Carbon Mitigation Potential of Heat Pump Integrated with Thermal Storage for Grid-Interactive Residential Buildings

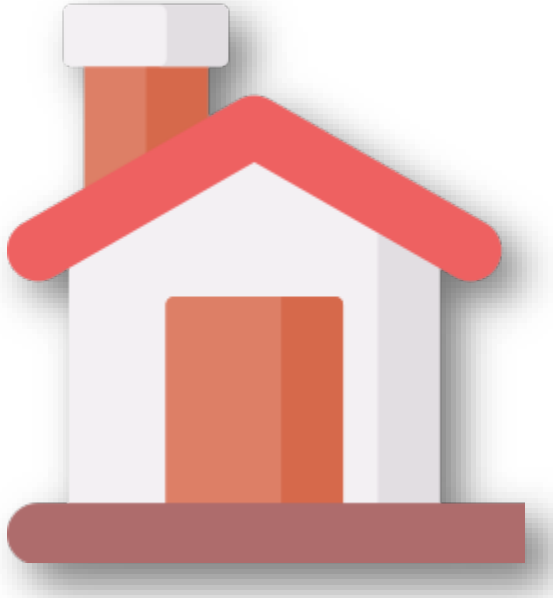
Sara Sultan, Ph.D.

Bredesen Center, University of Tennessee/Oak Ridge National Lab

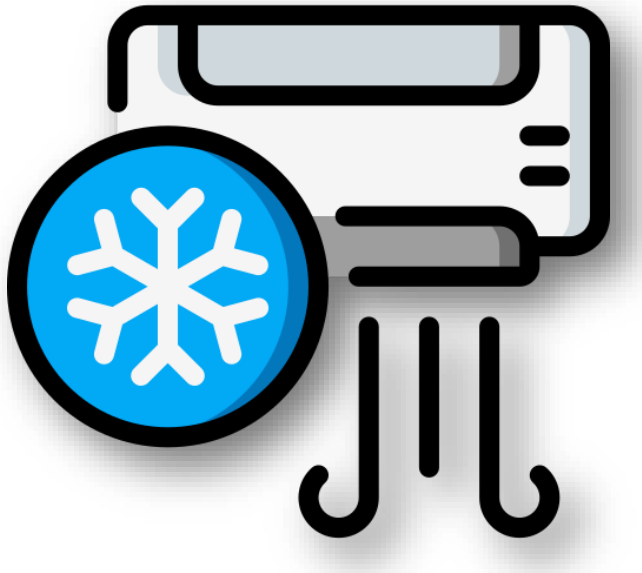
Building Energy Consumption

40%
global energy consumption

10%
global carbon emissions

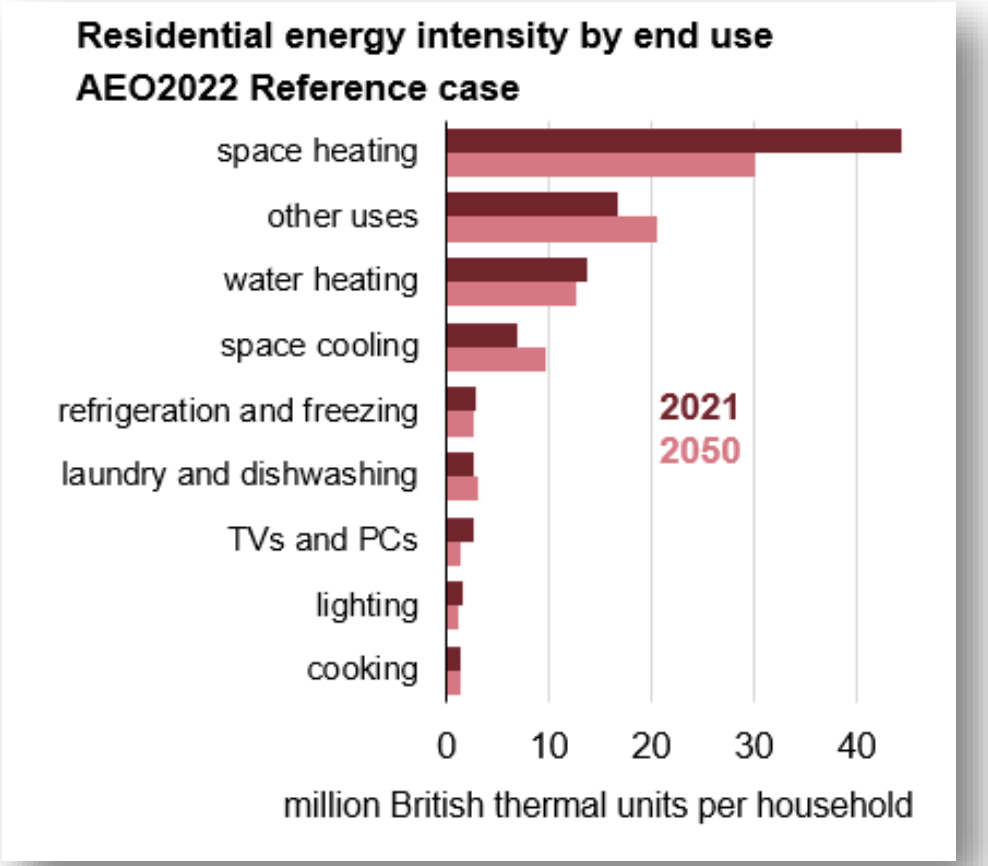


74%
electricity consumption in U.S.



50%
building electricity consumption

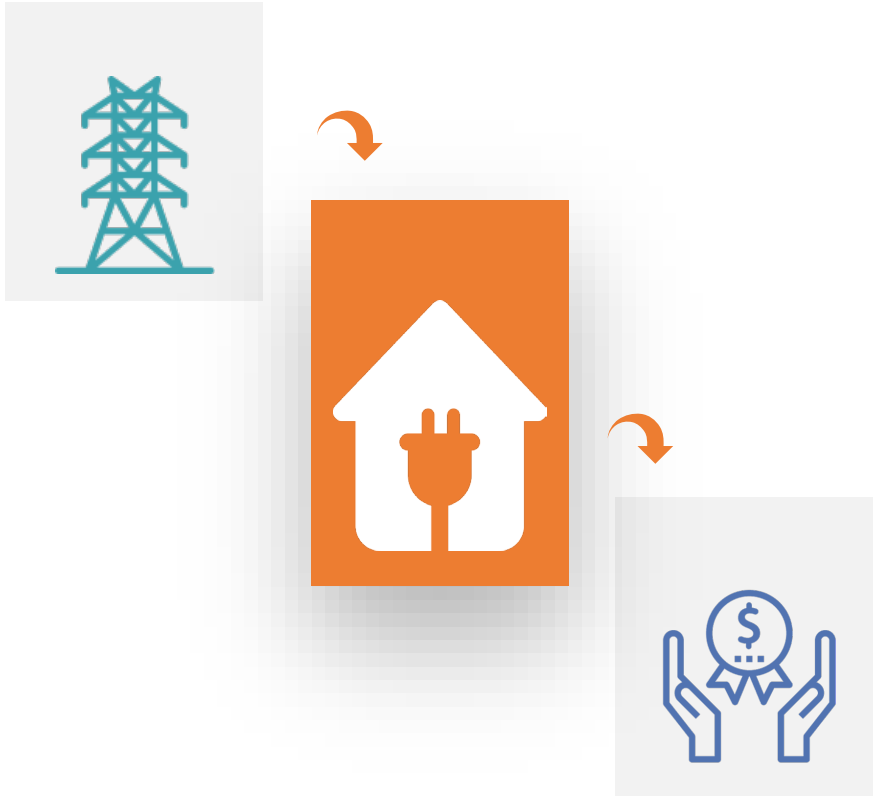
Residential Peak Load

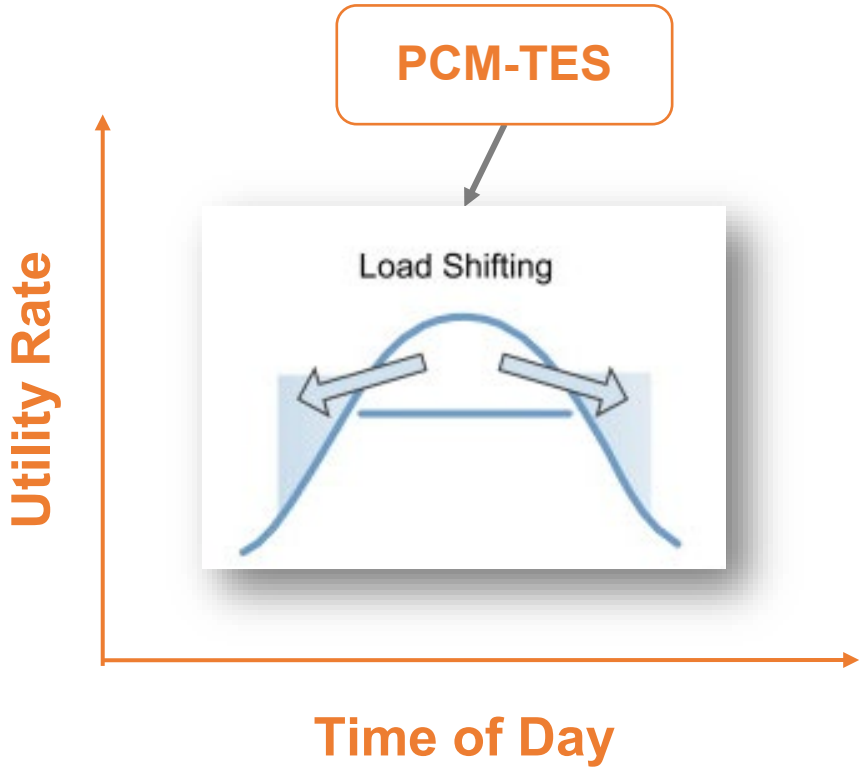


80%
electricity consumption in U.S.

78%
peak electric consumption from 2-8 PM

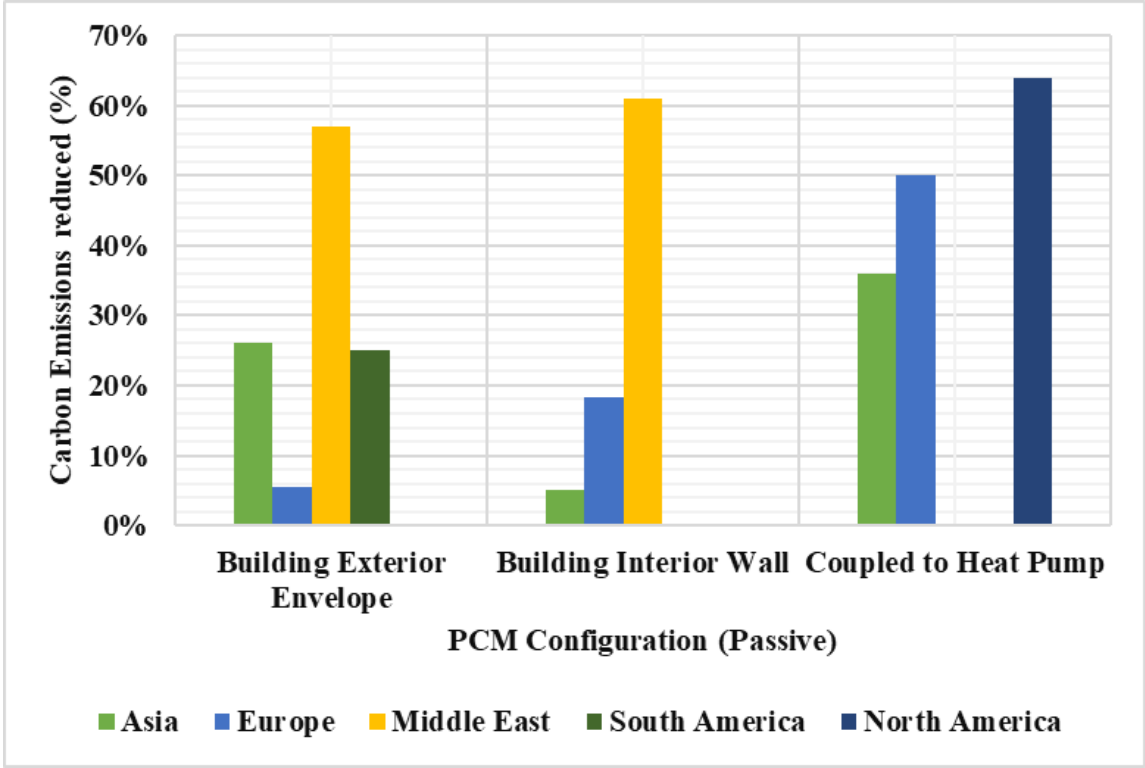
Load shifting using PCM-TES





Literature Review

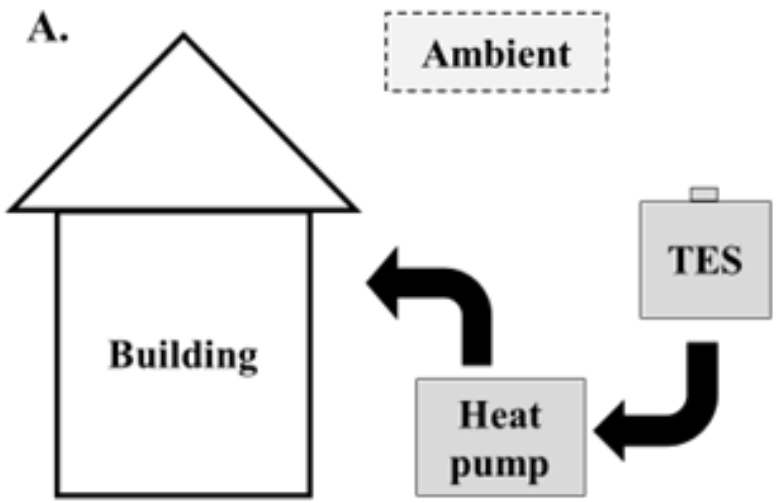
- Papers reported are either passive or hybrid TES.
- Majority of the works evaluate the electric HP emission reduction in comparison to gas furnaces as a reference
- DR control strategies to shift the peak load, and corresponding emissions were reported
- Emissions calculated by deriving relations to the energy consumption and power usage
- No studies use emissions data to develop control strategy for decarbonization



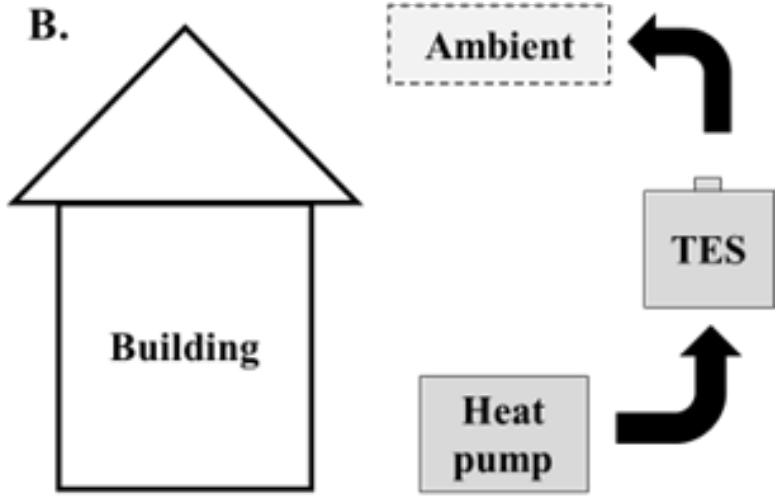
System Configuration

- TES does not cool the building directly, but heat transfer occurs through HP
- Modeled in Engineering Equation Solver and Excel

A) TES Discharging in Cooling mode

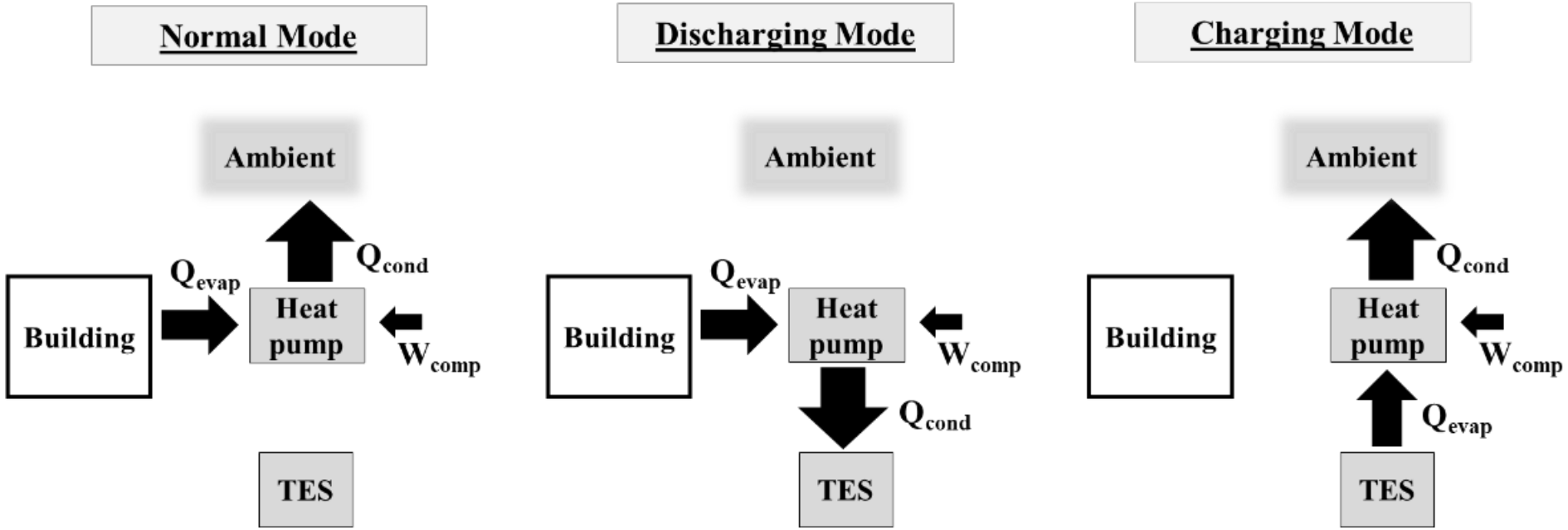


B) TES Charging in Cooling mode



System Configuration

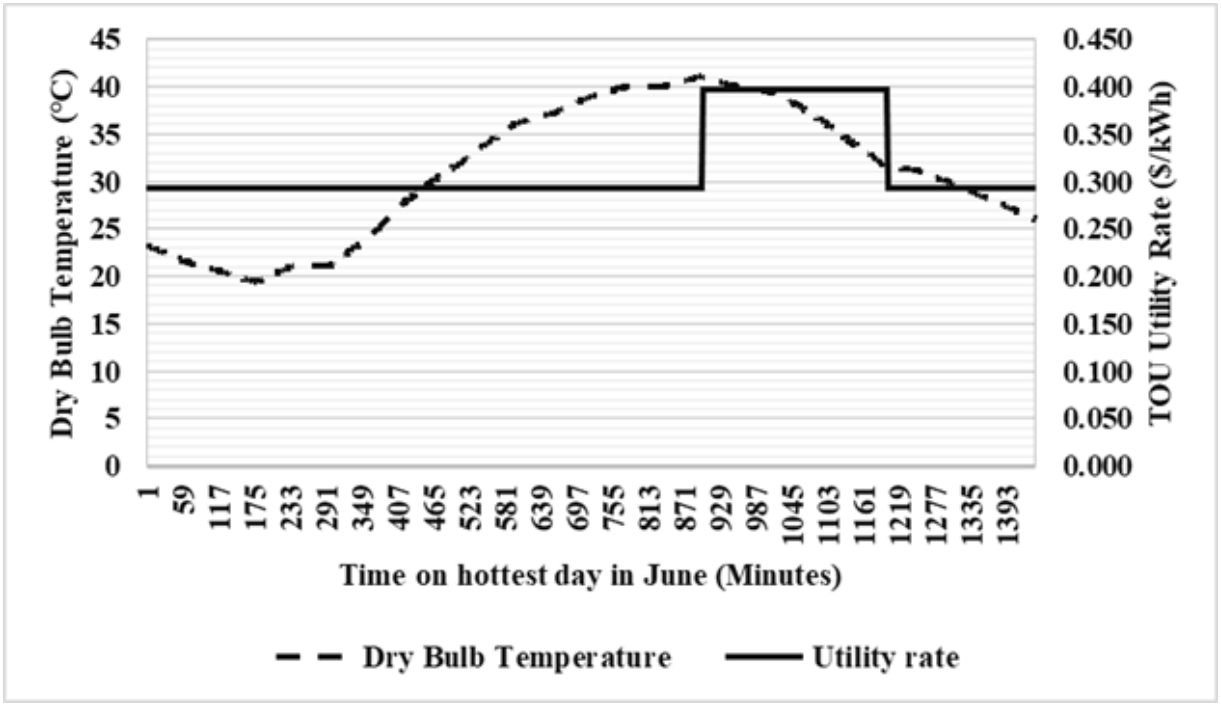
- R410A VCS coupled to water/ice-embedded TES at a constant 0°C
- VCS has a negative temperature gradient to move the building thermal load
- PCM heat exchanger as heat sink or source and analyzed for cooling mode



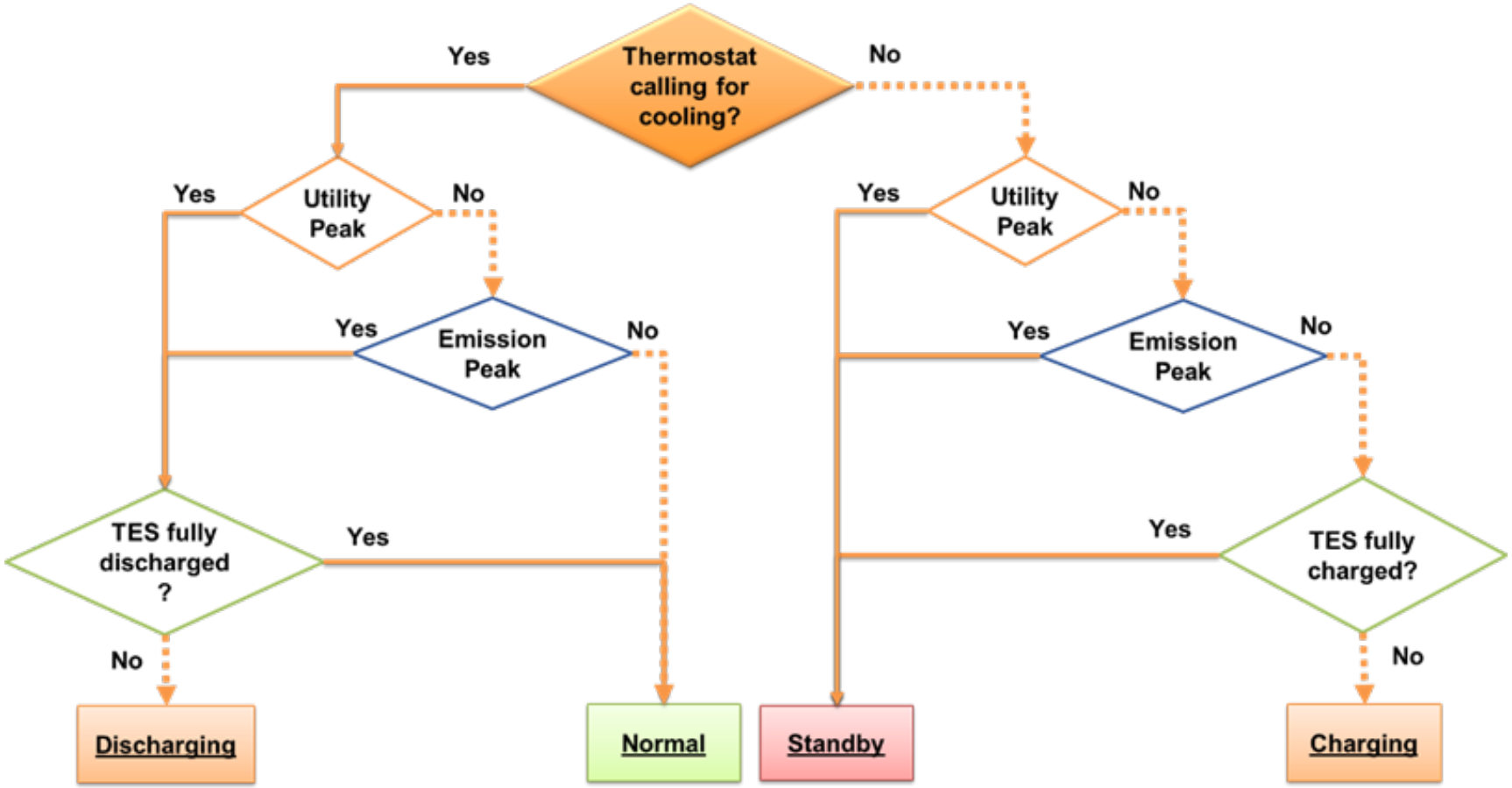
System overview and Utility tariff

- System's performance evaluated for cooling
- Hot week (June 24-30, 1994) of ASHRAE climate zone 3B
- TMY 3 weather data for Fresno, CA
- The location correlates to the utility pricing from residential Time-of-Use rate

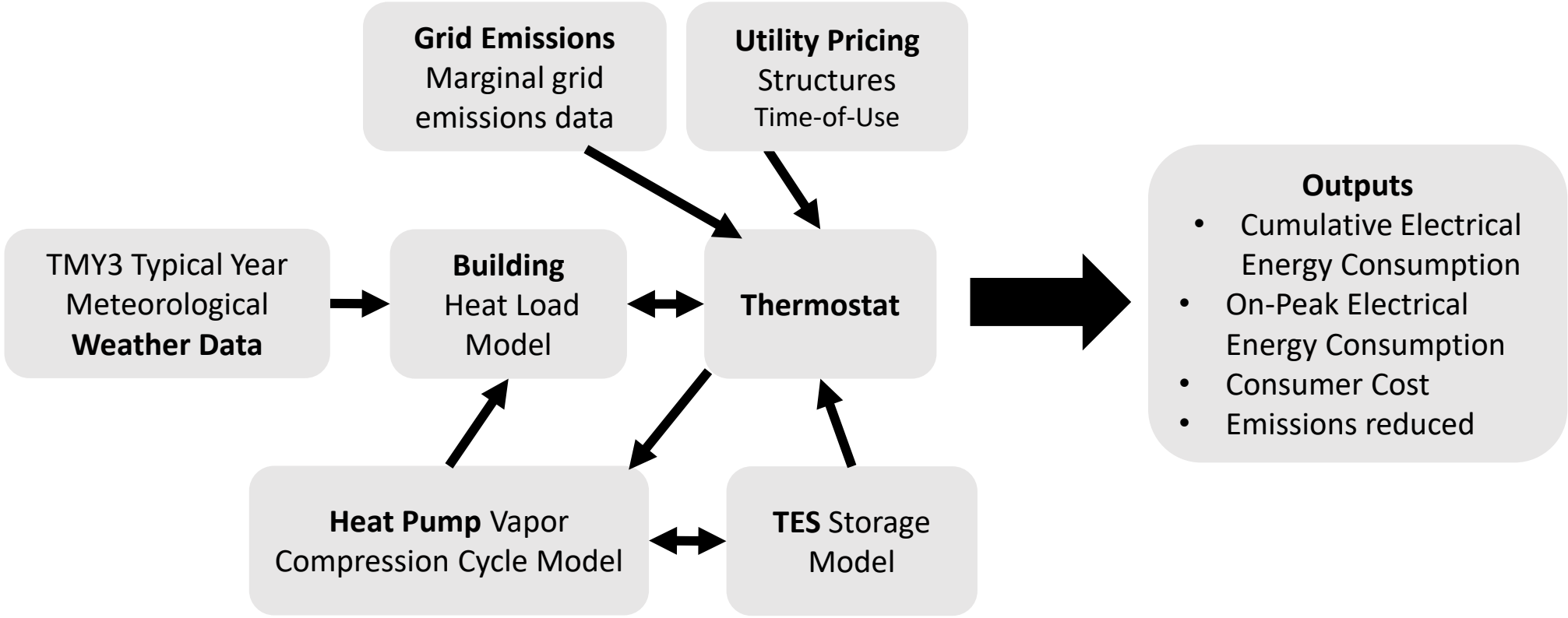
TOU Utility Tariff for ASHRAE climate zone 3B and 3C			
On-peak rate	**On-peak hours**	**Off-peak rate**	**Off-peak hours**
$0.39689/kWh	4pm-9pm, June1-Sep30, M-F	$0.29383/kWh	9pm-4pm, June1-Sep30, M-F All times, June1-Sep30, Sat & Sun



System Controls

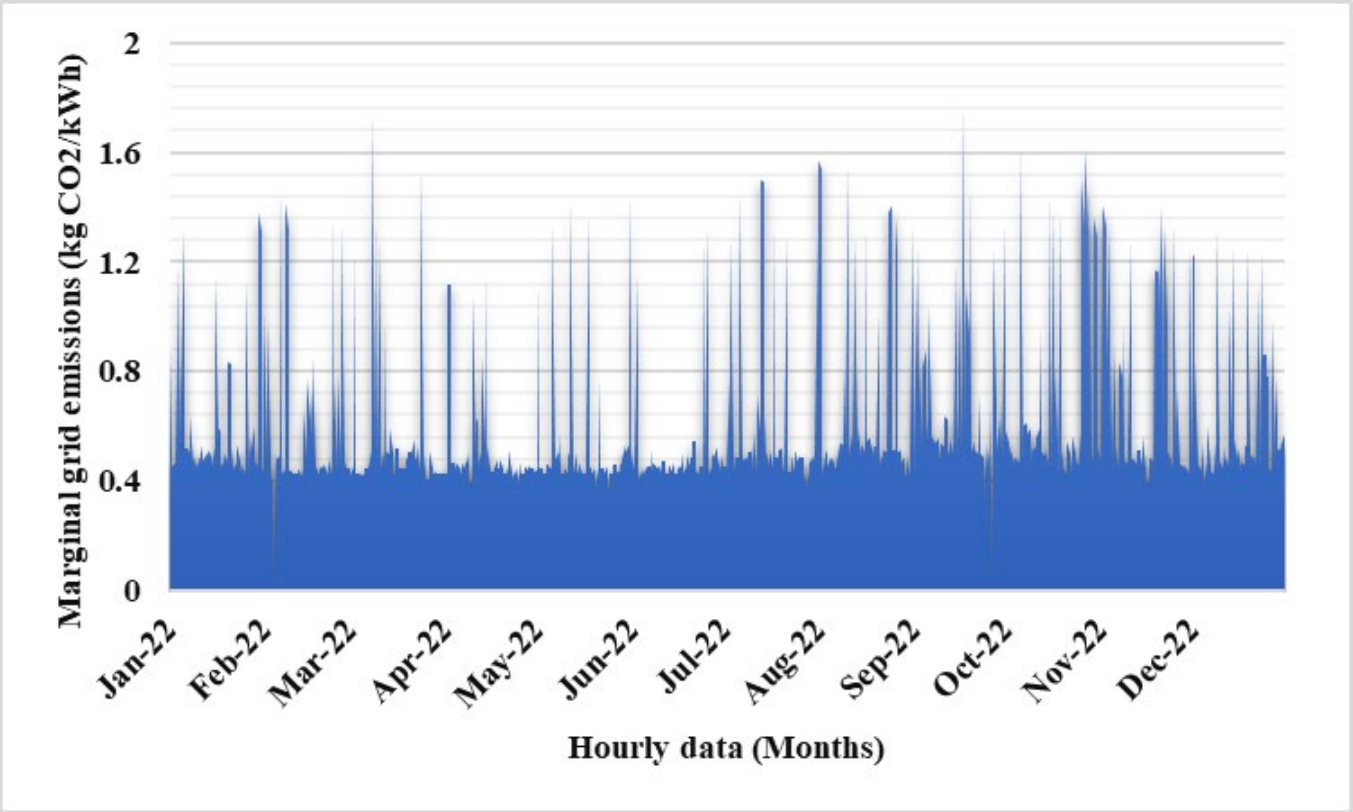


Information flow

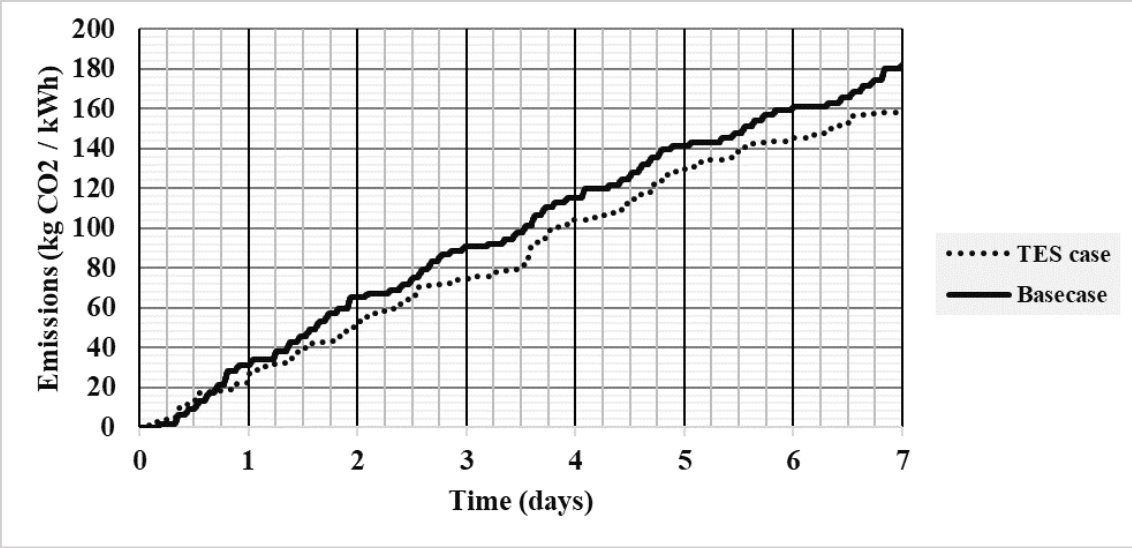


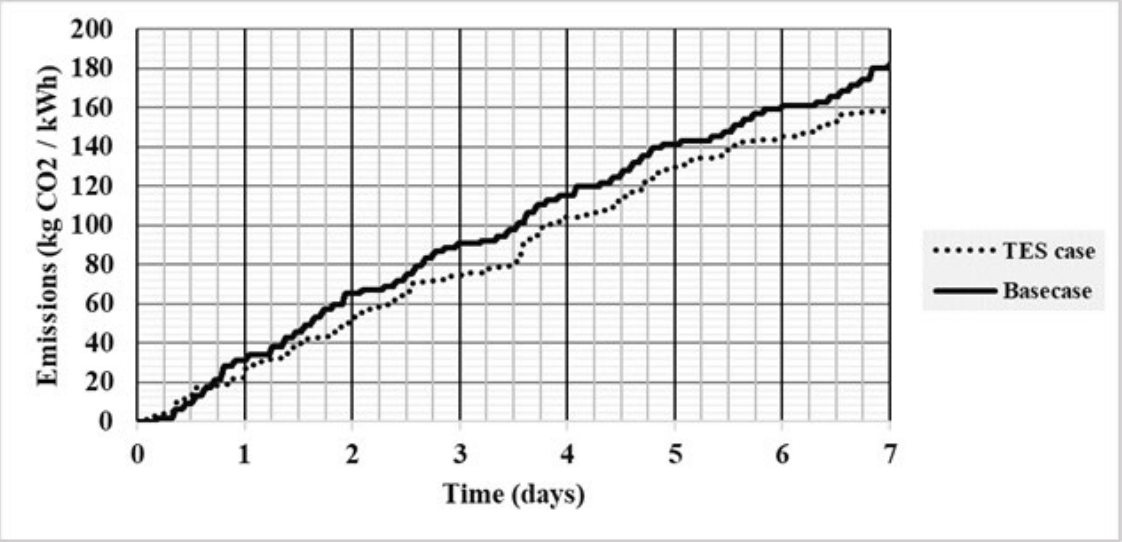
Grid emissions data

- Fresno annual grid emissions during 2022
- The tool generates emissions schedule based on continuous emissions and electricity generation data from major fossil fuel plants in the U.S.
- The data from January until November 15 is real time, and rest is projected based on historical data.



Emissions and Cost reduced with TES





11.9% reduced grid emissions

12.7% reduced consumer cost

Conclusions and Findings

- Carbon emissions reduction potential of HP-TES evaluated using a rule-based strategy accounting for marginal grid emissions data and time-of-use utility tariff.
- HP-TES performance evaluated for cooling (June 24-30, 1994)
- TMY 3 weather data for Fresno, CA (ASHRAE climate zone 3B)
- The utility cost for cooling was reduced by 12.68%
- The total electric consumption was reduced by 10.19%
- 50.2% of peak electric load was shifted to off-peak time.
- 11.92% of grid emissions were reduced

Acknowledgements

Kyle Gluesenkamp

This work was sponsored by the U. S. Department of Energy's Building Technologies Office under Contract No. DE-AC05-00OR22725 with UT-Battelle, LLC. This research used resources at the Building Technologies Research and Integration Center, a DOE Office of Science User Facility operated by the Oak Ridge National Laboratory. The authors would like to acknowledge Mr. Sven Mumme, Technology Manager, U.S. Department of Energy Building Technologies Office.

Benefits:

- Access to ORNL's global-leading scientific resources
- Mentoring by world-renowned UT and ORNL scientists
- Interdisciplinary, customizable curriculum
- Tuition waivers, insurance and competitive stipends

Contact:

UT-ORII Recruiter
Timothy Guthrie
tguthrie@utk.edu

Building America's Pipeline of Talent

UT-Oak Ridge National Laboratory Joint PhD Programs

Energy Science & Engineering

Data Science & Engineering

Genome Science & Technology

Arts & Sciences

- *Physics*
- *Biology*
- *Chemistry*
- *Mathematics*

Engineering

- *Materials Science*
- *Electrical & Computer Science*
- *Nuclear*
- *Mechanical, Aero & Biomed.*
- *Chem. & Biomol.*
- *Civil & Environmental*
- *Industrial & Systems*

Thank you

Sara Sultan
Graduate Research assistant / PhD Candidate
The University of Tennessee, Knoxville
The Bredesen Center for Interdisciplinary Research and Graduate Education, University of Tennessee, Knoxville, TN, USA
Email: ssultan1@vols.utk.edu
LinkedIn: https://www.linkedin.com/in/sarasultanaqib
https://bredesencenter.utk.edu/people/sara-sultan/