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Risks in Measurement and Verification (M&V) in Energy Performance Contracting (EPC) Projects: A Systematic Review

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ABSTRACT

Energy Performance Contracting (EPC) represents a promising approach to improving Energy Efficiency (EE) as well as reducing greenhouse gas emissions in various sectors. In the realm of EPC projects, accurate Measurement and Verification (M&V) with regard to energy savings is vital for these initiatives to be successful. Nevertheless, the risks related to M&V in EPC projects were not thoroughly studied. Moreover, the effectiveness with regard to EPC projects depends crucially on the accurate M&V of energy savings, which is often fraught with risks and uncertainties. This paper applied the pre-recording systematic reviews and meta-analysis (PRISMA) approach to finding the primary data based on a few keywords such as “risk or uncertainty, measurement and verification”. Based on advanced searching on SCOPUS and Web of Science (WOS), we found (n=32). Expert scholars decided to develop three themes, which are (1) challenges and issues in M&V, (2) methods of M&V, and (3) risk mitigation strategies in M&V. In summary, this systematic review provides a comprehensive overview of the critical challenges and issues surrounding M&V risks in EPC projects and offers a roadmap for enhancing the reliability and credibility of M&V. By addressing these challenges and implementing the recommended strategies, stakeholders can navigate the complexities of EPC projects more effectively, ultimately advancing the adoption of sustainable energy practices and achieving meaningful environmental and financial benefits.

1. Introduction

Energy Performance Contracting (EPC) has emerged as a promising approach to improving Energy Efficiency (EE) and reducing greenhouse gas emissions in various sectors [1-4]. In recent years, the implementation of EPC projects has gained momentum globally, driven by the increasing need to mitigate climate change and reduce energy consumption. Despite its potential benefits, EPC projects face numerous challenges and issues, particularly in the Measurement and Verification (M&V) phase

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[5-7]. Accurate M&V is crucial for ensuring the successful implementation and overall performance of EPC projects [8-10]. However, the risks associated with M&V in EPC projects have not been thoroughly explored.

This systematic review assesses and identifies the risks related to the M&V phase with regard to EPC projects. By synthesizing current literature on this topic, the review offers a comprehensive understanding of the challenges and potential pitfalls that stakeholders may encounter during the M&V process. This knowledge is essential for project developers, contractors, facility managers, and policymakers to effectively manage and mitigate risks in EPC projects, ultimately improving their success rate. The review will employ a systematic approach, following established literature search and selection protocols. Relevant studies will be identified through keyword searches in academic databases, as well as manual screening of relevant journals and conference proceedings. The selected studies will be assessed for their quality and relevance before being included in the review. Consequently, data extraction as well as synthesis will be performed to examine common themes, patterns, including trends related to the recognized risks.

This systematic review's results will strengthen the existing body of knowledge with regard to EPC projects and M&V. Understanding the risks associated with M&V in EPC projects will enable stakeholders to develop effective strategies for risk management, improve project outcomes, and enhance the credibility of the EPC approach. Additionally, the review will identify research gaps and provide recommendations for future studies to further advance this field of research.

2. Literature Review

Recently, there has been an increasing amount of literature on EPC. It is a useful tool for financing building retrofits, especially for owners with reduced funding. The contractor ensures minimum energy savings performance, which allows the owner to fund the project utilising utility savings over 12-15 years. However, literature on contractor risks in EPC building retrofits is lacking. This study proposed a project factors-based risk framework with regard to EPC building retrofits, refined through expertise from 19 experienced professionals [11]. In addition, Wang *et al.,* [12] identified 21 risk factors pertaining to EPC industry in China, establishing a universal method in prioritizing them as well as proposing policy implications for decision-makers. The study includes external environmental, managerial, operational, financial, technical, as well as client risks. Other than that, a Best-Worst Network (BWN) method was created to rank these factors, with results validated by the Analytic Network Process as well as Analytic Hierarchy Process [12]. The research study by Garbuzova-Schlifter and Madlener [13] also examines risk factors as well as causes related to EPC projects regarding three Russian sectors comprising housing and communal services, public services, including industrial. The findings present that regulatory as well as financial aspects contribute most to project riskiness, highlighting the need for sector-specific contractual schemes. The study emphasizes the importance of understanding and managing risks for Energy Service Company (ESCO) in the energy-inefficient Russian market [13]. In another study, the author examined the risks related to EPC projects in Hong Kong, focusing on energy savings for building owners. Key risks include payment default, baseline measurement uncertainty, as well as increased installation costs. Moreover, hosts' concerns include repayment ability, project complexities, and long payback periods. To enhance EPC adoption, respondents suggest promoting successful projects, modifying government procurement practices, and providing government loan backups [14].

In a different study, Lee *et al.,* [15] proposed a simulation-based method to assess energy saving shortfalls in EPC projects, considering variations in parameters like weather conditions and occupancy. The method uses sensitivity analysis, a Building Energy Simulation (BES) program, as well as Monte Carlo simulation techniques. A case study in Hong Kong demonstrates the method's effectiveness, showing potential energy savings of 2.86% to 10.8% [15]. In addition, Li [16] explored the use of the WBS-RBS method in EPC, focusing on the complexity of the project and its extensive risk factors, particularly section energy risk, to improve risk control and identify risks in building energy conservation projects. In another study by Shang *et al.,* [17], a credit risk identification model is generated to assess the credit status with regard to EPC project clients in China utilising the rough set theory. Note that the model, possessing data obtained from 120 listed companies, identifies information asymmetry as a major obstacle to EPC project implementation. The model may assist ESCO in determining client credit status, facilitate cooperation, as well as describe client dynamics over time [17]. The study by Wang *et al.,* [18] examined the hybrid fuzzy Multi-Criteria Decision-Making (MCDM) framework for ranking risk factors in energy EPC projects. The framework considers behavioral psychology, the bounded rationality of the decision-maker, as well as the interrelationship of criteria. Risk assessment is represented utilising picture fuzzy numbers, and the concept of distances between picture fuzzy sets is introduced. To prioritize risks, an optimization model and the MABAC method relying on prospect theory are employed. The framework is efficiently utilised in a hotel's EE retrofit, showing its effectiveness in risk ranking problems [18]. According to Berghorn and Syal [19], an evaluation model as well as risk analysis utilising quantitative, expert-based, as well as probabilistically derived information. The most Critical Risk Factors (CRFs) include reduced Energy Conservation Measures (ECMs), performing investment grade audits too quickly, facility age and current code requirements, unavailable facility information, as well as traditional design-bid-build procurement [19].

A study by Martiniello *et al.,* [20] found that Public Private Partnerships (PPPs) are increasingly used in EE projects, requiring a balance that exists between private as well as public interests. This paper answers questions about sharing benefits and determining the optimal long-term contractual agreement. A mathematical equation is established to measure the optimal percentage regarding benefits sharing, tested utilising a case study with regard to an Italian hospital's EE project. The study suggests enhancing the EPC-PPP contractual structure as well as analyzing risk allocation in EPC contracts for an "off-balance" accounting treatment. It encourages public decision-making in selecting contracts that transfer energy as well as management risks. [20]. According to Wu and Zhou [21], Urban Rooftop Distributed Photovoltaic (URDPV) development in China is urged by the government's EPC mode. However, the lack pertaining to effective risk assessment methods hinders further development. This paper identifies 11 CRFs with regard to EPC-URDPV projects and suggests a detailed risk assessment framework. Consequently, the results present that risk levels in relevant study areas are medium as well as relatively low, with Shanghai and Fujian having relatively high-risk levels. The study provides insights for PV investors and decision-makers [21]. In another study, Lee *et al.,* [22] examined a probabilistic approach to assess the performance risks related to the common lighting retrofit measures in EPC projects. It takes into account variations in key factors that impact EE, like the availability of daylight, occupancy rates, the condition of lamps, and patterns of lighting usage. Empirical data is employed to create probability distribution functions. Results show substantial variations in actual energy savings, posing a risk on guaranteed savings in EPC projects [22].

3. Material and Methods

3.1 Identification

The systematic review process involves three main phases to choose relevant articles for this research. The phases are Identification, Screening and Eligibility [23-25]. In the first phase, keywords were identified, and related terms were searched using various resources, for example, encyclopedias, dictionaries, thesauruses, as well as prior research. Once all relevant terms were chosen, search strings were developed for the Scopus as well as Web of Science (WOS) databases (see Table 1). In this study, a total of 217 papers were obtained from both databases during the initial stage with regard to the systematic review process.

Table 1
The search strings

Scopus	TITLE-ABS-KEY ((risk* OR uncertaint*) AND ("measurement and verification")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2023))
WOS	(risk* OR uncertaint*) AND ("measurement and verification") (Topic) and Article (Document Types) and 2023 or 2013 or 2014 or 2015 or 2016 or 2017 or 2022 or 2021 or 2020 or 2019 or 2018 (Publication Years)

3.2 Screening

During the screening phase with regard to the research process, a collection of potentially relevant research items was assessed to determine their alignment with the predefined research questions. Content-related criteria, such as the classification with regard to cervical cancer cells utilising Machine Learning (ML), were used to select the research items. Duplicate papers were excluded from the list regarding the searched papers. Subsequently, the screening process consisted of two stages, with 111 publications being removed in the first stage and 106 papers being investigated in the second stage based on particular exclusion as well as inclusion criteria. The primary criterion for inclusion revolved around the body of literature, which includes practical guidance, evaluations, meta-synthesis, meta-analytical studies, reviews, book series, chapters, as well as conference proceedings, with the exception of those from the most recent research. Moreover, only publications in the English language were taken into account. Meanwhile, the time frame related to the search was limited to the years 2013-2023. Ultimately, 41 publications were rejected due to duplication.

3.3 Eligibility

In the third step of the study, 65 articles were assessed for eligibility. During this stage, the titles and key content of each article were carefully reviewed to establish the inclusion criteria according to the study’s research aims. Consequently, 33 reports were excluded as they did not meet the requirements, such as being irrelevant to the scope of the study or lacking relevance to the study's objectives based on empirical evidence. Subsequently, 32 articles remained and were included for further review (refer to Table 2).

Table 2
The selection criterion employed is searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Time line / Years	2013 – 2023	< 2013
Literature type	Journal (Article)	Review, Book, Conference
Publication Stage	Final	In Press

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3.4 Data Abstraction as Well as Analysis

This research employed an integrative analysis as an assessment strategy, which combines various research designs such as mixed methods, qualitative, as well as quantitative. The study determined relevant subtopics as well as topics, considering the data collection stage as the initial step in theme development, as outlined in Figure 1. The authors meticulously analyzed 32 publications, searching for assertions or material regarding the topics of interest. They then evaluated the methodological approaches and research findings of these relevant studies, collaborating with co-authors to generate themes relying on the evidence within the study's context. It is worth mentioning that a log was maintained throughout the data analysis process to report any analyses, perspectives, questions, or other perceptions significant to data interpretation. Other than that, the authors conducted a comparison of the outcomes to maintain consistency during the theme development process, addressing any disputes through discussion. Subsequently, additional refinement was applied to the generated themes to uphold consistency. To determine the findings' validity, two experts conducted an analysis selection to validate the identified issues. The expert review phase offered appropriateness, relevance, as well as clarity of each subtheme, contributing to the study's domain validity.

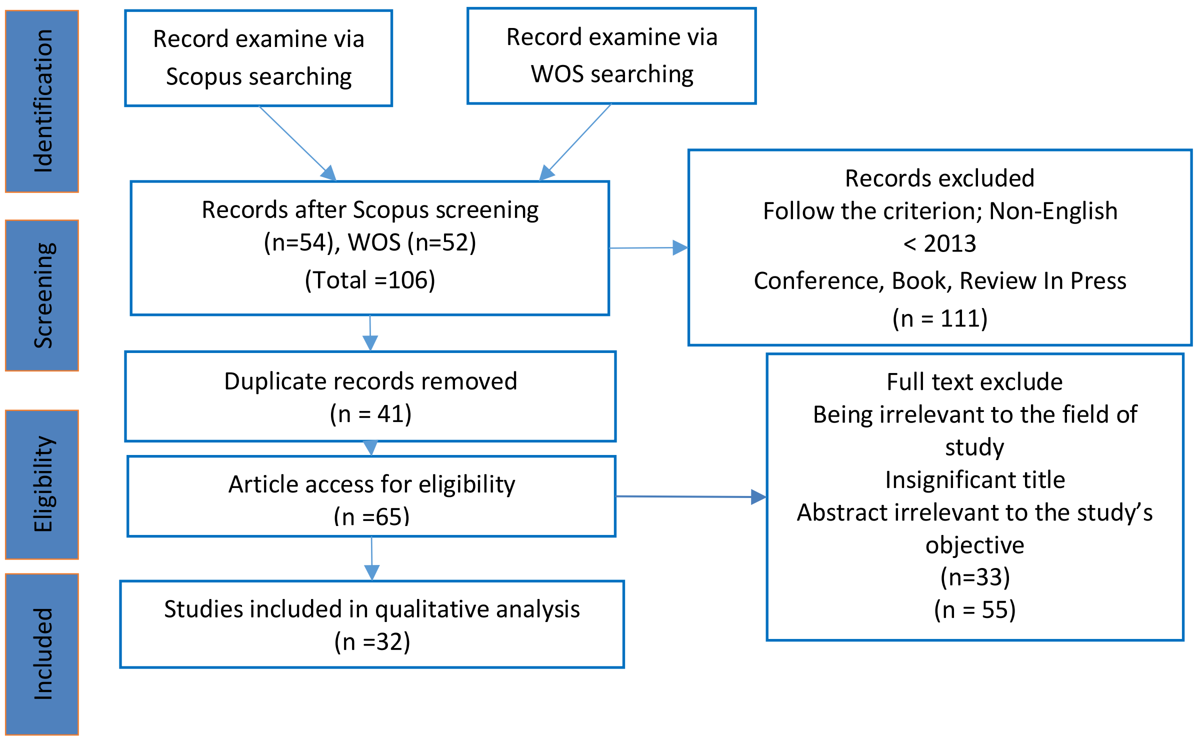

Fig. 1. The proposed searching study's flow diagram

4. Result and Finding

Given the searching method, 32 articles have been extracted and assessed. Note that all articles were divided into three main themes: challenges and issues in M&V (12 articles), methods of M&V (11 articles), and risk mitigation strategies in M&V (9 articles).

4.1 Challenges and Issues in M&V

M&V is a critical component of EPC projects, which aim to enhance EE as well as reduce energy consumption in facilities or buildings. Proper M&V is essential for ensuring that the promised energy savings are achieved and for providing confidence to both the ESCO and the client. However, M&V in EPC projects have several challenges and issues that practitioners and researchers need to clarify. Table 3 presents the summary of challenges and issues in M&V.

M&V in EPC projects is a diverse as well as complex task that demands data analysis, careful planning, as well as consideration of various challenges and issues. Researchers play a crucial role in developing improved methodologies, standards, and technologies to clarify these challenges and ensure the success of EPC projects in achieving energy savings and sustainability goals.

4.2 Methods of M&V

Understanding the M&V method is essential for ensuring that EE goals are met, and the contract's financial terms are upheld. Researchers in the field of M&V may focus on refining each step of this methodology, developing advanced technologies for data collection and analysis, and addressing specific challenges to enhance reliability as well as accuracy with regard to M&V in EPC projects. Table 4 provides the summary of methods in M&V.

The methodology for M&V in EPC projects is a structured and rigorous process that provides confidence to both the ESCO as well as the client that the promised energy savings have been achieved. Researchers in this field may focus on refining and standardizing these methodologies, developing innovative measurement technologies, and addressing specific challenges to enhance the reliability as well as accuracy related to M&V in EPC.

4.3 Risk Mitigation Strategies in M&V

Risk mitigation strategies in M&V in EPC projects refer to the proactive measures and actions taken to identify, assess, and minimize potential risks and uncertainties associated with the M&V process. These strategies are essential for ensuring the EPC projects' success, as they help to enhance the accuracy of energy savings calculations, maintain the trust of all project stakeholders, and ultimately achieve the intended EE improvements. Table 5 shows the summary of risk mitigation strategies in M&V.

By implementing these risk mitigation strategies, researchers and project teams can enhance the reliability and credibility of the M&V process in EPC projects, ultimately increasing the likelihood of achieving the intended energy savings and project success.

Table 3
Summary of challenges and issues in M&V

Authors	Title	Year	Source title	Challenges and Issues
Rouchier [26]	Bayesian Workflow and Hidden Markov Energy-Signature Model for Measurement and Verification	2022	Energies	Bayesian methodologies are rarely used in practice for M&V, possibly due to practitioners' unfamiliarity with the required tools.
Piccinini *et al.,* [27]	A novel reduced order model technology framework in supporting the estimation regarding the energy savings in building retrofits	2021	Energy and Buildings	The challenges and obstacles that can impede the adoption of EPC, for example, the process complexity and uncertainties related to post-retrofit building performance.
Newsham [28]	Measurement and verification ECM utilising whole-building electricity data from four identical office towers	2019	Applied Energy	The challenges in visually identifying ECM effects with regard to time-series data. It emphasizes the complexities and potential sources of error in such analyses.
Gallagher *et al.,* [29]	The suitability of machine learning to minimise uncertainty in the measurement as well as verification of energy savings	2018	Energy and Buildings	The complexity concerning energy systems in industrial buildings and identifies them as challenging environments for M&V.
Kim [30]	Examining the gaps and needs of building information technologies for energy retrofit of historic buildings in the Korean context	2018	Sustainability (Switzerland)	The constraints of limited time and budget typically allocated for energy audits.
Carstens *et al.,* [31]	Measurement uncertainty in energy monitoring: Present state of the art	2018	Renewable and Sustainable Energy Reviews	Electrical metering and sub-metering uncertainty, shedding light on specific aspects related to electrical measurement accuracy.
Ramos Ruiz and Bandera [32]	Validation of calibrated energy models: Common errors	2017	Energies	The common errors or mistakes that are often made when conducting validation measurements (uncertainty indices) for building energy models.
Hamer *et al.,* [33]	A practical approach to managing uncertainty in the measurement and verification of energy efficiency savings	2017	South African Journal of Industrial Engineering	The challenges of accurately quantifying EE savings in technical complexities and uncertainties associated with M&V in industrial settings.
Grandersona *et al.,* [34]	Application of automated measurement and verification to utility energy efficiency program data	2017	Energy and Buildings	The challenges and costs associated with current M&V methods, including time-consuming data acquisition.
Olinga *et al.,* [35]	A cost-effective approach to handle measurement and verification uncertainties of energy savings	2017	Energy	The budgetary constraints within EE programs necessitate careful planning to balance M&V costs with accuracy.
Harding and Nutter [36]	Measurement and Verification of Industrial Equipment: Data Logger Considerations and Sampling Interval	2016	Energy Engineering: Journal of the Association of Energy Engineering	The misapplication or misunderstanding concerning M&V protocols may lead to substantial errors in energy savings calculations.

Burkhart *et al.,* [37]	Measurement and verification of building systems under uncertain data: A Gaussian Process (GP) modeling approach	2014	Energy and Buildings	Uncertainty in sensor data, particularly in weather and occupancy data.

Table 4
Summary of methods in M&V

Authors	Title	Year	Source title	Methods
Grillone *et al.,* [38]	Baseline energy use modeling and characterization in tertiary buildings using an interpretable bayesian linear regression methodology	2021	Energies	Bayesian methodologies as a promising approach for energy baseline modeling.
Roth *et al.,* [39]	Uncertainty matters: Bayesian probabilistic forecasting for residential smart meter prediction, segmentation, as well as behavioral measurement and verification	2021	Energies	Bayesian Structural Time Series modeling with regard to the probabilistic load forecasting at the residential building level.
Touzani *et al.,* [40]	Evaluation of methods to examine the uncertainty in estimated energy savings	2019	Energy and Buildings	The application of the developed methodology to assess two uncertainty estimation methods, which includes the industry standard ASHRAE Guideline 14 approach.
Gallagher *et al.,* [41]	Development and application of a ML supported methodology for measurement and verification (M&V) 2.0	2018	Energy and Buildings	Integrating ML techniques into M&V 2.0 allows reliable and accurate savings' quantification.
Carstens *et al.,*[42]	Efficient longitudinal population survival survey sampling for the verification and measurement of lighting retrofit projects	2017	Energy and Buildings	A method for optimizing sample sizes in lighting retrofit verification as well as measurement projects.
Carstens *et al.,* [43]	Efficient metering and surveying sampling designs in longitudinal Measurement and Verification for lighting retrofit	2017	Energy and Buildings	The integration of metering and survey methods using the Mellin Transform Moment Calculation method.
Razali *et al.,* [44]	Visual basic GUI for an enhanced M&V framework considering risk assessment	2017	International Journal on Advanced Science, Engineering and Information Technology	Monte Carlo simulations to examine the risks associated with ECM projects.
Liang *et al.,* [45]	Enhancing the accuracy of energy baseline models for commercial buildings with occupancy data	2016	Applied Energy	Sensitivity analysis to assess the parameters' influence in baseline models.
Oses *et al.,* [46]	Uncertainty reduction in measuring and verification of energy savings by statistical learning in manufacturing environments	2016	International Journal on Interactive Design and Manufacturing	The calculation of energy savings by comparing energy consumption in post-ECM as well as pre-ECM periods while adjusting for pre-ECM operating conditions.
Granderson *et al.,* [47]	Automated measurement and verification: Performance of public domain whole-building electric baseline models	2015	Applied Energy	Methodology designed to identify the baseline energy predictions' accuracy.

Walter *et al.,* [48]	Uncertainty estimation enhances energy measurement and verification procedures	2014	Applied Energy	The use of cross-validation as an efficient method in computing uncertainty in energy use predictions.

Table 5
Summary of risk mitigation strategies in M&V

Authors	Title	Year	Source title	Mitigation strategies
Mavrigiannaki *et al.,* [49]	Measurement and verification of zero energy settlements: Lessons learned from four pilot cases in Europe	2020	Sustainability (Switzerland)	Integration of M&V processes throughout all phases of a project, emphasizing its significance in project management and development, as well as ensuring that it's not solely confined to the operational phase.
Gallagher *et al.,* [50]	IntelliMaV: A cloud computing measurement and verification 2.0 application for automated, near real-time energy savings quantification and performance deviation detection	2019	Energy and Buildings	An innovative application built on cloud computing technology that harnesses sophisticated ML methods and extensive datasets.
Maritz *et al.,* [51]	A practical guide to Gaussian Process (GP) regression for energy measurement and verification within the Bayesian framework	2018	Energies	The Bayesian framework using Gaussian Process (GP) regression with regard to M&V in EE projects.
Carstens *et al.,* [52]	Bayesian energy measurement as well as verification analysis	2018	Energies	Adopting the Bayesian paradigm as an alternative framework for Energy M&V.
Chen *et al.,* [53]	Inverse energy model development via high-dimensional data analysis and sub-metering priority in building data monitoring	2018	Energy and Buildings	Inverse regression model using advanced high-dimensional data analysis methods.
Ruiz *et al.,* [54]	Analysis of uncertainty indices used for building envelope calibration	2017	Applied Energy	The improvement of the calibration methodology for Building Energy Simulation (BES) models
Ismail *et al.,* [55]	Development of GUI system using web application tool of microsoft visual studio for option b energy saving IPMVP	2017	International Journal of Simulation: Systems, Science and Technology	GUI web application utilising Microsoft Visual Studio to support Option B energy savings calculations under the IPMVP.
Shonder and Avina [56]	New Directions in Measurement and Verification for Performance Contracts	2016	Energy Engineering: Journal of the Association of Energy Engineering	The combined approach to determine energy savings integrates the original utility bill-based method having retrofit isolation as well as annual re-commissioning.
Heo *et al.,* [57]	Quantitative risk management with regard to energy retrofit projects	2013	Journal of Building Performance Simulation	The Bayesian calibration in building energy models.

5. Discussion and Conclusion

The challenges and issues in M&V processes for EPC projects span a wide spectrum. First, practitioners often lack familiarity with Bayesian methodologies, hindering their application in M&V. Second, EPCs face complexities and uncertainties, necessitating clear contracts and risk assessments. Third, identifying the impact of ECMs in noisy time-series data is a challenge, demanding advanced analytics. Fourth, industrial energy systems' complexity requires tailored M&V approaches. Fifth, constrained time and budgets in energy audits affect data quality, making prioritization and automation critical. Sixth, metering uncertainties introduce errors, requiring regular calibration and redundancy. Seventh, validation measurement errors can propagate inaccuracies, necessitating rigorous protocols and third-party verification. Eighth, quantifying energy savings, especially in industrial contexts, is complicated and depends on robust statistical methods and process knowledge. Ninth, current M&V methods can be resource-intensive, but technology offers cost-effective alternatives. Tenth, budgetary constraints in energy programs call for efficient resource allocation and ROI demonstration. Eleventh, misapplication of M&V protocols can lead to errors, underscoring the importance of training and audits. Twelfth, uncertainties in sensor data, particularly in weather and occupancy, require redundancy and quality control for data accuracy. Addressing these multifaceted challenges and issues is vital for successful EE initiatives. The challenges and issues mentioned collectively underscore the complexity and intricacy with regard to M&V in the context of EE and performance improvement. Addressing these challenges and issues requires a multifaceted approach that involves education and training, improved data quality control, the development of specialized methodologies for industrial settings, and careful budget planning. Overcoming these challenges is essential for ensuring the full potential of M&V in achieving EE goals and ensuring the success of EPCs and other energy management initiatives.

The methods employed in M&V are essential for achieving accurate and reliable energy savings calculations. Firstly, Bayesian methodologies provide a robust framework for energy baseline modeling, allowing for the incorporation of prior knowledge and dynamic updates of probability distributions. Secondly, Bayesian Structural Time Series modeling assists in probabilistic load forecasting at the residential level, offering vital insights into energy consumption uncertainties. Thirdly, evaluating uncertainty estimation methods, including ASHRAE Guideline 14, ensures proper quantification of uncertainties in energy savings calculations. Fourthly, integrating ML techniques into M&V 2.0 enhances accuracy and reliability by handling complex data relationships effectively. Fifthly, optimizing sample sizes in lighting retrofit projects maximizes cost efficiency while maintaining statistical validity. Sixthly, the Mellin Transform Moment Calculation method improves data quality by integrating metering and survey methods. Seventhly, Monte Carlo simulations assess the risks associated with ECM projects, aiding in informed decision-making. Eighthly, sensitivity analysis identifies key parameters in baseline models, ensuring an accurate representation of energy consumption drivers. Ninthly, adjusting for pre-ECM operating conditions when calculating energy savings provides a more precise measurement. Tenthly, evaluating baseline energy prediction accuracy ensures that models are robust and reliable. Eleventhly, cross-validation enhances the accuracy of energy use predictions by validating model performance and estimating prediction errors. These methods collectively strengthen the foundation of M&V processes, facilitating better-informed decisions, risk management, and achieving EE goals. Note that the mentioned methods in M&V are instrumental in addressing the challenges and complexities of accurately quantifying energy savings. They offer innovative approaches for handling uncertainty, enhancing data quality, optimizing resource allocation, and ensuring that EE projects are effective and reliable. By incorporating these methods into M&V processes, stakeholders can make informed decisions, better manage risks, and achieve their EE goals more confidently.

Mitigation strategies in M&V are crucial for enhancing the accuracy and effectiveness of EE projects. These strategies encompass various innovative approaches and methodologies. First, integrating M&V processes throughout all project phases, rather than confining them to the operational phase, underscores its importance in project management and ensures comprehensive savings assessment. Second, developing cloud computing-based applications with advanced ML enhances real-time data analysis and predictive modeling, facilitating the identification of energy-saving opportunities. Third, adopting the Bayesian framework with Gaussian Process (GP) regression offers a probabilistic approach that accounts for uncertainty in energy consumption patterns. Fourth, embracing the Bayesian paradigm as an alternative framework enhances adaptability and reliability in M&V. Fifth, inverse regression models using high-dimensional data analysis are valuable for deciphering complex energy use factors. Sixth, improved calibration methodologies for BES models underpin accurate predictions and data-driven decision-making. Seventh, Graphic User Interface (GUI) web applications for IPMVP Option B calculations simplify the process, ensuring adherence to industry standards. Eighth, the combined approach integrating utility bills, retrofit isolation, and annual re-commissioning provides a comprehensive means of determining energy savings. Ninth, Bayesian calibration of building energy models enhances accuracy by incorporating prior knowledge and measurement data, aligning them closely with real-world conditions, and supporting sustainability goals. These mitigation strategies represent diverse, innovative approaches to enhance M&V processes in EE projects. They emphasize the importance of proactive integration, data-driven analysis, and the adoption of advanced methodologies such as Bayesian modeling and ML. By embracing these strategies, stakeholders can achieve more precise energy savings calculations, optimize energy performance, and make informed decisions to support sustainability goals.

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