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Benchmarking of Aggregate Residential Load Models Used for Demand Response

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Background (I/II)

- The power consumption of thermostatically controlled loads (TCLs) can be coordinated to help the electric power grid balance supply and demand
  - Large populations
  - Often residential air conditioners (ACs)
  - Can provide frequency regulation
- Often assume an aggregator receives a desired power signal and controls an aggregation of loads to match that signal
  - Often rely on control and estimation algorithms
- Recent work has sought to develop aggregate residential load models
  - Examples include [Mathieu 2013], [Zhang 2013], [Perfumo 2012], [Mahdavi 2016]
  - Capture the aggregation's total power consumption dynamics
  - Used in state estimation and control algorithms
  - Can improve control performance

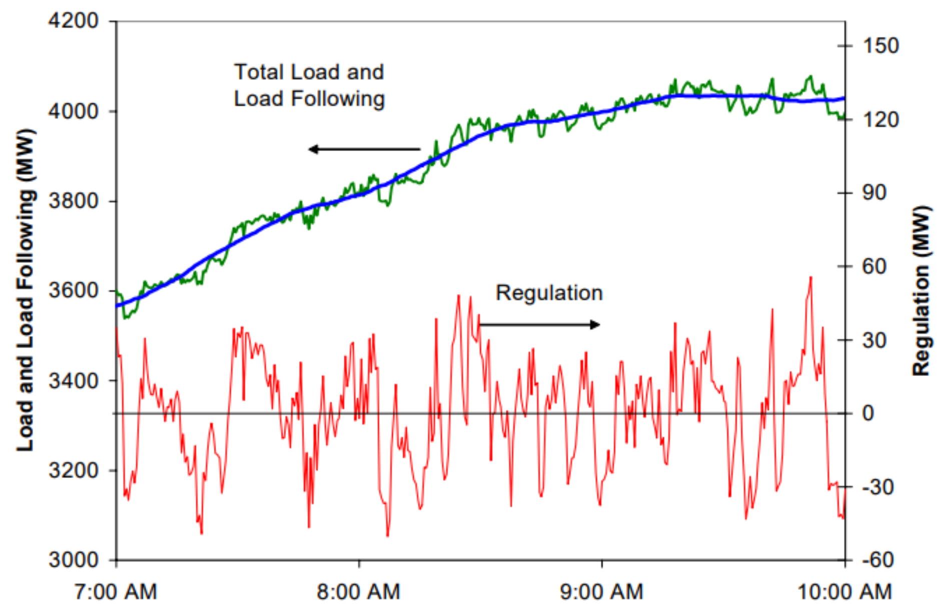
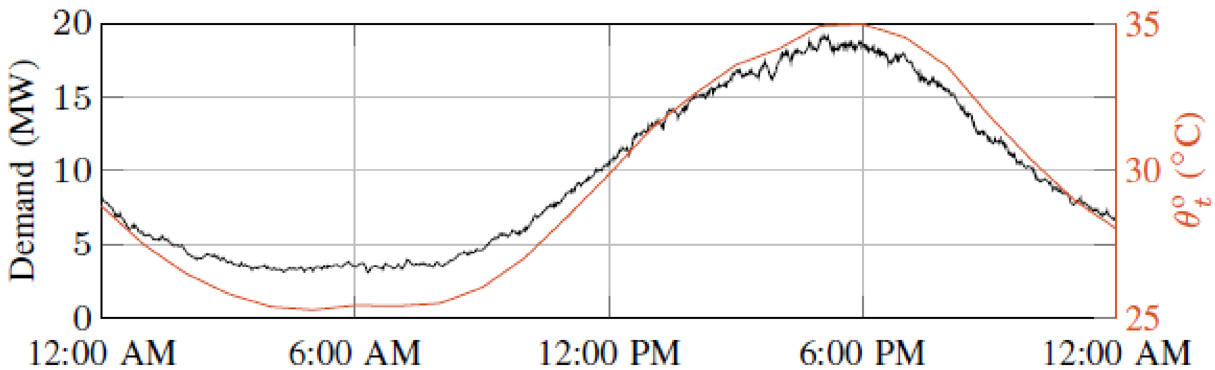


Figure: Kirby, Brendan J. *Frequency regulation basics and trends*. United States. Department of Energy, 2005.

Background (II/II)

- We only have a partial understanding of which models work best under which conditions
  - Developed under different assumptions
  - Validated in simulation studies that use simplifying assumptions
- **Research Goal:** seek a better understanding of the advantages and disadvantages of three aggregate load models representing a heterogeneous AC population.
  - Two models use Markov chains
    - J. L. Mathieu, S. Koch, and D. S. Callaway, "State estimation and control of electric loads to manage real-time energy imbalance," IEEE Transactions on Power Systems, vol. 28, no. 1, pp. 430–440, 2013.
    - W. Zhang, J. Lian, C.-Y. Chang, and K. Kalsi, "Aggregated modeling and control of air conditioning loads for demand response," IEEE Transactions on Power Systems, vol. 28, no. 4, pp. 4655–4664, 2013.
  - One model uses a transfer function
    - N. Mahdavi, J. H. Braslavsky, and C. Perfumo, "Mapping the effect of ambient temperature on the power demand of populations of air conditioners," IEEE Transactions on Smart Grid, 2016.
- Simulations include a time-varying outdoor temperature and a hybrid model representation of individual ACs with weather-dependent AC cooling capacity, coefficient of performance, and power draw

Results (I/II)



Abbreviation	Base Model	Model Details	RMSE (kW)
MM2-C	Two-State Markov Model	Uses outdoor temperature; data for model ID generated using constant outdoor temperatures	436.7
MM2-V	Two-State Markov Model	Uses outdoor temperature; data for model ID generated using a varying outdoor temperature	437.1
MM2-S	Two-State Markov Model	Uses outdoor temperature and its trend; data for model ID generated using a varying outdoor temperature	226.2
MM3-C	Three-State Markov Model	Uses outdoor temperature; data for model ID generated using constant outdoor temperatures	320.9
MM3-V	Three-State Markov Model	Uses outdoor temperature; data for model ID generated using a varying outdoor temperature	322.9
MM3-S	Three-State Markov Model	Uses outdoor temperature and its trends; data for model ID generated using a varying outdoor temperature	213.4
TF-O	Transfer Function Model	Assumed transfer function structure of two poles and one zero; parameters identified from TCL population parameters	504.4
TF-ID	Transfer Function Model	Transfer function structure of two poles and two zeros ; parameters identified from historical data	447.0

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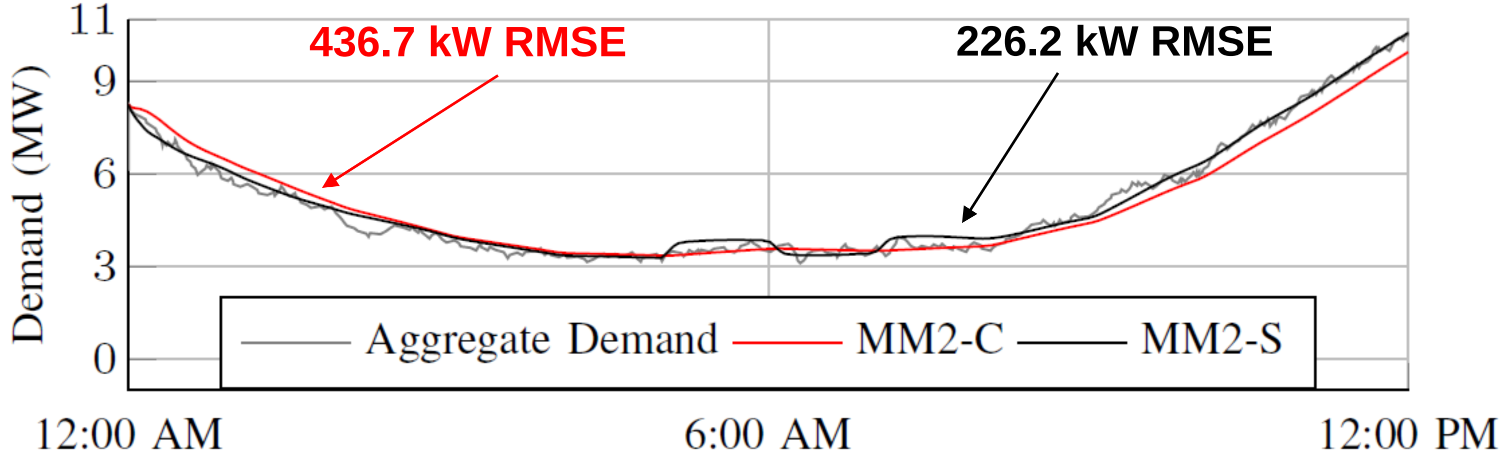
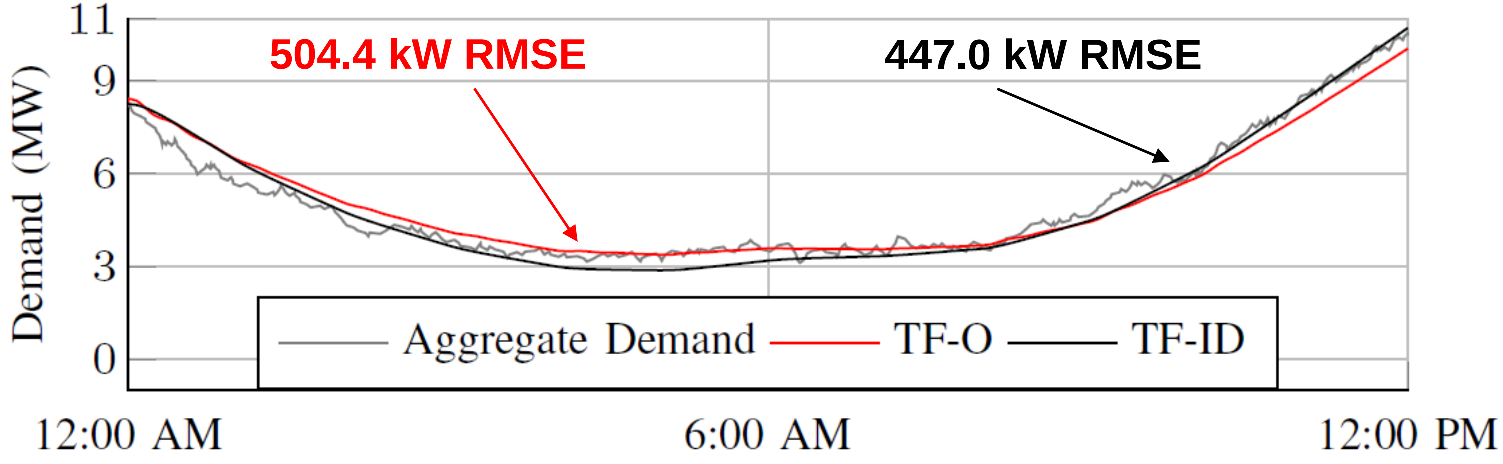
Results (II/II)



(a) Two-state Markov models



(b) Transfer function models

Conclusions/Recommendations

- The three-state aggregate model outperforms the other aggregate models
- Incorporating the temperature trend improves both Markov-based models
  - Reduces the gap in prediction accuracy between the two.
- The transfer function model is the least accurate of the three aggregate models
  - The identified transfer function resulted in reduced prediction error.
- The simpler two-state aggregate model offers a good tradeoff in complexity versus accuracy when including temperature trends into the model