IMPACT OF CONTINUOUS COMMISSIONING® ON THE ENERGY STAR®

RATING OF HOSPITALS AND OFFICE BUILDINGS

A Thesis

by

ADITYA ARUN KULKARNI

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2011

Major Subject: Mechanical Engineering

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Approved by:

Chair of Committee,	David E. Claridge
Committee Members,	Michael Pate
	Charles Culp
Head of Department,	Jerald Caton

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ABSTRACT

Impact of Continuous Commissioning® on the Energy Star® Rating

of Hospitals and Office Buildings. (December 2011)

Aditya Arun Kulkarni, B.E., Pune University

Chair of Advisory Committee: Dr. David E. Claridge

Re-commissioning, retro-commissioning, Continuous Commissioning® (CC®) are examples of successful systematic processes implemented in buildings to reduce overall building energy consumption, and improve efficiency of systems and their operations and control. The impact of the Continuous Commissioning® Process on the Energy Star® Rating (ESR) of office buildings and hospitals is examined in this thesis.

The improvement in performance of a building, and subsequently its ESR, is found to be influenced by its initial ESR, while its location has no impact on improvement. The improvement in ESR is observed to be almost linearly proportional to the percentage of energy saved. For 10% - 20% reductions in energy use typical of the CC® process, the ESR is increased by 10-19 ESR ranks for office buildings and by 13 - 26 ESR ranks for hospitals. The CC® process is found to potentially enable an office building of average initial ESR of 62 and a hospital of average initial ESR of 55, located anywhere in the US, to be eligible to achieve ESR of 75 and consequently the Energy Star® recognition.

The improvement of ESR is a function of the initial ESR and the building type; hence it is observed to be different for hospitals and office buildings in the study. For hospital and office building models occupying 100,000 ft^2 of floor area each, a difference of about 30% in the ESR improvement (greater for hospitals) is observed. The energy intensities may be different for buildings with same ESRs that have different location and/or type. An averaged maximum difference of energy intensity of approximately 10% is observed to exist for identical buildings and of the same type but located at different locations. Hospitals are observed to be more than twice as energy intensive as office buildings for the same location and equal ESRs. ESR plotted against % energy savings at site reveals the stepped nature of ESR system. At specific initial ESR and corresponding % savings a reduction of up to approximately 1% for office buildings and up to 1.5% for hospitals does not change the respective ESRs for the model set of buildings in the study.

DEDICATION

TO MY FAMILY

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1. INTRODUCTION

The increased demand for energy world over is a result of the simultaneous growth in demand for energy in the developing countries. There are limited investments and advancements in alternative energy sources while there are GHG or global warming and safety related concerns for newer technologies apart from volatility of the energy prices in the global market. In the United States 56% of its demand for oil is met through imports (Real Prospects for Energy Efficiency in the United States, 2010) and with the current set of economic concerns and environmental awareness the reduction in consumption by improving overall efficiency is apparently one of the most viable options to explore.

1.1 Energy Use in Commercial Buildings

Energy costs for an estimated total of 4.8 million commercial buildings in the United States are approximately $107.9 billion annually, while their contribution to the Green House Gas (GHG) emissions constitutes up to 17% of all the GHG emissions in the country as indicated by the most recent figures on the Energy Star® website (Energy Star®, 2011d). 39% of the total primary energy and 72% of electricity used in the United States in year 2006 was to support the operations in residential and commercial buildings in spite of the growing use of efficient appliances and equipment in the past three decades (Real Prospects for Energy Efficiency in the United States, 2010).

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This thesis follows the style of *ASHRAE Transactions*.

With all the available state of art technology and products operational inefficiencies still exist; for example, it has been found that about 30% of the energy in commercial buildings is used inefficiently (Energy Star®, 2011d). However due to varying interests of property builders, owners, tenants, etc, and due to the requirement of technical expertise and investments this activity may not receive priority. So, with the intent of helping building and home owners save money, and to safeguard the environment by promoting energy efficient products and practices, the U.S. Environmental Protection Agency (EPA) and the U. S. Department of Energy (DOE) launched a joint program called Energy Star® (Energy Star®). The program started off as a voluntary program and labeled computers and monitors for certifying their efficiency in 1992; it has now expanded in its scope and capabilities, by partnering with various private and public sector organizations in the past two decades. The Energy Star® label is now comprehensive enough to certify entire buildings/facilities which include but are not limited to commercial and residential buildings (Energy Star®, 2011c).

1.2 Commercial Buildings Energy Performance

In general more than 50% of energy consumed in commercial or residential buildings is for heating, ventilation and air conditioning (HVAC), and lighting. Electronics, cooking, refrigeration, and other appliances consume small portions of energy in a building (National Academy of Sciences, 2010). Commissioning, retro-commissioning or re-commissioning processes improve the energy efficiency, prevent the development of operating problems, reduce the requirement of system repairs and improve equipment life (Department of Energy, Office of Energy Efficiency and

Renewable Energy, 1998). Energy performance benchmarking, like any benchmarking, either compares the performance of a building with its past performance or with the performance of other buildings documented and/or normalized for comparison. In case of a set of buildings of a defined type benchmarking indicates the amount of improvement possible or required determined by comparing performance of the existing operating systems in a building with the systems in other buildings of its type. Typically, a building is categorized into a type such as an office, hotel, etc., based on the use of the majority of the space (more than 50% gross floor) inside the building for a realistic comparison. There are different ways and techniques adopted to analyze, compare and represent a building. Benchmarking is just another way of evaluating building energy performance. To benchmark the energy performance of commercial buildings in the United States and to set minimum energy performance standards, the United States Environmental Protection Agency (EPA) introduced the Energy Star® Rating which provides a means to measure the energy performance of buildings/facilities. The most energy efficient 25% of buildings in each category of building types are eligible to obtain recognition in the form of an Energy Star® Rating (ESR) certificate (Hicks & Neida, 2000).

1.3 Background and Purpose of Study

Consumption of energy in buildings has received attention owing to economic constraints and environmental concerns, and the building owners have responded by investing in commissioning activities for improving the performance of their buildings. Continuous Commissioning® (CC®), an ongoing commissioning process or technique is a proven success for improving building efficiency and saving energy, and thus subsequently saving money required to be spent on energy bills. Though the implementation of CC® improves the energy performance of a building, its impact cannot be measured on a relative scale. Evaluating and expressing energy performance in the form of an energy benchmark would be one of the best ways to project the credibility and the energy savings potential of the CC® process. Energy Star® generates benchmark rating for a building on a national level for a desired building in the US. Past efforts and achievements can be evaluated, and the persistence of the improved energy performance and savings can be emphasized using benchmark ratings while negotiating for long term service contracts and keeping up with the competition from other energy services companies. On the other hand, a systematic analysis of the building performance (using characteristics and consumption information) in terms of its Energy Star® Rating can assist energy service companies for screening, selecting, prioritizing buildings and determining the feasible energy conservation strategies.

The Energy Star® Rating can be determined free of cost using the software tool provided by EPA. With the growing trend of attaining environmental sustainability of buildings, the evaluation of the potential impact of the CC® process on enhancement of sustainability through Energy Star® benchmark rating will be helpful to prove the effectiveness of the process.

This study will include present the methodology used to generate the Energy Star® benchmark rating for Hospitals and Office Buildings in the United States. It will analyze the relationship between the intensity of energy consumption in buildings and their respective Energy Star® Ratings in case of both the types of buildings located anywhere in the United States. It will then determine the amount by which implementing the CC® process improves the Energy Star® Rating when the following are known:

- Location of the building in the US and thereby the weather conditions at the location, and
- Initial Energy Star® Rating of the building.

2. LITERATURE REVIEW

Technical material highlighting the benefits and advantages of the CC® process, its cost effectiveness, savings persistence, specific strategies, comparison study along with scope and description of processes such as retro-commissioning, re-commissioning, is available readily (Evan Mills, 2005) (EnergyStar®, 2007a), (Department of Energy, Office of Energy Efficiency and Renewable Energy, 1998), (Bourassa, Piette, & Motegi, 2004), (Energy Star®, 2011d), (Energy Systems Laboratory), (Toole, 2010), (Liu, Claridge, & Turner, 2001).There is however no study found that evaluates or demonstrates its impact on the improvement of the energy performance of a building measured on a relative scale with other buildings performing similar functions.

2.1 Building Commissioning Basics

The technical terminologies related to the building commissioning process in general are discussed in the text to follow before moving on to the details about benchmarking.

2.1.1 Commissioning

Commissioning in buildings is defined as "a quality-oriented process for achieving, verifying, and documenting that the performance of facilities, systems, and assemblies meet defined objectives and criteria" (ASHRAE Standards Committee, 2005). Commissioning is a systematic process that begins, ideally, in the design phase of a new building or a building retrofit project and lasts at least one year after the project is completed for the latter case (Department of Energy, Office of Energy Efficiency and Renewable Energy, 1998).

2.1.2 Retro Commissioning

Once in operation, buildings may undergo retro-commissioning for reducing power consumption and improving the overall efficiency of systems consuming energy in the building. A retro-commissioning process is typically a systematic investigation process that focuses on improvement of performance of the existing equipment such as lighting, HVAC, refrigeration, and optimization of the related control systems (Haasl, Potter, Irvine, & Luskay, 2001). It is the systematic process (similar to commissioning process) applied to existing buildings that have never been commissioned to ensure that their systems can be operated and maintained according to the owner's needs (EnergyStar®, 2007a).

As desired by the owner, retro-commissioning may improve the efficiency of systems in a building and reduce the power consumption against a calculated baseline, but it cannot be claimed with certainty that the building is operating at its maximum efficiency or is at par with the most efficient buildings in that region. A building, for example, may undergo a systems upgrade resulting in 20% savings on the overall energy use, but the normalized value of energy consumption calculated for the building could be greater than that of other buildings implying that inefficiencies exist in the building that can be addressed for further improvement. The savings realized by implementing the retro-commissioning process have been observed to persist beyond three years in a study of eight sample retro-commissioned buildings (Bourassa, Piette, & Motegi, 2004).

2.1.3 Re-commissioning

A building that has been commissioned or retro-commissioned previously is re-commissioned, a process similar to commissioning and carried out every three to five years. The frequency of re-commissioning depends upon factors such as changes in the use of building spaces, operating schedules, building capacity, occupant comfort issues, etc. The primary intention of performing re-commissioning is to maintain the building performance at around its peak efficiency all the time (EnergyStar®, 2007a).

2.1.4 Continuous Commissioning®

The Continuous Commissioning ® (CC®) Guidebook defines the CC® process as "an ongoing process to resolve operating problems, improve occupant comfort, optimize energy use and identify retrofits for existing commercial and institutional buildings, and central plant facilities." The Continuous Commissioning® (CC®) process, a process developed and trademarked by the Energy Systems Laboratory (ESL) at Texas A&M University targets the improvement of energy efficiency and occupant comfort, and the reduction of operating costs (Liu, Claridge, & Turner, 2001). The ESL has retro-commissioned over 300 commercial buildings in various states of the US and internationally to date and has demonstrated that the CC® process improves the operational efficiency of systems in buildings, resulting in lowered utility consumption (Energy Systems Laboratory). The CC® process is not only effective in creating savings;

a study by Toole has proven the persistence of savings, using a select set of buildings, for at least ten years with little degradation in the buildings that have undergone CC® (Toole, 2010).The effectiveness of the CC® process, like a retro-commissioning process, has not been benchmarked or evaluated by comparing with the performance of any other buildings (Toole, 2010).

2.2 Energy Star® Rating and Benchmarking Overview

Energy benchmarking is a tool for developing energy performance indices (Mills, 2008). Mills states in the same paper that energy benchmarking apart from evaluating and comparing building energy performance, and setting targets for improved performance can help to identify energy saving strategies and reference points for the retro commissioning process. It helps to establish design guidelines and set new standards based on performance of the existing benchmarked buildings. Depending upon the region, buildings are recognized for achieving required performance which can be a positive factor during property evaluation and hence impact rental rates.

The Energy Star® certification, an energy benchmark, is recognition awarded by the United States EPA to the 25% most energy efficient buildings in the United States. In 1991 EPA launched the Green Lights Program to promote installation of efficient lighting in the buildings in the USA. Due to increased popularity EPA decided to implement a building level approach which culminated in the Energy Star® Label (Lancashire, Jan 2004). EPA has developed a web based rating tool called Portfolio Manager that processes building utility consumption data and generates the energy benchmark rating. This rating indicates how efficient a building is with respect to the other buildings of its type in the country. California Assembly Bill 549 promoted benchmarking in California, and the state made it compulsory for non-residential building owners to disclose to prospective buyers and lenders the Portfolio Manager data and scores for a building being sold, leased, and financed or refinanced starting January 1, 2010 (Mills, 2008). California Energy Commission released a revised copy of the previous draft of 'Staff Draft Regulations', of August 2009, in May 2010 to implement the requirements of the Assembly Bill 1103 (Mayer, 2010). The latest update on the 'benchmarkrating.com' website states, "As of January 1, 2012 as required by California Law AB 1103 commercial property owners whose property is solely occupied by the owner or is more than 50,000 square feet, where the entire building is sold, leased or financed, must disclose Energy Star® Portfolio Manager benchmarking data and ratings, for the most recent 12-month period, to a prospective buyer, lessee, or lender. As of July 1, 2012 the law will apply to commercial property owners whose property is 10,000 to 50,000 square feet or owner occupied above 1,000 square feet" (Ecocosm, Inc). This is indicative of the efforts of government entities to ensure sustainability of buildings, and of the reliability of the Energy Star® performance benchmark rating. In any case EPA's Energy Star® Rating is a widely accepted energy performance benchmark rating and it continues to gain popularity. A total of 12,600 commercial buildings and 1.2 million homes have received the Energy Star® qualification by the end of 2010, implying that these commercial buildings consume 50% less energy and the homes consume 15% less energy than is typical in the respective building categories.

Benchmarking initiatives and development of tools have been undertaken in Australia, Singapore, the European Union, Canada, and Denmark which primarily focus on improving the energy efficiency of facilities and reducing emissions at a national and/or city level (Olofsson, Meier, & Lamberts, 2004). For example, an energy rating tool called e-Energy was developed by BCA-NUS Building Energy and Research Information Center at the University of Singapore, while the Australian Building Greenhouse Rating benchmarks performance of buildings in Australian states by comparing their greenhouse gas emissions (Olofsson, Meier, & Lamberts, 2004).

The US EPA's Portfolio Manager (PM) for the Energy Star® Rating program enables energy managers or staff to track and benchmark the energy performance of their own buildings (Lupinacci, 2008) by calculating the intensity of energy consumption of a building (located in the US) and comparing it with a select stock of buildings in PM's database. Upon entering the requisite information in the PM tool a building gets categorized into a specific building type within the tool; the type depends on the use of spaces inside a building, and subsequently its energy performance is rated. Most of the data like utility consumption, building square footage, etc., required to be entered into PM tool is collected during the CC® process.

The Energy Star® Rating contributes significantly toward gaining points required for obtaining Leadership in Energy and Environmental Design – Existing Buildings Operations and Maintenance (LEED-EBOM) certification; an initiative by the United States Green Building Council (USGBC). The LEED-EBOM certificate is a recognition confirming that the certified commercial building is energy efficient, environmentally sustainable, and cost effective in its operation (US Green Building Council, 2009). Clearly it will be helpful to study the impact of the CC® process on the Energy Star® benchmark rating of buildings, and on their environmental sustainability. Energy benchmark rating may be referred to as simply rating wherever obvious in the text to follow.

In general, benchmarking is beneficial for those buildings that are more energy efficient than their peers or buildings with the same space use, or the same type. Buildings with higher ratings tend to have increased resale values and rental rates. The ratings are also an indicator of the scope of improvement in operations and/or systems in a building (Olofsson, Meier, & Lamberts, 2004).

There is more than one approach to benchmark energy performance of buildings. These methods and the associated tools are categorized by the information provided. There are four methods of benchmarking the Energy Performance of the building as outlined by Sartor et. al (Sartor, Piette, Tschudi, & Fok, 2000). The four methods are Statistical Analysis, Points-Based Rating Systems, Simulation Model-Based Benchmarking, and Hierarchal and End-Use Metrics.

2.2.1 Statistical Analysis

In Statistical Analysis benchmarking, the Energy Use Index (EUI) of a building is calculated and compared with a benchmark generated by utilizing the energy consumption statistics for a population of similar buildings. The EUI of a building is the energy consumed by the building during a specific period of time per square foot of the building area (kBTU/sqft is the unit used by EPA for calculating Energy Star® Ratings). A large data set for every category of building is required to have a reasonable sample size of comparison buildings (Kinney & Piette, 2002). This method, also called distributional analysis, is incorporated in the Cal-Arch benchmarking tool (Kinney & Piette, 2003). Kinney and Piette have further pointed out that Cal-Arch produced histograms and summary statistics are displayed for each quartile of similar buildings grouped into the quartiles according to their calculated EUI values. Cal-Arch uses data from the California Commercial End Use Survey (CEUS) which is a comprehensive dataset of end use energy for California. The weather and climate parameters are not normalized and this tool is limited to commercial buildings in California. (Action oriented tool)

2.2.2 Points Based Rating System

This type of a rating system sets benchmarks in the form of standards or guidelines to measure the efficiency of the building on a point scale. It does not compare the performance with other buildings. US Green Building Council's Leadership in Energy and Environmental Design (LEED) rating system adopts this method to rate the environmental efficiency or sustainability of a building (Kinney & Piette, 2002). After a thorough initial review it is found that there is no tool that explicitly benchmarks the energy performance of buildings in the US using a points-based rating system.

2.2.3 Model Based Rating System

A simulation model based tool generates an idealized benchmark using the available building details and a program like DOE-2 for simulating the building. Unless there is an error in the simulation due to inaccurate details, the benchmarking is reliable and accounts for multiple factors in the systems that can be tweaked to achieve any set targets (Kinney & Piette, 2002).

An example of a regression model based system is the Energy Star® Rating system. Portfolio Manager, the benchmarking tool, calculates or predicts the energy requirement for a basic set of functional requirements, building location and physical characteristics for the required building type. This prediction is on the basis of normalized physical, operational and weather characteristics such that it is a representative model of the building. The unique capability of the PM tool is that it compares the actual and predicted consumption and gives a rank which indicates the percentage of buildings of the same type whose performance is not as good.

2.2.4 Hierarchal and End-Use Metrics Rating System

Hierarchal and End-Use Metrics refers to the method of generation of benchmarks that link energy use to climate and functional requirements (Kinney & Piette, 2002). The benchmarking is done in levels or hierarchically. For example benchmarking may begin with information pertaining to annual utility bills, and then proceed to operating characteristics; the next level could be requirement of hourly data to account for weather. Data required in such detail is however not readily available (Sartor, Piette, Tschudi, & Fok, 2000).

2.3 Energy Benchmarking Database

The Commercial Buildings Energy Consumption Survey (CBECS), as described on the Energy Information Administration's (EIA) website, is conducted by EIA every four years (since 1979) to provide the following information about commercial buildings:

- basic statistical information about energy consumption,
- basic statistical information about energy expenditures in U.S. commercial buildings, and
- information about energy-related characteristics of these buildings

The first of the two stages of CBECS is called the Building Characteristic Survey in which information about selected commercial buildings is collected by interviewing building owners, managers, or tenants on a voluntary basis. Questions are related to building size, space uses in the building, types of energy-using equipment and conservation measures that are present in the building, and the types of energy sources used. The amount and cost of energy used were also collected in the 1999 CBECS survey. The second stage is the Energy Suppliers Survey initiated to collect actual building consumption and expenditures information for the buildings that did not provide this data and it is obtained from the records maintained by energy suppliers. "Hot-deck imputation" is a technique used by EIA to account for/ fill up the building details that are not provided from the building side due to lack of understanding of any questions. In such cases, another similar building is randomly chosen and its value is then assigned to the building with the corresponding missing item. In the case of hospital buildings however the CBECS data was not found robust enough by EPA to fully account for variations related to the service in the healthcare sector and hence data recorded by the Electric Power Research Institute (EPRI) in 1997 for their Energy Benchmarking Survey is utilized (Energy Star®, 2001).

2.4 Energy Star® Rating Evaluation

Hicks and Neida conducted a study in 1999; a year after the certification was introduced, to evaluate the performance of the ninety Energy Star® Labeled Office buildings that had achieved this recognition (Hicks & Neida, 2000). The physical and operational characteristics of these ninety buildings were compared to CBECS and the Building Owners and Managers Association (BOMA) International Energy Exchange Report 1999 (EER) (BOMA 1999) datasets. The presence of building equipment and systems, amenities and management practices were assessed during this evaluation. After applying filters to the buildings from CBECS and BOMA datasets, there were 530 buildings from CBECS and 3364 buildings from the BOMA-EER database. 144 buildings belonged to the upper quartile and 125 belonged to the lower quartile of the CBECS database in terms of energy performance. The determination of the quartiles was done using the logic used for Energy Star® Benchmarking which will be explained in detail further in Sections 2.7 and 2.8. It was observed that the average site energy consumption intensity of Energy Star® buildings was 44% lower than the average

CBECS building stock with the worst performing certified building still 27% more efficient than CBECS average stock. The average cost intensity of $1.12 per square foot for the Energy Star® labeled buildings was 30% lower than the average CBECS building stock's cost intensity and 33% less than the average cost intensity reported in BOMA-EER 1999. The top quartile of CBECS buildings has comparable operating characteristics and installed equipment to Energy Star® buildings. The data also reveals that facility energy equipment upgrades, renovation, energy audit, retro-commissioning and amenity enhancement initiatives are more common in the Energy Star® buildings than in the top CBECS buildings stock quartile. The type of fuel was observed to not influence the ratings and there was no specific approach for improving the energy rating. Hicks and Neida concluded that the Energy Star® program promotes efficient technologies on a system level, participation of building operators for establishing good building operating and maintenance practices, and sets an energy efficiency target above the market average.

Satkartar and Piette (2002) state that, "perhaps the best-known and most technically robust building energy benchmarking tool is the EPA/DOE Energy Star® Benchmarking Tool". After a review of the office and school benchmarking tools in detail, they observed that the tools are unique and the most valuable initial screening tool available for building energy use analysis across the US (Kinney & Piette, 2002).

2.5 Portfolio Manager – Energy Star® Rating Tool

The space types as listed in Table 1 are eligible to obtain an Energy Star® Rating according to the Technical Methodology (Energy Star®, 2011a), released in March 2011.

Table 1: Space types eligible to obtain Energy Star® Rating

Bank/Financial Institutions	Hotels	Retail Stores
Courthouses	Houses of Worship	Senior Care Facilities
Data Centers	K-12 Schools	Supermarkets
Dormitories	Medical Offices	Warehouses
Hospitals	Offices	Wastewater Treatment Plants

Details of these space types are entered into the Portfolio Manager tool which processes the entered information and calculates the rating. As stated in the "ENERGY STAR® Performance Ratings – Technical Methodology", March 2011, EPA uses building data recorded by CBECS for most of the space types. The office type buildings use data from the CBECS database but hospitals use EPRI data for generating the ratings. This is national level data comprised of billing and operational details of over 6000 buildings across the country. PM handles data on a whole building level and not on a system level. It requires actual utility billing data to be entered along with the building's physical and operating characteristics. It uses a regression model developed by EPA for every building type to normalize the operating characteristics of a building and then compares the performance of the building with its peers from the dataset. The rating obtained is a percentile value of the energy performance (energy intensity of a building generally expressed in kBTU/ft^2 of Source Energy) of the building and it indicates the percentage of buildings in the dataset that are less efficient in operation.

2.6 Building Data Filters

PM calculates ratings for only the buildings from the above mentioned space types that operate for at least 30 hours per week. CBECS does not record chilled water purchased by a building; consequently PM is unable to accommodate such buildings owing to this limitation of data and hence cannot rate such buildings. Outliers are rejected for obtaining the best possible curve fit which consequently poses a limitation on the physical and/or operating characteristics for which accurate energy consumption can be calculated. For example, energy consumption for offices with a gross floor area of less than 5,000 ft^2 cannot be accurately estimated using the PM tool. Different space types have different constraints, and the PM does not accept or rate such buildings. These are some of the filters applied for overcoming limitations while maintaining accuracy (Energy Star®, 2011a). The total number of office buildings used to develop the regression model for the office building type is 498 after building filters are applied to the data recorded by CBECS (Energy Star®, 2007b), while 493 hospitals qualify when the building filters for hospitals are applied to EPRI records of a total of 701 hospital buildings (Energy Star®, 2001).

2.7 Energy Star® Rating Methodology Overview

All utility consumption data entered is converted into source energy data expressed in equivalent energy units. Source energy includes the energy consumed in generation and transmission along with the energy actually consumed on site. This approach holds the building users more accountable for the emissions and energy generation for every unit of energy consumed on site. The differences in the operating characteristics of the buildings are normalized by performing a statistical regression and the key drivers of energy use in buildings are identified. EPA uses a weighted ordinary least squares regression method for calculating source energy intensity dependent upon independent characteristics such as weather, floor area, operating hours, etc. The least squares regression method provides a descriptive, statistically valid equation for every building type. A normalized linear equation for each building type is derived where the coefficients correlate source energy use to the operating characteristics specific to the building type. EPA tests these equations with residual plots, model R^2, and individual coefficient significance levels for every space type and selects the equation having the best fit.

The Source Energy Use Intensity (Source EUI) is the dependent variable calculated using the independent variable values in the linear expression derived from performing ordinary least squares regression analysis. The ratios for every utility type used to calculate the source energy from site energy are given in Table 2 (Energy Star®, 2011b).

Table 2: Site energy to source energy conversion ratios

Fuel Type	Source-Site Ratio
Electricity (Grid Purchase) 3.34	3.34
Electricity (on-Site Solar or Wind Installation)	1
Natural Gas	1.047
Fuel Oil (1,2,4,5,6,Diesel, Kerosene)	1.01
Propane & Liquid Propane	1.01
Steam	1.21
Hot Water	1.28
Chilled Water	1.05
Wood	1
Coal/Coke	1
Other	1

The independent variables are building operating and physical characteristics that differ for each building type and do not include specific technical details such as type of lighting, certified equipment, etc. Heating Degree Days (HDD) and Cooling Degree Days (CDD) are the independent variables used to account for the weather conditions. EPA performed calculations and established that HDD and CDD are adequate to account for the humidity and dew factors.

PM calculates the Predicted Source EUI using the building characteristics and operating information provided, and then compares it with the Actual Source EUI calculated using information from the utility bill. This information varies with the space use type as shown in the Table 3 below and as tabulated in Glazer's report (Glazer, 2006). Zip Code and building gross floor area information is required for every type.

The ratio of Actual Source EUI to Predicted Source EUI or the ratio of the natural logarithm of the Actual Source Energy to the natural logarithm of the Predicted

Source Energy, depending upon the space type, is calculated. There is a specific range of this calculated ratio for every space type between which the building is rated between 1 and 100. This percentile value of the performance of the building is the Energy Star® Rating of that building. A look up table exists for every space type to obtain the rating for intermediate ratios. A sample calculation of Energy Star® Rating for an example office building is demonstrated in Appendix A.

2.8 Rating Buildings for CC® Impact Study

The scope of this study is limited to Hospital and Office Building types in different parts of the US. The following text details the operating characteristics or independent variables compared for the two building types along with the linear regression coefficients determined by EPA to generate ratings for each building type.

2.8.1 EPA Rating methodology – Office Type

EPA's Energy Star® Technical Methodology defines offices as "facility spaces used for general office, professional, and administrative purposes" and then benchmarks its performance using the Portfolio Manager tool (Energy Star®, 2007b). The operating characteristics that form the independent variables for the office type buildings are as follows:

- Natural log of gross square foot (CLnSqFt)
- Number of personal computers (PCs) per 1,000 square feet (CPCDen)
- Natural log of weekly operating hours (CLNWkHrs)
- Natural log of the number of workers per 1,000 square feet (CPCDen)

- HDD x (% building heated) (CHDDxPH)
- CDD x (% building cooled) (CCDDxPC)

The coefficients for the final linear regression equation derived by Energy Star® for offices are as tabulated below:

Table 3: Linear regression equation for calculating the predicted source EUI of an office type facility

Variables	Coefficients	Variables	Coefficients
Constant	186.6	CLNWkrDen	10.34
CLnSqFt	34.17	CHDDxPH	0.0077
CPCDen	17.28	CCDDxPC	0.0144
CLNWkHrs	55.96		

2.8.2 EPA Rating Methodology – Hospital Type

The hospital type is described by EPA's Energy Star® Technical Methodology as "a facility space used as Acute Care and Children's Hospitals between 20,000 and 5 million square feet in total gross floor area. These facilities provide acute care services intended to treat patients for short periods of time for any brief but severe medical condition, including emergency medical care, physician's office services, diagnostic care, ambulatory care, and surgical care" (Energy Star®, 2001). The operating characteristics that form the independent variables are as follows:

- Natural log of gross square foot (Ln(Sqft))
- Hospital in the Acute Care/Children's Category (1 = yes) (Acute)
- Provides of tertiary care (1 = yes) (Tertiary)
- Natural log of number of beds (Ln(# Beds))

- Natural log of maximum number of floors (Ln(Max # Floors))
- Above ground parking facility present (1 = yes) (A.G. Parking)
- Sum of heating and cooling degree days (DD)

The coefficients for the final linear regression equation derived by Energy Star® for hospital type are as tabulated below in Table 4.

Table 4: Linear regression equation for calculating the predicted source EUI of a hospital type facility

Variable	Coefficients	Variables	Coefficients
Constant	7.50492	Ln(# Beds)	0.10439
Ln(Sqft)	0.82798	Ln(Max # Floors)	0.11119
Acute	0.14794	A.G. Parking	0.10534
Tertiary	0.09278	DD	-0.00003

2.8.3 EPA Rating Methodology – Mixed Use Space Type

Mixed use types of buildings are called "Spaces with different Rating Model" (Energy Star®, 2011a). The PM tool accepts and processes space operating and physical characteristics information separately for the mixed use spaces. The utility consumption information is accepted both separately for each space type and in combined form together for the whole facility as available. The predicted source energy is calculated for each space type and the ratio of total actual source energy to total predicted source energy is calculated and this value is looked up in the lookup table. The lookup table is generated by the PM tool separately for every multi space type. The values in the lookup table are calculated by summing the actual to predicted source energy ratios in proportion to the ratio of the areas of the existing space type. The rating for multi use space is then calculated in the same way the rating for single use spaces is calculated. For the present study the priority is to analyze the trends for individual building types where the CC® process has been implemented. However it is useful to note that individual building types that make up a multi space type building influence its ESR in proportion to their areas and Source EUI.

2.9 LEED-EBOM Certification

The requirements of USGBC's Leadership in Energy and Environmental Design – Existing Buildings Operations and Maintenance (LEED-EBOM) certification include improvement in the energy efficiency of the systems in the building. LEED-EBOM certification, a Points Based System, awards credit points by evaluating the performance based on the Energy Star® Rating of the building or by measuring the whole building energy consumption in case the building is not of a type eligible to obtain a rating. Both hospitals and office buildings are eligible to receive ESR and the following Table 5 displays the points credited for achieving the respective Energy Star® Rating (US Green Building Council, 2009).

Table 5: Credit points achieved for particular Energy Star® Rating value

EPA Energy Star® Rating	Points
71	1
73	2
74	3
75	4
76	5
77	6
78	7
79	8
80	9
81	10
82	11
83	12
85	13
87	14
89	15
91	16
93	17
95	18

2.10 Summary of Literature Review

Documents available on the Energy Star® website (Energy Star®, 2011a) list the 15 types of building spaces that can be benchmarked or rated using EPA's Portfolio Manager Tool. The technical methodology for generating the Energy Star® Rating of all the building types is documented on the Energy Star® website and is accessible to the public. This implies that it is possible to accurately calculate the ESR without using the PM tool and develop a tool having required provisions and a higher level of flexibility to perform any analysis. Because of the large acceptance of the Energy Star® label country wide and the availability of technical information for performing analysis as elaborated in Section 2.2, this is an ideal selection of an energy performance benchmark to be chosen for analyzing the impact of the CC® process. Benchmarking tools such as the Cal-Arch® and EnergyIQ® are other accepted comprehensive benchmarking tools but their database is limited to California as it uses the California Commercial End-Use Survey's (CEUS) data (Berkeley Lab, 2008), (Mills, 2008).

On the basis of the literature reviewed (Liu, Claridge, & Turner, 2001) it can be speculated that the CC® process enhances the economic and environmental sustainability of buildings by primarily improving the efficiency of their systems, and their operation and control. The resultant savings in energy consumption help a building to obtain a higher Energy Star® Rating. There has however been no study that consolidates and quantifies the benefits of implementing energy conservation measures through any systematic processes, or the CC® process in particular, which have the potential to contribute significantly toward obtaining recognitions such as the Energy Star® label and LEED-EBOM certification that are preferred by some state governments, building owners and tenants. The exact correlations between specific Energy Star® Ratings and the corresponding LEED-EBOM credit points earned are found in the literature and as mentioned in Section 2.9. The impact of the CC® process on the energy performance of a building in the US in this way is evaluated from a different perspective and by using a national level scale.

3. METHODOLOGY FOR CC® IMPACT STUDY

A standard method of correlating any commissioning, retro-commissioning, re-commissioning or ongoing commissioning process and energy performance benchmark does not exist. The energy conservation measures, recommendations of retrofits, and the extent of improvements in the operation and control vary with each building. As a result the accuracy of prediction of the initial and final benchmark rating of a building will depend upon the extent of the availability of the building data and its consumption data.

In the CC® process the first step is conducting a preliminary or walk-through assessment where energy bills and certain building details are collected. This is a crucial stage as it is an opportunity to decide the suitability of the building for going ahead with implementation of the CC® process. At this stage, in addition to an estimated amount of savings, cost-benefit analysis, investment, etc., the knowledge of the amount of improvement of the buildings Energy Star® rating can be important considering the growing awareness among buyers and supportive regulations for the Energy Star® Rating program. It is necessary that the methodology adopted for studying the impact of the CC® process must yield outputs that demonstrate the impact of the CC® process post implementation and give an elaborate idea of the possible impact, based on the estimates of the walkthrough assessment. All variables should be accounted for and the analysis should assist in selecting the most cost effective solutions to improve the energy performance while gaining maximum environmental sustainability credits, for each building separately anywhere in the United States.

3.1 Background Information

Algorithms applied for calculating the Energy Star® Rating for any building type involve the calculation and use of Source EUI (Energy Star®, 2011a) for any building. Portfolio Manager, the tool provided by EPA calculates the Source EUI and generates ESR based on the input information and using the appropriate algorithm. The type of the building decides the algorithm and the input information consists of building consumption data, and some operating and physical characteristic data. This data is acquirable during a walkthrough, or by contacting building personnel for the buildings already commissioned. Building information in terms of characteristic and operating data required for hospital and office buildings is presented in Table 6 below.

Table 6: Building characteristic and operating data for hospital and office building types

Information	Offices	Hospitals
Weekly operating hours	x	
Number of occupants	x	
Number of workers	x	
Main shift staffing		
Number of personal computers/registers	x	
Number of licensed beds		x
Number of floors		x
Number of rooms		
Percent air-conditioned	x	x
Percent heated	x	x
Presence of tertiary care		x
Presence of above ground parking		x

The technical methodology reveals that for calculating Energy Star® Rating the amount of change of Source EUI depends upon the change in the consumption value of each utility. Knowledge of the change in the consumption of each utility for any building type is necessary to estimate the change in Source EUI and subsequently in the rating. Weather is a factor that is location dependent and hence its impact will be considered separately.

The availability of the ESR calculation methodology, and energy consumption data (before and after the CC® process), building characteristic and operating data, and weather data for both hospitals and office buildings are sufficient to study the impact of CC® on the ESR of any building of either of the two types.

3.2 Using Portfolio Manager Tool

The PM Tool is accessible only after connecting to the internet. A building has to be registered and the annual consumption data must be entered to obtain a rating for the building. PM rates a building using its most recent annual consumption data. It considers the oldest annual data as Baseline data, benchmarks the improvement against this baseline.

The data entered into and processed by PM can be downloaded for processing, but each entry needs to be made separately. To compare the improvement in ESR of a building because of implementation of the CC® process, the same building data having different consumption details is required to be entered. Analyzing and comparing data for multiple buildings can be uncomfortable and time consuming for the user especially because it will have to be imported from the online PM account to some software like MS Excel®. The rating generated based on statistical analysis is rounded off to the nearest whole number between 1 and 100 in the lookup table. There exists a range of lookup values (effectively the Source EUI values) for which there is no change in the rating. Based on the provisions provided in the PM tool, it can be said that PM does not enable the user to view this range of source EUIs for which the rating remains unchanged.

3.3 Accounting for Impact on Environmental Sustainability

LEED-EBOM, an environmentally sustainability certification, requires a minimum level of energy performance for a building to be eligible for obtaining the ‘Energy and Atmosphere Credit 1: Optimize Energy Efficiency Performance’ credit. A minimum Energy Star® Rating of 71 is required to obtain any points for this credit. Up to 18 points out of the 40 minimum points or up to 45% of the minimum points required to obtain LEED-EBOM certification can be earned by efficient building energy performance (LEED Reference Guide for Green Building Operations and Maintenance, 2009). By accounting for the impact that CC® can have on the building’s LEED-EBOM certification levels and GHG emissions reduction, the potential of the CC process can be emphasized more, and so can the level of investments to be made be influenced. The number of LEED credit points accumulated decides the level of certification to be awarded to any building; its scale is given below (LEED 2009 for Existing Buildings: Operations & Maintenance Rating System, 2011).

- Certified - 40–49 points
- Silver - 50–59 points

- Gold - 60–79 points
- Platinum - 80 points and above

3.4 CC® Impact Study

Analysis of the impact of any commissioning process on the Energy Star® benchmark rating requires an understanding of the technical methodology and the rating system adopted by EPA. CC® is implemented in buildings located in different parts of the United States. The different number of Cooling and Heating Degree Days at each location results in weather being a parameter that influences a building's ESR. In the case of hospitals and office buildings, the weather combined with the physical and operating characteristics of the building determine the level of its energy performance. Additionally, calculating the Energy Star® Rating and determining its sensitivity to the achieved energy savings in case of hospital and office type buildings will require handling and processing of multiple datasets. A dataset represents a building with unique physical characteristics, operating parameters and weather conditions.

In this study the improvement in the Energy Star® benchmark rating because of the energy savings (energy efficiency improvement) obtained by implementing the CC® process in buildings is studied and analyzed using sets of building data estimated to represent a building. The locations of both types of buildings are varied initially while keeping the rest of the parameters unchanged. Similarly, in the next step only the building consumption (which represents energy savings) is varied and the change in the Energy Star® Rating is observed. The sensitivity of change in magnitude of the Energy

Star® Rating with respect to the Energy Star® Rating calculated for the same building in its existing condition is obtained.

4. RESULTS AND OBSERVATIONS

The trend of variation of the ESRs with respect to the change in climatic conditions for the year 2010 is plotted. The buildings are assumed to be located in different parts of the US that represent the different climatic conditions in the country. The numbers of cooling and heating degree days in six select cities in the US are listed in Table 7.

Table 7: List of cities and CDD and HDD values to a base of 65 °F

City and Year	CDD	HDD
New York 2010	1548	4447
Chicago 2010	1200	5810
Houston 2010	3406	1646
College Station 2010	3424	1761
Los Angeles 2010	2198	916
Washington DC 2010	2123	3911

4.1 Influence of Location - Office Buildings

All office buildings are assumed to have identical physical and operating characteristics/parameters and the impact of weather is observed by assuming buildings to be located in each of the select cities and then generating their ratings. The floor area and the percentage of conditioned areas are arbitrarily assumed. The CBECS 2003 data available online has the density of occupants in Office Buildings documented for the Non-Mall type buildings in the United States. The Non-Mall type buildings are the types of buildings that exclude strip shopping centers and enclosed malls (U.S.E.I.A, 2008a). The average occupant density in office buildings, according to CBECS data is one person per 434ft^2 of office space and the average number of weekly office working hours is 55 hours (U.S. E.I.A., 2008b). Based on a report by IPD Occupiers it is assumed that a personal computer is allocated to every worker in the office (IPD Occupiers, 2007). All the fixed, common parameters assumed for forming the office building datasets have been summarized below.

- Floor Area = 100,000 ft2
- Number of PCs = Number of Workers = 1 person per 434 ft^2
- Operating hours = 55 hrs per week
- >50% gross floor area conditioned (heated and cooled)

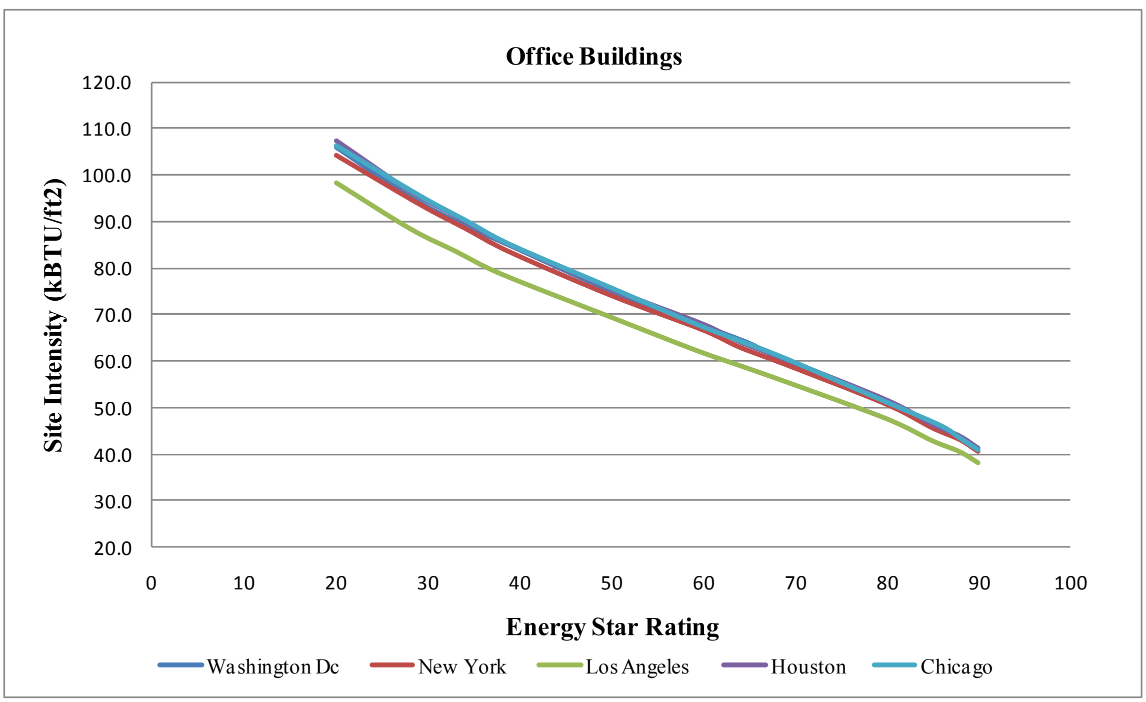

Figure 1: Plot of energy intensity against Energy Star® Rating of office buildings

Figure 1 consists of sixty sample points; twelve sample points for the representative buildings in each of the five cities. The source energy intensity/consumption of each building is initially fixed to values that result in Energy Star® Ratings of 20, 50 and 80. The consumption values are then proportionally reduced by 10%, 15%, and 20% for each of 20, 50 and 80 ratings to result in total of twelve sample points representing buildings in each city. A plot of site-energy consumption intensity values is plotted against the corresponding building Energy Star® Ratings. .

It is observed from Figure 1 that a building with the same characteristic features and the same energy intensity is rated more poorly in Los Angeles as compared to the other five select cities. Utilizing the values in Table 12 (Appendix B) the slope of the graph in Figure 1 for an average value of energy intensity of all buildings equates approximately to 1.25 (kBTUs/ft^2 per ESR).

4.2 Influence of Location - Hospitals

Hospitals, as in case of office buildings, are assumed to have identical physical and operating characteristics/parameters and the impact of weather is observed by assuming the buildings to be located in each of the select cities and then generating their ratings. The floor area is arbitrarily assumed and it is also assumed that every hospital has tertiary and acute care facilities, and above-ground parking is present. The value for the number of beds in a hospital used for all calculations related to hospital buildings is 2.8 beds per 1000 ft^2 of its gross floor area (South California Gas Company, 2010). All the fixed, common parameters assumed for forming the hospital building datasets have been summarized below.

- Floor Area = 100,000 ft2
- Number of Beds = 2.8 beds per 100 ft2
- Tertiary care and acute care present.
- Above ground parking present.

Figure 2, which demonstrates the impact of location on the Energy Star® Rating of hospitals, is plotted below.

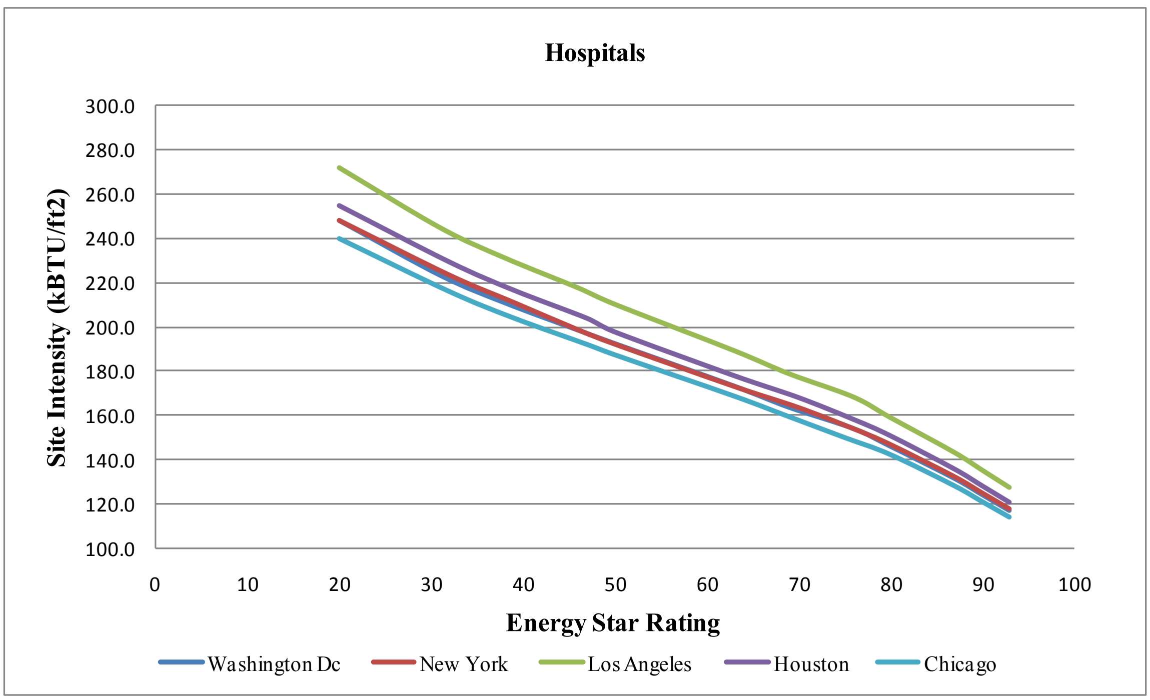

Figure 2: Plot of energy intensity against Energy Star® Rating of hospitals

Identical in procedure to the plot for office buildings, Figure 2 for hospital type buildings consists of sixty sample points, twelve for the representative buildings in each of the five cities. The source energy intensity/consumption of each building is initially fixed to values that result in Energy Star® Ratings of 20, 50 and 80. Energy Star® Ratings are obtained by reducing the consumption of a building with a rating of 20 by 10%, 15% and then by 20%. This process is repeated for buildings with ratings of 50 and 80 and thus a total of twelve sample points are obtained representing twelve buildings in each city.

It is noted by comparing Figure 2 and Figure 1 that the energy intensity of an office building that has a rating of 50 in Houston is approximately 75kBTU/ft^2 whereas the intensity is approximately 200kBTU/ft2 for a hospital in Houston with a rating of 50. Utilizing the values Table 13 (Appendix B) the slope of the graph in Figure 2 for an average value of energy intensity of all buildings equates approximately to 1.8 (kBTUs/ft^2 per ESR). It is further observed in Figure 2 that a hospital building with the same characteristic features and energy intensity is rated higher in Los Angeles as compared to the other five select cities very much unlike an office building which obtains a poorer rating in Los Angeles compared to the other four cities.

4.3 Influence of Initial Energy Star® Rating

The sensitivity of change in magnitude of the Energy Star® Rating with respect to the existing Energy Star® Rating of the building is studied by tabulating and plotting the two parameters. In the first plot, Figure 3, energy savings of 10% and 20% are arbitrarily assumed and the change in the rating is graphed at each value of the rating. This is done separately for both hospital and office building types. The Energy Star® Ratings are obtained by iterating and adjusting the energy consumption proportionally for each utility in every building dataset and then 10% and 20% reductions on these values are used to calculate the change in the rating in each case. The use of iteration where energy consumption is incremented allows obtaining of a maximum single value of the building energy consumption and the corresponding Energy Star® Rating. It may be said that if at any given rating in Figure 3 the consumption is reduced then there will be a magnitude for which the rating will remain unchanged. The Energy Star® Ratings are rounded off to whole numbers and the graph is consequently stepped in nature. This is illustrated in Section 4.5 in the text to follow.

The buildings physical and operating characteristics values for office buildings are the same as those used for studying the influence of location in section 4.1 and the climate parameters are as tabulated Table 7.

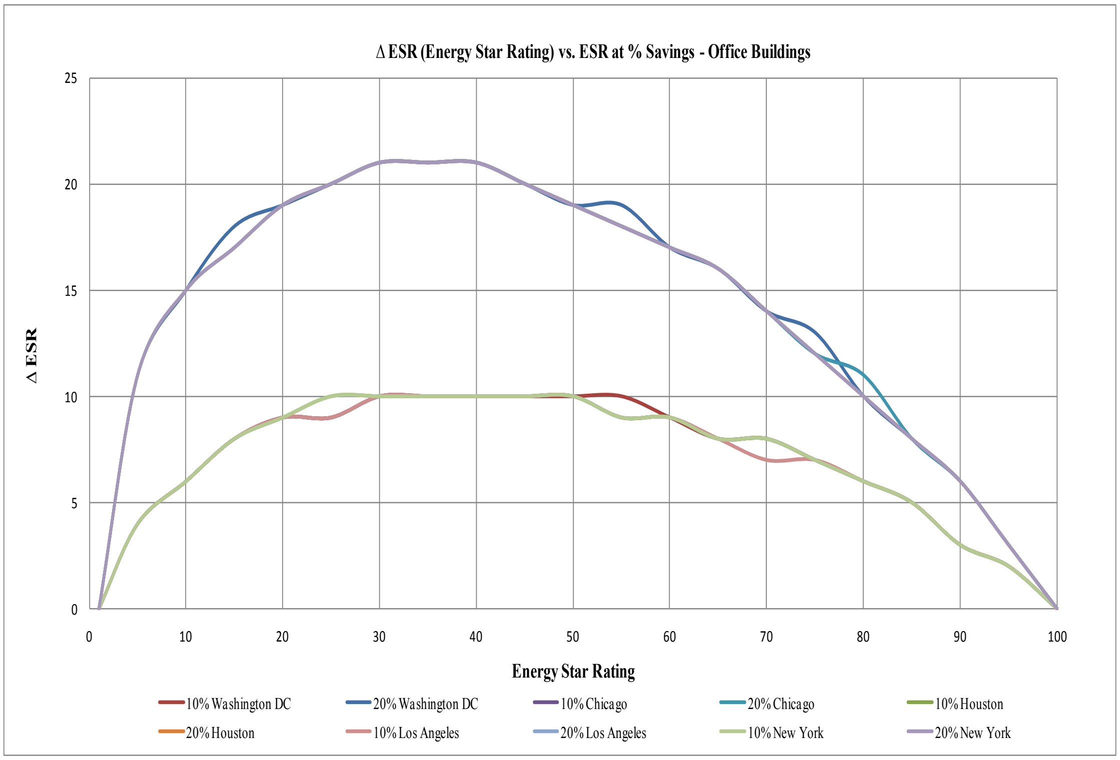

Figure 3: Sensitivity of office buildings to geographic locations for 10% and 20% energy savings

Table 14, Table 15 (both in Appendix B) and Figure 3 for office buildings indicate that source energy savings of 20% result in a maximum improvement of the Energy Star® Rating of 21 rating points, when the initial rating is in the range of 30 to 40. This observation is true for an office building located in any of the five cities considered up to this point in the study. The same consideration for the same set of buildings reveals that if 10% savings in source energy is achieved an improvement of a maximum of 10 rating points is achieved when the initial Energy Star® Rating is in the range from 30 to 50 for any building.

A similar plot for hospital type buildings is obtained using the same logic. Section 4.2 details the physical and operating characteristics values for hospitals and the weather parameters used are tabulated in Table 7. However in case of hospitals it may be observed from Table 17 , Table 16 (both in Appendix B), and Figure 4, that for 20% savings hospitals in all of the five cities show a maximum improvement in the range of approximately 30 thru 35 and in the range from 20 to 55 in any city for 10% savings in energy. It is noted that for savings of 10% the change in rating is almost identical for buildings in all of the cities, while there are variations for savings of 20% savings.

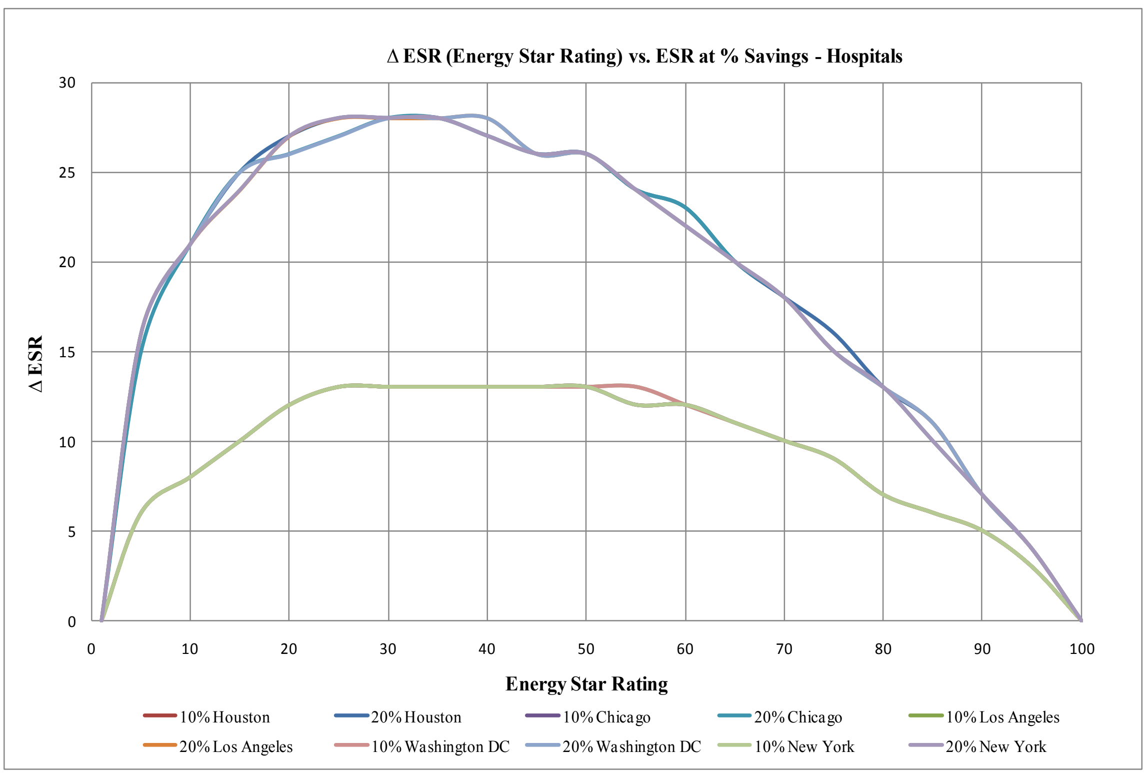

Figure 4: Sensitivity of hospitals to geographic locations for 10% and 20% energy savings

The maximum improvement in the rating of hospitals is 28, while it is 21 for offices for the same 20% savings on energy.

4.4 Energy Savings

In section 4.3, Figure 3 and Figure 4 demonstrate the improvement in the Energy Star® Rating of a building with varying performance at different locations in the US. This trend is for a fixed percentage of energy savings, 20% for both the plots. In this analysis the buildings are arbitrarily assumed to be located in Washington DC and graphs for savings of 10%, 15%, 20% and 25% are superimposed.

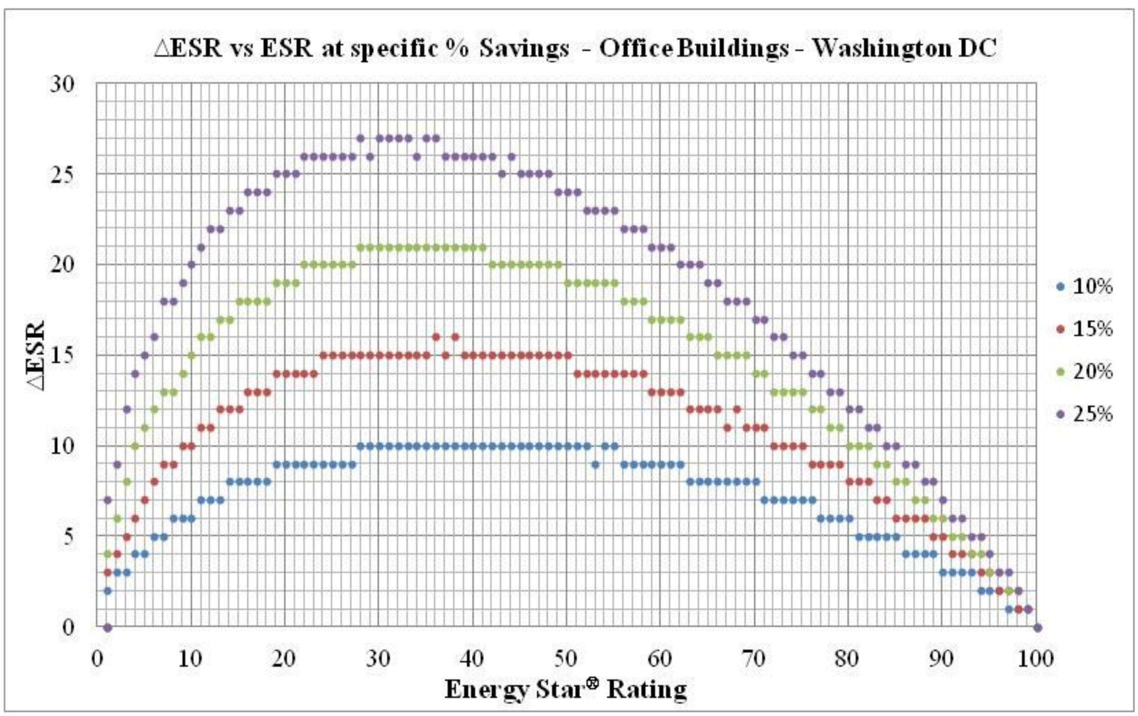

Figure 5: Sensitivity of office buildings in Washington, DC to specific constant % energy savings

In Figure 5 the nature of improvement in ratings for different percentage savings in office building energy consumption is revealed. Figure 5 represents the trend of improvement of Energy Star® Rating for specific percentages of energy savings achieved and as tabulated in Table 18 (Appendix B).

Figure 6 is a plot of the final ESRs versus initial ESRs for specific % energy savings. It incorporates the improvement of the ESR for a particular initial ESR and also provides better readability for % savings required to achieve desired final ESR.

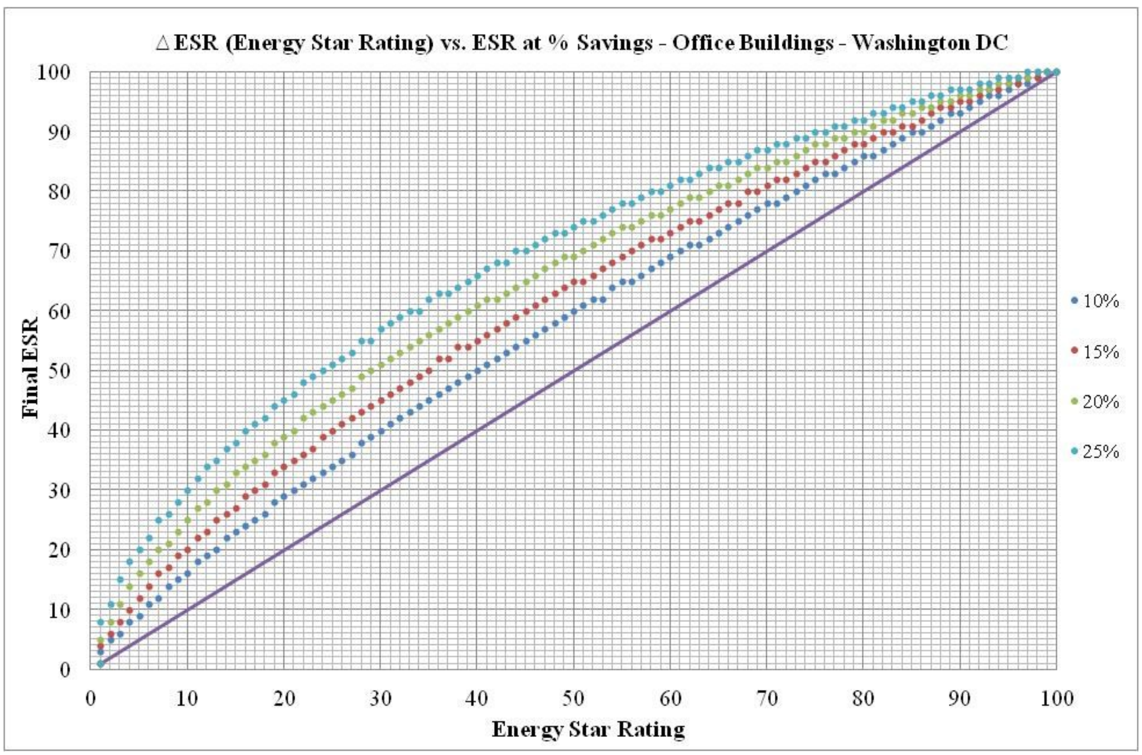

Figure 6: Final ESR versus initial ESR for office buildings in Washington DC at constant % energy savings

Following (Figure 7) is a plot for hospital buildings located in Chicago:

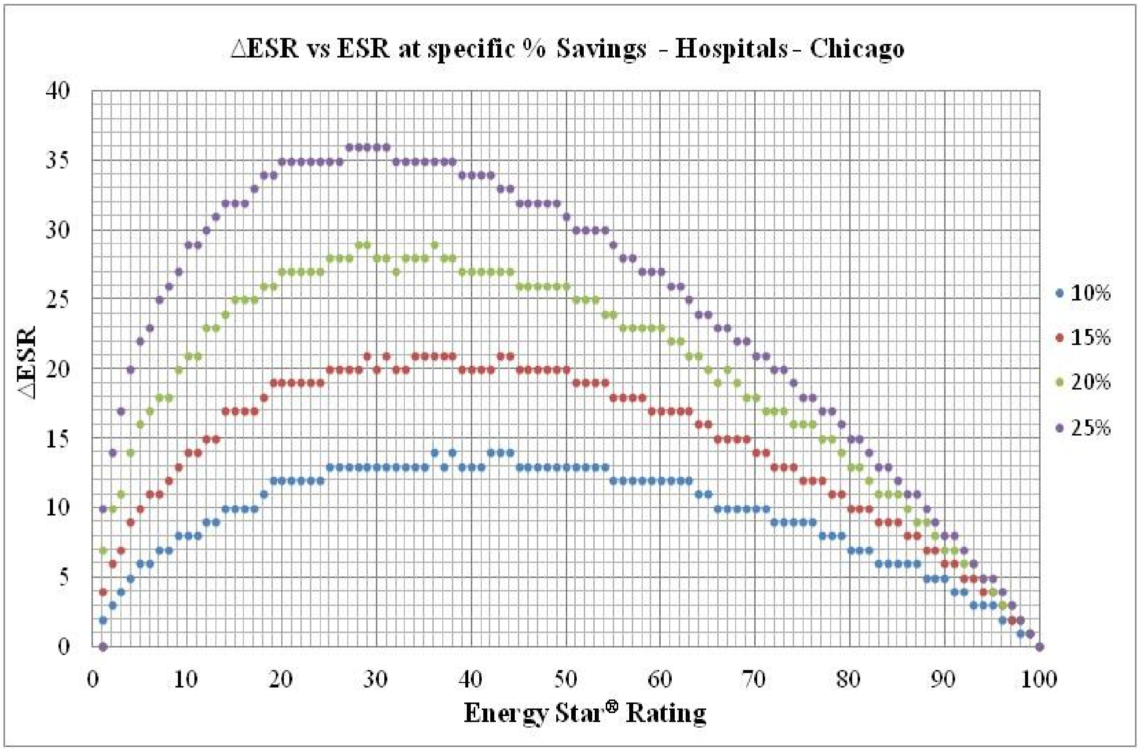

Figure 7: Sensitivity of hospitals in Chicago to specific constant % energy savings

As in case of office buildings, Figure 8 is a plot of the final ESRs versus initial ESRs for specific % energy savings. It incorporates the improvement of the ESR for a particular initial ESR and also provides better readability for % savings required to achieve desired final ESR.

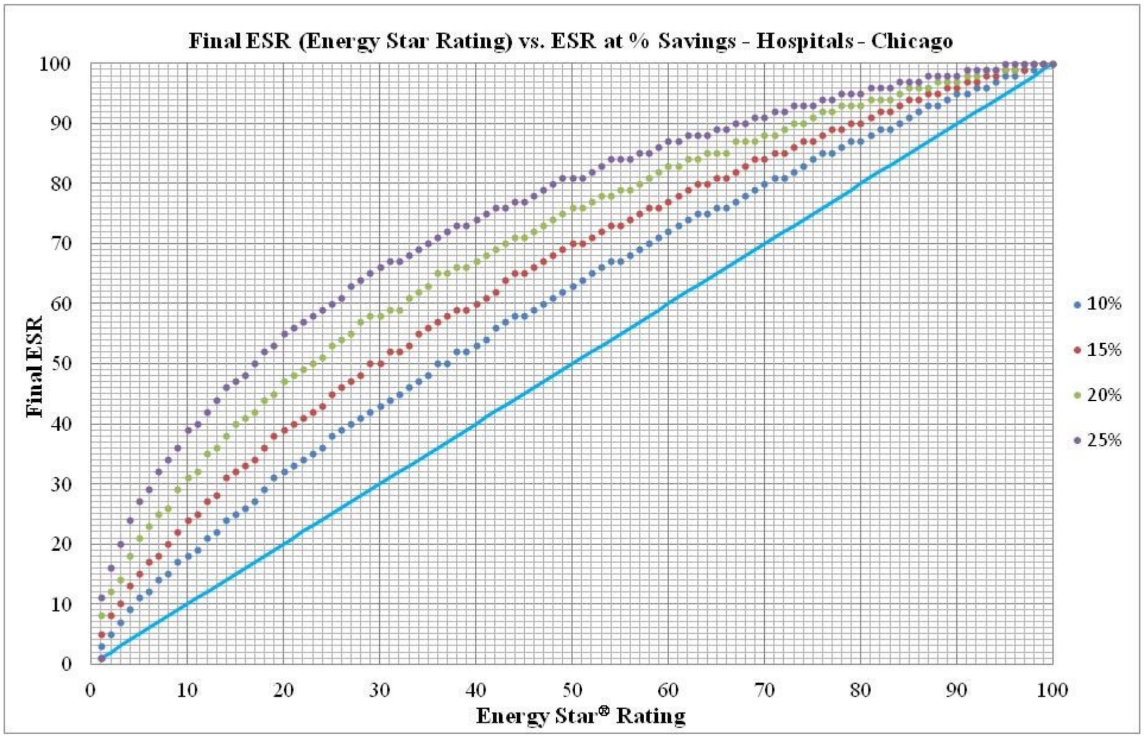

Figure 8: Final ESR versus initial ESR for hospitals in Chicago at constant % energy savings

It is observed by comparing Table 19, Table 18 (both in Appendix B), Figure 5 and Figure 7 that hospitals show better improvement in Energy Star® Rating than office buildings for the same percentages of energy savings.

4.5 Energy Star® Rating and Energy Intensity Reduction

The change in energy intensity of any building, office or hospital, causes the Energy Star® Rating to either improve or reduce depending upon decrease or increase in the building energy consumption. Figure 9 is a plot of a sample building with initial rating of 60 located in Washington, DC. Its ratings are calculated by reducing the consumption in steps of 0.1% up till 18% energy savings to observe the nature of change in the ratings.

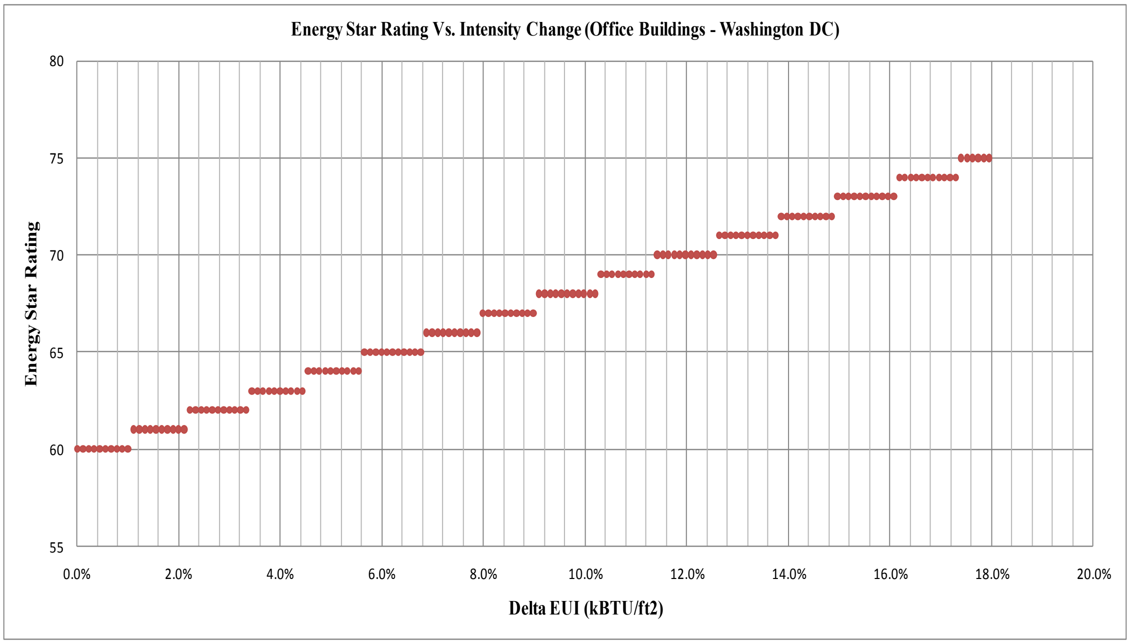

Figure 9: Energy Star® Rating versus % reduction in energy savings for offices

The change in the rating in Figure 9 is observed to be stepped in nature and not smooth. It indicates that for the example office building with an initial rating of 60, 1% reduction in energy savings does not improve the ESR of the building. Based on the observations from Figure 3 it can be stated that the trend obtained in Figure 9 is representative of an office building located anywhere in the US with rare but acceptable variations in the pattern. It is further noted that to improve the rating from 60 to 70, energy reduction of approximately between 11.5% and 12.5% yields the same resultant improvement.

Figure 10 is a plot similar to the plot in Figure 9 for office buildings and displays the relationship between Source EUI and the Energy Star® Rating for a hospital in Houston, Texas.

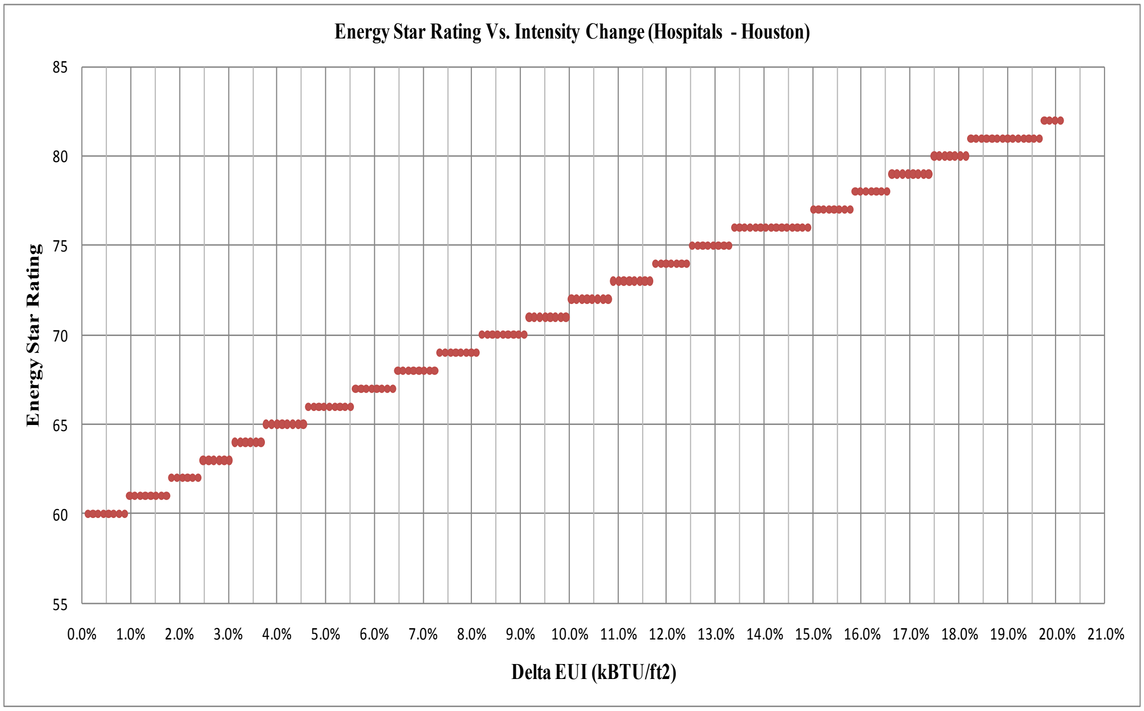

Figure 10: Energy Star® Rating versus % reduction in Energy Savings for hospitals in Houston.

Figure 10, representing a sample hospital building, shows that for a hospital building with an initial rating of 60 a reduction in energy consumption approximately in the range between 4.5% and 5.5% will improve the rating of the building to the fixed value 66, depending on the value of the original consumption within the spread of values giving an ESR of 60. Figure 10 also indicates that for any percentage of energy saved between 13.5% and 15%, the rating of the building will improve from 60 to 76. The unresponsive band in this case is 1.5%, starting from approximately 13.5% to 15% energy savings.

The percentage savings in energy consumption indicated to have been used for the graphs in Figure 5 and Figure 7 are the savings on the maximum energy intensity values to obtain the corresponding rating indicated for the building. The percentage of savings required to have maximum or the required improvement in the Energy Star® Rating can be decided based on the plots showing the impact of the initial Energy Star® Rating of the building (Figure 5 and Figure 7), and the Figure 9 that highlights the regions in which the energy savings up to certain magnitude do have an impact the Energy Star® Rating. There can be more ways to plot or analyze the relationships but the select method of using plots in Section 4.4 followed by plots in Section 4.5 helps to broadly gauge the trend of impact of savings and precisely determine the required performance parameters thereafter.

5. CONCLUSIONS

The location of a facility influences the Energy Star® rating of an office building when the weather conditions change with location.

- The office building in this study assumed to be located in Los Angeles must reduce its consumption, on an average, by 9% to obtain an equal ESR if it were to be located in Houston and by 8.5% if in Chicago.

The weather conditions when accounted for have influence on the ESR of an office building which is not negligible. Further, the ESR is not only sensitive to the aggregate values of degree days (DDs) but also to the values of CDD and HDD in isolation.

- An office building located in Chicago has 125% more DDs (in year 2010) and allows an excess consumption of 8.5% than an identical building in Los Angeles for the same ESR. An office building in Houston may consume 9% more than in Los Angeles for the same building in spite of having only 62% of excess DDs. This difference is due to the different CDD and HDD values which may be found in Table 7.
- If identical office buildings both having ESRs of 90 in Los Angeles and Houston are compared, since the calculated energy consumption will be least at ESR of 90, the difference in their energy consumption (approximately 9% as explained earlier) amounts to 339,343 kBTUs/year (99,455 kWh/yr equivalent). For ESR of 20 this difference is 898,936 kBTUs per year (263,463 kWh/yr equivalent).

The Energy Star® rating of hospital type buildings is sensitive to weather conditions that change with location. Consequently identical hospitals in different cities having equal ESRs may have different energy consumption.

- A hospital assumed to be located in Los Angeles can consume, on an average, approximately 5.6% more energy in Houston and 10.9% more in Chicago if the hospitals in each of the two cities are to obtain identical ESRs.

The energy intensity in hospitals is greater than that in office buildings (as observed by comparing Figure 1and Figure 2), and hence the influence of weather on the ESR of a hospital building is not negligible. Unlike for office buildings, the ESR in case of hospitals is sensitive only to the aggregate values of CDD and HDD.

- A hospital located in Chicago has 125% more DDs (in year 2010) but requires a reduced energy consumption by 10.9% than an identical building in Los Angeles to obtain the same ESR. For a building in Houston, which has 62% more DDs than Los Angeles, the required reduction is 5.6%.
- If identical hospital buildings both having ESRs of 93 in Los Angeles and Chicago are compared, since the calculated energy consumption will be least at ESR of 93, the difference in their energy consumption (approximately 10.9% as explained earlier) amounts to 1,339,763 kBTUs/year (392,662 kWh/yr equivalent). For ESR of 20 this difference in energy consumption is 3,196,427 kBTUs per year (936,819 kWh/yr equivalent).

Evidently, knowledge of merely the intensity of the energy consumed, and the physical and operating characteristics of a hospital or an office building are insufficient without the location of a building to precisely determine its ESR. The magnitudes of the energy intensity corresponding to any particular Energy Star® rating are specific to building type. The variation of Energy Star® rating with respect to energy intensity and in different cities is also type specific, and it is advisable to generate plots similar to Figure 1 or Figure 2 for each building type before drawing any conclusions related to location, intensity and rating. However, from Figure 3 and Figure 4 it is concluded that for a fixed percentage value of energy savings the location/weather does not influence the magnitude of change in the ESR with respect to its initial ESR.

- An office building with initial ESR of 40 has its rating improved by 10 ESR units for 10% energy savings and by 21 ESR units for 20% energy savings, irrespective of its location in the US.
- A hospital building with initial ESR of 30 has its rating improved by 13 ESR units for 10% energy savings and by 28 ESR units for 20% energy savings, irrespective of its location in the country.

It is further concluded that the initial Energy Star® rating influences the amount of improvement in the ESR. At fixed percentage of savings in building consumption energy the change in ESR of the building is a function of its initial ESR. The change in ESR tends to remain constant at its highest value or peak value over a certain range of initial ESR values. This peak has a broader range for lower values of percentage energy savings and the range of peak values tends to get reduced (but increase in magnitude) with increased percentage savings. This peak shifts towards the lower initial ESR values with increase in savings.

- The maximum change in ESR for 10% savings is 10 ESR units over range of 30 to 55 of initial ESR values for offices. This range reduces to between 30 and 40 for 20% energy savings having maximum 21 ESR units increment.
- In case of hospitals, the maximum change in ESR for 10% savings is 13 ESR units over range of 25 to 50 of initial ESR values. This range reduces to between 25 and 35 for 20% energy savings having maximum 28 ESR units increment.

Due to higher energy intensity, greater variation in energy intensity per unit variation of Energy Star® rating for hospitals as compared to office buildings, and almost equal number of sample buildings in the dataset (Section 2.6) used for developing regression based algorithm for Energy Star® rating calculation, it is beneficial to generate certain percentage of savings in Hospitals than in Office buildings as it results in greater improvement in the Energy Star® rating, given that their initial ratings are same.

- Savings of 20% of energy consumed in an office building with initial ESR of 30 results in its ESR increment by 21 units while for a hospital this increment is 28 ESR units.

The environmental sustainability of buildings can be improved along with Energy Star® benchmark rating, and measured in terms of LEED-EBOM points that the building becomes eligible to receive and the reduction in Green House Gas indirect emissions or emissions at the grid.

6. RECOMMENDATIONS AND FUTURE WORK

The approach applied for analyzing the impact of energy savings that are generated by implementing CC® process or any similar systematic process covers the weather or location, building type, and the existing building performance which influences the improvement in Energy Star® rating. It also enables to understand the sensitivity and precise magnitudes of impact of the two factors on desired final Energy Star® rating to be achieved. The scope of this study is however limited to Hospitals and Office Buildings, and it can be expanded to include other types of the buildings and combined space types in buildings.

The graphs are generated and the analysis is performed in MS Excel® because of the familiarity, convenience and acceptance of the tool. Any other tool capable of handling data, performing statistical analysis and executing programs faster than in MS Excel® with equal or higher precision can be utilized. The tool calculates average value of GHG emissions reduction at the grids in the US since the tool is not capable of classifying cities into respective eGRID sub-regions due to unavailability of this data in the required format. This feature can be added to the tool with the availability of required data and an accurate analysis of the GHG emissions reduction can be performed and documented.

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APPENDIX A

Sample Calculation of Energy Star® Rating for an example building

- Building Physical and Operational Characteristics:

Name of the Building	Washington DC Building 50
Select the city / year	Washington DC 2010
Gross Floor Area of the Facility (sqft)	100000
Weekly hours of operation (hrs)	55
Select the type of Building	Office
Square footage of the bank area only	0
Enter the # of Workers in the Bank	0
Enter the # of Workers, excluding Bank Workers	230
Enter the # of personal computers	230
Enter % Area Heated	>50%
Enter % Area Cooled	>50%

- HDD (Heating Degree Days) = 3911
- CDD (Cooling Degree Days) = 2123
- The Input Consumption Values and Units are as in the table below:

Total Electricity Consumption - Site (kWh)	3229000
Total Gas Consumption - Site (kBTUs)	0
Fuel Consumption - Site (kBTUs)	0
HHW Consumption - Site (kBTUs)	0
Steam Consumption - Site (kBTUs)	0
CHW Consumption - Site (kBTUs)	0

- Computing of Source EUI by converting each fuel into Site kBTU and then into Source kBTU by multiplying site kBTUs with factors from Table 2:

- Electricity:

  3229000kWh*3.412kBtu/kWh = 11017348.3 kBTU Site

11017348.3 Site kBTU*3.34 Source kBTU/Site kBTU)

= 36797943.3 kBTU Source

- Since consumption of other utilities for this building is 0 kBTUs Site, 36797943.3 kBTUs is the total energy consumption of the building at the source. The calculation is summarized in Table 8 below:

Table 8: Utility consumption in kBTUs

Total Electricity Consumption - Site	11017348.3	kBTUs
Total Gas Consumption - Site	0	kBTUs
Fuel Consumption - Site	0	kBTUs
HHW Consumption - Site	0	kBTUs
Steam Consumption - Site	0	kBTUs
CHW Consumption - Site	0	kBTUs
Total Energy Consumption - Site	11017348.3	kBTUs
Total Energy Consumption - Source	36797943.3	kBTUs

- Source EUI = 36797943.3 kBTUs/100000ft^2 = 367.98 kBTUs/ft^2
- Building Centered Variables (BCVs) are calculated and the Reference Centering Values are subtracted from each Building Variable Value calculated as shown in the following table.

– Building Centered Variables are then calculated as shown in Table 9 below:

Table 9: Determination of Building Centered Variables

Operating Characteristic	Building Variable Value (BVV) Formula	Building Variable Value (BVV)	Reference Centering Value (RCV)	Building Centered Variable (BVV-RCV)
CLnSqFt	Natural Log of ft^2	11.910	9.535	2.376
CPCDen	# of PCs /1000ft^2	1.55	2.231	-0.686
CLNWkHrs	Natural Log of # of hrs per week	4.007	3.972	0.035
CLNWkrDen	Natural log of # of workers /1000ft^2	0.435	0.5616	-0.126
CHDDxPH[1]	HDD x 1.0	3911	4411	-500.000
CCDDxPC[2]	CDD x 1.0	2123	1157	966.000
BANK_50 x CLNSqFt[3]	Bank ft^2 x 0	0.0000	NA	0.000
BANK_50 x CLNWkrDen	Bank ft^2 x 0	0	NA	0.000
BANK_50	Bank ft^2	0	NA	0

– Each BCV is then multiplied with the corresponding un-standardized coefficient for the building operating characteristic and the products are summed up and added to a constant value of an un-standardized coefficient to obtain the Predicted Source EUI for the building.

[1] PH value is 1.0 if 50% or more area is heated, 0.5 for less than 50% area and 0 for no heating.
[2] PC value is 1.0 if 50% or more area is cooled, 0.5 for less than 50% area and 0 for no cooling.

[3] LNSqFt is the natural logarithm value of bank square footage and is assumed as zero if a bank does not exist.

Table 10: Calculation of predicted source EUI

Operating Characteristic	Un-standardized Coefficients (UC)	Building Centered Variable (BCV)	UC x BCV
(Constant)	186.6	1	186.60000
CLnSqFt	34.17	2.375607026	81.17449
CPCDen	17.28	-0.685685327	-11.84864
CLNWkHrs	55.96	0.035333185	1.97725
CLNWkrDen	10.34	-0.126372438	-1.30669
CHDDxPH	0.0077	-500	-3.85000
CCDDxPC	0.0144	966	13.91040
BANK_50xCLNSqFt	-64.83	0.000	0.00000
BANK_50xCLNWkrDen	34.2	0.000	0.00000
BANK_50	56.3	0	0.00000

- Predicted Source EUI

  = ∑ (UC x BCV) kBTUs/ft^2

  = 270.221 kBTUs/ ft^2

- Energy Efficiency Ratio (EER)

  = Actual Source EUI/ Predicted Source EUI

  = 367.98/270.221

  = 1.362

- Lookup 1.362, the value of EER in the table developed by EPA based on the CBECs database it accessed.

- From the lookup Table 11 as below the Energy Star® Rating of the Office Building is 17.

Table 11: Lookup table for Energy Star® Rating given the calculated EER value

EER	Rating	EER	Rating	EER	Rating
0.278705	100	0.78005	66	1.13786	32
0.328379	99	0.78965	65	1.15098	31
0.36307	98	0.79923	64	1.16441	30
0.39086	97	0.8088	63	1.17816	29
0.41457	96	0.81838	62	1.19226	28
0.435548	95	0.82796	61	1.20674	27
0.454556	94	0.83756	60	1.22163	26
0.472069	93	0.84717	59	1.23696	25
0.488407	92	0.85681	58	1.25277	24
0.503796	91	0.86648	57	1.26911	23
0.518402	90	0.87618	56	1.28602	22
0.532352	89	0.88592	55	1.30357	21
0.545744	88	0.89572	54	1.32181	20
0.558657	87	0.90556	53	1.34083	19
0.571154	86	0.91547	52	1.36071	18
0.583289	85	0.92544	51	1.38155	17
0.595105	84	0.93549	50	1.40349	16
0.60664	83	0.94561	49	1.42667	15
0.617925	82	0.95582	48	1.45126	14
0.628989	81	0.96613	47	1.47749	13
0.639856	80	0.97653	46	1.50565	12
0.650546	79	0.98704	45	1.53609	11
0.661079	78	0.99767	44	1.56928	10
0.671471	77	1.00842	43	1.60585	9
0.681738	76	1.0193	42	1.64668	8
0.691894	75	1.03033	41	1.69307	7
0.70195	74	1.04151	40	1.74698	6
0.711919	73	1.05285	39	1.81169	5
0.72181	72	1.06437	38	1.8933	4
0.731635	71	1.07607	37	2.00532	3
0.741401	70	1.08797	36	2.19016	2
0.751118	69	1.10009	35	> 2.19	1
0.760793	68	1.11243	34		
0.770434	67	1.12501	33		

APPENDIX B

Table 12: Site energy intensity vs. Energy Star® Rating of offices - Weather Plots

Office Buildings - Weather plots					
Serial Number	Site kBTUs/ft2	Energy Star® Rating	Serial Number	Site kBTUs/ft2	Energy Star® Rating
1	106.0	20	31	62.9	64
2	95.4	28	32	59.2	69
3	90.1	33	33	50.7	80
4	84.8	39	34	45.6	85
5	75.1	50	35	43.1	88
6	67.6	60	36	40.5	90
7	63.8	65	37	107.2	20
8	60.0	69	38	96.5	28
9	51.5	80	39	91.1	33
10	46.4	85	40	85.8	38
11	43.8	88	41	75.5	50
12	41.2	90	42	67.9	60
13	106.0	20	43	64.1	64
14	95.4	28	44	60.4	69
15	90.1	33	45	51.7	80
16	84.8	39	46	46.5	85
17	75.1	50	47	43.9	88
18	67.6	60	48	41.3	90
19	63.8	65	49	98.2	20
20	60.0	69	50	88.4	28
21	51.5	80	51	83.5	33
22	46.4	85	52	78.6	38
23	43.8	88	53	69.3	50
24	41.2	90	54	62.3	59
25	104.1	20	55	58.9	64
26	93.7	29	56	55.4	69
27	88.5	34	57	47.4	80
28	83.3	39	58	42.7	85
29	74.0	50	59	40.3	88
30	66.6	60	60	37.9	90

Table 13: Site energy intensity vs. Energy Star® Rating of hospitals - Weather Plots

Hospitals - Weather plots					
Serial Number	Site kBTU/ft2	Energy Star® Rating	Serial Number	Site kBTU/ft2	Energy Star® Rating
1	248.3	20	31	178.5	69
2	223.5	31	32	168.0	76
3	211.1	38	33	158.8	80
4	198.6	46	34	142.9	87
5	192.5	50	35	135.0	90
6	173.3	63	36	127.0	93
7	163.6	69	37	254.6	20
8	154.0	76	38	229.2	32
9	146.1	80	39	216.4	39
10	131.5	87	40	203.7	47
11	124.2	90	41	197.6	50
12	116.9	93	42	177.8	63
13	248.4	20	43	167.9	70
14	223.6	32	44	158.1	76
15	211.2	39	45	150.7	80
16	198.7	46	46	135.6	87
17	192.2	50	47	128.1	90
18	173.0	63	48	120.6	93
19	163.4	70	49	239.8	20
20	153.8	76	50	215.8	32
21	146.6	80	51	203.8	39
22	132.0	87	52	191.9	47
23	124.6	90	53	187.2	50
24	117.3	93	54	168.5	63
25	271.8	20	55	159.1	69
26	244.6	31	56	149.8	75
27	231.0	38	57	142.0	80
28	217.4	46	58	127.8	87
29	210.0	50	59	120.7	90
30	189.0	63	60	113.6	93

Table 14: Office buildings' ΔESR values – 10% source energy savings

Energy Star® Rating (ESR)	10% Source Energy Savings – Office Buildings				
	Houston	Chicago	Los Angeles	Washington DC	New York
100	0	0	0	0	0
95	2	2	2	2	2
90	3	3	3	3	3
85	5	5	5	5	5
80	6	6	6	6	6
75	7	7	7	7	7
70	8	7	8	8	8
65	8	8	8	8	8
60	9	9	9	9	9
55	9	9	9	9	9
50	10	10	10	10	10
45	10	10	10	10	10
40	10	10	10	10	10
35	10	10	10	10	10
30	10	10	10	10	10
25	9	9	9	9	9
20	9	9	9	9	9
15	8	8	8	8	8
10	6	6	6	6	6
5	4	4	4	4	4
1	0	0	0	0	0

Table 15: Office buildings' ΔESR values – 20% source energy savings

Energy Star® Rating (ESR)	20% Source Energy Savings – Office Buildings				
	Houston	Chicago	Los Angeles	Washington DC	New York
100	0	0	0	0	0
95	3	3	3	3	3
90	6	6	6	6	6
85	8	8	8	8	8
80	10	10	10	10	10
75	12	12	12	12	12
70	14	14	14	14	14
65	16	16	16	16	16
60	17	17	17	17	17
55	18	18	18	18	18
50	19	20	19	19	19
45	20	20	20	20	20
40	21	21	21	21	21
35	21	21	21	21	21
30	21	21	21	21	21
25	20	20	20	20	20
20	19	19	19	19	19
15	17	17	18	18	17
10	15	15	15	15	15
5	11	11	11	11	11
1	0	0	0	0	0

Table 16: Hospital buildings' Δ ESR values – 10% source energy savings

Energy Star® Rating (ESR)	10% Source Energy Savings - hospitals				
	Houston	Chicago	Los Angeles	Washington DC	New York
100	0	0	0	0	0
95	3	3	3	3	3
90	5	5	5	5	5
85	6	6	6	6	6
80	7	7	7	7	7
75	9	9	9	9	9
70	10	10	10	10	10
65	11	11	11	11	11
60	12	12	12	12	12
55	12	12	13	13	12
50	13	13	13	13	13
45	13	13	13	13	13
40	13	13	13	13	13
35	13	13	13	13	13
30	13	13	13	13	13
25	13	13	13	13	13
20	12	12	12	12	12
15	10	10	10	10	10
10	8	8	8	8	8
5	6	6	6	6	6
1	0	0	0	0	0

Table 17: Hospital buildings' Δ ESR values – 20% source energy savings

Energy Star® Rating (ESR)	20% Source Energy Savings – hospitals				
	Houston	Chicago	Los Angeles	Washington DC	New York
100	0	0	0	0	0
95	4	4	4	4	4
90	7	7	7	7	7
85	11	10	11	11	10
80	13	13	13	13	13
75	16	15	15	15	15
70	18	18	18	18	18
65	20	20	20	20	20
60	23	23	22	22	22
55	24	24	24	24	24
50	26	26	26	26	26
45	26	26	26	26	26
40	27	27	28	28	27
35	28	28	28	28	28
30	28	28	28	28	28
25	28	27	28	27	28
20	27	26	27	26	27
15	25	25	24	25	24
10	21	21	21	21	21
5	16	15	16	16	16
1	0	0	0	0	0

Table 18: Office buildings - ∆ ESR values at specific % energy savings

Energy Star® Rating (ESR)	Washington DC - Office Buildings			
	10%	15%	20%	25%
100	0	0	0	0
99	1	1	1	1
98	1	2	2	2
97	2	2	3	3
96	2	3	3	4
95	3	4	4	5
94	3	4	5	5
93	3	5	6	6
92	4	5	6	7
91	4	6	7	8
90	5	6	7	8
89	5	7	8	9
88	5	7	9	10
87	6	8	9	11
86	6	8	10	11
85	6	9	11	12
84	6	9	11	13
83	6	9	11	13
82	7	10	12	14
81	7	10	13	15
80	7	10	13	15
79	8	11	14	16
78	8	11	15	17
77	8	12	15	17
76	9	12	16	18
75	9	12	16	18
74	9	13	16	19
73	9	13	17	20
72	9	13	17	20
71	10	14	17	21
70	10	14	18	21
69	10	15	18	22
68	10	15	19	22
67	10	15	20	23

Energy Star® Rating (ESR)	Washington DC - Office Buildings			
	10%	15%	20%	25%
66	10	15	19	23
65	11	16	20	24
64	11	16	21	24
63	12	17	21	25
62	12	17	22	26
61	12	17	22	26
60	12	17	23	27
59	12	17	23	27
58	12	18	23	27
57	12	18	23	28
56	12	18	23	28
55	12	18	24	29
54	13	19	24	30
53	13	19	25	30
52	13	19	25	30
51	13	19	25	30
50	13	20	26	31
49	13	20	26	32
48	13	20	26	32
47	13	20	26	32
46	13	20	26	32
45	13	20	26	32
44	14	21	27	33
43	14	21	27	33
42	14	20	27	34
41	13	20	27	34
40	13	20	27	34
39	13	20	27	34
38	14	21	28	35
37	13	21	28	35
36	14	21	29	35
35	13	21	28	35
34	13	21	28	35
33	13	20	28	35
32	13	20	27	35

Energy Star® Rating (ESR)	Washington DC - Office Buildings			
	10%	15%	20%	25%
31	13	21	28	36
30	13	20	28	36
29	13	21	29	36
28	13	20	29	36
27	13	20	28	36
26	13	20	28	35
25	13	20	28	35
24	12	19	27	35
23	12	19	27	35
22	12	19	27	35
21	12	19	27	35
20	12	19	27	35
19	12	19	26	34
18	11	18	26	34
17	10	17	25	33
16	10	17	25	32
15	10	17	25	32
14	10	17	24	32
13	9	15	23	31
12	9	15	23	30
11	8	14	21	29
10	8	14	21	29
9	8	13	20	27
8	7	12	18	26
7	7	11	18	25
6	6	11	17	23
5	6	10	16	22
4	5	9	14	20
3	4	7	11	17
2	3	6	10	14
1	2	4	7	10
1	0	0	0	0

Table 19: Hospitals - Δ ESR values at specific % energy savings

Energy Star® Rating (ESR)	Chicago – Hospitals			
	10%	15%	20%	25%
100	0	0	0	0
99	1	1	1	1
98	1	2	2	2
97	2	2	3	3
96	2	3	3	4
95	3	4	4	5
94	3	4	5	5
93	3	5	6	6
92	4	5	6	7
91	4	6	7	8
90	5	6	7	8
89	5	7	8	9
88	5	7	9	10
87	6	8	9	11
86	6	8	10	11
85	6	9	11	12
84	6	9	11	13
83	6	9	11	13
82	7	10	12	14
81	7	10	13	15
80	7	10	13	15
79	8	11	14	16
78	8	11	15	17
77	8	12	15	17
76	9	12	16	18
75	9	12	16	18
74	9	13	16	19
73	9	13	17	20
72	9	13	17	20
71	10	14	17	21
70	10	14	18	21
69	10	15	18	22
68	10	15	19	22

Energy Star® Rating (ESR)	Chicago – Hospitals			
	10%	15%	20%	25%
67	10	15	20	23
66	10	15	19	23
65	11	16	20	24
64	11	16	21	24
63	12	17	21	25
62	12	17	22	26
61	12	17	22	26
60	12	17	23	27
59	12	17	23	27
58	12	18	23	27
57	12	18	23	28
56	12	18	23	28
55	12	18	24	29
54	13	19	24	30
53	13	19	25	30
52	13	19	25	30
51	13	19	25	30
50	13	20	26	31
49	13	20	26	32
48	13	20	26	32
47	13	20	26	32
46	13	20	26	32
45	13	20	26	32
44	14	21	27	33
43	14	21	27	33
42	14	20	27	34
41	13	20	27	34
40	13	20	27	34
39	13	20	27	34
38	14	21	28	35
37	13	21	28	35
36	14	21	29	35
35	13	21	28	35
34	13	21	28	35
33	13	20	28	35

Energy Star® Rating (ESR)	Chicago – Hospitals			
	10%	15%	20%	25%
32	13	20	27	35
31	13	21	28	36
30	13	20	28	36
29	13	21	29	36
28	13	20	29	36
27	13	20	28	36
26	13	20	28	35
25	13	20	28	35
24	12	19	27	35
23	12	19	27	35
22	12	19	27	35
21	12	19	27	35
20	12	19	27	35
19	12	19	26	34
18	11	18	26	34
17	10	17	25	33
16	10	17	25	32
15	10	17	25	32
14	10	17	24	32
13	9	15	23	31
12	9	15	23	30
11	8	14	21	29
10	8	14	21	29
9	8	13	20	27
8	7	12	18	26
7	7	11	18	25
6	6	11	17	23
5	6	10	16	22
4	5	9	14	20
3	4	7	11	17
2	3	6	10	14
1	2	4	7	10
1	0	0	0	0

Table 20: Source energy intensity vs. ESR - Office Buildings

% Savings	Source intensity - kBTU/sqft	Energy Star® Rating
0.00%	226.1	60
0.10%	225.9	60
0.20%	225.6	60
0.30%	225.4	60
0.40%	225.1	60
0.60%	224.9	60
0.70%	224.6	60
0.80%	224.4	60
0.90%	224.1	60
1.00%	223.9	60
1.10%	223.6	61
1.20%	223.4	61
1.30%	223.1	61
1.40%	222.9	61
1.60%	222.6	61
1.70%	222.4	61
1.80%	222.1	61
1.90%	221.9	61
2.00%	221.6	61
2.10%	221.4	61
2.20%	221.1	62
2.30%	220.9	62
2.40%	220.6	62
2.50%	220.4	62
2.70%	220.1	62
2.80%	219.9	62
2.90%	219.6	62
3.00%	219.4	62
3.10%	219.1	62
3.20%	218.9	62
3.30%	218.6	62
3.40%	218.4	63

% Savings	Source intensity - kBTU/sqft	Energy Star® Rating
3.50%	218.1	63
3.70%	217.9	63
3.80%	217.6	63
3.90%	217.4	63
4.00%	217.1	63
4.10%	216.9	63
4.20%	216.6	63
4.30%	216.4	63
4.40%	216.1	63
4.50%	215.9	64
4.70%	215.6	64
4.80%	215.4	64
4.90%	215.1	64
5.00%	214.9	64
5.10%	214.6	64
5.20%	214.4	64
5.30%	214.1	64
5.40%	213.9	64
5.50%	213.6	64
5.70%	213.4	65
5.80%	213.1	65
5.90%	212.8	65
6.00%	212.6	65
6.10%	212.3	65
6.20%	212.1	65
6.30%	211.8	65
6.40%	211.6	65
6.50%	211.3	65
6.70%	211.1	65
6.80%	210.8	65
6.90%	210.6	66
7.00%	210.3	66
7.10%	210.1	66

% Savings	Source intensity - kBTU/sqft	Energy Star® Rating
7.20%	209.8	66
7.30%	209.6	66
7.40%	209.3	66
7.50%	209.1	66
7.60%	208.8	66
7.80%	208.6	66
7.90%	208.3	66
8.00%	208.1	67
8.10%	207.8	67
8.20%	207.6	67
8.30%	207.3	67
8.40%	207.1	67
8.50%	206.8	67
8.60%	206.6	67
8.80%	206.3	67
8.90%	206.1	67
9.00%	205.8	67
9.10%	205.6	68
9.20%	205.3	68
9.30%	205.1	68
9.40%	204.8	68
9.50%	204.6	68
9.60%	204.3	68
9.80%	204.1	68
9.90%	203.8	68
10.00%	203.6	68
10.10%	203.3	68
10.20%	203.1	68
10.30%	202.8	69
10.40%	202.6	69
10.50%	202.3	69
10.60%	202.1	69
10.80%	201.8	69

% Savings	Source intensity - kBTU/sqft	Energy Star® Rating
10.90%	201.6	69
11.00%	201.3	69
11.10%	201.1	69
11.20%	200.8	69
11.30%	200.6	69
11.40%	200.3	70
11.50%	200.1	70
11.60%	199.8	70
11.80%	199.6	70
11.90%	199.3	70
12.00%	199.1	70
12.10%	198.8	70
12.20%	198.6	70
12.30%	198.3	70
12.40%	198.1	70
12.50%	197.8	70
12.60%	197.6	71
12.70%	197.3	71
12.90%	197.1	71
13.00%	196.8	71
13.10%	196.6	71
13.20%	196.3	71
13.30%	196.1	71
13.40%	195.8	71
13.50%	195.6	71
13.60%	195.3	71
13.70%	195	71
13.90%	194.8	72
14.00%	194.5	72
14.10%	194.3	72
14.20%	194	72
14.30%	193.8	72
14.40%	193.5	72

% Savings	Source intensity - kBTU/sqft	Energy Star® Rating
14.50%	193.3	72
14.60%	193	72
14.70%	192.8	72
14.90%	192.5	72
15.00%	192.3	73
15.10%	192	73
15.20%	191.8	73
15.30%	191.5	73
15.40%	191.3	73
15.50%	191	73
15.60%	190.8	73
15.70%	190.5	73
15.90%	190.3	73
16.00%	190	73
16.10%	189.8	73
16.20%	189.5	74
16.30%	189.3	74
16.40%	189	74
16.50%	188.8	74
16.60%	188.5	74
16.70%	188.3	74
16.90%	188	74
17.00%	187.8	74
17.10%	187.5	74
17.20%	187.3	74
17.30%	187	74
17.40%	186.8	75
17.50%	186.5	75
17.60%	186.3	75
17.70%	186	75
17.80%	185.8	75
18.00%	185.5	75

Table 21: Source energy intensity vs. ESR - Hospitals

% Savings	Source intensity - kBTU/sqft	Energy Star® Rating
0.00%	594.1	60
0.10%	593.5	60
0.20%	592.8	60
0.30%	592.2	60
0.40%	591.6	60
0.50%	590.9	60
0.60%	590.3	60
0.80%	589.6	60
0.90%	589	60
1.00%	588.3	61
1.10%	587.7	61
1.20%	587.1	61
1.30%	586.4	61
1.40%	585.8	61
1.50%	585.1	61
1.60%	584.5	61
1.70%	583.8	61
1.80%	583.2	61
1.90%	582.6	62
2.10%	581.9	62
2.20%	581.3	62
2.30%	580.6	62
2.40%	580	62
2.50%	579.3	63
2.60%	578.7	63
2.70%	578.1	63
2.80%	577.4	63
2.90%	576.8	63
3.00%	576.1	63
3.10%	575.5	64
3.20%	574.8	64
3.40%	574.2	64

% Savings	Source intensity - kBTU/sqft	Energy Star® Rating
3.50%	573.6	64
3.60%	572.9	64
3.70%	572.3	64
3.80%	571.6	65
3.90%	571	65
4.00%	570.3	65
4.10%	569.7	65
4.20%	569.1	65
4.30%	568.4	65
4.40%	567.8	65
4.50%	567.1	65
4.70%	566.5	65
4.80%	565.8	66
4.90%	565.2	66
5.00%	564.6	66
5.10%	563.9	66
5.20%	563.3	66
5.30%	562.6	66
5.40%	562	66
5.50%	561.3	66
5.60%	560.7	67
5.70%	560.1	67
5.80%	559.4	67
6.00%	558.8	67
6.10%	558.1	67
6.20%	557.5	67
6.30%	556.8	67
6.40%	556.2	67
6.50%	555.6	68
6.60%	554.9	68
6.70%	554.3	68
6.80%	553.6	68
6.90%	553	68

% Savings	Source intensity - kBTU/sqft	Energy Star® Rating
7.00%	552.3	68
7.10%	551.7	68
7.30%	551.1	68
7.40%	550.4	68
7.50%	549.8	69
7.60%	549.1	69
7.70%	548.5	69
7.80%	547.8	69
7.90%	547.2	69
8.00%	546.6	69
8.10%	545.9	69
8.20%	545.3	69
8.30%	544.6	70
8.40%	544	70
8.50%	543.3	70
8.70%	542.7	70
8.80%	542	70
8.90%	541.4	70
9.00%	540.8	70
9.10%	540.1	70
9.20%	539.5	71
9.30%	538.8	71
9.40%	538.2	71
9.50%	537.5	71
9.60%	536.9	71
9.70%	536.3	71
9.80%	535.6	71
10.00%	535	71
10.10%	534.3	72
10.20%	533.7	72
10.30%	533	72
10.40%	532.4	72
10.50%	531.8	72

% Savings	Source intensity - kBTU/sqft	Energy Star® Rating
10.60%	531.1	72
10.70%	530.5	72
10.80%	529.8	72
10.90%	529.2	73
11.00%	528.5	73
11.10%	527.9	73
11.30%	527.3	73
11.40%	526.6	73
11.50%	526	73
11.60%	525.3	73
11.70%	524.7	73
11.80%	524	74
11.90%	523.4	74
12.00%	522.8	74
12.10%	522.1	74
12.20%	521.5	74
12.30%	520.8	74
12.40%	520.2	74
12.60%	519.5	75
12.70%	518.9	75
12.80%	518.3	75
12.90%	517.6	75
13.00%	517	75
13.10%	516.3	75
13.20%	515.7	75
13.30%	515	75
13.40%	514.4	76
13.50%	513.8	76
13.60%	513.1	76
13.70%	512.5	76
13.90%	511.8	76
14.00%	511.2	76
14.10%	510.5	76

% Savings	Source intensity - kBTU/sqft	Energy Star® Rating
14.20%	509.9	76
14.30%	509.3	76
14.40%	508.6	76
14.50%	508	76
14.60%	507.3	76
14.70%	506.7	76
14.80%	506	76
14.90%	505.4	76
15.00%	504.8	77
15.20%	504.1	77
15.30%	503.5	77
15.40%	502.8	77
15.50%	502.2	77
15.60%	501.5	77
15.70%	500.9	77
15.80%	500.3	77
15.90%	499.6	78
16.00%	499	78
16.10%	498.3	78
16.20%	497.7	78
16.30%	497	78
16.50%	496.4	78
16.60%	495.8	78
16.70%	495.1	79
16.80%	494.5	79
16.90%	493.8	79
17.00%	493.2	79
17.10%	492.5	79
17.20%	491.9	79
17.30%	491.3	79
17.40%	490.6	79
17.50%	490	80
17.60%	489.3	80

% Savings	Source intensity - kBTU/sqft	Energy Star® Rating
17.70%	488.7	80
17.90%	488	80
18.00%	487.4	80
18.10%	486.8	80
18.20%	486.1	80
18.30%	485.5	81
18.40%	484.8	81
18.50%	484.2	81
18.60%	483.5	81
18.70%	482.9	81
18.80%	482.3	81
18.90%	481.6	81
19.00%	481	81
19.20%	480.3	81
19.30%	479.7	81
19.40%	479	81
19.50%	478.4	81
19.60%	477.7	81
19.70%	477.1	81
19.80%	476.5	82
19.90%	475.8	82

APPENDIX C

Using the values from Table 7 and Table 12, values in Table 22 are obtained as calculated and listed below for office buildings. These values are calculated using values in Table 12 at points when all buildings in all of the cities have identical ESRs.

Table 22: Comparing values of weather and consumption of an office building in select cities

City and Year	CDD	HDD	CDD + HDD	Required reduction in Site EUI for LA to equal rating of building in rest of cities (kBTU/ft2)
Los Angeles 2010	0%	0%	0%	0.00%
New York 2010	-30%	385%	93%	6.60%
Chicago 2010	-45%	534%	125%	8.50%
Houston 2010	55%	80%	62%	9.00%
Washington DC 2010	-3%	327%	94%	8.40%

Using the values from Table 7 and Table 13, the values in Table 23 are obtained for hospitals. These values are calculated using values in Table 13 at points when all hospitals in all of the cities have identical ESRs.

Table 23: Comparing values of weather and consumption of a hospital building in select cities

Cities and Year	CDD	HDD	CDD + HDD	Required reduction in Site EUI for rest of cities to equal rating of building in LA (kBTU/ft2)
Los Angeles 2010	0%	0%	0%	0.0%
New York 2010	-30%	385%	93%	8.1%
Chicago 2010	-45%	534%	125%	10.9%
Houston 2010	55%	80%	62%	5.6%
Washington DC 2010	-3%	327%	94%	8.2%

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