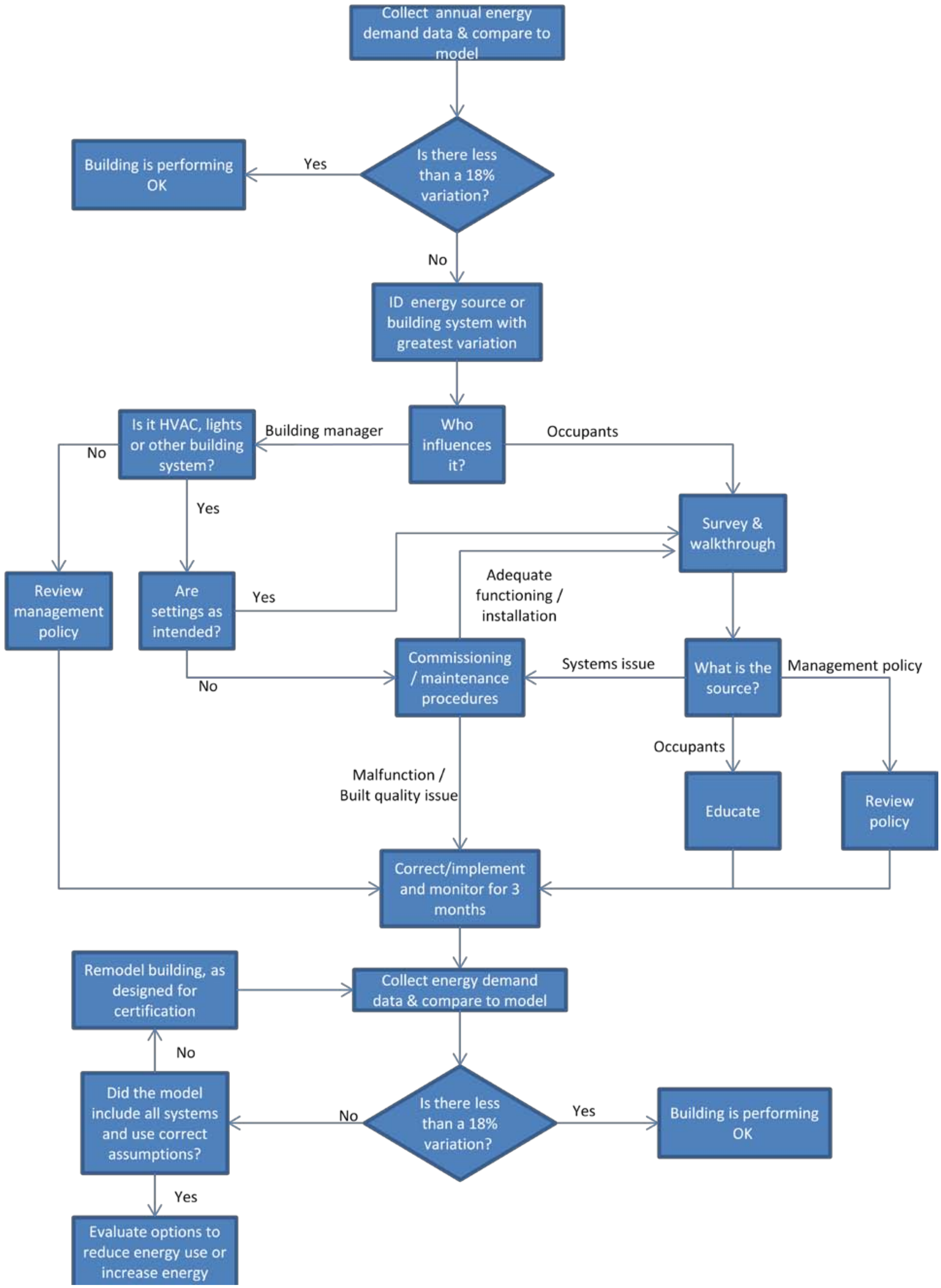


Figure 5: Decision tree

Instructions for using the decision tree are described in the following list. These are meant to clarify and give guidance on specific steps of the process, mainly related to calculations and POE methods.

1. *Predicted EUI*. Calculate from predictive energy model. Usually the model report will present a total EUI. It is important to note that only the site energy value should be used (source energy can be used, but needs to be converted using appropriate factors).

2. *Actual EUI*. Calculate from utility bills for 12 consecutive months. Typically a building will have several energy types being used, with electricity, natural gas and chilled water being the most common. Each one of these should be aggregated on an annual basis and then converted to kBtu using appropriate conversion factors (Energy Star). Once converted, add them and divide by total building area (sq ft) to obtain the actual EUI. Use the same building area value as used in the model.

3. *Performance gap*. Calculate by using the following formula:

   Energy performance gap = [(actual EUI – predicted EUI)/predicted EUI]*100

   The result of this calculation will determine if the building meets the desired performance gap threshold, currently fixed at 18%.

4. *ID energy source or building system with greater variation*. This will vary depending on building sub-metering and model outputs. Most models segment total EUI into building systems or energy type. In the same manner, sub-metered buildings record energy use from specific systems. The following table shows how to proceed with each possible scenario:

		Predictive energy model	
		Systems breakdown	**Energy type breakdown**
Building metering	**Sub-metering**	- Compare predicted and actual energy use of each system - Identify largest discrepancy - Follow decision tree for such system(s)	- Aggregate utility bill data by energy type - Compare to model breakdown - Identify largest discrepancy - List building system(s) that use such energy type - Follow decision tree for such system(s)
	No sub-metering	- Aggregate model output by energy type - Compare to utility bills - Identify largest discrepancy - List building system(s) that use such energy type - Follow decision tree for such system(s)	- Compare predicted and actual use of each energy type - Identify largest discrepancy - List building system(s) that use such energy type - Follow decision tree for such system(s)

Table 14: Building metering and predictive energy model breakdown

5. *Is it HVAC, lights or other building system?* The goal of this step is to differentiate between large system issues and policy decisions that might influence energy efficiency. In this context, "building system" refers to systems which are part of the overall building (plumbing, HVAC, electrical components, fire prevention). For instance, computers are not a building system, with energy use influenced by internal policy (turn on/off policies).

6. *Are settings as intended?* When building systems are installed, they are set to specific values. This value is usually related to the energy use of those systems (thermostat, light schedule).

7. *Survey & walkthrough.* These do need to be extensive, as the decision tree has already identified the system(s) affecting energy performance. Due to this, both methods should be specifically designed to target such system(s). The survey should be an open-question to a few building occupants (a small sample of the whole building population). The walk-through should also include only a small portion of all building rooms and have a few items on the checklist. Both samples should be selected based on their relation to the issue at stake. Sample questions and checklist items can be based on surveys and walkthrough checklists found in the appendixes. Results from these POE methods should point to whether the source of the issue is occupants, management or systems.

8. *Commissioning/maintenance procedures.* The building manager is knowledgeable on how to fix different system issues or can contact the adequate professionals to do so. Usually commissioning events are done on the whole building, but the decision tree will allow for savings (both in time and money) in this step, by clearly identifying the system that needs to be fixed.

9. *Educate.* Procedures for this include workshops, brochures, posters, competitions or other activities that will increase occupant engagement and energy awareness. Lately, the use of real-time energy display dashboards is being used to improve building performance by showing occupants actual energy use and comparing it to desired levels.

10. *Review policy.* Usually, building policies do not consider energy use when aiming at other issues. For instance, turning outside lights on at night is a common practice as it relates to security. However, by doing so the building incurs in additional energy use that can be reduced (without severely compromising security), by only turning on lights at specific locations instead of the whole array.

11. *Model assumptions.* One of the most difficult model inputs are related to occupancy and building characteristics. Good model reports include a list of such assumptions. If they are not included, it is advisable to contact the modeler and ask for such list. Comparing model assumptions with how the building was constructed, operated and occupied can shed light on why the performance is not as expected although the building is being managed correctly. Some building materials change from the design during the construction phase and occupancy characteristics (number of occupants, schedules, use) can be different from the original design. Modelers are very unlikely to include such changes, as the model is run before construction. If discrepancies between model assumptions and actual building characteristics or occupancy are significant, it is recommended to remodel the building. This is a fairly inexpensive procedure that will greatly help manage the building by using the model as a performance guideline.

12. *Options to reduce energy use or increase energy efficiency.* These can include upgrading systems, changing light bulbs to more efficient ones, educating occupants, generating on-site renewable energy or reviewing policies that influence energy use.

To further ease the task of reducing the performance gap, the following are a set of recommendations targeted towards each stakeholder, addressing issues identified in the decision tree as drivers of the gap.

BUILDING OCCUPANTS

Occupant behavior affects the performance gap since it affects the way in which energy is used in a building. Electronic devices, HVAC systems, lighting and other building features are commonly controlled by occupants to a certain degree. Organizing activities that increase occupant engagement and education campaigns, can reduce these issues.

- <u>Educate occupants on building systems and environmental issues.</u> This would improve the way in which buildings are used, as stated by Kaneda et al (2010), who describes issues related to receptacle load reductions and concludes that "providing simple easy to understand feedback to users on their individual energy use can affect behavior and improve energy savings as users become aware of their personal energy use and how their individual actions affect it and modify their behavior to use energy more efficiently." Awareness of energy scarcity, carbon footprint and general environmental impacts due to building underperformance should also be included to ensure an understanding of the importance of operating a green building in a proper way.

- Create energy and water conservation awareness. An effective way of doing this is through real-time energy competitions. Research in college dormitories has demonstrated that if residents can be made aware of the magnitude of their current resource use within dormitories and how it relates to climate change, pollution, habitat degradation, and resource depletion, they may feel motivated and empowered to conserve resources (Petersen, 2007). This shows that the desire to "do the right thing" for the environment, coupled with non-monetary incentives and competition among communities may be a considerable source of motivation for energy and water conservation. If real-time dashboards include a monetary value for the energy and water savings, occupants tend to be more inclined towards resource conservation. Behavior modification can also be done through empathetic and interpretive gauges (use of dynamic animated characters/landscapes to visualize energy and water consumption in a fun and informative way) and orbs (lights that translate energy performance to colors) (Lucid Design Group, 2011).

BUILDING MANAGERS

According to our research, building managers have a great opportunity to reduce the performance gap by dealing with occupant engagement and by implementing building management systems, relative to commissioning, monitoring and maintenance. Building managers need to create training and education program for occupants that include topics discussed earlier.

- Automate systems and procedures. Automated systems coupled with building management features, according to a Technology Brief from the Institute for Building Efficiency (Kummer, 2011), "significant cost reductions through automation are possible, especially if measurement and verification is integrated with energy information, performance monitoring, and fault detection and diagnostics." A main way of increasing building performance is by implementing continuous monitoring and commissioning with the installation of Building Automation Systems (BAS) or Facility Management Systems (FMS). The principal argument with this is that "buildings cannot be efficiently managed until their performance can be monitored and measured" (The Hammersmith Group, 2010). This is also mentioned in other literature (E Source, 2005) and by green building experts, highlighting benefits of these actions as a means of contributing to continuous improvement and improved system maintenance.

- Monitor building performance and occupant behavior. This is useful when designing education workshops and targeting specific trouble areas. In order of doing this, building managers should have a simple checklist to monitor occupant behavior to better synchronize energy usage with building design. Besides this, a more effective management and maintenance system can be used to monitor occupant complaints and concerns about building performance. This system malfunction protocol is easily implemented by having a dedicated email with a ticketing service to ensure occupants that their observations will be dealt with in proper timing. The system constitutes an important part of feedback loops that improve building operation.

- Generate building-specific solutions. Due to the complex and unique characteristics of each building's performance gap, solutions will vary greatly between each one. In this manner, the decision tree is used as a tool to identify issues and propose solutions.

BUILDERS AND DESIGNERS

Although this study does not evaluate construction quality, we do recognize that it is an important factor affecting building performance and model accuracy.

- Enhance information flows. Builders and designers can be extremely helpful to building managers if they explain and give a general overview of how the building was made and how it should operate. This will help understand systems and easily identify problem origins, reducing costs associated with the performance gap. Building managers also benefit from this by having more precise information to share with occupants.

- Cater building design to occupant needs. According to E Source (2005), "people don't want to interact with their building systems; they are busy doing their jobs". Therefore, a solution to this issue is utilizing hybrid controls that automate certain functions (lighting), but allow occupants to manually override the system to maintain their comfort level. At the Marine Science Research Building, elevator use is higher than in Bren Hall, mainly to poor design and access to stairs.

- Merge building and interior design. The mismatch between these is another source of the performance gap. The building will underperform if occupants are not instructed how to accommodate interior design to maximize building benefits. A clear example of this is the increase of glare on computer screens due to improper location and orientation of desks. As with builders, designers should educate building managers on efficient space allocation.

MODELERS

Calculating the energy performance gap takes into consideration model results, thus inaccurate models greatly affect that quantification. Modeling predicted energy performance is a complex task due to the wide array of factors that affect it: occupant behavior, climate, building use and capacity, construction quality and systems maintenance. Specifically, models usually underestimate receptacle load, occupancy schedules and lighting schedules.

- Improve estimations through research. This is not solely the modelers' fault, as they use their best estimate from available information for these factors. Therefore, there is an urgent need for more POE studies that can be used to improve on currently used estimates of the aforementioned inputs. The performance gap will be better estimated once models more closely represent actual building operation.

POLICY MAKERS

At the top of the ladder are policy makers which have influence on green building certification requirements. In this respect, several actions need be taken to reduce the performance gap, all of them relating to more stringent measures.

- Implement incentives to improve modeling. Modeling requirements have to require all energy sources to be modeled, without these changing between building types. As discussed earlier, modelers require better information to increase model accuracy, which can be partially solved with policy designed to promote POE studies.

- Enforce quality assurance and quality control protocols. Certified green buildings should require periodical review, commissioning and fixation of problems as necessary for keeping their label. First steps have been taken by establishing an operation label (EBOM) in LEED, but there is still room for improvement.

- Require higher energy efficiency. An interesting observation from our case studies is that energy efficiency points are not necessary to achieve LEED certification. The standard should be stricter in this sense and require a minimum quantity that ensures higher energy efficiency.

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APPENDIXES

APPENDIX A: POE METHODS

Method	Format/ techniques used	Focus	How long does it take?	When is/can it be used?	Reference
De Montfort method	Forum Walk-through of the buildings	Broadly covers the process review and functional performance	1 day generally	A year after occupation	www.architecture.com click on client forums
CIC DQIs (Design Quality Indicators)	Questionnaire	Covers functionality, building quality and impact	Questionnaire completion is online – takes about 20-30 minutes. Analysis is immediate	At design stage and after completion	www.dqi.org.uk
Overall Liking Score	Questionnaire: – hard copy – web based 7 point scale	Occupant survey Sectors include educational Diagnostic tool	10 minutes for each occupant	About 12 months after occupation	www.absconsulting.uk.com
PROBE	Questionnaire Focus groups Visual surveys Energy assessment Env. Performance of systems	User satisfaction / occupant survey - Productivity Systems performance Benchmarks developed	Overall process varies time needed 2 days (over two months?) One-person month	Any time but PROBE team recommend earliest at 12 months	www.usablebuildings.co.uk
BUS Occupant survey	Building walk-throughs Questionnaire backed up by Focus groups	Occupant satisfaction Productivity	10 – 15 mins to complete questionnaire	On its own or in conjunction with other methods Anytime but often after 12 months	www.usablebuildings.co.uk
Energy Assessment and Reporting Methodology	Energy use survey Data collection e.g. from energy bills	Energy use and potential savings	Full assessment up to one-person week	Once building is completed On its own or in conjunction with other methods e.g. PROBE	www.cibse.org
Learning from Experience	Facilitated group discussions or interviews	Team learning from its experience.	Ranges from single seminar to continuous evaluation	Can be used before, during and after project as 'Foresight, Insight and hindsight' reviews	

(Source: Higher Education Funding Council for England, 2006)

APPENDIX B: BUILDING PROFILES

SAN CLEMENTE VILLAGES
SANTA BARBARA, CA

54% energy cost savings

32% water use reduction

71% regionally sourced materials

LEED® Facts

San Clemente Villages
Santa Barbara, CA

LEED for New Construction v2.1
Certification awarded APRIL 30, 2009

Gold	**42***
Sustainable Sites	8/14
Water Efficiency	4/5
Energy & Atmosphere	12/17
Materials & Resources	6/13
Indoor Environmental Quality	7/15
Innovation & Design	5/5

**Out of possible 69 points*

San Clemente Villages

Sustainable Student Housing

San Clemente provides Mediterranean style sustainable community

PROJECT BACKGROUND

San Clemente Villages was designed to offer UC Santa Barbara graduate students a modern housing option in close proximity to campus and the beach. Staying consistent with the UCSB commitment to building green, the project team included many sustainable features that helped the building be one of the largest LEED Gold projects in the world.

ENHANCING WETLANDS

The project team partnered with the Cheadle Center for Biodiversity and Ecological Restoration (CCBER) at UCSB to include wetland restoration that enhances ecosystems and diverts stormwater. The project was a University of California and California State University Best Practice Award Winner.

STRATEGIES AND RESULTS

With such a large footprint (11.5 acres), it was a major goal for the project team to make energy efficiency a primary focus. Site orientation allows the building to maximize passive heating from solar gain and natural ventilation from prevailing winds. A decentralized boiler system demonstrates how early, collaborative planning can identify simple solutions for substantial energy savings.

Other highlights of sustainable achievement include responsible materials sourcing and recycling. 16% of building materials are from recycled content and 71% were sourced within 500 miles of the project site. Designing for operational performance will enable the building to achieve 100% of recyclables recovery post-occupancy. 97% of construction and demolition waste was diverted from landfills. It is anticipated that the combined trash and recycling efforts will lower the building CO_2 footprint by 40% over its lifetime.

ABOUT SAN CLEMENTE VILLAGES

Opened for fall semester in 2008, San Clemente Villages provides UCSB graduate students fully furnished housing in a beautifully landscaped community. Over 950 students in 21 buildings call San Clemente home every year.

"We are very proud that UC Santa Barbara continues to lead the way in research, teaching, and practice of sustainability."

Henry T. Yang
UCSB Chancellor

Architect: Sasaki Associates, Inc.
Engineers: ARUP
Contractors: Rogers-Quinn Construction, Inc.
Landscape: Sasaki Associates, Inc.
Sustainability Manager: Perrin Pellegrin

Project Size: 384,000 sq ft
Total Project Cost: $152 million
Cost per square foot: $396

ABOUT LEED

The LEED® Green Building Rating System™ is the national benchmark for the design, construction, and operations of high-performance green buildings. Visit the U.S. Green Building Council's web site at www.usgbc.org to learn more about LEED and green building.

www.usgbc.org
202-828-7422

MARINE SCIENCE RESEARCH BUILDING
SANTA BARBARA, CA

15% energy cost savings

25% water use reduction

99% of construction waste recycled

LEED® Facts

Marine Science Research Building
Santa Barbara, CA

LEED for New Construction v2.1
Certification awarded May 10, 2004

Certified	26*
Sustainable Sites	5/14
Water Efficiency	2/5
Energy & Atmosphere	6/17
Materials & Resources	4/13
Indoor Environmental Quality	4/15
Innovation & Design	5/5

**Out of possible 69 points*

PROJECT PROFILE

Marine Science Research Building

Continued Excellence in Sustainable Design at UCSB

Marine Science Research Building emulates design features of Bren Hall

PROJECT BACKGROUND

When it opened in May 2004, the Marine Science Research Building (MSRB) became the home of the Marine Science Institute (MSI) at UC Santa Barbara. The 65,000 square foot building is aptly perched on a bluff overlooking the Pacific Ocean, and brings together faculty, professional researchers, technical staff, graduate and undergraduate students from disciplines across the UCSB campus.

"Third-party verification through LEED confirms that the measures being taken in campus buildings like MSRB are having a positive impact."

Jordan Sager
LEED Program Manager, UCSB

STRATEGIES AND RESULTS

MSRB was sited to take advantage of ocean breezes. Offices have operable windows and transoms so no air conditioning is required. Heaters in the offices automatically shut off when windows are opened. The lighting plan incorporates energy-efficient fixtures and bulbs with daylighting controls for motion. To demonstrate a commitment to renewable energy, the building used 100% green power from wind for its first 2 years of operation. The project also received a LEED point for Innovation & Design for its specific fume hood commissioning.

Housing a school dedicated to the study of marine environments, the building demonstrates best practices in water use reduction. Waterless urinals, low flow sinks, and dual flush toilets reduce water use by 25% saving almost 670,000 gallons/year. Reclaimed water is used to irrigate drought tolerant landscaping.

Architect: Zimmer Cunsul Frasca
Engineers: Flack & Kurtz
Contractors: Pinner Construction
Landscape: Wallace Roberts Todd
Sustainability Manager: Perrin Pellegrin

Project Size: 60,542 sq ft
Total Project Cost: $26 million
Cost per square foot: $429

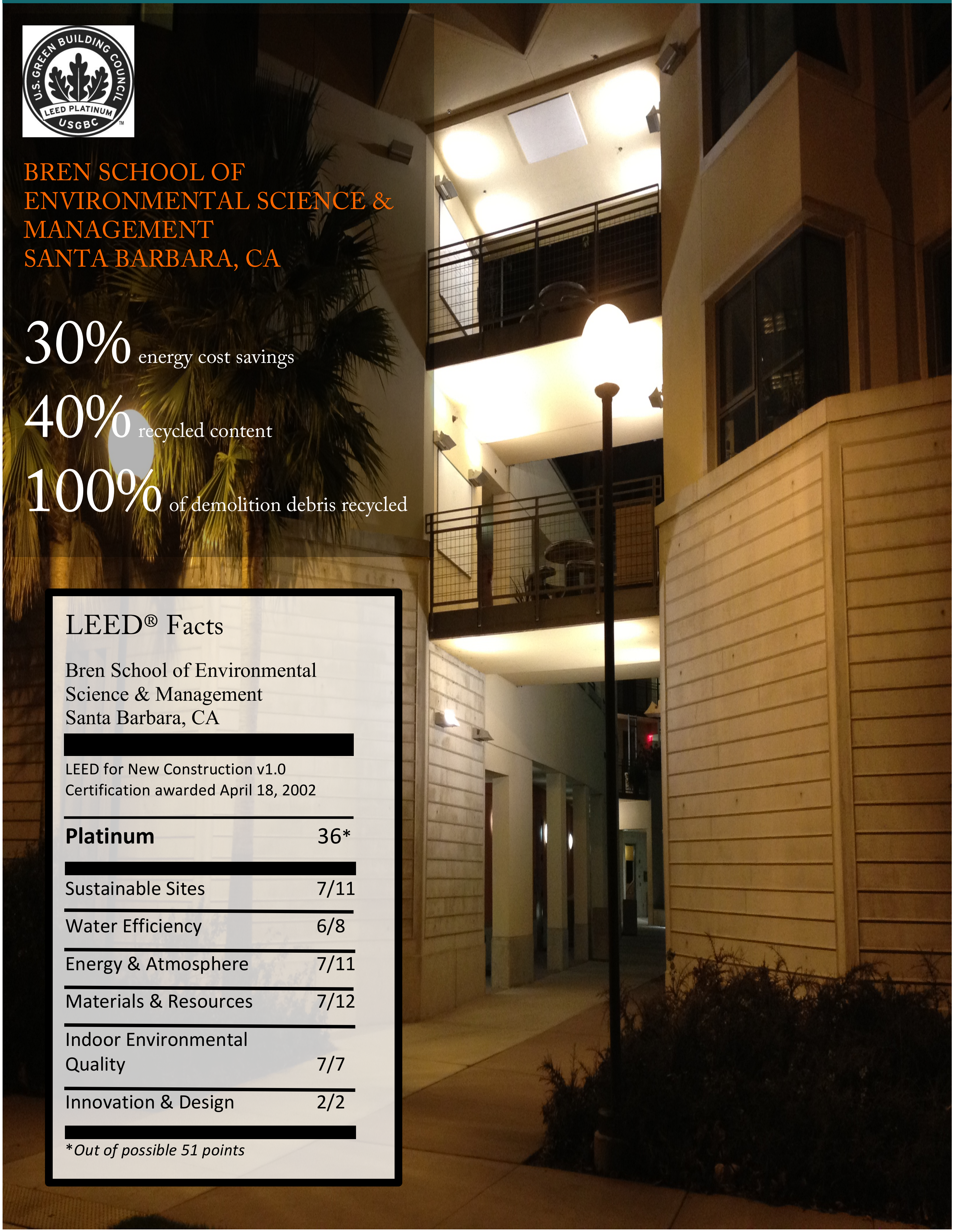
ABOUT THE MARINE SCIENCE INSTITUTE

The Marine Science Institute (MSI) at the University of California, Santa Barbara (UCSB), is committed to fostering innovative and significant research, to promoting effective stewardship, and to sharing the exciting discoveries of the world's oceans.

ABOUT LEED

The LEED® Green Building Rating System™ is the national benchmark for the design, construction, and operations of high-performance green buildings. Visit the U.S. Green Building Council's web site at www.usgbc.org to learn more about LEED and green building.

www.usgbc.org
202-828-7422



BREN SCHOOL OF ENVIRONMENTAL SCIENCE & MANAGEMENT SANTA BARBARA, CA

30% energy cost savings

40% recycled content

100% of demolition debris recycled

LEED® Facts

Bren School of Environmental Science & Management
Santa Barbara, CA

LEED for New Construction v1.0
Certification awarded April 18, 2002

Platinum	36*
Sustainable Sites	7/11
Water Efficiency	6/8
Energy & Atmosphere	7/11
Materials & Resources	7/12
Indoor Environmental Quality	7/7
Innovation & Design	2/2

**Out of possible 51 points*

PROJECT PROFILE

Bren School of Environmental Science & Management

Greenest Laboratory Building in the United States

Bren Hall: A physical manifestation of the School's mission

PROJECT BACKGROUND

When it opened in April 2002, Bren Hall was the first laboratory building in the United States to receive the U.S. Green Building Council's Platinum® certification since the USGBC established its LEED (Leadership in Energy and Environmental Design) program.

DESIGN TO BLEND INTO SURROUNDINGS

The project team designed Bren Hall to make students, faculty and visitors feel as if they are still part of the coastal ecosystem when in the building. Native coastal grasses surround the building and do not require irrigation. Natural daylighting and views of the Pacific Ocean in perimeter offices provide a healthy environment to work and study.

STRATEGIES AND RESULTS

A 42 kW photovoltaic solar reduces $CO2$ emissions by 36,000 lbs per year. ENERGY STAR® white-cap roofing reflects solar heat, limiting the project's contribution to heat-island effect and reducing internal cooling loads. The building's orientation is designed to utilize coastal outside air for cooling when possible. Occupancy sensors ensure that electric lights are turned off when rooms are unoccupied. Combined, the energy-efficient strategies are anticipated to reduce the school's energy cost by 30%.

The project team selected materials based on their environmental characteristics. Materials with recycled content include the foundation, structural steel, carpeting, insulation and linoleum flooring. Wood materials used in the building are Smart Wood™-certified, meeting requirements such as watershed stability, biological conservation, sustained yield forest management, and positive impact on local communities.

ABOUT THE BREN SCHOOL

Since opening in 1991, the mission of the Bren School is to play a leading role in researching environmental issues, identifying and solving environmental problems, and training research scientists and environmental professionals.

"In conceiving Bren Hall we knew we wanted to set a new sustainable design that would be an example for institutions and campuses in the State of California. The Bren School strives to be a world-class arena for scientific leadership and research so the building had to represent that mission."

Perrin Pellegrin
Sustainability Manager, UCSB

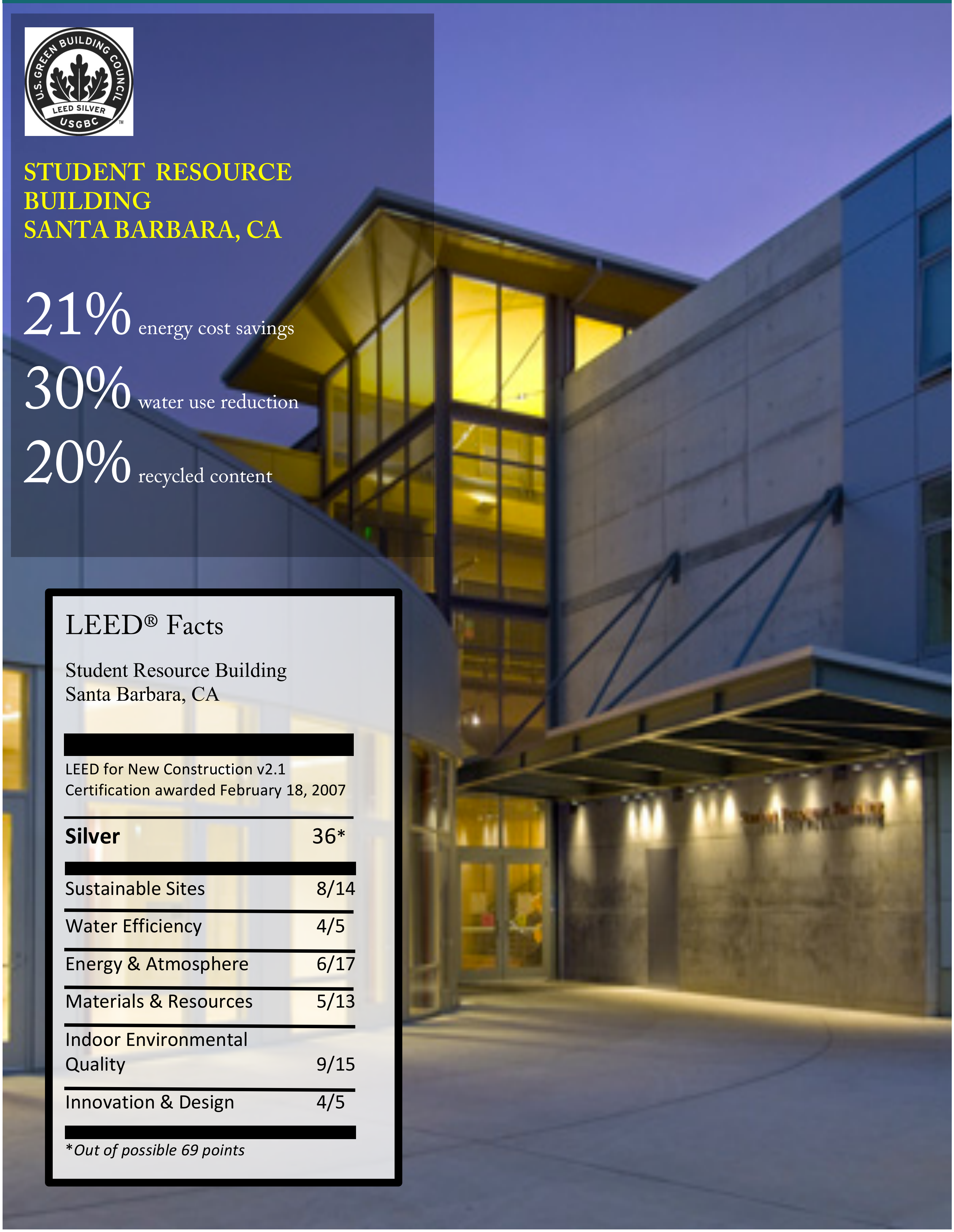
Architect: Zimmer Cunsul Frasca
Engineers: Flack & Kurtz
Contractors: Soltek Pacific
Landscape: Wallace Roberts Todd
Sustainability Manager: Perrin Pellegrin

Project Size: 84,672 sq ft
Total Project Cost: $26 million
Cost per square foot: $307

ABOUT LEED

The LEED® Green Building Rating System™ is the national benchmark for the design, construction, and operations of high-performance green buildings. Visit the U.S. Green Building Council's web site at www.usgbc.org to learn more about LEED and green building.

www.usgbc.org
202-828-7422



STUDENT RESOURCE BUILDING
SANTA BARBARA, CA

21% energy cost savings

30% water use reduction

20% recycled content

LEED® Facts

Student Resource Building
Santa Barbara, CA

LEED for New Construction v2.1
Certification awarded February 18, 2007

Silver	36*
Sustainable Sites	8/14
Water Efficiency	4/5
Energy & Atmosphere	6/17
Materials & Resources	5/13
Indoor Environmental Quality	9/15
Innovation & Design	4/5

**Out of possible 69 points*

Student Resource Building

Sustainability Through Passive Design

Student Resource Building offers a unique approach to air handling.

PROJECT BACKGROUND

When it opened in February 2007, the Student Resource Building (SRB) provided a venue the UC Santa Barbara campus was missing. It is a space for student use that encourages interaction and engagement across student groups. Funded, operated and utilized by students, the SRB represents the sustainability commitment of the UCSB community.

STRATEGIES AND RESULTS

Passive design was a major goal of the project team. SRB achieves over 20% savings in energy due to design that maximizes natural lighting and ventilation. Louvres along the west-facing wall are part of a building-wide, passive ventilation system. The entire system is linked to a sensor atop the building that measures real-time weather conditions and controls outdoor intake to maintain optimal comfort. Large windows line the upper walls of the atrium allowing maximum infiltration of natural light. Additionally, exterior windows line the south-facing offices and are equipped with indoor blinds to allow occupants to control the lighting and solar gain from sunlight.

Responsible sourcing of materials was another important goal of the project team. The flooring is recycled rubber vinyl with low Volatile Organic Compounds (VOCs). All wood doors and cabinetry are made from Forest Stewardship Council (FSC) certified wood that was harvested from sustainably managed forests.

ABOUT THE STUDENT RESOURCE BUILDING

Home to a wide range of University student groups; the SRB embodies the goals of the students for diversity and sustainability. It is utilized by the entire student body to provide comfortable, healthy spaces to meet, study and relax.

The picture below was taken in October 2007. The grove of Jacaranda trees will eventually grow to provide shade for the entire southeast lawn, further reducing heat gain.

Architect: Sasaki Associates, Inc.
Engineers: ARUP
Contractors: Rogers-Quinn Construction, Inc.
Landscape: Sasaki Associates, Inc.
Sustainability Manager: Perrin Pellegrin

Project Size: 63,000 sq ft
Total Project Cost: $24 million
Cost per square foot: $381

ABOUT LEED

The LEED® Green Building Rating System™ is the national benchmark for the design, construction, and operations of high-performance green buildings. Visit the U.S. Green Building Council's web site at www.usgbc.org to learn more about LEED and green building.

www.usgbc.org
202-828-7422

U.S. GREEN BUILDING COUNCIL

APPENDIX C: SURVEYS

Occupant Behavior Survey for Office Buildings

Occupant Behavior Survey Disclaimer

Thank you for offering to participate in this survey. The intention of this survey is to investigate the energy performance of climate-friendly buildings on the UCSB campus. This research is part of our master's group project at the Bren School of Environmental Science and Management at UCSB. The survey should take approximately 10-15 minutes to complete. Your participation is entirely voluntary. There are no risks associated with this survey. We will have exclusive access to the answers you provide. Any personal or sensitive information collected will be separated and coded. Confidentiality will be maintained and identifying data will be destroyed. You must be 18 years of age to participate in this survey.

Upon completing this survey you will be asked to provide your email address if you would like to be entered into a raffle to win an **$100 Apple Store gift card.** Entering the raffle is completely voluntary and your email address will be separated from the survey answers you provide. Your email address will remain completely confidential. It will not be used for any other purpose than to inform you if you win the raffle.

If you have any questions or concerns regarding this survey, please contact Fernando Accame (Project Manager) at faccame@bren.ucsb.edu or (805) 331-4464 at any time. Additionally, if you have any concerns regarding the intentions or procedures in this survey, please contact Kathy Graham at the UCSB Office of Research at graham@research.ucsb.edu or (805) 893-3807.

Your participation is greatly appreciated.

Sincerely,

Fernando Accame, Joel Cesare, Ying Chen, Edward Walsh, Qiong Wu
Bren Nanjing Group Project Team

Please answer all of the following questions with your workspace at Bren in mind.

1. Have you ever changed thermostat settings in your workspace?

- ◯ Yes
- ◯ No
- ◯ I don't have a thermostat
- ◯ I'm not sure if there is a thermostat

2. Is there information available on the correct use and operation of the thermostat in your workspace?

- ◯ Yes
- ◯ No
- ◯ I don't have a thermostat
- ◯ I'm not sure if there is a thermostat

3. If something malfunctions in your workspace, what do you do? Check all that apply.

- [ ] Contact the building manager or appropriate staff person
- [ ] Try to fix it myself
- [ ] Do nothing
- [ ] I do not know the proper means to report a malfunction

4. When you are in your workplace, do you leave your door open?

- [ ] My door is always open
- [ ] On warm or hot days
- [ ] On cooler or cold days
- [ ] Not applicable – I do not have a door
- [ ] Other (please specify)

5. For what reason(s) do you open your door? Check all that apply.

- [ ] I feel too hot (for cool outdoor air)
- [ ] I feel too cold (for warm outdoor air)
- [ ] Air circulation
- [ ] Not applicable – I do not have a door
- [ ] Other (please specify)

6. How often do you turn on the lights during the daytime (8am to 6pm)?

- ○ Very rarely
- ○ 1-2 hours/day
- ○ 3-4 hours/day
- ○ 5-6 hours/day
- ○ 7-8 hours/day
- ○ 8+ hours/day

Occupant Behavior Survey for Office Buildings

7. Why do you turn on the lights? Check all that apply.

- [ ] The natural light is not sufficient for my work
- [ ] There is an inconvenient glare on my computer screen
- [ ] I prefer working with the blinds closed
- [ ] Other (please specify)

8. If natural light glare on the computer screen is a problem, what do you do to adjust? Check all that apply.

- [ ] Close the blinds
- [ ] Turn on the lights
- [ ] Put on sunglasses
- [ ] Modify monitor colors or brightness
- [ ] Do nothing
- [ ] Other (please specify)

9. Do you leave your computer turned on overnight? Check all that apply.

- [ ] Yes, it is always on
- [ ] Occasionally
- [ ] No, I turn it off overnight on weekdays
- [ ] No, I turn it off overnight on weekends
- [ ] There is no permanent computer at my workspace (I use a laptop)

10. Do you have air conditioning (AC)?

- ○ Yes
- ○ No

Occupants with AC

11. Imagine you are feeling too *warm* in your office. What do you do? Select all that apply.

- [ ] Adjust thermostat to maximum then turn down when cool
- [ ] Adjust thermostat slightly
- [ ] Take off a layer of clothing
- [ ] Eat cold food or drink a cold beverage
- [ ] Open the window
- [ ] Open the door
- [ ] Move to different location
- [ ] Turn on a fan
- [ ] Do nothing
- [ ] Other (please specify)

***12. Now imagine that you are feeling too *cold* in your office. What do you do? Select all that apply.**

- [ ] Adjust thermostat to maximum then turn down when warm
- [ ] Adjust thermostat slightly
- [ ] Put on a layer of clothing
- [ ] Eat warm food or drink a warm beverage
- [ ] Close window
- [ ] Close door
- [ ] Move to different location
- [ ] Turn on a space heater
- [ ] Do nothing

Other (please specify)

Occupants without AC

13. Imagine you are feeling too *warm* in your workspace. What do you do? Select all that apply.

- [ ] Take off a layer of clothing
- [ ] Eat cold food or drink a cold beverage
- [ ] Open window
- [ ] Open door
- [ ] Move to different location
- [ ] Turn on a fan
- [ ] Do nothing

Other (please specify)

*** 14. Now imagine that you are feeling too *cold* in your workspace. What do you do? Select all that apply.**

- [ ] Turn on heating system
- [ ] Put on a layer of clothing
- [ ] Eat warm food or drink a warm beverage
- [ ] Close window
- [ ] Close door
- [ ] Move to different location
- [ ] Turn on a space heater
- [ ] Do nothing

Other (please specify)

15. Which of the following controls do you have over the lighting in your workplace? Check all that apply.

- ☐ Light switch
- ☐ Light dimmer
- ☐ Window blinds or shades
- ☐ Desk light
- ☐ None of the above
- ☐ Other (please specify)

16. Do you use any of the lighting controls in your workplace on a daily basis?

- ○ Yes
- ○ No
- ○ I don't have access to lighting controls.

17. Is there information on how the light systems function in your workplace (i.e. motion sensors, dimmers, switches, etc)?

- ○ Yes
- ○ No

18. At your workplace, do you find yourself turning off the lights in an unoccupied room?

- ○ Yes
- ○ No

19. When do you open windows during work? Check all that apply.

- ○ On warm or hot days
- ○ On cooler or cold days
- ○ I am not allowed to open windows
- ○ Not applicable - windows do not open
- ○ I don't have windows
- ○ Other (please specify)

20. For what reason(s) do you open your windows? Check all that apply.

- ☐ I feel too hot
- ☐ I feel too cold
- ☐ For air circulation
- ☐ I am not allowed to open windows
- ☐ Not applicable - windows do not open
- ☐ I don't have windows
- ☐ Other (please specify)

21. How do you utilize the blinds over your windows?

- ◯ They are always closed
- ◯ They are always open
- ◯ They are always partially open
- ◯ Depends on my comfort level (sometimes open, sometimes closed)
- ◯ I do not have blinds (or windows)
- ◯ My blinds don’t work
- ◯ Other (please specify)

22. How many hours on average per day do you spend in your workspace? Please ignore weekends.

- ◯ 1-2 hours
- ◯ 3-4 hours
- ◯ 5-6 hours
- ◯ 7-8 hours
- ◯ 9-10 hours
- ◯ 10+ hours

23. On average how many hours per week do you work outside of normal business hours (8am to 5pm) in your workspace?

- ○ None
- ○ 1-2 hours
- ○ 3-4 hours
- ○ 5-6 hours
- ○ 7-8 hours
- ○ 9-10 hours
- ○ 10+ hours

24. On a weekly basis, how many of these additional work hours are on the weekends?

- ○ None
- ○ 1-2 hours
- ○ 3-4 hours
- ○ 5-6 hours
- ○ 7-8 hours
- ○ 9-10 hours
- ○ 10+ hours

25. Do you unplug electrical devices when they are not in use?

- ○ Always
- ○ Sometimes
- ○ Never

26. Do you consider energy efficiency and potential savings when purchasing or using electrical devices in your home?

- ○ Always
- ○ Sometimes
- ○ Never

27. Have you ever made a different lifestyle choice (such as consumer purchases or transportation methods) to reduce your personal carbon footprint?

- Yes
- No

28. In general, which do you normally take?

- Elevator
- Stairs
- Not applicable

29. Is your building LEED certified?

- Yes
- No
- I don't know

30. Do you consider yourself an environmentalist?

- Yes
- No

31. Do you believe that climate change is occurring?

- Yes
- No
- I have no idea

32. Please describe any issues or concerns with you may have in regards to energy efficiency within your building or workplace.

Background Information

33. Your gender:

- Female
- Male

Occupant Behavior Survey for Office Buildings

34. Your age is:

35. Your completed education level:

- ◯ High school
- ◯ Undergraduate
- ◯ Master's
- ◯ PhD

36. Your occupation (check all that apply):

- ☐ Undergraduate student
- ☐ Graduate student
- ☐ Faculty
- ☐ Staff
- ☐ Research personnel

37. Thank you for your participation.

Follow us on twitter @ BrenGPnanjing

If you would like to be entered into a raffle to win an Apple Store gift card of $100, please enter your email address.

Occupant Behavior Survey for San Clemente

Occupant Behavior Survey Disclaimer

Thank you for offering to participate in this survey. The intention of this survey is to investigate the energy performance of climate-friendly buildings on the UCSB campus. This research is part of our master's group project at the Bren School of Environmental Science and Management at UCSB. The survey should take approximately 10-15 minutes to complete. Your participation is entirely voluntary. There are no risks associated with this survey. We will have exclusive access to the answers you provide. Any personal or sensitive information collected will be separated and coded. Confidentiality will be maintained and identifying data will be destroyed. You must be 18 years of age to participate in this survey.

Upon completing this survey you will be asked to provide your email address if you would like to be entered into a raffle to win an **$100 Apple Store gift card.** Entering the raffle is completely voluntary and your email address will be separated from the survey answers you provide. Your email address will remain completely confidential. It will not be used for any other purpose than to inform you if you win the raffle.

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Your participation is greatly appreciated.

Sincerely,

Fernando Accame, Joel Cesare, Ying Chen, Edward Walsh, Qiong Wu
Bren Nanjing Group Project Team

San Clemente Residents: Please answer all of the following questions with your apartment in mind.

1. Have you ever changed thermostat settings in your apartment?

- ◯ Yes
- ◯ No
- ◯ I don't have a thermostat
- ◯ I'm not sure if there is a thermostat

2. Is there information available on the correct use and operation of the thermostat in your apartment?

- ◯ Yes
- ◯ No
- ◯ I don't have a thermostat
- ◯ I'm not sure if there is a thermostat

3. If something malfunctions in your apartment, what do you do? Check all that apply.

- ☐ Contact the building manager or appropriate staff person
- ☐ Try to fix it myself
- ☐ Do nothing
- ☐ I do not know the proper means to report a malfunction

4. Which of the following controls do you have over the lighting in your apartment? Check all that apply.

- ☐ Light switch
- ☐ Light dimmer
- ☐ Window blinds or shades
- ☐ Desk light
- ☐ None of the above
- ☐ Other (please specify)

5. Do you use any of the lighting controls in your apartment on a daily basis?

- ◯ Yes
- ◯ No
- ◯ I don't have access to lighting controls.

6. Is there information on how the light systems function in your apartment (i.e. motion sensors, dimmers, switches, etc)?

- ◯ Yes
- ◯ No

7. At your apartment, do you find yourself turning off the lights in an unoccupied room?

- ◯ Yes
- ◯ No

8. When do you leave your door open?

- [ ] My door is always open
- [ ] On warm or hot days
- [ ] On cooler or cold days
- [ ] Other (please specify)

9. Why do you open your door? Check all that apply.

- [ ] I feel too hot (for cool outdoor air)
- [ ] I feel too cold (for warm outdoor air)
- [ ] Air circulation
- [ ] Other (please specify)

10. How do you utilize the blinds over your windows?

- ○ They are always closed
- ○ They are always open
- ○ They are always partially open
- ○ Depends on my comfort level (sometimes open, sometimes closed)
- ○ My blinds don't work

11. How often do you turn on the lights during the daytime (8am to 6pm)?

- ○ Very rarely
- ○ 1-2 hours/day
- ○ 3-4 hours/day
- ○ 5-6 hours/day
- ○ 7-8 hours/day
- ○ 8+ hours/day

12. Why do you turn on the lights? Check all that apply.

- [ ] The natural light is not sufficient for my work
- [ ] There is an inconvenient glare on my computer screen
- [ ] I prefer working with the blinds closed
- [ ] Other (please specify)

13. If natural light glare on the computer screen is a problem, what do you do to adjust? Check all that apply.

- [ ] Close the blinds
- [ ] Turn on the lights
- [ ] Put on sunglasses
- [ ] Modify monitor colors or brightness
- [ ] Do nothing
- [ ] Other (please specify)

14. Do you leave your computer turned on overnight? Check all that apply.

- [ ] Yes, it is always on
- [ ] Occasionally
- [ ] No, I turn it off overnight on weekdays
- [ ] No, I turn it off overnight on weekends
- [ ] There is no permanent computer (desktop) in my apartment

15. When do you open windows during while in your apartment? Check all that apply.

- [ ] On warm or hot days
- [ ] On cooler or cold days
- [ ] I am not allowed to open windows
- [ ] Not applicable - windows do not open
- [ ] I don't have windows
- [ ] Other (please specify)

16. Why do you open your windows? Check all that apply.

- [ ] I feel too hot
- [ ] I feel too cold
- [ ] For air circulation
- [ ] I am not allowed to open windows
- [ ] Not applicable - windows do not open
- [ ] Other (please specify)

17. Do you have air conditioning (AC)?

- ( ) Yes
- ( ) No

Occupants with AC

18. Imagine you are feeling too *warm* in your apartment. What do you do? Select all that apply.

- ☐ Adjust thermostat to maximum then turn down when cool
- ☐ Adjust thermostat slightly
- ☐ Take off a layer of clothing
- ☐ Eat cold food or drink a cold beverage
- ☐ Open the window
- ☐ Open the door
- ☐ Move to different location
- ☐ Turn on a fan
- ☐ Do nothing

***19. Now imagine that you are feeling too *cold* in your apartment. What do you do? Select all that apply.**

- ☐ Adjust thermostat to maximum then turn down when warm
- ☐ Adjust thermostat slightly
- ☐ Put on a layer of clothing
- ☐ Eat warm food or drink a warm beverage
- ☐ Close window
- ☐ Close door
- ☐ Move to different location
- ☐ Turn on a space heater
- ☐ Do nothing

Occupants without AC

20. Imagine you are feeling too *warm* in your apartment. What do you do? Select all that apply.

- [ ] Take off a layer of clothing
- [ ] Eat cold food or drink a cold beverage
- [ ] Open window
- [ ] Open door
- [ ] Move to different location
- [ ] Turn on a fan
- [ ] Do nothing

***21. Now imagine that you are feeling too *cold* in your apartment. What do you do? Select all that apply.**

- [ ] Turn on heating system
- [ ] Put on a layer of clothing
- [ ] Eat warm food or drink a warm beverage
- [ ] Close window
- [ ] Close door
- [ ] Move to different location
- [ ] Turn on a space heater
- [ ] Do nothing

22. How many hours per weekday do you spend in your apartment? Do not include weekends.

- ( ) 1-2 hours
- ( ) 3-4 hours
- ( ) 5-6 hours
- ( ) 7-8 hours
- ( ) 9-10 hours
- ( ) 10+ hours

23. On average how many hours per week are you in your apartment during normal business hours (8am to 5pm) in your apartment?

- None
- 1-2 hours
- 3-4 hours
- 5-6 hours
- 7-8 hours
- 9-10 hours
- 10+ hours

24. Do you unplug electrical devices when they are not in use?

- Always
- Sometimes
- Never

25. Do you consider energy efficiency and potential savings when purchasing or using electrical devices in your apartment?

- Always
- Sometimes
- Never

26. Have you ever made a behavioral change (such as consumer purchases or transportation methods) to reduce your personal carbon footprint?

- Yes
- No

27. In general, which do you normally take?

- Elevator
- Stairs
- Not applicable

Occupant Behavior Survey for San Clemente

Use this map for Questions 28 and 29

28. From the above map, in which zone is your apartment located?

- ◯ Zone A
- ◯ Zone B
- ◯ Zone C

29. On which floor is your apartment located?

- ◯ 1st floor
- ◯ 2nd floor
- ◯ 3rd floor

30. Is your building LEED certified?

- Yes
- No
- I don't know

31. Are you an environmentalist?

- Yes
- No

32. Do you believe that climate change is occurring?

- Yes
- No
- I have no idea

33. Please describe any issues or concerns with you may have in regards to energy efficiency within your building including apartment and/or common living spaces.

Background Information

34. Your gender:

- Female
- Male

35. Your age is:

36. Your completed education level:

- High school
- Undergraduate
- Master's
- PhD

37. Your occupation:

- ◯ Undergraduate student
- ◯ Graduate student
- ◯ Faculty
- ◯ Staff
- ◯ Research personnel

38. Thank you for your participation. If you would like to be entered into a raffle to win an Apple Store gift card of $100, please enter your email address.

APPENDIX D: WALKTHROUGH CHECKLIST

1. Room name/number			
2. Floor			
3. Purpose of room	Office, lounge, meeting, auditorium/lecture, lab, computer lab, kitchen, bathroom, mailroom, copy room, lobby		
4. Number of occupants in the room			
5. Name and number of energy-demand equipment in the room?	Equipment checklist Laptop Pc Printer Scanner Copier Paper shredder Kettle Space heater Fan Coffee maker Microwave Toaster Refrigerator Tv Stereo Speakers Microphone Projector		
6. Windows open? How many?			
7. AC on?			
8. Heater on?			
9. Sufficient natural ventilation but AC still on?			
10. Are occupants clothes indicating lack of comfort?	Commentary		
11. Any pressure anomalies in the room?			
12. Blinds open/closed?	Take notes		
13. Open window areas being obstructed?	Notes		
14. Electric lights on? What proportions are on?	25%, 50%, 75%		
15. Electric lights automatic or manual?	Could be both		
16. Is light switch easily available?			
17. Is there sufficient natural light from windows with electric lights on?	Observe areas with bright natural light and artificial lights on.		
18. Meter read--thermometer			
19. Other Comments	PC on without being used Unusual machine noises Drastic temperature		

APPENDIX E: INTERVIEWS

The following guidelines will be used throughout the interview process:

1. Building and laboratory managers will be contacted at least a couple days prior to the interview to explain its purpose, as well as selecting an appropriate date and time to conduct it.
2. Interviews should last approximately 30 minutes and will be conducted by no more than 2 students.
3. Notes will be taken from all answers, including background information on the interviewee (education, experience and other qualifications).
4. If there are some questions that the interviewee cannot answer, students should mark the question and find other ways of obtaining such information (e.g. from other people that could know).

Energy performance

1. How much energy does your building use on a monthly basis?
2. Is there seasonal variation?
3. What are the major energy sinks?
4. Is there a benchmark by which you can compare the building's energy use?
5. Do you know how it is actually performing?

Commissioning & maintenance

1. Ideally, with what frequency should commissioning audits be performed in a building like yours?
2. How often does commissioning actually take place in your building? Why?
3. Is there a special budget assigned to commissioning?
4. Who is in charge of managing commissioning activities?
5. Who pays for commissioning audits in your building?
6. Who performs the commissioning?
7. What were the most common issues found during commissioning events during the past 2 years?
    a. HVAC malfunction
    b. Window malfunction
    c. Lighting
    d. Blinds
    e. Boilers

f. Chillers

8. Are there any protocols for occupants to report building malfunctions?

9. If there is, please describe it focusing on:
    a. Response time (actual and suggested)
    b. Procedure
    c. Involved parties

Occupant behavior

1. Have there been education workshops or information made available to building occupants about the proper use of the facilities?

2. If so, what information was covered?

3. How often do they occur?

4. Who is in charge of these tasks?

5. In your building, what are the most common issues associated with occupant behavior that have an effect on energy performance?
    a. Thermostat use
    b. Lights on all day
    c. Open windows/doors with HVAC on
    d. Extra electric devices

6. Has anything been done to solve them?

7. Are there any incentives for occupants to be more energy efficient?

8. Do you think occupant behavior plays an important role in the building's energy performance?

APPENDIX F: RECEPTACLE LOAD

BREN

	TOTAL	Watts (each)	Total Energy (W)	Hrs/day	days/yr	kwh/yr
coffee maker	18.3	1750.0	32058.0	4.0	200.0	25646.4
copier	8.2	1440.0	11833.0	2.0	365.0	8638.1
desklamp	10.4	18.0	187.8	3.0	250.0	140.9
dishwasher	0.7	1300.0	866.7	1.0	150.0	130.0
fan	6.8	100.0	684.2	4.0	150.0	410.5
fax	5.2	35.0	182.6	4.0	150.0	109.6
kettle	17.0	750.0	12739.1	4.0	200.0	10191.3
laptop	106.4	30.0	3191.6	8.0	250.0	6383.2
large printer-copier	1.0	1440.0	1440.0	2.0	365.0	1051.2
microwave	18.3	1600.0	29310.1	1.0	150.0	4396.5
minifridge	10.4	500.0	5217.4	24.0	365.0	45704.3
monitors (pc or laptop)	194.7	57.0	11096.1	4.0	365.0	16200.3
paper shredder	6.2	500.0	3108.7	2.0	365.0	2269.3
pc on	454.7	90.0	40927.0	8.0	365.0	119506.9
pc sleep	454.7	76.0	34560.6	16.0	365.0	201833.8
printer	74.2	176.0	13065.1	2.0	365.0	9537.5
projector	12.1	250.0	3031.3	6.0	250.0	4546.9
refrigerator	10.5	1265.0	13282.5	24.0	365.0	116354.7
scanner	2.0	20.0	40.0	2.0	150.0	12.0
speaker	67.8	50.0	3391.3	6.0	250.0	5087.0
stove/oven (kitchen)	2.7	5200.0	13866.7	2.0	250.0	6933.3
toaster	1.3	1100.0	1466.7	1.0	150.0	220.0
TV	3.3	72.0	234.0	2.0	365.0	170.8
VHS	1.6	20.0	32.5	1.0	150.0	4.9

MSRB

	TOTAL	Watts (each)	Total Energy (W)	Hrs/day	days/yr	kwh/yr
coffee maker	13.5	1750.0	23637.7	4.0	200.0	18910.1
copier	3.0	1440.0	4382.6	2.0	365.0	3199.3
desklamp	31.1	18.0	559.6	3.0	250.0	419.7
fan	6.1	100.0	608.7	4.0	150.0	365.2
fax	1.0	35.0	35.0	4.0	150.0	21.0
kettle	25.5	750.0	19103.3	4.0	200.0	15282.6
laptop	28.5	30.0	855.4	8.0	250.0	1710.9
large printer-copier	9.1	1440.0	13147.8	2.0	365.0	9597.9
microwave	24.3	1600.0	38875.4	1.0	150.0	5831.3
minifridge	18.3	500.0	9130.4	24.0	365.0	79982.6
monitors (pc or laptop)	118.7	57.0	6765.7	4.0	365.0	9877.9
paper shredder	6.1	500.0	3043.5	2.0	365.0	2221.7
pc	303.6	90.0	27321.5	8.0	365.0	79778.8
Phone	20.5	7.0	143.6	4.0	150.0	86.1
printer	88.1	176.0	15508.4	2.0	365.0	11321.1
projector	4.0	250.0	1000.0	6.0	250.0	1500.0
refrigerator (office)	2.7	1265.0	3373.3	24.0	365.0	29550.4
refrigerator (lab)	33.3	1265.0	42166.7	24.0	365.0	369380.0
scanner	3.0	20.0	60.9	2.0	150.0	18.3
space heater	30.4	500.0	15217.4	8.0	160.0	19478.3
speaker	16.3	50.0	817.0	6.0	250.0	1225.5
stove/oven (kitchen)	14.4	5200.0	74985.5	2.0	250.0	37492.8
toaster	10.3	1100.0	11279.0	1.0	150.0	1691.8

SRB

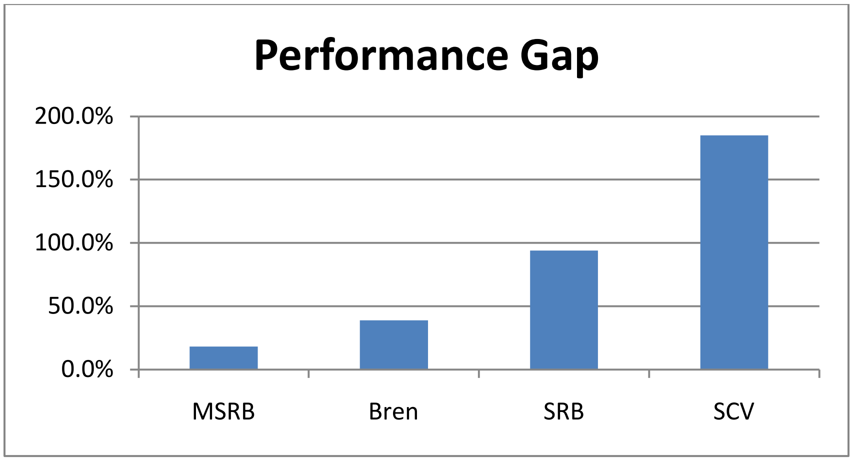
Office Equipment	Quantity	Watts (each)	Total Energy (W)	Hrs/day	days/yr	kwh/yr
Copier	21	1440	30240	2	365	22075.2
Digital Projector	1	250	250	0.5	150	18.75
Electric Heater	5	500	2500	4	120	1200
fan	5	100	500	150	4	300
Mini-Fridge	2	500	1000	24	365	8760
Monitor	190	57	10830	4	365	15811.8
PC	190	90	17100	8	365	49932
Phone	100	7	700	4	150	420
Printer	73	176	12848	2	365	9379.04
Refrigerator	7	1265	8855	24	365	77569.8
Scanner	10	20	200	2	150	60
TV	15	72	1080	2	365	788.4
Water Cooler	4	90	360	24	365	3153.6
Coffee Maker	10	1750	17500	4	200	14000
Microwave	5	1600	8000	1	150	1200
Oven (electric)	2	5200	10400	0.5	100	520
Tea Kettle (electric)	10	750	7500	4	200	6000
Toaster	1	1100	1100	1	150	165
Toaster Oven	5	1500	7500	1	150	1125

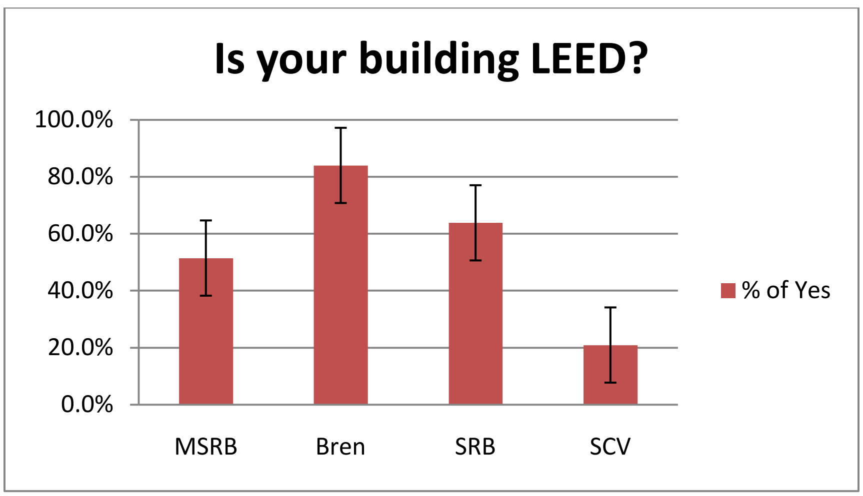
SCV

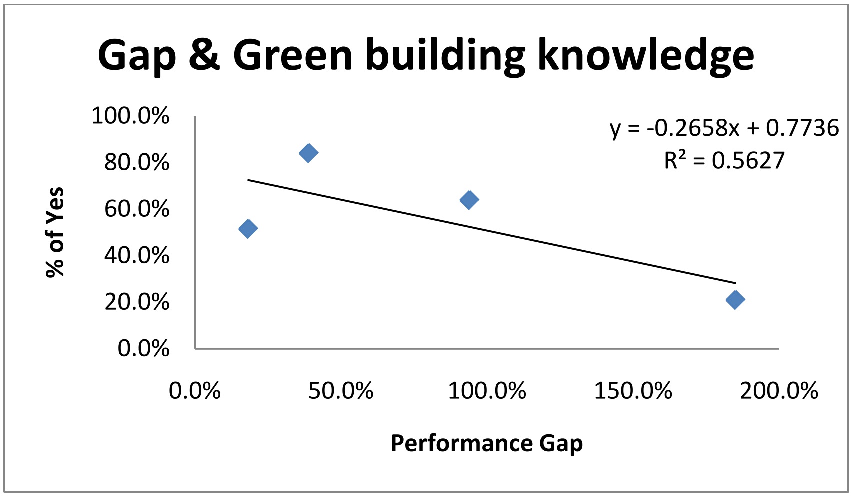
	observed devices	ratio (device/room)	TOTAL (device)	Watts (each)	Total Energy (W)	Hrs/day	days/yr	kwh/yr
Aquarium (small)	1.0	0.1	17.1	200.0	3421.1	24.0	365.0	29968.4
Blender	4.0	0.2	68.4	300.0	20526.3	0.1	200.0	410.5
cable connector	3.0	0.2	51.3		0.0			0.0
can opener	1.0	0.1	17.1	175.0	2993.4	0.1	250.0	37.4
coffee maker	12.0	0.6	205.3	1750.0	359210.5	1.0	365.0	131111.8
DVD	6.0	0.3	102.6	20.0	2052.6	2.5	365.0	1873.0
Electronic musical instrument	3.0	0.2	51.3		0.0			0.0
fan	3.0	0.2	51.3	100.0	5131.6	4.0	120.0	2463.2
Griller	2.0	0.1	34.2	1440.0	49263.2	0.4	150.0	2955.8
Hair dryer	7.0	0.4	119.7	1500.0	179605.3	0.3	365.0	16389.0
Iron	1.0	0.1	17.1	1400.0	23947.4	1.0	60.0	1436.8
kettle	9.0	0.5	153.9	750.0	115460.5	0.5	365.0	21071.5
laptop	55.0	2.9	940.8	30.0	28223.7	6.0	365.0	61809.9
mini-fridge	1.0	0.1	17.1	500.0	8552.6	24.0	365.0	74921.1
microwave	19.0	1.0	325.0	1600.0	520000.0	1.0	365.0	189800.0
oven	19.0	1.0	325.0	5200.0	1690000.0	2.0	365.0	1233700.0
refrigerator	19.0	1.0	325.0	1265.0	411125.0	24.0	365.0	3601455.0
Rice Cooker	9.0	0.5	153.9	500.0	76973.7	0.8	200.0	11546.1
Router	1.0	0.1	17.1	10.0	171.1	24.0	365.0	1498.4
speaker	2.0	0.1	34.2	50.0	1710.5	4.0	365.0	2497.4
Stereo	9.0	0.5	153.9	32.0	4926.3	4.0	365.0	7192.4
toaster	17.0	0.9	290.8	1100.0	319868.4	0.3	365.0	29188.0
TV	15.0	0.8	256.6	72.0	18473.7	4.0	365.0	26971.6
Vacuum	14.0	0.7	239.5	1200.0	287368.4	0.5	60.0	8621.1
Video games	8.0	0.4	136.8	100.0	13684.2	2.0	300.0	8210.5

APPENDIX G: SURVEY STATISTICS

Occupant knowledge of green buildings.

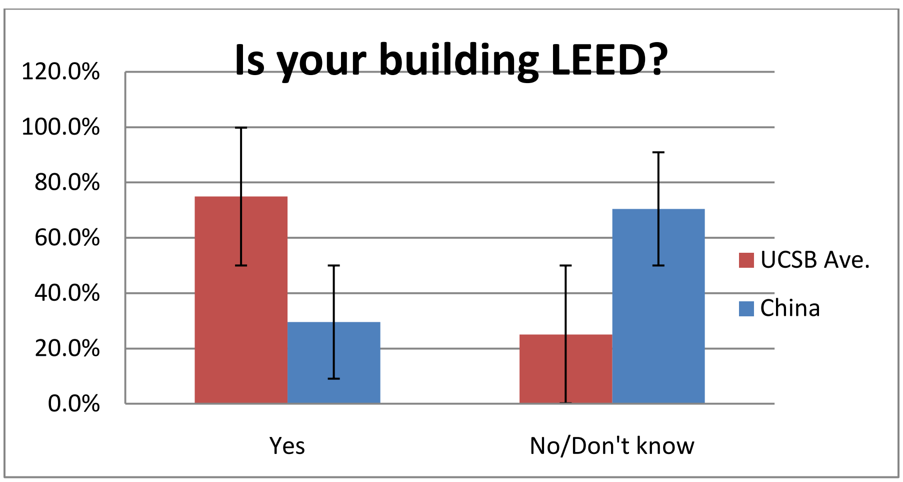






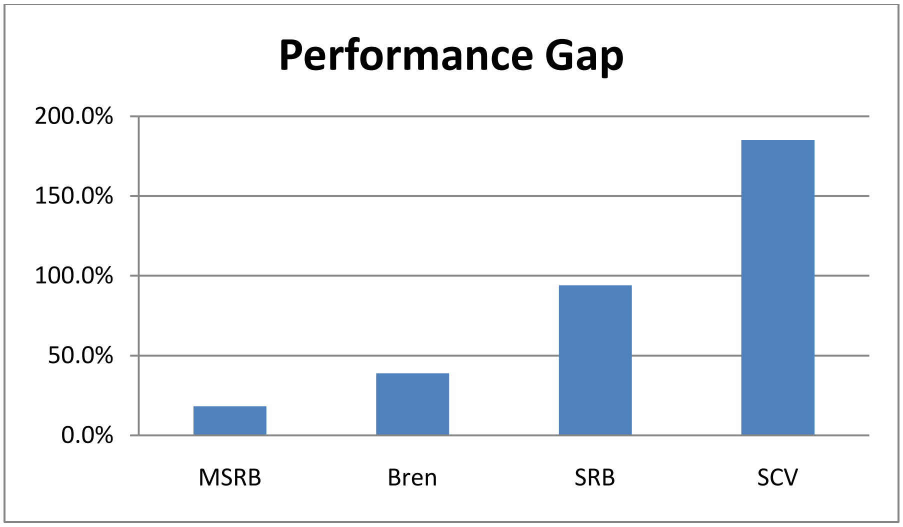
X-square test : X-squared = 157.8466, df = 6, p-value < 2.2e-16: AKA: buildings are different.

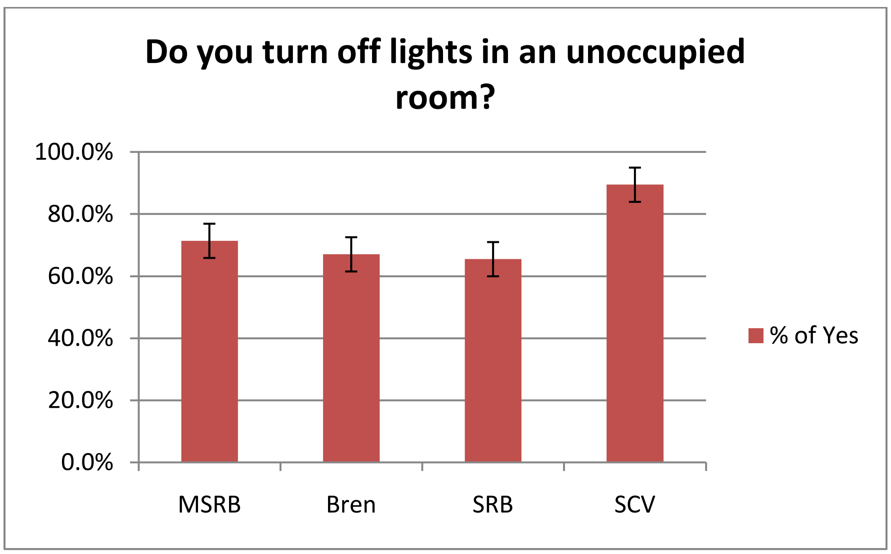
We did a regression to see the correlation between performance gap and the green building knowledge of occupants. We got a low R-square value which is 0.5627, so we reject our hypothesis that they are related. And they are not statistically related. However, we agree that we would get a more robust result if we can have more samples.



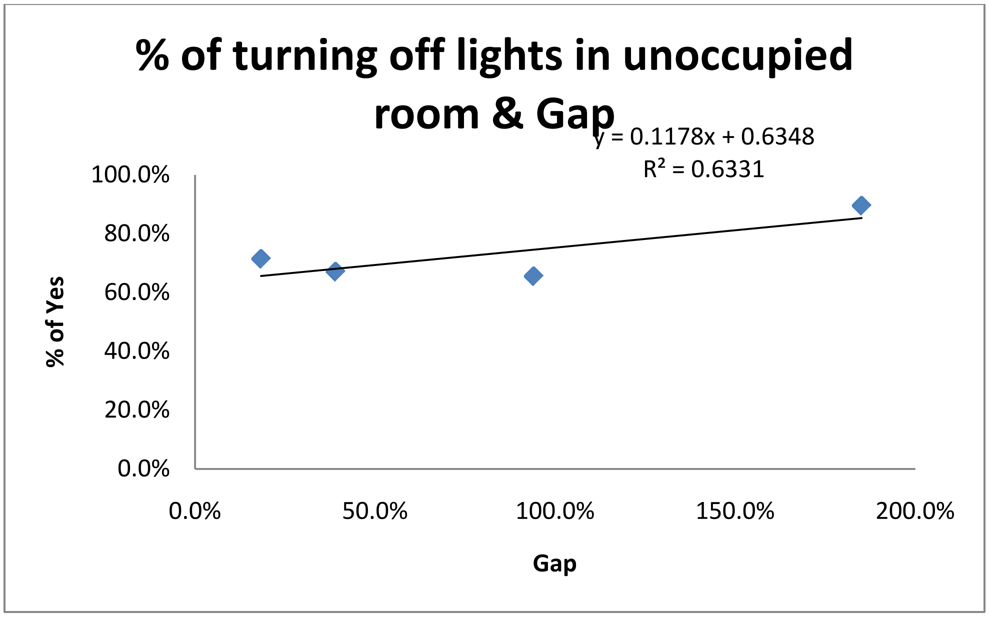
X-squared = 95.9716, df = 2, p-value < 2.2e-16

Unoccupied room lighting

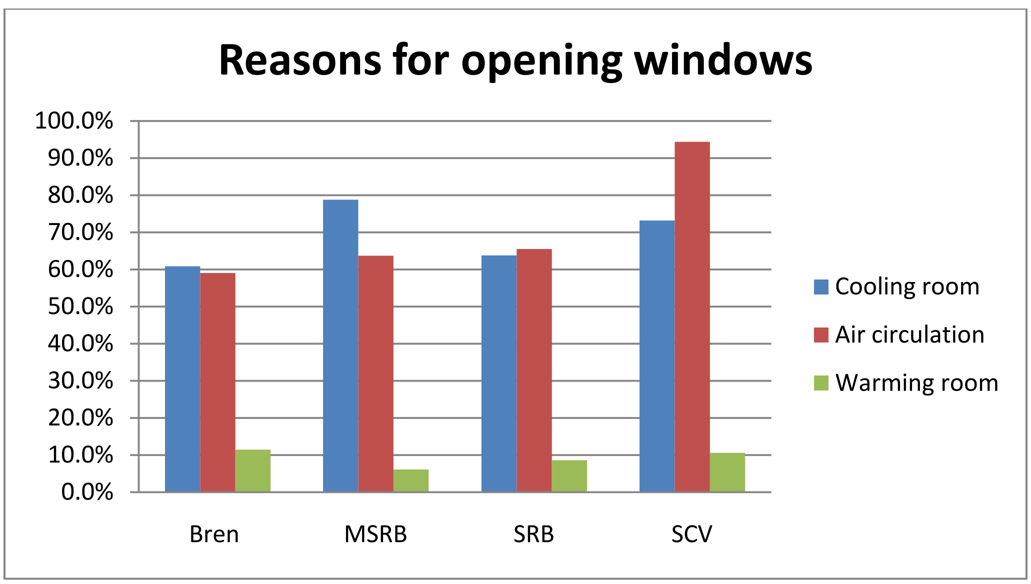




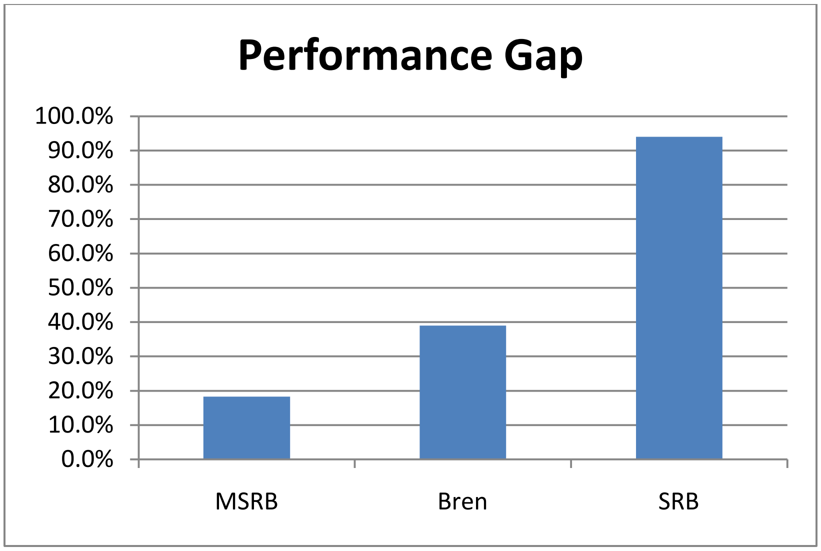
X-square test: (X-squared=0.3587, df=2, p-value=0.8358)

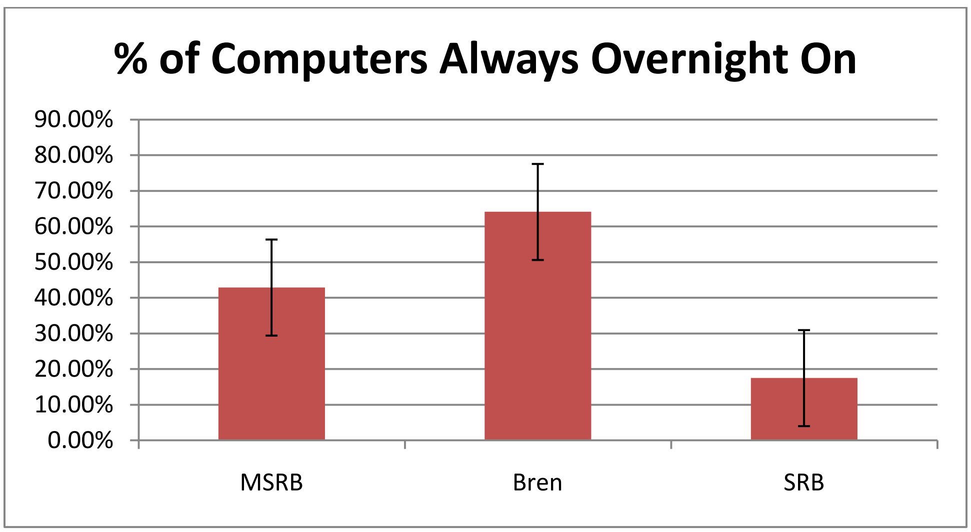


Reasons for opening windows

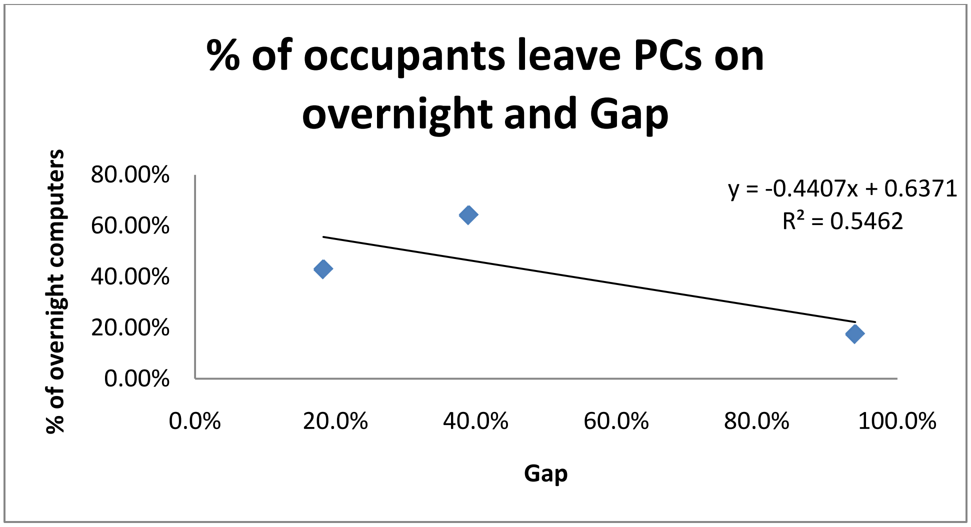


Computer overnight





X-squared = 71.2144, df = 8, p-value = 2.815e-12



Other survey stats:

Response

	Data Collection	Sample Size	Respondents	Response rate
Bren Office Occupants	Paper survey	160	80	50%
Bren Master's Students	On-line survey	178	105	59%
MSRB Office Occupants	Paper survey	76	35	46.1%
SRB Office Occupants	Paper survey	Approx. 150	58	38.7%
San Clemente Residents	On-line survey	965	144	14.9%