CALIFORNIA
TECHNICAL FORUM

Cal TF Technical Position Paper No. 3: Case for Using EnergyPlus as "Default" Modeling Engine for the "Electronic TRM" Project (Draft)

I. Overview

Cal TF is recommending that an "Electronic Technical Reference Manual (TRM)" be created as a repository for deemed measures, measure parameters (savings, incremental measure costs, expected useful lives and net-to-gross ratios) and measure documentation (including modeling runs and results, studies, and other information used for measure development). One question that needs to be resolved is what modeling tool should be used as a "default" tool for deemed measures that are modeled. For policy, operational and technical reasons, EnergyPlus should be the "default" modeling engine for the development of the Electronic TRM. The OpenStudio software development kit (SDK) and user interface—which works with EnergyPlus—can facilitate the development process and improve the transparency, portability, and utility of software representations of energy efficiency measures (EEMs).

II. Background and Definitions

End-user modeling tools typically consist of two parts: i) a non-graphical "engine" that performs physics calculations, and ii) a graphical "user interface" that accepts user input, presents results, and potentially implements some supporting functions such as setting of defaults, automatic generation of code-baseline buildings, etc. An engine may be tightly coupled with a single user interface. Notable examples of this arrangement include Trane TRACE and IES Virtual Environment/ApacheSim. Alternatively, an engine may support multiple user interfaces. A notable example here is EnergyPlus, which has the following interfaces: OpenStudio, DesignBuilder, AECOSim Energy Simulator, Sefaira Architecture & Systems, N++, Simergy, CBES, and CBECC-Com.

Current Practice—DOE-2.2 and eQuest/MAS

The DOE-2.2 engine, along with the eQuest/MAS interface, is currently the energy analysis modeling tool for deemed modeled measures in California, which are contained in both utility "non-DEER" workpapers and DEER. CPUC policy supports the use of DOE-2.2 for modeling weather sensitive measures,[1] but does not require its use.

The free eQuest user interface has made DOE-2.2 one of the most widely used programs throughout the US.[2] eQuest is embraced by users for its "wizard-like" organization which helps

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[1] CPUC Decision 12-05-015, p. 331.

[2] eQUEST is provided free through download from State of California's Energy Design Resources program (www.energydesignresources.com). Approximately 7,000 copies of eQUEST have been

guide the user through the modeling process and makes the program easy to learn, as well as for extensive use of defaults for missing data. eQuest also automates a number of EEMs and supports limited parametric analysis within the tool. Advanced users can leverage an input file macro facility to implement EEMs of their own.

MAS (Measure Analysis System) extends eQuest with capabilities that are specific to the CPUC deemed savings calculation process. It includes models of prototype buildings along with square footage weighting factors per California climate zone and California typical year weather files. MAS embodies the assumptions for measure development and California state-wide energy savings calculations and automates the latter process.

DOE-2.2, eQuest, and MAS are owned by J.J. Hirsch, ex ante consultant to the CPUC, and their development and maintenance is funded by California ratepayers. Critically, these software packages are "freeware" but not "open-source software". DOE-2.2 source code is available for inspection, but not in a way that can be compiled into executable code, making modification, improvement, and the creation of derivative works impossible. eQuest and MAS, which embody many defaults, assumptions, and measures are available in executable form only.

Current Practice—EnergyPlus and OpenStudio

The EnergyPlus engine and the OpenStudio interface are funded by the US Department of Energy and developed by the national labs—the National Renewable Energy Laboratory and the Lawrence Berkeley, Oak Ridge, Argonne, and Pacific Northwest National Laboratories—as well as competitively solicited contractors. EnergyPlus and OpenStudio are both open source software and as a result a broad community of software vendors and energy professionals have access to the software and are extending it, improving it, and customizing it for various purposes, and creating derivative works, using a variety of funding sources. Multiple commercial software vendors are selling or have announced EnergyPlus-based products.[3] EnergyPlus is currently used by several utilities[4], large equipment manufacturers[5] and a large number of energy design professionals throughout the US[6].

Although EnergyPlus is analogous to DOE-2.2, OpenStudio is a unique package that is not directly analogous to traditional interfaces like eQUEST/MAS. Specifically, OpenStudio is a software development kit (SDK) of energy modeling utility functions that enable creation and manipulation of both prototypical or customized building models. The SDK also facilitates the rapid development of graphical applications—the graphical OpenStudio is one such example

downloaded from the site. Energy Design Resources, EQuest Documentation (no date), p. 1. (www.doe2.com/download/equest/eQuestv3-Overview.pdf).

[3] Sefaira, DesignBuilder, Autodesk and Trane are a few firms who have released or announced EnergyPlus-based tools.

[4] Duke Energy, National Grid, Austin Energy, Others (source: Personal communication with Andrew Parker, NREL).

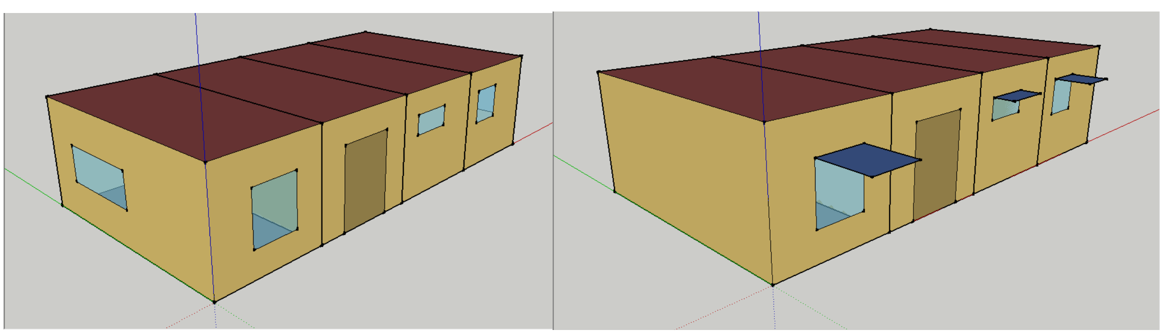
[5] TRANE, Carrier, AudoDesk, DesignBuilder, Bently currently use or are adopting EnergyPlus and are making significant investments along with DOE. Personal communication, Amir Roth US DOE. [Confirm allowed to make this public]

[6] 27,000+ downloads of every EnergyPlus version update. Amir Roth (US DOE) Presentation to Cal TF PAC on September 3, 2015. Available on www.CalTF.org.

application that was developed in about six months. Perhaps one of the most powerful capabilities enabled by the SDK are “OpenStudio Measures,”[7] small self-contained scripts (like Excel macros) that can manipulate models quickly and consistently. Measures are developed separately from individual models, easily extended, and may be applied to arbitrary models for specific or portfolio-scale analyses.

The name Measure comes from the fact that OpenStudio scripts are used to create energy efficiency measures (EEMs). Figure 1 shows the core Ruby script of an OpenStudio Measure that implements a simple daylighting strategy. The script iterates over all sub-surfaces in the model—in an OpenStudio model, windows are sub-surfaces embedded in wall surfaces—skips over sub-surfaces that are not outdoor-exposed windows, removes windows that face east (azimuth between 45 and 135) or west (azimuth between 225 and 315), and adds overhangs on windows that face south (azimuth between 135 and 225).

```ruby
model.getSubSurfaces.each do |s|
   # test if it is an exterior window
   next if not s.outsideBoundaryCondition == "Outdoors"
   next if not s.subSurfaceType == "FixedWindow"
   # get the azimuth for the surface
   azimuth =  OpenStudio::convert(s.azimuth,"rad","deg").get
   # east or west
   if (azimuth >= 45 and azimuth < 135) or (azimuth > 225 and azimuth < 315)
      s.remove
   # south
   elsif (azimuth >= 135 and azimuth < 225)
      s.addOverhangByProjectionFactor(1,0) # (projection factor, offset)
   end # if azimuth
end # model.getSubSurfaces.each do
```



Before *After*

Figure 1. OpenStudio Measure that implements a simple daylighting strategy, removing east and west facing windows and adding overhangs to south facing windows.

The example below shows a model before and after the application of the “Full Daylighting Package” OpenStudio Measure. Based on space type and orientation, this OpenStudio measure reconfigures fenestration, changes glazing, adds shading and skylights, and even adds daylight sensing. OpenStudio Measures have full access to the building model and can be arbitrarily sophisticated and surgical.

[7] Open Studio Measures can be written in commonly-used computer programming languages like Ruby.

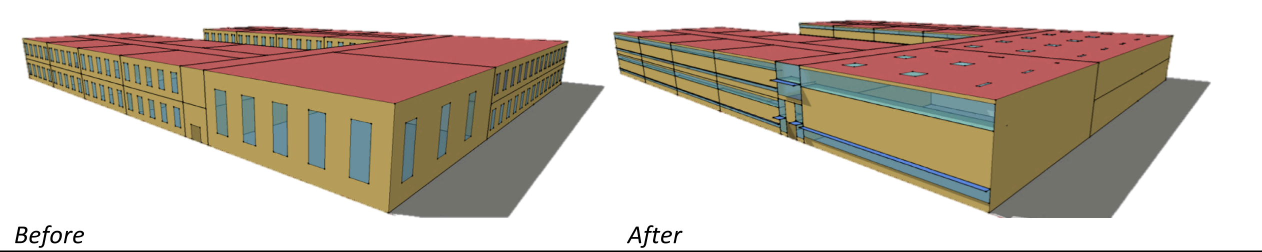


Figure 2 Primary school model before and after application of full daylighting package OpenStudio Measure.

The example illustrates one of the great benefits of OpenStudio Measures, their accessibility. Users can quickly download and apply a Measure to a model of interest and get useful results. Anyone interested in the details of the implementation may freely examine the Measure's Ruby code along with associated test cases and detailed design documents that outline the Measure intent, underlying engineering assumptions, modeling approach, and test case(s). Lastly, Measure scripts may be easily modified and shared with others to provide improved or variant functionality. Encapsulating EEM model transformations as OpenStudio Measures improves their transparency, portability, and utility.

The ability to perform transformations transparently, consistently, and efficiently makes OpenStudio Measures an especially powerful and convenient tool for the type of EEM analysis required to develop deemed values. These same scripts can also be used to dynamically generate whole models based on the desired building type, code, and climate zone. An OpenStudio Measure designed to generate the DOE commercial prototype building models[8] is currently being completed for release in early 2016. Residential prototypes will follow soon after. Combining the prototype and EEM measures with OpenStudio's cloud computing capability for parametric analysis enables efficient, scalable, and extensible assessment of measures spanning building types and climate zones.

Statement of Technical Forum Need

Prior to initiating work on the "Electronic TRM" project, Cal TF must decide certain key threshold issues. One key issue is what "default" modeling engine to use for modeled measures, recognizing that there is not a "perfect" solution for all measures. In deciding what energy modeling engine to use as a "default" tool, Cal TF needs to identify and consider policy/regulatory, operational and technical criteria that can be used to compare and select the default modeling engine.

III. Objectives

This technical position paper has three key objectives:

1. Identify Criteria for Comparing Modeling Engine: Identify key policy/regulatory, operational and technical criteria that Cal TF should consider in selecting the "default" modeling engine to use in the "Electronic TRM" project.

[8] https://www.energycodes.gov/commercial-prototype-building-models

2. Compare Energy Modeling Engines EnergyPlus and DOE-2.2 on policy, operational, and technical basis
    a. Compare Measure Development and Assessment Tools eQuest/MAS and OpenStudio on operational and technical basis
3. Recommend Which Default Modeling Engine to Use in "Electronic TRM" Project

IV. Cal TF Proposal

Cal TF Recommends:

1. Criteria: The following criteria should be considered in selecting a default modeling engine:
    - Policy/Regulatory – Policy and regulatory directives and goals.
    - Operational – Ease of accessing, using, modifying and extending modeling tools; ratepayer benefits; cost and cost-sharing opportunities; ability to collaborate in development/updating activities.
    - Technical – Technical capabilities for performing energy modeling for newer measures that are needed to support Title 24 standards, and meet California's energy savings goals.
2. Engines: The engines that should be considered and compared are DOE-2.2 and EnergyPlus.
    - DOE-2.2, because it is the current default engine for the California IOU ex ante processes, and
    - EnergyPlus, because of its advanced capabilities, transparency, large number of user interfaces, widespread and increasing use, adoption by the CEC for Title24 compliance (non-residential)[9], and strong support from US DOE and the national labs; and because OpenStudio—which works with EnergyPlus—provides a productive, transparent, and collaborative measure development platform, is widely used, and has strong support from US DOE and the national labs.
3. Recommended Default Engine: EnergyPlus should be default energy modeling engine based on policy, operational and technical criteria.

V. Analysis

Cal TF has, multiple times at both the subcommittee level and full TF level, discussed the criteria set forth in the table below as important in the broader context of developing deemed measures, and the more specific context of formulating criteria for components of the "Electronic TRM" project. Information on attributes of EnergyPlus (and OpenStudio) and DOE-2.2 (and eQuest/MAS) is from staff at DOE and the national labs (LBNL and NREL), comments and observations of Cal TF members, and independent research by Cal TF.

[9] California Simulation Engine (CSE) is currently used for Title 24 residential compliance. The CEC does not support using EnergyPlus for residential modeling until EnergyPlus has the capability of modeling duct leakage and radiant heat in unconditioned spaces. This work is planned for the first half of 2016.

Table 1.0: Comparison of Engines DOE-2.2 and EnergyPlus for Electronic TRM Project

Criteria	DOE-2.2	EnergyPlus
CA Regulatory & Policy Directives		
Transparency and Documentation[10]	Source code can be obtained for inspection in a form that cannot subsequently be compiled to an executable. DOE-2.1 algorithms are described in the Engineering Manual, however DOE-2.2 extensions are not.	Calculations, inputs, assumptions, and default values can be reviewed by anyone. EnergyPlus uses few default values. Algorithms and assumptions are fully documented.[11] Engineering as well as input/output reference updated continuously and available both in HTML and PDF.
Inter-Agency Coordination – statewide consistent energy savings values	Not used by CEC, requires consultants to create separate models for code-compliance and ex ante incentives.	Adopted by CEC Title 24 compliance (non-residential), allows consultants to use a single model for code-compliance and ex ante incentives.
Use of Public Funds	Ratepayer dollars used to develop proprietary software	Taxpayer dollars used to develop open-source software.
Operational		
Ownership	J.J. Hirsch	Regents of University of CA and Regents of University of IL
Licensing	Proprietary, source code not readily and freely available. Derivatives works are not permitted.	Commercialization-friendly open-source license that permits the development of proprietary derivative works and a variety of business models.
Funding	CA Ratepayers ($?)	DOE ($3.5 million/year); in-kind contributions from industry. Funding level has been stable since 2010.
Updates, Bug Fixes, and New Features	Few updates since 2009.	Smaller update released every other week, with major releases twice a year.
Opportunities to Collaborate and Cost-Share	Controlled by vendor.	Large communities of developers, and funding sources – work is readily peer reviewed and auditable for accuracy. CEC and DOE have a history of cost-sharing and collaboration.
Conflict of	Vendor who reviews/approves	US DOE is not a commercial entity

[10] Rule 10.3(3)(B) of the Commission's Rules of Practice and Procedure.
[11] https://energyplus.net/sites/default/files/pdfs_v8.3.0/EngineeringReference.pdf.

Interest/Bias	new deemed measures for CPUC also owns DOE-2.2 so has strong bias for exclusive DOE-2.2 modeling.	and has no influence over measure review/approval at CPUC.
Technical		
Programming Language	FORTRAN, legacy platform used by a small number of developers, with slowly advancing compiler support and few libraries.	C++, modern platform used by a large number of developers, with quickly advancing compiler support and a large number of libraries[12].
Development Team	JJ. Hirsch and associates.	Large and evolving pool of developers (approximately 30 at any given time) that includes individuals from national labs, universities, consultants and software vendors. Most developers are active in energy modeling professional, research, and standard-making organizations such as ASHRAE and IBPSA.
Development process & QA/QC	Development process is closed. Updates, including inputs, calculations, assumptions and default values not readily available or subject to public peer review process, so errors or incorrect approaches may not be identified.	New features and bug fixes undergo extensive review, testing, and documentation. Source code repositories, issue tracker, automated test dashboard, feature request system, and Q&A forum are publicly available.
Modeling capabilities[13][14]	In general, based on simplified equations developed when computation was more expensive ('70s and '80s).	In general, based on more sophisticated computations requiring greater computation power.
• **Time step**	Fixed one-hour time step precludes effectively modeling building controls, equipment cycling, and start/stop effects.	Variable timesteps as small as one minute can effectively model controls, equipment cycling behavior, and start/stop phenomena.
• **Solution of space loads and system response**	Sequential, space loads calculated first then passed to system simulation; unmet loads used to adjust zone air temperatures in simplified ways	Integrated, space loads and system response solved iteratively at every time step and unmet loads propagated to subsequent time step; allows for accurate space

[12] A "library" in this context refers to a computer program module that automates a function so that the function does not need to be coded from scratch.

[13] Extensive comparison between DOE-2.2 and EnergyPlus performed in Nov. 2010 by H. Rallapalli as Masters Thesis at Arizona State University under supervision of H. Bryan, M. Addison and T. Reddy, http://repository.asu.edu/attachments/56303/content/rallapalli_asu_0010n_10220.pdf

[14] DOE-2.2 modeling capabilities from eQUEST documentation from EDR website (www.doe2.com/download/equest/eQuestv3-Overview.pdf). EnergyPlus modeling capabilities from EnergyPlus documentation and personal communications with DOE and NREL staff.

	that are not accurate, especially for zones with heavy thermal mass construction.	temperatures crucial to EE system engineering, including system size, plant size, and occupant comfort.
• **Heat transfer**	Combined radiant and convective heat transfer doesn't accurately track surface temperatures, precluding thermal comfort calculations and limiting modeling of radiant systems.	Separate radiant and convective heat balance accurately predicts surface temperatures, and supports calculations of thermal comfort, condensation, and modeling of radiant heating/cooling.
• **Room air model**	Assumes perfect air-mixing, i.e., uniform air conditions within a zone. Requires users to input assumptions for modeling non-mixed air HVAC systems such as underfloor air, displacement ventilation, etc.	Provides both mixed and non-mixed air models for systems like underfloor air and displacement ventilation. Provides a user-defined room air model that allows users to more accurately characterize the physics of non-mixed air HVAC systems.
• **Moisture transfer**	Does not account for moisture transfer.	Calculates moisture penetration and condensation.
• **Lighting & Fenestration**	Simple split-flux lighting calculations that tend to overestimate daylighting. No ability to calculate visual comfort. Few advanced features, e.g., dimmable lights and controllable window shades.	Both split-flux and more sophisticated lighting and visual comfort calculation. Via OpenStudio, ability to integrate with state of the art open-source lighting engine Radiance for detailed illuminance and glare calculations. Models for dimmable lights, controllable window blinds and shades, switchable glazing, light redirecting devices, and other complex fenestration systems (CFS).
• **HVAC systems**	Limited to standard pre-defined HVAC systems. Alternative configurations modeled through "work-arounds" that may not reflect reality.	Flexible component-level HVAC modeling allows users to assemble arbitrary systems, supporting advanced configurations such as VRF (which is becoming increasingly common). Standard systems provided as templates for convenience.
• **HVAC, plant, lighting & process control**	A limited number of pre-defined control schemes; no user-defined control mechanism (can't model control schemes, need to take what is given)	A large number of built-in predefined control schemes as well as a user-defined control mechanism for simulating demand-response strategies, occupant behavior, and other dynamic data-dependent reactive phenomena. Control schemes can be customized.
• **Contaminant**	Simplified contaminant analysis	Directly models the balance of zone

analysis	and controls of HVAC systems that use contaminant levels as an input variable.	contaminants such as CO2. Supports user-defined contaminant generation rates. Directly models control strategies that use contaminant levels as a input.
• **Commercial refrigeration**	A separate build of DOE2.2 (DOE2.2R v52h) models commercial refrigeration equipment.	Models commercial refrigeration within the main (only) build.
• **Water energy & usage**	Models energy associated with service <u>hot water</u>.	Models the energy associated with both *<u>hot and cold</u>* water usage, including rain collectors, wells, water storage, and vegetated roofs.
• **Economics & utility tarriffs.**	Hourly time-step limits accuracy for utility tariffs requiring sub-hourly calculations. A single tariff calculation for each energy source requires generation and T&D tariffs to be lumped and may require complex tariff structures to be simplified.	Sub-hourly time-step accurately model utility demand tariffs requiring sub-hourly calculations. Multiple tariff calculations for each energy source to be flexibly defined, allowing generation and T&D tariffs to analyzed individually. Supports complex tariff structures.
• **Residential**	Supports residential modeling.	Supports residential modeling except for leakage and radiant heat losses for ducts in unconditioned spaces, so is not yet approved for Title 24 compliance for residential buildings[15].
Testing and Validation[16]	Refers to standardized, cross-engine testing and validation, not to product testing performed by the developer or associates.	
• **ASHRAE 140 – analytical & comparative**	Yes	Yes
• **Empirical**	Yes, for older technologies	Yes, for older technologies. Empirical validation continues for new technologies through Flexlab at LBNL.

[15] DOE has scheduled completion of this function by the end of this DOE fiscal year, ending September 30, 2016.

[16] Validation of building energy simulation engines uses a combination of analytical tests (do simulated results match analytical results for simple configurations?), comparative tests (do different analytically sound engines produce similar results for more complex configurations?), and empirical tests (do simulated results match measured field results?).

Table 2.0: Comparison of Measure Development Tools eQuest/MAS and OpenStudio for Electronic TRM Project

Criteria	eQuest/MAS	OpenStudio
CA Regulatory & Policy Directives		
Transparency and Documentation	Building prototypes only partially described[17] Energy Efficiency Measures (EEMs) contain default values that are not readily available; EEM documentation appears to provide a narrative of the measure and computer commands to model the measure, but little in the way of algorithms and default assumptions[18].	Building prototype methodology and input data fully described. EEMs described in narrative form. All algorithms and assumptions clearly set forth. Parameters used in prototype models and EEMs are explicitly visible and documented in the source code, test files, and supporting documentation.
Operational		
Ownership	J.J. Hirsch	US DOE
Licensing	Proprietary, source code not freely available. Derivatives works are not permitted.	Commercialization-friendly open-source license permits development of proprietary derivative works.
Funding	CA Ratepayers ($?)	DOE ($1.5 million/year consistent over the past five years); cost-share from state and public organizations, utilities & industry.
Updates, Bug Fixes, New Features, and New Measures	Few updates since 2009. New measures can only be authored by vendor.	SDK is updated every two weeks with major releases every quarter. Measures can be authored, and an expanding pool of consulants has measure authoring capability, enabling competitive solicitations for new measure content.

[17] Installer for the DEER-specific version of eQUEST includes spreadsheet "2004 DEER non-Res Prototype Charateristics.xls" which includes constructions by climate zone, vintage and type, fenestration materials and frame assumptions, HVAC equipment efficiencies and systems types by vintage and capacity. However, does not include information about other key parameters that should be used to define model building prototypes, such as geometries of each building type, typical constructions with corresponding materials and material properties, space types with corresponding lighting power densities, equipment power densities, occupancy levels, ventilation requirements, other internal loads, breakdown of each zone into % space type assumptions, assignment of zones to HVAC systems, default performance curves by component type, vintage and capacity. Personal communication, Andrew Parker, NREL.

[18] The DOE 2 website has a link to the DOE 2 documentation. The link is to over a dozen "zip" files with names that are not in any way clear or descriptive. Each zip file, in turn, contains an amalgam of files in various formats with non-descriptive names. All files that this author attempted to open were password protected. http://doe2.com/download/doe-22/

Technical		
Language & Platform	FORTRAN	SDK written in C++, Measures written in scripting language Ruby.
Development Team	JJ Hirsch and associates.	A large team of approximately 20 developers that includes national labs and consultants. Significant number of consultants with Measure writing capability.
Development Process & QA/QC	Proprietary.	SDK features and bug fixes undergo extensive review, testing, and documentation. Source code repositories, issue tracker, automated test dashboard, feature request system, and Q&A forum are publicly available. Measures are revision controlled and distributed via an online repository that supports provenance and privacy settings. Regression testing currently being implemented.
Parametric Analysis[19]	Allows up to nine design alternatives.[20] Advanced users can take advantage of parametric analysis feature which runs on local computing resources.	OpenStudio Server image can be loaded onto Amazon Elastic Compute Cloud (EC2) for large-scale parametric studies. Spreadsheet specifies prototype buildings, weather files, measure combinations, and sensitivity/ uncertainty parameters.[21]
Code Baseline Updates	Updating modeled measures for code baseline changes is slow, laborious and expensive	Code baseline transformations are implemented as OpenStudio Measures and can be composed with any analysis.

[19] Parametric runs are used to define and run multiple, alternative simulation cases. Parametric runs can be used to modify the base building to allow for range of cases like altering orientation of building, changing wall properties, roof properties, glass properties, altering lighting power densities and equipment, modifying schedules and occupancies, etc. Parametric runs can be used in new building design to optimize building performance.

[20] Energy Design Resources, EQuest Documentation (no date), p. 4. (www.doe2.com/download/equest/eQuestv3-Overview.pdf).

[21] Large scale, highly automated parametric analysis feature can be used for two key functions: 1. Provide analytic approach to whether measure should be custom or deemed. In other words, can be used to assess whether measure varies sufficiently across variations of a building type such that it should be a custom rather than a deemed measure, and 2. can be used to reduce measure complexity by identifying which measures in different climate zones, building types

VI. Conclusion

Cal TF recommends replacing DEER with an "Electronic TRM" that would be a repository for all deemed measure values in California. One critical path item for this project is deciding what "default" modeling tool should be used for this project; Cal TF recommends that EnergyPlus be used for developing modeled deemed measures for the Electronic TRM based on policy/regulatory, operational and technical criteria as described herein.

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