BUILDING AN URBAN ENERGY PERFORMANCE FRAMEWORK: INTEGRATING SPATIAL ANALYSIS AND BUILDING SIMULATION TOOLS FOR CAMPUS PLANNING

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ABSTRACT

The tools that currently benchmark energy consumption beyond the building level are limited. This paper describes a framework utilizing simulation and spatial analysis tools to identify a credible set of campus energy performance indicators integrating both the building and site levels and taking into account the spatial arrangement surrounding each building. The research method propose a series of simulation experiments for a predefined group of building and site performance metrics classified under three categories: form, orientation and location. Building energy performance is calculated using building simulation tools. The remainder of the building and site level metrics is computed using environmental simulation and spatial analysis tools. The resulting indicators are normalized, weighted and aggregated to form an urban Campus Energy Performance Index (CEPI). The research will aid stakeholders to make decisions and can be used as a communication tool at different stages of site planning.

KEYWORDS

Campus Energy Performance Indicators, Building Simulation, Spatial Analysis, Integration, Site Planning

INTRODUCTION

Increased demands for both precise and professional knowledge in the building design and site planning fields have become a central part of sustainable development. Ongoing research projects to develop tools are producing steadily more detailed data on present and planned systems. The level of detailed results, however, can be confusing rather than helpful for decision-makers in the absence of a systematic method. Much effort is, therefore, being put into formulation of criteria, indicators, decision-support, and process-support tools of various systems.

The urban campus is a sub-system of any city; and functions within an intricate energy system that is in constant need for new methods to operate efficiently, thus fulfilling institutional commitment towards the academic and environmental mission. Among the main challenges for energy efficiency are building depreciation, commitment to deferred maintenance, and tool potential to aid in the decision-making process. Furthermore, the difficulty in data collection and assessment of energy and the continuous demand for simple straight forward interpretations constitute a continuous management challenge.

Current Assessment Frameworks in Use

Several sets of frameworks to measure sustainability in the built environment have quickly evolved in the recent years. Research and development in these frameworks is driven by either assessments of buildings alone, by buildings and sites together, or by performance-based building models..

Frameworks driven by building assessment alone are generally focused on the building’s internal systems and exterior envelope characteristics such as: the ASTM Standards on Whole Building Functionality and Serviceability; the Building for Environmental and Economic Sustainability (BEES); the Energy Star® program of the U.S. Department of Energy (DOE) and the Environmental Protection Agency (EPA); and the US DOE High- Performance Buildings Metrics Project.

The ASTM Standards on Whole Building Functionality and Serviceability (Davis and Szigeti 1997; ASTM 2003) are focused on building manageability, known as the Operations and Maintenance (O&M) aspect of the building; these measures are referred to as the “Serviceability Tools and Methods” or “Serviceability Standard.” The serviceability standard is a rating tool for measuring an owner's and tenant's needs in a facility against the objective qualities of a facility. It focuses on a facility's potential to support the required program and functions of facility users and owners, however, there is no focus on building energy and the surrounding context. It addresses few issues to provide decision makers with means to evaluate the impact of their choices. It's a rating system based on an ascending scale of preference from one to nine where users and owners are asked to compare what they expect in a building with what a particular building offers. Users look at an array of factors from the sound and visual environment to information technology infrastructure to the building envelope.

Each factor is rated according to what users expect or need, and what a particular space offers.

The Building for Environmental and Economic Sustainability (BEES) measures the environmental performance of building products by using the life-cycle assessment approach; it incorporates two levels of performance: the environmental waste and the economic level, which are represented in a form of an aggregated overall score. The BEES user specifies the relative importance of different factors used to combine environmental and economic performance scores and may test the sensitivity of the overall scores by using different sets of relative importance weights.

The Energy Star® program of the U.S. Department of Energy (DOE) and the Environmental Protection Agency (EPA) is an energy-performance rating system that certifies products and buildings that meet strict energy-efficiency guidelines. The Benchmarking tool is internet based; it analyzes the input data, taking into consideration several variables such as the building location, weather conditions and then issues a score card of energy performance. The energy performance results provide a benchmark energy score from 0 to 100. Buildings that score 75 or higher are eligible for an Energy Star® Building label. To qualify a building for a label, a certified professional engineer is required to verify the building's energy performance and to confirm that the indoor environment properties are in conformance with industry standards.

The US DOE High-Performance Buildings Metrics Project is an initiative of the DOE Building Technologies Program. It includes a Performance Metrics Research Project to standardize the measurement and characterization of building energy performance, a toolbox that contains: design guidelines, energy simulation software, a charrette guide for high performance projects, and a high performance buildings database featuring case studies.

Frameworks driven by both building and site assessments are generally in the form of an assessment tool that is based on either a full point system or a combined point and weighting systems such as: the US Green Building Council’s Leadership in Energy & Environmental Design Rating System (LEED™); the Building Research Establishment Environmental Assessment Method (BREEAM); the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE); the Hong Kong Building Environmental Assessment (HK-BEAM); the Green Communities, and Green Globes™ online tools.

The US Green Building Council’s Leadership in Energy & Environmental Design Rating System (LEED™) is a point based qualitative assessment tool that offers building and site level credits for sustainable design metrics. It is widely used in the United States as an assessment tool but fails to operate within an integrated framework. The LEED system is primarily used for rating new buildings, new commercial construction, major renovation projects, and existing building operations and maintenance, other used include commercial interiors, core and shell development, homes, schools and retail. It is a point based and credit system where credits are awarded for satisfying pre-defined criteria. For example, credits for highly developed designs that include building energy efficiency and indoor air quality, credits are awarded for using materials that are manufactured locally and that contain recycled content, disposal of old material and building waste. Additional credits are awarded for environmental site considerations, conservation of water, and for reducing the heat island effect. The total number of credits will indicate whether a building is able to satisfy the minimum of 28 credits to be certified, and if it goes beyond to fit into one of four rating categories: platinum, gold, silver and bronze.

The Building Research Establishment Environmental Assessment Method (BREEAM) is a tool that allows the owners, users and designers of buildings to review and improve environmental performance throughout the life of a building. Similar to LEED, BREEAM covers not only the building’s envelope and systems, but also its operation and management with respect to issues of energy, water, environmental impact, hazardous materials, indoor environmental quality, and productivity. BREEAM combine two levels of assessments: it focuses on before-and-after analyses, and provides a plan with recommendations for improving the rating. It also utilizes a credit-building system that classifies the buildings into categories of fair, good, very good and excellent. Decision makers utilize these ratings in marketing the building, and in further optimization of the building performance.

While BREEAM assessment in itself is not a self-certifying system like LEED, it also requires to be performed by licensed assessors. A report is produced at the completion of the process that includes a current rating and identifies opportunities for improvements. The decision maker can then decide what improvements to implement in accordance with the issued recommendations. Following the improvements, a final walk-through analysis is done and a report is issued with a certificate of performance. BREEAM is a widely accepted and respected scheme in the United Kingdom that sets a benchmark for environmental performance on the building, infrastructure, and transportation levels. It provides an assessment framework to guide the sustainable design of new developments, but it is unclear how the building and site levels are integrated in its framework.

The Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) is intended for building environmental assessment which is based on concepts such as Building Environmental Efficiency (BEE). The BEE is based on the ratio between the Building Environmental Quality & Performance, and Building Environmental Loadings. The Building Environmental Quality & Performance deals with the improvement in living amenity for the building users that exist within a hypothetical enclosed space “the private property”, while the Building Environmental Loadings evaluates the negative aspects of environmental impact which go beyond the hypothetical enclosed space to the outside “the public property”.

The Hong Kong Building Environmental Assessment (HK-BEAM) defines performance criteria for a range of sustainability issues relating to the planning, design, construction, commissioning, management, operations and maintenance of buildings. Credits are awarded where standards or defined performance criteria are satisfied. The HK-BEAM incorporates both building performance credits such as material, building systems, and environmental loadings, and site level credits such as emissions, site aspects and land use credits.

Other emerging frameworks such as the Green Communities, and Green Globes™ online tools generally provide a similar point system assessment on the building level, and a few additional credits on the urban level such as for the proximity to development and infrastructure, and east-west orientation. However, they are not as popular as the previous three frameworks due to the complexity of their structure, which prevents them from being robust and easy to use.

Frameworks driven by performance based building models such as the Performance Based Building Network (PeBBu) thematic framework. These frameworks were in development few years ago and focused predominantly on the required outcomes (the “end”) and not with how these outcomes are achieved (the “means”)(International Council for Building (CIB), CIB 1975, CIB 1982, Foliente 2003, Foliente 2004, Foliente and Becker 2001). This is in contrast to the traditional prescriptive approach which tends to focus on specifying the method or solution for achieving the required outcomes. The framework provides higher levels of integration and a clear focus to build buildings with a higher level of systems performance; however, the entire project is conceptual and was not developed in a tool interface that is ready for implementation.

While most of the above described frameworks provide a detailed building analysis and few site credits, it not clear how they recognize, and credit the spatial characteristics of the building, the impact of this building on the neighboring buildings, and the overall contribution to the surrounding urban environment.

Observations, Questions and Scope of Research

Many of the available energy assessment frameworks consider building performance only. This is problematic because it aggregates the sum of performances of buildings and systems without considering the surrounding context such as the spatial properties and urban context.

Can a building location, form and orientation influence the overall campus energy performance? Can the existing tools address the need to assess a group of buildings at once? The available tools may address parts of these questions, but not in a systematic integrated approach. Therefore, a new method is required that takes into account different levels of integration between building and urban level performances.

This paper discusses a framework that integrates both building and site level indicators utilizing building simulation and spatial analysis tools to create a credible set of campus indicators in an effort to quantify the overall campus energy performance. This framework will aid in policy and energy planning assessment and help in the evaluation of preliminary plans for future campus development.

CAMPUS ENERGY PERFORMANCE FRAMEWORK

The focus of the framework is on the spatial relationship of the buildings and their overall impact on the campus energy. Since the availability of a building site is often limited by constraints which can be political, economic, or other that are not driven by urban design or a specific planning strategy, the research presented in this paper rules out the former constraints and focuses on the spatial structure aspect only.

It assumes that building spatial characteristics such as Form (F), Orientation (O), and location (L) are major drivers for energy consumption. This assumption allows us to scale the analysis beyond the building level and into the site level within a campus scale as an initial step in advance of a full deployment to a city scale.

Similar to the model applied on the building level (Debajyoti et al. 2006), this framework is based on a similar Input/Output (I/O) concept. The building and site level indicators are treated as “Input” that undergoes a series of simulation experiments under specific environmental conditions to obtain the behavior of the system. Then it is aggregated and represented by an overall performance indicator "Output."

The framework consists of three components (Figure 1); the Performance Indicator Component (PIC), the Performance Measurment Component (PMC), and the Aggregation Component (AC).

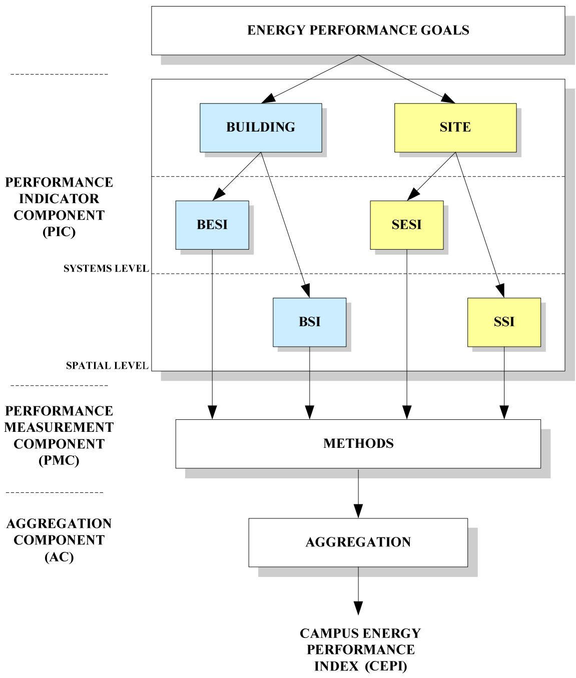

Figure 1 The Campus Energy Performance Conceptual Framework

The Performance Indicator Component (PIC) classifies the campus energy indicators to building and site levels within two indicator categories: Systems and Spatial level indicators. The building level is divided into the Building Elements and Systems Indicators (BESI), and the Building Spatial Indicators (BSI). Similar to the building level, the site level is divided into the Site Elements and Systems Indicators (SESI), and the Site Spatial Indicators (SSI).

The BESI indicator (Figure 2) is used to obtain the status of the building energy performance at the site level. This occurs by aggregating the Energy Performance Indicator (EPI) for each building located on campus.

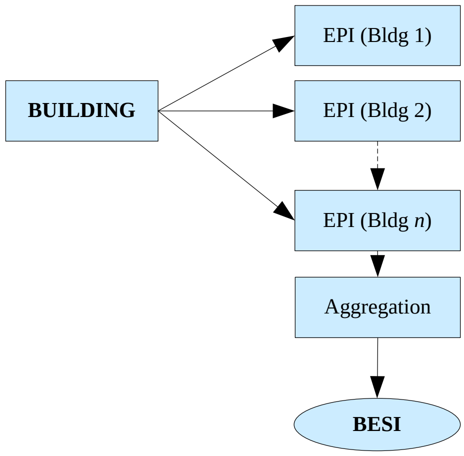

Figure 2 The Building Elements and Systems Indicator (BESI)

The BSI indictor (Figure 3) is used to obtain the status of the building spatial characteristics and its effect on the building overall energy performance. This occurs by aggregating the building spatial indicators for each building on site with respect to Form (F), Orientation (O) and Location (L).

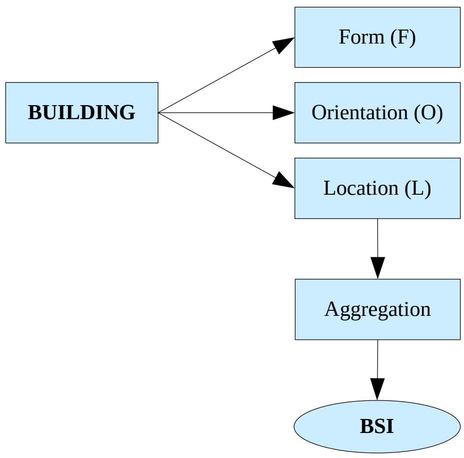

Figure 3 The Building Spatial Indicator (BSI)

The SESI indicator (Figure 4) is used to obtain the status of the site energy performance at the site level. This occurs by aggregating the Systems Performance Indicators (SPI) for each of the site systems that has both a direct and indirect relationship with building energy performance.

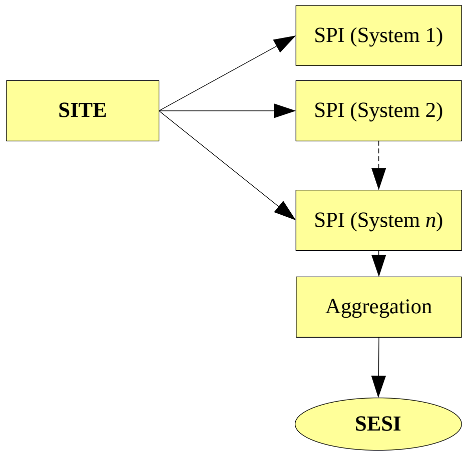

Figure 4 The Site Elements and Systems Indicator (SESI)

The SSI indicator (Figure 5) is used to obtain the status of the site spatial characteristics and its effect on the site overall energy performance. This occurs by aggregating the site spatial indicators.

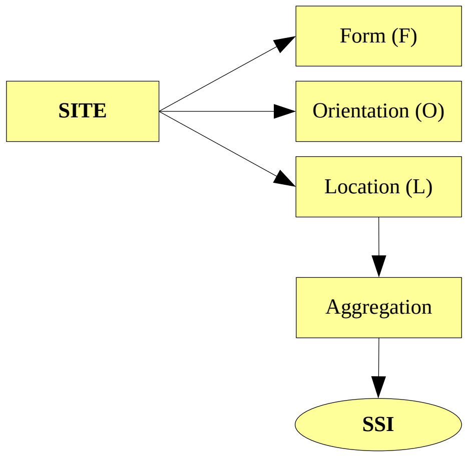

Figure 5 The Site Spatial Indicator (SSI)

All the previously selected indicators are selected based on:

- Their ability to be quantified,
- Relevance to energy performance, and
- Relevance to the campus building and site spatial characteristics

The selected indicators undergo experimental simulations to establish the status of each indicator using the Performance Measurement Component (PMC). Different methods are employed in order to quantify each indicator using building simulation and spatial analysis tools such as ECOTECT, Arc View, CWSAT (DOE), etc. The values of each indicator to be aggregated at the completion of experiments for each indicator. In advance of the overall aggregation in the Aggregation Component (AC), the indicators must share similar characteristics such as ratio in order to be normalized successfully.

In the Aggregation component (AC), the resulting values undergo normalization similar to the "categorical scale" method utilized in the composite indicator method (Saisana and Tarantola 2002). Applying the categorical scale method, each indicator is assigned a categorical score, which can be either numerical (e.g. one, two, three) or based on the percentiles of the distribution of the indicator value across the zone. For example, using the building spatial metric ratio, the top 10% of the buildings with minimum ratios receive a score of 100, buildings in the 80th - 90th percentiles receive 80 points, and so on. The normalized indicators are then aggregated as functions of their associated weights. Additive aggregation method can be utilized, which is the linear summation of weighted and normalized indicators. The implementation process applied to a campus scale is explained below.

3. IMPLEMENTATION PROCESS

The following describes the process using a selected group of indicators using a step by step approach to obtain the overall energy performance indicator for a complex system such as a university campus.

First, to minimize the error in the data and because it is difficult to study 152 buildings all at once, the concept of Energy Analysis Zones (EAZ) is proposed by dividing the campus into a number of analysis zones grouped by location. Each zone will be considered a subsystem of the overall campus system, and will contain 8-18 buildings on average.

At the building level, the BESI and the BSI indicators are calculated as follows:

For the BESI aggregate indicator, the energy performance indicator (EPI) for each building is calculated. All calculations are based on the Dutch NEN2916, which provides the calculation standard that underpins the Energy Performance Norm (EPN). The EPN was developed to regulate the total energy use of commercial buildings in The Netherlands, and slight variations of this norm are being tested in other European countries (Debajyoti et al. 2006).

The PMC uses the Building Performance Analysis Toolkit Plus (BPAT+) to calculate the building energy consumption (Penn Sustain Phase I Report 2006). The BPAT+ calculates the total energy consumption of a building as the sum of the consumption of individual functions: heating, cooling, humidifying, lighting, domestic hot water, fans, and pumps.

For the BSI aggregate indicator, three spatial indicators are selected: the surface to volume (S/V) ratio (Form Indicator), percent of façade exposed to sunlight (Orientation Indicator), and the proximity to district heating and cooling (Location Indicator). The "S/V" indicator is a ratio that indicates minimum heat transfer based on the building form against its total surface area (Knowles 1981). It is computed as the sum of all opaque and glazed surfaces divided by the building volume. The resulting ratios for all buildings are averaged to obtain the S/V ratio for the selected EAZ. The "Percent of façade exposed to sunlight" indicator is computed using environmental simulation tools such as ECOTECT. The "proximity to district heating and cooling" indicator is calculated using CAD and is defined as the length of pipe from the source of campus cooling generation to each building divided by the total pipe length used on campus in linear feet. The pipe length, size and pathway are available on the utility campus maps and available in AutoCAD format.

At the site level, the SESI and the SSI indicators are calculated as follows:

For the SESI aggregate indicator, the systems performance indicator (SPI) is calculated for each campus system such as Transportation, District Heating, District Cooling, and Electrical Systems, using shareware tools available at the Department of Energy (DOE) resource website such as, the Chilled Water System Analysis Tool (CWSAT) Version 2.1, and the Steam System Analysis Tool (SSAT) to compute the energy performance of the two systems. The transportation and electrical performance data are often available from the university data resources.

For the SSI, three spatial indicators are selected: Density (Form Indicator), Percent of shaded areas by buildings (Orientation Indicator), and the Sky View Factor (SVF) (Location Indicator). The "Density" indicator is computed as the sum of all building footprints divided by the total area for the EAZ. The "Percent of shaded areas by buildings" indicator is computed using environmental simulation tools such as ECOTECT. The "SVF" indictor, which is a ratio between the total amount of radiation received from a plane surface and that received from the whole radiant environment (Souza and Rodriguez 2006), is computed manually or using Arc View SVF extension (Souza and Rodriguez 2006).

A sensitivity analysis is then employed to determine the weighting coefficients for each of the computed indicators. For each computed indicator, the aggregated value is correlated to energy use intensity to determine the level of dependency between the input "indicator value" and the output response building "Energy Use Intensity" (EUI).

Finally, the Campus Energy Performance Index (CEPI) is calculated by aggregating the four indicators: BESI, BSI, SESI, and SSI. Since we have four indicators, the index will be a score that can range from 1 to 4. The potential to quantify performance data can be utilized to provide a decision-making tool that can aid in the early stages of campus planning, for energy efficient site planning decision making, and to provide a performance assessment framework at the urban level.

CONCLUSIONS

Creating a holistic performance indicator on the building and site level is a process that has to incorporate both observation and measurement aspects, thus aiming at a synthesizing capability. Therefore, the proposed performance framework is expected to be an asset to develop an integrated energy efficient process for site planning. Establishing such a framework is, however, not just a matter of addressing distinct features, but also very much a concern of how the future campus plans are assessed.

The significance of this research is its emphasis on integration from the building and urban design viewpoints. The theoretical hypothesis is based on borrowing the principle of system and spatial indicator aggregation at the building level and applying it on the urban "site" level. The theory is grounded on the fact that a building is a sub-system of a city, and that the entire system behavior is similar. The research method is an attempt to explain the city system by borrowing the same methods used to assess energy performance at the building level, and applying these methods to the site level.

Crossing fields between urban planning and architecture gives this approach a new scope that is different in nature from traditional and stand-alone performance analysis. In particular, the engagement of planning and design and the coverage of the entire range of environmental design scales, from rooms to buildings to urban blocks, blended with quantitative assessment tools, highlight the importance of integration and the long-term synthesizing efforts expected from this project.

A pilot study is currently in development for the University of Pennsylvania Campus. Creating an integrated campus energy performance framework and a set of quantitative indicators that is applicable to the campus will provide rules of thumb for site planners, architects and administrators for benchmark use as it is applied to other campuses.

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