Do certified sustainable buildings perform better than similar conventional buildings?

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Abstract: The aim of this study is to assess the performance of sustainable buildings. Its objective is to compare certified green buildings with similar in location, size, age and function conventional buildings by testing hypotheses that green buildings perform better than conventional ones. Objective data including building costs, energy and water consumption, material recycling, indoor pollution sources and proximity to public transportation and subjective information on occupant comfort, recycling systems and indoor pollution conditions were gathered by interviews of occupants and engineers of 20 buildings, the 10 certified sustainable buildings in the study area and 10 conventional buildings. Criteria for sustainable performance are (1) the five LEED certification components (2) 39 sustainability performance characteristics or attributes, at least seven within each component. Analyses with non-parametric tests indicate that there is no statistically significant difference between sustainable and conventional buildings in 49% of the attributes. Conventional buildings perform statistically better in 10% of the attributes examined. Green buildings perform better than conventional buildings for the remaining 39% of building performance attributes. We conclude that labelling buildings as sustainable, making use of design and construction plans does not guarantee sustainable building performance and recommend periodic performance evaluation of certified buildings.

Keywords: sustainable buildings; building performance; energy conservation; building siting; water conservation; material selection; indoor environmental quality.

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1 Introduction

Good intention, commitment, optimism, urgency and celebration of design and artistic success motivate the sustainable building community. These motivating factors increase public awareness, a necessary but not sufficient condition for sustainable building development to reach its maximum engineering potential.

1.1 Sustainable building development: a definition historic snapshot

The United Nations World Commission on Environment and Development defines sustainable development as a process that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (Gissen, 2002). Since the 1990s, sustainability has been defined as the

> "ability of a society, ecosystem, or any such on-going system to continue functioning into the indefinite future without being forced into the decline through the exhaustion or overloading of key resources on which that system depends" (Joseph, 2002).

In a UK Green Building Handbook, sustainability is defined with a careful consideration of all conflicting design issues, whether they be "decisions about layout, relationship with site, the effects of wind and weather, possible use of solar energy, orientation, shading, ventilation, specification of materials and structural systems" (Woolley, 1997).

Whatever their definition, scientists, engineers, regulators, consumers and advocates use the words green and sustainable interchangeably to denote environmental and ecological concepts that aim to balance long-term human necessities with careful environmental considerations. These terms are also used interchangeably in this paper. Considerable work has been devoted to correct the ambiguity of sustainable development by developing quantitative indicators of sustainable development (Levin, 1995, 2000; Rees,1995; Wackernagel and Rees, 1996; Whomas and Kates 2003; and many others.)

1.2 Sustainable development: the problem and the built environment

The United Nations Population Division estimates that today's population of 6.2 billion will grow up to 10.9 billion by 2050 (Flavin et al., 2002). Humans are consuming resources at an alarmingly and unsustainable rate that increases as the world population grows. Most of this inefficient and, on occasion, reckless use of resources takes place in urban settings. Buildings consume more than half of the energy used worldwide and consume inefficiently at least millions of gallons of water a day (Gissen, 2002). It is estimated that buildings use up one-sixth of the world's fresh water withdrawals, one-quarter of its wood harvest, two-fifths of its energy flows, and three billion tons of total raw materials annually (Kats et al., 2003). In the US alone, commercial and residential buildings consume 65.2% of the country's total electricity (US DoE, 2001), 36% of USA's primary energy use (National Renewable Energy laboratory, 2004), and produce about 30% of the country's greenhouse gas emissions (US DoE, 1999) along with 136 million tons of construction and demolition waste (US EPA, 1998) Moreover, buildings consume one-eighth of potable water in the US (US Geological Service, 1995) and occupy, some assert waste, land that has immense ecological value (Roodman and Lenssen, 1955). Excessive consumption of energy for conditioning building indoor environments contributes to producing the harmful gaseous emissions which lead to acid rain, ground level ozone, atmospheric ozone depletion, smog and unpredictable climate and weather patterns globally. The problem of potential global warming is further exacerbated by the short period of about 30 to 40 years required for corrective action. If action is not taken within this period the world community will not be able to reverse projected catastrophic effects of global warming (Flannery, 2005).

Building environmental conditions indoors affect the health, comfort and productivity of occupants. In fact, the US Environmental Protection Agency (EPA) ranks indoor air quality among the top five environmental risks to public health (US EPA, 1993). Maintaining good environmental quality and comfort of the indoor environment cannot be ignored and should be considered as an integral element of sustainable development.

1.3 Sustainable building development: programmes and overseers

In the US sustainable building initiatives are dominated by the Green Building Council (USGBC), an independent, non-profit organisation with more than 2600 members including engineers, architects, building contractors/managers, industrial designers, public policy-makers, project coordinators, corporate executives, academics and others. The council was established in 1995 in response to the US market's demand for a definition of a 'green building' and for measuring sustainable buildings. The USGBC in turn established the Leadership in Energy and Environmental Design (LEED) Green Building Rating System, which legally certifies buildings as sustainable or green. Although there are smaller green building organisations only the USGBC headquarters in Washington DC have the influence to certify buildings on a national level. The LEED system is given credit for increasing public awareness regarding sustainable building construction and instituting guidelines for designing, constructing, operating and certifying the world's greenest buildings. The rating system is considered both nationally and internationally as the green building design standard or the benchmark for sustainability (Applegath and Wigle, 2002).

Before the LEED certification process commences a building must satisfy a minimum set of prerequisites, see Table 1. Once a building satisfies the LEED prerequisites, the LEED certification programme commences and credits are awarded using the LEED six Category (component) rating system. Each category is an indicator of sustainable development, which has clearly identified goals. Depending on the degree of attainment of these goals a building is awarded a number of points, see Table 2. The LEED programme certifies buildings at one of four levels, the larger the number of points a building secures the higher the awarded level of LEED certification (see Table 3).

Table 1 LEED prerequisites

LEED category	*Prerequisite points*	*Comment*
Sustainable sites	1	Building methods must avert soil erosion and sedimentation that occur in run-offs of stormwater
Water efficiency	0	No prerequisites in this category
Energy and atmosphere	3	A building must meet minimum criteria of energy performance
		CFC reduction in the HVAC is required
		Use low mercury content light bulbs
Materials and resources	1	A specific space must be identified for collection and storage of recyclable items
Indoor environmental quality	2	The building must satisfy the ASHRAE 62.1-2004 voluntary standard for indoor air quality
		Prohibit smoking
Innovation and design process	0	No prerequisites in this category

Source: Modified from GSA (2005).

Table 2 LEED criteria for certification

Component 1: Sustainable sites; Points: 14
Goals: (1) develop only on appropriate site, (2) reuse existing buildings and/or sites, (3) protect natural and agricultural areas, (4) support alternative transportation, and (5) protect and/or restore natural
Component 2: Water efficiency, Points 5
Goals: (1) reduce the quantity of water needed for the building, (2) reduce municipal water supply and treatment burden
Component 3: Energy and atmosphere, Points 17
Goals: (1) establish energy efficiency and system performance, (2) Optimise energy efficiency, (3) encourage renewable and alternative energy sources, and (4) support energy protection protocols
Component 4: Materials and resources, Points 13
Goals: (1) use materials with less environmental impact, (2) reduce and manage waste, (3) reduce the amount of materials needed
Component 5: Indoor environmental quality, Points 15
Goals: (1) establish good indoor air quality, (2) eliminate, reduce and manage sources indoor air pollutant sources, (3) ensure thermal comfort and system controllability, (4) provide occupant connection to the outdoor environment
Component 6: Innovation and design process, Points up to 5 additional points
Goals: (1) recognise exemplary performance in any achieved LEED credit, (2) recognise innovation in green building categories not addressed in LEED credits, (3) include LEED accredited professional on the team

Source: Modified from LEED (2001).

Table 3 LEED certification categories and points

Category of certification	*Points*
Certified	26–32
Silver	33–38
Gold	39–51
Platinum	52–69

Source: Modified from LEED (2001).

1.4 Study motivation

Both anecdotal (not peer reviewed) information and academic assessments motivate this work. One of the most telling anecdotal motivations relates a building in Colorado fitted with a solar-water heating system. The operations staff concerned with the possibility of frozen water in the pipes shut down the system before the first winter of its operation, replaced it with a conventional heating system and forgot to turn the sustainable system back on for succeeding summers (Becker, 2004). In a thought provoking opinion Udall and Schendler (2005) assert that

> 'some buildings, although they achieve LEED certification, are hardly green. Instead, the buildings are a compilation of green technologies stacked on a standard building, like putting lipstick on a pig, but more expensive. The Bren School in California, which received a platinum rating, was cited by a well known green design professional/author as an example of this flaw in the process'.

The literature clearly shows that these concerns are not shared by many LEED practitioners, yet Udall and Schneider, also LEED practitioners, express what appears to be an increasing concern.

Although performance based building codes are subject of extensive attention, the scientific literature is nearly void of critical evaluation of green building performance after certification. Regulatory options and the challenge associated with establishing performance-based regulatory systems is discussed by Mecham et al. (2005). Another paper addresses the development of building performance assessment tools based on energy, lighting, thermal comfort, maintenance and indoor air quality (Augenbrose and Park, 2005). A third article asserts that the US federal government has integrated a performance based approach and that the US Coast Guard has been challenged to incorporate this approach on building performance (Hammond et al., 2005). A service life time planning model simulates expected service for buildings and their components to assess design alternatives and argues that a rational scheme must be formulated to enable communication across all concerns in the 'relevant design processes' (Trinious and Sjostrom, 2005). Duncan (2005) points out that performance-based codes have advantages and proceeds by listing the challenges involved in their implementation. The emphasis of these and similar papers is on policy, design, energy conservation and to a lesser extent on water conservation, but not on a comprehensive performance after occupation.

Only two studies have assessed potential specific and measurable benefits from green building, and only one of them compared a green building with a similar in size, age and function conventional building. The first study, an early illustration of the emphasis on building energy conservation analyses the energy performance of a newly constructed academic building, the Oberlin College Adam Joseph Lewis Center located in northeastern Ohio, and compares the building's energy data with data from other buildings on the same campus or from a national building energy database (Scofield, 2002). Analysis of 24 months of energy performance data illustrates that the building's energy consumption was three times higher than originally projected and three times higher than the amount of energy that can be produced by the building's rooftop photovoltaic array. Despite the building's green label advertising as a model of superior construction and example of a host of green technologies, its on-and off- site energy consumption was no better than that for a comparable, conventional buildings.

Another performance study compares occupant psychological and social well being characteristics of two Buildings:

1 of the Herman Miller SQA (Simple, Quick, Affordable) Building located in Holland, Michigan green building

2 a similar conventional building.

The study goal was to develop a conceptual framework and methodology for assessing benefits of green buildings including good energy efficiency, indoor air quality and day lighting. The site incorporated restored wetlands and prairie landscape. The uniqueness of this study is that the subject occupants are the same individuals working for the Herman Miller Company before and after the construction of the SQA green building (Heerwagen, 2000). The author justifiably claimed that in 2000 this research was one of the earliest to present evidence that green buildings link occupant worker well being green building, in this case the SQA building, features. Literature review for this paper confirms that this study was the earliest of its kind. The study concluded that the SQA green building lends credence to 'green building hypothesis' that green buildings are better for people because they generate superior, healthier, more habitable spaces than comparable standard-practice buildings.

The following motivate the need for post occupation performance assessment of certified sustainable buildings:

1 a scarcity of comparative performance studies

2 comparative studies found in the literature reach different conclusions regarding the performance of green buildings

3 a plethora of anecdotal and inconclusive evidence regarding performance.

2 Objectives

Equipped with healthy scepticism regarding the performance of sustainable buildings this paper aims to determine whether green buildings perform better than conventional buildings by assessing the performance of sustainable buildings. The objective of this paper is to compare LEED certified green buildings with similar in location, size, age and function conventional buildings in the Chicago Metropolitan area. The objective of this paper is *not* to provide a critical evaluation of the LEED programme; rather it is to critically evaluate the performance of Sustainable or Green Buildings. The USGBC's LEED rating programme is used because it is a comprehensive rating system and the most successful one in certifying buildings as sustainable. Moreover the green buildings in the Chicago Metropolitan where the study was carried out are either LEED certified or registered to be certified using the LEED certification system.

Accordingly, this study tests the hypothesis that green buildings perform better in each of the five LEED categories. In statistical nomenclature, the null hypothesis is that there is no performance difference between green and conventional buildings in each of the LEED categories.[1] The database is composed from both objective data and subjective information collected from 20 buildings, 10 green buildings and 10 similar in size, age, location and function conventional buildings. The specific objectives of this study are to:

1 Generate a database of objective building information that is obtained from building managers, owners, architects or construction engineers.

2 Generate a database of subjective information that is obtained from building occupants.

3 Probe differences, if any, between green and conventional buildings and interpret the output of statistical analyses.

3 Methods

This section begins by addressing building selection, continues with a discussion of data collection and concludes by defining building performance and describing the data analysis methods that are used to assess building performance.

3.1 Building selection

The challenge of selecting buildings was to convince Green Building owners/managers to participate in this study. At the time of this study, only 10 Green Buildings were LEED certified, occupied and operated within the Chicago nine-county metropolitan area; all participated in this work. LEED certification is assumed to denote a green or sustainable buildings in accordance to the city of Chicago, which has recently promulgated a law that uses the term 'green' for every LEED certified building at any level (US DoE, 2004). Of the 10 'certified' buildings half were LEED certified and the rest were LEED registered projects to be certified. This study assumes that they would be certified. Of the five that were certified, one is a LEED platinum building, one is a LEED gold building, one is a LEED silver building and the other two are just LEED certified buildings. There were other green buildings in the Chicago area at that time, but they were not selected because they were not occupied for at least one year. At the time of this study, all buildings were occupied for a period of one to four years.

The following four building characteristics were employed to select correspondingly similar buildings: size, location, age and type or function. It was not expected that one could match perfectly a conventional building with a green building, but the goal was to find a conventional building that would come as close as possible to the green building. Size selection also considered the number of floors and the number of occupants to normalise costs per occupant and/or building area. Similarity in location requires that the green and conventional building should be at least in the same municipality to assure the same costs per unit of electricity and water consumed and similar costs for building construction. Matching buildings based on age is important because all green buildings (at the time of study) were no older than four years old. A comparison of a four-year-old green building with a twenty-year-old conventional building would bias construction costs.

3.2 Data collection

Both objective data and subjective information were selected for this study. Building occupants and technical personnel such as engineers, architects and building managers were the study 'monitors' and responded to questions posed regarding each building. Occupants provided objective information and technical personnel provided subjective information not available to occupants. The surveying process was conducted in an interview like manner, where the field researcher was able to discuss selected occupants one by one in person. The process was not the typical questionnaire administered by field personnel; rather it was a survey/discussion between the field researcher and the subject. The researcher had a list of subjects to be addressed, indeed he had the questions written but the survey allowed for follow-up questions and discussion. The same surveying process was used with occupants and technical personnel.

Building occupants are preferred to environmental monitors because they monitor environmental conditions continuously as they occupy the building

1 are inexpensive and numerous for achieving statistically sound results

2 do not require instrumentation that may be both expensive and intrusive

3 provide insights that are not provided by sampling pollution instruments

A total of 11 questions were discussed with the occupants for a maximum of 15 min per person. 10 random employees were selected randomly in each office building and laboratory. This number of subjects represents 10–100% of the occupants of building areas studied. In residential buildings, only one occupant was surveyed. Questions addressed to occupants sought their perceptions and observations regarding the quality of the building performance and environmental conditions.

Technical personnel questioned were either involved in the design and construction of the building or, at the time of this study, in the building operation. 28 questions were given to the technical personnel; the interview required half an hour to an hour. Objective information sought includes

1 cost data about the building such as electrical bills, maintenance bills and construction costs

2 types of energy saving technologies installed

3 types of architectural design features implemented

4 types of materials used throughout the building, and any other environmentally friendly practices done in the building.

3.3 Typical questions

The survey posed questions for at least seven characteristics or attributes of each of the five components or criteria for LEED building certification. Thus a total of 39 performance attributes were investigated by this study. Example questions for two criteria along with a brief justification provide a general picture of the interview. For each criterion one example question on a specific attribute is addressed to the occupant and a second to technical personnel.

3.3.1 Criterion 1: sustainable sites

Justification of questions to follow: Sustainable siting of green buildings deals with land based issues including protection of natural habitats, building space efficiency, undeveloped land conservation, retrofit construction practices, reduction of automobile use through public transportation, reduction of night pollution and replanting of native plant species.

Comment and question to an occupant: A green building location should be in an area that provides easy access to public transportation thus enabling occupants to reduce automobile use.

How do you commute to and from your building?

1 walk

2 train

3 car

4 carpool

5 bicycle

6 bus

7 taxi

8 other __________

Comment and question to technical personnel: Green buildings should utilise existing building spaces to minimise excessive consumption of natural resources used in the construction of completely new building spaces on undeveloped land. Conserving precious undeveloped land space can also save money because renovated buildings (retrofit buildings) usually cost less than completely new buildings.

Is the building renovated (retrofitted) or is it completely built new?

(a) Retrofit

(b) completely new constructed building

What was the initial cost of your building's construction?

$________ initial construction cost

3.3.2 Criterion 2: water efficiency

Justification of questions to follow: Water efficiency strategies include advanced landscaping, plumbing, architectural strategies that help a building conserve water, recycling run-off rainwater or greywater to be used by the building occupants and or stored for other purposes. Water conservation technologies include installation of water efficient technologies such as low-flow water devices, and implementation of a hot water recirculation system to maintain hot water use for occupants without wasting water.

Comment and question to an occupant: Green buildings should use a hot water recirculating system (hot water on-demand system) that provides occupants with hot water as soon as they turn on the faucet and saves thousands of gallons of water each year (Gleick, 2003; USGBC, 2002) and reduces energy consumption.

> Does hot water come out of the hot water faucet immediately or do you experience more than 30 sec delays before the water heats up? Yes OR No

Comment and question to technical personnel: Green buildings should collect rainwater because this water harvesting technique allows a building to channel run-off water to planted areas or store it for later use by occupants.

> Does your building collect rainwater so that occupants can use it? Yes OR No

The discussion topics for the remaining criteria (energy and atmosphere, materials and resources, and indoor environmental quality) and all attributes addressed in this study were justified in a similar approach to assure that only relevant information was collected.

3.4 Data analysis

This section defines building performance, presents the statistical methods used and discusses strengths and weaknesses of the analysis approach.

3.4.1 Building performance

Building performance is defined in the literature (ISIAQ, 2006) as "a set of measured responses of a building, as a system, to define forcing functions or criteria." Measured responses – valid and reliable values of system parameters are selected to characterise the intent of the performance during design, construction and operations (e.g. health, safety, security, occupant performance, productivity, energy and economics). Forcing functions – physical and social forces that perturb the building system, are characterised in terms of parameters (e.g. interior and exterior loads or source strengths) and values (e.g. intensities of structural, thermal, contaminant, lighting, acoustic loads – normal conditions and intensities and frequencies of natural and man-made and cyber threads – extraordinary conditions) to which the responses occur.

The criteria for performance comparison of sustainable and conventional buildings are

1 the five LEED certification components

2 the 39 performance attributes.

Building performance is assessed by statistical comparisons of measured responses firstly individually by attribute, secondly integrated by LEED component and finally, as one entity for all LEED components. The metric of comparison is simple: a Green Building (GB) performs better than a similar Conventional Building (CB) when the one-tailed alternative hypothesis ($\tilde{x}_{GE} > \tilde{x}_{CB}$) is selected by data analysis for the majority of statistical tests. Specifically, a sustainable building performs better than a corresponding conventional building if and only if

1 within each criterion at least 50% of the attributes are rated better for the sustainable buildings

2 the difference of at least three (50%) of the criteria is significant and the sustainable buildings are 'better' than conventional buildings.

3.4.2 Statistical tests

The database generated includes objective data (measured quantities) and subjective information (occupant perceptions) for 39 characteristics relating to building performance. These data were analysed using the following three non-parametric statistical tests:

1 the Sign Test

2 the Wilcoxon Signed-Rank Test

3 the Wilcoxon Rank-Sum Test (Kleinbaum et al., 1987).

All analyses were performed with one-tailed tests and a significance level value of 0.05. One tailed test was selected because for a predetermined level of significance, the power of the one-tailed test is larger when the population mean is in the range of the alternative hypothesis. Additionally, the one-tailed test decides if on the average sustainable buildings perform better than conventional buildings rather than differently from sustainable buildings.

The sample size of $n = 10$ for each building classification may appear small but at the time of this study it contained the population of sustainable buildings or, equivalently, LEED certified buildings in the Chicago Metropolitan Area. Given the small number of one-to-one comparisons non-parametric tests are more suitable than parametric tests because non-parametric or distribution free tests assume independence of observations but make no assumptions about the distribution of the population.

Most of the data collected for this study are categorical or ordinal in the sense that they fit in a small number of discrete categories that can be ordered. Only a few questions lead to continuous data such as cost data. For analysis of the data in this work continuous data were also categorised because of the limited sample size. For multiple category responses, a scoring scheme was designed to enable statistical comparisons between sustainable and conventional buildings on an equivalent basis.

Nonparametric tests

- are used with small sample size[2]
- make less stringent demands of the data
- are capable of investigating measurements from different populations
- are clearly suitable for data that fall into ranks naturally such as scores with exact categories
- provide a freedom of objectivity when there is no dependable unique scale for the original data and there is concern that results of standard parametric techniques would be under scrutiny for relying too much on an artificial metric (Montgomery and Runger, 2003).

The following example from this work illustrates the last point: Occupants in a building might be asked whether the quality of their indoor lighting fixtures makes them feel highly satisfied, satisfied, neutral, unsatisfied, or highly unsatisfied. Assigning scores to these categories of satisfaction becomes rather ambiguous; moreover it is not guaranteed that a slight change in scoring can change the outcome. Such concerns are less critical when data are converted to ranks and subsequently analysed with non-parametric methods.

Limitations of non-parametric tests include:

- *Loss of original data*: Non-parametric tests do not use measurement values rather they use secondary or derived information such as signs or ranks.
- *Low power*: Owing to the use of derived data non-parametric tests have less statistical power (are less sensitive) than parametric tests.
- Failure to study higher interactions.

4 Results and discussion

A series of preliminary questions established that study subjects (both residential tenants and employees) of all 20 buildings occupied the building for at least half a year and on average two years. The office buildings had an average of 30 occupants; the laboratories had about many more occupants and the residences an average of three individuals. The area of subject structures varied from 2000 to 5000 sq for residences. For the laboratories the floor area of the laboratories was about 300,000 sq and that of office buildings varied between 30,000 to 60,000 sqft.

4.1 Examples of analysis by criterion

This section provides examples of analysis for each LEED component or criterion.

4.1.1 Criterion 1: sustainable sites

A total of nine questions focused on sustainable siting, the first, LEED criterion for sustainable certification and related attributes. There was a statistical difference for five-siting related questions: the green buildings performed better than conventional buildings for three attributes and the conventional buildings performed better than the green buildings for two attributes. There was no statistical difference between matching green and conventional buildings for four perceived by occupants or subjective (data driven) siting attributes.

4.1.2 Criterion 2: water efficiency

Seven questions were asked regarding this criterion with an emphasis on obtaining objective information from technical personnel. Attributes investigated include use of landscaping techniques such as xeriscaping, recycling of grey-water, water consumption costs and others. Analyses of both objective and subjective information about the efficiency of water use and consumption indicate that green buildings perform better than conventional buildings in four of the seven characteristics examined and are statistically no different in the other three.

4.1.3 Criterion 3: energy and atmosphere

Seven questions were asked regarding this criterion; six were addressed to technical personnel and one to occupants. Attributes examined include, whether windows were aligned to capture solar heat, the number and type of light bulbs used, type of shading devices used for summer cooling, the number of energy conserving operated, the number of renewable energy devices and/or technologies operating in the subject building cost for energy consumption over a two year period and the like. The performance of sustainable buildings was not statistically different in two of seven energy conserving characteristics including costs for energy consumption, was statistically better than conventional buildings in four characteristics and worse than conventional buildings in one energy conserving characteristic.

4.1.4 Criterion 4: materials and resources

Relevant attributes include:

1 Occupant perception regarding the quality of a building's recycling system with respect to
   - a frequency of use of the recycling system
   - b the accessibility of the system.

2 Technical data on the use post consumer recycled content materials as opposed to using postindustrial recycled content materials.

3 Distance to the local hardwood and the closest facility for delivering recycle materials and/or purchasing such material.

4 Maintenance costs in dollars per square foot and occupant for the two year period investigated by the study.

5 Wood material used for construction, which nay differentiate between green and conventional structures and others. Special scoring schemes were developed for many of these questions. Using the Wilcoxon-signed rank test on the number of materials recycled routinely by occupants we conclude that the difference between green and conventional buildings is statistically significant and that the green buildings recycle a greater number of items. Moreover, a significant difference was found between green and conventional buildings for the number of construction items recycled during construction, the green buildings recycled more items.

4.1.5 Criterion 5: Indoor environmental quality

Building administrations responded to the following attributes of this criterion by providing objective data on

1 building wide smoking prohibition

2 on site presence of an advanced Heating, Ventilation, and Air Conditioning Carbon Dioxide (HVAC CO_2) monitoring system

3 the presence/absence of an on-site Indoor environmental quality management team

4 existence of an Indoor environmental management team and their duties, and reports

5 the number of indoor environmental quality features (such as task lighting, room temperature controls and operable windows) *controlled* by occupants. Occupants provided information on the number of

   a occupant complaints related to Indoor Environmental Quality registered by the occupant/management IAQ team

   b potential sources of indoor air pollution

   c occupied areas with sufficient sunlight (daylight) brought into spaces and others.

The performance of green buildings was not as good as that of conventional buildings in one IEQ assessing characteristic, equal to that of conventional buildings in three characteristics and better than conventional buildings in four characteristics.

5 Assumptions, conclusions and recommendations

The objective of this study is to assess the performance of sustainable buildings by determining if they perform better than matched by size, age, site and function conventional buildings. This study employed 10 pairs of matched sustainable and conventional buildings and compared their performance.

5.1 Assumptions

This performance assessment assumes that

1 buildings in the process of LEED certification will be certified

2 non-parametric analysis of both objective data and subjective responses to questions posed are representative of additional questions that could be posed

3 unlike partial or ranked sustainable certification, building sustainable performance cannot be partial and building performance is either sustainable or not, that is sustainable building performance either satisfies the metric formulated and used in this study or LEED certified buildings do not perform better than conventional buildings.

6 Conclusions

Analyses of objective and subjective data indicate that there is no statistically significant difference between sustainable and conventional buildings in 49% of the sustainability performance attributes investigated. Conventional buildings perform statistically better in 10% of the attributes examined. Green buildings perform better than conventional buildings for the remaining 39% of building performance sustainable characteristics. Moreover, of the five comparison criteria, the five LEED certification components, only two, energy and atmosphere and water efficiency, register a statistically significant difference between the two types of buildings for over 50% of attributes studied. The materials and resources register only 12% of sustainable attributes statistically different and better than those of conventional buildings, while a 33% and a 50% of attributes are registered for sustainable sites, and Indoor Environmental Quality, respectively. The conclusion reached is that the subject buildings do not satisfy performance criteria set by this study and the 10 sustainable buildings do not perform sustainably.

This study was completed in 2005, but a period of 24 months was reserved to determine if the buildings registered as sustainable would be revisited for performance evaluation. None of the certified buildings was visited for performance evaluation. Accordingly, the second conclusion of this study is that building performance is not an element of the sustainable certification process.

It may be argued that conventional buildings are constructed to perform as well as sustainable buildings. Yet conventional buildings are built in accordance to codes but are not designed specifically to conserve energy, water, land, construction materials and other natural resources, and they do not use building materials and other furnishings that protect the indoor environment and the health and comfort of building occupants. This study ascribes the lack of difference between sustainable and conventional buildings to the accreditation system that certifies sustainable buildings on preconstruction design and ignores post occupation building performance.

7 Recommendations

The present culture of sustainable building development must change and the focus on design must be enhanced to include performance assessment. Ignoring building performance is equivalent to an environmental regulatory system that invests material and intellectual resources to develop and implement a control strategy but fails to assess the efficiency of the control strategy to protect public health. This simply does not occur. Similarly in sustainable building development the implementation scope must be augmented to include performance evaluation.

What possible advantage will the effort to build sustainable buildings that perform in accordance with sustainable criteria bring about to the global community? Buildings that perform in accordance to sustainable principles will reduce waste of valuable resources. Under the worst case scenario building certification continues without a performance assessment and after 10 or 20 or worst 50 years society recognises that both sustainable and conventional buildings lead to waste of energy, water, land and other ecological resources, and keep on polluting the environment. In the US the built environment is the source of about 30% of the country's greenhouse gas emissions along with 136 million tonnes of construction and demolition waste. The concern is further exacerbated by the continuing urbanisation of societies around the globe. Moreover, climatologists assert that the next 20 to 30 years are critical in the effort to avoid global warming resulting from emissions of CO_2 and other greenhouse gases. Accordingly, continuing to pollute the global environment leads to an *irreversible waste of valuable time*.

The architect and construction engineer must not be responsible for the occupation phase of a residence, consequently, we recommend that building certification programmes combine planning and design with post-occupation performance assessment. Building commissioning will augment the present scope of certification of sustainable buildings. In its broadest sense building commissioning ensures that a building, as a system, is designed, installed, *tested, operated and maintained* according to sustainable principles. Moreover, we recommend that certification authorities require building commissioning of all certified buildings on regular time intervals and suggest that failure to carry out such commissioning activities or failure to implement corrections recommended by commissioning should result in certification removal because such buildings do not perform sustainably.

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Notes

[1]The sixth category is not considered here because conventional buildings do not seek LEED membership of the architects or building contractors.

[2]Although this study investigates all available sustainable buildings in the study area, the sample size is small and the use of nonparametric tests is the only available analysis option.