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Prof. Hansjürg Leibundgut

Towards a Heat Pump with a COP over 10

José Antonio Sánchez Ihl

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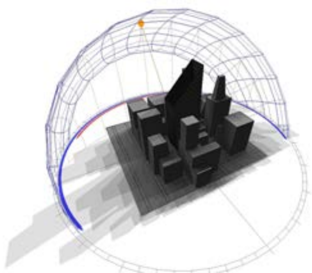
Global Energy Performance



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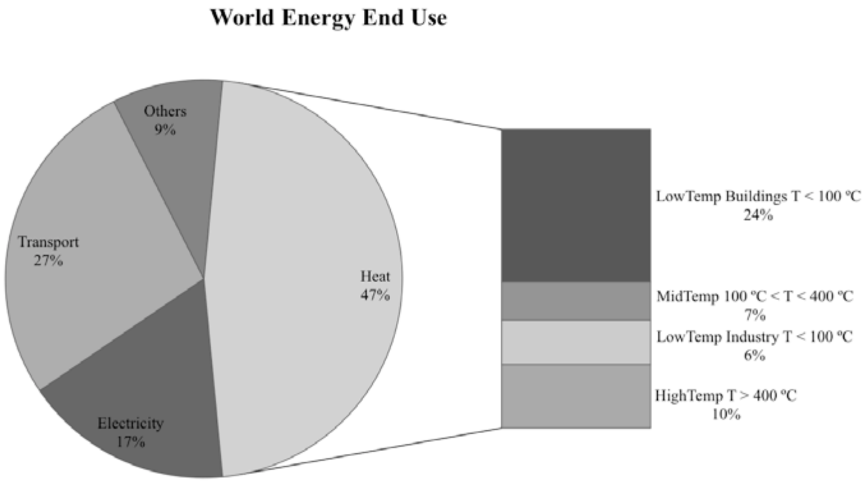
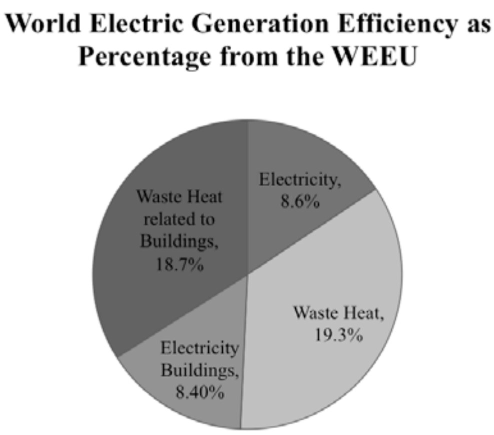
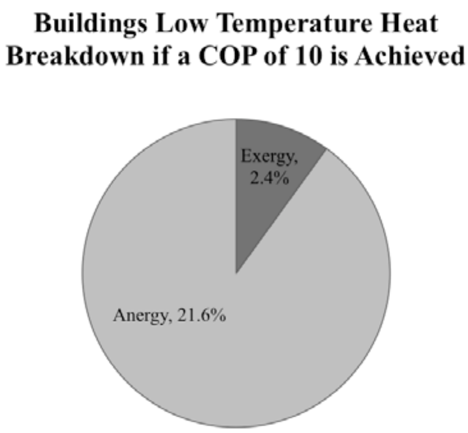
World Energy End Use Breakdown







- Electricity generation has a global efficiency of 31%, it needs to be more renewable and CO_2 free
- All the low temp heat demand for buildings could be supplied with CHP ie. reduction in primary energy of 24%
- If HP with a COP >10 are used, primary energy consumption would be reduced in 16%

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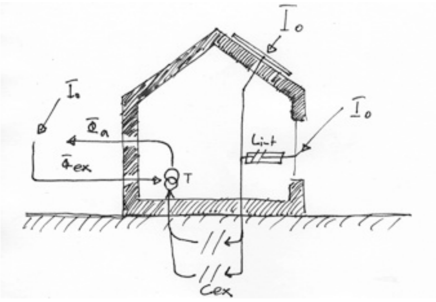
Dynamic Assessment



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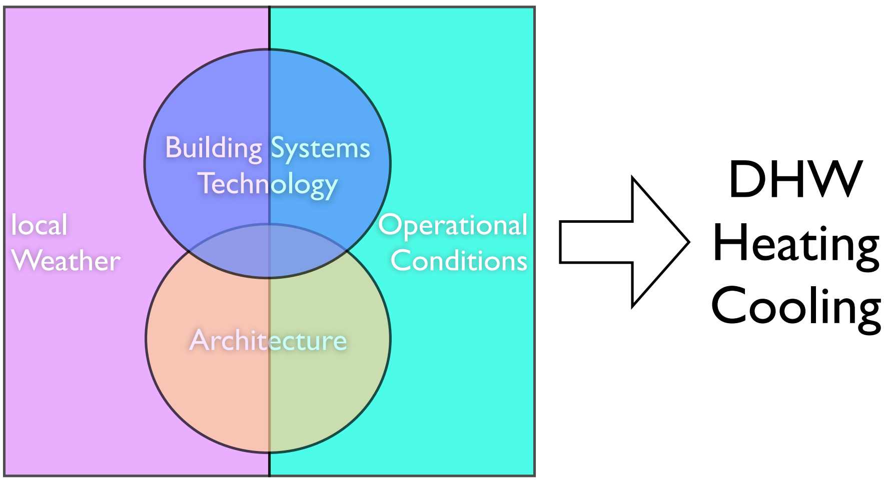
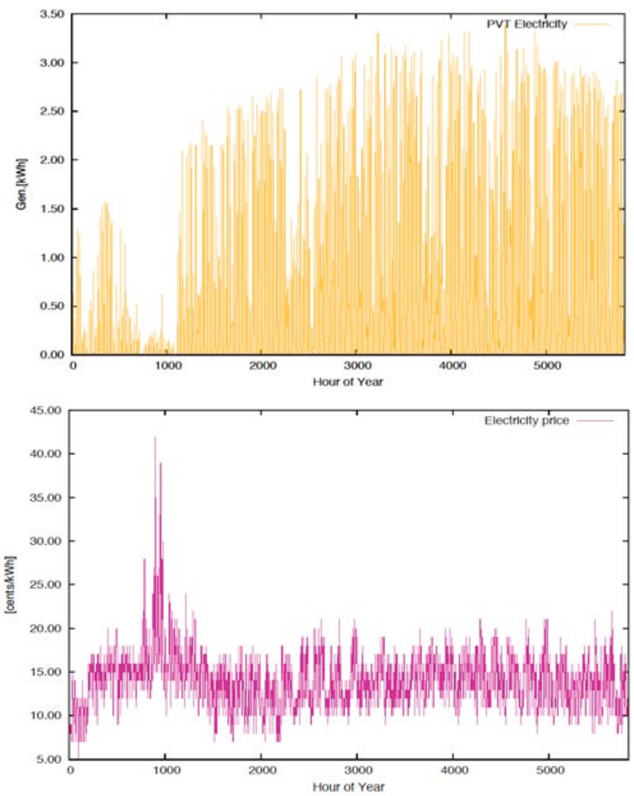
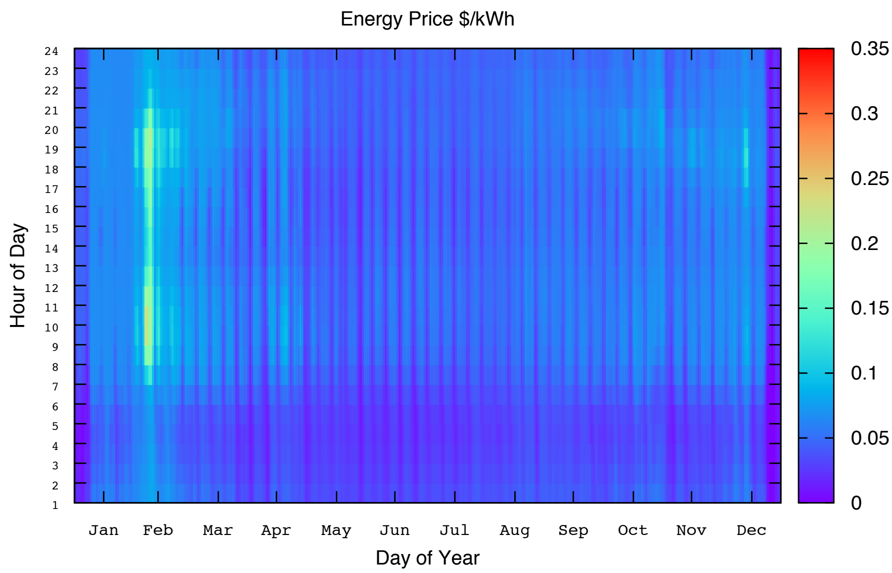
Variables that Influence Buildings Heat Consumption



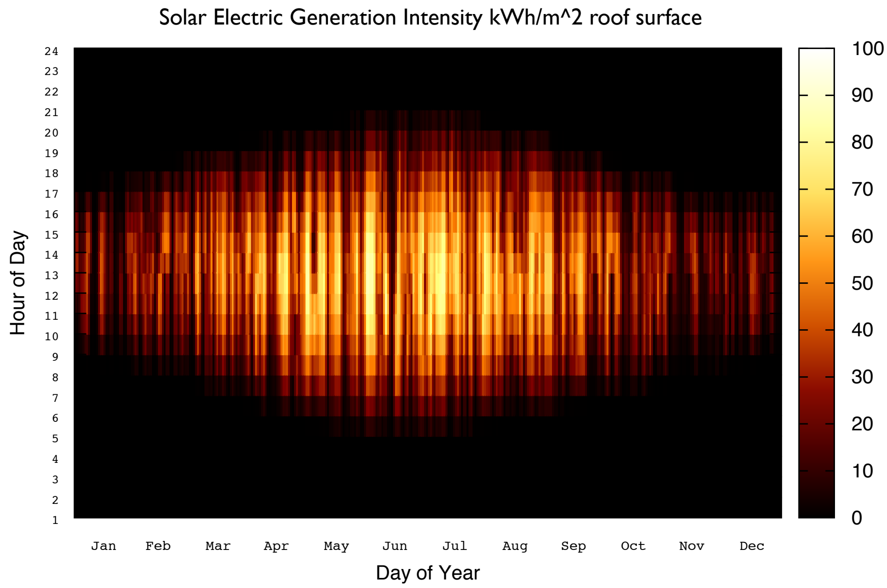
B35's PV generation vs Market Price (2012)



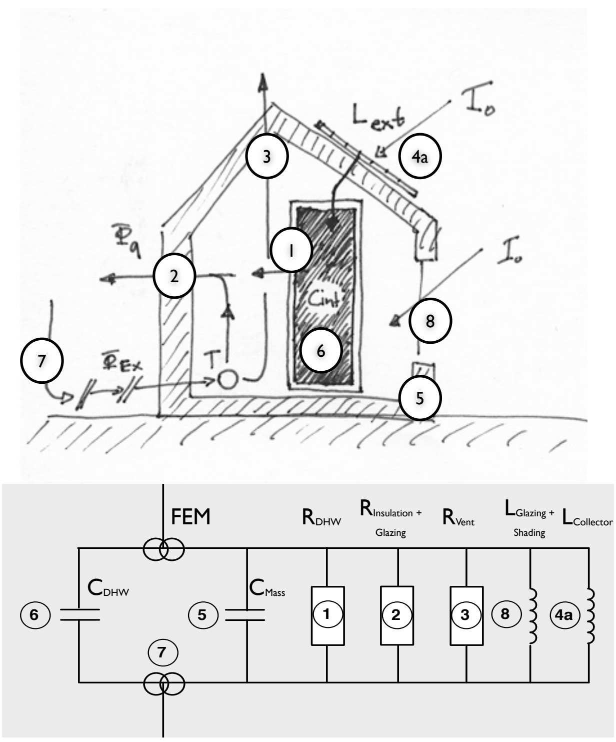
Swiss Spot Market Price 2012



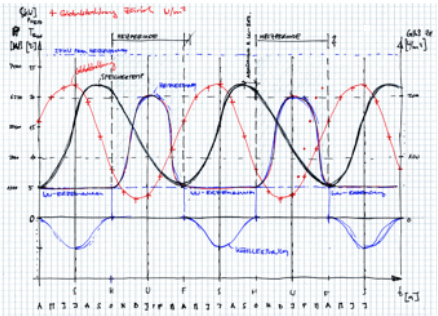
Mean PV Energy Generation for Zürich



Architecture, Passive Design, Bioclimatic

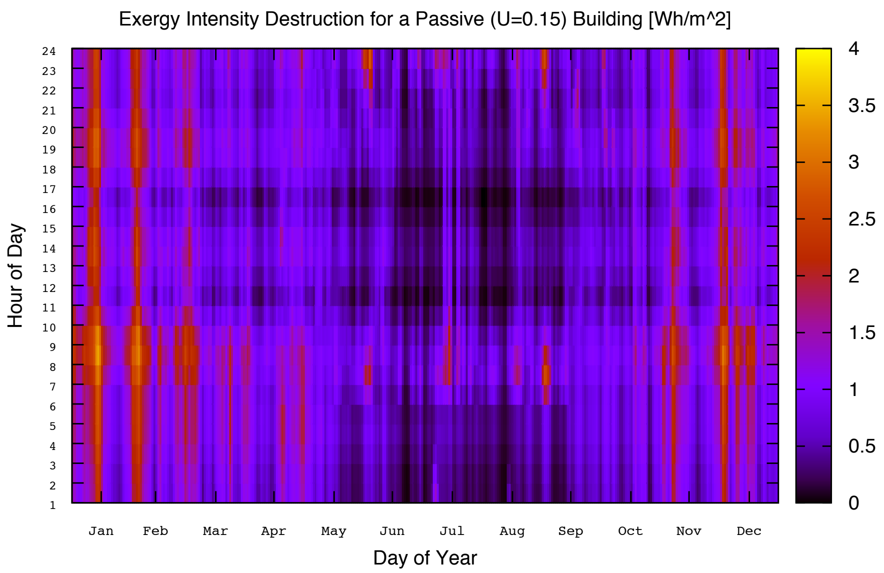


Dynamic System, Oscillating System

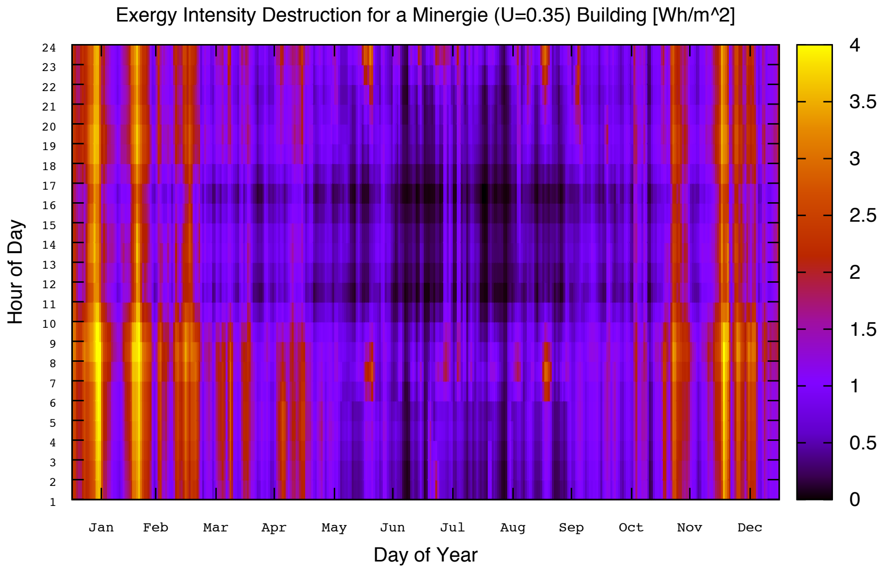


$$A\frac{d^2\phi}{dt^2} + B\frac{d\phi}{dt} + C\phi = f(t)$$

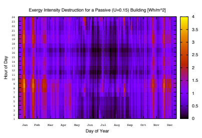
Passive Footprint: Exergy destruction for a single family building in Zürich with an U_value = 0.15 [W/m²K]

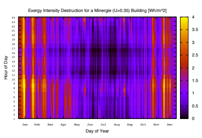


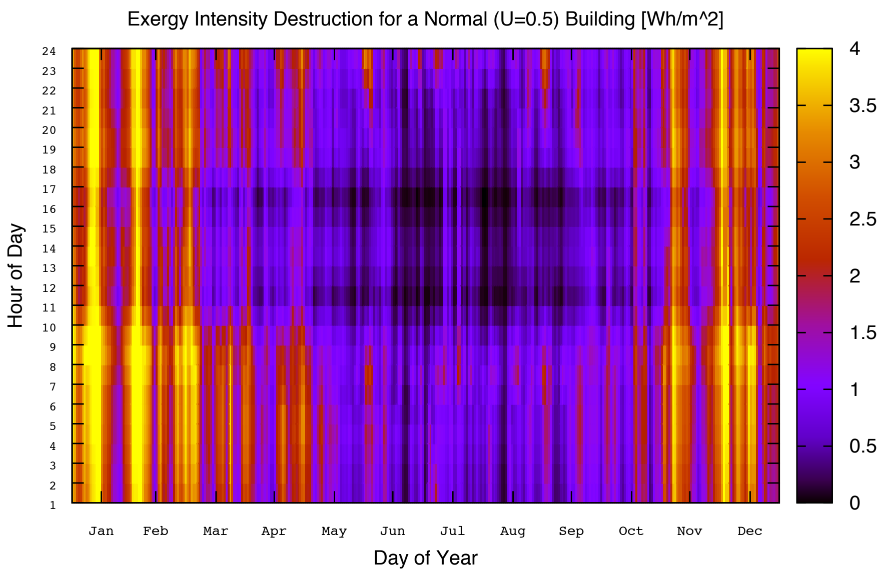
Passive Footprint: Exergy destruction for a single family building in Zürich with an U_value = 0.35 [W/m²K]



Passive Footprint: Exergy destruction for a single family building in Zürich with an U_value = 0.5 [W/m²K]

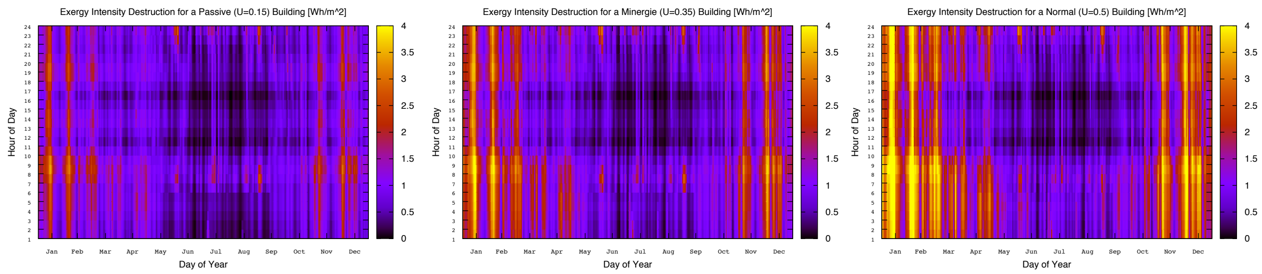




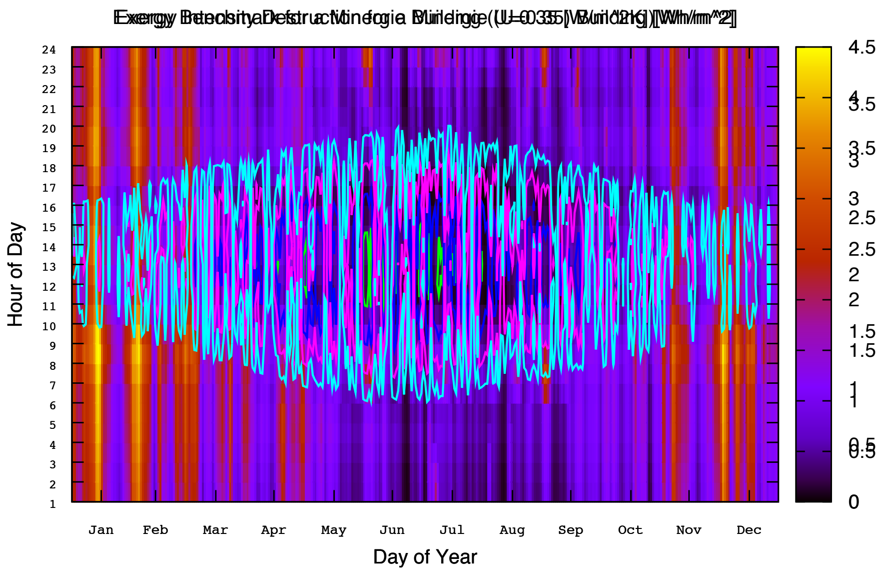


Passive Footprint: Exergy destruction for a single family building in Zürich with 3 different insulation levels

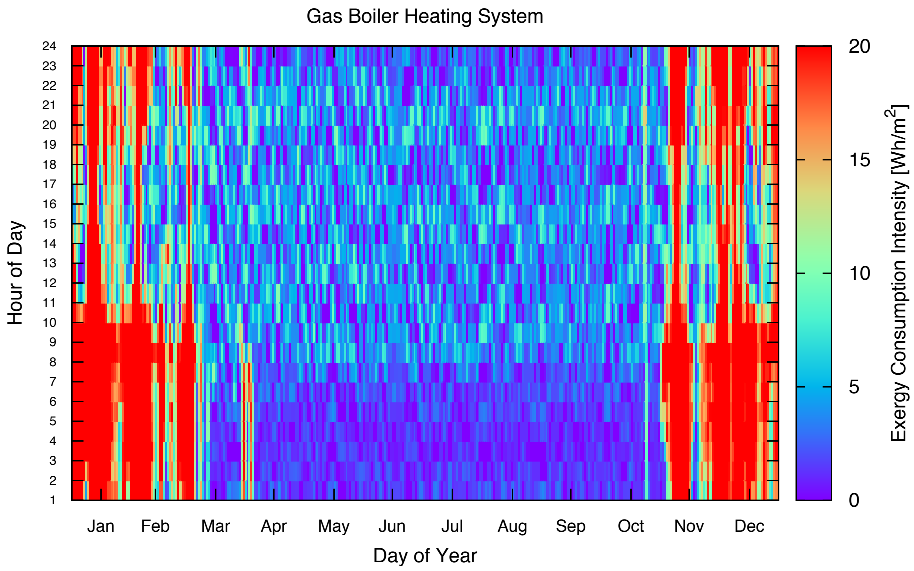
U=0.15 U=0.35 U=0.5



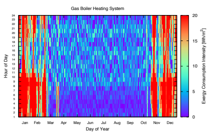
Passive Footprint: Exergy destruction for a single family building in Zürich

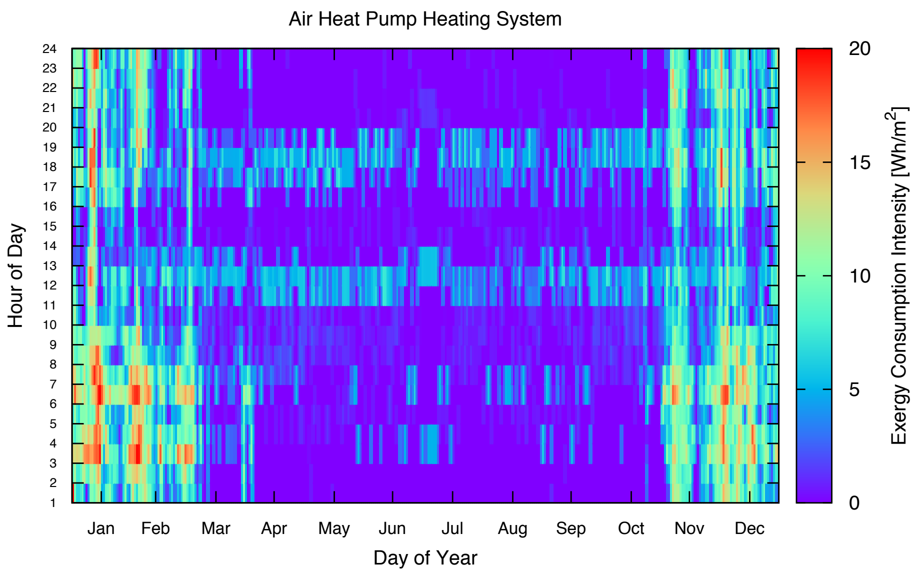


Active Footprint: Exergy consumption for a single family building in Zürich with an U_value = 0,35 & a Gas Boiler Heating System

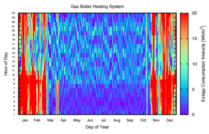


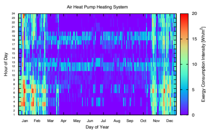
Active Footprint: Exergy consumption for a single family building in Zürich with an U_value = 0,35 & a Air Heat Pump Heating System

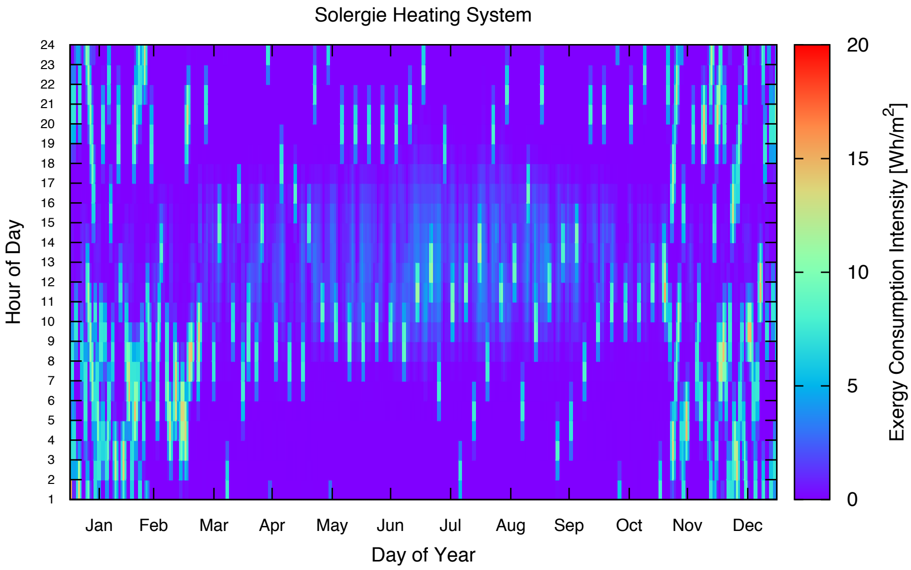




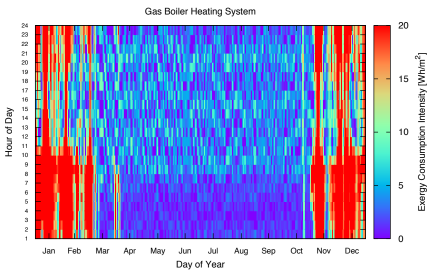
Active Footprint: Exergy consumption for a single family building in Zürich with an U_value = 0,35 & a LowEx (COP>10) Heating System

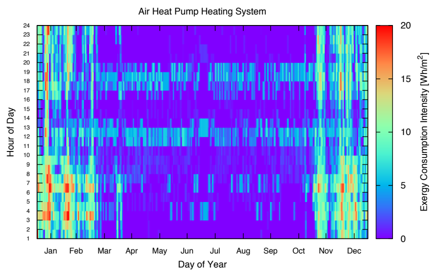


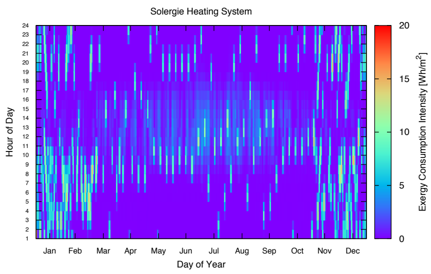


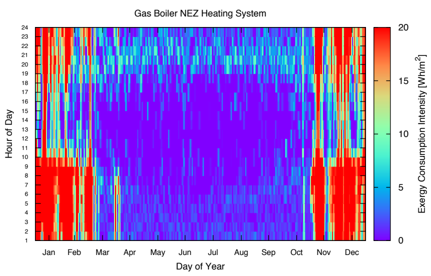


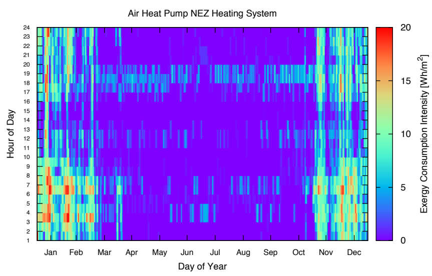
Active Footprint: Exergy consumption for different heating systems without and with PV generation

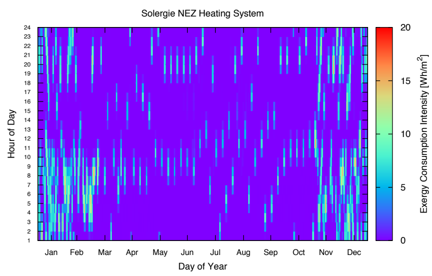












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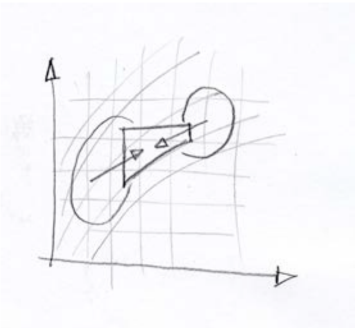
How?



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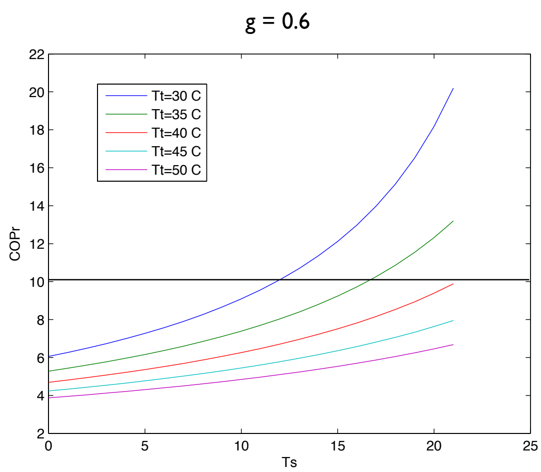
Towards a HP with COP over 10

Variables that affect a HP's COP_R:

- **g: figure of merit, quality factor, isoentropic eff**
- **T_t: target temperature (Low Ex system: 45ºC DHW, 30ºC Heating, 17ºC Cooling)**
- **T_s: supply temperature (heat reservoir available temperature)**

$$COP_r = g\left(\frac{T_t}{|T_t - T_s|}\right)$$

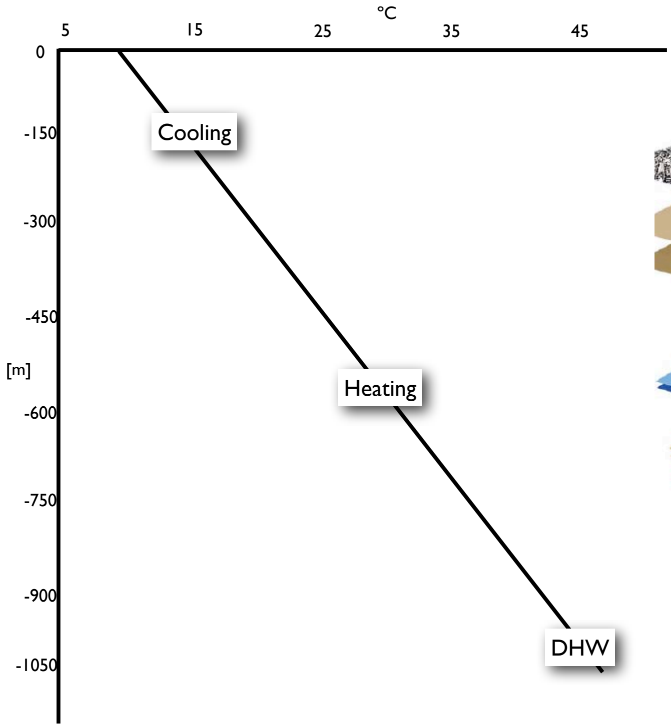
$$g = f(\Delta T)$$

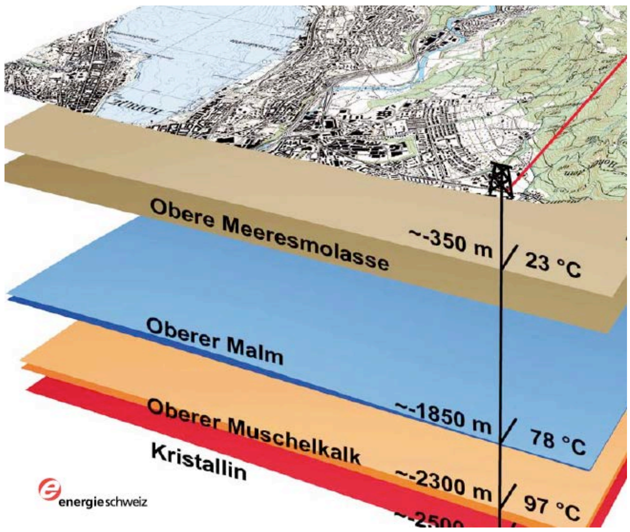


The Importance of the Source Temperature in a HP's COP_R

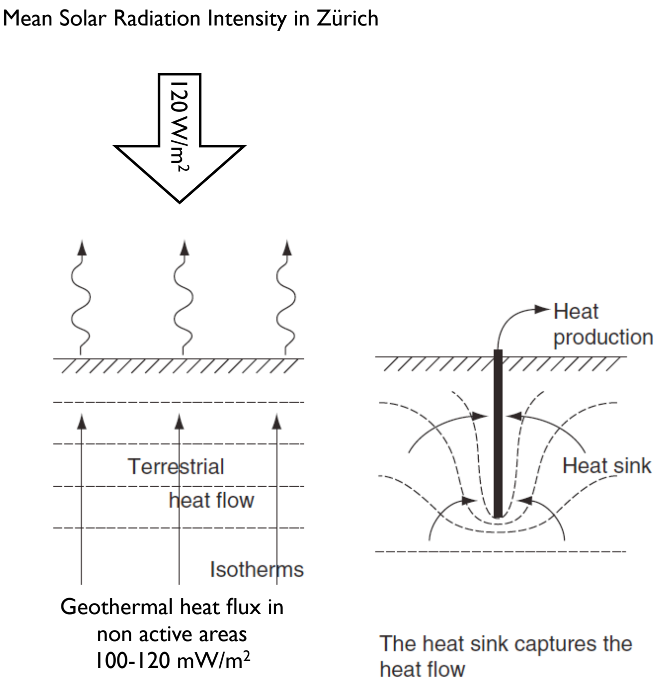
- **The Ideal Case:**
  3 infinite heat sources with the required temperature (17, 30 and 45 °C).
- **Problems:**
- **Source of heat with the required Temp.**
- **Recharging process is needed (natural or artificial).**
- **Solution:**
- **For a place like Zürich, with continental climate and four distinct seasons, a good source of heat is the ground.**

Heat Sources as Function of the Ground Temperature Gradient

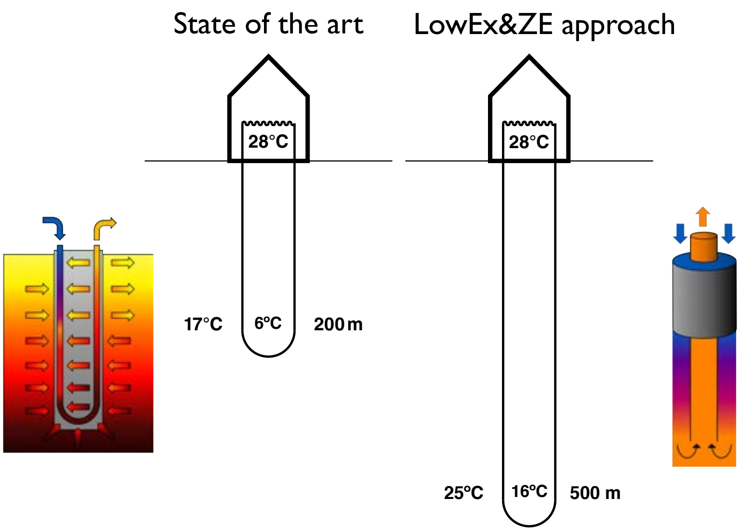




Boreholes Heat Exchangers (BHE)

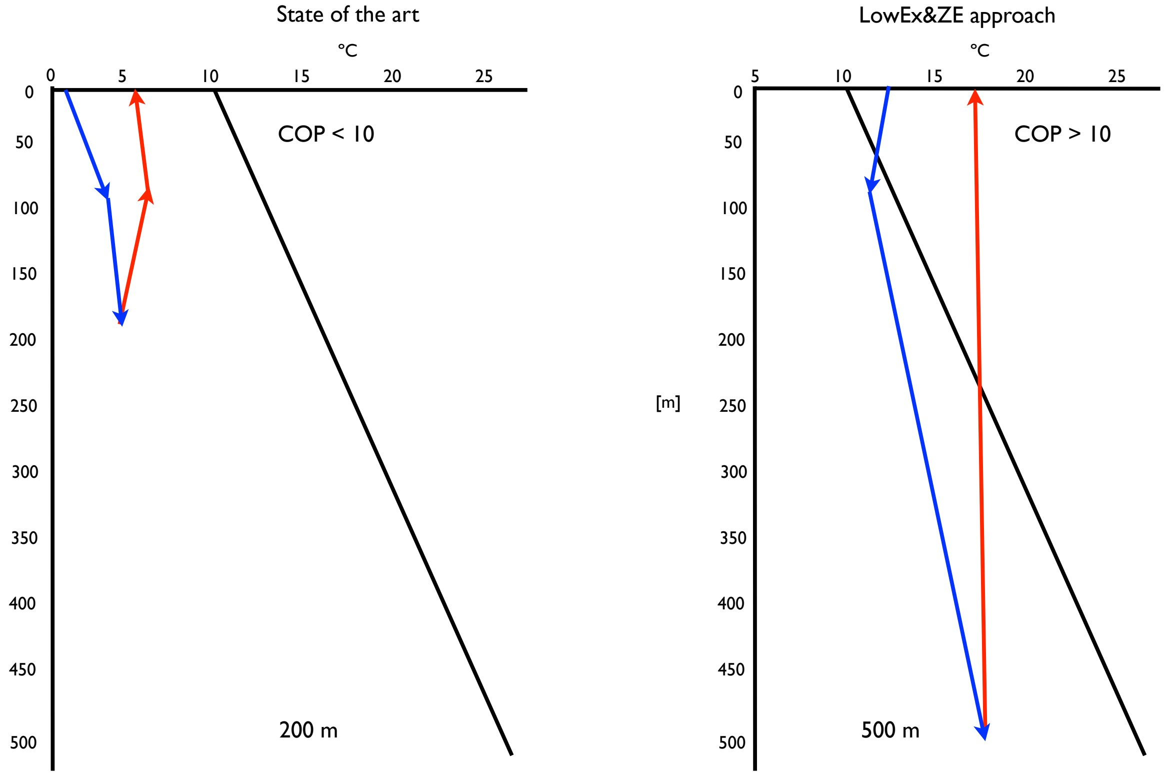


Comparison Between State of the Art and LowEx BHE

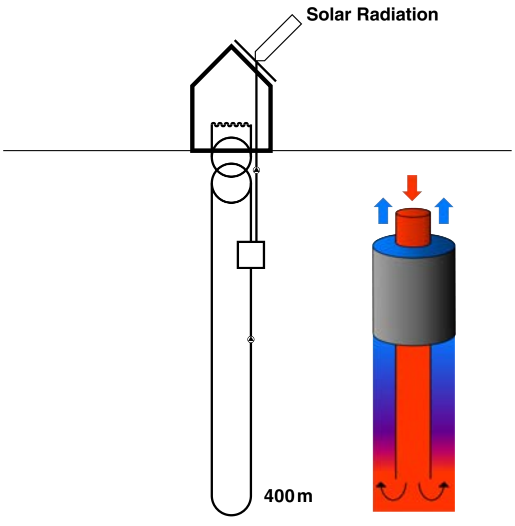


Opportunity

Working Fluid Temperature's Theoretical Behavior



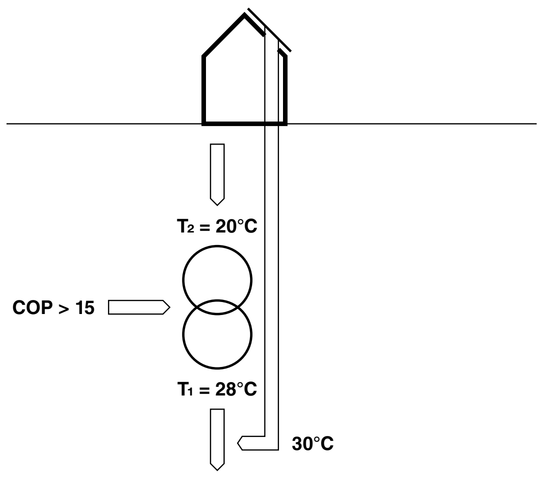
Recharging the Ground

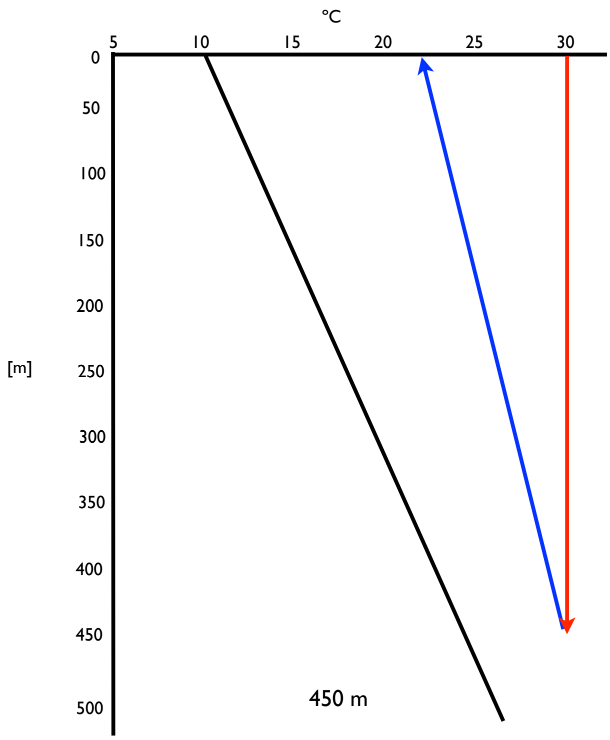


LowEx-System with Hybrid Solar Collectors

Recharging Process

- Active Cooling During Summer





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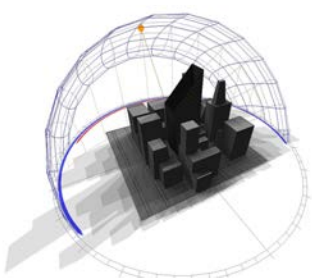
What?



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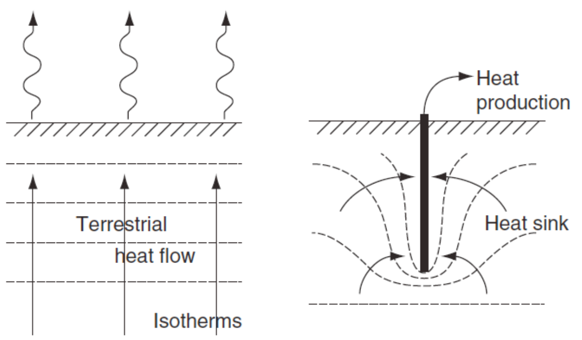
Methodology

- 1 Analytical am numerical BHE models assessment
- 2 Model Validation
- 3 CBHE Optimization
- 4 Development

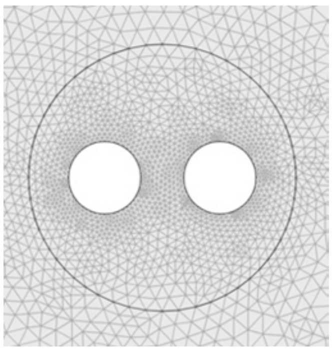
Borehole Modeling

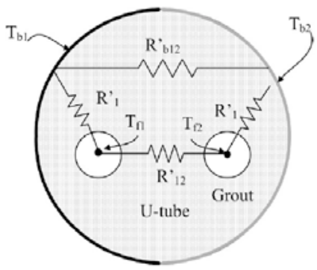
Far Field	Near Field



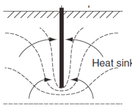
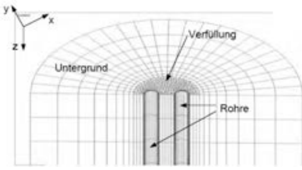
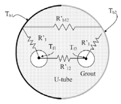
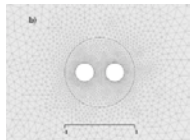
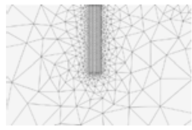
The terrestrial heat flow is lost to the atmosphere

The heat sink captures the heat flow

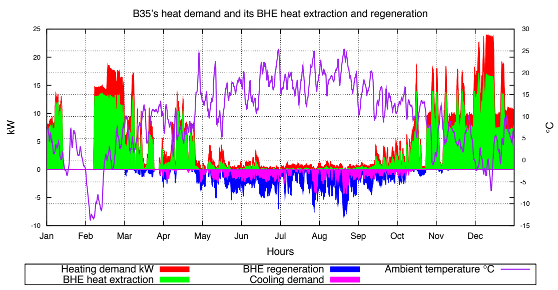


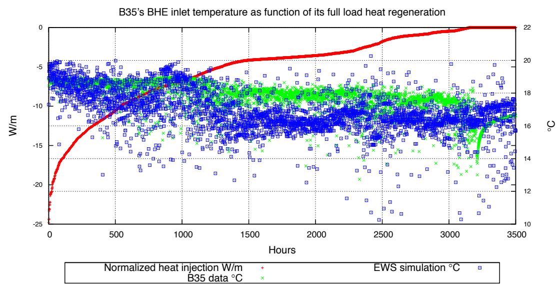


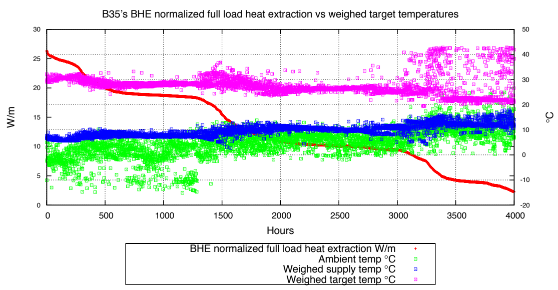
Borehole Models

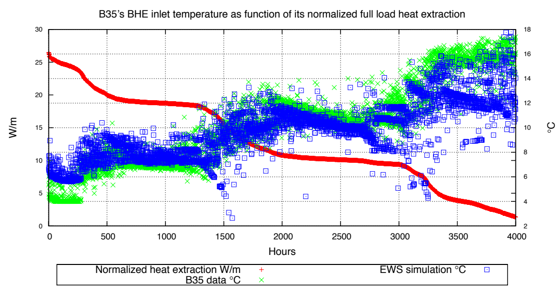
	Analytical Models	Mix Models	Numerical Models
Far Field	ILS, ICS, FLS ⇩ g-functions  $(T_b - T_g)\cdot\frac{2\pi\lambda_g}{\dot{q}} = g\left(\frac{t}{t_s},\frac{r_b}{H}\right)$ ← constant specific heat extraction rate per borehole length	g-functions	FEM  $\rho c_p \frac{dT}{dt} = \nabla(\lambda_g \nabla T)$
Near Field	Resistance models  Short time g-function $(T_b - R_b\dot{q} - T_g)\cdot\frac{2\pi\lambda_g}{\dot{q}} = g\left(\frac{t}{t_s},\frac{r_b}{H}\right)$	FEM	FEM  CFD $\frac{dU}{dt} = q_i'' dA - q_{i+1}'' dA$ 

Analytical Model Validation with B35's yearly data

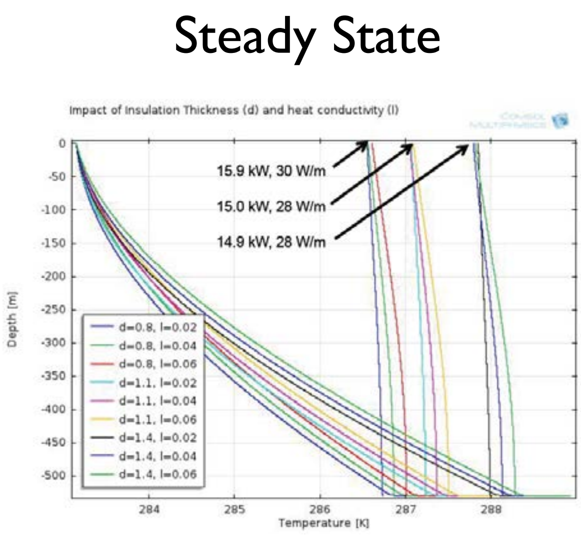


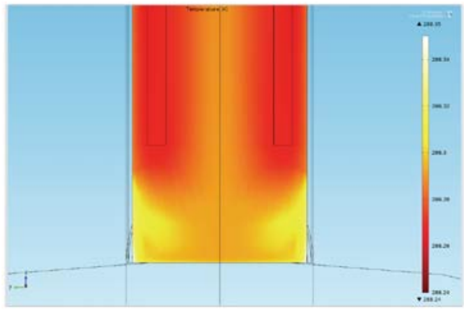


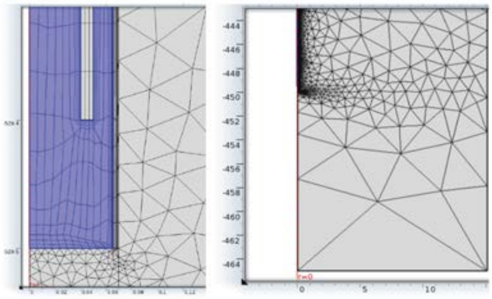




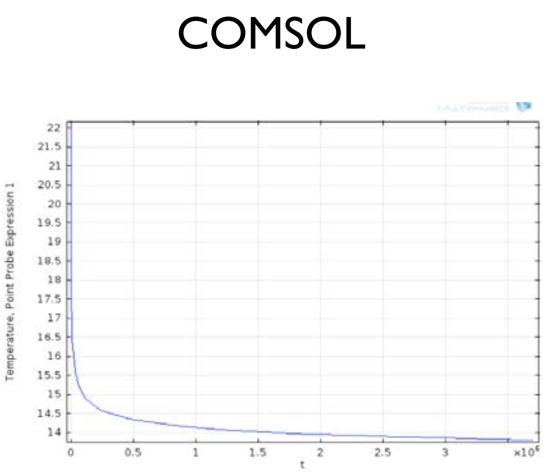
Comparison between Analytical model and CFD

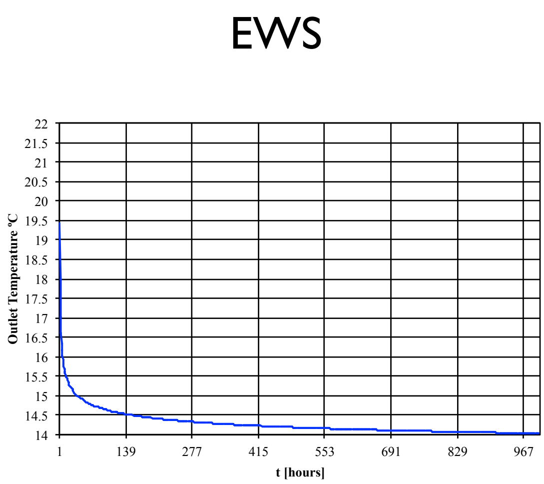




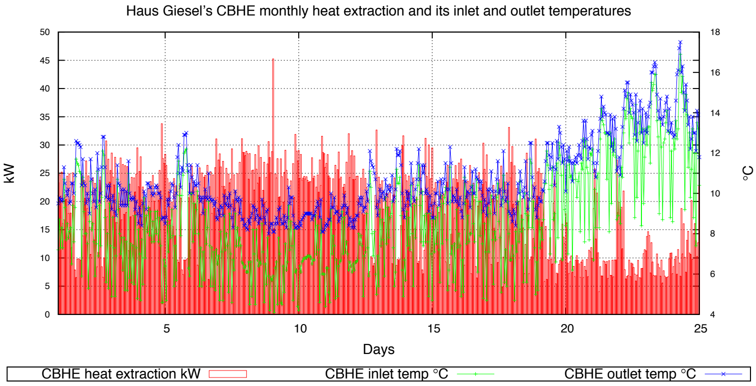


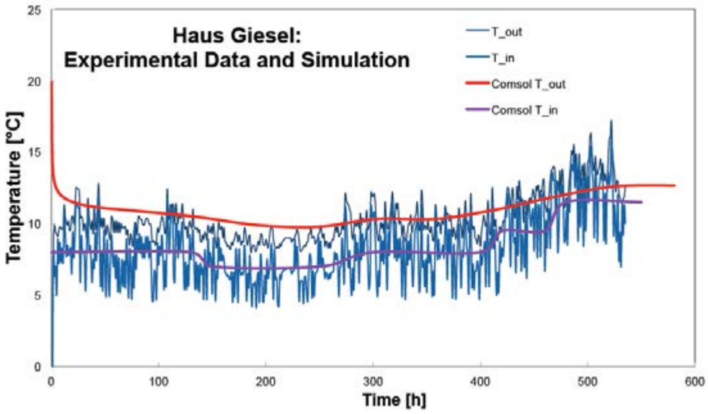
Thermal Response Test



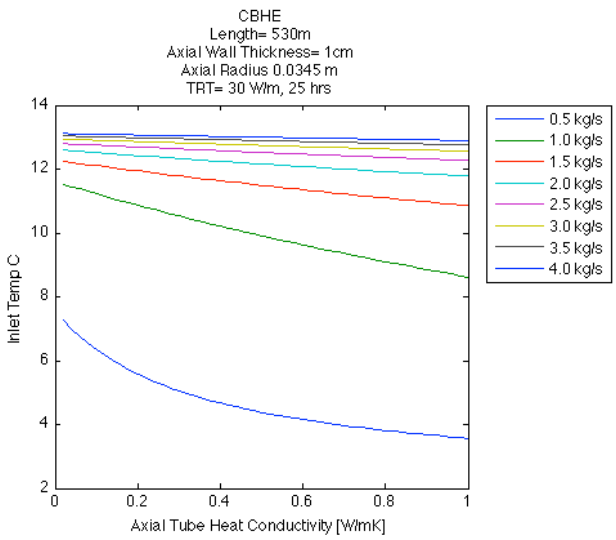


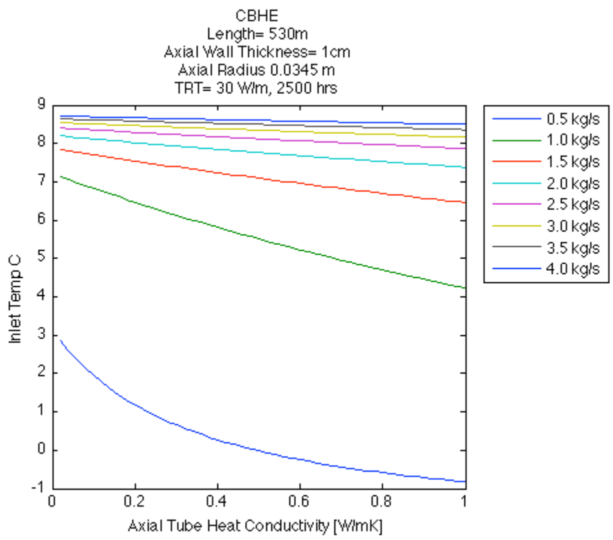
Haus Giesel





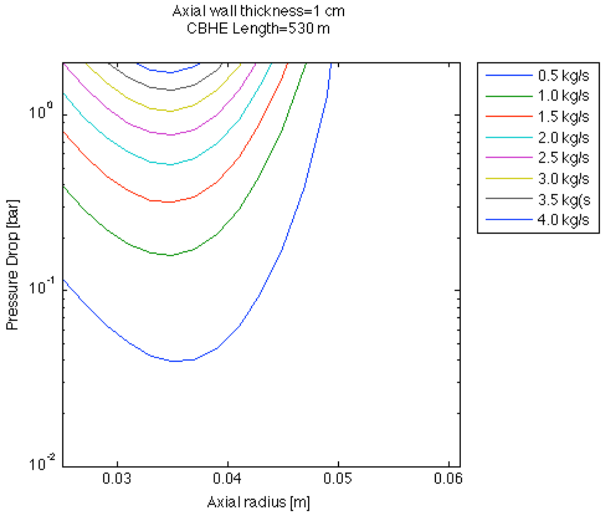
CBHE Optimization

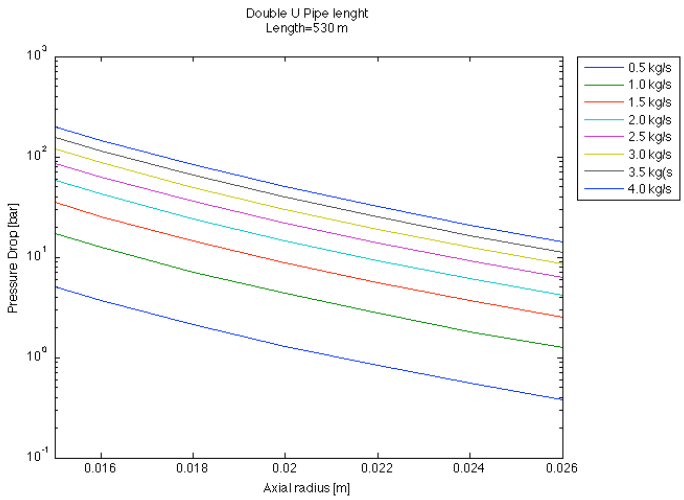




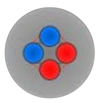
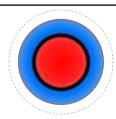
CBHE Optimization

- **Pressure Drop**





Comparison between state of the art and new BHE's design

	State of the art BHE	New design features
Design	· Double U pipes with a diameter of 40x45 mm (k=0.4 W/mK)	· Insulated (k=0.1 W/mK) axial tube (70x10 mm) and a semipermeable annular tube (130x2 mm)
Depth	· Around 200 m length	· 500 m length
Active Perimeter	· 285 mm 	· 400 mm 
Water Storage Capacity	· No short time storage capacity	· Insulated water storage capacity 2000 l (about 30 kWh or 1/2 hour of capacity)
Pressure Drop/m	· ca. 3.9 mbar/m	· ca. 0.4 mbar/m

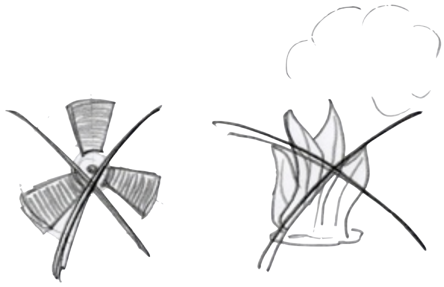
CBHE Development

Drilling and Installation first prototype

CBHE Development

Drilling and Installation first prototype

Which path shall we take?



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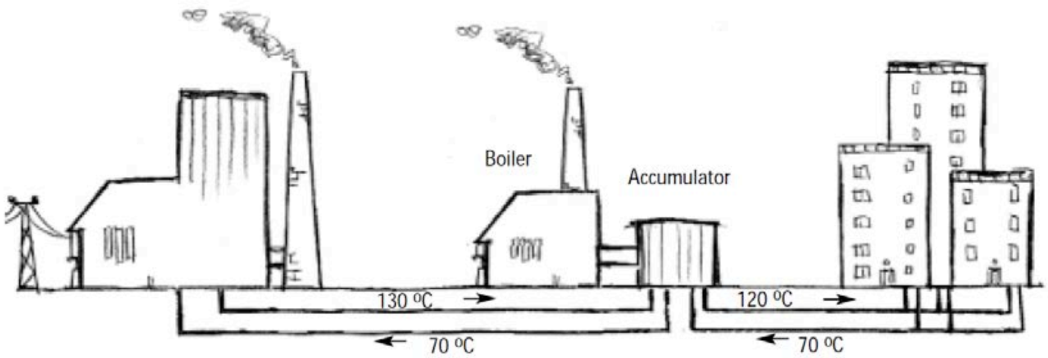
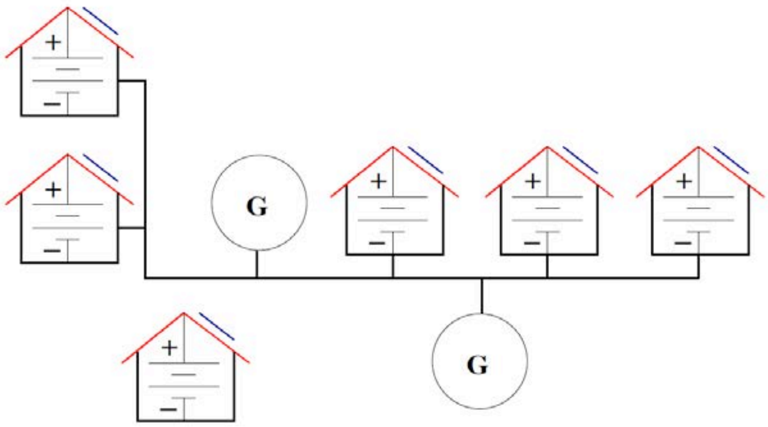
Swiss Federal Institute of Technology Zurich

CHP?

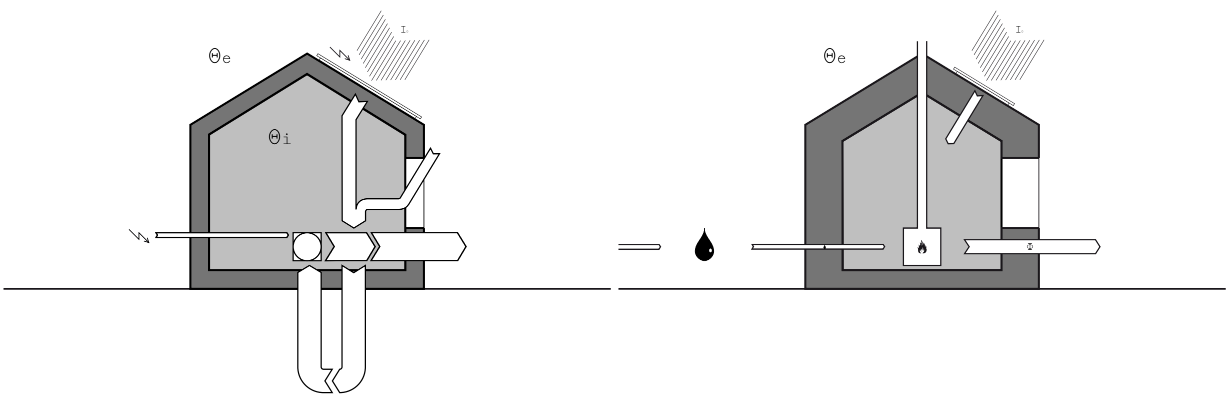


Temperatures in a local district heating system.

Micro grid?



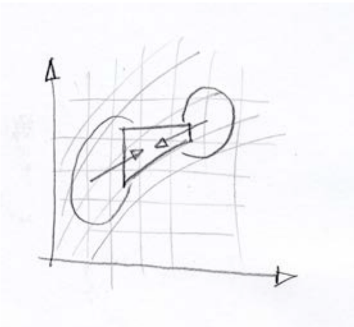
Active or Passive ?



Bu Sy

Chair of Building Systems
Prof. Hansjürg Leibundgut

All of them!



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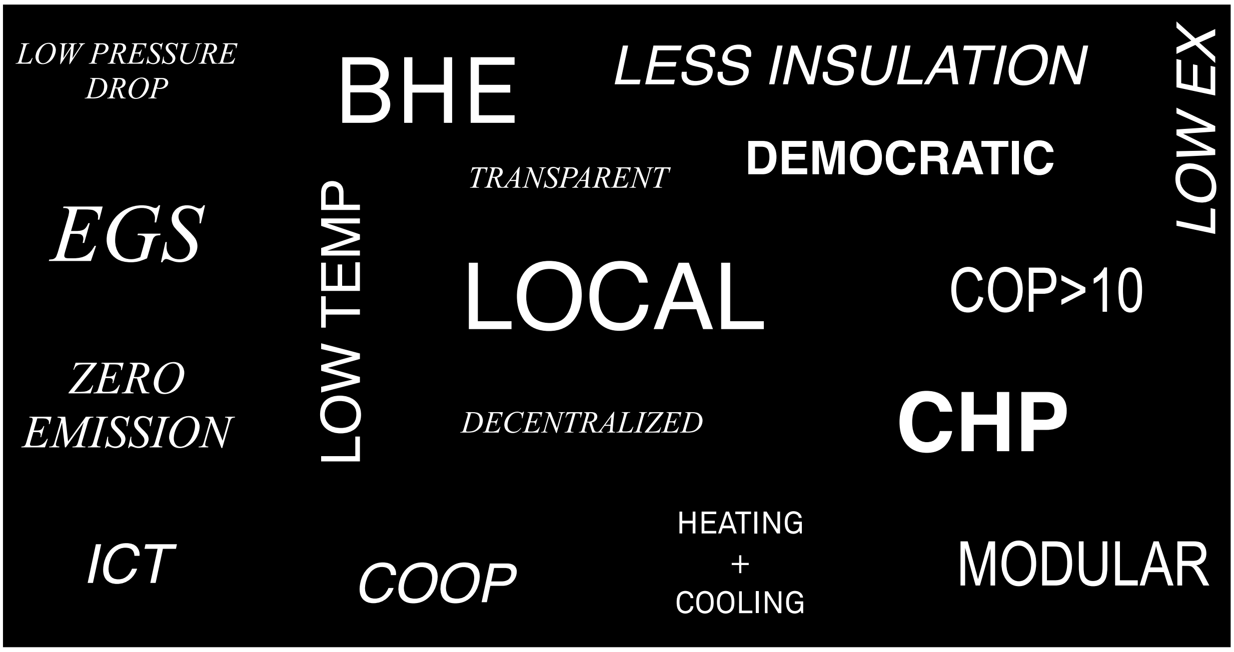
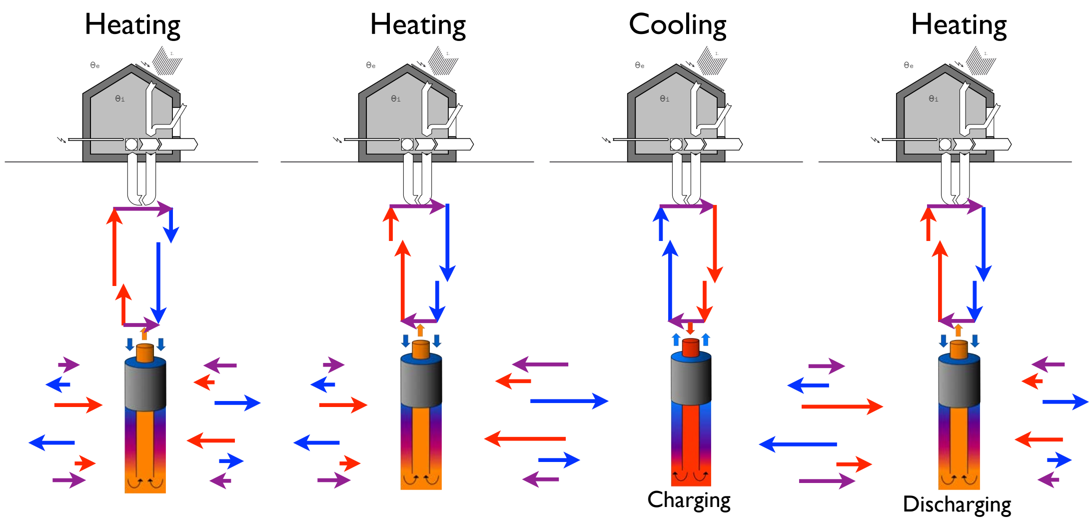
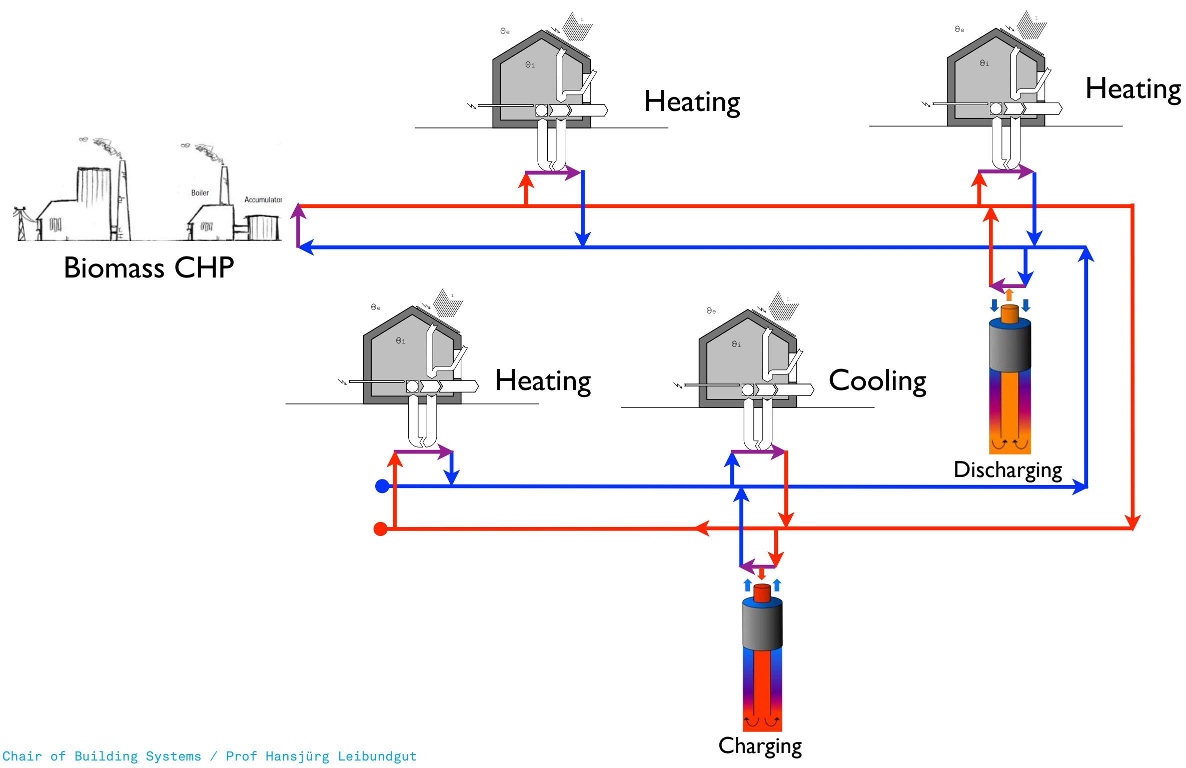
Anergy Network



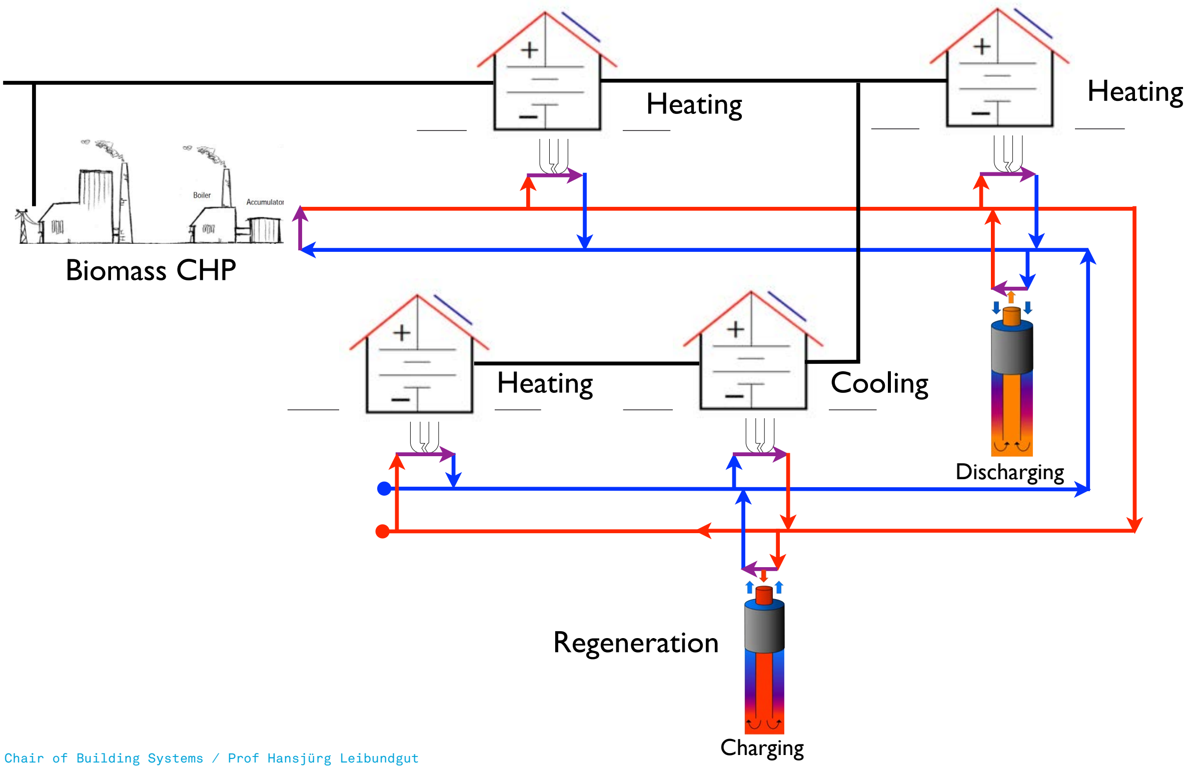
Vertical Anergy Network (Source and Supply)



Horizontal Anergy Network (Source and Supply)



Micro grid with electrical storage (Demand side Management)



A, B, C: Anergy Network

- Supply Temp =16°C
- Return Temp =12°C
- 1kg/s each 12 [W/m² EBF]
- Less insulation
- More diameter
- Less pressure drop, even thought you need about 10 times more water flow
- Same heat loss
- Net heat balance needs to be 0 at the end of the year.
- Local CHP to cover power peaks