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MODULE
5

Physical and Statistical Models

KRISHNAJI PAWAR - CEO & FOUNDER

LEED AP(BD+C),GSAS CGP,GCP,ISO 14001

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This chapter explores the distinction between physical and statistical models in measurement and verification (M&V), highlighting their characteristics, applications, advantages, limitations, and demonstrative examples to ensure accurate data interpretation and decision-making in M&V contexts.

Learning Objectives

- Introduction and Course Outline
- Contexts and Concepts: The M&V Specialist's Function
- Standards of Practice
- Practical Considerations for M&V
- Physical and statistical models
- System boundary in M&V
- Baseline: Additional Considerations
- Special Baseline Considerations for Utility Programs
- Implementing the baseline model and data from the reporting period
- Granularity and load shapes
- Using Statistics to Communicate Uncertainty

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INTRODUCTION

- Statistical models are based on actual energy data collected and analyzed in the baseline period. They aim to establish parameters that represent the behavior of the energy consuming system in the baseline period.
- Physical models represent the underlying processes and interactions that give rise to the energy data. They use mathematical or computational techniques to simulate the behavior of the system over time.
- Common physical models in M&V include models of individual systems and whole facility models that combine the performance of all systems within a building.
- Statistical models are more concerned with estimating relationships between variables using data, while physical/simulation models require understanding of the underlying mechanisms and processes that give rise to the data.
- The choice of model depends on the specific research question and available data.
- The classification of models is not unique to energy management and M&V, but is used for prediction and comparison.

PHYSICAL AND STATISTICAL MODELS IN MEASUREMENT AND VERIFICATION

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Physical Models

- Represent real-world systems based on physics and engineering principles.
- Components include system identification, mathematical formulation, and parameter estimation.
- Useful for predicting energy use and indoor climate under various scenarios.
- Provides a structured approach to understanding complex systems.
- High accuracy when parameters are well-defined and measurements are precise.
- Complexity in model development often requires sophisticated mathematical tools and computational resources.

STATISTICAL MODELS

- Focus on relationships between variables using statistical techniques.
- Inherently probabilistic and designed to account for variability and uncertainty in data.
- Components include data collection, model selection, and parameter estimation and inference.
- Useful for analyzing empirical data where noise and randomness are present.
- Flexibility to model complex relationships without needing detailed physical knowledge of the system.
- Robustness to noise and uncertainties in the data.
- Easier to implement and interpret with existing data.

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INDEPENDENT VARIABLES IN M&V

- M&V is crucial in analyzing facility energy use variability.
- Independent variables, such as weather conditions, occupancy levels, production output, and equipment usage, influence energy consumption but aren't directly related to energy-saving measures.
- Identifying the best independent variables involves reviewing historical data, conducting site assessments, and consulting with stakeholders.
- The M&V professional's role is to decide which variables to include in the baseline model.
- Common independent variables include weather conditions, production output, time of day, equipment schedules, lighting schedules, HVAC set points, building envelope characteristics, and changes in operational procedures.
- The specific variables used will depend on the facility type, energy systems, and project goals.

PHYSICAL MODELS IN BUILDING ENERGY ANALYSIS

Physical Models:

- Mathematical representations of physical processes determining energy consumption.
- Range from sophisticated energy simulation tools to simple spreadsheet models.
- Simulation modeling can be applied to any energy-consuming system, but typically refers to building simulations.
- Simulations use physics and engineering principles to model energy use under different conditions.
- Inputs include building geometry, insulation, HVAC system, and occupancy patterns.
- Simulation models capture more detail and complexity than simple physical models.

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ASHRAE STANDARD 140

- Defining minimum requirements for facility energy simulation software.
- Provides a methodology for evaluating the accuracy and reliability of facility energy simulation software.
- Includes guidelines for testing software against benchmark models, requirements for software documentation, model input and output formats, and model calibration procedures.

Advantages of Spreadsheet Models:

- Offer more transparency and are easier to understand.
- Use basic equations and assumptions to estimate energy use.

CALIBRATION OF MODELS IN SIMULATION SOFTWARE

- Simulation software algorithms tested using real-world data.
- Models of actual project facilities also need calibration for M&V purposes.
- Calibration adjusts simulation model inputs to match actual energy consumption.
- Challenges include factors influencing facility energy use like plug loads, HVAC efficiency, and occupancy schedules.
- Calibration process is time-consuming and requires skilled professionals.
- Recent M&V researchers are applying Bayesian analysis to physical models.

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UNDERSTANDING IMPERFECT MODELS AND TYPES OF UNCERTAINTY IN M&V

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Challenges in Implementing Counterfactual Method

- Baseline model must be accurate and relevant to expected reporting conditions.
- Non-routine adjustments are necessary when changes are not anticipated in the baseline model.

Uncertainty Analysis

- Aleatory uncertainty arises from inherent randomness and variability in a system.
- Epistemic uncertainty arises from lack of knowledge or understanding of a system.
- These types of uncertainty can be reduced with the right tools and effort, but often require addressing unforeseeable events in the reporting period.

UNDERSTANDING UNCERTAINTY IN M&V

- Non-routine events can introduce both types of uncertainty.
- These concepts are relevant to many disciplines, including engineering, physics, economics, and finance.
- Understanding and quantifying sources of uncertainty and risk is crucial for informed decision-making and accurate interpretation of results.

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MODEL SELECTION REQUIRES JUDGMENT IN M&V

- The challenge in M&V is to find a "good enough" model that meets all needs, goals, and stakeholder requirements.
- Professional judgment is needed in selecting or developing a model, assessing the model's realism, data quality, and relevance to the real world.

Problematizing Judgment

- Mental shortcuts like heuristics and biases can undermine rational decision-making.
- Heuristics are practical rules of thumb that can lead to systematic errors, especially when more information or a complex decision-making process is needed.
- Biases favor a given conclusion over others, often based on preference, emotion, or recent information.
- While heuristics and biases cannot be completely eliminated, they can be limited by recognizing their role in judgment and decision-making.

Inset: Finite Transcendence

- Plato's concept of "finite transcendence" suggests that the human mind is limited in its ability to understand the true nature of reality.

INTEGRATION OF PHYSICAL AND STATISTICAL MODELS

- Physical models provide a theoretical framework and predictions.
- Statistical models validate and refine these predictions based on empirical data.
- Integration of these modeling techniques ensures a holistic view, facilitating better predictions, verifications, and sustainable practices in various fields.

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BAYESIAN METHODS IN M&V

- Bayesian statistical techniques are increasingly used in M&V due to their flexibility and expressiveness.
- Bayesian statistics can be used in counterfactual methods to incorporate prior knowledge about model parameters.
- Google's CausalImpact'5 is a useful tool for simple Bayesian analysis in M&V, demonstrating how to estimate the impact of an energy management project.
- CausalImpact uses a Bayesian structural time-series model to estimate the outcome variable in the absence of the intervention and compare it to the observed outcome variable to estimate the causal effect of the intervention.
- CausalPy'° is a similar tool for Python users, offering similar capabilities.
- John Shonder and Herman Carstens conducted original research on using Bayesian methods for M&V.
- Stan is a programming language used for performing complex Bayesian analyses, allowing users to build models and generate optimized C++ code for Bayesian inference.
- Stan's efficiency in sampling from complex posterior distributions is due to its hybrid Monte Carlo algorithm that can adapt to the shape of the posterior distribution.

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CONTACT US

+91 6363032722

info@beyondsmartcities.in

learn.beyondsmartcities.in

#55,HMR Layout ,Bengaluru ,India

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