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# Brick : Metadata schema for portable smart building applications

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## HIGHLIGHTS

- Deployment of building energy applications is inhibited by heterogeneity of metadata.
- Brick introduces semantic model to comprehensively describe building infrastructure.
- Schema development based on six commercial buildings, eight energy applications.
- Brick uses standard RDF and SPARQL tools to support machine readability and querying.
- Brick is an opensource and its ecosystem for actual adoption is presented.

## ARTICLE INFO

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## ABSTRACT

Buildings account for 32% of the energy use worldwide. A new regime of exciting new “applications” that span a distributed fabric of sensors, actuators and humans have emerged to improve building energy efficiency and operations management. These applications leverage the technological advances in embedded sensing, processing, networking and methods by which they can be coupled with supervisory control and data acquisition systems deployed in modern buildings and with users on mobile wireless platforms. There are, however, several technical challenges before such a vision of smart building applications and cyber-physical systems can be realized. The sensory data from and to the distributed systems end-points need significant curation before it can be used meaningfully. This is largely a manual, cost-prohibitive task and hence such solutions rarely experience widespread adoption due to the lack of a common descriptive schema.

Recent attempts have sought to address this through data standards and metadata schemata but fall short in capturing the richness of relationships required by applications. This paper describes *Brick* , a uniform metadata schema for representing buildings that builds upon recent advances in the area. Our schema defines a concrete ontology for sensors, subsystems and relationships among them, which enables portable applications. We demonstrate the completeness and effectiveness of Brick by using it to represent the entire vendor-specific sensor metadata of six diverse buildings across different campuses, comprising 17,700 data points, and running eight unmodified energy efficiency applications on these buildings.

## 1. Introduction

Buildings account for 32% of the energy and 51% of the electricity demand worldwide as of 2010 [1]. Improving the energy efficiency of buildings can reduce energy demand by up to 90%, will help reduce operational cost, curb carbon emissions, improve indoor air quality, and keep occupants healthy and productive [1]. Driven by the availability of inexpensive embedded sensing and networking devices, modern buildings are being integrated with a variety of networked sensors and equipment for centralized operation and management.

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Technological innovations in what is now called the “Internet of Things” (IoT) have led to connected lights, power meters, occupancy sensors and electrical appliances that are capable of interfacing with the underlying SCADA (supervisory control and data acquisition) systems used in building automation. These technological improvements hold the promise of significant advances in energy efficient operations [1–3]. For example, research shows that up to 40% of HVAC energy use can be reduced by mitigating faults in these systems [4] and there are hundreds of Automated Fault Detection and Diagnosis (AFDD) algorithms available in the literature that could be used to identify these faults [5]. As of 2012, 14% of the commercial buildings in the U.S. had deployed Building Management Systems (BMS) to manage data collection and remote actuation of the connected building infrastructure [6]. Newer buildings are equipped with BMS by design, and many older buildings are being retrofitted with networked systems for improved efficiency. Furthermore, integration with the Internet presents an exciting possibility for value-creation through a network of buildings that can actively participate in smart grids. Leveraging these technologies a number of innovative software applications have emerged that pose to transform building energy dynamics such as model predictive control [7], automated demand response [8], occupancy based control [9], energy apportionment [10], fault diagnosis [11], participatory feedback [12], and architectural design iterations [13].

These emerging applications present an excellent opportunity for creating an “app store” like those available for smartphones to provide new capabilities to building operators and occupants alike. In this scenario, an energy solution can be deployed across multitude of buildings that support the requisite infrastructure with minimal configuration. Yet, this vision is far from realization - most deployments require significant investments and building specific domain expertise. Even the most modern BMS present a cacophony of data and information flows that vary by buildings, vendors and across locations. Unlike the mobile phone landscape, there is no standardized operating system or hardware abstraction layer for building applications.

The lack of a common data representation prevents interoperability between buildings and limits deployment of energy applications as developers need to map the heterogeneous data of each building to a common format. This problem has been recognized for a while now. NIST in 2004 estimated that the U.S. building industry lost $15.8 billion annually due to lack of interoperability standards [14]. Attempts have been made to address this problem. Building Information Models (BIM) [15] were introduced to address the interoperability concerns both for the design and operation of buildings. Schemata such as the Industry Foundation Classes (IFC) [16], and more recently the Green Building XML (gbXML) [17], are useful but they remain largely oriented towards design and construction efforts. As a consequence, only limited support is provided for BMS operations, energy management and data analysis. More recently, several other schemata (e.g. Project Haystack [18], SAREF [19]) have emerged to highlight the importance and use of building operations *metadata*, i.e., the information that captures the properties of different equipment, sensors and controls used in buildings. Brick builds upon these efforts to devise a practical schema that demonstrates use of several energy applications in a number of buildings across the U.S. and Europe.

The technical challenge here is to design a schema that can, at the very least, capture the information that the building engineers and facilities managers chose to put into real-life deployments across a diverse set of buildings. The schema needs to be expressive enough to capture the contextual information for building subsystems, the sensors installed and the data they generate so that canonical energy applications such as fault detection/diagnosis [20] and demand response [21] can be easily developed and deployed. Recent work has shown that the existing schemata fall short in capturing the important relationships and concepts necessary for applications for even one real building BMS [22].

Designing a comprehensive schema for the emerging IoT universe in order to run *any* conceivable application in *any* context is a difficult task but unnecessary for the current scope of creating a usable platform spanning commercial buildings. Therefore, we focus on creating an information exchange platform focused on commercial buildings where interactions among devices and building spaces are core to sophisticated applications. In developing such a platform, we are guided by the sensors, attributes and relationships that have been shown to be useful in the published literature with a view towards composability and extensibility. In designing Brick, we ask the following important questions and seek answers with demonstrated effectiveness:

- **Completeness:** Can Brick represent all the metadata information (such as a sensor's location, type, etc.) contained in a building's BMS?
- **Expressiveness:** Can Brick capture all important relationships between building entities that are (a) explicitly or implicitly mentioned in a building's BMS, and (b) expressed in canonical energy applications in published academic literature?
- **Usability:** Can Brick represent the information in a way that is easy to use for both the domain expert and the application developer unambiguously? Can the schema support automation with machine readable data formats and querying tools? Can it be extended for new concepts in a unified way?

Due to the highly diverse and changing nature of buildings across the world, these questions can only be answered with a representative sample of current buildings, and it is important for our schema to remain extensible and open in order to accommodate the evolving BMS landscape. Thus, our design of Brick is grounded by the information from BMS across six buildings spread across two continents, comprising more than 630,000 sq-ft of floor space. The information in a BMS is characterized by *data points* that correspond to values reported by sensors, configuration parameters such as a temperature setpoint and status of equipment. Brick design is based on more than 17,700 data points supplied by BMS from six different vendors, and have vastly varying subsystems and sensors. We further refine our design requirements using eight canonical energy applications that require integrated information across commonly isolated building subsystems: air conditioning, heating, lighting, spatial and power infrastructure.

We demonstrate that 98% of BMS data points across our six buildings can be mapped to Brick, and our eight applications can easily query the mapped building instances for required information. We open source the Brick schema files, the BMS metadata from our buildings, the application queries that run on top of Brick and tutorials on how to map existing building metadata to Brick. Brick schema and documentation can be found at http://brickschema.org/.

This paper is based on our earlier work [23] where we presented the initial version of the Brick schema and how it modeled building equipment, locations, sensors and the relationship between them. This paper extends the work by presenting methodologies actually needed for deploying such metadata schema in real systems. First, we show methodologies to instantiate Brick in large scale by exploiting existing information sources including raw point names in building management systems and other schemata as Project Haystack and IFC to ease the adoption of Brick. Second, we propose an architecture for the integration of Brick with actual building operating systems as well as two concrete open-source implementations, XBOS [24] and BuildingDepot 3.0 [25]. Third, We validate the extensibility of our model by our community contribution model and the integrations with other schemata for diverse aspects beyond Brick 's original coverage.

## 2. Background

### 2.1. Building applications and energy efficiency

U.S. Department of Energy reports that the commercial sector,