Design, Benchmarking and Graphical Lasso based Explainability Analysis of an Energy Game-Theoretic Framework

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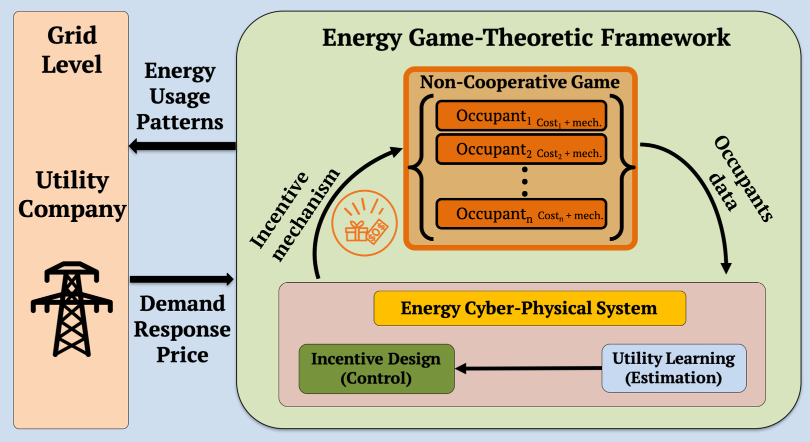
Introduction

Buildings, both residential and commercial, account for more than ~50% of global electricity consumption and ~40% of worldwide CO_2 emissions!

- Attempts to improve energy efficiency in buildings include implementing control and automation approaches alongside techniques like incentive design and price adjustment to more effectively regulate the energy usage.
- But, occupants typically lack the independent motivation necessary to optimize their energy usage.
- **Energy Game-Theoretic Framework:** Incentivize occupants to modify their behavior in a competitive game setting so that the over-all energy consumption in the building is reduced.
- The framework can also be integrated with the power grid to have dynamic protocols for demand response.

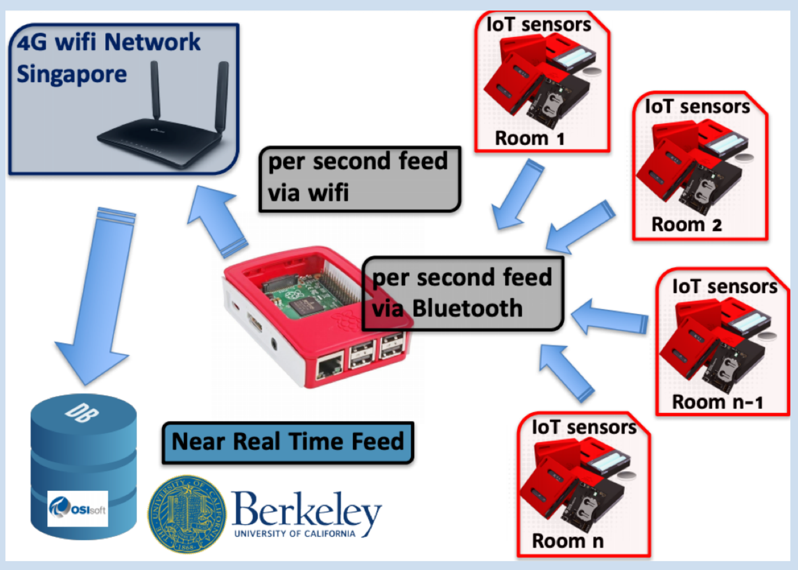


Interplay between electric grid and proposed framework

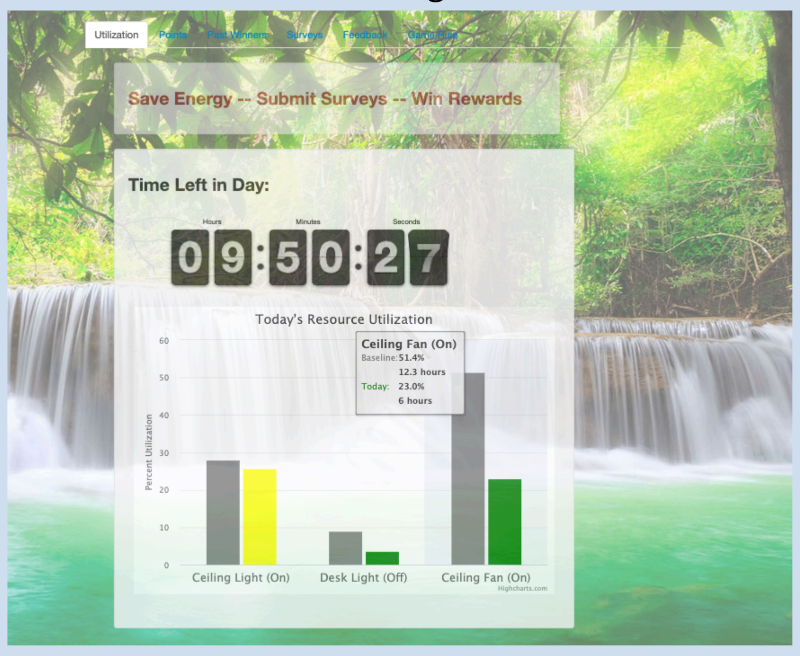
We present a benchmarked open-sourced dataset from an energy social game experiment at Nanyang Technological University (NTU), Singapore.

Social Game Experiment

- Experimental environment: Residential housing single room apartments at NTU
- Deployed IoT sensors for energy resource observation and employed an web-interface for interaction with players



IoT Sensors Configuration



Web Interface

- The front-end was a web portal to report the occupants about real-time status
- Occupants were observed before game for one month, which serves as our baseline
- We employed a lottery mechanism consisting of gift cards to incentivize occupants, where the probability of winning was proportional to the players points in the game,

$$\hat{p}_i^d(b_i, u_i) = s_i \frac{b_i - u_i^d}{b_i}$$

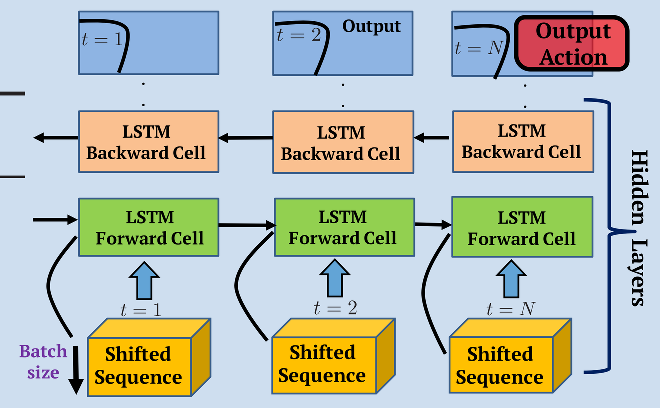
where $\hat{p}_i^d$ is the points earned, u_i^d is the usage on day d for resource i, b_i is the resource's baseline and s_i is a points booster for inflating the points as part of framing.

- We use sequential non-cooperative discrete game concept for the game design [1].

Benchmarking of Energy Resource Usage Forecast

Since human interaction data in general is imbalanced, we use the Synthetic Minority Over-Sampling(SMOTE) technique for providing balanced data sets first. Reported are AUC scores for various models with step ahead (sensory data accounted) vs sensor free cases.

"Step-ahead"/"Sensor-free"	Ceiling Fan	C. Light	Desk Light
Logistic regression	0.83 / 0.65	0.78 / 0.61	0.78 / 0.68
Penalized l_1 Logistic regression	0.80 / 0.65	0.77 / 0.56	0.78 / 0.64
Bagged Logistic regression	0.84 / 0.66	0.80 / 0.59	0.79 / 0.68
LDA	0.81 / 0.65	0.78 / 0.58	0.74 / 0.68
K-NN	0.76 / 0.53	0.77 / 0.56	0.74 / 0.55
Support Vector Machine	0.82 / 0.65	0.78 / 0.60	0.76 / 0.68
Random Forest	0.91 / 0.60	0.78 / 0.59	0.98 / 0.63
Deep Neural Network	0.80 / 0.55	0.76 / 0.60	0.78 / 0.64
Deep Bi-directional RNN	**0.97** / **0.71**	**0.85** / **0.66**	**0.99** / **0.76**

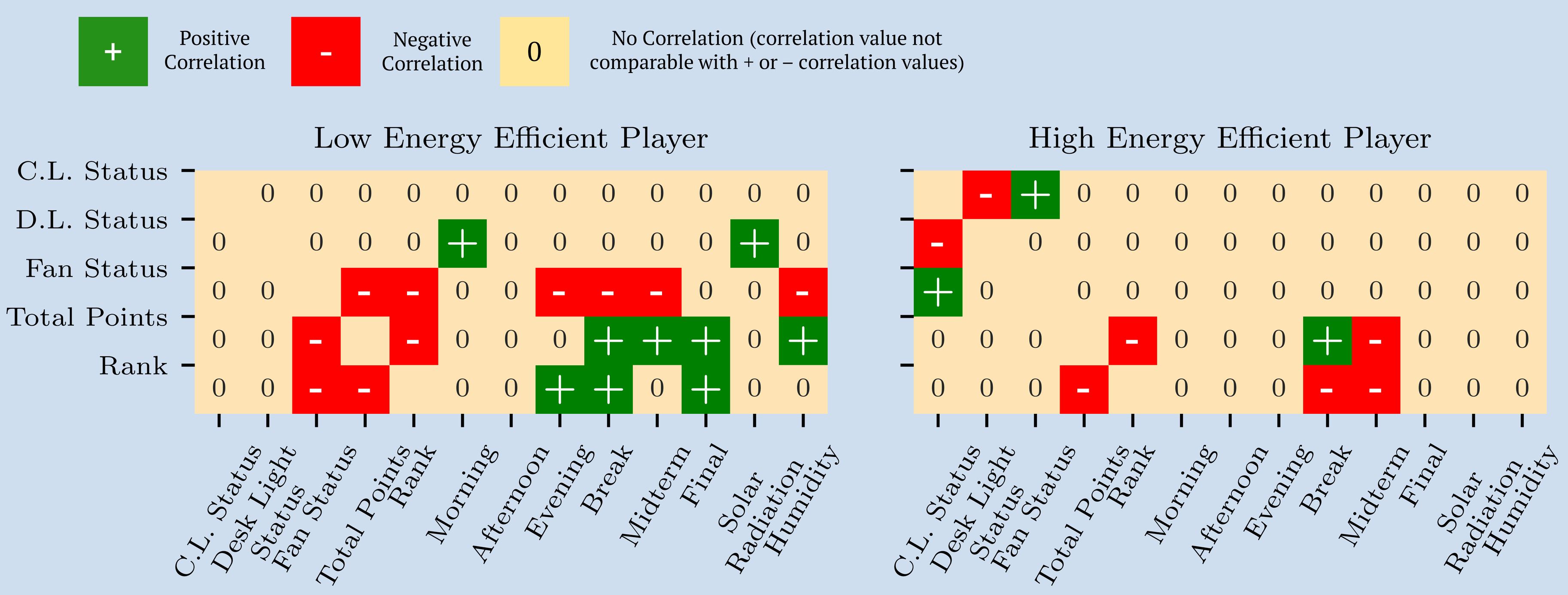


Deep Bi-directional RNN

Energy Savings achieved in the Social Game

	Weekday				Weekend			
Device	Before	After	p-value	Δ %	Before	After	p-value	Δ %
Ceiling Light	417.5	393.9	0.02	5.6	412.3	257.5	0	37.6
Desk Light	402.2	157.5	0	60.8	517.6	123.3	0	76.2
Ceiling Fan	663.5	537.6	0	19.0	847.1	407.0	0	51.9

Feature Correlation Learning using Graphical Lasso[1,2]



Open-Sourced Dataset

Paper **Dataset/ Demo**

References

[1] I. C. Konstantakopoulos et al. Design, Benchmarking and Explainability Analysis of a Game-Theoretic Framework towards Energy Efficiency in Smart Infrastructure. arXiv preprint arXiv:1910.07899, 2019

[2] H. P. Das et al. A Novel Graphical Lasso based approach towards Segmentation Analysis in Energy Game-Theoretic Frameworks. arXiv preprint arXiv:1910.02217, 2019

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