On the Need for a Unified and Collaboratively Developed Residential Building Simulation Platform

Preprint

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ABSTRACT

Residential building energy simulations are increasingly pervasive. They form the basis of energy-efficient building design, zero energy goals, codes and standards, home certification and ratings industries, utility programs, regional/state planning, and technology assessments. Yet the residential building simulation community is highly fragmented with a patchwork of simulation platforms with varying models, inputs, assumptions, and results. This inconsistency degrades confidence, increases industry-wide development and maintenance costs, and slows the availability of new efficiency technology models.

The need for collaboration on an impartial, transparent, and capable residential building simulation platform has never been greater. But developing and maintaining a state-of-the-art simulation platform requires dedicated and sustained investment. By leveraging existing resources and expertise from multiple entities/regions, a unified and collaboratively developed simulation platform can provide increased levels of energy efficiency at an accelerated pace.

This paper presents the advantages and disadvantages of a unified residential building simulation platform in relationship to four real-world examples: RESNET's Home Energy Rating System, utility programs, California's Title 24, and the U.S. Department of Energy. The paper covers recent developments and improved capabilities that might move us closer to an ideal simulation platform and what challenges remain. The hope is to spur frank and honest dialogue about how to better collaborate to achieve deeper and more reliable energy savings in the residential buildings industry.

Introduction

Residential building energy simulations play an increasingly significant role in reducing the energy consumption of our housing stock. These simulations are used to design new homes, inform energy and climate goals, develop building energy codes and standards, create ratings and green certification labels, incentivize efficiency technologies through utility and other programs, and assess new/emerging efficiency technologies. Hundreds of thousands of homes are modeled each year using residential building software tools. More than 225,000 homes were rated by the Home Energy Rating System (HERS) in 2017 (RESNET 2018a). More than 75,000 homes have had Home Energy Scores calculated since 2012 (DOE 2017a). Approximately 35,000 homes each year are improved through the Weatherization Assistance Program (WAP) as informed by building simulations (DOE 2017b). And building simulations are used increasingly to demonstrate state/local code compliance.

In aggregate, building simulations represent an opportunity to increase the efficiency of the residential buildings sector at scale. But for a production homebuilder to integrate a high-performance technology into their new homes, for a homeowner to purchase more efficient equipment or insulation, or for a state planner to develop more aggressive, cost-effective building energy codes, the software tools must be able to evaluate and credit the newest and most efficient technologies on the market.

In addition, the consistency of these building simulations across the multitude of residential software tools and simulation engines is of great importance. This is not just academic; real homes are being built on the choice of software engine. There is a strong need for an even playing field across software tools with uniform standards for evaluating performance.

Developing and maintaining a state-of-the-art simulation platform requires substantial, dedicated investment and a thriving development team. The core simulation engine must be capable of evaluating a vast set of building technologies/components, and it is only one of many moving parts inside a capable and modern simulation tool. These tools must also include a user interface, input translation, standards/rule sets, component libraries, output translation, reporting, and user support and documentation. It can be expensive for private sector companies to develop and maintain this complete software ecosystem given limited revenue streams.

This paper discusses the current landscape and capabilities of residential building energy simulation tools with a focus on how well the needs of a burgeoning industry are being met. The paper highlights the pros and cons of the design of several real-world programs: RESNET's HERS ratings, utility programs, California's Title 24, and the U.S. Department of Energy (DOE). Finally, the paper makes the case that the competitive and fragmented nature of the building simulation industry is, rather than spurring innovation, limiting the uptake of new efficiency technologies, producing inconsistent results, duplicating efforts, and increasing barriers to entry—and that a unified, collaboratively developed, open-source residential building simulation platform is the best solution to address these issues.

Residential Simulation Landscape

The residential buildings industry comprises a large array of software tools and calculation engines that are used for different purposes or programs. Different software tools have typically been created to address the specialized requirements of different programs—e.g., residential vs. commercial, new construction vs. existing homes, asset vs. operational, and different occupancy assumptions. For example, the RESNET standards (RESNET 2018b) dictate occupancy assumptions that generally reflect national averages, whereas California's Title 24 (CEC 2018) uses assumptions that reflect homes in the State of California. States and municipalities adopt different versions of the International Energy Conservation Code (IECC) for code compliance (DOE 2017c). Utilities often track energy savings relative to custom reference buildings. Tracking all these programs/uses over time is complex, so software tools tend to specialize in certain programs or geographic areas.

Table 1 presents 16 common residential simulation engines spanning dozens of software tools used across the United States. The simulation engines vary widely in their capabilities, ease of use, software licenses, and user bases. The simulation engines can generally be categorized into two groups:

1. **Custom-built simulation engines** are designed for specific software tool and/or program needs. These engines are generally built with small development teams and have simpler inputs, employ less sophisticated algorithms/models, and have fewer capabilities for modeling new/efficient technologies.

2. **General-purpose simulation engines** are designed to be leveraged by third-party user interfaces for a variety of needs. These engines are generally built with larger development teams; many were developed to tackle complex commercial buildings. They have detailed inputs, often allow choices of different algorithms/models, and have more capabilities for modeling new/efficient technologies.

Table 1. Common Simulation Engines Used by Residential Software Tools

Simulation Engine	Interface(s)	Primary Sector(s)	General Purpose?	Capability	Active Development	Open-Source License?
CSE	CBECC-Res, Right-Energy, EnergyPro	Res	Yes	+++	++	Yes
DOE-2.1e	Home Energy Score, EnergyGauge, Beacon	Res/Com	Yes	+++		
DOE-2.2	eQUEST	Res/Com	Yes	+++	++	
Ekotrope	Ekotrope	Res		++	++	
EnergyPlus	DesignBuilder, BEopt, Sefaira, Autodesk Insight360, TRACE 3D Plus, CBECC-Com, etc.	Res/Com	Yes	+++++	+++++	Yes
ESP-r	ESP-r	Res/Com	Yes	+++++	++	Yes
HEED	HEED	Res		++	+	
HOT2000	HOT2000	Res		++	++	
Optimiser	Optimiser, Snugg	Res/Com		++	+	
PHPP	PHPP	Res		++	++	
REM/Rate	REM/Rate	Res		+	+	
SEEM	SEEM	Res		++	+	
SIMPLE	CakeSystems	Res		+	+	
SUNREL	TREAT	Res	Yes	++		
TRNSYS	TRNSYS	Com	Yes	+++++	++	
TrueHome	TrueHome	Res.		+	+	

Notes: This table presents a high-level overview of the simulation engines; comprehensive evaluation and description of each simulation engine is beyond the scope of this paper. *Primary Sector(s)* refers to residential buildings and/or commercial buildings. *Active Development* represents best estimates at an active level of development being directed toward energy modeling/simulation; a blank entry implies that the engine is unmaintained. *Capability* represents best estimates considering the breadth of technologies modeled as well as sophistication of model algorithms.

Anatomy of a Software Tool

Although the simulation engine is often thought to be the sole, or primary, contributor to an energy simulation prediction, it is one of many software components that combine to form a modern building software tool. Each piece requires significant development and maintenance and can substantially influence the simulation results.

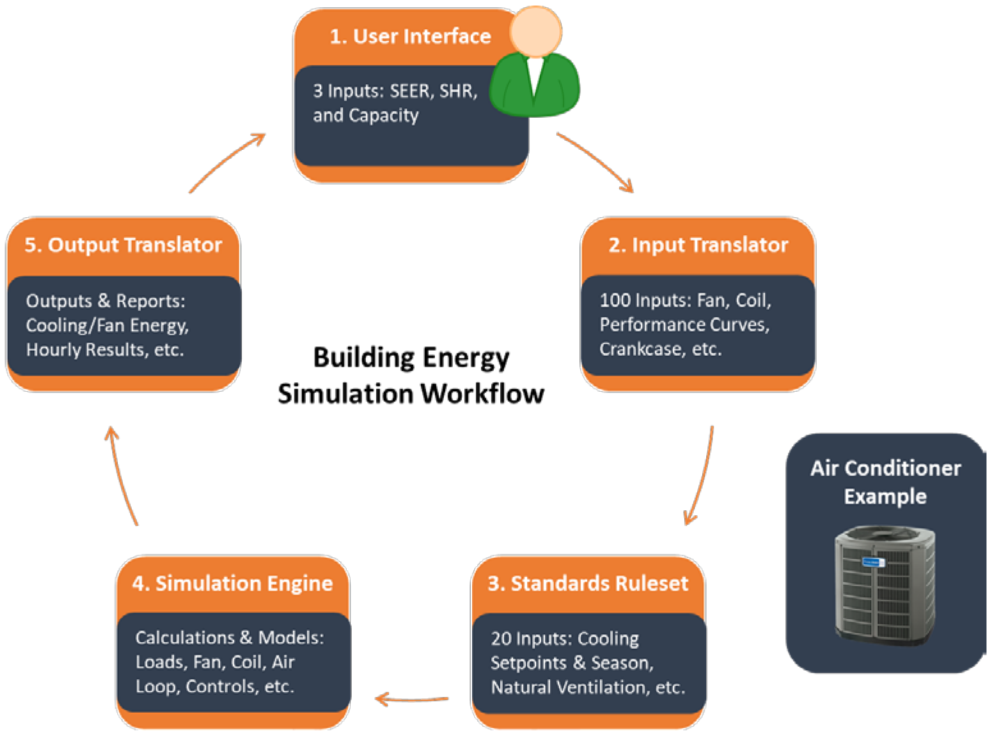

Figure 1. Anatomy of a residential software tool. Similar inputs are needed for any detailed simulation engine (e.g., EnergyPlus, DOE-2, CSE, ESP-r) for an air conditioner.

Figure 1 illustrates the workflow common to most residential software tools using an air conditioner example. The individual software components are:

1. **User interface**. Collects a set of inputs about the house (and sometimes about the occupants). Software tools can differ significantly in the depth and breadth of inputs collected, which can result in difficulty providing equivalent inputs in different tools.
2. **Input translator**. Expands/characterizes each building component. For example, this can be many lines of code to expand a small number of rated performance inputs to a large number of detailed inputs needed to estimate energy consumption outside the rated conditions. Decisions made here on how to characterize the technology's performance often have greater influence on simulation results than the underlying simulation engine.
3. **Standards rule set**. Implements standards, such as those written by RESNET and California, which are lengthy, detailed documents describing assumptions and methodologies to be used by the software tools. In some cases, software developers must independently interpret and implement the many lines of software code needed to follow these standards, introducing significant discrepancies among software tools.
4. **Simulation engine**. Performs detailed heat-transfer calculations to predict the energy consumption of a home. Simulation engines can vary significantly in their approach, from empirical-based regressions to physics-based equations.
5. **Output translator**. Converts the raw simulation outputs (e.g., annual and/or hourly energy consumptions by end use) into other metrics (e.g., HERS Index, Home Energy Score, Title 24 compliance, utility bills, savings-to-investment ratio) and/or reports. The software tool might also need to transmit results to a central program registry or database.

In most cases, software tools are independently developing and maintaining all these pieces—simulation engine algorithms, input translations, multiple rule set implementations—in addition to user interface development. This leads to 1) duplication of efforts among software tools, which translates into increased total costs across the industry; 2) inconsistency of results among software tools, which translates into lack of confidence from homebuilders, the real estate market, homeowners, etc.; 3) slower adoption of new technology models; and 4) fewer innovations around the user experience (user interface, user support, etc.) because significant effort is diverted toward maintaining more basic capabilities and modeling requirements.

Real-World Examples

Four real-world examples of programs using building energy simulations as a core component are provided to illustrate the various ways in which these programs can be structured. Discussion will include benefits and challenges that have been identified and/or addressed.

Example 1: RESNET HERS Ratings

RESNET is nonprofit membership corporation that develops standards and runs the largest building energy-efficiency rating and certification system in the United States. More than 2 million HERS ratings have been performed (RESNET 2018a), the large majority of which are for new homes. Ratings are calculated by third-party accredited HERS software tools that 1) comply with RESNET's standards (RESNET 2018b) and 2) pass the RESNET accreditation tests (RESNET 2018c). These requirements are meant to provide uniform energy ratings for residential buildings among disparate software tools. HERS software tools produce a HERS Index score, which ranges from 0 (a zero net energy building) to 100 (energy consumption equivalent to a 2006 IECC home of same size/location) or higher.

The HERS rating industry has grown in recent years, and the increased availability of, and competition among, software tools has resulted in increased awareness and concern—particularly from national production homebuilders—that different HERS accredited software tools can produce different scores for the same building. As the HERS Index gains traction as the de facto metric for new home energy-efficiency ratings (for example, by integration into real-estate Multiple Listing Services listings), public confidence in the accuracy of these scores becomes critically important.

Inconsistencies among software tools occur for multiple reasons[1]. The primary reasons involve 1) fundamental differences in simulation engines and model algorithms, 2) different interpretations of the standards language and subsequent software implementations, 3) differences in characterizations of building technologies (e.g., heating, ventilating, and air-conditioning equipment), and 4) differences in user interfaces and how home descriptions are entered. These inconsistencies perversely incentivize home energy raters and software vendors to choose models, algorithms, and/or assumptions that yield better HERS Index scores relative to their competitors (and disincentivize improvements to their software that worsen HERS Index scores). This problem—the race to the lowest HERS Index—occurs despite the standards and accreditation tests that are in place.

[1] Variability between users can lead to significant inconsistencies regardless of the software tool(s) being used. Additional processes (QA/QC, training, etc.) can help to ameliorate this issue.

Figure 2 illustrates the current structure for how HERS software tools are developed/maintained. As indicated, each software tool separately develops and maintains their graphical user interface, the standards implementation layer, the technology characterization layer, and the simulation engine. Software tool developers also participate in multiple RESNET activities/committees, including the development of the standards. HERS software providers institute user fees to support their software ecosystems and activities.

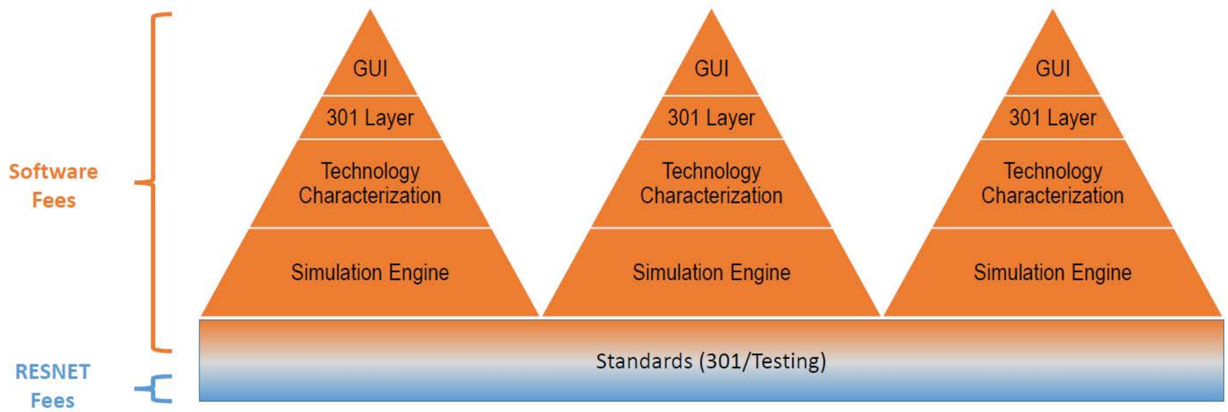

Figure 2. HERS software providers develop and maintain siloed software ecosystems by instituting software fees for their users. Much of these software ecosystems have substantial technical overlap but are developed independently.

During the past several years, RESNET has been investigating numerous approaches to addressing software inconsistencies. First, RESNET is exploring the possibility of developing/using an open-source, common simulation platform (RESNET 2016). This solution would virtually eliminate all sources of inconsistency among the different software tools. Proponents believe this approach would reduce long-term industry-wide costs, eliminate redundant software development efforts, reduce barriers to entry, reduce vendor lock-in and “black box” solutions, and accelerate the inclusion of new/emerging technologies; however, there are concerns about the upfront costs to transition current software tools to the single simulation platform solution.

Second, RESNET in parallel convened a Software Consistency Task Group to identify ways to improve consistency of the available tools (RESNET 2018d). The task group proposed 1) a collaborative modeling process through which software discrepancies can be identified, formally investigated, and resolved in conjunction with a newly formed Software Consistency Committee; and 2) the development of a common schema (i.e., a building description in a standardized file format). The common schema increases interoperability among existing software tools and provides uniformity of data inputs, allowing further exploration of software discrepancies; it is also a necessary piece for implementation of a unified solution. Finally, RESNET also adopted a timeline requiring all accredited HERS software tools to be based on hourly simulation calculations.

RESNET’s all-of-the-above approach to resolving rating software inconsistency is evidence of the high level of industry concern for this issue. There is some inefficiency in pursuing a single simulation platform while making incremental improvements to the software tools’ current simulation platforms, but it’s encouraging to see RESNET taking serious action.

Example 2: Utility Programs

Utilities spend nearly $2 billion on residential gas and electric efficiency programs each year (CEE 2017), which plays a significant role in driving the adoption of building efficiency technologies into the market. Although utilities vary wildly in how they implement their programs, the use of building energy simulations, specifically in new homes programs, is widespread. According to a study of HERS raters in the Northeast, 64% of ratings were prompted by utility/state program participation (Cuppernell and Greely 2017).

For example, ICF is a third-party organization implementing 19 utility new homes programs across the country that use building energy modeling for program design and to claim energy savings. Historically, programs used the HERS Index to provide incentives and struggled with inconsistency, even though HERS software tools can more easily produce consistent HERS Index scores than household energy consumption results (Fairey 2017). With the shift toward using energy savings calculations over a specified baseline to provide program incentives, using various in-field rating software makes it difficult to calculate consistent energy savings among the software tools.

Further, utilities are increasingly concerned with not only how much energy can be saved but *when* the energy is consumed. Some utilities are beginning to implement incentive programs tied to when energy is saved, not only annual savings. Although many HERS accredited software tools can produce hourly energy consumption, the RESNET standard is silent in important areas (lighting, hot water, plug loads, etc.) that affect hourly results, thus allowing each software tool to develop its own approach.

A recent RESNET Board Working Group on HERS software and utility new homes programs, comprising utility stakeholders and HERS software providers, identified the largest problems utilities are experiencing (RESNET 2017). The problems are, listed in priority order:

1. Savings calculations are not perfectly consistent or standardized among software tools.
2. Reference homes are difficult to build and maintain, especially in multiple software tools.
3. Hourly calculations are not always available.
4. Lots of data transfer file formats and data manipulation occurs.
5. It is difficult for utility program administrators to support multiple software tools.
6. Calculations might not be "utility grade" for some utilities.

Beyond improving the consistency of software tools, utilities are clearly interested in standardizing workflows (input/output file formats and reference home generation) to reduce administrative costs and complexity as well as increase the consistency, accuracy, and granularity of simulation results.

Example 3: California's Title 24

Title 24 is California's Building Standard Code that contains regulations governing the construction of buildings in California (CEC 2018). For the performance method, compliance is demonstrated by calculating the time-dependent valuation (TDV) energy use of the proposed design relative to the TDV energy use of the standard (reference) design. Starting with the 2013 standards, all software programs used for the performance method must use a single interpretation of the performance compliance rules as provided in CBECC-Res, a desktop simulation tool developed by the California Energy Commission. In addition to the CBECC-Res tool, which provides a simple user interface for describing a building, two other third-party software tools are available and approved by the California Energy Commission as computer compliance programs. All software tools, via CBECC-Res, use the California Simulation Engine (CSE) as the underlying physics-based engine.

Because all software tools use a common simulation engine and interpretation layer, the tools produce identical results given identical inputs. In addition, the application programming interface (API) provided by CBECC-Res reduces the burden for third-party software tools to connect to the platform. The use of both public and private software tools—where CBECC-Res is a simple, free, state-provided user interface but third-party private sector software tools can compete on user experience, support, and capabilities—is unique to California.

Although California has similar workflows in place for both residential and nonresidential building compliance, there are a couple significant differences. First, residential simulations are performed by CSE, whereas nonresidential simulations are performed by EnergyPlus. EnergyPlus is the DOE open-source, flagship simulation platform (Crawley et al. 2000). CSE was developed as a new residential simulation engine for the 2013 Title 24 standard rather than choosing EnergyPlus because "EnergyPlus lacks some needed features (e.g., duct loss model) and has many (many) capabilities that are not needed and is thus a large application. Missing models could have been added to EnergyPlus, but the result would remain a large installation package. In contrast, CSE is very lightweight. … In addition, CSE development is streamlined due to its small, dedicated code base that can be modified without worrying about implications for a wide user community" (Barnaby, Wilcox, and Niles 2013).

The primary drawback to this approach is that new technology models need to be independently implemented in both simulation engines and can be inconsistent. For example, the CSE development team is considering and/or implementing models for foundation heat transfer and moisture buffering that are already available in the EnergyPlus engine; in other cases, capabilities were added to CSE that were not available in EnergyPlus. Also, although the CSE development can be streamlined by not being concerned about a wider user community, a wider user community surrounding an engine provide numerous benefits including increased resources and expertise, stronger support for users, and developmental efficiencies.

Example 4: Department of Energy

DOE uses building simulations for several programs, including Home Energy Score (DOE 2018), Weatherization Assistance Program (Gettings, Mahlhotra, and Ternes 2015), and Building America (Christensen et al. 2005). Together, these programs account for tens of thousands of residential building simulations each year. Home Energy Scores rates the energy efficiency of existing homes from 1 (highest energy use) and 10 (lowest energy use). Home Energy Score includes a central web API with which nine third-party residential software tools currently connect. Weatherization Assistant is a suite of energy audit software tools that target reduced energy costs for existing low-income households through energy-efficiency measures.

As these programs grew out of specialized requirements at different points in time, their building simulation platform implementations largely prevent sharing workflows, assumptions, and technology models. This results in simulation programs with varying capabilities for modeling efficiency technologies, different assumptions, and potentially inconsistent results. To solve this problem, DOE has in recent years committed to transitioning their software programs to a common, open-source simulation platform that will bring consistency, reduce software redundancies, and accelerate the development of new technology models. The simulation platform can ultimately support additional capabilities—such as calculation of the Energy Rating Index (ERI, the basis of RESNET's HERS Index score), code compliance, and user-defined reference homes—so that it can be leveraged by other software tools for non-DOE programs/needs.

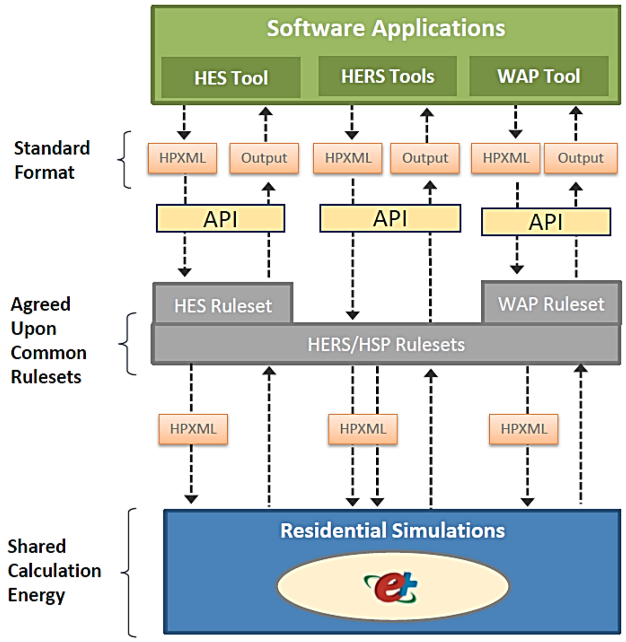

Figure 3. Workflow for the open-source simulation platform under development based on EnergyPlus and HPXML. It currently targets the DOE's Home Energy Score (HEScore), RESNET's HERS, and WAP's audit tools.

Figure 3 shows the workflow for this open-source simulation platform under development. The workflow includes the following steps: 1) ingest standardized Home Performance XML (HPXML) input file from the software tool, ideally through an API; 2) apply rule set(s) (e.g., HERS) as HPXML transformations; 3) translate inputs to EnergyPlus and run simulations; and 4) provide relevant outputs back to the software tool. Over the next few years, Home Energy Score and Weatherization Assistant will be migrated to this EnergyPlus-based simulation platform. A proof-of-concept, open-source workflow for calculating an EnergyPlus-based ERI is also currently available on GitHub (NREL 2018).

With the collaboration of multiple private-sector software vendors, efforts are underway to formalize the HPXML input file, expand the available technologies, optimize the run time performance of the workflow, and provide testing results. These efforts address the primary reservations historically held by software developers regarding the use of EnergyPlus, namely that it is too complex and/or too slow to use, while allowing its significant modeling capabilities to be more easily leveraged. By solely requiring an HPXML file from software tools, the simulation platform significantly reduces the effort to connect to the EnergyPlus simulation engine. Numerous existing software developers have committed to transitioning to this simulation platform.

Conclusion

The role of energy simulations in the residential buildings industry has expanded significantly in a short period of time. Energy simulations are now pervasive as the basis for code compliance, ratings and certification programs, utility programs, building design, regional/state planning, and so on. Unfortunately, residential software tools have not kept up with the needs of the industry—too many resources are being devoted to the independent development of the most basic capabilities (e.g., simulation engines, rule sets, input translations, and technology models) instead of to creating new and innovative capabilities and improving user support.

All real-world examples described have a common thread: they encourage competition among private sector software vendors. But programs where the underlying simulation platforms are individually developed have experienced more problems and have incurred higher industry-wide development costs than those with collaboratively developed systems.

A set of requirements for a collaboratively developed simulation platform is proposed to avoid the observed pitfalls. These requirements are:

- Open-source license and collaborative development
- Large user base and pool of developers
- Long-term user support
- Capable simulation engine
    - Suitable for all building types (e.g., residential and commercial)
    - Adaptable to future needs.
- Standardization for private sector tools
    - Input/output data exchange formats
    - Rule sets/languages (e.g., per standards and/or user-defined reference homes)
    - API or equivalent interface.
- Suitable run time performance.

An open-source simulation platform based on EnergyPlus—currently under development for Home Energy Score, the HERS industry, and WAP—would be a logical candidate because it meets the listed requirements and has broad support among key industry stakeholders. It can be further leveraged for code compliance, utility programs, and other needs.

It is acknowledged that a common simulation platform has its disadvantages. While it reduces long-term development and maintenance costs, it requires significant upfront development costs to transition from the current multiengine model. And there can be challenges to using a single simulation platform for a diverse set of programs' needs and uses cases.

But the benefits greatly outweigh the costs. Coalescing around a single, open-source simulation platform fosters collaboration and virtually eliminates calculation inconsistencies through standardized inputs, assumptions, and physics-based calculations. It increases market competition among private-sector software vendors by allowing resources to be more substantially devoted to the user experience while also reducing barriers to entry for new players. And most importantly of all, it would lead to increased levels of energy savings by accelerating new building technologies into the market and restoring public confidence in residential building energy modeling tools.

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