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RAPID MODELING OF LARGE AND COMPLEX HIGH PERFORMANCE BUILDINGS USING ENERGYPLUS

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ABSTRACT

EnergyPlus has long been relegated to a niche within the professional building performance modeling world due to a steep learning curve and the time needed to deliver complex models. However, advancement of energy codes, high performance design, and net zero energy aspirations have increased simulation complexity and the desire for accuracy. Achieving these goals requires design teams to quickly evaluate complex building systems, yet maintain flexibility to revise models as the design progresses. Designing high performance buildings requires assessment of numerous strategies including advanced envelopes, complex airflow arrangements, high-efficiency hydronic systems, custom control sequences, and the like. DOE's EnergyPlus simulation engine is a natural choice as it is flexible, programmable, includes sophisticated heat transfer models, enables component controls, etc.

This paper demonstrates how state-of-the-art computing techniques can be used to create modular EnergyPlus models for cloud-powered rapid simulation and visualization. The authors introduce this modeling platform and describe the process automation achieved, resulting in input uniformity while maintaining zones, systems and plant customization. The authors also present results for tests carried out to evaluate the scalability and robustness of these models to demonstrate the viability of incorporating EnergyPlus in standard modeling workflows for rapid consulting. This process allows teams to leverage EnergyPlus to more accurately model building physics while reducing model assembly time. Simulation runtime reduction is also discussed. Results are presented for two buildings – i) a 385,000 sf laboratory and office facility with ZNE goals; and ii) a 780,000 sf mixed use campus with rapid design-assist modeling needs.

INTRODUCTION

Building Performance Modeling is increasingly playing a more dominant role in the design of high performace buildings. The primary motivation is to help project teams make informed design choices to optimize energy and water efficiency; enhance occupant experience; build greater resilience to weather extremes; reduce construction, operation, and maintenance costs; and achieve other project specific goals. However, numerous practical impediments exist to effectively using high-fidelity models to make timely and informed design choices for large and complex high performance buildings. Some of these are – greatly compressed project schedules; built-in annoyances in repititive workflows; the absence of quality model input data; mostly fragmented data, research, and tools market; insufficient validation for existing calculation methods for advanced design and controls technologies; the lack of clearly defined metrics for performance comparison; few easy-to-use interfaces; and the like.

The focus of this paper is Building Energy Modeling (BEM). BEM is a mature science and traces its history all the way back to the energy crisis of the 1970s. Numerous simulation engines have been developed for BEM over the past decades including the Post Office Program, DOE-2, BLAST, TARP, EnergyPlus, ESP-r, and many others. Over time, desktop based user interfaces were also created to enable non-programmers such as energy analysts and engineers to deploy these simulation engines using a graphical user interface (GUI). One of the most well-known examples is eQUEST, a widely-used desktop application with a GUI for the DOE-2 (DOE 2012) simulation engine. The interface allows users to easily create model gemetry, and more importantly, the concept of a model wizard allows simpler projects to set up farily quickly using a set of user forms with predefined model inputs. Other examples of popular user interfaces include IES-VE, OpenStudio, DesignBuilder (DesignBuilder 2017), etc.

Although these tools have evolved overe time to provide an improved user experience and incorporate greater accuracy, they have not reacted fast enough to the significant advances being made in the area of computation technology. Therefore, numerous standalone programs are now being built to compensate for these deficiencies and allow present-day analysts to deploy more state-of-the-art computation methods that allow parallel processing to reduce runtime, run cloud simulations to store and manage data, develop self-healing models, and advance the concepts of data-driven modeling. Although these efforts help overcome significant limitations, there still exist substantial gaps in the overall workflow.

As discussed in the DOE's Research and Development Roadmap (Barbour et al. 2016) for BEMs the primary limitations facing the industry include – time-consuming transfer/translation of input data; lack of contemporary presentation formats for simulation outputs; the absence of quality model input data; and the overall lagging of BEM capabilities when compared to computing technology advances. Moreover, as the reports concludes, increasing modeling costs have a detrimental impact on quantifying a clear value proposition for BEM. These problems are further compounded when working on large and complex high performance buildings as process inefficiencies are magnified, turning minor workflow pain-points into major workflow limitations.

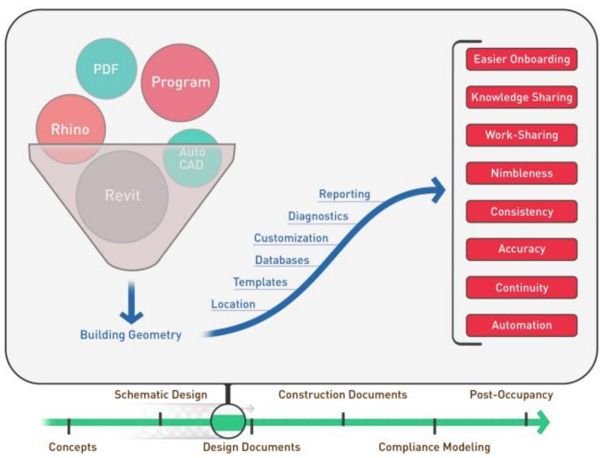

Figure 1 Building Energy Modeling

Guglielmetti et al. 2011 discusses an OpenStudio based approach to developing a software development kit and application programming interface that to address some of the limitations previoulsy mentioned. This ecosystem has since developed significantly to provide a robust SDK, the building components library, OpenStudio measures, Parametric Analysis Tool, etc.

The following sections discuss an overview of the technical aspects of a web application developed to facilitate Rapid Consulting and Production Modeling (RCPM) for practitioners. The web application is designed to be a modern, continuously-evolving, and easy-to-use building modeling tool that runs EnergyPlus simulations in the cloud with built-in automation, diagnostics, QC, and visualization. These sections also describe how a central information repository can be effectively utilizezd to develop and share EnergyPlu models to foster a deeper sense of collaboration between energy analysts.

WHY RCPM?

As energy standards become more stringent and projects push for more ambitious energy efficiency goals, there is an ever-increasing need for the adoption of advanced simulation engines that have modular capabilities yet are easy to work with. Further, as building design and construction timelines continue to condense as a cost saving measure, to truly make a difference on a project, a sharp analyst needs to be accurate, nimble, and consistent. These are conflicting requirements that are even harder to achieve when working with large and complex buildings.

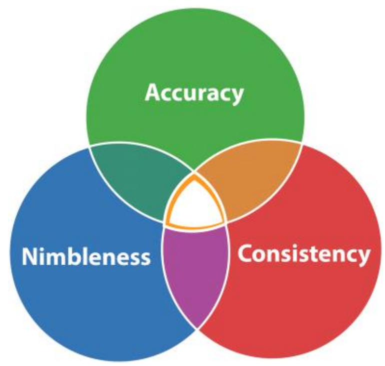

Figure 2 Maximize Target Area

Development of EnergyPlus user interfaces has somewhat lagged such that scripting has been pushed as a solution to solve the problem of increased model setup time. As discussed in Automation of Common Building Energy Simulation using Python (Miller et al. 1999), solutions have been proposed to templatize inputs and to parse input data into simulation objects. Scripting is an effective means to reduce repetitive tasks. However, it is impractical to expect design teams to deploy custom scripts repeatedly without a central repository for these custom programs.

Openstudio Measures (OpenStudio Measures 2017) and the Building Component Library were specifically designed to solve this problem. However, practitioners' skillset has typically revolved around having a building science background or a HVAC system design background, and this workflow still places a high entry barrier for practitioners who are non-programmers. For some analysts, this problem is further exacerbated by the fact that large models are harder to manage in the OpenStudio application, on the other hand, although the application now provides access to most EnergyPlus components and features, power users are left wanting for more.

Developers of simulation input interfaces have been overzealous pushing the need for scripting skills, such that a skills gap has been assumed to be an issue preventing effective EnergyPlus workflow adoption, rather than addressing the deficiencies which create cumbersome workflows lacking effective input translation into model input syntax. Scripting becomes effective when the user interface establishes a robust standardization ruleset, with an effective user interface that utilizes a more modern computing environment.

The RCPM engine is a web-based collection of user scripts that are always available to all users, with the standardized ruleset already implemented. It also includes standard data sources such as weather data, information from typical building design standards, etc.

The concept of RCPM is built around the idea of developing a simulation engine agnostic web interface that is specifically designed to facilitate consulting for high performance building projects.

Modular simulation components, such as the ones used in EnergyPlus, by necessity have input and output connections that can be reassigned to suit the needs of the system configuration. With this flexibility comes greater need for standardization of connection points to facilitate rapid model adjustments. Without standardization of connection naming the practitioner is tasked with manual editing, a time-consuming endeavor. A possible solution is an increase in modeler collaboration with a user interface that can facilitate the collaboration process.

The following section discusses the design and features of a web application that was developed using the RCPM engine for building energy modeling.

THE RCPM ENGINE

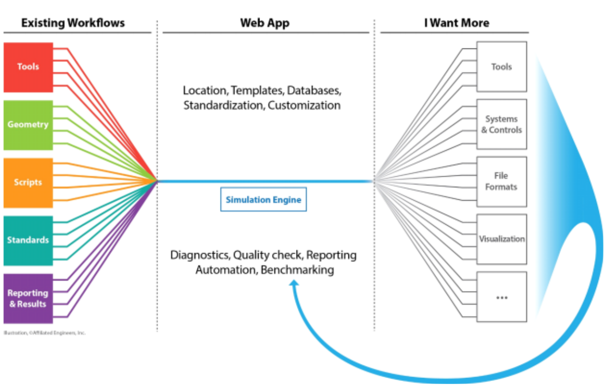

Figure 3 The RCPM Engine

Figure 3 shows a schematic diagram outlining basic data flows for the web application. Successful decoupling of the simulation engine (EnergyPlus) from the input web forms and output "views" allowed on-demand model generation.

The software architecture is designed to enable complete model discretization. This modular approach to generating model files allows analysts to create numerous combination although each component was individually designed, tested, and deployed. Input and output APIs allow the client-side program to call specific feature sets, as and when necessary.

A centralized database holds key model input parameters, system components, design inputs, control sequence selections, component libraries, cost models, etc. to ensure input uniformity. All model component names follow a predefined ruleset for nomenclature, thus ascribing all the necessary attributes to each entity in the BEM. This not only helps in model generation, but also helps new users understand the basic anatomy of the EnergyPlus IDF.

The web technology stack was chosen after careful deliberation to maximize overall process efficiency where BEM was a component in the overall design workflow to bring design strategies to fruition. The web application is developed using the Django framework and eppy as existing python programs can be used as is. Using python for back-end and server-side programming makes it easier to interface with calculation and analysis tools used by the design teams.

The following sections provide a basic description of some of the key elements of BEM setup and how they were addressed in the design and development of this tool.

Location and Weather Data

Figure 4 shows the web form used to create a new project. It uses the google map API to allow a simple location selection. Pertinent weather data along with some of the key weather parameters are displayed in the input form itself. A single form for all weather data and design day selections made weather inputs seamless.

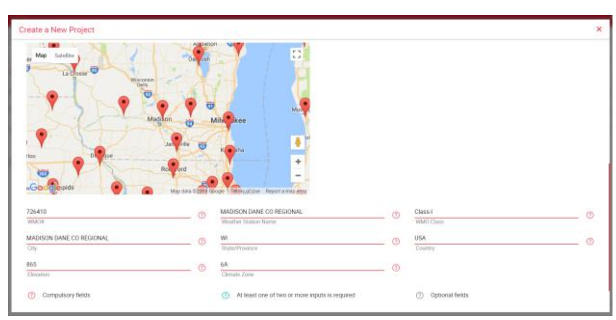

Figure 4 Location and Weather Data

Building Geometry

Flexible geometry inputs pathways are a key aspect of design-assist modeling. Depending on project goals and analysis objectives, the energy model may be developed anywhere from Schematic Design (SD) to Construction Documents (CD) phase. In fact, energy analysts are increasingly being engaged even earlier in the project when little design information is available and frequent changes are the norm. the RCPM modeling environment tackles this problem by providing three distinct geometry input options to the analyst. Each of these is discussed below.

Program-only Models:

A key element of high performance building design is the integrated design process (IDP). IDP requires early-stage modeling so that energy saving opportunities may be identified sooner, and planned for. In fact, more and more projects require some form of building energy modeling for project interviews as well. Although these models play a key role in narrowing the range of available design options, they are not prioritized because they are generally discarded later in the project when design parameters change significantly, requiring a complete restart of the modeling process. Reduced reusability reduces their value proposition.

The RCPM engine allows model discretization so the tool has the ability to create building program-based models that allow analysts and consultants to generate simpler EnergyPlus geometry input files to – i) either test design strategies early in the project, or ii) prototype systems configurations for large more complex models. A simple input table allows modelers to account for basic orientation, architectural design, exterior boundary conditions, and envelope performance. The smart geometry update mechanism allows modelers to update this geometry input table by keeping all the model elements that were unchanged during a program update, while building the new components necessary for the geometry components added.

Standard Building Types:

The DOE prototype buildings serve an invaluable purpose for the broader industry, but certain building types are not currently included among the prototype buildings. (namely, laboratories and in-patient facilities).

The web tool includes a list of predefined standard building type models. These are i) Research Laboratory – Small, Research Laboratory – Medium, iii) Research Laboratory – Large, iv) Healthcare (Inpatient) – Medium, and v) Healthcare (Inpatient) – Large.

These geometry models serve as a good starting point for quick analyses early on in a project when not enough is known about the building being designed. These space type list, typical program, use schedules, etc. are gathered from the catalouged buildings in the Affiliated Engineers, Inc. project benchmarking tool.

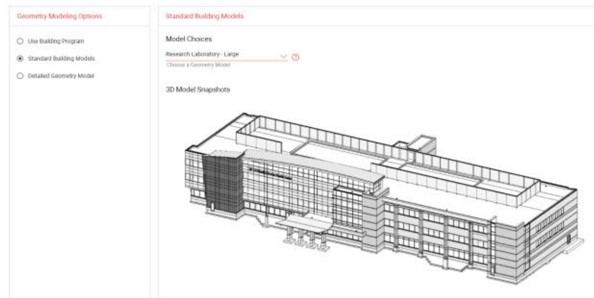

Figure 5 Standard Building Types

Detailed Geometry:

When detailed building architectural design is available, geometry files created in SketchUp using the OpenStudio plugin can simply be uploaded into the tool. The zonelist is maintained in the database and dynamic space type assignments can be made using a floorplan view. It is tedious and time-consuming to name zones in large models, so the tool automates the zone naming process using a standard naming ruleset. Figure 6 shows the interface that is used to make space type assignments.

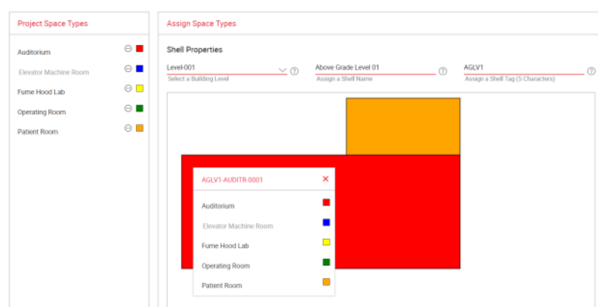

Figure 6 One-click Space Type Assignments

A major advantage of using the RCPM engine for early-stage modeling is that the geometry model uploaded to the tool can be updated such that only the zones that have moved need to new space type and system assignments. All zones that remained unchaged stay as is. This makes it much easier to update models through the life of the project.

Air-side Systems

Three types of air-side systems are currently available in the tool – i) air-loop HVAC, ii) fan coil units, and iii) unitary systems with DOAS. However, various combinations of components are possible, including outside air dampers, cooling coils, heating coils, humidifiers, fans and filters. The inputs forms are designed to facilitate greater interaction between design teams and energy analysts. For instance, the flow diagrams are set up to reflect system and component setups in EnergyPlus, but component inputs are clearly separated into two categories – design, and operation. Design inputs include typical information found in basis of design, equipment schedules, design standards, etc. while operation inputs equipment performance curves, economizer operation and other control sequences that are typically found in controls drawings. Another example is the separation of fan static pressure input into its components, such as ductwork pressure drop, filter pressure drop, coil pressure drop, etc. at each individual component.

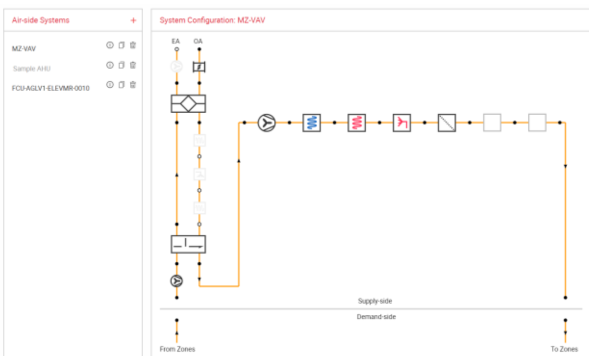

Figure 8 An Air-Loop HVAC Template

A variety of zone HVAC equipment and air terminal units is also available. The web interface is designed such that the selection options adjust to accommodate EnergyPlus rules for these components, e.g. only one air-terminal unit type is allowed for per zone.

Figure 8 shows the typical layout of an airloophvac system with a supply fan, a cooling coil, a heating coil, a humidifier, and the filters & sound attenuators.

Water-side System

A high level of flexibility is available with modeling plant systems where active and passive components can be turned on or off to create custom configurations. Up to three primary heating and cooling loops are provided, each with up to three secondary and tertiary loops.

The list of components includes chilled water meters, air-cooled chillers, water-cooled chillers, heat recovery chillers, hot water meters, conventional boilers, condensing boilers, storage tanks, dry coolers, cooling towers, and heat exchangers.

On the demand-side, each loop can have up to three secondary heat exchangers, process loads, system coils, and storage tanks.

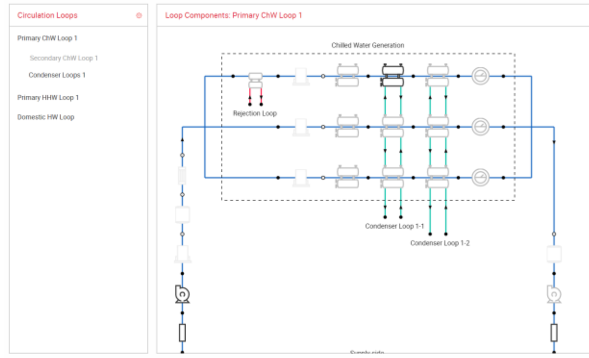

Figure 9 Supply-side on a Primary Chilled Water Loop

Standardization and Templates

A key element of work sharing is the ruleset that governs it. To facilitate onboarding, work-sharing, collaboration, and crowdsourced development, it is imperative that a standard ruleset be established for as many model elements as possible. Therefore, a naming convention was developed for all components be it zones, space types, schedules, systems, systems components, utility rate structures, control sequences, performance curves, etc.

Another important application design choice was the persistent support for templates. Numerous template options are available throughout the application. This includes space types, use schedules, systems, individual system components (such as coils, fans, etc.).

The combined use of standard naming conventions and the ability to create templates allows for seamless interfacing between all modular components, at all levels.

Diagnostics, Visualization and Output Tables

Numerous checks are built into the tool. A pre-run check report points to component incompatibilities and input inconsistencies detected even before the simulation begins. Once a simulation run completes, a graphical diagnostics tool is the first step in QC. These charts include load duration curves and other proven tools that further help bridge the gap between analysis and design. Finally, output reports that provide an overall summary of the simulation run can be downloaded for more information.

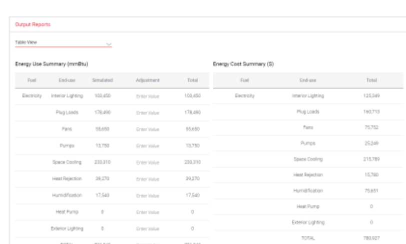

Figure 10 Sample Table Output

Automated Baseline Generation

Most designs need to demonstrate energy efficiency compared to a baseline. It is tedious and time-consuming, but it also lends itself well for automation as the rules for developing energy efficiency baselines are well-defined.

The RCPM engine currently includes a built-in ruleset for the development of energy cost budget (ECB) and performance rating method (PRM) baseline for ANSI/ASHRAE/IES 90.1-2010 and ANSI/ASHRAE/IES 90.1-2013 baseline models. These are part of default outputs generated by the RCPM engine, but can be turned off, if not needed.

Being able to spend minimal time developing a baseline for efficiency comparison allows the analyst to focus on the proposed design itself, thus providing greater value to the design team.

WORKFLOW TESTING

A limited set of projects was carefully selected to test workflow viability, scalability, and overall robustness. Two important cases are presented in the following subsections. Together they cover both scale and complexity.

A Confidential Healthcare Project

Modeling very large buildings in EnergyPlus presented a unique set of challenges in the past. Creating geometry information for very large models can certainly be time-consuming, but long run-times pose a practical challenge to effectively using EnergyPlus when turnaround times are small. Therefore, a 780,000 sf mixed-use healthcare campus was chosen to test scalability and runtime optimization.

A large healthcare provider is in the process of setting up a new medical campus in the state of Indiana. The campus includes a school of medicine, an in-patient facility, and an out-patient clinic. Figure 11 shows the geometry model that was developed to represent the building. The analysis began in SDs and needed timely feedback on energy use target, and an energy use comparison with respect to ASHRAE/ASHE standard 189.3-2017 (ASHRAE 189.3).

Two separate analysts worked on the same building simultaneously. One of them developed the geometry model, and the other concurrently built the air-side and water-side systems.

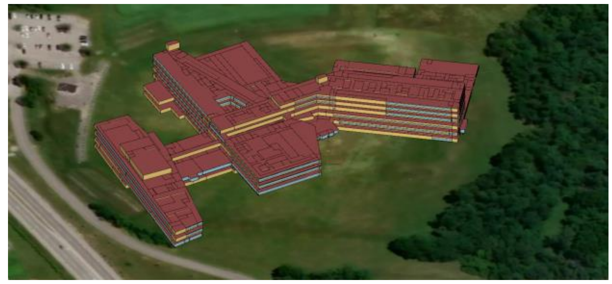

Figure 11 Detailed Building Geometry

Some key findings are listed below.

1. Multiple modelers working on the same project with a predefined nomenclature for space types made it much easier to identify zone and assign space type templates. With over 50 space types inputs and use schedules, this significantly reduced coordination and model setup time.
2. The modular nature of the RCPM engine meant that the energy model could be built one "shell" at a time. The model could be tested in smaller pieces and debugged when errors when encountered. This significantly reduced the time required to fine-tune the model to ensure quick and error-free runs once all the separate pieces were assembled.
3. The time saved in model setup and refinement were used to further improve other aspects of the modeling workflow, such as, a creating better use schedules for in-patient facilities. Some of these had a significant impact on model accuracy.
4. When program udpates were made in DDs, simply a new geometry file was uploaded into the tool requiring the modelers to update only parts of the building that had changed.
5. Although the ASHRAE 189.3 baseline model was not directly available, the 90.1-2013 baseline was used to provide timely feedback on the energy use comparison for the candidate proposed designs.
6. Finally, as a full template set was developed for typical healthcare buildings, the setup time for future healthcare models will also be significantly reduced as these templates can be reused.

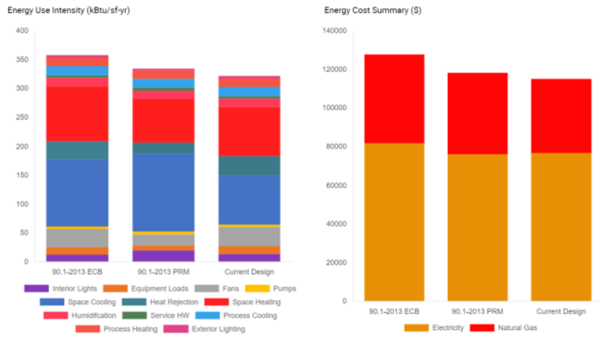

Figure 12 Sample Output Charts

California Air Resources Board

Modeling complex system configurations with multiple iterations during a short timeline in EnergyPlus had presented a unique set of challenges in the past. Setup and testing of multiple novel air and hydronic system configurations is a time-consuming process. Component connections must be made, controller sequences established, and simulation outputs must be examined for accuracy. Simulating a net zero laboratory facility offers an opportunity to explore novel system solutions, and frequently requires a non-standard HVAC approach.

The California Air Resource Board is constructing a new 385,000 sf engine testing laboratory facility in Riverside, California. The facility includes light and heavy-duty engine test bays, chemical laboratories, supporting offices, and public components such as an educational auditorium. The facility design is required to be delivered as a net zero facility. The project analysis began during a design competition phase with limited time for analysis and development of the design strategy. Three analysts worked simultaneously on the analysis, - one of them developing the full consolidated model, one working on office and public components of facility, and the third supporting air and hydronic system configuration development and output analysis.
Some key findings are listed below.

1. The RCPM engine allowed for modelers to collaborate on the energy model construction, this project is an example of collaborative workflows as it pertains to HVAC system configurations. Multiple modelers working on the same project with a predefined nomenclature for system node connections made it easier to identify connection points for inserting prototype air or hydronic components configurations into a functioning model.

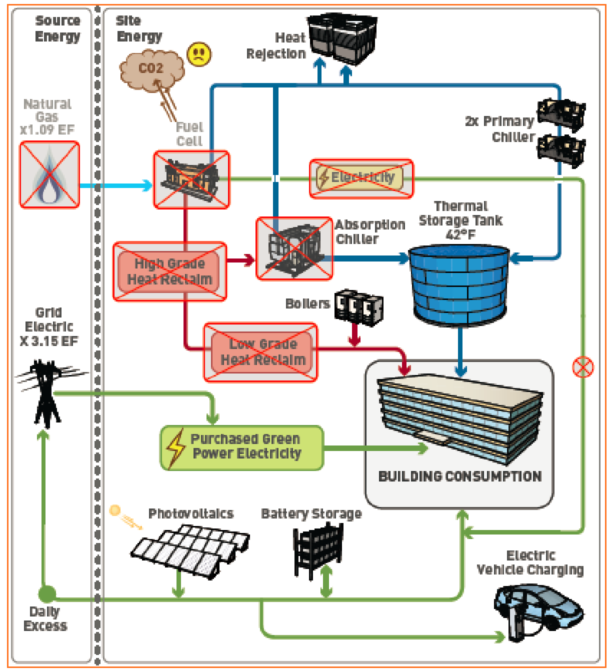

Figure 12 California Air Resource Board Example System Diagram

2. Novel system setup configurations were tested in side-stream models. These models can be light on zone and surface information compared to the whole building model, significantly reducing simulation time. Thus more time is proportionally consumed on debugging or analyzing outputs. Nimble modeling and rapid prototyping of configurations in side models allowed for the primary model to continue to be developed. The integration process aided by connection node naming conventions that are key to the success of the RCPM engine.
3. The time saved in model setup and refinement allowed for addiitonal parameteric system configurations to be tested within the deliverable timeline.
4. Finally, ease of model integration between collaborating analysts allowed for additional time to comb the detailed outputs and generate informative graphics to demonstrate key performance improvements gained by the HVAC system configurations.

CONCLUSION

The successful implementation of the RCPM engine using the web interface has demonstrated that a cloud-powered building energy modeling that leverages modern computing technologies to simulate high-fidelity models to inform design and demonstrate compliance is feasible.

Subject-matter experts were able to develop, test and deploy vetted component models that significantly improved workflow efficiency and accuracy.

The onboarding of new EnergyPlus was easier as model component names were standardized and a graphical interface made it simpler to connect the separate model components.

Built-in diagnotics, visualiztion and auto-baseline generation drastically reduced analysis times permitting analysts to develop other necessary skills such as keeping abreast with the latest standards, learning new modeling tools, and general project consulting.

Overall, the RCPM Engine is an effective tool for analysts working with high-fidelity models at low costs to quickly and continously inform building design.

FUTURE WORK

Although commonly used system configurations are currently available in the tool, additional support for more EnergyPlus components is necessary, and will be developed. Further, additional APIs for greater integration with other platforms will be made available.

Look for avenues to make enough interfacing connections to expand the platform to include other building performance modeling tools.The RCPM engine has set the stage for simple, low-cost and accurate cloud-based building energy modeling. However, the team intends to build on this and start exploring the of using data-driven models for quick consulting.

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