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Good morning everyone,

My name is An and I'm a postdoc at School for environment and sustainability , working with Dr. Michael Craig

Today I'm gonna present about the value of thermal energy storage coupled with HEAT PUMPS FOR RESIDENTIAL SPACE HEATING IN U.S. CITIES

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First I'm gonna go over a brief motivation for this research,

So decarbonization of the residential sector is important in the effort to decarbonize energy sector because it is 17% of the energy sector's CO_2 emission.

In the US, this sector consumes 22% of US primary energy, of which 32% is space heating, making space heating the biggest source of energy consumption in the residential end use sector

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In the near- and long-run, this heating load will continue to be electrifed as the residential sector decarbonizes and renewable energy prices continue to fall, increasing electricity demand even further.

One of the most cost effective and common ways of electrifying residential space heating is via replacing all fossil fuel heating with air-source heat pump.

In general, Because ASHP can effciently extract heat from outside when temperature is not extremely cold, its operation often requires less electricity input than traditional heating systems such as electric baseboard or electric furnace

However, ASHP can be inefficient when outdoor temperatures are low in winter months, especially in colder climates.

Because of ASHP's disadvantage of being inefficient at lower outdoor temperatures, on going research have been looking at ways to enhance heat pump's efficiency during these time periods. One of the technologies that can enhance heat pump's effciency during low temperature periods is coupling it with a storage system.

battery is the most popular choice. However, in applications like building space heating, battery storage might not be the most affordable option due to its high capital cost and short life time.

On-site short-term thermal energy storage (TES) can be a storage alternative to battery in this application. When coupled with heat pump, TES can reduce total system's electricity consumption by providing thermal energy to directly serve heating load when heat pumps are inefficient.

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A lot of previous Literature have explored different heat pump-TES designs using experimental systems. However, they do not offer insights into the effectiveness of different TES materials and designs as they mostly focus on water tank heat storage as TES.

They also estimate heating load based on the difference between outdoor temperature and indoor temp setpoint, therefore ignores a lot of actual building characteristics that might effect heating loads.

Studies that explore the performances and economic analysis of different TES materials and designs are rare. And those that do focus on grid-scale TES storage materials and characteristics that are not suitable to be applied to building applications.

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So in this research, we fill these research gaps by exploring the effects of different TES materials and designs on the value of TES for serving heating load in residential building. We do so by answering the following research question:

What are the relationships between various TES system design parameters and their impacts on total system cost and energy consumption for space heating in U.S. residential buildings?

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One of the main differences of our work compared to previous works is that we consider salt hydrates as TES materials, compared to the use of water tank as TES which is common in TES-heat pump system literature.

The main reason we choose to consider salt hydrate is energy density. Thermochemical salt hydrates are 10-50 times more energy dense than sensible heat, like a water tank. Also, theoretically you can store thermochemical energy indefinitely loss free, compared to other latent heat materials where you always have to keep it at a certain temperature. Here we consider 4 types of salt hydrates that vary in their relationships between power density and energy density, magnesium sulfate, magnesium chloride, posstasium caborate, and strontium bromide.

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There are multiple ways to size a building TES system. In this experimental design, we size TES based on the building peak load, which is then translated into the amount of salt needed to satisfy that load in a given hourly at full charge while satisfying both the salt energy and power requirements to reach such peak load.

Because of the differences between specific energy and power of these salts, to reach the same peak load, the mass requirements for these salts are different. For ex: $MgSO_4$ has higher energy density and requires less salt mass compared to say magnesium chloride.

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With these modeling framework, we can now look at a couple of main results

First,

TES CAN SERVE UP TO 24% TO 42% OF ANNUAL SPACE HEATING LOAD IN AN INDIVIDUAL BUILDING

The total TES discharging to serve load highly depends on the sizing of TES. Here I size the TES system based on peak load, so the TES discharging ranges among these salts are not too different. However, we have to keep in mind the volume of salt required to reach these range of TES charging fraction are very different among the salts

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Next, we look at the TES discharging and charging behaviors. For this I'm using a high load building in January which is a peak load month for space heating to demonstrate this.

Here, I have a graph of TES and heat pump output to serve load. X axis is hours, y axis is kWh, the blue curve is the buildings heating load, dark green is heat pump output to serve load and light green is TES output to transfer load, and yellow line is heat pump COP.

We can see that TES discharges when COP declines which is associated with outdoor temperature falls and heat pump becomes more inefficient. In these periods TES discharges to reduce electricity purchased from utility to power heat pumps and reduce cost.

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TES charging follows the opposite pattern. Here the green line is total heat pump output when not coupled with TES, so it is the load shape. And the blue line is total heat pump output when heat pump is coupled with TES.

Here TES charges when heat pump's COPs increase, meaning heat pump becomes more efficient. In these hours, heat pump both charges TES and provide load, which increases total heat pump output.

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TES charging and discharging behaviors also vary based on different types of salt used for TES system. Here I'm comparing the discharging behavior of TES using two different salts, the $MgSo_4$ and the K_2CO_3. Due to our method of TES sizing, the K_2CO_3 salt mass is larger because it has much larger specific power compared to the $MgSO_4$, which indicates its higher power rating. However, TES using K_2CO_3 discharges less than using $MgSO_4$ because the K_2CO_3 has much lower specific energy, meaning it takes much more salt to draw out the same kWh of energy to serve load, resulting in smaller TES discharge.

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In terms of cost saving, using fixed rate, annual cost saving due to TES can be up to between $112M to $230 M across salts. This is equivalent to around 4% of saving due to TES in Detroit. Individual building can save up to 7% in electricity bill a year or about $130 a year.

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These cost savings increases significantly if TOU rate is used instead of fixed rate. Here we are able to show that while with fixed rate cost saving due to TES is up to 7%, with TOU rate this cost saving can be as high as 24%.

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This is due to TES being discharged more when TOU rate is applied because now TES is not only incentivized to discharge when heat pump is inefficient, but also when electricity price is low. Here, we see TES being discharged even when temperature is not low because electricity cost is high. And here we see TES being discharged even when electricity price is low because temperature is extremely low which drives heat pump inefficient.

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Another value of TES is that is can reduce peak load. Here I change the modeling framework a little to maximize the amount of peak load reduction that TES can achieve while keep cost the same as no TES is available to couple with heat pump. Model result shows that TES can reduce peak load in an individual building by 26%, serving as a useful tool for demand response in these hours.

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And that is the end of my presentation. I want to thank my collaborators in this research including collaborators from Mechanical engineering for providing inputs of TES system parameters. And also thanks to Parth, Claire and Pam for helping with model inputs, comments and feedbacks. I'll take any questions that you have.