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# Application of Building Performance Simulation and Post Occupancy Evaluation in Building Sustainability

*Dr. Ammar Sadik Dahlan* [1, *]

[1] *Architecture Department, Faculty of Architecture and Planning-King Abdulaziz University-Jeddah, Saudi Arabia, adahlan@kau.edu.sa*

** Dr. Ammar Sadik Dahlan, adahlan@kau.edu.sa, DOI: 10.21608/pserj.*

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## ABSTRACT

Globalization on one end has increased urbanization but on the other extreme was a major parameter of depletion of non-renewable resources. United Nation as a custodian of human rights has provided a long-term strategy of sustainability-Vision 2030 a long-term perspective that was initiated in 2015 having 17 sustainable development goals (SDGs) constituting 169 global targets related to the SDGs with a focus to improve the social, economic and environmental concerns of a human being". Sustainable building of cities and communities is its 11th SDG. This paper provides a sound basis to use building performance simulation (BPS) in buildings to reduce the level of energy consumption in Saudi Arabia (KSA). A Survey was conducted evaluating the knowledge of BPS around the construction community along with a case study that is done to analyze the impact of BPS on overall energy efficiency. The results reveal a mixed knowledge level of the audience where most people are unaware of BPS and the professionals also have a very diminutive knowledge of this. However, it was observed that BPS has wide applications in building design as 50% energy efficiency is achieved as compared with the traditional approach of designing. The study discloses the fact of boosting up a country's economy by application of BPS as it lowers the energy consumption and carbon footprints. Moreover, a relationship of BPS with customer satisfaction and a framework for implementing sustainability in architectural projects are also suggested

**Keywords**: Building performance evaluation, Users Satisfaction, Energy Efficiency, Sustainability

## 1.INTRODUCTION

Middle East countries have vast petroleum resources, and they are exporting these non-renewable reserves worldwide to tackle the demands of other countries resulting to boost up their economies. But these resources are limited and have polluted our environment. In contrast to that, sustainability is the use of resources productively for the current population in a way so that does not compromise the need of the future generation **Error! Reference source not found.**. United Nations has 15 years long agenda for the achievement of SDGs, each goal has multiple targets that collectively become 169 Nos while there are overall 232 indicators **Error! Reference source not found.**.

Sustainable development covers three aspects of life; Environmental, Social, and Economy. United Nations sustainable development goals (SDGs) have wide applications in each sector; it imposes regulations for countries and private sectors to make the rules and regulations and strategic planning according to what is written in SDGs **Error! Reference source not found.**. Organizations of any capacity are trying to align their strategic goals with the goals of the United Nations SDGs. It is noteworthy to mention that goals related to the environment have a direct influence on social and economic aspects of human beings and vice versa **Error! Reference source not found.**.

Technological advancement has changed the way of businesses from a traditional approach to a customer-centric approach. This paper is focusing to sustain the environment in such a way so that to be more productive in the terms of energy efficiency of a constructed structure. Sustainable building of cities and communities is the 11th sustainable development goal of the united nation.

Building and construction sector is known to be a major contributor to global warming. In a report **Error! Reference source not found.** published in 2015, 30% of worldwide global warming is due to construction, out of which 22% is associated with the residential sector. It is estimated that global warming can increase the temperature up to 2 degrees Celsius by 2050. A limit to global warming can be reduced to 77% by reducing $CO_2$ emissions in the construction industry **Error! Reference source not found.**. Therefore, it is essential to invest in a sustainable housing sector in the future.

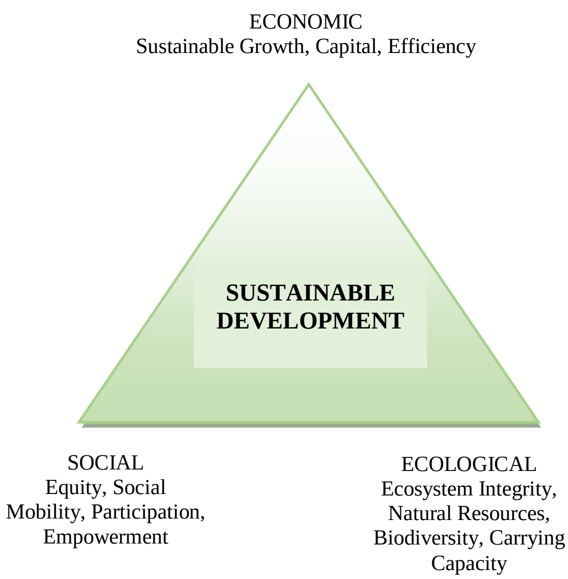


Fig.1: Triangle of Sustainable Development **Error! Reference source not found.**

"Saudi Arabia is a country that has grown tremendously due to factors such as growth, population, economic growth and modernization" **Error! Reference source not found.**. "In Saudi Arabia, 80% total energy consumption occurs during the operation of the building while less than 20% is consumed in initial construction and pre-construction phases" **Error! Reference source not found.**. "Building Performance Evaluation (BPE) can identify areas where energy consumption can be reduced and overall, it can result in long-term environmental and economic savings" **Error! Reference source not found.**.

As per the report of the United Nations **Error! Reference source not found.**, people are migrating towards urban areas in abundance, and it is expected that two-thirds of the world population would be urbanized by 2050. We must think differently to transform our built environment for the implementation of SDGs. The objective of sustainable cities as per the concept of sustainable development is to create business opportunities, safe and affordable prices, and improving urban planning for user satisfaction.

Architects need to know their core user requirements before starting any project. In residential projects, residents, designers, leaving communities, and regulatory government bodies are direct or indirect users.

The traditional approach was to deliver the building to the customer. The holistic approach is a continuous survey that does not end with completing and transferring the building to the customer, it is the first step of using the building. More than one green building achievement criterion is required before and after to determine the success of a building.

### 1.1 POST OCCUPANCY EVALUATION:

A post-occupancy assessment was dole out within the 1960s to live building performance and to spot important problems by specifying in the viewpoint of making efficient buildings and wishes of building occupants [10],[12]. it's an evaluation method used for buildings that are built and occupied for a particular period of your time [11]. POE is employed to look at how satisfied building users are with the environment by obtaining feedback and to produce information to boost building performance in future projects [12]. The utility of POE is diverse; it will be used not just for existing buildings but also for brand new buildings and to live the overall building delivery cycle [10]. POE is to boost the mix of materials and human needs that ends up in performance improvement [13],[14]. A. Ilesanmi (2010) emphasize that POE is a crucial method to demonstrate continuous improvement in building design quality and is expounded to customer satisfaction and profit maximization [15].

### 1.2 BUILDING PERFORMANCE EVALUATION:

The Building Performance Evaluation (BPE) methodology was introduced by Preiser and Schramm in the 1990s to develop a PoE framework and create a new way of developing knowledge. **Error! Reference source not found.**,**Error! Reference source not found.**. This framework helps to improve quality at every stage of the building life cycle. Building performance links, the excellence of the workplace with the impact of performance to create an adaptable, durable, energy-efficient, liveable and safe building **Error! Reference source not found.**.

POE was upgraded to BPE to ensure the quality of the building through the Strategic planning, Programming, Design, Construction, Occupancy, and Recycling phase. In addition, this method is used as a method suitable for defining the real performance of a building and making decisions at every stage. For this reason, BPE is an important framework (Fig.2) that can be widely used in the field of Business Performance and can lead to operational performance and future needs **Error!**

**Reference source not found.**. Each of these phases is described under:

### 1.2.1 Phase 1-Strategic Planning:

To obtain information to determine the objectives market needs analysis is done. Strategy is a medium or long-term plan that provides a road map covering each planning of building construction [17].

The results of the strategies are written according to the plan and at this stage, the results should be matched with the results of the SDGs. Efficiency is compared to the designed goals and ultimately takes a big picture to decide whether to go to the next stage.

### 1.2.2 Phase 2 Programming:

Programing/short document describes the client's needs, goals, resources, and context for the project. Programming takes place among key stakeholders in consultation with construction experts **Error! Reference source not found.**,**Error! Reference source not found.**,**Error! Reference source not found.**.

A review of strategic planning is done after discussion with each stakeholder. Programs are being evaluated step by step and it is merged in a strategic plan **Error! Reference source not found.**.


**Fig.2: Building Performance Evaluation Process Model** Error! Reference source not found.

### 1.2.3 Phase 3-Design:

In the design process, different alternative designs are made according to the needs of the customers and then, after meeting with the customer, a single design is developed from the alternatives. Finally, a contract of construction document is made for the final design.

"The design phase includes customers or their representative, programmer and designer. Building information modeling (BIM) and the development of computer-aided design (CAD) make it possible to evaluate solutions in the early stages of design. At this stage, the designer controls the different perspectives of the building and can still be changed" **Error! Reference source not found.**.

### 1.2.4 Phase 4-Construction:

At this stage, construction managers and architects have a share in construction management and quality control to ensure compliance with the contract. In addition, safety regulations and national quality parameters/construction rules must be observed. It may be possible to define new requirements that increase the overall budget.

At this stage, an inspection is made and staple lists are provided to check whether the building is built for its intended use and that all requirements are met. This stage aims to check whether all legal and mandatory conditions are met.

### 1.2.5 Phase 5-Occupancy:

Building Performance Evaluation (BPE) plays a role at this stage because it is based on feedback and evaluation, so it has a long-term perspective. It also includes occupancy time to improve the quality of the decisions made in the previous stages. Earlier occupancy may take between months and years.

At the occupancy stage, "BPE is activated as POEs that provide feedback on what works and what needs to be improved at the facility. POE can be used to identify problems in the occupied building and form the basis of the improvement" **Error! Reference source not found.**.

### 1.2.6 Adaptive Re-use/Recycling:

It is now very common to turn the train station building into a shopping mall and something like that. In these cases, minor external or internal changes are required for a particular user.

The question of how well a building adapts and can be recycled is crucial not only for sustainable building practices but also for the adaptation to new uses **Error! Reference source not found.**. This stage ends after the end of the life of a building. Building materials with the potential for reuse are separated and hazardous materials are removed during recycling.

This end of the building means that the next building life cycle begins. It means evaluating the rehabilitation potential of a potential region in terms of future needs.

## 1.3 USER SATISFACTION:

User satisfaction is the user’s ease and acceptability of any facility provided to him [23]. It is an outcome of any architectural design. The definition of user satisfaction has been proposed in many works of literatures. However, the user satisfaction in BPS is in terms of how well the buildings users are satisfied with the provided environment. Users are interested in more specific environmental and residential satisfaction **Error! Reference source not found.**,**Error! Reference source not found.**,**Error! Reference source not found.**. However, “the application of satisfaction with environmental assessments first observes is based on the assumption that the environment is used and perceived, but the environment is looked after and that many problems in the built environment are the result of neglecting the views of users” **Error! Reference source not found.**.

### 1.4 BUILDING PERFORMANCE SIMULATION (BPS):

By carefully planning energy efficiency, it is estimated that a significant amount of energy can be saved from a traditionally designed building. Heating, ventilation, air conditioning (HVAC), and lighting are important parts of constructed building energy efficiency. It is vital to understand and optimize the performance of basic building services and systems to save energy **Error! Reference source not found.**.

“The building's energy requirement depends not only on the components of the envelope (walls, windows, and ceilings) and the individual performance of the HVAC and the lighting system but also on its overall performance as an integrated system within the unique building” **Error! Reference source not found.**,**Error! Reference source not found.**.

For a large, constructed infrastructure, complex and dynamic communication systems and facilities must be modeled and analyzed for analysis. It is the current technical building designed for energy efficiency, architects, engineering, and building managers **Error! Reference source not found.**.

“Before the computer-assisted building was revolutionized, architects and building services engineers were already exposed to the available calculations using selected design conditions, and often familiarized themselves with the “numerical rule” approach. This approach results in low energy efficiency, often due to the extremely partial load operation. For large or complex buildings, it is unrealistic to estimate that energy-assisted designs can be replicated to computer-assisted detailed building simulation programs (BSPs). Today, BSP allows architects and engineers to test new architectural designs on personal computers before building construction” **Error! Reference source not found.**.

## 2.BPE METHODOLOGY FOR ENERGY EFFICIENCY IN ARCHITECTURAL DESIGN:

The BPE methodology focused on measuring KPI (Key Performance Indicators) with easily distributable collection tools. The KPI (Table I) categories examined include occupancy factors and energy factors.

The study used data collection both quantitatively and qualitatively. Analysis methods are based on intensive literature review and further refined by the research [8],**Error! Reference source not found.**,**Error! Reference source not found.**,**Error! Reference source not found.**. The performance of constructed infrastructure is compared in Table II (Occupancy of persons) and Table III (Energy Units Intensity) with the estimated objective goals (which were estimated during BPE life phases) vs. the actual results. The difference between the estimated/benchmark and actual is shown in a form of % a gap.

Table 1: Key Performance Indicators **ERROR! REFERENCE SOURCE NOT FOUND.**

| | |
|---|---|
| Level A | Building Owner (Discussion) |
| | Building (Walking through Observation) |
| | Energy Consumption and demand (Analysis) |
| | Discussion with owner / operator |
| Level B | Interview design team / owner |
| | Occupant satisfaction survey |
| | Report Findings |
| Level C | Field Measurement (Occupants, Energy) |
| | Re-calibration of energy model |
| | Building envelope investigation |
| | HVAC system investigation |
| | In-depth study of specific key performance indicators |
| | Observation study occupants |
| | Recommending actions |
| | Receiving outcomes |
| | Determining Design Guidelines |

## 3.RESULTS FINDINGS

There are many performance indicators as mentioned in BPE Methodology, but this research study focused only on the occupant’s behavior to use the buildings in Riyadh, KSA and energy efficiency measurement of the buildings. All the building types i.e., educational, religious, administrative, commercial, public, and health care were chosen for a comprehensive analysis on occupant's behavior and energy usage. Religious buildings include mosques, educational buildings include schools and universities, administrative buildings include some offices and statutory bodies, public buildings include structures owned by government agency, and commercial buildings include markets, malls, offices, and warehouses.

### 1.5 OCCUPANT'S BEHAVIOR (ACTUAL VS PREDICTED):

As per the methodology of BPE, occupants on different buildings as per the previous design were checked in 6 months. A Gap is checked to investigate whether the building is performing as per the design or not. Results are mentioned in Table II.

Table 2: Gap of Estimated Vs Actual Occupants Operating Hours [23]

| Building | Daily occupancy (person/h) | | | Typical weekly operating hours (No. of Hours) | | |
|---|---|---|---|---|---|---|
| | Estimated | Actual | Gap% | Estimated | Actual | Gap% |
| Religious Building | 85 | 68 | -20 | 57 | 57 | 0 |
| Educational Building | 2000 | 1600 | -20 | 50 | 60 | 20 |
| Administrative Building | 396 | 365 | -8 | 45 | 80 | 78 |
| Mixed-use Commercial Building | 2200 | 2249 | 2 | 40 | 68 | 70 |
| Public Building | 250 | 200 | -20 | 45 | 60 | 33 |
| Health Care building | 378 | 305 | -19 | 45 | 50 | 11 |
| Commercial Building | 42 | 38 | -10 | 66 | 68 | 3 |

In table II, different building occupants' study is presented. Estimated occupants' calculations are the ones that were required by the users in their buildings while designers designed the building. Moreover, actual occupancy calculations are measured by installing the sensors in buildings for 6 months. A Gap is written in percentage so that to understand the difference of designed vs actual building occupants. Daily occupants' behavior varies in different buildings ranging from -20% to 2%. It means that buildings have still the capacity to merge more occupants.

In operating hours case, buildings are designed to operate for a certain period on weekly basis. For example, a religious building was designed to be operated for 57 hours per week for 85 occupants per hour (4845 occupants per week). Buildings are operating excess as compared with the designed estimated hours ranging from 3 to 78%.

### 1.6 ENERGY EFFICIENCY (ACTUAL VS PREDICTED):

Fig.3 shows comparisons of predicted vs actual performance of building against the energy units intensity values (kWh/m²/yr.). A methodology was adopted to check the energy unit's intensity of building (Estimated during BPE life cycle vs actual performance). Building energy meter calculations are used to compare the actual energy units with the expected units. POE tends to collect the information on buildings, energy usage, and user satisfaction as it informs the users if the building is energy efficient which ultimately helps in reducing the operational cost of building and makes it greener. POE tools and BPE life cycle phases were applied to the building in terms of obtaining feedback on building's performance.

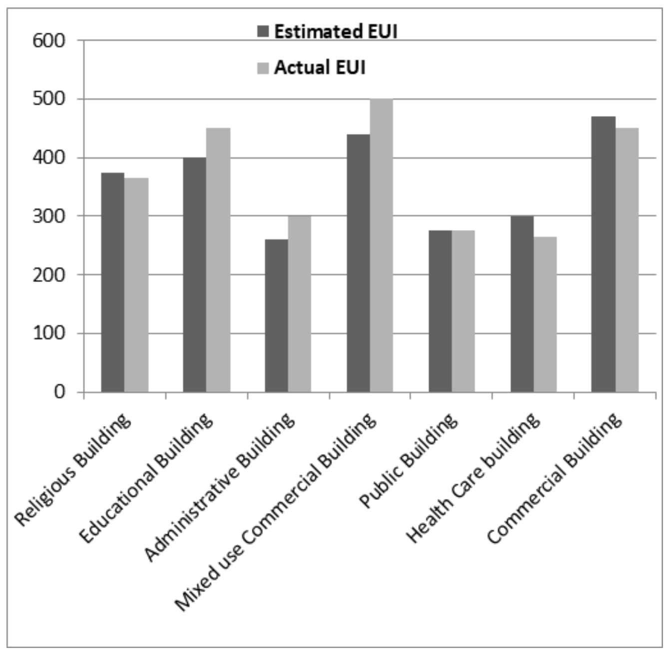


Fig. 3: Estimated vs. Actual Energy unit Intensity of the buildings

Table 3: Estimated Energy Unit Intensity Vs. Actual Energy Unit Intensity [31]

| Building | Estimated Energy Units Intensity | Actual Energy Units Intensity | Gap % |
|---|---|---|---|
| | Estimated Energy Units ((kWh/m²)/yr) | Actual Energy Units ((kWh/m²)/yr) | |
| Religious Building | 375 | 365 | -3 |

| | | | |
|---|---|---|---|
| Educational Building | 400 | 450 | 11 |
| Administrative Building | 260 | 300 | 13 |
| Mixed-use Commercial Building | 440 | 500 | 12 |
| Public Building | 275 | 275 | 0 |
| Health Care building | 300 | 265 | -13 |
| Commercial Building | 470 | 450 | -4 |

It can be concluded from Table III that energy intensity units are varied between -13% to 13%. The public building shows benchmark measurements, 3 buildings show an increase in the requirement of energy demands while 3 others showed a decrease in energy demands. Out of 7 buildings, 4 buildings show more than 90% energy efficiency.

### 1.7 SURVEY TO EVALUATE THE KNOWLEDGE OF BPE:

A survey was conducted in Riyadh to ask different stakeholders related to the construction industry to tell the knowledge level against the BPE. The survey was in-person in the form of questionnaire distributed among architectures, building planners, Civil engineers, energy consultants, and contractors.

A total of 405 no of responses were obtained and the percentage of responses is shown below.

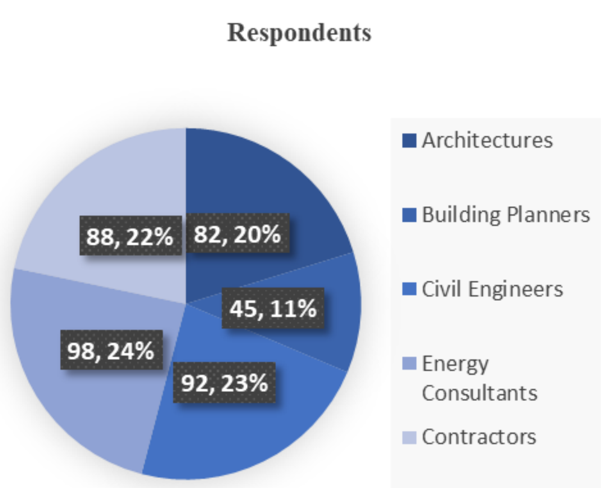


**Figure 4: Respondent Percentage**

**Results:**
The results obtained are shown as under.

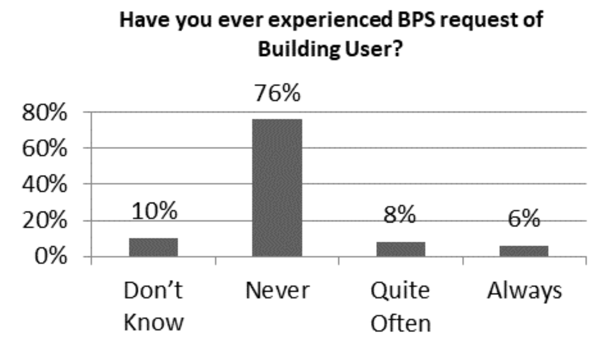


**Fig.5: Use of BPS Request**

In general, survey results indicate that BPS has very small roots in the KSA construction industry. The users are not well known for this concept and they never asked to launch during the building life cycle. Professionals are not known of the BPS tools which make energy-conscious decisions. Out of 9 different field respondents, all of them were not aware of the BPS technique or they haven't used it in their decision-making of design construction and operation process.

## 4.CONCLUSION

The occupant's behavior in Table II and Energy Units in Table III has a direct linkage with each other. The Religious building has shown benchmark calculation in Table II while building consumed 3% less energy as shown in Table III. The Administrative building is using by more occupants (365*80=29,200 Nos) while estimated occupants were (396*45=17,820 Nos) and for a 78% longer period (35 hrs.) therefore energy requirements for the building have been increased to 13%. It cannot be said that energy calculations are not accurate, but the building is using for a longer period that's why the units were extra consumed.

Similarly, mixed-use commercial building was occupied by a large number of occupants (2249*68=152,932 Nos) as compared with expected occupants (88,000 Nos). The case is again same as the building was used for a longer duration (hrs./week) of time (68 hrs.) as compared with the estimated (40 hrs.). Energy units are therefore increased to 12%.

The energy efficiency of the buildings is under the estimated range because the user's expectation was met in designing each building. EPS Tools of building life cycle phases are used until the user is satisfied with the designed calculation. In case, the results are not achieved as expected then again, the life cycle of EPS will be started-the root causes of each problem will be checked and mitigate actions will be done to again take the measurements until the results are matched with the estimated measurement calculations.

In the second case, survey results for finding out the level of knowledge of BPS tools and techniques are presented in Fig.4. The survey reveals that respondents are not aware of BPE techniques and overall, 86% of participants respondent that they never used this technique in building design or never asked from the users. In addition to that, all the stakeholders must ensure to make a plan for the effective implementation of BPE using BPS techniques. It will reduce global warming and hence sustainable development goals can be achieved in KSA.

Users' satisfaction in buildings is achieved after effective implementation of BPS in terms of reducing their energy needs, reduced carbon emissions and waste, lower exposure to toxins, and prioritizing the use of safer materials. The environment will become safer by using low energy consumption/low carbon footprints and hence energy efficiency will boost up the country's economy and social lives of the human being.

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