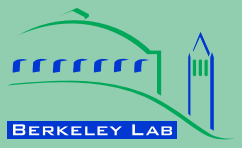

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EnergyPlus Analysis Capabilities for Use in California Building Energy Efficiency Standards Development and Compliance Calculations

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Introduction

Project Background

California has been using DOE-2 as the main building energy analysis tool in the development of building energy efficiency standards (Title 24) and the code compliance calculations. DOE-2 was first developed by Lawrence Berkeley National Laboratory (LBNL) as a computer tool for building simulation in the late 1970s to help architects and engineers design energy efficient buildings. Currently Title 24 uses DOE-2.1E as the reference engine for code development and compliance calculations. However, DOE-2.1E is a mature program that is no longer supported by LBNL on contract to the U.S. Department of Energy (USDOE), or by any other public or private entity. With no more significant updates in the modeling capabilities of DOE-2.1E during recent years, DOE-2.1E lacks the ability to model, with the necessary accuracy, a number of building technologies that have the potential to reduce significantly the energy consumption of buildings in California. DOE-2's legacy software code makes it difficult and time consuming to add new or enhance existing modeling features in DOE-2. Therefore the USDOE proposed to develop a new tool, EnergyPlus, which is intended to replace DOE-2 as the next generation building simulation tool. EnergyPlus inherited most of the useful features from DOE-2 and BLAST, and more significantly added new modeling capabilities far beyond DOE-2, BLAST, and other simulations tools currently available. For a detailed comparison of modeling capabilities among EnergyPlus and 19 other tools, refer to Drury Crawley's paper "Contrasting the capabilities of building energy performance simulation programs" listed on EnergyPlus web site www.energyplus.gov.

With California's net zero energy goals for new residential buildings in 2020 and for new commercial buildings in 2030, California needs to evaluate and promote currently available best practice and emerging technologies to significantly reduce energy use of buildings for space cooling and heating, ventilating, refrigerating, lighting, and water heating. The California Energy Commission (CEC) needs to adopt a new building energy simulation program for developing and maintaining future versions of Title 24. Therefore, EnergyPlus became a good candidate to CEC for its use in developing and complying with future Title 24 upgrades. In 2004, the Pacific Gas and Electric Company contracted with Architectural Energy Corporation (AEC), Taylor Engineering, and GARD Analytics to evaluate EnergyPlus in its ability to model those energy efficiency measures specified in both the residential and nonresidential Alternative Calculation Method (ACM) of the Title-24 Standards. The AEC team identified gaps between EnergyPlus modeling capabilities and the requirements of Title 24 and ACMs. AEC's evaluation was based on the 2005 version of Title 24 and ACMs and the version 1.2.1 of EnergyPlus released on October 1, 2004. AEC's final project report recommended CEC to adopt EnergyPlus for use with Title 24. The report also raised issues and concerns of EnergyPlus in the following areas:

- Modeling Capabilities

  EnergyPlus 1.2.1 lacked some modeling capabilities for Title 24 ACMs, and modeled some features differently than Title 24 ACMs.

- Computer Run Time

  EnergyPlus 1.2.1 was slow in simulation runs. It took EnergyPlus 1.2.1 much longer than DOE-2.1E to run typical building simulations.

- User Interface

  It is much more complex to manually prepare input files for EnergyPlus than for DOE-2.1E, and there was no available user interface for EnergyPlus which could cover most of EnergyPlus' modeling features, especially the user customizable loop-based HVAC systems. The concept of a compliance shell using EnergyPlus as the calculation engine was also discussed.

- Accuracy Tests

> The ACM accuracy tests were developed based on DOE-2. When EnergyPlus was used to perform these accuracy tests, lots of issues were discovered. The most important was how to address the discrepancies in model inputs and simulation results between EnergyPlus 1.2.1 and DOE-2.1E.

AEC's evaluation is useful for understanding the functionality and technical merits of EnergyPlus for implementing the performance-based compliance methods described in the ACMs. However, it did not study the performance of EnergyPlus in actually making building energy simulations for both the standard and proposed building designs, as is required for any software program to be certified by the CEC for use in doing Title-24 compliance calculations. In 2005, CEC funded LBNL to evaluate the use of EnergyPlus for compliance calculations by comparing the ACM accuracy test runs between DOE-2.1E and EnergyPlus. LBNL team identified key technical issues that must be addressed before EnergyPlus can be considered by the CEC for use in developing future Nonresidential Title-24 Standards or as an ACM tool.

With Title 24 being updated to the 2008 version (which adds new requirements to the standards and ACMs), and EnergyPlus having been through several update cycles from version 1.2.1 to 2.1, it becomes crucial to review and update the previously identified gaps of EnergyPlus for use in Title 24, and more importantly to close the gaps which would help pave the way for EnergyPlus to be adopted as a Title 24 compliance ACM. With this as the key driving force, CEC funded LBNL in 2008 through this PIER (Public Interest Energy Research) project with the overall technical goal to expand development of EnergyPlus to provide for its use in Title-24 standard compliance and by CEC staff. The project has three technical tasks as follows:

- Task 2.1.1 - Extend the modeling capabilities of EnergyPlus so that it can be used in the development of Title-24 standards and code compliance calculations,
- Task 2.1.2 - Decrease the computer run time of EnergyPlus for greater implementation in the standards and design communities, and
- Task 2.1.3 - Provide training and technical assistance for CEC staff related to their use of EnergyPlus for analyses related to Title-24.

This project will address two areas raised in AEC's evaluation report – the Modeling Capabilities and the Computer Run Time.

About This Report

This is the report for Task 2.1.1 - EnergyPlus Analysis Capabilities for Title 24. The report will:

- Summarize the gaps in EnergyPlus for use in Title 24,
- Prioritize the gaps in EnergyPlus analysis capabilities,
- Identify new modeling capabilities gaps between EnergyPlus 2.1 and Title 24-2008,
- Update the gaps in EnergyPlus for use in Title 24 as identified in previous AEC's work based on EnergyPlus 2.1, the currently available public release,
- Recommend methods to close the modeling gaps: either by enhancing EnergyPlus or by modifying the ACM modeling rules or calculation algorithms, and
- Discuss EnergyPlus modeling capabilities beyond current ACMs for development of future versions of Title 24.

The format of this report will be mostly tabular.

Gaps Analysis of EnergyPlus for Use in Title 24

It should be pointed out first that while EnergyPlus achieves its purpose of incorporating the latest and most advanced methods of simulating building energy performance, it is only an engine. It is not a compliance tool which must have the user interface, preprocessor, post-processor, data libraries, and reporting tools required by CEC. Since AEC's report was released in 2005, the EnergyPlus development team has made significant progress in adding new features and enhancing existing features in EnergyPlus to bridge the gaps in EnergyPlus modeling capabilities for use in Title 24. However, there are still gaps that need to be addressed. This section of the report summarizes the important gaps under two categories: Title 24 Code Compliance Generic Gaps and ACM Modeling Capabilities Gaps. Other sections of the report prioritize the gaps and categorize the gaps under different sources.

Title 24 Code Compliance Generic Gaps

ACM Manual for EnergyPlus

An ACM manual for EnergyPlus needs to be developed. This is similar to the current Title 24 ACM manual for DOE-2. The ACM manual shall provide adequate details in documenting all model assumptions, reference data, and modeling rules for generating the standards design and the proposed design, sizing calculations, and compliance reports. The ACM manual for EnergyPlus becomes more important and crucial as, unlike DOE-2, EnergyPlus has very limited default values for IDD objects.

The current Title 24 nonresidential ACM manual is tied to DOE-2. It needs to be completely overhauled to be calculation engine neutral. A modeling guideline or ACM appendices can be developed for EnergyPlus to be used for Title 24. This can be the reference manual of the EnergyPlus compliance software to be developed by National Renewable Energy Laboratory (NREL) for CEC.

ACM Accuracy Tests for EnergyPlus

One important difference between EnergyPlus and DOE-2 lies in their approach. EnergyPlus uses a heat balance approach whereas DOE-2 uses a weighting factor approach for calculating heating and cooling loads. This can cause the two programs to produce different results.

Although the Title 24 ACM specifically references DOE-2 for the non-residential energy simulation runs and CALRES for residential simulation runs, the ACM also allows for other calculation methods to be used as long as they meet the accuracy tests. The current nonresidential ACM tests are relative to DOE-2 results. As DOE-2.1E is no longer being enhanced by the USDOE, it is vital for CEC to adopt a new reference method that can keep pace with the current energy trends and modeling algorithms in order to provide the most reliable and accurate programs for compliance.

For EnergyPlus to be approved as an ACM calculation engine, it has to pass the ACM accuracy tests based on DOE-2. A number of problems were identified in the previous LBNL project to convert these tests from DOE-2 files to EnergyPlus files, run them, and compare results. These tests have to be restructured and criteria revised in order to let EnergyPlus pass. The main issue is that DOE-2 and EnergyPlus models can be based on different algorithms and thus produce different results. It is recommended to develop new ACM tests with reference to several test suites used by EnergyPlus development team including:

- Analytical Tests
    - HVAC tests, based on ASHRAE Research Project 865
    - Building fabric tests, based on ASHRAE Research Project 1052
- Comparative Tests
    - ANSI/ASHRAE Standard 140-2004

- International Energy Agency Solar Heating and Cooling Programme (IEA SHC) BESTest (Building Energy Simulation Test) methods
- EnergyPlus HVAC Component Comparative tests
- EnergyPlus Global Heat Balance tests

Details of these tests are available on the EnergyPlus web site www.energyplus.gov.

Time Dependent Valuation Values

Title 24-2008 has new sets of Time Dependent Valuation (TDV) values. New datasets of TDV values need to be developed for EnergyPlus in order to calculate the Title 24 TDV budget for both the standards design and the proposed design.

Weather Data

The ACM uses 16 California climate zone weather data for annual simulations and design day weather data from the Reference Appendices for sizing calculations. EnergyPlus has 16 weather files converted from the 16 DOE-2 weather files for each California climate zone. EnergyPlus also provides datasets of design day weather data based on the 2005 ASHRAE Handbook of Fundamentals. These datasets do not provide adequate coverage of California. New datasets of California design location data need to be developed for EnergyPlus.

Compliance Tags

The information required for Title 24 code compliance calculations goes beyond that required in more conventional energy simulations by EnergyPlus. EnergyPlus input data is contained in a text file called an input data file (IDF). For ACM calculations, the IDF may need to be extended to include code compliance tags. For example, the building type (either residential or nonresidential), number of stories of the building, climate zone (1 to 16), space category (office, guest room, etc), surface category (exterior wall, roof, floor, and slab), construction type (for walls: mass, metal frame, wood frame, etc), project type (new or alternation), and compliance scope (envelope, mechanical, and/or lighting). The compliance software would rely on these compliance tags to apply the standards envelope criteria, lighting power, HVAC system types and efficiencies to the standards design. New input data dictionary (IDD) objects and new fields for existing IDD objects need to be developed and added to EnergyPlus IDD.

Another approach is to keep the compliance tags in a supplementary file. If contained in a supplementary file, then data would have to be associated with specific EnergyPlus objects by name, reference number, and so on.

It is recommended to integrate the compliance tags into EnergyPlus IDD and IDF so that the IDF for the code compliance run is complete and independent of the interface/software that is used to create the IDF. This holds true for generic code compliance calculations with Title 24 and ASHRAE Standards 90.1, and also for specific energy performance rating systems like California Savings By Design program, the USGBC LEED for green buildings, and ASHRAE Standards 189.1 for high performance buildings.

Compliance Reports

The ACM specifies the content and formats of standards compliance reports to be submitted for approval. These reports should be generated by the EnergyPlus Compliance Software to be developed by NREL.

Sizing Calculations

The ACM defines sizing calculation methods and rules for both the standards design and the proposed design. The sizing calculations should be implemented by the EnergyPlus Compliance Software. The sizing calculations based on design day simulations should be done before the annual simulation runs.

Opaque Constructions

The ACM requires the use of opaque constructions from the Reference Appendices. While these standards constructions are listed with overall U-factor, EnergyPlus needs detailed layer-by-layer material definitions for a construction. New datasets of these opaque constructions need to be developed for EnergyPlus.

Systems of Units

The ACM uses Inch-Pound units while EnergyPlus uses SI units. It is recommended to have dual units in the new ACM manual for EnergyPlus.

Conservative Tweaks

Although EnergyPlus is more accurate in modeling heating and cooling loads, CEC prefers to err on the side of caution and would be loath to part from their ability to tweak the DOE-2.1E models to produce conservative estimates. CEC finds a need for sidebar calculations to degrade actual performance in order to simulate long-term performance. The fact is, most equipment (as well as building construction) does not operate at its optimal performance level, and cannot realize its full energy savings potential. User ignorance, equipment depreciation, construction installation faults, and more contribute to this. EnergyPlus, to some extent, can facilitate the tweak by degrading the equipment efficiencies or using performance curves to represent actual or long term operating conditions.

ACM Modeling Capabilities Gaps

Title 24 residential and nonresidential ACM manuals specify required and optional modeling capabilities of an ACM tool. Modeling rules and certain inputs based on DOE-2 are defined in the ACM manuals. EnergyPlus can model most ACM features. It sometimes does more accurate modeling, sometimes models features differently than DOE-2, and there are still missing capabilities that need to be addressed.

Fenestration Performance

Title 24 and ACM use overall U-factor and SHGC (Solar Heat Gain Coefficient) to represent the performance of fenestration products, while EnergyPlus needs totally different fenestration properties as inputs. EnergyPlus takes layer-by-layer fenestration definitions either directly in the IDF files or with a reference to a data file created with the Window fenestration modeling tool. New datasets of commonly used fenestrations including windows and skylights need to be developed for EnergyPlus. A challenging issue here is to create detailed fenestration models with Window tool to match certain U-factor and SHGC values. Sometimes multiple fenestrations meet the criteria; sometimes there are none that get close. Title 24 should specify other fenestration properties like the visible light transmittance (VLT) to help streamline the matching process.

A short term solution to this is to find a reliable approach to take a fenestration construction with NFRC rated or manufacturer provided U-factor, SHGC, and VLT, and map to a Window tool style layer-by-layer descriptions. A long term solution is for NFRC to provide a Window data file besides the overall fenestration properties for each fenestration to be rated.

It is recommended to adopt the EnergyPlus method which is more accurate and flexible than current ACM.

HVAC Equipment Efficiency Inputs

The ACM allows efficiency inputs like SEER, AFUE, HSPE etc for HVAC equipment. While EnergyPlus may not be able to take these inputs directly into IDF files, most of the time these inputs can be converted using ACM defined algorithm. For example, ACM defines formula to convert SEER to EER which can then be converted into COP (= EER/3.413) as an input to EnergyPlus. Similarly, AFUE can be converted first into HIR (Heat Input Ratio), and then into thermal efficiency as an EnergyPlus input.

It is recommended to adopt current ACM formula to convert efficiency inputs for EnergyPlus if there are no direct matches.

HVAC Equipment Performance Curves

The ACM defines some performance curves of HVAC equipment to be used for compliance calculations. These curves were developed by CEC with the intention of degrading actual performance of HVAC equipment operating performance due to issues of design, installation, lack of commissioning, and reliability. Most of these performance curves can be converted and used by EnergyPlus if EnergyPlus and DOE-2 have similar models. Otherwise new performance curves need to be developed for EnergyPlus in order to match the current ACM performance levels.

Refrigerated Warehouse

Title 24 has mandatory requirements for refrigerated warehouse in terms of building shell insulation, evaporator fan controls, condenser fan power and controls, compressor controls, and interior lighting levels. EnergyPlus can model refrigerated cases but cannot straightforwardly model refrigerated warehouses. Even though ACM does not provide a performance path to show compliance for refrigerated warehouse, it is recommended to add a new feature to EnergyPlus to model refrigerated warehouses so that energy efficiency measures can be analyzed and may be incorporated into future versions of Title 24 for the refrigerated warehouse.

Pool and Spa

Title 24-2008 added requirements for pool and spa systems to have time switch control to run pumps during off peak electric demand periods. EnergyPlus does not have a swimming pool/spa model yet, but a proposal has been in place to add this new feature to EnergyPlus in 2009. The EnergyPlus swimming pool/spa models will allow heater on/off control, pump on/off schedule, pool cover, and constant or variable speed pumps. The EnergyPlus Pool and Spa model would calculate the energy use as well as water consumption.

Demand Control Ventilation

Title 24-2008 added demand control ventilation (DCV) requirement for multizone systems with DDC to the zone level. EnergyPlus does not calculate DCV directly based on CO2 concentration. Instead, it converts the CO2 limit to an outside air flow requirement by assuming typical outside air CO2 concentration and CO2 released by occupants. EnergyPlus can only model DCV for single zone systems. It is recommended to enhance the EnergyPlus DCV algorithm for multizone DCV based on ASHRAE Standards 62.1-2007.

Slabs-on-Grade, Basement Walls/Floors

The ACM defines new modeling rules for slabs-on-grade and underground surfaces. EnergyPlus uses monthly ground temperatures calculated by the Slab and Basement tools and assumes a uniform equivalent one-dimensional heat transfer through the slabs and underground surfaces. ASHRAE Standard 90.1sets maximum C-factor for below-grade-wall and F-factor for slabs-on-grade which cannot be directly inputted to EnergyPlus.

It is recommended to use the EnergyPlus approach, but a user guide should be developed on how to map a construction defined with C-factor or F-factor to a detailed layer-by-layer construction. Parametric analysis also needs to be done to compare results between EnergyPlus and ACM for slabs and underground surfaces.

Daylighting and Controls

The ACM uses lighting power adjustment factors or alternate lighting schedules to model window daylighting and controls. For skylight daylighting and controls, the ACM uses the DOE-2 DAYLIGHTING command. EnergyPlus has two methods to model daylighting controls:

1) With the Daylighting:Detailed object which is similar to DOE-2 daylight model that allows up to two daylight reference points and can provide continuous or stepped dimming;

2) With the Daylighting:Delight objects which allow more than two reference points, and can model complex fenestration/shading systems with optically complicated glazings, but cannot model complex dynamic shading controls (changes in electrochromic glazing transmittances and blind slat angles) or glare calculations.

A third and more accurate and flexible model under development is to link Radiance to EnergyPlus.

It is recommended to adopt EnergyPlus window and skylight daylighting and controls models which are more accurate and flexible than ACM.

Distributed Energy Storage Direct Expansion Air Conditioner

The ACM defines an optional compliance capability to model Distributed Energy Storage Direct Expansion Air Conditioner (DES/DXAC) through a developed DOE-2 user function. The DES/DXAC system is a refrigerant based ice storage system for DX cooling. DES/DXAC systems can move peak demand during the day to off-peak during the night. If deployed in volume, DES/DXAC can help California mitigate the issue of peak power demand.

EnergyPlus cannot model DES/DXAC yet, but NREL has a proposal to add this feature to EnergyPlus.

Variable Refrigerant Flow Systems

The ACM defines an optional compliance capability to model variable refrigerant flow (VRF) systems through a developed DOE-2 user function. VRF systems have multiple indoor DX units for multizone zones, multiple (usually variable speed) compressors, a common refrigerant loop connecting indoor units and an optional heat recovery controller for the outdoor condensing units. VRF systems can run either in single cooling or heating mode, or in heat recovery mode which allows some zones in cooling while others in heating mode. VRF systems can be energy efficient especially during part load conditions and heat recovery operation mode.

EnergyPlus cannot model VRF systems yet, but FSEC (Florida Solar Energy Center) has a proposal sponsored by Daikin to add this modeling capability to EnergyPlus.

Thermal Energy Storage

The ACM defines chiller-based thermal energy storage (TES) as an optional capability. The TES types allowed include: Chilled Water Storage, Ice-on-Coil, Ice Harvester, Brine, Ice-Slurry, Eutectic Salt, and Clathrate Hydrate Slurry. EnergyPlus can model ice-on-coil type ice storage system with chillers and ice tanks run in parallel or in series, but it does not model other TES types directly. By using corresponding performance curves, EnergyPlus may be able to model other types of ice storage systems.

The chilled water storage system is very different from other TES types and cannot be approximated with performance curves. It is recommended to add the chilled water storage model to EnergyPlus.

Under Floor Air Distribution

The ACM (DOE-2), like conventional simulation tools, assumes complete mixing of space air which has uniform properties of temperature, humidity etc. Therefore, it is not possible for ACM to accurately model air stratification in under floor air distribution (UFAD) systems. As an optional capability, Title 24-2008 ACM added new modeling rules for UFAD systems. ACM assumes 40% of internal loads (from occupants, lights, and equipment) go to supply plenum, 51% to space, and 9% to return plenum. There is no description of how to split the envelope loads.

EnergyPlus uses the 'ROOMAIR MODEL' object to determine which air model is available for use in a given zone during the simulation. If no 'ROOMAIR MODEL' object is specified (for each zone or the whole building), then EnergyPlus will run with the conventional, fully mixed air model. Include a 'ROOMAIR MODEL' for each zone that the user wants modeled using a more detailed method. Currently only a

single 'RoomAir Model' object can be specified for each zone. However, the UCSD Displacement, Cross Ventilation and UFAD models switch from displacement to mixing ventilation when the operating conditions do not give rise to unmixed flow. Entering the keyword 'UCSD UFAD INTERIOR' specifies the two-node interior zone under floor air distribution model developed by the University of California, San Diego. The UFAD model for perimeter zones is under development and will be incorporated in future EnergyPlus release.

It is recommended to adopt the EnergyPlus UFAD models which are more accurate and flexible. Parametric analysis is needed to compare the UFAD results between EnergyPlus and ACM.

Air Economizer

Title 24 requires air side economizer for most systems with more than 75,000 Btu/h of cooling capacity and more than 2500 cfm of design air flow. For systems with economizers, the maximum outside air fraction (DOE-2 keyword MAXOA-FRACTION) is set to 0.9 which discounts the imperfect operation of air economizers. EnergyPlus allows the input of maximum outside air flow rate in m3/s for air economizer, but does not provide a maximum outside air fraction. It is recommended to add maximum (minimum as well) OA fraction for economizer in EnergyPlus.

As an optional capability, the ACM allows an air economizer to be controlled by variable enthalpy which is equivalent to Honeywell W7400 or H205 humidity biased enthalpy control using set-curve A. A proposal has been in place to add variable enthalpy economizer control to EnergyPlus in 2008.

Title 24 requires an air economizer for fan coil units above a certain size. EnergyPlus 2.1 cannot model air economizer for fan coil systems, but this feature is being developed and is scheduled to be done in 2008.

Cooling Tower

The ACM allows inputs of number of cells for a cooling tower. EnergyPlus cooling tower models can only allow one cell per tower. One way to address this is to use multiple towers to model multiple cells in EnergyPlus. Another way is to implement multiple cells capability to EnergyPlus cooling tower models.

The ACM allows both types of cooling tower: open and closed. EnergyPlus 2.1 does not model closed circuit type cooling tower (fluid cooler), but a proposal has been in place to add fluid cooler model to EnergyPlus in 2009.

As optional capabilities, ACM allows cooling tower cooling capacity control by fluid bypass or modulating fan discharge damper. EnergyPlus can model single speed, two-speed, and variable speed cooling towers. The fan discharge damper control can be modeled as variable speed fan with a specific fan curve. The fluid bypass cannot be modeled by EnergyPlus. It is recommended to add cooling tower fluid bypass control to EnergyPlus.

Absorption Chiller

As an optional capability, the ACM allows absorption chillers for cooling. Enhancements need to be made to EnergyPlus absorption chiller models to improve accuracy and allow more types of absorption chillers including multiple stage absorption, steam fired, and hot water fired.

Boiler

The ACM boiler models do not calculate boiler cycling loss explicitly, instead it uses performance curves HIR(PLR). Enhancements can be made to EnergyPlus boiler model to calculate cycling loss explicitly.

High efficient boilers like condensing boilers have efficiency depending on supply and return water temperatures. EnergyPlus cannot model condensing boilers yet, but the development is in place.

Heat Recovery

The ACM allows reuse of heat recovered from condensers for space heating or service water heating (SWH). EnergyPlus is able to capture heat recovery from desuperheaters, generators, and double-bundle chillers for space heating or service water heating. EnergyPlus cannot model heat recovery for absorption chillers. The desiccant wheel heat recovery is under development for EnergyPlus. The run-around loop heat recovery for outside air and exhaust air needs to be added to EnergyPlus.

Pump Controls

As optional capabilities, the ACM allows multiple types of pump controls for variable flow applications: variable speed, riding curve, and two-speed/stages. For two-speed/stages, pump is staged, or pump has two-speed motor, to maintain pressure requirements. Pump rides characteristic curve between stages. For riding curve, pump rides characteristic performance curve as a function of head pressure. Head pressure will vary depending on the water demands of cooling and heating coils and the amount of water bypassing different zones.

EnergyPlus can model constant and variable speed pumps and allows part load performance curves for variable speed pumps, but EnergyPlus does not model two-speed/stages or riding curve controls. The water loop pressure model is under development for EnergyPlus which should allow the riding curve pump control.

Title 24-2008 added supply pressure reset control by demand for chilled water VAV with reheat system and four-pipe fan coil with central plant system if proposed system has DDC controls. This cannot be modeled by EnergyPlus as it does not have pump curves that relate flow rate to pump head. It is recommended to add this feature to EnergyPlus.

Air Duct Loss

The ACM defines certain algorithms to calculate the air duct loss due to air leakage and conduction heat transfer for non-residential single zone spaces serving less than 5000 square feet. These algorithms have been developed to model conservative estimates of duct efficiency since it has been shown that many ducts are installed improperly. The algorithms also allows for credits to be given when tightly sealed or heavily insulated ducts are field-verified.

EnergyPlus can model air duct loss by leakage or conduction loss, but the algorithm is different from the ACM which uses lots of empirical formula. It is recommended to adopt EnergyPlus air duct models with necessary enhancements to match the ACM models.

Service Water Heating

Both residential and nonresidential ACM has detailed water heating models to calculate hourly water heating energy use outside DOE-2. EnergyPlus has multiple objects, Water Heater:Mixed, Water Heater:Stratified, and Heat Pump:Water Heater, to model water heaters. The WATER HEATER:MIXED object simulates a well mixed, single-node water tank. The WATER HEATER:STRATIFIED object simulates a stratified, multi-node water tank. Both water heater objects can be appropriate for simulating many types of water heaters and storage tanks, including gas and electric residential water heaters, and a variety of large commercial water heaters. Both objects share similar features, such as stand-alone operation, on- and off-cycle parasitic loads, and thermal losses to the zone.

The heat pump water heater is a compound object consisting of a water heater tank, a direct expansion (DX) “coil”, and a fan to provide air flow across the air coil associated with the DX compression system. These objects work together to model a system which heats water using zone air, outdoor air, or a combination of zone and outdoor air as the primary heat source.

Unfortunately EnergyPlus’ water heater models, even coupled with plant loops, do not address the recirculation loss of a SWH system. It is recommended to study the ACM SWH models and add them to EnergyPlus.

Photovoltaic

CEC developed a PV calculator for the New Solar Homes Partnership (NSHP) program. EnergyPlus has multiple PV models with different levels of details. The simple EnergyPlus PV model (Generator:PV:Equivalent One-Diode) is similar to the CEC PV Calculator which is based on one-diode five-parameter model. EnergyPlus can also model Building Integrated PV (BIPV).

The CEC PV Calculator has an inverter model which takes into account the inverter efficiency. EnergyPlus PV models do not have inverter models yet. CEC and NREL have run some parametric runs to compare the DC (direct current) outputs between the CEC PV Calculator and EnergyPlus PV models. EnergyPlus PV models need to add inverter models, be further benchmarked, and be adopted by CEC.

Prioritized List of Gaps of EnergyPlus Analysis Capabilities for Use in Title 24

Table 1 summarizes the prioritized list of gaps of EnergyPlus analysis capabilities for use in Title 24 as an ACM calculation engine. Other requirements of EnergyPlus as ACM compliance software are covered in previous section of the report and are not listed here. The list is based on Title 24-2008 and EnergyPlus 2.1.

The priority of gaps, listed in the Priority column, is represented by a numeric type major category followed by an alphabet type minor category. In the major category, 1 means first priority, 2 means second, and so on. The minor category follows the alphabet order with 'a' as the highest priority followed by 'b', and so on. The first priority gaps are important and need to be addressed sooner rather than later. The second priority gaps are either mandatory or prescriptive ACM modeling capabilities that need to be added to EnergyPlus or to be evaluated by comparing results between ACM and EnergyPlus. The third priority gaps are optional ACM compliance capabilities that need to be added to EnergyPlus. Benchmarking the performance of the CECPV Calculator against EnergyPlus PV models is listed as the 4th priority.

With NREL to develop the compliance software using EnergyPlus as the calculation engine, the standards datasets for Title 24 will be created. The datasets will contain most of the data in the ACM Reference Appendices and will help close the gaps of 1c to 1f listed in Table 1.

Table 1—Prioritized List of Gaps between Title 24 Compliance Calculation Requirements and EnergyPlus Capabilities

Priority	Gap	Description	Category	Scope	Recommended Solutions
1a	Compliance Tags	Code compliance calculations require some high level inputs normally not directly used by simulation engines, but they are necessary information for compliance software to automatically generate the standards design and adjust the proposed design. These inputs include building type, compliance scope, space occupancy use, construction type, climate zone, lighting compliance approach, etc.	General	Non-Res and Res	Add new IDD objects and new fields for existing IDD objects to EnergyPlus Input Data Dictionary to facilitate these compliance tags in the IDF files. Coordinate the effort between LBNL and NREL for development in this area.
1b	Compliance Case Studies	So far EnergyPlus has been tested against the DOE-2 based ACM accuracy tests to identify gaps and issues of EnergyPlus' analysis capabilities in code compliance calculations. As the ACM tests use simple buildings and are limited in variations of modeling features, it is recommended to perform more comprehensive and in-depth case studies to demonstrate EnergyPlus' capabilities of being used in Title 24, and further identify gaps and issues.	General	Non-Res and Res	As NREL is adapting the DOE commercial benchmarks for Title 24-2008, LBNL would play the role of reviewing these Title 24 models for quality assurance purpose and helping identify discrepancies and issues.
1c	Fenestration Properties	ACM uses overall window properties U-factor and SHGC to represent fenestration performance.	Envelope	Non-Res and Res	Adopt EnergyPlus fenestration models which use layer-by-layer definitions. Develop datasets of standards and common windows and skylights for EnergyPlus.

1d	Opaque Constructions	ACM Reference Appendices specify U-factor or R-value for construction assemblies to be used in compliance calculations.	Envelope	Non-Res and Res	Develop datasets of standards and common constructions (with layer-by-layer material properties) in the Reference Appendices for EnergyPlus.
1e	Performance Curves	ACM specifies certain performance curves to be used in HVAC calculations.	HVAC	Non-Res and Res	If EnergyPlus uses same or similar HVAC models as DOE-2, convert these curves from DOE-2; otherwise, develop new curves for EnergyPlus.
1f	Equipment Efficiency	ACM allows efficiency inputs of SEER, AFUE, and HSPE.	HVAC	Non-Res and Res	Use ACM formula to convert these efficiencies to EnergyPlus inputs, e.g. COP and thermal efficiency.
2a	DCV	Added demand control ventilation (DCV) requirement for multizone systems with DDC to the zone level	HVAC	Non-Res Mandatory	Enhance EnergyPlus DCV algorithm for multizone systems based on ASHRAE Standards 62.1-2007.
2b	UFAD	Added modeling rules for under floor air distribution (UFAD) systems. ACM assumes 40% of internal loads (from occupants, lights, and equipment) to supply plenum, 51% to space, and 9% to return plenum. No mention how to split the envelope loads.	HVAC	Non-Res ACM	Adopt EnergyPlus UFAD model as it is more accurate and flexible. Verify the performance of EnergyPlus UFAD systems.
2c	Air Economizer	For systems with economizers, the maximum outside air fraction (DOE-2 keyword MAXOA-FRACTION) is set to 0.9.	HVAC	Non-Res ACM	Add maximum (minimum as well) OA fraction for air economizer in EnergyPlus.
		Air economizer can be controlled by variable enthalpy which is equivalent to Honeywell W7400 or H205 humidity biased enthalpy control using set-curve A.	HVAC	Non-Res ACM	Add variable enthalpy control to air economizer for EnergyPlus. This feature will be implemented in 2008 and is scheduled to be released with EnergyPlus 2.2.
		Large fan coil systems are required to have air economizer.	HVAC	Non-Res	This feature is under development for EnergyPlus. Need to verify the new feature.
2d	Service Water Heating	ACM has detailed water heating models to calculate water heating energy use which counts distribution system types and recirculation loss.	SWH	Non-Res and Res ACM	EnergyPlus has different water heater models which do not match ACM. Enhance EnergyPlus SWH models to have consistent performance level as ACM's.
2e	Air Duct	ACM has algorithm to calculate air duct loss outside the DOE-2 engine.	HVAC	Non-Res and Res ACM	Enhance EnergyPlus air duct model to match ACM performance.
2f	Daylighting and Controls	Use adjusted lighting schedules or fixed Power Adjustment Factor (PAFs) for modeling daylighting benefits.	Daylighting	Non-Res ACM	Adopt EnergyPlus windows and skylight models for daylighting and controls which are more accurate and flexible. Compare results between ACM and EnergyPlus to verify EnergyPlus daylighting performance.
2g	Cooling Tower	ACM allows inputs of number of cells for a cooling tower.	HVAC	Non-Res ACM	EnergyPlus cooling tower models can only allow one cell per tower. Either use multiple towers to model multiple cells in EnergyPlus or add multiple cells capability to EnergyPlus cooling tower models.
		ACM allows cooling tower capacity control by fluid bypass or fan discharge damper.	HVAC	Non-Res ACM	Add cooling tower fluid bypass control to EnergyPlus.
		ACM allows closed type cooling tower.	HVAC	Non-Res ACM	The closed circuit (fluid cooler) type cooling tower is scheduled to be added to EnergyPlus in 2009. Need to verify the new feature.

2h	Boiler	Neither DOE-2 nor EnergyPlus calculates boiler cycling loss explicitly. They use HIR(PLR) performance curves instead.	HVAC	Non-Res ACM	Enhance the EnergyPlus boiler model to calculate boiler cycling loss explicitly.
		Neither DOE-2 nor EnergyPlus can accurately model condensing boilers whose efficiency depends on supply and return water temperatures.	HVAC	Non-Res ACM	Add condensing boiler model to EnergyPlus. This feature is being developed and is scheduled to be completed by end of 2008.
2i	Pump Controls	ACM allows pump controls: constant speed, variable speed, riding curve, and two-speed/stages.	HVAC	Non-Res ACM	Add two-speed/stages pump controls to EnergyPlus. The hydronic loop pressure model is under development for EnergyPlus which will allow the pump riding curve control.
		Added supply pressure reset by demand for chilled water VAV with reheat system and four-pipe fan coil with central plant system if proposed system has DDC controls.	HVAC	Non-Res ACM	Add hydronic pressure reset control to EnergyPlus.
3a	VRF	Added variable refrigerant flow (VRF) system as a compliance option.	HVAC	Non-Res ACM	Provide technical support for FSEC in adding VRF to EnergyPlus. Adopt the AEC developed DOE-2 VRF function.
3b	DES/DXAC	Added Distributed Energy Storage Direct Expansion Air Conditioner (DES/DXAC) as a compliance option.	HVAC	Non-Res and Res ACM	Provide technical support for NREL in adding DES/DXAC to EnergyPlus. Adopt the AEC developed DOE-2 DES/DXAC function.
3c	Absorption Chiller	ACM (DOE-2) and EnergyPlus do not have a good model for absorption chillers.	HVAC	Non-Res ACM	Improve the absorption chiller models in EnergyPlus. Add steam and hot water fired absorption chiller models to EnergyPlus.
3d	Slab, Basement Walls and Floors	New modeling rules	Envelope	Non-Res and Res ACM	Adopt EnergyPlus approach of calculating heat transfer through slabs and basement walls, but develop a guideline to map a construction defined with C-factor and F-factor to a detailed layer-by-layer definitions.
3e	Refrigerated Warehouse	Added requirements for refrigerated warehouse: building shell insulation, evaporator fan controls, condenser fan power and controls, compressor controls, and interior lighting levels	Envelope, HVAC, Lighting	Non-Res Mandatory	Need to add refrigerated warehouse modeling capability to EnergyPlus.
3f	Pool and Spa	Added requirements for pool and spa system to have time switch control to run pumps during off peak electric demand periods.	Others	Non-Res and Res Mandatory	A proposal is in place to add swimming pool/spa models to EnergyPlus which allow heater on/off control, pump on/off schedule, and pool cover. Need to verify the new feature.
3g	TES	Added chiller-based thermal energy storage (TES) as a compliance option. Allows these TES type: Chilled Water Storage, Ice-on-Coil, Ice Harvester, Brine, Ice-Slurry, Eutectic Salt, and Clathrate Hydrate Slurry.	HVAC	Non-Res ACM	EnergyPlus can only model ice-on-coil type ice storage system with chillers and ice tanks run in parallel or in series. Add chilled water storage to EnergyPlus. Developed performance curves for other TES system types.
4	PV	CECPV Calculator determines performance of PV systems	Renewable	Res NSHP	Compare PV system performance between CECPV Calculator and EnergyPlus PV models.

Gaps of EnergyPlus 2.1 Analysis Capabilities for Use in Title 24-2008

With the 2008 Title 24 being finalized, there are new requirements in the standards as well as ACMs. This section of the report lists those new requirements that have impacts on building energy simulations and code compliance calculations. The gaps analysis is based on the 45 and 15-day languages of Title 24-2008 standards and ACMs. The list will be updated for the CEC adopted version of Title 24-2008 in this project's final report.

Table 2—Title 24-2008 Requirements and Related EnergyPlus 2.1 Modeling Capabilities

T24-2008 Requirements	Section	Description	Category	Scope	Recommended Solutions for EnergyPlus and/or ACM
Title 24 – 2008 Standards Requirements					
TDV	102	Updated sets of Time Dependent Valuation (TDV) values	General	Non-Res and Res	Update the TDV datasets for EnergyPlus.
Envelope Criteria	143	Updated envelope criteria for opaque and fenestration constructions.	Envelope	Non-Res Prescriptive	Develop the T24 construction datasets for EnergyPlus.
Cool Roof	118(i)	Added Solar Reflectance Index (SRI) as an alternate to cool roof requirements of thermal emittance and 3-year aged solar reflectance.	Envelope	Non-Res and Res Mandatory	No action needed for EnergyPlus. ACM need to define formula to convert a specific SRI to equivalent solar reflectance and thermal emittance. EnergyPlus takes inputs of thermal absorptance (= 1 – thermal emittance) and solar absorptance (=1 – solar reflectance).
Indoor Lighting Power	146	Updated indoor lighting criteria for the three lighting compliance approaches: the complete building method, the area category method, and the tailored lighting method.	Lighting, Indoor	Non-Res Prescriptive	No action needed EnergyPlus allows multiple LIGHTS objects for a space which takes design LPDs as inputs.
Indoor Lighting Controls	119, 130, 131, 134	Added requirements for lighting controls – automatic shutoff, multi-level switch, occupancy sensors, daylighting controls	Lighting, Indoor	Non-Res Mandatory	No action needed EnergyPlus has LIGHTS objects which take LPDs, lighting schedules, and fractions replaceable as inputs. T24 lighting controls can be modeled as adjustment to LPDs, lighting schedules, or daylighting control fractions.
Outdoor Lighting Power	147	Updated maximum outdoor lighting power for the four lighting zones	Lighting, Outdoor	Non-Res Prescriptive	No action needed EnergyPlus models outdoor lighting with one or more ExteriorLights object which takes total lighting power as inputs.
Outdoor Lighting Controls	132	Added requirements for outdoor lighting controls	Lighting, Outdoor	Non-Res Mandatory	No action needed EnergyPlus provides two types of outdoor lighting controls: 1) based on fraction type lighting schedule, and 2) Astronomical Clock which overwrites the lighting schedule to turn off outdoor lighting if the sun is up.
Appliance Efficiency	110-112	Updated minimum efficiency values for air conditioner, heat pumps, PTAC, and heat rejection equipment to match ASHRAE 90.1 values	HVAC	Non-Res and Res Mandatory	No action needed for EnergyPlus.

Refrigerated Warehouse	126	Added requirements for refrigerated warehouse: building shell insulation, evaporator fan controls, condenser fan power and controls, compressor controls, and interior lighting levels	Envelope, HVAC, Lighting	Non-Res Mandatory	Need to add this modeling feature to EnergyPlus.
Pool and Spa	114(b)	Added requirements for pool and spa system to have time switch control to run pumps during off peak electric demand periods.	Others	Non-Res and Res Mandatory	Need to add swimming pool/spa models to EnergyPlus which allow heater on/off control, pump on/off schedule, and pool cover.
DCV	121(c)3	Added demand control ventilation (DCV) requirement for multizone systems with DDC to the zone level	HVAC	Non-Res Mandatory	EnergyPlus can model single zone DCV. Need to modify current EnergyPlus DCV algorithm for multizone DCV based on T24-2008.
Demand Response	122(h)	Added automatic demand shed controls to adjust the thermostat up or down by 4F or more for non-critical zones with zone level DDC during demand response periods.	HVAC	Non-Res Mandatory	No direct action needed. EnergyPlus can model electric demand limited controls which shut off or reduce the power to non-essential loads in order to reduce the overall building demand. Some typical controls: • shut off or dim electric lights either indoor or outdoor • shut off or turn down electric equipment • reset the zone thermostatic setpoints • reduce the load of a set of similar components by rotating one or more components "off" for a short time interval Currently, EnergyPlus has demand limited controls for EXTERIORLIGHTS, LIGHTS, ELECTRIC EQUIPMENT, and ZONE CONTROL:THERMOSTATIC objects. EnergyPlus can model multiple demand limited controls activated in sequence or simultaneously.
	131(g)	Added demand responsive automatic lighting controls to reduce lighting power by 15% or more for retail buildings with sales floor area greater than 50,000 sf.	Lighting	Non-Res Mandatory	
SAT Reset	144(f)	Removed exception of supply air temperature (SAT) reset for VAV systems with VSD fans.	HVAC	Non-Res Prescriptive	No action needed. EnergyPlus can model SAT reset for VAV systems.
WLHP	144(j)7	Added requirement of a minimum water loop temperature dead band of at least 20°F between initiation of heat rejection and heat addition by the central devices for hydronic heat pumps connected to a common heat pump water loop with central devices for heat rejection and heat addition. Exception applies to systems with loop temperature optimization controls.	HVAC	Non-Res Prescriptive	No action needed. EnergyPlus can model WLHP.
Single Zone System	144(l)	Added VAV controls (two-speed, VSD, etc) for single zone DX systems with >= 110,000 Btu/h cooling capacity. This requirement becomes effective on 1/1/2012.	HVAC	Non-Res Prescriptive	No action needed. EnergyPlus has Coil:DX:MultiSpeed:CoolingEmpirical object which can model single zone VAV systems.

Table 2 - continued

T24-2008 Requirements	Section	Description	Category	Scope	Recommended Solutions for EnergyPlus and/or ACM
T24-2008 Non-Res ACM Modeling Capabilities					
Slab, Basement Walls and Floors	ACM	New modeling rules	Envelope	Non-Res	Adopt EnergyPlus methods for slabs and underground surfaces. Need to develop a guideline to create equivalent constructions for EnergyPlus.
Lighting Controls	ACM	Use either lighting power adjustment factor or alternative lighting schedules. The savings from most of the lighting controls are based on alternative lighting schedules with lower lighting percentage fractions to account for lights being turned off or dimmed.	Lighting	Non-Res	No action needed. EnergyPlus takes adjusted LPDs and lighting schedules as inputs.
Skylight Daylighting	ACM	New daylighting modeling rules for skylights	Daylighting	Non-Res	Adopt EnergyPlus skylight models and daylighting controls which are more accurate and flexible.
Daylighting Controls	ACM	Use adjusted lighting schedules instead of fixed Power Adjustment Factor (PAFs) for windows daylighting. The skylight daylighting controls are modeled using the daylighting algorithms in the DOE-2 DAYLIGHTING command.	Daylighting	Non-Res	
DES/DXAC	ACM	Added Distributed Energy Storage Direct Expansion Air Conditioner (DES/DXAC) as a compliance option.	HVAC	Non-Res Compliance option	Need to add DES/DXAC to EnergyPlus. Adopt the AEC developed DOE-2 DES/DXAC function.
VRF	ACM	Added variable refrigerant flow (VRF) system as a compliance option	HVAC	Non-Res Compliance option	Need to add VRF to EnergyPlus. Adopt the AEC developed DOE-2 VRF function. Coordinate Daikin's effort in adding VRF to EnergyPlus.
TES	ACM	Added chiller-based thermal energy storage (TES) as a compliance option. Allows these TES type: Chilled Water Storage, Ice-on-Coil, Ice Harvester, Brine, Ice-Slurry, Eutectic Salt, and Clathrate Hydrate Slurry.	HVAC	Non-Res Compliance option	EnergyPlus can only model ice-on-coil type ice storage system with chillers and ice tanks run in parallel or in series. Need to add other TES types to EnergyPlus.
Hydronic Loops	ACM	Added multiple hydronic circulation loops as a compliance option. eQuest/DOE-2.2 can model multiple water loops.	HVAC	Non-Res	No action needed. EnergyPlus can model multiple hydronic loops.
UFAD	ACM	Added modeling rules for under floor air distribution (UFAD) systems. ACM assumes 40% of internal loads (from occupants, lights, and equipment) to supply plenum, 51% to space, and 9% to return plenum. No mention how to split the envelope loads.	HVAC	Non-Res	Adopt EnergyPlus UFAD model as it is more accurate and flexible.
FDD for AHU and VAV Boxes	ACM	Added adjustment of cooling efficiency and minimum VAV box position for systems with verified fault detection and diagnostics systems.	HVAC	Non-Res	No action needed. EnergyPlus takes adjusted values as inputs.
Hydronic Pressure Reset	ACM	Added supply pressure reset by demand for chilled water VAV with reheat system and four-pipe fan coil with central plant system if proposed system has DDC controls.	HVAC	Non-Res	Need to add pump pressure reset by demand to EnergyPlus.

Air Economizer	ACM	For systems with economizers, the maximum outside air fraction (DOE-2 keyword MAXOA-FRACTION) shall be set to 0.9.	HVAC	Non-Res	EnergyPlus allows the input of maximum outside air flow rate in m3/s. Need to add maximum OA fraction for economizer in EnergyPlus.

Table 2 - continued

T24-2008 Requirements	Section	Description	Category	Scope	Recommended Solutions for EnergyPlus and/or ACM
T24-2008 Res ACM Modeling Capabilities					
DHW	ACM	New distribution system multipliers	DHW	Res	Enhance the DHW model for EnergyPlus. ACM and EnergyPlus have different DHW models.
Attic	ACM	New modeling rules for attics	Envelope	Res	No action needed. EnergyPlus can model attic as a separate zone.
Slab	ACM	New modeling rules for slab perimeter losses	Envelope	Res	Add a new slab model to EnergyPlus with the ACM algorithm.
DES/DXAC	ACM	Added Distributed Energy Storage Direct Expansion Air Conditioner (DES/DXAC) as a compliance option.	HVAC	Res Compliance option	Need to add DES/DXAC to EnergyPlus. Adopt the AEC developed DOE-2 DES/DXAC function.
Evaporative Cooler	ACM	Added evaporative cooling as a compliance option	HVAC	Res Compliance option.	Adopt EnergyPlus evaporative cooling model.
Evaporative-Cooled Condensing Units	ACM	Added evaporative-cooled condensing unit as a compliance option by adjusting ARI rated EERs.	HVAC	Res Compliance option.	Adopt EnergyPlus evaporative-cooled condenser model which is more accurate.
PV	NSHP	CEC developed a PV calculator for the NSHP program	Renewable	Res	Adopt EnergyPlus PV model. Need to compare calculation results between CECPV Calculator and EnergyPlus PV module.

Updates on the Gaps of EnergyPlus Analysis Capabilities for Use in Title 24-2005

AEC's EnergyPlus evaluation project contains a high-level overview of the gaps between EnergyPlus and ACM requirements, and a description of how to adapt one to the other, or both, as appropriate. The gaps are organized into five separate tables addressing overall, nonresidential, residential, nonresidential-optional, and residential-optional engine requirements. AEC's evaluation was based on Title 24-2005 and EnergyPlus 1.2.1. With the current release of EnergyPlus 2.1, EnergyPlus added and enhanced many modeling features. Therefore it is necessary to revisit and update the gaps.

Tables 3 to 7 are updates to the original five tables with a new column added to describe the latest status of each gap based on EnergyPlus 2.1.

Table 3—T24-2005 Overall ACM Engine Requirements and EnergyPlus Capabilities

Section(s)	Topic	Conflict	Adapt ACM	Adapt EnergyPlus	Latest Status (March 2008, E+ 2.1)
NonRes 2.3.5.6 2.3.5.7 2.3.5.8 Res 2.2.6 2.2.7 2.2.8 4.3	Fenestration and Thermal Properties including Solar Heat Gain	EnergyPlus does not use the standard inputs required by the ACM such as U-factor, SHGC, and VLT. As a result, the calculation method is also different.	EnergyPlus does calculate U-factors and SHGCs by combining the thermal properties of each layer of construction. The ACM can be modified not to require thermal inputs for the entire construction assembly since the method EnergyPlus uses is just as accurate. EnergyPlus has a specific algorithm for distributing the solar gains to the surfaces of the zone. This is the intent of the section but the algorithm is likely superior than the ACM factors.	Use the Window tool to develop a library of fenestrations from the Reference Appendices and a choice can then be made from this library for EnergyPlus. A more accurate way is to use these detailed layer-by-layer definitions with full spectral data directly in EnergyPlus IDF files.	EnergyPlus does not use U-factor or SHGC directly; it needs layer-by-layer definitions. Adopt EnergyPlus methods and develop datasets of T24 fenestrations.
NonRes 2.5.2 Res 2.2.16 4.6 4.7	Heating and Cooling Equipment Performance Data and Efficiencies	The heating and cooling equipment are embedded into DOE-2, whereas EnergyPlus uses both DOE-2 and BLAST. As a result, the two do not use the same inputs required by the ACM or the same models. EnergyPlus cannot model the parasitic electric use of the forced draft fan.	In many cases EnergyPlus has better models to characterize efficiency and performance curves. The reference should change to use these models. The ACM could also create a new way of specifying curves or add new curves.	EnergyPlus needs to adopt a model for the parasitic electric use of the forced draft fan for boilers and furnaces.	Most of ACM efficiency data and performance curves can be converted and added to EnergyPlus datasets and made available to public. EnergyPlus 2.1 calculates parasitic electric use of the forced draft fan for boilers and furnace. There is a tool to convert DOE-2 curves in IP units to SI units for EnergyPlus. Maximum and minimum values of independent variables of DOE-2 curves also need to be converted into the curves for EnergyPlus.

Section(s)	Topic	Conflict	Adapt ACM	Adapt EnergyPlus	Latest Status (March 2008, E+ 2.1)
NonRes 2.6.1 Res 2.2.21 3.7 4.10	Water Heating	EnergyPlus does not accept inputs for recirculating water or electrically traced water. EnergyPlus also needs an input schedule for cold water. ACM and EnergyPlus have different algorithms for water heater energy consumption. EnergyPlus doesn't accept standard efficiency inputs for water heaters. No pipe heat loss model in EnergyPlus. Recirculation controls cannot be modeled in EnergyPlus nor can electric heat pump water heaters.	The reference methods do not follow the ACM rules for water heating either. Water heating is calculated separately outside the engine. Change ACM to accept EnergyPlus algorithm for water heater energy consumption.	EnergyPlus needs to incorporate cold water input schedules. EnergyPlus can also be modified to allow for standard inputs. EnergyPlus also needs to develop a better water heater model to include cold water input schedules, recirculation controls, and electric heat pump water heaters.	EnergyPlus allows cold water schedule and takes thermal efficiency as input. EnergyPlus has three water heater models, but none matches ACM. Need to enhance the EnergyPlus water heater models based on ACM algorithms.
NonRes 2.3.5.12 Res 3.3.5 3.3.6	Window Management and Shading Devices	Default shade and window management may be used. EnergyPlus does not have default window management, but a schedule can be selected. ACM requires modeling from SHGC and factors whereas EnergyPlus calculates factors from the layer-by-layer construction.	The ACM can be modified to not require thermal inputs for the entire construction assembly since the method EnergyPlus uses is just as accurate.	Develop a window management schedule that meets the ACM requirements.	EnergyPlus 2.1 has fairly detailed and robust models for windows, shades, and shading controls. Adopt EnergyPlus models.
NonRes 7.1 Res 2.2.18 2.2.19 4.8 4.9	Duct Systems Supply Duct System Details Air Distribution Ducts	ACM uses various adjustment factors and multipliers to calculate duct losses whereas EnergyPlus uses real thermal simulation.	ACM should allow the EnergyPlus method to calculate duct loss because it is more accurate.	EnergyPlus duct losses model should be updated to cover conduction losses.	EnergyPlus allows inputs of duct air leakage and can calculate the air duct conduction losses with the AirflowNetwork model. There is also a simple duct loss model for large commercial VAV systems which doesn't require the use of AirFlowNetwork. Enhance and adopt EnergyPlus models.

Table 4—T24-2005 Nonresidential ACM Engine Requirements and EnergyPlus Required Capabilities

Section(s)	Titles	Conflict	Adapt ACM	Adapt EnergyPlus	Latest Status (March 2008, E+ 2.1)
2.4.1.2 2.4.1.3	Occupancies and Occupant Loads	EnergyPlus currently does not accept inputs for sensible or latent heat. EnergyPlus uses an internal algorithm for this process.	The ACM should be modified to allow EnergyPlus to calculate the latent and sensible heat for the occupancy area.	There could be an override function that allows the user to specific the latent and sensible heat. In this instance, the user inputs would be used.	EnergyPlus allows input of a schedule of total heat gain per occupant. The sensible and latent split portions can be calculated internally or specified by users.
2.4.2.2	Interior Lighting	EnergyPlus and ACM have similar lighting models, except the ACM specifies a different model for daylighting.	EnergyPlus has daylighting capabilities but they do not exactly match the formulas in the ACM manual. The daylighting algorithm in EnergyPlus is more detailed and more accurate than the approximations implied in the formulas.	Not recommended as EnergyPlus' method is more accurate.	Adopt EnergyPlus daylighting models.
2.5.2.4	Standard Design Systems	EnergyPlus cannot model fan coils with economizers and does not have a built-in hard-wire template for basic systems.		EnergyPlus can incorporate a library for the canned systems used in DOE-2. Further, EnergyPlus needs to develop the ability to model fan coils with economizers.	EnergyPlus has compact HVAC objects to model common HVAC systems. The EnergyPlus Four Pipe Fan Coil model with air economizer is under development and is scheduled to be done in 2008.
2.5.3.8	Sizing Requirements	ACM requires systems to be sized with a load methodology from the ASHRAE *Handbook*. EnergyPlus uses a heat balance method. EnergyPlus cannot specify a minimum cfm/ft² regardless of zone load.	The ACM should be changed so the cfm/ft² requirement is removed. The heat balance approach in EnergyPlus is just as telling.	Not recommended as EnergyPlus' method is more accurate.	EnergyPlus allows standards-type calculation of design supply air flow and outside air flow rates based on cfm/ ft². EnergyPlus also allows inputs of min cooling and max heating limits on design supply air flow rates.
2.5.3.14 2.5.3.15 2.5.3.16	Chiller Characteristics	The ACM chiller characteristics and performance are based on DOE-2 curves. EnergyPlus has a variety of chiller models, one which is based on DOE-2.	Change the ACM to accept EnergyPlus chiller models.	EnergyPlus should also add the Gordon-Ng chiller model.	EnergyPlus has the DOE-2 chiller model.
2.5.3.17	Cooling Towers	ACM and EnergyPlus have different calculations for the cells of the cooling towers.	Change ACM to accept EnergyPlus' method of calculating cooling tower cells.	Modify EnergyPlus code to calculate the cells according to DOE-2.	Need to enhance the EnergyPlus cooling tower model.
2.6.1.4	Boilers			EnergyPlus needs to adopt a model for the parasitic electric use of the forced draft fan for boilers and furnaces.	EnergyPlus can calculate the parasitic electric use of the forced draft fan for boilers and furnaces.

Section(s)	Titles	Conflict	Adapt ACM	Adapt EnergyPlus	Latest Status (March 2008, E+ 2.1)
2.6.1.5	Unfired Indirect Water Heaters (Storage Tanks)	Tank loss calculations are different between ACM and EnergyPlus.			Need to enhance EnergyPlus DHW models.

Table 5—T24-2005 Residential ACM Engine Requirements and EnergyPlus Required Capabilities

Section(s)	Titles	Conflict	Adapt ACM	Adapt EnergyPlus	Latest Status (March 2008, E+ 2.1)
2.2.20	Special Systems, Hydronic Distribution Systems and Terminals	EnergyPlus is unable to model pipe loss for hydronic systems with over 10 feet of piping.		EnergyPlus should develop the capability to model piping loss. Pipe losses can also be approximated in EnergyPlus by adjusting the loads for each hour.	EnergyPlus can calculate plant loop piping loss.
3.2.6	Slab-on-Grade Perimeter Losses	ACM requires slab loss factors taken from Table R3-5, whereas EnergyPlus performs an actual simulation.	ACM could allow EnergyPlus to perform the simulation of slab loss instead of using factors from a table.	While EnergyPlus could adopt the loss factors from Table R3-5, an actual simulation may have better results. Currently, EnergyPlus only uses one ground temperature for the entire year; perhaps it can incorporate ground temperatures for different months.	EnergyPlus has GroundTemperatures object which uses monthly ground temperatures to calculate heat transfer through slabs.
3.4	Thermal Mass	EnergyPlus models thermal mass using a heat balance method and conduction transfer functions.	ACM should adopt EnergyPlus model for thermal mass.	Not recommended as EnergyPlus' method is more accurate.	Use EnergyPlus heat balance method.
4.5	Infiltration/ Ventilation Free Ventilation Area	ACM uses embedded equations to figure out ventilation.		EnergyPlus may want to support the use of COMIS in conjunction with mechanical cooling.	EnergyPlus uses AirFlowNetwork to model infiltration and natural ventilation. .
4.2.1 4.2.2	Radiant Barriers Cool Roofs	While ACM requires the modeling of cool roofs and radiant barriers from U-factors, EnergyPlus uses a more accurate thermal model.	ACM should allow EnergyPlus to model radiant barriers and cool roofs via its more accurate thermal model and not require the use of U-Factors.	Not recommended as EnergyPlus' method is more accurate.	Use EnergyPlus heat balance method.

Table 6—T24-2005 Nonresidential ACM Engine Requirements and EnergyPlus Optional Capabilities

Section(s)	Titles	Conflict	Adapt ACM	Adapt EnergyPlus	Latest Status (March 2008, E+ 2.1)
3.3	HVAC Systems and Plants	ACM refers directly to the performance curves in DOE-2.1E. EnergyPlus does not use the DOE-2.1E curves by default.	We might want to change the ACM as it is restrictive. There are better models of HVAC systems available. Some of them are already in EnergyPlus.	Not recommended as EnergyPlus' method is more accurate.	EnergyPlus has datasets of performance curves converted from DOE-2 curves for some HVAC equipment.
3.3.1	Absorption Cooling Equipment	ACM uses DOE-2.1E models whereas EnergyPlus uses BLAST models.	The ACM should be modified to accept the BLAST approach used in the steam absorption chiller model.	The steam-fired absorber does not take advantage of recovered heat because the absorber model in EnergyPlus still needs further development.	Need to enhance EnergyPlus absorption chiller models.
3.3.2	Gas-Engine Driven Chillers and Heat Pumps	EnergyPlus does not currently model engine-driven heat pumps.		EnergyPlus needs to develop the capability of modeling engine-driven heat pumps.	Need to add engine-driven heat pump to EnergyPlus.
3.3.3	Chiller Heat Recovery	EnergyPlus cannot fully model recovered heat in chiller heat recovery.		The use of recovered heat in EnergyPlus can be expanded. EnergyPlus can model heat recovery, but currently has no way to utilize it.	EnergyPlus can model heat recovery from engine-driven and gas turbine chillers. The heat recovered can power a hot water loop as heating source.
3.3.4	Exhaust Heat Recovery	The ACM prescribes a model following DOE-2, whereas EnergyPlus has its own model.	Allow the ACM to adopt the EnergyPlus model for exhaust heat recovery.		EnergyPlus allows heat recover at the AHU level and ERV at zone level. The run-around loop still cannot be modeled.
3.3.8	Cooling Towers Types	Cooling tower types shall be able to model towers that are open with axial fan, closed circuit fluid cooler and natural draft with control by discharge dampers, tower bypass or fans with VSDs.		EnergyPlus can only model single-speed or two-speed towers. EnergyPlus needs to develop the capability to model tower control with discharge dampers, tower bypass, or fans with VSDs. Towers with variable speed fans are planned for the next release of EnergyPlus.	EnergyPlus can model cooling towers with VSD fans, but still cannot model fluid bypass. The discharge damper control can be modeled as VSD fan with a specific fan curve.
3.3.12	Air Economizers Control Strategies	ACM has an optional capability to model differential enthalpy.		EnergyPlus needs to develop the capability to model differential enthalpy.	EnergyPlus can model most ACM types of economizer controls except the variable enthalpy.
3.3.13	Water Side Economizers			EnergyPlus needs further development on free cooling controls.	EnergyPlus can model water economizer either integrated or non-integrated

Table 7—T24-2005 Residential Optional ACM Engine Requirements and EnergyPlus Capabilities

Section(s)	Titles	Conflict	Adapt ACM	Adapt EnergyPlus	Latest Status (March 2008, E+ 2.1)
6.2.2 6.2.3	Hydronic Space/Water Heating	EnergyPlus is able to model hydronic systems but unable to model using AFUE and pipe loss.	Allow ACM to adopt the EnergyPlus model for dedicated hydronic systems.	EnergyPlus needs to develop the capability to model pipe loss.	EnergyPlus can calculate pipe conduction loss if SWH is modeled as a hot water loop. EnergyPlus takes inputs of Thermal Efficiency which is the efficiency from fuel energy input to heat energy for the heater element or burner. This is not the same as the overall efficiency of the water heater.
6.2.4	Controlled Ventilation Crawl Spaces (CVC)	The ACM requires the floor separating crawl space from conditioned space to have a 400 ft^2 U-factor of 0.342 and the remainder to have a U-factor of 0.199.	While EnergyPlus can model two thermal zones, a conditioned zone for the house, and unconditioned zone for the crawlspace, it does not use U-factors but a zone and construction layer approach. The ACM can be modified to accept this approach.	A library of constructions from Joint Appendix IV can be created (including layers, etc.) and a choice can then be made from this library. EnergyPlus can also create a schedule for openings.	Use EnergyPlus heat balance method and detailed layer-by-layer construction definitions.

EnergyPlus Analysis Capabilities beyond Current Title 24 ACM

This section summarizes some of the important EnergyPlus modeling capabilities beyond the current Title 24-2008 ACM requirements. Though these capabilities are not mentioned in the ACM, they are important for an up-to-date codes and standards program. An evolving codes and standards program depends on the ability for certain emerging technologies or features to be modeled by an energy simulation engine. Many of the technologies that can be used to gain credits for code compliance never become standards because of the limitations of the current reference method (DOE-2.1E) and current compliance software.

EnergyPlus combines the most popular core features and capabilities of BLAST and DOE-2. BLAST and DOE-2 differ in their calculation of energy loads, with BLAST using a zone heat balance approach and DOE-2 using a room weighting factor approach. The heat balance approach used by EnergyPlus is similar to BLAST's, allowing interaction between thermal zones and the environment at a user-specified time step. At each time step, heating and cooling system and plant loads are calculated. Loads not met by the system are reflected in the next time step calculation. As a result, EnergyPlus uses an integrated solution between loads, systems, and plants that predicts space temperature and system loads with greater accuracy, and therefore simulates energy usage with more precision. Further, EnergyPlus incorporates a multitude of modeling capabilities that are not currently supported by DOE-2, some of the more important capabilities are listed in Table 8.

The calculation engine is only one part of the compliance process, but it determines which measures can be considered and which can't. Each time Title 24 is updated, new innovations are considered for inclusion—either as compliance options or as mandatory or prescriptive requirements. One criterion the Energy Commission uses for evaluating new measures is whether it can be accurately modeled with the reference method. If the answer is negative, then it is quite difficult to include the measure as either a compliance option or as a requirement.

Programs like Savings By Design, LEED, and CHPS, which encourage designers to produce buildings that are significantly more efficient than code minimum, create great demand for measures that push the boundaries of conventional design. Without the ability to accurately model these innovative measures, features, or design strategies, making the margin is extremely difficult.

The capabilities and potential of tools to model advanced energy efficiency measures defines the frontier. EnergyPlus has the potential to advance the frontier and open a new horizon for more energy efficient buildings. Without the ability to advance the state-of-the-art in energy modeling, the entire standards development process is stifled. Below are a few features in EnergyPlus that will be able to help California achieve goals of zero energy buildings in 2020 for residential and 2030 for nonresidential.

The current reference methods are missing some important features offered in EnergyPlus.

- A heat balance (as opposed to transfer function + weighting factors) method to characterize time delays in heat transfer due to thermal mass and other material properties in the nonresidential ACM calculations.
- More accurate modeling of natural ventilation, offered by the AirflowNetwork model of EnergyPlus.
- A comfort model that considers not just dry-bulb temperature, but humidity, mean radiant temperature, and other factors.
- Zones served by more than one HVAC system.
- The ability to model heat stratification for each zone (two or three node model) to better approximate the benefits of under floor air distribution and/or thermal displacement ventilation.
- The ability to model air flow between zones.

- Generic HVAC models and flexibility in the modeling of air distribution and water loops. (With DOE-2, the user must choose from just a few "standard" systems that were initially defined in the 1980s, and the residential ACMs are far more limited.)
- The capability of modeling a wider variety of control strategies.

These features are elaborated in Table 8.

Table 8—EnergyPlus Advanced Modeling Capabilities beyond DOE-2

Item	EnergyPlus	DOE-2 (both 2.1E and 2.2 unless otherwise noted)
HVAC Loads	Uses the heat balance method which is more accurate. Also performs radiant and convective calculations at each surface. Can model thermal mass effect more accurately. Improved ground heat transfer modeling. Anisotropic sky model provides good diffuse solar calculations.	Uses the transfer function method with custom weighting factors. This method is an approximation of the heat balance method, is less accurate and more prone to user error through misapplication of weighting factors. Errors are probably the greatest for building envelope components that have thermal mass.
Integrated Simulation of Loads and Systems	Building response to thermal loads is calculated simultaneously with system operation. This expands the range of conditions that can be analyzed to include ones where the building temperatures are not always in control (e.g., natural ventilation, undersized systems). Feedback from HVAC system operation can affect building loads.	Building response to thermal loads is calculated independently of system operation. Load calculations assume building temperatures are in control. Limits applicability of simulation to mechanically conditioned spaces. Limited feedback from HVAC system operation affects building loads and zone temperatures. This prevents DOE-2 from accurately simulating systems and heat transfer where zones are under heated or under cooled.
Radiant Exchange	Explicitly models radiant exchange between surfaces. Users have control over solar, visible, and thermal absorptance and emittance for each surface. Surface temperature is a factor in heat transfer. It should be noted that the program uses simplified calculation in lieu of explicit view factors that account for area and orientation of surfaces.	Models radiant exchange only through combined radiation / convection coefficients applied to each surface. The convection and radiant heat transfer do not vary with surface temperature for opaque surfaces.
Thermal Comfort	Can develop surface temperatures for consideration of radiant comfort. Includes three thermal comfort prediction models: Fanger PMV, Pierce 2-node, and Kansas State University 2-node.	Cannot directly model zone thermal comfort as it cannot develop surface temperatures.
HVAC Systems	Systems are built up out of fundamental components. This is a more flexible and robust approach to specifying system characteristics. While the process to specify an HVAC system is more complex, templates and wizards help simplify the process. Through a link to SPARK, custom HVAC equipment component models can be modeled to provide further flexibility.	Systems are pre-designed types. This has several limitations: 1) You cannot easily model some systems because there is no pre-designed model for them; 2) Enhancements to the program (like evaporative cooling) have to be implemented on each of the different system types. 3) Only one system can be assigned to a zone. You cannot model a system with a perimeter fan coil for heating and a cooling only VAV box for cooling.
Displacement Ventilation Systems	Can model both radiation and thermal stratification through a 3-node stratification model. Both of these are critical elements to displacement systems.	Assumes all zones are fully mixed (uniform temperature throughout), which is not appropriate for displacement ventilation systems.
Under-Floor Air Distribution Systems	Can model UFAD systems for interior and perimeter zones.	Assumes all zones are fully mixed (uniform temperature throughout), which is not appropriate for UFAD systems. Cannot model supply plenums.

Item	EnergyPlus	DOE-2 (both 2.1E and 2.2 unless otherwise noted)
Radiant Cooling and Heating Systems	Can model radiant cooling and heating systems.	No direct models for radiant cooling or heating systems.
Natural Ventilation	Can model natural ventilation with Airflow network which allows wind- and buoyancy-driven airflow calculations to be performed simultaneously with building thermal response and system operations calculations.	Can model simplified natural ventilation via operable windows in a few single zone system types (RESYS, RESYS2, PSZ, and EVAP-COOL).
Hydronic Loops	Heating and cooling systems can be separated into distribution loops that can be connected to one another. This provides a much more accurate model of system pumping energy. This can be used for evaluation of alternative hydronic distribution systems like primary-only variable flow, primary/secondary and primary/secondary/tertiary systems.	This feature is only available in eQuest (DOE 2.2). It is not available in the reference method DOE-2.1E. In 2.2 only limited configurations of constant and variable flow systems are available.
Moisture Migration	The combined heat and mass transfer model allows EnergyPlus to model moisture migration and its affect on cooling loads. Neglecting moisture migration can cause errors in sensible and latent heat transfers.	Cannot model moisture migration.
Multiple Time Steps	Heating and cooling loads are calculated on a time-step basis and passed through to the HVAC portion of the simulation. Loads that are unable to be met by the system are fed back into the engine and result in zone temperature/humidity changes for the next time step. The default time step for EnergyPlus is 15 minutes, however, it can be reduced down to 1 minute.	Can only calculate loads on an hourly basis. There is also no feedback between loads and systems.
Air Emission	EnergyPlus can calculate air emissions associated with energy use within a building. This is useful in determining environmental impacts of new energy efficiency measures for code development.	DOE-2 cannot calculate air emissions directly. It has to rely on post-processing.
Water Usage	Water usage becomes more and more important for California. EnergyPlus can calculate water usage for buildings.	DOE-2 does not have this capability.
Renewable Energy	Can model PV either standalone or BIPV.	DOE-2.2 can model PV.
Cogeneration	Can mode cogeneration with IC engine, micro CHP, and fuel cells.	DOE-2 cannot model IC engine or fuel cells.
Daylighting and Controls	EnergyPlus has detailed daylighting models.	DOE-2 tends to overestimate daylighting benefits.
Windows and Shading Controls	EnergyPlus has more shading controls for windows and skylights.	DOE-2 has limited shading controls.
Demand Response Controls	EnergyPlus has demand limiting controls for lighting, equipment, and zone thermostat.	DOE-2 has none.
Outdoor Lighting and Controls	EnergyPlus can model outdoor lighting and controls.	DOE-2 cannot.
Green Roof	EnergyPlus can model green roofs.	DOE-2 cannot.
Visual Comfort	EnergyPlus calculates visual comfort.	DOE-2 does not.

How Advanced Modeling Capabilities Relate to Codes and Standards Development

By setting minimum requirements for energy-efficient design and construction, energy codes and standards force older, less efficient technology out of the market. As less efficient technology is driven out of the market by more stringent codes, there is a push for research and development in emerging technologies that take their place. However, with a move towards more energy-efficient technologies comes a necessity to be able to model these technologies. As a result, the development of EnergyPlus and its advanced modeling capabilities is vital to the progress of energy efficiency codes and standards. The current reference method is becoming outdated and unable to support many of the new technologies used for energy-efficient design. Being able to model these technologies is a necessity for an evolving codes and standards program. This coupled with the fact that the development and support for DOE-2.1E by the USDOE has come to an end, as their research focus has shifted to EnergyPlus.

Many of the new codes and standards incorporated into Title 24 started off as energy-efficient measures. A prime example is cool roofs. In the 2001 Title 24 Standard, cool roofs were used to gain credit over the baseline during code compliance. Later, in the 2005 Title 24 Standard, cool roofs evolved into a prescriptive measure.

Many measures go through a test period as a compliance option before they become a prescriptive or mandatory requirement of the standard. The Energy Commission usually requires a measure to be modeled accurately in order for credits to be calculated and measures to be adopted. Currently, DOE-2.1E, DOE-2.2, and CALRES are the only three reference methods that the Energy Commission considers for modeling capabilities. The limitations of these two programs are making it harder to expand the scope and depth of the standards. There is a need to switch reference methods, or at least accept EnergyPlus as an additional reference method, in order to maintain an up-to-date codes and standards program.

Integrated Solution Manager and Modular Code

In DOE-2, heating and cooling loads are calculated and run through the simulation for systems and plants without feedback from one another, in a sequential fashion. In EnergyPlus, the building, system, and plant all interact with one another at each time step in the simulation. By integrating load calculation and simulation, EnergyPlus can get feedback from the load calculation during each time step. This provides better understanding and evaluations of the building environment, including accurate temperature and comfort predictions.

Its modular code is another reason to consider EnergyPlus as the reference method. The current DOE-2 “spaghetti code” structure hinders the development of advanced models from being added to DOE-2. The modular code of EnergyPlus written in Fortran 90 allows developers to independently develop new models and add them to the existing program. The ability to easily add new models and hence new energy efficient measures to the existing code is what allows building simulation and energy standards to reach their full potential in maximizing efficiency.

The EnergyPlus source code is open for public inspection through a license agreement, and is written in an easy-to-understand format. Fortran 90 is a modern language and has support for multiple compilers and operating systems. The standardized object-based structure separating objects and fields by a comma significantly decreases the learning curve to develop new modules for EnergyPlus. Also, Fortran 90 allows for mixed language modules. As a result, developers from around the world are able to develop new modules, algorithms, or interfaces easily that can keep pace with the latest building research.