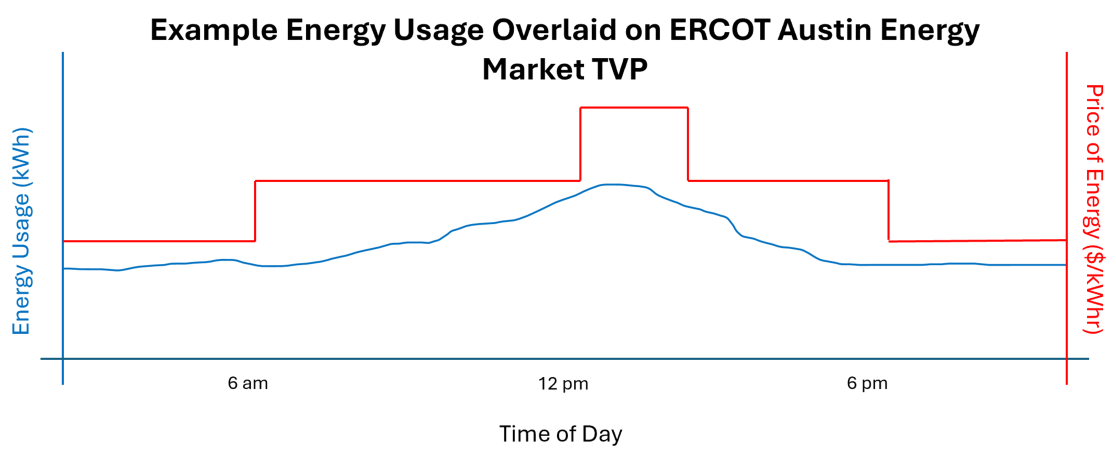
Modeling Phase Change Material (PCM) Enhanced Insulation in Time Variable Pricing (TVP) Energy Markets

TEXAS
The University of Texas at Austin

Author: Pascal Stevens, Cockrell College of Engineering, pfs342@utexas.eid.edu
PI: Dr. Andrew J. Fix, Maseeh Department of Civil, Architectural, and Environmental Engineering, fix@utexas.edu

Background

- Heating and cooling of buildings use ~40% of U.S. energy, contributing to rising grid strain and load variability [1]
- Pairing PCMs with TVP-aware HVAC control has shown to create passive load shifting
- Under TVP, load shifting has been shown to save costs and reduce strain on energy grids



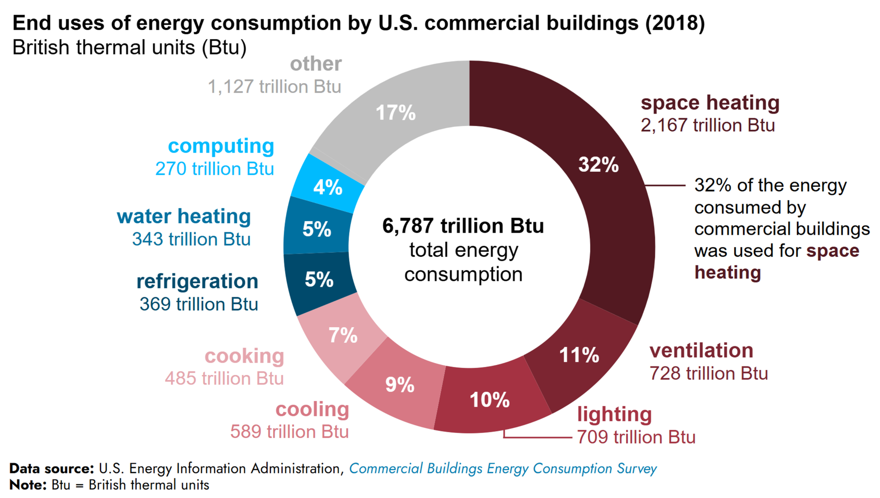


FIGURE 1 (UP): Displays a typical daily energy load in kW for a building in the summer in Austin (blue) overlaid with the price of energy per kWhr (red) according to ERCOT's 2023 TVP adjustment for the greater Austin area.

FIGURE 2 (UP): More than 40% of commercial energy consumption in the US is used for space heating or cooling [1}.

Methods

- Composite wall modeled with Fourier's Law as a 1-D thermal conduction resistance network
- Latent heat and phase fraction tracked to model melting/freezing according to each material's property
- Second-by-second simulation over dynamic time duration with Weather, PCM, and TVP inputs imported from Excel
- Used MATLAB's vectorized arrays to reuse timestep data for rapid PCM and non-PCM comparisons

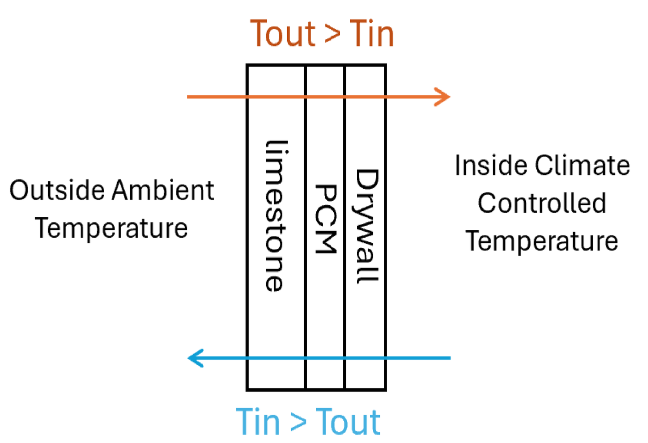
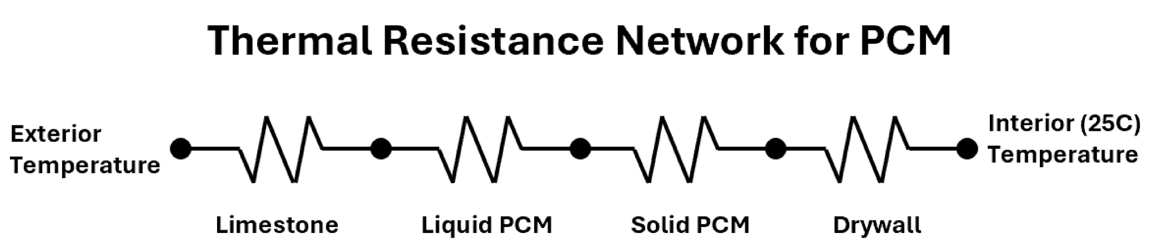


FIGURE 3 (LEFT): Diagram of the resistance modeling in the simulation, demonstrating directional heat flows.

FIGURE 4 (DOWN): Thermal resistance network and Fourier's law showing heat flux and resistance calculation preformed at each timestep.



$q = \frac{T_{outside} - T_{inside}}{Area * \sum Resistance}$, Resistance (R) = $\frac{\text{Length (L)}}{Area\ (A) * Thermal\ Conductivity\ (k)}$ for each

Results

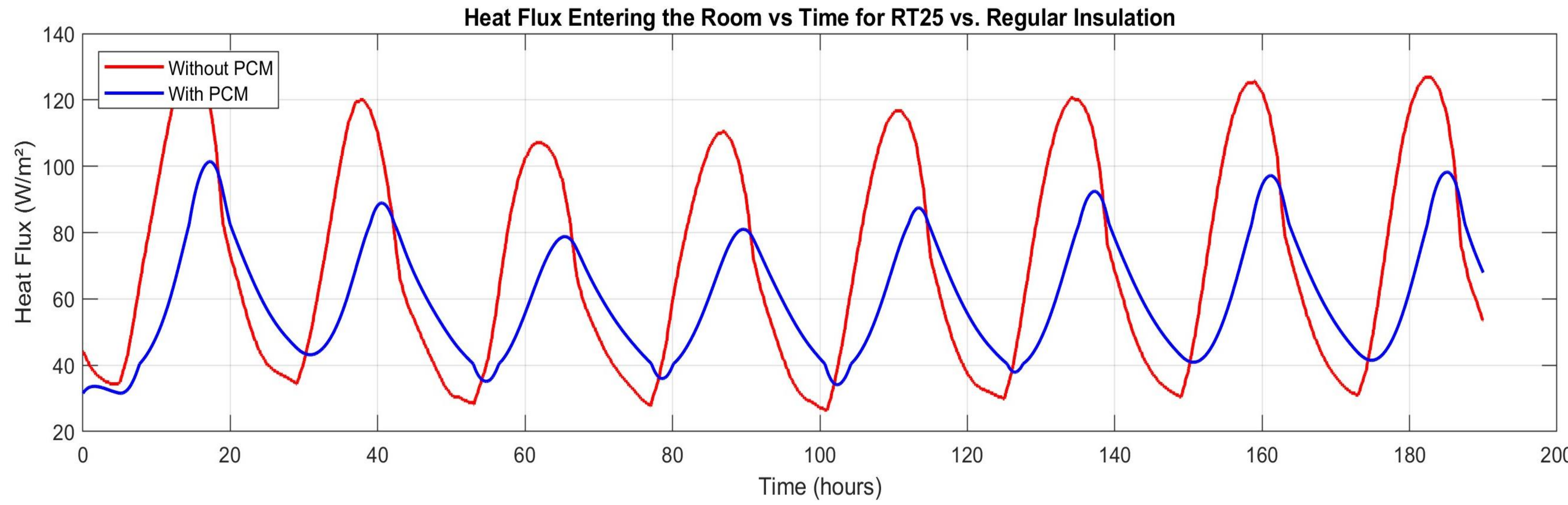


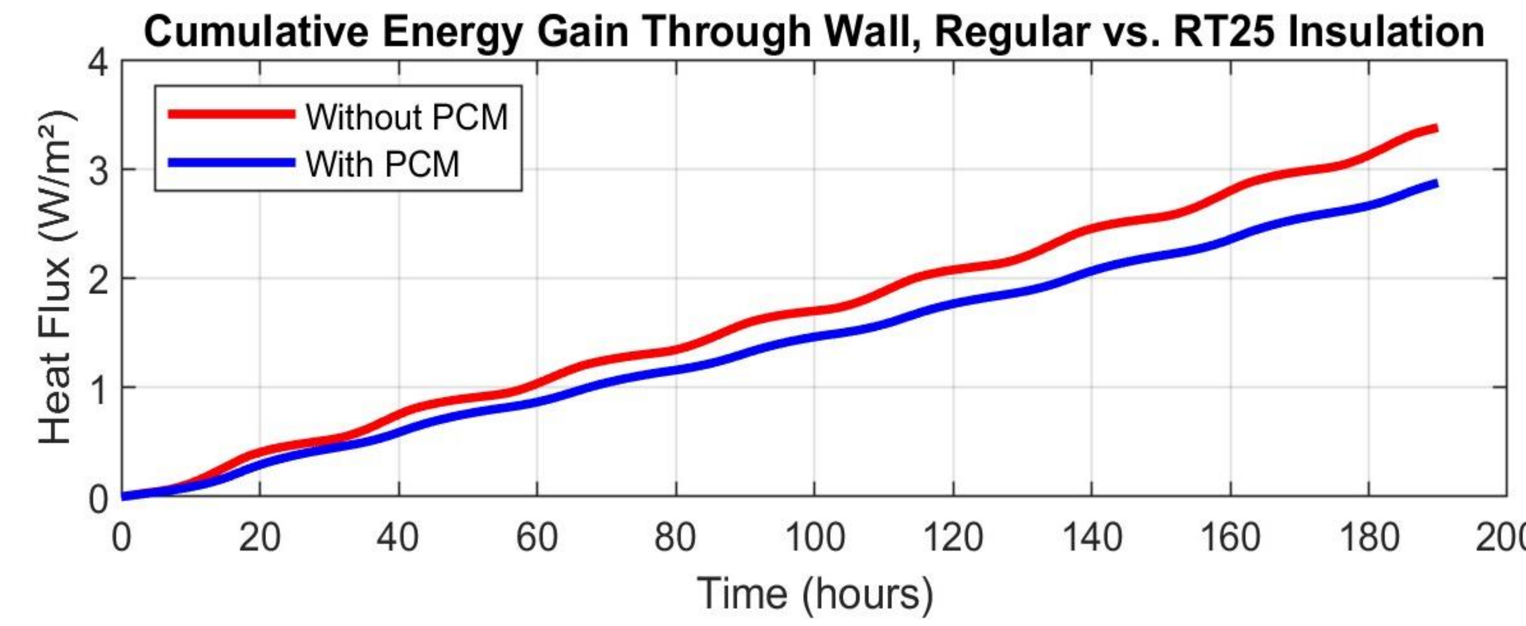
FIGURE 5 (TOP LEFT) Simulated heat flux through a composite wall using RT25 PCM compared to standard insulation. Note the lower peaks of the PCM figure, and the shift of the peak nearly two hours later for each cycle.

FIGURE 6 (BOTTOM LEFT): Simulated energy and cost differences between different PCM materials. RT25, the material used for figures five and seven, is highlighted. It demonstrates both the largest energy and cost savings.

FIGURE 7 (BOTTOM RIGHT): Difference in cumulative energy that is passed through the wall over the entire simulation cycle between PCM and regular insulation.

Energy & Cost Differences For Various PCMs Compared to Regular Insulation Baseline (per meter squared, over 190 simulated hours)

PCM	ENERGY		COST	
	Net Difference (kW)	Percent Difference (%)	Net Difference ($)	Percent Difference (%)
RT25	-0.5047	-14.94	-0.0326	-17.80
ATP 23	-0.4241	-12.56	-0.0283	-15.40
S27	0.4401	13.03	0.111	6.03
GAIA HS PCM24	0.2987	8.85	0.0092	5.02
PCM22	0.3904	11.56	0.019	10.23
SP 25 E2	0.2077	6.15	-0.0025	-1.37
SP 26 E	0.0236	6.98	-0.0031	-1.71



Discussion

- Results vary dramatically depending on properties of PCM (particularly thermal constant & latent heat storage)
- Some PCMs (RT25, ATP23) demonstrate significant energy usage reductions and price reductions, others (S27, PCM22) cause energy and cost increases
- The average heat flux entering the space was considerably lower (-14 W/m^2) for RT25 compared to regular insulation over the simulated time frame
- All PCMs shift peak energy usage later in the day, contributing to a reduction in price when Austin's TVP was considered
- Weather, TVP structure, and climate make considerable differences when considering material insulation feasibility and cost-reduction analysis

Model Validation & Limitations

- Model validation was limited to "gut checks" that Q_{in} and Q_{out} behavior matched expected PCM phase change physics on each wall boundary
- Direct validation against published models difficult, as this PCM–TVP–control framework does not match existing literature approaches
- Simplifying assumptions in PCM phase transition geometry limit accuracy, though relative performance trends between materials remain robust

Conclusions & Future Research

- Strong indication for PCM–TVP integration to reduce both HVAC energy use and operating cost, contingent on proper material selection and control alignment
- Future work will refine internal heat transfer logic and phase-transition modeling to better capture transient conduction and storage dynamics
- Additional literature and/or physical validation and full material cost–benefit analysis are needed to verify simulation accuracy and assess real-world economic feasibility

References

1. Stevens, P. (2025). *Phase Change Materials (PCM) Modeling in MATLAB – Undergraduate Research Report*. Fix Lab, University of Texas at Austin. https://utexas.app.box.com/s/spg118o26hdje4ui51olcubyrudmr49y
2. Yoon, J. H., Baldick, R., & Novoselac, A. (2016). *Demand response control of residential HVAC loads based on dynamic electricity prices and economic analysis*. *Science and Technology for the Built Environment*, 22(6), 705–719. https://doi.org/10.1080/23744731.2016.1195659
3. Zhu, N., Wang, S., Ma, Z., & Sun, Y. (2011). *Energy performance and optimal control of air-conditioned buildings with envelopes enhanced by phase change materials*. *Energy Conversion and Management*, 52(7), 3197–3205. https://doi.org/10.1016/j.enconman.2011.05.011
4. Sultan, S., Gluesenkamp, K. R., Cui, B., Li, Z., & Ross, S. (2024). *Equity, Electrification, and TOU Rates: Coupling Thermal Energy Storage with Heat Pumps for Improved Efficiency*. *ACEEE Summer Study on Energy Efficiency in Buildings*. 10.13140/RG.2.2.33227.81442
5. Saffari, M., de Gracia, A., Ushak, S., & Cabeza, L. F. (2017). *Economic impact of integrating PCM and thermal storage in residential buildings under TOU tariffs*. *International High Performance Buildings Conference*. Purdue University. https://docs.lib.purdue.edu/ihpbc/370
6. Environmental Defense Fund. (2015). *Time-Variant Electricity Pricing Fact Sheet*. April 2015. https://www.edf.org/sites/default/files/time-variant_pricing_fact_sheet_-_april_2015.pdf
7. Austin Energy. (2021). *City of Austin – Electric Tariff (Residential TOU rate description)*. https://austinenergy.com/rates/approved-rates-schedules
8. Austin Energy. (2025). *News Release: "Austin Energy Boosts Energy Savings with Major Expansion of Commercial Demand Response Program."* July 10, 2025. https://austinenergy.com/about/news/news-releases/2025/demand-response-expansion
9. Public Utility Commission of Texas. (2022). *Docket on Energy Efficiency and Peak Demand Reduction*. *RTO Insider*, News summary. Available at: https://www.rtoinsider.com/30711-texas-regulators-open-energy-efficiency-docket/