Energy-Efficient Ventilation Using Hybrid Geothermal Preconditioning and Exhaust-Air Regeneration in AHUs

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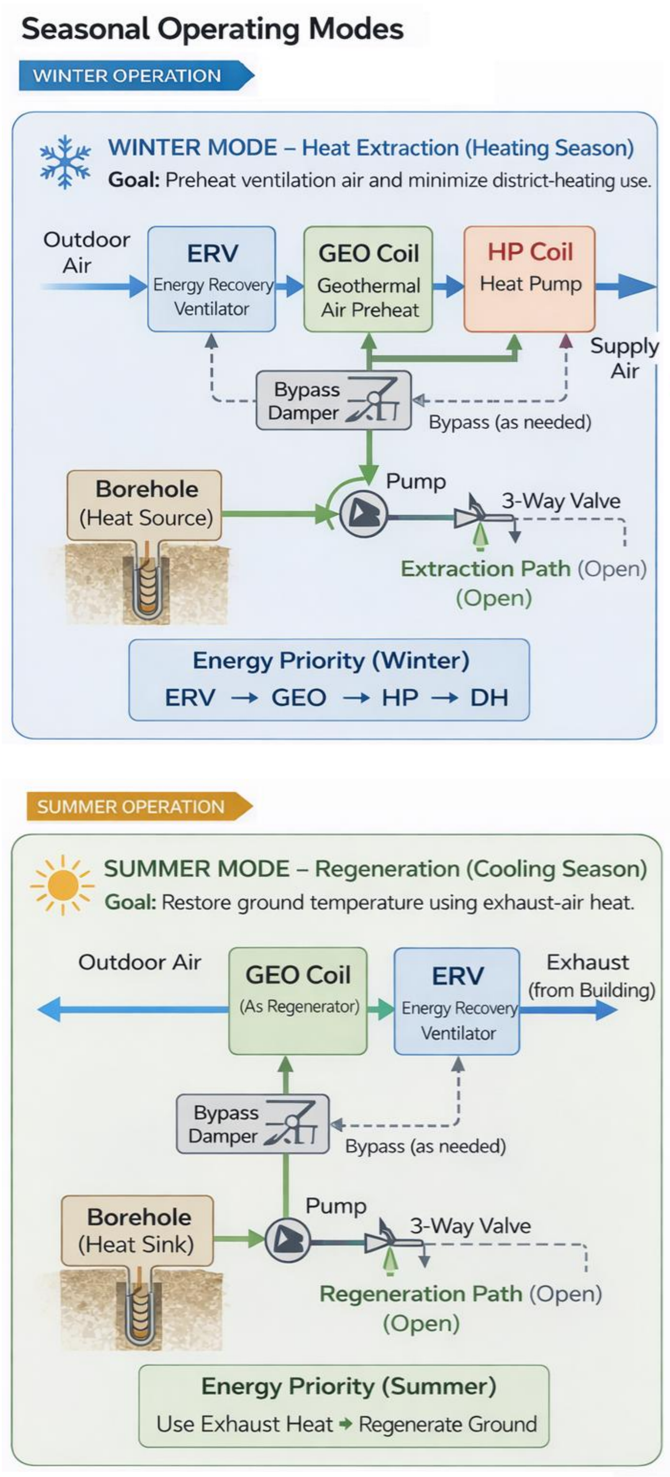
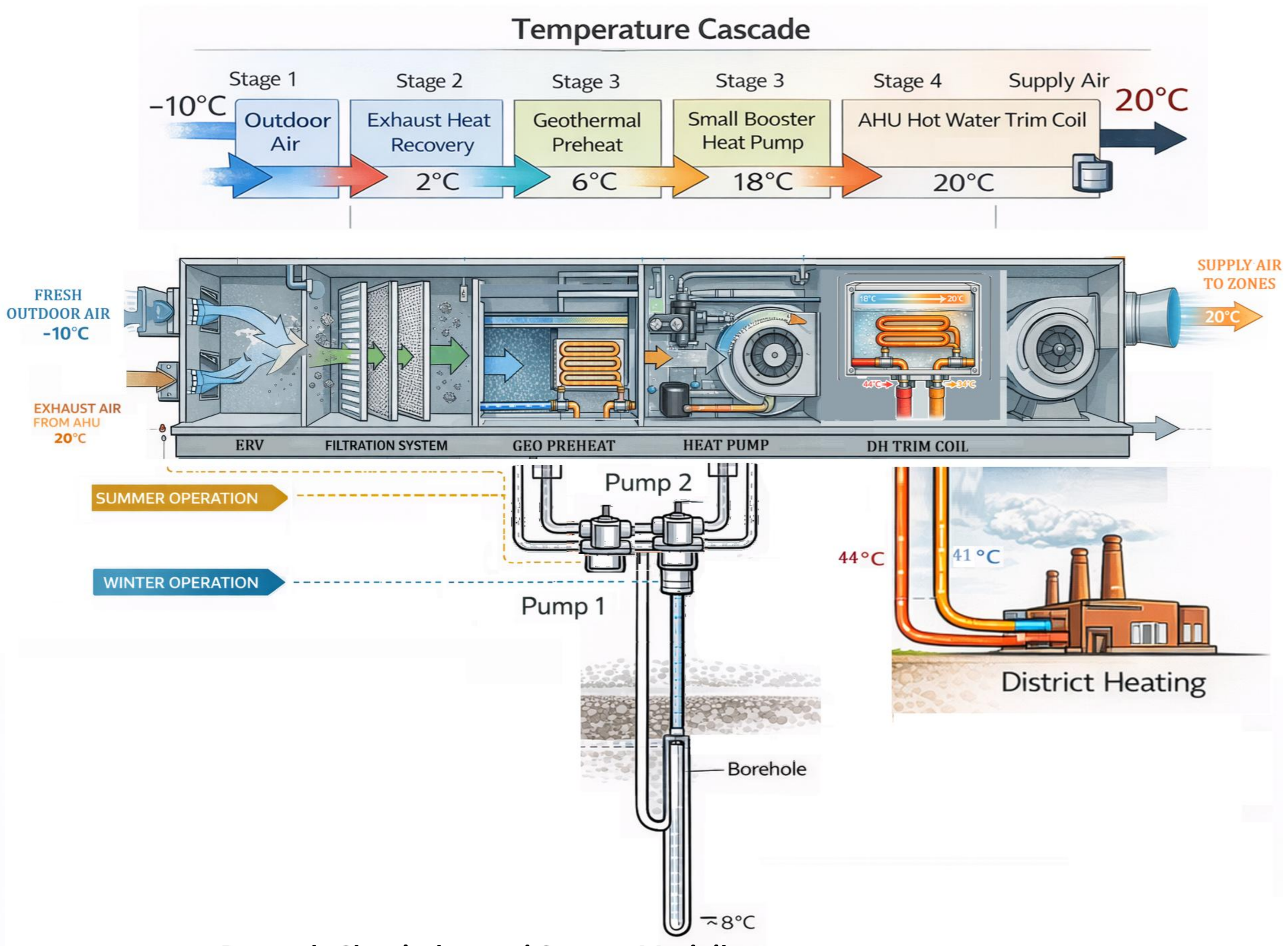
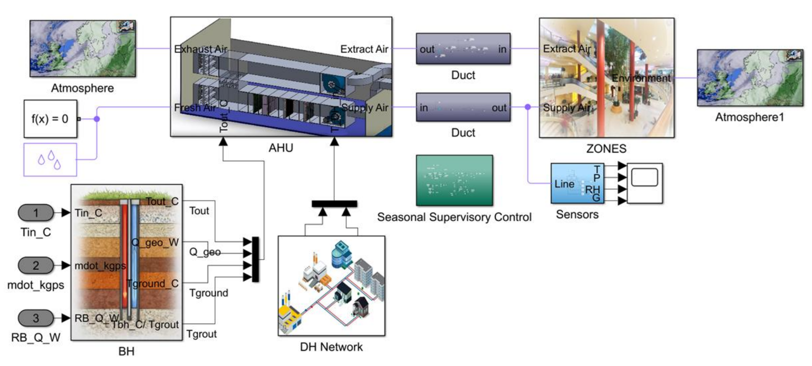
Exhaust-air-assisted shallow borehole geothermal regeneration reduces district-heating demand in energy-efficient ventilation systems.

- Geothermal preconditioning increases inlet-air temperature from 2°C to 6°C (ΔT ≈ 4°C), reducing heat-pump lift and improving COP by roughly 10–30%.
- ERV exhaust air provides passive geothermal loop regeneration, stabilizing borehole source temperature.
- Improved energy-efficient ventilation operation.
- Reduced auxiliary district-heating demand during cold outdoor conditions.
- Suitable for energy-efficient HVAC systems.





Dynamic Simulation and System Modeling

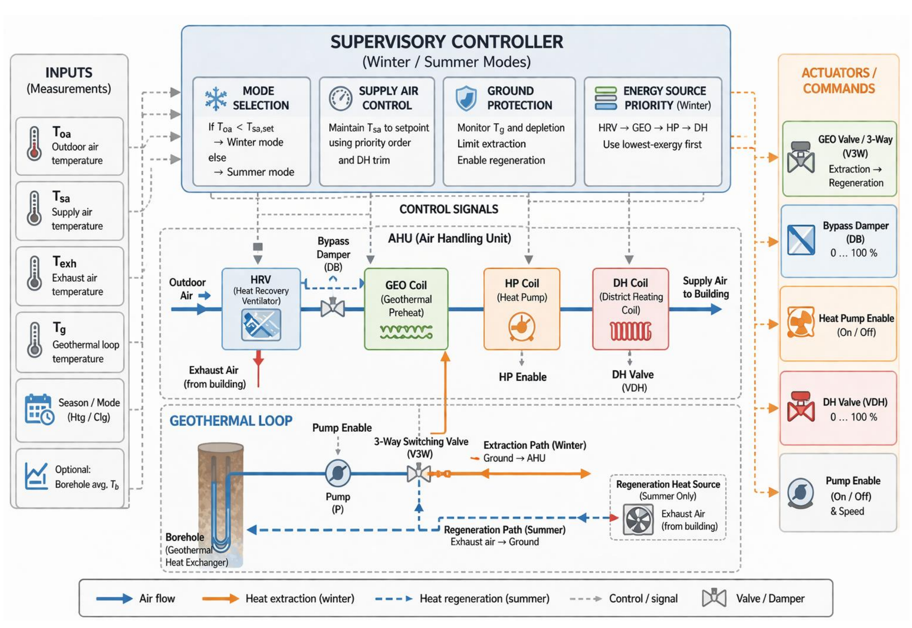


Introduction

- Buildings consume significant energy for ventilation heating.
- Conventional AHU systems rely on auxiliary district heating after ERV.
- The same geothermal loop provides both inlet-air preconditioning and the heat-pump evaporator source.
- Exhaust-air regeneration improves seasonal source stability.
- Hybrid solutions support low-temperature district-heating networks.

Modeling and Control Framework

- Physics-based dynamic AHU modeling
- Physics-based dynamic geothermal borehole modeling
- ERV → GEO → HP → DH trim cascade
- Coupled ground thermal response modeling
- Exhaust-air-assisted geothermal regeneration
- Supervisory control minimizing district-heating demand



Algorithm 1 Supervisory operating strategy for hybrid geothermal ventilation preconditioning in HVAC air handling units

Require: Outdoor air temperature T_{oa}, heat-recovery outlet temperature T_{hr}, ground-loop temperature T_g, supply air setpoint $T_{sa,set}$; model parameters; time step Δt

for $n = 0, 1, \ldots, N-1$ **do**

  Evaluate geothermal temperature difference:

$$\Delta T_g^n = T_g^n - T_{hr}^n$$

  Geothermal stage decision:
  If $\Delta T_g^n > \Delta T_{\min}$, activate preheating mode
  If $\Delta T_g^n < -\Delta T_{\min}$, activate precooling mode
  Otherwise, bypass geothermal loop

  Geothermal flow modulation: Adjust $\dot{m}_g^n$ according to selected mode

  Compute geothermal outlet air temperature:

$$T_{pc}^n = T_{hr}^n + \frac{Q_{geo}^n}{\dot{m}_a c_{p,a}}$$

  Heat pump activation:
  If $T_{pc}^n < T_{sa,set}$, enable heat pump
  Otherwise, disable heat pump

  Heat pump modulation: Adjust compressor power P_{comp}^n to reach target T_{hp}^n

  Trim heating control:

$$Q_{trim}^n = \dot{m}_a c_{p,a} \left(T_{sa,set} - T_{hp}^n\right)$$

  Enforce admissibility:

$$Q_{trim}^n \geq 0$$

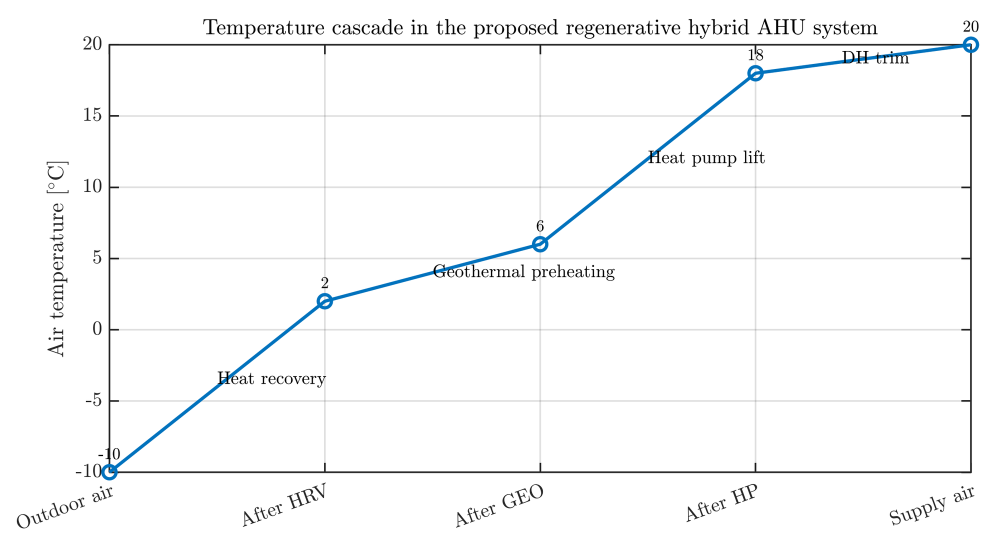
  Update geothermal loop temperature:

$$T_g^{n+1} = T_g^n + \Delta t \left(-\kappa_1 Q_{geo}^n - \kappa_2 Q_{evap}^n + \kappa_3 Q_{reg}^n\right)$$

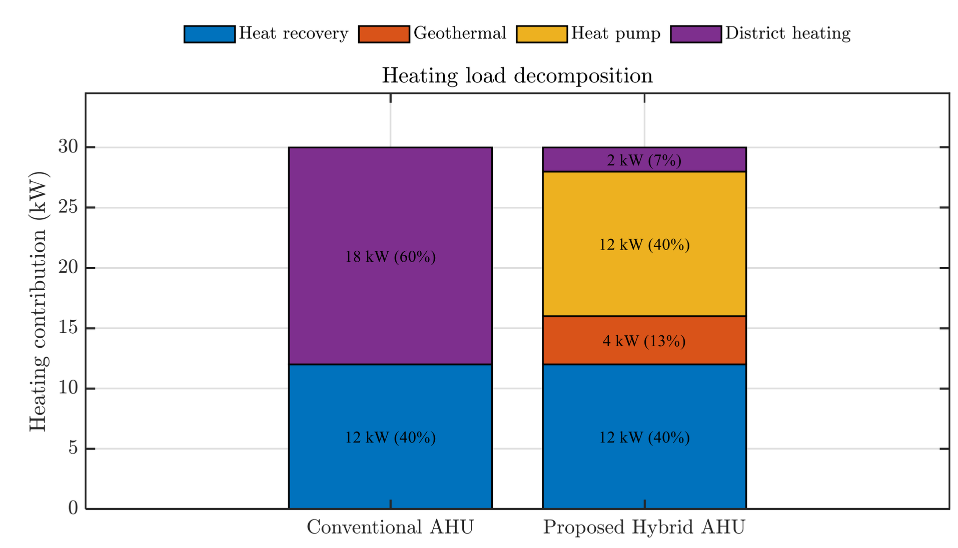
end for

Results

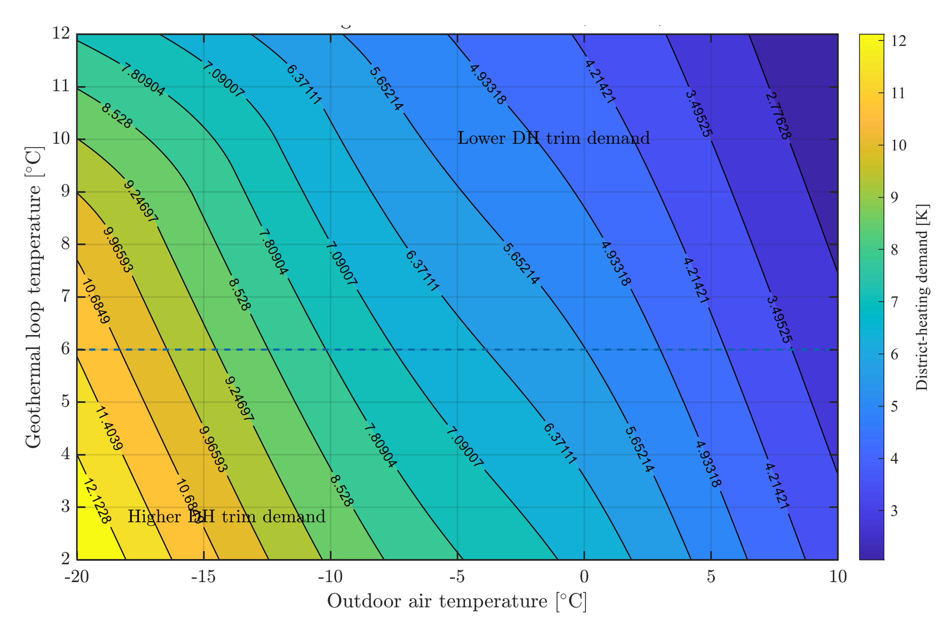
👉 **Geothermal preconditioning reduces heat pump lift**



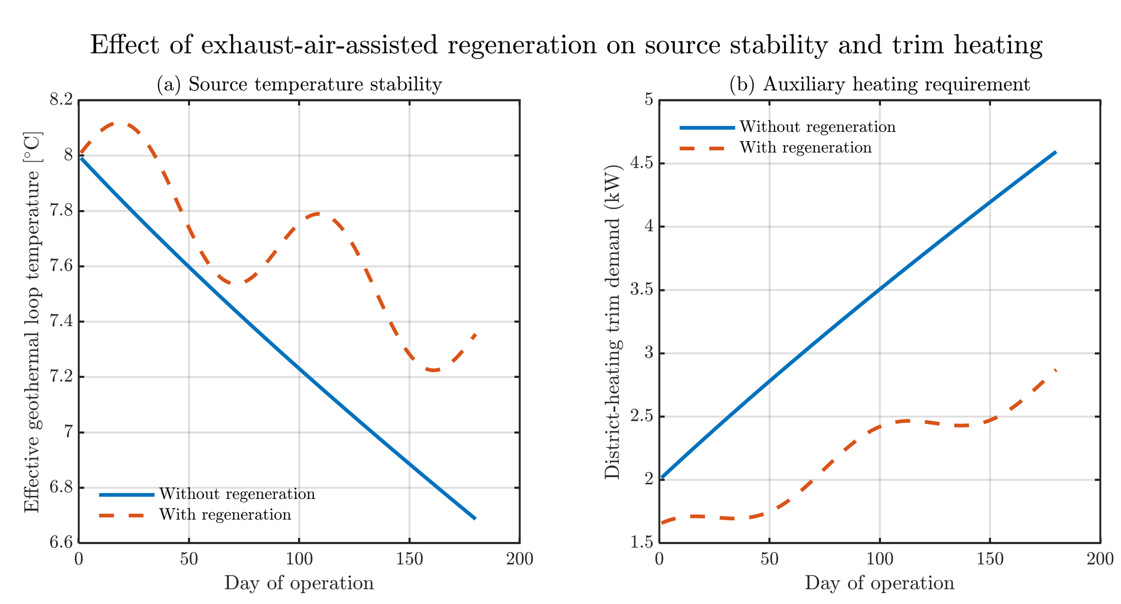
👉 **Heating demand shifts from DH to renewable sources in AHU**



👉 **Remaining DH demand after upstream stages (ERV + GEO + HP)**



👉 **Exhaust-air regeneration stabilizes source and reduces DH demand**



References

DH – *District Heating*
ERV – *Energy Recovery Ventilator*
AHU – *Air Handling Unit*
GEO – *Geothermal Heat Exchanger*
HP – *Heat Pump*
COP – *Coefficient of Performance*

[1] Kirschstein et al., *Energy and Buildings*, 2024.

[2] Allaerts et al., *Energy and Buildings*, 2017.

[3] Lepiksaar et al., *Environmental and Climate Technologies*, 2021.