

# **Broken Information Feedback Loops Prevent Good Building Energy Performance: Integrated Technological and Sociological Fixes are Needed**

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## **ABSTRACT**

Information feedback loops for building performance range from the long-term—including university education of building designers and their experiential learning from past work on a time scale of years or decades; to the short term—including building occupants seeking to manage their environment with operable windows and thermostats, to building controls themselves on a time scale of seconds or minutes. In between are owners seeking to make informed renovation and retrofit decisions on a time scale of years, and operators looking for ongoing commissioning opportunities on a time scale of hours to months.

Unfortunately all of these feedback loops are often broken, with meaningful convenient performance information typically unavailable for decision-making. Even automatic building controls often fail to perform as expected because of erroneous or missing data from sensors. We examine the current typical disconnects for each of the feedback loops, their interactions, and potential solutions.

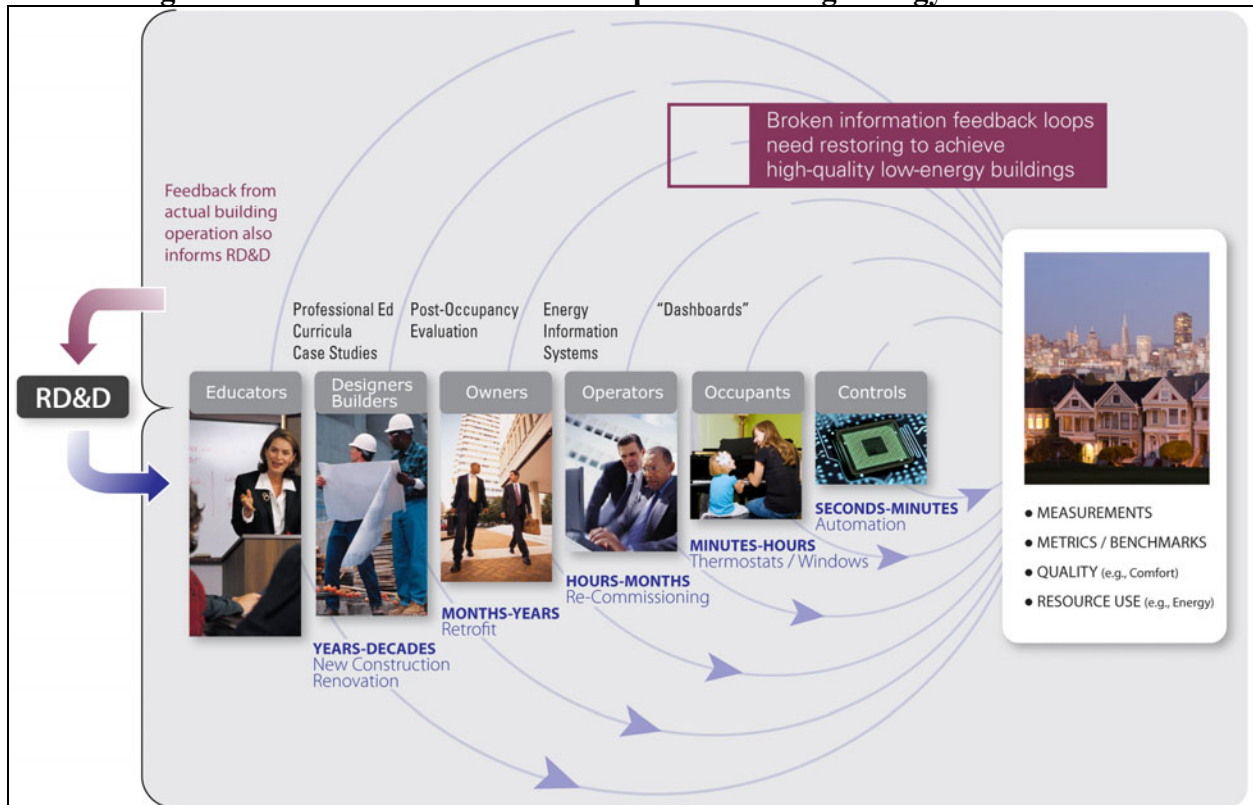
Both improved technology and organizational change are needed to fully establish all the feedback loops for building performance, achieving the twin goals of building quality (e.g., comfort) and reduced resource use (e.g., energy). Currently research sometimes provides an intervention to temporarily close one or more of the feedback loops. However, closing of information feedback loops is often inhibited by perceptions of professional or business risk. Achieving the vision of ubiquitous deep efficiency for buildings will require research, development and demonstration integrating both technological and sociological issues to durably establish feedback at all time scales in building design and operation.

## **Introduction**

There are multiple expanding sources of information about building performance available from building automation systems (i.e., controls) and building energy information systems, as well as from the experience of all the actors in the social network of buildings: occupants, operators, owners, designers/builders, educators, and scientists. There are also multiple opportunities for the social network of buildings to use that information to improve building performance for the benefit of all the participants, as well as to protect our climate and other aspects of our environment from the impact of buildings.

Unfortunately, the vast majority of building performance is disappointing and new construction generally continues to fall short of the performance that some, building scientists in particular, might hope for (NBI 2007). Most of the opportunities to use available building performance information as feedback may be missed. The potential feedback loops for building performance information are illustrated in Figure 1.

**Figure 1: Information Feedback Loops for Building Energy Performance**



Source: University of California—California Institute for Energy and Environment

Figure 1 is simplified to only include the self-use loops for each of the social groups, plus the “automated” loop for building controls. Clearly there are additional potential loops interconnecting the social groups with each other and with the building controls. These intertwining loops may be at least as important as the illustrated self-use loops toward potential improvements in building performance, as well as being the most dysfunctional.

The simplified set of feedback loops is organized according to the rough time scale for each of the social groups and the automated controls. Automated controls generally operate on the shortest time scale of seconds to minutes, while educators generally operate on the longest time scale of decades. Building scientists involved in research development and demonstration (RD&D) activities can operate on a range of time scales. RD&D makes use of performance information generated by the building controls and the social network, as well as providing pilot scale interventions that may from time-to-time close loops in a local network.

This paper briefly reviews the general state of function or dysfunction for the feedback loops connecting the social groups and the building itself. Some of the RD&D and other pilot scale interventions that have been attempted are described along with some discussion of the results including persistence or lack thereof. Key decision points needing decision support from information feedback loops are identified for each social network group. The role of potential sociological complements to technological fixes is explored.

# The Current State of Building Performance Feedback Loops

## Controls and Metering

Automated controls intended to maintain indoor environmental quality are arguably the most functional of the feedback loops for building energy performance. Feedback control is the explicit intent of automated temperature control. Daylight harvesting controls also incorporate a classic feedback loop. These controls sometimes work as intended.

However, individual control of offices is the exception, with a common scenario being several offices controlled based on temperature feedback from a single thermostat. There are often no dead bands or seasonal resets in temperature control systems. The tight control increases simultaneous heating and cooling and wastes energy. Broken or mis-calibrated sensors, broken actuators, and mistakes in programming are additional sources of dysfunction in building automation. These problems are commonplace because systems are often inadequately commissioned, and remain undetected because control systems rarely make graphical display of time-series performance data accessible to building operators for review.

## Occupants

Existing feedback about occupant comfort indicates that many people are uncomfortable, often overcooled (Mendel and Mirer 2009). Automated controls are not well integrated with occupant feedback mechanisms. Occupants are often not given control in form of thermostat input or operable windows, while dress codes often give occupants feedback out of sync with building performance aspirations. Systems that can provide individualized heating or cooling to occupants are not yet common, with the present examples not well integrated with ambient building systems and often wasteful (e.g., individual space heaters).

If more occupant control is provided in the form of occupant control of ambient conditions or more discretion in dress, occupants will need information about how these decisions impact building operations.

**Occupant interactions with the other parts of the building network.** Occupant interface with automatic controls or building energy monitoring is often lacking. Building energy dashboards are still a nascent development. Occupant opportunities to provide feedback are often in the crude form of hot and cold “calls” for building maintenance, with more sophisticated means such as survey tools still not common (see subsequent sections for more discussion of owner/tenant manager use of occupant survey tools).

Occupants may get feedback from operators regarding use of space heaters or operable windows. This may need more energy performance information context to be effective.

## Operators

Until recently, operators and the supporting building engineering, commissioning, and maintenance industry have not had access to good timely building performance information. Building automation systems have emphasized monitoring for automatic control, as opposed to monitoring as feedback for better assessing building performance metrics and improving building performance.

**Operator interaction with other parts of the building network.** Operators are generally not getting, or not assimilating comprehensive feedback from building occupants. Feedback is often limited to hot and cold “calls” that prompt a reactive approach to controls adjustment as opposed to an approach that integrates energy management and provision of indoor environmental quality. This feedback may be treated as numerous isolated events, as opposed to systematic analysis of patterns that could lead to diagnosis of more profound issues with building operation. Operators may be inhibited about obtaining more comprehensive information because of their, or the owner’s perception of risk (see subsequent section on owner/tenant manager decisions on the use of occupant survey tools).

## **Owners**

Building owners are not typically using energy performance information to make key decisions related to their valuable investments. Until recently building energy performance information has not been available as a part of the valuation of a building or of leasable space at the time of sales or leasing decisions.

**Owner interactions with other parts of the building network.** The typical design process does not include good communication between owners and designers/builders on goals for energy efficiency. Owners may expect a U.S. Green Building Council Leadership in Energy and Environmental Design (LEED™) rating to guarantee great energy performance for the building, with designer/builders perhaps not communicating to them that a LEED™ rating may not have emphasized energy credits and that LEED™ energy credits only cover a part of the overall building energy performance (Brown et al 2010, Diamond et al 2006, New Buildings Institute 2008). Energy performance or indoor environmental quality is often pushed to the background in interactions with building operators regarding maintenance decisions.

Owners or tenant managers may be avoiding communication with occupants as well. Although survey tools are commonly used in business, surveys about building operation and indoor environmental quality have traditionally been very rare. Some have suggested that use of available survey tools is inhibited by owner’s perception of risk of distracting workers, risk of surfacing disproportionately negative information, and risk of negative information impacting leasing opportunities (Homburg and Furst 2007). Ironically, such avoidance of feedback may actually be incurring larger risks of lost productivity

## **Designers/Builders**

Some leading designer/builder practitioners are providing exemplary deep efficiency building designs to “early adopter” owners. However, these projects represent only a small fraction of new construction and major renovation projects (New Buildings Institute 2007). Feedback available to designers and builders commonly includes identification of functional or aesthetic deficiencies for contract-mandated remediation. However, poor energy performance is not typically a deficiency for which recompense is available. Post-occupancy evaluation is rare, with building designers, especially mechanical engineers getting no real feedback on the success of their designs in lowering energy use.

**Designer/Builder interactions with other parts of the building network.** Circumstances in the real-world design environment that inhibit or encourage energy-efficient or comfort-enhancing design are not systematically communicated back to architecture and engineering educators, and so curriculum materials tend to be idealized. Once in practice, graduates may be unprepared for the challenges of putting their learned skills to the most effective use.

## **Educators**

Owners lament a shortage of professionals with the education and training necessary to do deep efficiency designs, and professionals lament the lack of associated emphasis in their educational opportunities. This indicates feedback about the need for or the potential to implement deep efficiency designs is not getting from the field back into curriculum development.

## **Research and Pilot-Scale Interventions**

### **Monitoring and Operators—Monitoring-Based Commissioning**

The complete range of research and pilot-scale initiatives for building controls and monitoring is beyond the scope of this paper. One interesting intervention is the paradigm shift of monitoring-based commissioning, a form of building retro-commissioning. While monitoring-based commissioning is making inroads in closing key feedback loops integrating building operators with controls and metering, it is notable that some of the key barriers to more rapid expansion of retro-commissioning include cultural inertia in both the commissioning industry (agents of building operators) and energy efficiency incentive program design.

Commissioning agents traditionally prefer modeling to measurement in doing savings accounting for retro-commissioning, ignoring an opportunity to set-up a long-term feedback loop for building energy performance. Energy-efficiency program designers prefer “snapshots” of savings accounting to meet their short-term program administration needs, leaving the long-term feedback that might be available from ongoing accounting of savings “on the table” (Meiman, Brown, and Anderson 2012). Some of this tendency is cost-driven, but by avoiding long-term monitoring costs they risk missing savings opportunities of larger value.

### **Occupants, Operators, and Owners—Indoor Environmental Quality Surveys**

The Occupant Indoor Environmental Quality (IEQ) Survey™, developed by the University of California (UC) Berkeley’s Center for the Built Environment (CBE), is a research-based intervention closing one key feedback loop on a pilot scale (UCB 2012a). Use of such survey tools is now encouraged by the LEED™ rating system through the new construction indoor environmental quality credit for thermal comfort verification.

However, the market penetration of this information tool may currently be limited by owner perceptions of risk (Homburg and Furst 2007). First, owners may perceive a risk of diminishing productivity by distracting workers. Owners may also perceive a risk that negative information may be disproportionately provided by occupants. The substantial CBE survey database of occupant responses suggests the opposite. The mean votes for indoor environmental quality categories are consistently on the satisfied side of the scale and the overall building

satisfaction scores exceed the mean of the categories. The consistency of scoring among buildings suggests that people share their perceptions of building quality directly. Also, because there is virtually no correlation between the survey response rate in a building and the respondent's satisfaction scores in that building, it is unlikely that the benchmark data set reflects the responses of dissatisfied occupants. Recent case studies suggest that data and tools like the CBE survey have provided the needed evidence to support operators' suggestions about changes to the building that were controversial/organizationally difficult. (Goins and Moezzi, 2012).

### **Owners, Operators, and Occupants—Incentives for Reducing Energy Use**

As part of recent campus reorganization, UC Berkeley has initiated an incentive program for academic departmental units to reduce energy use in the buildings they occupy (UC Berkeley 2012b). While self-funded auxiliary units such as housing, dining, and parking have traditionally been recharged for energy; the campus has previously centrally funded energy use by academic units supported by state, tuition, and research sponsors. Energy has essentially been “free” for these campus units.

Modeled partly on experience at Stanford University (Stanford University 2012), the new incentive program will reward academic units with funds and maintenance credits for reducing electricity use below baselines. In unusual circumstances the units can be recharged for excess energy use. An energy outreach campaign will accompany the incentive program. Feedback will be provided through a public energy dashboard for campus buildings, displaying real time electricity consumption information and facilitating benchmarking. (UC Berkeley 2012c). The robust monitoring environment on UC campuses has also led to faculty/student-organized dashboards with additional capabilities (UC Berkeley 2012d, UC San Diego 2012).

During the initiative's design phase, the design team debated the level of influence that occupants or department staff had on building energy use. Some perceived that these groups could influence only a small fraction of energy use when acting alone. However, others observed that these groups could influence a large fraction of building energy use when acting in concert with other building social groups such as building operators and other campus facilities staff.

### **Owners—Disclosure of Building Benchmark Information**

Many of the key decision points for owners in achieving good building performance surround the purchase or construction of a new building. Information about the potential performance of the prospective building has been had to come by in either scenario. There are some promising interventions to close this feedback loop.

One promising beyond-pilot scale development for building owners is the new California law (Assembly Bill 1103) requiring benchmarking of building energy performance at the time of major transactions for the building such as sale or leasing. This intervention may be becoming mainstream quickly in other venues (Institute for Market Transformation 2010).

The implementation of the California law is including working groups to enable the utility provision of billing information in a suitable manner for benchmarking, as well as marketing, education, and outreach including promotional efforts by customer trade groups for customers. Part of these efforts are to overcome perceptions within utilities that energy information in itself has no value worthy of the investment in organizing the energy use data into usable information. The perception that “...it can be a challenge to justify the costs associated

with a robust benchmarking program because they cannot contribute directly to energy savings goals” (Barr et al 2010) is in contrast to the business maxim that “You cannot manage what you cannot measure.” Also, some effort was required to help customers recognize that “...instead of a regulatory burden, AB1103 can be viewed as a unique marketing opportunity...” (Barr et al 2010). These observations indicate that overcoming negative perceptions of what some would identify as a useful business tool is partly a sociological exercise.

### **Owners and Designer/Builders—Selection of the A&E Team**

An energy efficiency expert was involved in the selection of Architect & Engineer team members for the first buildings of the new UC Merced campus. Inclusion of energy efficiency expertise in the selection process enables communication of credible information about team candidate’s experience to owners. This led to success in meeting energy performance targets for the first buildings as documented by measured performance cases studies (Elliot & Brown 2010). The selection process was documented in a highly rated conference presentation (Brown, Diamond, and Hughes 2005) and developed into a seminar for capital projects managers on several UC and California State University campuses. However, energy performance remains a limited part of team selection, with strong cultural barriers preventing more widespread use.

### **Owners and Designer/Builders— Energy Performance Goal Setting**

Benchmark-based energy performance goal setting is employed in the design process for the new UC Merced campus (Brown et al 2010). Actual measured performance information about the energy use of similar existing campus facilities allows the establishment of comprehensive energy performance targets at the whole-building level, including all end-uses. This feedback intervention led to great success with measured energy performance of the first buildings coming-in below targets, giving the campus confidence to follow-through on the plan for progressively more stringent targets, and leading to a new campus goal of zero-net energy by 2020 (Elliott and Brown 2010).

The benchmark-based goal setting has endured in UC Merced campus practice, with another similar initiative—the zero Energy Performance Index (zEPI™) advocated by credible experts (Eley 2009). There is clear understanding and documentation of the current limitations to prediction of new building performance through modeling associated with regulatory compliance or current rating schemes (Diamond et al 2006, NBI 2008). However, there have been only nascent attempts by other campuses to adopt the promising benchmark-based goal setting methods. One barrier is a perception of risk by designer/builders that they are creating expectations about the performance of end-uses not directly under their control (e.g., plug loads). This can be a real risk, but managing this risk by communicating effectively with owners about all energy end-uses may lead to the best overall result.

### **Designer/Builders and Owners—Sizing of Heating, Ventilation and Air-Conditioning (HVAC) Equipment**

Another research intervention was introduced to designers and owners in the design process for the first buildings of the new UC Merced campus—a method for providing feedback from previous UC experience to designer/builder decisions for the design of the campus plant.

More recently called the “most likely maximum” method for sizing of HVAC equipment, this intervention was successful in improving energy efficiency and lowering capital costs of the chiller and thermal energy storage plant, with an indirect effect on the ability to pay for more efficiency in other parts of the design (Brown 2003, Brown 2010). The intervention was unsuccessful with the central boiler plant, and not able to prevent excessive over sizing of the original plant. There was a costly follow-on project to install a smaller boiler and there is ongoing costly maintenance of the original boilers.

Despite the clear impacts of using or not using the feedback intervention, the method has not found its way into more mainstream use. Mechanical designers perception of risk may be a barrier. Risks of under sizing are more obvious to the designer/builder than risks of over sizing. Mechanical designers may be reluctant to illuminate the costs of over sizing by communicating with the owner in this way. Again, strong cultural barriers, in this case in the in the mechanical design industry, are preventing more widespread use of an information feedback tool.

### **Educators and Designer/Builders—Curriculum Development**

The “Vital Signs” Curriculum Materials Project at UC Berkeley was a pilot scale intervention providing feedback from assessment of actual building operation to the education of future architects. The project website (UC Berkeley 2012b) is old but still largely functional showing the wide variety of curriculum innovations created by this project, many of which are still used in architectural and building science education. Vital Signs student activities always involved the formation and testing of hypotheses about building performance, which lead to deeper understanding of physical phenomena. Testing was assisted by an instrumentation library that lent out instrument sets to participating architecture schools. SBSE held numerous workshops and retreats for faculty. These events continue today in the Society for Building Science Educators annual retreats.

During the Vital Signs project, the Pacific Gas and Electric Company’s Pacific Energy Center (PEC) was also getting started in San Francisco. Its focus is on training and assisting architecture/engineering/contracting professionals on building energy use. There was a lot of synergy between the programs, and the continuing PEC programs have a lot of similarities to Vital Signs, especially in the tool lending library, model laboratory, and workshops (numbering 200 a year). The PEC-developed Universal Translator software allows access to trend data from typical building automation systems—a key feature for learning building performance. Professional and research students have performed case studies using this tool.

The legacy of the Vital Signs project continues today in a utility energy center venue, but did not endure in its original university architecture department because of lack of funding for ongoing data-collection activities to maintain the freshness and relevance of case studies. The emergence of ubiquitous monitoring and trending of building energy performance information could lower the cost of maintaining feedback-based curricula like Vital Signs in the university environment. A robust closing of this feedback loop will depend on a critical mass of the emerging building performance data becoming publicly available. Some public sector organizations are making this information public, often in the form of energy dashboards (UC Berkeley 2012c, UC San Diego 2012). However, many organizations may be reluctant to disclose building performance information because of perceived risks ranging from



safety/security, to valuation of property, to competitive advantage. Cultural inertia in the design professions and in the architectural educational environment may also be a barrier to closing critical feedback loops for building performance.

## The Path to Closure of Building Performance Information Feedback Loops

Research interventions to close feedback loops for building performance, while often successful in prototype or pilot implementations, have usually not found their way into the mainstream or had a significant impact in solving the problem of chronic building dysfunction. A first step in identifying a path toward more enduring integrated and comprehensive solutions is a mapping of building social groups, critical decisions made by each group, other groups for which interface is need for good decisions, information needs, and barriers. The partial mapping in Table 1 illustrates interconnections and the importance of communication between building social groups surrounding decisions for building performance. Risk aversion appears as a frequent barrier to the adoption of new information. Cultural inertia is sometimes present.

**Table 1: Decisions Needing Good Information from Building Performance Feedback Loops**

Building Social Group	Decision Scenarios	Desirable Communication Interfaces	Barriers	Information Needed
Occupants	Using operable windows	Operators Monitoring	Perceived risk of wasting energy	Desirable timing
	Adjusting temperature set points	Operators Monitoring	Perceived risk of wasting energy	Impact on energy footprint
	Choosing seasonally appropriate clothing	Operators Owners/Managers	Dress codes	Interrelationship between clothing and comfort
Operators	Setup and tuning of controls	Occupants, Designer/Builders Monitoring	Lack of trend logging in control systems	Design intent Energy performance
	Adjustments for changes-in-use of building	Owners Designer/Builders		Performance expectations Achievable scenarios As-built information
	Building operations	Occupants Owners	Industry norms	Energy performance information
	Using occupant surveys	Occupants Owners	Perceived risks to owners (or managers)	Accurate comprehensive information on comfort
Owners	Selection of designer/builder team	Operators Occupants Benchmarks	Perceived risk to competitive advantage	Relative importance of expertise: energy, IEQ, other
	Setting of performance goals	Occupants Operators Benchmarks	Perception of risk of raised expectations	Maintainability Environmental footprint Economic criteria
	Value-engineering	Designer/Builders Monitoring	Cultural under-valuing of energy or IEQ	Marginal first costs Cost benchmarks
Designers/ Builders	Sizing of HVAC equipment	Owners	Perceived risk of under sizing (cultural barrier)	Risk of over sizing (e.g., energy waste & first cost)
	HVAC system and controls selection and configuration	Operators Occupants Owners		Relative energy & comfort performance
	Building orientation, façade and fenestration design	Owners		Relative importance of: solar control, views, aesthetics, energy use
Educators	Curriculum design	Designer/Builders	Cultural inertia	Design industry needs
		Monitoring Owners	Perceived risks of disclosure of energy performance information	Publicly available energy performance information

## **Conclusions and Recommendations**

Decision-makers lack crucial building performance information when making decisions affecting building energy efficiency and indoor environmental quality. Feedback loops that might provide this information are broken. Research interventions to close the feedback loops sometimes enjoy transient success, but often run up against strong cultural barriers against using certain types of information or communicating with other groups in the building social network.

A need for communication with other groups in the building social network often appears as a key success factor for building decision makers. Communication tools that help these groups share information about building performance could improve decision-making.

Perception of risk associated with using new information about building performance shows up consistently as a key barrier. Distinguishing real risks from unfounded fears, mitigating risks, and balancing risks against avoided cost or benefits are key steps in closing performance building performance feedback loops.

### **The Important Role of the Social Sciences in Closing Information Feedback Loops for Building Performance**

There is increasing investment in information technology to improve building performance. Advancement in information technology is spilling-over to benefit the buildings sector with easier access and lower cost for information. Some information feedback loops will eventually close with just easing of access or costs, but many may remain broken because of communication, risk perception or cultural inertia barriers.

Barriers associated with inhibited communication between building social groups, risk aversion, or cultural barriers lend themselves to social science –based solutions. Investment in social science research into these barriers should accompany investment in the “technology” in order to capture the full benefits of the technology. Research or pilot scale interventions aimed at closing building information feedback loops should include sociological components to provide integrated comprehensive solutions that optimize how people use information technology.

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