CMVP Capstone Project
Instructor Guide

Greenfield Municipal Center
M&V Plan Development Workbook

Prepared for Steve Kromer

CMVP Course Instructor • Association of Energy Engineers

Contents

1   3-Day Schedule & Timing

Day 1: Context, Boundaries, and Approaches

Time	Activity	Module	Capstone Work	Tools
8:00–8:45	Welcome, scenario intro	0	Distribute paper packets Open capstone site: Overview tab	Paper packet cmvp-capstone.vercel.app
8:45–9:30	Context & stakeholders		Worksheet 1A: Stakeholder & risk matrix	Building graphic on Overview tab
9:30–9:45	Break			
9:45–10:30	Stakeholders cont., risk	2	Complete Worksheet 1A: All 4 risk domains	
10:30–11:15	Approaches, boundaries	3	Worksheet 1B: Boundaries Worksheet 1C: Approach selection	Single line diagram (paper packet)
11:15–11:30	Break			
11:30–12:00	Approach selection cont.	3	Complete Worksheet 1C: Justifications for each ECM	
12:00–1:00	Lunch			
1:00–1:45	Statistics interlude	3.1	Explore Scatter Plots tab Identify patterns in data	Statistics_Exercise.xlsm Descriptive_Stats.xlsx
1:45–2:30	Descriptive stats	3.1	Population sampling exercise Mean, variance, CV	Descriptive_Stats.xlsx
2:30–2:45	Break			
2:45–3:30	Regression concepts	3.1	Scatter plot observations Group discussion: what model?	Least_Squares_Matrix.xlsx Scatter Plots tab
3:30–4:15	Model concepts intro	3.1	Electric & gas scatter review "What type of model fits?"	Scatter Plots tab
4:15–4:30	Break			
4:30–5:00	Day 1 wrap & preview		Review Worksheets 1A–1C Preview Day 2 modeling	

Day 2: Modeling, Baselines, and Adjustments

Time	Activity	Module	Capstone Work	Tools
8:00–8:45	Baseline modeling intro	4	Review baseline data Identify significant parameters	Model Fitting tab
8:45–9:30	Model fitting	5	Auto-Fit 5P model Worksheet 2A: record statistics ■ Teaching Moment: change points	Model Fitting tab
9:30–9:45	Break			
9:45–10:30	Manual model exploration	5	Manual sliders: try 48/63°F Compare R^2 values ■ Teaching Moment: G14 fail	Model Fitting tab

Time	Activity	Module	Capstone Work	Tools
10:30–11:15	Static factors & NRAs	4	Worksheet 2B: static factors NRA protocol design	Time Series tab
11:15–11:30	Break			
11:30–12:00	NRA discovery	4	Time Series tab: find the step change ■ Teaching Moment: NRA discovery	Time Series tab (toggle electric/gas)
12:00–1:00	Lunch			
1:00–1:45	Lighting stipulation	6	Worksheet 2C: fixture inventory Lighting Stipulation tab	Lighting Stipulation tab
1:45–2:30	Interactive effects	6	Compare stipulation vs. model ■ Teaching Moment: interactive effects	Savings Calculator tab
2:30–2:45	Break			
2:45–3:30	VFD analysis	6	VFD Analysis tab: fan law Select each AHU ■ Teaching Moment: cubic relationship	VFD Analysis tab
3:30–4:15	VFD metering plan	6	Worksheet 2D: metering plan What, where, how long, why	OEH_M_V_planning.xlsx
4:15–4:30	Break			
4:30–5:00	Day 2 wrap & preview		Review Worksheets 2A–2D Preview Day 3 plan assembly	

Day 3: Planning, Reporting, and Defense

Time	Activity	Module	Capstone Work	Tools
8:00–8:45	M&V plan assembly	7	Worksheet 3A: plan checklist Confirm all sections present	OEH_M_V_planning.xlsx
8:45–9:30	Metering specifications	8	Finalize metering specs Cost-benefit of M&V	Paper packet
9:30–9:45	Break			
9:45–10:30	Significant digits, rounding	8.1	Sig figs in savings reporting Group exercise	
10:30–11:15	Savings calculation	9	Savings Calculator tab Worksheet 3B: monthly table ■ Teaching Moment: gas increase	Savings Calculator tab
11:15–11:30	Break			
11:30–12:00	NRA adjustment & uncertainty	9	Toggle NRA on/off Fractional savings uncertainty ■ Teaching Moment: NRA revisited	Savings Calculator tab
12:00–1:00	Lunch			
1:00–1:45	Valuation & CO■	9	Apply rates, calculate CO■ Complete Worksheet 3B	Savings Calculator tab (valuation section)
1:45–2:30	Report drafting	9	Exec summary draft Worksheet 3C: defense prep	Paper packet
2:30–2:45	Break			

2:45–3:30	Plan defense presentations	5-minute presentations Peer challenge questions	Paper packet (all worksheets)
3:30–4:15	Defense cont. & discussion	Remaining presentations Instructor challenge questions	
4:15–4:30	Break		
4:30–5:00	Course wrap & exam prep	Final Q&A, domain review Collect packets, evaluations	

2   Teaching Moments Embedded in the Data

Six deliberate teaching moments are built into the Greenfield dataset. Each surfaces a real-world M&V challenge that students must discover and resolve. The prompts in the capstone app point students toward these moments without giving away the answer.

■ 1. Physics vs. Statistics — Change Point Tradeoff

Day 2 AM · Model Fitting tab

What happens: The auto-fit algorithm finds optimal change points at 35/71°F (R^2 = 0.91). These are mathematically optimal but physically unrealistic — no building switches from heating to cooling at 35°F. Students use manual sliders to try 48/63°F and watch R^2 drop to ~0.65.

Facilitation: This is the core professional judgment moment: do you report the model with the best statistics, or the one that makes physical sense? There is no single right answer, but students must justify their choice. Expect 15–20 minutes of group discussion.

■ 2. Gas CV(RMSE) Fails Guideline 14

Day 2 AM · Model Fitting tab

What happens: The gas model CV(RMSE) is ~16.1%, which exceeds the ASHRAE Guideline 14 threshold of 15%. The prompt asks: "Does that mean it's unusable?"

Facilitation: The answer is nuanced. The large constant baseload (DHW, kitchen) compresses the temperature signal. CV(RMSE) punishes models with high baseload-to-weather ratios. Students should discuss whether G14 is a bright line or a guideline, and what additional evidence supports the model.

■ 3. NRA Discovery — The Data Center Expansion

Day 2 late AM · Time Series tab

What happens: Starting in month 8, reporting-period electric consumption jumps ~15,000–19,000 kWh/month above what the model predicts. Students see this as a step change in the Time Series tab.

Facilitation: In the Savings Calculator, months 8–12 show red bars (negative savings). When students toggle the NRA adjustment on, the bars flip green. This is the visceral "aha" — without NRA, the project looks like it failed. With NRA, savings are real. Prompt: what evidence would you need?

■ 4. Interactive Effects — Lighting ≠ Model

Day 2 PM · Lighting Stipulation tab vs. Savings Calculator

What happens: The lighting stipulation calculates ~157,000 kWh saved based on fixture counts and hours. But the whole-facility model shows different total savings.

Facilitation: Why? Less lighting waste heat means less cooling load in summer (good) but more heating load in winter (bad). The whole-facility model captures these interactive effects; the stipulation does not. This motivates the exam topic of interactive effects and why whole-facility and retrofit isolation give different answers.

■ 5. Fan Law Cubic Relationship

Day 2 PM · VFD Analysis tab

What happens: The Speed vs. Power scatter shows the classic cubic fan law. A 35% speed reduction yields ~73% power reduction. Students can toggle between AHUs to see consistent behavior.

Facilitation: This motivates why VFDs are such effective ECMs and why continuous verification (not just pre/post spot measurement) is the right approach. The fan law also explains why small speed errors cause large power errors — a key uncertainty discussion.

■ 6. Gas Went Up — Did the Retrofit Fail?

Day 3 AM · Time Series tab (gas view) + Savings Calculator

What happens: Reporting-year gas consumption is higher than baseline. Students initially think the roof insulation (ECM-3) made things worse.

Facilitation: The model prediction (counterfactual) shows gas would have been even higher without the retrofit — the reporting year simply had colder weather. The purple prediction line sits above the green actual line, confirming positive savings. This is the entire point of counterfactual thinking.

3   Module-by-Module Facilitation Notes

Module 0: Introduction   *Day 1 AM*
• Distribute paper packets — have students write name on cover
• Project the capstone site Overview tab on screen
• Walk through the building graphic: 4 wings, HVAC assignments, ECM markers
• Emphasize this is an ESPC contract — savings are contractual obligations
• Ask: "Who are the stakeholders? What does each one care about?"

Modules 1–2: Context & Stakeholders   *Day 1 AM*
• Worksheet 1A: stakeholder matrix. Students fill in interests and risks
• Cover all 4 risk domains: technical, commercial, legal, regulatory
• Discussion prompt: "What happens if M&V shows zero savings?"
• Domain 9 (Contextual Considerations) — this is where it gets tested

Module 3: Approaches & Boundaries   *Day 1 late AM*
• Worksheet 1B: measurement boundaries on single line diagram (paper packet)
• Worksheet 1C: approach selection for each ECM with justification
• Key decision: ECM-2 (chiller) — whole facility or retrofit isolation? Both are defensible
• ECM-1 lighting: stipulated hours or metered? Cost vs. accuracy tradeoff
• Domain 2 (Fundamental Approaches) — this is the primary touchpoint

Interlude 3.1: Statistics Refresher   *Day 1 PM*
• Open Statistics_Exercise.xlsm — population simulation, sampling, CV
• Open Descriptive_Stats_Step_1.xlsx — fixture wattage sampling exercise
• Then move to capstone Scatter Plots tab — "What do you see?"
• Optional: Least_Squares_Matrix_Formula.xlsx for advanced students
• Purpose: build vocabulary (R², CV(RMSE), NMBE) before Day 2 modeling

Modules 4–5: Baseline Modeling   *Day 2 AM*
• Model Fitting tab — students click Auto-Fit, record statistics in Worksheet 2A
• Then use manual sliders to explore alternative change points
• ■ **Teaching Moment 1: physics vs. statistics tradeoff**
• ■ **Teaching Moment 2: gas CV(RMSE) fails G14**
• Worksheet 2B: static factors inventory, NRA protocol
• Time Series tab: switch to gas view, then electric — find the NRA
• ■ **Teaching Moment 3: NRA discovery**
• Domain 4 (Whole Facility) + Domain 8 (Modeling) + Domain 1 (Adjustments)

Module 6: Retrofit Isolation   *Day 2 PM*
• Lighting Stipulation tab — students verify 740 fixtures, edit hours, check totals vs. Worksheet 2C
• ■ **Teaching Moment 4: stipulation total ≠ whole-facility model savings**

• VFD Analysis tab — select each AHU, observe fan law cubic

• ■ **Teaching Moment 5: fan law cubic relationship**

• Worksheet 2D: design the VFD metering plan (what, where, how long, why)

• Domain 3 (Retrofit Isolation) + Domain 7 (Metering)

Modules 7–8: M&V Planning & Metering   *Day 3 AM*

• Worksheet 3A: M&V plan assembly checklist — confirm all sections present

• OEH_M_V_planning_tool.xlsx: show the professional template (9 tabs)

• Discuss significant digits and rounding (Module 8.1)

• Discuss metering cost-benefit: how much M&V is enough?

• Domain 5 (M&V Planning) + Domain 7 (Metering)

Module 9: Savings & Reporting   *Day 3 mid-AM*

• Savings Calculator tab — students record monthly savings in Worksheet 3B

• ■ **Teaching Moment 3 revisited: toggle NRA on/off, see bars flip**

• ■ **Teaching Moment 6: gas went up — did the retrofit fail?**

• Valuation section: apply rates ($0.105/kWh, $1.15/therm), calculate CO■

• Fractional savings uncertainty at 90% confidence

• Domain 6 (Savings Reporting)

Module 9 cont.: Defense   *Day 3 PM*

• Worksheet 3C: prepare 5-minute presentation (4 sections)

• Each student presents; peers ask one challenge question

• Instructor challenges: "Why did you pick that change point?" "What if the data center expansion happened in month 3 instead?" "How would you explain negative gas savings to the county manager?"

• This is exam prep — every question maps to a domain

4   Answer Scaffolding

The capstone is designed with no single right answer — professional judgment is the point. Below are **defensible ranges** and key points to look for, not answer keys.

Worksheet	Key Points to Look For
1A: Stakeholders	At least 4 stakeholders identified. Risk domains should include all 4 (T/C/L/R). County owner cares about budget certainty; ESCO cares about performance guarantee.
1B: Boundaries	ECM-1 boundary at lighting circuits (Wings A & B). ECM-4 at individual AHU. Whole-facility boundary = utility meter. Students should note fuels: electric for all, gas for ECM-3.
1C: Approaches	ECM-1: retrofit isolation / stipulated is standard. Some may argue for measured hours. ECM-2: either whole facility or retrofit isolation — both defensible with justification. ECM-3: whole facility (no way to isolate envelope). ECM-4: retrofit isolation / measured.
2A: Baseline	Electric 5P model. Change points: 35–50°F (heating), 63–71°F (cooling). R^2 range: 0.65–0.91 depending on change points chosen. NMBE should be near 0. Gas model: 3P or 5P. CV(RMSE) around 16% — above G14 but defensible.
2B: Static Factors	At least: occupancy, operating schedule, data center load, conditioned area. NRA trigger for data center: server count or IT load exceeds baseline +/- threshold.
2C: Lighting	Total: ~157,000 kWh/yr (740 fixtures × ΔW × hours). Should match app calculation. Key judgment: annual hours per space. Students should cite building schedule as basis.
2D: VFD Metering	Fan motor kW, speed (Hz or %), airflow (CFM), supply air temp. Pre-retrofit period: at least 2 weeks covering range of operating conditions. Meter types: CT-based power meter, VFD internal readout, pitot traverse or anemometer.
3A: Plan Checklist	All 9 boxes checked. Schedule should show quarterly reporting. Budget for M&V should be 3–5% of project cost (industry rule of thumb).
3B: Savings	With NRA: positive savings all 12 months. Without NRA: negative months 8–12. Total electric savings (with NRA): approximately 400,000–500,000 kWh/yr. CO_2 reduction: roughly 170–210 tonnes/yr (depends on NRA magnitude chosen).
3C: Defense	Students should articulate: why this approach, how good the model is, what the NRA means, and what the final savings and uncertainty are. Challenge question readiness: at least 2 prepared responses.

5   Companion Tools & Interactive Sites

Interactive Web Applications

Resource	Description
CMVP Capstone	This capstone — 7-tab workbench for Greenfield Municipal Center
Counterfactual Designs	Full course: fundamentals, workbench, case studies, Bayesian intro
IPMVP Translation	IPMVP-aligned M&V; course with terminology crosswalk
Learning Path	Progress tracker across all modules and sites
Central Hub	Landing page linking all resources

Companion Spreadsheets (distribute electronically)

Resource	Description
Statistics_Exercise.xlsm	Population simulation, sampling, CV, sample size calculator. Day 1 PM.
Descriptive_Stats_Step_1.xlsx	Fixture wattage sampling → mean, variance, CV. Day 1 PM.
Least_Squares_Matrix_Formula.xlsx	OLS matrix algebra walkthrough (X'X, β). Day 1 PM.
OEH_M_V_planning_tool.xlsx	Professional M&V; plan template (9 tabs). Australian OEH format.

Reference Documents

Resource	Description
CMVP Exam Scheme v1.2	9 domains, task weights, exam specifications. Open-book reference.
CMVP Body of Knowledge v1.2.1	Study guide topics and references for all 9 domains.
IPMVP Core Concepts (2022)	Free download from EVO. The foundational protocol.
ASHRAE Guideline 14-2023	Measurement of Energy, Demand, and Water Savings. G14 criteria.
Steve Kromer, The Role of the M&V; Professional	River Publishers, 2024. Course textbook.

Appendix A   Curated Web Links by Topic

The following links are organized by topic for use as supplemental references during the course or for student self-study after the training.

Energy Efficiency & Building Performance

Resource	Description
Power of Existing Buildings	Book on improving building efficiency (Amazon)
Liftoff Energy — VPP	Virtual power plant resources and utility strategies
Building Energy Score	DOE energy performance scoring tool
ACEEE 2024 Summer Study	Energy efficiency in buildings research
GHG Protocol	Greenhouse gas accounting standards
WattTime — Methodology	Energy data science methodology validation
MRETS Tracking	Renewable energy certificate tracking
FlexValue (Recurve)	Energy efficiency valuation platform
DOE Life Cycle Cost	FEMP building life cycle costing tools
WattCarbon Blog	Energy and carbon market insights
RETScreen (NRCan)	Clean energy project analysis tool

Statistics, Data Analysis & Modeling

Resource	Description
Khan Academy — Statistics	Free educational resource for stats fundamentals
LINEST Function (Excel)	Excel regression function — used in multiple exercises
TINV Function (Excel)	Student-t inverse for confidence intervals
Coefficient of Determination	R^2 explanation (Wikipedia)
Google CausalImpact	Bayesian causal inference tool for time series
scikit-learn	Python machine learning library
Spurious Correlations	Humorous examples — great for teaching correlation ≠ causation
Reimagine Energy — Code Tutorial	Energy-related coding tutorials
Chong — Calibration Models	Calibrating simulation models for M&V; (academic paper)

Environmental Standards & ESG

Resource	Description
ISO 14064 — GHG Verification	Greenhouse gas inventory verification standard

| ASHRAE Standards | Read-only versions of ASHRAE standards |
| GRESB Benchmark | Real estate sustainability benchmarking |

Building Design & Engineering Tools

Resource	Description
Carbon Craft Design	Sustainable design solutions
Engineering Toolbox	Engineering calculations reference
IBPSA BEST Directory	Building performance simulation tools
SkySpark for M&V	Applying SkySpark for IPMVP-based M&V;
IES VE — Eaton House	Digital twin / building simulation case study
DOE Tools (ORNL)	Department of Energy modeling tools

Measurement & Verification Resources

Resource	Description
BPA M&V Sampling Guide	Bonneville Power sampling reference
CEDMC EM&V Forum	California energy measurement & verification forum

Weather & Climate Data

Resource	Description
OpenWeatherMap API	Weather data API for energy calculations
DegreeDays.net	Degree day calculations for M&V;

Energy Markets & Grid

Resource	Description
CAISO Today's Outlook	California ISO daily supply and demand
CAISO Prices	Real-time California energy prices
Grid Status Live	Live grid conditions across US ISOs
AI Surge & Coal Plants	AI data center energy demand impact

Educational Resources & Professional Networks

Resource	Description
Bloom's Taxonomy	Learning framework (Vanderbilt)
River Publishers eLibrary	Academic resource library
RMI Energy Modeling Summit	Building energy modeling pre-read

| CMVP LinkedIn Group | Professional networking for CMVPs |
| Adrien Devriendt (LinkedIn) | Energy M&V; thought leader |

Research Methodology & Video Content

Resource	Description
COS Preregistration	Research preregistration initiative
Royal Society — Preregistration	Preregistration in science event
Phil Price — "Everything..."	M&V; video presentation (Vimeo)
Andrej Karpathy	AI/data science video channel
Facility Condition Assessment	Overview of facility assessment methods