Pompes à chaleur dans le résidentiel collectif:
Du retour d'expérience à la généralisation par simulation

Carolina Fraga

carolina.fraga@unige.ch

Cycle de formation
énergie-environnement

11 mai 2017

Groupe Systèmes Énergétiques
Département F.-A. Forel des Sciences de l'Environnement et de l'Eau
Institut des Sciences de l'Environnement
FACULTÉ DES SCIENCES

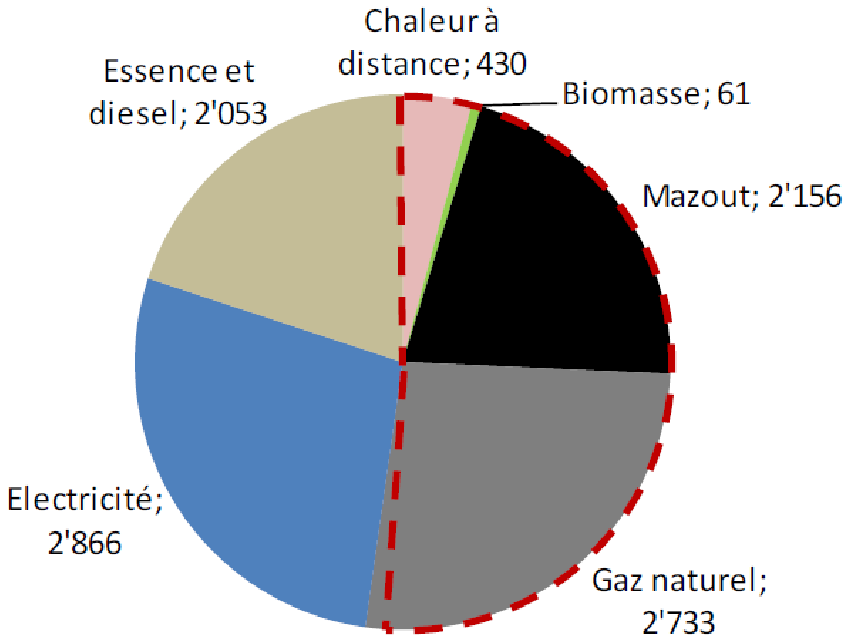
UNIVERSITÉ DE GENÈVE

Pourquoi?

Pompes à chaleur dans le résidentiel collectif:

Du retour d'expérience à la généralisation par simulation

Consommation d'énergie finale dans le canton GE en 2014 (GWh/an)



Besoins de chaleur (2014, in GWh/yr)

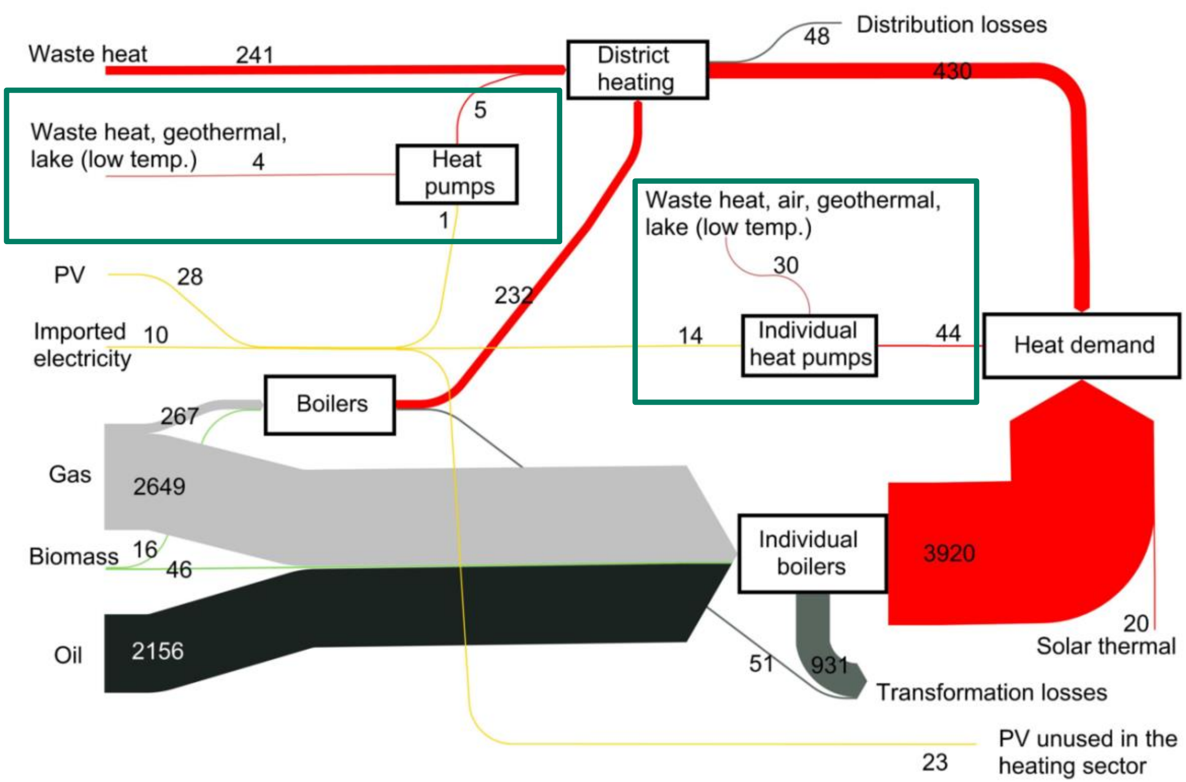
Objectifs du canton pour ce secteur à l'horizon 2035:
moins 18% des besoins
Plus 34% de renouvelables

Source: Quiquerez, 2017

Pourquoi?

Pompes à chaleur dans le résidentiel collectif: Du retour d'expérience à la généralisation par simulation

Approvisionnement chaleur des bâtiments du canton en 2014 (GWh/an)



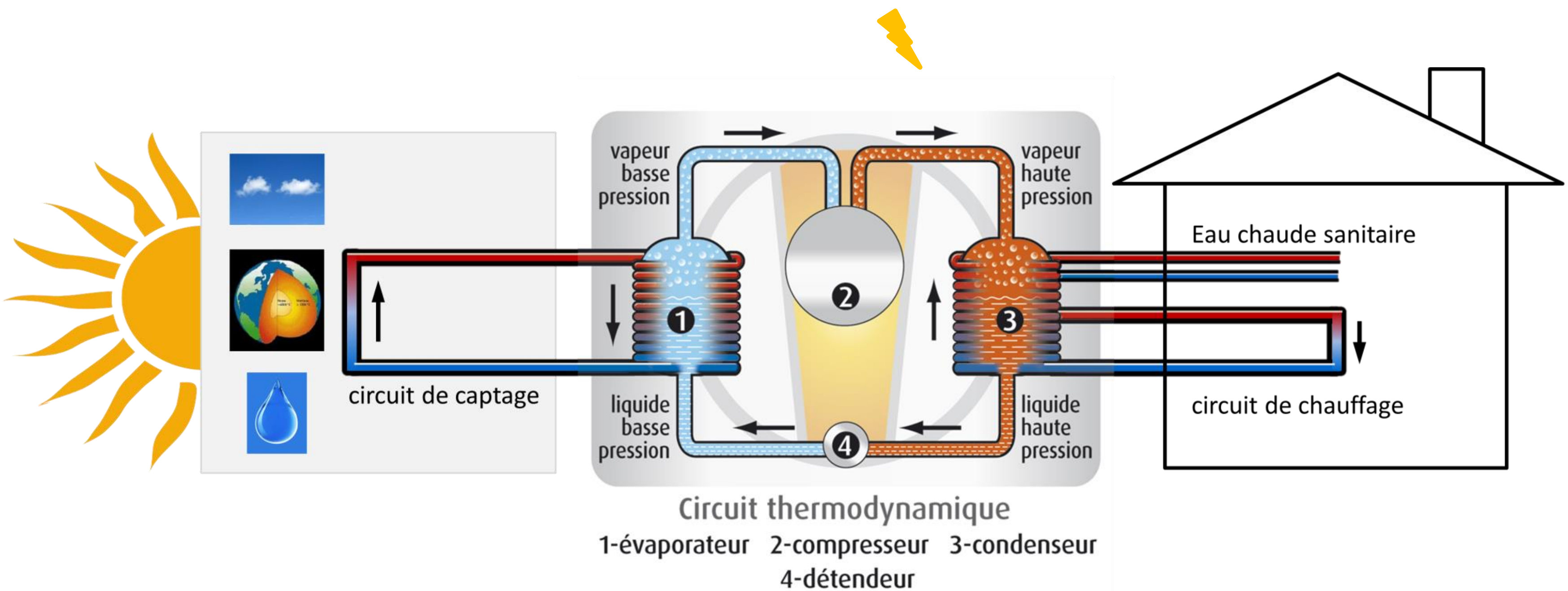
Pompes à chaleur

Energie renouvelable (ou chaleur fatale)

Source: Quiquerez, 2017

Comment?

Pompes à chaleur → Energie renouvelable (ou chaleur fatale)

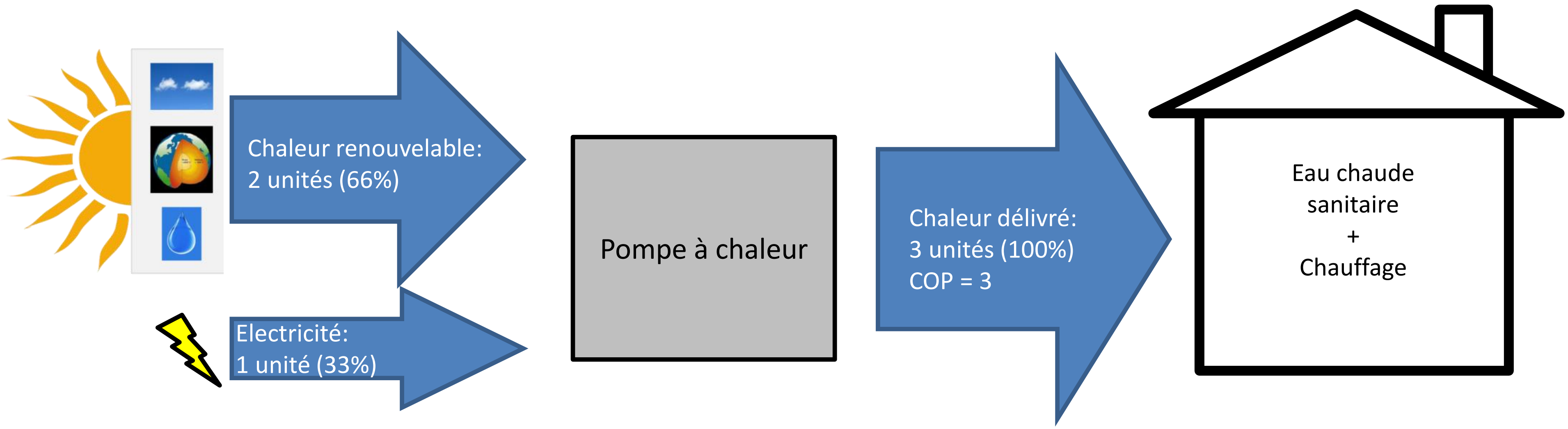


Source: http://free-stock-illustration.com

Comment?

Pompes à chaleur → Energie renouvelable (ou chaleur fatale)

HP technology context



Coefficient de performance : $COP = \frac{Puissance\ thermique\ produite}{Puissance\ electrique\ consommée}$

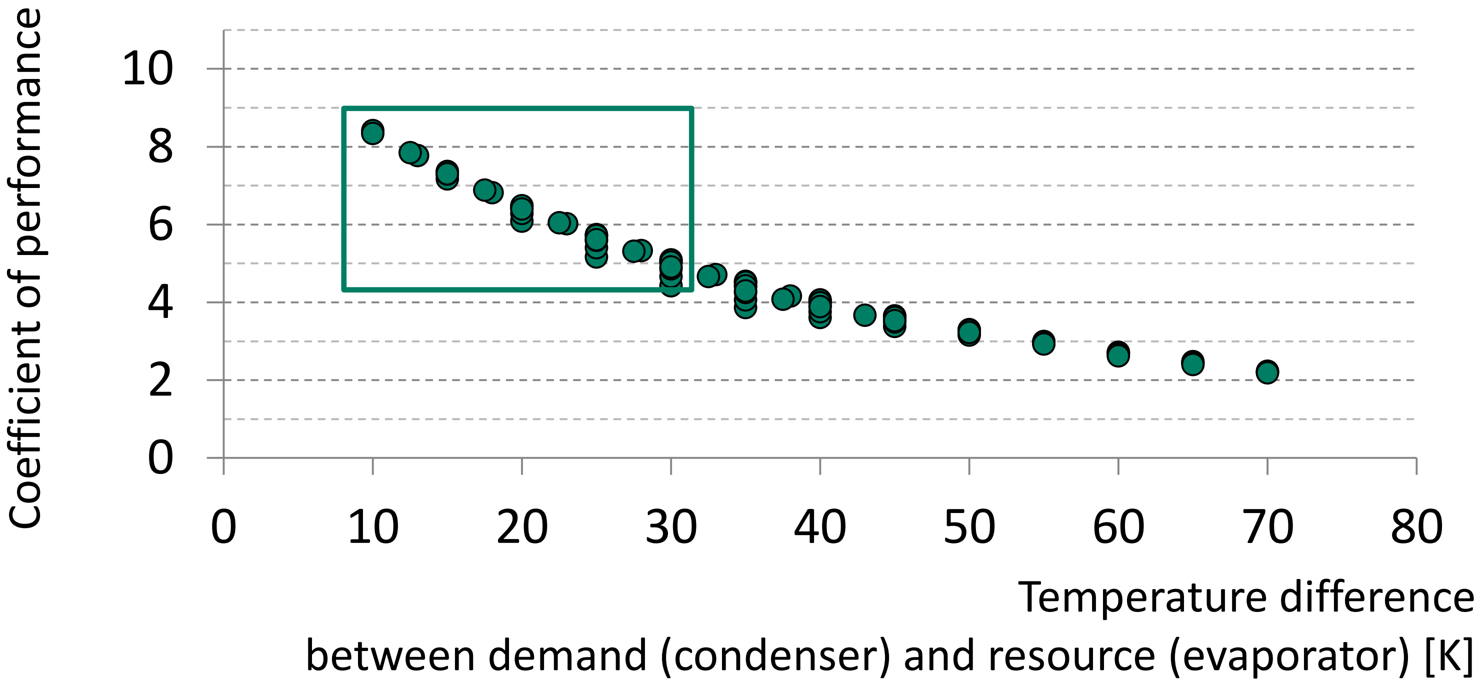
Performance dépend des températures : de la ressource et de la demande

$$COP = \eta \, . \frac{T_{demand}}{T_{demand} - T_{ressource}}$$

Comment?

Pompes à chaleur → Energie renouvelable (ou chaleur fatale)

Performance dépend des températures : de la ressource et de la demande



Source: Fraga et al., 2015

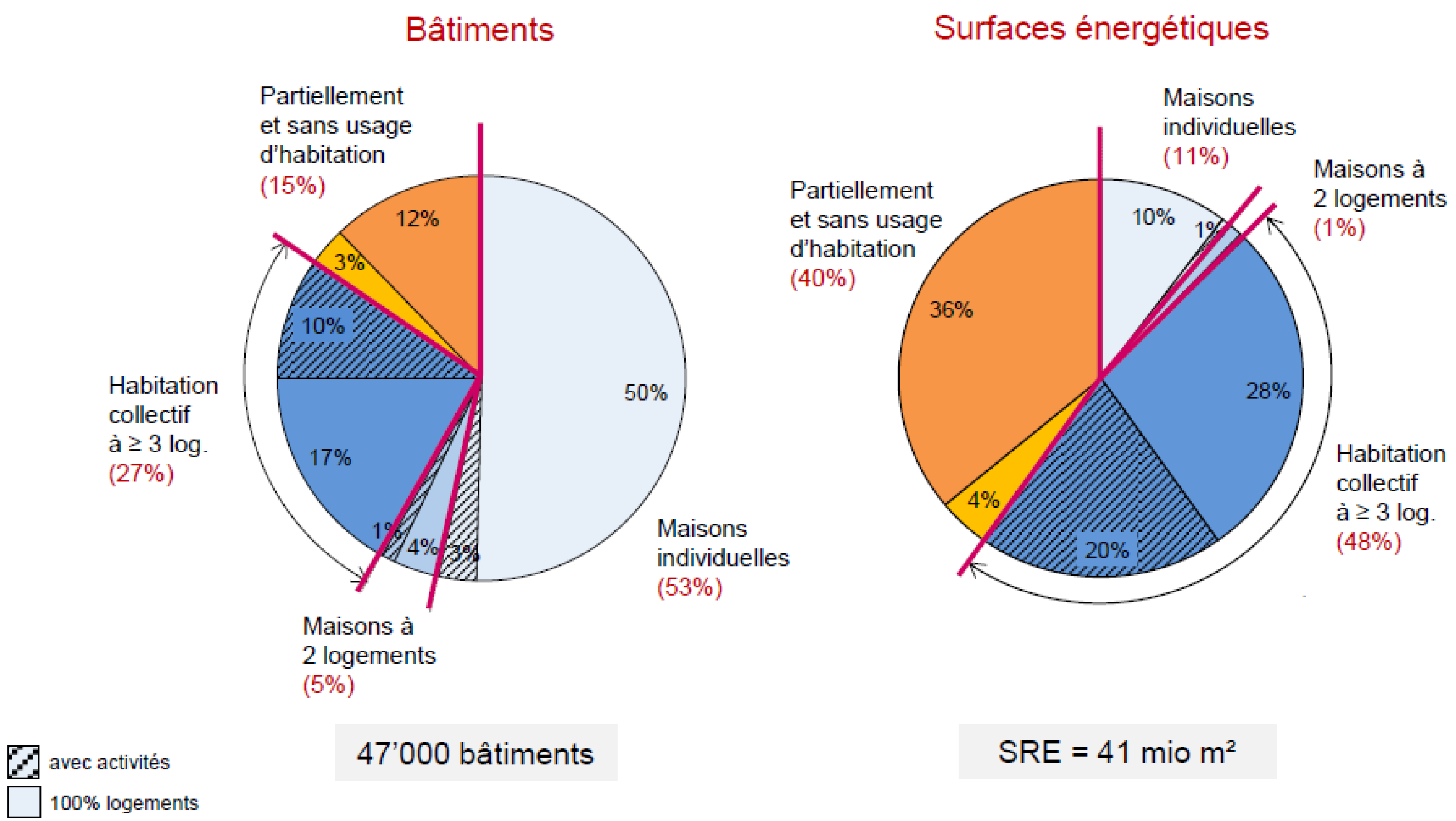
Pourquoi?

Pompes à chaleur dans le **résidentiel collectif**:

Du retour d'expérience à la généralisation par simulation

Geneva context

Building stock in 2010:



Source: Khoury, 2014

Pourquoi?

Pompes à chaleur dans le **résidentiel collectif**:
Du retour d'expérience à la généralisation par simulation

Geneva context

Building stock in 2010:

27% of the buildings = 48% of the heated surface

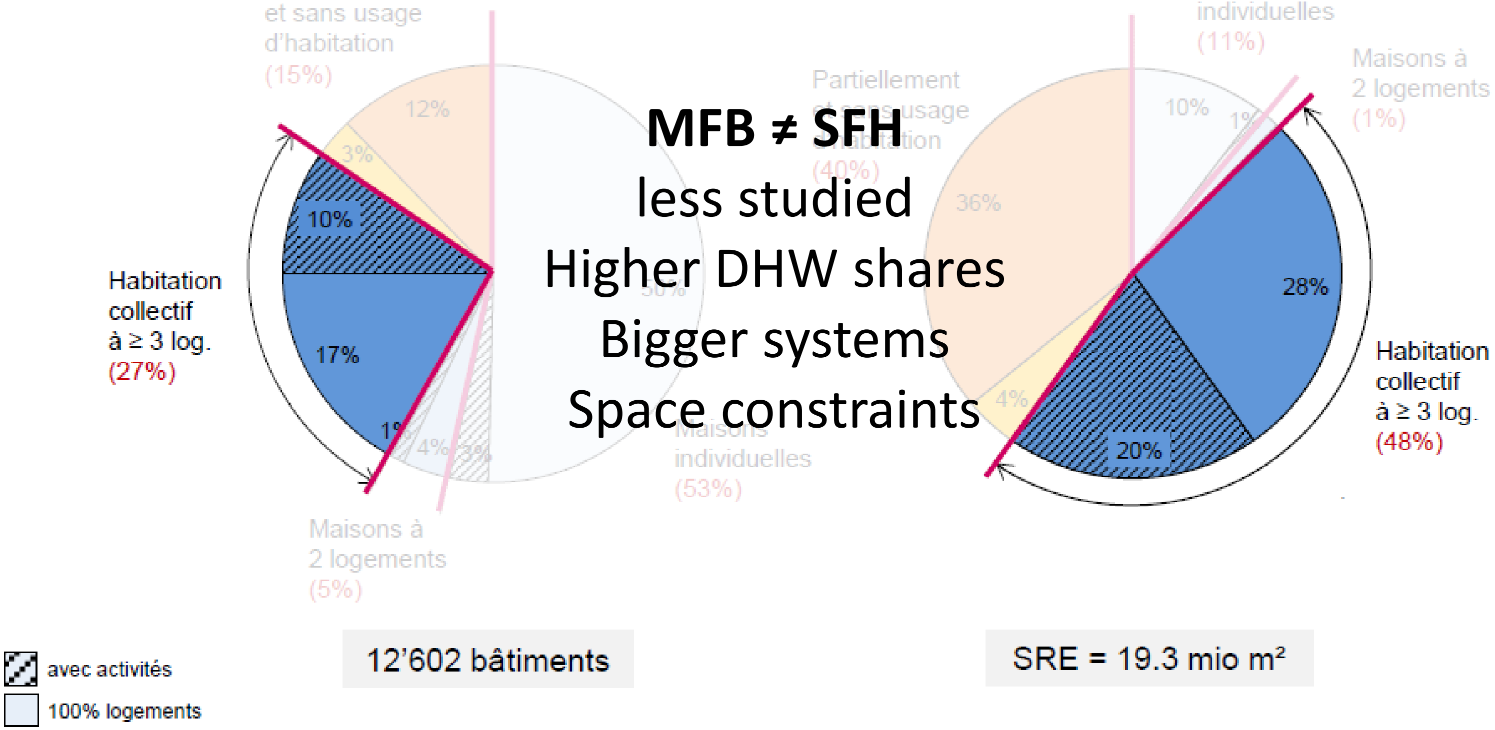
MFB ≠ SFH

less studied

Higher DHW shares

Bigger systems

Space constraints



Source: Khoury, 2014

Du retour d'expérience à la généralisation par simulation

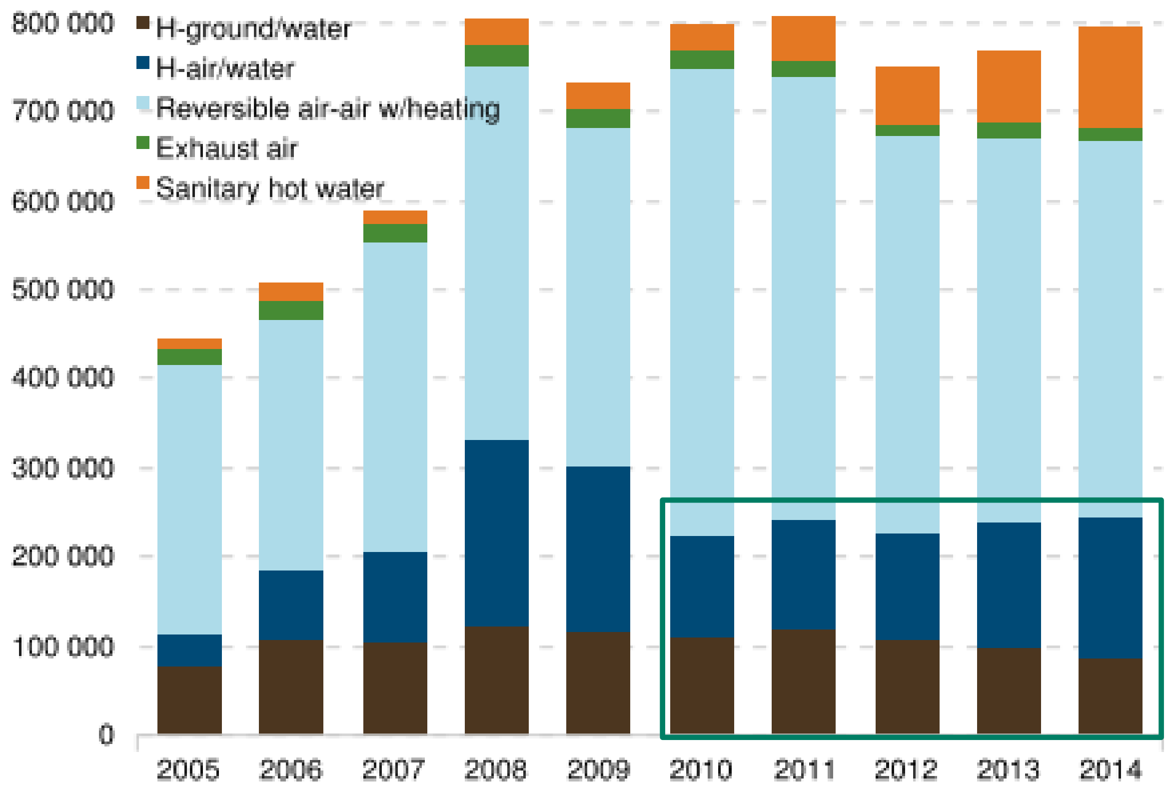
Content

1.	Analysis of an innovative solar assisted HP system	in situ monitoring
2.	Sensitivity analysis (technical layout, building demand)	numerical simulation
3.	Comparative analysis (diverse HP sources + building demand)	numerical simulation

Content

1. Analysis of an innovative solar assisted HP system
2. Sensitivity analysis
   (technical layout, building demand)
3. Comparative analysis
   (diverse HP sources + building demand)

1. Analysis of ~~an~~ Why? innovative solar assisted HP system



Source: EHPA, 2015

Figure 1-1: Development of heat pump sales in Europe 2005–2014, by category

Market dominated by air and ground HPs

Air

Variable T_{source}, ↘Winter

COP ~ 2.8

Ground

More stable T_{source}, ↗Winter

COP ~ 3.7

Space/implementation constraints

Solar

Improve Air T_{source} ?

Improve COP_{Air} ?

Less space/implementation constraints than Ground ?

1. Analysis of an innovative solar assisted HP system

Monitored building

Energy concept

System operation modes and priorities

Monitoring results

Conclusions

Monitored building

Solarcity (Satigny)

Minergie building complex (built 2010)

- 4 buildings / 10 blocks
- 1 block monitored in detail:
  - 927 m² heated surface
  - Space heating (SH) ~20 kWh/m²/yr

  (good thermal envelope)
  - Domestic hot water (DHW) ~50 kWh/m²/an (high)

Energy concept

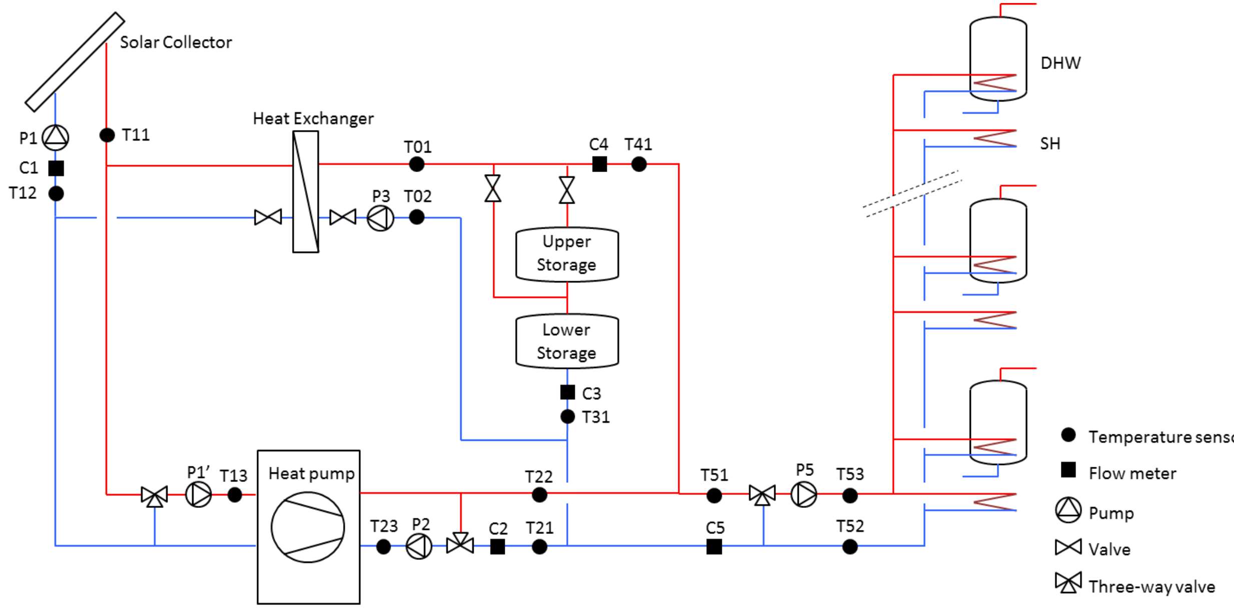
Solarcity (Satigny)

Heating system (per block)

- 116 m² unglazed solar collectors
- Heat pump: 35 kWth, COP: 4.5 (B0/W35)
- Centralized heat storage: 6000 lit
- Backup electric heating (HP failure)

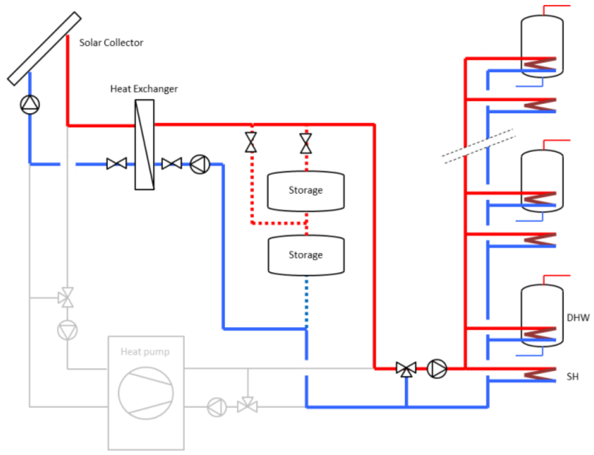
Heat distribution

- Alternate SH/DHW distribution
- Decentralized DHW storage: 300 lit per flat
- Floor heating (30 °C)

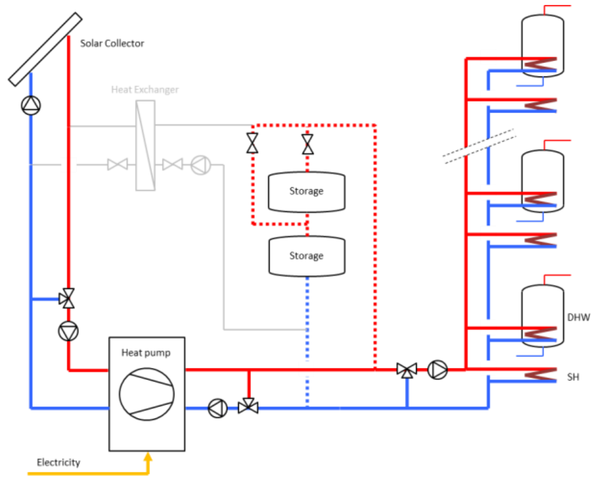


System operation modes and priorities

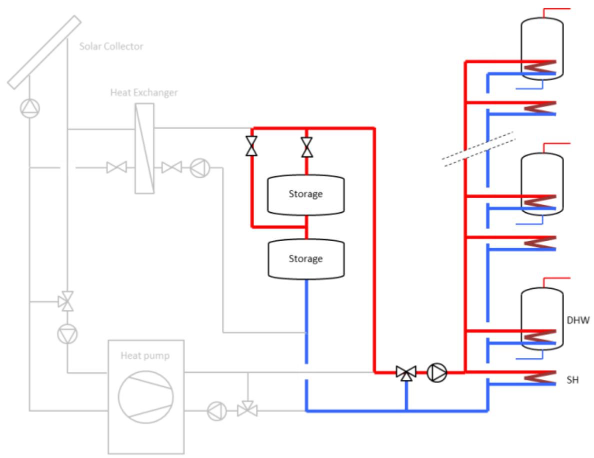
1) Solar ➔ Building and/or storage



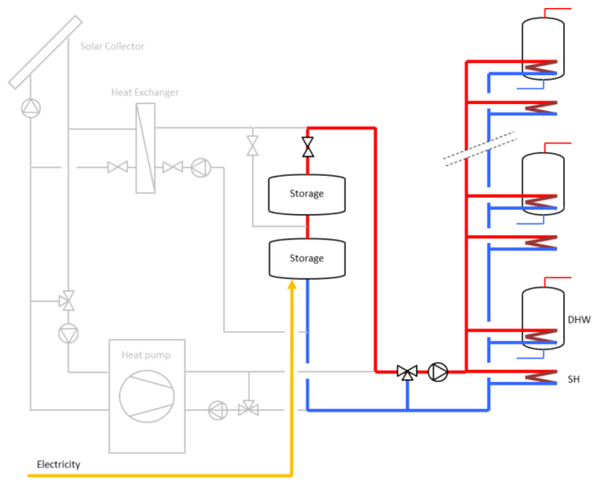
3) Solar/Ambient ➔ HP ➔ Building and/or storage



2) Storage ➔ Building

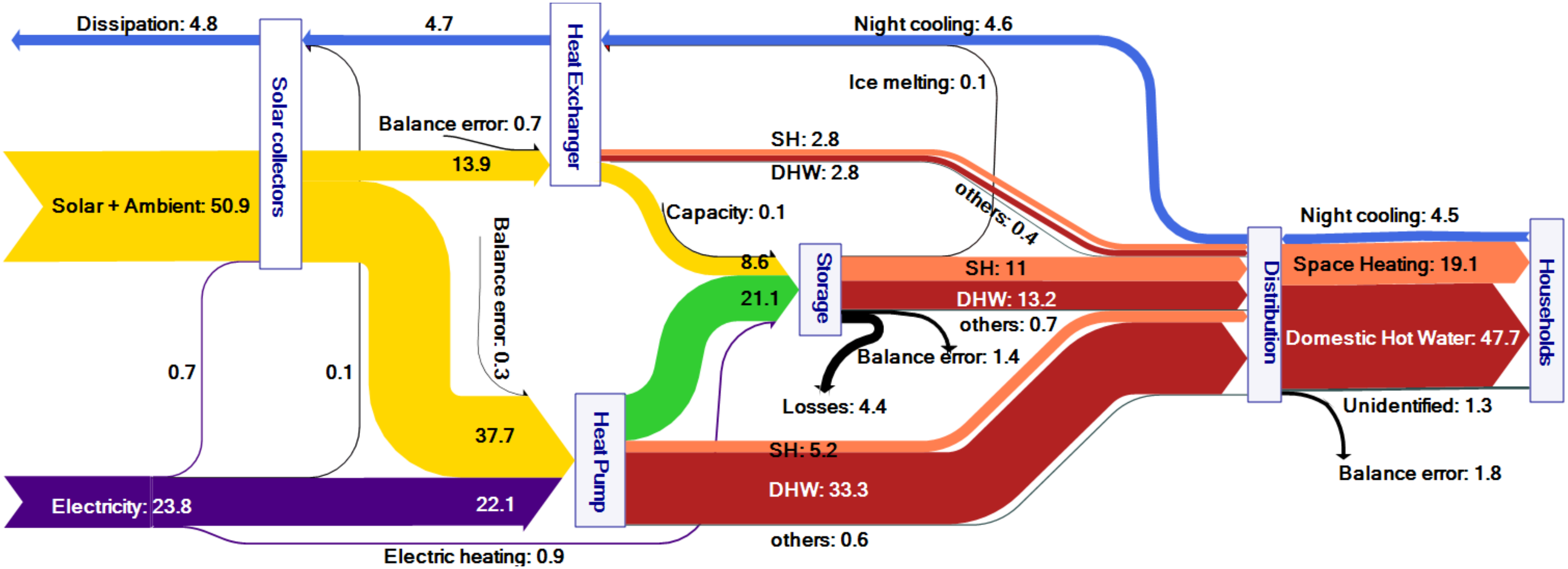


4) Backup electric heating



Monitoring results

Energy flows of the studied building block, 2012 (units: kWh/m²)



Input:

- Renewable heat: 68% (direct solar: 19%)
- Electricity HP: 30%
- Electricity backup: 1%
- Electricity auxiliaries: 1%
- Renewable energy: 100% (green elec.)

Performance:

- SPF HP: 2.7 (monthly COP HP 2.5 – 3, even in summer because HP only for DHW at 60°C)
- SPF System: 2.9 (2.5 in winter, 4.4 in summer)
- Total electricity: 24 kWh/m²

Storage:

- 28% of HP production to storage

1. Conclusions

- excellent system reliability
- electric backup hardly needs to be used
- Absolute electric consumption (24 kWh/m^2/yr) reasonable due to a low thermal demand (68 kWh/m^2/yr)

Why SPF system of 2.9, when ~ 5 expected?

1. single heat distribution circuit with decentralized DHW storage, no solar preheating
2. excess heat for DHW (60°C) stored, for subsequent SH (30°C)
3. low SH with high DHW (30% and 70%)
   heat produced at a high temperature (60°C);
4. no insulation of the unglazed solar collectors

Content

Introduction

1. Analysis of an innovative solar assisted HP system
2. Sensitivity analysis
   (technical layout, building demand)
3. Comparative analysis
   (diverse HP sources + building demand)

2. Sensitivity analysis

Numerical model

Validation

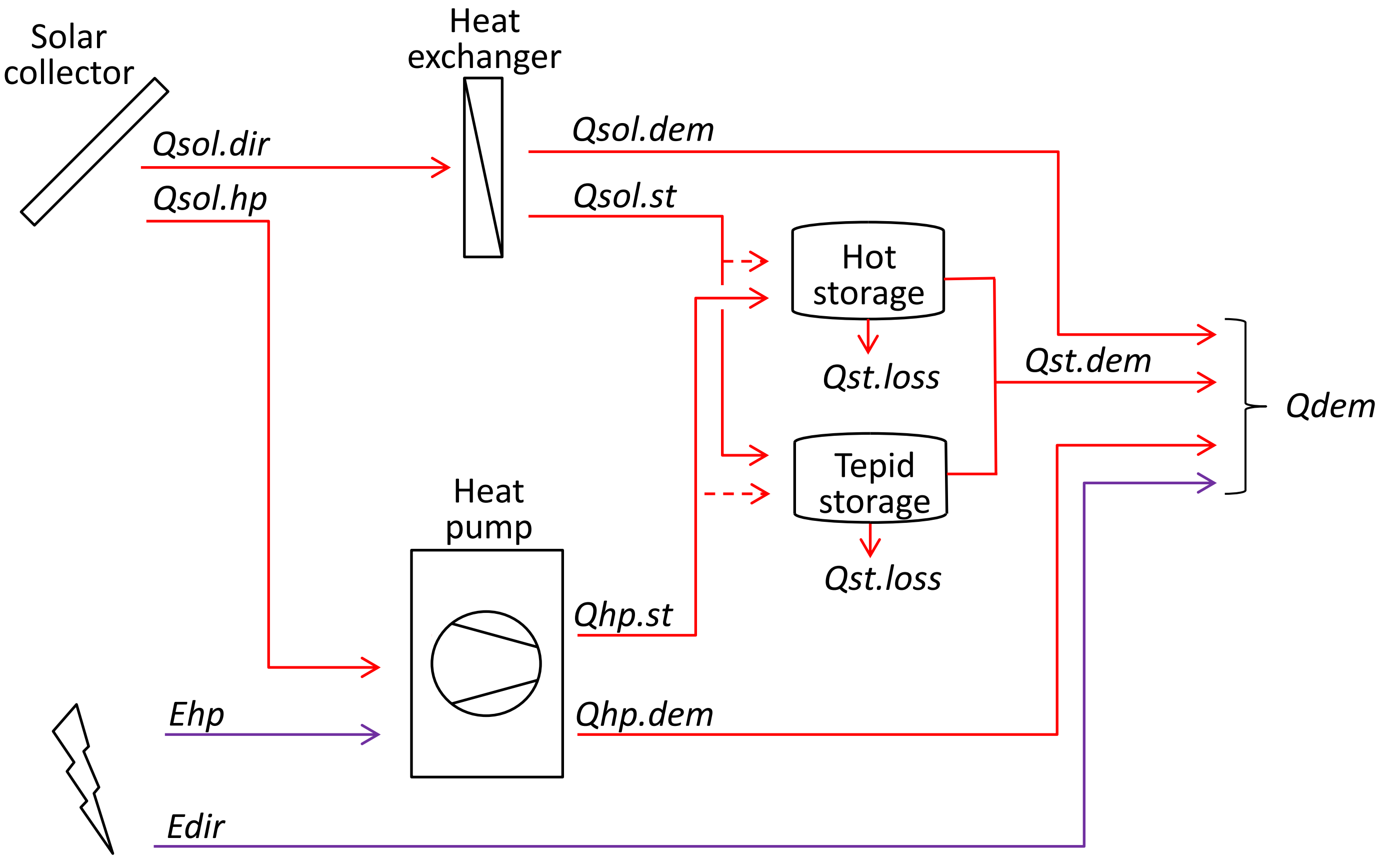
Normalization to standard distribution/centralized heat storage

Sensitivity to heat demand

Sensitivity to solar collector area

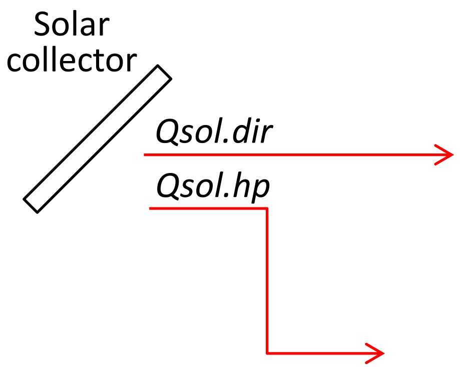
Conclusions

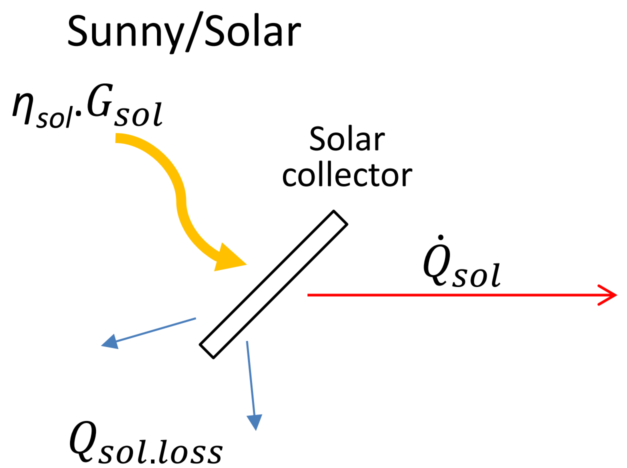
Numerical model



Numerical model

Solar collectors

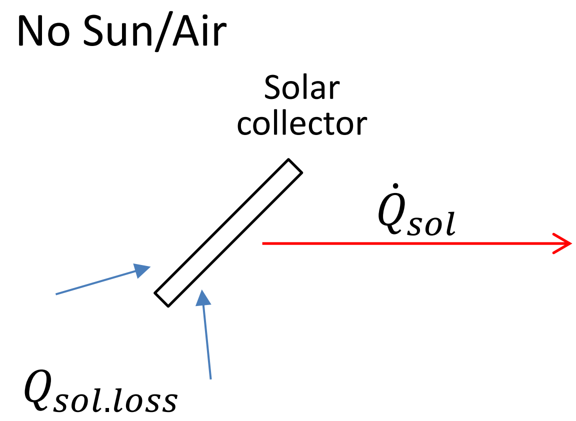




$$\dot{Q}_{sol} = A_{sol}(\eta_{sol}G_{sol} - Q_{sol.loss})$$

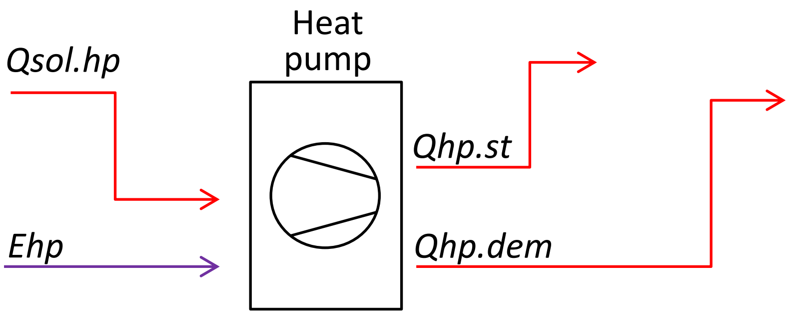
$$\dot{Q}_{sol.loss} = (h_{sol,o} + h_{sol,v}v)(T_{sol} - T_{ext})$$

$$\dot{Q}_{sol} = Q_{sol.dir} + Q_{sol.hp}$$



Numerical model

Heat pump



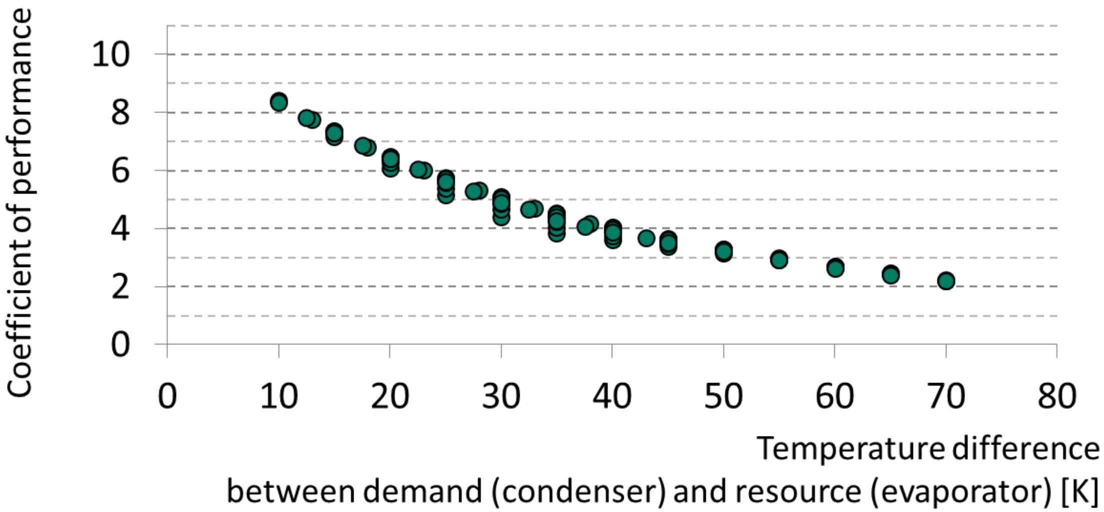
$$\dot{Q}_{hp} = f\left(T_{cond}, T_{evap}\right)$$

$$\dot{E}_{hp} = f\left(T_{cond}, T_{evap}\right)$$

$$\dot{Q}_{evap} = \dot{Q}_{hp} - \dot{E}_{hp}$$

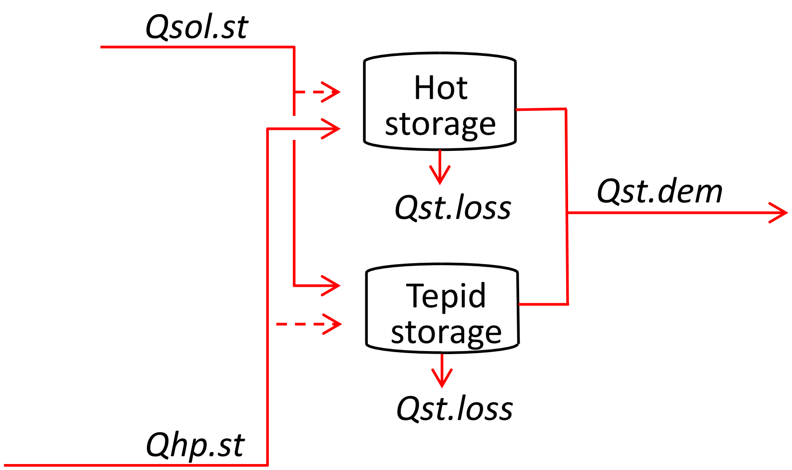
$$COP = \frac{\dot{Q}_{hp}}{\dot{E}_{hp}}$$

Data from manufacturer:



Numerical model

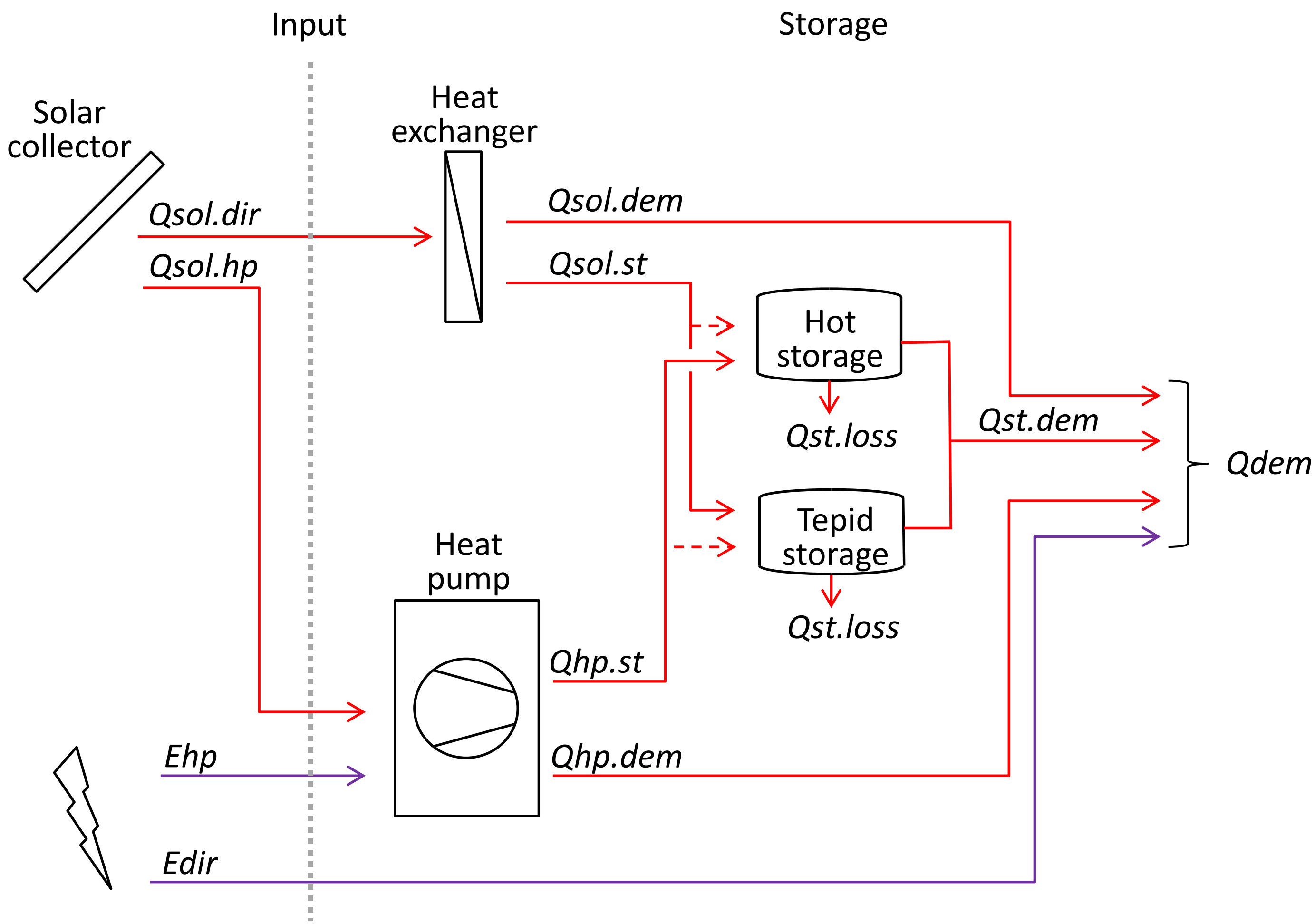
Storage



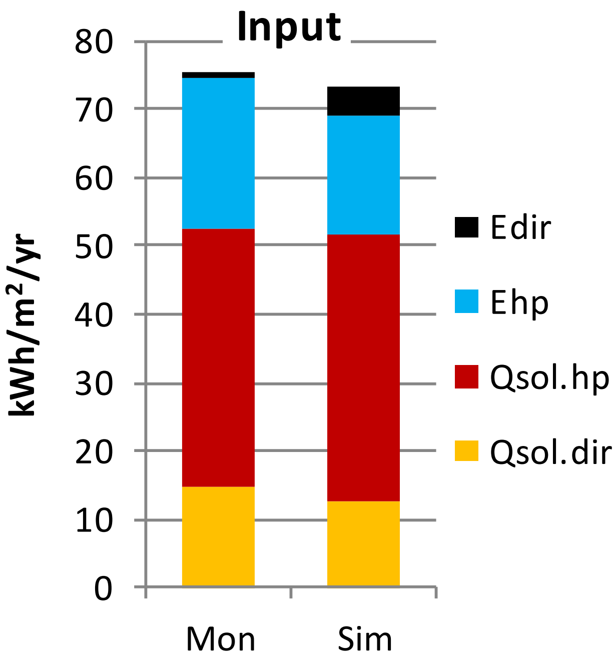
$$\dot{Q}_{st,in} - \dot{Q}_{st,out} - \dot{Q}_{st,loss} = V_{st} c_{wat} \rho_{wat} (T_{st} - T_{st,t-1}) / dt$$

$$\dot{Q}_{st,loss} = A_{st} h_{st} (T_{st,t-1} - T_{room})$$

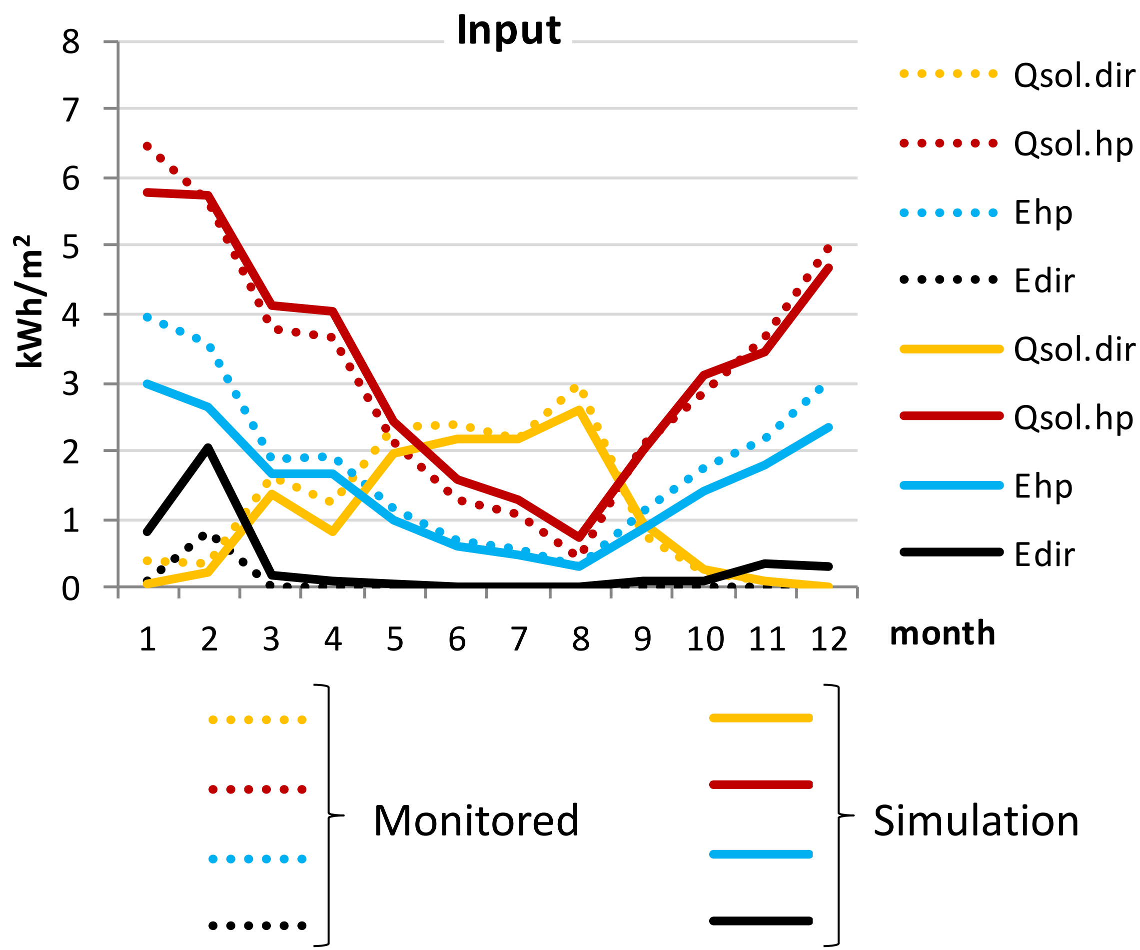
Numerical model



Validation



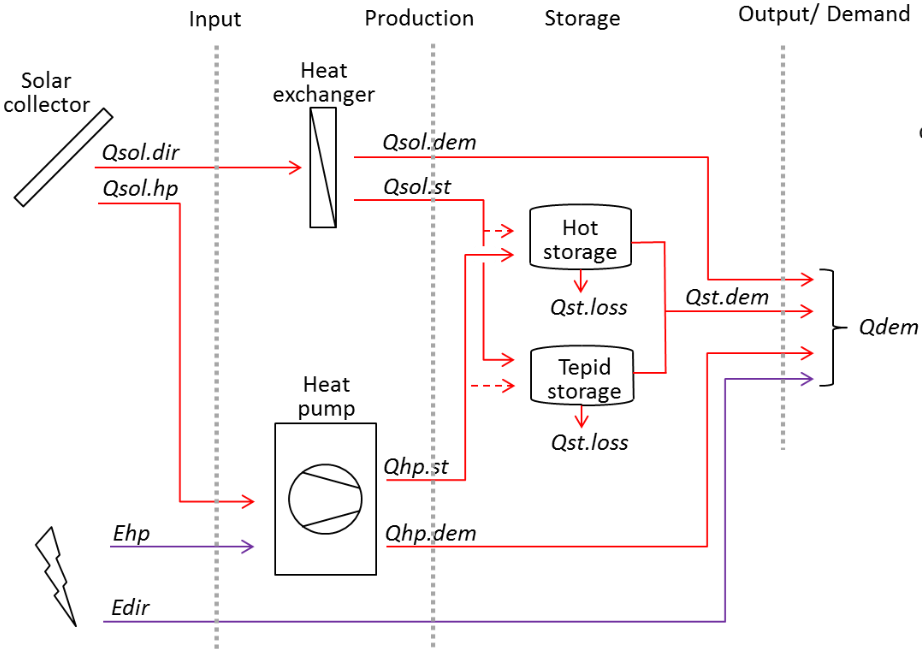
Input
kWh/m²/yr
0
10
20
30
40
50
60
70
80
Mon
Sim
Edir
Ehp
Qsol.hp
Qsol.dir



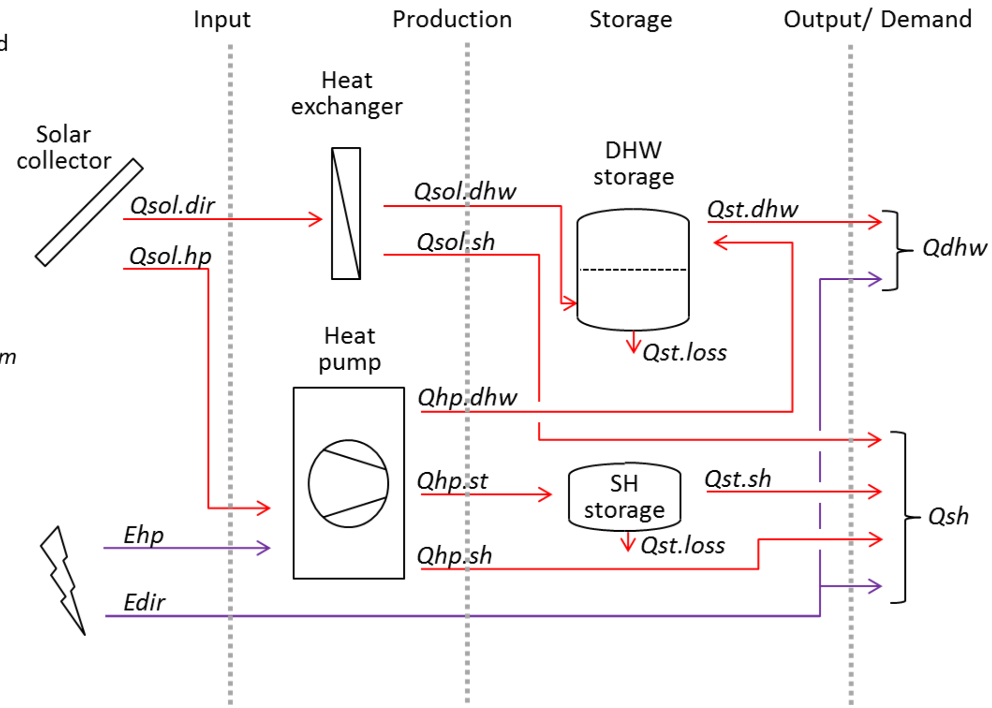
Input
kWh/m²
0
1
2
3
4
5
6
7
8
1 2 3 4 5 6 7 8 9 10 11 12
month
Qsol.dir
Qsol.hp
Ehp
Edir
Qsol.dir
Qsol.hp
Ehp
Edir
Monitored
Simulation

Normalization to standard heat storage/distribution

Decentralized DHW

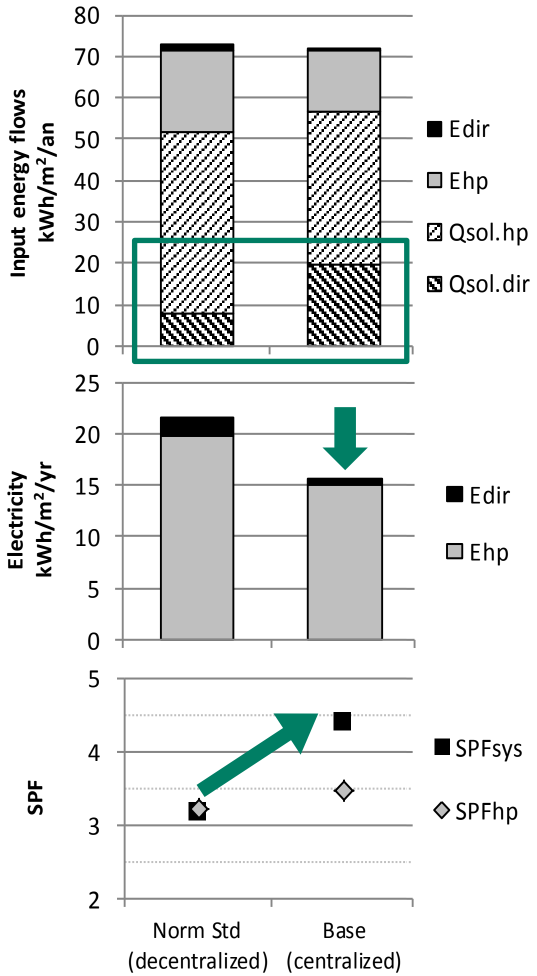


Centralized DHW



Identical components in both layouts

Normalization to standard distribution/heat storage



For the overall system performance: System configuration is as important as individual components performance

Sensitivity to heat demand

Building sample

- 1) New, high DHW
- 1’) New

T_{sh} 30°C

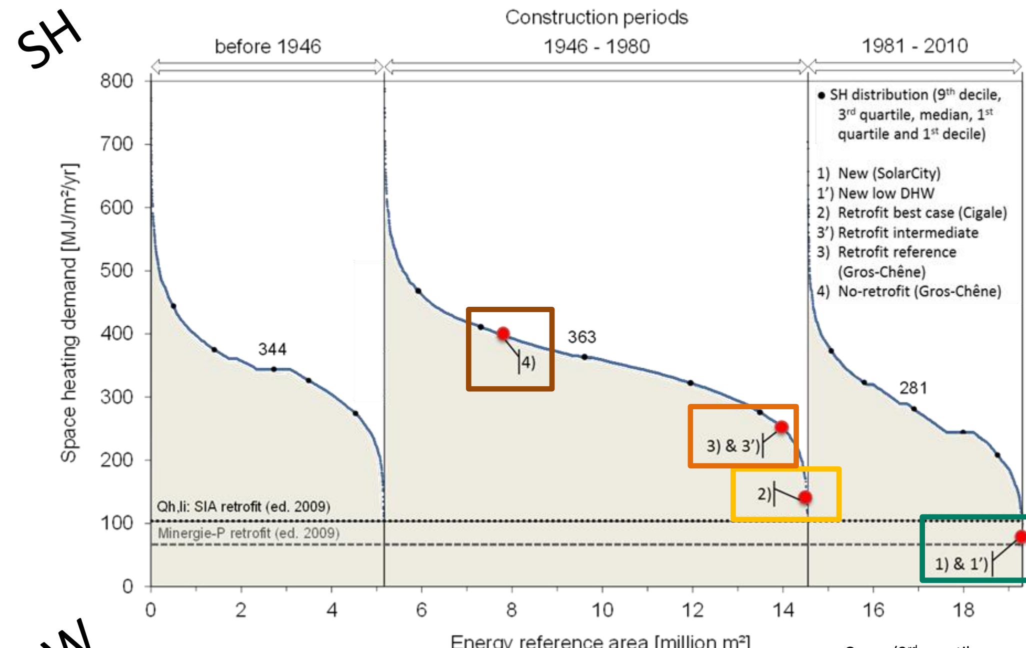
- 2) Retrofit best case
- 3’) Retrofit intermediate

T_{sh} 40°C

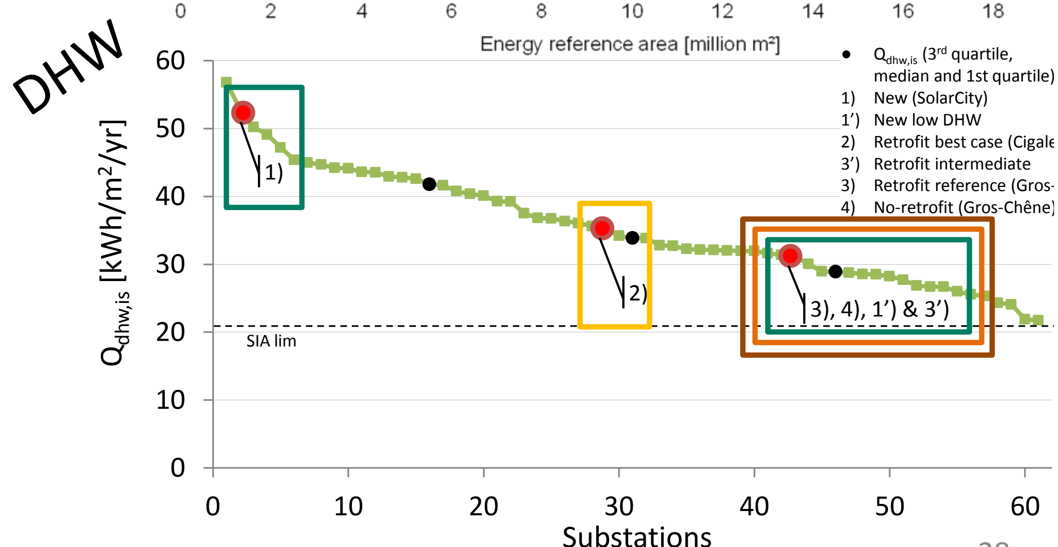
- 3) Retrofit reference
- 4) No-retrofit

T_{sh} 50°C

Case study
(1) Solar City
(1’) Solar City, adapted
(2) Cigale
(3’) Gros Chêne, adapted
(3) Gros Chêne, build. A
(4) Gros Chêne, build. B

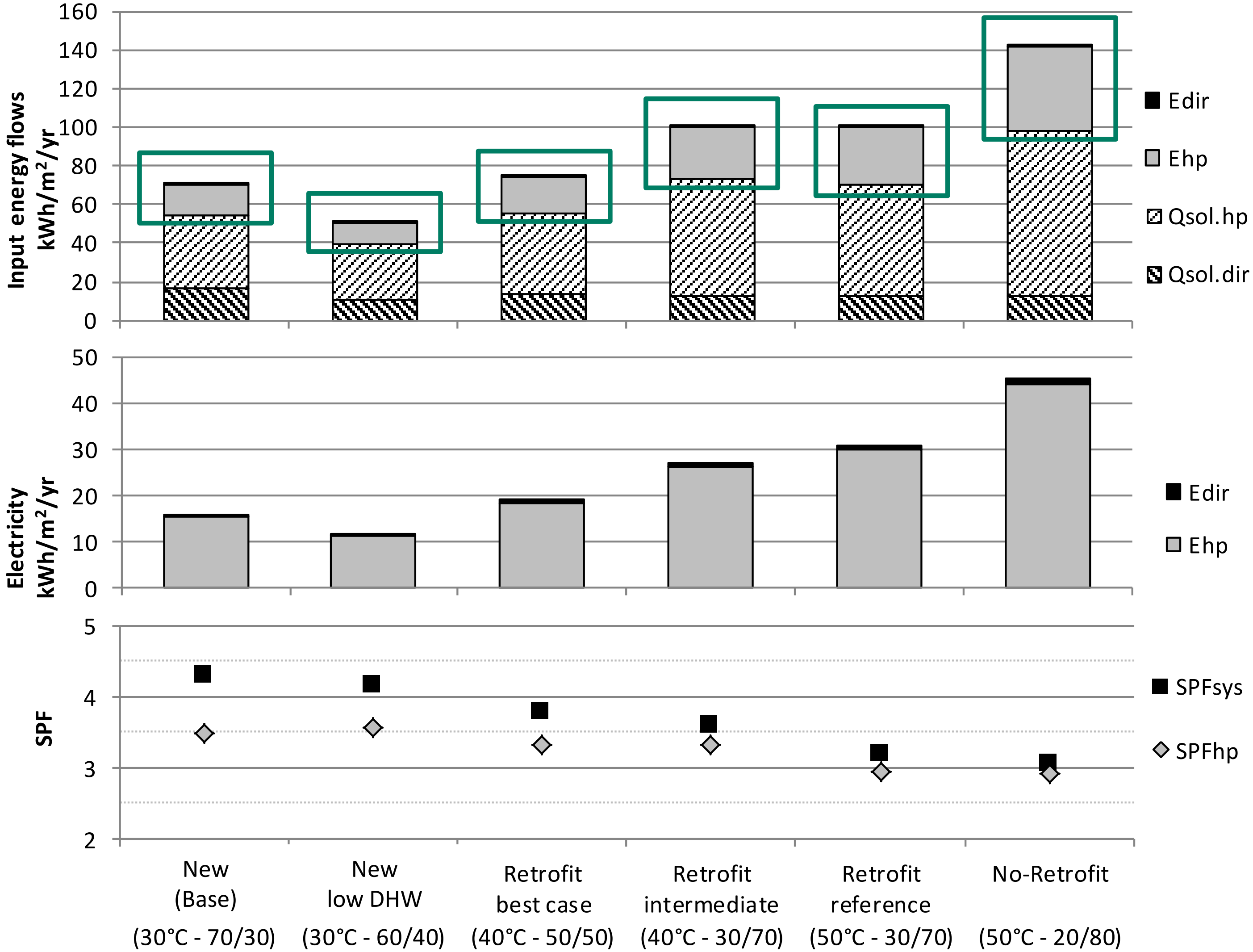


Source: Khoury, 2014



Source: Quiquerez, 2017

Sensitivity to heat demand



In relative values:

E_{dir} < 1%

E_{tot}: 24% to 33%

In absolute value:

From 16 to 45 kWh/m²/yr

Sizing:

$A_{sol} = 3.32\ m^2/kW_{hp}$?

HP 100% Qdem

Space constraints:

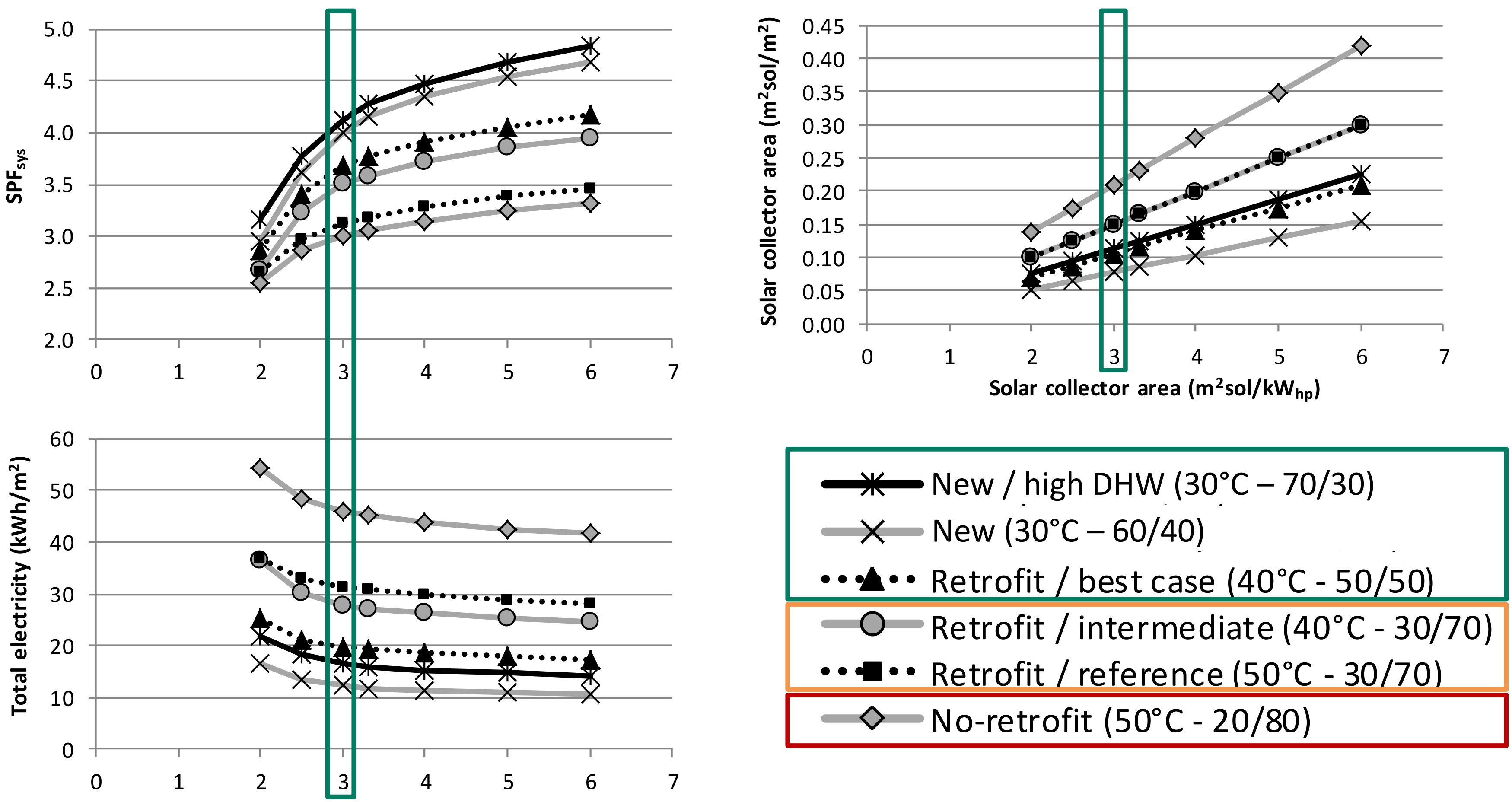
A_{sol}/ heated area

0.13 to 0.23 m^2/m^2

(~8 floors to ~3 floors)

Sensitivity to solar collector area

For Geneva's weather condition: 3 m^2/kW_{hp} (HP 100% Q_{dem})



2. Conclusions

Why SPF system of 2.9, when ~ 5 expected?

Due to decentralized DHW (no solar preheating)

With centralized DHW: SPF_{sys} 4.4

> For the overall system performance, system configuration is as important as individual components performance

Can Solar HP system be used in Retrofitted and Non Retrofitted MFB buildings?

New and Best Case Retrofitted MFB, yes.

Retrofitted and No-retrofitted, be careful with Electricity and Solar Area

Can SPF_{sys} of 5 be achieved ?

Yes, but only in New buildings, with low SH temperature and high collector area (0.20 - 0.25 m^2 per m^2 heated area ➔ less than 4 storeys)

Moreover:

- available roof area is not unlimited
- doubling solar collector area for small electricity saving may not be worthwhile

Content

Introduction

1. Analysis of an innovative solar assisted HP system
2. Sensitivity analysis
   (technical layout, building demand)
3. Comparative analysis
   (diverse HP sources + building demand)

3. Comparative analysis

Resources

System layout and sizing

HP sources potential:

- Disregarding available area constraints
- HP & PV systems with available area constraints

Discussion

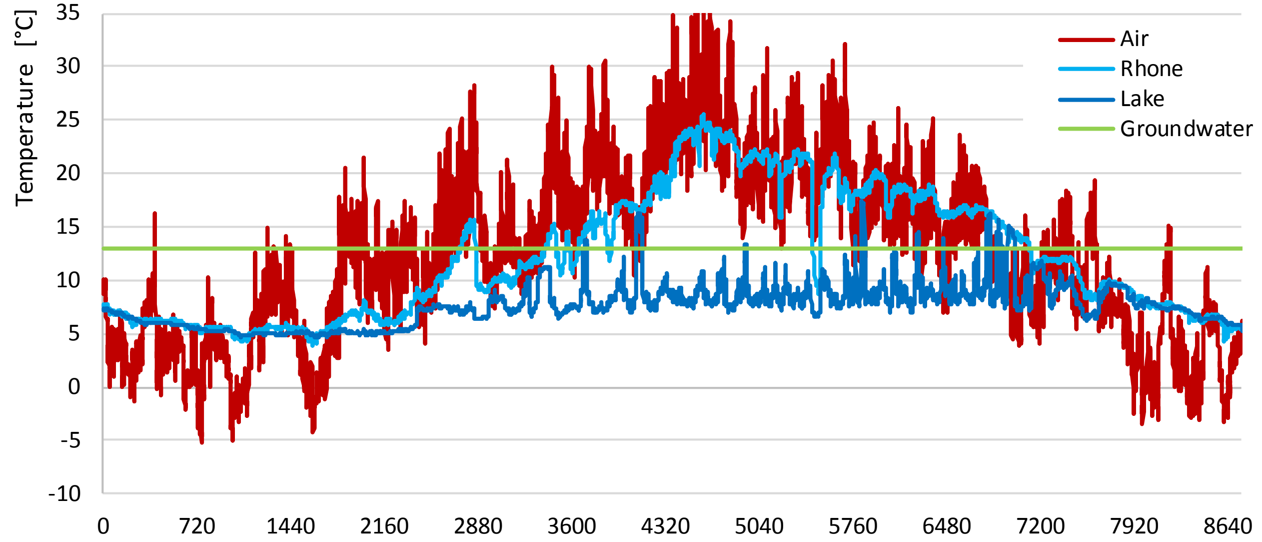
Potential effect on regional load curve

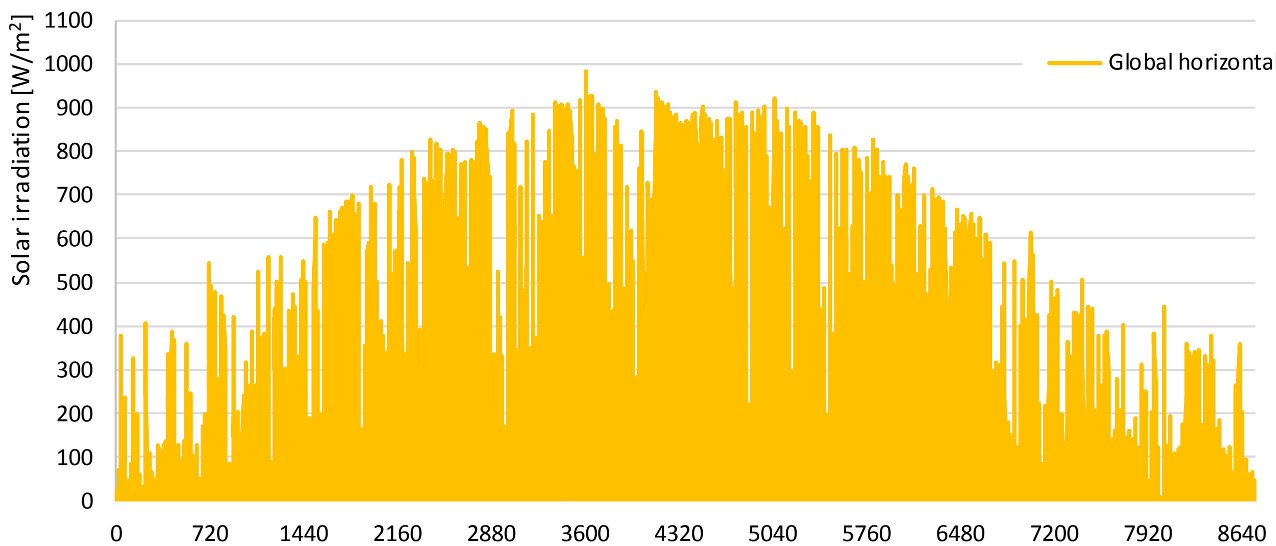
Conclusion

Resources

Air
Geothermal (boreholes)
Lake (Geneva, 35m)
River (Rhone)
Groundwater
Solar

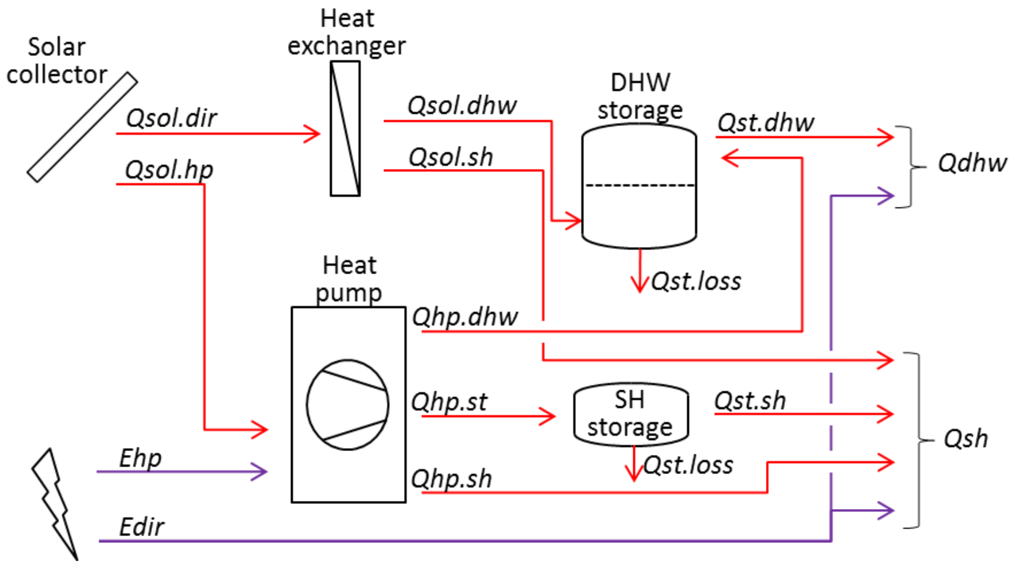
Year: 2010



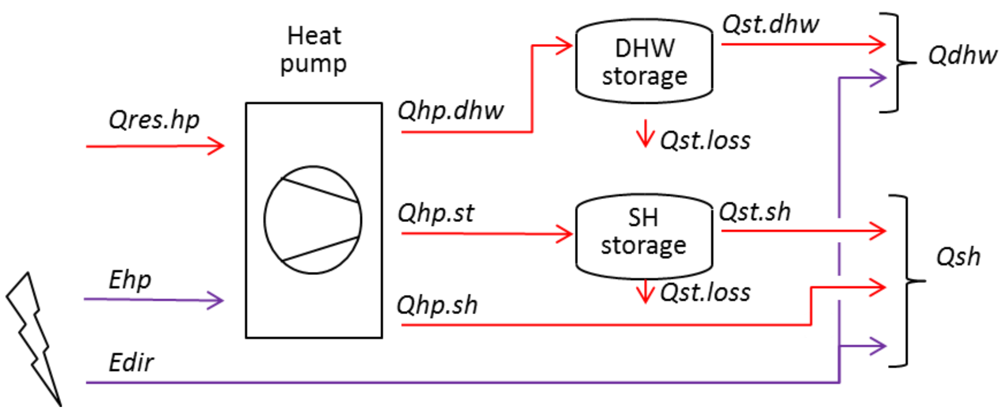


System layout and sizing

Solar HP system



Other sources HP system



Components size:

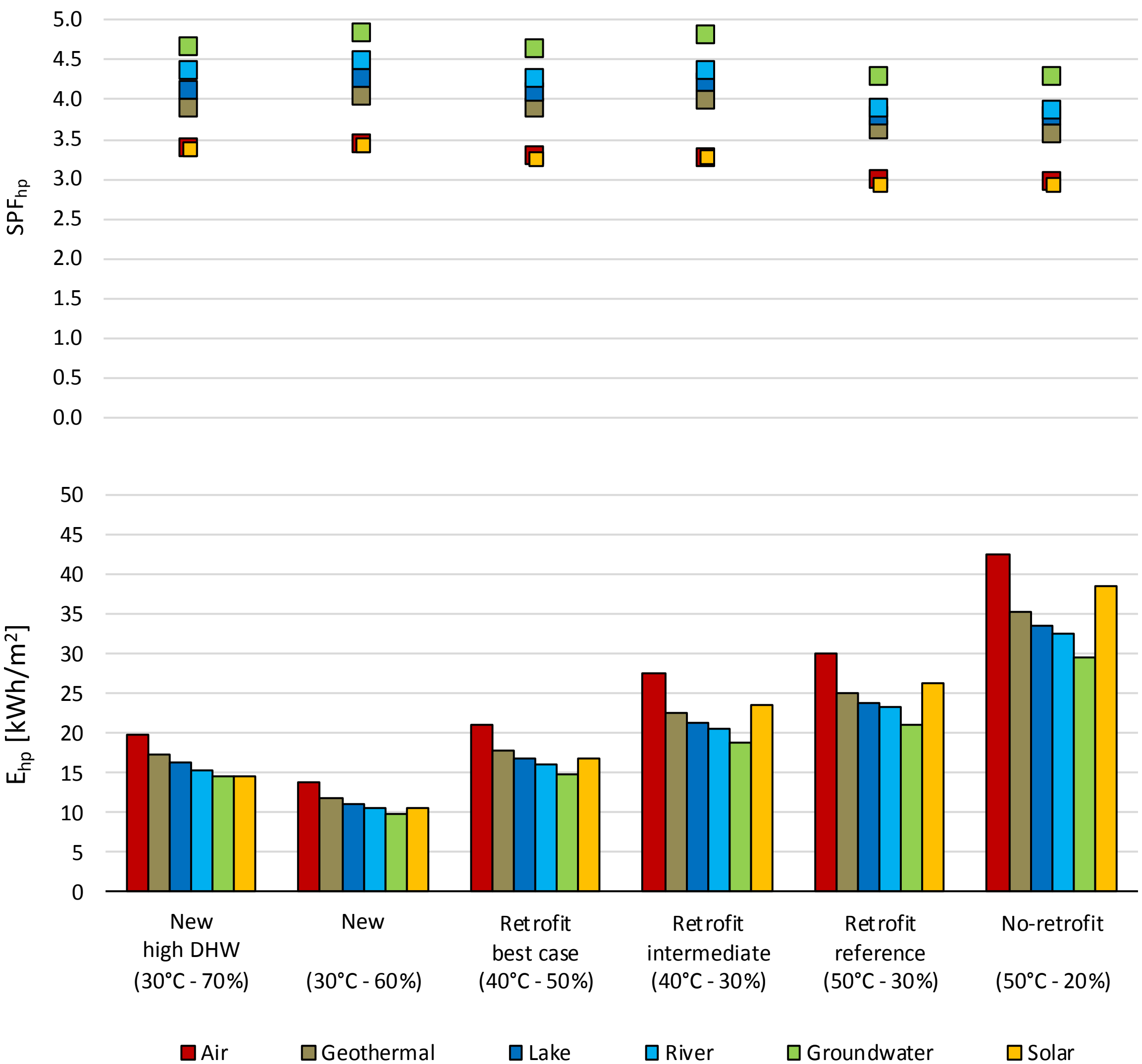
Solar: A_{sol} set to 3 m^2/ kW_{hp}

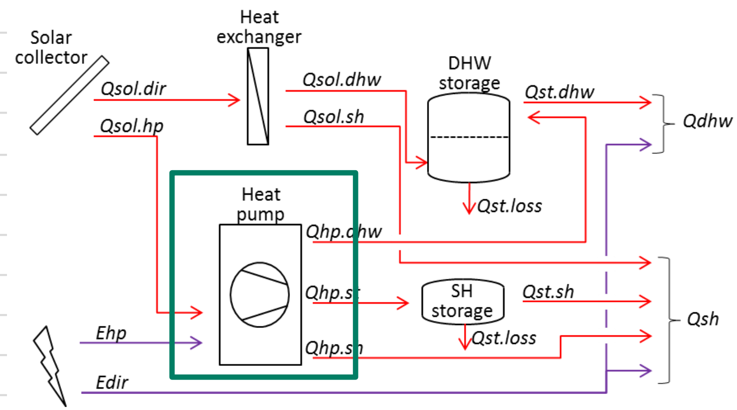
Geothermal: 250m, 36 m^2/borehole
Nb boreholes adjusted so that T_{geo} >1.5 °C in 50 years
Without recharge
(simulation with pilesim)

Air, Lake, River and Groundwater:
No sizing values because they are not space extensive

HP sources potential

Disregarding available area constraints – HP performance



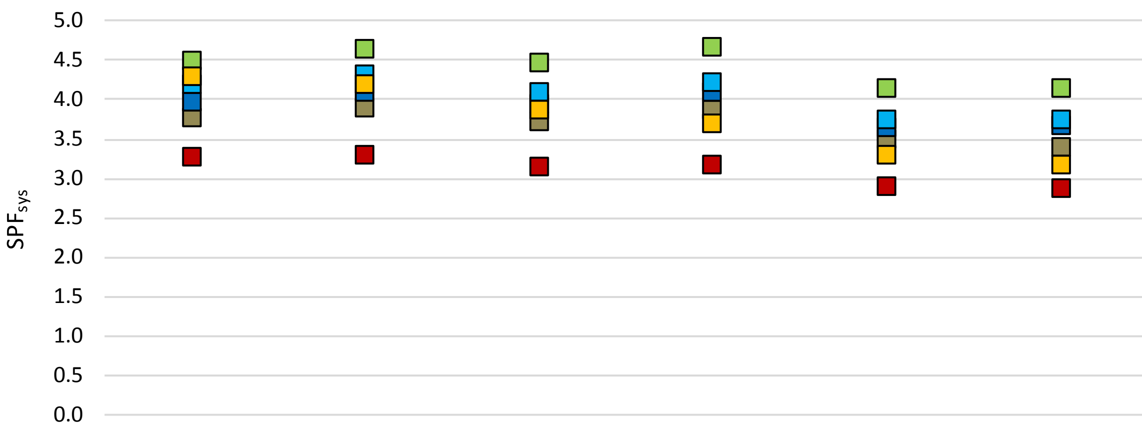


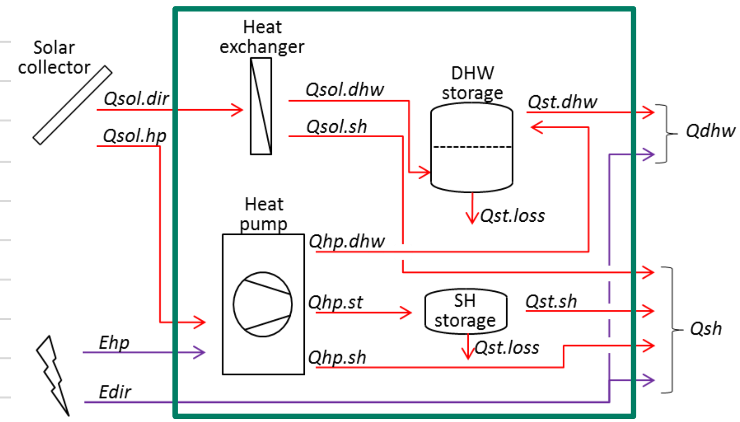
Resource classification:

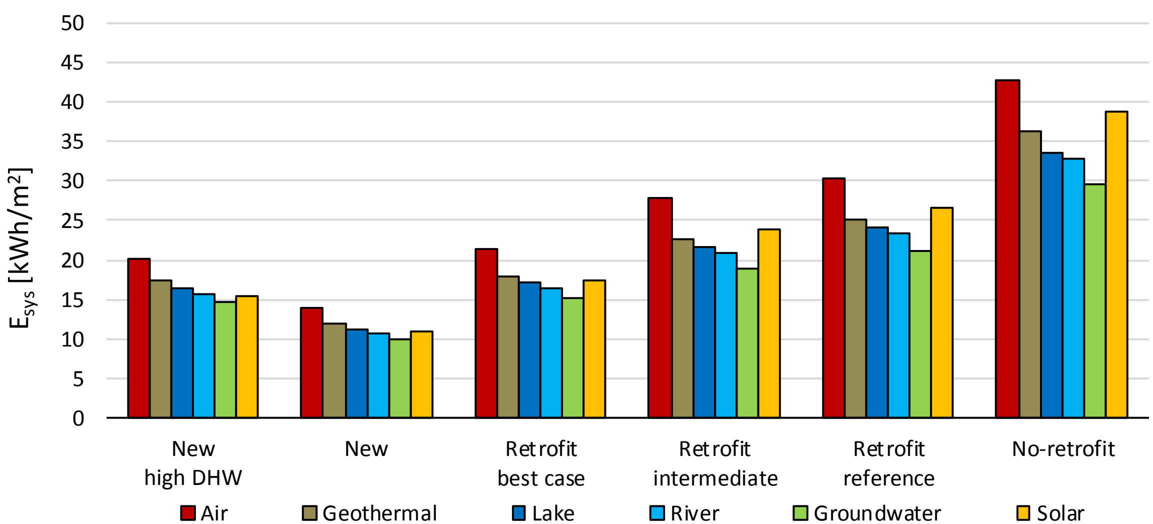
- Groundwater
- River
- Lake
- Geothermal
- Air & Solar

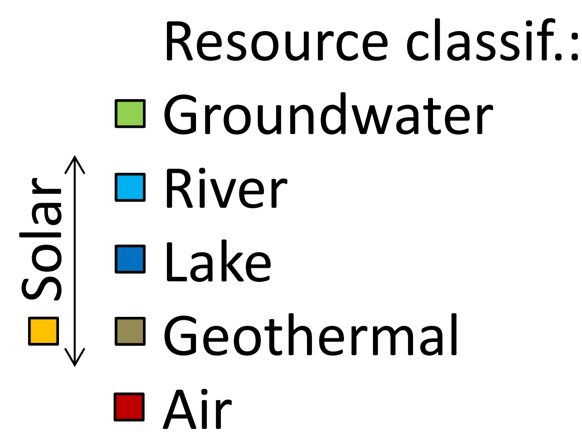
HP sources potential

Disregarding available area constraints – system performance



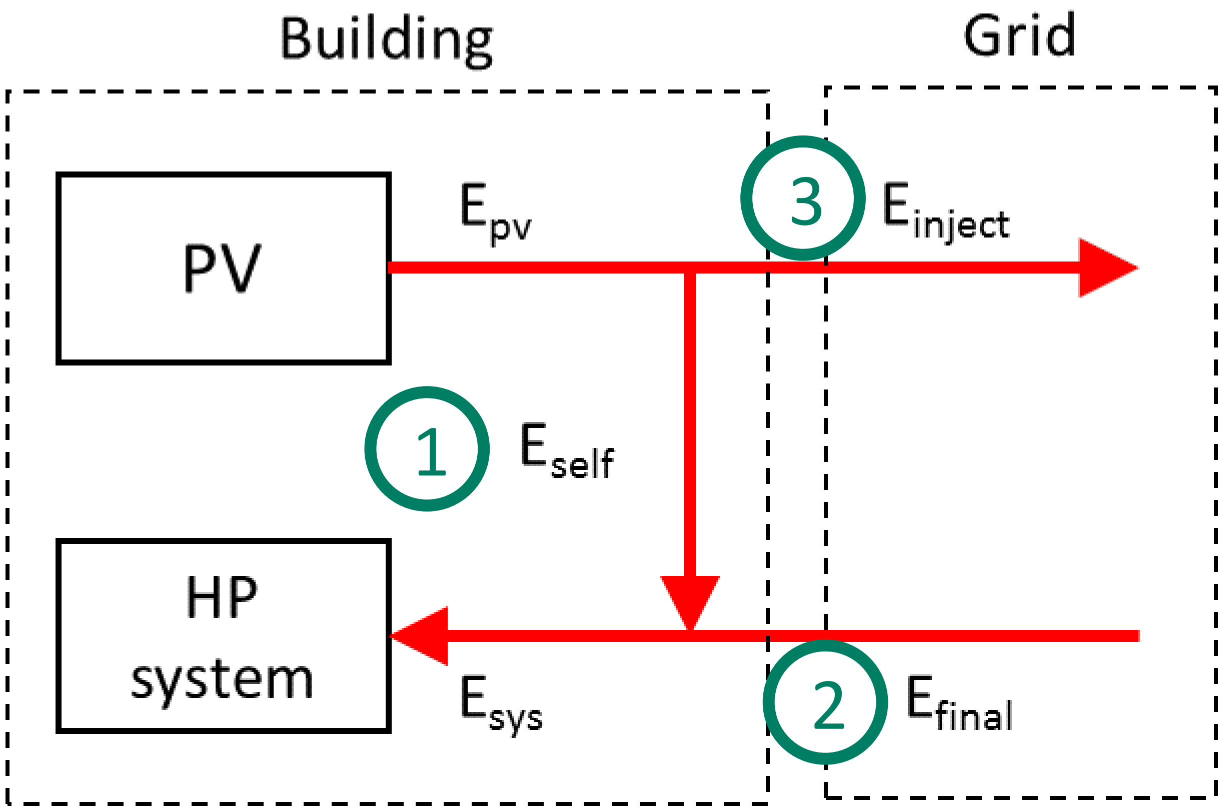






Available area constraints, HP & PV systems

Available area – 0.2 m^2_{roof}/m^2_{SRE} →Low-rise Building (4 storeys)



1 – E_{self} (self cons.)

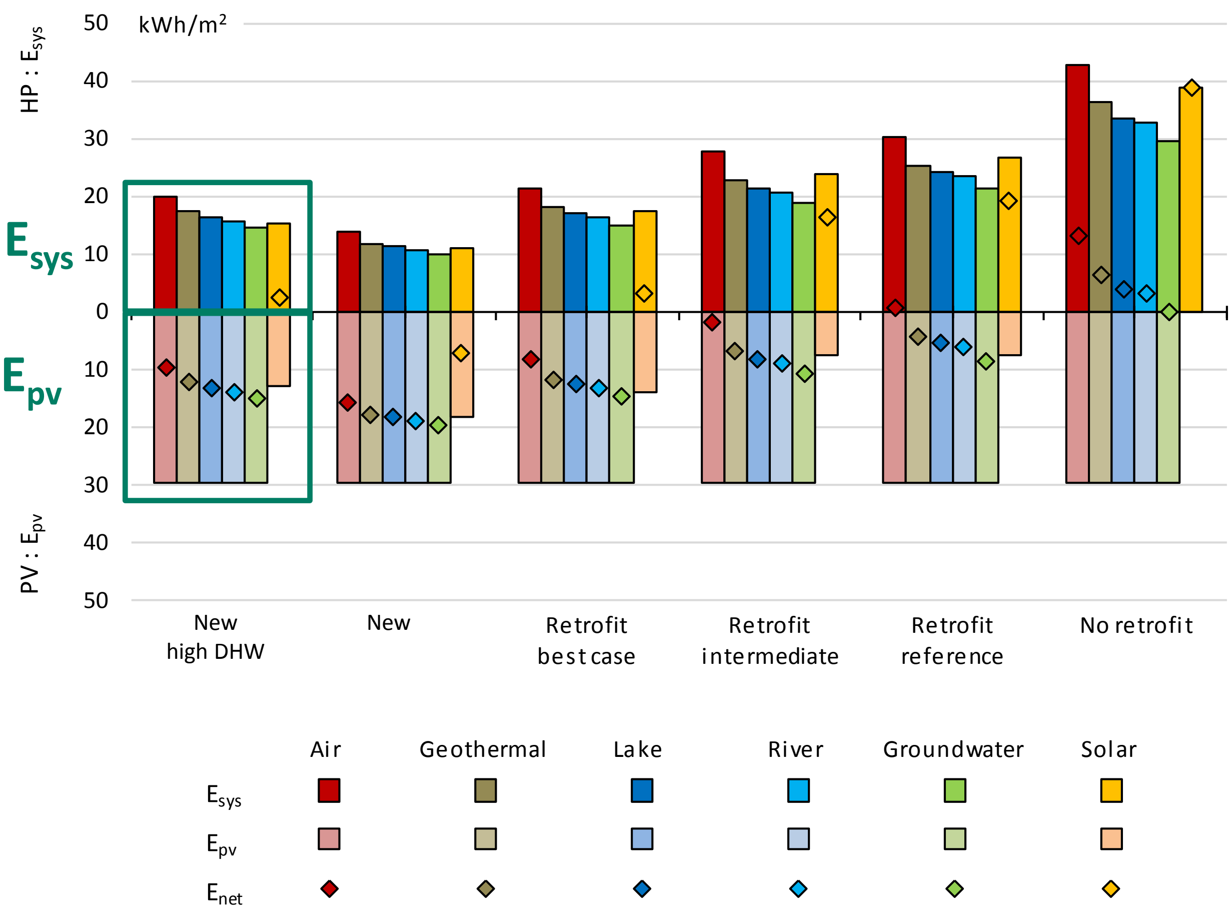
2 – E_{final} (compl. to E_{self})

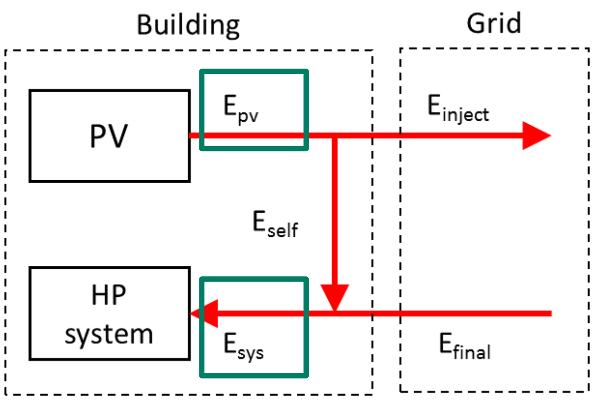
3 – E_{inject} (excess E_{pv})

Daily match

HP & PV systems

System performance – low rise building



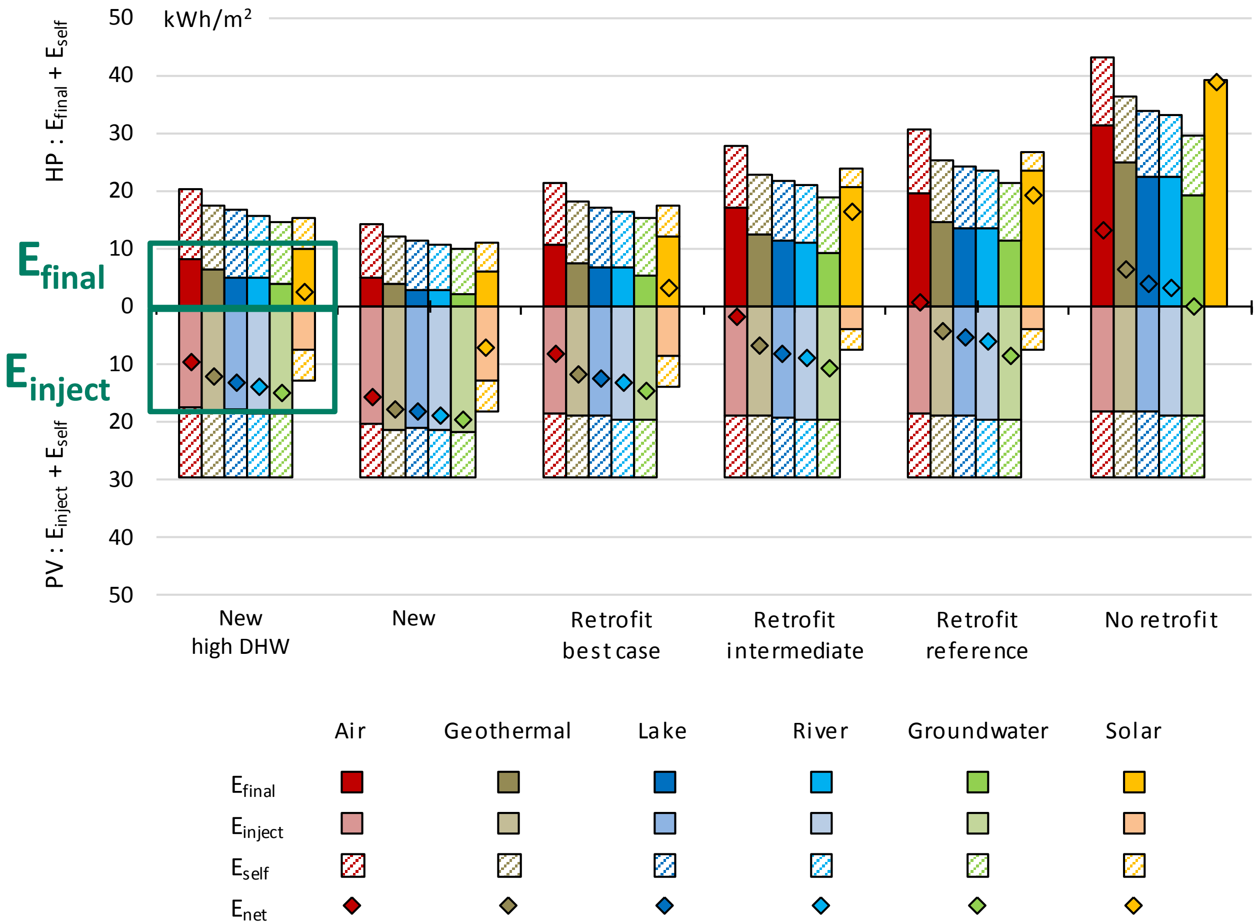


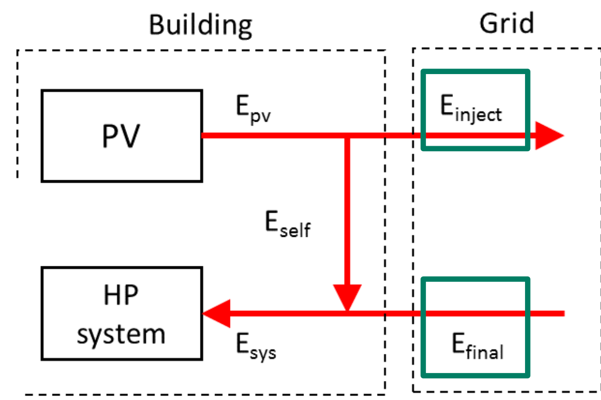
$E_{pv} > E_{sys}$

Except No ret. & Solar HP

HP & PV systems

System performance – low rise building





$E_{pv} > E_{sys}$

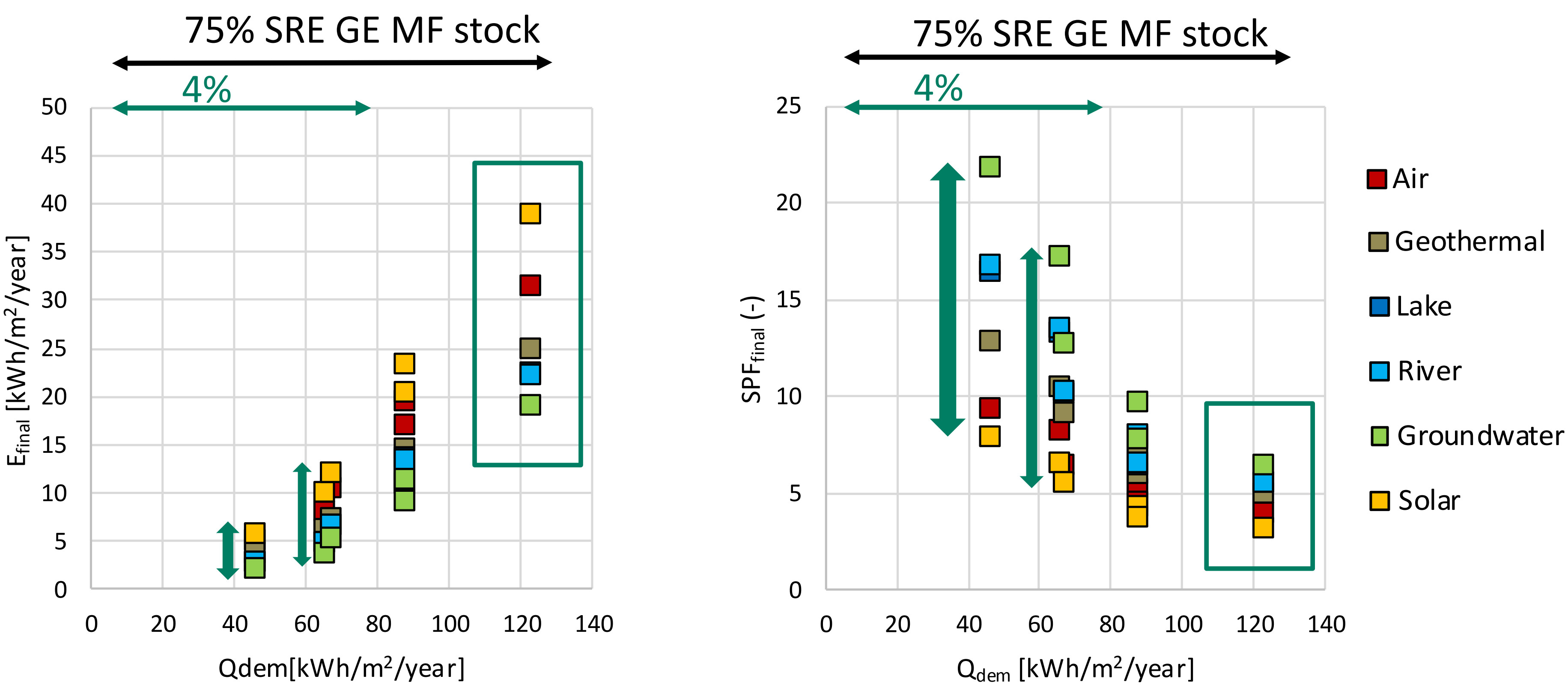
Except No ret. & Solar HP

Seasonal mismatch PV / heat demand:

$E_{final} >> 0$

Discussion

Final electricity consumption and SPF - low rise building



Low demand buildings (< 80 kWh/m^2)

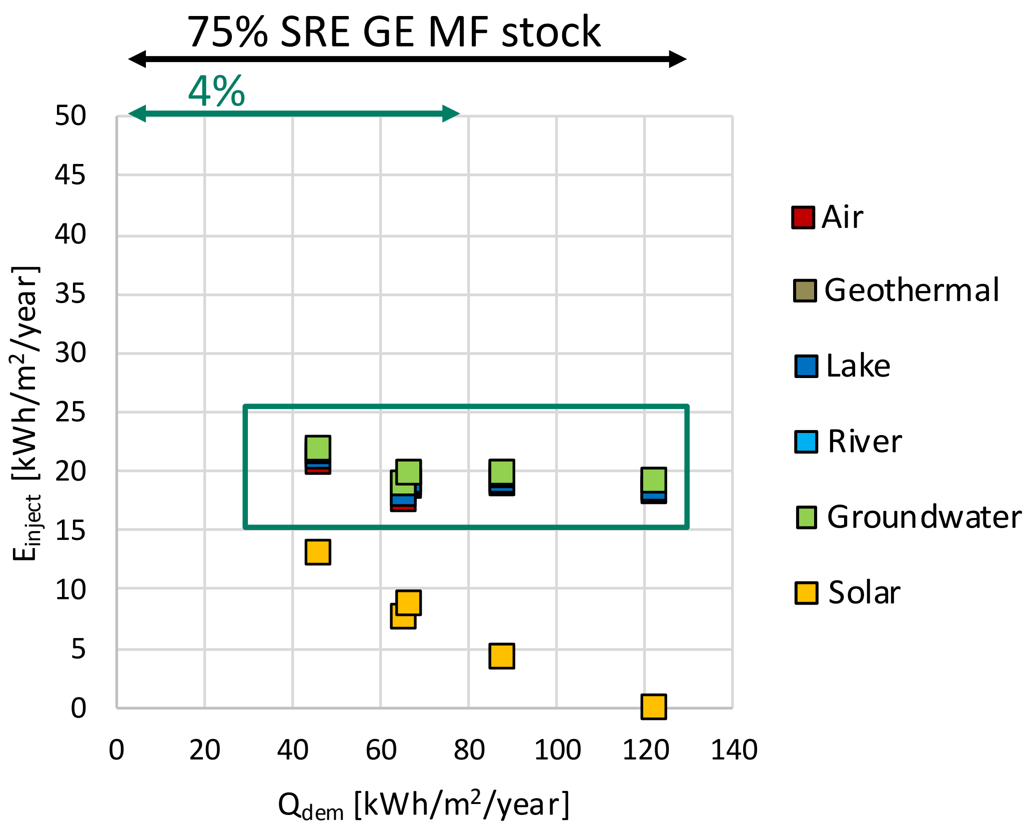
Choice of resource may not be driven by energy performance

SPF → Alone, not a sufficient indicator of system performance

→ Complementary indicators: Electricity consumption

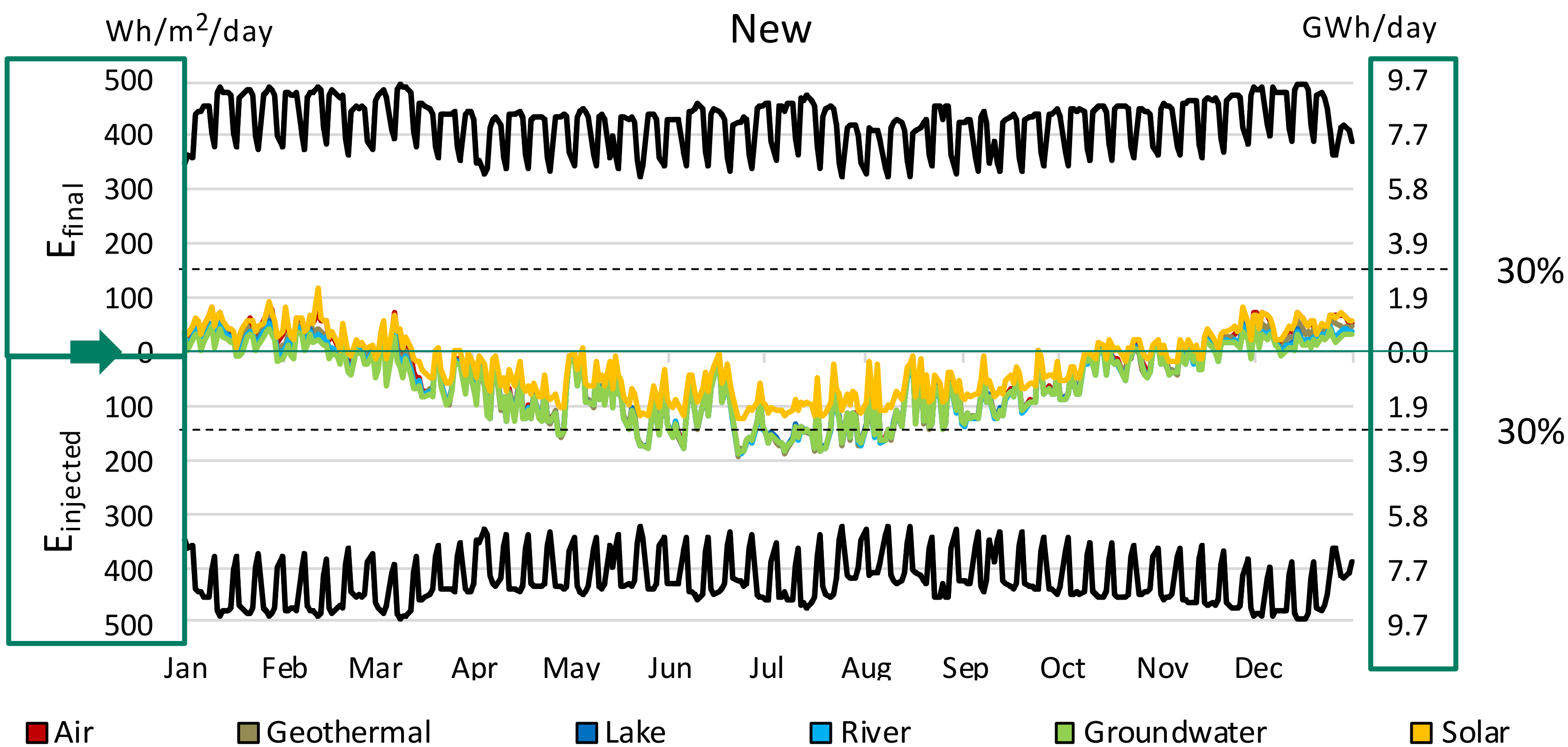
Discussion

Electricity injected in grid - low rise building:



Potential effect on regional load curve

low rise building



Potential effect on regional load curve

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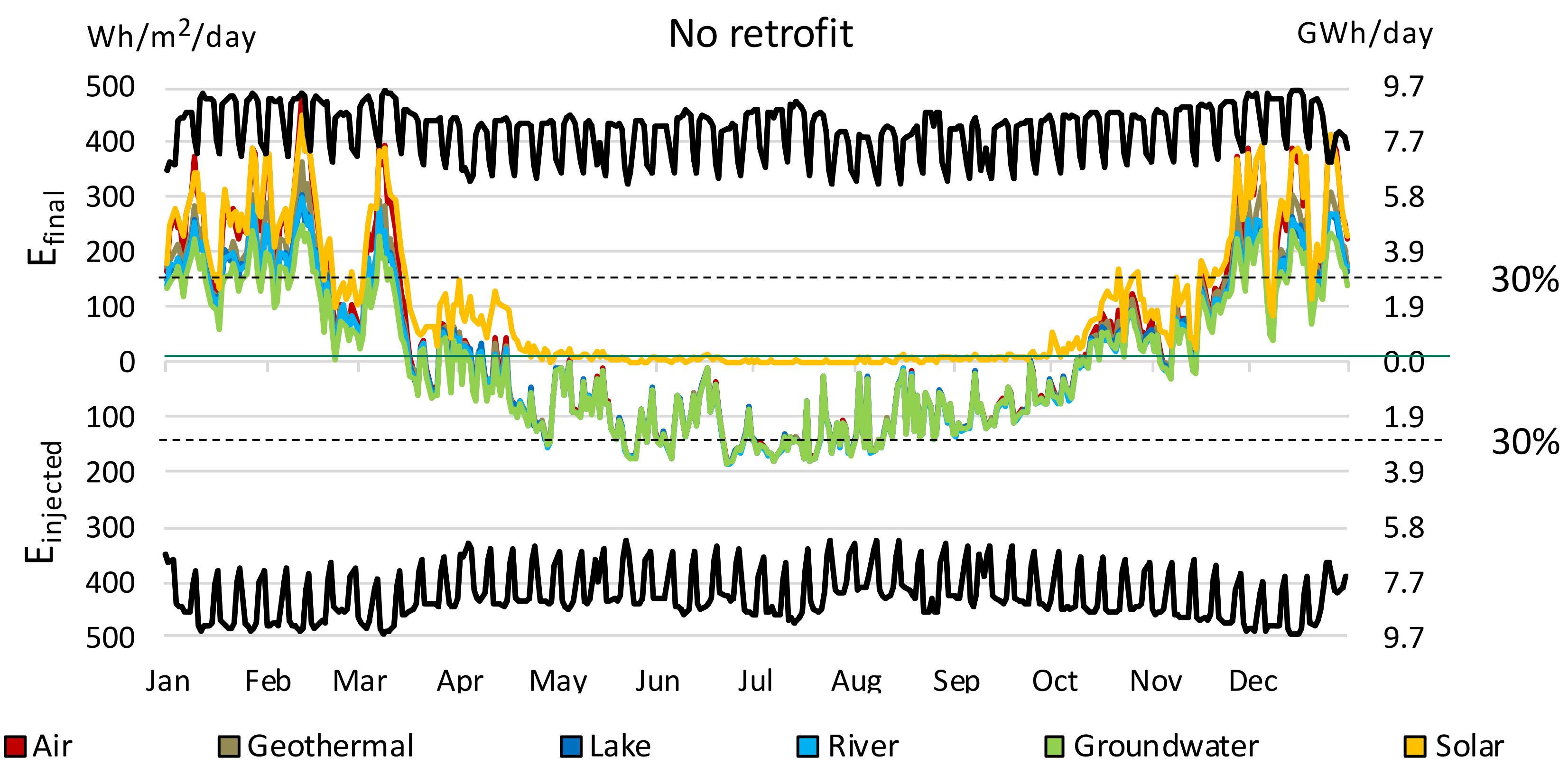

3. Conclusions

Resource classification (system performance)

Groundwater > River > Lake > Geothermal > Air

Solar depends on building demand

HP & PV system

$E_{pv} > E_{sys}$ (yearly balance)

E_{final} and E_{inject} have important values

→ Seasonal mismatch of PV and heat demand

Generalisation

Buildings < 80 kWh/m^2

Choosing resource will depend on other factors than energy performance

SPF → Alone, not a sufficient indicator of system performance

→ Complementary indicators: Electricity consumption & Peak loads

Conclusions/summary

Pompes à chaleur dans le résidentiel collectif:
Du retour d'expérience à la généralisation par simulation

Retour d'expérience

Analysis of an innovative solar assisted HP system

- excellent system reliability
- electric backup hardly needs to be used
- Absolute electric consumption (24 kWh/m^2/yr) reasonable due to a low thermal demand (68 kWh/m^2/yr)

Why SPF system of 2.9, when ~ 5 expected?

Due to decentralized DHW (no solar preheating)

With centralized DHW: SPF_{sys} 4.4

Simulation

For the overall system performance, system configuration is as important as individual components performance

Can SPF_{sys} of 5 be achieved ?

Yes, but only in New buildings, with low SH temperature and high collector area (0.20 - 0.25 m^2 per m^2 heated area ➔ less than 4 storeys)

Moreover:

- available roof area is not unlimited
- doubling solar collector area for small electricity saving may not be worthwhile

Pompes à chaleur dans le résidentiel collectif:
Du retour d'expérience à la généralisation par simulation

Can Solar HP system be used in Retrofitted and Non Retrofitted MFB buildings?

New and Best Case Retrofitted MFB, yes.

Retrofitted and No-retrofitted, be careful with Electricity and Solar Area

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HP & PV system

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E_{final} and E_{inject} have important values → Seasonal mismatch of PV and heat demand

Generalisation

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SPF → Alone, not a sufficient indicator of system performance

→ Complementary indicators: Electricity consumption & Peak loads

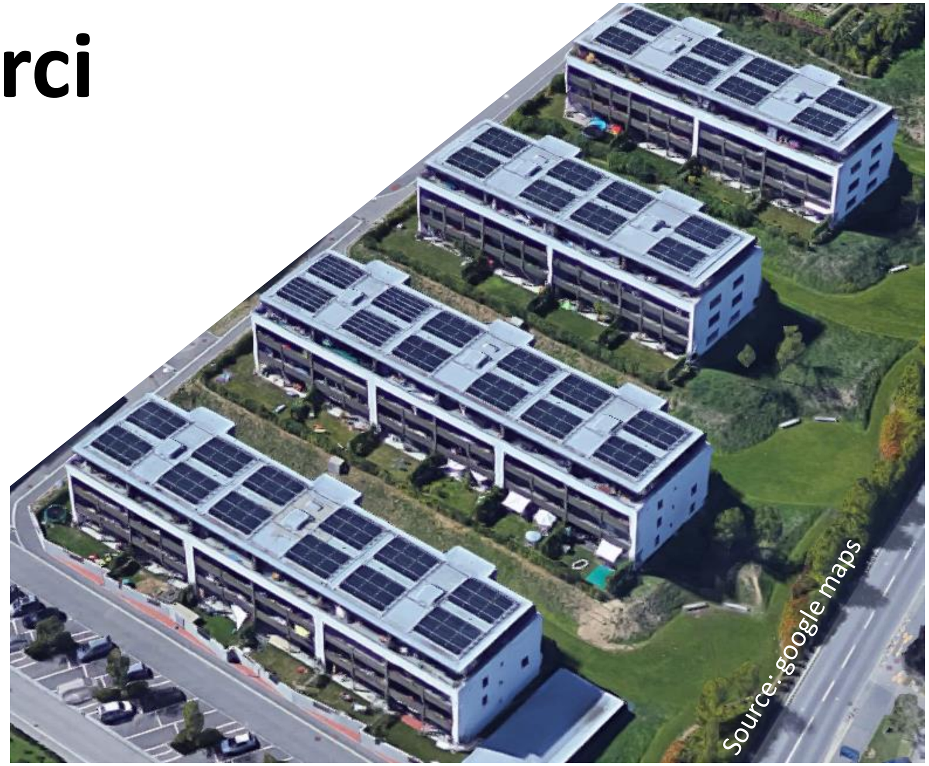
Future developments

Monitoring of:

- Air HP systems (mono and bivalent).
- Waste heat HP systems (used domestic hot water).
- Centralized groundwater + industrial waste heat HP system.

Pompes à chaleur dans le résidentiel collectif:
Du retour d'expérience à la généralisation par simulation

Merci



Carolina Fraga

carolina.fraga@unige.ch

11 mai 2017

Groupe Systèmes Énergétiques
Département F.-A. Forel des Sciences de l'Environnement et de l'Eau
Institut des Sciences de l'Environnement
FACULTÉ DES SCIENCES
UNIVERSITÉ DE GENÈVE