M&V Fundamentals

& the
International Performance Measurement and Verification Protocol

For Energy Managers

Introduction

Your Instructor

- Sandeep Dahiya from India
- BE (Mechanical) + MBA
- Have a *Corporate Work Experience* of 15 years with Alfa Laval, Thermax & York
- Am *Self Employed* since Aug'14 and my work is improving Operational Efficiency of HVAC Systems in Existing Buildings **(RCx)**
- This is my 8th CMVP Workshop as a Trainer

Introduction 2

How About You?

- Tell us about your activities related to:
  - energy costs and budgets
  - energy management retrofit projects
  - M&V:
    - your experience
    - your expectations of this course

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Course - Agenda

1. Introduction
2. Key Concepts
3. Short Examples
4. M&V Planning
5. Critical Issues
6. Statistics
7. Retrofit Isolation Details
8. Option C Details
9. Option D Details
10. Other M&V applications
11. Summary and review of a detailed M&V plan

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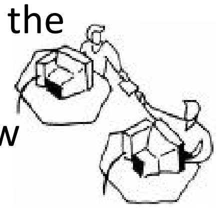
Course - Benefits

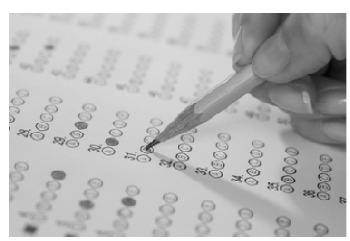
- EVO Certificate of Attendance upon request
- Access to Subscriber Section of EVO website for one year
- Ability to ask your tutor questions on the Protocol
- Ability to share experience with fellow colleagues



Course - Exam

A four-hour CMVP Exam will follow the training on the 3rd day:

- Open book exam: you will have access to the printed copies of the IPMVP and presentations
- 107 questions, multiple choices
- 6 points each, some at 18 points each marked with a *
- Need 70% to pass
- No mark-off for wrong answers
- You only need a basic calculator. Scientific calculator are allowed.
- No telephone, computer or other electronic devices will be allowed.



Introduction - Agenda

- Definition and context of M&V
- Introduction to:
  - EVO
  - IPMVP
- Purpose of M&V

Introduction 7

What is M&V?

"Measurement & Verification (M&V) is the process of using measurements to reliably determine actual saving created within an individual facility by an energy management program."

Ref: IPMVP Core Concepts 2014, Chapter 3, 3.5

Introduction 8

Context of M&V

- M&V is usually used whenever the savings need to be verified, such as in:
  - EE project
  - EPCs
  - Regulated EE programs
  - When an owner wants this verification for internal accounting purposes, etc.
- M&V is also part of good energy management

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Fundamentals Course

- We focus on Fundamentals, so you can follow the evolving complex art and science of M&V.
- It only dusts the topics of metering and statistics.
- Your job is to Ask Questions.
- The Instructor will answer complex questions, possibly deferring some until a break.

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EVO®

- Efficiency Valuation Organization (EVO)
  www.evo-world.org
  - The home of the IPMVP
  - A non-profit U.S. corporation
  - Led by volunteers around the world

Introduction 11

IPMVP® - Overview

- Presents a framework and defines terms used in determining ‘savings’ after implementation of a project.
- Specifies the topics to be addressed in an M&V Plan for a specific project.
- Allows flexibility in creating M&V Plans while adhering to the principles of accuracy, completeness, conservativeness, consistency, relevance and transparency.

Introduction 12

IPMVP - Benefits

- Defines standard approaches to "measuring" and "savings calculation" to reassure facility owners.
- Legitimizes ESCO projects through international recognition of the payment through the savings.
- Provides guidance on the trade-off between measurement "accuracy" and measurement cost.
- Helps parties to create transparent, repeatable performance contract terms and emission trades regarding savings settlement.
- Provides general, not specific guidance, and a framework under which specific methodologies are created and used.

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Performance Contracts

- M&V plays a critical role in performance contracts:
  - maximizes the savings and the persistence of savings over the contract term (when long-term M&V is used)
  - documents what savings were achieved and acts as the "cash register" for the exchange of value
- Performance contracts allocate the costs and benefits of M&V accuracy between the ESCO and Owner.
- Carefully consider contract motivations of all parties before designing the M&V. Append the M&V Plan to the contract.

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Energy Management - ISO 50001

- Establishes a framework to manage energy for industrial commercial, institutional or governmental facilities, enabling them to:
  - Develop a policy for more efficient use of energy
  - Fix targets and objectives to meet the policy
  - Use data to better understand and make decisions concerning energy use and consumption
  - Measure the results
  - Review the effectiveness of the policy
  - Continually improve energy management.
- Can be implemented individually or integrated with other management system standards.

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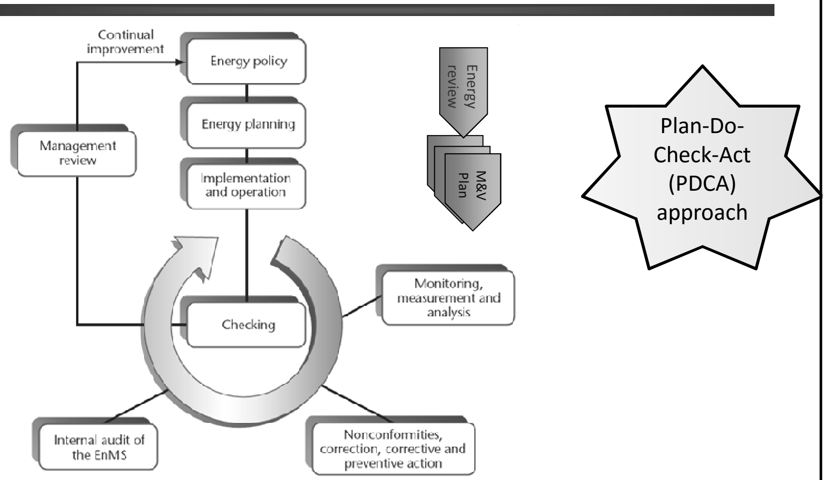
Energy Management - ISO 50001



Introduction 16

IPMVP Is Not Everything

- IPMVP does NOT cover in detail:
  - Design of EE measures
  - Design of meter and instrumentation systems
  - Cost estimating of M&V activities
  - Energy engineering
  - Statistical analysis
- IPMVP is NOT a Cookbook
  - It still needs careful application to each project.

Purposes of M&V

- Increase Energy Savings
- Document financial transactions
- Ultimately enhance financing for efficiency projects
- Improve design, operations and maintenance
- Account for variances from the utility budget
- Support evaluation of efficiency programs
- Educate facility users about their energy impacts
- Improve score in Green Building Certifications or Sustainability rating systems such as LEED (Leadership in Energy & Environmental Design).

The Purpose of M&V

Simply

M&V provides

PROOF

of the effectiveness of energy management

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Next Topic

1. Introduction
2. **Key Concepts**
3. Short Examples
4. M&V Planning
5. Critical Issues
6. Statistics
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8. Option C Details
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M&V Fundamentals

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International Performance Measurement and Verification Protocol

For Energy Managers

Key Concepts

Key Concepts - Program

- Measurement?
- IPMVP's basic equation
- Adjustments of savings
- Four options
- M&V cost
- Short intro on statistics

The “M” in M&V

The **M** in M&V stands for:

Measurement

Not *Monitoring*

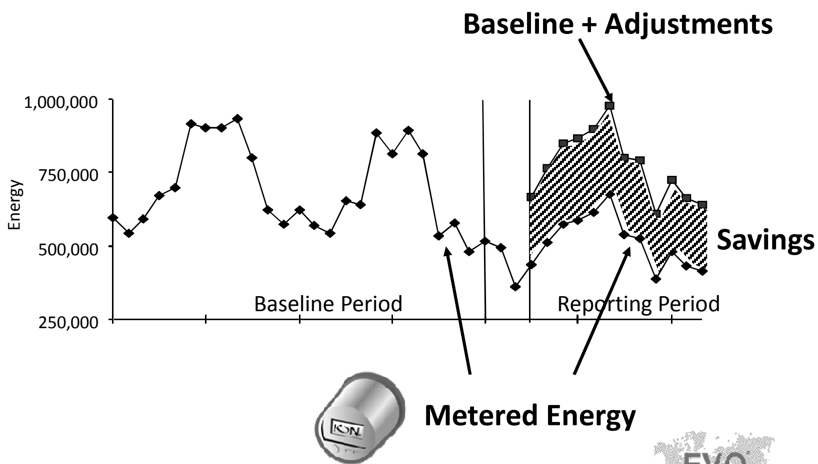
(Monitoring is a separate activity from the determination of savings. It is the process of observing energy use for prediction, cost-control and diagnostic purposes.)

Measure Savings?

- Savings are the absence of energy use.
- We can *not* measure what we do not have.
- We do ***not*** ‘measure’ savings!

- We ***do*** measure energy use.
- We *analyze* measured energy use to **determine** savings.

A Notional Baseline



Key Concepts 5

IPMVP Basic Equation

The Basic IPMVP Savings Equation #1:

Savings reported for any period

= Baseline Period energy

- Reporting Period energy

+/- Adjustments

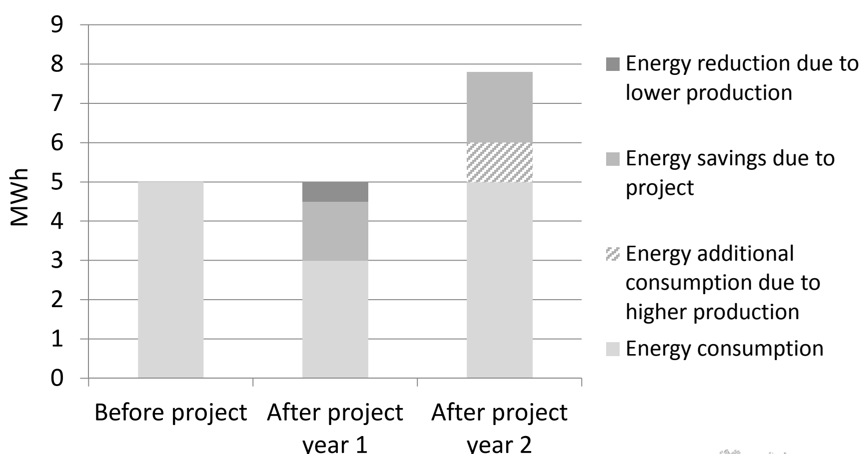
Key Concepts 6

Adjustments

- An example of why we need Adjustments:
  - An energy retrofit was performed but plant *production was also lower* this year than last.
  - How much of the resultant cost reduction was due to the retrofit and how much was due to the production change?

Key Concepts 7

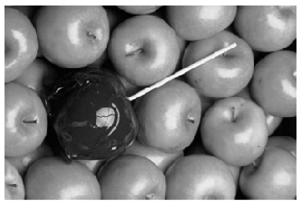
Adjustments – an example

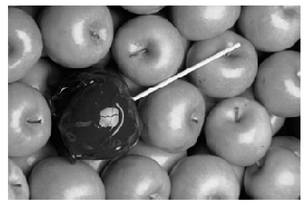


Key Concepts 8

Adjustments (continued)

Performance measurement requires an **“apples to apples”** comparison.





Baseline Period Reporting Period

We adjust baseline and reporting period energy use to the **same** set of conditions for valid comparisons.

Key Concepts 9

Adjustments

- The Adjustments can be trivial, simple or complex.
- They can consist of engineering calculations.
- The extent of the Adjustments depends on:
  - the need for accuracy,
  - the complexity of factors driving energy use,
  - the amount of equipment having its performance assessed (i.e. ‘measurement boundary’), and
  - the available budget.

Key Concepts 10

Savings?

What do you mean when you say Savings?

Key Concepts 11

'Savings' or 'Avoidance'?

- Energy users *usually* want to know how much their bills **would have been** if they had not taken energy efficiency action. They want to know how much energy or cost they **avoided**.
- To report **avoided cost**, M&V engineers ***adjust*** baseline period energy use to the conditions of the reporting period. They sometimes simply call cost avoidance 'savings' at risk of confusion with accounting terminology.

Ref: IPMVP Core Concepts 2014, Chapter 5.3.3

Key Concepts 12

Accounting Savings

Accountants often use the word 'savings' to describe 'cost reductions.' They make **no adjustments**.

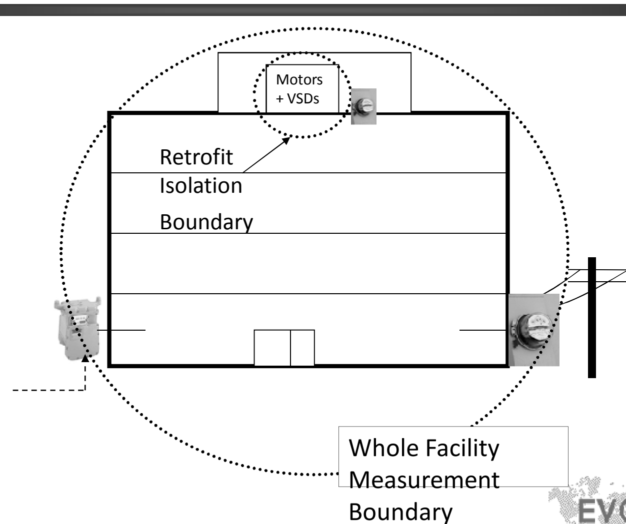
So, when talking about 'savings' we **have to be very careful to explain our meaning**.

We must report the common set of conditions (apples) we are using for stating "savings."

Key Concepts 13

How Much to Measure?

Setting the boundary



Key Concepts 14

Two Basic Methods

Whole Facility Method:
Measures **all** effects in the facility:

- Retrofits AND other changes (intended and **un**intended)
- Often uses the utility meter
- Adjustments can be complex

Retrofit Isolation Method:
Measures the effect of the retrofit, **only**

- Savings are unaffected by changes beyond the measurement boundary
- Usually requires a dedicated meter
- Adjustments can be simple

Selecting a Method

Decide what you are concerned about!

If you want to manage your **total** energy use:

- select the Whole Facility Method.

If you want to assess a particular **retrofit**:

- select the Retrofit Isolation Method.

Terminology

- Retrofit Isolation – Option A or B (and D)
- Whole Facility – Option C or D

Two flavours of each method – to allow flexibility for various situations

Key Concepts 17

Retrofit Isolation

Select between Options A and B:

Option A – Retrofit Isolation: Key Parameter Measurement

Option B – Retrofit Isolation: All Parameter Measurement

Key Concepts 18

Retrofit Isolation (continued)

Option A (called Retrofit Isolation: Key Parameter Measurement) allows a **possible reduction in measurement cost**, but **introduces some uncertainty** in the estimated quantity.

All parties must accept the uncertainty associated with the estimate.

The choice between Options A and B allows flexibility to suit the situation.

Key Concepts 19

Whole Facility

Select Option C or D, based data availability:

C – Whole Facility

Need both baseline and reporting period data

D – Calibrated Simulation

When there is no meter (or facility to meter) in the baseline, baseline data can be 'manufactured' under controlled circumstances.

Key Concepts 20

The M&V Cost

M&V Cost

Key factors affecting M&V Cost:

- Meter quality
- Number of independent variables to be monitored
- Frequency of measurement and reporting
- Length of the baseline and reporting periods
- Sample size, if all equipment is not measured
- Other uses for meter information, to share costs
- Skill levels required

M&V Cost vs. Uncertainty

There is no *absolutely* correct savings number. There is always some uncertainty.

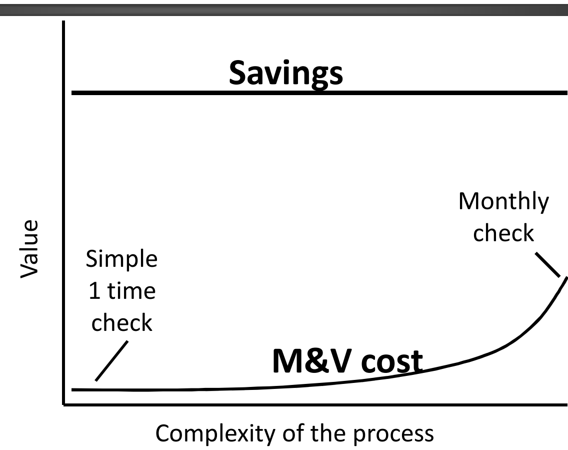
Decide how much uncertainty can you accept or afford.

Each owner finds its own balance between reporting uncertainty and cost for each project.

Ref: IPMVP Core Concepts 2014, Chapter 7.11

Key Concepts 23

Limits to M&V Cost



So how much is enough?

Key Concepts 24

How Much M&V Is Enough?

- Total annual cost to determine savings should normally be less than 10% of the annual savings. This maximum might be exceeded for special situations.
- 3-5% is a more common expenditure (for ESCO projects)
- 0% is often chosen (= “deemed savings”). No measurement means uncertain savings. This is NOT an IPMVP method
- The cost/accuracy tradeoff is made for each project

Key Concepts 25

Very short intro to Statistics

Statistics and Uncertainty for IPMVP 1:2014

Why bother ?

Consider IPMVP's equation 1a :

Savings = (Baseline energy - Reporting-Period energy)
+/- Routine adjustments
+/- Non-Routine adjustments

- **Baseline energy + Routine adjustments** may be derived from baseline data using various ***modeling*** techniques.
- **Baseline energy** data may be ***sampled*** in order to minimize costs.
- **Savings** are calculated from measured data. By nature this data cannot be absolutely accurate, there always is a ***measurement uncertainty***.

IPMVP Core Concepts 2014, Chapter 5, 5.3.3

Modeling

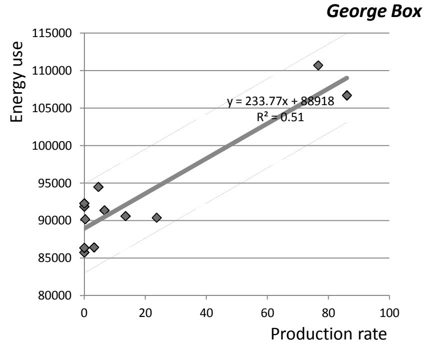
We build models to help us predict the Energy use we would have had without the ECM put in place.

We may not have a defined theory relating energy consumption to certain.

But we may observe *a relationship* between energy use and the variation of a production rate for example, leading us to conjecture an *empirical model* of how Energy use is driven by production rate.

All models are wrong, some models are useful.

George Box



This sort of question is answered by the statistical technique of *regression analysis. We will later address some useful aspects of this technique in a chapter of the Statistics module and describe tools that may help.*

Statistics and Uncertainty for IPMVP 1:2014, Chapter 2

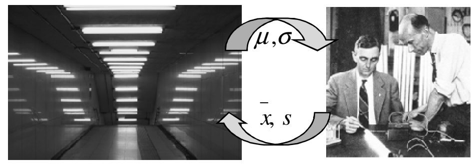
Sampling

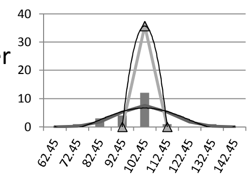
Establishing a Baseline energy use:

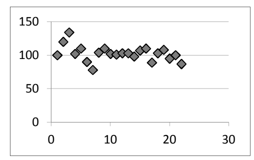
Let us consider the measurement of the power draw of 1288 identical fluorescent lamps in a building.

Shall we measure individually all the lamps?

Is there a way to limit the number of measurements to a small sample without increasing the uncertainty of our assessment beyond some acceptable limits?







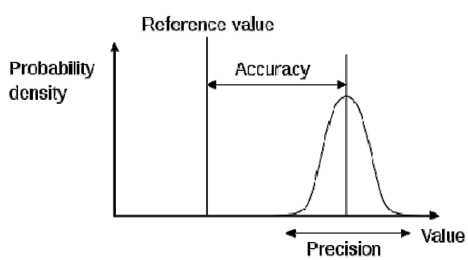
This sort of question is answered by the statistical technique of *sampling analysis. We will later address some useful aspects of this technique in a chapter of the Statistics module, and describe tools and method that may help.*

Key Concepts 29 ***Statistics and Uncertainty for IPMVP 1:2014, Chapter 3***

Metering uncertainty

There is no “true” value meter. Any device used to measure is prone to some uncertainties.

Resolution, Precision and Accuracy (plus reading error) are the most common influential factors.



We will later address these errors in a chapter of the Statistics module and describe tools and method that may help.

Key Concepts 30 ***Statistics and Uncertainty for IPMVP 1:2014, Chapter 4***

Savings determination uncertainty

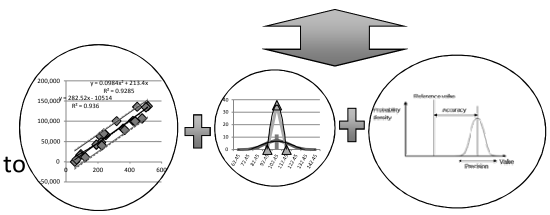
Measurement uncertainty comprises, in general, many components.

We usually consider:

- *model uncertainty*
- *sampling uncertainty*
- *metering uncertainty*

as the major contributors to the overall savings determination uncertainty.

Savings = (Baseline energy - Reporting-Period energy)
+/- Routine adjustments
+/- Non-Routine adjustments



This sort of question is answered by a technique which allows to combine uncertainty elements and propagate the probability distribution of the elements through the Savings equation. We will later address some useful aspects of this technique in a chapter of the Statistics module and describe tools and method that may help.

Key Concepts 31 ***Statistics and Uncertainty for IPMVP 1:2014, Chapter 5***

Next Topic

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Key Concepts 32

M&V Fundamentals

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International Performance Measurement and Verification Protocol

For Energy Managers

Short Examples

Short Examples - Program

- Multiple ECM Building Retrofit
- New building
- Lighting Efficiency Improvement
- Compressed Air Leakage Control

Which option would you choose for each case?

Multiple ECM Building Retrofit

Commercial Building in Canada

Energy Conservation Measures	Simple Payback (years)
Lighting retrofit	4.5
Energy efficient motors	5.6
HVAC modifications	5.4
Control system	3.4
Building leakage reduction	2.1
Training and awareness	0.5

Option C - Whole Facility

Selected Option C to assess total performance

- Use data from utility meters (gas and electric).
- Analyze baseline gas meter data relative to weather to determine the correct weather *adjustments*. Weather will be expressed in heating degree days ($HDD_{65\ F}$).

You will compute savings for two months.

Sample Option C

Baseline Data

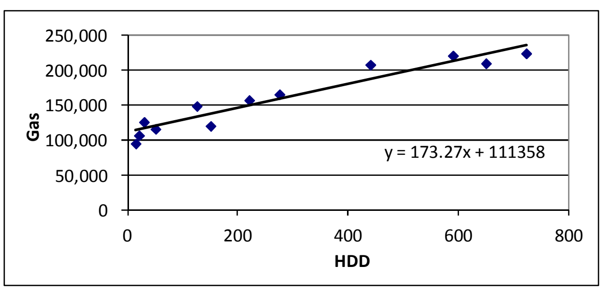
Meter Reading Date	Heating Degree Days (65F)	Gas Consumption mcf
February 5, 2008		
March 5, 2008	650	210,692
April 7, 2008	440	208,664
May 6, 2008	220	157,886
June 5, 2008	150	120,793
July 7, 2008	50	116,508
August 7, 2008	20	107,272
September 5, 2008	14	95,411
October 6, 2008	29	126,423
November 6, 2008	125	149,253
December 4, 2008	275	166,202
January 6, 2009	590	221,600
February 5, 2009	723	224,958
	3,286	**1,905,662**

Short Examples 5

Sample Option C

Baseline Model

The Gas vs. Heating Degree Day relationship was found by regression analysis to be:



Gas = 173.27 * $HDD_{65\,F}$ + 111,358

Short Examples 6

Sample Option C
Method

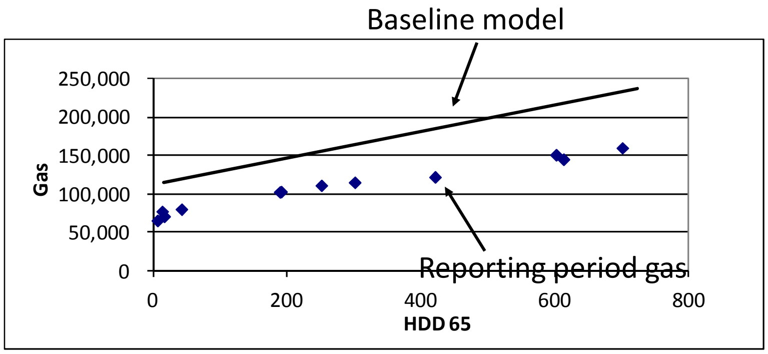
1. Obtain the current weather (HDD_{65F})
2. For each month after retrofit, compute what the baseline gas use *would have been* for those HDD by plugging HDD into the baseline model:

$$Gas = \underbrace{173.27}_{(slope)} * HDD_{65F} + \underbrace{111{,}358}_{(intercept)}$$

3. Compare the computed baseline gas with actual reporting period gas to determine 'avoided gas.'
4. Apply the current utility price to both baseline and actual to calculate cost avoidance.

Short Examples 7

Sample Option C
Graphical View Of Savings



Short Examples 8

Sample Option C

Computations

Meter Reading Date	Reporting period data		Adjusted baseline data			Savings	
			Intercept (Baseload)	Slope (Weather Sensitive)	Total	Gas (mcf)	Value
	Consumption	HDD	*Factors*				*Price =*
	mcf	(65F/18C)	*111,358*	*173.27*			*$ 6.232*
March 6, 2009	151,008	601	111,358	104,135	215,493	64,485	$ 401,871
April 4, 2009	122,111	420	111,358	?	?	?	?
May 6, 2009	102,694	188	111,358	32,575	143,933	41,239	$ 257,001
June 5, 2009	111,211	250	111,358	43,318	154,676	43,465	$ 270,874
July 5, 2009	80,222	41	111,358	7,104	118,462	38,240	$ 238,312
August 6, 2009	71,023	15	111,358	2,599	113,957	42,934	$ 267,565
September 8, 2009	65,534	5	111,358	866	112,224	46,690	$ 290,972
October 9, 2009	77,354	12	111,358	?	?	?	?
November 4, 2009	103,000	190	111,358	32,921	144,279	41,279	$ 257,251
December 10, 2009	115,112	300	111,358	51,981	163,339	48,227	$ 300,551
January 7, 2010	160,002	700	111,358	121,289	232,647	72,645	$ 452,724
February 4, 2010	145,111	612	111,358	106,041	217,399	72,288	$ 450,499
Total	**1,304,382**				**1,616,409**	**511,492**	**$ 3,187,620**

Short Examples 9

Option C - Best Applications

- Significant energy saving (10% or more of consumption measured by the utility meter)
- All factors which significantly affect energy usage can be clearly identified and quantified (during baseline and after implementation)
- Adjustments are simple
- Individual ECM measurement is not required
- Multiple ECMs
- Complex ECMs
- Soft savings ECMs (eg. building leakage reduction, operator training, occupant/user awareness)

Short Examples 10

Option C
Advantages & Disadvantages

Advantages:
- Evaluates performance of the entire facility.
- Includes interactive effects amongst ECMs, and between ECMs and the rest of the facility.

Disadvantages:
- No separation of the impact of different ECMs.
- Used often as a saving control method, but be aware that normal unexplained facility variations may obscure individual months' savings. However, the method provides annual reconciliation.

Short Examples 11

New Building - Example

- Construction of a new University Campus
- Building designed to be more efficient than required by the local energy efficiency Building Code
- Local government agency provides incentives for buildings that consumes 30% less energy than the equivalent building designed upon the local energy efficiency Building Code requirements
- Project promoters must then compare the **actual** energy performance to the EE Building Code
- A computer model is used to simulate the baseline

Short examples 12

Option D - Example

To compare the **actual** energy performance to the EE Building Code:

1. After full occupancy begins, gather energy metered data (calibration data)
2. Prepare a computer simulation of the building energy use (as built)
3. Compare simulated and actual energy use
4. Calibrate (or adjust) the simulation until the differences are acceptable
5. The calibrated simulation now shows energy use of: 5,000,000 kWh
6. Remove energy efficiency measures from the calibrated simulation (to simulate a building designed according the EE Building Code). Simulated energy use is: 7,000,000 kWh
7. Avoided energy use: 2,000,000 kWh

Sh

Option D - Best Applications

- If missing either baseline or reporting period data, due to a lack of meters, for example for buildings built in a compound with one central meter.
- Gives the opportunity to use the IPMVP with a new building.
- Can help determine a building performance relative to a Standard, a Code, or to some energy performance objectives.

Short examples 14

Option D
Advantages & Disadvantages

Advantages:
- Evaluates performance of the entire facility **and** individual ECMs.
- Evaluates performance of individual systems.
- Includes interactive effects amongst ECMs, and between ECMs and the rest of the facility.

Disadvantages:
- Can be expensive and complicated.
- Special skills needed for simulation.
- Hard to calibrate simulation to real energy data.

Short Examples 15

Sample M&V Project
Retrofit Isolation

As an example, consider the M&V design for a **Lighting ECM**, using Option A, Retrofit Isolation: Key Parameter Measurement.

Key Parameter: Lighting Fixture Power
- Before and after sample power measurements

Non-Key Parameter: Operating Hours
- Assume operating hours of lights.

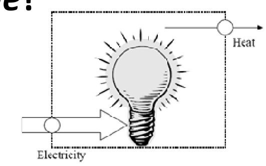
Short Examples 16

Sample Option A

Lighting - Measurement Boundary

To set the measurement boundary, consider:

What parameters affect energy use *inside*?



- lamp efficiency improvement
- operating hours
- fraction of lamps burned out

What interactive energy effects happen *outside* the boundary?

- less cooling
- more heating
- task lights added to un-measured circuits

Short Examples 17

Sample Option A

Design

Measurement:

- measure at randomly selected light switches
- use clamp-on true RMS wattmeter, calibrated
- measure for 1 second before and 1 second after retrofit

Assumptions:

- 100 hrs/month of operation in the savings reporting period, based on a measurement in the baseline
- ignore cooling and heating energy change and added task lights, as they are considered insignificant
- 5% of lamps/ballasts are burned out at any time

Short Examples 18

Sample Option A

Observations

	Pre-retrofit	Post-retrofit
# Samples	73	30
Measured average watts per operating (not burned out) fixture	193.1	102.1
Number of fixtures	2,000	1,950

Sample Option A

Computations

	Pre-retrofit	Post-retrofit
Total kW (95% of fixtures operating)		
Lighting load reduction		kW
Monthly energy savings		kWh/month

Sample Option A

Notes

- Option A is known as "**Retrofit Isolation: Key Parameter Measurement.**" The key parameter in this example is power change in the fixtures, so it is measured.
- This sample was IPMVP "Option A" because we *Assumed* the operating hours, even though we logged operating hours in the baseline.
- Manufacturer supplied data is not field measured. IPMVP treats it as *assumed*. To adhere to IPMVP Option A the manufacturer data cannot be the **key parameter,** but it can be another (non-key) parameter.

Short Examples 22

Option A - Best Applications

- Operating conditions (e.g. occupancy) are regularly changing.
- A contractor is not responsible for all parameters affecting energy use.
- Able to assume a parameter with a level of certainty acceptable to all parties.
- On-going measurement is not required. But to be sure savings are still happening in future, regularly verify that equipment remains in place and is operated properly, i.e. perform operational verification (See IPMVP Core Concepts 2014, Chapter 5.2).

Short Examples 23

Option A

Retrofit Isolation: Key Parameter Measurement

Advantages:

- Cost effective where numerous energy influencing factors cannot be tracked (such as in a hospital or in a complex industrial process)
- Easy to administer

Disadvantages:

- Assumed factor may introduce error
- Not reconciled to total facility utility usage
- Does not track on-going facility performance

Short Examples 24

Sample M&V Project

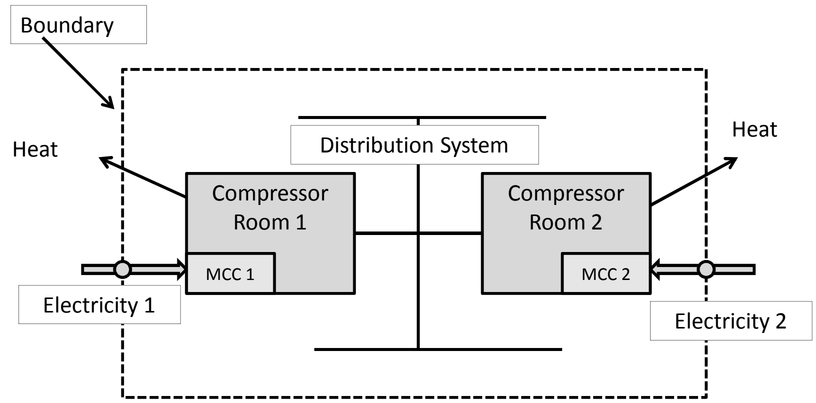
Retrofit Isolation

- For this example we will determine the savings from a Compressed Air Leakage Reduction ECM at a textile mill.
- Retrofit Isolation style of M&V was used because many aspects of the plant are changing and not relevant to the performance of the ESCO who designed and built the ECMs.
- Continuous control of leakage is desired, through compressor energy measurement. Use **Option B, Retrofit Isolation: All Parameter Measurement** to track savings.

Short Examples 25

Sample M&V Project

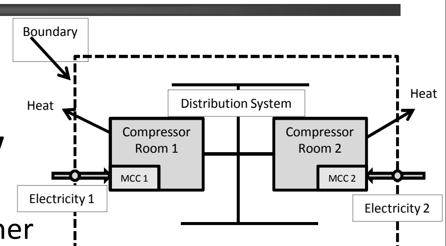
Measurement Boundary



Short Examples 26

Sample Option B

Measurement Boundary



To set the measurement boundary, decide:

What parameters affect energy use *inside* the boundary?

- Mill operating hours (mill either operates steadily or is shut down)
- Compressor efficiency
- Leakage in compressed air distribution system

What interactive energy effects happen *outside* the boundary?

- less heat rejected from compressor room – ignore

Short Examples 27

Sample Option B

M&V Plan

During Baseline Period:

1. Measure compressor plant electricity consumption (kWh) continuously for a month.
2. Determine mean energy use per operating hour and per non-operating hour.

During Reporting Period:

a) Record plant operating and non-operating hours each month
b) Compute what baseline energy use would have been for operating and non-operating hours from baseline test, 2) above.
c) Measure monthly compressor plant electricity consumption.

Energy Avoidance = b) minus c)

Short Examples 28

Sample Option B

Baseline Test

Averaged over the one month baseline period test:

Mode	Energy Use (kWh/hr)
Mill ON (operating)	135.1
Mill OFF (not operating)	102.3

Note: Energy use was constant in each mode.

Baseline Energy =

(135.1 * ON hrs) + (102.3 * OFF hrs)

Short Examples 29

Sample Option B

2009 Reporting Period Actual Data

	Plant Hours		Actual
	On	Off	Energy (kWh)
January	496	248	61,005
February	448	224	52,321
March	496	248	61,987
April	480	240	59,921
May	496	248	60,111
June	480	240	60,191
July	200	544	50,345
August	496	248	62,255
September	480	240	58,765
October	496	248	61,178
November	480	240	59,232
December	150	594	48,822

Short Examples 30

Sample Option B

Energy Avoidance

During 2009, no new machines were added and no modifications were made to existing machines affecting their use of compressed air.

Quizz: What is the energy avoidance for January?

Adjusted baseline = ?

Actual = 61,005

Energy Avoidance = ?

Short Examples 31

Sample Option B
Cost Avoidance

a) Apply the current full utility rate to the Adjusted Baseline

b) Apply the current full utility rate to the Actual use

Cost Avoidance = a) – b)

Notes:
- Rates must include all aspects of the rate structure.
- ***If*** the utility rate structure can be confidently simplified to one Marginal Price, Cost Avoidance is also the product of the Energy Avoidance and the Marginal Price.
- Rates may change during the reporting period.

Option B - Best Applications

- A contractor is responsible for all aspects of energy use in the system that was retrofitted.
- On-going measurement helps to verify that the ECM remains in place.
- Metering system installation, operation, maintenance and data evaluation costs are small relative to savings.

Option B

Retrofit Isolation: All Parameter Measurement

Advantages:

- Savings reports correlate closely with production changes
- Actual savings determined from direct metered usage
- Meters provide extra operational feedback

Disadvantages:

- Can be expensive to install *and maintain* meters
- Not reconciled to total facility utility costs
- Difficult to establish baseline loads for varying process and energy consumption levels

Short Examples 35

Next Topic

1. Introduction
2. Key Concepts
3. Short Examples
4. **M&V Planning**
5. Critical Issues
6. Statistics
7. Retrofit Isolation Details
8. Option C Details
9. Option D Details
10. Other M&V applications
11. Summary and review of a detailed M&V plan

Short Examples 36

M&V Fundamentals

& the

International Performance Measurement and Verification Protocol

For Energy Managers

M&V Planning

M&V Planning

Before we look at detailed examples, we must review M&V Planning theory and details.

“Failing to Plan
Is
Planning to Fail”

M&V Planning 2

M&V Planning - Program

- Why and when do an M&V Plan?
- Fundamental principles
- Setting the boundary of measurement
- Types of 'Savings'
- Baseline data
  - Independent variables
  - Static factors
  - Getting the right data
- Adjacent Measurement Periods
- Measurement equipment
- Routine procedures for reporting
- A standard template for M&V plan

Why an M&V Plan?

The preparation of an *M&V Plan* is a recommended part of *savings* determination. It also allows to:

- Direct actions.
- Ensure proper information is archived for later use.
- Resolve major issues in cold blood, before "money is on the table."

When to do an M&V Plan?

- The M&V Plan should be developed *while* energy conservation measures (ECMs) are being designed in order to:
  - include the cost of M&V when deciding project economics, and
  - record baseline data and methodology for savings calculations while baseline conditions are still measurable, while memories are fresh and before any savings happen.
- You complete the design of any new metering equipment while the ECM design is being completed.

M&V Planning 5

Principles of M&V

In alphabetic order:

- Accurate – as limited by the budget
- Complete – consider all effects, measure significant ones
- Conservative – err on the low side
- Consistent – amongst reports and energy types
- Relevant – focus on measuring the selected key performance parameter(s)
- Transparent – full disclosure as defined in IPMVP Vol. I 2012, Chapters 5 and 6

M&V Planning 6 See IPMVP Core Concepts 2014, Chapters 7 and 8

Boundaries of Measurement

- Are we assessing the energy use of:
  - the entire facility?
  - a system or group of systems (lighting, HVAC, compressed air, steel mill reheat furnace ……)?
  - a component or group of components (boiler, chiller, motor, light fixture, pump, fan …….)?
- To set the boundary, you need to consider:
  - the responsibilities of possibly different parties for energy use and for the retrofit;
  - your ability to track changes to the facility and its use - *within the chosen boundary;*
  - the significance of effects *beyond the chosen boundary*, known as "**Interactive Effects**".

Interactive Effects - Example

- Consider replacement of old lighting with high efficiency lighting, using 10 kW less power.
- Possible "interactive effects" (*beyond the measurement boundary*), are:
  - decreased cooling energy requirements;
  - increased heating energy requirements in winter;
  - increased re-heating of ventilation air;
  - increased plug load from new task lamps, or lights turned off less if occupants feel under-lit.

Interactive Effects - Example
Lighting & Cooling

- The lighting ECM reduces heat gain by 10 kW.
- Reduced heat gain in the facility can reduce the mechanical cooling energy required. It can also increase heating energy in the winter.
- A typical cooling system might see a savings of about 3 kW (from a separate engineering calculation that is not part of this course or IPMVP.)
- So the **Interactive Effect** is **estimated** to be 30% more savings than just the lighting energy (for locations and times when mechanical cooling is used).

M&V Planning 9

Interactive Effects - Conclusion

- Decide which interactive effects are **significant** relative to savings.

Note: You may decide to adjust the measurement boundary to include measurement of a significant effect (so it is no longer an interactive effect, rather a measured effect).

- Define the means of **estimating** any significant interactive effect (e.g. 30% addition to the energy savings during the cooling season).

M&V Planning 10

Types of "Savings"

When you say "Savings," do you mean:

- **Energy (Cost) Avoidance**?

or

- **Normalized Savings**?

It is important to understand the difference!

M&V Planning 11

"Energy (Cost) Avoidance"

When reporting "savings" we commonly mean:

"Our bills are less than they **would have been** without the retrofit."

To make such a statement of 'avoided cost,' we need to *determine what costs would have been in the reporting period* if there had not been any retrofit.

To report "avoided" energy or cost, we must adjust:

- baseline period energy use/demand to the conditions of the reporting period.

M&V Planning 12

"Energy (Cost) Avoidance"

Basic IPMVP Equation as per IPMVP Core Concepts 2014, Chapter 5.3.3 becomes:

Savings reported for any period
= Adjusted Baseline Period energy (cost)
- Reporting Period energy (cost)
(± Non-Routine Adjustments of baseline energy to reporting-period conditions)

See IPMVP Core Concepts 2014, Chapter 5.3.4

Note: The *adjustment* amount changes from period to period, for the common situation of variable reporting period conditions.

M&V Planning 13

"Normalized Savings"

A more stable way to report savings is:

"Under *normal* conditions savings would have been ……"

Normal conditions may be any *fixed* set of conditions – (eg. long term average, or 2006 values, or …..).

To report "normalized savings," both baseline and reporting period energy (costs) must be under the same set of *normal* conditions.

We must adjust:

- baseline period use to the fixed normal conditions, and
- reporting period use to the fixed normal conditions.

M&V Planning 14

"Normalized Savings"

Savings= (Baseline-Period Use or Demand – Reporting-Period Use or Demand) ± Adjustments

becomes:

Savings reported for any period
= Adjusted Baseline Period energy (cost)
- Adjusted Reporting Period energy (cost)

Non-routine adjustment should also be taken into account.

See IPMVP Core Concepts 2014, Chapter 5.3.5

M&V Planning 15

$$S = (B \pm A_{BN}) - (R \pm A_{RN})$$

Normalized Savings – Example

Using the Option C Example from Module 3

Step 1 – Restate Baseline Gas under Normal conditions

Normal date	Normal HDD	Adjusted Baseline Gas (Normal Conditions)		
		Baseload	Weather Sensitive	Total Normal Baseline Gas (step 1)
		intercept	slope	
		111 358	173,27	
March	551	111 358	95 472	206 830
April	482	?	?	?
May	301	111 358	52 154	163 512
June	200	111 358	34 654	146 012
July	55	111 358	9 530	120 888
August	12	111 358	2 079	113 437
September	30	111 358	5 198	116 556
October	66	?	?	?
November	201	111 358	34 827	146 185
December	311	111 358	53 887	165 245
January	677	111 358	117 304	228 662
February	603	111 358	104 482	215 840

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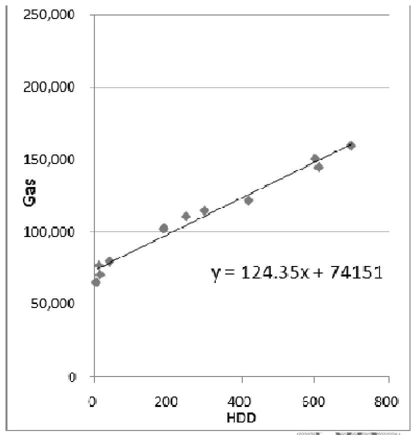
Normalized Savings – Example

Step 2 – Develop Reporting Period model

Meter Reading Date	Reporting period data	
	Consumption mcf	HDD
March 6, 2009	151,008	601
April 4, 2009	122,111	420
May 6, 2009	102,694	188
June 5, 2009	111,211	250
July 5, 2009	80,222	41
August 6, 2009	71,023	15
September 8, 2009	65,534	5
October 9, 2009	77,354	12
November 4, 2009	103,000	190
December 10, 2009	115,112	300
January 7, 2010	160,002	700
February 4, 2010	145,111	612
total	**1,304,382**	



M&V Planning 17

Normalized Savings – Example

Step 3 – Restate Reporting Period gas under Normal conditions

Meter Reading Date	Normal HDD	Total Normal Baseline Gas (step 1)	Adjusted Reporting Period Gas			Normalized Savings
			Intercept (baseload)	Slope (weather sensitive)	Total	Gas (mcf)
			Factors			
			74,151	124.35		
March 6, 2009	551	206,830	74,151	68,517	142,668	64,162
April 4, 2009	482	?	?	?	?	?
May 6, 2009	301	163,512	74,151	37,429	111,580	51,932
June 5, 2009	200	146,012	74,151	24,870	99,021	46,991
July 5, 2009	55	120,888	74,151	6,839	80,990	39,898
August 6, 2009	12	113,437	74,151	1,492	75,643	37,794
September 8, 2009	30	116,556	74,151	3,731	77,882	38,674
October 9, 2009	66	?	?	?	?	?
November 4, 2009	201	146,185	74,151	24,994	99,145	47,040
December 10, 2009	311	165,245	74,151	38,673	112,824	52,421
January 7, 2010	677	228,662	74,151	84,185	158,336	70,326
February 4, 2010	603	215,840	74,151	74,983	149,134	66,706

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Normalized Savings – Example

Comparison with "Avoided" gas (Module 3)

Meter Reading Date	"Avoided" Gas	"Normalized Savings"	Difference in Savings	Actual HDD	Normal HDD	Difference in HDD
March 6, 2009	64,485	64,162	323	601	551	50
April 4, 2009	?	?	?	420	482	(62)
May 6, 2009	41,239	51,932	(10,693)	188	301	(113)
June 5, 2009	43,465	46,991	(3,526)	250	200	50
July 5, 2009	38,240	39,898	(1,658)	41	55	(14)
August 6, 2009	42,934	37,794	5,140	15	12	3
September 8, 2009	46,690	38,674	8,016	5	30	(25)
October 9, 2009	?	?	?	12	66	(54)
November 4, 2009	41,279	47,040	(5,761)	190	201	(11)
December 10, 2009	48,227	52,421	(4,194)	300	311	(11)
January 7, 2010	72,645	70,326	2,319	700	677	23
February 4, 2010	72,288	66,706	5,582	612	603	9
Total	*609,595*	*617,166*	(7,571)	3,334	3,489	(155)
	Including April + Oct		-1.2%			-4.6%

M&V Planning 19

Which Type of Savings?

Cost Avoidance:

- To explain the impact on current costs;
- Variable conditions mean savings change even though the ECM may be unchanged;
- The most common way of reporting the benefit of an ECM.

Normalized Savings:

- To explain how savings compare to predictions made under "normal" conditions;
- To stabilize savings reports, so they do not fluctuate with current conditions.

M&V Planning 20

Baseline Data

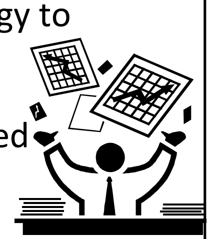
What data?

For what period?

What Baseline Data?

Baseline data must include for the baseline period:

- all energy use (and demand) data;
- all independent variable data (for routine adjustments);
- all other factors significantly affecting energy to recognize when a change from baseline conditions has taken place (needing a non-routine adjustment). These factors are called **Static Factors**, to distinguish them from variables which are routinely changing.



M&V Planning 22

Independent Variables

Independent Variables are the energy driving factors that ***routinely*** vary and significantly affect energy.

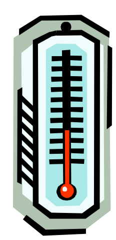
- What variables *routinely* affect energy use in your facility?
- How significant is each effect?
- How costly is it to get data for each?

Choose Wisely!

M&V Planning 23

Choosing Independent Variables

- Operations:
  - production rate
  - product type, raw material type
  - hotel occupancy
  - sales
- Weather:
  - outdoor temperature
  - degree days (total of the period or peak of the period)
  - humidity
- Measurement:
  - meter period length
  - number of operational days in the period



M&V Planning 24

Choosing Independent Variables

It's tempting to choose many variables to account for as much variation in the baseline as possible.

Recommendation: choose only the variables needed to *reasonably* account for variations in the baseline data.

Q. What is reasonable?

A. Statistics and Uncertainty for IPMVP 1:2014 presents statistical terms to help define "reasonable" and techniques to choose independent variables. (More details later.)

M&V Planning 25

Using Independent Variables

To make Basic IPMVP Equation **Adjustments**, we find the relationship between energy and each chosen **significant** independent variable. We call this the "baseline relationship" or the "baseline model."

A baseline relationship can take many forms, for example, in the steel mill:

Furnace gas (gas units/h) =

3.4078 + (0.4574 x tons of production per hour)

All other possible variables are 'in the noise.'

M&V Planning 26

Definition of Static Factors

Those characteristics of a *facility* which affect *energy* use within the chosen *measurement boundary*, but which are not used as the basis for any *routine adjustments*. These characteristics include fixed, environmental, operational and maintenance characteristics. They may be constant or varying.

Ref. IPMVP Core Concepts 2014, Chapter 5.3.3.b

M&V Planning 27

Examples of Static Factors

- Product mix
- Number of production shifts
- Facility size and envelope features
- Number of occupants & occupancy periods
- Operating practices: production, lighting, ventilation, temperature control
- Office and lab equipment load and operating periods
- Equipment nameplates & operating practices
- Breakdown periods

Note – you only need Static Factors that affect energy use within the measurement boundary

M&V Planning 28

Getting Baseline 'Static' Factors

Static Factor information is usually obtained during an energy audit without any extra work.

Don't lose it!

Archive it in the M&V Plan

(in the appendix)

M&V Planning 29

Monitoring 'Static' Factors

To make adjustments for a proper "apples to apples" comparison in Equation #1, changes in Static Factors must be noted and recorded. The M&V Plan should show:

- what Static Factors are to be monitored,
- the Static Factors that are already being routinely logged by operations staff, and
- the static factors needing to be specially logged **and by whom.**

(ESCO Contract clauses requiring the owner to report changes should refer to the Static Factors recorded in the M&V Plan and identified for the owner to report.)

M&V Planning 30

Where Do We Get Data?

There are many possible sources of data.

Energy data comes from utility meters or bills, or isolation meters.

Independent variable data comes from government weather stations, facility logs, control systems , ……..

Static factors come from facility logs, control systems, etc.

For each possible source of data consider its A-A-C-C:

- **A**ccuracy of data
- **A**vailability of data when we need it
- **C**redibility of data to others
- **C**ost of getting the data

M&V Planning 31

Utility Data Sources

- Electricity (kW, kWh, kVA)
- Gas volume & demand
- Steam/hot water
- Chilled water
- Delivered oil, coal, propane, biomass or other
  - Track inventory data

Consider:

Accuracy **A**vailability **C**redibility **C**ost

M&V Planning 32

Isolation Meter Data Sources

To isolate a retrofit's energy use from the rest of the facility, we might measure: amps, watts, power factor, chilled water energy, hot water energy, steam flow or energy, condensate, gas volume, operating hours, number of cycles, ………..…

Consider:

Accuracy **A**vailability **C**redibility **C**ost

M&V Planning 33

Independent Variable Data Sources

For weather variables we might use:

- government weather station reports;
- on site sensor(s).

Consider:

Accuracy **A**vailability **C**redibility **C**ost

M&V Planning 34

Other Independent Variables or Static Factor Data Sources

For other independent variables or Static Factor, like: production volume, product mix, plant hours, guest room use, sales, store hours, vacancy rate, …… we must find appropriate formal or informal methods of capturing such data.

Consider:

Accuracy **A**vailability **C**redibility **C**ost

M&V Planning 35

How Long Baseline Period?

- One Second?
- One Hour?
- One Week?
- One Month?
- One Year?
- Two Years?
- Three Years?
- Ten Years?

M&V Planning 36

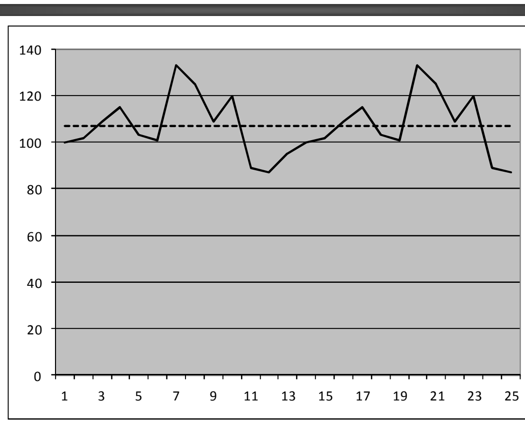
Baseline Period Length

- The primary constraint is *quality* and *relevance* of data. Use a period **long enough** to:
  - get good data without introducing more hidden data gaps or flaws, and
  - span one full cycle of energy use: hourly, daily, weekly, yearly or long enough to prove that a load is constant.
- Use a period **short enough** to avoid unnecessary cost and uncertainty.

Clearly, judgment is needed!

M&V Planning 37

Look For A Repeating Pattern



An energy audit usually examines more than one cycle to confirm baseline period selection.

M&V Planning 38

Baseline Memory

Watch Out:

- The further back in time you stretch the baseline period, the less likely you are to be able to remember or find records of all the relevant routine or exceptional events (independent variables **and** static factors).
- Normally the baseline period should be *no longer than the most recent **full cycle*** (e.g. most recent year for loads operating on an annual cycle).

See IPMVP Core Concepts 2014, Chapter 5.3.2

M&V Planning 39

Example

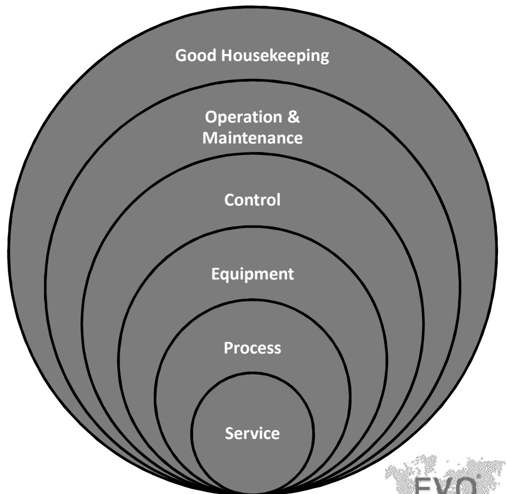
You are writing an M&V plan for a leisure centre. The improvement to be installed is new high efficiency condensing boiler, efficient controls, etc. The old boiler was a standard boiler. The boiler supplies heat to the leisure centre and the swimming pool. Estimated 65% heat used for the pool, 35% space heating.

What the independent variables and Static Factors are ?

M&V Planning 40

Peeling the layers – Onion Diagram

A method to look at all potential independent variables and static factors across the facility operation



M&V Planning 41

Adjacent Measurement Periods

ON - OFF

- Some ECMs can be turned On and Off easily, such as a control change or a heat recovery device.
- With the ECM Off, the facility may behave as it did without the ECM, and the baseline period energy can be measured.
- With the ECM On, the reporting period energy can be measured.
- The savings attributable to the ECM are the difference between the two readings, *providing all other factors affecting energy use do not change*.

M&V Planning 43

Adjacent Measurement Periods

- All other factors affecting energy use *may* be unchanged if back to back ("adjacent") time periods are used for the ON and OFF measurements.
- Where the ECM can be easily switched ON and OFF, the baseline and reporting periods can be adjacent to minimize the chances of conditions changing.

See IPMVP Core Concepts 2014, Chapter 5.3.2.3

M&V Planning 44

Adjacent Measurement Periods

- Savings may be computed using IPMVP Core Concepts 2014, Chapter 6.3.2

  Savings = Baseline Energy – Reporting Period Energy
- This method can be used at the retrofit level or the whole facility level. It is a method of implementing Option A or Options B or C with short reporting periods.
- The adjacent measurement period test process is also called the On/Off test method.

M&V Planning 45

On/Off Example – Whole Facility

New control program changing a number of settings on a continuous process industrial system.

- ON - Operate the plant with the new control program long enough to ensure stable operation. Measure hourly energy and production parameters (volume and type of product, temperature, pressure …….).
- OFF - Switch back to the old program and repeat the test. Check that production parameters are the same.
- The difference in hourly energy is the savings for an hour under one set of plant operating conditions.
- Repeat under other plant conditions to build up a profile of efficiency improvements across the range of operations.

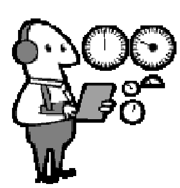
M&V Planning 46

Caution!

- An ECM which can be easily switched On and Off may be switched Off when it is believed to be On. (Operating staff may prefer the old way, or accidentally switch it Off.)
- After testing, steps should be taken to *verify* that the ECM remains On.
  - These verification steps *may* end up requiring continuous measurement to prove operation. Then savings are reported for longer reporting periods, not just a short On period test.

M&V Planning 47

Measurement Equipment



Meter Accuracy

- **Size** the meter for the appropriate range.
- Select a meter for the rates occurring most of the time.
- If accuracy beyond the available meter range is important, use two-stage flow meters: high and low flow elements.
- Watch out for loss of accuracy through 'truncation' by data communication or software translation (8 bit data vs. 16 bit data)
- Use the same meter for 'before' and 'after' readings.

Meter Accuracy

- Specify accuracy as defined in the relevant industry standard (e.g. ANSI C12 for electric revenue metering).
- Make sure you know whether the meter manufacturer quotes accuracy as "x% of reading" or "x% of full scale."
- Accuracy is most correctly reported with its associated confidence level, usually 95%. However, few manufacturers offer the corresponding confidence level.

Other Uses for M&V Meters

Concerned about the cost of meters? You may be able to share the M&V meter costs with other purposes such as:

- load analysis for ECM planning;
- process control, optimizing or sending alarms about system or component conditions;
- sub-billing of tenants;
- allocation of costs to responsible departments;
- confirming utility bills;
- forecasting;
- load profiling for negotiation with a power supplier.

Not all meter costs need to be borne by the M&V.

Metering

Application	Instrument
Electricity	True RMS Wattmeter, power meter
Illumination	Luxmeter, operating hour logger
Occupied hours	Occupancy sensor (Data logger)
Rotational speed	Tachometer (contact, stroboscopic, and optic)
Air flow	Anemometer
Pressure	Digital manometer
Temperature	Digital thermometer or Digital data logger
Humidity	Digital hygrometer
Air quality	Gas analyser: CO_2
Combustion	Combustion analyser
Process	Data logger – Process signal
Liquid Flow	Flowmeter - See next slide

Electrical Metering

Watts = Amps x Volts x Power Factor

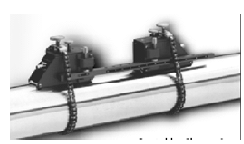
- Do you know the power factor? Since power factor is 1.0 for resistive loads (e.g. incandescent lighting), amps and volts are all that must be measured for circuits containing only such loads.
- Do you know the effect of harmonic distortion of power being measured? Distortion can come from many devices, not just the measured device.

The best practice is to always measure **true RMS Watts**, not simply amps and volts, to be sure of including all possible (unexpected) power factor and harmonic influences.

M&V Planning 53

Flow Meter Types

- Intrusive:
  - Orifice Plate
  - Turbine (hot tap possibilities)
  - Vortex Shedding
  - Positive Displacement
  - Magnetic (non-restrictive)
- Non-Intrusive:
  - Ultrasonic
  - Bucket & Stop watch is a cheap method of spot measurement for open systems



M&V Planning 54

Meter Installation and commissioning

- Always follow manufacturer's instructions (if you can).
- If you need conduit and/or concealment for wires, costs go up significantly. Is this the place for wireless?
- Use labels and seals to protect meters and cabinets against neglect by others, damage and mistreatment.
- Program data loggers for the correct channels.
- Check to hand held instruments.
- "End to end" initial site calibration – from measured quantity to computer readout.

M&V Meters and Control Systems

A computerized control system can provide much of the monitoring necessary for data collection.

However, the system must be capable of combining measurement and control functions into without slowing processing speed or reducing available storage capacity.

Meter Maintenance

- The cost of maintenance is often overlooked in M&V budgeting.
- Re-calibrate initially as recommended by the manufacturer. Change calibration frequency as learned from experience in the particular environment for the particular meter type.
- Digital electricity meters are not a maintenance concern, once they are installed properly.

M&V Planning 57

Meter Operations - 1

Murphy's Law*:* some data will be bad or lost.

So take precautions:

1. Decide how to assess the validity of each piece of data. For example:
    - Range checks
    - Relationship checks
    - Check times (& time zones) on logger clocks
    - Check sums for transmitted data

M&V Planning 58

Meter Operations - 2

2. Decide how to deal with:
   – missing data (when/how to “backfill”)
   – unobtainable data
   – data from a meter that has been found to be significantly out of calibration
3. Establish a data error or loss rate which indicates that meter system repairs are required.

Meter Data Management

- Log all adjustments to raw data;
- Log all meter system maintenance activities;
- Turn mountain of data into useful information by making two plots:
  – One as function of time to check range of values;
  – One as function of meaningful variable, e.g. fuel use vs. production or outdoor temperature;
- Develop an archiving procedure.

How Long to Measure?

The length of the reporting period depends on your purpose:

- If you want to control performance
  → measure forever.
- If you want to report on achievement of savings
  → measure until satisfied.

Measurement equipment costs money to manage and maintain.

Choose wisely!

M&V Planning 61

Metering Costs

- Costs have been dropping - now often just a few hundred $ per point.
- *Soft* costs usually *exceed* hard costs. So plan time (= cost) for staff to nurse the sensor/logger/data management system.
- Plan expense for telephone line and travel.
- Internet connection costs.

M&V Planning 62

Routine Procedures

- Quality Control
- Reporting

M&V Quality Control

- Some techniques:
  - Restrict data access to trained individuals.
  - Use ‘check’ data to test input, e.g. meter readings on utility bills can be used to catch consumption data entry errors.
  - Check data intervals, relationships …..
  - Separate review of reports by a qualified person who is not routinely involved.
  - Archive all data, including M&V Plan.
- Develop a procedures manual (ISO 9001).

M&V Planning 64

Quality Control – Case Study

- Many errors found by a verifier.
- ESCO confessed it allowed clients be the quality control!
- ESCO says there's no longer enough money in M&V to support the quality control it used to do!

Proper consideration of uncertainty may help to raise M&V budgets.

Reporting

Understand the audience. Use *their* language.

- Operations staff:
  - Report frequency and timing should match the facility cycles (e.g. deliver a report on winter savings during the winter).
  - Review reports with operations staff and record insights gained about facility energy use patterns.
- Management
- Occupants or others

Report Contents

- Raw data for the reporting period
- Corrections to raw data
- Estimated values (for Option A)
- Energy price used
- Explanation of any non-routine baseline adjustment
- Savings in energy and money units

See IPMVP Core Concepts 2014, Chapter 8

M&V Planning 67

The M&V Plan

Summary of Contents

See IPMVP Core Concepts 2014, Chapter 8

Review of a M&V Plan template

Let's look at a M&V Plan template for an Option C

M&V Planning 69

M&V Plan Contents – special cases

For Option A:

- Justification of the estimate(s) used
- Periodic equipment inspections that will be made after retrofit

For Option D:

- Name and version of software used for simulation
- Input data and method of measuring any parameters used to support input values
- Output from software
- Calibration data and accuracy achieved by simulation

M&V Planning 70

M&V Plan References

- IPMVP Core Concepts 2014, Chapter 8
- Fully worked M&V Plans and Reports are on the EVO subscriber website www.evo-world.org

Next Topic

1. Introduction
2. Key Concepts
3. Short Examples
4. M&V Planning
5. **Critical Issues**
6. Statistics
7. Retrofit Isolation Details
8. Option C Details
9. Option D Details
10. Other M&V applications
11. Summary and review of a detailed M&V plan

M&V Fundamentals

& the

International Performance Measurement and Verification Protocol

For Energy Managers

Critical Issues

Critical Issues - Program

- Missing Data
- M&V Budget
- Baseline Adjustments (BLA)
- BLA squabble
- Applying utility prices to value savings
- Verification
- Adherence

Critical Issues 2

Missing data

Murphy's Law

Murphy's Law for M&V

The something that inevitably goes missing will be vital.

- Sensors fail
- Data capture systems lose communication or power
- Erroneous readings
- Utility bills get lost
- Utilities make "estimated" meter readings
- ……………………..

Critical Issues 4

Murphy's Law
In The Baseline

If missing data from the **baseline period**:

- Survive with less data if uncertainty is OK.
- Use data from a comparable period outside the period.
- Consider using a different (or longer) period for all meters (but also need more information about static factors).
- Record the nature of the change made to deal with missing data.

Do not make up baseline data,
i.e. do not "backfill" the baseline from a trend line.

Critical Issues 5

Murphy's Law
In the Reporting Period

If missing data in the **reporting period**:

- The true value is unlikely to be zero.
- In the case of an outage, it is inappropriate to assume a value as if the retrofit continued to perform until after the outage and there is evidence that the retrofit continued to perform.

Critical Issues 6

Murphy's Law
In the Reporting Period

Hence:
- Make best estimates ("backfill") from adjacent data or from the trend line of a whole cycle of operations.
- Report "backfill" assumptions.
- Correct system flaws so the problem does not continue.

Critical Issues 7

The M&V Budget

Balancing Cost and Uncertainty

M&V Cost

M&V Cost depends on the:

- amount of data needed and difficulty of getting good data
- installation/maintenance of new meters
- amount of data analysis needed
- reporting format and frequency
- length of reporting period
- complexity of systems and ECM
- Required uncertainty
- IPMVP Option chosen.

Critical Issues 9

M&V Budget

The M&V budget should depend on:

- how much saving there is
- how long the payback period is
- how closely this project is to be scrutinized
- how much ***uncertainty*** you can accept.

Critical Issues 10

Remember

There is no absolutely correct savings number.

All numbers are estimates, some are better than others.

Critical Issues 11

How Much M&V Is Enough? - 1

	M&V Design X	M&V Design Y
Annual Savings	$100,000	$100,000
Uncertainty	+/- $25,000	+/- $5,000
Annual M&V Cost	$6,000	How much would you pay? Why?

Critical Issues 12

How Much M&V Is Enough? - 2

Total cost to determine savings should normally be less than ….% of the savings.

Critical Issues 13

How Much M&V Is Enough? - 3

A balancing act between:

- Lower uncertainty (= higher M&V cost). More complex M&V. Gives operating staff better feedback and tighter control **= more savings**.
- Higher uncertainty (= lower M&V cost). Simple M&V approach. Leaves more money for retrofits **= more savings**.

Clearly each project's M&V design must consider issues broader than just M&V.

Use as little M&V as customer will allow.

Consider whether reduced M&V uncertainty will affect contract payments to an ESCO.

Critical Issues 14

Baseline Adjustments (BLA)
(Non-routine)

- Why?
- When?
- Who?
- How? - Example

Baseline Adjustments

IPMVP Core Concepts 2014, Chapter 5.3.3:

Savings = Baseline Energy – Reporting period Energy
+/- Routine Adjustments
+/- Non-Routine Adjustments

- **Routine Adjustments** involve: independent variables, baseline models and routine calculations established in the M&V Plan.
- **Non-Routine Adjustments** are also needed because Static Factors are not static. Non-Routine Adjustments are normally called simply "**Baseline Adjustments**" (BLA).

Critical Issues 16

Why Do BLAs? - 1

Unexpected changes to Static Factors (*within the measurement boundary)*:

- New industrial product line
- Change to three shifts per day from two
- New standards (light, temperature, ventilation, etc.)
- Addition to facility
- Change in use of part of the facility
- Loss/gain of tenants
- More tenant equipment
- Replacement roof with more insulation
- ………………………

Critical Issues 17

Why Do BLAs? - 2

Simple Building Example:

- In the baseline period, with 100% occupancy, energy use was 10,000 kWh/day
- Several months after retrofit and normal occupancy, the occupancy dropped to 75%, lowering use by a calculated 1,000 kWh/day
- 1,000 kWh/day of the apparent savings are not due to the retrofit and should be removed.
- Adjust the baseline to 9,000 kWh/day.

Critical Issues 18

When Do a BLA?

- Change in Static Factors may be:
  - gradual (creeping load growth) or sudden
  - permanent or temporary.
- Monitor Static Factors relative to those recorded in the M&V Plan for the baseline period.
- Do a BLA when a change in Static Factors is *recognized* ***or at least annually*** – while memories are fresh and other possibly necessary data is still available.
- Avoid changes to long past accounting periods.

Critical Issues 19

Who Does BLAs?

Divided interests:

- Baselines often increase - hiding savings. The person claiming savings is motivated to watch for such BLAs.
- The possibility of baselines *dropping* requires equal vigilance to ensure baseline reductions are noted.

The M&V Plan should show who will track each Static Factor so that BLAs can be computed.

Critical Issues 20

Who Does BLAs?

- Some Static Factors are naturally recorded in:
  - facility control system logs
  - operator logs
  - facility operational records
  - maintenance records
  - purchasing department records
- Create a path for this naturally recorded information to the M&V department.
- Decide who will observe and record all other factors.
- An annual audit of miscellaneous equipment may be needed.

Critical Issues 21

How?

Each BLA is a ***custom engineered*** calculation.

When multiple BLAs are agreed in any period, it is human to overlook some. Don’t forget to record all BLAs in project archives and relevant calculation software.

Critical Issues 22

Example BLA

- 300 new personal computers replace 200 old ones.
- 100 new printers replace 75 old ones.

A typical set of assumptions and calculations follow:

Critical Issues 23

Example BLA - Part 1

	Number	Wattage		Hours/week		Energy	Diversity	Demand
		Peak	Standby	Peak	Standby	kWh/wk	Factor	kW
Old								
CPU	**200**	**200**	175	80	88	6,280	0.80	32
Monitor	**200**	**110**	110	130	38	3,696	1.00	22
Printer	**75**	**550**	90	130	38	5,619	0.90	37
Total						15,595		91
New								
CPU	**300**	**300**	50	80	88	8,520	0.80	72
Monitor	**300**	**125**	15	130	38	5,046	1.00	38
Printer	**100**	**600**	25	130	38	7,895	0.90	54
Total						21,461		164
Increase					kWh/wk	5,866		72
					kWh/mo	25,400		

Well known facts are **bolded**. The rest are assumptions.

Critical Issues 24

Example BLA - Part 2

- Estimated increase in load from the computer change:
  - 25,400 kWh/month
  - 72 kW
- Add an estimate (engineering calculation) of the related cooling energy change:

	kWh/mo	kW
Winter Increase (computers only)	**25,400**	**72**
Estimated Air Conditioning Impact	8,467	29
Summer Increase	**33,866**	**101**

Example BLA – Part 3

	Electricity Consumption			Electric Demand		
	Last Baseline	**BLA**	**New Baseline**	Last Baseline	**BLA**	**New Baseline**
Jan	1,350,000	**25,400**	1,375,400	3,375	**72**	3,447
Feb	1,250,000	**25,400**	1,275,400	3,125	**72**	3,197
Mar	1,150,000	**25,400**	1,175,400	2,875	**72**	2,947
Apr	1,250,000	**25,400**	1,275,400	3,125	**72**	3,197
May	1,300,000	**33,866**	1,333,866	3,250	**101**	3,351
Jun	1,400,000	**33,866**	1,433,866	3,500	**101**	3,601
Jul	1,770,000	**33,866**	1,803,866	4,425	**101**	4,526
Aug	1,820,000	**33,866**	1,853,866	4,550	**101**	4,651
Sep	1,700,000	**33,866**	1,733,866	4,250	**101**	4,351
Oct	1,500,000	**25,400**	1,525,400	3,750	**72**	3,822
Nov	1,250,000	**25,400**	1,275,400	3,125	**72**	3,197
Dec	1,200,000	**25,400**	1,225,400	3,000	**72**	3,072
Total		**347,130**			**1,013**	

Not Got Data for a BLA?

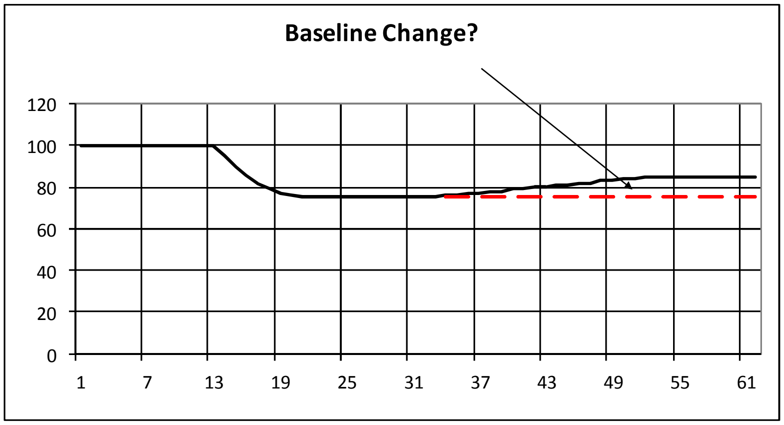
Sometimes the facts describing a BLA have been lost (there's *Murphy* again!)

– **Do not** use post-retrofit metered energy use to determine how much change must have happened.
– **Do** agree on an educated guess about what changes must have happened. Compute ***their*** energy impact.

A Classic BLA Squabble - 1

- ESCO project for a large multiple school project.
- Option C was being used – the Whole Facility approach. That meant the ESCO was reporting energy performance of the whole building.
- Savings were initially achieved as planned, but then an apparent savings shortfall was noted.
- The ESCO claimed that the owner had changed something without giving notice of "material change" as required in the contract.

A Classic BLA Squabble - 2



Critical Issues 29

A Classic BLA Squabble - 3

- The ESCO claimed its retrofits were working.
- The ESCO derived a BLA from trends in current utility meter data (i.e. the BLA was set equal to all the 'missing' savings).
- The contract said the owner would report any "material change" to the facilities.
- ESCO acknowledged it did not have baseline Static Factors for comparison.
- There is clearly a lack of data gathering regarding static factors from both the ESCO and the owner.

Critical Issues 30

A Classic BLA Squabble - 4

- The arbitration panel approved only BLAs supported by agreed facts about facility changes (such as agreed but assumed facts about the net number of new computers and portable classrooms).

Lessons:

- The meter used to determine savings cannot be the only system used to detect and measure baseline change.
  IPMVP Core Concepts 2014, Chapter 7.10

Critical Issues 31

Applying Utility Prices to Value Savings

Utility Rates for M&V

Basic Price Issues

- Energy prices are complex and change often.
- Use the proper **full utility price schedule** or carefully chosen *appropriate* marginal price.
- An ESCO Contract defines **the** prices, minimums and maybe inflation factors to be used.
- The M&V plan should specify the energy prices that will be used to value the savings and whether and how savings will be adjusted if prices change in future.

Critical Issues 33

Cost Savings

- Saved energy can be valued at:
  - price when the project was designed (or contract signed), or
  - price at the time of design plus an assumed escalation factor for inflation, or
  - actual price, as it actually changes in the future.
- The valuation method used must be:
  - defined in advance (in the contract);
  - have a logical relationship to the current rate structure;
  - consider energy, demand, time-of-use and seasonal variation in rates.

Critical Issues 34

Pricing Method

- Apply the energy price to the energy consumed (and demanded) for:
  - the adjusted baseline, and
  - the actual energy use of the reporting period (adjusted if needed to report 'normalized savings').

  IPMVP Core Concepts 2014, Chapter 7.8
- If the utility price structure involves a different price for different levels of consumption in any one month:
  - Use the ***full price structure*** for Whole Facility methods (Options C and D).
  - Use the ***true marginal price*** for Retrofit Isolation methods (Options A and B).

Critical Issues 35

Pricing Method Example

Consider an example with energy savings of:

- Adjusted baseline energy use = 270,000 kWh,
- Reporting period energy use = 200,000 kWh
- The energy savings are = 70,000 kWh.

We will find the currency value of the energy savings.

Critical Issues 36

Example Electricity Price Structure

An example electrical consumption price structure has a different price for consumption in each "block" of monthly consumption:

First 250 kWh/mo	$0.2900/kWh
Next 9,750 kWh/mo	$0.1510/kWh
Next 240,000 kWh/mo	$0.0723/kWh
Balance (all >250,000 kWh/mo)	$0.0611/kWh

Critical Issues 37

Example Value Calculation

Price Blocks		Adjusted Baseline	Reporting Period
kWh	Price	270,000	200,000
250	$ 0.2900	$ 73	$ 73
9,750	$ 0.1510	$ 1,472	$ 1,472
240,000	$ 0.0723	$ 17,352	$ 13,737
Balance	$ 0.0611	$ 1,222	$ -
	Total	**$ 20,119**	**$ 15,282**

Savings for the example month are:

$20,119 - $15,282 = $4,837

For this example, if the savings had been determined at an "isolation" meter (not utility meter), is there a *single marginal* price per kWh which can be used to value savings for all months?

Critical Issues 38

Single Price per kWh?

Price Blocks		Adj Baseline		Reporting Per		Savings	
kWh	Price		270,000		200,000		70,000
250	$ 0.2900	$	73	$	73	$	-
9,750	$ 0.1510	$	1,472	$	1,472	$	-
240,000	$ 0.0723	$	17,352	$	13,737	$	3,615
Balance	$ 0.0611	$	1,222	$	-	$	1,222
	Total	**$**	**20,119**	**$**	**15,282**	**$**	**4,837**
Average	$ / kWh	$	0.0745	$	0.0764	***$***	***0.0691***
Marginal	$ / kWh	$	0.0611	$	0.0723		?

$0.0691 is the only single price you can apply to the 70,000 kWh savings to get $4,837.

However, you cannot get this single price from an average or block price. It has to be computed for each month.

Critical Issues 39

Single Price Simplification?

Be CAREFUL!

- Option C or D – To use a simplified single price, every month's consumption must be at the same price and all extras must be included. ***It's safer to always use the full price structure***.
- Option A or B – Pick a marginal price carefully, ***possibly making some assumptions***.

Subsequent examples will use *appropriate* simplifications.

Critical Issues 40

Price Extras

Also ensure that pricing includes all energy supplier charges for commodity items such as:

- demand (electric or gas)
- peak/off peak rates
- minimum demands ("ratchets")
- electrical power factor
- transformer losses
- overages and underages
- fuel adjustments
- tax

Critical Issues 41

Retrofit Isolation Price

For Retrofit Isolation Methods (Options A & B) a price needs to be set for the energy at the point of metering, possibly different from the price at the utility meter.

Establish an agreed *marginal* price at the retrofit, considering all price extras and **distribution system losses** between the utility meter and the retrofit.

Critical Issues 42

Valuing "Savings"

Statements of *Cost Avoidance* (akin to Avoided Energy) would normally use the current utility rate.

Statements of *Normalized Savings* may use a fixed utility rate or the current rate.

The V in M&V

- Operational Verification
- Independent Verification:
  Why, Who, What, When?
- Retrofit Isolation Verification

The V in M&V

Measurements and calculations are used to **Verify** that the EE idea worked.

Three dimensions to specifically discuss:

- The operational verification;
- The role of an independent "Verifier";
- Verifying continued performance of the unmeasured parts when using Retrofit Isolation.

Critical Issues 45

Operational Verification

- Operational verification (OV) activities are accomplished through comprehensive commissioning of affected systems supplemented by data-driven activities. To ensure persistence of savings, OV should be completed prior to implementing M&V savings verification activities.
- Operational verification approaches include:
  - Visual Inspection
  - Sample Spot Measurements
  - Short-Term Performance Testing
  - Data Trending and Control-Logic Review

Critical Issues 46

See IPMVP Core Concepts 2014, Chapter 5.2

Why Independent Verification?

- If there is a credibility gap arising from the difference in the energy expertise of the parties to a performance contract.
- Energy performance contract terms with an ESCO may (be perceived to) give the two parties divergent interests.
- Requirements of the contract itself (especially in the public sector or as part of a program).
- Requirements of an emission trading program.

Who should Verify?

- An engineer experienced in ECM design and implementation
- A credible person with M&V experience
- True independence is actually impossible, unless the verifier is not paid by any party directly interested in the savings (i.e. paid by government, utility or emission trading program)

Verifying within an EPC

Begin verification with study of the Energy Performance Contract (EPC).

It defines key terms.

Critical Issues 49

What to Verify? – a) The M&V Plan

Before commitment to ECMs, verify:

- Baseline data record is consistent:
  - Energy
  - Independent variables
  - Static Factors
- No modeling bias
- Reasonable expected uncertainty of results
- Robust metering and data collection plan
- Meter maintenance plan

Critical Issues 50

What to Verify? – b) Savings Reports

Verify Savings Reports:

- Periodically, after receipt of several savings reports.
- At least annually so that any necessary corrections are in or close to the affected accounting period.

What to Verify? - c) BLAs

Verify Baseline Adjustments:

- Each BLA should be reviewed.
- BLAs involve owner records of agreed changes in use.
- The owner needs to verify that raw data about operational changes are correct, while verifier reviews the BLAs energy engineering.

Retrofit Isolation Verification

- Retrofit Isolation techniques (Options A & B) focus on the retrofit.
- Under Option A, field conditions should be **verified** to ensure savings persistence (IPMVP Core Concepts 2014, Chapter 6.2.4)
- Total utility cost may not reflect these savings, due to energy use patterns beyond the boundary of measurement.
- If there is concern about total utility cost:
  - Plan to use Option C, or
  - Set up a means of **verifying** that all other operations are under control.

Critical Issues 53

Adherence

- Users claiming adherence with IPMVP must:
  - identify the responsible person
  - develop a complete M&V Plan as per the IPMVP Core Concepts 2014, Chapter 7
  - follow the plan, and
  - prepare M&V report as per the IPMVP Core Concepts 2014, Chapter 8.
- When wishing to specify the use of IPMVP in an EPC, one may use phrases such as "The determination of actual energy and monetary savings will follow current best practice, as defined in IPMVP Core Concepts 2014."

Critical Issues 54

See IPMVP Core Concepts 2014, Chapter 9

Adherence

- In an M&V report, savings should be presented as follows:
  - Savings that are measured during the test period adhere to the IPMVP.
  - Savings that are reported without being measured are estimates based on measured data over the test period.
- This is especially applicable to option A reported savings.

Critical Issues 55

Next Topic

1. Introduction
2. Key Concepts
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6. **Statistics**
7. Retrofit Isolation Details
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Critical Issues 56

M&V Fundamentals

& the
International Performance Measurement and Verification Protocol

For Energy Managers

M&V Calculations

Agenda

1. Introduction
   - Statistics and IPMVP
2. Sampling
3. Regression
4. Uncertainty and rounding

1.Introduction

Introduction

- Statistics = tools for analyzing data
- Why do we use statistics?
  - To better understand measurement data.
  - To describe them in a uniform and consistent way.
  - To make a sound and objective decision.
- Statistics deals with the **collection, analysis, interpretation and presentation** of numerical data.

Statistics 4

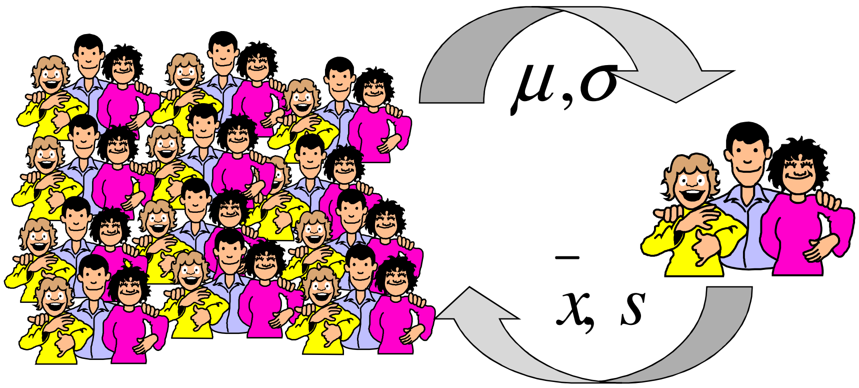
Introduction

Exercise to understand some useful basic concepts :

- Distribution and probability distribution
- Mean
- Variance
- Standard deviation

Sampling

Sampling



It is more important to get a **representative** sample rather than a large sample!

Statistics 7

Sampling

- Random sampling
  - Each item is chosen entirely by chance and each member of the population has a known, but possibly non-equal, chance of being included in the sample.
- Stratified Sampling
  - Population is segmented (stratified) into groups (lat. *strata*) in order to reduce variation.

Statistics 8

Stratified Sampling

- Members of group as similar as possible
- Random sampling in each group
- Sample size determined for each group
- Example:

Location	Fraction of lighting load
Offices	12 %
Corridors	9 %
Classrooms	65 %
Locker rooms	5 %
Auditorium	9 %

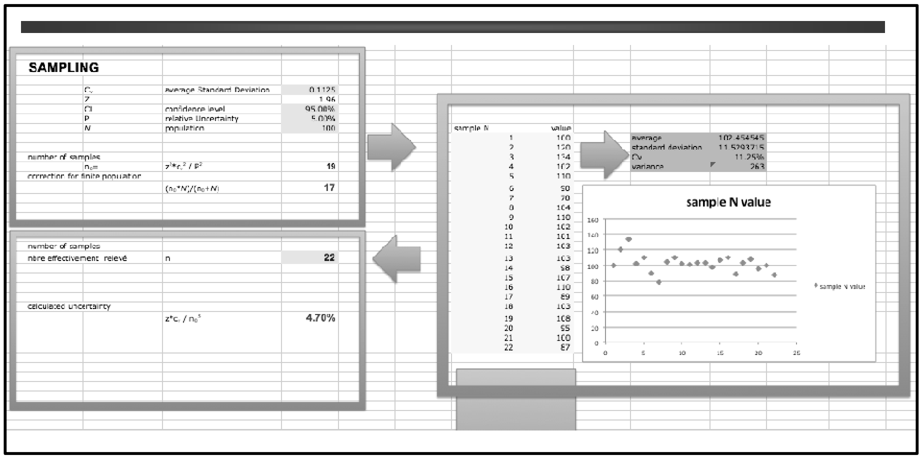
Exercise

The retrofit of fixtures of the same type should be estimated. What sample size is needed to be 95 % confident of being correct within ± 5 %? On basis of previous experience it could be guessed that the coefficient of variation should not be bigger than 30 %. A pilot study of n = 15 measurements was made, showing following data:

Adjust the sample size for the estimated coefficient of variation.
Adjust the sample size for the population size N= 100.

sample N	value
1	100
2	120
3	134
4	102
5	110
6	90
7	78
8	104
9	110
10	102
11	101
12	103
13	103
14	98
15	107

Sampling Process Demo



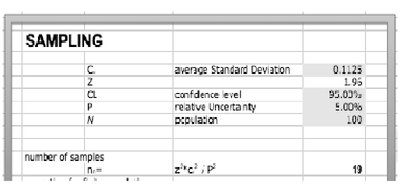
Sample size when estimating a mean

Value (coverage factor) estimated from target confidence level

$$n = \left(\frac{z \cdot CV_{\%}}{e_{\%}} \right)^2$$

Mostly unknown, shall be guessed for first run, measured afterwards

Target value for a precision of a mean estimate



See Statistics and Uncertainty for IPMVP 1:2014, Equation 16

Finite Population Correction

- If more than 5% of the population is sampled (e.g. small population), the confidence interval can be reduced by the finite population correction factor:

$$n_{\text{red.}} = \frac{nN}{n + (N-1)} \approx \frac{nN}{n+N}$$

- Or sample size could be reduced:

SAMPLING			
	C_v	average Standard Deviation	0.1125
	Z		1.96
	CL	confidence level	95.00%
	P	relative Uncertainty	5.00%
	N	population	100
number of samples			
	n_0=	$z^2 * c_v^2 / P^2$	19
correction for finite population			
		$(n_0 * N)/(n_0 + N)$	17

See Statistics and Uncertainty for IPMVP 1:2014, Equation 17

Statistics 13

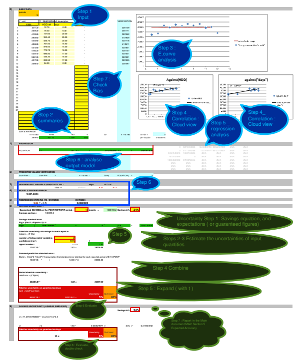
The Sampling Process

- Define the population.
- Determine if the population is homogenous or heterogeneous. If heterogeneous:
  - Segregate the population into groups.
  - Choose simple or stratified method.
- Decide on acceptable precision & confidence.
- Estimate or assume c_v ; calculate sample size.
- Make sample readings.
- Calculate and report actual c_v and precision.

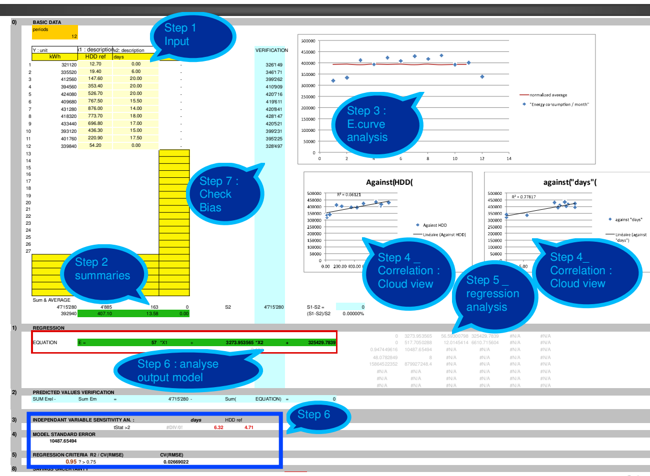
Statistics 14

Regression Analysis

Both regression analysis and uncertainty calculation will be illustrated using a calculation spreadsheet, appendix of our M&V Plan case study: School A



School A calculation sheet example



Regression Analysis

- A statistical procedure used to find relationships among a set of variables
- Dependent variable:
  - Energy
- Independent variables:
  - Weather
  - Occupancy
  - Production volume
  - Time
  - ...

Statistics 17

Steps in Regression Analysis

- Collect data (Step 1)
  - Collect significant data
  - Check relevance
  - Input data
- Screen data (Step 2)
  - Check Summaries
- Check energy curve and cycle (Step 3)

Statistics 18

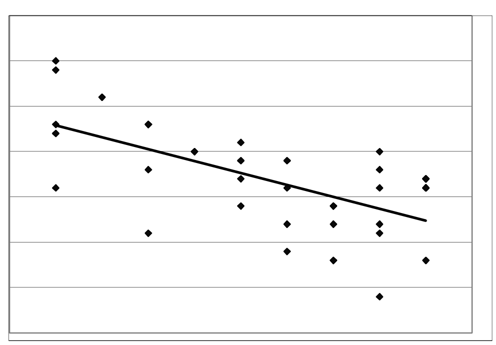
Steps in Regression Analysis

- Scatter plot Step 4
  - Graphical representation of data
- Correlation Step 4
  - The measure of the strength and direction of the relationship between the variables
- Regression Step 5
  - A model for predicting one variable from other variable(s).

Statistics 19

Scatter plot Step 4

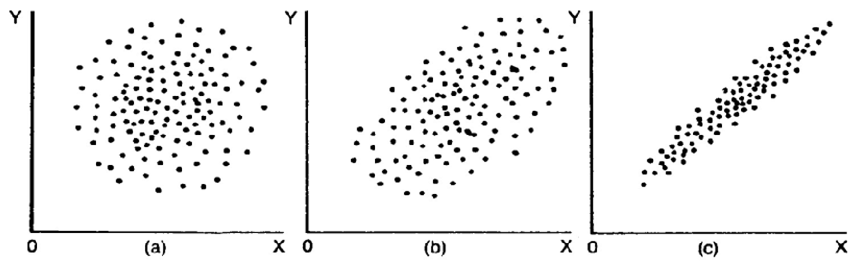
- Shows visually:
  - The strength of the relationship between the variables
  - The direction of the relationship between the variables
  - Linear or non-linear relationship
  - Existence of outliers



Statistics 20

Correlation

Step 4



- Correlation is only concerned with strength of the association between two variables.
- No causal effect is implied with correlation.

Statistics 21

Regression Models

Step 5

- Linear Regression

$$Y = b_0 + b_1 X_1$$

- Multiple Linear Regression

$$Y = b_0 + b_1 X_1 + b_2 X_2 + \dots b_k X_k$$

- Nonlinear model:

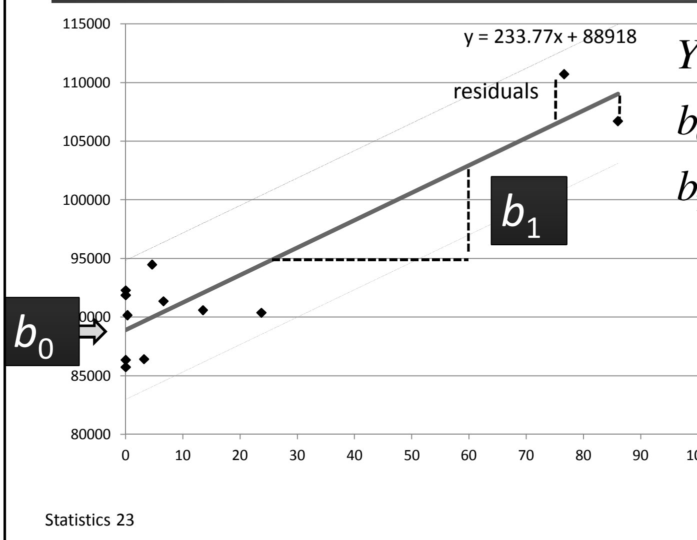
$$Y = f(X)$$

The linear regression equation provides an estimate of the population regression line.

Statistics 22

Step 5

Linear Regression Model



$$Y = b_0 + b_1 X$$

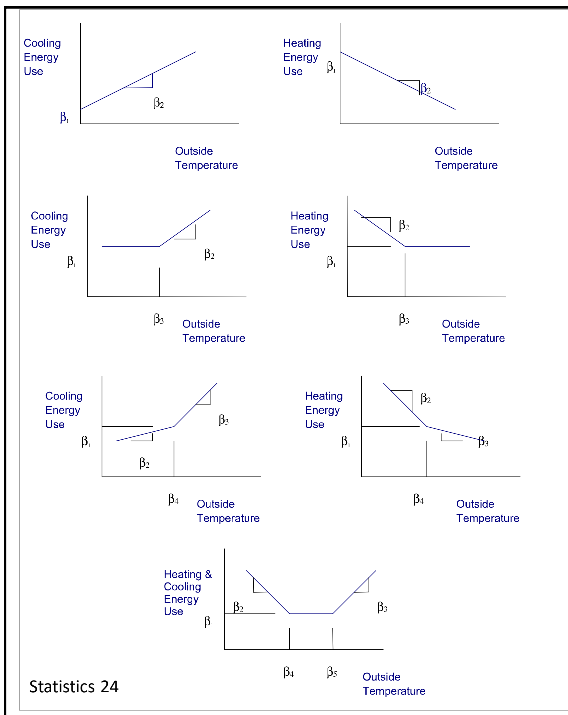
$$b_0 \Rightarrow \text{intercept}$$

$$b_1 \Rightarrow \text{slope}$$

Statistics 23

Step 5

Other linear regression models



The 5 models at the bottom are "piece-wise" regression models,

Statistics 24

Linear Regression - Example

Step 5

Create Linear regression model from Energy Consumption data:

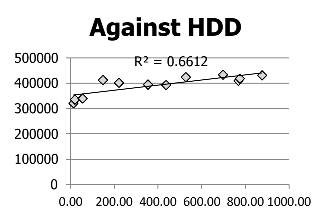
File: Example Option C.xls

Meter Reading Date	Days	Heating Degree Days	Gas Consumption mcf
February 5, 2008			
March 5, 2008	29	650	210'692
April 7, 2008	33	440	208'664
May 6, 2008	29	220	157'886
June 5, 2008	30	150	120'793
July 7, 2008	32	50	116'508
August 7, 2008	31	20	107'272
September 5, 2008	29	14	95'411
October 6, 2008	31	29	126'423
November 6, 2008	31	125	149'253
December 4, 2008	28	275	166'202
January 6, 2009	33	590	221'600
February 5, 2009	30	723	224'958
	366	**3'286**	**1'905'662**

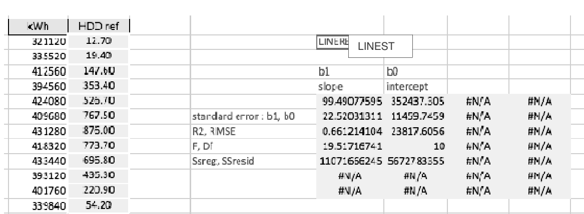
Linear regressions using Excel

Step 5

- Create a correlation graph using a cloud diagram
- Create a trend line



- Try to configure a function « Linest » and explore the elements of data calculated (see Excel help for « Linest »)



kWh	HDD ref					
321120	12.70		LINEST			
335520	19.40					
412560	147.60		b1	b0		
394560	353.40		slope	intercept		
424080	526.70		99.49077595	352437.305	#N/A	#N/A
409680	767.50	standard error : b1, b0	22.52031311	11459.7459	#N/A	#N/A
431280	875.00	R2, RMSE	0.661214104	23817.6056	#N/A	#N/A
418320	773.70	F, Df	19.51716741	10	#N/A	#N/A
433440	695.80	Ssreg, SSresid	11071666245	5672783355	#N/A	#N/A
393120	435.30		#N/A	#N/A	#N/A	#N/A
401760	220.90		#N/A	#N/A	#N/A	#N/A
339840	54.20					

Simple vs. Multiple Linear Regression

Step 5

$$Y = \beta_0 + \beta_1 X_1 + \varepsilon$$

- One dependent variable *Y* predicted from one independent variable *X*
- One regression coefficient
- ***R*²**: proportion of variation in dependent variable *Y* predictable from *X*

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots \beta_k X_k + \varepsilon$$

- One dependent variable *Y* predicted from a set of independent variables (X_1, X_2 …. X_k)
- One regression coefficient for each independent variable
- ***R*²**: proportion of variation in dependent variable *Y* predictable by set of independent variables (*X*)

Statistics 27

Degree of Correlation Coefficient of determination

Steps 4,5,6

- Pearson's Correlation Coefficient *r*: A measure of the degree to which two variables are **linearly** related

$$-1 \le r \le 1$$

- Coefficient of Determination R^2: (>0.75)
- Coefficient of variation of the RMSE: CV_{RMSE} : (<0.20)

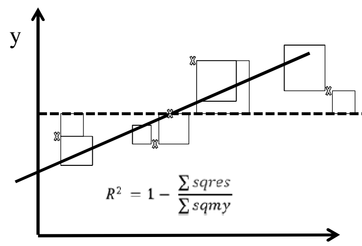
Both R^2 and CV_{RMSE} are good indicators of the quality of a model

Statistics 28

Degree of Correlation Coefficient of determination

Steps 4,5,6

- R^2, the *Coefficient of determination*
  - quantify the proportion of variability in a data set that is accounted for by the statistical model.
  - The better the model fits the data in comparison to the simple average, the closer the value of R^2 is to 1.
  - If R^2 is 0.9 one can say that 90% of the variation of Y may be described by the model.
  - R^2 is improper to qualify models with low slopes (as they are close to the average value) and hence should not be used to qualify the dispersion of the observations.



□ Square of the distance btw observation in y and mean value of y: *sqmy*

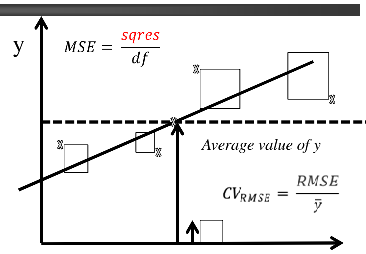
□ Square of the distance btw observation in y and modeled value of y: *sqres*

Statistics 29

Degree of Correlation Coefficient of variation of RMSE

Steps 4,5,6

- CV_{RMSE} is a different - albeit similar- indicator
  - it calculates the proportion between the dispersion of the observations (RMSE), and the average value of the dependent variable.
  - The closest CV_{RMSE} is to 0, the better the model fits to the observations.
  - If CV_{RMSE} is 0.20, one can say that the magnitude of model error to the average value is 20%.

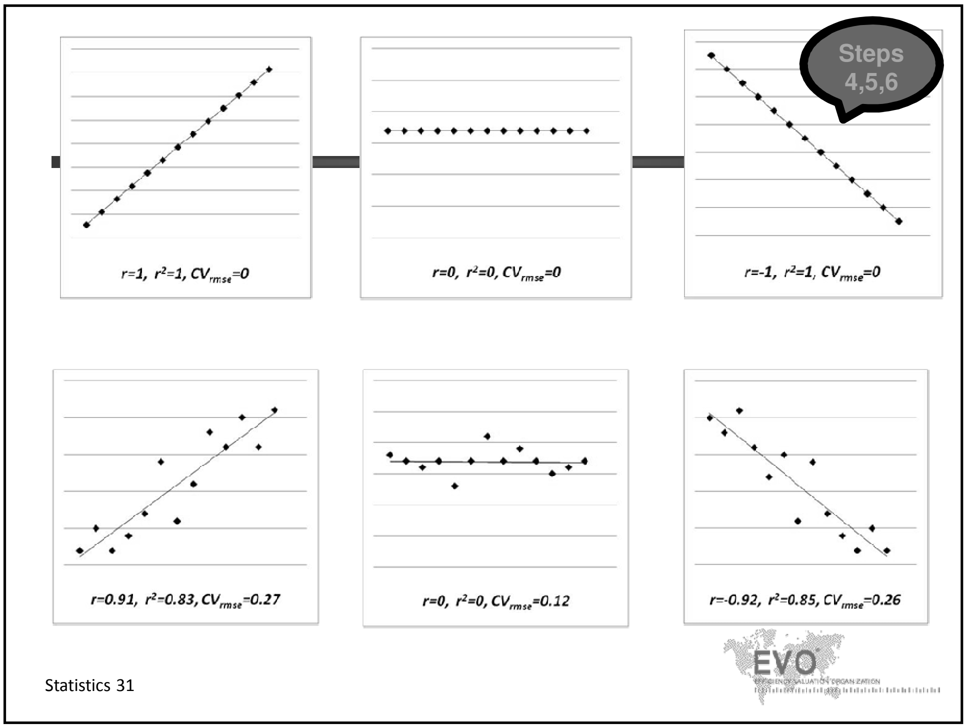


□ Square of the distance btw observation in y and modeled value of y: *sqres*

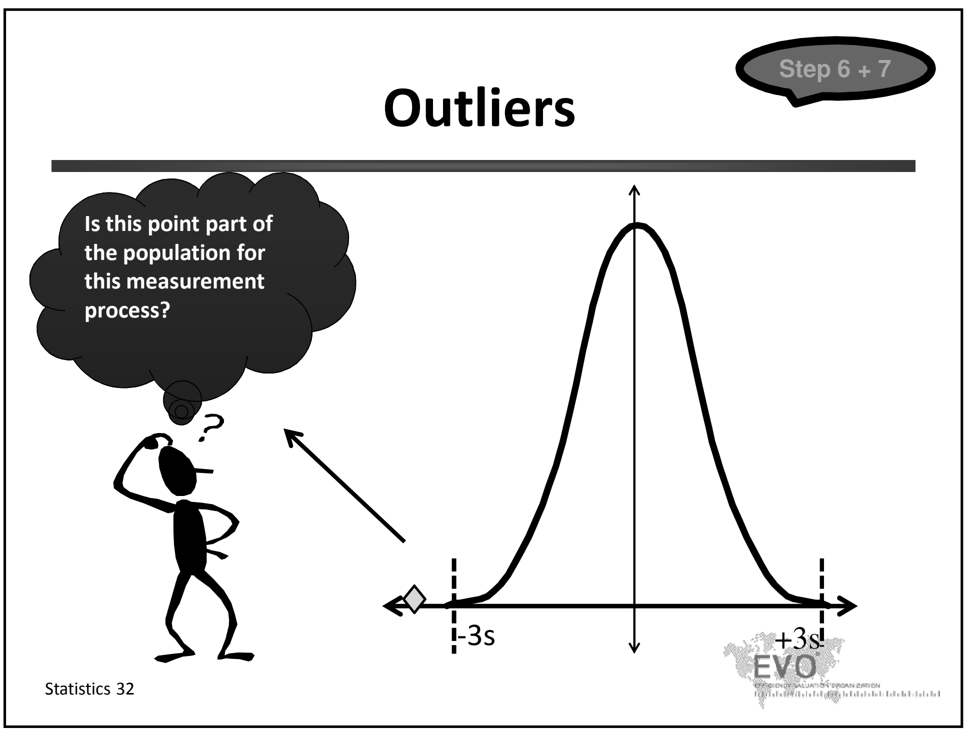
□ "Average" of the sum of squared distance btw observations in y and modeled value of y: *MSE*

↑ Root square of MSE: *RMSE*

Statistics 30



Steps 4,5,6
r=1, r²=1, CV_rmse=0
r=0, r²=0, CV_rmse=0
r=-1, r²=1, CV_rmse=0
r=0.91, r²=0.83, CV_rmse=0.27
r=0, r²=0, CV_rmse=0.12
r=-0.92, r²=0.85, CV_rmse=0.26
EVO
Statistics 31

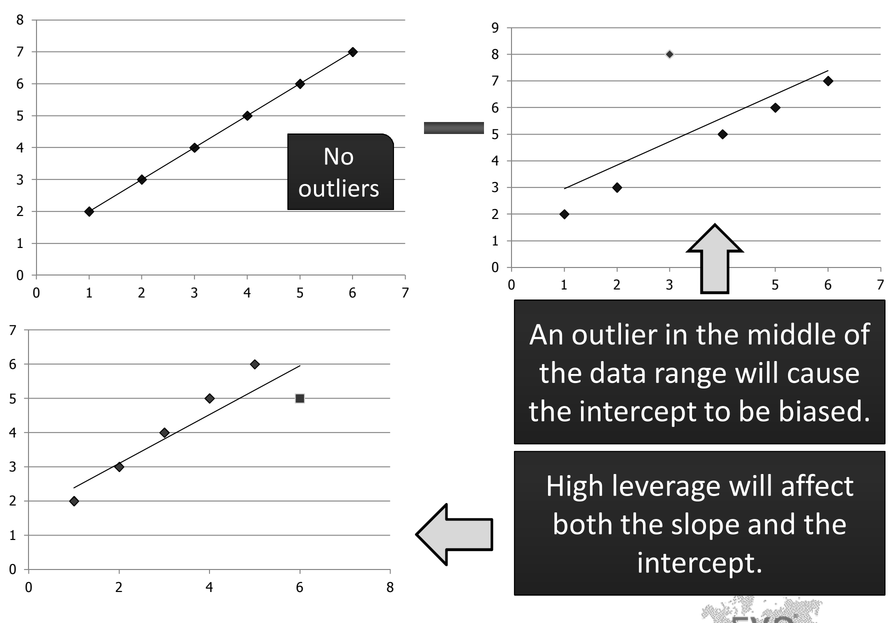


Step 6 + 7
Outliers
Is this point part of the population for this measurement process?
-3s
+3s
EVO
Statistics 32

Outliers

- Outlier is an observation that is numerically distant from the rest of the data.
- It can change statistics:
  - Can bias the mean in a small sample or if very extreme;
  - Can increase the standard deviation;
  - In regression can change slope or intercept, r^2

Statistics 33

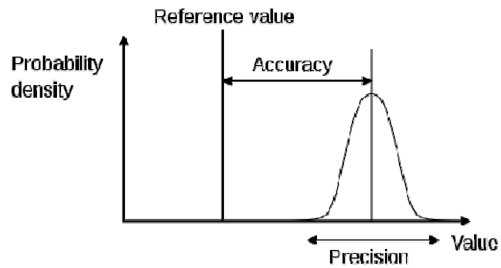


Statistics 34

Bias Check

Step 7

Performing a bias check allows, in principle to be sure that the sum of the predicted values matches the observed values for the reference data. This bias (or accuracy on the predicted reference period energy consumption) should be lower than 0.005%



An easy technique to perform this test is to plug in the reference model the data observed and to sum up the predicted energy consumptions for the same period. The difference between this sum and the total observed (or invoiced) for the same period should be such that its relative value to the observed total should be lower than 0.005%.

Introduction 35

Regression model validity tests

- A simple or multiple variable regression model based on the OLS (Ordinary Least Square) supposes a number of basic hypothesis to be true. Some tests help validate that the model provides a good description of the underlying reality. Some of the tests are detailed in a separate course.
- Be careful when using RMSE in uncertainty calculations. In case of doubts remember to be on the conservative side.
- Doubts : Many outliers, R^2 and Cv_{RMSE} are close to their limits, CV(RMSE) is above 10%.

Statistics 36

Uncertainty and rounding

Statistics 37

Uncertainty: a key topic for M&V

- Balancing uncertainty and costs :
  - What is uncertainty ?
  - How do we express uncertainty ?
  - How do we assess uncertainty ?

Uncertainty is ultimately about confidence…

Statistics 38

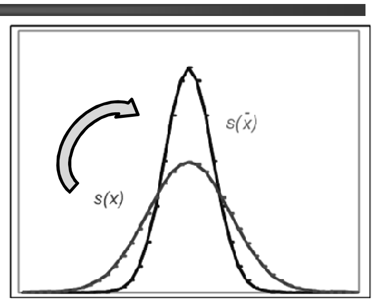
Uncertainty & Confidence

- The M&V Plan, (IPMVP Core Concepts 2014, Chapter 7.11) should indicate the expected accuracy associated with the *measurement, data capture*, *sampling* and *data analysis.*
  - This assessment should include qualitative and feasible quantitative determination of the ***confidence interval*** within which one expects the true savings value would be.
  - It is also requested to state the ***confidence level***: the probability to have the ***true*** savings result/measurement within the defined ***confidence interval (advanced M&V course).***
- Let us take an example.

Statistics 39

Sample standard deviation of the mean

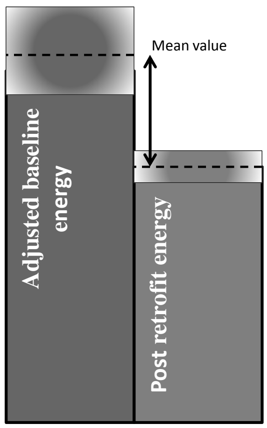
- Synonym: **Standard Error (of the mean)**
  (IPMVP : SE)
- It represents the variation associated with a **mean value**. It is less than the sample standard deviation because it estimates the variation of averages, which tends to be more "centered" and hence less spread than the original population from which it was derived.
- This equation implies that sampling error decreases as sample size increases.
- This is important because it suggests that if we want to make sampling error as small as possible, we need to use as large of a sample size as we can manage.



$$s(\bar{x}) = \frac{s}{\sqrt{n}}$$

Statistics 40

Uncertainty & Confidence



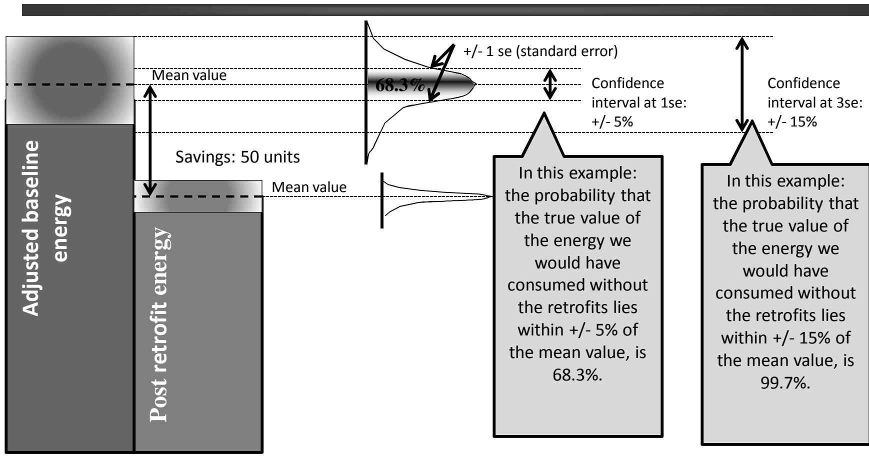
Savings = (Baseline energy - Reporting-Period energy)

+/- Routine adjustments

+/- Non-Routine adjustments

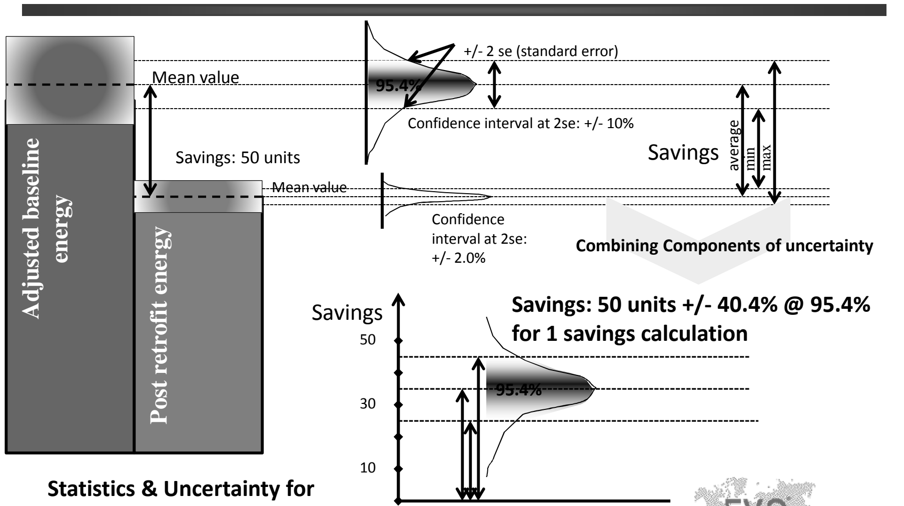
Consider an adjusted baseline energy consumption of 200 units and a guaranteed savings value of 50. The relative standard error of the modeled adjusted baseline energy is, say: +/- 5%, and the relative standard error of the measured post retrofit energy is: +/- 1.0 %.

Confidence levels and intervals



Statistics & Uncertainty for IPMVP 2014 - 1.1

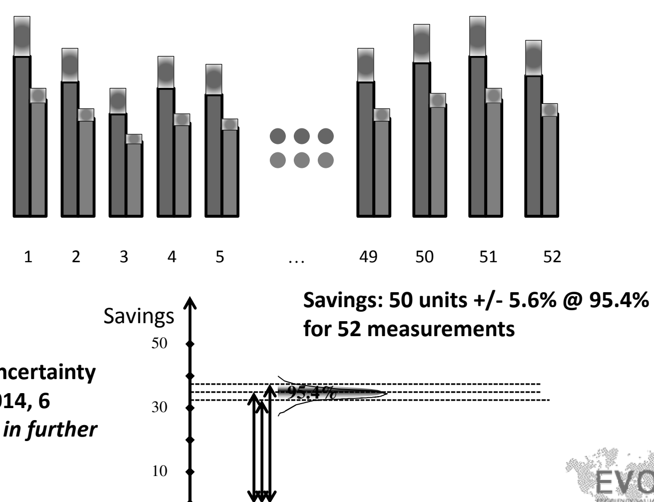
Confidence levels and intervals



Statistics & Uncertainty for IPMVP 2014, 5

Statistics 43

Confidence levels and intervals



Statisics & Uncertainty for IPMVP 2014, 6
Math details in further slides…

Statistics 44

Steps in Combining Uncertainties

1. Specify
2. Identify and estimate the components
3. Convert to Standard Deviations
4. Combine, u_c
5. Expand, $U\ (k)$
6. Evaluate
7. Report

Step 1

Step 2

Step 3

Step 4

Step 5

Step 6

Step 7

Statistics 45

Step 1: Write the Savings Equation

Step 1

- A mathematical formula that shows how all the necessary "input" quantities are combined to obtain measurement result:

Energy Savings = $E_b - E_r$ ⇒ $y = x_1 - x_2$

Input quantities (x_i):

E_b - adjusted baseline energy

E_r - reported period energy (adjusted)

Statistics 46

Step 2-3: Estimate the uncertainty of the "input" quantities, *u*

Step 2,3

- If they are estimated by statistical methods (e.g. from regression equation, etc.) use relevant standard error of the estimate.
- If not, apply non-statistical methods based on *a priori** distributions and:
  - Previous measurement data
  - Experience and knowledge
  - Manufacturer's specifications
  - Data from calibration

Statistics 47

Step 4: Combining

Step 4

- To get standard uncertainty of the final result, u_c, the uncertainties of input components shall be combined.

Statistics 48

How To Combine Uncertainties? Special Simple Case 1

Step 4

- If the model function *f* is a **sum or difference** of the input quantities X_{i}, then simply add standard uncertainties in quadrature.

$$y = x_1 \pm x_2 \pm x_3 \pm .....$$

$$u_c = \sqrt{u_{x_1}^2 + u_{x_2}^2 + u_{x_3}^2 + ...}$$

Statistics and Uncertainty for IPMVP 1:2014, Chapter 5, Equation 19

Statistics 49

How To Combine Uncertainties? Special Simple Case 2

Step 4

- If the measurement equation consists entirely of multiplication and divisions, then the **relative standard uncertainties** can simply be added in quadrature.

$$y = \frac{x_1 \cdot x_2}{x_3}$$

Statistics and Uncertainty for IPMVP 1:2014, Chapter 5, Equation 20

$$\frac{u_c}{y} = \sqrt{\left(\frac{u_{x_1}}{x_1}\right)^2 + \left(\frac{u_{x_2}}{x_2}\right)^2 + \left(\frac{u_{x_3}}{x_3}\right)^2}$$

Statistics 50

Step 5: Computing Expanded Uncertainty *U*

Step 5

- An expanded uncertainty quantifies how much a measurement (individual or combined) result will deviate from the measurand with a **given probability.**
- Formula is:

$$U = k \cdot u_c$$

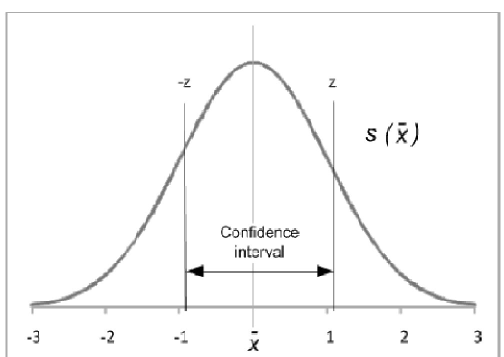
Statistics and Uncertainty for IPMVP 1:2014, Chapter 1.3 : Precision

- The coverage factor *k* depends on a coverage probability and distribution attributed to the measurand.

Statistics 51

Step 5: Computing Expanded Uncertainty *U*

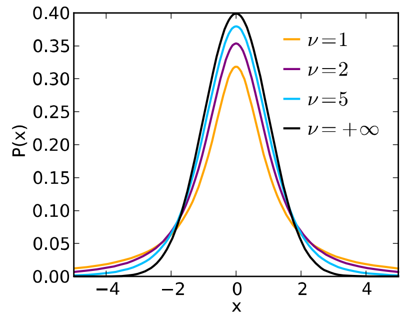
K: Z value Or t values	Confidence level
1	68.3 %
1.64	90 %
1.96	95 %
2	95.4%
3	99.7 %
6	99.9999998 %



Statistics 52

Step 5: Computing Expanded Uncertainty *U*

- When number of observations is lower than 100, the normal distribution may not reflect the correct distribution of the errors.
- In principle one should then find the adequate distribution to be used
- However, very often, if the distribution is bell shaped one can use the Student's distributions family.

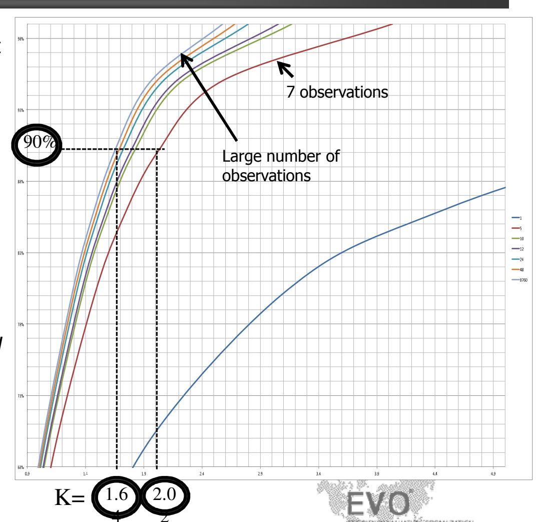


T Student distributions for different df. See also Statistics and Uncertainty for IPMVP 2014 Table 1

Statistics 53

Step 5: Computing Expanded Uncertainty *U*

- Extract of the cumulative function (CDF) of some Student t distributions for 1 parameter :
- The brown CDF, on the right, shows the k coverage factor to be used, for a given Confidence level for 7 observations
- The grey CDF, on the extreme left, shows the k coverage factor to be used, for a given Confidence level for approx. 8760 observations (The *Normal* distribution)



Statistics 54

Step 6: Evaluate

Step 6

- Is it reasonable? Does it make sense?
- Were the calculations done properly?
- Have all components been included?
- What component contributes the most?
- Does the uncertainty need to be reduced to meet needs?

Statistics 55

Step 7: Report the Uncertainty

Step 7

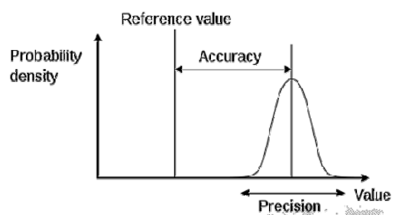
- Result ± Expanded Uncertainty
- Document in the Annex of M&V Plan:
  - Uncertainty components
  - Type of evaluation (calc. or estim.)
  - How they are combined
  - Level of confidence (*p*)
  - Make reference to the Statistics and Uncertainty for IPMVP EVO 10100 - 1:2014

Statistics 56

Rounding

- In science and engineering, convention dictates that **<u>unless a margin of error is explicitly stated</u>**, the number of significant figures used in the presentation of data should be limited to what is **warranted by the precision*** of those data.

**Precision refers to the stability of that measurement, when repeated many times. While accuracy refers to the closeness to the true value.*



Statistics 57

Rounding

- The numerical values of standard uncertainty $u_c(y)$ and expanded uncertainty U should be given with **the appropriate number of** significant digits: *simply the number of figures that are known with some degree of reliability.*
- Output (y) and input estimates (x_i) should be rounded to be consistent with their uncertainties.
- Round the final results not intermediate ones.

Statistics 58

Next Topic

1. Introduction
2. Key Concepts
3. Short Examples
4. M&V Planning
5. Critical Issues
6. Statistics
7. **Retrofit Isolation Details**
8. Option C Details
9. Option D Details
10. Other M&V applications
11. Summary and review of a detailed M&V plan

Statistics 59

M&V Fundamentals

& the

International Performance Measurement and Verification Protocol

For Energy Managers

Retrofit Isolation Details

Retrofit Isolation - Program

- **Option B**
  - Review of Method
  - Detailed Example
  - Summary of Issues
- **Option A**
  - Review of Method
  - Detailed Example
  - Summary of Issues

Retrofit Isolation
Options A & B - Method

Isolate the ECMs energy use from that of the rest of facility.

Energy use outside the Measurement Boundary has no effect on **reported** savings, but may affect the **actual** savings.

Retrofit Isolation
Options A & B - Method

Interactive effects should be evaluated during the design stage to see if they are significant.

- If they are not, they can be ignored.
- If they are significant,
  - the boundary could be moved to include them;
  - additional measurements could be made to account for them.

Option B Step 1 (Scope)

- Decide location of the *measurement boundary* (isolation meter locations).
- Assess *interactive effects* beyond the boundary.
- Decide what *independent variables* affect energy use.
- Design the metering system.
- Decide the baseline period.

Retrofit Isolation 5

Option B   New Example

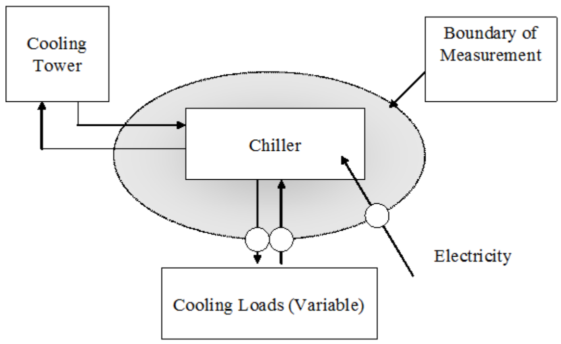
A new electric chiller replaces an old electric chiller (cooling tower and entering condenser water temperature are unchanged).

- Electricity use is affected primarily by: a) chilled water load, and b) chiller efficiency.
- There will be some reduction in cooling tower energy due to lower heat rejection. Ignore this interactive effect for simplicity of the example.

Retrofit Isolation 6

Measurement Boundary

Meter chilled water energy & compressor electricity.



Retrofit Isolation 7

Baseline Period

The baseline period will be a *performance test* of the old chiller immediately before its removal.

Retrofit Isolation 8

Option B Step 2 (Basis)

Decide to re-state baseline performance (old chiller) under post-retrofit period conditions.

This basis for adjustments will report savings as "avoided energy use" or "cost avoidance."

Option B Step 3 (Baseline data)

- Install thermal energy and electricity meters.
- Calibrate meters.
- Collect full operating characteristics of the old chiller - average hourly load (tons) and kW.

Option B Step 3 (Baseline data)

Gathered data from several weeks of testing:

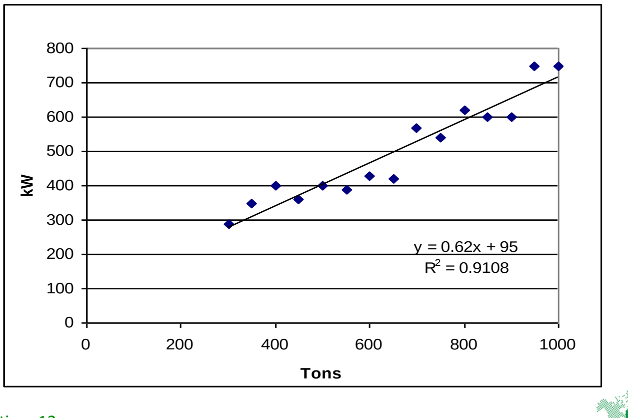
Tons	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
Measured kW	290	350	400	360	400	390	430	420	570	540	620	600	600	750	750

For later reference:

- Total of cooling load data = 9,750 tons
- Total of electrical measured average kW data = 7,470 kW

Option B Step 4 (Model)

Establish baseline load-energy relationship by regression analysis:



Option B Step 4 (Assess model)

- Assess uncertainty, i.e. data scatter from the trend line.
- R^2 of 91% is good.
- *If* R^2 is below 75% and/or C_vRMSE > 20%, consider:
  - taking more readings,
  - improving accuracy/repeatability of thermal meter (too bad you already bought one),
  - adding more variables such as outdoor temperature or wet-bulb temperature (if using cooling tower),
  - try a second order equation (with caution).

Option B Step 5 (Bias Check)

Check for mathematical model *Bias* as follows:

- Use the mathematical model to predict total electricity use for the **15** test period cooling loads.
- Since they total **9,750 tons** a shortcut calculation is:

  = (0.62 * **9,750)** + (95 * **15**)

  = 6,045 + 1,425

  = 7,470 kW
- Total of actual electricity readings = 7,470 kW
- Therefore bias is 0 kW (0.0000%). **The model is OK.**

(ASHRAE criteria is that bias must be < 0.005%)

Option B Step 6 (Predict)

- Replace the chiller.
- Measure & record hourly average cooling load (Tons) and electrical load (kW) on the new chiller.
- Plug new independent variable load data in Tons into the old chiller's mathematical model:

$$kW = 0.62 * Tons + 95$$

to predict what monthly kWh (and peak kW) would have been with the old chiller under current load conditions.

Retrofit Isolation 15

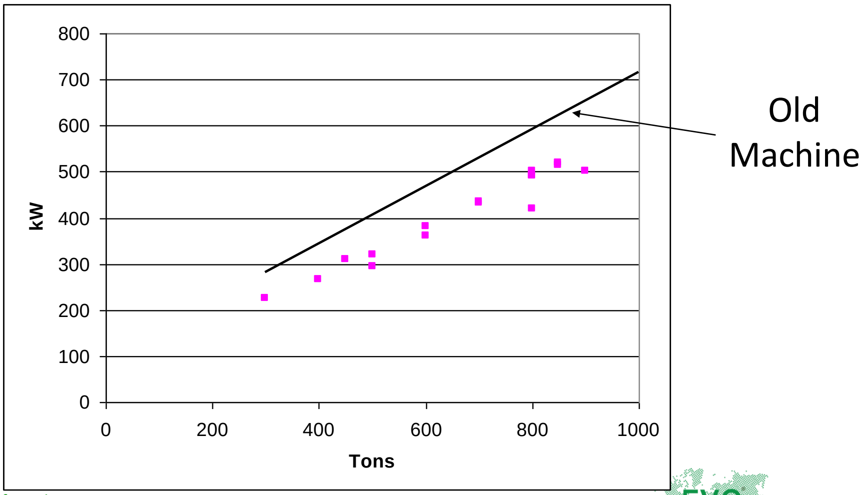
Option B Step 6 (Predict)

For One Day

	New Machine		Old Machine			Savings
	Actual Post-Retrofit Data		Predicted Electricity (kW)			
			Factors			
Time	Avg kW	Avg Load	Fixed	Load	Total	kW
23-Jul-09		Tons	95	0.62		
6:00	500	900	95	558	653	153
7:00	420	800	95	496	591	171
8:00	225	300				?
9:00	265	400	95	248	343	78
10:00	310	450	95	279	374	64
11:00	320	500	95	310	405	85
12:00	382	600	95	372	467	85
13:00	435	700	95	434	529	94
14:00	500	800	95	496	591	91
15:00	490	800	95	496	591	101
16:00	520	850	95	527	622	102
17:00	515	850				?
18:00	490	800	95	496	591	101
19:00	430	700	95	434	529	99
20:00	360	600	95	372	467	107
21:00	295	500	95	310	405	110

Retrofit Isolation 16

Option B Step 6 (Predict)



Retrofit Isolation 17

Option B Step 7 (BLA)

- At least annually, review Static Factors to ensure baseline is still appropriate (e.g. cooling tower difficulties might have increased average condensing temperature).
- If necessary, re-compute baseline data, mathematical model and predicted use.

We will assume no BLA is needed in this example.

Retrofit Isolation 18

Option B Step 8 (kWh Savings)

- We showed savings for 16 hours of one day (you computed two of them).
- For the entire month of July, the hourly savings were totaled.
- The total July consumption savings were found to be **55,240 kWh** (calculations is not shown).

Option B Step 8 (kW Savings)

To find the July demand savings, determine:

- the time of the utility meter's peak demand - July 29, 15:50
- new chiller tons at July 29, 15:50 - **1,000 tons**
- new chiller kW at July 29, 15:50 – **616 kW**

At **1,000** tons, the baseline model predicts **715** kW for the old chiller. So demand savings for July are 715 – 616 = **99 kW.**

Option B Step 9 (Valuing)

July 2009	Units	Marginal Price	Value
Consumption	55,240 kWh	$0.0723	$3,994
Demand	99 kW	$12.57	$1,244
Total			**$5,238**

Note: What is a better way to express the savings?

Option B Issues - Metering

- Establish meters at a boundary which minimizes unmeasured energy (interactive) effects with systems outside the boundary.
- Accuracy of meters
- Cost of maintaining meters
- Coping with missing data
- Synchronizing demand with utility meter

Option A
Key Parameter Measurement

- Only requires measurement of *key* parameters – i.e. some estimation (assumption) is allowed.
- Measure *key* parameters, estimate others where:
  - plausible errors will not significantly affect reported savings, OR
  - estimated factors are not the responsibility of the entity whose performance is being evaluated by the M&V.
- Must assess the impact of possible errors due to the estimate.

In all other respects Option A is the same as Option B.

Option A Example

As before, a new electric chiller replaces an old electric chiller.

(Analysis will be done somewhat differently just to show there are many ways to analyze any given situation.)

Option A Step 1 (Scope)

- Decide what variables affect annual energy savings:
  - chiller efficiency
  - annual chiller cooling load (ton-hours).
- Consider whether plausible values of both variables make one the *key* factor in governing possible error.

Option A Step 2 (Assumption)

- Chiller efficiency is chosen as the *key* parameter for either or both reasons:
  - Ratio of plausible variation in chiller efficiency is largest.
  - Improved chiller efficiency is the objective of the ECM.
- Therefore:
  - **Measure** the change in chiller efficiency.
  - **Assume** the annual chiller load to be 2,000,000 ton-hours per year (also stipulate the load profile: hours at each load level and the peak load for each operating month).

Option A Step 3 (Meter Design)

- To measure fairly, measure new and old chiller with the same meter, at the same location.
- Plan two efficiency tests:
  – old chiller before removal;
  – new chiller after installation and commissioning.

Option A Step 3 (Meter Design)

- Decide isolation meters needed:
  – chilled water thermal energy (tons),
  – compressor electricity (kW).
- Design the metering system:
  – Independent digital recording true RMS wattmeter (not the chiller manufacturer's), cost $1,000.
  – Recording thermal meter with clamp-on ultrasonic flow meter and independent temperature sensors on the pipe surface. Calibrated before installation, cost $5,000.

Option A Step 3 (Meter Design)

Meter accuracies:

– Thermal Meter: **+/- 1.0%** *of reading*

over a range of 200 - 900 tons

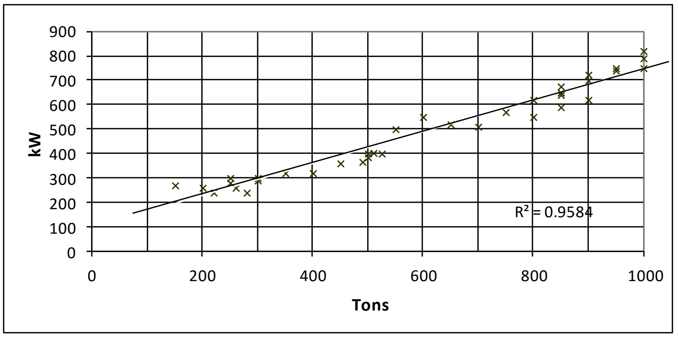
– Electricity: +/-0.5% *of full scale* 1,000 kW

(= +/-5 kW)

- expected range of readings 150 to 800 kW
- actual accuracy will be **+/- 0.6% to +/- 3.3%**

Option A Step 4 (Baseline)

Measure old chiller performance characteristic and plot it.



R^2 is computed just to assess how well behaved the data is.

Option A Step 4 (Baseline)

Establish Mean kW and kW/ton in each load range or 'bin'.

Tons	Mean kW	kW/ton	Time	Product
200	250	1.250	5%	0.0625
300	290	0.967	20%	0.1933
400	315	0.788	20%	0.1575
500	375	0.750	15%	0.1125
600	435	0.725	15%	0.1088
700	505	0.721	10%	0.0721
800	600	0.750	5%	0.0375
900	700	0.778	5%	0.0389
1000	805	0.805	5%	0.0403
			100%	**0.823**

Old Chiller Weighted Average kW/ton = **0.823**

Option A Step 4 (Baseline)

E.load kW	T.load Tons	date	time
244.9148	152	07.05.06	09:30:56
245.903	158	07.05.06	10:15:10
...			
246.5858	162	09.05.06	08:35:20
256.277	210	09.05.06	09:45:00
255.1385	205	09.05.06	09:00:12
...			
261.6428	232	06.06.06	11:02:20
...			
245.4035	155	05.06.06	09:20:54
...			
244.9148	152	17.06.06	08:40:00
...			
248.009	170	07.07.06	12:00:50
246.242	160	07.07.06	11:45:30
...			
259.8725	225	17.07.06	10:12:00

Establish Mean kW and kW/ton in each load range or 'bin'.

The Bin Method is developed from historical data. Data collection may be performed using load range bins which are created by recording all hourly occurrences of closely related load data. Historical records that fall into a certain range of the load are collected and then distinguished by the mid-point of the range.

Data extracted from historian for the first 100 T 'bin' (150-249.99 Tons), 5' samples

Option A Step 5 (Assess Model)

Old chiller performance test data fits the trend line with R^2 = 96%.

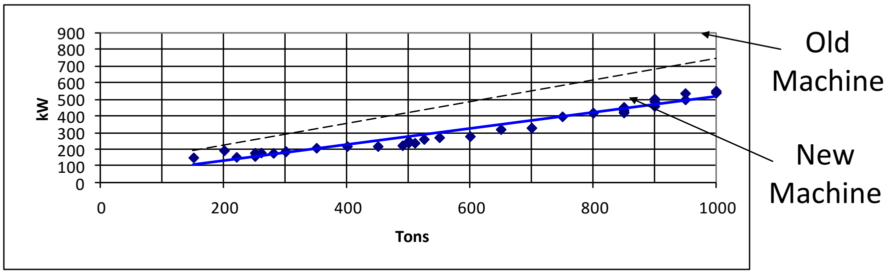
Data dispersion facts provide acceptable certainty.

If they were not acceptable certainty, consider:

- taking more readings,
- getting a more accurate wattmeter,
- use more variables such as outdoor temperature or wet-bulb temperature (if using cooling tower),
- try second order equation (with caution).

Option A Step 6 (New Chiller)

The same test is done on the new chiller, plotted below.



Option A Step 6 (New Chiller)

Tons	Mean kW	kW/ton	Time	Product
200	175	0.875	5%	0.0438
300	190	0.633	20%	0.1267
400	205	0.513	20%	0.1025
500	250	0.500	15%	0.0750
600	300	0.500	15%	0.0750
700	350	0.500	10%	0.0500
800	405	0.506	5%	0.0253
900	480	0.533	5%	0.0267
1000	550	0.550	5%	0.0275
			100%	**0.552**

New chiller weighted average kW/ton = **0.552.**

Option A Step 7 (Energy Savings)

- Weighted average efficiency improvement:
  - Old Chiller = 0.823 kW/ton
  - New Chiller = 0.552 kW/ton

  Improvement = 0.271 kW/ton
- Assumed 2,000,000 ton-hours annual load.
- Energy Savings = 0.271 * 2,000,000

  = 542,000 kWh/yr

Option A Step 8 (Demand Savings)

Demand Savings (for the entire cooling season):

	Assumed Load	Computed Demand Reduction
May	500 tons	135.5 kW
June	800 tons	216.8 kW
July	900 tons	243.9 kW
Aug	1000 tons	271 kW
Sept	900 tons	243.9 kW
Oct	500 tons	135.5 kW
Total		1,246.6 kW-mo

Assume chiller peak demand coincides with the utility meter time of peak.

Option A Step 9 (Valuing)

Consumption Savings:

= 542,000 kWh * $0.0723/kWh

= **$39,187**

Demand Savings:

= 1,246.6 kW-mo * $12.57/kW-mo

= **$15,670**

Total savings:

= $39,187 + $15,670 = $54,857 for the season

How should we present the savings?

Option A (Future)

- Certainly verify periodically that key indicators of chiller efficiency are suggesting good performance.
  - Condenser pressure vs. average condenser water temperature.
  - Compressor amps as f(load).

Repeat the chiller test in future years if budget permits.

Option A Test 1

Now, suppose:

- old chiller = 0.71 kW/ton
- new chiller= 0.55 kW/ton

What would annual $ savings have been?

Option A Test 2

Now Suppose:

- Chiller tests were as original (0.271 kW/ton improvement).
- Annual load was 1,800,000 ton-hours.
- Peak loads are unchanged.

What would annual $ savings have been?

Retrofit Isolation 42

Option A Reports

If you assumed an annual load pattern, such as the 2,000,000 ton-hours, can you say "the avoided energy cost was $50,000 for the year?"

No!

It's better to say "based on IPMVP Option A tests in May of 2008 annual avoided energy costs are estimated to be $50,000."

Retrofit Isolation 44

Retrofit Isolation
Option A Issues - Assumption

What can you assume?

- Consider plausible assumption errors
- Consider responsibilities of the parties

Assume the parameter where error is not significant or where the parameter is not the responsibility of the party whose performance is being evaluated. Effort may be needed to get data to justify the assumption so that all can agree on it.

Manufacturer specs are assumptions under IPMVP (because they are not field measured).

Next Topic

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2. Key Concepts
3. Short Examples
4. M&V Planning
5. Critical Issues
6. Statistics
7. Retrofit Isolation Details
8. **Option C Details**
9. Option D Details
10. Other M&V applications
11. Summary and review of a detailed M&V plan

M&V Fundamentals

& the
International Performance Measurement and Verification Protocol

For Energy Managers

Option C Details

Option C - Program

- Review of Method
- Detailed issues

Option C Method

- The *whole facility* is within the measurement boundary.
- Assesses performance of the whole facility, retrofitted ***and non-retrofitted systems*** or areas*.*
- Usually involves utility bills but may involve:
  - manual reading of utility meters,
  - automated reading of utility meters,
  - non-utility sub-meters.
- Apply the method to each meter separately (avoid adding meters of the same energy type before analysis).

Option C 3

Option C Step 1 (Scope)

- Identify the buildings/systems served by the meter.
- Select appropriate independent variables (often weather).
- Select the baseline period.

Option C 4

Option C Step 2 (Basis)

- Decide whether to adjust baseline data to the (variable) conditions of the reporting period or to a normal (fixed) set of conditions.
- Savings will be reported as either "avoided energy" (IPMVP Core Concepts 2014, Chapter 5.3.4) or "normalized savings" (IPMVP Core Concepts 2014, Chapters 5.3.5).
- In this example report savings as avoided energy.

Option C 5

Option C Step 3 (Baseline Data)

- Select 12 months of energy data (may need 13 utility bills).
- Select weather data for the exact same baseline period (synchronize days, don't use nearest calendar month).
- Assemble Static Factors gathered during the energy audit.

Option C 6

Option C Step 3 (Baseline Data)

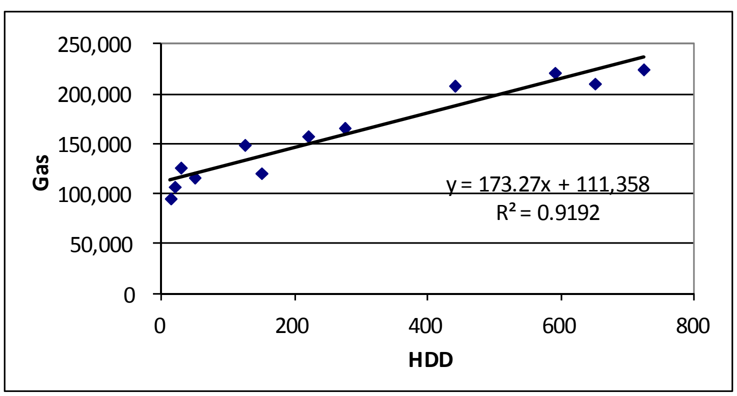
Let's drill into data of the previous Option C example

Meter Reading	Gas	Heating
Date	Consumption	Degree
February 5, 2008	units	Days
March 5, 2008	210,692	650
April 7, 2008	208,664	440
May 6, 2008	157,886	220
June 5, 2008	120,793	150
July 7, 2008	116,508	50
August 7, 2008	107,272	20
September 5, 2008	95,411	14
October 6, 2008	126,423	29
November 6, 2008	149,253	125
December 4, 2008	166,202	275
January 6, 2009	221,600	590
February 5, 2009	224,958	723
Total	**1,905,662**	**3,286**

Option C 7

Option C Step 4 (Model)

Establish baseline Gas-HDD relationship:



Option C 8

Option C Step 4 (Assess Model)

Assess the model (data scatter from the trend line):

- R^2 of 91.9% is good (usually acceptable R^2 is >75%).
- *If it were not good*, consider:
  - adjusting for the number of weekend days each period, as well as HDD.
  - choosing a two year baseline, if there is a good record of the Static Factors.

Therefore, accept the baseline mathematical model:

Gas = 173.27 * HDD + 111,358

Option C 9

Option C Step 5 (Bias Check)

Check for baseline model Bias as follows:

- Use the mathematical model to predict **annual** baseline gas use for the baseline's annual **3,286 HDD**:
  = (173.27 * **3,286** HDD) + (111,358 * **12**)
  = 569,365 + 1,336,296
  = 1,905,661
- Actual Baseline total is 1,905,662.
- Therefore, bias is 1 unit (= 0.00005%) **OK**

(ASHRAE criteria is that Bias must be < 0.005%)

Option C 10

Option C Step 6 (Predict)

After retrofit, for each month predict what the baseline gas use would have been under conditions of the current month's weather (i.e. the adjusted baseline).

Procedure:

1. Record the weather (HDD)
2. Plug HDD into the mathematical model:

Gas = 173.27 * HDD + 111,358

Option C Step 7 (BLA)

- Review current Static Factors to ensure there were no changes from recorded Baseline conditions, at least annually.
- If necessary, make BLAs (non-routine baseline adjustments).
  - Revise the baseline data.
  - Prepare a new mathematical model.

Option C Step 8 (Savings)

For this example, we decided to compare model predicted gas (adjusted baseline) to actual gas, to determine energy savings as "avoided energy use."

(Avoided energy use is derived using IPMVP Core Concepts 2014, Chapter 5.3.4)

Option C 13

Option C Step 9 (Valuing)

Apply the current full utility price to the adjusted baseline (Slide 12) and to the current gas use each month.

Determine "cost avoidance".

Option C 14

Option C Step 8 & 9 (Savings and Valuing)

Meter Reading Date	Reporting period data		Adjusted baseline data			Savings	
			Intercept (Baseload)	Slope (Weather Sensitive)	Total	Gas (units)	Value
	Consumption units	HDD	*Factors*				*Price =*
			111 358	*173,27*			*$ 6,232*
March 6, 2009	151 008	601	111 358	104 135	215 493	64 485	$ 401 871
April 4, 2009	122 111	420	111 358	72 773	184 131	62 020	$ 386 509
May 6, 2009	102 694	188	111 358	32 575	143 933	41 239	$ 257 001
June 5, 2009	111 211	250	111 358	43 318	154 676	43 465	$ 270 874
July 5, 2009	80 222	41	111 358	7 104	118 462	38 240	$ 238 312
August 6, 2009	71 023	15	111 358	2 599	113 957	42 934	$ 267 565
September 8, 2009	65 534	5	111 358	866	112 224	46 690	$ 290 972
October 9, 2009	77 354	12	111 358	2 079	113 437	36 083	$ 224 869
November 4, 2009	103 000	190	111 358	32 921	144 279	41 279	$ 257 251
December 10, 2009	115 112	300	111 358	51 981	163 339	48 227	$ 300 551
January 7, 2010	160 002	700	111 358	121 289	232 647	72 645	$ 452 724
February 4, 2010	145 111	612	111 358	106 041	217 399	72 288	$ 450 499
Total	**1 304 382**				**1 913 977**	**609 595**	**$ 3 798 998**

Option C 15

Option C Issues - Utility Bills

- An "estimated bill" is not valid data for the period. The next real reading will correct estimated consumption (and demand) but yields valid data for only the combined period (two months).
- The possibility of estimated bills creates delay in reacting to anomalies, making correction of seasonal operating errors difficult. Utility bill based *measurement* methods do not facilitate *monitoring* of savings.

Option C 16

Option C Issues - % savings

- It's hard to detect savings below 10%:
  - this is a rule of thumb; it is often higher,
  - depends on the length of the reporting period (see IPMVP Core Concepts 2014, Chapter 6.4),
  - should be based on the uncertainty of the savings, which for avoided energy use is largely the uncertainty of the regression model.
    - If uncertainty is high and savings are below 10%, the minimum amount of savings will become too small to justify the ECMs.

Option C 17

Utility Bill Software

Software for utility bill analysis:

- helps to manage utility bills for many buildings,
- helps early detection of billing errors,
- must show all input data, mathematical model used and all changes from raw data,
- should demonstrate that baseline model has no bias.

Option C 18

Next Topic

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Option C 20

M&V Fundamentals

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International Performance Measurement and Verification Protocol

For Energy Managers

Option D Details

Option D - Program

- Why – Why Not
- Method/Examples
- Industrial Processes
- Issues

Option D – Why?

- If missing either baseline or reporting period data, due to a lack of or bad meters, use computer simulation to "make up" data.
- To establish the impact of individual ECMs separately, by computer simulation.
- To determine a building performance relative to a standard .
- For LEED BD&C EA credit 5.

For new *buildings* see IPMVP Volume III, Part 1

Option D 3

Option D – Why Not

Option D can be expensive and complicated:

- Results are no better than assumptions.
- Special skills needed, special software.
- Hard to calibrate simulation to real energy data but necessary for reliable results.

Option D 4

Simulation during the design phase

During the design phase, a simulation model is often used to evaluate the building energy consumption

- If the building exists:
  - Build simulation model of baseline equipment and conditions.
  - Develop "what if" models to estimate performance of proposed measures.
  - Select most cost-effective package.
  - Compare proposed to baseline.

These simulations are used to *predict* savings from retrofits before construction.

Option D 5

Simulation during the design phase

- For a new building:
  - Build simulation model of baseline equipment and conditions, for example according to a standard requirement.
  - Develop "what if" models to estimate performance of proposed measures.
  - Select most cost-effective package.
  - Compare proposed to standard.

Option D 6

Option D – Basic Method

If no computer simulation of the building energy use has been performed during the design phase, proceed as follows:

i. Build a computer simulation model of energy use.
ii. Gather real energy use data.
iii. 'Calibrate' the computer model to make it fit the real energy data.
iv. Run the calibrated model with and without retrofits. Savings are the difference in energy use of the two runs.

Option D Examples

We will examine a building example, using the two IPMVP Core Concepts 2014, Chapter 6.5.4, Equations 1 & 2 approaches.

Option D Example - 1f)

- Various ECMs were implemented in a lecture/office building on a university campus including weatherization and new operating procedures.
- There is a district steam heating system and a central campus electric meter. The building has its own electric chiller.
- No building meters existed during the baseline.
- Building meters were added as part of the retrofit.

Option D Step 1 (Scope)

- Define system(s) and building to be simulated.
- Decide baseline period.

Option D Step 2 (Basis)

- Decide to report "avoided energy use" or "normalized savings".
- Choose to report savings under baseline conditions and long term average weather.
- So we report "normalized savings."

Option D Step 3 (Software)

- Select staff for simulation (e.g. BEMP or BESA certified).
- Select software and verify suitability for application.
- Document software name and version number.

Option D Step 4 (Baseline data)

- Gather following data :
  - Building size and shape,
  - Envelope characteristics,
  - Equipment size and efficiency.
- Record conditions of the baseline:
  - space temperatures at various seasons,
  - equipment operating hours, setpoints,
  - lecture schedules and occupancy,
  - office equipment.

Option D 13

Option D Step 5a (Calib. data)

Following retrofit construction:

- Collect 12 months of *post-retrofit* energy data;
- Collect weather data for the same 12 periods;
- Check *post-retrofit* occupancy patterns and space conditions (static factors).

Option D 14

Option D Step 5a (Calib. Data)

Post-retrofit period actual energy data - for Calibration

	Steam		Electricity		
	units	Days	kWh	kW	Days
Jan	1,200,000	31	140,000	340	31
Feb	1,100,000	28	120,000	350	28
Mar	1,000,000	31	140,000	350	31
Apr	800,000	30	150,000	380	30
May	300,000	31	160,000	450	31
June	200,000	30	170,000	570	30
July	200,000	31	190,000	650	31
Aug	200,000	31	195,000	650	31
Sept	400,000	30	180,000	640	30
Oct	500,000	31	160,000	600	31
Nov	800,000	30	150,000	380	30
Dec	1,000,000	31	120,000	320	31

Also get many other weather and operating parameters.

EVO

Option D Step 5b (Calibrate)

- Run simulation, with *post-retrofit* conditions and retrofitted equipment.
- Verify that model simulates actual indoor conditions properly.
- Check *monthly* predicted vs. actual post-retrofit energy for *all* energy types.
  - Monthly calibration ±15% / NMBE ±5%.

  (Normalized Mean Bias Error is deviation from annual use.)

EVO

Option D Step 5b (Calibrate)

The Normalized Mean Bias Error is calculated as follows:

$$NMBE = \frac{\sum^{n}(y_i - \hat{y}_i)}{(n-p) \times \bar{y}} \times 100$$

where:

n = number of data points or periods in the baseline period

$\hat{y}$ = simulation predicted data

y_i = utility data used for the calibration

$\bar{y}$ = arithmetic mean of the sample of n observations

p = 1

Option D 17

Option D Step 5c (Variances)

Compare Metered and Predicted values for each month of the post-retrofit period.

	Steam(units)			Electricity Consumption (kWh)			Electric Demand (kW)		
	Metered	Predicted	**Diff**	Metered	Predicted	**Diff**	Metered	Predicted	**Diff**
Jan	1,200,000	1,120,000	**-7%**	140,000	150,000	**7%**	340	330	**-3%**
Feb	1,100,000	1,115,000	**1%**	120,000	121,000	**1%**	350	330	**-6%**
Mar	1,000,000	1,060,000	**6%**	140,000	138,000	**-1%**	350	330	**-6%**
Apr	800,000	823,000	**3%**	150,000	145,000	**-3%**	380	380	**0%**
May	300,000	305,000	**2%**	160,000	175,000	**9%**	450	480	**7%**
June	200,000	188,000	**-6%**	170,000	165,000	**-3%**	570	600	**5%**
July	200,000	194,000	**-3%**	190,000	199,000	**5%**	650	700	**8%**
Aug	200,000	202,000	**1%**	195,000	200,000	**3%**	650	700	**8%**
Sept	400,000	402,000	**1%**	180,000	185,000	**3%**	640	650	**2%**
Oct	500,000	495,000	**-1%**	160,000	158,000	**-1%**	600	500	**-17%**
Nov	800,000	795,000	**-1%**	150,000	147,000	**-2%**	380	380	**0%**
Dec	1,000,000	1,070,000	**7%**	120,000	108,000	**-10%**	320	330	**3%**
Ann	7,700,000	7,769,000	**1%**	1,875,000	1,891,000	**1%**	5,680	5,710	**1%**

Monthly differences indicate whether prediction follows actual patterns properly. Annual represents NMBE.

Option D 18

Option D Step 5d (Iterate)

- Revise simulation to reduce monthly differences to an acceptable level.
- More site data may be needed to get better calibration (e.g. determine what really happens in the facility in the middle of the night, as compared to what operators think happens).
- Once differences are acceptable, the simulation is called a “calibrated simulation” of the post-retrofit period.

Option D Step 6 (Savings)

Rerun the *calibrated* simulation twice, with:

- Long term average weather and post-retrofit occupancy – retrofits (as built).
- Long term average weather and post-retrofit occupancy - no retrofits (baseline).

Normalized Savings are the difference between the two simulations.

Option D Step 6 (Savings)

E.g. Steam Savings - from comparing two simulations:

	Predicted Steam (units)		
	No Retrofits	**With Retrofits**	**Savings**
Jan	1,400,000	1,120,000	280,000
Feb	1,350,000	1,115,000	235,000
Mar	1,250,000	1,060,000	190,000
Apr	920,000	823,000	97,000
May	360,000	305,000	55,000
June	250,000	188,000	62,000
July	245,000	194,000	51,000
Aug	260,000	202,000	58,000
Sept	455,000	402,000	53,000
Oct	570,000	495,000	75,000
Nov	902,000	795,000	107,000
Dec	1,302,000	1,070,000	232,000
Total	**9,264,000**	**7,769,000**	**1,495,000**

Option D Step 7 (Valuing)

Apply the utility price schedule to the two simulations.

Compute the cost savings under normalized conditions in this example.

Option D - Long Term

- Calibrate the model annually for each year after retrofit? This is not likely suitable now that we have meters in place which enable another approach.
- Switch to Option C using the first year after retrofit as the new "baseline". Expect zero savings relative to this first year.
- Keep the calibrated simulation as it may be useful in case of BLA or savings evaluation for individual ECM.

Option D 23

Option D form 1 vs. form 2

- In this example, using IPMVP Core Concepts 2014, Chapter 6.5.4, Equation 1, actual post-retrofit data is for calibration of the simulation *only*.
- Savings come from comparing "before and after" simulations.
- The first form is the most common approach.
- LEED BD&C EA c5 prescribes the second form approach.
- Make adjustment the calibration error (NMBE).

Option D 24

Option D - Example second form

A new building was built to be 10% more energy efficient than the requirements of ANSI/ASHRAE/IESNA Standard 90.1 2007.

To earn a LEED rating (Leadership in Energy and Environmental Design – Green Buildings Council) the owner must prove its 'savings' relative to that Standard.

Option D – Example second form

1. Simulate the "as built" equipment and operations over the first year and 'calibrate' it to the first year's energy use. This "**Calibrated As-Built Model**" had a mean error of +3% relative to the actual first year's energy use.
2. Rerun the Calibrated As-Built Model with the hypothetical equipment of the Standard (the "**Standard Model**").

Option D - Example second form

Two ways of computing savings:

= Standard Model – Calibrated As Built Model

As in IPMVP Core Concepts 2014, Chapter 6.5.4, Equation 1

or

= (Standard Model – 3%) – Actual Utility Use

IPMVP Core Concepts 2014, Chapter 6.5.4, Equation 2)

The 3% *correction* factor removes the model error found by calibration. This correction could also be done by applying each month's calibration error to each month's Standard Model value before subtracting each month's actual utility value.

Option D 27

Option D - Example second form

The second approach (IPMVP Core Concepts 2014, Chapter 6.5.4, Equation 2) of correcting for calibration error helps to make non-technical people understand.

The available utility data is used to make the savings seem more 'real'. Just remember to make the calibration *correction*.

Option D 28

Option D - Industrial

- Buildings are all similar in thermal processes. There are several widely used public domain software programs for simulating building energy systems.
- Industrial processes can be as complex users of energy as buildings. However, industrial processes differ widely amongst each other so there is no common software.
- Some large industries have their own custom simulation for design and optimization of their plant. However, persuading outside parties that their software is ‘calibrated’ to reality may be a challenge.

Option D 29

Option D Issues

Simulation Quality

- Skill & experience of the simulation person
- Trusted or publicly available software, suited to modeling the particular type of facility
- Use facility performance logs to provide simulation input wherever possible
- Accuracy of calibration, and getting agreement that it is accurate enough
- Documentation of input, output and software

Option D 30

Next Topic

1. Introduction
2. Key Concepts
3. Short Examples
4. M&V Planning
5. Critical Issues
6. Statistics
7. Retrofit Isolation Details
8. Option C Details
9. Option D Details
10. **Other M&V applications**
11. Summary and review of a detailed M&V plan

M&V Fundamentals

& the
International Performance Measurement and Verification Protocol

For Energy Managers

Other M&V Applications

Persistence of savings

Other Applications of M&V

- Persistence of energy savings can be achieved beyond the M&V reporting period by completing follow on efforts that build on M&V. Two approaches can seamlessly follow the M&V process to ensure the persistence of savings.
  - Recommissioning
  - Monitoring and targeting.

M&V in a Recommissioning Context

Other M&V use 3

About Recommissioning (RCx)

- Method to reduce expenses and increase revenue through improved building operations.

Table 1: Improving building performance approaches.

Terminology	New Construction	Existing Building	Previously Commissioned	Not Previously Commissioned
Commissioning	✓			
Retrocommissioning		✓		✓
Recommissioning		✓	✓	

Adapted from: Jim Poulos. "Existing Building Commissioning," ASHRAE Journal, Sept. 2007, pages 66-78.

- In addition to sharing common goals, the recommissioning process features several steps similar to those involved in the M&V process.

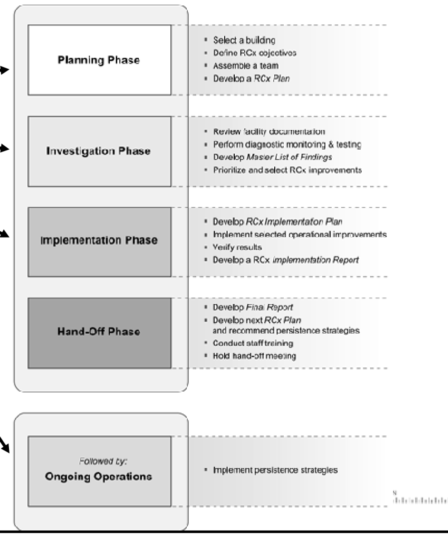
Other M&V use 4

M&V and RCx Process

M&V Process

1. Before implementation of any energy efficiency project:
   a) Design the M&V process.
   b) Gather the baseline data (all energy and operating conditions).
   c) Document the M&V plan.
2. After implementation:
   a) Verify that the proper equipment/systems were installed and are performing to specifications.
   b) Calibrate meters as necessary.
   c) Gather energy and operating data.
   d) Compute savings as defined in the M&V plan.

RCx Process



Why Use M&V in RCx Projects

- M&V procedures provide the means to state energy savings within confidence limits.
- Savings are based on energy measurements before and after an improvement has been made.
- Savings based on M&V procedures are:
  - Independent of prior energy savings estimates.
  - Transparent in that their methodologies are well known and publicly documented.
  - Repeatable such that they can readily be reviewed and validated by third parties.

M&V and Monitoring and Targeting

Other M&V use 7

About Monitoring and Targeting (M&T)

- M&T techniques provide feedback on operating practices and results yielded by energy management projects while estimating expected energy consumption for a given period.
- M&T draws on the following concepts:
  - Monitoring: data gathering to establish baselines and monitor resulting impacts due to changes.
  - Targeting: identification of reduction targets based on past data.
  - Reporting: energy consumption analysis to make informed decisions on the measures required to meet targets.

Other M&V use 8

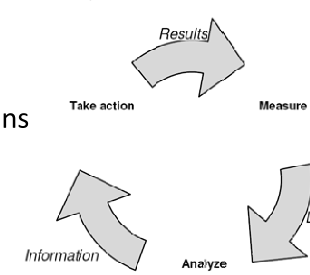
M&T Benefits

- Significant energy savings (between 5% and 15%)
- Very short payback period (less than 2 years)
- Energy cost management
- Greenhouse gas emission reductions
- Quantification of potential savings
- Promotion of financing options for energy efficiency projects
- Energy savings projections

Other M&V use 9

M&V and M&T Methodology

- The M&T process is conducted according to M&V good practices.
- M&T is an ongoing M&V process, requiring constant feedback in order to consistently improve performance similarly as in ISO 50001. Steps are:
  – Measuring energy data
  – Defining the baseline
  – Monitoring the variations
  – Identifying causes
  – Setting targets
  – Motoring results



Other M&V use 10

Best Options for M&T

- M&T often combines Option C with Options A and B to improve the performance of the whole process:
  - With Options A and B, systems causing variations in energy consumption can be identified thus facilitating efficiency improvements.
  - Option C provides an overview of the facility's overall energy performance and allows companies to set targets for the whole facility. Such targets are more meaningful than targets set for individual equipment.

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For Energy Managers

Summary

Summary - Program

- Adherence with IPMVP
- Selecting an Option
- Quiz
- Your other questions

Summary 2

Adherence

With IPMVP

(see IPMVP Core Concepts, Chapter 9)

With a Performance Contract

(see that contract)

Summary 3

Adherence with IPMVP

To claim adherence with IPMVP you must:

- identify the responsible person.
- develop an M&V Plan as per Chapter 5.
- follow the Plan.
- prepare M&V reports of Savings as defined in the M&V Plan (ref. Chapter 6).

Summary 4

Reports which Adhere

- If you measure energy use following IPMVP for five seconds after the retrofit, you can only state that the savings reported for the test period adhere to IPMVP.
- Savings reported without a repeat measurement can only be described as *estimates* based on the IPMVP adherent savings determined from the five second test.

Summary 5

Summary

Selecting An Option

Summary 6

Selecting an Option

- Each project is different.
- Each situation must be analyzed.
- Consider costs relative to savings and desired accuracy.
- The following are just *suggestions* of common "best fit" applications.
- See IPMVP Core Concepts, Chapter 9, Annex A for a simplified Option selection logic diagram.

Selecting - 1

	A	B	C	D
Assess retrofits individually	X	X		X
Assess facility only			X	X
Savings <10% of utility meter's energy	X	X		X
Industrial	X	X		X

Selecting - 2

	A	B	C	D
Significance of variables is unclear.		x	x	x
Interactive effects cannot be easily estimated.			x	x
Expect many future changes within the measurement boundary (= many BLAs)	x			x
Long term assessment	x		x	
No baseline energy data				x

Summary 9

Selecting - 3

	A	B	C	D
Need non-technical people to understand the meaning of savings reports	x	x	x	
Have metering skill and experience	x	x		
Have simulation skill and experience				x
Have utility bill reading skill			x	

Summary 10

Quiz!

Option Selection

Read the question carefully

Summary 11

Which Option?

- Counted light fixtures of each type before and after retrofit
- Measured the load of a 5% random sample of each type of fixture, using a portable true RMS wattmeter, before and after retrofit of a lighting system. Minimal variation was found within each set of samples.
- Measured operating hours before retrofit.

Summary 12

Which Option?

Avoided electrical consumption was computed by multiplying together:

- Change in total calculated load using average of each sample;
- Operating hours measured before retrofit.

Which IPMVP Core Concepts Option is this?

Summary 13

Which Option?

Now, suppose instead of measuring samples of fixtures, manufacturer rating sheets were used for the particular lamp/ballast combinations.

Which IPMVP Core Concepts Option is this?

Summary 14

More Questions?

Summary 15

Let's now prepare an M&V plan

Summary 16

The Project

- The client: School Board in Québec City
- The building: A Professional training center of a 1000 students
- The project: Implementation of 12 ECM to reduce the overall energy consumption by 46% (reduction of natural gas consumption but increase of electricity consumption)
- ECM will be implemented by an ESCO who guarantees the savings.
- Have a look at sections 1 and 2 of the M&V Plan

Summary 17

Your task: design the M&V plan

- Which option?
- Define boundary.
- Select independent variables.
- List static factors.
- Define how you will adjust the baseline data.
- Define energy cost.
- Identify data to be collected during the reporting period, and who will collect them.
- Establish the budget.

Summary 18

Please Fill Out Evaluations Now!

They Are Important To Us

Summary 19

For Those Taking the Exam

Best Wishes!

Read the Questions carefully.

Take your time.

Summary 20

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Thank you!

