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Hybrid Time-Series Forecasting and Cost Optimization for Smart Homes Using Decomposition and Machine Learning

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Abstract

This paper proposes a hybrid framework for short-term residential energy forecasting and cost optimization in smart home environments. The study leverages a synthetically generated dataset comprising appliance-level energy consumption across 10 households during 2022, sampled at 15-minute intervals and enriched with environmental and behavioral features. The forecasting methodology integrates Seasonal-Trend decomposition using LOESS (STL) to isolate trend and seasonal components, with a Random Forest regressor trained on the residuals using lagged load features, rolling statistics, indoor and outdoor conditions, occupancy indicators, and electricity pricing as exogenous predictors. Forecast generation is formulated as the additive combination of the decomposed trend, seasonal components, and residual predictions. The model is evaluated using a time-based train-test split, with forecasting accuracy assessed through Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), and Mean Absolute Percentage Error (MAPE). In parallel, a cost optimization module is developed under a time-of-use (TOU) pricing scheme, where washer operation sessions are detected at 15-minute resolution and reallocated using a greedy heuristic to minimize daily costs while respecting operational constraints. Experimental results demonstrate that the hybrid model improves prediction accuracy relative to baseline methods, while the optimization strategy yields tangible reductions in electricity expenditure. This work highlights the potential of combining decomposition-driven forecasting with appliance-level scheduling to support energy-efficient smart home management.

Keywords: *Smart home energy management, Hybrid forecasting, Time-series decomposition, Random Forest regression, Demand-side management, Time-of-use pricing, Appliance scheduling, Energy cost optimization, IoT-based energy analytics, Residential load forecasting*



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