Leadership in Sustainable Infrastructure

Leadership en Infrastructures Durables

Vancouver, Canada

May 31 – June 3, 2017/ Mai 31 – Juin 3, 2017

HOW ARE WE EVALUATING BUILDING PERFORMANCE? A REVIEW OF UP-TO-DATE PRACTICES FOR THE iiSBE LEVEL II PROTOCOL

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Abstract: Building Performance Evaluation (BPE) is critical in order to validate the development of green and sustainable buildings. In recognition of this, iiSBE Canada, part of an international group committed to advancing the sustainable building agenda across the globe, has initiated a project to develop a BPE Protocol for Post Occupancy Evaluations. Problematically, the development of a BPE Protocol has recognized challenges and the industry is still in an iterative process of testing, learning, and improving. Furthermore, the use of inadequate metrics and procedures can hinder the evaluation process, limiting the potential benefits to society and stakeholders. This paper's objective is to present up-to-date practices of BPE, with a central focus on the collected data. For this purpose, the paper identifies, examines, and compares three tested protocols, with similar objectives and scope to the new iiSBE Protocol. It also reviews case studies that employ these protocols. The main contribution of this paper is the presentation and discussion of eight tables, each one summarizing data collected to describe and evaluate buildings in a different category: building description and characteristics, occupancy and schedules, energy use, water use, thermal comfort, indoor air quality, lighting, and acoustics. The aim of this paper is to assist in the development of the iiSBE Protocol and other BPE efforts, an area where consensus has not been reached and there is still opportunity for improvement.

1 Introduction

At its core, Building Performance Evaluation (BPE) is the process of systematically comparing the actual performance of a building to its expected performance (Preiser and Vischer 2005). When the process is carried out after a building has been occupied, we also refer to it as Post Occupancy Evaluation (POE). BPE and POE have gained increasing attention as ways to validate the development of green and sustainable buildings, generating information that justifies the efforts to enhance building performance (NRC et al. 2002). More generally, when done correctly, BPE serves four broad objectives: to understand how a building is working, to evaluate whether it works as intended, to learn how it may be improved, and to understand how future buildings may be improved (Preiser and Vischer 2005). Without BPE, the assertion that a building is green is an unsubstantiated and unproven one. A troubling fact is that BPE usually finds performance gaps between the building's expected and its actual performance.

Acknowledging this, the Canadian chapter of the International Initiative for a Sustainable Built Environment, iiSBE Canada, which is a non-profit group devoted to the advancement of the green building agenda in Canada and across the world, developed a Level I Protocol. The protocol was used to conduct POE of nine green buildings across Canada. The main objectives were to better understand the operational performance of the buildings, assess possible performance gaps, and identify lessons for their owners, design teams and the construction industry (Bartlett et al. 2014). Having identified opportunities for improvement, and aiming to extend the scope of the Level I Protocol, iiSBE Canada has initiated a project to develop a Level II Protocol. Besides being aligned with the purpose of the group, the protocol is currently intended to evaluate energy use, water use and water quality, indoor environmental quality, building environmental footprint, operational waste and recycling, transportation energy for commuting and supplying, occupancy data, and other parameters such as job stress. Another goal of the protocol is the development of a benchmarking methodology.

In support of this project, this paper presents the results of an examination and comparison of three tested and recognized BPE protocols. The protocols where selected for their comprehensiveness and completeness, their similarities with iiSBEE's objectives, and the reputation of their authors. The selected protocols are:

- ASHRAE: Performance Measurement Protocols for Commercial Buildings
- Pacific Northwest National Laboratory: Building Cost and Performance Metrics: Data Collection Protocol
- EcoSmart: Post Occupancy Evaluation Protocol

The three protocols were also compared with iiSBE's Level I Protocol. The purpose was to assess the state of the Level I Protocol and to identify possible areas for expansion and improvement.

This paper contains three sections. First, a literature review presents the main aspects of the selected protocols, including their objectives, audiences, and recommendations. Second, a comparison and discussion of the protocols is shown, emphasizing their recommended metrics and presenting case studies that have used them. Third, the main conclusions are presented.

2 Literature review

2.1 ASHRAE: Performance Measurement Protocol for Commercial Buildings

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) was founded in 1894 and is recognized worldwide as a leader in technical and educational information in subjects related to building systems, energy efficiency, and indoor air quality. ASHRAE's Performance Measurement Protocol for Commercial Buildings, published in the year 2010, is a document containing three BPE protocols. The main differences between the protocols is the level of accuracy and the cost of the evaluation, adapting to the needs and economic capabilities of the evaluator and providing a sequential approach to building evaluation. Some of the protocols' objectives were to standardize the collection of data and to allow an appropriate comparison of commercial buildings (ASHRAE 2010). The protocols are divided into six different performance categories: energy, water, thermal comfort, indoor air quality (IAQ), lighting, and acoustics.

The Basic (indicative) Protocol is intended to be low cost while revealing possible causes for further assessment, where the Intermediate (diagnostic) and Advance (investigative) level protocols would be used. Together, these protocols are one of the richest publications regarding BPE procedures; containing what should be measured, measurement methods and their cost, recommended indicators, industry standards, and benchmarks. The intended users of the protocols are building owners and operators, facility managers, architects and designers, government officials, and researchers interested in whole-building performance (ASHRAE 2010).

As the title of the document indicates, the protocols were conceived to be applied to commercial buildings. However, the document does not give an explicit definition of commercial buildings, nor a specific list of building types for which the protocols are applicable. Also, the document does not recommend modifications or considerations for the evaluation of other building types. For multipurpose buildings, the Basic Protocol suggests the use of the 'ASHRAE Standard 105 form' to report the area allocated to each building type. The 'ASHRAE Standard 105 form' includes several building types beyond commercial (e.g. office, apartment, education, health care, hotel, and assembly buildings), seemingly exceeding the originally intended scope of the protocols.

For Indoor Environmental Quality (IEQ) satisfaction, the protocols refer the user to a number of possible surveys, including surveys developed by the Center for the Built Environment (CBE). CBE is an Industry/University Research Collaboration at the University of California Berkeley. A demo of the IEQ surveys is available on the organization's website. One advantage of using these surveys is the access to a database containing the results of past evaluations, allowing the benchmarking of occupant satisfaction. The surveys can include additional questions and be adapted to different building types. The recorded data includes the surveyee's background, workspace location and description, thermal comfort, air quality, lighting, and acoustics. The surveys have requests for comments in various sections and also record the level of control that the occupants have over the different features of the building (e.g. windows, blinds, switches, etc). Abbaszadeh et al. (2006) presents a study that uses this survey and its database to evaluate IEQ Occupant Satisfaction in green and non-green office buildings.

The protocol also addresses how to properly conduct thermal comfort surveys. ASHRAE has found thermal sensation to be a poor indicator of satisfaction or acceptability. The indicator reports how the occupant is feeling and not how the occupant would like to feel, which can cause misinterpretations (ASHRAE 2010). For example, 'slightly cool' might be the preferred sensation of the occupant, but reporting it may raise an erroneous concern to the evaluator. To prevent this issue, acceptability or comfort should also be measured. It is also recommended that the survey be symmetrical to avoid skewing the results (i.e. if the option very uncomfortable exists, the option very comfortable should also be included). Finally, all major aspects of IEQ should be covered in one survey. Separate surveys can create biases since dissatisfied people are more likely to respond. Overall, the evaluator should recognize that the wording of the surveys is important, and that introducing untested surveys can generate unexpected problems in the collected data.

2.2 Pacific Northwest National Laboratory: Building Cost and Performance Metrics: Data Collection Protocol

The Pacific Northwest National Laboratory (PNNL) was founded in 1965 as one of the United States Department of Energy's national laboratories. It is a research and publication powerhouse, having filed more than 2000 patents and consistently being ranked among the top 1% in publications and citations by 'Essential Science Indicators'. Besides its renowned publisher, the protocol also draws validation from its Technical Advisory Group, formed by selecting experts in sustainable development and design. The list of the members can be found in the protocol.

A second version of this protocol was published in 2009, five years after the publication of the first version, and is available on the PNNL website. The 2009 version claims to be a revised protocol, reflecting lessons learned from using the 2005 version. Because observing how the protocol has evolved gives the valuable opportunity to infer what was working in the original version and what was not, both versions have been analyzed and compared. The results are presented in the comparison and discussion section of this paper. Some of the lessons learned are also mentioned in the 2009 protocol, for example:

- Building managers should be engaged early in the process.
- The building should be fully functioning and occupied for at least six months before the POE.
- When comparing "Total Potable Water Use" between buildings, the same uses should be included in both buildings, and additional uses should be factored out.

The protocol was conceived to capture differences in the performance of sustainably designed and typically designed buildings (PNNL 2009). However, the protocol does not specify building types for which it is best applicable. The Intended audience includes building managers and sustainable design professionals. Made to persuade federal decision makers, the protocol has a strong focus on cost measurements. These measurements allow life cycle cost analyses and to show the benefits of sustainably designed buildings. Furthermore, the protocol devotes a chapter to 'Data Visualization', exposing appropriate graphical representations to communicate with stakeholders. The collected information is separated into "Building and Site Characteristics" and "Building Cost and Performance Metrics". The first set of information is useful for filtering buildings, allowing a valid comparison between them. The second set of information are measurements of the actual performance of the building, and is separated into Water, Energy, Maintenance & Operations, Waste Generation and Recycling, IEQ, and Transportation. Finally, the protocol differentiates between required and optional metrics. The optional metrics are usually too difficult and/or costly to measure, but should be collected whenever possible since they can add significant information to the evaluation (PNNL 2009). The required and optional criteria is summarized in the tables presented in the Comparison and Discussion section of this paper.

The PNNL protocol has perhaps the most insightful information when it comes to metric selection. The protocol discloses both, the selection criteria and the scores of the selected metrics. The main parameters are ease of collection, usefulness of information, and quality of data; resembling the recommendations of Preiser and Vischer (2005) for a feasible POE. Furthermore, in alignment with the objective of the protocol, the capacity of each metric to impact sustainable, economic, environmental, and equity indicators was reviewed. Among other applications, this protocol was used to evaluate fourteen buildings of the U.S. Air Force and twenty-two buildings of the General Service Administration. Both of these studies are available on the PNNL website.

2.3 EcoSmart: Post Occupancy Evaluation Protocol

EcoSmart is a not-for-profit Canadian corporation founded in 1999. It is focused on creating collaborative industry-government partnerships to further green building and sustainable construction practices. As a pilot project, EcoSmart developed a POE protocol and tested it on six buildings, the final reports are available on its website. The final protocol that incorporates the lessons learned from the pilot project is also available online. Only the final protocol has been reviewed for the purposes of this paper.

The protocol is available in Excel format, with blank fields to be filled by the evaluator. The intent of the protocol is to provide an opportunity to compare buildings across different evaluators and create a database. For this purpose, the protocol has been put in the public domain and public presentations were carried out to promote it across building designers. An email address enabling users to provide direct feedback to EcoSmart is included. Another objective of the protocol is to ensure continuous improvement of design methods by providing feedback to designers on the effectiveness of their choices (EcoSmart 2006)

The protocol explicitly indicates that it was conceived to evaluate office buildings that have undergone at least one year of operation. The protocol goes beyond indicating the data that should be collected, and also mentions the structure of the BPE team needed to perform a successful evaluation. The organizational structure includes a Team Leader, an Acoustics Consultant, an Indoor Air Quality Consultant, a Lighting Consultant, and a Controls and Commissioning Consultant (EcoSmart 2007). The tasks of each member are also presented. The protocol is specially telling when it comes to interviews that should be carried out. It includes outlines for a kickoff meeting with the owner, an interview with the design team and the building operator, and a final meeting. Most of these interviews serve to collect qualitative data, useful to spot sources of problems in the building's operation, including the goals of the design, the strategies related to performance that are being implemented, the level of training and familiarity of the building operator, etc. For occupancy satisfaction, the protocol also recommends the use of surveys developed by CBE.

The aspects of performance that are evaluated are: Energy Consumption, Water Consumption, Indoor Air Quality, Lighting, Acoustics, and Thermal Comfort. The specific gathered data is presented in the Comparison and Discussion section.

3 Comparison and discussion

Because each protocol is unique, the different metrics and indicators have been reorganized and condensed into the following eight different groups (each presented as a table in this section): Building Description and Characteristics, Occupancy and Schedules, Energy Use, Water Use, Thermal Comfort, Indoor Air Quality, Lighting, and Acoustics. Table 1 shows data collected to categorise the building. This is particularly important when benchmarking due to the one-of-a-kind nature of buildings. The usual stance of the industry is that, at least, the compared buildings should be of the same type and located in the same climate (Pérez-Lombard et al. 2009). A more radical stance is that, to properly compare buildings, every parameter not traceable to design, with a potential to impact building performance, should be the same among the compared buildings (Pérez-Lombard et al. 2009). For practical reasons, however, an intermediate approach is often taken with buildings being filtered until they are judged to be similar enough for comparison. For example, in multipurpose buildings, ASHRAE requires the percentage of area corresponding to each building type to be reported (ASHRAE 2010). Also, when different operation modes are encountered throughout the year, posing a potential impact on the collected data, the data should be collected by operation mode (ASHRAE 2010). Both of these recommendations are good practices to properly characterize a building. Interestingly, even though a building's envelope has been recognized to heavily impact energy consumption and comfort (Aksamija, 2013), none of these protocols collect data to describe it.

Table 1: Building description and characteristics

Description	ASHRAE	iiSBE	EcoSmart	PNNL 2009	PNNL 2005
Location	Basic	Required	-	Required	Required
Climate zone	-	Required	-	-	-
Building type	Basic	-	✓	Required	Required
Discrepancies between intended and actual use	-	-	✓	-	-
Primary year of construction	Basic	Required	-	Required	Required
Expected building life	-	-	-	-	Optional
Gross floor area	Basic	Required	-	Required	Required
Gross ground floor area	-	-	-	Optional	Optional
Heated and cooled area	Basic	Required	-	Optional	Optional
Parking area	-	-	-	Optional	Optional
Landscape area	-	-	-	Optional	Required
Maintained exterior area	-	-	-	-	Optional
Undeveloped site area	-	-	-	-	Optional
Total building site area	-	-	-	Optional	Required
Number of floors	-	Required	-	Optional	Optional
Number of conditioned floors	Basic	-	-	Optional	Optional
Building conditioned volume	-	-	-	-	Optional
Ratings or awards	-	-	-	Optional	-
Key building features/design intent	-	-	✓	Required	Required
Operational concerns	-	-	✓	Required	-

Table 2: Occupancy and schedules

Description	ASHRAE	iiSBE	EcoSmart	PNNL 2009	PNNL 2005
Occupancy type	-	Required	✓	Required	Required
Discrepancies between intended and actual occupancy	-	-	✓	-	-
Occupant gender ratio	-	-	-	Required	Optional
Typical daily occupancy during normal operating conditions	Basic	Required	✓	Required	Required
Person-hours of occupancy per year	-	Required	-	-	-
Key policies regarding occupancy (sick leave, vacations, etc.)	-	-	-	Optional	Required
Percentage of the building being occupied or in use during the year	Basic	Required	-	-	-
Occupancy schedules	Basic	-	✓	-	-
Months of operation in the reported year	Basic	-	-	-	-
Average weekly hours of operation	Basic	Required	-	Required	Required
Number of years operating with full occupancy	-	Required	-	-	-
Lighting schedules	Basic	-	-	-	-
Thermostat setpoint schedules	Basic	-	✓	-	-

With regard to Table 2, it has been recognized that correctly describing a building's occupancy has important technical advantages. Building occupants are the most significant factor in sustainable building operations (PNNL 2009). Occupancy data is also used to normalize the building cost and performance data for comparative analyses (PNNL 2009). iiSBE has clear opportunities of expansion in this area.

Table 3: Energy use evaluation

Description	ASHRAE	iiSBE	EcoSmart	PNNL 2009	PNNL 2005
Site energy use	Basic	Required	✓	Required	Required
Source energy	Basic	-	-	Optional	Optional
Sources of energy	Basic	Required	✓	-	-
On-site renewable energy production	Basic	Required	-	Optional	-
Energy exported off-site	Basic	Required	-	-	-
Sub-metered energy use	Int. & Adv.	Optional	✓	-	-
Energy uses exterior to the building	Basic	Optional	-	-	-
Annual peak demand	Basic	-	-	Optional	Optional
Energy-intensive spaces	Basic	-	-	-	-
Energy demand of special equipment	-	-	-	Optional	-
Operational costs	Basic	-	-	Required	Required
Expected performance	-	Required	✓	-	-

Regarding energy use, described in Table 3, iiSBE currently approaches sub-metered energy by differentiating between delivered electricity, fossil fuels, and other. ASHRAE proposes a higher breakdown, differentiating between purchased electricity, natural gas, steam, hot water, chilled water, oil, propane, coal, and other according to table 3-1 of the protocol (ASHRAE 2010). Another possible area of expansion is “Energy-intensive spaces”. ASHRAE has found the need to subtract these spaces and their energy use to correctly compare similar buildings (ASHRAE 2010). Regarding performance indicators, Energy Use Intensity (EUI) is the most widely used, computed by normalizing energy use to the building’s area. However, it should be kept in mind that EUI does not consider the impact of occupant density or operating hours (PNNL 2010), and can thus lead to erroneous conclusions when comparing buildings or against a benchmark. In its study of 22 buildings, PNNL normalized the buildings’ energy use by their floor area, the hours of regular occupancy, and the number of full-time occupant equivalents, obtaining three indicators as instructed by the Energy Star Portfolio Manager (ESPM). The Denver (L) FB building rises from a score of 64 when normalizing by floor area, to a score higher than 90 when normalizing by operation hours or full-time occupant equivalents (PNNL 2010). In residential buildings, EUI is even more questionable since data shows that increasing the floor area per household reduces the EUI, but increases the energy use per capita (Kallaos and Bohne 2013), exposing a troublesome disconnection between the indicator and sustainability. Further evidence that improvement is required in this area is the work done by Hyonjin Kim. Applying the ASHRAE Protocol, she found that using different benchmarks yielded different results. For example, against the ASHRAE benchmark, a building was categorised as below average, while the ESPM benchmarks categorised the building as average (Kim 2012).

Table 4: Water use evaluation

Description	ASHRAE	iiSBE	EcoSmart	PNNL 2009	PNNL 2005
Water use	Basic	Required	✓	Required	Required
Submetered water use	Int. & Adv.	Optional	-	Optional	Optional
Recycled or captured water use	Intermediate	Required	-	-	-
Water used in the recycling process	Intermediate	-	-	-	-
Total storm sewer output	-	-	-	Optional	Optional
Expected performance	-	Required	✓	-	-
Protocol assess cost	Basic	-	-	Required	Required

Regarding water use (Table 4), ASHRAE gives an extensive list of indices for benchmarking different building types, including water used per bed per day for medical hospitals, and per customer per day for restaurants (ASHRAE 2010). ASHRAE and PNNL recognise the importance of collecting the different operational costs of the building. The PNNL Protocol was developed to impact decision making, and thus cost is one of its cornerstones. Proving that green buildings tend to have lower operational costs than others can be a huge incentive for owners and developers. In its study of 22 buildings, PNNL found the sustainably designed buildings of the General Service Administration (GSA) to be, on average, 19% lower than the baseline when evaluating operating cost (PNNL 2010). In a different study, seven LEED certified buildings where, on average, 43% below the baseline (PNNL 2014).

Regarding Indoor Environmental Quality (IEQ), presented in Table 5, the ASHRAE Protocol proves to be a good source of information, containing a greater number of metrics. For the Intermediate Level, self-initiated ‘right-now’ surveys are recommended, whereby occupants can report how they are feeling at any precise moment (ASHRAE 2010). When implementing these surveys, physical data describing the thermal environment should be taken continuously. However, with IEQ and all other metrics, one should keep in mind that increasing the collected data will increase the cost of the evaluation. The ASHRAE Protocol estimates the cost of a Basic evaluation at $3,000 USD, rising to $20,000 USD for an Advance evaluation. EcoSmart takes a more economical approach to IEQ, recommending to take at least morning and afternoon measurements (EcoSmart 2007).

Table 5: IEQ thermal comfort evaluation

Description	ASHRAE	iiSBE	EcoSmart
Air temperature	Basic	Required	✓
Globe temperature	Basic	Required	-
Surface temperatures	Basic	-	-
Mean radiant temperature	Basic	-	✓
Operative temperature	Basic	-	-
Setpoint temperatures	-	-	✓
Setback temperatures	-	-	✓
Humidity	Basic	-	✓
Solar gain	Basic	Required	-
Air speed	Basic	-	✓
Vertical temperature gradient	Advanced	-	-
Horizontal temperature gradient	Advanced	-	-
Radiant asymmetry	Advanced	-	-
Rates of temperature change	Advanced	-	-
Occupant satisfaction	Basic	Required	✓
Local sources of thermal discomfort	Basic	-	-
Time when discomfort occurs	Basic	-	-

Regarding indoor air quality (Table 6), the ASHRAE Protocol argues CO_2 to be a poor indicator of air ventilation in many circumstances. It should also be reported relative to occupancy levels, and generally should not be used for controlling human-generated biofluids. Regarding CO, the measurement is especially important when combustion sources are present.

Table 6: IEQ indoor air quality evaluation

Description	ASHRAE	iiSBE	EcoSmart
CO_2 spot measurements	Intermediate	Required	✓
CO_2 indoor-outdoor differential	Intermediate	-	✓
CO spot measurements	Basic	-	✓
Contaminants of concern (CoC)	Advanced	-	-
Composite VOCs	Advanced	-	✓
Fine particulates	Advanced	Optional	✓
Ultrafine particulates	Advanced	Optional	✓
Outdoor air quality	Basic	-	✓
Outdoor airflow rate	Basic	-	✓
Report building HVAC system configuration	Basic	-	-
Occupant satisfaction	Basic	-	✓

Regarding lighting evaluation (Table 7), a basic evaluation may be based on 'spot-illuminance' measurements, using them to compute average illuminance. At the Intermediate Level, spacing between measurement points should be one-fourth of the spacing between luminaires. The Advance Level recommends High Dynamic Range (HDR) photographs which may also be used to assess discomfort glare.

Table 7: IEQ lighting evaluation

Description	ASHRAE	iiSBE	EcoSmart
Horizontal or task plane illuminance	Basic	Required	✓
Vertical illuminance	Basic	Required	-
Interior surface reflectance	Basic	-	-
Discomfort glare	Intermediate	-	✓
Comfort ratio: incident light/background	-	-	✓
Comfort ratio: computer screen/background	-	-	✓
Daylight factor	Basic	Optional	-
Occupant level of satisfaction	Basic	-	✓

Looking at Table 8, we also see an opportunity for the improvement of acoustic evaluation. A first approach could come from gathering data of the physical space.

Table 8: Acoustic evaluation

Description	ASHRAE	iiSBE	EcoSmart
Physical space description	Basic	-	✓
Acoustic properties of flooring and wall coverings	Basic	-	-
A-weighted sound pressure level	Basic	Required	-
Occupant satisfaction	Basic	Required	✓
Background noise	Intermediate	Required	✓
Reverberation time	Intermediate	-	✓
Speech privacy	Advanced	-	✓
Speech communication	Advanced	-	✓
Sound isolation	Advanced	-	✓

As a general observation, additional differences between the compared protocols are the frequency and methods used to collect the performance data. Frequency and methods have a strong impact on the precision and quality of the evaluation, as well as the final cost. This aspect has been mostly left outside the scope of this paper, but the presented protocols are good sources of additional information.

4 Conclusions

Three different protocols have been reviewed and compared to iiSBE's Level I Protocol. The selected protocols share objectives and/or areas of interest with the upcoming Level II Protocol. This makes them valuable sources of information for the consideration of new metrics and indicators that could be adopted. Ultimately, the decision is an economical one, as expanding the collected data comes with a higher implementation cost. A detailed benefit-cost analysis should follow. Besides the presented indicators, there are additional opportunities for improving and differentiating iiSBE's Level II Protocol, including capturing data to describe a building's envelope.

When collecting occupant satisfaction data, and in general when using surveys for BPE, employing tested surveys is recommended. Developing and introducing surveys without sufficient development and testing can lead to erroneous conclusions.

Care is advised when using EUI as a performance indicator, as it alone does not provide a complete picture of energy performance, and is instead better understood and interpreted by keeping occupancy, operation hours, and energy intensive spaces in mind. Additionally, iiSBE's approach to gather sub-metered energy use can be further broken down as proposed by table 3-1 of the ASHRAE Protocol.

Finally, gathering data related to the operational cost can help to advance the sustainable building agenda as a source of incentive for owners and developers.

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