Residential Load and Building Temperature Dynamic Models for DR and VPP Studies

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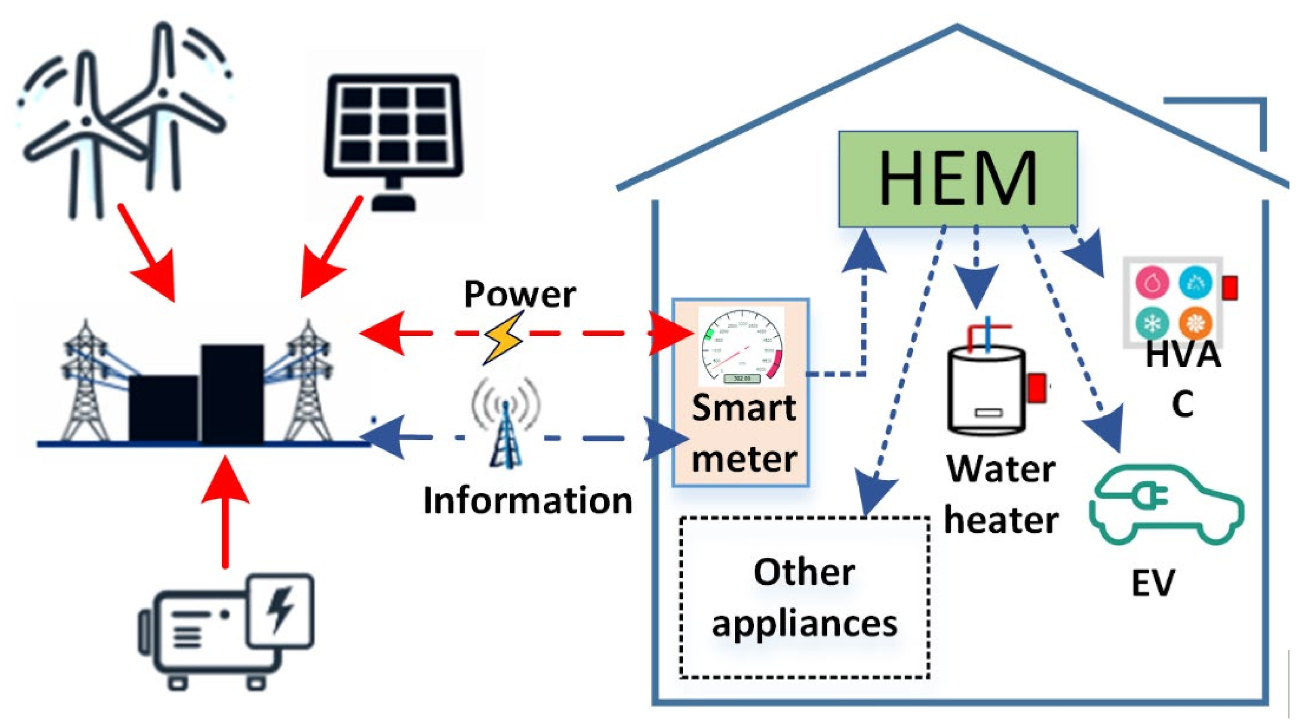
2022 IEEE PES GM Undergraduate Poster Competition

Problem Formulation

- One possible method to decrease load during peak hours is to control HVAC systems and water heaters to shut off at certain hours of the day when unused.
- In this experiment, a home under normal HVAC operation is compared to the same home with the HVAC controlled to be off from 8 a.m. to 1 p.m. to analyze the energy consumption in each scenario.

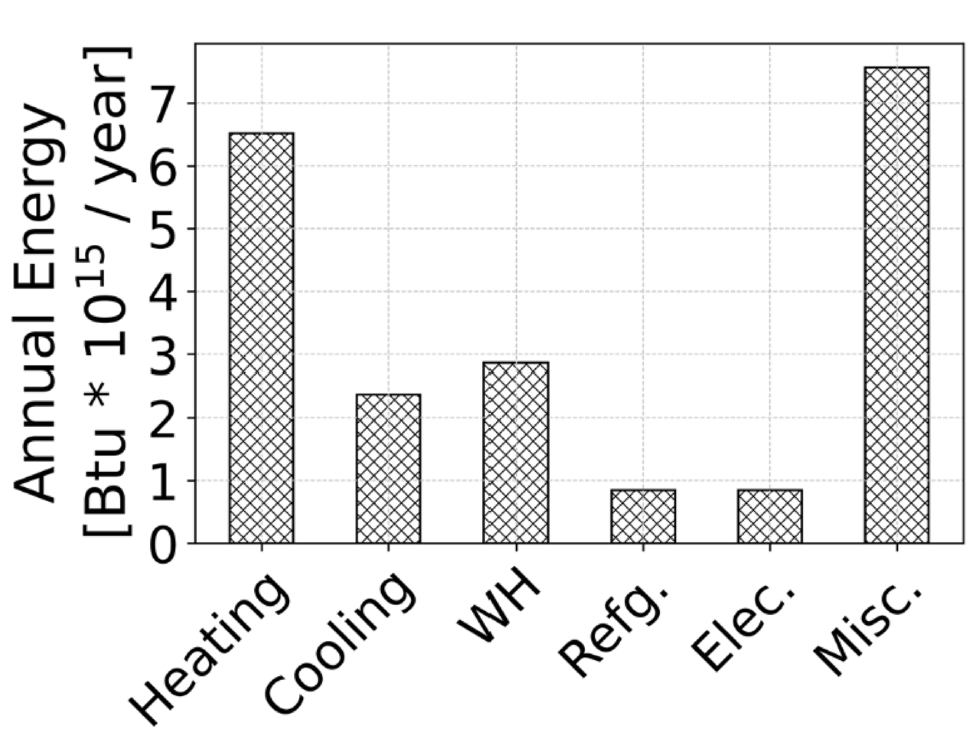
Connection to HEMS Applications

- A Home Energy Management System (HEMS) can control these appliances to shut off at times the home is unoccupied, for example, when a resident is away at work.

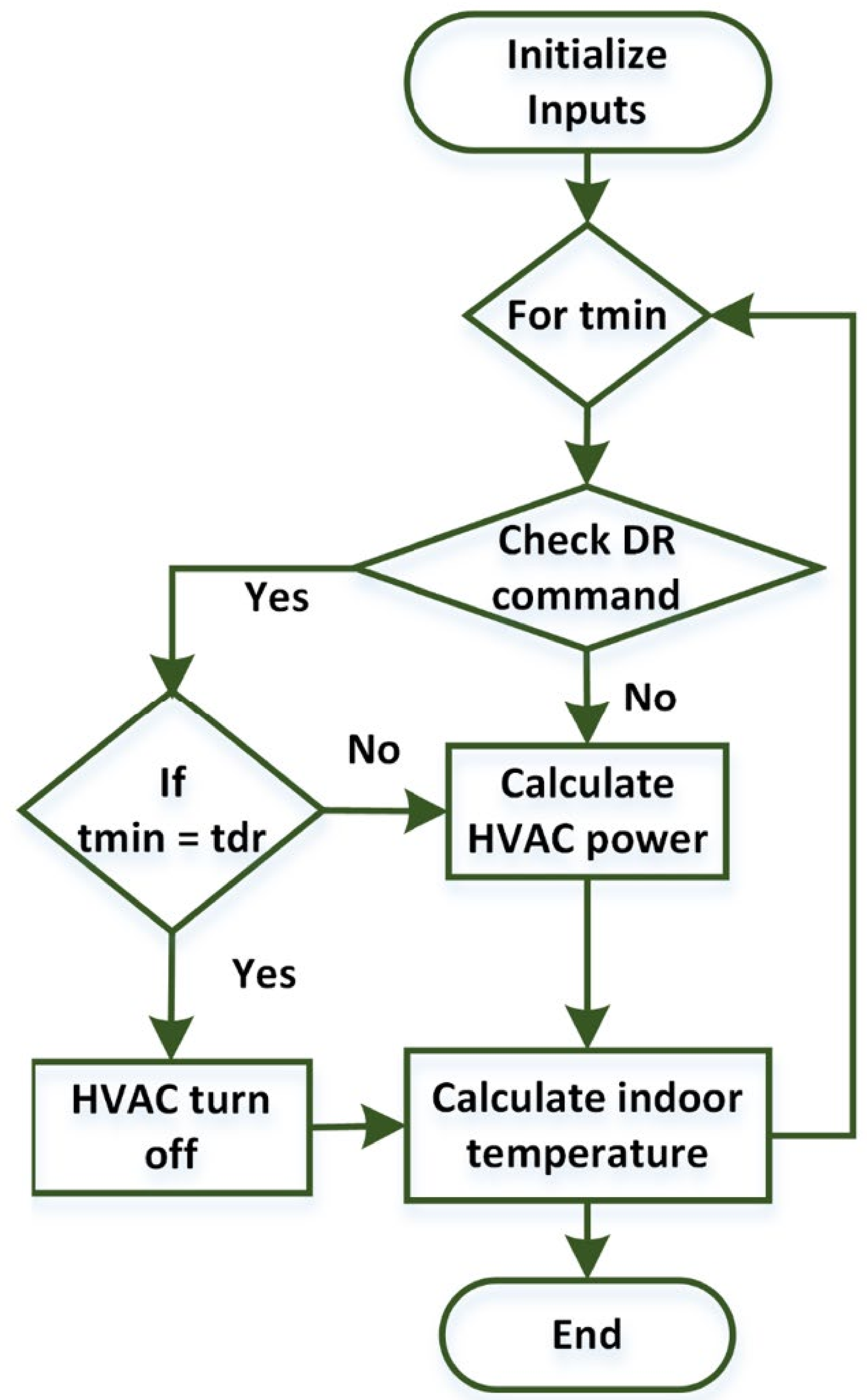


HVAC Control Case Study

- A digital twin, including equivalent thermal and machine-learning models of a smart home managed by the Tennessee Valley Authority (TVA) was used to calculate the HVAC load and indoor temperature per weather inputs.
- For each trial, two simulations were ran using the digital twin: the home under normal HVAC operation, and the same home with the HVAC controlled to be off at selected hours.
- Results of the simulations are shown below. A summer day with high outdoor temperature was chosen. In the controlled HVAC simulation, the indoor temperature was returned to the set-point before 5 p.m.



- The figure to the left shows the annual energy consumption of household appliances as found by the US Energy Information Administration (EIA).
- Space heating, space cooling, and water heating have great influence on residential loads.



- The flowchart to the left shows the process used in the Python script to calculate power consumed by the HVAC and indoor temperature over the course of a given day.
- Every minute the script checks if the time is within controlled hours, then calculates the indoor temperature depending on the status of the HVAC. This process is then repeated for every minute in the day.

Analysis of Results

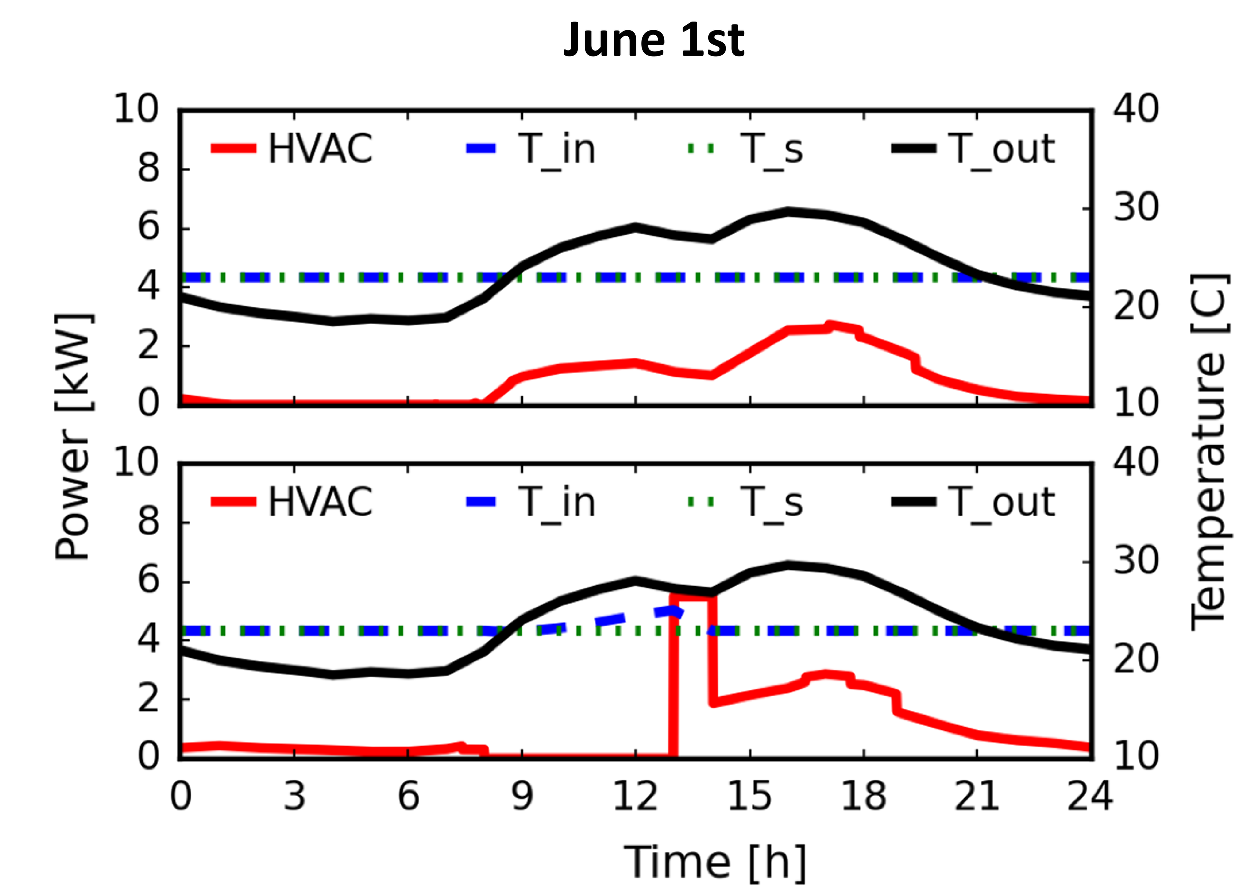
- Energy consumed over time can be calculated as follows:

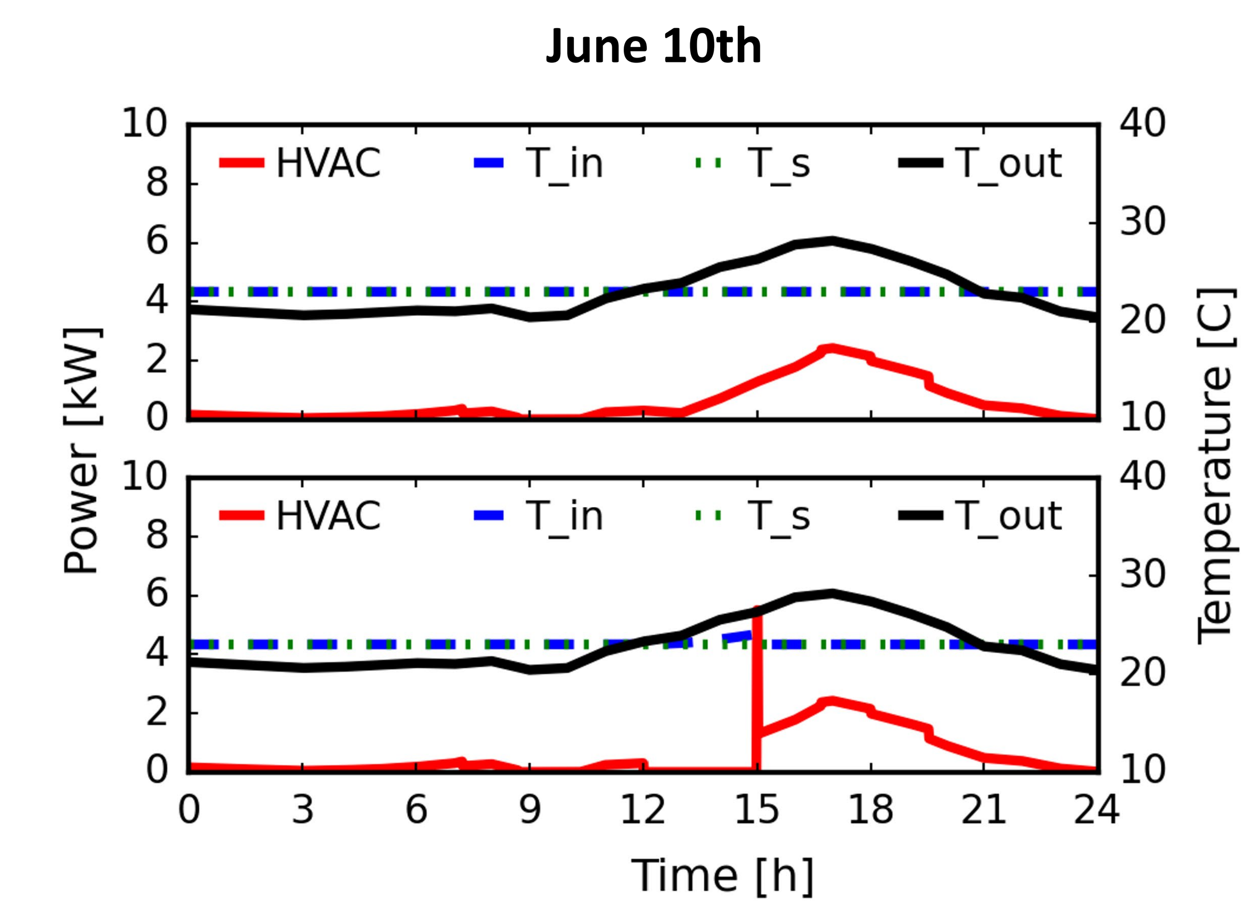
$$W = \int_{t_o}^{t} P(t)dt$$

- An energy calculation was included in the Python script to calculate energy used by the HVAC in each scenario.
- The total energy consumed by the HVAC on June 1st was approximately 1.8 kWhr for the HVAC when uncontrolled and approximately 1.5 kWhr when controlled.
- The total energy consumed by the HVAC on June 10th was approximately 1.25 kW for the HVAC when uncontrolled and approximately 1.02 kW when controlled.

Coefficient of Performance (COP)

- The coefficient of performance (COP) describes how efficiently a cooling system transfers heat for the energy it consumes.
- HVAC systems with a higher coefficient of performance save electricity since they can keep indoor temperature at a comfortable level using less energy.
- The HVAC system used in this experiment has a COP of 3.37, which is slightly above average. Results will vary depending on the COP of each HVAC system.





Conclusions

- Implementing DR by controlling household appliances through a HEMS can save electricity and decrease the load on the utility grid during peak hours while also allowing a comfortable indoor temperature during hours of occupancy.

Future and Ongoing Work

- Work is ongoing with two additional houses to compare the effects of DR on HVAC systems with various Coefficients of Performance (COP) and Seasonal Energy Efficiency Ratios (SEER). Additional calculations include daily energy usage minimization and TOU pricing calculations for behind-the-meter (BTM) user benefit assessment.

Acknowledgement

- This paper is based upon work supported by the National Science Foundation (NSF) under Award No. 1936131. Any opinion, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of NSF.”