Heating Ventilation Air-conditioning (HVAC) System Analysis and Optimization for Revit with the OpenStudio Analytical Framework

Cooperative Research and Development Final Report

CRADA Number: CRD-18-00785

NREL Technical Contacts: Matthew Steen, Alex Swindler, and Noah Pflaum

NREL is a national laboratory of the U.S. Department of Energy
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Technical Report
NREL/TP-5500-96549
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Cooperative Research and Development Final Report

Report Date: June 13, 2025

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the CRADA final report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: Autodesk, Inc.

CRADA Number: CRD-18-00785

CRADA Title: Heating Ventilation Air-conditioning (HVAC) System Analysis and Optimization for Revit with the OpenStudio Analytical Framework

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Sponsoring DOE Program Office(s):

Office of Energy Efficiency and Renewable Energy (EERE), Building Technologies Office

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources Government In-Kind
Year 1 Year 2	$50,000.00 $300,000.00
TOTALS	$750,000.00

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Executive Summary of CRADA Work:

This project proposes to integrate the NREL-developed OpenStudio (OS) and its accompanying Analytical Framework (OSAF) into Autodesk's (ADSK's) market leading suite of building information modeling (BIM) tools. As a result, BIM users will gain access to advanced (but user-friendly) building energy modeling (BEM), calibration, and design optimization capabilities. Following integration, the BIM software will automatically generate a consistent OS-based BEM model, allowing users to develop projects in an integrated manner, moving back and forth between architectural and engineering perspectives without redundancy or data loss, saving time and effort.

CRADA benefit to DOE, Participant, and US Taxpayer:

- Assists laboratory in achieving programmatic scope
- Adds new capability to the laboratory's core competencies
- Enhances the laboratory's core competencies
- Uses the laboratory's core competencies
- Enhances U.S. competitiveness by utilizing DOE developed intellectual property and/or capabilities.

Purpose

This project proposes to integrate the NREL-developed OpenStudio (OS) and its accompanying Analytical Framework (OSAF) into Autodesk's market leading suite of building information modeling (BIM) tools. As a result, BIM users will gain access to advanced (but user-friendly) building energy modeling (BEM), calibration, and design optimization capabilities. Following integration, the BIM software will automatically generate a consistent OS-based BEM model, allowing users to develop projects in an integrated manner, moving back and forth between architectural and engineering perspectives without redundancy or data loss, saving time and effort. This project will:

- Alleviate the lack of BIM-BEM integration, identified by DOE's Buildings Technology Office (BTO) as one of the largest market barriers to use of BEM in the design process
- Help BTO achieve building energy use intensity reduction targets by giving industry practitioners the tools they need to design low energy buildings
- Improve industry confidence in BEM accuracy

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Statement of Work

Project Plan.

The overall plan for the project is for NREL to work with Autodesk to establish a persistent connection between the design and analytical environments to support widespread adoption of building energy modeling. Details of the plan are provided below:

Technical Plan.

The first step in the project is to remove the barriers associated with the lack of BEM-BIM integration, before adding advanced analytical capabilities. The near-term goal is to develop a workflow resembling the following:

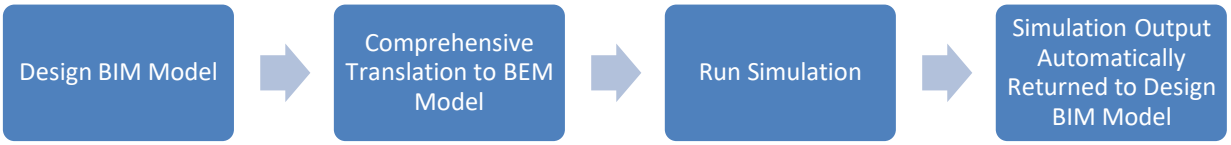

Figure 1: Short Term Vision of Workflow

Significant work has already been performed on Autodesk's side using a point-cloud voxel model to enable a seamless translation of geometry from an architectural BIM model to an analytical model suitable for BEM. This voxel model is a working feature in current releases of Revit and is the current algorithm used in Revit's gbXML generation.

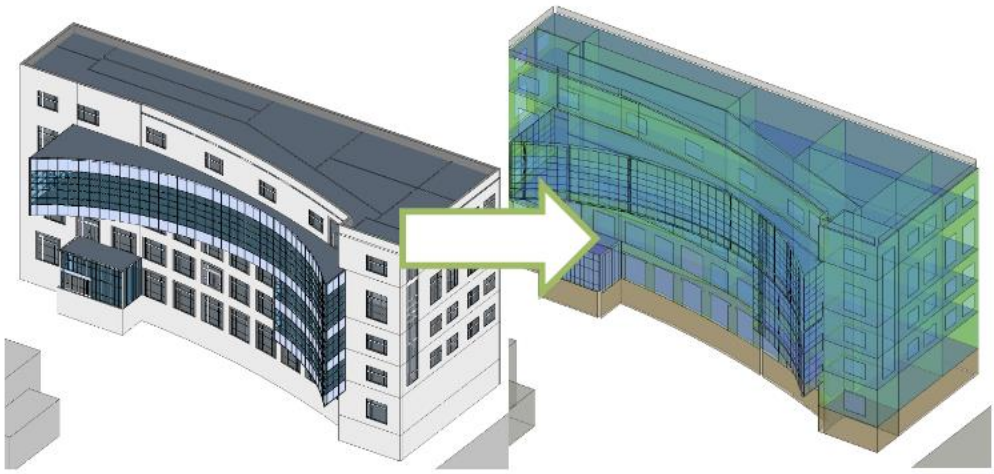

Figure 2: Design BIM Model to Analytical Model

After this initial stage, the project will fork in two directions: a workflow focused on early stage analysis and a workflow for highly detailed design.

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Early Stage Analysis.

At the earliest stages of design, very little is known about a building besides an expected programming that details the presence of different space types. A variety of building forms may be considered, different construction types, window-to-wall ratios, lighting power densities, HVAC systems and so on. For this reason, it will be possible to examine a large portion of the possible parameter space using the OSAFs sampling capabilities; this analysis will not only provide a range of Energy Use Intensity (EUIs), but also provide a means to examine which design parameter choices lead to better energy performance. As the design moves from the preliminary design (PD), more parameters become known and the range of uncertain parameters tighten as the design progresses, reducing the project's likely EUI range. BEM analysis will help lower the final EUI range as much as possible.

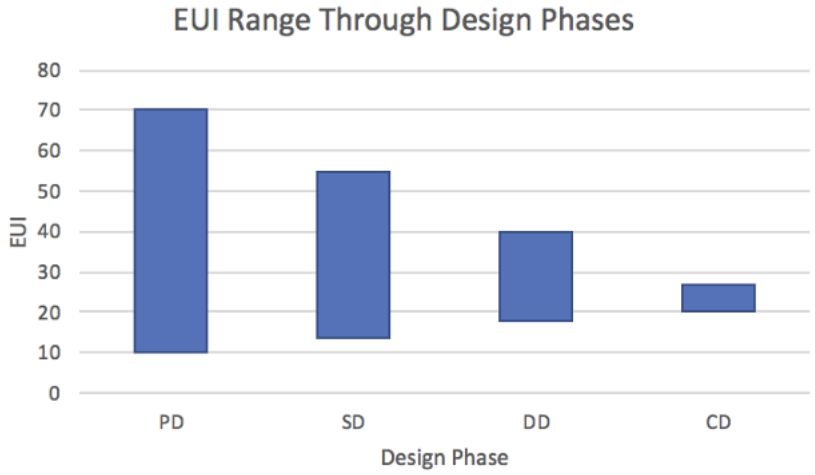

Figure 3: EUI Projections Throughout Design Phases

The project intends to use existing and new NREL-authored Measures that allow a design team to customize the parameter space they wish to consider. Of high priority is development of a series of Measures focused on detailed HVAC analysis. These Measures need to be written, validated to make sure they produce expected results, and then further tested directly with the Revit generated models to ensure compatibility between the BIM and BEM models. In addition to providing a greater off-the-shelf selection of parameters to explore than other commercial products, the project will allow for users to develop and contribute their own Measures, providing unlimited extensibility.

Autodesk's technical focus will be on providing market strategies related to direction and outreach, and testing the framework to ensure stability of the platform. Autodesk will also be responsible for ensuring compliance with local data protection requirements for the markets they serve.

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Detailed Design.

As stated above, the design BIM model geometry has an analytical analog that encapsulates all the fields required for simulation while retaining a reference to its equivalent in the design model. The intent is to carry this pattern throughout the various design objects in Revit, which will require collaboration between the Autodesk and OpenStudio teams to generate such mappings for each design object. Once created, this will allow the design model to generate the analytical model whose results then feedback to the design model for the purposes of mechanical design. As ductwork, piping and other physical design features of a building are laid out, this will then allow the parameters of the physical system (i.e. static pressure in the duct work) to feed to energy model for a more exacting analysis. This detailed design stage will not only improve the accuracy of analysis for new construction but will enable as built BIM models to seed the BEM model needed for calibration purposes, which can lead to much more accurate energy efficiency measure (EEM) analysis.

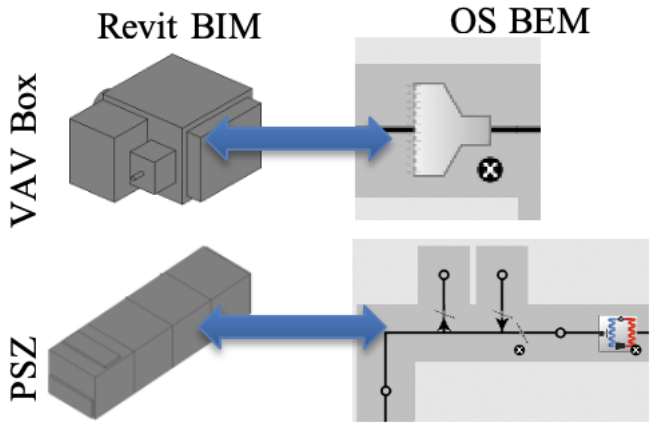

Figure 4: BIM and BEM Linked Objects

Task Descriptions

The project team has identified a set of tasks specific to each party, as well as a variety of tasks that will take collaboration between Autodesk and NREL. The general split is for Autodesk to provide market strategy and insight, and to test the robustness and engineering quality of the results produced. The NREL team will focus on additions to the OSAF and any code development that will be required for analysis purposes. Autodesk does not intend to write code for development in association with this CRADA and the partnership will leverage existing Revit features or features being developed separately in parallel outside of this CRADA, including but not limited to development work associated with Autodesk under this Joint Work Statement. The list of tasks and the associated schedule can be seen on the following page, along with a list of project milestones whose success the team will be tracking closely.

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		Responsibility	
#	Task	NREL	ADSK
1	**Project status reporting**	x	x
2	**Manage product development**		x
2.1	Assemble industry focus group		x
2.2	Conduct demonstrations and gather industry feedback		x
2.3	Communicate user stories to respective development teams		x
3	**HVAC Measure Analysis**	x	
3.1	Establish list of most common mechanical designs	x	x
3.2	Develop measures for systems where they don't exist	x	
3.3	Develop testing framework for these measures	x	
3.4	Develop infrastructure skeleton for parametric analysis from Revit	x	
4	**Early Stage Analysis**		
4.1	Deploy OSAF on desired cloud platform		x
4.2	Parallelize each simulation for faster runtime	x	x
4.3	Create Measure to interface generator to allow for user extensibility	x	x
5	**Develop BIM/BEM seamless integration**		
5.1	Perform testing for stability and engineering quality		x
5.3	Develop measures to map Revit data to BEM data	x	
5.4	Create output of BEM results that can be used for further reporting	x	

Summary of Research Results:

This section introduces and summarizes the software products that resulted from the specific tasks that are described in more detail in the following section. The results of this CRADA include two main software products, Revit Systems Analysis[1] and Insight[2], that use existing DOE tools.

1 https://www.autodesk.com/blogs/aec/2019/08/21/revit-systems-analysis/
2 https://www.autodesk.com/products/insight/overview

This report is available at no cost from NREL at www.nrel.gov/publications.

Revit Systems Analysis

As a result of this CRADA, Autodesk's desktop software product Revit added a feature called Systems Analysis that allows users to run an annual energy simulation to estimate the energy use of their overall building design, or run mechanical sizing to estimate the sizes of their HVAC system components. These features are contained in the OpenStudio Command Line Interface (CLI) for Revit[3], developed by NREL, that integrates the following into a standalone Windows-compatible installer that is included with Revit installations.

- A customized version of EnergyPlus4
- The OpenStudio CLI from the OpenStudio Software Development Kit (SDK)5
- OpenStudio Measures6
- OpenStudio Workflows7

Insight

As a result of this CRADA, Autodesk's cloud software product Insight added the ability to perform annual energy simulations using the following DOE tools developed by NREL. Insight previously used a different simulation engine.

- OpenStudio SDK8, an unmodified release of the OpenStudio SDK that is compatible with Autodesk's cloud platform.
- OpenStudio Insight Measures9, a collection of OpenStudio Measures for Insight and an OpenStudio Workflow file to run simulations

Detailed Task Results

Task 1: Project status reporting

Task 1 Result:

Project status reporting consisted of three parts to maintain coordination between Autodesk and NREL: (1) Autodesk internal meetings, (2) NREL internal meetings, and (3) Autodesk and NREL meetings.

Autodesk followed Scrum[10] and all Scrum Events for its internal meetings: Sprints (2 weeks), Sprint Planning, Daily Scrum, Sprint Review, and Sprint Retrospective.

3 https://github.com/NREL/gbxml-to-openstudio/
4 https://energyplus.net/
5 https://openstudio.net/
6 https://nrel.github.io/OpenStudio-user-documentation/getting_started/about_measures/
7 https://nrel.github.io/OpenStudio-user-documentation/reference/command_line_interface/
8 https://github.com/NREL/OpenStudio/releases/
9 https://github.com/NREL/openstudio-insight-measures
10 https://scrumguides.org/

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NREL conducted regular internal meetings to discuss specific issues with our tasks. These included detailed discussions about the importing of BIM data to OpenStudio via the Green Building XML (gbXML) Schema (e.g. constraints and performance), and development of the software building process for the OpenStudio CLI for Revit, which packages the OpenStudio SDK with the OpenStudio Measures and Workflows developed by NREL for this CRADA into a Windows-compatible installer.

Autodesk and NREL regularly met during the Sprint Planning and the Sprint Review Scrum Events to report on the project's status. Additionally, Autodesk and NREL attended a backlog refinement session to refine the scope of work to be done in the Sprints.

Task 2: Manage Product Development

1.1 Assemble Industry Focus Group
1.2 Conduct demonstrations and gather industry feedback
1.3 Communicate user stories to respective development teams

Task 2 Result:

2.1: Assemble industry focus group

Autodesk used its extensive customer base and recruiting team to find focused customer groups to solicit feedback about their needs for BEM capabilities. Autodesk assembled a group of customers that were present at each Sprint Review to provide feedback during the process of developing the software products for this CRADA.

2.2: Conduct demonstrations and gather industry feedback

Autodesk conducted three demonstrations to showcase the products from this CRADA and gather industry feedback. One feedback event was Inside The Factory (ITF) where Autodesk flew customers to their Boston office to test the software on their own real-world projects, allowing them to give feedback in real time on issues they encountered. During this event, members of the Autodesk team were able to observe how successfully users could complete tasks and where they struggled. In addition to ITF, Autodesk hosts an annual conference, Autodesk University (AU), where thousands of customers come together for classes, training, and other events. At AU 2019, two classes were hosted that showcased Systems Analysis. The first covered the basic workflows and user interface for everyday users that want to use it out the box for load calculations and energy analysis[11].

11 https://www.autodesk.com/autodesk-university/class/Revit-Systems-Analysis-Features-and-Framework-Introduction-2019

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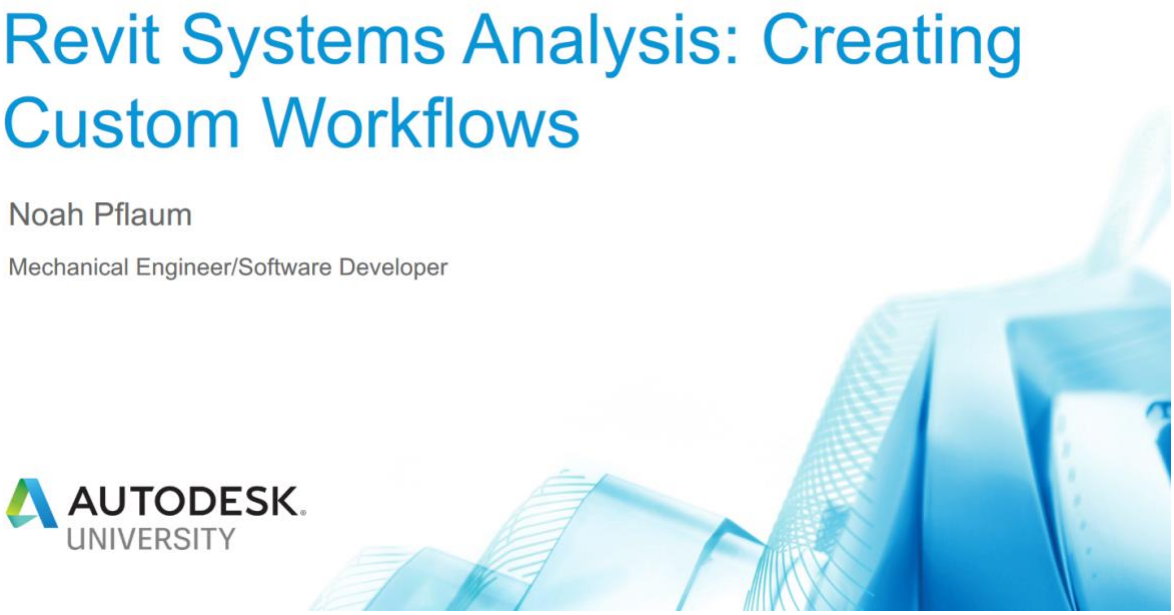
The second class focused on how a user could customize Systems Analysis for their needs to extract more data from Revit, edit OpenStudio Measures, and have that data be consumed on the backend EnergyPlus simulations[12].



[12] https://www.autodesk.com/autodesk-university/class/Revit-Systems-Analysis-Features-and-Framework-Creating-Custom-Workflows-2019

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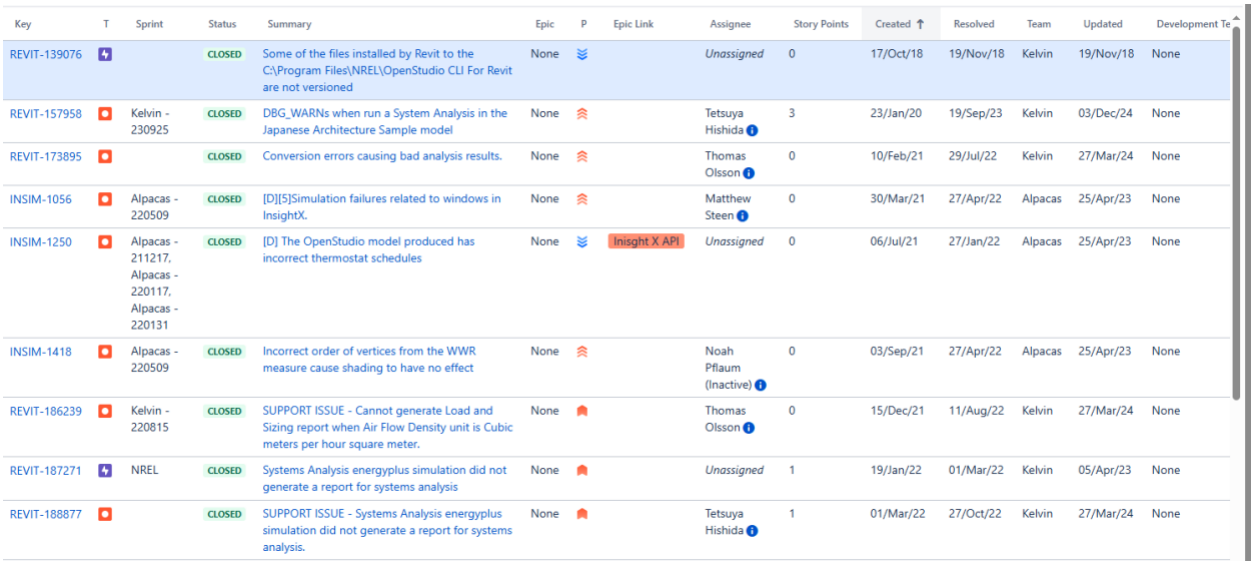
2.3: Communicate user stories to respective development teams

Autodesk teams use Jira for tracking their work and priorities. They would create stories for the work needed from NREL, review them with NREL personnel, and size them. The stories were used to track progress. The image below shows an example of the Jira tracking system.



Key	T	Sprint	Status	Summary	Epic	P	Epic Link	Assignee	Story Points	Created ↑	Resolved	Team	Updated	Development Te
REVIT-139076			CLOSED	Some of the files installed by Revit to the C:\Program Files\NREL\OpenStudio CLI For Revit are not versioned	None			*Unassigned*	0	17/Oct/18	19/Nov/18	Kelvin	19/Nov/18	None
REVIT-157958		Kelvin - 230925	CLOSED	DBG_WARNs when run a System Analysis in the Japanese Architecture Sample model	None			Tetsuya Hishida	3	23/Jan/20	19/Sep/23	Kelvin	03/Dec/24	None
REVIT-173895			CLOSED	Conversion errors causing bad analysis results.	None			Thomas Olsson	0	10/Feb/21	29/Jul/22	Kelvin	27/Mar/24	None
INSIM-1056		Alpacas - 220509	CLOSED	[D][5]Simulation failures related to windows in InsightX.	None			Matthew Steen	0	30/Mar/21	27/Apr/22	Alpacas	25/Apr/23	None
INSIM-1250		Alpacas - 211217, Alpacas - 220117, Alpacas - 220131	CLOSED	[D] The OpenStudio model produced has incorrect thermostat schedules	None		Inisght X API	*Unassigned*	0	06/Jul/21	27/Jan/22	Alpacas	25/Apr/23	None
INSIM-1418		Alpacas - 220509	CLOSED	Incorrect order of vertices from the WWR measure cause shading to have no effect	None			Noah Pflaum (Inactive)	0	03/Sep/21	27/Apr/22	Alpacas	25/Apr/23	None
REVIT-186239		Kelvin - 220815	CLOSED	SUPPORT ISSUE - Cannot generate Load and Sizing report when Air Flow Density unit is Cubic meters per hour square meter.	None			Thomas Olsson	0	15/Dec/21	11/Aug/22	Kelvin	27/Mar/24	None
REVIT-187271		NREL	CLOSED	Systems Analysis energyplus simulation did not generate a report for systems analysis	None			*Unassigned*	1	19/Jan/22	01/Mar/22	Kelvin	05/Apr/23	None
REVIT-188877			CLOSED	SUPPORT ISSUE - Systems Analysis energyplus simulation did not generate a report for systems analysis.	None			Tetsuya Hishida	1	01/Mar/22	27/Oct/22	Kelvin	27/Mar/24	None

Communication was done via Slack, comments in Jira, and a recurring weekly meeting. Below is a sample of the communication summarizing a planning meeting.

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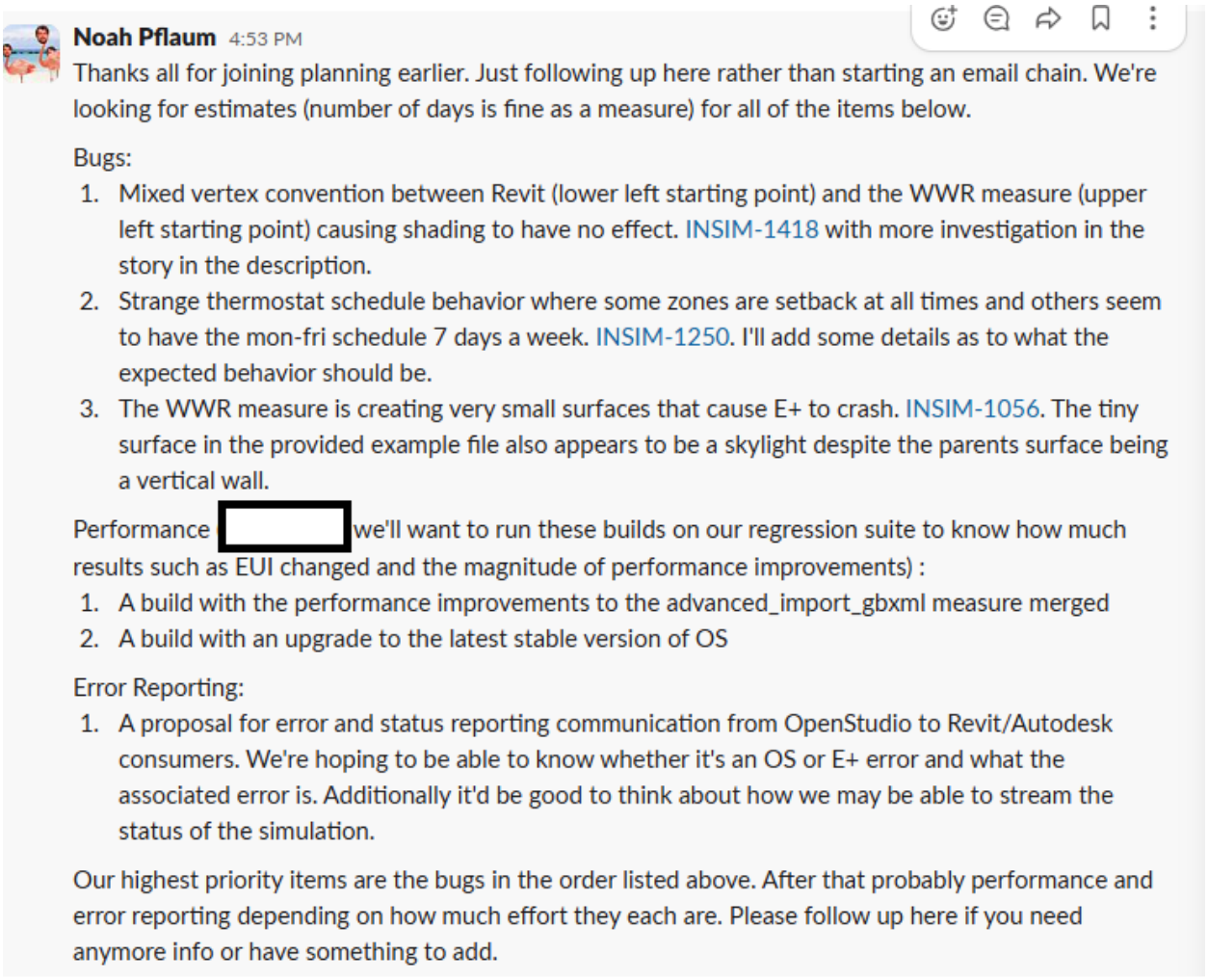

Noah Pflaum 4:53 PM

Thanks all for joining planning earlier. Just following up here rather than starting an email chain. We're looking for estimates (number of days is fine as a measure) for all of the items below.

Bugs:

1. Mixed vertex convention between Revit (lower left starting point) and the WWR measure (upper left starting point) causing shading to have no effect. INSIM-1418 with more investigation in the story in the description.
2. Strange thermostat schedule behavior where some zones are setback at all times and others seem to have the mon-fri schedule 7 days a week. INSIM-1250. I'll add some details as to what the expected behavior should be.
3. The WWR measure is creating very small surfaces that cause E+ to crash. INSIM-1056. The tiny surface in the provided example file also appears to be a skylight despite the parents surface being a vertical wall.

Performance [redacted] we'll want to run these builds on our regression suite to know how much results such as EUI changed and the magnitude of performance improvements) :

1. A build with the performance improvements to the advanced_import_gbxml measure merged
2. A build with an upgrade to the latest stable version of OS

Error Reporting:

1. A proposal for error and status reporting communication from OpenStudio to Revit/Autodesk consumers. We're hoping to be able to know whether it's an OS or E+ error and what the associated error is. Additionally it'd be good to think about how we may be able to stream the status of the simulation.

Our highest priority items are the bugs in the order listed above. After that probably performance and error reporting depending on how much effort they each are. Please follow up here if you need anymore info or have something to add.

Task 3: HVAC Measure Analysis

3.1 Establish list of most common mechanical designs
3.2 Develop testing framework for these measures
3.3 Develop infrastructure skeleton for parametric analysis from Revit

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Task 3 Result:

3.1: Establish list of most common mechanical designs

Autodesk and NREL worked together to establish a prioritized list of mechanical systems based on feedback from the industry focus group that was assembled for Task 2.1. This list, summarized below, included a majority of the most common systems currently being designed by mechanical engineers.

- Baseboard heating (convective and radiant)
- Constant air volume terminal boxes
- Four pipe fan coil units
- Chilled beams (active and passive)
- Fan-powered terminal units (parallel and series)
- Packaged terminal air conditioner
- Packaged terminal heat pump
- Radiant panel
- Unit heater
- Unit ventilator
- Variable air volume terminal units
- Variable refrigerant flow system
- Water-source heat pump

3.2: Develop measures for systems where they don't exist

NREL developed a single OpenStudio Measure (*gbxml_hvac_import*)[13], based on the prioritized list of systems in Task 3.1, to enable Revit to produce a corresponding BEM with a user-specified HVAC system type.

3.3: Develop testing framework for these measures

In the early stages of development, NREL relied on Autodesk's software regression tests to identify significant changes between iterations that were used to focus our fixes and improvements. Later, NREL developed a unit testing framework that covered all system types enabled by the *gbxml_hvac_import* Measure[14].

3.4: Develop infrastructure skeleton for parametric analysis from Revit

NREL developed a collection of OpenStudio Measures and an OpenStudio Workflow for Autodesk's Insight cloud product, which connects their desktop product, Revit, to the cloud for parametric OpenStudio simulations.

13 https://github.com/NREL/gbxml-to-openstudio/tree/v1.0.3/measures/gbxml_hvac_import
14 https://github.com/NREL/gbxml-to-openstudio/tree/develop/test/gbxml_hvac_import

This report is available at no cost from NREL at www.nrel.gov/publications.

Task 4: Early-Stage Analysis

4.1 Deploy OSAF on desired cloud platform
4.2 Parallelize each simulation for faster runtime
4.3 Create Measure to interface generator to allow for user extensibility

Task 4 Result:

4.1: Deploy OSAF on desired cloud platform

Autodesk deployed OpenStudio simulations with Docker and CentOS 7 on the Amazon Web Services (AWS) cloud platform.

4.2: Parallelize each simulation for faster runtime

Autodesk has a cloud compute platform built on top of AWS that allows for large scaling of parallel workers, i.e. workers for BEM simulations. The system was successfully stress tested at a capacity of 20,000 parallel simulations without issue. Any failing instances are automatically spun back up and the simulations are rerun.

NREL developed a separate repository[15] of OpenStudio Measures and an OpenStudio Workflow to run a single simulation that Insight uses to run parallel simulations.

4.3: Create Measure to interface generator to allow user extensibility

Autodesk developed a user interface in Revit for selecting either an annual energy simulation or a system sizing run, which can be customized and extended by users. This feature was demonstrated at the AU 2019 class as noted in Task 2.2.

15 https://github.com/NREL/openstudio-insight-measures

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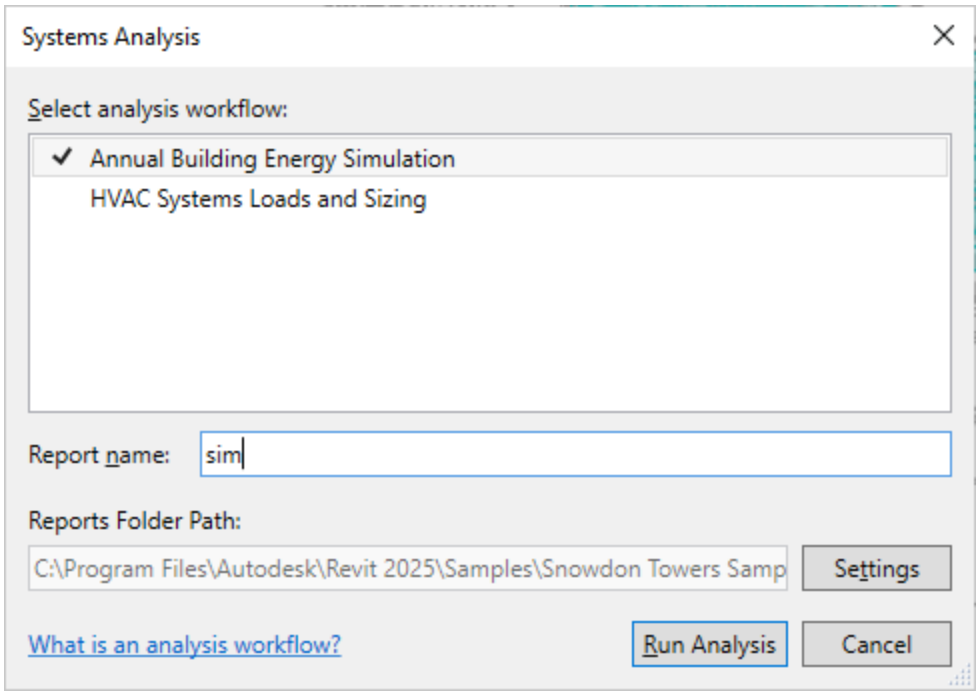
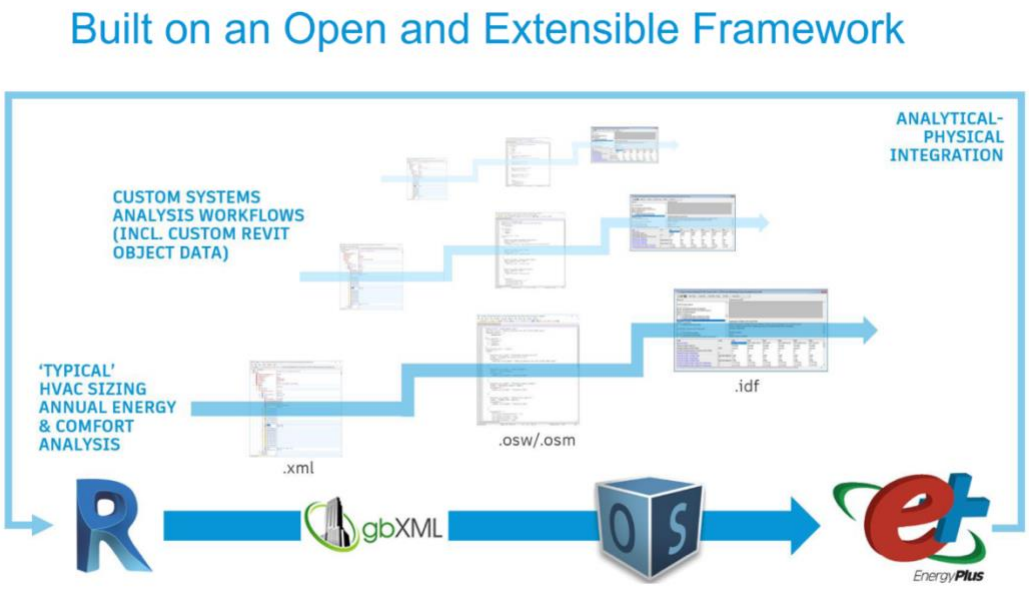


NREL developed OpenStudio Workflow templates (.osw files that specify which Measures to apply to a model) to enable annual energy simulation and mechanical sizing runs from Revit[16]. These Workflows and the accompanying Measures provide a framework for users to extend Systems Analysis to other applications.



16 https://github.com/NREL/gbxml-to-openstudio/tree/v1.0.3/workflows

This report is available at no cost from NREL at www.nrel.gov/publications.

Task 5: Develop BIM/BEM seamless integration

5.1 Perform testing for stability and testing quality
5.2 Develop measures to map Revit data to REM data
5.3 Create output of BEM results that can be used

Task 5 Result:

5.1: Perform testing for stability and engineering quality

Autodesk developed automated testing for Systems Analysis to check for stability and quality whenever there are changes to it. For example, whenever a bug fix, new feature, or new version is committed to the repository the continuous integration (CI) system automatically runs tests. The CI system includes the following:

1. Test fixtures: a suite of approximately 40 models to run the tests on
2. Integration tests: software tests to test that the parts of the software product work together after changes are introduced
3. Regression tests: software tests to test that the performance of the software product as a whole does not significantly change after changes are introduced

5.3: Develop measures to map Revit data to BEM data

NREL developed the following OpenStudio Measures to map Revit data (via the gbXML schema) to BEM data[17]. These Measures collectively enable the translation of a Revit BIM to an OpenStudio BEM, which is not possible using OpenStudio's built-in gbXML import feature (contained within the *import_gbxml* Measure). In particular, the *advanced_import_gbxml* and *gbxml_hvac_import* Measures create complex building attributes in OpenStudio, such as schedules and HVAC systems, from a gbXML, that enable Revit users to successfully perform annual energy simulations and mechanical sizing.

1. import_gbxml
2. advanced_import_gbxml
3. gbxml_hvac_import
4. gbxml_to_openstudio_cleanup
5. set_simulation_control

5.4: Create output of BEM results that can be used for further reporting

NREL developed two OpenStudio Reporting Measures to report the output of BEM results to Revit users. The first was a customized version of the OpenStudio Results Measure[18], which combines summary graphical results with detailed tabular results from EnergyPlus both shown below.

17 https://github.com/NREL/gbxml-to-openstudio/tree/v1.0.3/measures
18 https://github.com/NREL/gbxml-to-openstudio/tree/v1.0.3/measures/openstudio_results

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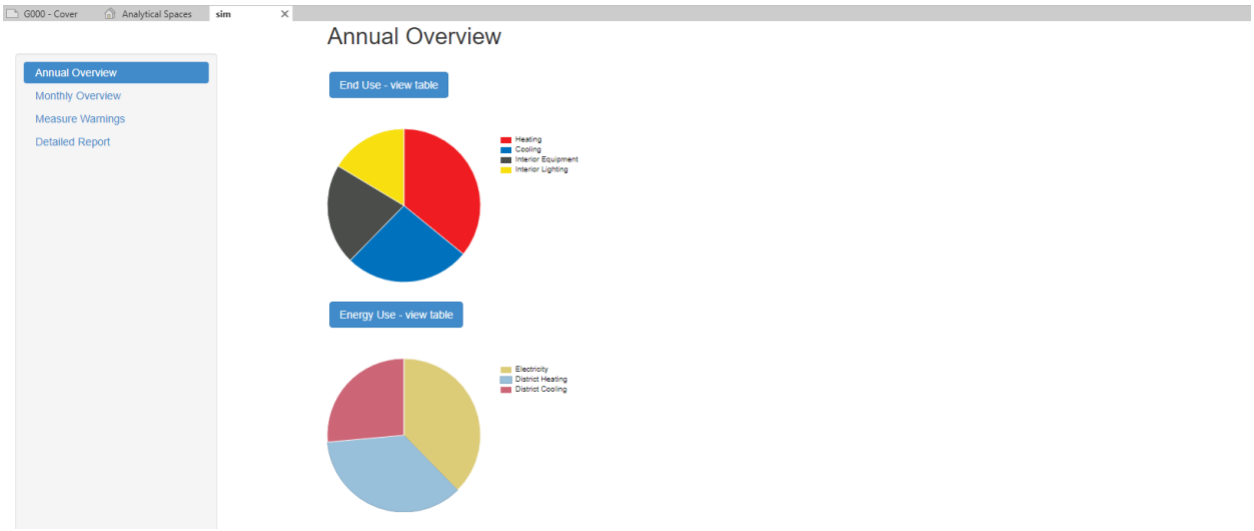

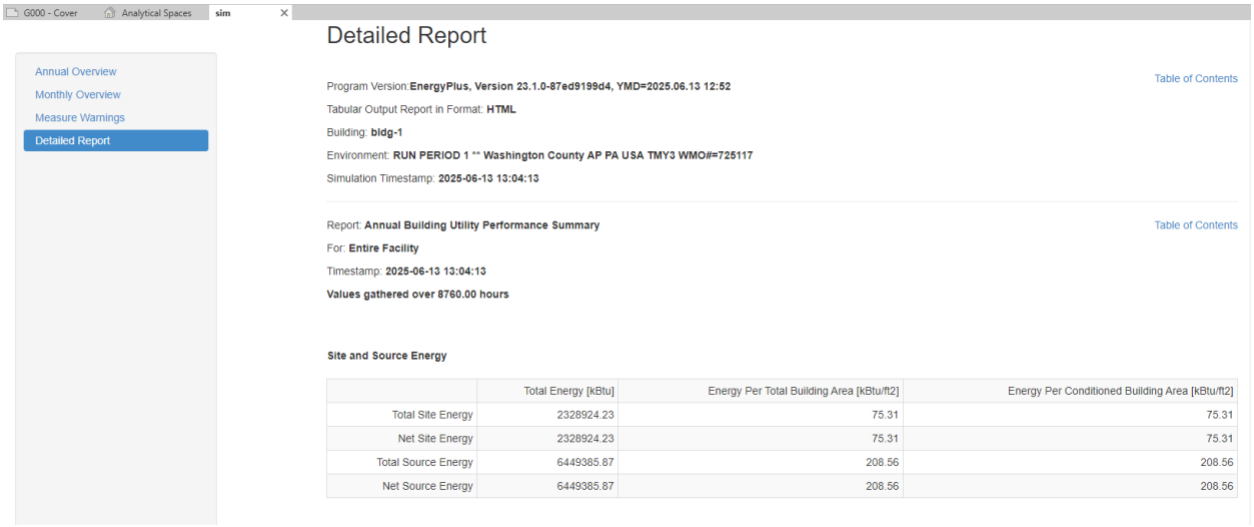

The second was the Systems Analysis Reports[19] software library to report and visualize the output of a mechanical sizing simulation performed by the Systems Analysis feature in Revit. This library includes the *systems_analysis_report_generator* Measure that generates an interactive report of sizing output (shown in image below) and the EPlusOut library that allows users to easily access the data from an EnergyPlus simulation. EPlusOut allows users to easily access extensive data from an EnergyPlus simulation by implementing a software pattern that's agnostic of the modeling tool.

19 https://github.com/NREL/SystemsAnalysisReports/

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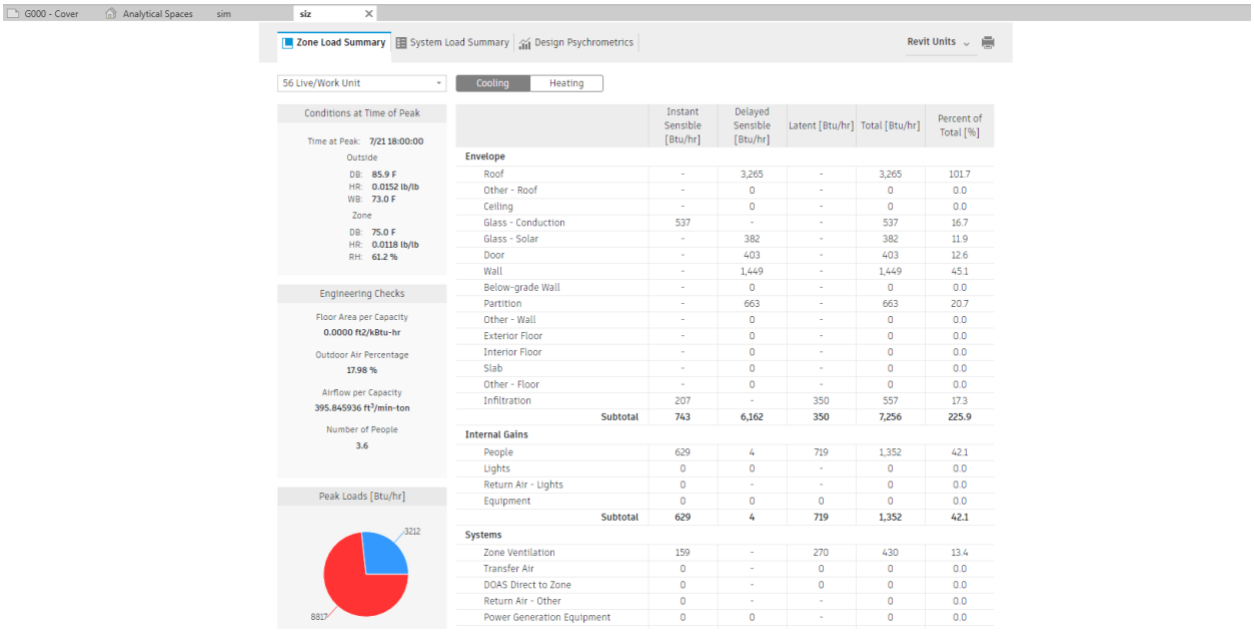

This report serves to meet the requirement for the CRADA Final Report with preparation and submission in accordance with the agreement's Article X.

References:

None

Subject Inventions Listing:

None

ROI:

None

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