INTEGRATING A RULE BASED CODE COMPLIANCE SOFTWARE PLATFORM INTO A BUILDING SIMULATION FRONT END

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ABSTRACT
Performance-based code compliance checking relies on the use of simulation models to assess the performance of a specific building design. In the past, tools that implemented code checking did not separate compliance rules from other software code. These interwoven software tools are hard to maintain and update for code changes. The CBECC-Com (California Building Energy Code Compliance for commercial buildings) software platform was developed by others to address this shortcoming and provide a rule-based mechanism to assess performance-based code compliance. Experts can adopt these rules for other standards or update them due to changes in the code more easily than with earlier software-based solutions. In order to increase the usability of the CBECC-Com software platform, it can be integrated into comprehensive building simulation front end. This paper describes an approach for integrating the CBECC-Com software platform into simulation interfaces in general, provides an example of such an integration and discusses strengths and weaknesses of the overall concept.

INTRODUCTION
There is significant focus on the development of new and improved building codes and standards to address current challenges in context of designing buildings. Therefore, automatic checking of codes and standards is becoming more and more important. Traditionally, most of this checking is still a manual process and, as such, is time-consuming and error prone. Today’s existing energy code compliance tools have limited data exchange capabilities and hence require re-entering of data and thus more preparation time than necessary.

In the energy code-checking context, COMcheck-Plus implemented the ASHRAE 90.1-1989 Energy cost budget that uses rules outside of compiled source code. eQUEST (James J. Hirsch & Associates, 2010) adapted the COMcheck-Plus ruleset features and extended them to Title-24 rules. While eQUEST is freeware it is not an open-source product (Brook & Criswell, 2012). For Title-24 assessment is based on the so-called Performance Method. For this method, the program automatically generates a baseline model derived from the minimum requirements of the energy code. The results generated by the model of the proposed design are then compared to the results from this baseline and the building is considered compliant to the energy code if its performance is at least as good as the baseline.

The limitations of the DOE-2 engine (used by eQUEST and other applications) and the drive for greater efficiency and more complex buildings leads to more tools that use the newer simulation engine EnergyPlus. For example, detailed natural ventilation or solar components are not supported in eQUEST/DOE-2 (Maile, Fischer, & Bazjanac, 2007). For the 2013 Title-24 energy code, a new platform called CBECC-Com (California Building Energy Code Compliance for Commercial buildings) was developed by others for the California Energy Commission (CBECC-Com, 2015). The platform provides both a rule-checking engine and a user interface and generates EnergyPlus models of the proposed design and the baseline that are used to check compliance. The platform is open source and supports third party applications by providing necessary library functionality. This platform uses a newly developed data model, called SDD (Standards Data Dictionary), and a text-based format to define and store the rules. While the CBECC-Com platform also provides a graphical user interface (GUI), this GUI has limited capabilities such as no visual representation of system diagrams and no 3-dimensional view of the building geometry. Thus, integrating CBECC-Com functionality within more sophisticated simulation interfaces will provide designers with an integrated design and compliance analysis environment.
This paper describes the CBECC-Com platform and its underlying process. In the second section, we describe the general process of integrating CBECC-Com into a comprehensive building simulation front end. Furthermore, we show an example integration for the Simergy building simulation front end (Simergy, 2015). After describing limitations, we discuss this approach and summarize the paper in the conclusion.

THE CBECC-COM PLATFORM

CBECC-Com is an open source project to develop a platform for demonstrating performance-based code compliance. The platform is based on EnergyPlus but is designed to be integrated with design analysis environments based on simulation engines other than EnergyPlus. The current version of CBECC-Com (version 3b) supports energy code compliance for Title-24 (the California energy code). In context of the CBECC-Com platform, a new data model called SDD (Standard Data Dictionary) was developed to support data transmission between the different software tools of this platform. In the following, we describe the process used in the platform, the SDD data model and the Title-24 rule sets.

CBECC-Com compliance process

Figure 1 illustrates the data flow of the CBECC-Com compliance process, starting with a GUI (Graphical User Interface) to define the building model. The CBECC-Com GUI itself supports HVAC systems, components and properties through object-based screens and a tree object view as well as simplified geometry. An alternative possibility for more complex geometry is to use SketchUp with the OpenStudio plug-in to generate the geometry and then transfer the geometric data via SDD into the CBECC-Com GUI. Once the building model is completed, it can be saved in SDD input format. The rules engine processes this SDD file and the ruleset files as input and generates two separate SDD simulation files. A baseline building model is generated that corresponds to the minimum requirements of the given standard. The user-generated proposed model is simulated along with the baseline model and results are compared and reported. If the overall performance of the proposed model is at least as good as the baseline, the design complies with the energy code. Thus, the output of the rule engine is one SDD file for the baseline model and another one for the proposed model.

Both files are then converted into IDF (EnergyPlus input) data files, simulated with EnergyPlus and finally sent to the report generator that assesses the compliance status and provides the related reports.

SDD data model

The SDD data model is a controlled vocabulary that covers the following three domains (CEC, 2013):

- Building Models
- Building Energy Efficiency Standards
- Energy Simulation

The primary purpose of this data model is its use within the CBECC-Com compliance project. It was mainly developed because gbXML (gbXML, 2014) does not contain enough detail in this area (CEC, 2013). CBECC-Com uses a rather small number of objects, most of which contain a large number of properties. For example, internal loads are characterized by direct parameters of the space in SDD, whereas most other data models have separate objects to represent internal loads.

The building envelope is defined in SDD according to the hierarchy illustrated in Figure 2. This geometric hierarchy aligns quite well with most other data models such as IFC or gbXML. On the HVAC side, an important aspect is the connectivity between components. In contrast to most other data models, SDD uses a reference and parent/child relationship scheme to represent these connections. For example, a pump is represented as a child to a boiler to represent their connectivity.

One important aspect to consider in the context of the SDD data model is the two different views it contains. There is the input view that contains only properties that are relevant for input to the rule engine. The second view, the so-called simulation view, contains additionally properties that are added during the rule checking. The objects in both views are the same; only the properties are different. In addition, the simulation view contains summary results after a successful simulation run.
Title-24 rules sets
As of CBECC-Com version 3b, only rules for Title-24 exist. These rules are based on the Title-24-2013 and 2016 code which is more fully defined in the so-called ACM Reference Manual (CEC, 2015). This manual defines the objects and properties of a data or simulation model in context of Title-24. It defines restrictions, units and default values, together with the applicability of each. The ACM Reference Manual is the basis for developing the Title-24 rule set. Brook & Criswell (2012) define syntactical details of these rules. Each rule contains the following data: a unique name that consist of the object and property name, metadata such as data type (e.g., string or integer), input class (what type of property it is), units, default values or minimum and maximum values. In addition, there are equations for the various different simulation models required—proposed, baseline sizing and baseline—that are instantiated during the generation of the different models.

Testing of CBECC
To be accredited by the CEC, compliance software is required to pass the ASHRAE Standard 140-2007 tests within limits defined by the CEC. In addition, it must pass the ruleset implementation tests defined by the CEC (CEC, 2015). These tests contain seven prototype models with five different geometries:
- Small Office Building
- Medium Office Building
- Large Office Building
- Warehouse Building
- Small Hotel.

Each prototype model has a standard design and various climate and model variations, leading to 176 different test cases. The tester compares each test case to reference results for several different output variables. These include annual site energy consumption overall and for each end-use, total unmet load hours and annual time dependent valuation (TDV) and change of TDV and total end use site energy. For each test case, the change in energy must be in the same direction as the Reference Method test case result, and must be equal to the Reference Method test case percentage change in TDV energy, plus or minus 0.5% of baseline TDV energy. If any of the results of the tests required for the Title-24 compliance feature set fails to meet these criteria, the applicant software will not be accepted for compliance use (CEC, 2015).

INTEGRATION OF CBECC INTO A SIMULATION SOFTWARE
CBECC-Com itself provides a GUI to create building models with simplified geometry, import geometry that is more complex, and define and edit HVAC systems and components. Furthermore, CBECC-Com provides an API to access the compliance functionality in other third party tools. In this paper, we describe integration with other tools in general and then illustrate it with an example integration with Simergy.

General process
The overall process of integrating CBECC-Com into a simulation software platform involves six steps and
Figure 3: General integration process

is shown in Figure 3. The first step is to generate a building model internally in the GUI. In order to reduce difficulties in the later steps, we recommend to properly connect and contain all required properties. An example of the former is a rule that checks that at least one fan is present in each air loop. To convert the internal data model into the SDD data model, mapping rules between the two data models need to be established. We recommend storing those rules outside of the source code to enable more flexibility during the development. Once these rules are applied and a SDD model generated, the model needs to be exported in an SDD.xml file. In addition, the GUI needs to control the compliance manager process at a high level, displaying errors or, after a successful simulation run, displaying the reports.

Requirements for the integration

The ACM Reference Manual lists various requirements that integration GUIs need to fulfil. In particular, requirements that are not met by the GUI must be documented. For example, it must support at least 50 thermal zones and at least 15 separate HVAC systems. Furthermore, it must be certified by the CEC in order to run an official Title-24 analysis. For further details, we refer to the ACM Manuals (CEC, 2015). Most requirements are already satisfied when using the EnergyPlus engine.

Challenges for the integration

Integrating the CBECC-Com platform also involves a number of different challenges for the GUIs: different feature sets and different sources for errors. The first challenge is the possibility that the integration GUI and the CBECC-Com platform have different feature sets. It is possible that some features of the integration GUI are not contained in SDD or vice versa. Thus, another step is necessary to address these possible feature differences. Depending on the feature set of the software tool, a mechanism to add more data or reduce the existing data to the feature set of the current CBECC-Com version may be needed. At a minimum, the tool should highlight these issues so the user can manually adjust or correct them.

Another challenge is to deal properly with errors generated by CBECC-Com; there are four different possible sources of errors:

1) Syntactical errors in compliance rules (e.g., a required property is missing)
2) Model errors in compliance rules (e.g., a reheat air terminal is missing a heating coil)
3) Model errors in EnergyPlus (e.g., branches are not correctly defined)
4) Simulation errors in EnergyPlus (e.g., temperature values failing to converge)

These errors may be very difficult for the end-user to understand. More challenging is determining the source of the error. The end user can correct errors in the building model (thus our recommendation to check for them early in the process). We recommend providing help to the users for common errors and possible ways to fix them. For example, missing objects in a model will cause errors, such as no service hot water objects.

Testing of the CBECC integration

In order to be a Title-24 certified software application, the integration GUI needs to perform the sensitivity tests as described earlier in the CBECC-Com section. Two important criteria are: (i) that the GUI is supporting the data input and data variations for the test cases, and (ii) the simulation results are within the specified limits for all test cases. For software developers, dealing with such a large set of test cases (176) is a major undertaking and, potentially, a time-consuming process for each new version of CBECC-Com. This is why recertification is needed only for a smaller subset of test cases.

THE CBECC-SIMERGY INTEGRATION

For a successful integration of the CBECC-Com platform into Simergy, we applied the generic process outlined above. Some additional enhancements are included in this process and highlighted in Figure 4 with red rectangles. Similar to the generic process, the end user first needs to create a building model within Simergy. Here, all
the different possible ways to generate a model are supported including the internal detailed geometry generation. Simergy contains a large set of rules that are executed to check for, and report, any inconsistencies in the internal data representation.

One enhancement in context of the generic workflow is the use of views. For Simergy, the Title-24 view has a special set of validation rules that check the model for readiness for the compliance check. Once the model is ready, it is transformed internally into an SDD model and subsequently exported using SDD.xml.

After a successful export, the next step for the integration is the orchestration of calling and running the CBECC-Com dynamic linked libraries. This includes both the display of the generated reports and the generation of summary results.

**SDD to SimModel mapping**

SimModel (Donnell et al., 2011) is a simulation domain data model and is the data model used in Simergy. For most objects and parameters, the mapping is straightforward since the SDD data model targets the IDD data model for EnergyPlus simulations and SimModel supports the complete IDD data model. However, while SimModel contains all the object and parameter types of IDD, SDD uses a higher level of abstraction to hide some of the technical details from the end user. Within the CBECC-Com process, the SDD data is processed using Title-24 rules and a data conversion step into IDD data. In Simergy, data transformation is exactly the opposite direction from IDD (contained in SimModel) to SDD data. Figure 6 shows an example mapping between SimModel and SDD for a pump object. The SimModel object hierarchy contains a class, type and subtype for each object. For the pump, the corresponding class is SimFlowMover and the Type is Pump. This figure shows two subtypes: VariableSpeed and ConstantSpeed. In the SDD data model, both subtypes correspond to the same Pump object. The SDD property ControlMethod contains the information about which subtype is relevant. In SimModel, each subtype has a different set off parameters, whereas in SDD the pump object just contains all parameters of all pump configurations.

The concept of the Title-24 view

Due to the significantly larger feature set of Simergy compared to the CBECC-Com platform, we needed to develop a mechanism that could deal with this difference. To reach the goal that each simulation model that is generated with Simergy can also be sent to CBECC-Com and a Title-24 analysis performed, an additional data transformation step is necessary. The concept we developed in Simergy is that of a specialized view, in this case, the Title-24 view.

These specialized views are copies of a design alternative (or a building model) as shown in Figure 6. A special set of validation rules is applied to this view and highlights systems, objects and parameters that are not supported by CBECC-Com. Currently, the end user needs to address those issues manually to make the Title-24 view ready for analysis. For example, if the proposed design in Simergy contains a heat pump
model that is currently not supported in SDD, this heat pump model needs to be replaced with another, supported, model. The advantage of this view concept is that these manual adjustments are independent of the design alternative. That means the original design alternative stays intact and can still be used for other analyses.

Specific Title-24 property dialogs
Since the properties of the SDD model overlap the properties in SimModel and thus, Simergy, it is difficult at times to know if properties are identical, derived from other properties or unique to the Title-24 view. Thus, we implemented a specific Title-24 property view in addition to the existing EnergyPlus property view. Each of those views contains either Title-24 or EnergyPlus properties correspondingly. Title-24 properties that can be derived from EnergyPlus properties are displayed in view mode only (slightly grey background in Figure 5) whereas the end user can edit and modify the Title24 specific properties in this view.

DISCUSSION
Based on our review of the CBECC-Com documentation and relevant literature and our implementation of an integration GUI, we identify the following discussion topics:

Dividing source code from rules
The CBECC platform supports the division of rules from source code. This is an important advantage from other and earlier solutions. Specifically the development of rule sets for other similar standards, for example ASHRAE Standard 90.1, is made easier than before. Development compliance tools for new standards is possible by developing a new set of rules and leaving most of the source code largely untouched.

The SDD data model
The SDD data model employs a commonly used technology, XML, to communicate with other tools. This feature allows third party tools to use commonly available XML toolsets to generate and read these XML files. The SDD data model was developed because gbXML is lacking detail in the HVAC area. Furthermore, this new SDD data model provide flexibility for the CBECC platform to properly implement necessary features. Third party tools such as Simergy can independently support data exchange with common data models such as the IFC data model.

The feature set
The current version of CBECC-Com (3b) does not support all features of EnergyPlus. However, CBECC-Com development is still ongoing and is expected to include common and energy efficient HVAC system features in future versions.

Limitations of EnergyPlus
While EnergyPlus is a sophisticated and increasingly commonly used engine, some limitations result from the use of EnergyPlus in the CBECC-Com platform. For example, water loops are limited to only one set of parallel branches in each half loop (Supply or Demand). Maile, Bazjanac, & Fischer (2012) describe more examples of EnergyPlus limitations.

FUTURE WORK
Based on this discussion, we identify the following topics for future work in the context of the CBECC-Com platform.

Extending CBECC-Com feature set and rules
It is anticipated that CEC will extend the current feature set of CBECC-Com. In addition, development of CBECC-Com rule sets for standards other than Title-24, in particular ASHRAE Standard 90.1 Appendix G and the Indian energy code ECBC, is currently in progress.

Improvements for the SDD data model
The SDD data model uses a rather small set of objects with a large set of parameters. This leads to a relatively straightforward hierarchy of objects, but causes problems with different sets of parameters. Depending on the type of an object (e.g., an electric or gas heating coil) the relevant parameter set is different. A possible improvement of the SDD data model could clearly define these different parameter sets based on the object types. One way to achieve this could be to define an XSD schema for SDD.

Improvements for the Simergy integration
Simergy provides a mechanism to make manual adjustments related to Title-24 analysis in the Title-24 view. The automation of these currently manual adjustments would support the end user in this area. In addition, the changes in the underlying design alternatives are currently not considered in the Title-24 view. Another future improvement could include...
synchronization of changes between the underlying
design alternative and the Title-24 view.

CONCLUSION
This paper describes the CBECC-Com platform, its
SDD data model and the overall compliance process.
The CBECC-Com platform successfully separates
Title-24 rules from source code. Thus, development of
new rules for this platform is easier than with previous solutions. We described the integration process for the
CBECC-Com platform in general and then illustrated
that process using the example of its integration with Simergy. In context of this integration, we developed various enhancements to Simergy to support Title-24 analysis by end users.

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REFERENCES


