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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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ABSTRACT

The Building Energy Standards Modeler project is an effort to identify and develop technical solutions for creating a revolutionary building energy efficiency standards development platform.The primary objective of this platform is the re-expression of the California Title 24 Building Energy Efficiency Standards (the Standards) in a Digitally Competent Information Space which is accessible and can be unambiguously interpreted by both humans and computers. This tool, when complete, will revolutionize the creation, validation, maintenance and use of the Standards. Currently, the Standards are created and maintained in natural language, i.e. English. Moving the development to a Digitally Competent Information Space will allow computer programs to directly access, correctly interpret, and manipulate building energy efficiency standards while actually improving direct human access as well. The fully-functional software platform will provide powerful computerized support for users to rapidly locate, compare, query, modify and test the standards, in real time, as they are being developed or simply explored. Another goal of this research is to discover and prototype software solutions that will provide the greatest possible *transparency* in all Standards management processes. The term transparency here means moving operations from computer code to *declarative* locations (primarily publicly available, schema-controlled eXtended Markup Language documents). This research effort focuses heavily on the use of building energy simulation engines to assess the effects of proposed changes to the Standards. Technical approaches that were researched and prototyped include rule set language, business rules engines, database and metadata engineering and technologies founded on eXtended Markup Language Schema Definition Language , XPath, and XQuery.

Keywords: California Title 24 Building Energy Efficiency Standards, standards development software platform, business rules engines, standards data dictionary, XQuery, XPath, SharePoint

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EXECUTIVE SUMMARY

Project Description

The Building Energy Standards Modeler (BESM) project was a research and development effort to improve the content, usability and accessibility of the California Title 24 Building Energy Efficiency Standards (hereafter referred to simply as the Standards).

The goal of the BESM research was to define and prototype a group of sophisticated software modules and integrate them into a full-featured Standards Development Platform which could be used to express any building energy efficiency standards, including the California Title 24 Building Energy Efficiency Standards.

Purpose

The main purpose of the BESM project was to improve the way the Standards are created, maintained and used. Since their inception, the Standards have been created and maintained as a collection of text documents. These text documents are expressed in natural language, the same basic language used by all of us in communicating via speech or writing. Despite more than 40 years of effort, the ability of computer programs to directly utilize the content of such natural language documents remains inadequate for a large body of complex regulatory information such as the Standards. A main goal of the BESM project was to express the Standards as a Digitally Competent Information Space (DCIS).

The essential nature of a DCIS is that it is accessible and unambiguously understandable to people and also to appropriately designed computer programs. The research and prototyping efforts of the BESM project focused on identifying technical solutions that will allow standards professionals to use computers to read, correctly interpret, and manipulate the Standards.

Project Objectives

The following are the main objectives that guided the research and development efforts of the BESM team:

- Analyze the Standards in their current natural language form in order to understand the types of text-based information which constitute the Standards.
- Relate the types of Standards information to the most promising storage technologies now in use for digitally-accessible data.
- Identify ways in which the existing natural language of the Standards can be re-expressed unambiguously in a Digitally Competent Information Space. These new requirements for expression of the Standards are termed canonical forms.
- Develop a controlled vocabulary for the re-expressed Standards as a foundation for representing the building energy compliance data model.
- Design a building description schema in eXtended Markup Language (XML, a means of transferring information across the internet) to represent all information required to conduct

energy use simulations as well as to determine compliance with the Standards for a given building.

- Design and implement the following proof-of-concept prototypes:

  o Rule Set Manager for converting representative Standards rules as "points" in the digital information space that can be edited by standards professionals.

  o Building Description Manager for creating and editing specific building descriptions, expressed as XML instances within the building description XML schema.

  o Rules Engine for extracting required rule values from the digitally accessible Standards and mapping them to the correct rule targets in a building description XML document in order to perform energy use simulations and Standards compliance analysis.

  o Simulation Launcher for managing the process of performing an energy simulation using the energy simulation engine, EnergyPlus.

  o BESM platform, a web-based platform that manages all of the above described prototype software modules. This platform will allow for continuous testing as the different prototype software modules mature.

Outcomes

During the course of the BESM project, with limited exceptions, each of the objectives listed above was achieved. However, unforeseen challenges in some cases required altering approach or scaling back the scope of work. The massive scale of the Standards quickly made it clear that processing them all into a complete rule set would require resources far beyond those of the project contract. Therefore, with the guidance of the contract manager, the BESM team focused on a small footprint prototype that would provide proof of concept of all basic functions. This meant that, at the end of the project, the software would not be complete enough to warrant the end user testing and surveying task defined in the original scope of work. Another significant change was the addition of a task to develop a prototype module to replace the National Renewable Energy Laboratory's (NREL) software for performing EnergyPlus simulations. This change is explained in detail in the section below on the BESM Integration Test Platform.

BESM Data Manager and Standards Data Dictionary

The BESM Data Manager was developed on a Microsoft SharePoint™ site because SharePoint is a web-based platform with a rich set of functions to support collaborative data-centric projects. Throughout the BESM project the Data Manager underwent several major redesigns as needed to expand some areas and diminish or drop other functionality. The twin guiding objectives in this process have been to develop a controlled vocabulary that expresses building energy efficiency standards and to provide access to this controlled vocabulary in support of the 2013 Standards development efforts. The first objective has been satisfied with the development of the Standards Data Dictionary (SDD) which is represented in the BESM Data Manager SharePoint lists. The second objective was accomplished by collaborating with other standards development projects and developing additional functionality to support their unique needs.

At the time of writing the following standards development projects are using the BESM Data Manager:

- 2013 Nonresidential Alternate Compliance Method (ACM) manual development
- 2013 Nonresidential Compliance Engine Software
- 2013 Residential Compliance Document XML schema project

There are also plans for using the BESM Data Manager on a United States Department of Energy project to develop a rule set to express the American Society of Heating, Refrigeration, and Air Conditioning Engineers standard for commercial building energy use, widely known as ASHRAE Standard 90.1.

Standards Maintenance Module

The BESM team researched several different technologies for developing a software platform that would allow end users to directly create and modify the Standards as rules expressed in a Digitally Competent Information Space.

L'Monte analyzed the Standards and identified five different types of data: reference information (R-type or rule classifiers), primary standards information (S-type), equations (E-type), binding information (B-type) and exceptions.

Of the five information types identified in the Standards, L'Monte developed digitally-accessible forms for rule classifiers, primary standards and rule binding information. Rule classifiers and primary standards were expressed in relational database tables, and rule binding information was expressed in the Rules Mapper XML schema.

A digitally-accessible form for equations was identified but not demonstrated in working code. The BESM team believes that special relational database tables and a symbolic equation evaluation engine is the appropriate mechanism to store and evaluate this type of information.

The fifth type of information found in the Standards is the long lists of exceptions that accompany every section of the Standards and exempt certain building elements from being affected by specific rules. Work has been done to characterize the nature of exceptions and develop solutions to handle them, some of which work reasonably well. However, exceptions remain a significant challenge and further development is needed in order to fully express them in a digitally accessible form.

Once the types of information in the Standards were characterized, L'Monte began experimenting with several information technologies for storing, accessing and editing the Standards. The most powerful and flexible candidate was the use of relational databases augmented by metadata engineering and business rules engine technology. Applying these concepts, L'Monte prototyped a Standards rules database and developed the Standards Maintenance module, a Web-based application for editing the rules stored in the system. This small footprint prototype used rules from the Standards covering envelope fenestration.

BESM Building Description Manager, Rules Engine and XML Schemas

Building Description Manager and the Building Description XML Schema

The BESM team developed a working prototype of the Building Description Manager. This is a web-based application for selecting a building from a catalog of typical buildings, and editing it for use in compliance analysis. The first task in developing the Building Description Manager was designing and developing the BESM building description XML schema to represent the user's proposed building.

Analysis of existing building XML schemas made it clear that there were none existing that were adequate for Standards use. Nor were there any existing building XML schemas that captured all of the performance metrics and compliance data required for performing a compliance analysis on a proposed building. Using XML Schema Definition Language (XSDL), L'Monte designed an XML schema to hold both the user's proposed building and any performance metrics required for compliance analysis. The customary baseline building, typically required for a performance-based compliance analysis, can also be described using this approach. This schema-controlled building description maximizes code reuse and also supports built-in data validation. In order to use the building description XML schema in the development of other prototyping efforts such as the Simulation Launcher Module, the schema development was limited to a moderate number of cases. This limited version could represent a small footprint prototype XML schema that covered overall high level design and also captured such elements as units conversion and details on envelope fenestration.

The BESM Standards Data Dictionary continued to be developed following the original schema design but going well beyond envelope with the addition of lighting and HVAC. This was possible through the collaborative work with other projects previously mentioned. The BESM team explored the idea of using the SharePoint platform combined with XML Schema Definition Language and Excel macro functionality to generate BESM building description XML schema directly. The team then implemented this technical solution, which allows end users to develop and assess the Standards Data Dictionary terms and definitions on the user-friendly BESM Data Manager. They could then export the SDD to a spreadsheet and apply the BESM macro to automatically generate the BESM building description XML schema set. This process avoids a great deal of error-prone and tedious rework. The BESM team also developed functionality for generating portable documentation in the form of an Excel workbook that contains the entire SDD for a given project. SDD workbooks have been generated for the 2013 Nonresidential Compliance Software and the 2013 Residential Compliance Software.

Rules Mapper and Rules Engine

The rules, which are stored in relational database tables, must be mapped to the XML description of a building as the first of two steps required for a performance-based energy compliance analysis of that building. The Rules Mapper is a platform element whose function is to locate those parts of a building description which require values from the Standards database. It also determines which unique Standards relational database table contains the rule which may be used in a specific application. L'Monte designed an XML schema for the Rules Mapper and developed functionality to navigate the building description to find appropriate

applications for the rules. It also developed a Rules Engine module, which helps to assign the value for a specific rule application. L'Monte also designed a general-purpose data access layer (part of the Rules Engine module) for processing database queries. Query results are then applied to the building description for both the proposed and the standard buildings.

BESM Integration Test Platform and Simulation Launcher

The BESM platform consists of five major executable modules, each with numerous components and subcomponents. In addition, platform operations depend on a large, complex relational database which may grow to more than 1000 relational tables. Operations also depend upon a large metabase (data about the database tables) and a half-dozen XML schemas. The sheer scope of the BESM effort mandates great care in building out too far in any one direction before being certain that all data store schemas are correct and that algorithm design is adequate for executables. The BESM Integration Test Platform (ITP) is a test and control module which serves this validation requirement.

The ITP controls and validates all of the other modules. As new functionality is developed, it is placed under the control of the ITP. Each module, component and subcomponent must function correctly, not only on its own but in concert with every other executable BESM element. The BESM platform must function correctly with a very large number of separate data stores, primarily relational database tables and XML documents. This too must be validated using the ITP. As the schema for each new relational table emerges from design it must be added to the growing list of tables under control of the ITP Similarly, as new complex types are added to an XML schema, instances of the augmented schema must be tested before further development can be based upon them.

The ITP actually has a second purpose. Growth of the BESM platform proceeds, as must all modern software development of very large systems, under the guidance of a software development life cycle. A software development life cycle is a unique collection of high-level strategies for the creation, testing, deployment and maintenance of large applications. Of the dozen or so well-known and tested life cycles, L'Monte chose Evolutionary Prototyping. Evolutionary Prototyping is especially well suited to large development projects with a heavy R&D component. Under this life cycle the testing platform eventually evolves into the deliverable product. In other words, the ITP is the embryonic form of the fully-functional BESM platform.

The Simulation Launcher Module

One module that was originally to be provided by a third party was the Simulation Launcher module. The purpose of this module is to control building energy simulations using the EnergyPlus simulation engine. Originally the proposed plan was to integrate the BESM platform with software developed by the National Renewable Energy Laboratory (NREL) which provided frontend processing and simulation runs using EnergyPlus. The NREL software team provided this support in the form of a large class library called OpenStudio and indicated that this library was to be used by L'Monte in creating its own Simulation Launcher module. Unfortunately, L'Monte encountered numerous difficulties with this approach. After

an intense, 13-week effort, L'Monte concluded that integration of OpenStudio into the existing BESM platform was infeasible. The specific problems are detailed in Chapter 3 below.

L'Monte subsequently began a new Simulation Launcher development effort which proved successful. This development effort produced several component-level elements as parts of the Simulation Launcher. These included the Simulation Control Editor and the Simulation Engine Articulator. Significant advantages which followed from this development were that all components and subcomponents of L'Monte's Simulation Launcher embody the fundamental design principles underlying the BESM architecture. Most significant of these are *Modularity* and *Transparency*. These principles are also detailed in Chapter 3.

Over the course of the BESM project as prototypes were completed, they were added to the BESM Integration Test Platform, tested individually and together with the other modules. At the end of the project the BESM Integration Test Platform included the Standards Maintenance module for editing Standards, the Building Description Manager for editing a building description, viewing the building catalog and selecting a building for analysis, and the Simulation Launcher with functions for translating a BESM building description to an EnergyPlus Input Data File (IDF), performing an EnergyPlus simulation analysis, and viewing the results.

Conclusions

In the course of this project there were many research questions that were explored. The most promising technical solutions were prototyped. As the project proceeded, obstacles and scope not obvious from an initial high level view were revealed. Among these were several that had a major impact on the results of the BESM project. To begin with, the team soon realized that the magnitude of the task of re-expressing all of the Standards to create a digital information space where Standards professionals could directly edit the standard rules used in a compliance analysis, was beyond the scope of the BESM project resources, especially given the other defined tasks. The decision to limit development efforts for every major task to a small footprint prototype meant that the team could develop a proof of concept for all individual modules as well as the overall BESM platform developed itself as a small foot print prototype, the BESM Integration Test Platform. The other major change resulted from discovering that NREL's OpenStudio software for managing EnergyPlus simulation runs had been rewritten in an unmanaged version of C++. Problems related to this resulted in major time spent on efforts that were in the long run unsuccessful and caused delays in the development of other components. In hindsight, the BESM team feels that the final approach to interface directly with EnergyPlus was a better solution.

Technology Transfer Recommendations

Recommendations for the BESM Data Manager and Standards Data Dictionary

The Standards Data Dictionary developed on the BESM Data Manager SharePoint site has been adopted by several Standards development efforts and should continue to promote the use of the same controlled vocabulary throughout the Standards documentation and compliance software. It should be extended to hold all terms required to express the Standards either in required compliance reports and documents or in the official expression of rules in any

compliance software. The naming conventions and relationship requirements for generating a XML schema from any version of the SDD should be developed and shared with interested parties. Efforts should be made to establish the BESM Data Manager and Standards Data Dictionary as a national resource for developing rule sets and XML schema representing building energy efficiency standards.

The Standards, as they are currently expressed in unrestricted natural language, don't communicate logical rules that can be unambiguously interpreted by both computers and people, even if they are subject matter experts. Often when a BESM team member had a question about a table, standards professionals were unable to explain it. A project is needed to completely process the Standards into rule tables using the techniques developed by the BESM team to recast how the Standards are documented. Once input into unambiguous database tables, the Standards documentation could be generated using XML technologies currently being developed for the compliance reporting engine.

Recommendations for the BESM Integration Test Platform

The BESM Integration Test Platform is an important tool for performing energy simulations using EnergyPlus because it provides functionality that does not exist elsewhere. This functionality includes the ability to edit compliance rules, apply them to a building, translate the building into an EnergyPlus Input Data File, perform an energy simulation on it, and view the results. As such it should be extended to its full capability so that the building energy efficiency community can use it to develop better Standards.

The great bulk of the effort during the contract period was limited to first identifying and then demonstrating workable solutions for the major challenges which lie on the road to recasting the existing Standards into a computer-comprehensible form. In the process of reaching this point, the BESM Integration Test Platform provides the ability for authorized users to access, query, create and maintain a small set of Standards in their digital form and edit a few parts of a BESM building description and perform energy use simulations applying a small set of output parameters in a simulation control group.

All of the implemented solutions are viable and together form a small footprint prototype that has been proven to work, but is far from a fully functional standards development platform. The next step is to expand the prototype to complete coverage of the Standards and complete functionality required to edit all parts of a building, convert additional building descriptions into the BESM building description format, and perform more sophisticated energy analysis and view the results.

To complete standards editing functionality will involve developing means of capturing equation data and exceptions in digitally-accessible forms, implementing them, and integrating them into the BESM Standards Maintenance module and Rules Database.

Once that task is complete, the program must rapidly produce a very large volume of software. For example, the BESM team estimates the Standards Maintenance Module will require somewhere between 500 and 1000 relational database tables in order to hold all of the Standards after they have been expressed in unambiguous, machine-interpretable form. In addition each

such database table must be backed by its own Web page for editing and supporting code. The source code for just the Standards Maintenance Module could run to more than one million lines of code. This illustrates the scope of the BESM challenge. In order to manage a task of this size, the most efficient techniques of code implementation become the next effort. The identification and refinement of these techniques, specialized for each of the major BESM modules, must be successful in order to develop a user-ready platform. It will take a software team with mature, sophisticated software engineering experience to explore novel combinations of known volume implementation techniques and, where necessary, invent new ones.

The Integration Test Platform would then be extended with new relational database tables and their supporting code modules. Existing prototyped code will need to be revised to use the BESM XML building description schema generated directly from the Standards Data Dictionary. Once the BESM building description schema is complete, conversion functionality using the same design pattern as developed for the Rules Mapper and EnergyPlus Mapper should be developed.

Finally, the BESM Integration Test Platform which currently runs on a local intranet, must be modified with required security features and an installation package must be developed for deployment to a public Website. This phase will require extensive end user testing and attack testing to establish that the BESM platform on a public Website is secure.

Benefits to California

Changes to the Standards are driven by both a need to reach the goal of zero net energy (ZNE) buildings and the relentless nature of technological advance. Therefore, creation and maintenance of the Standards must be made as efficient as possible. The BESM platform is designed to greatly simplify and shorten this process. Once fully implemented the BESM platform with its web accessibility and end user functionality will provide Standards professionals, energy consultants and building designers with the power to test new energy efficiency materials, equipment and fast track them into the Standards. This will improve the final product while shortening the effort to produce a new version of the Standards.

CHAPTER 1:
BESM Data Manager, Standards Data Dictionary and Rule Set Manager

1.1 Project Approach

1.1.1 Background

For many years, the California Title 24 Building Energy Efficiency Standards have been developed and maintained using traditional text-based tools, such as word processor software. Such traditional tools make it almost impossible for a large cadre of knowledge workers to restrict themselves to the same term for a given building element or more abstract concept. Therefore, multiple and sometimes ambiguous terms, for a single concept, have crept into the published Standards. Word processing tools also do not provide the embedded intelligence required to enforce logical expression of the Standards or identify gaps in rule coverage or inconsistent use of units, decimal places or range limits. A major goal of the BESM project was to identify and prototype a standards development platform that uses more powerful software technologies to improve the accuracy, completeness and understandability of the Standards.

At the start of the BESM project, the team performed a literature search to find any existing or past efforts to define computer representations of building energy efficiency standards that would allow end users to edit the standards in a digitally competent information space. The literature search did not uncover any existing production level software solutions, however there were several research projects focused on computer representations of prescriptive standards.

Through a collaborative effort led by James Garrett, College of Engineering, Carnegie Mellon University, the team evaluated a current effort by one of his graduate students and also reviewed several papers including a paper co-authored by Garrett, which reviewed the history of efforts to develop computer representations of design standards and building codes starting in 1966. (S.J. Fenves, 1995)

Another project that the team reviewed was an ICC project, called the SMARTcodes which used a method of marking up code language to identify different parts of prescriptive rules in the 2006 International Energy Conservation Code (IECC).

All of the efforts that the team reviewed were for prescriptive standards only and the methods usually required a certain amount of programming skills which didn't satisfy another major goal of the BESM project, namely to create a system for editing the Standards in software that would not require programming skills. Although there were no solutions that could be adopted, the exercise provided context and ideas for designing a solution to the problem. Given the extensive history of efforts to solve this problem and the lack of any successful production solution, the team used an evolutionary prototyping approach to minimize risk throughout the project. In this approach all development efforts involve designing and implementing a small piece of functionality, testing and reviewing the result, identifying areas

to change, improve or remove and using this feedback, to develop the next iteration of the prototype. The evolutionary prototyping approach resulted in the modules that are robust even if they cover only a small part of the scope.

The team explored other approaches to similar problems and found the most promising technical solution was business rules engineering (Chisholm, 2004) which uses relational database and meta data engineering to create software for editing logical rules that are applied to control and constrain a process, similar to the Standards rules that constrain and control energy efficiency measures in a building. Microsoft SQL Server was selected for the database platform because of its tight integration with the L'Monte Microsoft .NET development environment.

1.1.2 Expressing the Standards in a Digital Information Space

Developing a relational database begins with developing a data dictionary to model the controlled vocabulary and structure of the database. The team began this process by holding workshops with CEC standards staff to engage them as subject matter experts in defining the terms for the controlled vocabulary, which was called the Standards Data Dictionary (SDD).

After evaluating several platforms for developing the SDD, the BESM team selected the SharePoint platform because it is a collaborative Web platform with a rich set of built-in functionality for creating and managing a data dictionary.

In addition to gathering input from subject matter experts, the team analyzed the Standards to identify the basic elements of a rule, the different types of rule data, and the requirements for expressing each type of rule data in a database.

1.1.3 Designing the Standards Maintenance Web Graphical User Interface (GUI)

A Web-based software platform was the solution the team chose for the GUI because it provides the broadest access to the Standards for editing them as well as performing all of the other functions in performing a building energy efficiency compliance analysis.

The Web GUI was designed to satisfy two major requirements: simple easy-to-use interface that allowed maximum reuse of code. This meant using the same pattern of controls across similar Web pages, for example all Web pages for editing use a dashboard for selection of objects and a set of radio buttons for different editing functions.

1.2 Project Outcomes

During the course of researching and prototyping functionality for end users to directly edit the Standard used in a compliance analysis, the greatest challenge was the fact that the Standards documents contain thousands of embedded rules. The process of extracting the rules and transforming them from unrestricted natural language to a form that could be used in software involved many players and many steps. The initial development of the Standards Data Dictionary (SDD), was interrupted several times when the team was directed to use a different source for the standards text. In each case the changes involved introducing new users to the BESM Data Manager and making changes to the existing SDD to accommodate the changes in

the new standards source. In some cases the problem was compounded by the fact that the standards source itself was also undergoing major development, making it a moving target.

As the magnitude of the task of processing all the Standards became clear, the team decided to continue work on processing the Standards but to freeze the BESM XML schemas and database tables at a certain point in order to allow prototyping of other components like the rules engine and the building description manager to proceed in parallel. This eventually resulted in implementing a small footprint prototype that provided proof of concept of all parts of the BESM platform, called the BESM Integration Test Platform which is described in detail in chapter 3.

1.2.1 Modeling Rule Tables to Represent the Standards

Early analysis of the 2008 Title 24 Standards Part 6, and later as directed by CEC, analysis of the COMNET manual resulted in the design of a rule table system for storing primary standards rules. With this design a small footprint prototype, the Standards Maintenance module with rule database and metabase tables, rules engine code and Web application was developed. Later when the 2013 Title 24 Standards were being developed, the BESM team analyzed 2013 Standards Title 24 Part 6 Sections 140.3 and 140.6 and Tables 140.3, 140.3-B, 140.3-C, 140.3-D, 140.6-A, 140.6-B, 140.6-C, 140.6-D, 140.6-E, and 140.6-G covering prescriptive standards for envelope and lighting. In processing these sections the team modeled the rules using decision tables which are the source for generating additional BESM rules database tables. Analysis of each section of the Standards was captured in an excel workbook, with overview worksheet for each table and the decision tables developed for each Standards table on subsequent worksheets. The workbook also captured interpretation and design issues as well as recommendations for changes in the Standards to improve accuracy and understandability. In each decision table the rule table elements were defined and each decision in the spreadsheet is equivalent to an atomic rule. The following section defines the structure of a rule and its parts, and the requirements for expressing them in the rules database, referred to as canonical form.

1.2.1.1 BESM Rule Table Structure and Elements

Rule Target

The purpose of each BESM rule table is to set a default, minimum, or maximum value established by the Standards for a specific building property which is called a Rule Target. An example of a Rule Target is the minimum aged solar reflectance for roofs defined in 2013 Title 24 Part 6 Section 140.3.

Rule Classifier

Object properties that must be evaluated in order to determine the default, minimum, or maximum value for a Rule Target are called Rule Classifiers. For example, the Rule Target minimum aged solar reflectance for roofs established in 2013 Title 24 Table 140.3-B is dependent on roof slope (steep or low) and climate zone. These two properties are thus Rule Classifiers in this case.

Rule

Each row (database table "record" or "tuple") in a Rule Table constitutes a single Rule whereby when the set of Rule Classifier values in that Row are compared against an input set of values from a proposed building, that Row can be evaluated as being either True or False. If True, then the Rule Target property is assigned the Rule Target value for that Row. If False, then processing continues until it finds a row in the Rule Table that matches the input set of values.

Binding Information Table Classifier

Binding information table classifier identifies a specific object property to be used as a filter to determine which BESM Rule Table should be used to establish a specific Rule Target value. Binding information table classifiers often apply at a higher level in the object hierarchy. For example the property BuildingClassificationMethod defines whether the project is using an occupancy type for the whole building only or is using different space level occupancy types for compliance. This would be applied as a binding information table classifier for rules that require either whole building or the space by space method.

1.2.1.2 Types of Rule Database Tables

Analysis of the Standards defined four types of data: reference, standards, equation and exception data. Because reference and standards data are the essential parts of a rule, the team focused their efforts on developing the reference and standards database tables.

Reference Tables

There is a reference table for every unique rule classifier which contains the acceptable values for that rule classifier. For example the reference table for the rule classifier, climate zone contains sixteen records with the climate zone number, and the city, latitude, longitude and elevation associated with that climate zone.

Primary Standards Tables

There is a primary standards table for every unique rule target. In a primary standards table there is a row for every rule or combination of rule classifiers that result in assignment of a unique value to the rule target. For example there is a primary standards table for the prescriptive solar heat gain coefficient rule target for skylights. Every row contains a different set of values for the rule classifiers that are evaluated in order to assign the prescribed default, minimum, or maximum value to the solar heat gain coefficient rule target.

1.2.1.3 Rule Table Conventions: Canonical Form

In analyzing the nature of the rules represented in the Standards, certain requirements for re-expression in relational database tables were identified which are referred to as their canonical form.

Unitarity requirement

Any rule table will hold rules for exactly one precisely defined rule target. This leads to simple logical rules that are essential when modeling a complex information space like building energy efficiency standards.

Atomicity requirement

Each row in a rule table is an atomic rule that unambiguously assigns exactly one value to the rule target.

Orthogonality requirement

Each rule classifier must be logically unique and not overlap the meaning of another rule classifier. Rule classifiers must avoid ambiguity and interdependence.

Furthermore, the set of rule classifier allowable values must be of consistent meaning and type, must not overlap (i.e., must be mutually exclusive), and must cover all possible values for that rule classifier (i.e., must be all inclusive). For example, Table 140.3-B (2013) is intended to establish maximum area-weighted U-factors for vertical fenestration of various types. Classifying values (column headings) in this section include: Fixed Window, Operable Window, Curtainwall or Storefront, and Glazed Door. Curtainwall is not defined within the Standards, but what if portions of a Curtainwall can be either Fixed or Operable? In this case there would be an ambiguous overlap in possible values. The solution is to define two separate rule classifiers: fenestration type and fenestration operability.

Similarly each rule target must be logically unique and not overlap the meaning of another rule target. To be logically unique, a rule target must have appropriate specificity, meaning that it is not so broad that it encompasses more than one set of rule classifiers.

Completeness requirement

Every allowable value for a rule target must be addressed within each rule table. This is a completeness requirement, which means that there are no cases where an allowable value is never assigned to the rule target across all rules (Rows) in a rule table. Similarly every allowable value for all rule classifiers must be addressed in each rule table.

1.2.1.4 Rule Table Conventions: Ranges and Decimal Places

All rule tables must adhere to agreed upon range conventions to avoid missing values. The proposed BESM conventions are as follows:

Ranges are expressed with the lower bound included and upper bound excluded, that is, minimum inclusive, maximum exclusive.

The round-off rule for values with higher precision than expressed in the range is: if the digit to the right of the rounding digit is 0, 1, 2, 3, or 4 do not change the rounding digit; if the digit is 5, 6, 7, 8, or 9, the rounding digit rounds up by one.

Further details about the Standards table processing effort including examples of how a specific Standards table is processed can be found in Appendix A2.

1.2.2 Issues Encountered While Processing Title 24 Standards Tables

A number of issues were encountered while processing the Title 24 Standards tables for envelope and lighting that lead to problems in interpreting and maintaining the Standards tables. This is especially true in cases where a single Standards table contains multiple rule targets with different sets of rule classifiers. The effort it takes to understand how to apply the rules in such a table is often a barrier to using them properly. Furthermore, such tables make it very difficult to ensure that all possible scenarios are covered and that there are no conflicts embedded in a table. In analyzing the Standards tables the team found use cases that were missing from the tables, such that there was no assigned target value and other use cases where there was more than one assigned value and this potentially leaves the door open to gaming the system. The only way to establish that the table is correct is to do the same type of reformulation that has been performed in the BESM project to prepare the tables for representation in a relational database. Some of the specific issues encountered in BESM reformulation to date are discussed below.

1.2.2.1 Multiple often disparate Rule Targets and Rule Classifiers in one Standards table

Multiple Rule Targets

Many tables currently contained in the Standards include more than one Rule Target, requiring separation into individual BESM rule tables. Standards Table 140.3-B on Prescriptive Envelope Criteria is a good example of this. Table 140.3-B establishes rule target values for Maximum U-factor (for individual Roofs/Ceiling, Walls, Floors/Soffits, and Exterior Doors), Maximum Area Weighted U-factor (for Vertical and Skylight Fenestration), Aged Solar Reflectance and Thermal Emittance (for Low-Sloped and Steep-Sloped Roofing Products), Maximum Area Weighted U-factor, Maximum Area Weighted RSHGC, Minimum Area Weighted VT, and Maximum WWR% (for Vertical Fenestration), and Maximum Area Weighted U-factor, Maximum Area Weighted SHGC, Minimum Area Weighted VT, and Maximum SRR% (for Skylight Fenestration), with a true/false requirement for an Air Barrier thrown in.

That is at least ten rule targets (depending on reformulation) in a single Standards table. This makes maintenance of this single table difficult as Standards change. Subdividing this table into multiple rule tables based on BESM conventions would greatly simplify this maintenance.

This disparate collection of rule targets in a single table may be acceptable for human parsers of this information, though it certainly adds difficulty with this complexity. However, reliable computable parsing of this collection would be very difficult if not impossible.

Multiple and Disparate Rule Classifiers

Table 140.3-B also contains multiple rule classifiers that are different for different rule targets. For example, Air Barrier is only dependent on Climate Zone, Maximum U-factor for Walls is dependent on Climate Zone and Construction Type, Maximum U-factor for Vertical Fenestration is dependent on Window Operation and Window Type, but not on Climate Zone,

and is an area-weighted value rather than an individual surface value as it is for Walls, and Maximum WWR% is not dependent on any rule classifier.

Again, this disparate collection within a single table increases the difficulty of human parsing and maintenance, and makes computable parsing impossible.

Incomplete and inconsistent specification of rule target and classifier values and ranges

Standards Table 140.3, shown below, is an example of incomplete and inconsistent specification of rule target and rule classifier values and ranges that violate the BESM database requirements of atomicity and completeness. These violations also potentially lead to inconsistent results even for human processing of tables.

Table 140.3: Roof/Ceiling Insulation Tradeoff for Aged Solar Reflectance

Nonresidential					
Aged Solar Reflectance	Metal Building Climate Zone 1-16 U-factor	Wood Framed and Other Climate Zone 1 &5 U-factor	Wood Framed and Other Climate Zone 2-4, 9-16 U-factor	Wood Framed and Other Climate Zone 6 U-factor	Wood Framed and Other Climate Zone 7 & 8 U-factor
0.62-0.60	0.061	0.045	0.036	0.065	0.059
0.59-0.55	0.054	0.041	0.034	0.058	0.053
0.54-0.50	0.049	0.038	0.032	0.052	0.048
0.49-0.45	0.047	0.035	0.030	0.047	0.044
0.44-0.40	0.043	0.033	0.028	0.043	0.040
0.39-0.35	0.039	0.031	0.027	0.039	0.037
0.34-0.30	0.035	0.029	0.025	0.037	0.035
0.29-0.25	0.033	0.027	0.024	0.034	0.032

Source: Proposed 2013 Building Energy Efficiency Standards Title 24, Part 6

The U-factor values listed in each column in Table 140.3 imply ranges for each row, but are instead listed as a single value in each row. Conversely, each row in the table contains a specified range for Aged Solar Reflectance even though the Standards text that references this table implies that each row is really establishing a minimum allowable value exception.

For example, for a Nonresidential building type with a Metal Building roof construction type in all Climate Zones, the first row in Table 140.3 indicates that if the Roof U-factor does not exceed 0.061 (with units of measure not specified), then the allowable Aged Solar Reflectance is 0.62-0.60. But why specify a range of 0.62-0.60? Doesn't this row simply establish a new minimum allowable Aged Solar Reflectance of 0.60 if the Roof U-factor does not exceed 0.061?

Similarly looking at the second row in this table, doesn't this row simply establish a new minimum allowable Aged Solar Reflectance of 0.55 if the Roof U-factor does not exceed 0.054?

Now, what happens for the case with a Roof U-factor of 0.059? A reviewer of this table could reason that since 0.059 exceeds the 0.054 value in the second row, but does not exceed the 0.061 value in the first row, that the first row applies to this case. But to make this table computable, the applicable U-factor range must be specified for each row.

So in this table, the U-factor Rule Classifier should be expressed as a range in each row, and the Aged Solar Reflectance Rule Target should be expressed as a single value in each row.

Furthermore, each range must adhere to known conventions for interpreting the lower and upper bounds and rounding off values with greater precision than shown in the table.

Lastly, cases with a Roof U-factor greater than 0.061 are not handled by Table 140.3, which is a violation of the completeness requirement.

Each of these issues has been addressed in the following reformulation into BESM rule tables.

Table 140.3: Roof/Ceiling Insulation Tradeoff for Aged Solar Reflectance

Nonresidential					
Aged Solar Reflectance	Metal Building Climate Zone 1-16 U-factor	Wood Framed and Other Climate Zone 1 &5 U-factor	Wood Framed and Other Climate Zone 2-4, 9-16 U-factor	Wood Framed and Other Climate Zone 6 U-factor	Wood Framed and Other Climate Zone 7 & 8 U-factor
0.62-0.60	0.061	0.045	0.036	0.065	0.059
0.59-0.55	0.054	0.041	0.034	0.058	0.053
0.54-0.50	0.049	0.038	0.032	0.052	0.048
0.49-0.45	0.047	0.035	0.030	0.047	0.044
0.44-0.40	0.043	0.033	0.028	0.043	0.040
0.39-0.35	0.039	0.031	0.027	0.039	0.037
0.34-0.30	0.035	0.029	0.025	0.037	0.035
0.29-0.25	0.033	0.027	0.024	0.034	0.032

Source: Proposed 2013 Building Energy Efficiency Standards Title 24, Part 6

The U-factor values listed in each column in Table 140.3 imply ranges for each row, but are instead listed as a single value in each row. Conversely, each row in the table contains a specified range for Aged Solar Reflectance even though the Standards text that references this table implies that each row is really establishing a minimum allowable value exception.

For example, for a Nonresidential building type with a Metal Building roof construction type in all Climate Zones, the first row in Table 140.3 indicates that if the Roof U-factor does not exceed 0.061 (with units of measure not specified), then the allowable Aged Solar Reflectance is 0.62-0.60. But why specify a range of 0.62-0.60? Doesn't this row simply establish a new minimum allowable Aged Solar Reflectance of 0.60 if the Roof U-factor does not exceed 0.061?

Similarly looking at the second row in this table, doesn't this row simply establish a new minimum allowable Aged Solar Reflectance of 0.55 if the Roof U-factor does not exceed 0.054?

Now, what happens for the case with a Roof U-factor of 0.059? A reviewer of this table could reason that since 0.059 exceeds the 0.054 value in the second row, but does not exceed the 0.061

value in the first row, that the first row applies to this case. But to make this table computable, the applicable U-factor range must be specified for each row.

So in this table, the U-factor Rule Classifier should be expressed as a range in each row, and the Aged Solar Reflectance Rule Target should be expressed as a single value in each row.

Furthermore, each range must adhere to known conventions for interpreting the lower and upper bounds and rounding off values with greater precision than shown in the table.

Lastly, cases with a Roof U-factor greater than 0.061 are not handled by Table 140.3, which is a violation of the completeness requirement.

Each of these issues has been addressed in the following reformulation into BESM rule tables.

Table 140.3a: Minimum Aged Solar Reflectance for Metal Building Roof/Ceiling

Binding Information Classifiers	**Building Type: *Nonresidential Building*** **Roof Slope: *Low-Sloped Roof*** **Construction Type: *Metal Building Roof/Ceiling***
Rule Classifier	**Rule Target**
Ufactor (minInclusive, maxExclusive)	**MinimumAgedSolarReflectance**
GTE 0.062	0.63
0.055 to 0.062	0.60
0.050 to 0.055	0.55
0.048 to 0.050	0.50
0.044 to 0.048	0.45
0.040 to 0.044	0.40
0.036 to 0.040	0.35
0.034 to 0.036	0.30
LT 0.034	0.25

Source: Hitchcock Consulting, based on the Standards TABLE 140.3

Table 140.3b: Minimum Aged Solar Reflectance for Wood Framing and Other Roof/Ceiling

Binding Information Classifiers	**Building Type: *Nonresidential Building*** **Roof Slope: *Low-Sloped Roof*** **Construction Type: *Wood Framing And Other Roof/Ceiling***	
Rule Classifier	**Rule Classifier**	**Rule Target**
ClimateZone	**Ufactor (minInclusive, maxExclusive)**	**MinimumAgedSolarReflectance**
1	GTE 0.046	0.63
1	0.042 to 0.046	0.60
1	0.039 to 0.042	0.55
1	0.036 to 0.039	0.50
1	0.034 to 0.036	0.45
1	0.032 to 0.034	0.40
1	0.030 to 0.032	0.35
1	0.028 to 0.030	0.30
1	LT 0.028	0.25
5	GTE 0.046	0.63
5	0.042 to 0.046	0.60
5	0.039 to 0.042	0.55
	table truncated here to save space…	

The first row of these BESM rule tables set the minimum allowable Aged Solar Reflectance to 0.63 for Roofs with U-factors greater than or equal to 0.062. The second row sets the minimum allowable Aged Solar Reflectance to 0.60 for Roofs with U-factors within the range of 0.055 (inclusive) to 0.062 (exclusive). Values with greater precision than the 3 significant digits shown in this range are rounded off according to a consistent round off convention.

Inconsistent terminology and values used within Standards

Table 140.6-A Lighting Power Adjustment Factors contains a rule classifier named "Type of Area" for which values are free-form text. Table 140.6-C on the other hand contains a rule classifier named "Primary Function Area" that adheres to a list of possible values that are used consistently throughout the Standards text. Table 140.6-C is consequently much easier to reformulated and maintain over time than Table 140.6-A.

Table 140.6-B contains a rule classifier named "Type of Building" that adheres closely to a list of possible values established elsewhere in the Standards text. However, the table does not contain a row with the building type value of "Data Center Building" which is in this list.

The tables in Standards Section 140.3 use a rule classifier of Roof Slope with possible values of low or steep. Section 100.1 of the Standards define a criterion to determine if a roof slope is low or steep (a roof that has a ratio of rise to run of greater than 2:12 (9.5 degrees from the horizontal) is considered steep). However, this criterion is not restated in Section 140.3 nor as a footnote to its tables making this a potentially ambiguous classifier.

Numerous text-based details and exceptions that significantly modify application of Standards tables

Table 140.3 supports an exception to Table 140.3-B. This is one of the few examples in the Title 24 Standards where textual details and exceptions to existing Standards tables are actually expressed in secondary tables. For the most part, such details are expressed solely in text that can only be interpreted by a human reader. Alternative approaches to encoding Standards for automated computer processing require extensive rule sets based on precise customized rule syntax that must be compiled and maintained by experts in both the Standards and the specified rule syntax. The BESM Rules Engine approach to encoding the Standards in database conformant rule tables is designed to be accessible to Standards developers who are not required to be expert rule writers and computer software developers.

1.2.3 Developing the BESM Standards Data Dictionary

The Standards Data Dictionary (SDD) development continued in parallel with all the other development activities in the BESM project. Initially the team focused on developing the SDD coverage for envelope and lighting systems with the plan to tackle HVAC and water heating systems next. However, initial resources budgeted for developing the SDD were insufficient to complete the task and furthermore subject matter experts originally assigned to work on the HVAC systems were no longer available. At this point the team embarked on several collaborative technology transfer activities in order to advance the development of the SDD in the areas of HVAC and water heating in return for providing collaborating groups with the functionality of the BESM Data Manager for developing customizations of the SDD required for their development efforts.

In particular, the BESM team provided the 2013 California Building Energy Code Compliance (CBECC) nonresidential compliance software team with the BESM SDD as a starting point for developing their standards data dictionary that would be the data foundation of the 2013

nonresidential ACM rules and data exchange output. To accommodate this required adding functionality to the SharePoint lists because the 2013 CBECC nonresidential compliance software had a very flat internal data model not well suited to XML schemas or relational databases which were BESM's main data storage and exchange technologies. Now that other standards efforts were using the BESM SDD to express their version of the SDD, the BESM team also developed functionality to generate an excel workbook with an outline of the particular SDD data model as well as worksheets for all the terms in the SDD, which provided a more portable SDD that was very useful in SDD review sessions with multiple team members.

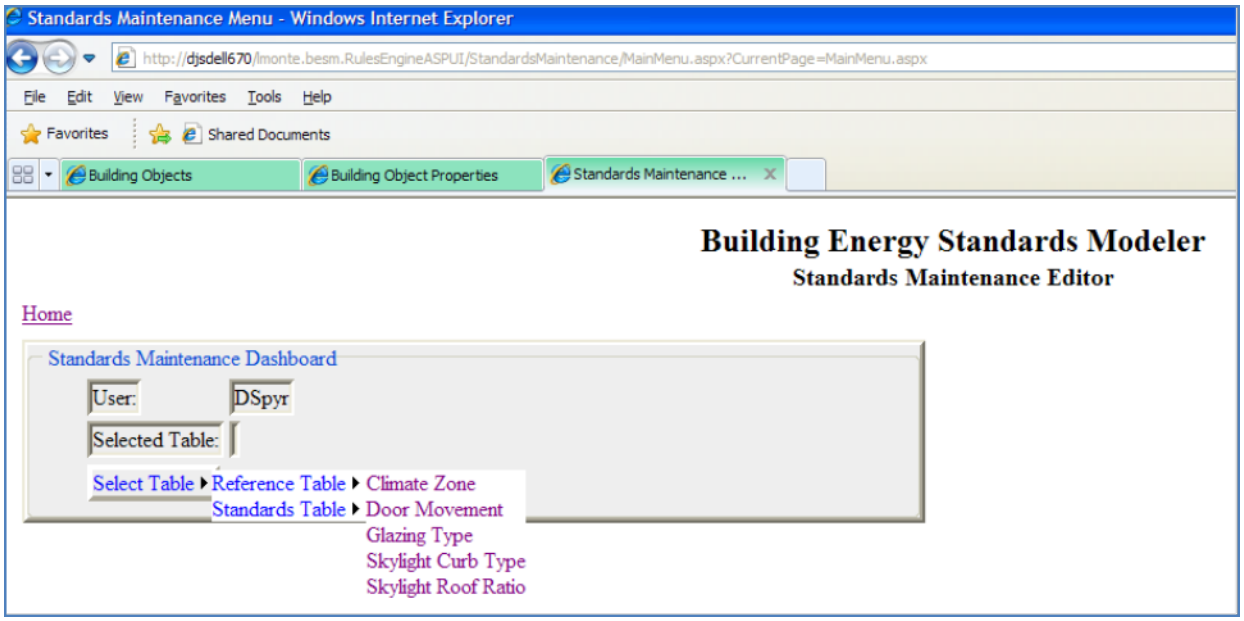
Success in using excel macro technology to generate the SDD workbook led the BESM team to prototype using this approach to generate XML schema types directly from the BESM SDD stored in the SharePoint lists. This effort required new XSD specific columns and views in the BESM SharePoint lists, new source excel workbook template with specific worksheets containing schema directives for specific lists, and new macro functions for extracting and processing the SDD terms to generate the BESM XML schema namespaces, simple and complex types, and identity constraints which provide built-in data validation. The result of the effort was the successful generation of the complete BESM XML schema set directly from the BESM SDD recorded in the SharePoint lists.

1.2.4 Standards Maintenance Web Application

The Standards Maintenance Web application, part of the BESM Integration Test Platform described in detail in chapter 3, was developed to allow Standards professionals to view and edit the Standards rule tables in the BESM small footprint prototype. The following are a series of screenshots with explanatory text which demonstrate the GUI and end user functionality implemented in the Standards Maintenance Web application. The goal of the GUI design was a simple consistent layout of functionality across all tables making it easy to use even for first time users.

The following screenshot is displayed after the user has successfully logged on and selected the Standards Maintenance menu link from the Dispatcher Web page. In the displayed dashboard the user has selected Reference Tables menu and a submenu of available reference tables is displayed.

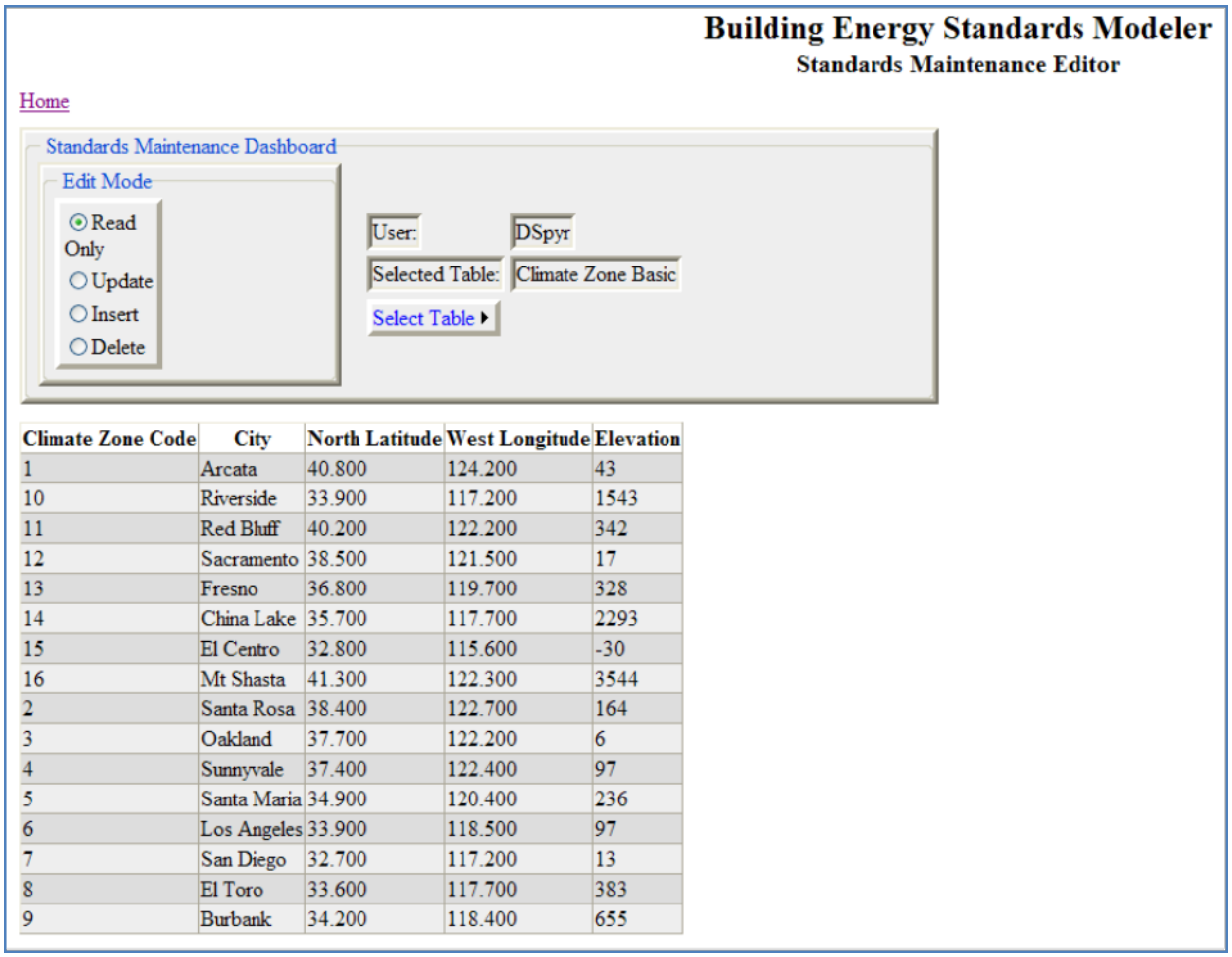
Figure 1: BESM Standards Maintenance: Selecting a Reference table



Source: LMonte.Besm.RulesEngineAspUI/BdmClient/StandardsMaintenance/MainMenu.aspx running on L'Monte local machine

The next screen shot shows the Web page displayed after the user has selected to view the Climate Zone reference table. The Edit me nu is now displayed in the dashboard, with the Read Only radio button selected by default.

Figure 2: BESM Standards Maintenance: Viewing the Climate Zone Reference table

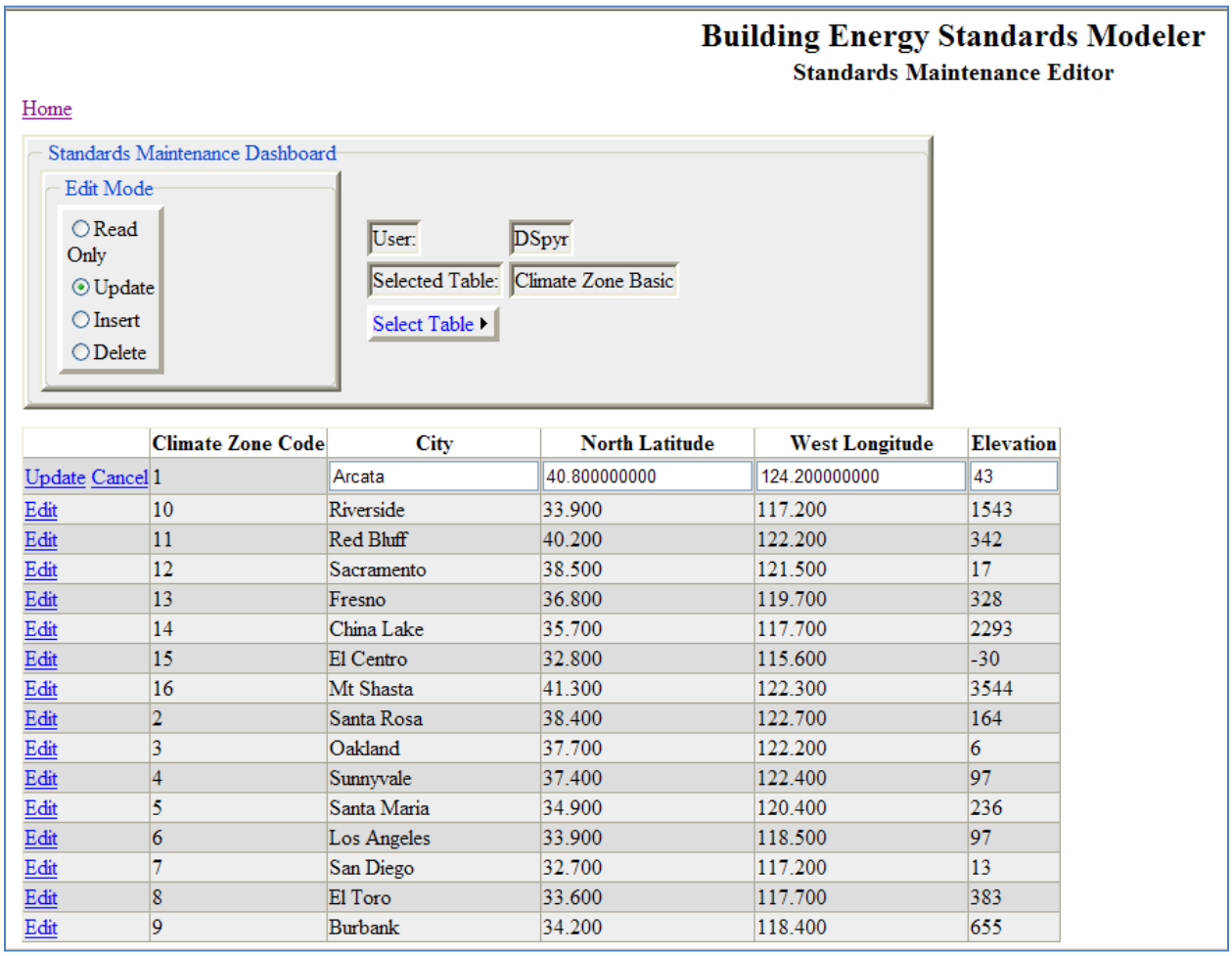


Climate Zone Code	City	North Latitude	West Longitude	Elevation
1	Arcata	40.800	124.200	43
10	Riverside	33.900	117.200	1543
11	Red Bluff	40.200	122.200	342
12	Sacramento	38.500	121.500	17
13	Fresno	36.800	119.700	328
14	China Lake	35.700	117.700	2293
15	El Centro	32.800	115.600	-30
16	Mt Shasta	41.300	122.300	3544
2	Santa Rosa	38.400	122.700	164
3	Oakland	37.700	122.200	6
4	Sunnyvale	37.400	122.400	97
5	Santa Maria	34.900	120.400	236
6	Los Angeles	33.900	118.500	97
7	San Diego	32.700	117.200	13
8	El Toro	33.600	117.700	383
9	Burbank	34.200	118.400	655

Source: LMonte.Besm.RulesEngineAspUI/BdmClient/StandardsMaintenance/Reference/ ClimateZoneBasic.aspx running on L'Monte local machine

The next screen shot displays what happens when the user selects Update mode from the dashboard and then selects Edit next to the first row in the table. In this mode the user could change the representative climate city and it's latitude, longitude and elevation, or the user could correct an error in any of these fields.

Figure 3: BESM Standards Maintenance: Editing the Climate Zone Reference table

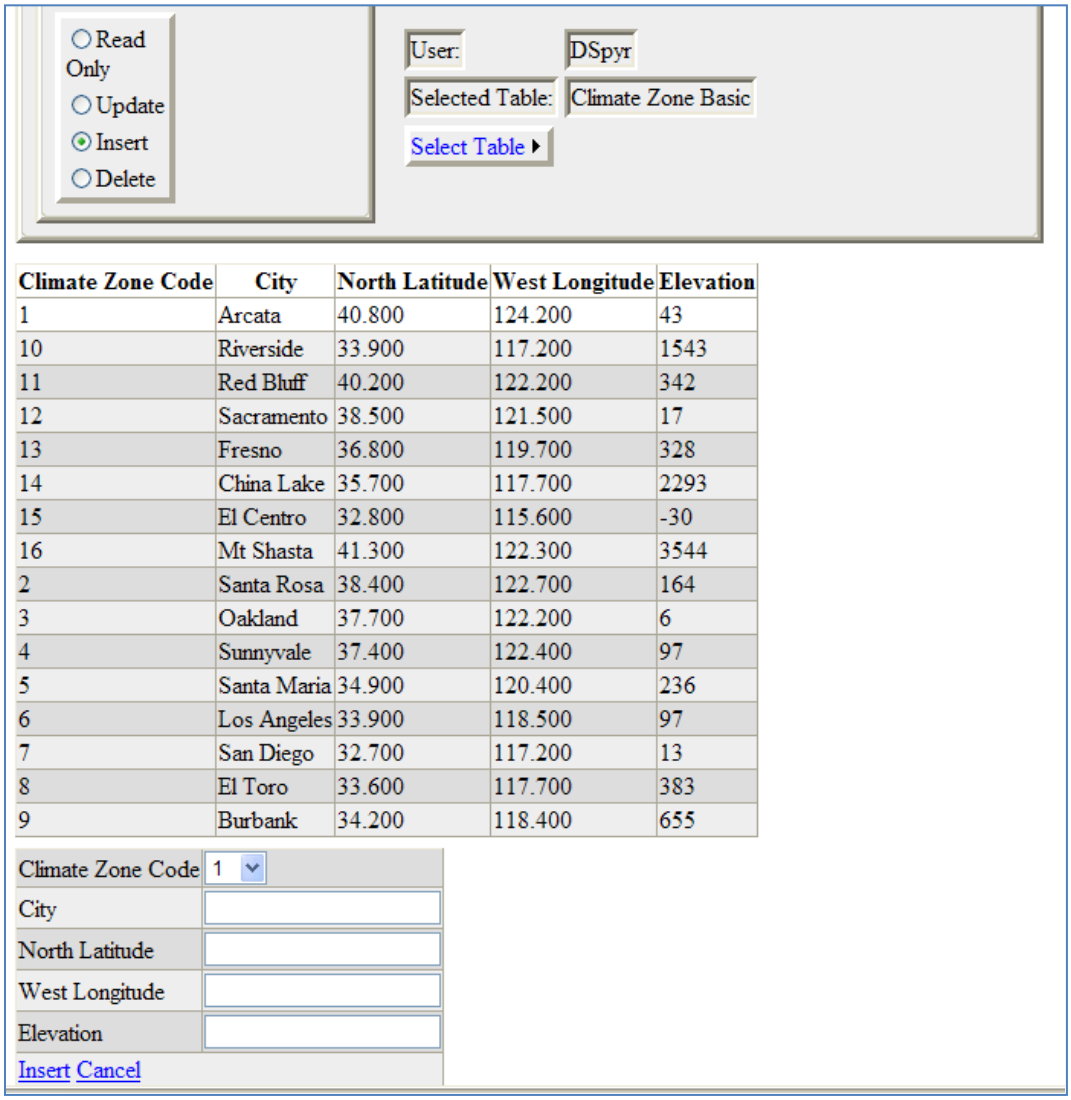


	Climate Zone Code	City	North Latitude	West Longitude	Elevation
Update Cancel	1	Arcata	40.800000000	124.200000000	43
Edit	10	Riverside	33.900	117.200	1543
Edit	11	Red Bluff	40.200	122.200	342
Edit	12	Sacramento	38.500	121.500	17
Edit	13	Fresno	36.800	119.700	328
Edit	14	China Lake	35.700	117.700	2293
Edit	15	El Centro	32.800	115.600	-30
Edit	16	Mt Shasta	41.300	122.300	3544
Edit	2	Santa Rosa	38.400	122.700	164
Edit	3	Oakland	37.700	122.200	6
Edit	4	Sunnyvale	37.400	122.400	97
Edit	5	Santa Maria	34.900	120.400	236
Edit	6	Los Angeles	33.900	118.500	97
Edit	7	San Diego	32.700	117.200	13
Edit	8	El Toro	33.600	117.700	383
Edit	9	Burbank	34.200	118.400	655

Source: LMonte.Besm.RulesEngineAspUI/BdmClient/StandardsMaintenance/Reference/ClimateZoneBasic.aspx running on L'Monte local machine

The following screen shot shows what is displayed after the user selects Insert from the Edit menu in the dashboard. If research showed that a given climate zone covered too wide a range in temperatures, perhaps due to extremes in elevation, a new climate zone could be defined for the Standards in this screen.

Figure 4: BESM Standards Maintenance: Inserting a new record in the Climate Zone Reference table

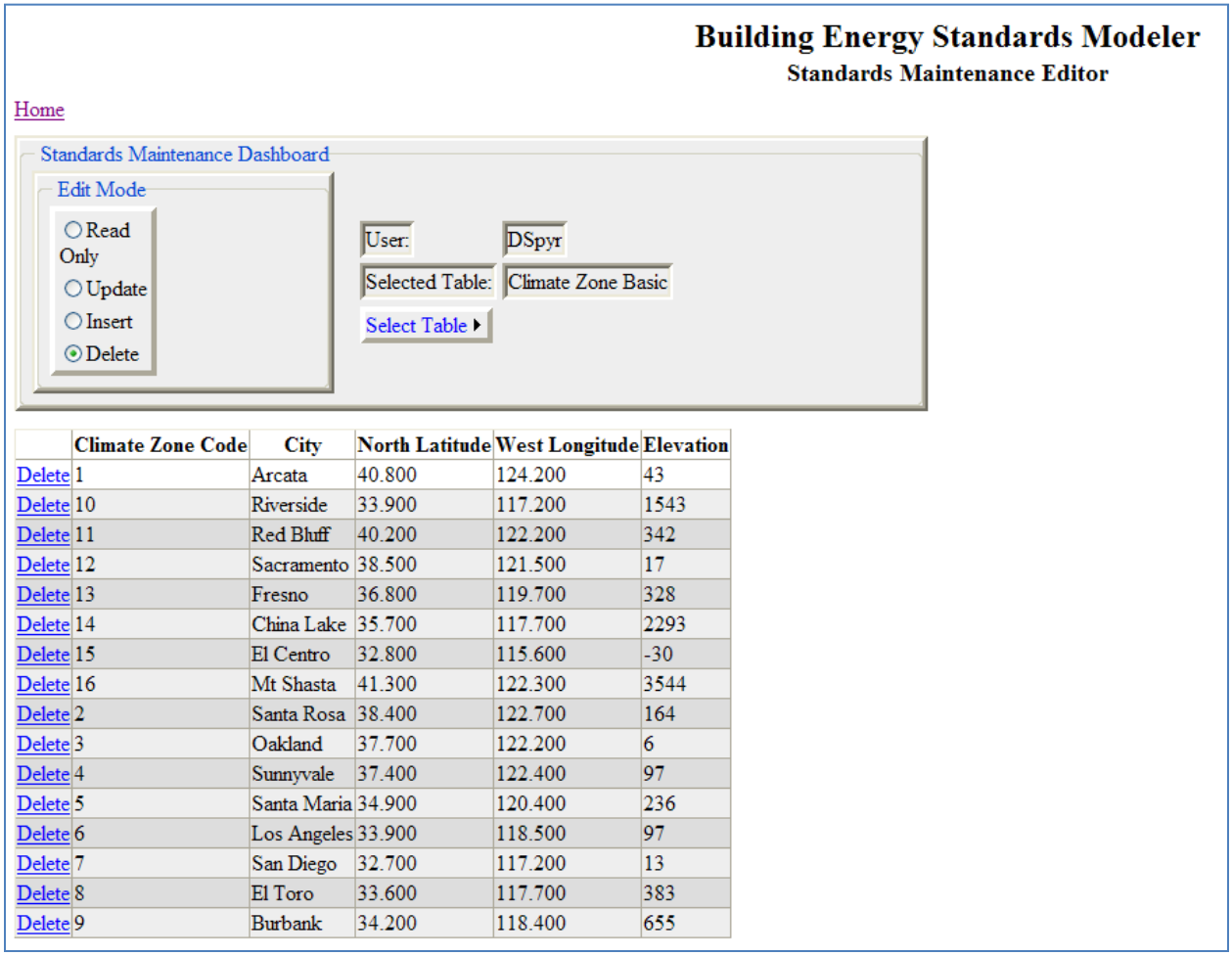


Climate Zone Code	City	North Latitude	West Longitude	Elevation
1	Arcata	40.800	124.200	43
10	Riverside	33.900	117.200	1543
11	Red Bluff	40.200	122.200	342
12	Sacramento	38.500	121.500	17
13	Fresno	36.800	119.700	328
14	China Lake	35.700	117.700	2293
15	El Centro	32.800	115.600	-30
16	Mt Shasta	41.300	122.300	3544
2	Santa Rosa	38.400	122.700	164
3	Oakland	37.700	122.200	6
4	Sunnyvale	37.400	122.400	97
5	Santa Maria	34.900	120.400	236
6	Los Angeles	33.900	118.500	97
7	San Diego	32.700	117.200	13
8	El Toro	33.600	117.700	383
9	Burbank	34.200	118.400	655

Source: LMonte.Besm.RulesEngineAspUI/BdmClient/StandardsMaintenance/Reference/ClimateZoneBasic.aspx running on L'Monte local machine

The following screenshot shows what is displayed when the user selects Delete from the edit menu. To delete a record the user would click on Delete. A warning message requiring confirmation is then displayed to allow for cancelling the operation if it was selected in error. If the user proceeds to delete the record, it is removed from the database.

Figure 5: BESM Standards Maintenance: Deleting a record in the Climate Zone Reference table

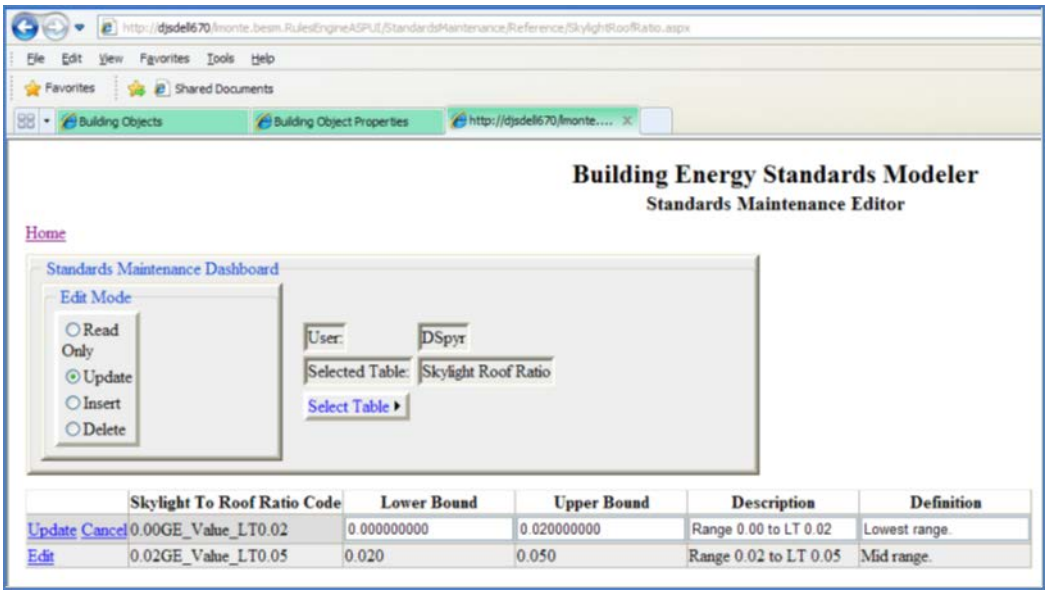


	Climate Zone Code	City	North Latitude	West Longitude	Elevation
Delete	1	Arcata	40.800	124.200	43
Delete	10	Riverside	33.900	117.200	1543
Delete	11	Red Bluff	40.200	122.200	342
Delete	12	Sacramento	38.500	121.500	17
Delete	13	Fresno	36.800	119.700	328
Delete	14	China Lake	35.700	117.700	2293
Delete	15	El Centro	32.800	115.600	-30
Delete	16	Mt Shasta	41.300	122.300	3544
Delete	2	Santa Rosa	38.400	122.700	164
Delete	3	Oakland	37.700	122.200	6
Delete	4	Sunnyvale	37.400	122.400	97
Delete	5	Santa Maria	34.900	120.400	236
Delete	6	Los Angeles	33.900	118.500	97
Delete	7	San Diego	32.700	117.200	13
Delete	8	El Toro	33.600	117.700	383
Delete	9	Burbank	34.200	118.400	655

Source: LMonte.Besm.RulesEngineAspUI/BdmClient/StandardsMaintenance/Reference/ClimateZoneBasic.aspx running on L'Monte local machine

Climate Zone is only one of the reference tables. The following screen shot shows the user editing a different reference table, the Skylight Roof Ratio table.

Figure 6: BESM Standards Maintenance: Editing the Skylight Roof Ratio Reference table



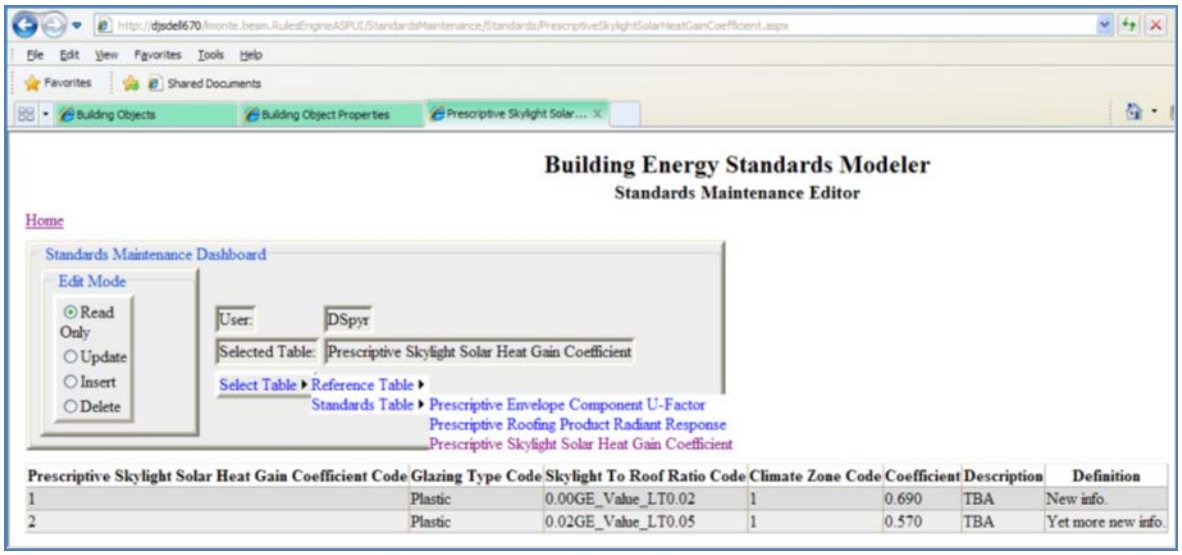
Source: LMonte.Besm.RulesEngineAspUI/BdmClient/StandardsMaintenance/ Reference/SkylightRoofRatio.aspx running on L'Monte local machine

Each reference table contains all possible values for a specific rule classifier as well as documentation that could be used in generating a Standards report.

Every rule target requires a primary standards table that contains all of the rule classifiers it depends on as foreign keys. This makes all the possible values for each rule classifier available to the user when defining a new rule or modifying en existing rule for that rule target.

The following screenshot shows what is displayed when the user selects the Standards table menu from the dashboard, and then select the Prescriptive Skylight Solar Heat Gain Coefficient Standards Table. The same edit menu is available in the dashboard for modifying the standards table which opens by default in Read Only mode.

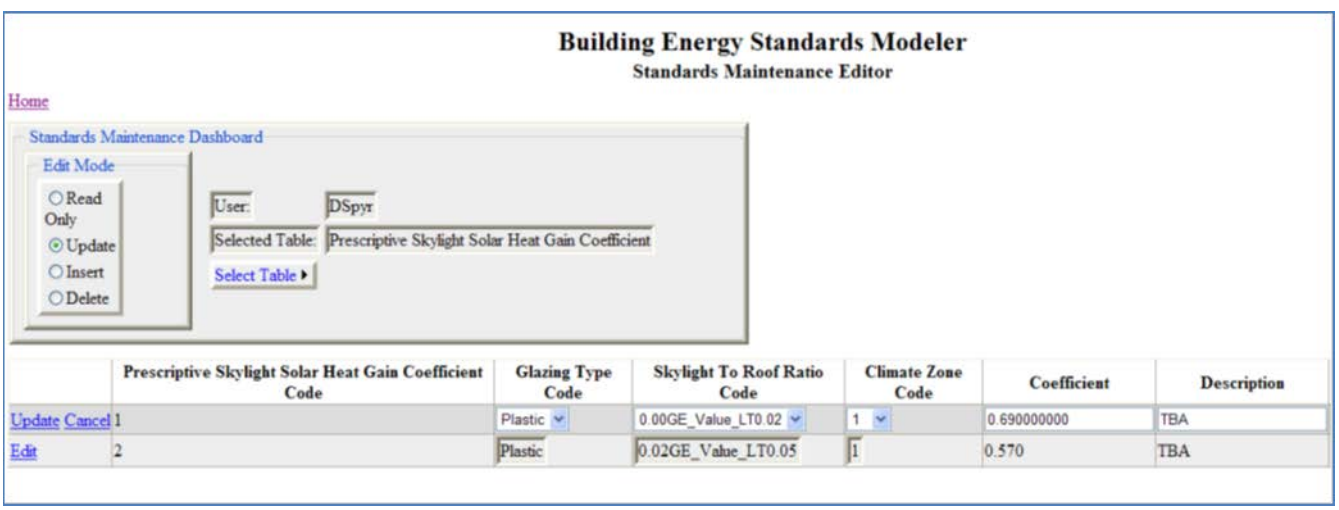
Figure 7: BESM Standards Maintenance: Viewing the Prescriptive Skylight Solar Heat Gain Coefficient Standards table



Source: LMonte.Besm.RulesEngineAspUI/BdmClient/StandardsMaintenance/Standards/ PrescriptiveSkylightSolarHeatGainCoefficient.aspx running on L'Monte local machine

The following screen shot shows what is displayed when the user selects Update from the edit menu and selects the Edit link on the first record in the table.

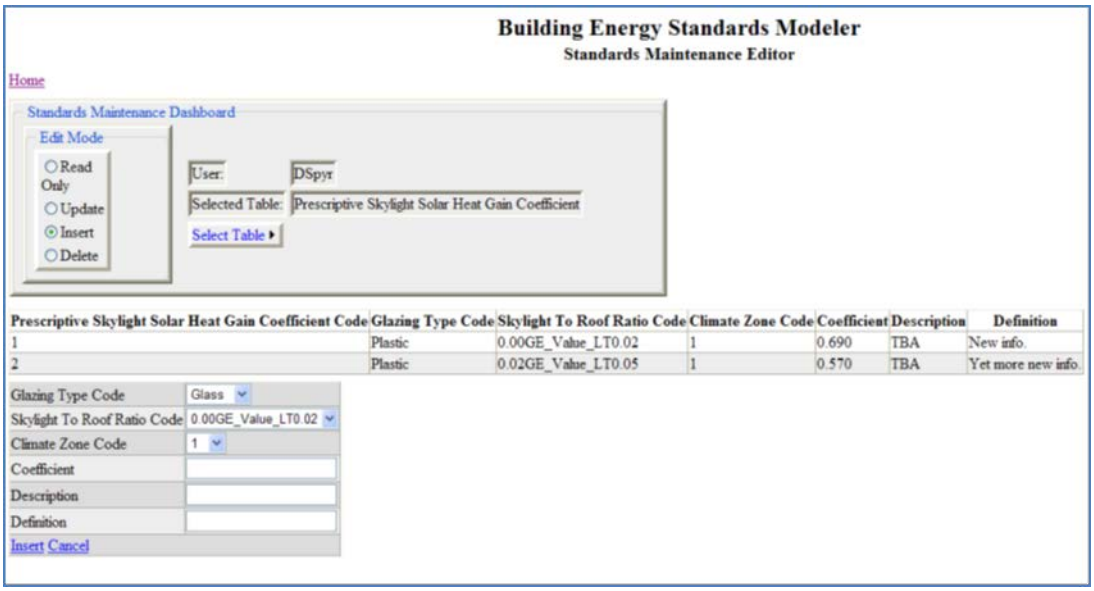
Figure 8: BESM Standards Maintenance: Editing the Prescriptive Skylight Solar Heat Gain Coefficient Standards table



Source: LMonte.Besm.RulesEngineAspUI/BdmClient/StandardsMaintenance/Standards/ PrescriptiveSkylightSolarHeatGainCoefficient.aspx running on L'Monte local machine

The following screen shot shows what is displayed when the user selects Insert from the edit menu in order to create a new rule for this rule target.

Figure 9: BESM Standards Maintenance: Inserting a new record in the Prescriptive Skylight Solar Heat Gain Coefficient Standards table



Source: LMonte.Besm.RulesEngineAspUI/BdmClient/StandardsMaintenance/Standards/ PrescriptiveSkylightSolarHeatGainCoefficient.aspx running on L'Monte local machine

As with all tables in the Standards Maintenance module, the user can also select to delete a row which in a primary standards table, means removing a rule.

1.3 Conclusions

During the course of prototyping the BESM Data Manager, Standards Data Dictionary and Standards Maintenance module, the team developed a solution to its most critical requirement – allowing standards developers to directly edit the standards rules that can be used in a compliance analysis. The prototype established a proof of concept of the business rules engine approach of expressing the Standards as logical rules in a relational database with metabase tables that are used by the rules engine in accessing the rules. Early on in the project, it became clear that only a small footprint prototype could be developed due to the massive number of rules embedded in the Standards and the amount of processing required to reexpress them as logical rules in a rules database table. This decision to limit scope allowed development to proceed on other BESM components rather than using up additional resources to further complete the rule tables.

On the other hand, continuing the development of the Standards Data Dictionary (SDD) past the small footprint prototype allowed the BESM team to introduce the use of a controlled vocabulary to other Standards development efforts and expanded the functionality of the SDD to support development of different versions of the SDD and the capability of generating a portable excel workbook of an entire SDD with a representation of the data structure for use in review sessions

Another significant benefit to completing the SDD following well defined naming conventions, was the development of capability of generating a more full BESM XML schema directly from a SDD.

1.4 Recommendations for Technology Transfer

1.4.1 Apply BESM Rule Processing to Improve the 2016 Standards

The procedures developed during the BESM project to process the Standards should be adopted by the CEC as quality control procedures to improve the Standards in several ways.

Improve accuracy and completeness

Applying the reformulation process developed in the BESM project to Standards tables identifies and correct conflicts and missing cases that are difficult to identify by simply reading the Standards.

Improve human readability

Replacing complex tables that contain multiple rule targets and different sets of rule classifiers with straightforward, easy to digest tables would greatly improve the ability of users to interpret the Standards, increasing the number of qualified users.

Improve the correct application of the Standards

Removing ambiguities and inaccuracies that make it difficult for infrequent users to understand and consistently apply the Standards, and open the potential for gaming of the system, could improve the desired outcome of the Standards, which is to significantly increase energy efficiency across the California building stock.

1.4.2 Use Standards Data Dictionary Terms in the 2016 Standards language

The terms in the SDD were developed and vetted by numerous subject matter experts and are now being used in the 2013 CBECC nonresidential compliance software for expressing rules and in the generated XML file that contains the results of the compliance analysis.

The development of the 2016 Standards should adopt the SDD terms as its controlled vocabulary.

1.4.3 Use SDD XML Schema Capability in the 2016 Standards Residential and Nonresidential Compliance software and compliance reports.

The BESM team developed the ability to express a standards data dictionary on a SharePoint collaborative web site and they developed the functionality to generate XML schema with namespaces, type definitions and identity constraints directly from the SharePoint SDD lists.

This functionality should be extended for use in the 2016 residential and nonresidential compliance software to produce an XML schema that can be used by third party vendors for developing a front end to either software. This XML schema should also be used as the foundation for the compliance document schemas used to specify data exchange requirements between the compliance software, the compliance document engine and the data registries.

CHAPTER 2:
BESM Building Description Manager and the Building Description XML Schema

2.1 Project Approach

At the beginning of this task, the team evaluated existing building description formats to identify necessary and appropriate data, definitions, and model structures to adopt in the BESM building model. An informal survey was created and posted on the BESM SharePoint site where BESM team members, the Program Advisory Committee (PAC) members, and a list of recommended building energy software experts were able to respond. In addition to the survey results the team analyzed candidate building description formats and building information resources including EnergyPlus IDD, DOE2.1e BDL, DOE2.2 BDL, IFC, gbXML, COMNET, and CEUS and created a document showing the high-level structural hierarchy (outline) of the key elements of each model. The survey tool, "BESM Building Description Project Survey.docx" can be found in the Appendix A1 and the "Building Description Formats Evaluation Report" and "Building Data Model Structures.docx" are posted on the BESM SharePoint Website https://lmonte.sharepointsite.net/T24ComplianceSW/BESM/Shared%20Documents/Forms/AllItems.aspx

The initial plan was to design a Building Description Manager that provided access to a catalog of buildings, functionality to make edits to the building description and provide conversion routines to convert one or two popular formats into the internal BESM building description format.

2.1.1 BESM Building Description Model Conversion Methods

The BESM team considered two basic approaches to converting, or transforming, data between different format specifications: the relatively straightforward data pattern mapping approach, and more involved programmatic transformation methods. XSLT (Extensible Stylesheet Language Transformations) is a language developed to support data pattern mapping, not only between XML (Extensible Markup Language) data formats, but also other formats including plain text. Any programming language such as C# can be used to implement programmatic transformation methods, with some development environments providing built-in support for specific formats such as XML.

The data pattern mapping approach is particularly useful when two data model formats are relatively similar, which is generally the case in business applications such as conversion between two sales transaction documents. The programmatic approach may be preferred when two data model formats are significantly different, which is often the case in building data models. In this case additional programming may be necessary, for example, to perform complex transformations (e.g., determine the vertex list order for correct surface orientation), to test for and correct inaccuracies (e.g., wrong assigned surface type), or to supply missing data (e.g., missing adjacent space assignment). XSLT does support more involved programming-like structures. However, the programmatic approach often provides a more fully supportive

development environment. Applying lessons learned from previous conversion projects, the team selected to follow the programmatic transformation methods approach.

2.2 Project Outcomes

2.2.1 Building Description XML Schema

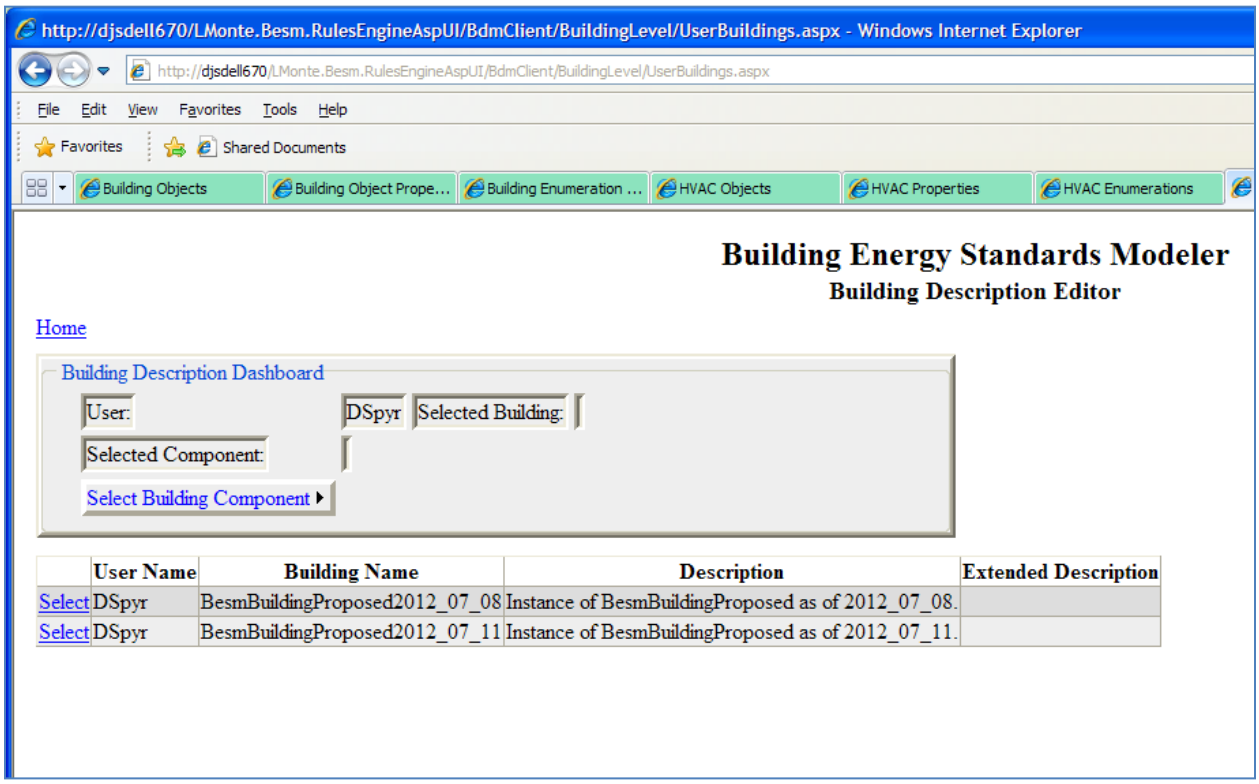
When the BESM team designed the original XML schema to represent the BESM building description format, the current source for developing the SDD was the building descriptors in the COMNET manual, chosen because the COMNET manual was the basis for the next nonresidential ACM manual. The BESM building description XML schema was designed to leverage the power of XML technologies such as XPath and XQuery and built-in data validation provided through careful definition of types, use of namespaces to allow reuse of common types and the use of identity constraints. The original BESM building description XML schema captured the high level organization of main building systems and defined more detailed data structures for the building envelope, particularly fenestration. At version 0.16 the BESM XML schema was frozen in order to have a stable schema for testing other software prototypes. However as explained in Chapter 1 the Standards Data Dictionary continued to be developed beyond this small footprint prototype scope. Eventually functionality was developed to generate the BESM building description XML schema from the SDD lists on the BESM SharePoint site. The SDD version of the BESM building description XML schema follows the same design however, identity constraints were not fully implemented in the SDD SharePoint lists.

2.2.2 Building Description Manager

The Building Description Manager (referred to as BDM) software prototype was developed using the BESM building description schema version 0.16. Functionality for editing and managing the user's building catalog were developed and the required Web pages for displaying those parts of building that are contained in the small footprint expressed in version 0.16. The BDM prototype includes a building description editor Web application that was integrated into the BESM Integration Test Platform described in detail in chapter 3. The following screenshots of the building description Web application demonstrate the GUI and end user functionality that has been implemented in the Building Description Manager small footprint prototype.

This screen shot appears after the user has successfully logged on, selected the Building Description menu link from the Dispatcher page and selected to view his catalog of buildings.

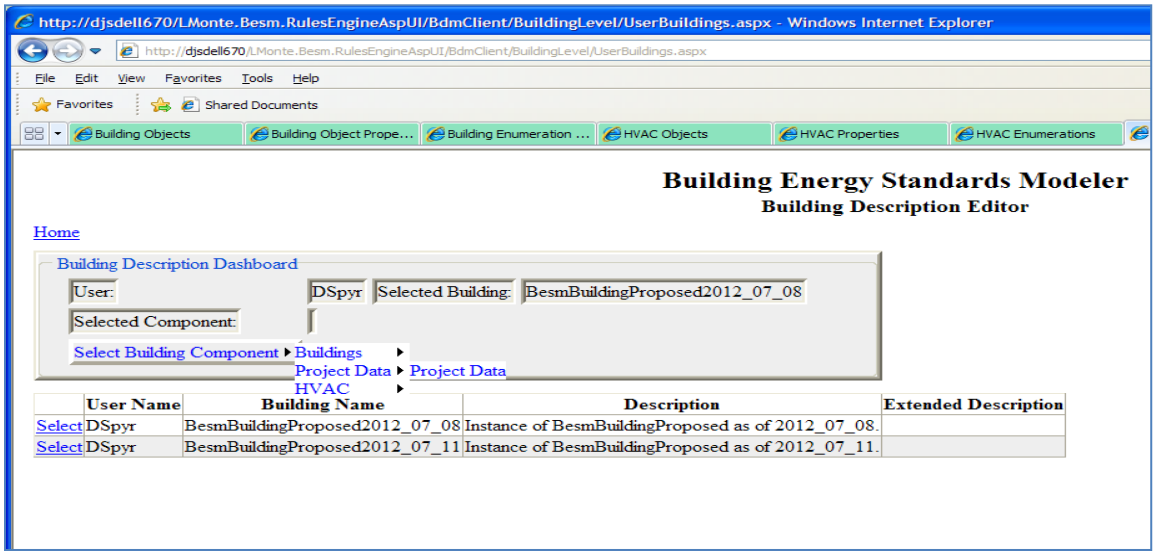
Figure 10: BESM Building Description Editor: User's Building Catalog Screen



Source: LMonte.Besm.RulesEngineAspUI/BdmClient/BuildingLevel/UsersBuildings.aspx running on L'Monte local machine

The next screen shot is the Web page displayed after the user selects a building from his catalog and is in the process of selecting to view the building's Project Data elements

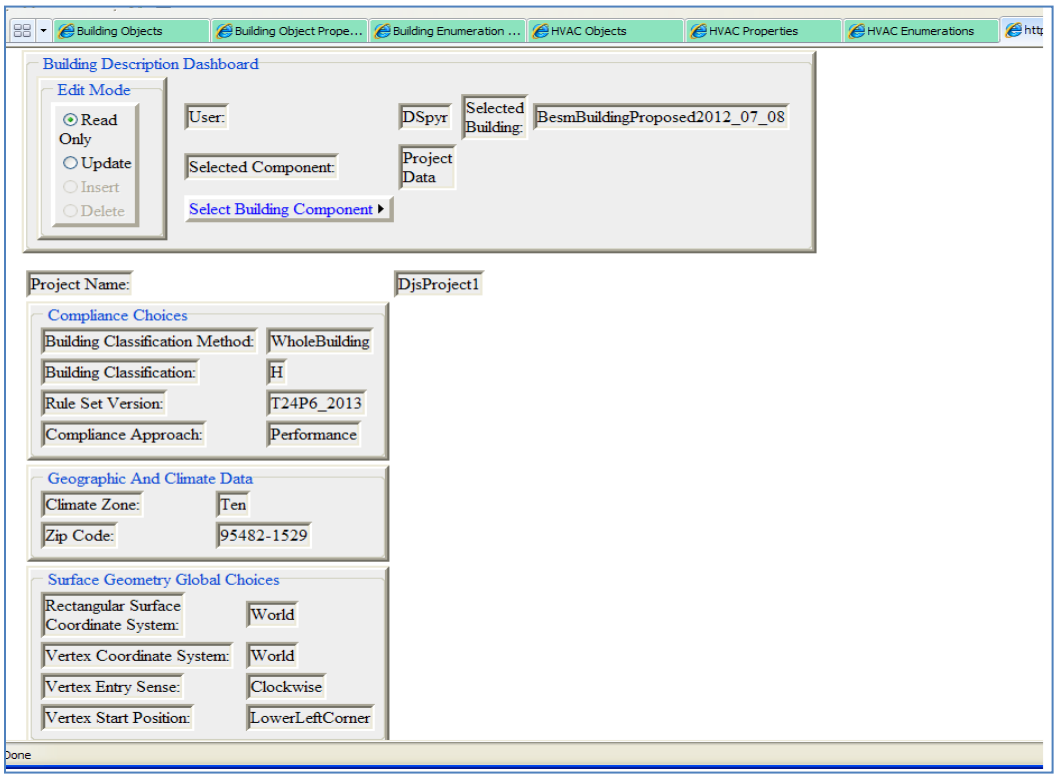
Figure 11: BESM Building Description Editor: User selecting to view Building Project Data



Source: LMonte.Besm.RulesEngineAspUI/BdmClient/BuildingLevel/UsersBuildings.aspx running on L'Monte local machine

Once the user clicks Project Data the following Web page is displayed.

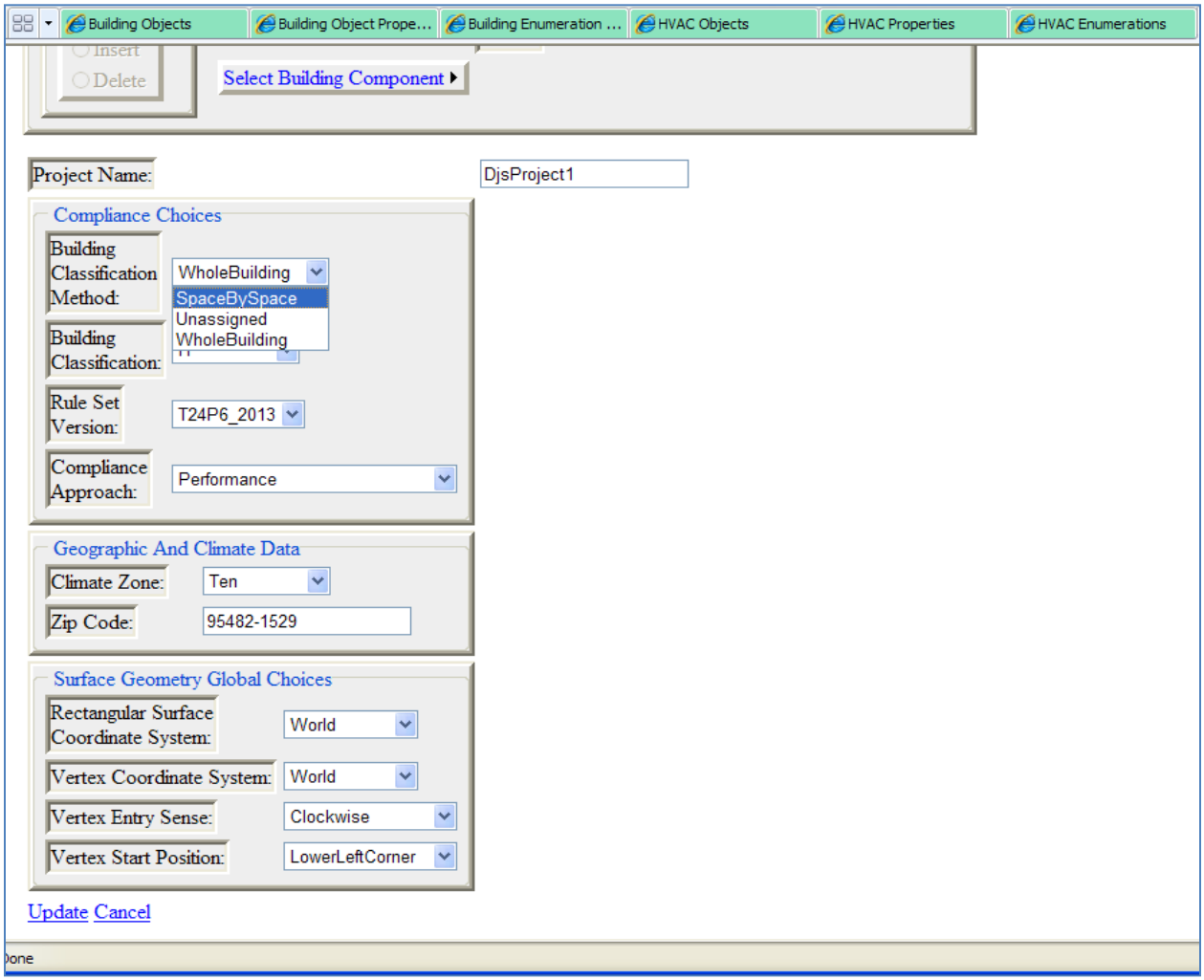
Figure 12: BESM Building Description Editor: Building Description Project Data



Source: LMonte.Besm.RulesEngineAspUI/BdmClient/BuildingLevel/UsersBuildings.aspx running on L'Monte local machine

The next screen shot is the Web page displayed when the user selects Update in the Dashboard Edit Mode box, and the user have selected to change the Building Classification Method to SpaceBySpace from the WholeBuilding method. The user can edit any of the fields which are either text boxes or list boxes. Once the editing is finished the user would select the Update link to save the changes to the building description.

Figure 13: BESM Building Description Editor: Editing the Project Data Building Classification Method



Source: LMonte.Besm.RulesEngineAspUI/BdmClient/BuildingLevel/UsersBuildings.aspx running on L'Monte local machine

2.2.3 BESM Building Description Model Conversion Methods

An initial neutral internal data class model was specified in a relatively generic structure intended to be easily modifiable and extensible as the BESM XML schema was defined. The class structure focused on the envelope elements of a building, which are the primary elements that are populated by common BIM-authoring software that export building models in IFC and gbXML formats. The class library included import conversion methods implemented for both IFC and gbXML formats. The IFC import methods made use of a third-party IFC toolbox named BSProLib that enables geometric interpretation of IFC building models from a building services perspective compatible with energy simulation tools such as EnergyPlus. The gbXML import methods employed the Visual Studio Language-Integrated Query (LINQ) to XML assemblies that provide the language syntax of C# with standard programming patterns for querying and updating data in XML documents. The functionality was implemented to import

IFC or gbXML data formats into the SDD-like internal BESM Building Model class library that provided a consistent structure and format for the imported data model. The plan was to gradually replace the generic data model with complex type classes that were being developed to represent the BESM XML schema complex types. This means that further development of the conversion methods was dependent on the completion of the BESM XML schema set.

However, as mentioned previously, the development of the BESM XML schema was frozen at version 0.16 in order to proceed with development of other functionality in the BESM platform. At version 0.16 the BESM XML schema contained high level definitions of building systems and detailed definition of the envelope system, including fenestration. This decision to freeze development of the schema meant that further work on conversion routines could not continue until the BESM XML schema was built out to a full definition of a building.

2.3 Conclusions

Historically, building description data models have been developed in isolation within the context and confines of an individual standalone software tool project such as DOE-2 or EnergyPlus. Each such data model has been tailored specifically to its host software tool to support the internal representation of data required by that tool. Users of each standalone tool were then required to manually create input building models unique to that tool. If a user wanted to employ different tools to analyze the same building they were required to separately create the unique input models for each tool.

The field of Building Information Modeling (BIM) has developed in response to this situation. The goal of BIM is to specify a neutral building description data model capable of supporting numerous software tools. A single BIM building description model could then be created and used to drive multiple analysis tools without the user having to intervene. However, since most software tools still have their own unique internal data model (i.e., they do not use a neutral BIM as their internal data model), transformation is still required to convert data from the BIM format into the unique internal format for each tool.

The BESM software environment has its own unique data requirements due to the combination of Standards data and energy simulation data needed to process Standards rules and perform compliance simulation. Therefore, the BESM software must contain methods for converting input building models, whether they are in a BIM neutral format or another specified format, into the internal data representation used within BESM.

Initial analysis of existing building models including IFC, gbXML EnergyPlus IDF, and DOE2 BDL versions 2.1E and 2.2 revealed that many of the formats did not use XML schema definition language to specify the format. Those building models that had an XML schema, did not use of namespaces, type definitions, or identity constraints which provide essential data validation and specification. This results in a lack of reliability in instance files and makes a pattern matching approach to conversions impossible. The team found this to be true of IFC and gbXML instance files in initial conversion efforts which required significant additional validation testing and correction methods to be performed as part of the transformation

process. This input model reliability issue remains a significant barrier to robust transformation results.

Recognizing that a well designed building model XML schema is the foundation for high quality conversions, the BESM team delayed further conversion method development until the small footprint prototype BESM schema could be extended to provide complete coverage of all building systems and components.

The Building Description Manager web application introduced requirements for displaying data extracted from the original building description XML file including an additional data access layer for separating out the individual pieces of data from the XDocument object. It also meant that the team had to use a different type of web control for displaying the building description components and could not reuse the user interface code developed for the Standards Maintenance web application.

2.4 Recommendations for Technology Transfer

The next step in further developing the BESM Building Description Manager is to take the XML schema generated from the Standards Data Dictionary and extend it to contain the same level of data validation in its type definitions and identity constraints as the original BESM schema version 0.16. Once the final BESM building description XML schema is complete and represents all the possible combinations of building systems and components required both for compliance and energy simulation a number of components in the Building Description Manager can be built out beyond the current small footprint prototype. In particular, the remaining web pages for editing any part of the building description should be completed. The building model conversion routines should also be completed using the same type of mapper XML design pattern as the BESM team developed for converting the BESM building description XML instance into an EnergyPlus IDF format. Using the EnergyPlus mapper, a conversion should be created to go the other way – from an EnergyPlus IDF to the BESM building description. This would allow sharing of building models between the BESM platform and any other software that generates IDF formats. The conversion method begun for gbXML should be completed and a conversion method should be developed for the CBECC nonresidential compliance software building model which uses the same basic SDD and should therefore be fairly compatible although it does have a flatter hierarchy.

Buildings representing a range of building types should be converted to develop a catalog that can be used for testing the Standards. Given that the CBECC nonresidential compliance software includes a number of buildings selected for their coverage of different configurations, these should be the first building files to convert for the catalog. Once the conversion methods are in place and testing within the BESM Integration Test Platform, other building models should be evaluated for conversion including IFC.

CHAPTER 3:
BESM Integration Test Platform

3.1 Project Approach

For decades, the Title 24 Building Energy Standards (the Standards) have been created and maintained as natural language text documents. As such, the many individual rules comprising the Standards are inaccessible to computer software beyond the primitive ability of word processing programs to perform functions such as key word text searches and spell checking. The overarching purpose of the BESM platform was to revolutionize the creation, maintenance and use of the Standards by re-expressing them in a Digitally Competent Information Space (DCIS). With the Standards expressed in this way, the components of the BESM platform can actually locate, understand, modify and manipulate the individual rules comprising the Standards. The fully-implemented BESM platform can then support many novel processes such as vetting proposed rule changes via immediate, round-trip rule testing which consists of the following sequential operations.

- Using the BESM Standards Maintenance module, a standards worker makes a proposed change to a rule (expressed as a single row of a relational database table).
- Using the BESM Building Description module, the standards worker selects a representative building from the BESM Building Descriptor table and makes changes, if needed, to the building description.
- Using the BESM Simulation Launcher module, the standards worker selects simulation control objects from the BESM Simulation Control table. These will determine the specific variables and meters which will appear in the output of the building energy simulation run.
- From the Simulation Control Dashboard, the standards worker pushes the Launch button which begins the process of preparing the selected building for submission to the target simulation engine (currently EnergyPlus is the only supported engine).
- The BESM Rules Mapper module traverses the description (an XML file) of the selected building and maps all applicable values from the Title 24 rule set, including the changes made to the proposed rule, into the building description file.
- The BESM Simulation Engine Articulator module converts every applicable element, from the mapped building description , to a form natively understood by the target simulation engine. (Currently, this takes the form of an EnergyPlus input data file or IDF).
- The Simulation Launcher module then sends the input data file to the simulation engine which performs the requested simulation on the building and returns the results in the form of a SQLite database.
- The Simulation Launcher module then extracts the relevant results from the returned SQLite database and presents them to the standards worker using the Results Viewer (an application developed by the National Renewable Energy Laboratory).

What makes the above round-trip process revolutionary is that it allows the standards worker to immediately see the effect, on the selected building or set of buildings, of a proposed rule change. Moreover, this process is controlled entirely by a standards worker without the intercession of a consultant (which may have required weeks or months of preparation and contractual negotiation).

The BESM vision is an ambitious, full-featured software environment which supports every aspect of rule creation, testing, maintenance, validation and use. The BESM vision requires identifying and solving many novel research and development questions which, to the best of L'Monte's knowledge, have never before been successfully accomplished. The great bulk of the work performed under the current contract has been to identify, characterize and find practical solutions to these major R&D questions. When an R&D issue became sufficiently well characterized, a proposed solution was implemented in software for testing. Each such solution had to be tested not only for its own merits but also in terms of how well it worked in connection with existing BESM components which had already emerged from previous R&D cycles. A testing vehicle was therefore required which could

- Hold the successful products (software subcomponents) of earlier R&D cycles.
- Incorporate the new subcomponent.
- Provide a testing environment for all interdependent subcomponents sufficient to show proof-of-concept for the whole.

The testing vehicle which emerged from this cyclic R&D process was called the Integration Test Platform (ITP). The ITP is thus the vehicle for demonstrating proof-of-concept for the many interconnected modules and components which are the building blocks required for the full BESM platform. It is important to understand the difference between the ITP and the full BESM platform. The most critical difference is size. The BESM Standards Maintenance module will serve as an example.

When complete, the Standards Maintenance module will allow every rule in the Title 24 Building Energy Standards to be re-expressed as a digitally competent entity (i.e. as a single row in a well-defined relational database table). L'Monte estimates that the Standards will eventually require somewhere between 500 and 1000 distinct relational database tables. The supporting software for each such table will require 5 dedicated, object-oriented classes for an approximate total of 1700 lines of code (in the C# programming language) per table. This means the Standards Maintenance module of the fully-implemented BESM platform will require somewhere between 1 million and 2 million lines of support code. The present BESM architecture includes a total of 8 major modules. Using the estimated size of the Standards Maintenance module, the completed BESM platform, as currently envisioned, can be roughly approximated at 8 to 16 million lines of code. By any measure, this is very large software development effort.

Using the estimated size of the Standards Maintenance module, another important feature of the ITP can be understood. This is the Incremental Validation principle. The meaning of

"incremental validation" is this. Data storage formats and supporting software which work successfully for one set of relational tables (e.g. building fenestration objects) may be inadequate for another set (e.g. HVAC or lighting objects). Furthermore, the round-trip rule testing process outline above involves all 8 major BESM modules. This means every module must be tested to see if it can handle the contents of every type of table. Experience so far has revealed many cases where redesign of existing modules or existing table schemas was required. The important fact here is this: **Extensive testing must be done with the minimum possible implementation effort.** To discover a critical omission in relational table structure after one million lines of support code have already been written would surely be fatal to the BESM development effort. No software development effort could sustain such costly mistakes. It is therefore of critical importance that the Integration Test Platform be used to prevent uncorrectable oversights.

With the foregoing background, it is now possible to clearly understand the fundamental nature of the ITP. The ITP, in its current form, is not intended as an operational version of the full BESM platform. Rather, it is a vital test vehicle designed to incrementally demonstrate proof-of-concept of all prototyped R&D solutions which must be found to support a completed platform. The ITP therefore is the software deliverable which L'Monte specified, in the Contract, as the BESM prototype. At the same time, a word should be said about the eventual fate of the ITP. The software development methodology L'Monte chose for the BESM platform is one of a dozen or more well-known methodologies currently used for large-scale software projects. The methodology is called Evolutionary Prototyping and is appropriate for use when the project involves a heavy R&D component. The significant fact here is that the ITP will eventually evolve into the final BESM platform. This means the entire code base of the ITP, together with all its data stores, will eventually be released as the fully-implemented BESM platform.

3.2 Project Outcomes

3.2.1 BESM Integration Test Platform Web Application And Master Control Module

Because the Integration Test Platform will gradually evolve into the fully-operational BESM system, the ITP was implemented as a Web application. This application type is the only one which supports all of the fundamental design principles underlying the BESM architecture. Briefly, these principles are:

- Digitally Competent Information Space (DCIS) – 100% of the information in the BESM system (e.g. all Standards rules and building descriptions) is maintained in a form fully accessible to both machine and human.
- Accessibility – multiple users, in unpredictable geographic locations, have simultaneous access to all BESM features for which they are authorized.
- Consistency – all users may access the same basic data stores even as those data stores are undergoing modification.
- Modularity – the BESM platform is designed to support multiple rule sets and multiple simulation engines. This is done through the use of the Adapter Design Pattern.

- Transparency – wherever possible, operations are not hidden in computer code. Instead, they are placed in publicly visible XML files. BESM software modules continually access these files for operational information. Interested users may freely inspect the same files to determine exactly what the software is doing "under the hood".

It should be understood that the choice of a Web-based application has its costs, primarily the following:

- Complexity – Web applications introduce many additional operations not required of traditional desktop applications. This is no small issue. Complexity is the central difficulty in creating, validating and maintaining software. Web application development therefore requires more resources - time, money and specialized skills.

- Vulnerability – Hostile attacks on Web applications are far more frequent than on desktop applications. Protecting data from damage or theft requires additional development time and specialized skills.

- Latency – The fundamental nature of Web transport protocols makes it inevitable that users will experience lag times during which they are waiting for requested results to appear.

A Web application is necessarily burdened by these additional costs. However, on balance, no other application type could have satisfied all of our design requirements. L'Monte believes that the most powerful, best integrated development environment for Web applications is Microsoft's ASP.NET which was the choice for the Integration Test Platform. Additional functionality is available from Microsoft's SharePoint product (which is now substantially based on ASP.NET). This functionality was appropriate for the BESM Data Manager module and is the reason that L'Monte implemented the Data Manager on a SharePoint Web site.

By definition, the Integration Test Platform architecture includes, and is intended to validate, all BESM elements including executable modules as well as data stores. Among these elements are the BESM Data Manager, Standards Data Dictionary and Rule Set Manager (discussed in Chapter 1) as well as the BESM Building Description Manager and the Building Description XML schema (discussed in Chapter 2). The following sections discuss the outcome of work on BESM elements not previously covered.

Application Services

Application Services is a component-level element which provides services to many BESM modules. Services include membership and role management, user credential validation, authentication and login as well as site personalization (user preferences). One of the advantages of ASP.NET is the availability of numerous existing support classes, in the .NET Framework Class Library, which can be harnessed to do much of this work. Application Services helps greatly in the administration of the BESM Web site as well as providing some of the front line security functions required in any Web application.

Status: Operational. Support for certain optional features (e.g. user preferences) has been created but is not yet fully implemented

The BESM Dispatcher

The BESM Dispatcher is a master control module which regulates high-level navigation around the Web site and also provides communication services to the main BESM modules. For example, the Dispatcher helps to coordinate the operations required to perform a building energy simulation. In the operational BESM platform, users will be selecting buildings and simulation control objects from centralized BESM data stores but, in some cases, running the actual simulations on machines which are in their own local area network. A completed simulation will therefore involve a great deal of data transport across the Web. This is facilitated by Web services which are made available from within the Dispatcher.

Status: Operational for execution on the server. Partial implementation for remote user support

The Simulation Launcher

The Simulation Launcher is a high-level module which provides top-level control of most of the operations required for performance-based building energy studies. Depending upon specific simulation requirements, the Simulation Launcher may call on other major modules such as the Building Description Manager. In all simulations, the Simulation Launcher will require support from certain of its components including the Simulation Control Editor, the BESM Rules Mapper and the Simulation Engine Articulator. These Simulation Launcher components are discussed below.

Simulation Control Editor

The Simulation Control Editor is one of a number of BESM elements built using the Adapter Design Pattern. Under this design pattern, the Simulation Control Editor is really an alias for an arbitrary number of specialized editors. Each such editor provides access to a particular BESM data store, a relational database table, containing objects used to control a target simulation engine. Currently, the BESM platform supports only EnergyPlus but, when the need arises, the platform architecture is designed to allow one or more additional simulation engines to be added on a modular basis.

Status: The EnergyPlus Simulation Control Editor has been designed and its data store exists in a populated state. The implementation is incomplete and currently allows only selection of existing simulation control objects from the EnergyPlus Simulation Control table

The BESM Rules Mapper

The BESM Rules Mapper is a component which comes into play after a simulation run has been launched. A building description XML file must pass through two transformational stages before it can actually be sent off to a simulation engine for processing. The first of these stages is called rules mapping in which building element properties (e.g. the U-factor of a window) must be assigned a value from an applicable rule in the Standards. This need may arise either because it is a limit value (which is required for a compliance check) or because it is an actual

value which the user failed to provide. In this context, the building element property is said to be a rule target. In either of these cases, the Rules Mapper discovers the missing value by traversing the building description file, line by line, and consulting a rule-set specific XML file which is an instance of the BESM Binding schema (or B-type schema). The B-type instance document contains the information required by the Rules Mapper to determine all of the following required information:

- Does this rule target require a value from the BESM Standards database?
- Which S-type or E-type table, in the BESM Standards database, should be queried for a rule which may fire to provide a value for this rule target?
- Which rule classifier values must be obtained from the building description file in order to construct a valid query for this particular table?

When the required information is obtained, the Rules Mapper sends a message, with the classifier list and target table name, to the BESM Rules Engine. The BESM Rules Engine constructs the required SQL query statement, directs the query through the primary standards data access layer to the appropriate table and, assuming the corresponding rule fires, returns the needed value back to the Rules Mapper. The Rules Mapper assigns the value to the rule target (a process called tagging). This tagging process is then repeated on each line of the building description.

Two additional points should be made about the Rules Mapper. First, the Rules Mapper is another component constructed using the Adapter Design Pattern. This means the Standards database is really a pluggable data store which allows the BESM platform to support multiple sets of Standards. Thus routine compliance runs would be made against whatever is the currently published Title 24 Standards. Meanwhile, standards workers creating the next edition of the Standards could select an experimental database containing proposed changes for the next Standards cycle.

The second point is that the Rules Mapper exemplifies the fundamental design principle of Transparency. The B-type (binding) information used by the Rules Mapper is not buried in computer code. Binding information is accessible to any BESM user authorized with a sufficient permission level. Moreover, because binding information is defined and controlled in a publically available XML schema, it is intelligible to humans and directly understandable to the Rules Mapper.

Status: The Rules Mapper is the most sophisticated and complex software component in the BESM platform. Currently the Rules Mapper design has been extensively validated by public design walk-throughs. The B-type schema and instance documents have been partially implemented but the full collection of Rules Mapper classes is incomplete.

The Simulation Engine Articulator

The Simulation Engine Articulator comes into play with each request for a building energy simulation run. The basic task of the Simulation Engine Articulator is to transform a mapped

BESM building description XML file into a form which is natively recognized by the target simulation engine. Thus, the Articulator manages the second of the two transformation stages required for a simulation run on a BESM building description.

The Simulation Engine Articulator is another BESM component created using the Adapter Design Pattern. This means the Articulator is an alias for any of a number of possible components each of which is unique to a supported simulation engine. Currently only the EnergyPlus simulation engine is supported but the design pattern will allow other simulation engines to be "plugged in" if and when the need arises.

In operation, the EnergyPlus Articulator reads a mapped BESM XML building description. For every complex XML type in that description file, which has an EnergyPlus equivalent, the Articulator creates the equivalent EnergyPlus object. These objects are defined in the EnergyPlus Input Data Dictionary (IDD) which is the source of the intelligence required to do the conversion. The collection of IDD objects is then assembled into an EnergyPlus Input Data File (IDF) and returned to the Simulation Launcher where it is ready to be transmitted to the simulation engine.

The Articulator is another example of the Transparency design principle. The conversion algorithm used by the EnergyPlus Articulator is parameterized using an XML schema (the EnergyPlus Articulator Mapper schema). This schema contains the detailed steps for converting a given BESM complex XML type into the corresponding EnergyPlus object. The schema is publicly available for inspection by users who wish to know exactly how such a conversion is made by the Articulator.

The EnergyPlus Articulator has two important subcomponents. These are the Input Data Dictionary Parser and the Units Converter.

The Input Data Dictionary Parser

The EnergyPlus Input Data Dictionary (IDD) is published by the United States Department of Energy. Version 6.0.0.023 of the IDD consists of more than 62 thousand lines of text which describe each possible object that can be submitted to the EnergyPlus simulation engine. T he Input Data Dictionary Parser was created by L'Monte to extract all information for each of the 614 objects described by this version of the IDD . The parser extracts the information for each object and converts it to an IddType (the name of a BESM object-oriented class) which holds the information in formally structured manner. Finally, the parser adds all IDD types to an IddType hashtable for high-speed access in a subsequent phase of Articulator processing.

Status: Operational.

The Units Converter

Building energy simulation engines must process input containing many different types of denominate numbers. Such a number is characterized by having specific units of measure, such as meters or inches, and the unit for each denominate number must be unambiguously specified. The units system used by the Title 24 Standards in the Inch-Pound (IP) system

whereas that for the EnergyPlus simulation engine is the International System (SI). Therefore, each denominate number in a BESM Building Description file must be converted from its native IP units to the correct SI units expected by EnergyPlus. This is the function of the BESM Units Converter subcomponent. The Units Converter is another example of the Transparency design principle. All BESM Building Description files contain a complex XML type named Units. The Units complex type contains all information required to determine the exact units of each denominate number in the building description as well as the exact conversion factors between supported units systems.

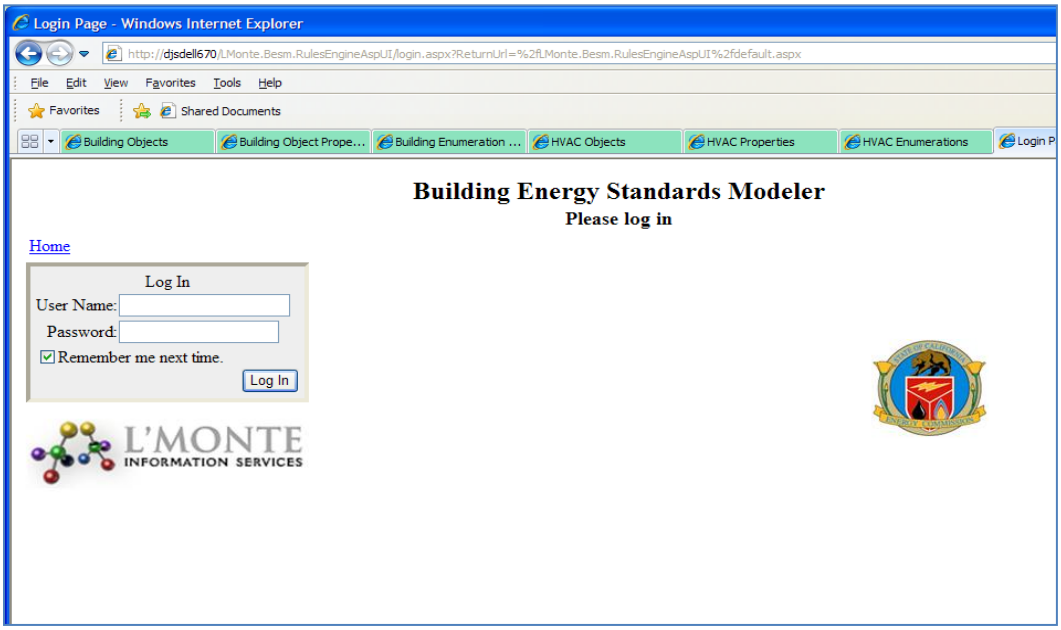
Status: Operational.

Overall Status of the EnergyPlus Articulator: Operational consistent with the *Incremental Validation principle.*

3.2.1.1 Screen Shots.

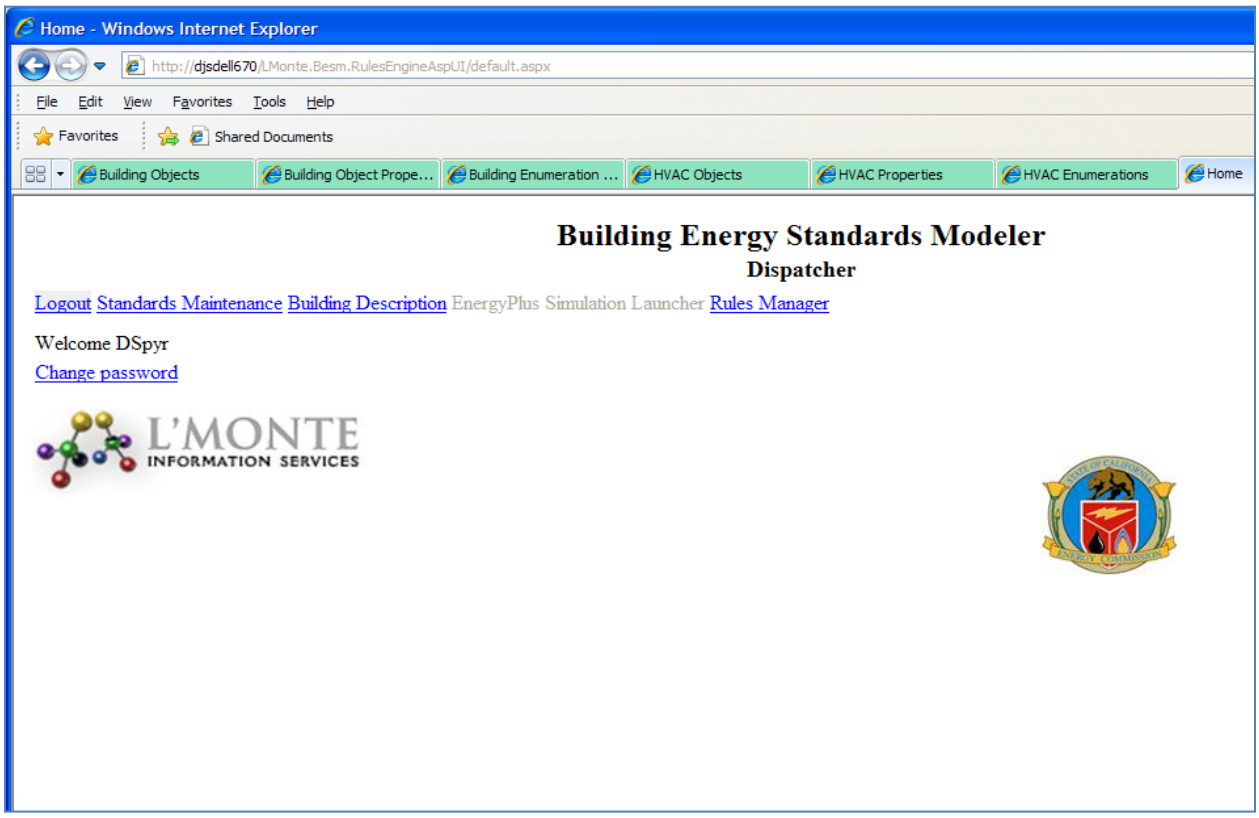
The current functionality of the BESM Integration Test Platform is demonstrated in the following screen shots for logging on and the dispatcher Web page with a menu for accessing different parts of the BESM platform. The Energy Plus Simulation Launcher link is disabled because there is no building selected.

Figure 14: BESM Integration Test Platform Log On Screen



Source: LMonte.Besm.RulesEngineAspUI.login.aspx running on L'Monte local machine

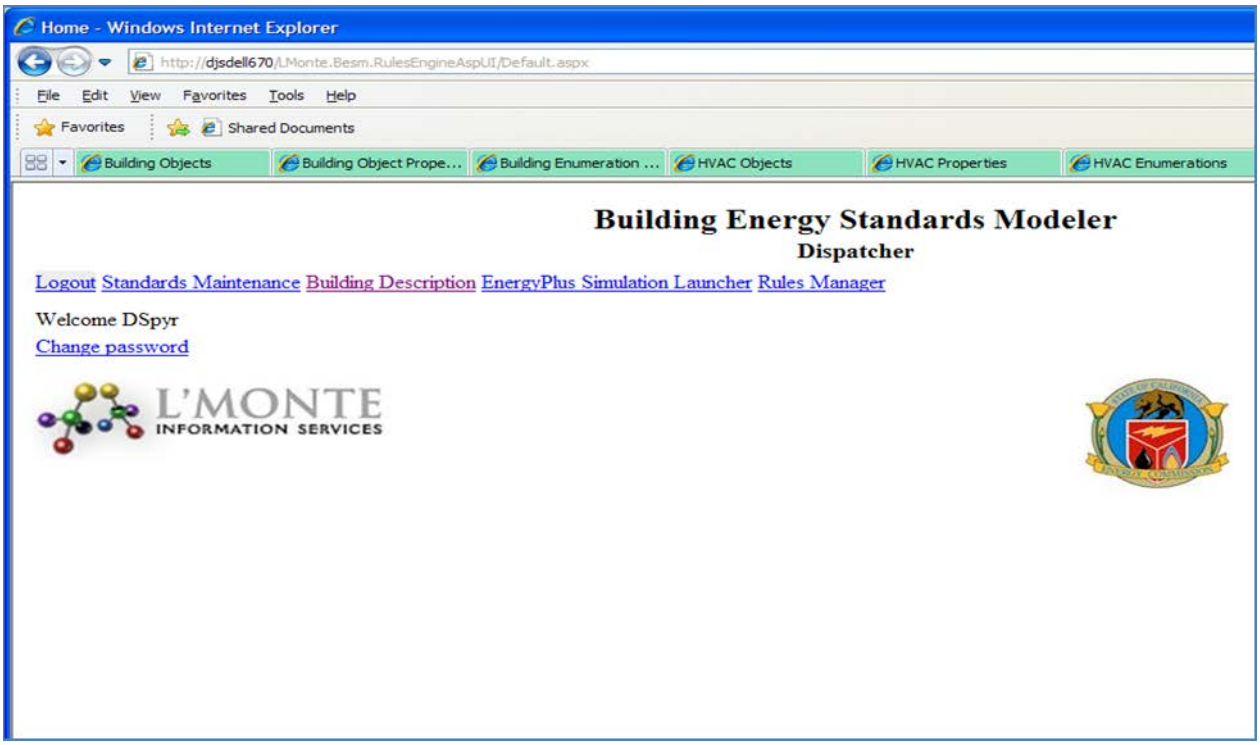
Figure 15: BESM Integration Test Platform Dispatcher Screen



Source: LMonte.Besm.RulesEngineAspUI.default.aspx running on L'Monte local machine

Once a building description is selected in the Building Description Manager, the EnergyPlus Launcher is enabled as shown in the next screen shot

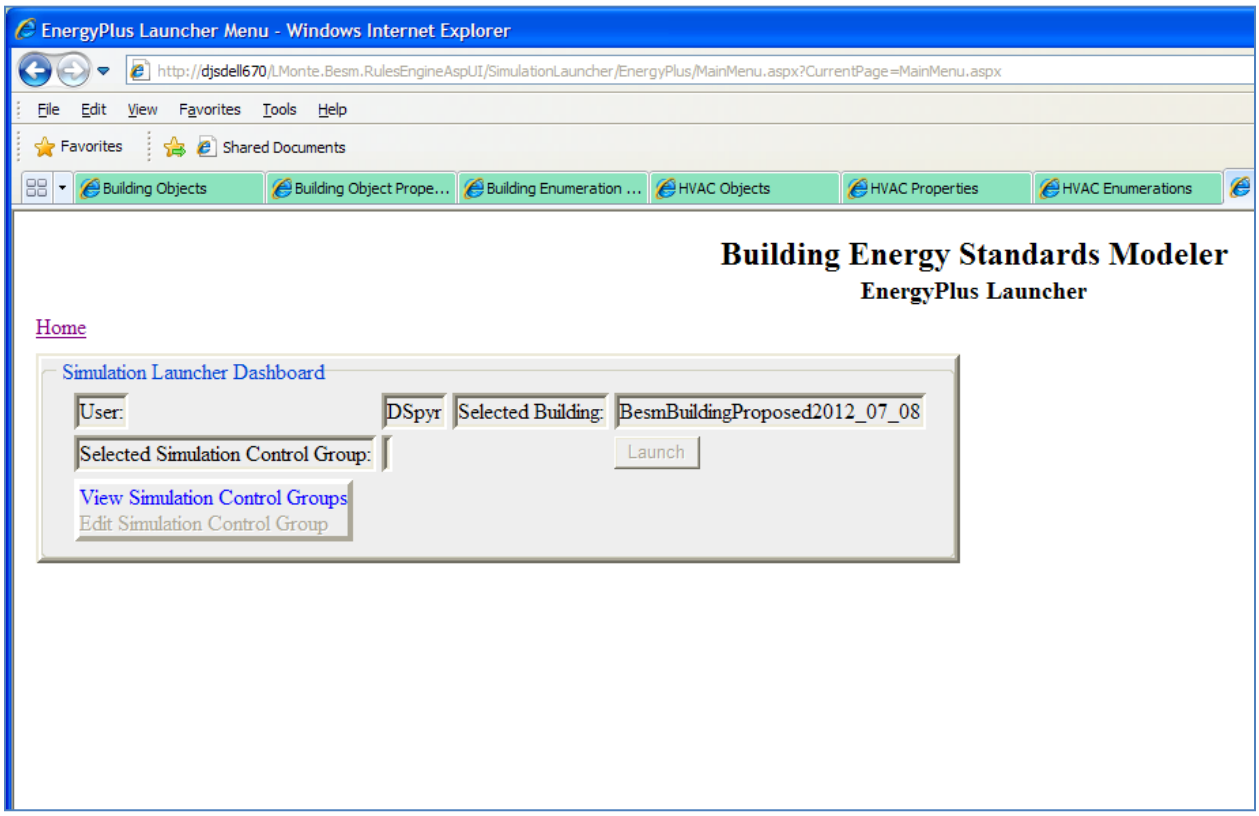
Figure 16: BESM Integration Test Platform Dispatcher Screen with EnergyPlus Simulation Launcher enabled



Source: LMonte.Besm.RulesEngineAspUI.default.aspx running on L'Monte local machine

Selecting the EnergyPlus Simulation Launcher displays the Simulation Launcher Dashboard which includes a control for viewing the user's simulation control groups for the selected building.

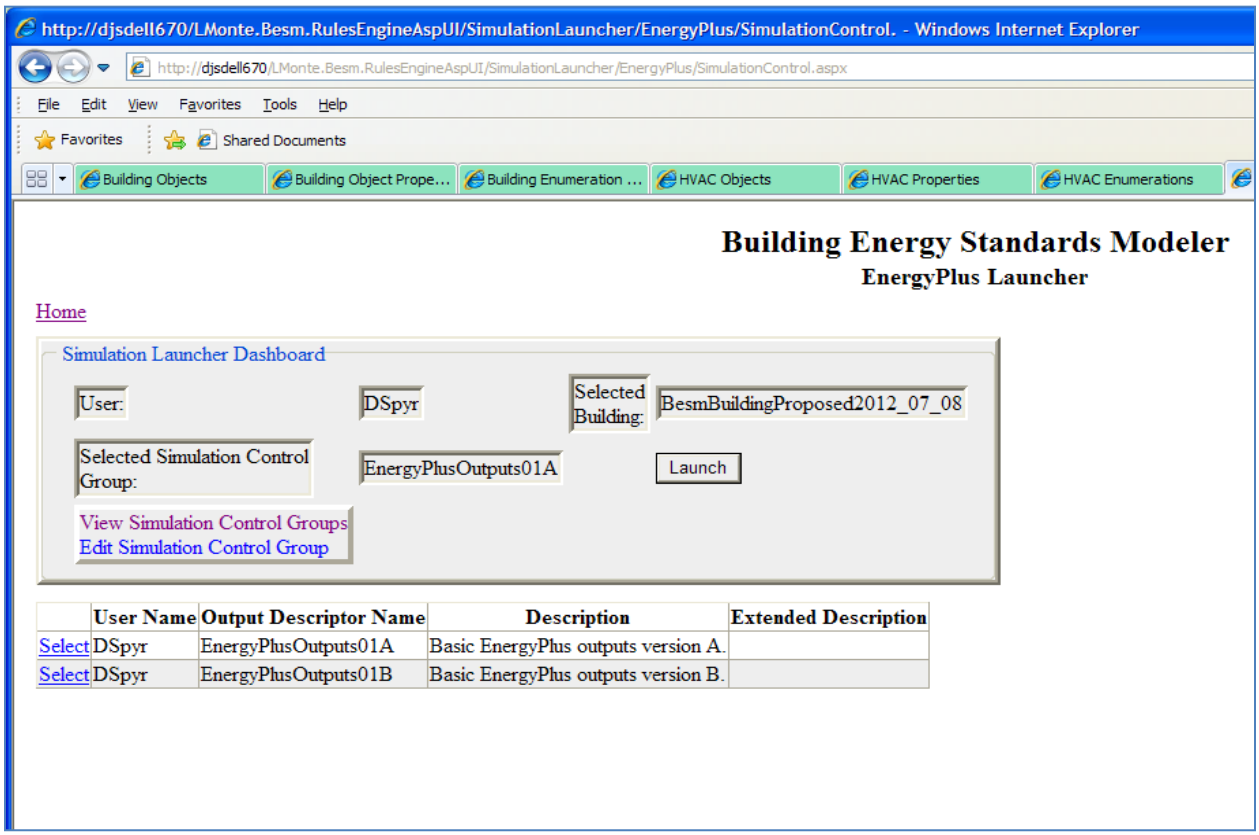
Figure 17: BESM Integration Test Platform EnergyPlus Simulation Launcher Dashboard



Source: LMonte.Besm.RulesEngineAspUI/SimulationLauncher/Energyplus/MainMenu.aspx running on L'Monte local machine

When the user selects View Simulation Control Groups, the simulation control groups owned by the user are displayed and the user can now select one or more of them. Each such simulation control group contains output variables or meters which will then appear in the subsequent reports produced by the simulation run on the selected building.

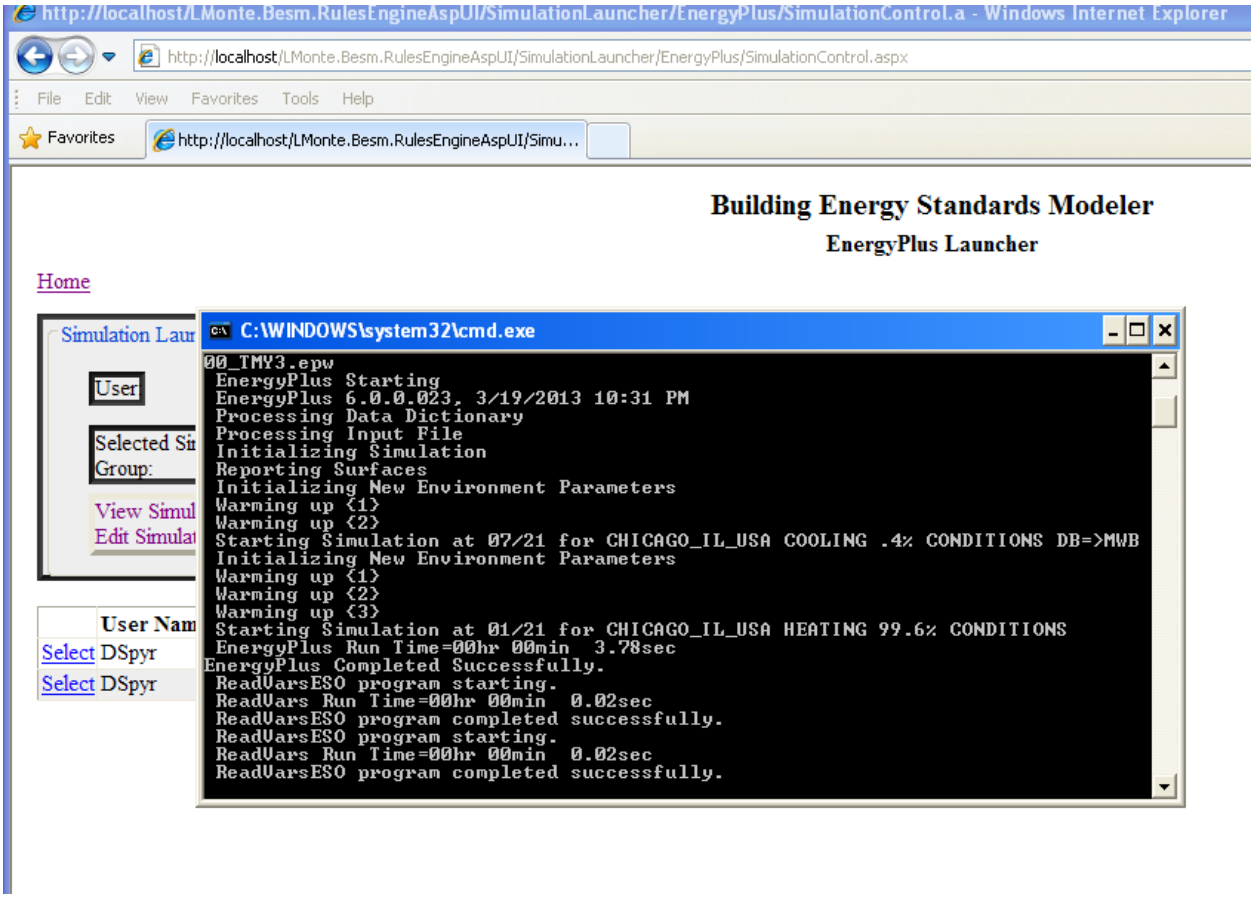
Figure 18: BESM Integration Test Platform Viewing Simulation Control Groups



Source: LMonte.Besm.RulesEngineAspUI/SimulationLauncher/Energyplus/SimulationControl.aspx running on L'Monte local machine

When the user has selected both a building and one or more simulation control groups, the Launch button becomes enabled. A push on the launch button activates a complex sequence of events. The first step in this sequence is activation of the BESM Rules Mapper which locates rule targets in the building description XML file for the selected building. The Rules Mapper also finds assignable values, in appropriate Standards database tables, for these rule targets and writes the values into the building description file. The second step is activation of the EnergyPlus Articulator which converts all applicable complex XML types, from the building description, into corresponding EnergyPlus objects as defined by the EnergyPlus Input Data Dictionary (IDD). In the final step, the Articulator collects all IDD objects into a single Input Data File (IDF) and submits this to the EnergyPlus simulation engine. The next thing the user sees is the real-time output from EnergyPlus which is visible in the screen shot below.

Figure 19: BESM Integration Test Platform Viewing EnergyPlus Command Window



Source: LMonte.Besm.RulesEngineAspUI/SimulationLauncher/Energyplus/SimulationControl.aspx running on L'Monte local machine

Description Manager can be found in chapters 1 and 2 respectively.

3.2.2 NREL's OpenStudio Replaced with the Simulation Engine Articulator

While the BESM proposal was in preparation, L'Monte had numerous discussions with the NREL team about collaborating on the project. By this time, L'Monte had decided the project would be developed using ASP.NET and C# on the Microsoft .NET technology platform. At that time the NREL team was considering rewriting their software but had not decided on a technology platform. Negotiations with NREL centered on the translation of the BESM Building Description format to a form natively understood by the EnergyPlus simulation engine. Initially the arrangement was to provide NREL with the BESM Building Description XML schema and let NREL develop the actual conversion software. However, by the time the contract was awarded, NREL had decided to focus its efforts on creating the OpenStudio class library. The intent of OpenStudio was to provide the building energy software community with a common code base, as well as some completed executables, for developing their own applications.

NREL's OpenStudio project is a collection of executable applications, such as ResultsViewer and RunManager and a large C++ class library (the SDK) which is intended to support cross-platform application development for building energy modeling. The BESM EnergyPlus Articulator is such an application whose purpose is to extract relevant information from the BESM Building Description format and convert this into an input data file (IDF) suitable for simulation runs using EnergyPlus.

Beginning August 1 of 2011, L'Monte made a vigorous, 13-week effort to use the OpenStudio SDK, version 0.4.0, to create the articulator which the BESM platform requires in order to perform building energy simulations using EnergyPlus. On November 1, 2011, this effort was abandoned after an extensive review showed that development progress with the SDK did not warrant continuation. The reasons for this disappointing result fall into the following three categories.

- Severe problems integrating unmanaged C++ code (in which OpenStudio is written) into the managed .NET environment in which the BESM platform is written.
- Lack of adequate documentation for the OpenStudio SDK.
- Effective use of the OpenStudio SDK carried the practical requirement of familiarity with a vast collection of dependent source code libraries and applications many of which present serious incompatibilities with the .NET environment.

The Managed-Unmanaged Boundary

The .NET development environment was chosen for the BESM project because, in L'Monte's opinion, it represents the most powerful, productive and integrated tool set for developing secure Web-based applications. In particular, C# managed code is used throughout BESM development for reasons of design-time productivity, run-time efficiency and resistance to hostile Web-based attack. Unfortunately, the inclusion of a large body of unmanaged, C++ code from the OpenStudio SDK resulted in both compile-time and run-time problems which eventually proved impractical to fix.

OpenStudio SDK Documentation

No software development kit (SDK) can be considered usable without abundant and accurate documentation. The plain fact is that, as of release 0.4.0, the documentation pages available for a great many crucial APIs were completely empty of useful information. It was possible, by making phone calls to designated NREL personnel, to get answers to specific questions. However, the size and complexity of the OpenStudio SDK would have required literally thousands of such calls. This made the attempt to use the SDK prohibitively frustrating and time-intensive.

Dependent Applications and Source Code Libraries

Simply building the OpenStudio SDK into usable binaries required downloading and mastering more than a dozen complex software tools which were either completely unfamiliar to L'Monte (such as the SWIG wrapper generator) or which (like the C++ compiler), L'Monte had

abandoned more than a decade ago for more modern tools. Altogether, the required downloads totaled more than 70,000 files. Furthermore, the nature of the build and run-time bugs L'Monte encountered during the 13-week effort required frequent reference to many of these files. This was particularly true for the Boost and QT libraries where L'Monte encountered the worst incompatibilities with the managed .NET environment.

3.3 Conclusions

Because the Integration Test Platform, by design, will evolve into the fully-functional BESM platform, the conclusions here are stated for the BESM platform as a whole. The Building Energy Standards Modeler is an advanced Standards development platform which will put game-changing power in the hands of building energy professionals. The BESM vision will revolutionize the creation, maintenance and use of the Standards as a computerized rule set which is completely transparent to human users and actually understood by the BESM software itself. BESM will support rapid, performance-based evaluation of new rules and automated rule publication in variable formats. BESM's adaptive architecture will support multiple rule sets and can be configured for multiple simulation engines.

3.4 Recommendations for Technology Transfer

As explained in the Project Approach section of Chapter 3, the sheer size and complexity of the BESM platform required that BESM development be done in the context of the Integration Test Platform (ITP) guided by the principle of Incremental Validation. L'Monte believes that the most effective way to control the considerable risks of very large scale software development is to continue with incremental development and validation using this principle. The following recommendations are those for incrementally advancing the current state of the ITP to the point of full BESM functionality.

E-Type (Equations) Information Management

Of the five information types found in the Standards, three have been successfully captured in digitally-accessible form. The prototype, supporting software for these three has been written and this constitutes proof-of-concept for this information group. A digitally-accessible form for the fourth type (equations) has been identified but not demonstrated in working code. The BESM team believes that special relational database tables and a symbolic equation evaluation engine is the appropriate mechanism to store and evaluate this type of information. Representing equations in symbolic (as opposed to numeric) form and creation of a symbolic (as opposed to calculator-like) evaluation engine constitutes a novel technological advance which is crucial because of the heavy use of equations throughout the Standards.

Exception Information Management

The fifth type of information found in the Standards is the long lists of disparate exceptions which can exempt certain building elements from being affected by specific rules. The technical problems of making such information digitally-accessible are challenging and, to the best of our knowledge, have never been solved. This is an R&D issue for which a practical solution must be found.

Production Methods of Software Class Development

Before the BESM vision becomes a user-ready Standards Development Platform, the R&D phase of the program must give way to a high-gear implementation phase in which a very large volume of software is produced. The Project Approach section of Chapter 3 gives an estimate of the total lines of code required for the completed BESM platform. In order to manage a task of this size, the most efficient techniques of code implementation become, in themselves, the subject of an R&D effort. The identification and refinement of these techniques, specialized for each of the major BESM modules, must be successful in order to move from R&D to a user-ready platform. On the basis of some preliminary investigation of possible techniques, L'Monte believes software factory production methods exist which can support such large-scale development at acceptable cost.

Hardening the BESM Platform against Attack

The BESM platform must be resistant to malicious attack. It is a sad truism that computer hackers cause millions of dollars in damage to online systems regardless of how important these systems may be to a nation and its citizens. All of the software developed to date for the BESM platform has been experimental. As a direct consequence of this, many of the modules have been repeatedly redesigned and re-implemented. For this reason, the intricate, often costly, defenses which must be placed in the code have not received the attention they must have for a secure platform. This must be addressed before the existing software modules can be extended and placed into service on a public-facing Web site. These required software defenses will be based upon the most advanced software technologies available including Code Access Security.

Developing Automated Publication of the Standards

The BESM platform should have automated means of publishing the Standards in whatever form the Energy Commission deems desirable. In order to make the Standards computer navigable, the BESM platform uses relational database tables. The BESM platform should be able to "slice and dice" the entire corpus of the Standards and reorganize them, in an error-free, publication-ready form. The general technology here is that of "report generation".

Make the Completed BESM Platform Accessible to All Authorized Users

The final step in technology transfer is to place an operational version of the BESM platform on a public Web site for testing by CEC and other professionals such as California IOUs, architects and interested engineering firms. This is an essential step equivalent to a "shakedown cruise" of a new naval vessel. For the first time, building energy professionals will have a tool set which provides complete transparency of operation in Standards creation, maintenance, what-if analyses and publication.

GLOSSARY

Term	Definition
BESM	See Building Energy Standards Modeler
Binding Information Set	An XML complex type which contains properties that are evaluated to perform high-level filtering in order to identify the correct Primary Standards table and the specific rule in that table to apply to a rule target.
Binding Information Table Classifier	A specific property in the Binding Information Set (q.v.).
Building Energy Standards Modeler	Building Energy Standards Modeler is a software platform for developing standards for regulating energy usage in buildings. L'Monte Information Services is the prime contractor who is responsible for the BESM prototype being under PIER research contract #500-08-035.
Canonical form	Any carefully prescribed constraint on the expression of information. Canonical forms are widely used in mathematics to specify useful ways expressing information such as in matrices or differential equations. Canonical forms were found, in the BESM project, which allow expressing building energy efficiency standards in a Digitally Competent Information Space (q.v.).
DCIS	See Digitally Competent Information Space.
Declarative	Said of a computer program control element which is understood by and under the control of an information system administrator rather than a computer programmer. Such control elements are typically expressed in a controlled natural language vocabulary rather than in computer code.
Digitally Competent Information Space	(Acronym DCIS) An abstract space whose contents are directly accessible, navigable and understandable to correctly written computer software as well as being directly accessible to humans with or even without computer assistance. Such a space can theoretically hold any type of information include a large body of regulatory requirements such as the Standards.
EnergyPlus Articulator	The basic task of the EnergyPlus Articulator is to transform a mapped BESM building description XML file into an input data file (IDF) which is EnergyPlus' natively recognized building description.
Evolutionary Prototyping	A software development life cycle most appropriate for large code base development which must contend with many high-risk R&D challenges. The BESM platform is being developed using this life cycle.

Incremental Validation Principle	A software development principle most appropriate for developing very large code bases in the face of numerous, high-risk R&D challenges. The principle holds that validation of interacting components and data storage schemas should reach a high confidence level before build out occurs. The basic point of the principle is to optimize risk management.
L'Monte	L'Monte Information Services, Inc.
Natural language	Any spoken, written or signed language which is or was historically used by humans in ordinary communications. The term is used to mean a linguistic system which developed without planned control over word meanings, sentence construction and the gradual changes in these which inevitably occur over time. Natural languages are characterized by innumerable ambiguities which have so far confounded more than 40 years of attempts at creating general-purpose software for natural language understanding.
Primary standards table	Primary standards table is a table in the BESM relational database that contains the rules for one rule target. Each row in a primary standards table is a rule which has values for one or more rule classifiers and the corresponding value assigned to the rule target. The rule classifiers are foreign keys from reference tables
Rule	A rule in the BESM Rule Set Manager is a statement that evaluates several attributes, called rule classifiers in order to assign a value to the rule target, which represents a mandatory, prescriptive or performance required maximum, minimum or default value. All rules are atomic which means they only assign one value to the rule target.
Rule classifier	Rule classifier is an attribute that is evaluated in order to assign a value to a rule target. Each rule classifier has a reference table that contains all the possible values for the rule classifier as well as a documentation field describing the significance of the rule classifier
Rules Engine	A major BESM module which has direct access to and complete control over all Standards database and metabase relational tables.
Rules Mapper	A BESM component which locates rule targets, in a building description XML document, searches out a rule which may supply a value for that target and 'tags' the rule target with the value.
Rule Table	Rule tables are a tool for identifying the rule targets and rule classifiers in a primary Standards table

Rule target	A building element property, in a BESM XML building description, that is regulated by a rule from the Standards. A rule target therefore has a mandatory or prescribed value assigned to it by exactly one precisely determined rule in a single Standards relational database table. An example is a fenestration product for which the Standards specify a U-factor limit value.
Schema	The structure of an information bearing object as opposed to the content of that object. A correctly specified schema will allow any information containing object (which is an instance of that schema) to be understood and validated by either computer software or manually by a human. Schemas are essential in managing the content of schema instances such as relational database tables and XML documents.
Standards	California Building Energy Efficiency Standards including Title 24 Part 6 and the Nonresidential ACM. In most cases the reference is to the 2013 Standards unless otherwise defined.
Transparency	An attribute of information management systems which maintain critical process controls, whenever feasible, in public, human-readable forms such as schema-controlled XML documents. The alternative to transparency is to bury such process control in computer code where it is accessible only to computer programmers.
XML Schema Definition Language	(Acronym XSDL) A markup language, developed and supported by the World Wide Web Consortium (W3C) XML Schema Working Group, for creating XML schemas.
XSDL	See XML Schema Definition Language.

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APPENDIX A:
Supporting BESM Documentation and Materials

A.1 Building Energy Standards Modeler (BESM) Building Description Project Survey

by Robert J Hitchcock, Hitchcock Consulting

As part of the California Energy Commission's PIER Building Energy Standards Modeler (BESM) Research Program, we are requesting feedback on building data models and specification development for the BESM Building Description Project.

The purpose of the BESM Building Description Project is to specify and implement a building data model and associated methods capable of supporting: 1) the import into the BESM environment of building models in a variety of formats, 2) the creation of a persistent BESM Buildings Catalog for testing standards rule sets, and 3) other internal operations within the BESM environment such as transforming building data into the format required by the Compliance Analysis Manager and capturing results from compliance analyses.

Below is a short survey asking for project input. This is not a formal survey. Any and all comments and questions on this document are welcome.

For more details on the project, please refer to the following background document - BESM Building Description Project Background. For any questions, please contact Rob Hitchcock (RJHitchcock@gmail.com).

Thank you for your participation.

CANDIDATE BUILDING DATA MODELS

The initial task of the BESM Building Description Project is two-fold: 1) to evaluate existing building description formats to identify necessary and appropriate data, definitions, and model structure to adopt in the BESM building model; and 2) to identify candidates for developing import conversion methods. It is not the intent of this Project to develop a completely new building data model. However, it is anticipated that BESM requirements will necessitate modifications and extensions to adhere to BESM conventions such as the Data Dictionary, and to support compliance-specific operations that existing data models do not.

What type of building data models do you have experience in?

Data Model	None	Some (1-3 years)	Moderate (4-6 years)	High (7 years or more)
CEUS				

Data Model	None	Some (1-3 years)	Moderate (4-6 years)	High (7 years or more)
Comnet				
DOE-2 BDL				
EnergyPlus IDD				
gbXML				
hpbML				
ICC SMARTcodes				
IFC				
LBNL EnergyPlus GUI				
Specify your own value:				
Specify your own value:				
Specify your own value:				
Specify your own value:				

Please indicate your approval of evaluating the following existing building data models, and list any additional data models you would like to see considered.

Data Model	Don't Know	1 =Very Low Priority	2 = Low Priority	3 = Moderate Priority	4 = High Priority	5 = Very High Priority
CEUS						
Comnet						
DOE-2 BDL						
EnergyPlus IDD						
gbXML						
hpbML						
ICC SMARTcodes						
IFC						
LBNL EnergyPlus GUI						
Specify your own value:						
Specify your own value:						
Specify your own value:						

Data Model	Don't Know	1 =Very Low Priority	2 = Low Priority	3 = Moderate Priority	4 = High Priority	5 = Very High Priority
Specify your own value:						

Explain your reasoning for including or excluding candidates for evaluation.

_____

_____

SPECIFICATION DEVELOPMENT

It would be nice if there were an existing building model capable of supporting all BESM requirements for internal data representation and manipulation, and a persistent buildings catalog. Until the first task of model evaluation is completed, it is not known if this is feasible.

Please discuss your opinion on the feasibility of adopting an existing building data model and perhaps extending it to support additional BESM requirements.

Is there an existing data model the BESM project can fully adopt?

Yes

No

Don't Know

If Yes, please explain which existing data model should be used and why?

_____

_____

Do you think the Project should define a new internal and persistent data model based on the evolving BESM Data Dictionary and the best of existing data models?

Yes

No

Don't Know (Skip to question 9)

If Yes, please explain which existing data model(s) should be used and why?

_____

_____

If No, please explain why?

_____

_____

Is it acceptable to default some building data during import based on high level information such as HVAC system type, rather than attempt to fully map all data elements?

Yes

No

Don't Know

Because an unambiguous BESM data dictionary is required for creating Standards as rule sets that are processed for code compliance, does this require a single BESM environment data model rather than separate Compliance Analysis and BESM building description models?

Yes

No (Skip to question 12)

Don't Know (Skip to question 12)

If yes, please explain your reasons why?

_____

_____

Are there any other issues the BESM Building Description project should consider?

_____

_____

How can we make this survey better? Who should we ask to complete it? Any other comments or questions you would like to ask - please post here.

_____

_____

OPTIONAL - Please provide your name and contact information below:

Name _____

Title _____

Company _____

A2. Building Energy Standards Modeler (BESM) Rule Table Implementation

Robert J. Hitchcock, Ph.D.
Hitchcock Consulting

Prepared Under Subcontract LIS-09-02-01 for:

L'Monte Information Services

Under Prime Contract #500-08-035-01 between L'Monte and the California State Energy Resources Conservation and Development Commission

Introduction

The data representation of Title 24 Standards rules in BESM is based on what are referred to here as *Rule Tables*. BESM Rule Tables are initially identified from the Title 24 Standards text-based tables such as Table 140.3 and Table 140.3-B in Section 140.3 of the Part 6 document. The Standards tables are then analyzed and reformulated using BESM rules processing conventions that lead to a BESM database conformant representation supporting the expression of Standards rules as entity relationships in a relational database. Database technology was chosen for the BESM Rules Engine because it allows the representation of individual rules for editing by Standards professionals without requiring software programming skills.

This document describes the BESM Rule Table development process, issues encountered in reformulating existing Title 24 Standards tables to BESM Rule Tables, and recommendations for improving Title 24 tables in future versions of the Standards.

BESM Rule Table Implementation

An initial review of existing tables contained in the Title 24 Part 6 Standards has been performed to represent the tables according to the conventions required for BESM rules processing. This initial review has focused on envelope and lighting related sections of the Standards Part 6 document including Sections 140.3 and 140.6; and Tables 140.3, 140.3-B, 140.3-C, 140.3-D, 140.6-A, 140.6-B, 140.6-C, 140.6-D, 140.6-E, and 140.6-G.

BESM Rule Table Conventions

Rule Table Elements

BESM rules processing requires that Rule Tables be represented using the following elements:

- ***Rule Target***: The purpose of each BESM Rule Table is to set a default, minimum, or maximum value established by the Standards for appropriate Standards Data Dictionary (SDD) object property terms. The SDD term that is assigned such a value is called a Rule Target. An example of a Rule Target is the *minimum aged solar reflectance for roofs* that is established in Part 6 Section 140.3.
- ***Rule Classifier***: The SDD object property terms that must be evaluated in order to determine the Standards-established value for a Rule Target are called Rule Classifiers. For example, the Rule Target minimum aged solar reflectance for roofs is established in Table 140.3-B dependent on *roof slope* (steep or low) and *climate zone*. These two properties are thus Rule Classifiers in this case.
- ***Rule (Rule Table Row)***: Each Row (database table "record" or "tuple") in a Rule Table constitutes a single Rule whereby when the set of Rule Classifier values in that Row are compared against an input set of values, that Row can be evaluated as being either True or False. If True, then the Rule Target is assigned the Rule Target value in that Row. If False, then processing continues to another Row in that Rule Table.
- ***Binding Information Classifier***: Binding information supports high-level filtering of elements to which a particular BESM Rule Table applies. A Binding Information Classifier identifies the specific SDD object property to be used as a filter to determine which BESM Rule Table is to be used to establish a specific Rule Target value. Binding Information Classifiers are very similar to Rule Classifiers and the differentiation between the two depends on the particular Standards table being reformulated to BESM Rule Tables. For example, Standards Table 140.3-B establishes values for maximum U-factor for a wide variety of building surface elements including *roofs*, *walls*, and *floors*. Each of the surface element types is further categorized by construction type such as *metal-building* or *wood-framed* roof. The subdivision of this complex Standards Table into multiple BESM Rule Tables adhering to BESM conventions discussed below could be based on a Binding Information Classifier of either building surface *element type* or *construction type*, which would in turn influence how the Rule Classifiers are defined.

Rule Table Conventions

BESM rules processing requires that Rule Tables be represented using the following conventions:

- For each Standards table, each SDD term that is a Rule Target will have its own BESM Rule Table. This leads to simple logical rules that are essential when modeling a complex information space like building energy efficiency standards. In database terminology this meets the Unitarity requirement.

- Each Rule Target must be logically unique and not overlap the meaning of another Rule Target. To be logically unique, a Rule Target must have appropriate specificity, meaning that it is not so broad that it encompasses more than one set of rule classifiers. For example, if U-Factor was defined as a Rule Target that was to be assigned to all building surface types including floors, walls, roofs, etc., the resulting Rule Table would necessarily include Rule Classifiers related to roofs (e.g., slope) that don't apply, or wouldn't have the same meaning, in relationship to walls. To ensure in this example that each Rule Table is solely focused on one set of Rule Classifiers that apply to its unique Rule Target, U-Factor should be separated into Floor U-Factor, Wall U-Factor, Roof U-Factor, etc. (Specificity requirement)
- Each Rule Classifier must be logically unique and not overlap the meaning of another Rule Classifier. Rule Classifiers must avoid ambiguity and interdependence. Furthermore, the set of Rule Classifier allowable values must be of consistent meaning and type, must not overlap (i.e., must be mutually exclusive), and must cover all possible values for that Rule Classifier (i.e., must be all inclusive). For example, Table 140.3-B (2013) is intended to establish maximum area-weighted U-factors for vertical fenestration of various types. Classifying values (column headings) in this section include: Fixed Window, Operable Window, Curtainwall or Storefront, and Glazed Door. Curtainwall is not defined within the Standards, but what if portions of a Curtainwall can be either Fixed or Operable? In this case there would be an ambiguous overlap in possible values. (Orthogonality requirement)
- Every allowable value for a Rule Target must be addressed within each Rule Table. This is a Completeness requirement, which means that there are no cases where an allowable value is never assigned to the Rule Target across all Rules (Rows) in a Rule Table.
- Every allowable value for all Rule Classifiers must be addressed in each Rule Table (Completeness requirement).
- One and only one value can be assigned to a Rule Target for each allowable combination of values of Rule Classifiers contained in a Rule Table. This is an Atomicity requirement, which means that there is never a case where a Rule Target does not get assigned a value after processing all Rows in a Rule Table, and also never a case where a Rule Target can be assigned more than one value after Rule Table processing. In other words, there is one and only one Row within a Rule Table that applies for each unique combination of Rule Classifier values.
- Ranges used, or implied, in Rule Target or Rule Classifier values must adhere to agreed upon conventions to avoid missing values. The proposed BESM conventions are as follows:

- Ranges are expressed with the lower bound included and upper bound excluded, that is, minimum inclusive, maximum exclusive
- The round-off rule for values with higher precision than expressed in the range is: if the digit to the right of the rounding digit is 0, 1, 2, 3, or 4 do not change the rounding digit; if the digit is 5, 6, 7, 8, or 9, the rounding digit rounds up by one

Rule Table Scope

Current example BESM Rule Tables only address the actual Standards tables reviewed to date. The Standards text sections related to each Standards table provide further details and exceptions that must eventually be captured to fully process the intent of the Standards. While implementation of these additional details and exceptions is beyond the scope of this document, a series of Use Cases are documented elsewhere in this final report explicating the requirements for complete Standards rule processing

BESM Rule Table Reformulation

Each Title 24 Standards text-based table must be reformulated using the BESM Rule Table Conventions specified above. This reformulation process is discussed here. A spreadsheet has been created containing the status of each envelope and lighting Standards table that has been analyzed to date (see BESMRuleTableStatusYYYYMMDD.xlsx). BESM Rule Tables that have been reformulated into spreadsheet format are contained in spreadsheet workbooks for each domain (see T24EnvelopeTablesYYYYMMDD.xlsx and T24LightingTablesYYYYMMDD.xlsx).

The reformulation process begins by identifying all Rule Targets within a given Standards table. Secondly, a list of all Rule Classifiers within the Standards table is identified. Then, the list of Rule Classifiers is analyzed to determine which, if any, should be made Binding Information Classifiers.

Separate BESM Rule Tables are then created for each identified Rule Target. Identified Binding Information Classifiers further subdivide the original Standards table into separate BESM Rule Tables for each possible Binding Information Classifier value. A relatively simple example based on Standards Table 140.3, shown below, which supports the following Standards text, will help illustrate this process.

EXCEPTION 4 to SECTION 140.3(a)1Aia (Nonresidential Low-Sloped Roofs in all Climate Zones): *An aged solar reflectance less than 0.63 is allowed provided the maximum roof/ceiling U-factor in TABLE 140.3 is not exceeded.*

Nonresidential

Aged Solar Reflectance	Metal Building Climate Zone 1-16 U-factor	Wood Framed and Other Climate Zone 1 &5 U-factor	Wood Framed and Other Climate Zone 2-4, 9-16 U-factor	Wood Framed and Other Climate Zone 6 U-factor	Wood Framed and Other Climate Zone 7 & 8 U-factor
0.62-0.60	0.061	0.045	0.036	0.065	0.059
0.59-0.55	0.054	0.041	0.034	0.058	0.053
0.54-0.50	0.049	0.038	0.032	0.052	0.048
0.49-0.45	0.047	0.035	0.030	0.047	0.044
0.44-0.40	0.043	0.033	0.028	0.043	0.040
0.39-0.35	0.039	0.031	0.027	0.039	0.037
0.34-0.30	0.035	0.029	0.025	0.037	0.035
0.29-0.25	0.033	0.027	0.024	0.034	0.032

Table 140.3 establishes minimum allowable *Aged Solar Reflectance*, which is thus identified as the only Rule Target for this Standards table.

The value of this Rule Target is explicitly dependent upon the Roof/Ceiling construction type ("Metal Building" or "Wood Framed and Other"), the Roof/Ceiling U-factor, and the Building Climate Zone (for Wood Framed and Other construction type) through inclusion of these attributes in the Standards table. These attributes are thus identified initially as Rule Classifiers. Note also, that this Standards table implicitly (through its reference in the Standards text Exception) applies only to exceptions for nonresidential building types and low-sloped roofs, so these qualifiers should also be kept in mind as potential Rule Classifiers.

Decisions now need to be made as to which, if any of the initially identified Rule Classifiers might become Binding Information Classifiers to simplify the set of BESM Rule Tables that are created from this Standards table. Nonresidential vs. Residential certainly seems a candidate for Binding Information Classifier. This would facilitate rule processing on submitted buildings since all Residential buildings would simply ignore processing this table. Since this Standards table only applies to Low-Sloped Roofs, this should also be a Binding Information Classifier (if Roof Slope were a Rule Classifier in this case, all Rules (Rows) in the resulting Rule Table would have the same value of "low-sloped"). Roof/Ceiling construction type might also be considered as a candidate for Binding Information Classifier. Since a single set (column) of U-factors apply across all Climate Zones for Metal Building types, subdividing by this attribute would result in a simpler BESM Rule Table for this type.

For this example, we will decide that Standards Table 140.3 contains a single BESM Rule Target (Roof/Ceiling Aged Solar Reflectance), either one or two BESM Rule Classifiers (Building Climate Zone and Roof/Ceiling U-factor) depending on construction type, and three BESM Binding Information Classifiers (Building Type [Nonresidential or Residential], Roof Slope [Low or Steep]

and Roof/Ceiling Construction Type [Metal Building or Wood Framing and Other]). These decisions lead to the creation of two BESM Rule Tables as shown below.

Note that for the Metal Building Construction Type Rule Table, Building Climate Zone is not needed as a Rule Classifier since a single Rule Target value applies across all climate zones.

Binding Information Classifiers	***Building Type: Nonresidential Building*** ***Roof Slope: Low-Sloped Roof*** ***Construction Type: Metal Building Roof/Ceiling***
Rule Classifier	***Rule Target***
Ufactor (minInclusive, maxExclusive)	***MinimumAgedSolarReflectance***
GTE 0.062	*0.63*
0.055 to 0.062	*0.60*
0.050 to 0.055	*0.55*
0.048 to 0.050	*0.50*
0.044 to 0.048	*0.45*
0.040 to 0.044	*0.40*
0.036 to 0.040	*0.35*
0.034 to 0.036	*0.30*
LT 0.034	*0.25*

Binding Information Classifiers	***Building Type: Nonresidential Building*** ***Roof Slope: Low-Sloped Roof*** ***Construction Type: Wood Framing And Other Roof/Ceiling***	
Rule Classifier	***Rule Classifier***	***Rule Target***
ClimateZone	***Ufactor (minInclusive, maxExclusive)***	***MinimumAgedSolarReflectance***
1	*GTE 0.046*	*0.63*
1	*0.042 to 0.046*	*0.60*
1	*0.039 to 0.042*	*0.55*
1	*0.036 to 0.039*	*0.50*
1	*0.034 to 0.036*	*0.45*
1	*0.032 to 0.034*	*0.40*
1	*0.030 to 0.032*	*0.35*
1	*0.028 to 0.030*	*0.30*
1	*LT 0.028*	*0.25*
5	*GTE 0.046*	*0.63*
5	*0.042 to 0.046*	*0.60*

Binding Information Classifiers	Building Type: Nonresidential Building Roof Slope: Low-Sloped Roof Construction Type: Wood Framing And Other Roof/Ceiling	
Rule Classifier	**Rule Classifier**	**Rule Target**
ClimateZone	**Ufactor (minInclusive, maxExclusive)**	**MinimumAgedSolarReflectance**
5	0.039 to 0.042	0.55
5	0.036 to 0.039	0.50
table truncated here to save space…		

BESM Rule Table Processing

The BESM Rules Engine would process the above Rule Tables as follows:

1. Binding Information Classifiers are evaluated for a submitted Proposed Building.
2. If the Proposed Building is Nonresidential, has a Low-Sloped Roof, and that Roof is of Metal Building construction type, then the first Rule Table shown above will be processed.
    a. In this case the single Rule Classifier of Roof Ufactor is now evaluated. The appropriate Rule (Rule Table Row) is identified based on the Ufactor value, and the corresponding MinimumAgedSolarReflectance value is assigned as the Rule Target value.
3. If the Proposed Building is Nonresidential, has a Low-Sloped Roof, and that Roof is of Wood Framing and Other construction type, then the second Rule Table shown above will be processed.
    a. The two Rule Classifiers Climate Zone and Ufactor are now evaluated, the Rule that matches both values is indentified, and the corresponding MinimumAgedSolarReflectance value will be assigned as the Rule Target value.
4. If the Proposed Building is Residential OR has a Steep-Sloped Roof, then neither of the Rule Tables shown above will be processed.

Note that a more detailed description of the BESM Rules Engine processing is given elsewhere in the BESM Final Report.

Standards Table Issues

A number of issues have arisen while analyzing the existing envelope and lighting Title 24 Standards tables and reformulating them to BESM Rule Tables. These issues lead to problems in interpreting Standards tables by users as well as other Standards staff and to long-term maintenance of these tables. This is especially true in cases where a single Standards table

contains multiple rule targets with different sets of rule classifiers. The effort it takes to understand how to apply the rules in such a table is often a barrier to using them properly. Furthermore, such tables make it very difficult to ensure that all possible scenarios are covered and that there are no conflicts embedded in a table. Missing data or conflicting rules mean for some cases there is either no assigned target value or more than one assigned value and this potentially leaves the door open to gaming the system. The only way to establish that the table is correct is to do the same type of reformulation that has been performed in the BESM project to prepare the tables for representation in a relational database. Some of the specific issues encountered in BESM reformulation to date are discussed below.

Multiple often disparate Rule Targets and Rule Classifiers in one Standards table

Multiple Rule Targets

The Standards Table 140.3 example discussed above contains only a single Rule Target, *Aged Solar Reflectance*. However, many tables currently contained in the Standards include more than one Rule Target, requiring separation into individual BESM Rule Tables. Standards Table 140.3-B on Prescriptive Envelope Criteria is a good example of this. Table 140.3-B establishes Rule Target values for *Maximum U-factor* (for individual Roofs/Ceiling, Walls, Floors/Soffits, and Exterior Doors), *Maximum Area Weighted U-factor* (for Vertical and Skylight Fenestration), *Aged Solar Reflectance* and *Thermal Emittance* (for Low-Sloped and Steep-Sloped Roofing Products), *Maximum Area Weighted U-factor*, *Maximum Area Weighted RSHGC*, *Minimum Area Weighted VT*, and *Maximum WWR%* (for Vertical Fenestration), and *Maximum Area Weighted U-factor*, *Maximum Area Weighted SHGC*, *Minimum Area Weighted VT*, and *Maximum SRR%* (for Skylight Fenestration), with a true/false requirement for an *Air Barrier* thrown in.

That is at least ten Rule Targets (depending on reformulation) in a single Standards table. This makes maintenance of this single table difficult as Standards change. Subdividing this table into multiple Rule Tables based on BESM conventions would greatly simplify this maintenance.

This disparate collection of Rule Targets in a single table may be acceptable for human parsers of this information, though it certainly adds difficulty with this complexity. However, reliable computable parsing of this collection would be very difficult if not impossible.

Multiple and Disparate Rule Classifier

Table 140.3-B also contains multiple Rule Classifiers that are different for different Rule Targets. For example, Air Barrier is only dependent on Climate Zone, Maximum U-factor for Walls is dependent on Climate Zone and Construction Type, Maximum U-factor for Vertical Fenestration is dependent on Window Operation and Window Type, but not on Climate Zone,

and is an area-weighted value rather than an individual surface value as it is for Walls, and Maximum WWR% is not dependent on any Rule Classifier.

Again, this disparate collection within a single table increases the difficulty of human parsing and maintenance, and makes computable parsing impossible.

Incomplete and inconsistent specification of Rule Target and Classifier values and ranges

Standards Table 140.3, shown above, is an example of incomplete and inconsistent specification of Rule Target and Rule Classifier values and ranges that violate the BESM database requirements of atomicity and completeness. These violations also potentially lead to inconsistent results even for human processing of tables.

The U-factor values listed in each column in Table 140.3 imply ranges for each row, but are instead listed as a single value in each row. Conversely, each row in the table contains a specified range for Aged Solar Reflectance even though the Standards text that references this table implies that each row is really establishing a ***minimum allowable*** value exception.

For example, for a Nonresidential building type with a Metal Building roof construction type in all Climate Zones, the first row in Table 140.3 indicates that if the Roof U-factor does not exceed 0.061 (with units of measure not specified), then the allowable Aged Solar Reflectance is 0.62-0.60. But why specify a range of 0.62-0.60? Doesn't this row simply establish a new ***minimum allowable*** Aged Solar Reflectance of 0.60 if the Roof U-factor does not exceed 0.061?

Similarly looking at the second row in this table, doesn't this row simply establish a new ***minimum allowable*** Aged Solar Reflectance of 0.55 if the Roof U-factor does not exceed 0.054?

Now, what happens for the case with a Roof U-factor of 0.059? A human parser of this table could reason that since 0.059 exceeds the 0.054 value in the second row, but does not exceed the 0.061 value in the first row, that the first row applies to this case. But to make this table computable, the applicable U-factor range must be specified for each row.

So in this table, the U-factor Rule Classifier should be expressed as a range in each row, and the Aged Solar Reflectance Rule Target should be expressed as a single value in each row.

Furthermore, each range must adhere to known conventions for interpreting the lower and upper bounds and rounding off values with greater precision than shown in the table.

Lastly, cases with a Roof U-factor greater than 0.061 are not handled by Table 140.3, which is a violation of the completeness requirement.

Each of these issues has been addressed in the first example BESM Rule Table shown above. The first row of this BESM Rule Table sets the ***minimum allowable*** Aged Solar Reflectance to 0.63 for Roofs with U-factors greater than or equal to 0.062. The second row sets the ***minimum***

allowable Aged Solar Reflectance to 0.60 for Roofs with U-factors within the range of 0.055 (inclusive) to 0.062 (exclusive). Values with greater precision than the 3 significant digits shown in this range are rounded off according to the convention given above.

No documented range or round-off conventions to assure consistency within and across Standards tables.

The Table 140.3 example discussed above illustrates this issue and its suggested resolution.

Inconsistent terminology and values used within Standards

Table 140.6-A Lighting Power Adjustment Factors contains a Rule Classifier named "Type of Area" for which values are free-form text. Table 140.6-C on the other hand contains a Rule Classifier named "Primary Function Area" that adheres to a list of possible values that are used consistently throughout the Standards text. Table 140.6-C is consequently much easier to reformulated and maintain over time than Table 140.6-A.

Table 140.6-B contains a Rule Classifier named "Type of Building" that adheres closely to a list of possible values established elsewhere in the Standards text. However, the table does not contain a row with the building type value of "Data Center Building" which is in this list.

The tables in Standards Section 140.3 use a Rule Classifier of Roof Slope with possible values of *low* or *steep*. Section 100.1 of the Standards define a criterion to determine if a roof slope is low or steep (a roof that has a ratio of rise to run of greater than 2:12 (9.5 degrees from the horizontal) is considered steep). However, this criterion is not restated in Section 140.3 nor as a footnote to its tables making this a potentially ambiguous classifier.

Numerous text-based details and exceptions that significantly modify application of Standards tables.

Table 140.3 supports an exception to Table 140.3-B. This is one of the few examples in the Title 24 Standards where textual details and exceptions to existing Standards tables are actually expressed in secondary tables. For the most part, such details are expressed solely in text that can only be interpreted by a human reader. Alternative approaches to encoding Standards for automated computer processing require extensive rule sets based on precise customized rule syntax that must be compiled and maintained by experts in both the Standards and the specified rule syntax. The BESM Rules Engine approach to encoding the Standards in database conformant Rule Tables is designed to be accessible to Standards developers who are not necessarily expert rule writers and computer software developers.

Standards Table Recommendations

Addressing the issues described above would improve Standards professional end-user usability and help to avoid gaming from ambiguous rules that can be favorably interpreted. The result of issues of this type is that all but dedicated energy code consultants are discouraged from delving into the Standards because the assumption is that there is inside knowledge somewhere that would be missed by the part-time user, similar to the IRS tax codes. The following recommendations could also improve the overall usability of the Standards tables.

Incorporate text-based details and exceptions in Standards tables

Section 140.3(a)1Aia *Envelope Component Approach* of the 2013 Title 24 Part 6 Standards contains several text-based exceptions that modify the Rule Target values assigned by Table 140.3-B. This section is shown below.

(a) **Envelope Component Approach.**

1. **Exterior roofs and ceilings.** Exterior roofs and ceilings shall comply with each of the applicable requirements in this subsection:

A. **Roofing Products.** Shall meet the requirements of Section 110.8 and the applicable requirements of Subsections i through ii:

i. Nonresidential buildings:

a. Low-sloped roofs in climate zones 1 through 16 shall have:

1. A minimum aged solar reflectance of 0.63 and a minimum thermal emittance of 0.75; or

2. A minimum Solar Reflectance Index (SRI) of 75.

EXCEPTION 1 to Section 140.3(a)1Aia: Wood-framed roofs in climate zones 3 and 5 are exempt from the requirements of Section 140.3(a)1Aia if the roof assembly has a U-factor of 0.039 or lower.

EXCEPTION 2 to Section 140.3(a)1Aia: Metal building roofs in climate zones 3 and 5 are exempt from the requirements if the roof assembly has a U-factor of 0.048 or lower.

EXCEPTION 3 to Section 140.3(a)1Aia: Roof constructions that have thermal mass with a weight of at least 25 lb/ft² over the roof membrane are exempt from the requirements of Section 140.3(a)1Aia.

EXCEPTION 4 to SECTION 140.3(a)1Aia: An aged solar reflectance less than 0.63 is allowed provided the maximum roof/ceiling U-factor in TABLE 140.3 is not exceeded.

b. Steep-sloped roofs in climate zones 1 through 16 shall have a minimum aged solar reflectance of 0.20 and a minimum thermal emittance of 0.75, or a minimum SRI of 16.

Statement (a)1Aia1 simply restates the MinimumAgedSolarReflectance and MinimumThermalEmittance Rule Target values established by Table 140.3-B for Low-sloped roofs in all climate zones. Statement (a)1Aib restates the Rule Target values established in Table 140.3-B for Steep-sloped roofs in all climate zones.

Statement (a)1Aia2 introduces a Rule Target of MinimumSolarReflectanceIndex that is not even mentioned in Table 140.3-B. Solar Reflectance Index (SRI) is defined in the Definitions section and is briefly discussed in one paragraph of Section 110.8 Mandatory Requirements, but

is not otherwise mentioned except in the above quoted Section and an Appendix reference to a relevant ASTM document.

Exceptions 1 through 4 modify the Table 140.3-B established Rule Target values for various cases. Exceptions 1 and 2 simply exempt roofs in certain climate zones given low enough U-factors. Exception 4 exempts roofs with thermal mass and roof membrane.

Exception 4 states the case for use of Table 140.3 instead of Table 140.3-B for trade-offs between roof U-factor and aged solar reflectance. Note that Exceptions 1 and 2 are in conflict with Exception 4 since they exempt roofs with U-factors less than or equal to 0.039 and 0.048 respectively, while Exception 4 still sets MinimumAgedSolarReflectance values for roofs with U-factors lower than these.

The sum effect of these exceptions is that Standards users must determine when Table 140.3-B applies and when it does not, and whether or not to use it in those conflicting cases. Extracting Rule Targets MinimumAgedSolarReflectance and MinimumThermalEmittance from Table 140.3-B for representation in separate BESM Rule Tables results in the following extremely simple Rule Tables. MinimumAgedSolarReflectance in Table 140.3-B is dependent on a single Rule Classifier for Roof Slope. MinimumThermalEmittance is not dependent on any Rule Classifier.

Roof Slope	Min Aged Solar Reflectance
Low	0.63
Steep	0.20

Min Thermal Emittance
0.75

It would be preferable in this case to incorporate the modifying exceptions into these separate Rule Tables so that the Standards user no longer needs to determine when the tables apply; they apply in all cases. It would appear that Table 140.3 is a partial attempt to accomplish this by implementing Exception 4 in a separate table. However, this approach has only further complicated things by now forcing the Standards user to understand when Table 140.3 should be used instead of Table 140.3-B, and created a conflict between Exceptions 1 and 2, and Exception 4.

The Rule Table below is a partial example of how Tables 140.3 and 140.3-B can be combined along with Standards text in Section 140.3(a)1Ai, including text-based Exceptions, into a single table that would cover the combined information in a complete manner without requiring Standards users to determine when each portion applies.

Roof Slope	Construction Type	Climate Zone	Ufactor	Thermal Mass	Min Aged Solar Reflectance	Note

Roof Slope	Construction Type	Climate Zone	Ufactor	Thermal Mass	Min Aged Solar Reflectance	Note
Steep	NA	NA	NA	NA	0.20	Section 140.3(a)1Aib and Table 140.3-B
Low	NA	NA	NA	GTE 25.0	NA	Section 140.3(a)1Aia Exception 3
Low	Wood Framing and Other	1	GTE 0.046	LT 25.0	0.63	Section 140.3(a)1Aia1 and Table 140.3-B
Low	Wood Framing and Other	1	0.042 to 0.046	LT 25.0	0.60	Table 140.3
			rows deleted ...			
Low	Metal Building	1	GTE 0.062	LT 25.0	0.63	Table 140.3
Low	Metal Building	1	0.055 to 0.062	LT 25.0	0.60	Table 140.3
			rows deleted ...			
Low	Wood Framing and Other	1	GTE 0.0391	LT 25.0	0.63	Section 140.3(a)1Aia1 and Table 140.3-B
Low	Wood Framing and Other	3	LT 0.0391	LT 25.0	NA	Section 140.3(a)1Aia Exception 1
			rows deleted ...			

Consistently position rule target in rightmost table column

Consistent positioning of Rule Classifiers and Rule Targets within a Rule Table are recommended to lead to ease of human interpretation. The BESM convention is to position the single Rule Target in each Rule Table as the rightmost column in the table with Rule Classifier columns to the left. This leads to a natural reading of a table from left to right along each row such as, "if classifier #1 is X and classifier #2 is Y, then the target value is Z."

Table 140.3 shown in the previous section does not adhere to this convention, but instead places the Rule Target *Aged Solar Reflectance* in the leftmost column potentially confusing users into thinking this is a Rule Classifier.

Document and consistently use range and round-off rules

Ranges are commonly used in Standards tables as discussed above. It is recommended that the Standards clearly document Range and Round-Off Rules in the Definitions section of Part 6, and then consistently use these rules within Standards tables. The following rules are suggested.

Value Range Rule

- Ranges are expressed with the lower bound included and upper bound excluded, that is, minimum inclusive, maximum exclusive

Round-Off Rules

- The round-off rules for values with higher precision than expressed in Standards tables are as follows.
    - Values in Standards tables are expressed to the indicated level of precision. The rightmost digit in this value is known as the rounding digit. User values that have a higher level of precision (i.e., more significant digits) must be rounded off to the level of precision in a Standards table.
    - If the digit to the right of the rounding digit is 0, 1, 2, 3, or 4 do not change the rounding digit
    - If the digit is 5, 6, 7, 8, or 9, the rounding digit rounds up by one
    - If there are more than one significant digits to the right of the rounding digit, apply the round-off rules to first round-off the digit to the right of the rounding digit

Conclusion

The issues and recommendations described in this report are not only intended to document the procedures used in the BESM project, but are also intended to help improve the Standards in several ways.

Improve quality (i.e., accuracy and completeness): applying the reformulation process developed in the BESM project to Standards tables could help identify and correct conflicts and missing cases.

Improve human readability: replacing complex tables that contain multiple rule targets with different sets of rule classifiers with straightforward, easy to digest tables, one for each rule target could greatly improve the ability of users to interpret the Standards, increasing the number of qualified users.

Improve correct application of the Standards: removing ambiguities and inaccuracies that make it difficult for infrequent users to understand and consistently apply the Standards, and open the potential for gaming of the system, could improve the desired outcome of the

Standards, which is to significantly increase energy efficiency across the California building stock.