Aalto University
School of Engineering

Thermal energy storage, exergy and flexibility

Thermal Energy Storage lecture

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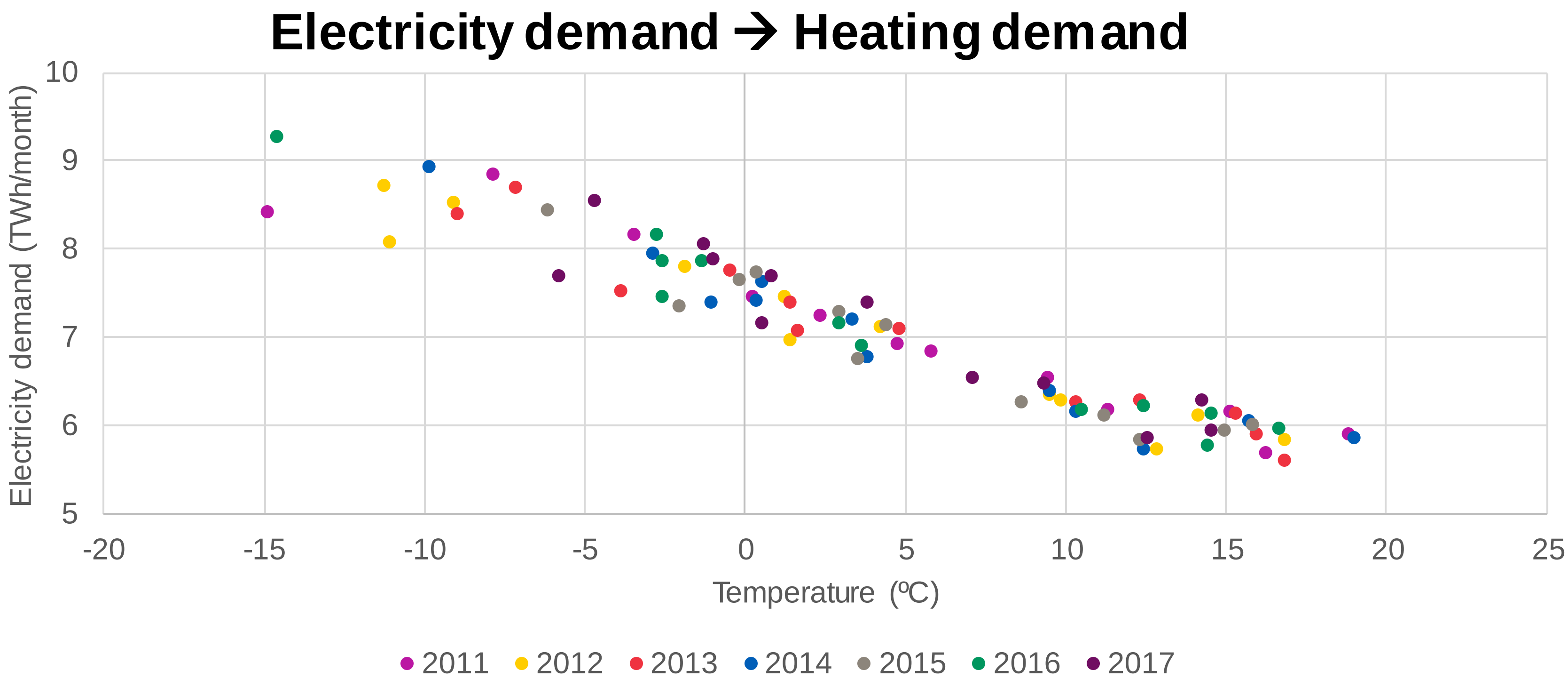
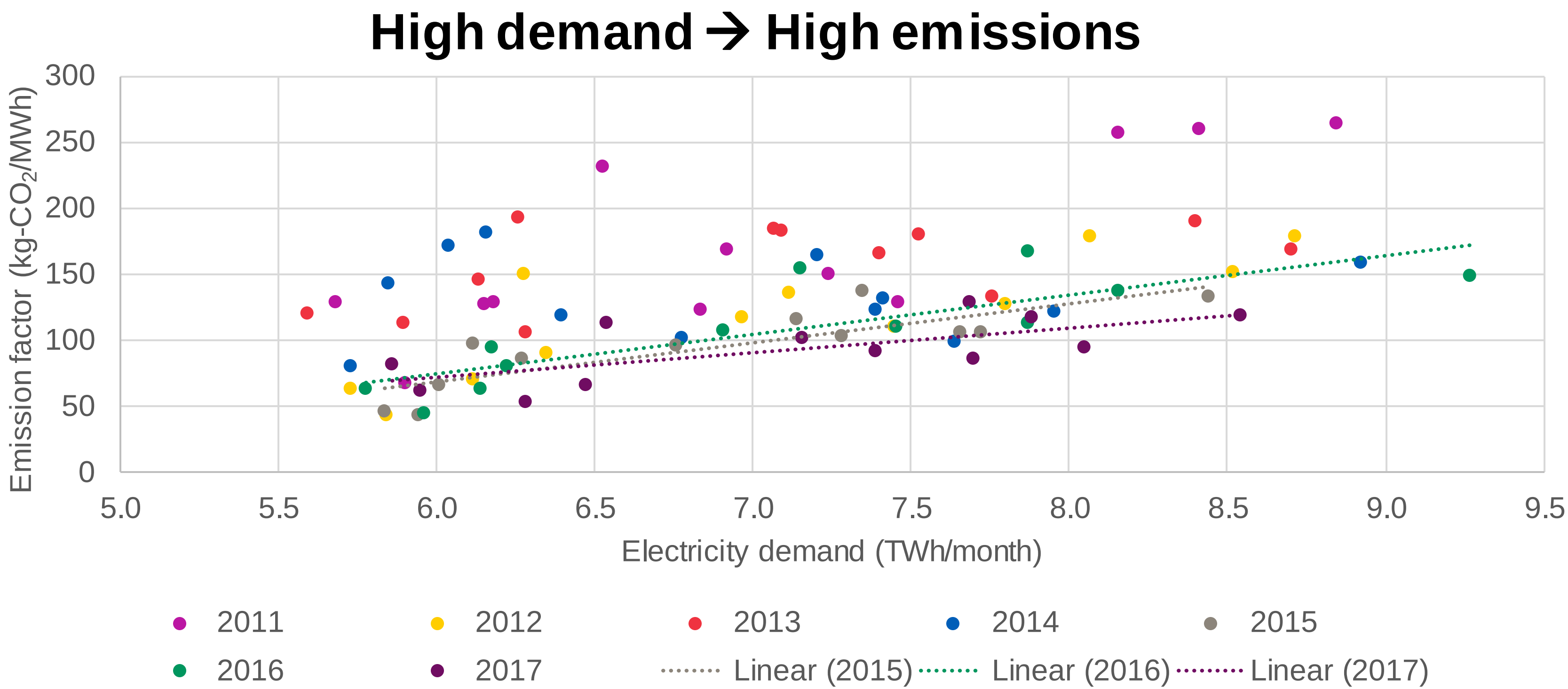
Thermal vs. electricity storage

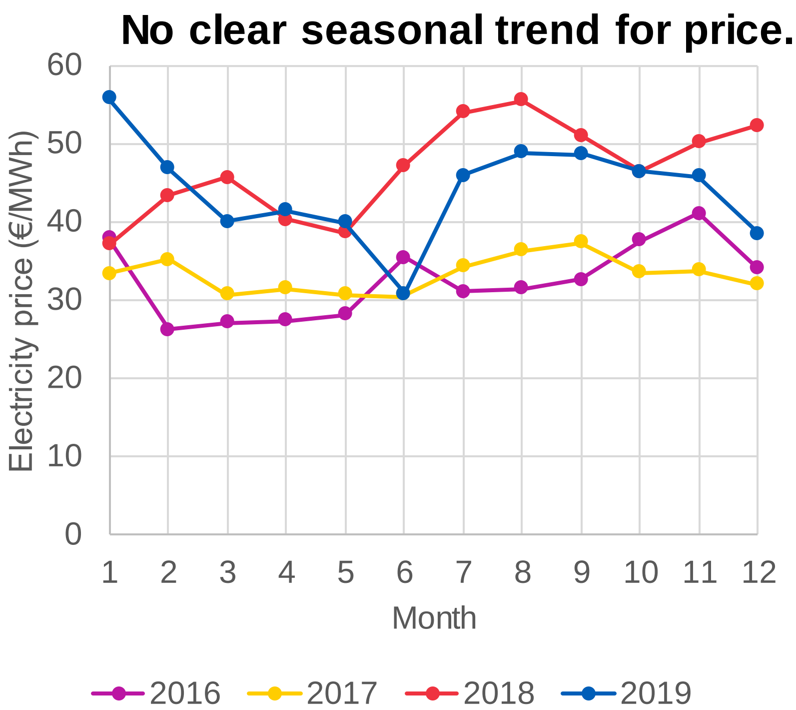
Temperature vs. electricity demand

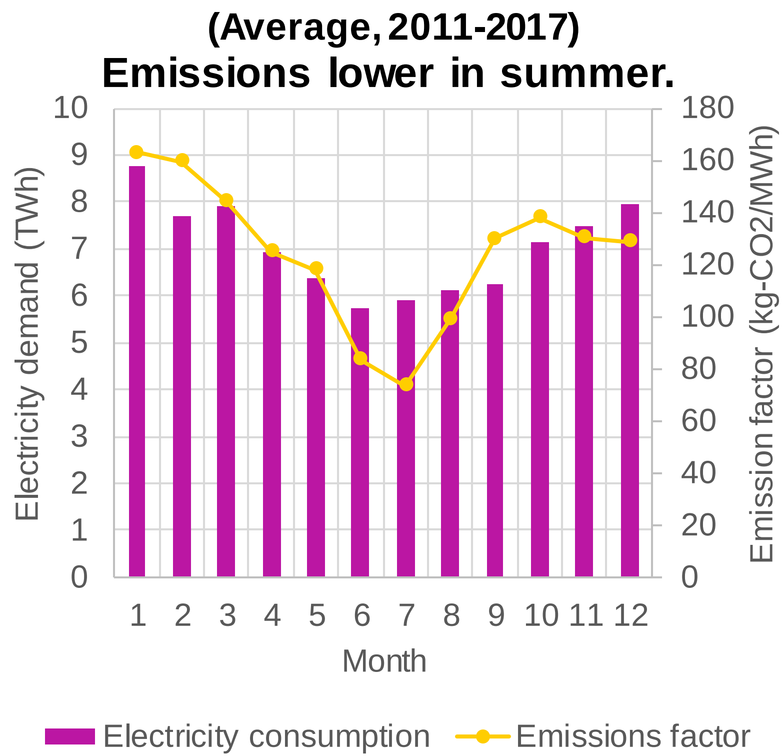


Electricity demand vs. emissions

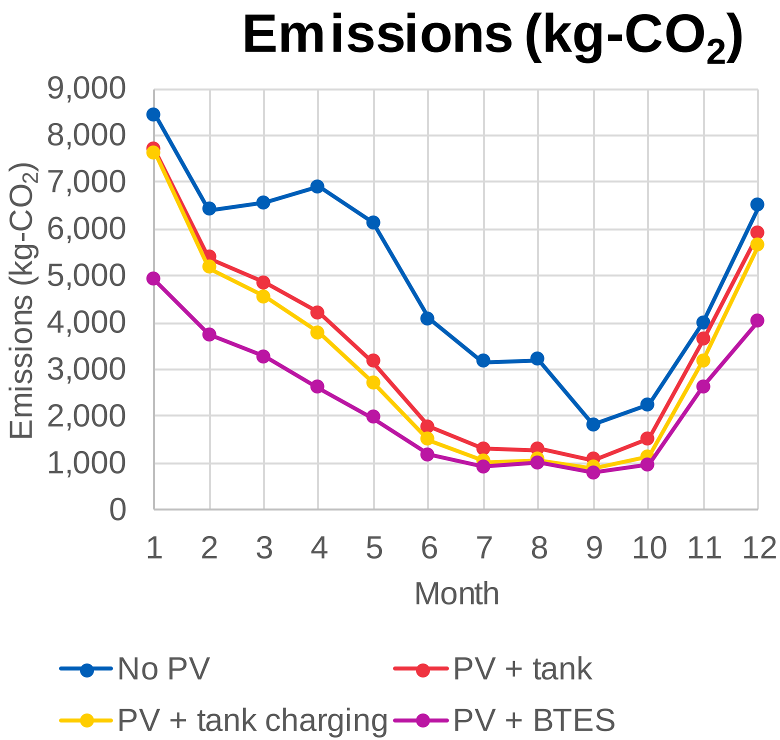


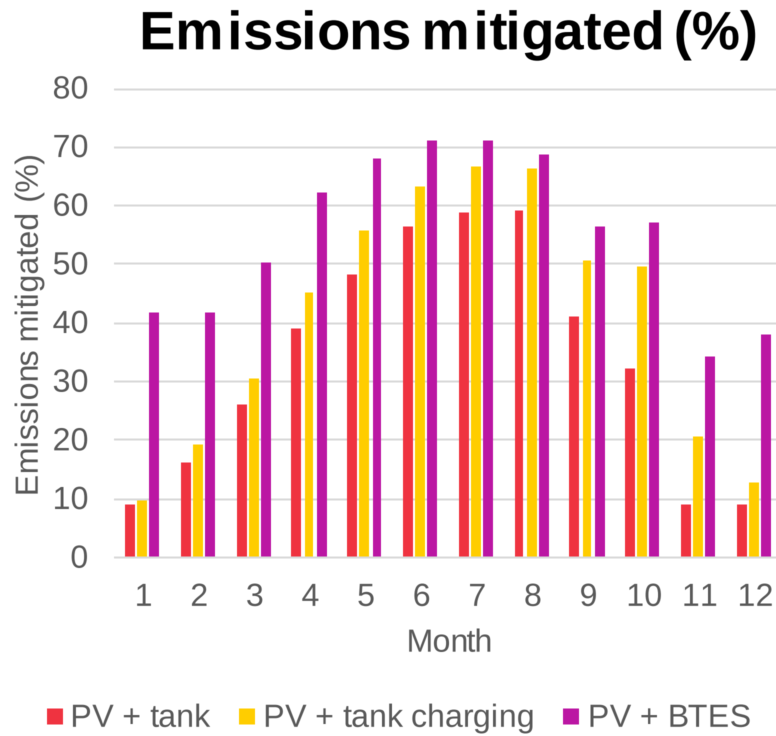
Monthly electricity prices and emissions



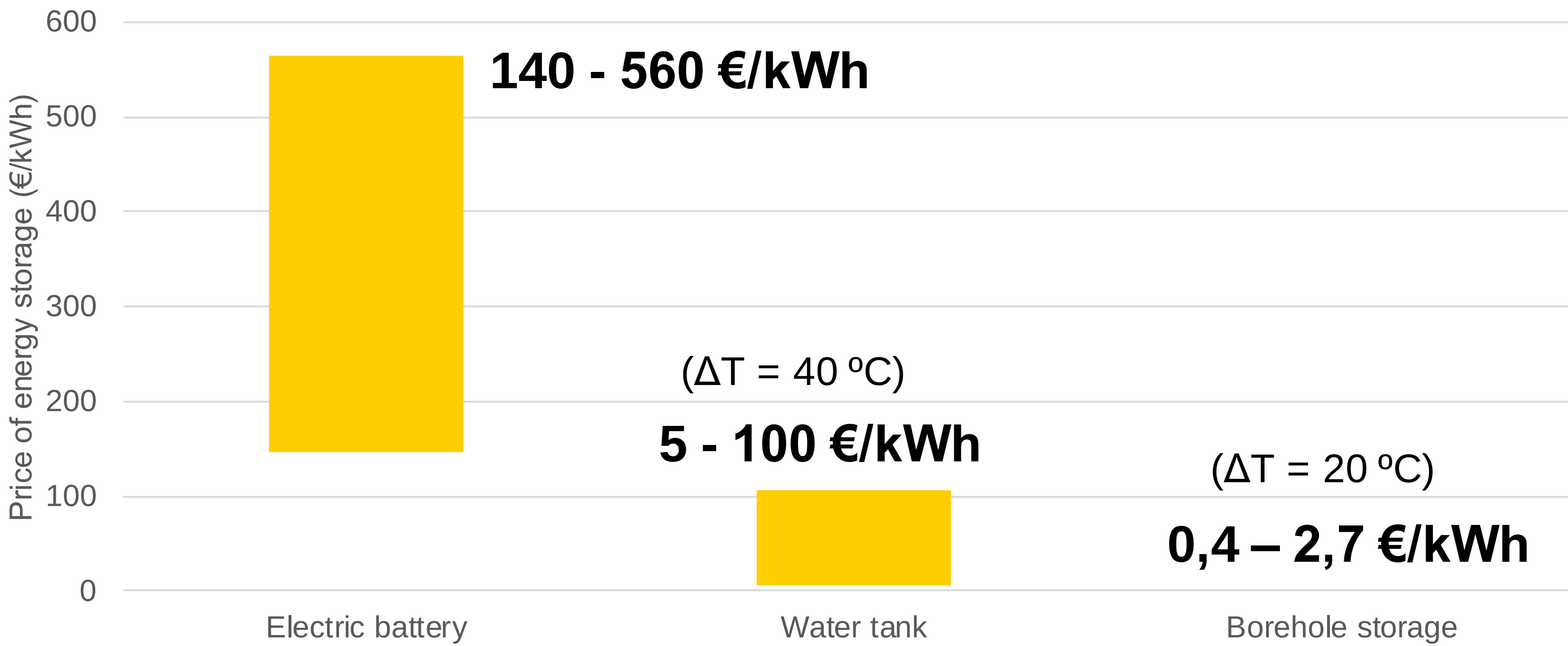


Emissions for solar community (2015)





Prices of energy storage



Thermal energy storage is often the sensible choice

Exergy

Student question

When someone wants to sell you a 1000 MWh of heat, what should be your first question?

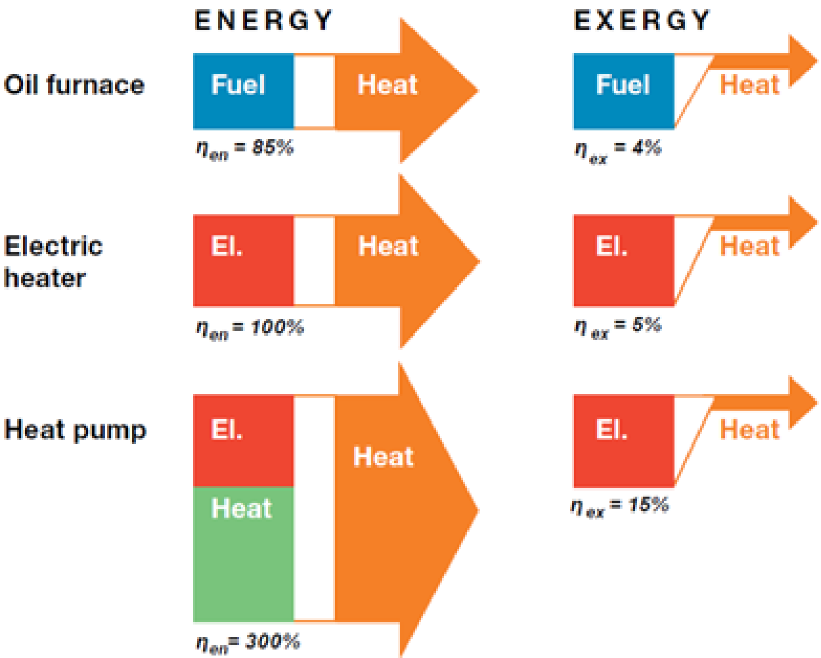
Student question

When someone wants to sell you a 1000 MWh of heat, what should be your first question?

“At what temperature?”

$$E = m\, c_p\, (T_2 - T_1)$$

Exergy = Quality of energy

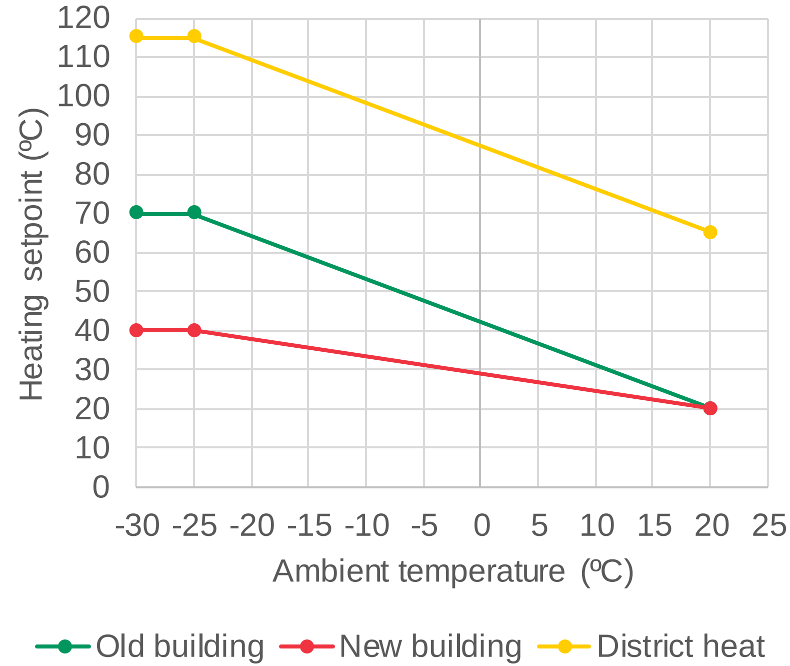


https://exergyeconomics.wordpress.com/exergy-economics-101/what-is-exergy/

- **Exergy is lost when high quality energy (**electricity, chemical energy**) is converted into low quality energy (**heat**)**
  - Heat cannot be perfectly converted back to electricity
- **Thermal energy moves from hot to cold**
  - Temperature difference needed
    - *Energy source vs. point of use*

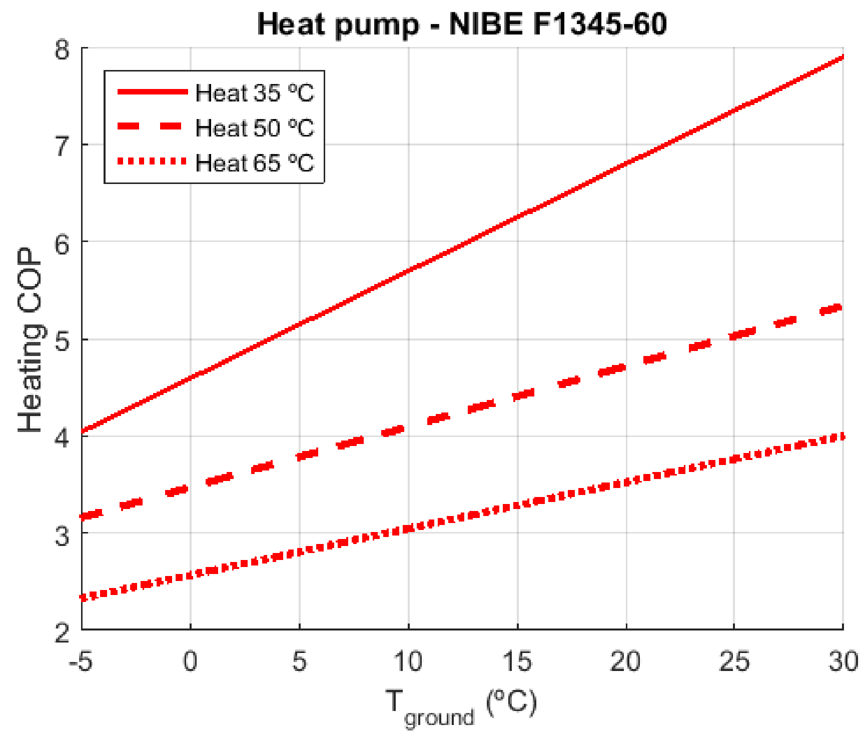
Temperature levels of demand

- **Can we utilize the stored heat if it is at**
  - 120 degC?
  - 50 degC?
  - 20 degC?



Benefits of heat pumps

- **HP helps utilize low temperatures**
- **COP improves as source temperature rises**
  - COP lowered as output temperature increases



Temperature levels of supply

- **Energy sources for storage**
  - Solar energy (30 - 80 ^oC)
  - Industrial process heat
    - *High temperature (400+ ^oC)*
    - *Medium temperature (100 – 400 ^oC)*
    - *Low temperature (<100 ^oC)*
  - Residential heat
    - *Ventilation (21+ ^oC)*
    - *Sewage (15 - 30 ^oC)*
  - Data center heat
    - *Air-cooled (25 - 35 ^oC)*
    - *Liquid-cooled (50 - 60 ^oC)*

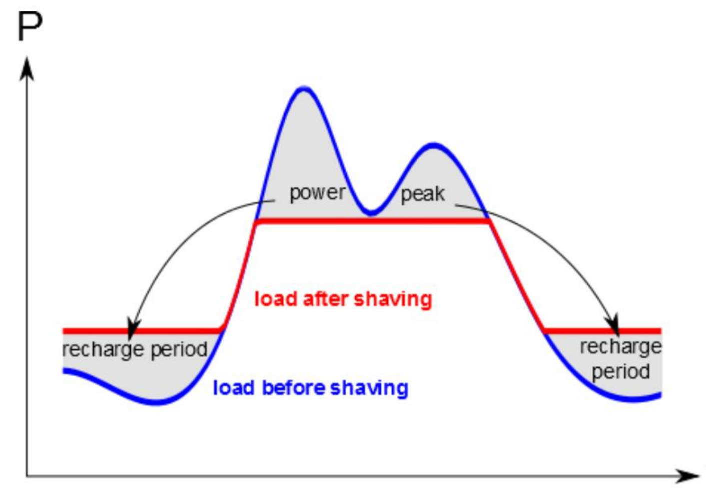
- **Energy storage considerations**
  - Solar thermal efficiency vs. temperature
    - *Less energy at high temperature*
  - Energy storage efficiency vs. temperature
    - *Large storage has lower losses*
      - More energy needed to raise temperature

What would be useful for Helsinki?

Flexibility

Flexibility and demand response

- **Demand response (DR) adjusts demand to better match supply**
  - Typically increases demand during low energy prices and lowers it during high prices
    - *Benefits both the consumer and producer*
- **Relies on energy storage**
  - Heat capacity of buildings
  - Hot water tanks
  - Seasonal storage
- **On-site energy use**
- **Predictive control algorithms**



https://www.sandia.gov/ess-ssl/EESAT/2013_papers/Peak_Shaving_Control_Method_for_Energy_Storage.pdf

Thermal storage capacity comparison for demand response

Apartment building

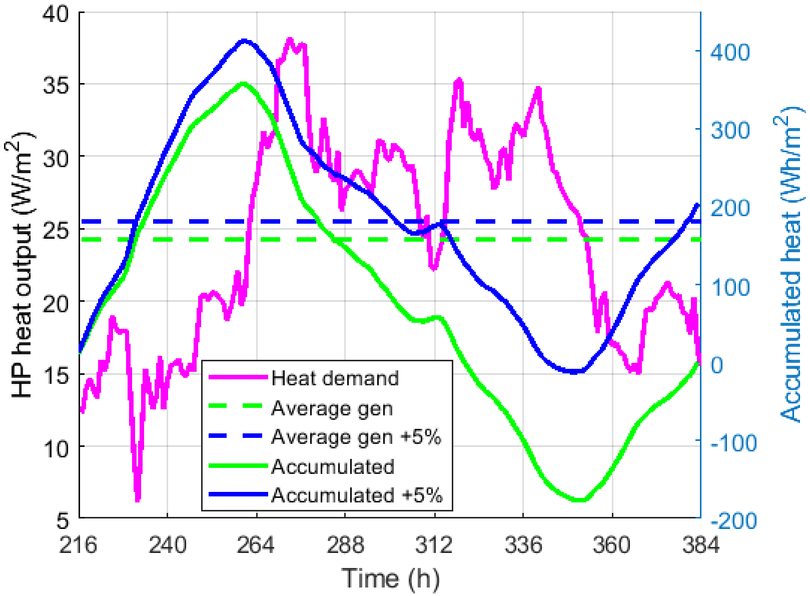
Storage type	Tank (Water)	Room air (Air)	Building envelope (Brick)	Unit
Specific heat capacity	4190	1010	1000	J/kgK
Density	1000	1.22	1500	kg/m^3
Volume	3	10 000	200	m^3
Temperature change	40	4	3	ºC
Stored energy	140	14	250	kWh

Fast **Slow**

Comfort considerations

Demand response example

Constant power generation vs. variable load



4050 m^2 apartment building, 27 m^3 water tank needed!

- **Demand response can lower required investments to generation capacity and the use of expensive backup power**
- **Long periods of high demand are an issue**

Hourly electricity prices, March

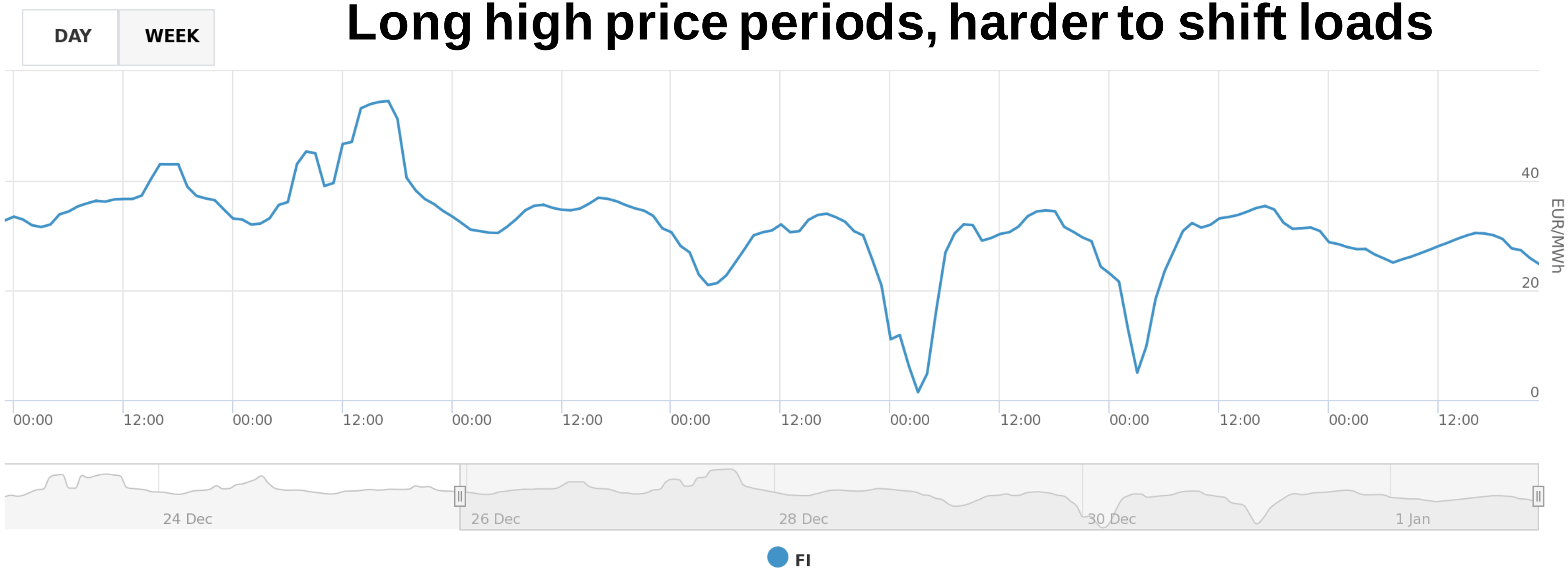
Day-ahead prices - ALL - Hourly - EUR/MWh

Lots of daily variance, easy to shift loads

https://www.nordpoolgroup.com/Market-data1/Dayahead/Area-Prices/ALL1/Hourly/?view=chart

Hourly electricity prices, December

Long high price periods, harder to shift loads



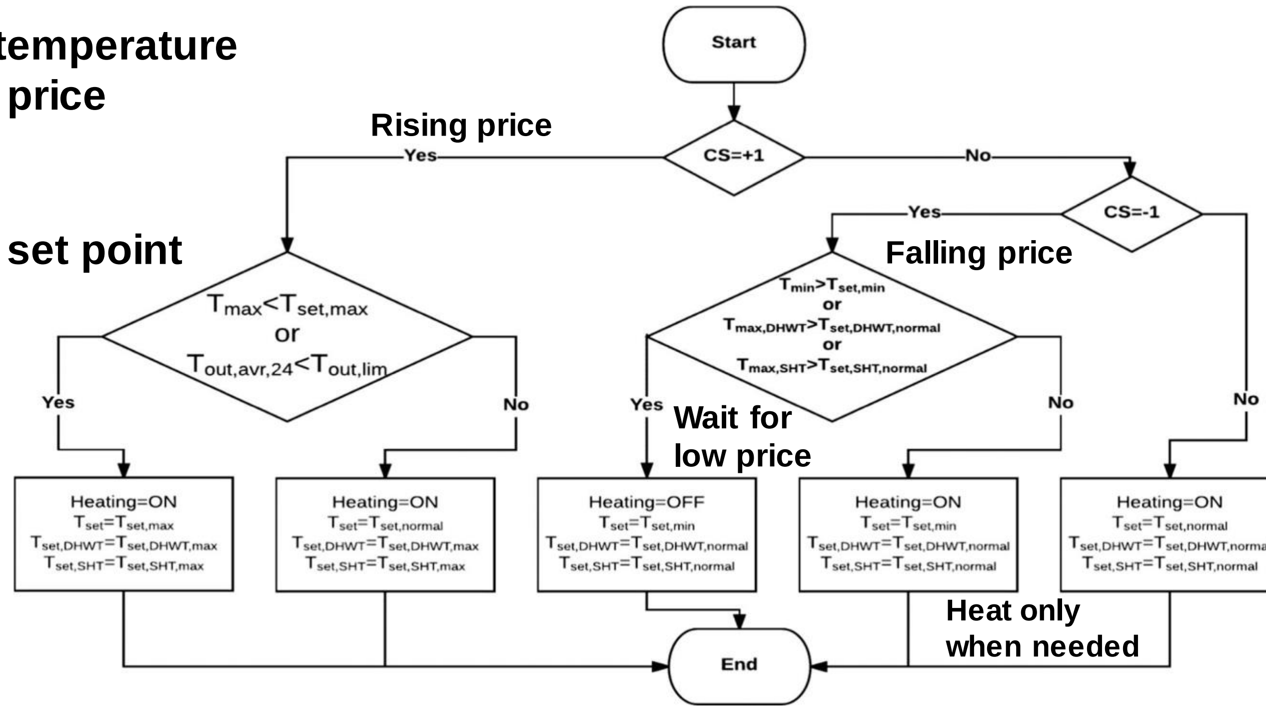
Can you design your own algoritm?

Rule-based predictive DR algorithm

Monitor indoor and tank temperature
Monitor future electricity price

Define indoor set point
Define SH and DHW tank set point

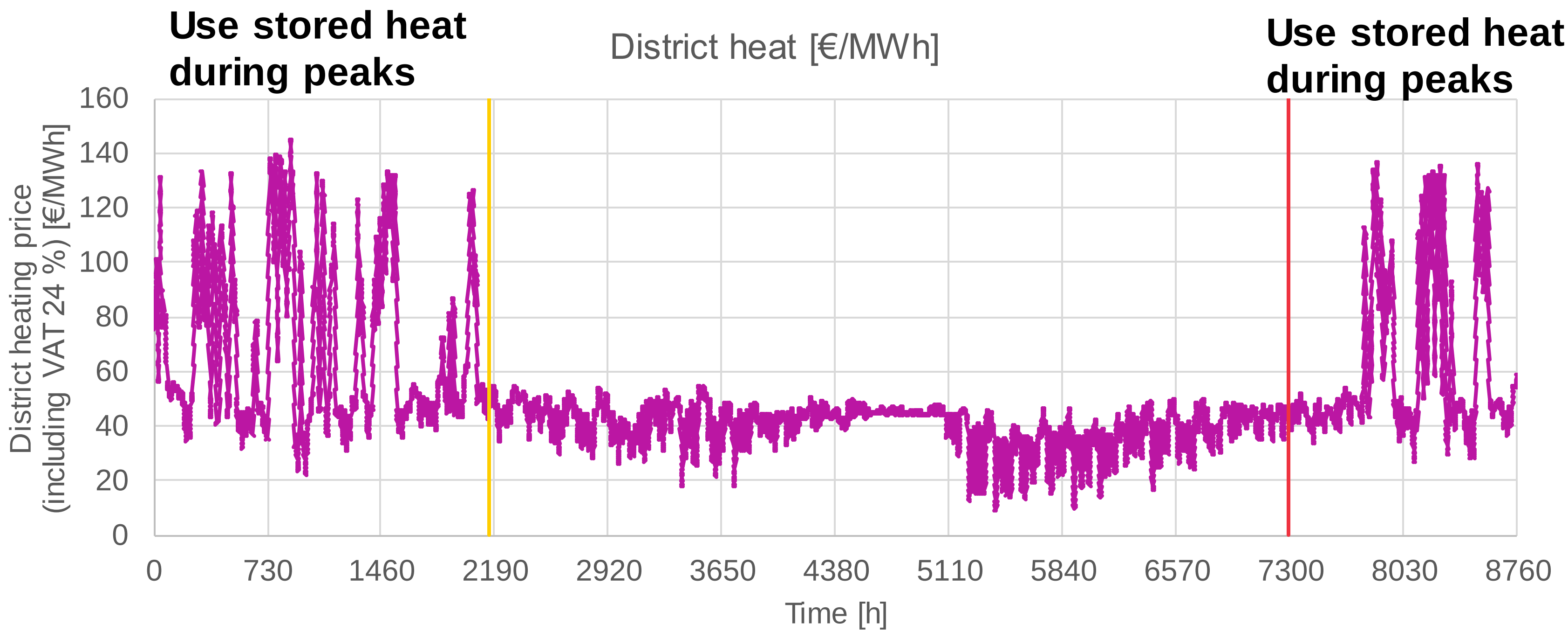
Raise set points, charge tank



14% cost savings achieved in the study

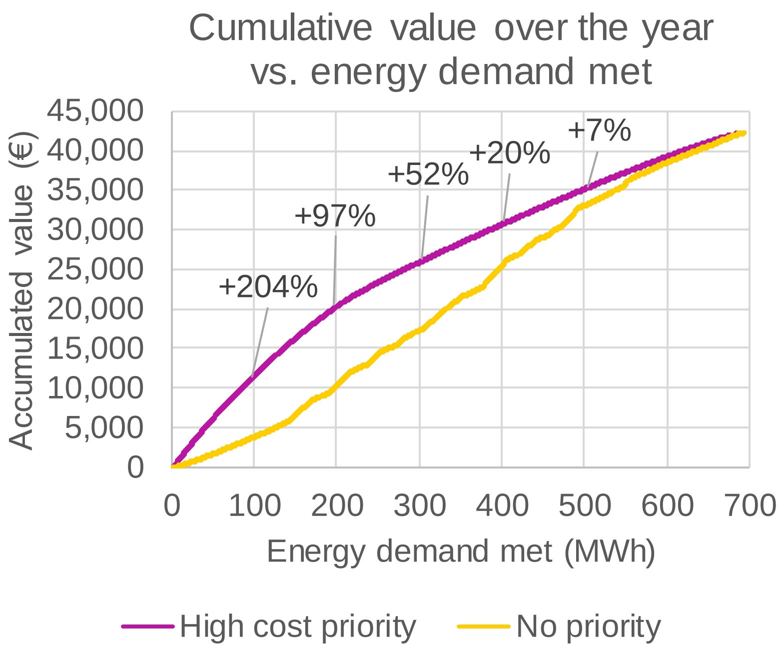
Alimohammadisagvand et al., 2018, Applied Energy, Vol 209
Comparison of four rule-based demand response control algorithms in an electrically and heat pump-heated residential building

Theoretical hourly pricing of district heat



Samuli rinne, unpublished

Optimal timing of stored heat utilization



Only discharge when price is high

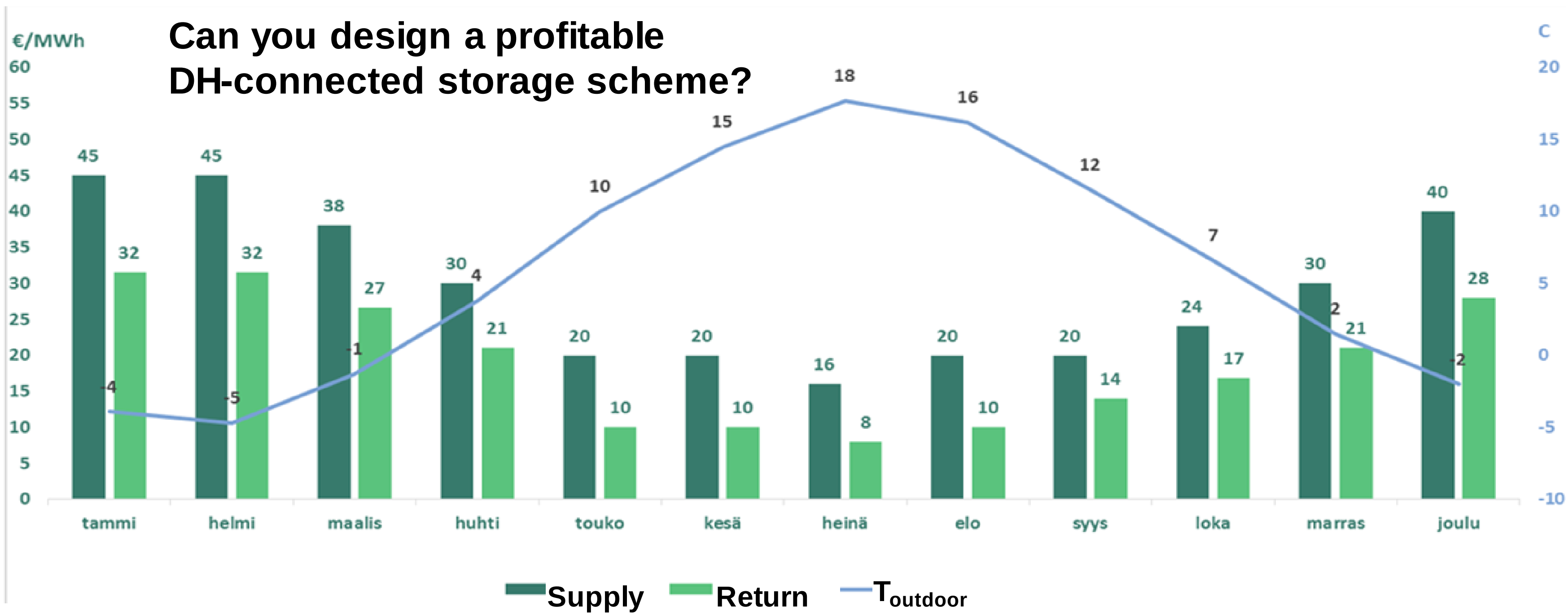
Start discharging at Fall

- **BTES charged with waste heat**
- **Meeting all loads vs. perfectly choosing when to discharge**
  - If storage capacity is limited, meeting only expensive loads improves value
    - *Perfect prediction not likely*

Real DH pricing - Fortum Open Heat

$T_{outdoor}$	Ulkolämpötila °C	-20	-16	-12	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	16	20
Price (€/MWh)	Supply	50	50	50	50	50	45	45	40	30	30	30	25	20	20	20	20	15
	Return	35	35	35	35	35	32	32	28	21	21	21	18	14	10	10	10	8

Can you design a profitable DH-connected storage scheme?



Reflection questions

1. What low quality heat could be utilized for decarbonizing Helsinki and how?
2. Is it feasible to use a seasonal thermal energy storage system for peak shaving instead of base load generation?
3. Can you design a demand response algorithm?
4. Consider the design of a BTES system, when connected to solar thermal collectors or a waste heat source. What influences the efficiency, power and energy storage capacity of the system? How do you maximize the utility of the system? Could you profit from Fortum Open Heat?