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Cloud computing platform for real-time measurement and verification of energy performance

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HIGHLIGHTS

- Application of PSO algorithm can improve the accuracy of the baseline model.
- M&V cloud platform automatically calculates energy performance.
- M&V cloud platform can be applied in all energy conservation measures.
- Real-time operational performance can be monitored through the proposed platform.
- M&V cloud platform facilitates the development of EE programs and ESCO industries.

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ABSTRACT

Nations worldwide are vigorously promoting policies to improve energy efficiency. The use of measurement and verification (M&V) procedures to quantify energy performance is an essential topic in this field. Currently, energy performance M&V is accomplished via a combination of short-term on-site measurements and engineering calculations. This requires extensive amounts of time and labor and can result in a discrepancy between actual energy savings and calculated results. In addition, the M&V period typically lasts for periods as long as several months or up to a year, the failure to immediately detect abnormal energy performance not only decreases energy performance, results in the inability to make timely correction, and misses the best opportunity to adjust or repair equipment and systems.

In this study, a cloud computing platform for the real-time M&V of energy performance is developed. On this platform, particle swarm optimization and multivariate regression analysis are used to construct accurate baseline models. Instantaneous and automatic calculations of the energy performance and access to long-term, cumulative information about the energy performance are provided via a feature that allows direct uploads of the energy consumption data. Finally, the feasibility of this real-time M&V cloud platform is tested for a case study involving improvements to a cold storage system in a hypermarket.

Cloud computing platform for real-time energy performance M&V is applicable to any industry and energy conservation measure. With the M&V cloud platform, real-time and long-term energy performances can be obtained. By tracking fluctuations in energy performance, real-time monitoring or correction of the operating performance of equipment or system can help to maintain good energy performance. Thus, real-time energy management can be accomplished based on the above attributes. In addition, the cloud computing platform developed in this research can improve our national M&V level. Specifically, it helps government in promoting energy efficiency programs and the development of energy service industries.

1. Introduction

Of the numerous energy policies implemented by countries worldwide to effectuate energy-saving carbon reduction, energy efficiency improvement is considered the fastest and most efficient method. Under the Tradable White Certificate (TWC), Clean Development Mechanism (CDM), and Demand-Side Management (DSM), Energy Service Companies (ESCO) and Energy-Saving Performance Contracting (ESPC) energy performance is quantified through measurement and verification (M&V) procedures. M&V procedures have become indispensable key items in the energy efficiency field.

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Nomenclature

AEPCA	Australasian energy performance contracting association
AMI	advanced metering infrastructure
ASHRAE	American society of heating, refrigerating and air-conditioning engineers
CDM	clean development mechanism
CVRMSE	coefficient of variation of the RMSE
DSF	double skin façade
DSM	demand side management
ECM	energy conservation measure
EEDSM	energy efficiency and demand-side management
EPC	energy performance contracting
EPCPs	energy performance contracting projects
ESCO	energy service company
ESPC	energy saving performance contracting
EVO	efficiency valuation organization
FEMP	federal energy management program
GAE	Google app engine
GP	Gaussian process
gbest	group's best position
HERO	home energy rebate offer
IPMVP	international performance measurement and verification protocol
IoT	Internet of Things
k	iteration number
L_1	cognitive learning factor
L_2	social learning factor
MCEM	Monte Carlo expectation maximization algorithm
M&V	measurement and verification
P	energy consumption (kW)
$P_{Adjusted}$	pre-installation energy consumption (kW)
$P_{Measured}$	post-installation energy consumption (kW)
PSO	particle swarm optimization
pbest	personal best position
Q_e	refrigeration capacity (kW)
R^2	coefficient of determination
r	random numbers
T_{OA}	atmosphere temperature (°C)
T_{eva}	refrigerant evaporation temperature (°C)
TWC	tradable white certificate
Vmax	maximum particle velocity
Vmin	minimum particle velocity
w	inertia weight
Xmax	maximum particle position
Xmin	minimum particle position
x_i	position of particle i
Z	relative error
Z_minAvg	convergence condition

Due to the importance of M&V, various M&V guidelines have been published to illustrate the concepts and methodologies of M&V to let users quickly understand M&V through simple case descriptions.

Related literatures such as the study by Bertoldi and Rezessy [1] described the concept and main elements of TWC scheme in the European Union (EU). In TWC, energy saving is viewed as a tradable commodity. Hence, proper quantification of energy saving through M&V is regarded as an important element of TWC. Michaelowa and Jotzo [2] used quantitative model to explore the relations between the markets of "transaction cost and institutional rigidities" and CDM. Transaction cost comprises of numerous costs such as baseline development, monitoring costs, and verification and certification. The reduction of transaction costs positively impacts the CDM market. Eskom [3] described that energy efficiency and demand-side management (EEDSM) projects cover a wide range of electricity-related activities and strategies in South Africa. The M&V can be used to provide an impartial quantification and assessment of project impacts and savings that result from EEDSM activities. Vine et al. [4] described standard M&V procedures and contract terms that can help both end users and the financial companies better understand performance contracting. Gan [5] described current situations, barriers, and corresponding removal measures of ESCO industries in China. One of the stimulative measures is to build standard energy performance contracts and M&V procedures. Bertoldi et al. [6] considered the result of reviews and analyses of ESCO industries in the EU and the new accession countries to formulate a long-term strategy. One of the actions is to standardize contracts and M&V procedures; it will help both end users and the financial community to easily understand the M&V procedures. Lee et al. [7] used two questionnaire surveys to identify the risks in energy performance contracting projects (EPCPs). The results indicated that M&V risks are one of the top three key risk factors. Qian and Guo [8] developed the bargaining model of the shared savings contract and the basic model of the forecast-commitment contract to analyze the uncertainty of the value of EPCPs. The result showed that third-party M&V mechanism can reduce energy savings risk. International Performance Measurement and Verification Protocol [9] has been widely adopted internationally. It provides M&V concepts and methodologies to determine energy and water savings for various energy conservation measures (ECMs) in existing and new buildings and industrial processes. American Society of Heating, Refrigerating and Air-Conditioning Engineers Guideline 14 [10] is used for M&V of energy and demand savings in building energy management projects and in commercial transactions between ESCOs and end users. Australasian Energy Performance Contracting Association developed the best practice guide [11]. This guide provides M&V concepts and methodologies to calculate energy and water savings. This M&V guide can be applied in residential, commercial and industrial buildings, and industrial processes. Federal Energy Management Program M&V Guideline [12] contains M&V methods and plans for quantifying the energy and water savings in performance-based contracts.

However, different energy conservation measures require different methods to calculate the baseline model and energy saving performance. Therefore, many M&V studies have been conducted. Lee [13] suggested that long-term monitoring produces accurate energy savings calculations for individual cases because actual lighting conditions at individual sites may differ from client-provided data and this difference may introduce errors in the energy savings calculations. Dalgleish and Grobler [14] used linear regression to construct a baseline model for conveyor belts; their model verified that installing a motor sequencing controller on conveyor belts reduced energy use and demand. Dong et al. [15] used regression analysis to construct a baseline model for energy consumption in a building. The parameters for the baseline energy consumption were the outdoor dry-bulb temperature, relative humidity, and global solar radiation. The accuracy of the baseline model was verified using statistical indicators such as the coefficient of determination (R^2) and the coefficient of variation of the root-mean-square error (CVRMSE). Reddy and Claridge [16]