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M&V for industrial projects: Using Option D

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Learning objectives

Understand M&V methods for "Option D" projects

Examine Option D projects through M&V case studies (real projects, realistic numbers)

Agenda

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Your role in M&V?

- Option D: what is the method, and why use it?
- Industrial case studies:

Oil pipeline	Water treatment plant	Natural gas processing plant

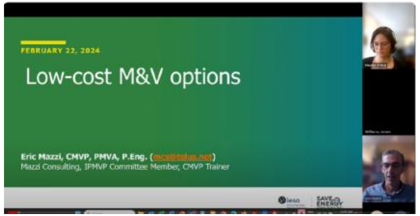
Abbreviations

ASHRAE	American Society of Heating Refrigeration and Air Conditioning Engineers
BPT	Balance Point Temperature
CFM	Cubic Feet per Minute
Cv(RMSE)	Coefficient of Variation of Root Mean Square Error
CUSUM	Cumulative Sum of Differences
DDC	Direct Digital Control system
DHW	Domestic Hot Water
EEM	Energy Efficiency Measure
GAHP	Gas Absorption Heat Pump
GJ	Gigajoule
HDD	Heating Degree Days

IPMVP®	International Performance Measurement and Verification Protocol®
HVAC	Heating, Ventilation and Air Conditioning
KW & kWh	kilowatt(s) & kilowatt-hour(s)
M&V	Measurement & Verification
MBH	M (1,000's) Btu per Hour
MUA	Makeup Air Unit
MURB	Multi-unit Residential Building
OAT	Outdoor Air Temperature
PMVA	Performance M&V Analyst
VFD	Variable Frequency Drive

Fourth and final M&V webinar in this series

- Save on Energy website: https://saveonenergy.ca/Training-and-Support
- [Introduction to M&V]
- [Low-cost M&V options]
- [High-value M&V options for commercial and industrial processes]



Review: important steps when planning M&V

For any M&V, these items **should** be documented in M&V plans:

- Reasons for investing in M&V
- EEM system description and measurement boundary
- Identify key variables that might be needed for adjustments
- Lead M&V professional for the project
- Specific variable(s) to be metered

Continued…

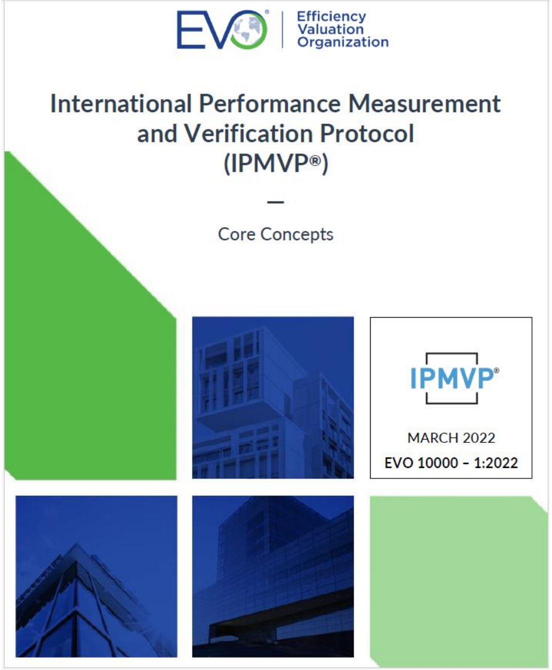
- Site verification
- Analysis description and methodology
- Reporting: who, how, when

Option D: what is the method?

When energy simulation software is used to predict facility or system energy consumption, then IPVMP® classifies this as Option D.

- Simulation software is based on engineering science (physics) equations
- Use of regression (statistical) models is not IPMVP Option D
- Option D may or may not be whole facility. Could be system specific *(see case studies)*

Source: International Performance Measurement and Verification Protocol®, Core Concepts EVO 10000 – 2022:1



Review of Models and Data: How do scientific methods work?

Box 1: Real World Systems

Spatial boundaries
Time boundaries
Social/institutional boundaries

compare

Box 2: Models

Physics equations (e.g. $Q = m\ C_p\ \Delta T$)
Statistical equations (e.g. $E = \alpha + \beta_1\ x_1$)
Visual models (e.g. scaled diagrams)
Computerized (e.g. spreadsheet)
Physical models (e.g. scaled model)

Data used to build models

Box 3: Data

Energy consumption
Pollutant concentrations
Health outcomes (e.g. mortality)
Financial expenditures
Voting outcomes

compare

Box 4: Predictions

Energy consumption
Pollutant concentrations
Health outcomes (e.g. mortality)
Financial expenditures
Voting outcomes

Two types of models used in M&V

1. Engineering science (physics equations) models

$$\frac{p_1}{\gamma} + z_1 + \frac{V_1^2}{2g} - f\frac{L}{D}\frac{V^2}{2g} - K_L\frac{V^2}{2g} + H_{pump} - H_{turbine} = \frac{p_2}{\gamma} + z_2 + \frac{V_2^2}{2g}$$

$$\dot{Q}_{in} + \dot{W}_{in} + \sum_{in}\dot{m}_{in}\left(h_{in} + \frac{V_{in}^2}{2} + gz_{in}\right) = \dot{Q}_{out} + \dot{W}_{out} + \sum_{out}\dot{m}_{out}\left(h_{out} + \frac{V_{out}^2}{2} + gz_{out}\right)$$

Use for new construction projects, or when baseline data are not available

Typically more expensive → must justify the cost

2. Statistical models: linear regression $E = \alpha + \beta_1 x_1 + \text{error}$

Use when: a) Regression model is useful and sufficient to meet M&V objectives

b) To save M&V cost ($)

c) Data are available to produce acceptable regression models

What are “data” in the practice of science?

“Data” are observations of real-world systems. Examples:

- Electricity kW or kWh from a building submeter
- # hours that lighting systems are “on” vs. “off” from a sensor
- # ticket sales per week for a recreation centre from accounting records

“Forecasts” are estimates of parameters using models for the <u>future</u>

It is NOT POSSIBLE to have data for future events

“Estimates” are parameters calculated using models. Estimates could be for past events/processes, or future forecasts.

Two utility bills, only one is real data. How would you find out?

Sample ATCO gas bill

Transactions in effect during January 2019: 3.4523 GJ

Initial Settlement Detail

	Total Volume	Term Volume	Term WAP	Tolerance B
01-Jan-19	2.2891	2.2891	$3.8900	
02-Jan-19	1.7555	1.7555	$3.8900	
03-Jan-19	2.5169	2.5169	$3.8900	
04-Jan-19	3.1343	3.1343	$3.8900	
05-Jan-19	3.2771	3.2771	$3.8900	
06-Jan-19	3.2883	3.2883	$3.8900	
07-Jan-19	3.8789	3.8789	$3.8900	
08-Jan-19	4.3220	4.3220	$3.8900	
09-Jan-19	3.8728	3.8728	$3.8900	
10-Jan-19	3.2777	3.2777	$3.8900	
11-Jan-19	2.6870	2.6870	$3.8900	
12-Jan-19	2.5568	2.5568	$3.8900	
13-Jan-19	3.0709	3.0709	$3.8900	
14-Jan-19	3.4256	3.4256	$3.8900	

Sample Piedmont gas bill

Consumption Customer 1002942858001 xxx

Broker DIRECT ENRG BUS MK

Date	Burned	therms	Btu
01-Jan-2015	61.9	619.0	61,900,000
02-Jan-2015	50.6	506.0	50,600,000
03-Jan-2015	52.6	526.0	52,600,000
04-Jan-2015	56.6	566.0	56,600,000
05-Jan-2015	72.0	720.0	72,000,000
06-Jan-2015	69.9	699.0	69,900,000
07-Jan-2015	95.9	959.0	95,900,000
08-Jan-2015	101.1	1011.0	101,100,000
09-Jan-2015	81.6	816.0	81,600,000
10-Jan-2015	81.5	815.0	81,500,000
11-Jan-2015	67.0	670.0	67,000,000
12-Jan-2015	53.5	535.0	53,500,000
13-Jan-2015	68.0	680.0	68,000,000
14-Jan-2015	67.0	670.0	67,000,000
15-Jan-2015	66.8	668.0	66,800,000

Two utility bills, only one is real data. How to find out:

Sample ATCO gas bill

Transactions in effect during January 2019: 3.4523 GJs @$3.8900

Initial Settlement Detail

	Total Volume	Term Volume	Term WAP	Tolerance Band	Index Volu
01-Jan-19	2.2891	2.2891	$3.8900	100%	
02-Jan-19	1.7555	1.7555	$3.8900	100%	-(
03-Jan-19	2.5169	2.5169	$3.8900	100%	
04-Jan-19	3.1343	3.1343	$3.8900	100%	
05-Jan-19	3.2771	3.2771	$3.8900	100%	
06-Jan-19	3.2883	3.2883	$3.8900	100%	-(
07-Jan-19	3.8789	3.8789	$3.8900	100%	
08-Jan-19	4.3220	4.3220	$3.8900	100%	
09-Jan-19	3.8728	3.8728	$3.8900	100%	(
10-Jan-19	3.2777	3.2777	$3.8900	100%	(
11-Jan-19	2.6870	2.6870	$3.8900	100%	
12-Jan-19	2.5568	2.5568	$3.8900	100%	(
13-Jan-19	3.0709	3.0709	$3.8900	100%	-(
14-Jan-19	3.4256	3.4256	$3.8900	100%	
15-Jan-19	4.1577	4.1577	$3.8900	100%	

1. Regression model of GJ vs. HDD was too perfect.

2. Checked with the utility

"Dear Eric Mazzi, Thank you for your additional email to ATCO Gas. **ATCO Gas reads low and medium use sites monthly**. High use sites that consume more than 8000 GJ/year are read daily or more often. High use sites are the only sites that are billed on 24 hr demand ($/GJ/day)."

The facility consumption was well under 8,000 GJ/yr and no GJ/day charges on the gas bill.

- Monthly gas values are **data**
- Daily gas values are **estimates**

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Two utility bills, only one is real data. How to find out

Sample Piedmont Natural Gas bill

Consumption Customer 1002942858001 xxx

Broker DIRECT ENRG BUS MI

Date	Burned	therms	Btu
01-Jan-2015	61.9	619.0	61,900,000
02-Jan-2015	50.6	506.0	50,600,000
03-Jan-2015	52.6	526.0	52,600,000
04-Jan-2015	56.6	566.0	56,600,000
05-Jan-2015	72.0	720.0	72,000,000
06-Jan-2015	69.9	699.0	69,900,000
07-Jan-2015	95.9	959.0	95,900,000
08-Jan-2015	101.1	1011.0	101,100,000
09-Jan-2015	81.6	816.0	81,600,000
10-Jan-2015	81.5	815.0	81,500,000
11-Jan-2015	67.0	670.0	67,000,000
12-Jan-2015	53.5	535.0	53,500,000
13-Jan-2015	68.0	680.0	68,000,000
14-Jan-2015	67.0	670.0	67,000,000
15-Jan-2015	66.8	668.0	66,800,000

"Good morning Eric Mazzi

Thank you for contacting Piedmont Natural Gas. Our meters are read daily. All of our meter have automatic meter reading devices. "

This message from customer service confirms meters are read daily. These are **data**

When to use Option D?

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How to estabish
hypothetical baselines?

When baseline energy data does not exist:

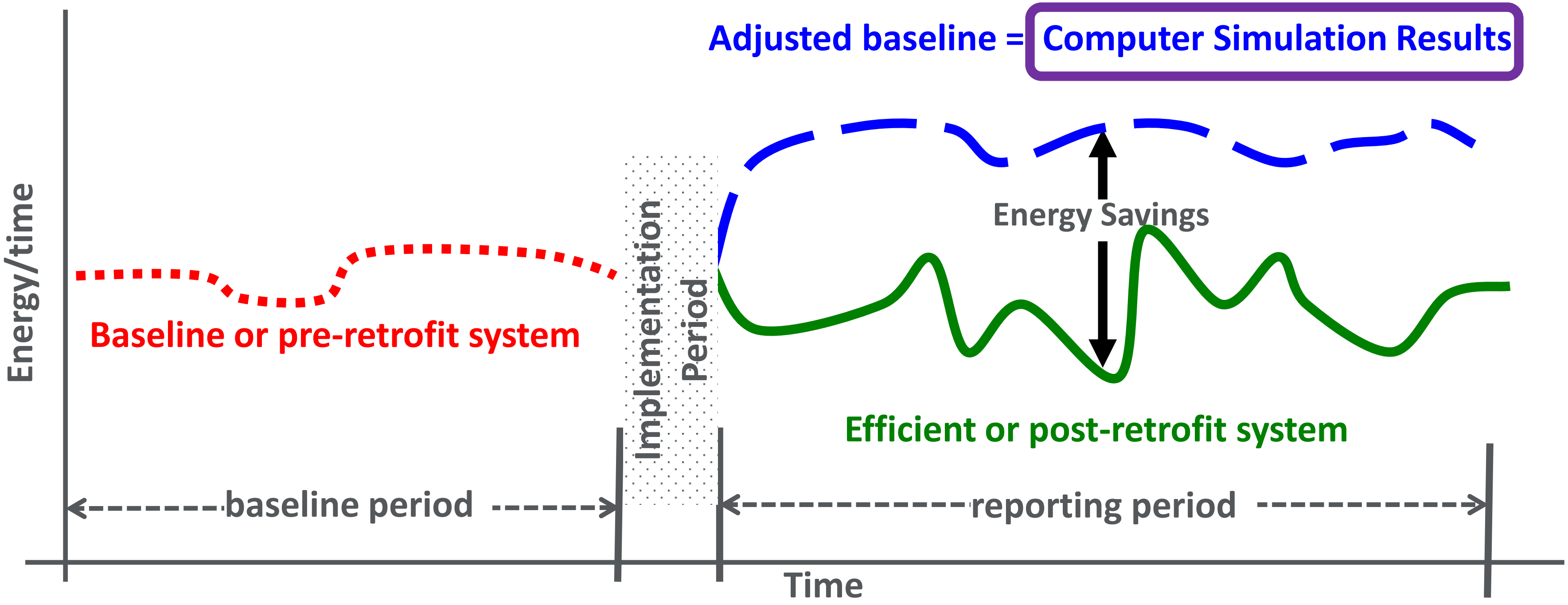
- Retrofit where baseline not metered, or
- New construction which requires a hypothetical baseline.

Retrofit isolation methods are not feasible or too costly.

Multiple EEMs with complex interactions.

Source: International Performance Measurement and Verification Protocol®, Core Concepts EVO 10000 – 2022:1

Option D: energy savings calculation



Source: International Performance Measurement and Verification Protocol®, Core Concepts EVO 10000 – 2022:1

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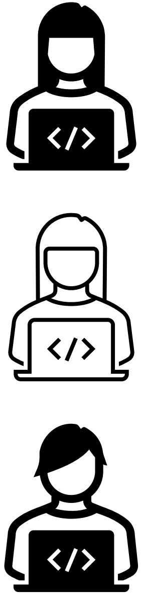
Which industrial applications have you worked on?

Unique issues with industrial Option D M&V

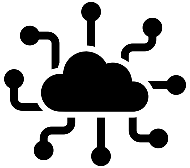
- Wide variety of processes
- Requires specialized process knowledge
- Requires specialized modelling tools & expertise
- Requires M&V expertise

Rarely can process knowledge, modelling expertise, and M&V expertise be found with one person (or even one organization)



Industrial process simulation software examples

- Synergi Pipeline Simulator (previously SPS) www.dnv.com
- Cadsim Chemical Process Simulation Software www.aurelsystems.com
- PIPE-FLO Fluid System Simulation Software https://revalizesoftware.com
- Symmetry process simulation software www.slb.com (Schlumberger)
- IDEAS simulation software for kraft pulp & paper www.Andritz.com
- HYSYS process simulation www.aspentech.com



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Model calibration survey what accuracy?

Model calibration in 7 steps

7 Steps
1. Develop input parameters, confirm assumptions, document sources
2. Gather data for calibration: flows, power, temperature, etc.
3. Run the simulation model
4. Compare simulation energy results to metered energy data
5. Compare model operating parameters to confirm represent actual operation
6. Evaluate consistency of load shapes, examine end-use patterns, and calibration data (e.g. time series, X vs Y scatter plots)
7. As needed, revise model inputs and assumptions, repeat steps 3 to 5 to **bring predicted results within project calibration requirements as documented in the M&V plan**

Source: International Performance Measurement and Verification Protocol®, Core Concepts EVO 10000 – 2022:1

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Sample Option D savings calculation

IPMVP Option D: energy savings calculations

Energy Savings = **Baseline Period Energy from the Calibrated Model updated to Baseline Conditions** − **Reporting Period Energy from the Calibrated Model**

Source: International Performance Measurement and Verification Protocol®, Core Concepts EVO 10000 – 2022:1

Case study #1: new oil pipeline

System and EEM descriptions

New construction EEMs:

- Efficient pumps (~ 75%)
- Variable speed
- High efficiency motor (~ 96.5%)
- High efficiency transformer (~ 96.6%)

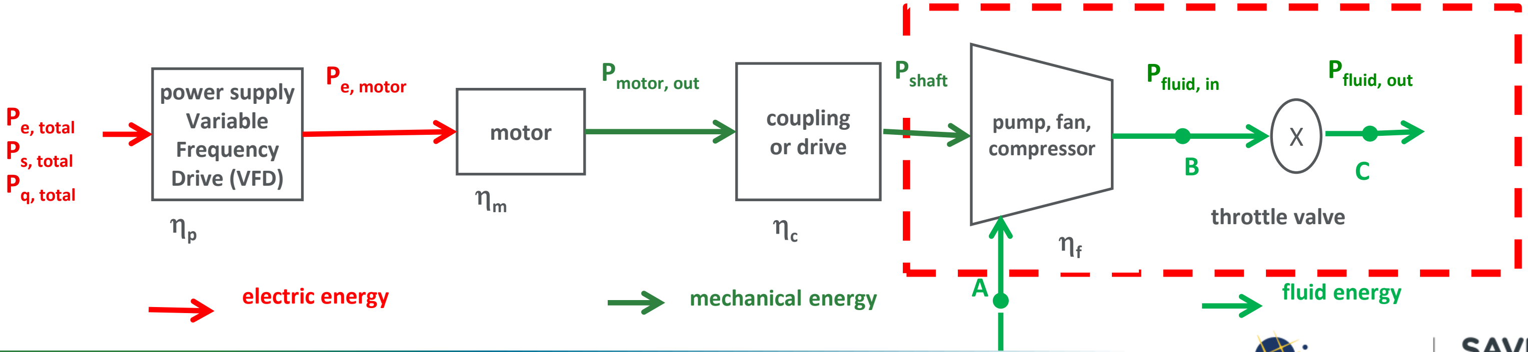
Baseline:

- Standard efficiency pumps (~ 60%)
- Valve control @ fixed speed
- Standard efficiency motor (~ 94.0 %)
- Standard efficiency transformer (~ 96.5%)

image source: pixabay.com

Case study #1: oil pipeline – methodology

- Option D because baseline system never exists. It must be simulated.
- Hydraulics modelled with commercial hydraulic software: Pshaft estimates based on fluid system design, fluid properties, and monthly flow rates.
- Electrical energy savings modelled with spreadsheet calculations using manufacturer specifications for efficiencies: η_p and η_m (assume η_c = 0).
- Savings are total electrical energy savings, combined for all EEMs



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Case study #1: oil pipeline – M&V results

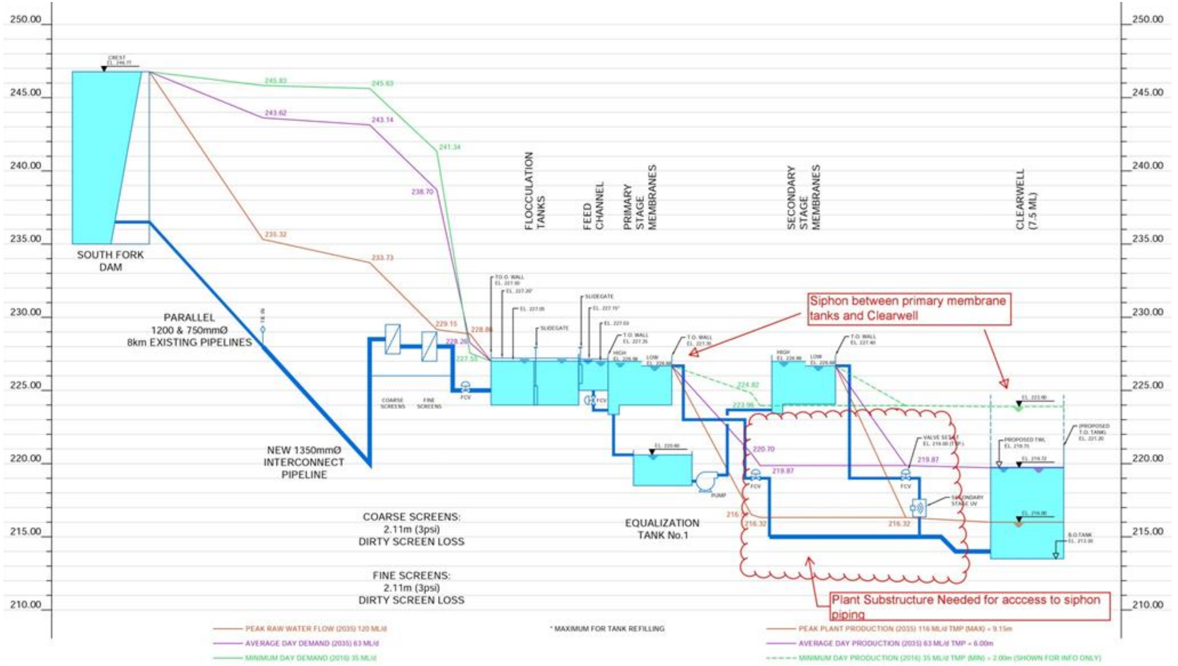
- 12-month reporting period energy measured = 102,500 MWh/yr
- As-built system model (high efficiency): build pipeline model and calibrate to reporting period data. Model predicts 106,600 MWh/yr.
- Model error = 106,600 – 102,500 = + 4,100 MWh/yr
- Baseline model (standard efficiency): modify the model to simulate less efficient equipment that was never installed. Predicts 139,000 MWh/yr for same production.
- Energy savings = adjusted baseline – (efficient + model error)
  = 139,000 – (102,500 + 4,100) = **32,400 MWh/yr**
- IPMVP Equation 10: Savings = 139,000 – 106,600 = = **32,400 MWh/yr**

Case study #2: wastewater treatment plant siphon system

Project description:

- Expansion of an existing wastewater treatment plant
- New water treatment modules / membranes added
- **Baseline**: pumped system
- **EEM**: eliminate pumps, add compressed air injectors

Case study #2: WWTP siphon system – system schematic



Case study #2: WWTP siphon system – methodology

- Option D because baseline system (i.e. pumps) never exists.
- Reporting period:

  Pump energy = 0.0 kWh/yr

  Injector compressor energy spot readings
- Baseline simulated using a standard pumping configuration & fluid mechanics:

  $P_{fluid} = \gamma \dot{V} H_{pump}$ is fluid power (kW) that what would have been produced by pumps

  $P_{electric\ input} = P_{fluid} / (\eta_{motor} * \eta_{pump})$

  $\eta_{motor} = 94\%$

  $\eta_{pump} = 75\%$

Case study #2: WWTP siphon system – methodology

$P_{fluid} = \gamma \dot{\mathcal{V}} H_{pump} / 1{,}000$

P_{fluid} = fluid power added by the pump, kW

γ = specific weight, N/m^3 [$\gamma_{water} = 9{,}810\ N/m^3$]

$\dot{\mathcal{V}}$ = metered volume flow rate of water, m^3/s

H_{pump} = fluid head added by pump, m

Pump head determined using measured pressure loss & equation:

$H_{pump} = \Delta p * 1{,}000 / \gamma$

Δp = pressure loss, kPa

$\gamma_{water} = 9{,}810\ N/m^3$

Case study #2: WWTP siphon system – M&V Results

Energy Savings Calculation Results

ECM	Baseline Average Power kW[a]	Baseline % Hours Operating[b]	Baseline Energy Consumption kWh/yr	Post-retrofit Average Power kW[c]	Post-retrofit hours[d]	Post-retrofit Energy Consumption kWh/yr	Annual Energy Savings kWh/yr[e]
Siphon system	60.9	8,760	533,525	19.9	1,214	24,230	509,000

[a] Baseline energy was calculated using the data and formulas as described in Section 3.2.

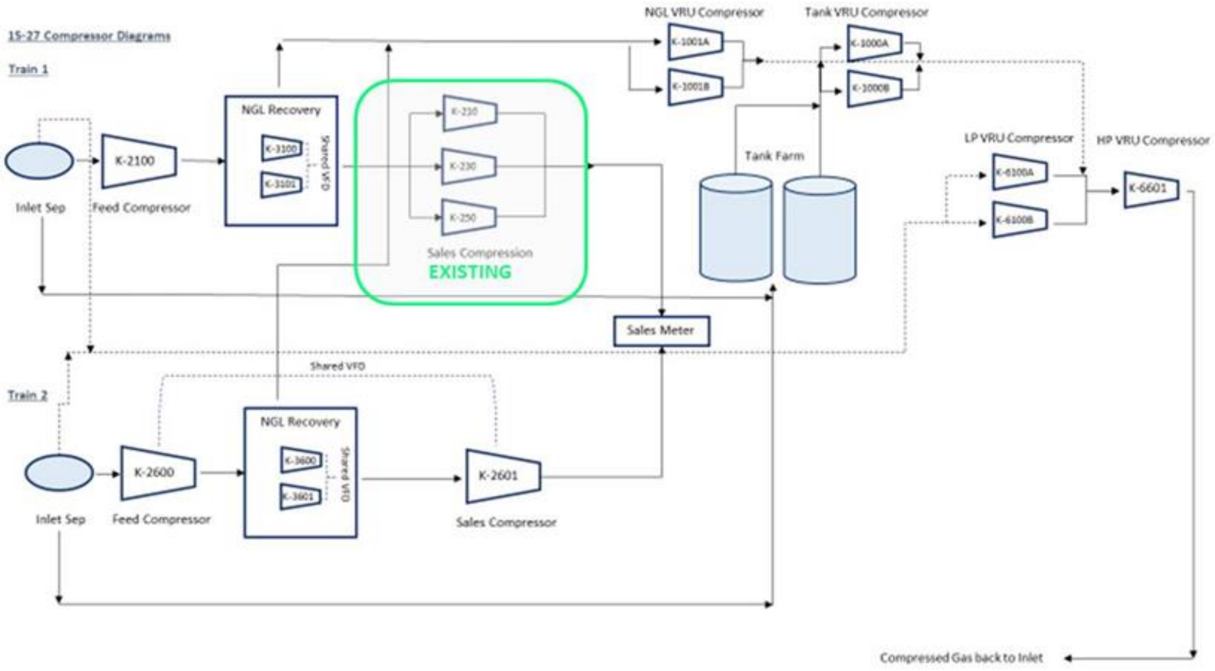
[b] The treatment plant operates 8,760 hours per year

[c] Post-retrofit power includes only the estimated power for the air injectors (two compressors, each 30 hp).

[d] This is the combined annual hours for the two compressors

[e] Total energy savings are rounded to the nearest 1,000 kWh

Case study #3: new natural gas plant – system schematic



Case study #3: new NG plant – EEMs and design parameters

EEM	Equipment	Baseline control	EEM measure	Motor nameplate
1	Feed gas compressor	Single speed, recirculation + valve	Variable frequency drive (VFD)	31,400 hp
3	Recycle gas compressor	Single speed, recirculation + valve	VFD	7,750 hp
5	Vapour recovery unit	Single speed, recirculation + valve	VFD	450 hp
7	High efficiency motor	Least cost technically viable custom motor	Higher cost, higher efficiency custom motor	Multiple motors
8	Large diameter sales pipeline	Small diameter pipe	Large diameter pipe	Saves feed gas motor power

Partial list of EEMs

Case study #3: new NG plant – Methodology

- Option D because baseline system never exists. It must be simulated.
- Hydraulics modelled with Schlumberger software : P_{shaft} estimates based on fluid system design, fluid properties, and flow rates.
- 8,760-hour analysis based on actual production and energy
- Some EEM savings modelled with spreadsheet calculations using manufacturer specifications for efficiencies.
- Savings are determined for individual EEMs

Sample VFD specification

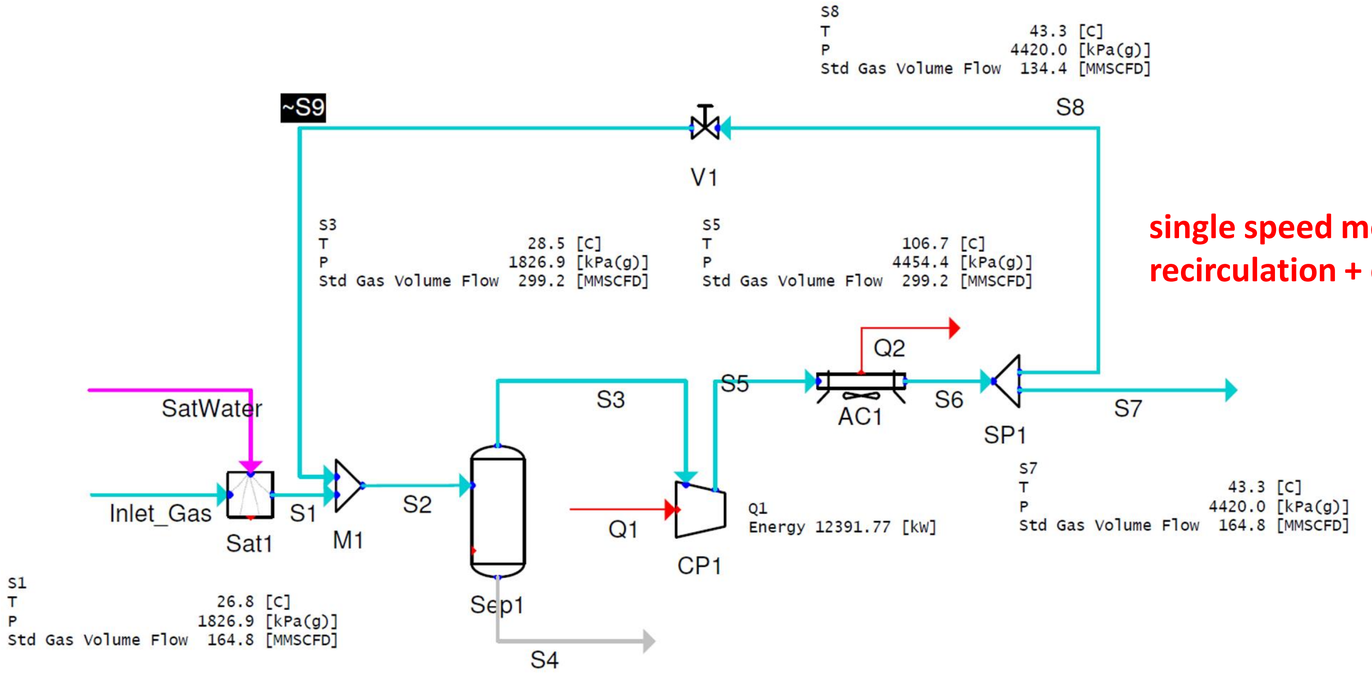
VFD Performance:

☑ Required HP (kW): **31400 (23415)**
☐ Constant Torque ☑ Variable Torque
☑ Required Speed Range: Min: 1136 RPM
☐ Minimum Acceleration Torque: ______

◊ Efficiency

		%Speed			
		25	50	75	100
%Load	25	90	94	96	97
	50		95	96.5	97
	75			96	97
	100				96.5

Case study #3: new NG plant – sample baseline model



single speed motor
recirculation + control valve

Case study #3: new NG plant – M&V Results

EEM	Data bin	Operating hours	Actual power, kW	Modelled actual power, kW	Modelled baseline power, kW	Calibration error, kW (%)	Power savings, kW	Energy savings, kWh
1	A	937	10,085	9,251	12,025	834 (8.3%)	2,774	2,599,238
1	B	2,756	7,242	6,570	11,985	672 (9.3%)	5,415	14,923,740
1	C	4,855	9,367	8,560	11,742	807 (8.6%)	3,182	15,448,610
1	total	8,548						**32,972,000**

EEM #1 only

Case study #3: new NG plant – baseline model dispute

- Owner's consultant model results: 32,971 MWh/yr savings for EEM1
- Utility engineers: argued ~40% lower savings (e.g. ~20,000 MWh/yr for EEM1) and question whether recirculation control is technically viable without compressor surge and/or stalling
- Counting multiple projects in the industrial program and 2-tier rate energy savings claims, **cumulative savings for natural gas VFDs (vs. baseline single speed + control valve) > 500 GWh/yr** (~1% of all of electricity consumption in utility jurisdiction)
- Discussion: what activities would <u>you</u> propose to resolve this dispute?

Industrial Option D M&V: key issues and summary

- Heterogeneity: wide variety of processes, wide variation in scale (e.g. small manufacturing to large plants)

- Need for specialized process knowledge (experienced people): often the process specialist has limited M&V knowledge or training, and vice-versa

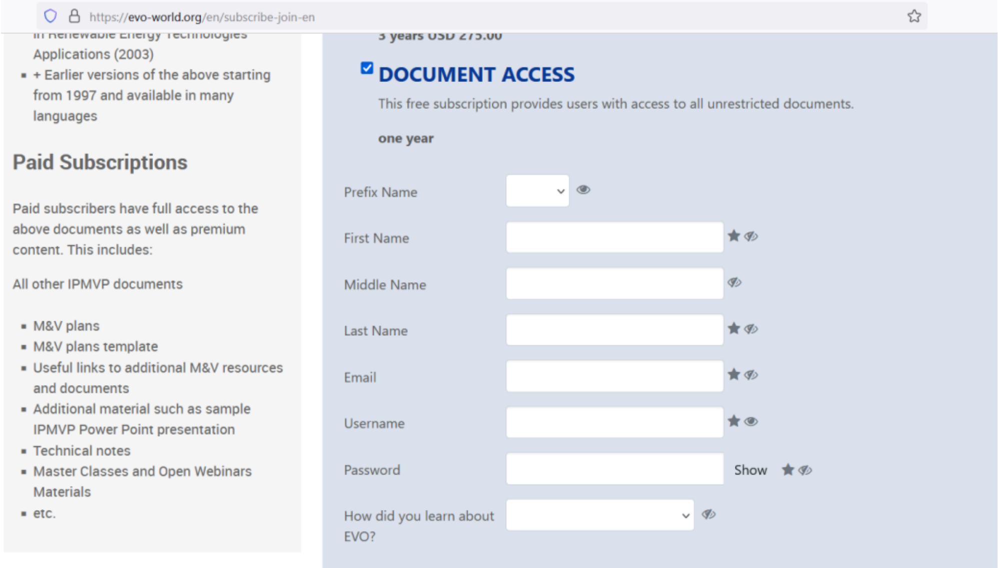
- Simulation Models:
  - Often specialized process models
  - Sometimes basic engineering models / formulas (e.g. fluid mechanics)

Industrial Option D M&V: key issues and summary

- Process and energy metering are critical. Metering requirements are project specific, wide variation of needs.
- Calibration Error and Model Validations: no standard exists for industrial, +/-5% for annual energy has been found to be feasible for complex systems
- Normalized Mean Bias Error (see ASHRAE 14-2023): sometimes feasible (e.g. monthly results), sometimes not clear how (e.g. varied time periods & bins)
- Reliance on simulation ⟶ Disagreement over modelling results can occur

M&V Option D resources

- IPMVP® Core Concepts (2022)
- IPMVP® Uncertainty Assessment Guide (forthcoming early 2025)
- IPMVP® Option D Assessment Guide (forthcoming mid 2025)



Source: https://evo-world.org/en/subscribe-join-en

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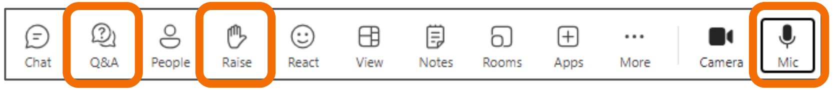
Questions and answers

Post in Q&A window or raise hand and unmute



Stay connected with tools and resources

- Virtual one-on-one coaching: post-webinar support intake form for tailored support for organizations to manage energy resources effectively
- Monthly bulletin: sign up to receive monthly training updates on all Save on Energy training and support new tools and resources
- Live training calendar: visit this page to easily register for upcoming events and workshops
- Training and support webpage: visit this page to access all training and support materials

Thank you!

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