ATES contribution to the housing energy balance: a simple assessment methodology

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Problem statement

- The reduction of GHGE goes through a sum of solutions among which the use of WASTE HEAT and RENEWABLE ENERGIES as calorific sources for the residential and tertiary sector:
  → 44% of the total energy consumption in France
  → 24% of total CO_2 emissions *(ADEME, 2006)*
- Focus on massive heat supply via heat networks
- Seasonal misfit between production and consumption calls for seasonal energy storage solutions, among which Aquifer Thermal Energy Storage (ATES) in untapped or non-strategic aquifers

Objective

- A quantitative methodology to size and assess a heat storage project as a function of:

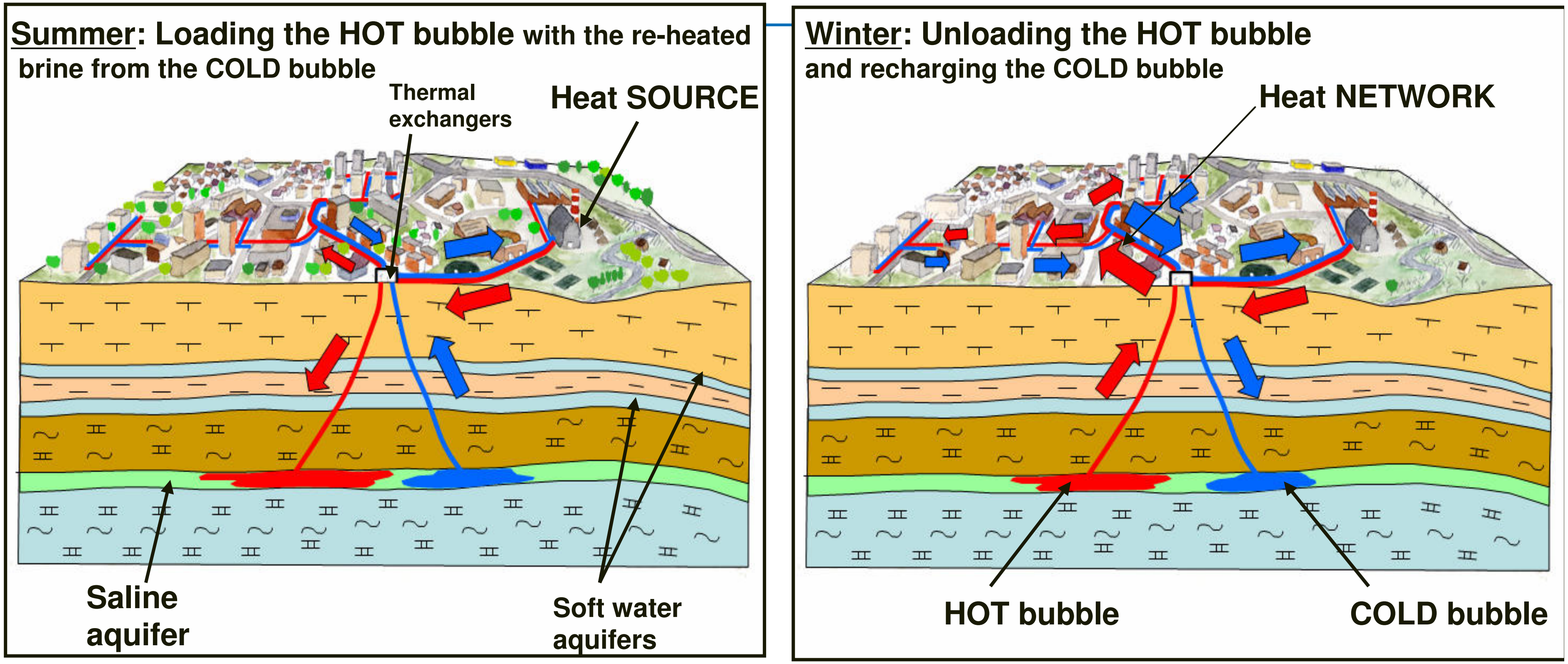
  - the heat production and consumption characteristics

  and

  - the aquifer performance.

- Point out determinant transfer mechanisms and parameters for the purpose of aquifer selection or ATES monitoring.

The DOUBLET technique for AQUIFER Heat Storage



from Ungerer and Le Bel, Revue des Ingénieurs des Mines, Vol. 423, Nov.-Déc. 2006

Outline

- **Characterization of heat consumption and heat sources**

  → STOrage Requirement

- **Sizing a heat storage project:**
  - **Matching Production and Consumption**

- **Factors influencing the Recovery efficiency of an ATES**
  - ***Reservoir heat losses***
  - ***Other heat losses***

- **Conclusion: guidelines for designing an ATES project**

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- **Characterization of heat consumption and heat sources**

  → ***Seasonality criteria (PSF, CSF)***

  → ***STOrage Requirement***

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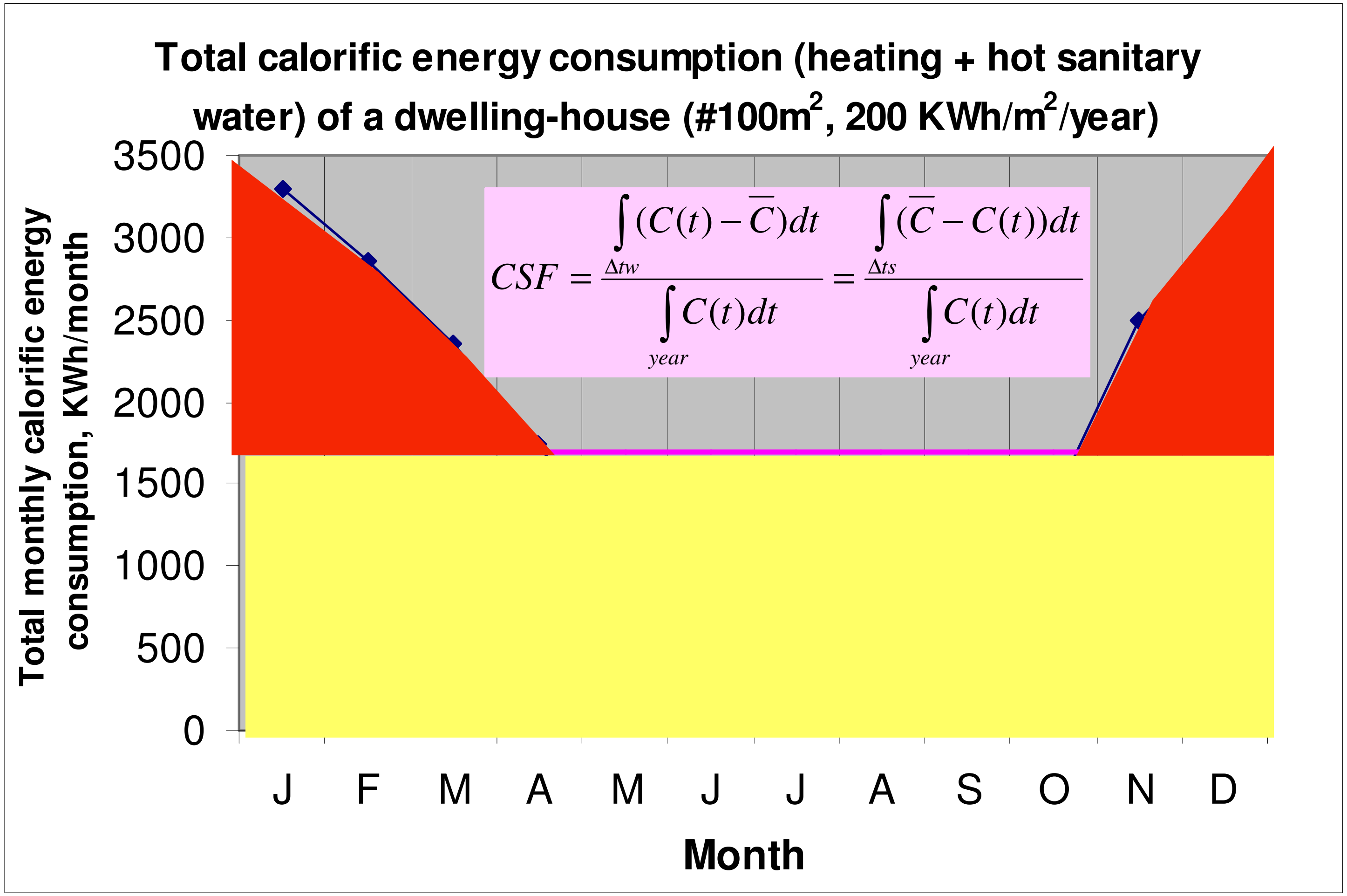
Characterization of heat consumption



(Consumption trend, from INES website)

Consumption Seasonality Factor (CSF)

CSF=

Characterization of heat sources.

Waste heat sources: massive (centralized), <u>constant-power</u>

• urban incineration plants

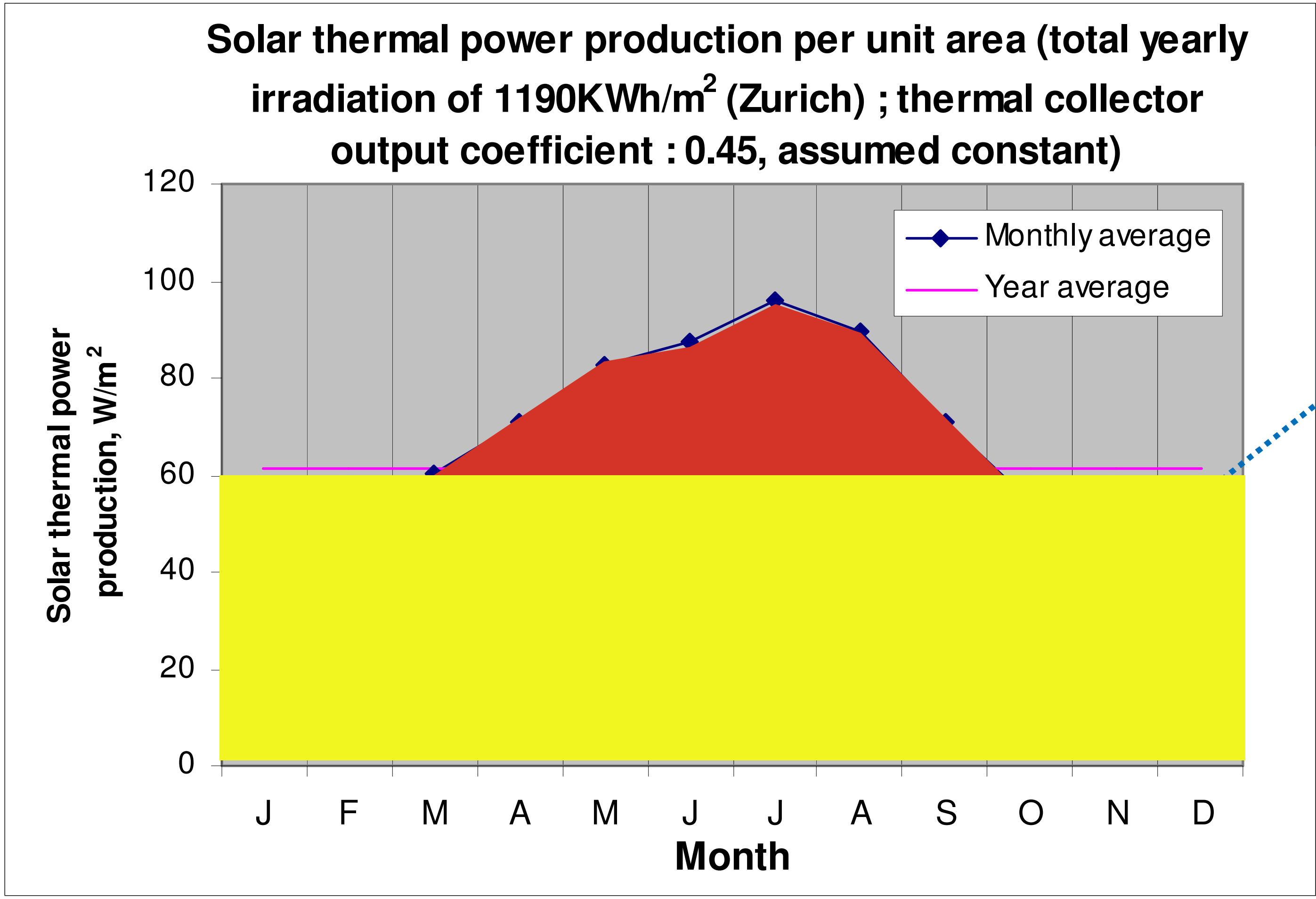
• energy-intensive plants (raw materials)

Renewable energy sources: <u>highly-variable</u> power

. solar thermal fields: out of phase with respect to consumption

➔ ATES (and geothermal energy) compensates the lack of flexibility of previous sources

Characterization of heat production – Solar thermal source

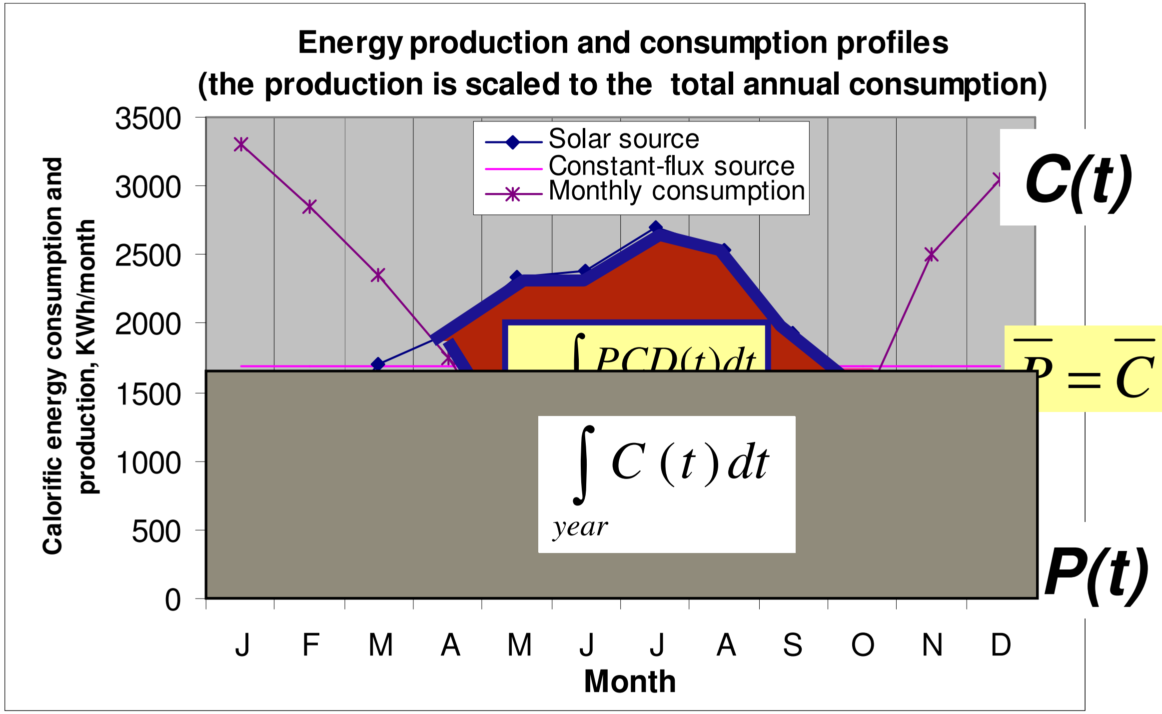


Production Seasonality Factor (PSF)

PSF=


The heat storage requirement indicator: STOR

$$STOR = \frac{\int_{t,PCD(t)>0} PCD(t)dt}{\int_{year} C(t)dt}$$



	CSF	PSF	CSF+PSF	STOR
CONSTANT-FLUX source	28.2%	0%	28.2%	28.2%
SOLAR source	28.2%	17.9%	46.1%	44.8%

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Sizing the ATES project

A heat balance between:

- **Recovered (supplied) heat from the ATES (winter unloading)**

and

- **Winter heat needs in excess to winter production**

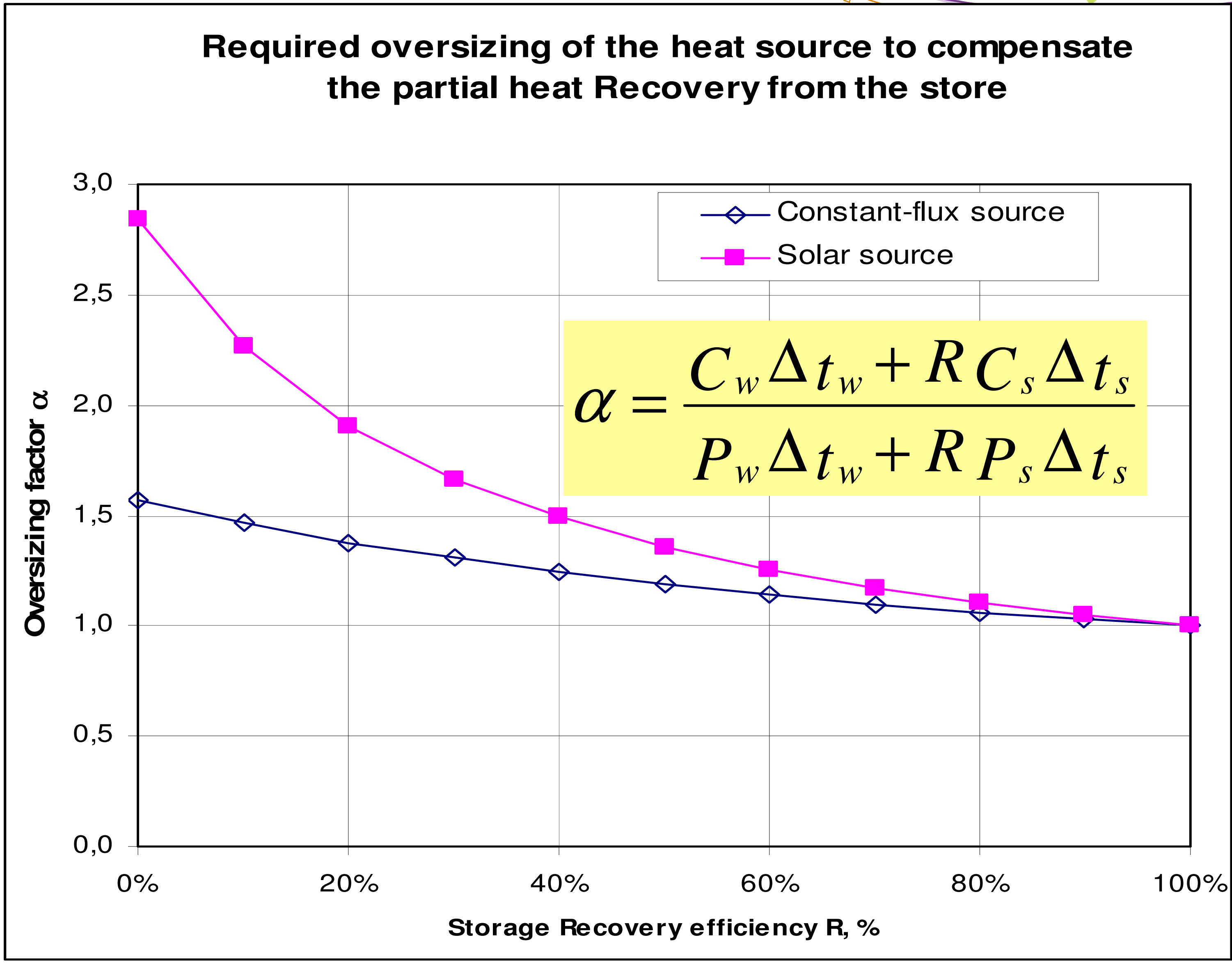
$$R \int_{t,\alpha P(t)>C(t)} (\alpha P(t) - C(t))dt = \int_{t,\alpha P(t)<C(t)} (C(t) - \alpha P(t))dt$$

P(t) and C(t): **production and consumption powers scaled with respect to one another on a yearly basis**

R **= *Recovery* Efficiency: a Determinant Sizing Parameter**

α **= the Source Oversizing Factor**

(accounts for all Heat Losses involved in the Storage process: R<1)


Required oversizing of the heat source to compensate the partial heat Recovery from the store
Constant-flux source
Solar source
$\alpha = \frac{C_w \Delta t_w + R C_s \Delta t_s}{P_w \Delta t_w + R P_s \Delta t_s}$
Oversizing factor α
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0%
20%
40%
60%
80%
100%
Storage Recovery efficiency R, %

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  - ***Reservoir heat losses***
    - ***Convective transfers: hydrodynamism, segregation/convection***
    - ***Conduction:***
      - *local-scale thermal equilibrium*
      - *losses across upper and lower boundaries*
      - *impact of internal aquifer heterogeneities*
    - ***Conclusion for the selection and assessment of an aquifer.***
  - ***Other heat losses (surface-aquifer transport)***

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Factors influencing the ATES recovery efficiency
Reservoir heat losses

- ***Convective*** **mechanisms of heat dispersion**

  - **natural hydro-dynanism**
    - **decreases with increasing depth**
  - **density and viscosity differences between injected and in-situ fluids**

    → **thermal segregation and/or fluid flow instabilities *(hindered by heterogeneities)***
  - **reservoir heterogeneities in terms of permeability**

    → **strong interaction with CONDUCTION**

Factors influencing the ATES recovery efficiency
Reservoir heat losses

- ***MULTI-SCALE conduction*** **phenomena**

  - **at a local scale: thermostatic equilibrium between the injected fluid and the rock grains.**
  - **at the reservoir scale: heat transfers across reservoir bottom and top boundaries**
  - **at an intermediate scale: *depending on the reservoir internal structure,* heat transfers between the permeable reservoir zones and embedded impermeable bodies or layers**

Local-scale thermostatic equilibrium: Hydraulic and Thermal bubble radius

- **Material balance:** *injected volume determines a swept area ("hydraulic bubble")*

$$R_h = \sqrt{\frac{V_{inj}}{\phi.\pi.H}}$$

- **Energy balance:** *thermostatic equilibrium between injected hot fluid and solid rock determines a smaller heated area ("thermal bubble")*

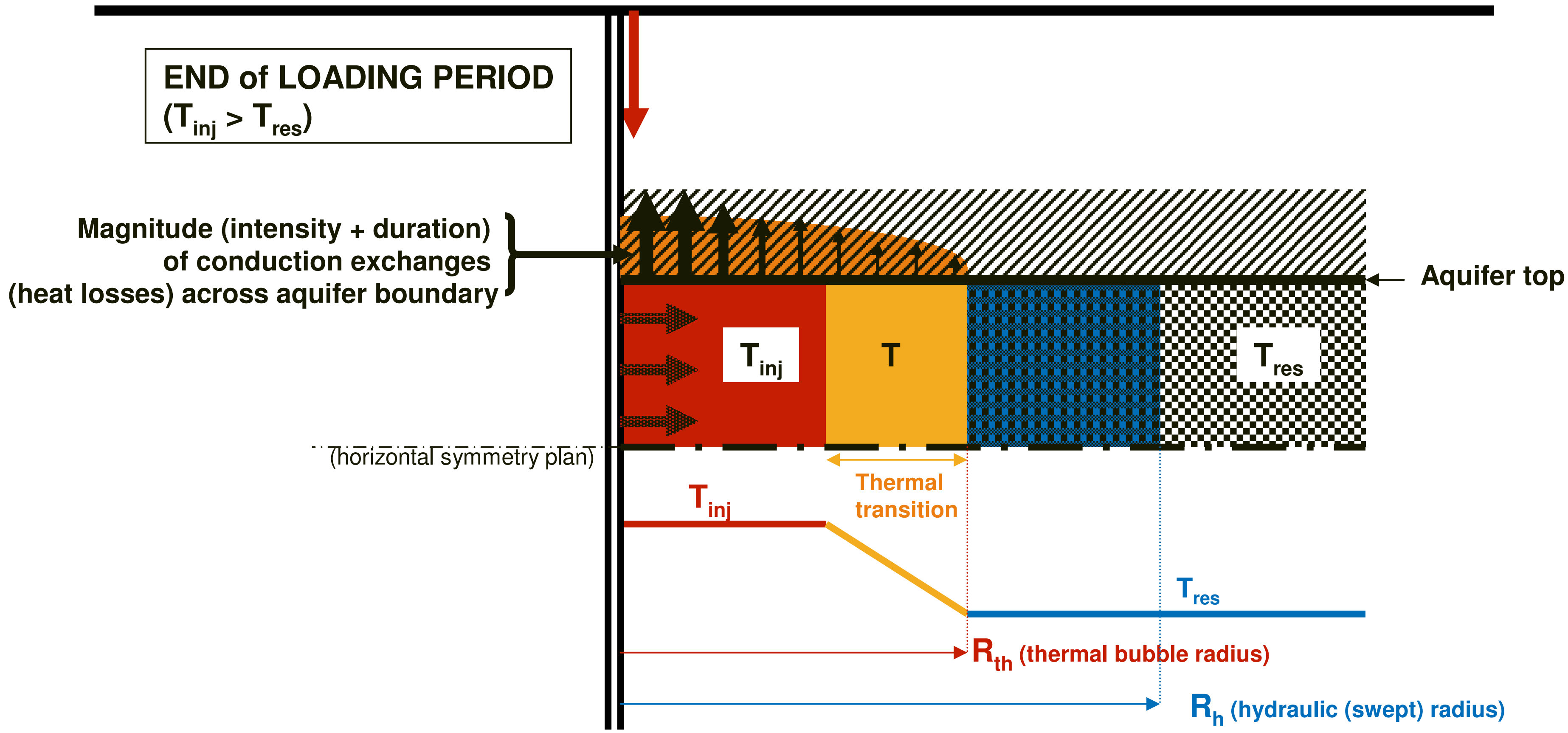
$$R_{th} = R_h \cdot \sqrt{\frac{\phi.\rho_w \cdot c_{pw}}{\phi.\rho_w \cdot c_{pw} + (1-\phi).\rho_s \cdot c_{ps}}}$$

Order of magnitude of Thermal Bubble Radius (carbonate ρ_s & c_{ps}):

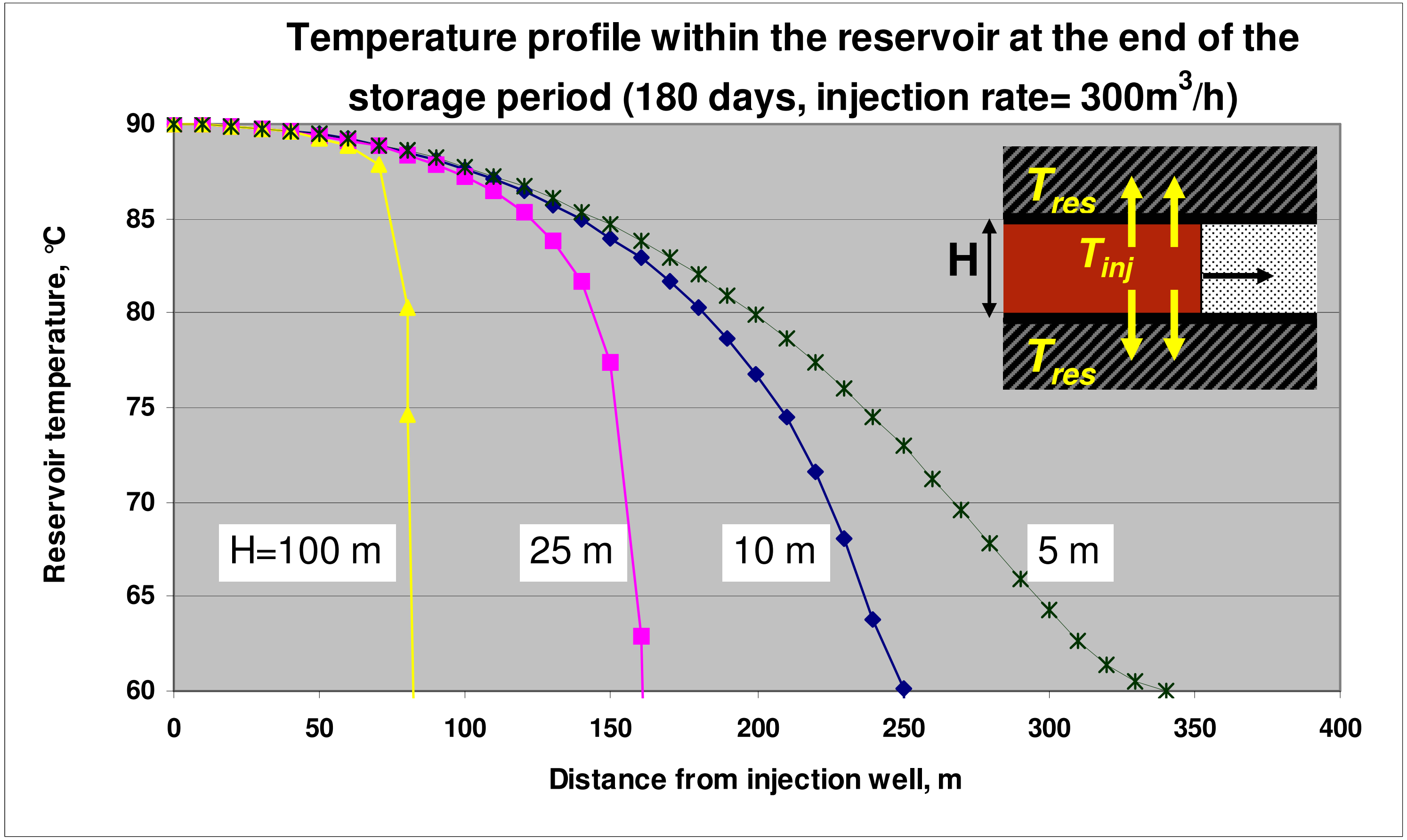
$\phi = 20\%$	→	$R_{th} = 0.56\, R_h$
$5\% < \phi < 40\%$	→	$0.3 R_h < R_{th} < 0.75 R_h$

Innovation Energie Environnement

First Heat Loading of a homogeneous aquifer

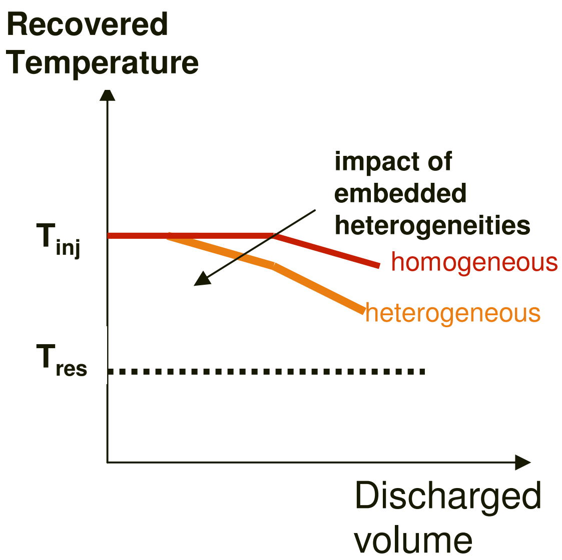


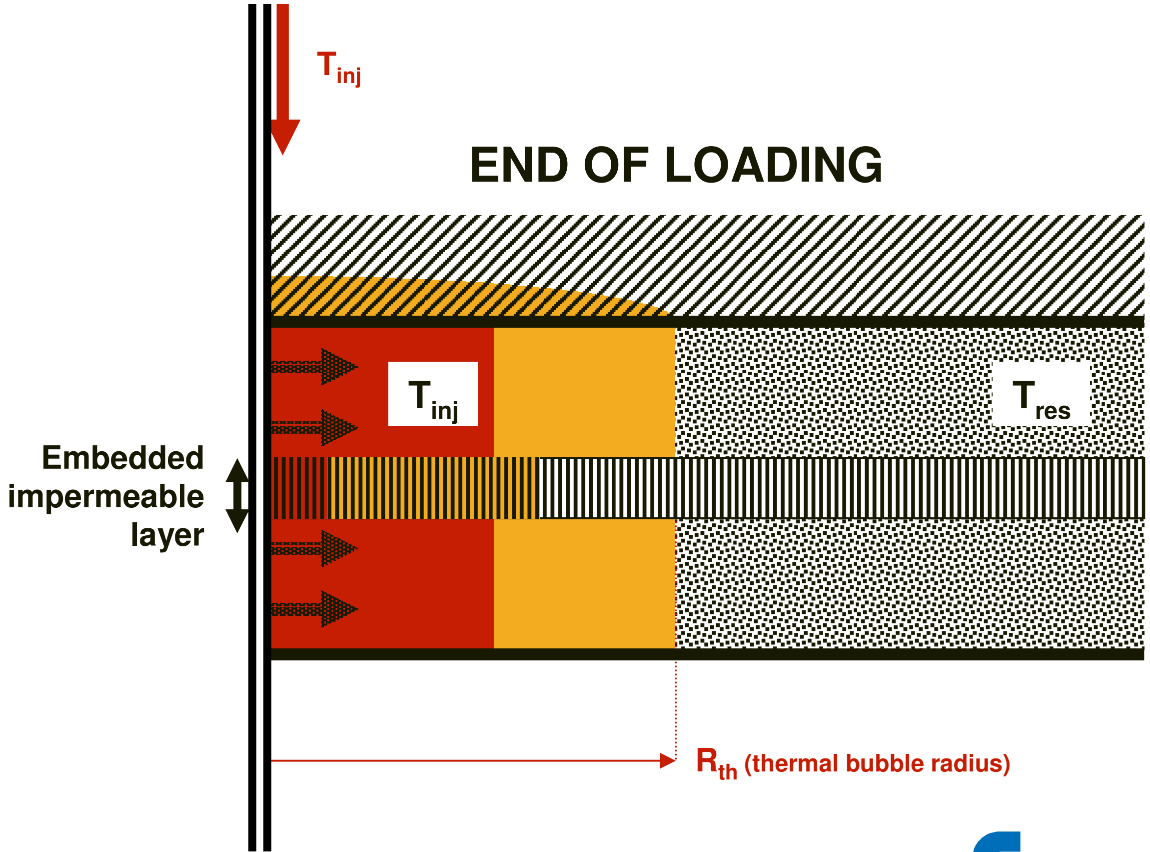
Impact of conduction across aquifer top and bottom boundaries on the heat store temperature profile



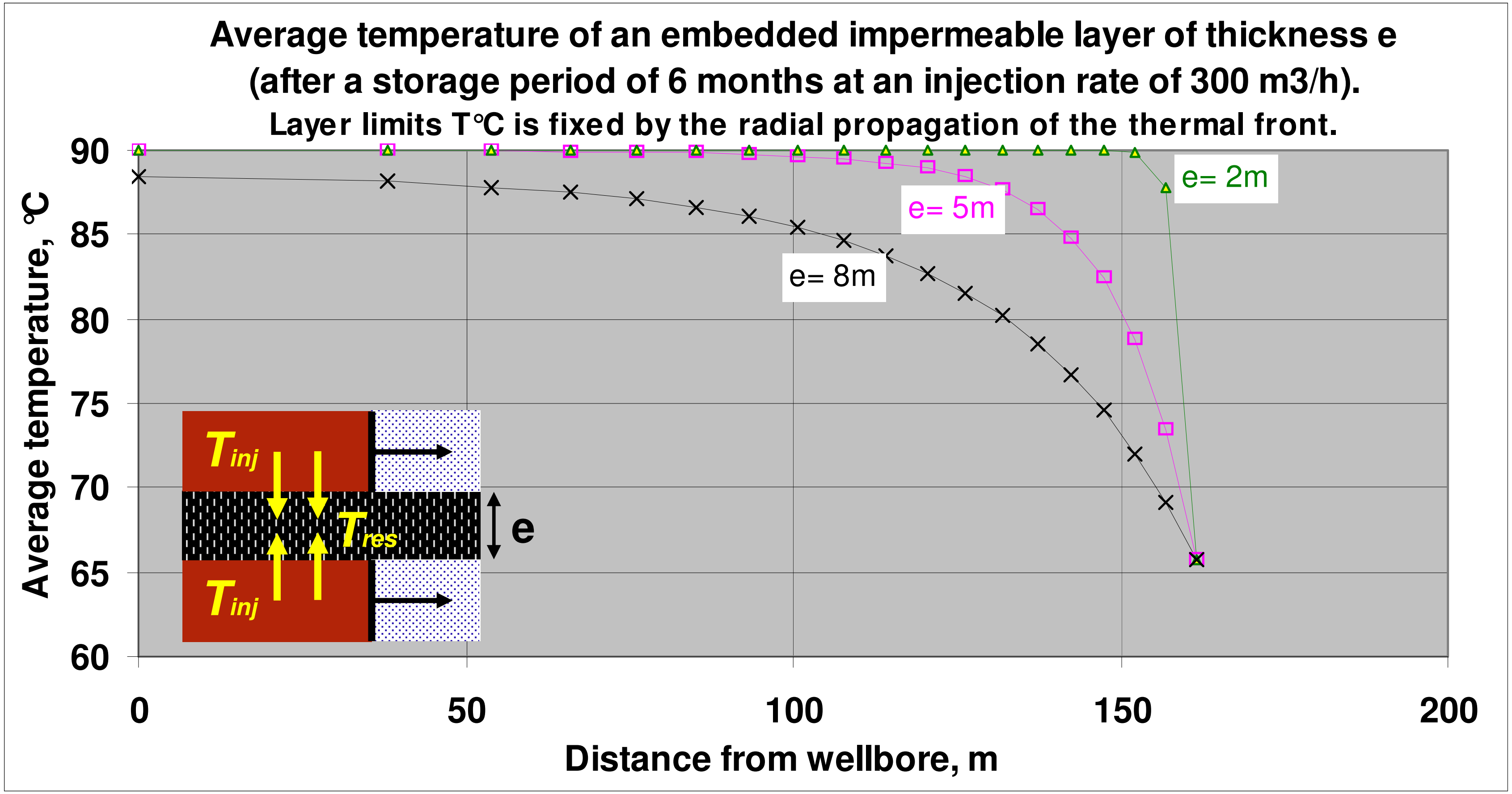
(Analytic solutions, from Lauwerier's Eqn)

First heat loading of a HETEROGENEOUS aquifer





Thermal behaviour of embedded non-conductive heterogeneities



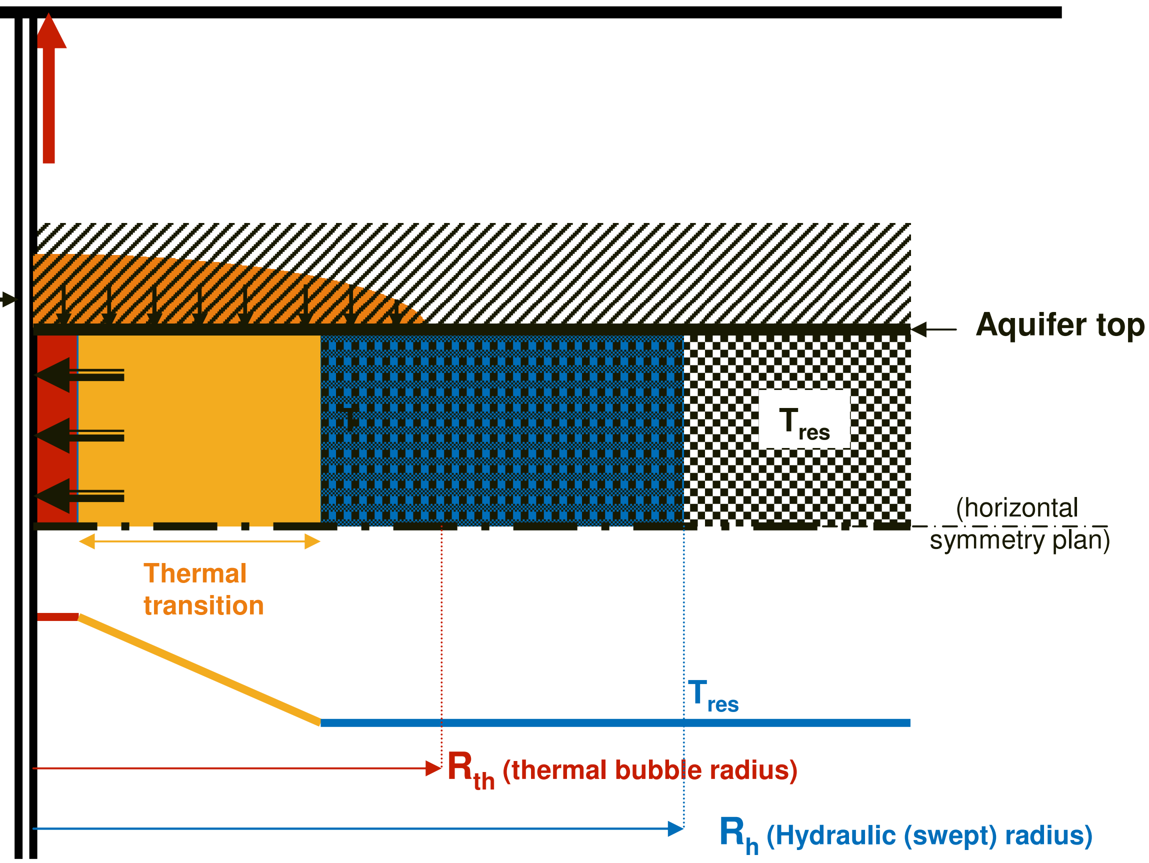
(Analytic approximate solution, from Lim & Aziz / Carlslaw & Jaeger)

Unloading Heat from a homogeneous aquifer

Limited conduction exchanges across aquifer **boundaries** (recovery of lost heat)

N cycles

A heated environment for the thermal bubble
➔ *a low driving ΔT for conduction*



Reservoir heat losses: criteria for the selection and assessment of an aquifer.

- a sufficient overall thickness of the aquifer to mimimize energy losses across its upper and lower boundaries

- absence of thick (metric-plus) heterogeneities (impermeable bodies or layers) within the reservoir, in order to preserve a good thermal quality of the unloaded fluid

➔ however, the presence of thin/small embedded heterogeneities may be considered as a favourable criterion:
  - compact thermal bubble
  - hindering of convection phenomena

Factors influencing the ATES recovery efficiency
Surface-ATES transport losses

- ***Involved parameters:*** *flow rate, well/pipes length, transfer coefficient (insulation), temperature contrast*
- ***For a given project, the main variable is flow rate***
- ***Flow rate = a parameter depending on***
  - *The initial (intrinsic) reservoir quality (aquifer permeability – height product)*
  - *Equipment /material + a monitoring/surveillance program preventing risks of corrosion, precipitates and solid particles susceptible to clog the near-wellbore aquifer formation*

- ***Well productivity/injectivity drop has a dramatic impact on heat losses and economic viability***

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- Characterization of heat consumption and heat sources

  → *Seasonality criteria (PSF, CSF), STOrage Requirement*
- Sizing a heat storage project:
  - Matching Production and Consumption: dependence on seasonality criteria and the heat Recovery
- Factors influencing the Recovery efficiency of an ATES
  - *Reservoir heat losses*
    - ***Convective transfers:*** ***hydrodynamism, segregation/convection***
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Tentative Guidelines for designing an ATES project (1)

- ***Confronting heat consumption and production characteristics to quantify the heat STOrage Requirement***

- ***Setting up a storage project***

  - ***A heat store <u>size</u> estimated from the STOR <u>and</u> the expected recovery performance of the ATES***

  - ***A power <u>deliverability</u> implying certain number of doublets depending on the aquifer productivity/injectivity (K.H)***

Tentative Guidelines for designing an ATES project (2)

- ***Best Aquifer candidates for a <u>high recovery and thermal quality of the stored heat</u>:***
  - ***thickness & internal heterogeneity structure leading to compact thermal bubbles (low R_{th}/H) in thermostatic equilibrium***
  - ***good intrinsic deliverability (K.H)***

- ***Preserving the heat deliverability is also essential for a long-term ATES project: dedicated equipment & monitoring programme.***

ATES opportunities in Deep Saline Aquifers

- **Less constraints regarding the possibility to exploit saline non-potable aquifers than low-depth fresh water resources**

BUT

- **Higher capital expenditure: drastic increase of well costs with depth**

➔ Best aquifer candidates to be found at the lowest allowable depth (assuming favourable reservoir criteria are met)