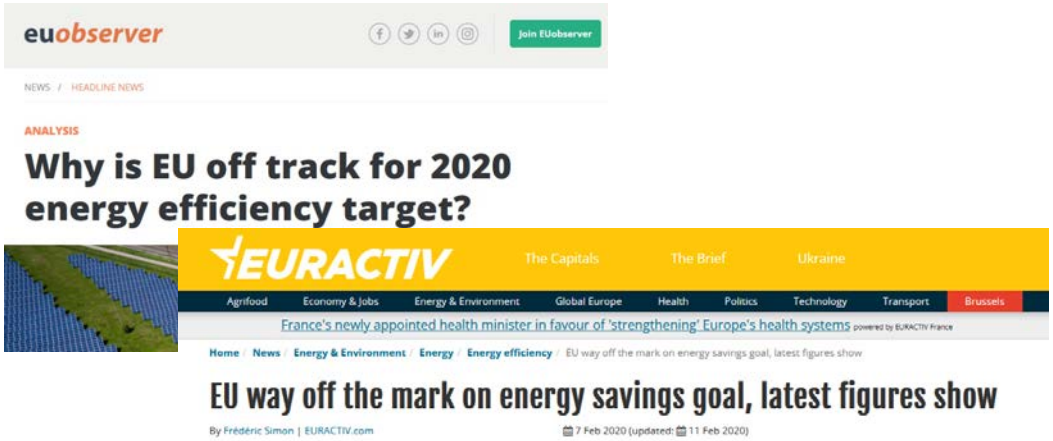


Potsdam Institute for Climate Impact Research

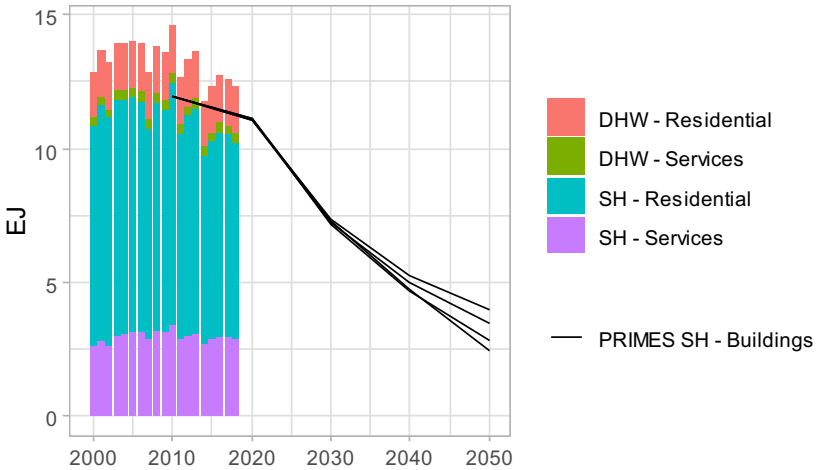
The roles of energy efficiency for the decarbonisation of buildings

Heat energy demand trends are not in line with the 1.5°C goal



12% of buildings undergo some energetic renovation every year, but only **0.2%** with deep renovations instead of **3%** (claimed by BPIE)

EU Buildings Heat demand



→ **Do these trends jeopardise the decarbonisation of the sector?**

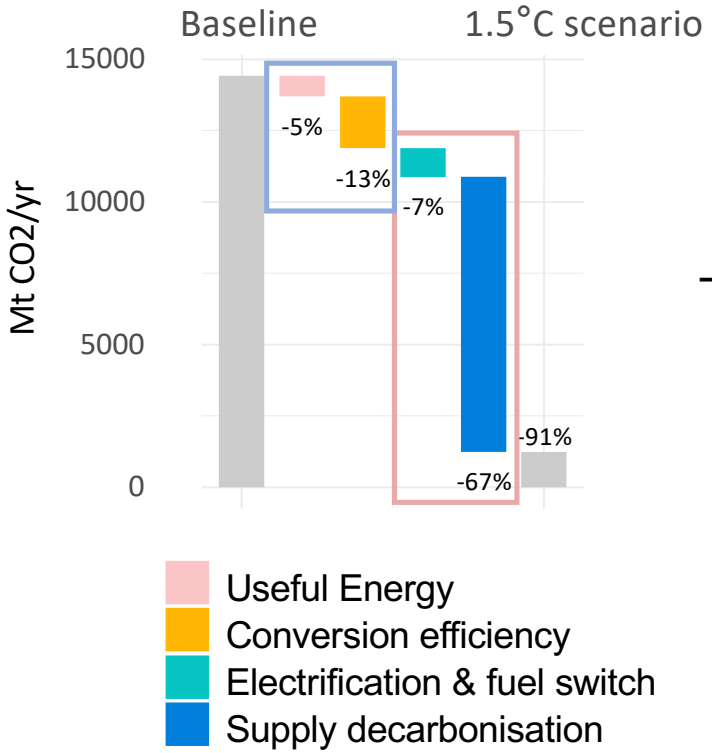
→ **What are the roles of efficiency for the decarbonisation?**

There are essentially two strategies to decarbonise buildings

$$CO_2 = UE \times \frac{FE}{UE} \times \frac{CO_2}{FE}$$

Reducing energy demand

Reducing emission content of energy



→ **Decarbonisation comes first and foremost from the decarbonisation of the energy consumed**

Levesque et al. (2021)

Energy efficiency enables the reduction of the carbon content of energy

$$CO_2 = UE \times \frac{FE}{UE} \times \frac{CO_2}{FE}$$

$$\frac{CO_2}{FE} = \sum_{ec} sh_{ec} \left(\frac{CO_2}{FE}\right)_{ec}$$

Switch to low-carbon energy carriers

Decarbonise the energy supply

Energy efficiency is also an enabler of the reduction of the carbon content

1st role

Lowering heating system temperatures

2nd role

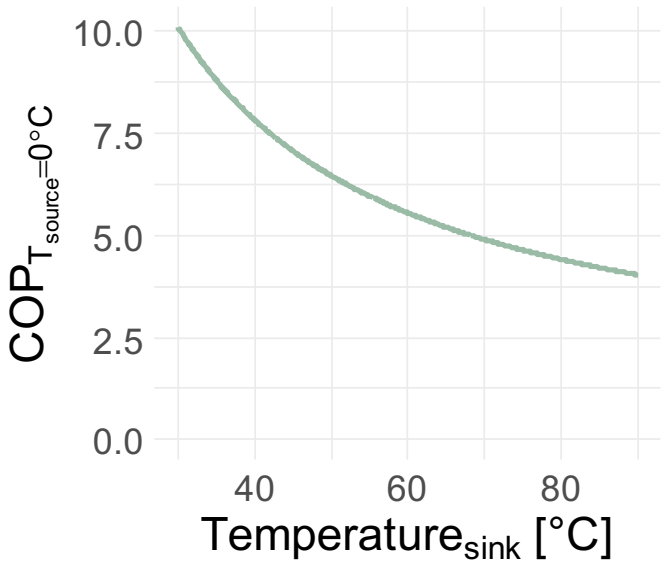
Smoothing the electrification of heat

Low heating system temperatures as a key enabler for renewable heat sources

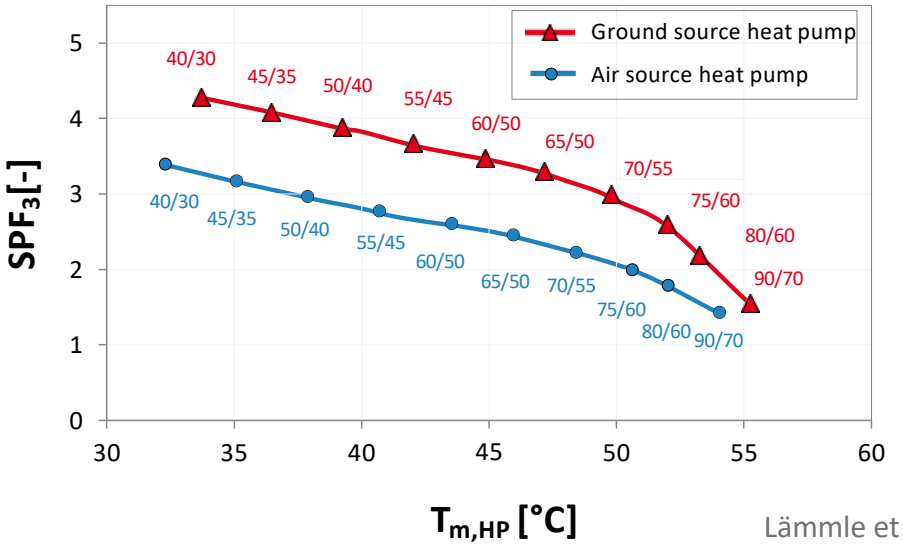
High heating temperatures reduce the efficiency of heat pumps

One point in time

$$COP_{Carnot} = \frac{T_{Sink}}{T_{Sink} - T_{Source}}$$



Annual average: $$SPF = \frac{Q_{HP} + Q_{BU}}{E_{HP} + E_{BU} + E_{SRC}}$$



Lämmle et al. (2022)

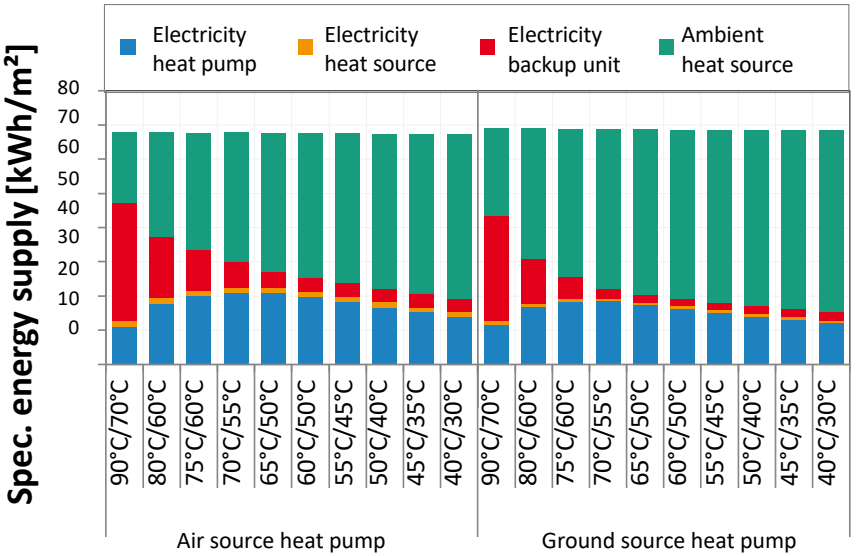
Reducing the temperature by 1°K increases the SPF by 0.10-0.13 points

The average efficiency is determined by mild temperature conditions

Here, 90% of the demand for space heating at temperatures above -4°C → SPF mostly determined by the performance of the heat pump above this temperature

Common heat pumps cannot deliver temperatures above 50-60°C, depending also on the source temperature → back-up heating for very cold conditions

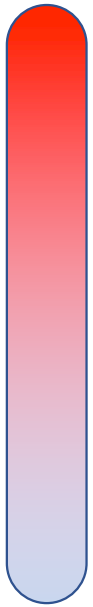
For high temperature heating systems, the share of heat supply generated by the inefficient back-up unit can reach half the yearly heat generation of the heating system.



Lämmle et al. (2022)

District heating decarbonisation would benefit from lower temperatures

Decarbonised DH sources



Industrial Excess Heat

Geothermal

Solar Thermal

Urban Excess Heat

Rivers, Lakes

Air

Benefits from lowering temperatures in district heating:

- Reduction of distribution losses (10-30% of supplied heat). Losses proportional to temperature difference to ground

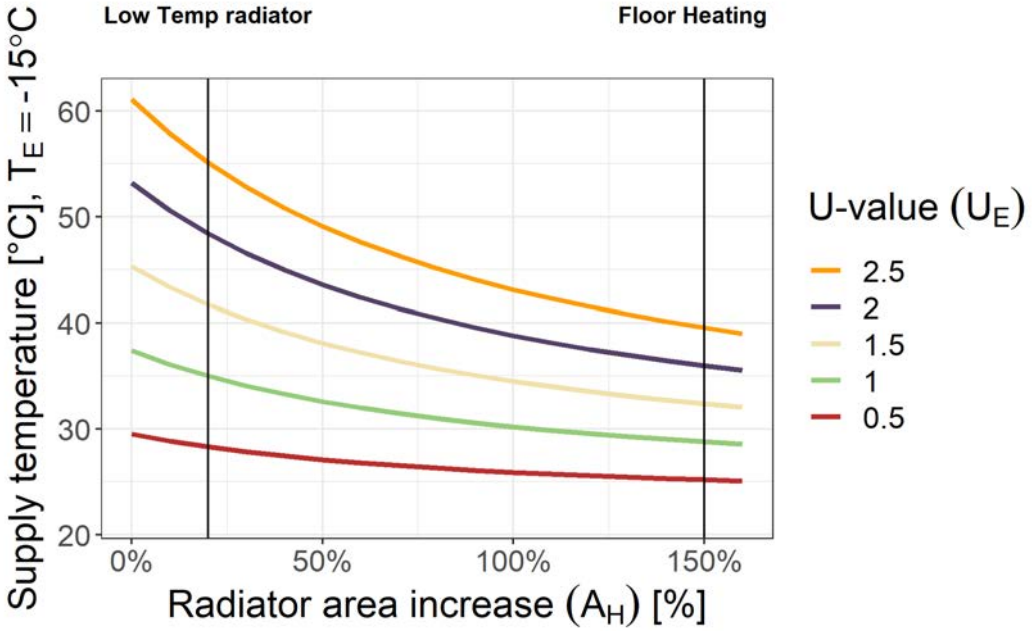
- Lower supply costs
  - Larger potential for direct use of high temperature sources (excess heat, geothermal, ...)
  - Higher COP for large-scale heat pumps using unconventional heat sources
  - Higher potential of geothermal and solar thermal
  - Higher heat storage capacities
  - More efficient CHP and incineration facilities
  - Possibility to generatre more electricity in CHP plants

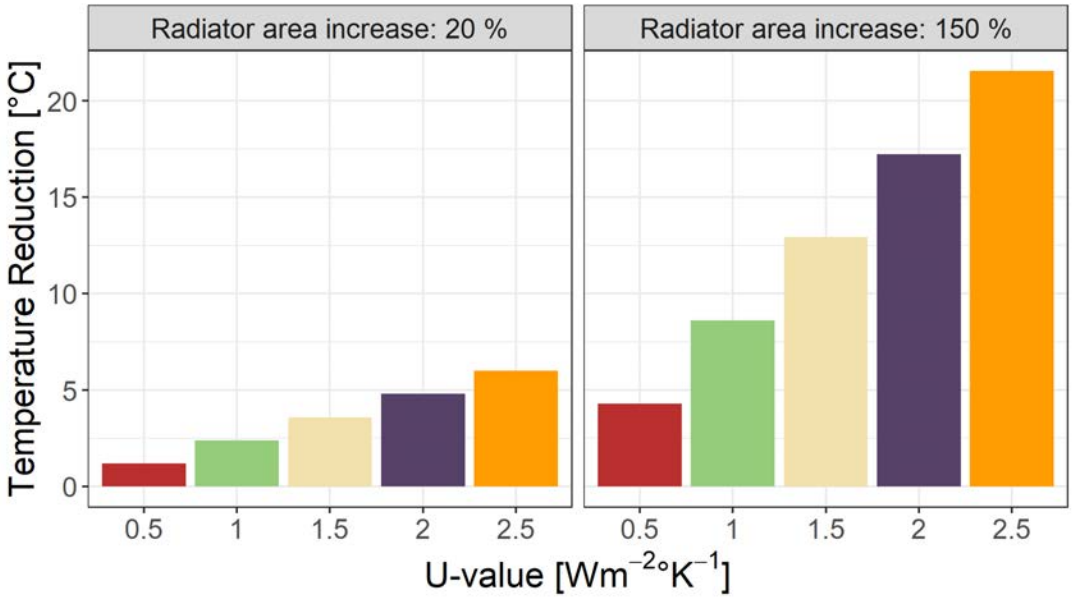
Benefits are five times as important for renewable energy. The LCOH of heat pumps could be decreased by 15€/MWh for a 30°C (5-20% of LCOH) (Averfalk(2020), Geyer(2020))

Buildings insulation and radiator area determine the heating temperature

$$T_S = T_Z + \frac{U_E A_E (T_Z - T_E)}{\dot{m}c\left(1 - \exp\left(-\frac{A_H U_H}{\dot{m}c}\right)\right)}$$

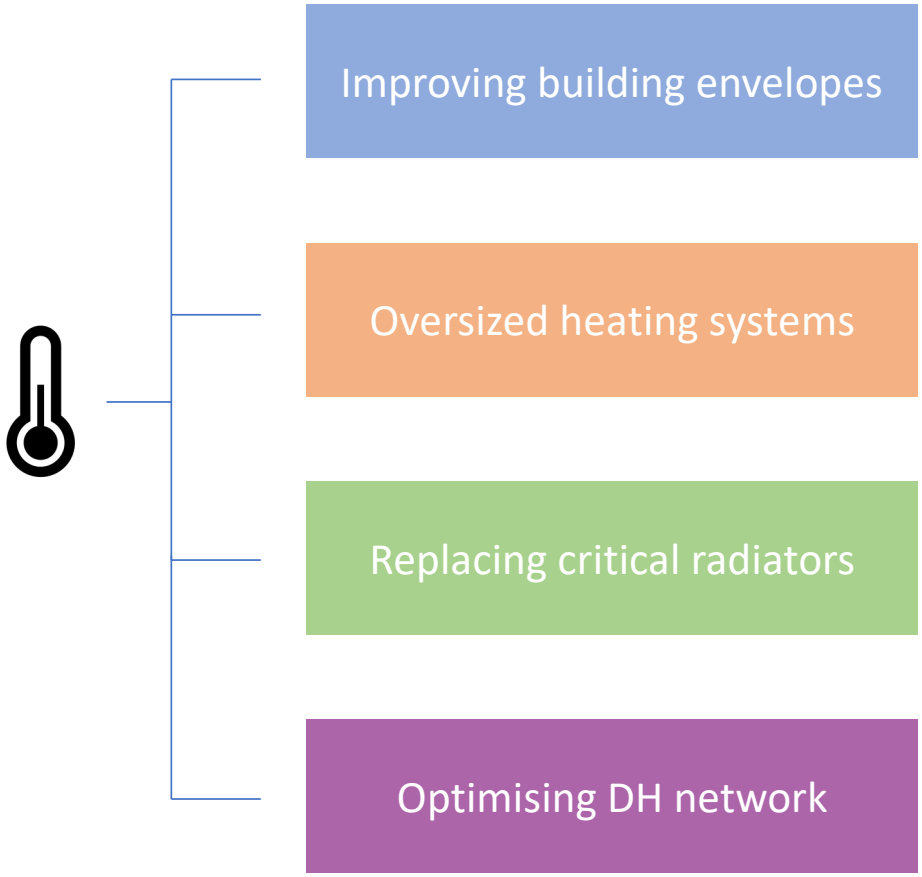
T_S = Supply temperature
T_Z = Indoor temperature
T_E = Outdoor temperature
U_E= Building's envelope performance
A_H= Radiator surface





Parametrization following Nagy et al. (2014)

There are several options to decrease temperatures



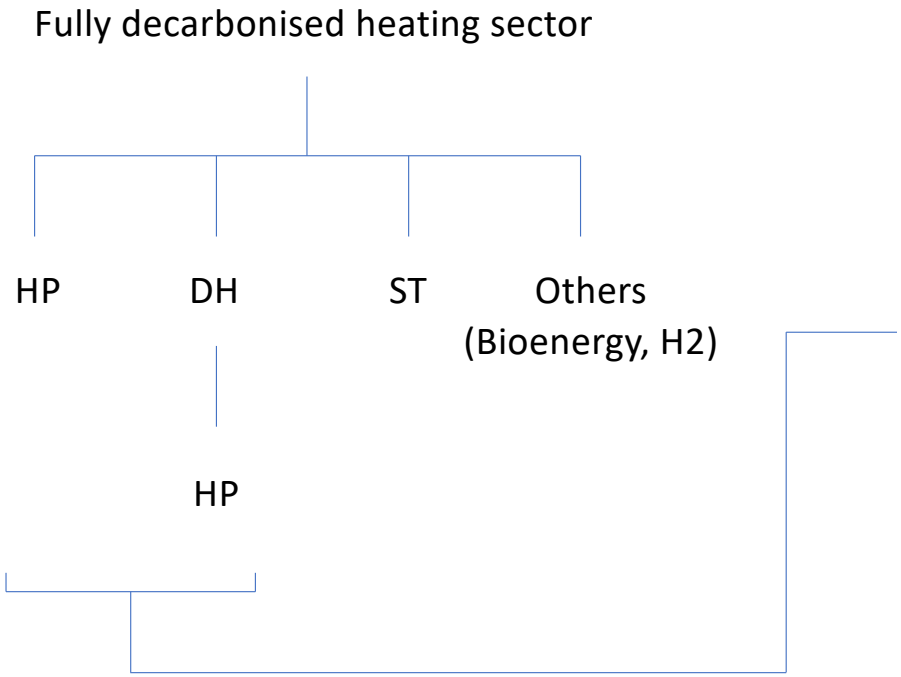
- Reduces heat load
- High up-front costs

- calibrated extremely low temperature that rarely happen
- old buildings might have undergone some efficiency improvements
- Østergaard and Svendsen (2018) find that about 80% of surveyed Danish buildings could use low temperature with existing radiators
- Lamme et al. (2022): 7-52% of radiators should have been replaced to lower the temperature from 75°C/60°C to 55°C/45°C
- The type of radiators also matters: : drops in temperatures can reach up to 15°C (Günther et al., 2020)
- Replacing radiators is quite an economical option, but potential is also limited

- Address critical substations (Averfalk 2021)
- Fix by-passes
- Optimisation of radiator control systems

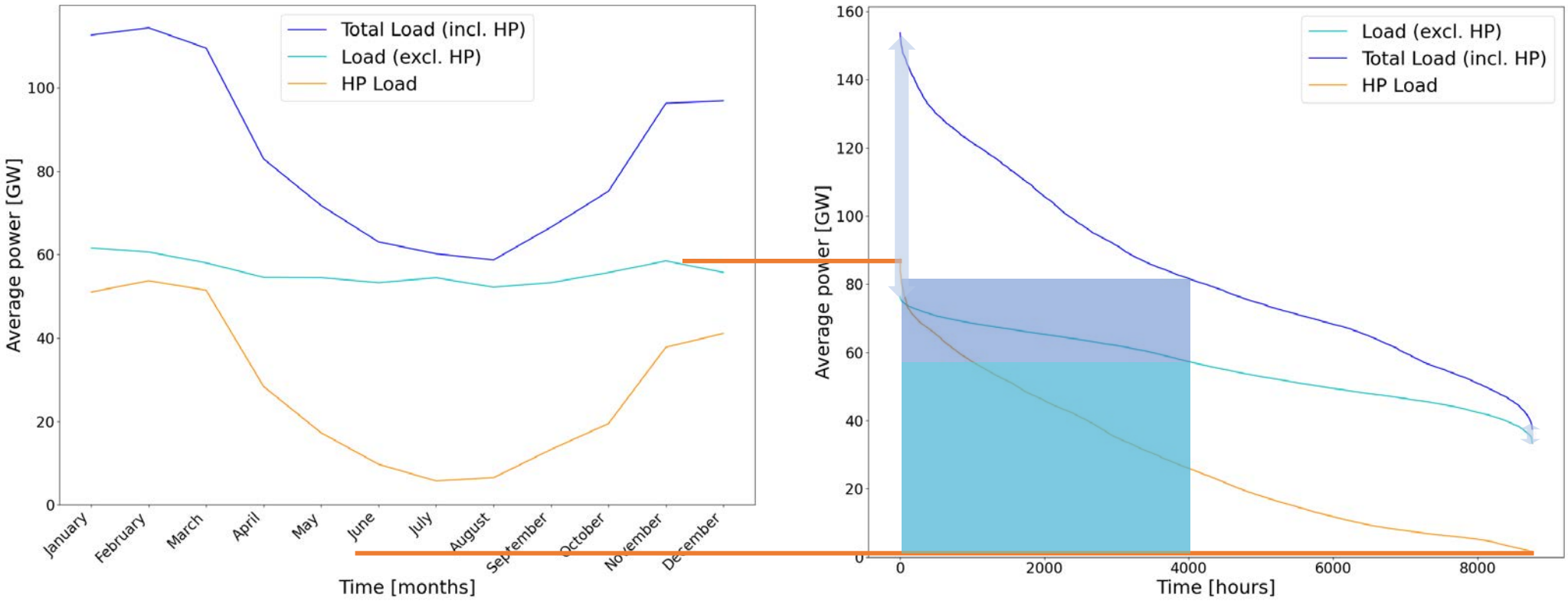
Energy efficiency can smoothen the electrification of heat

Displacing fossil fuels from the heating sector implies high electrification

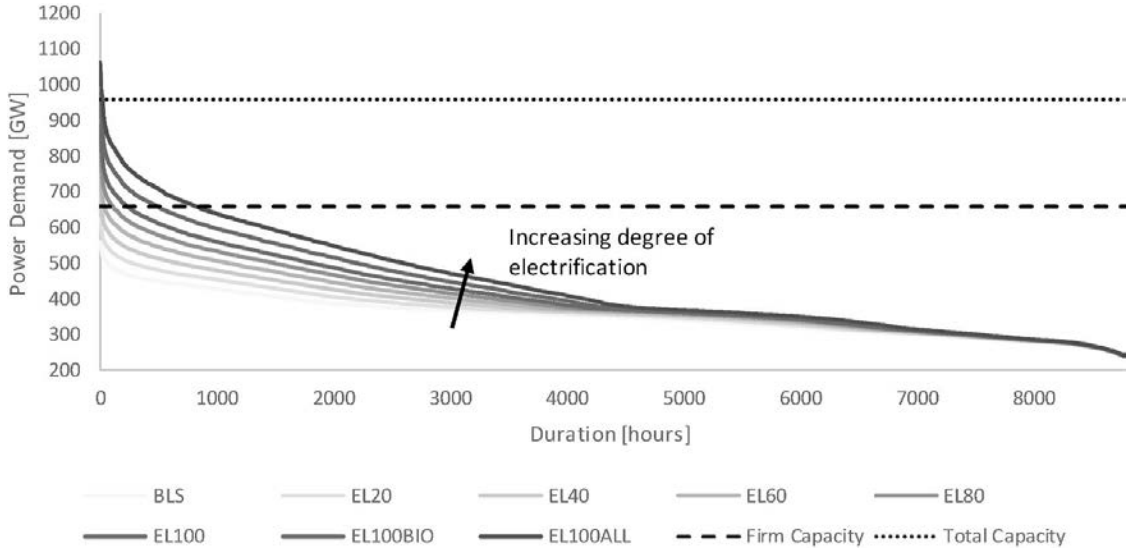


Decentralized and large-scale heat pumps will drive the electrification of buildings' heat.

Heat electrification raises the challenges on the power system



Challenges are substantial but heterogenous across regions



Thomaßen et al. (2021)

Large heterogeneity in challenges:

- Share of heat in total demand (hot vs. cold countries)
- Current share of fossil fuels to be replaced (e.g. Scandinavian countries)
- 11 EU MS could fully replace their decentralized FF with HP and cover peak with existing firm capacity (Thomaßen)

Higher peak demand:

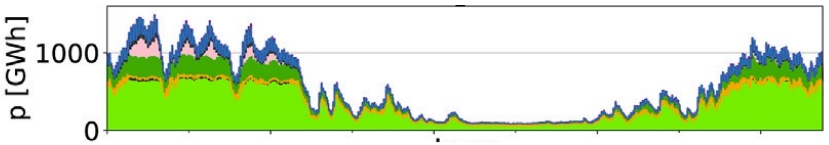
- Thomaßen et al. (2021): between -12% and 128%, with a median of 51%
- Kavvadias et al. (2019): between 20 and 70%, with an average of 41%
- Fawcett et al. (2015): UK peak load +65%
- Waite and Modi (2020): US capacity +70%

Shape of LDC:

- Thomaßen et al. (2021): median ratio between peak and minimum increases by 46% (max = 128%, min = -10%)
- Fawcett et al. (2015): peak-to-mean ratio would increase from 1.58 to 2.11 (+34%)

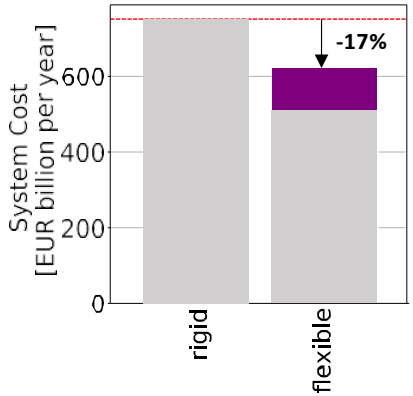
A key role of efficiency is to manage the load shape of heat demand

Normal Load



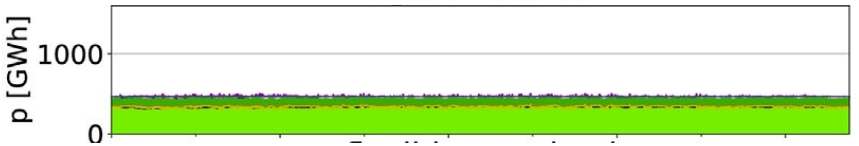
Zeyen et al. (2021)

Total annual system costs

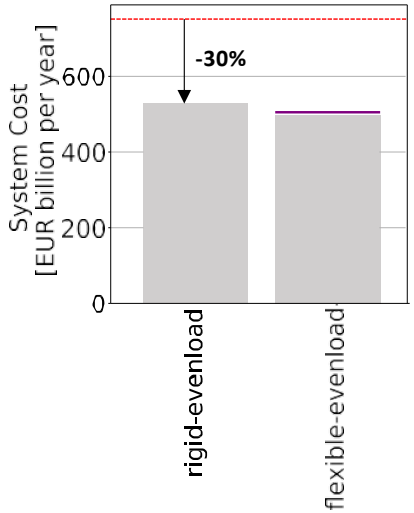


- -51% of thermal demand
- -55% of peak
- Renovations not evenly distributed (DH, regions)

Even Load



Total annual system costs



- -8% of thermal demand compared to the rigid scenario

Building renovation investments

Other system costs

"building renovation is mainly needed to manage those peaks and not to reduce the total energy demand" Zeyen et al. (2021)

Conclusion

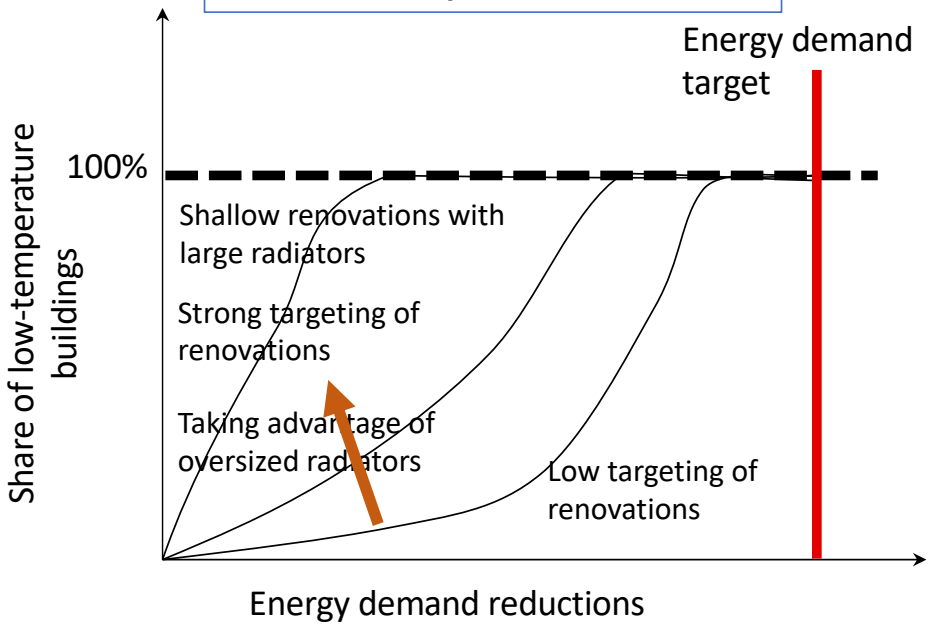
Policies should address both roles of efficiency to guard against failure

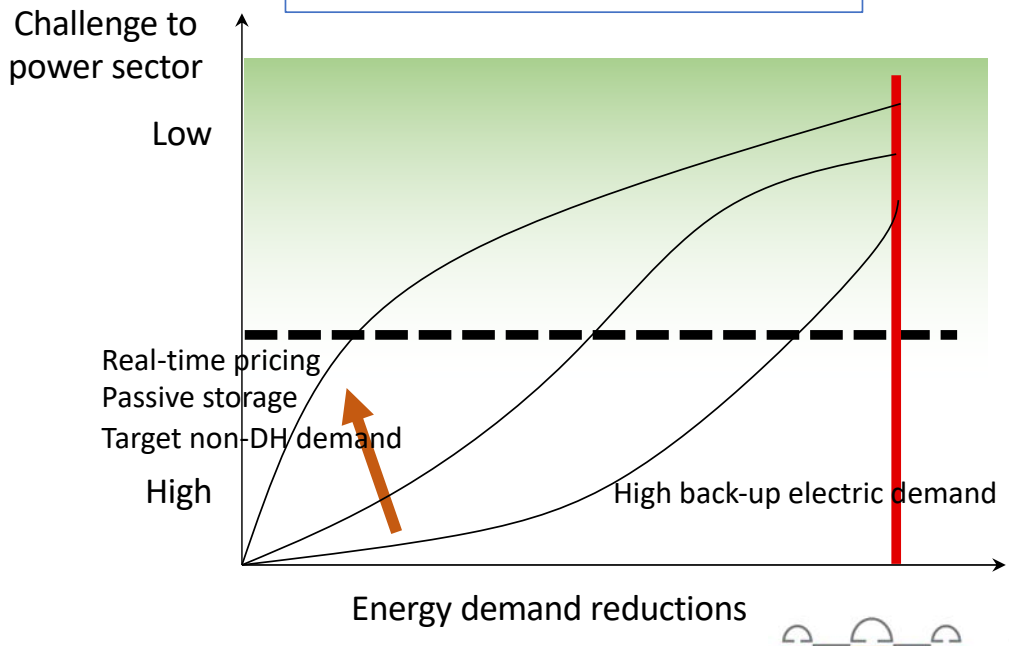
$$CO_2 = UE \times \frac{FE}{UE} \times \frac{CO_2}{FE}$$

Energy efficiency

1st role: decreasing temperatures

2nd role: smoothing electrification





Thank you

SPONSORED BY THE
Federal Ministry of Education and Research
KOPERNIKUS PROJEKTE
Ariadne
Die Zukunft unserer Energie

Efficiency policies should address these roles of efficiency

- Low heating temperatures are an enabler for renewables-based technologies
- High heating loads, more current with poorer insulation, constitute a barrier to low heating temperatures
- Several options to decrease temperatures beyond efficiency improvements
- Low temperatures can be reached even in buildings that are not very efficient
- On a yearly basis, even HP systems with much back-up heating reach high efficiencies
- But, on the days with the highest demand, the efficiency is the lowest, especially if back-up units are activated

The double role of efficiency to contribute to energy decarbonisation

$$CO_2 = UE \times \frac{FE}{UE} \times \frac{CO_2}{FE}$$

Energy efficiency

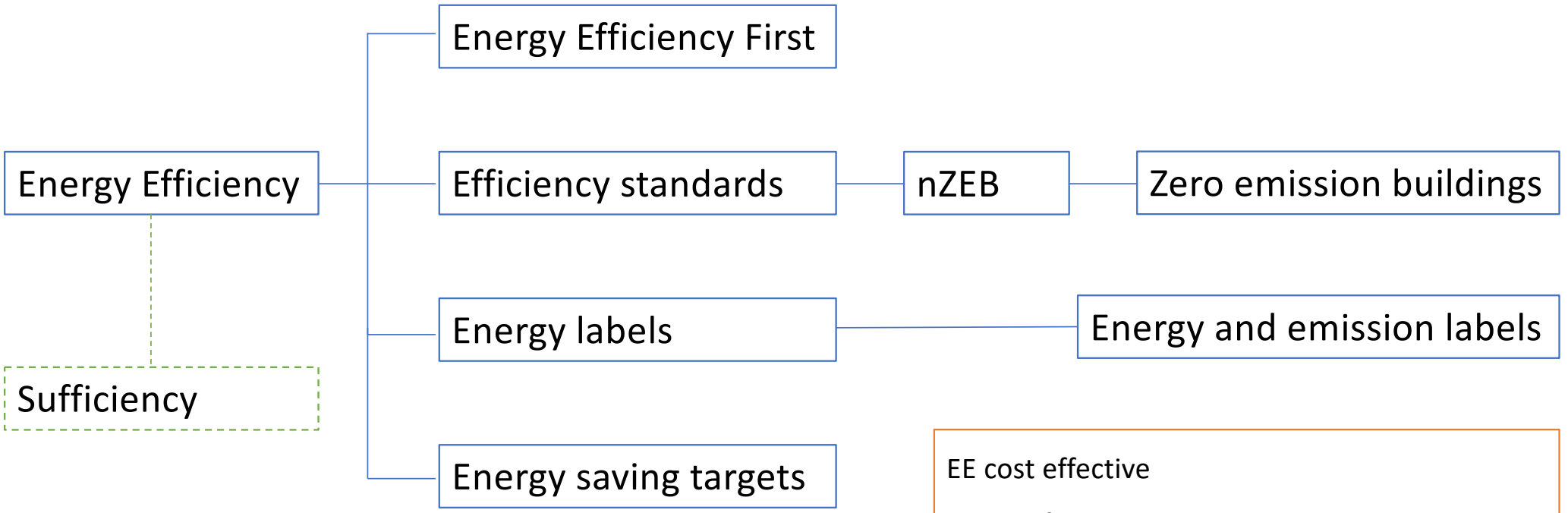
1st role: lowering heating temperature for carbon-free technologies

2nd role: smoothing the electrification of heat

- High peak
- Lower capacity factor
- Integration of RE

- Avoiding inefficient back-up at peak
- Passive storage and real-time pricing
- Reduce share of heat in power demand

Buildings decarbonisation is strongly framed around energy efficiency



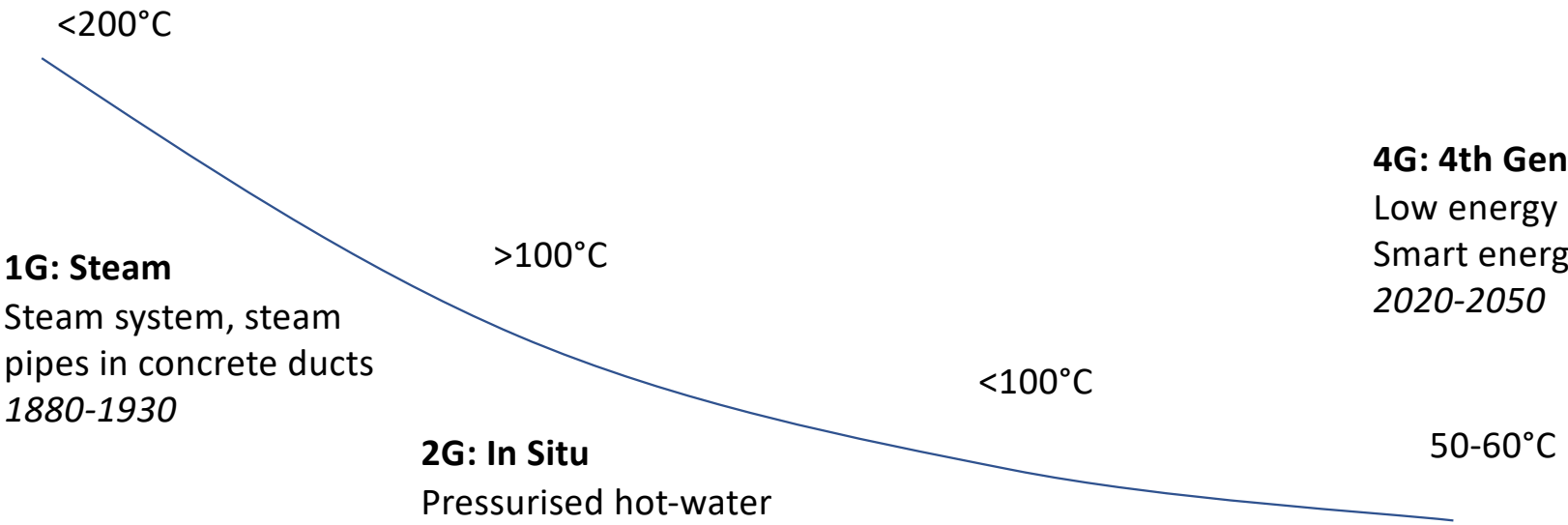
EE cost effective

Shields from energy poverty

Creates jobs and fosters economic growth

Enhances comforts and health (co-benefits)

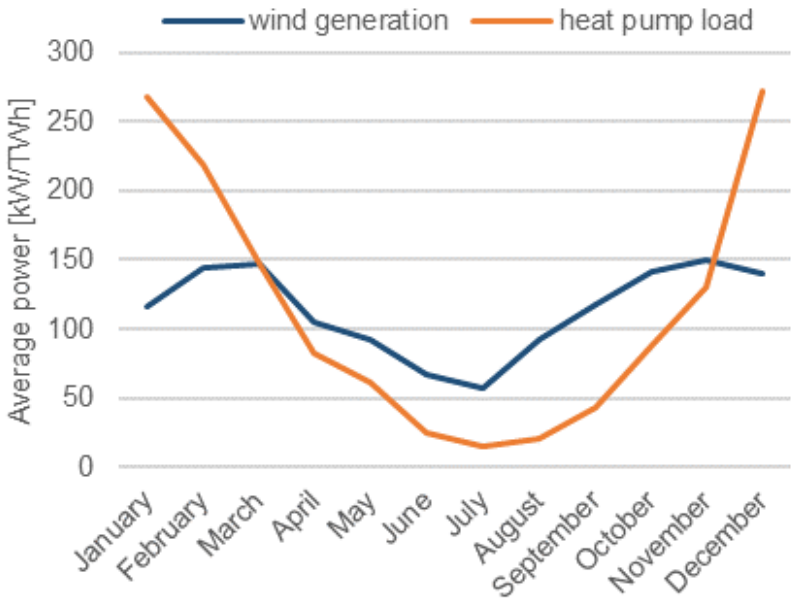
Reduction of temperatures is also long discussed in the DH literature



Adapted from
Lund et al. (2014)

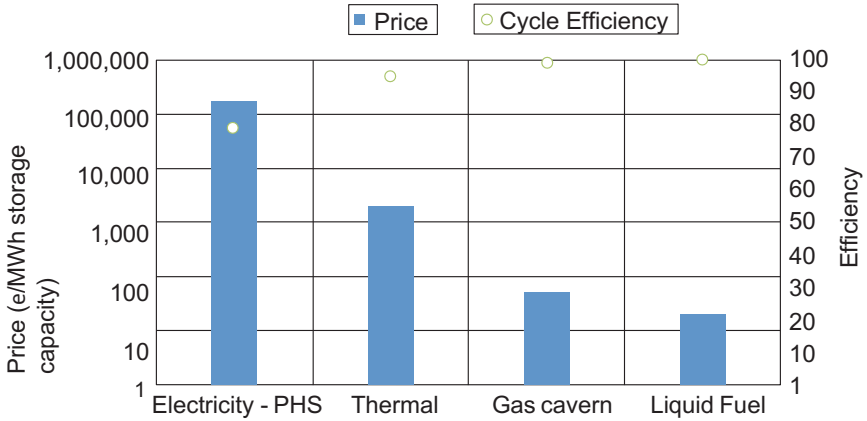
The heat sector could also alleviate the integration of renewable energy

Wind and Heat seasonal correlation



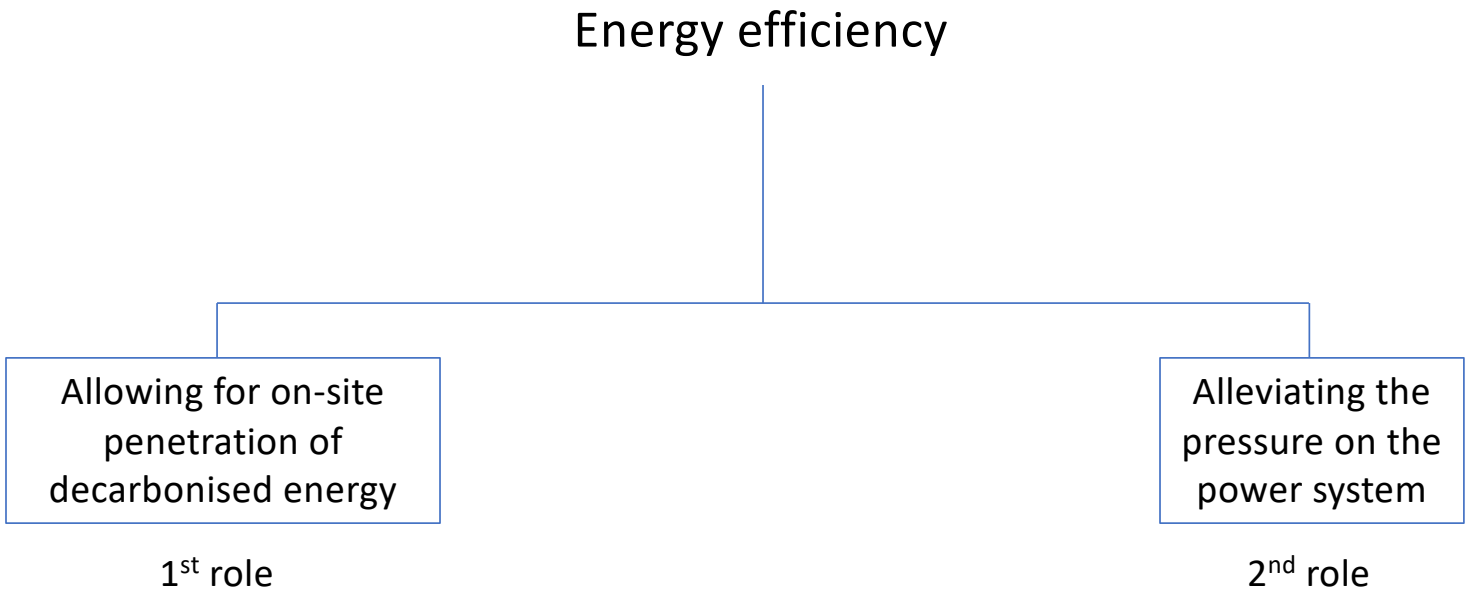
Ruhnau et al. (2020)

Cheaper thermal storage

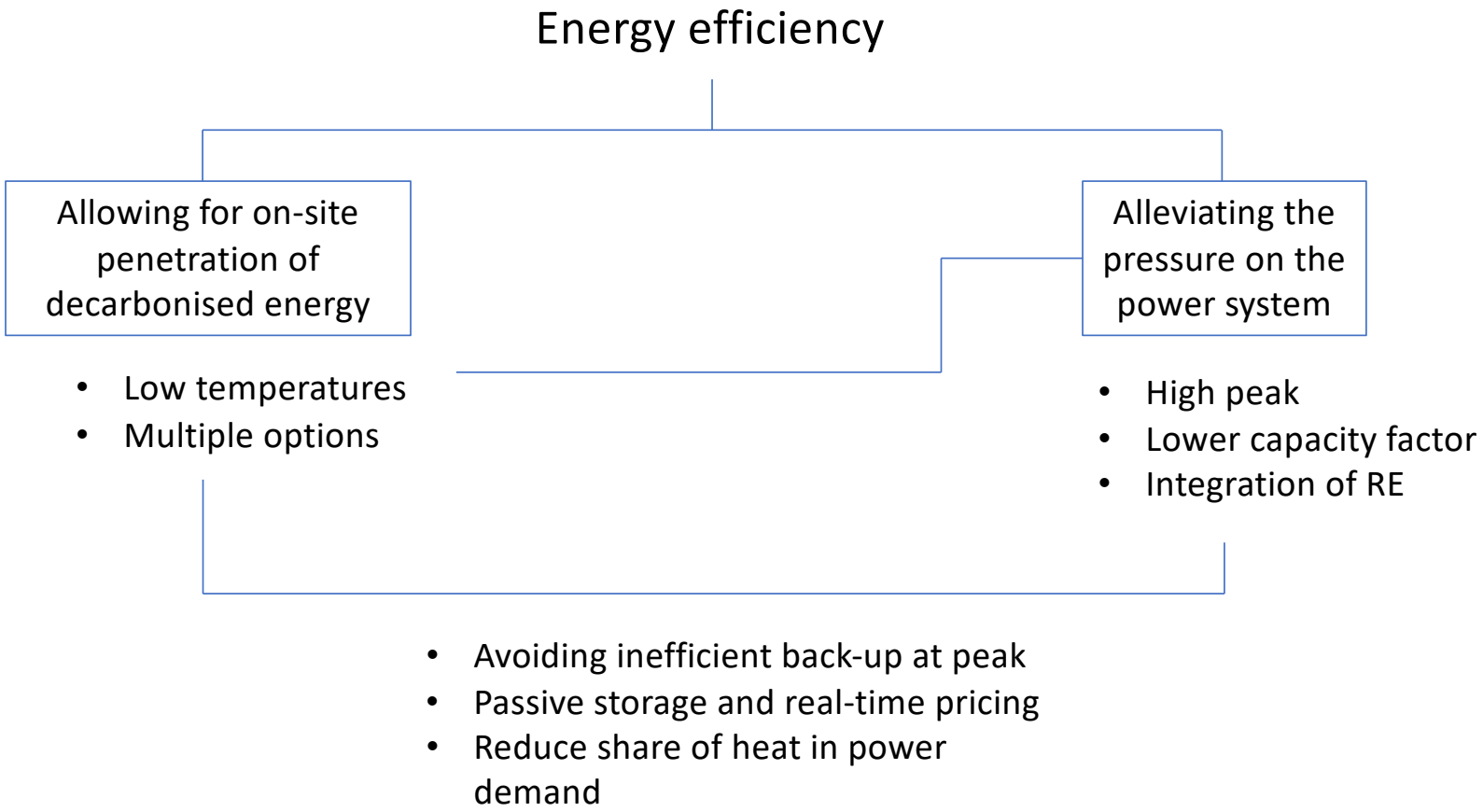


Lund et al. (2016)

Energy efficiency as an enabler for the decarbonisation of heat

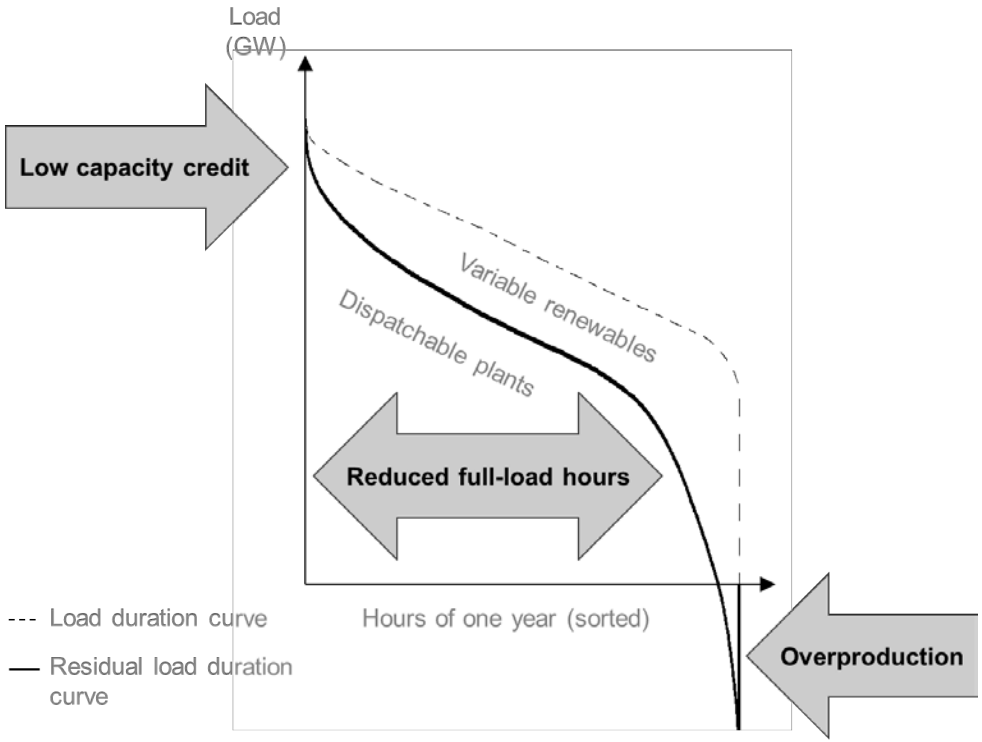


The double role of buildings efficiency to contribute to decarbonisation

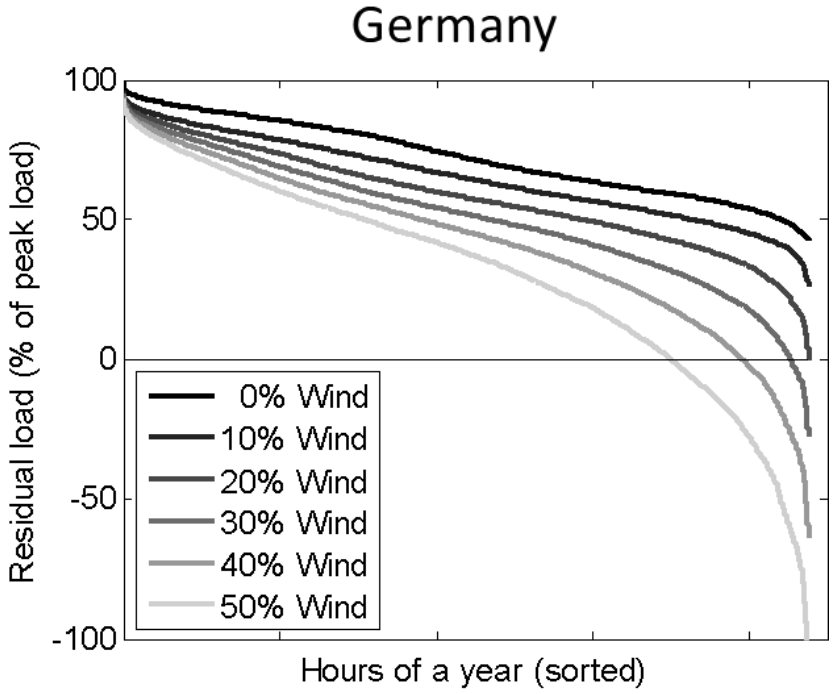


New challenges also come from the integration of renewables

Residual LDC = LDC – Renewable Generation



Ueckerdt et al. (2015)



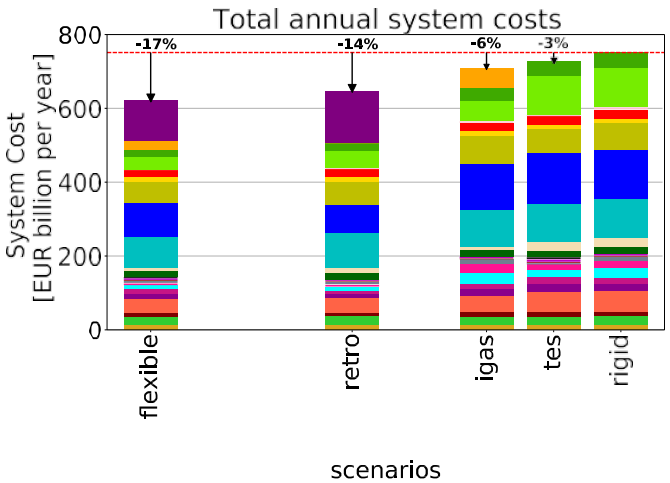
Energy efficiency reduces the pressure and costs in several ways

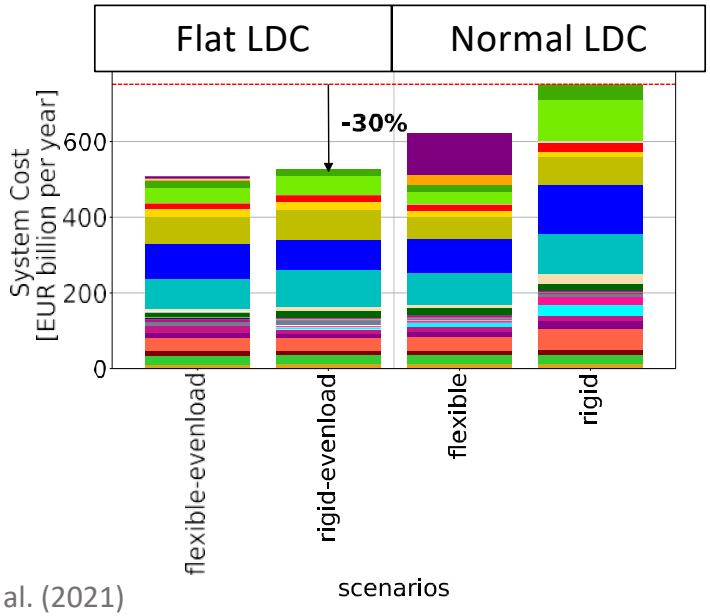
Energy efficiency

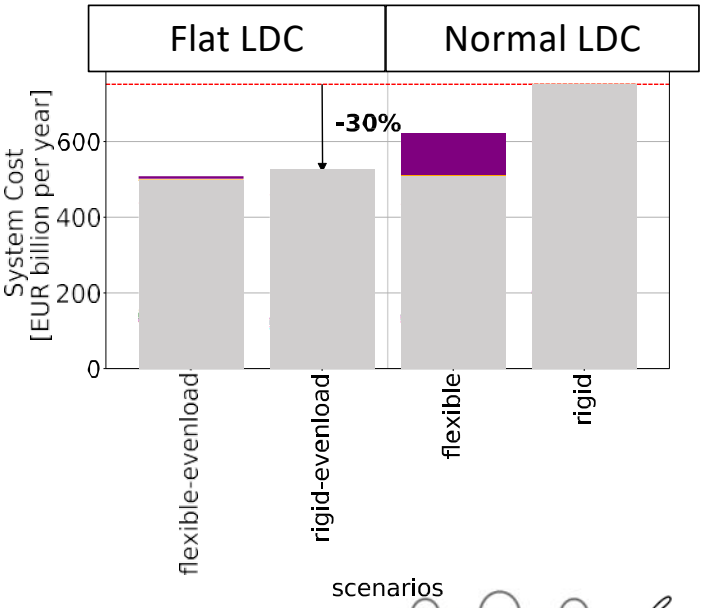
Reducing total demand

Reducing peak and slope

Passive storage







Building retrofitting investments

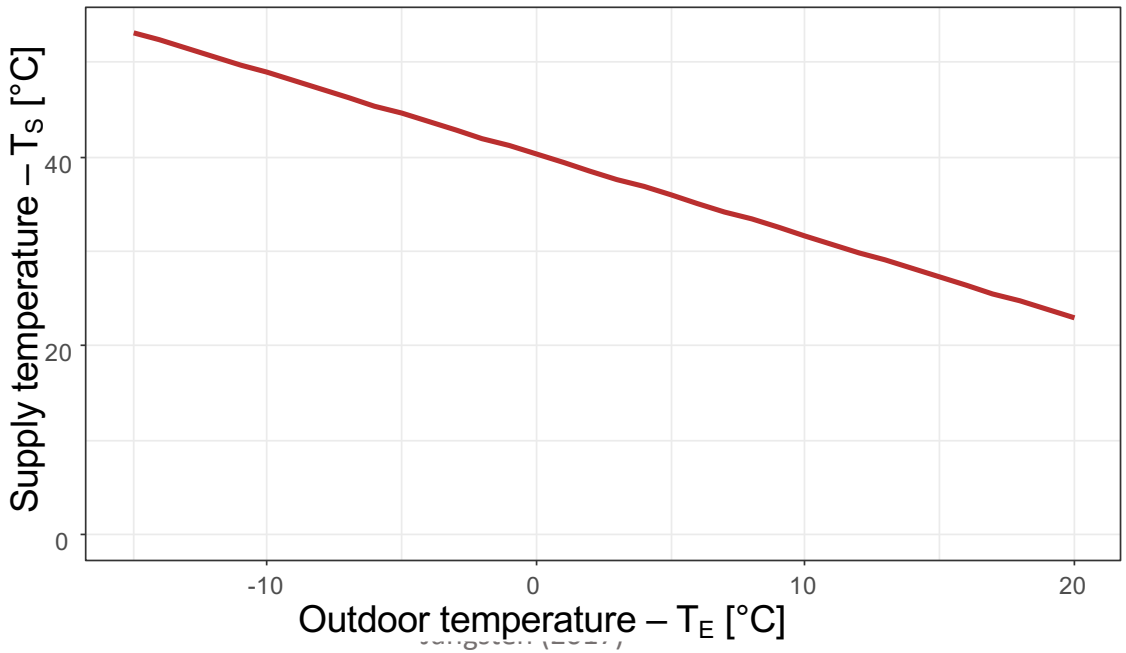
Zeyen et al. (2021)

Heating system temperatures depend on outdoor and indoor temperatures

The heating temperature is not the indoor temperature

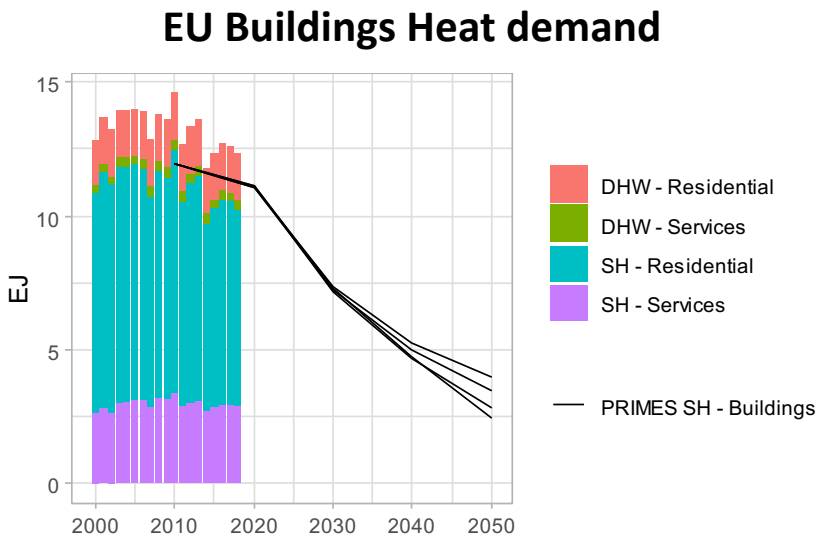
$$T_S = T_Z + \frac{U_E A_E (T_Z - T_E)}{\dot{m}c\left(1 - \exp\left(-\frac{A_H U_H}{\dot{m}c}\right)\right)}$$

T_S = Supply temperature
T_Z = Indoor temperature
T_E = Outdoor temperature
U_E= Building's envelope performance
A_H= Radiator surface



High temperatures achievable for fossil fuels, but problematic with renewables

Heat energy demand trends are not in line with the 1.5°C goal



12% of buildings undergo some energetic renovation every year, but only **0.2%** with deep renovations instead of **3%** (claimed by BPIE)

→ **Do these trends jeopardise the decarbonisation of the sector?**

→ **What are the roles of efficiency for the decarbonisation?**