Streamlining Energy Analysis of Existing Buildings with Rapid Energy Modeling

Improved building performance is critical for decreasing greenhouse gas emissions and reducing energy costs. However, identifying potential candidates for energy efficiency retrofits poses significant challenges. Building professionals, developers, owners, facility managers, insurers, financiers, and regulators are all struggling to get the information they need to support their building decisions.

To systematically evaluate and update existing building portfolios, the building industry needs a scalable process to assess building performance quickly, cost-effectively, accurately and efficiently. Rapid energy modeling is a streamlined process that helps you analyze and estimate building energy consumption using Building Information Modeling (BIM) solutions. With a smaller budget, shorter timeframe, and less initial data, building professionals can evaluate expected building performance and identify areas for improvement.

This paper outlines rapid energy modeling workflows using Autodesk solutions and documents results from real-world validation.

Figure 1:

Rapid energy modeling is a streamlined process to move rapidly, and with minimal data, from existing building conditions to energy and carbon reduction analysis through a simplified simulation process.

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Introduction

Scalable Energy Assessments

The implementation of efficiency measures and renewable energy generation in existing buildings represents a significant opportunity to reduce energy costs and hedge against energy price risk. In light of this, there are an increasing number of national and regional building directives to promote better performing buildings. These mandates and other factors such as energy security, global climate change and economic stimulus programs are driving energy efficiency retrofits of commercial buildings around the world.

To respond to these economic and energy challenges at the scale, speed, and efficiency needed, the building industry must be able to quickly and cost effectively prioritize, mobilize, and focus its retrofitting efforts. However, we face major challenges in determining the potential energy savings in existing buildings—data that is essential for identifying retrofit and renovation candidates.

Many of the current methods of performing energy assessments are expensive and laborious. The types of assessments that achieve the greatest savings are those based on whole building energy analysis and follow the steps below:

- Data collection of existing conditions – Design (geometry) of the building, utility history, performance of equipment and materials, weather data, operating schedules, etc.
- Energy model creation – Using above data develop whole building energy model.
- Calibration – Modify unknown parameters in energy model to ensure energy results match utility history within acceptable threshold
- Energy efficiency measures – Modify energy model to estimate energy and cost savings for various energy efficiency measures. Estimate costs for implementing measures and prioritize list based on simple payback.

What's "rapid" about rapid energy modeling?

- Fast process that doesn't require specialized resources
- Quick learning curve due to simplified modeling and analysis software
- Early screening method to identify buildings in need of a deeper energy assessment

These assessments require a high level of technical expertise and sometimes the assessments are inaccurate due to a lack of data, time, or budget. In short, they are not scalable.

Rapid Energy Modeling for Existing Buildings

Rapid energy modeling is a streamlined, scalable approach for performing energy assessments of existing buildings. While the umbrella term can represent a number of solutions, a typical workflow consists of three steps: capture, model, and analyze.

Step 1: First, you ***capture*** existing building conditions. Starting from as little as photos, satellite images, aerial images, or laser distance meters, you collect basic information about a building such as geometry, location, orientation, and structural or operational anomalies.

Step 2: This digital information is calibrated and converted into a simplified 3D building ***model***. Your model can be a:

- Conceptual massing model that defines the internal volumes of the building (which is all that is necessary for basic energy modeling), or a
- Detailed model using design elements such as walls, floors, windows, roofs, and rooms or spaces.

Step 3: In this step, you ***analyze*** the building model by performing energy analyses to assess expected building performance.

The core value proposition of rapid energy modeling is the democratization of the portfolio energy assessment process. It makes energy assessments quick and cost-effective, and results in easy to understand and actionable conclusions based on building science, the building's geometry, and local climate conditions.

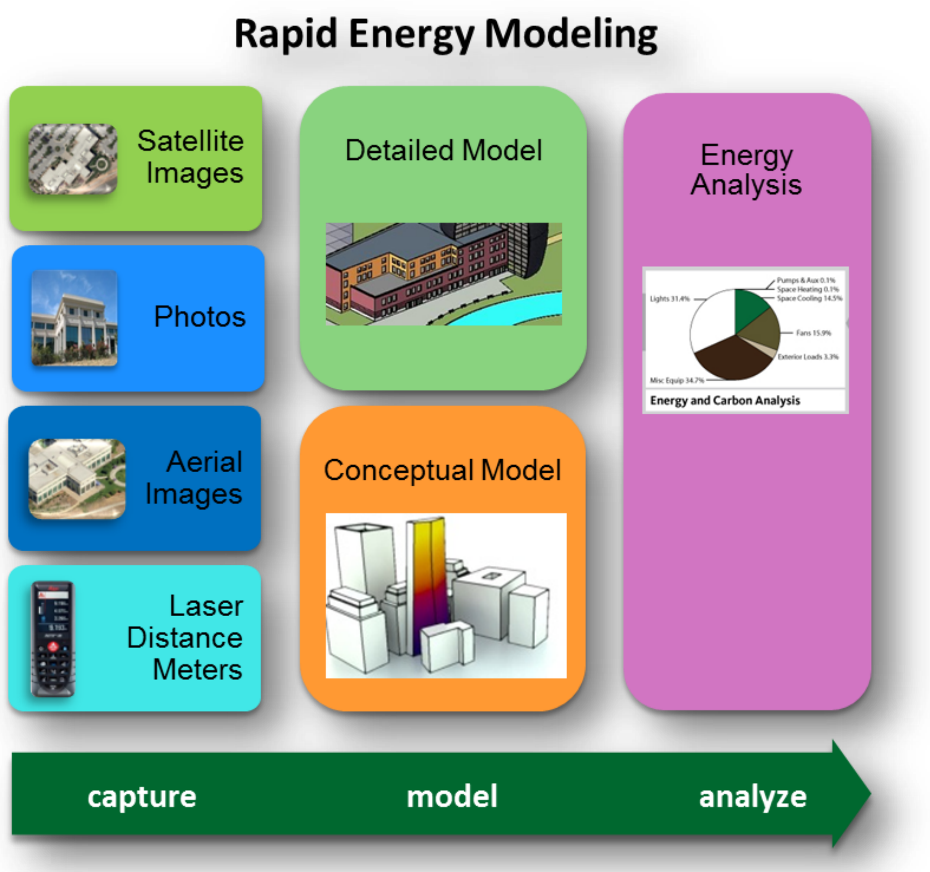


Figure 2:

Rapid energy modeling includes three key elements: capture, model, and analyze.

Uses for Rapid Energy Modeling

Rapid energy modeling can accelerate the initial steps of an energy assessment process that is used to:

- ***Screen a building portfolio for high potential retrofit candidates***. Building owners, property managers, and tenants with large portfolios can use rapid energy modeling to estimate the energy consumption and carbon footprint of an entire set of buildings. They can use it to assess factors such as energy costs and carbon emissions across several buildings, and identify outliers as well as buildings with high potential for improvement and ROI.

- ***Prioritize retrofit investments and energy efficiency measures***. Developers, building owners, facility managers, or tenants can use rapid energy modeling to quickly understand and compare potential retrofit and renovation options, and drill down into the energy model of existing buildings to make post-analysis recommendations on energy efficiency upgrades.
- ***Evaluate the lifecycle impact of retrofit decisions***. Designers, architects, contractors, and construction companies can use rapid energy modeling to quickly evaluate various design alternatives for intended retrofits and identify solutions that optimize lifecycle impact.
- ***Streamline asset rating***. Insurers, financiers, regulators, and real estate brokers may find rapid energy modeling valuable in getting the information they need to support their asset rating process in a cost-effective manner.

Autodesk Software for Rapid Energy Modeling

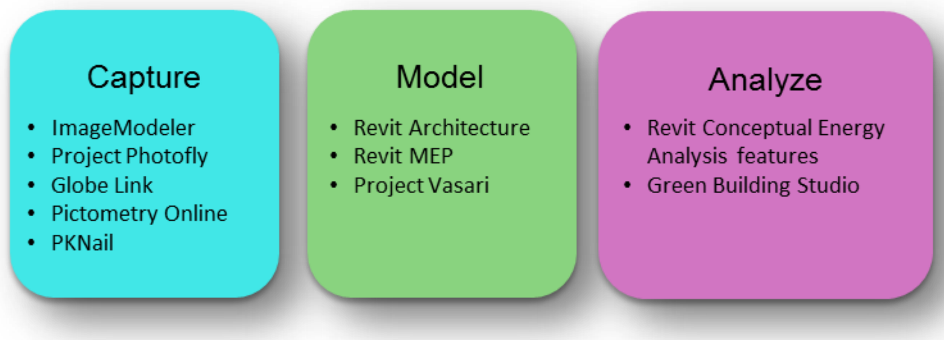
A broad selection of Autodesk software solutions can be used to support rapid energy modeling, including:

- Autodesk® Revit® Architecture or Autodesk® Revit® MEP software.
- Autodesk® ImageModeler™ software (available to Revit Architecture and Revit MEP Autodesk Subscription customers during the term of their Subscription).
- Autodesk® Revit® Conceptual Energy Analysis features (available to Revit Architecture and Revit MEP Autodesk Subscription customers during the term of their subscription).
- Autodesk® Green Building Studio® web service.
- Workflows can also take advantage of technology previews available on Autodesk Labs including Project Photofly[1] (to help capture existing conditions), Project Vasari (for modeling), and Globe Link (for importing information from Google Earth™ mapping service to your Revit application).

[1] Project Photofly and Project Vasari are pre-release products and services that are licensed to the end-user under an agreement, which among other things, prohibits use of these pre-release products and services for commercial, professional or other for-profit purposes.

- In addition, some of the workflows described in this document can use non-Autodesk software, including Pictometry Online (POL) from Pictometry International Corp., PKNail from PointKnown, and Google Earth from Google.

The table below shows how the various software options are used in the three-step rapid energy modeling process.



The combination of these various software options translate into a series of distinct rapid energy modeling workflows. Your particular workflow for rapid energy modeling will depend on the method of capturing existing building conditions and the desired level of analysis. The next section describes the three key steps of the workflow—capture, model, and analyze.

Key Elements of Rapid Energy Modeling

Existing Conditions

The most common forms of existing building conditions are:

- ***Digital photographs***: These are photographs of your building taken specifically for rapid energy modeling.
- ***Aerial images***: You can download oblique aerial images from Internet sites such as Google Earth or Microsoft® Bing™ mapping services. Alternatively, you can use images from commercial providers of geo-referenced aerial and oblique image libraries such as Pictometry.
- ***Satellite images***: Like aerial images, you can download orthogonal images of your building from sites such as Google Earth.

- ***Laser distance meters***: These low-cost laser meters are common surveying tools, and you can also use them onsite to capture key measurements of your building.

There are advantages and disadvantages to using these various formats. For example, you can create sufficiently detailed buildings models based on digital photographs, but the photographs must be taken from different points of view and have as many common points as possible between them to enable the capture software (Project Photofly[2] for example) to calculate their 3D coordinates. As such, it requires an onsite resource. The same is true for measurements from a laser distance meter, which also requires training on the device and the capture software.

Aerial and satellite images are much easier to obtain and need minimal training, but they do require you to obtain additional information about the building from the facilities manager. For example, if not all the sides of your building are visible in aerial photographs, you will need some other source of information to fill in the missing building surfaces. Orthogonal satellite images can also be insufficient and require you to, at a minimum, obtain the building's height and number of levels.

Regardless of how you capture your existing conditions, you will need some minimal information about your building and its operations, such as:

- Square footage
- Operating schedule (12/7, 10/5 etc.)
- Information on structural anomalies not visible in pictures (such as atriums, basement, and storage areas)
- Operational idiosyncrasies such as inefficient HVAC, simultaneous heating/cooling, or high server load
- Utility bills (for comparison)

Step 1: Capturing Existing Conditions

The first step in the rapid energy modeling process is to capture the existing conditions of your building(s). The format of the existing conditions (i.e. digital photographs, aerial or satellite images, or laser distance meter measurements) will dictate the exact steps and software needed to help capture and process those existing conditions:

Digital Photographs

ImageModeler is image-based modeling and photogrammetry software that helps you generate models from digital photographs. Alternatively, Autodesk Project Photofly is photogrammetry software that converts pictures to 3D point clouds and meshes.

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Both solutions enable you to stitch together the photographs of your building, set the coordinate system and scale, and then model over the images to create a 3D wireframe model of your building.

Once the wireframe model is complete, you then export it as a DWG™ and use it in your BIM solution to help create a full 3D model of your building (see the “Creating a Building and Energy Model” section below).

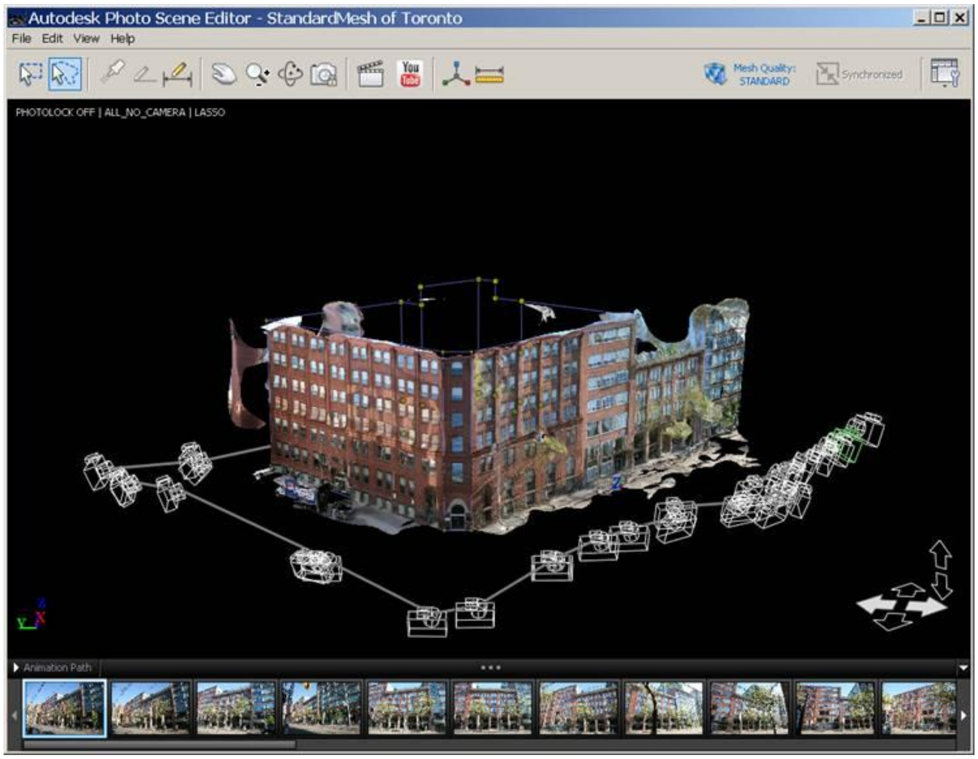

Figure 3:

Project Photofly converts pictures to 3D point clouds and meshes, and creates 3D wireframe models that you can use for rapid energy modeling.

Satellite Images

If you use satellite images to help capture your existing building conditions, you can use Globe Link for Autodesk Revit Architecture or Autodesk Revit MEP to download the image from Google Earth and pull it into Revit Architecture 2012 or Revit MEP 2012. You can also import a scaled Google Map satellite image directly into Project Vasari. Because the satellite image only displays the building footprint, you will need to know (at a minimum) the approximate height of the building and/or floor-to-floor height per floor as well as the approximate window-to-wall ratio (i.e. the glazing percentage) before proceeding with modeling.

Aerial Images

You can download oblique aerial images from Internet sites such as Google Earth or Microsoft Bing and process them in a manner similar to satellite images. However, a "birds-eye view" of your building may not always be available or the quality of the pictures may be insufficient.

Alternatively, you can also use aerial images and software from Pictometry (fee required, see www.pictometry.com). In addition to providing the aerial images, the software enables you to extract building information that you can use for modeling such as distance and area measurements, number of windows, orientation of the building, and coordinates of the building location. Pictometry's Pictometry Online software outputs a KML file that can be imported directly into Revit Architecture or Revit MEP to create a full 3D model of your building.

Laser distance meter

If you plan to capture existing conditions using a laser distance meter, you can use PKNail software from PointKnown (www.pointknown.com) to process those measurements and create a Revit model of your building. By inputting a few simple field measurements PKNail will build a Revit model of the existing structure, in the field, in real time. This approach involves trained survey personnel that walk around the perimeter of a building and measure key points on the building.

The PKNail software utilizes Bluetooth®-enabled laser distance meters to capture dimensional data in the field and send it directly to a laptop loaded with the Revit Architecture or Revit MEP. By capturing data in a specific sequence, the PKNail software creates a Revit model representing the skin of your building as it is being measured. Once the measurements are finished, you then complete the modeling processing by manually adding floors, zones and roofs.

Step 2: Creating a Building Model

After capturing your existing building conditions, you then use the data from Step 1 to create either a conceptual massing model or a more detailed model that incorporates building elements such as walls, floors, windows, roofs, and rooms/spaces.

For a first-pass energy assessment, a conceptual massing model is often sufficient. To create the conceptual model, you can use either Revit Architecture or Revit MEP software. Both solutions offer conceptual design tools that can help you quickly create building forms using the geometry captured in Step 1. However, if you know in advance that you may need a more detailed building model for further engineering driven analysis, for design, or for facility management purposes, you may want to create a detailed model.

If you use digital photographs or aerial images to help capture the existing conditions of your building, you simply import the DWG or KML file into Revit Architecture or Revit MEP and use the wireframe model as a reference to create your conceptual model. If you use satellite images, you start the modeling process by tracing over the building footprint in Revit Architecture or Revit MEP and then use additional information about your building (such as its height and number of floors) to create a model. If you used a laser distance meter to help capture existing conditions, you use Revit Architecture or Revit MEP to complete the model created by the PKNail software.

Another option for creating conceptual models is to use Project Vasari[3], which is currently available as a technology preview on Autodesk Labs. Project Vasari is a standalone conceptual modeling and energy analysis tool, designed to increase accessibility for early design phase conceptual energy analysis. The software includes the Conceptual Energy Modeling features described below.

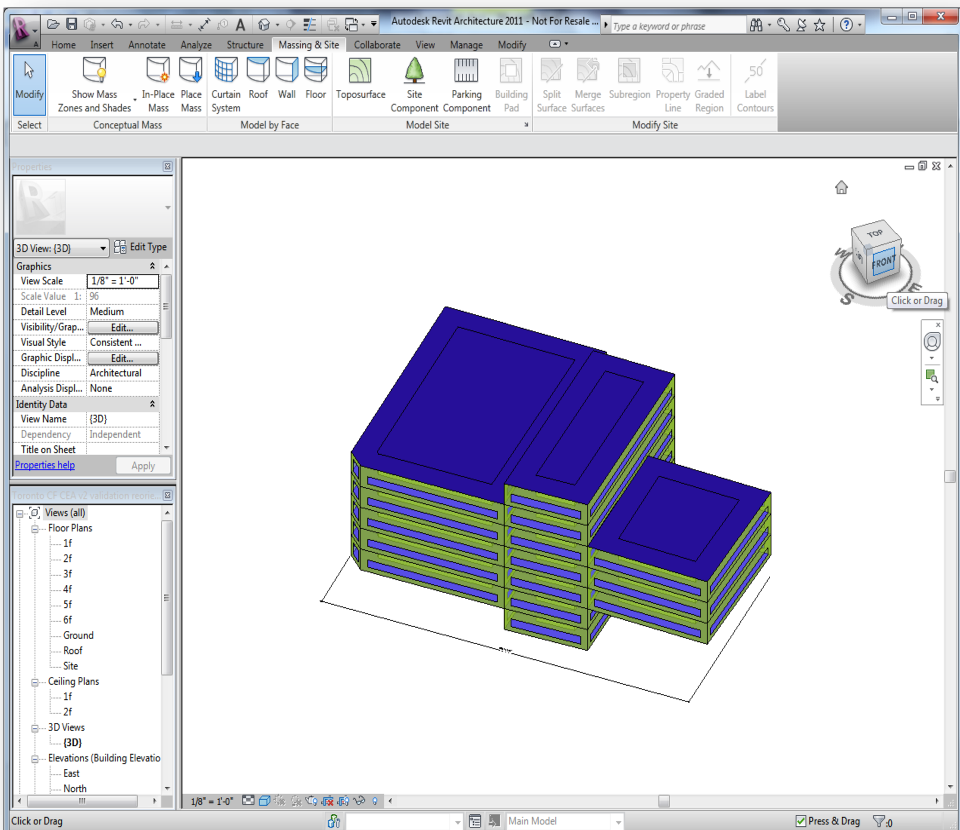

Figure 4:

Use Revit Architecture or Revit MEP software to more quickly create building forms for rapid energy modeling.

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Step 3: Analyzing Energy Consumption and Carbon Emissions

Once your building model is complete, you are ready for energy simulation and analysis. You can use the Revit Conceptual Energy Analysis features for your initial analysis and/or use Green Building Studio for more detailed whole building analyses.

The Revit Conceptual Energy Analysis features generate an energy analysis from your Revit Architecture or Revit MEP conceptual model and give you results based on user-defined parameters such as building location and type, and hours of operation. You view the results of the analysis in a separate window via graphs, charts, and tables.

Green Building Studio web service uses the DOE-2 simulation engine for energy analysis and offers options to fine-tune your analyses and perform whole building analysis if needed. The user also has the ability to continue analysis in other software by using gbXML files that can be exported from both Revit Conceptual Energy Analysis features and Green Building Studio.

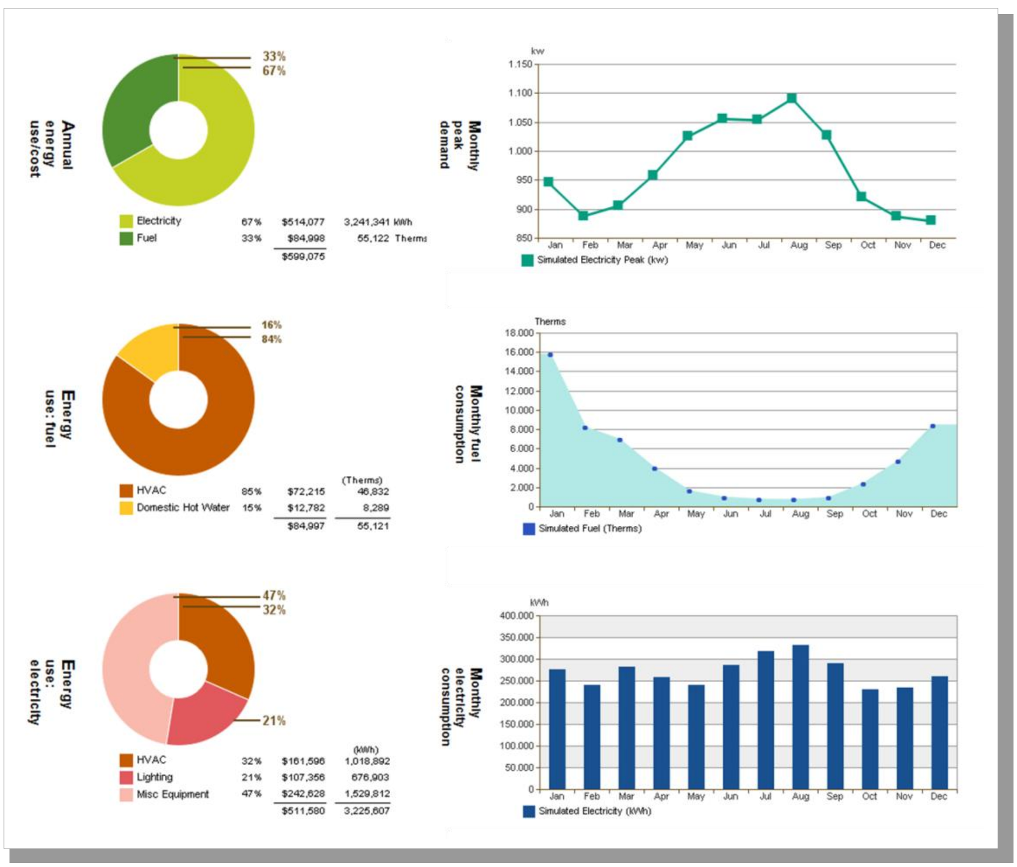

Figure 5:

Autodesk Revit Conceptual Energy Analysis features help you simulate your building performance.

Findings from Preliminary Trials

The various rapid energy modeling workflows have been given preliminary road tests by Autodesk, its customers, and professional services firms, such as URS-Scott Wilson, a globally integrated design and engineering consultancy for the built and natural environments in the United Kingdom, and DPR Construction, a leading general contractor in the United States, specializing in technically complex and sustainable projects.

> Based on my experience, once you get past the learning curve of using the reality-capture software, a typical three-story office building can be modeled and simulated for energy analysis in just eight to twelve hours. That is very rapid indeed!
>
> - Jack Hammons
>   BIM Manager
>   DPR Construction

Results

The project teams conducting these pilot trials modeled existing building conditions and performed building energy analysis in just a few days, and in many cases with no previous experience using Autodesk tools, all of which led to encouraging insights.

The results of these trials were comparable to actual building performance data and deemed reasonably satisfactory by the stakeholders. Even deviations from actuals pointed to useful insights:

- Incorrect or inadequate assumptions can be easily changed in the software.
- Deviations can uncover important operational insights or even inefficiencies that are in need of fixing.

These rapid energy modeling studies have been encouraging from a number of perspectives.

> The rapid energy assessment is scalable and delivers a level of information to inform our clients' decision making that previously would have taken much more resource to achieve. Now we can deliver a more cost effective entry service to our clients while providing a high value audit.
>
> - Robert Spencer
>   Chairman of URS/Scott Wilson's Sustainability Board (UK)

Time ("Rapid")

Time (and hence cost) saving is one of the most obvious and significant benefits of rapid energy modeling. The process promises to drastically bring down variable costs associated with modeling for energy analysis and hence allow large-scale assessments in a shorter time. Figure 6 below demonstrates this point, presenting the results of rapid energy modeling experiments carried out with the help of Autodesk software.

As a case in point, Autodesk performed rapid energy modeling for six Autodesk facilities on three continents in a matter of days for each facility (and in some cases only hours) without any project team members needing to travel to the building sites and with no previous experience using the Autodesk tools. (Photographs of the buildings were taken by local onsite resources.)

Given these results, the word "rapid" in rapid energy modeling takes on different connotations. The modeling process itself is streamlined and does not require specialized energy personnel. In addition, learning the process is fast due to simplified modeling and analysis software. Finally, the process can be a quick screening method to identify buildings in need of a deeper energy assessment.

[Note: The results shown in Figure 6 are based on experiments using Autodesk software. The data for other workflows assumes the use of non-Autodesk software and is based on informal surveys of resident subject matter experts. Designated yellow area represents rapid energy modeling workflows that use Autodesk software at the core and also 3rd party solutions such as PointKnown and Pictometry.

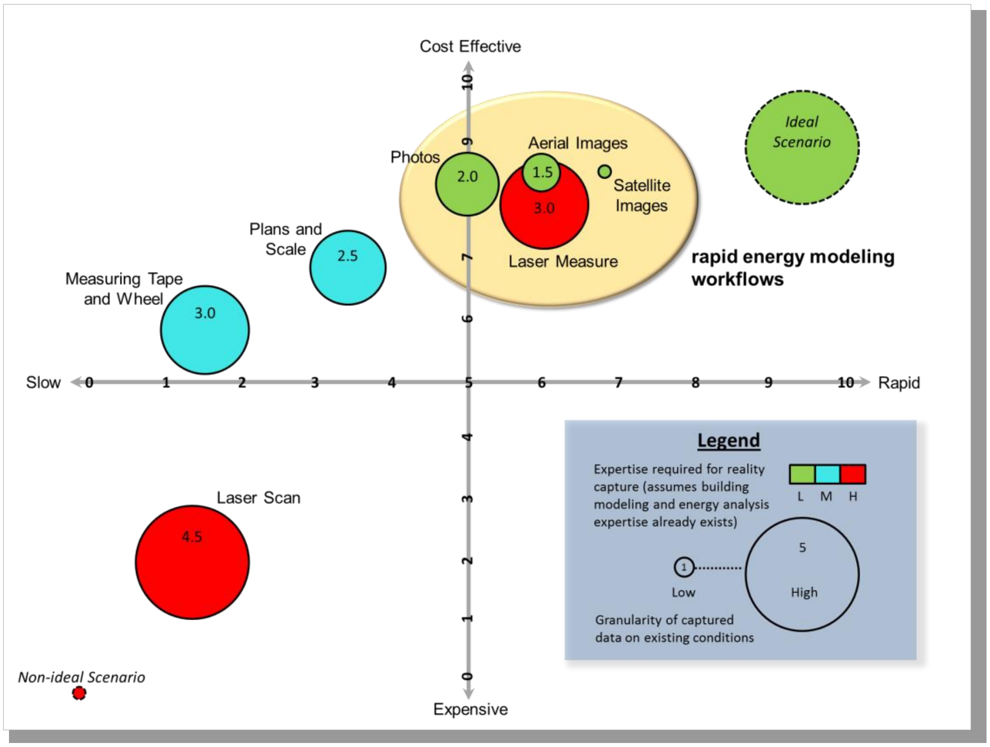

Figure 6:

The benefits and tradeoffs of different rapid energy modeling, workflows, based on accuracy, cost, and time.

Electricity and Fuel Consumption ("Energy")

Electricity consumption often represents the bulk of a commercial building's energy use and therefore is a key criterion for energy assessment. The various rapid energy modeling workflows tested by Autodesk and its customers were found to be reasonably accurate in this regard, again considering the amount of time and effort expended.

For all the workflows tested, the estimated electricity intensity numbers were found to be quite close to the building's real energy consumption (as determined by actual utility bills). A chart showing results from one of the workflows is shown below in Figure 7. The only outlier was the facility in Manchester, New Hampshire. After the rapid energy modeling process was complete, the team discovered that the building has a data center that wasn't modeled and that significantly drove up electricity consumption.

These results underscore the importance of learning beforehand about a building's structural anomalies (such as atriums) or operational idiosyncrasies (such as large data centers) before drawing conclusions about the building's performance.

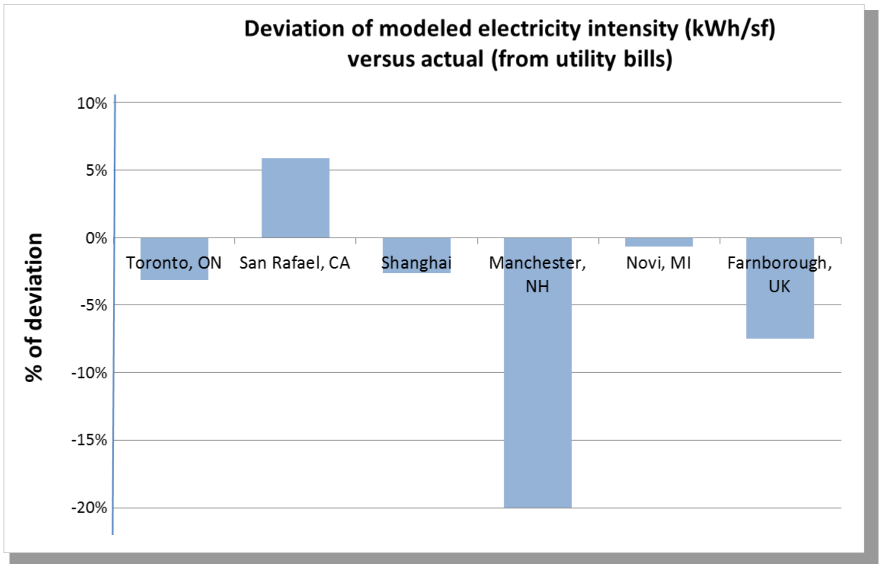

Figure 7:

Rapid energy modeling is a reasonably effective predictor of actual electricity consumption.

The fuel estimates, on the other hand, were not found to be close to the actuals for two of the three Autodesk facilities that were able to supply fuel data. It should be noted that the fuel consumption costs took up a relatively small percentage of these buildings' overall utility bills (ranging from approximately 13-17%). Electricity use is often more predictable because it is based upon set operating schedules in most commercial buildings. On the other hand, natural gas consumption has a higher sensitivity to occupant behavior and climate fluctuations, making it harder to predict. Nevertheless, natural gas consumption for a number of buildings is a significant utility cost. It may even outweigh electrical costs for certain building types and geographic locations. Hence more due diligence needs to be conducted to determine the root cause of these deviations.

Geometry ("Modeling")

The building geometry and the corresponding square footage calculations resulting from in-house experiments and customer pilots were also quite close to the actuals. Figure 8 below shows the results from one of the experiments. The calculated areas of all of the buildings were within 7%, with the exception of the San Rafael, California facility.

That outlier was due to a modeling error—a structural anomaly that was not visible from photos but could be seen when looking at building floor plans. To keep the study double blind, the researchers purposefully avoided looking at available floor plans during the rapid energy modeling process.

While it is very easy to go back and fix the model, this error again brought to light the need to augment building images with additional information on structural anomalies.

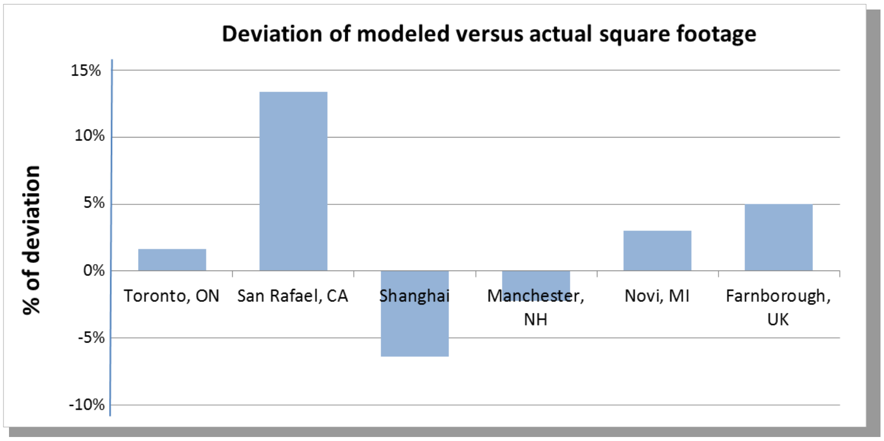

Figure 8:

Project teams successfully modeled existing building conditions and performed building energy analysis of these facilities in just a few days.

Validating Other Key Parameters

It should also be noted that the team took pains to validate other structural and operational parameters such as glazing percentage, floor heights, and loads, as well as square footage and energy consumption, in an attempt to reduce the risk of false positives or false negatives. Results from one such validation exercise are illustrated in the table below.

	Validation Results	Actual Value	Modeled value	Absolute difference	% Error
	Modeled Geometry (Imperical measurements)				
1	**Length of the building (feet)**	202	198	-4	-2%
2	**Breadth of the building (feet)**	133	134	0	0%
3	**Total roof area (sf)**	Not validated (assumed to be equal to maximum floor area)			
4	**Total skylight area (sf)**	N/A			
5	**Glazing %**	31%	28%	-3%	-10%
6	**Total leased area (sf)**	101,090	102,760	1,670	2%
8	**Floor area for each floor (sf)**	16,287	16,832	545	3%
9	**Sum of all floor areas (sf, from Revit schedules)**	114,301	122,769	8,468	7%
11	**Floor to floor height for each floor (sf)**	10.9	11.5	0.6	5%
12	**Building height (feet)**	78.3	80.0	1.7	2%
	Loads				
13	**Type of HVAC**	11.3 EER Packaged VAV, 84.8% boiler heating	11.3 EER Packaged VAV, 84.8% boiler heating		
14	**Lighting Power Density (W/ft^2)**	Could not be validated	1.5	N/A	
15	**Equipment Power Density (W/ft^2)**		1.65		
16	**Peak Electric Demand (kW)**	500	593.7	93.7	19%
17	**Peak Demand density (W/ft^2)**	4.95	5.78	0.83	17%
18	**Total Electricity Use (kWh/year)**	1,785,163	1,757,257	-27,906	-2%
19	**Electricity Intensity (kWh/sf)**	17.66	17.10	-1	-3%
20	**Total Fuel Use (therms/year)**	29,672	24,889	-4,783	-16%
21	**Fuel Intensity (therms/sf)**	0.29	0.24	0	-17%

Figure 9:

The team validated key building and load parameters to reduce the risk of false positives or false negatives.

Conclusion

Rapid energy modeling has been shown to reduce the time needed for the initial steps of an energy assessment, which can help professionals perform building energy assessments and carbon reduction analysis faster and more economically. A range of stakeholders from building owners and tenants to real estate brokers and financiers stand to benefit from this approach.

Rapid energy modeling can bring down the variable costs associated with energy assessments. This enables large-scale assessments in a short time—leapfrogging traditional modeling methods for energy analysis and building audit techniques, and thus helping the building industry create a low-carbon built environment.