

ASSESSMENT OF FREE ADVANCED MEASUREMENT & VERIFICATION TOOLS

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A detailed look at the ins-and-outs of five freely available tools shows how advanced M&V tools have been evolving over time, adding features to cover gaps and improve the application of the models. These tools have varying degrees of learning curves, depending on the practitioner and the tool. Although some include a user-interface and are relatively straightforward, others require skills in executing software code. Regardless of the tool used, all require an understanding of the underlying statistics and options for evaluating and improving results.

Although some of the model development features are automated¹, most require several judgment-points when developing a model. Decisions may include the type of model, data-increment (e.g., hourly, daily, monthly), and the number of day-types needed to represent the building's load profiles.

Each of the five tools examined (ECAM, RMV2.0, OpenEE Meter, UT3 M&V Module, and NMECR) includes nuances and modifications which are fundamental to their efficacy. Described below and detailed in Table 1 (see Appendix), all of these tools are free, and most are open-source.

ECAM. Currently available through SBW Consulting², this open-source tool is appropriate for M&V of commercial projects. It is accessed via an Excel add-in, which includes a user-interface. The tool accepts 15-minute utility data to create change-point models based on hourly, daily or monthly data. ECAM calculates both avoided energy consumption and normalized savings.

ECAM recommends day-types and develops load shapes to confirm them, accepts annual holiday schedules, allows custom day-types, defined occupancy periods and start-up and shut-down phases. Individual change-point models are developed for each day-type and occupancy mode (e.g., Weekdays-Occ, Weekdays-Unocc, etc.), and then combined into a single model.

RMV2.0. Developed by Berkeley Lab, this open-source tool is appropriate for M&V of residential and commercial projects. It is accessed via R-Studio and includes a user-interface accessible via a web browser. The tool requires

¹ Automated model development routines may lack the acuity of custom analyses due to simplifying assumptions.

² Developed by Bill Koran across multiple organizations.

pre-processed utility data to create TOWT or GBM models based on hourly data. RMV2.0 calculates avoided energy consumption.

RMV2.0 implements the original TOWT model, which includes weighting adjustments intended for demand response models. The Gradient Boost Machine (GBM)³ modeling option is also included in the tool.

OpenEE Meter. Developed by OpenEE/Recurve, this open-source tool is appropriate for EM&V of residential programs. It is accessed via Jupyter Notebook and does not include a user-interface. The tool accepts 15-minute utility data to create either change-point models using custom degree days based on daily or monthly data, or modified TOWT_OpenEE models based on hourly data. OpenEE meter calculates avoided energy consumption.

OpenEE Meter implements the 'CalTRACK Methods' via Python code, including a modified TOWT approach (TOWT_OpenEE) that uses hourly data to create 12 weighted 'monthly' TOWT models, rather than the typical annual modeling approach.

UT3 M&V Module. Added to the PG&E UT3 (Universal Translator) by Quantum Energy Services & Technologies, Inc. (QuEST), this free tool (not open-source) is appropriate for M&V of commercial projects. It is accessed via the UT3 tool's user-interface. The tool accepts 15-minute utility data to create either change-point models based on daily data, or modified TOWT_UT3 models based on hourly or daily data. UT3 M&V Module calculates both avoided energy consumption and normalized savings.

The UT3 M&V Module is part of the UT3 data analysis tool and allows for the filtering of data based on time-of-day or week schedules, or different building operation modes (e.g., Holidays, Summer school). The change-point and modified TOWT (TOWT_UT3) algorithms can be used with sub-hourly, hourly, or daily data and may be modified to produce time-of week only (TOW_UT3) or temperature-only models. Models created for each schedule are combined using a 'Model Assembler'.

NMECR: Developed by kW Engineering, this open-source tool is appropriate for M&V of commercial projects. It is accessed via R-Studio and does not include a user-interface. The tool accepts 15-minute utility data and allows the creation of change-point models based on daily or monthly data, or a modified TOWT model (TOWT_NMECR) using hourly or daily data. NMECR calculates both avoided energy consumption and normalized savings.

Released in November 2019, NMECR provides scripts coded in R to create energy models. NMECR uses indicator variables to describe different operation modes in buildings. The TOWT/TOW_NMECR models allow for the inclusion of additional day-types (e.g., holidays, summer-school), and the weighting factor that was included in RMV2.0 for demand response analysis can be disabled.

³ More information on the GBM model is available through Berkeley Lab and [GitHub](#).

Details of Selected Free Advanced M&V Tools (Unabridged)



See IPMVP's Snapshot on Advanced Measurement & Verification for additional information.

Tool Overview						Savings Type		Energy Data Used			Notes		Industry Data		Tool Features											
Tool	Model Type(s)	Variables & Inputs Used	User Interface	Level of User Adjustments	Equations of Model(s) Shown	Avoided Energy Use	Normalized Savings	Interval Data Accepted	Hourly	Daily	Monthly	Version #, Date	Notes	Best Applications	Owner / web link	Level of Automation (e.g., Portfolio Screening)	Software Used	Code Language	Open Source	NRE detection	Data Coverage Assessment / Limiting	Performance Period Weather Data	Residual Review for Autocorrelation	Model Statistics Provided	Notes	
ECAM	Average	None	Yes	High	Yes	Yes	Yes	Yes	■	■	■	V6r5, 2018	[1] Coefficients are given, but equation form is published elsewhere for change-point models	Commercial	SBW Consulting	Medium	Microsoft Excel	Excel Add-in	Yes	Yes	Yes	Yes	Yes	Yes	Adjusted R ² , Cv(RMSE), NDB (%), other	ECAM is a powerful add-in for Excel that develops load shapes, recommends day-types, accepts annual holiday schedules, allows custom day-types, defined occupancy periods and start-up and shut-down phases, if appropriate. Individual change-point models are developed for each day-type and occupancy mode (e.g., Weekdays-Occ, Weekdays-Unocc, etc.), and then combined into a single model.
	Linear	OA Temperature (or other independent variable); Daily & Annual Schedules			■				■	■																
	Change-point (3P to 6P)	■			■				■																	
RMV2.0	TOWT	OA Temperature	Yes	Low	No	Yes	No	No	■			V1, 2016		Commercial & Industrial	Lawrence Berkeley National Lab	High	R-Studio & Firefox/Safari	R	Yes	Yes	Yes	No	Yes	R ² , Cv(RMSE), NMBE	RMV2.0 was developed by LBNL for DR applications; Time of week and temperature (TOWT) hourly data to create models for high and low use hours and use an indicator variable for each hour of the week; Adjustable data weighting for DR applications.	
	GBM	OA Temperature; Holidays		Medium	No			■			V1, 2017	Gradient Boosting Machine (GBM) method; many modifications can be made to the hyper-parameters; can add vacation days (GBM only).														
OpenEE Meter	Average, linear, and change-point (3-P to 5-P)	OA Temperature	No	High (via code)	Yes [note 1]	Yes	No	Yes		■		v2.8.5, 11/21/2019	[1] Coefficients are given, but equation form is published elsewhere for change-point models; [2] TOWT_OpenEE modifications use CalTRACK methods and create 12 'monthly' TOWT models with data weighting.	Residential	OpenEE Meter / Recurve	High	Jupyter Notebook	Python	Yes	No	Yes	Yes	No	R ² , Cv(RMSE), NMBE and other metrics	OpenEE Meter implements the 'CalTRACK Methods' via Python code and is accessible via Jupyter Notebook; Create either change-point models using custom degree days based on daily or monthly data, or modified TOWT_OpenEE models based on hourly data; the modified TOWT_OpenEE approach uses hourly data to create 12 weighted 'monthly' TOWT models, rather than the typical annual modeling approach. These 'monthly' models help account for seasonal variances in residential buildings.	
	TOWT_OpenEE [note 2]				■																					
UT3 M&V Module	Average	None	Yes	High (via code)	Yes	Yes	Yes	Yes	■	■	■	Universal Translator 3 M&V Module v1, 2014	[1] Coefficients are given, but equation form is published elsewhere for change-point models; [3] TOWT_UT3 modifications allow for filtering based on load profiles, e.g., Holidays, Summer school; TOWT model can be used with daily or hourly data; Models are combined using a 'Model Assembler'	Commercial	kW Engineering / PG&E	Low	Universal Translator (UT)	Microsoft .NET	No	No	No	No	No	Yes	Adjusted R ² , Cv(RMSE), NDB (%), other	Built into the UT3 tool's user-interface, the M&V Module allows for the filtering of data based on time-of-day or week schedules, or different building operation modes (e.g., Holidays, Summer school). The tools creates either change-point models based on daily data, or use modified TOWT_UT3 models with sub-hourly, hourly, or daily data and may be modified to produce time-of-week only (TOW_UT3) or temperature-only models. Models are created for each schedule then combined using a 'Model Assembler'.
	Linear	OA Temperature (or other independent variable)			■				■	■																
	Change-point (3-P to 6-P)	OA Temperature; Daily & Annual Schedules			■				■	■																
	TOWT_UT3 [note 3]				No				■	■																
	TOW_UT3 [note 3]				No				■	■																
NMECR	HDD/CDD	OA Temperature, optional second independent variable	No	High (via code)	Yes	Yes	Yes	Yes			■	Version: 1.0.1, 11/27/2019	[4] TOWT_NMECR modifications allow for filtering based on load profiles (e.g. Holidays, Summer school); Weighting factor for demand response event can be disabled; Automated determination of operating schedules for day-typing	Commercial	kW Engineering	Medium	R and R-Studio (integrated developer environment)	R	Yes	No	Yes	No	Yes	Adjusted R ² , Cv(RMSE), NDBE, MBE, # parameters; Savings Uncertainty	NMECR provides scripts coded in R to create a variety of empirical models. The modified TOWT/TOW_NMECR models uses indicator variables to describe different operation modes in buildings, and the weighting factor that was included in RMV2.0 for demand response analysis can be disabled. Results include key stats for specific model types for easy comparison. Normalized Savings calculations require user savvy to re-run scripts with appropriate data sets; its in R, so anyone knowing R can make adjustments. The user can add additional independent variables, or indicator variables.	
	Linear	OA Temperature (or other independent variable); Daily & Annual Schedules							■	■	■															
	Change-point (3-P to 5-P)	OA Temperature							■	■	■															
	TOWT_NMECR [note 4]	OA Temperature; Annual Schedule (additional day-types, e.g., Holidays)							■	■	■															
	TOW_NMECR [note 4]								■	■	■															

These free and mostly open-source AM&V tools have a variety of features that help complete meter-based savings analyses. Key features that vary between tools include:

- » The user interfaces to facilitate analyses and level of user guidance documents;
- » Data management and visualization tools;
- » Automated analyses of load shapes;
- » Model types included, the complexity of models and the variables/inputs included;
- » Expertise, level judgement, and effort required;
- » Level of automation possible and level of sophistication in automated modeling strategies;
- » Statistical reporting and ease of comparing models;
- » Detail provided on the calculations themselves (the equations);
- » Calculation of both avoided energy and normalized savings;
- » Automated retrieval of ambient temperature data for use in adjustments;
- » Savings tracking capabilities;
- » Identification of periods with unexpected performance and potential non-routine events;
- » The tracking of non-routine events.



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