POLYTECH.MONS

Integrated Modelling of a Dwelling and its Heating System

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I. Aim of the Research

EPB Directive:

- calculation of primary energy consumption

The heating system is a heat pump:

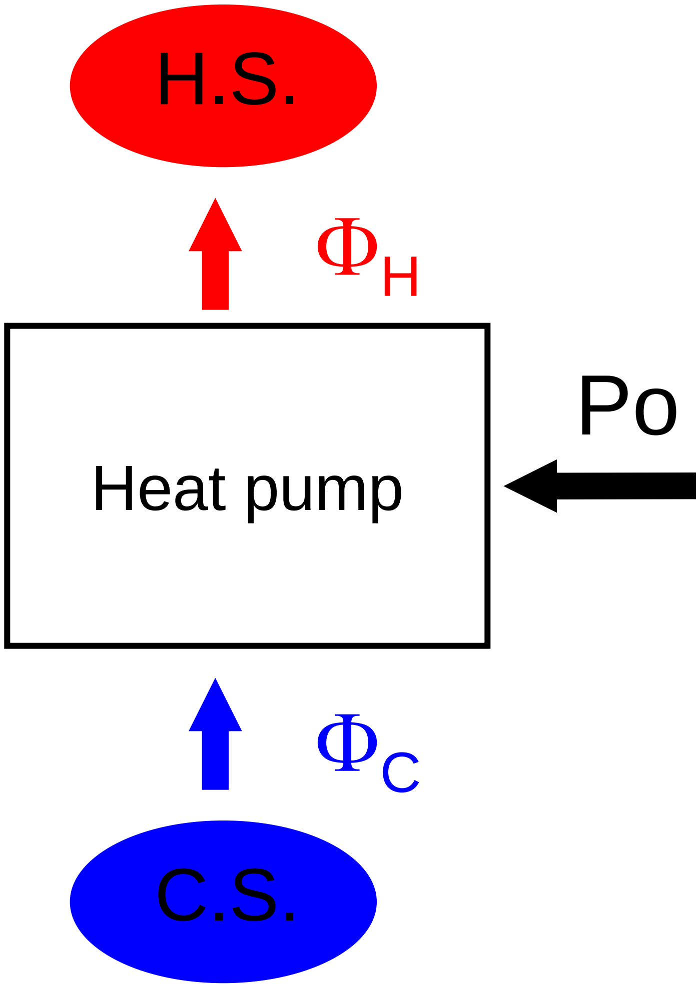
- heat delivered by a heat pump is more difficult to predict than the one delivered by an oil or gas burner

- Performance (COP) of the heat pump and primary energy consumption depend on the coupling between the building and the heat pump

Study of the heat demand and of the performance of a heat pump installed in a single-family dwelling in Belgium:

- simulation of the building and the heat pump

- comparison with experimental data (monitoring)



Heat sinks (H. S.):

- Floor heating
- Forced air Heating
- ...

Cold sources (C. S.):

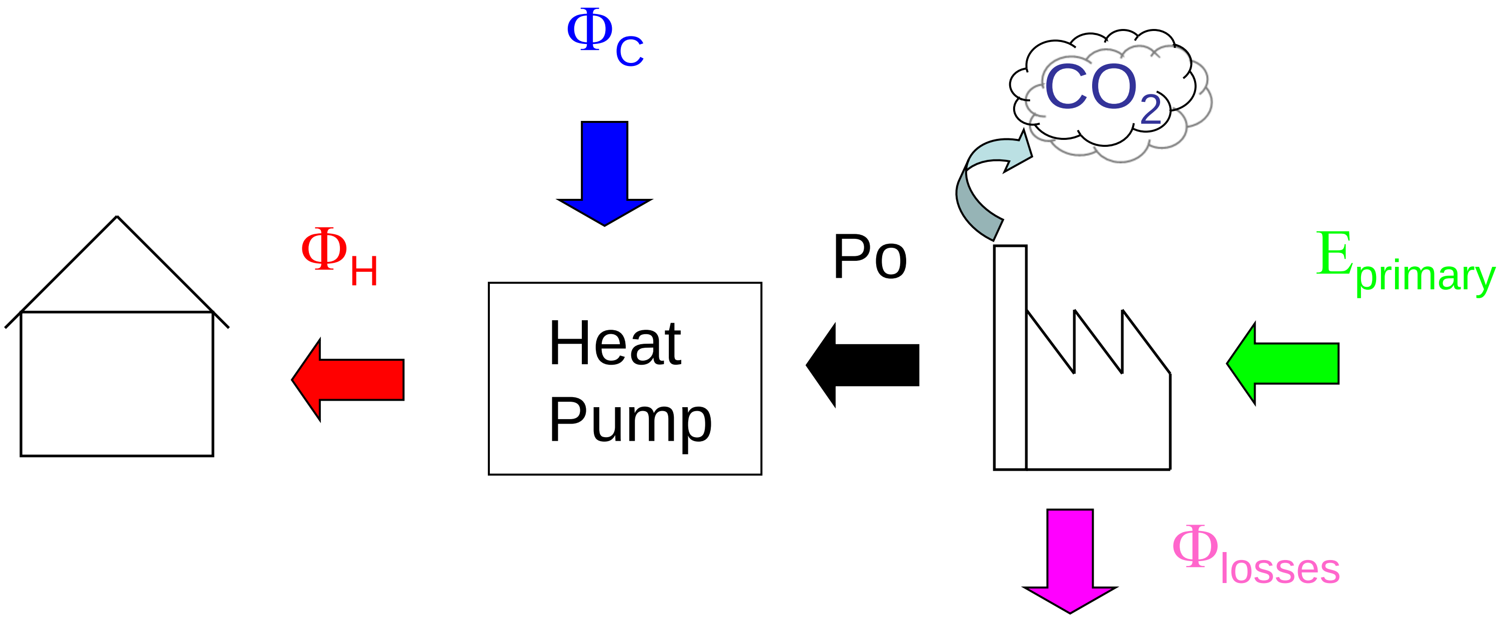
- Outdoor air
- Backyard ground
- Underground water
- ...

Coefficient of Performance:

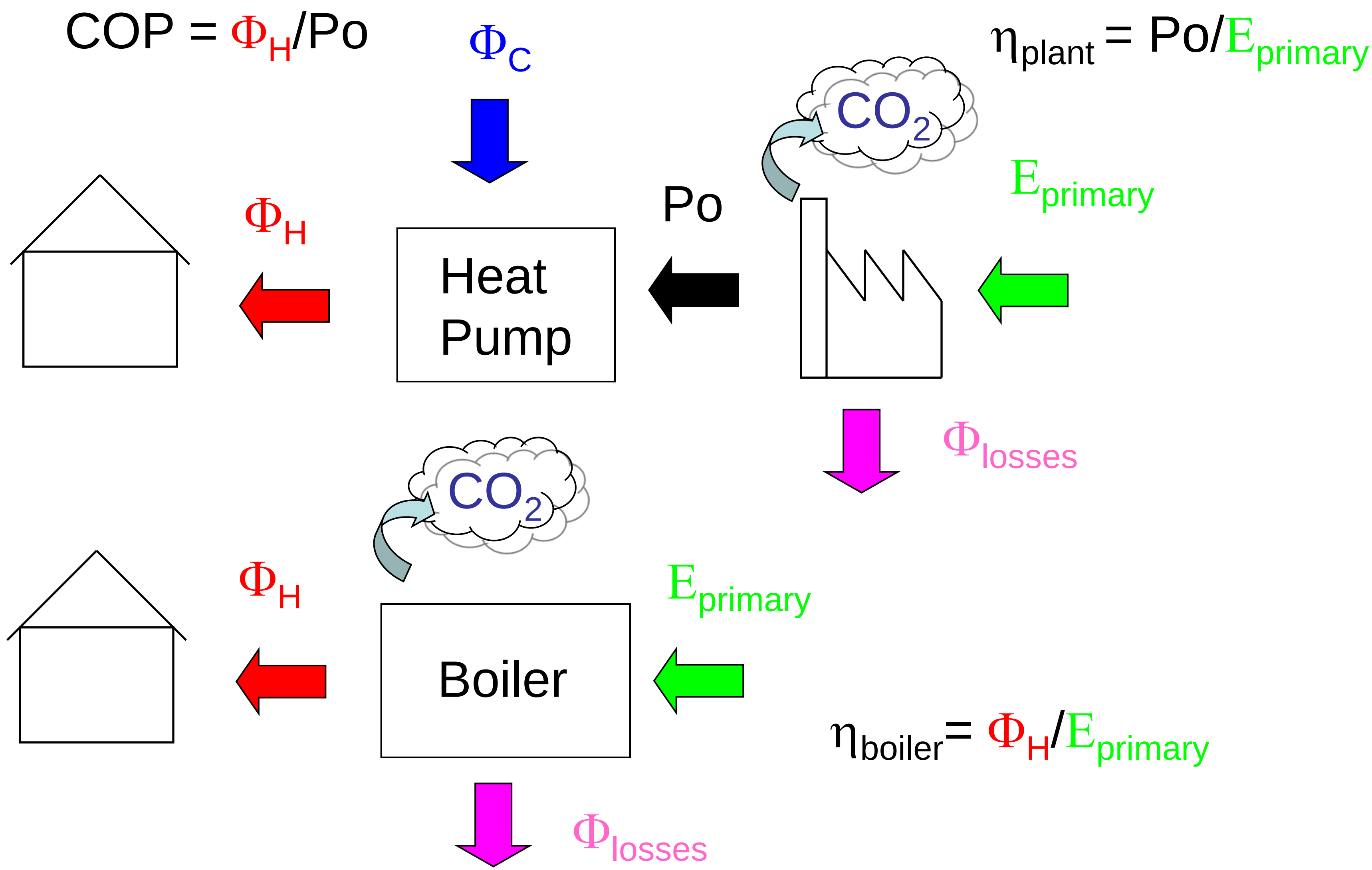
COP= Φ_H/Po

P_O is an electrical energy not a primary energy.

Electricity is produced in power plants from primary energy (renewable or not)



II. Heat Pumps



$$E_{primary} = \Phi_H / (\eta_{plant} COP)$$

$$E_{primary} = \Phi_H / (\eta_{boiler})$$

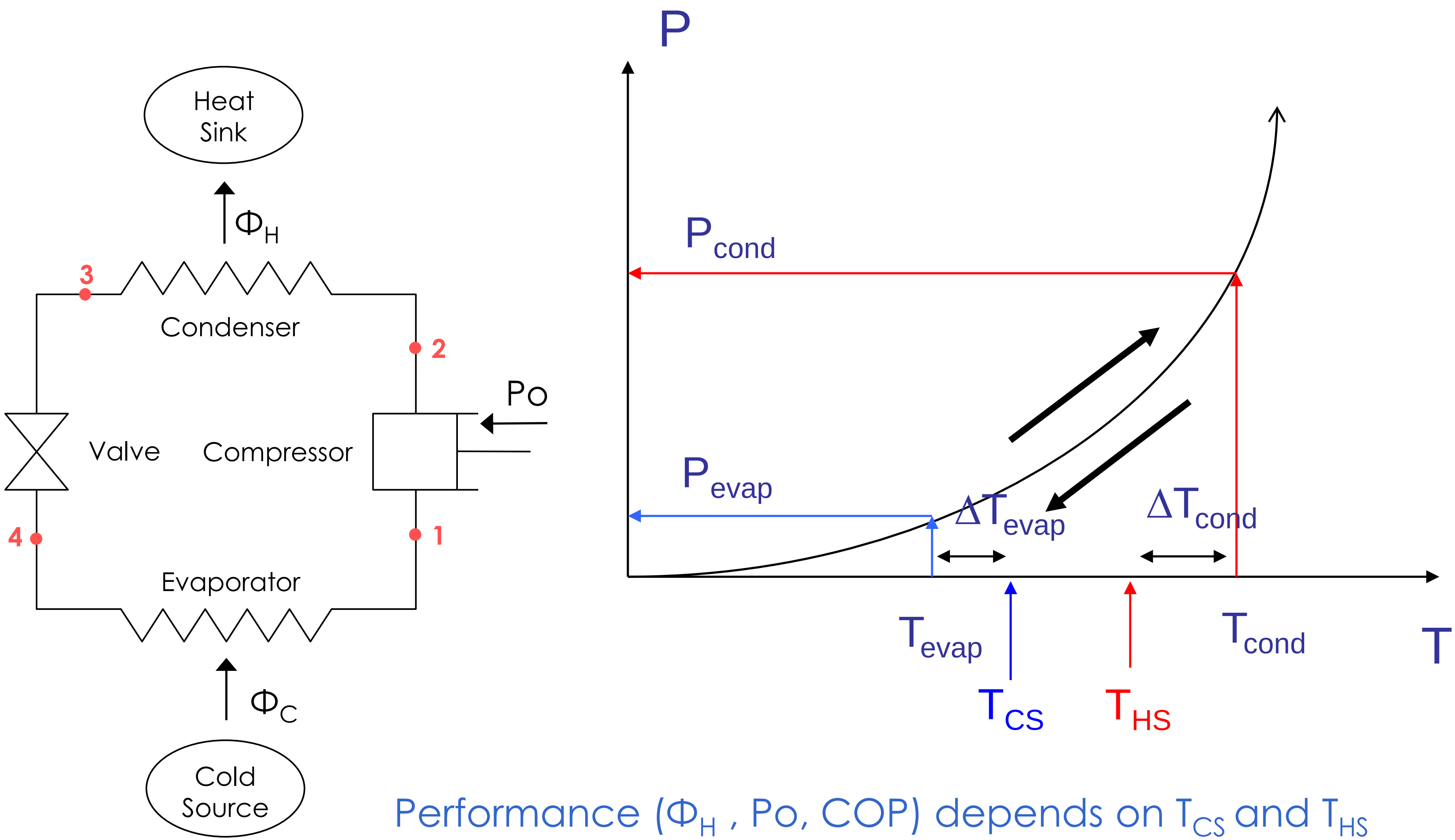
$$\eta_{plant} COP > \eta_{boiler}$$

η_{boiler} **= 0.9**

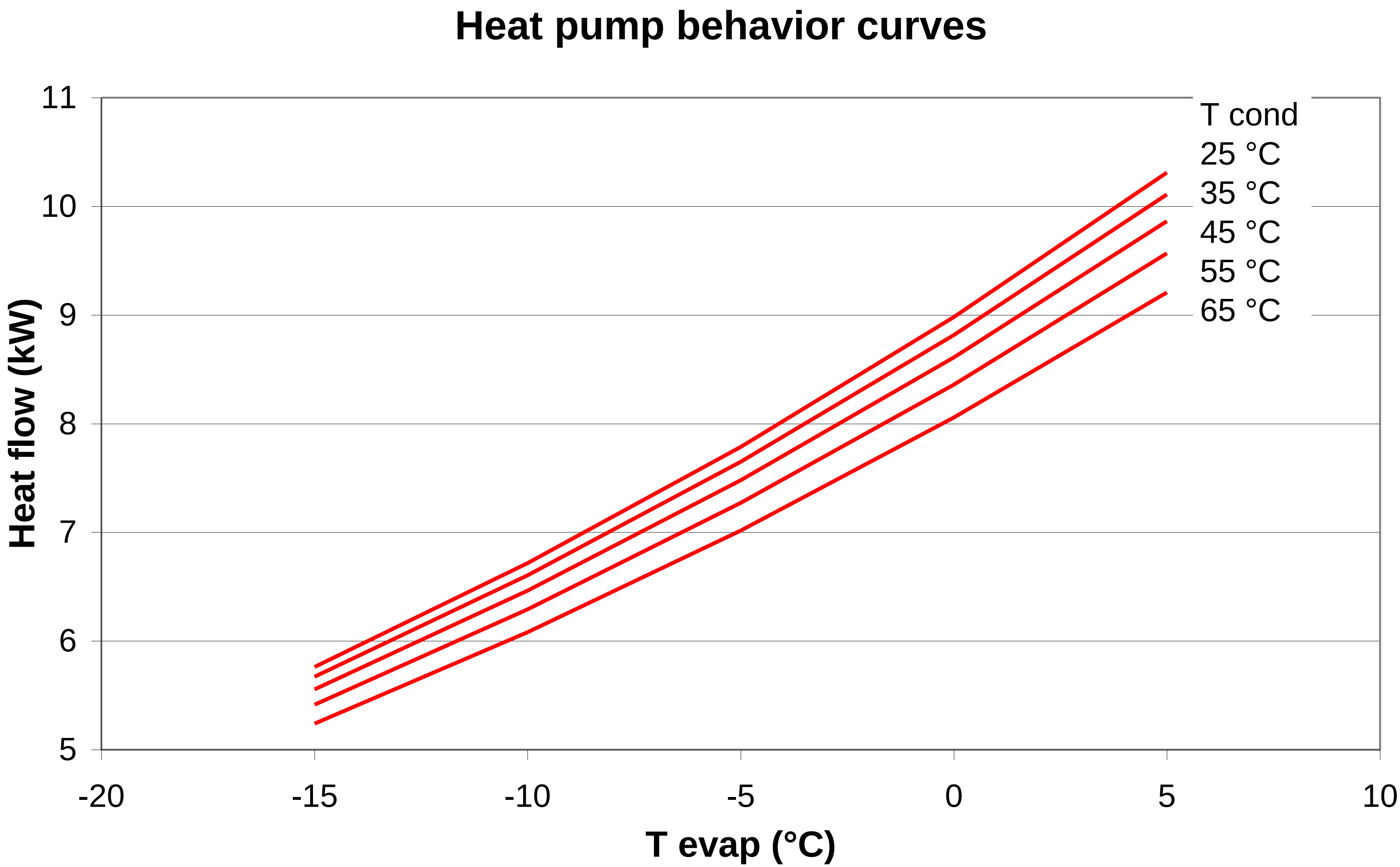
η_{plant} **= 0.4 (in Belgium)**

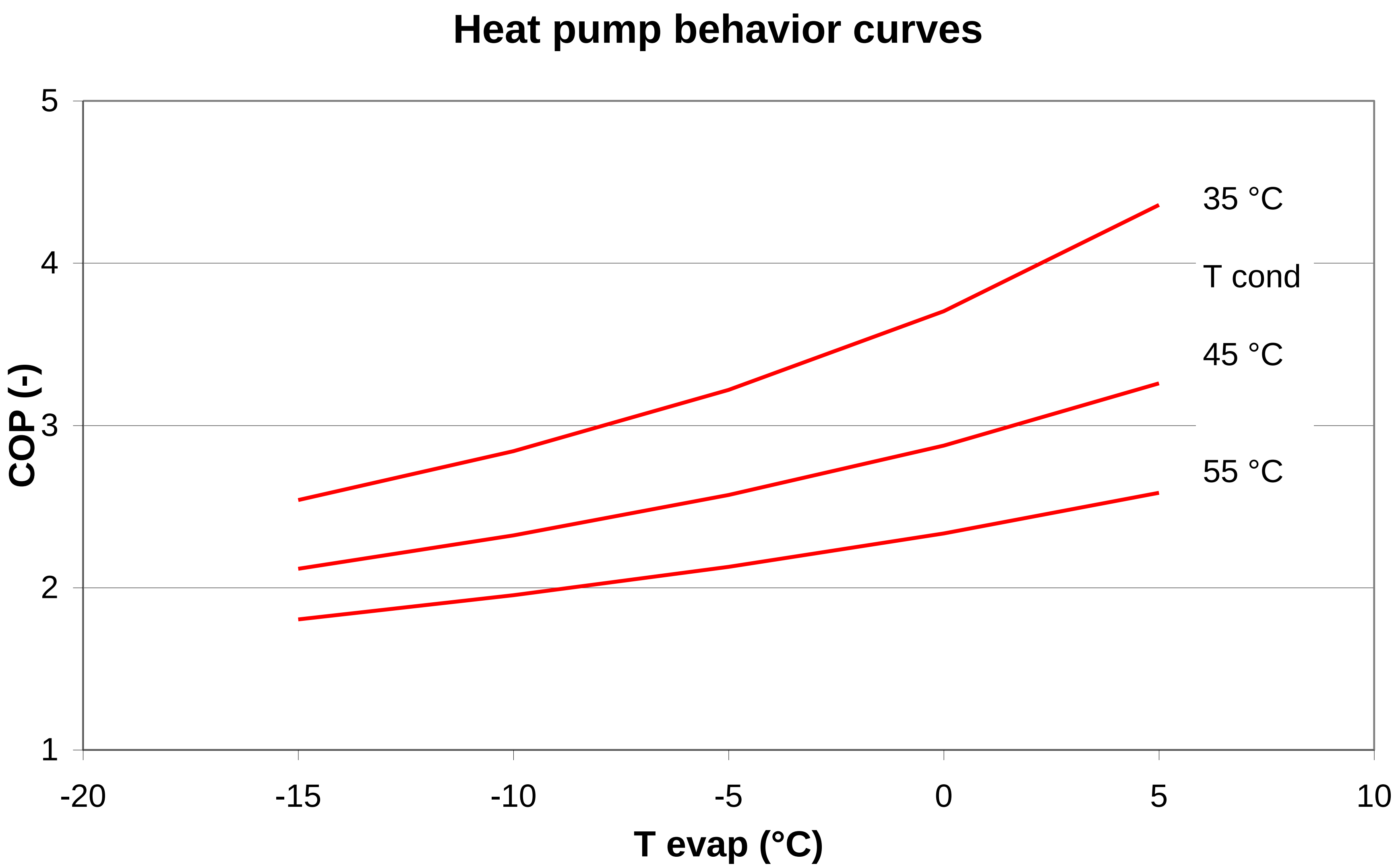
COP up to 3.0 (measurements)

- **COP > 2.2 for energy savings**
- **COP > 1.8 for CO_2 emission reduction**
- **For costs, it depends on the peak and off-peak prices and the off-peak running rate**



Performance (Φ_H , Po, COP) depends on T_{CS} and T_{HS}


Heat pump behavior curves
Heat flow (kW)
11
10
9
8
7
6
5
-20
-15
-10
-5
0
5
10
T evap (°C)
T cond
25 °C
35 °C
45 °C
55 °C
65 °C


Heat pump behavior curves
5
4
3
2
1
COP (-)
-20
-15
-10
-5
0
5
10
T evap (°C)
35 °C
T cond
45 °C
55 °C

III. Dwelling

Single-family detached house in a village: Leuze (centre of Belgium)

<u>Data</u>: - Insulation: rock wool : 14 cm (walls), 16 cm (roof)

- Windows : 23 m², k_v=1.1 W/m².K
- Walls and roof Area: 364 m²
- Heated volume: 439 m³
- Average heat loss coefficient: 0.38 W/ m²K

III. Dwelling

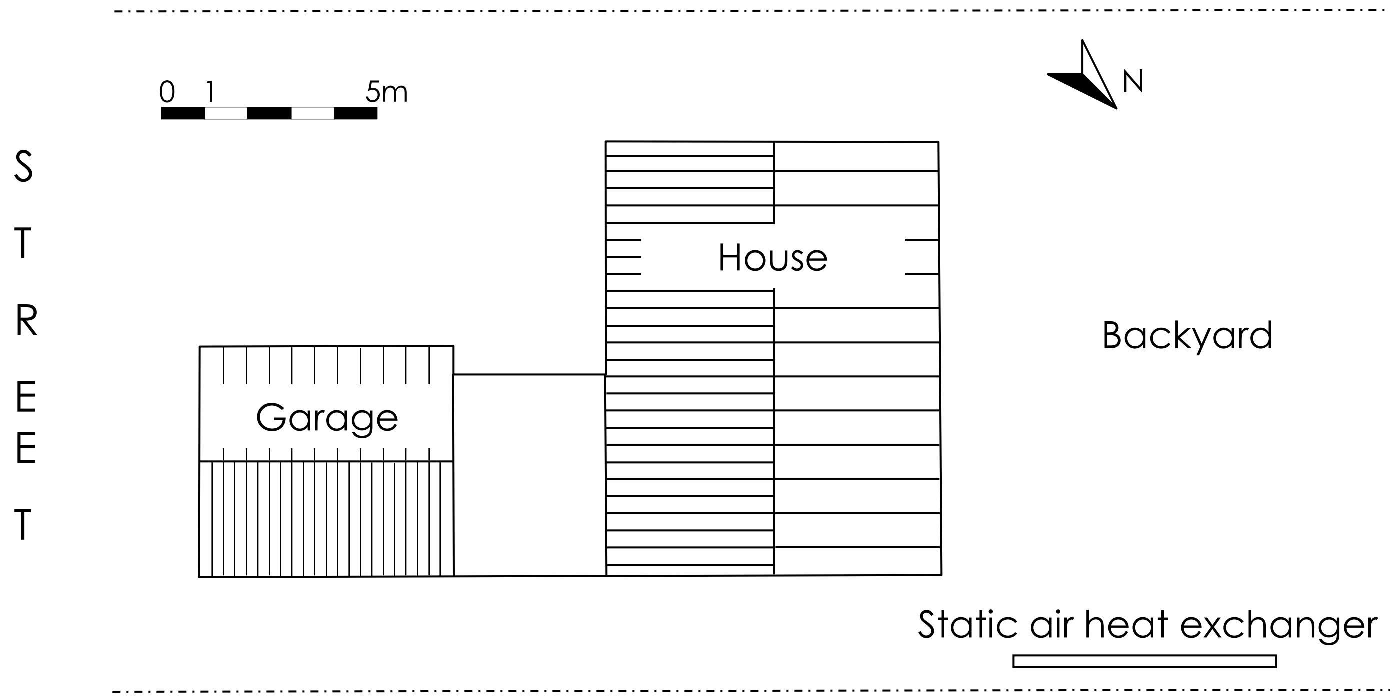
Heating: Air-to-water heat pump

low temperature (35 °C) heating floor

Cooling: no mechanical cooling

Domestic hot water: solar panes (5 m^2) and electric resistor

Ventilation: mechanical air extraction with counter-flow heat exchanger



III. Dwelling

<u>Heat sink</u>:

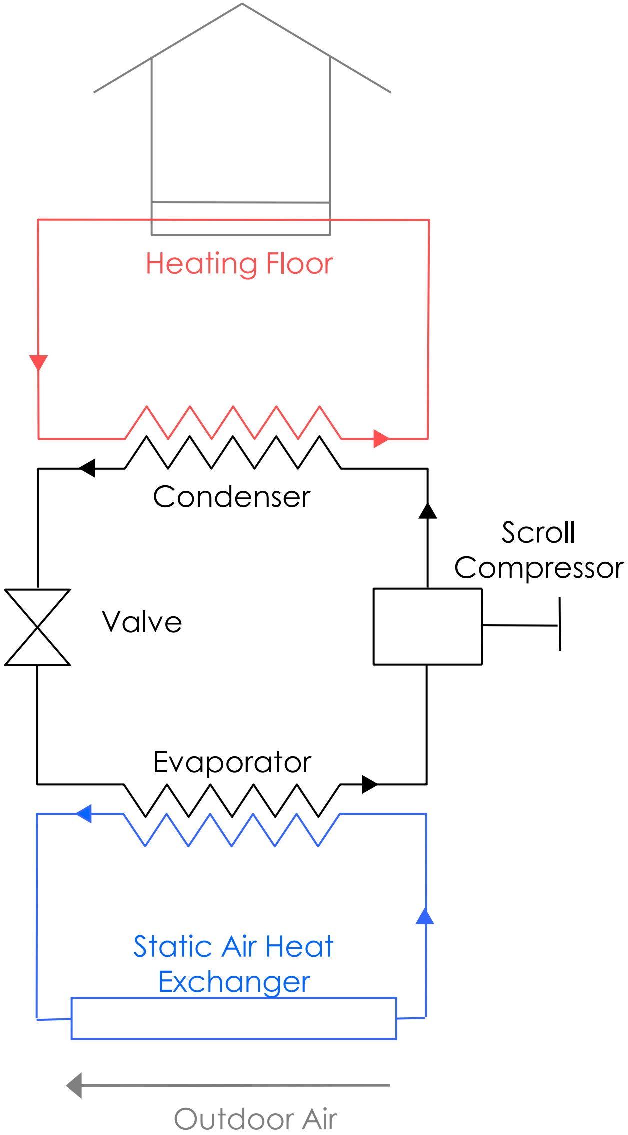
-Heating floor

-Water

<u>Cold source</u>:

-'static' air heat exchanger (natural convection)

- glycol-water blend



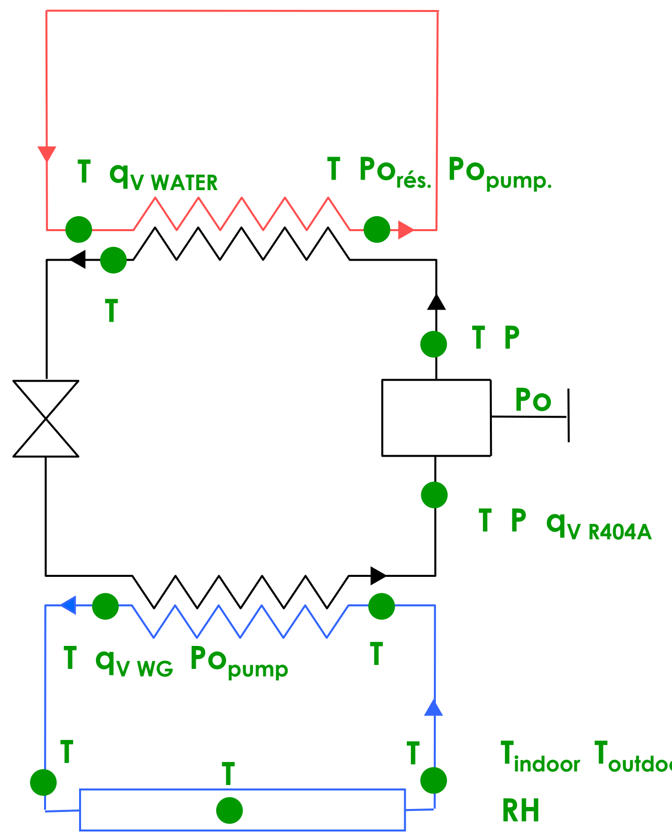
IV. Performance Monitoring

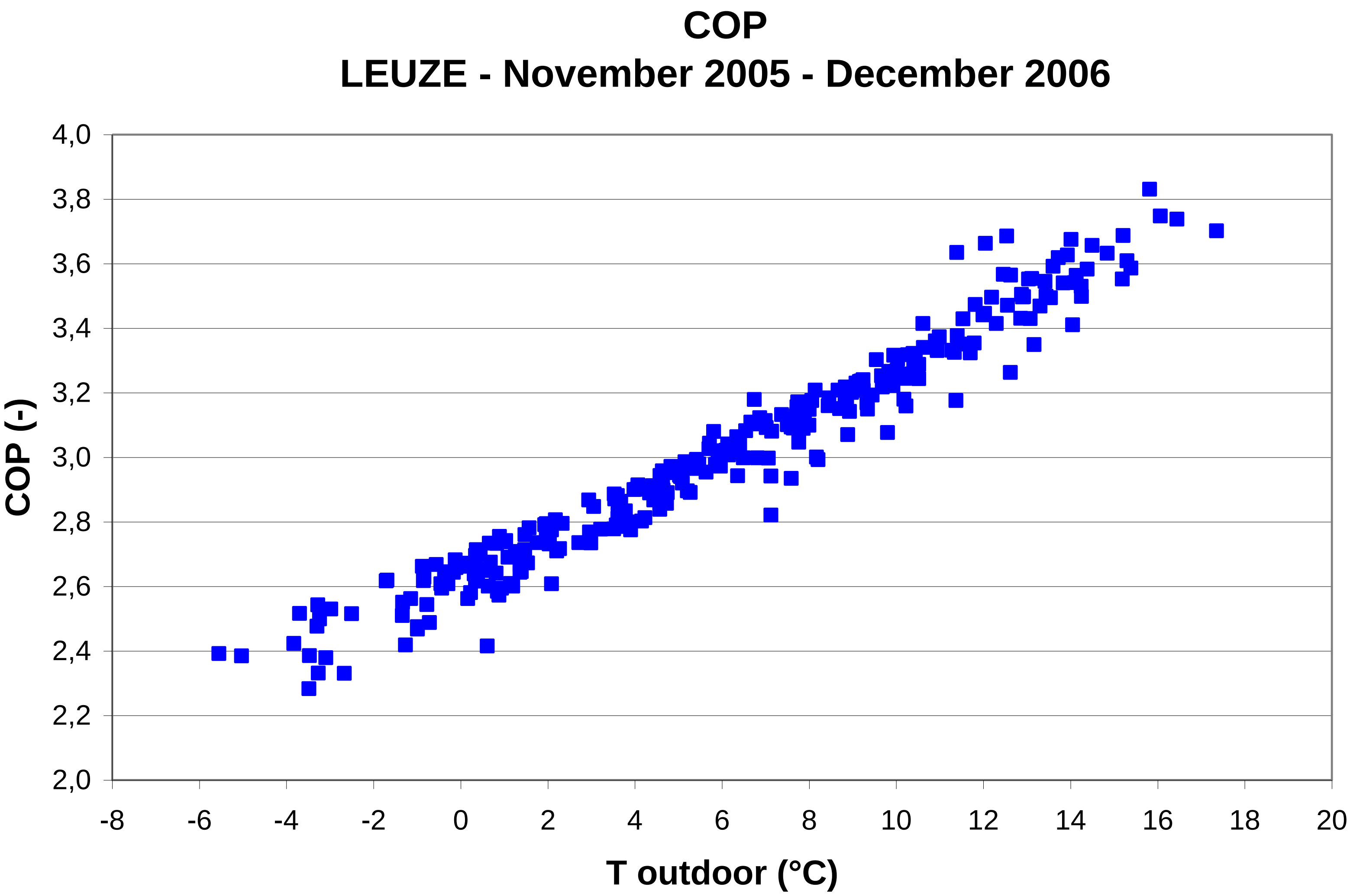
Monitoring of the heat pump during 2 years (november 2005 – may 2007):

Measurements: temperatures, pressures, volumetric flow rates (water, glycol-water, refrigerant (R404A)), electric consumption (compressor and pumps), various other measurements (climate)

Computation of:

- $\Phi_H = q_{M\ R404A} \cdot \Delta h_{cond}$ (R404A)
- $\Phi_H = q_{M\ WATER} \cdot c_p \cdot \Delta T$ (water)
- $COP = \Phi_H / P$
- Evaporation and Condensation temperatures




COP
LEUZE - November 2005 - December 2006
COP (-)
4,0
3,8
3,6
3,4
3,2
3,0
2,8
2,6
2,4
2,2
2,0
-8
-6
-4
-2
0
2
4
6
8
10
12
14
16
18
20
T outdoor (°C)

IV. Performance Monitoring

Heat pump		
Annual heat	(kWh)	8744
COP	(-)	2,82
Annual electrical consumption	(kWh)	3103

Costs		
Electricity (Peak rate)	Eur/kWh	0,180
Electricity (Off-peak rate)	Eur/kWh	0,090
Natural gas	Eur/kWh	0,065
Fuel Oil	Eur/l	0,550

CO_2		
Electricity (Belgium)	kg/kWh	0,300
Natural gas	kg/kWh	0,251
Fuel Oil	kg/kWh	0,306

Heating Costs (Eur/year)	
Heat pump	414
Natural gas efficiency = 90%	632
Fuel Oil efficiency = 90%	575
Electricity	1163

CO_2 production (kg)	
Heat pump	930
Natural gas	2439
Fuel Oil	2973
Electricity	2623

Building Simulation

-Heat transfer equations in MATLAB

-Monozone simulation

-Standard solar Irradiance for Belgium with shadowing factor (0.6)

-Standard internal gain

-Experimental outdoor temperature and RH

-Heating floor: model based on TRNSYS model

Heat Pump Simulation

-Software developed in our department (FRIPAC)

-Heat transfer equations for various heat exchangers: needs geometrical data of the exchangers

-Model for scroll and reciprocating compressors from: parameters determined from fit of experimental or manufacturer data

Coupling

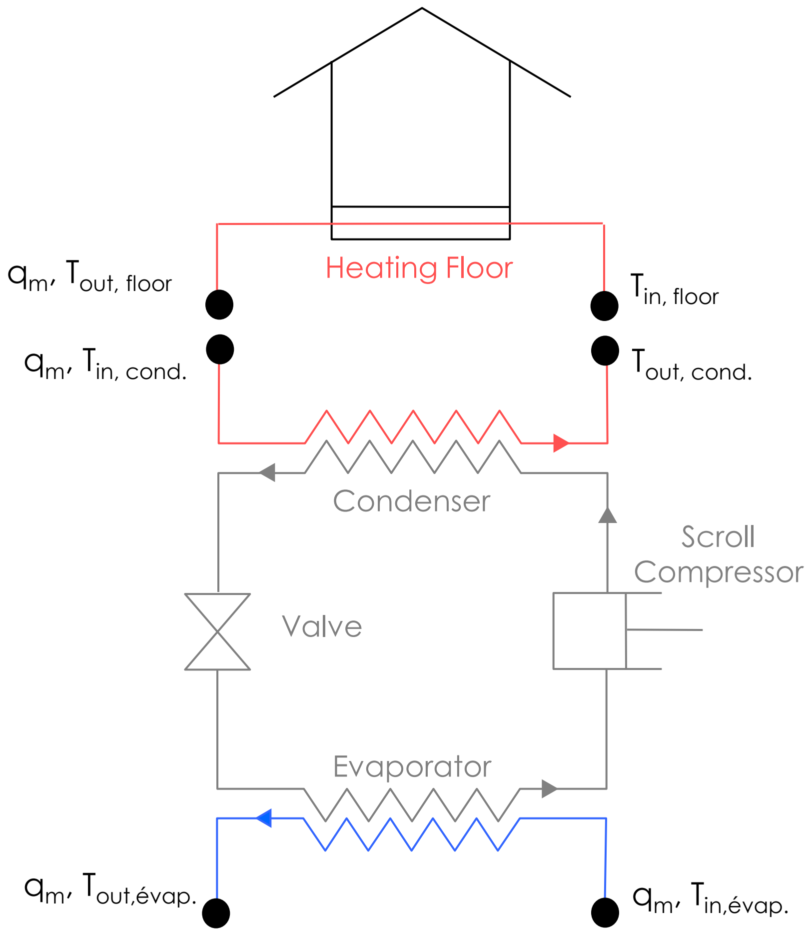
- Building model, heating floor model and heat pump model are coupled in MATLAB

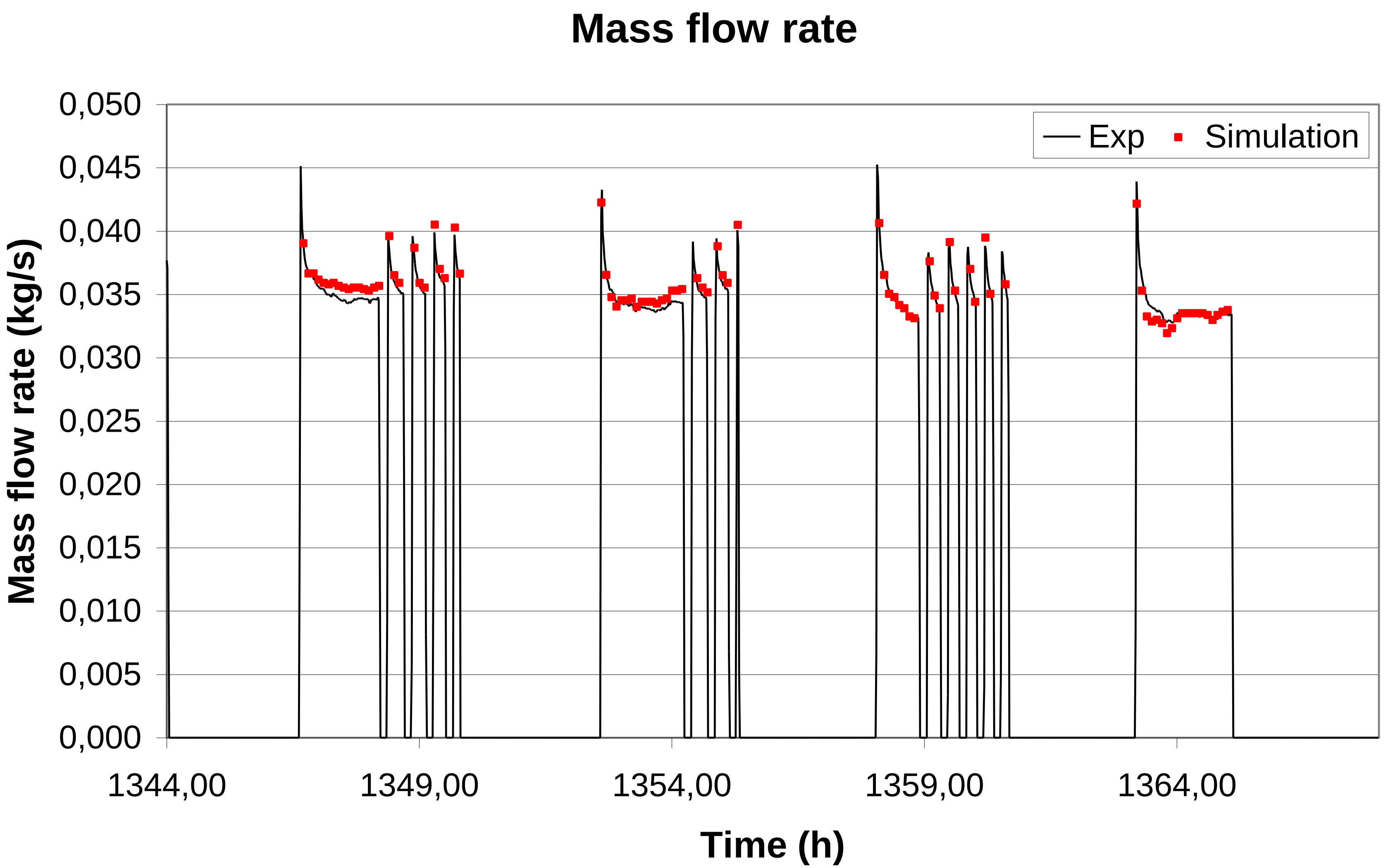
- Static Air Heat Exchanger not modelled yet

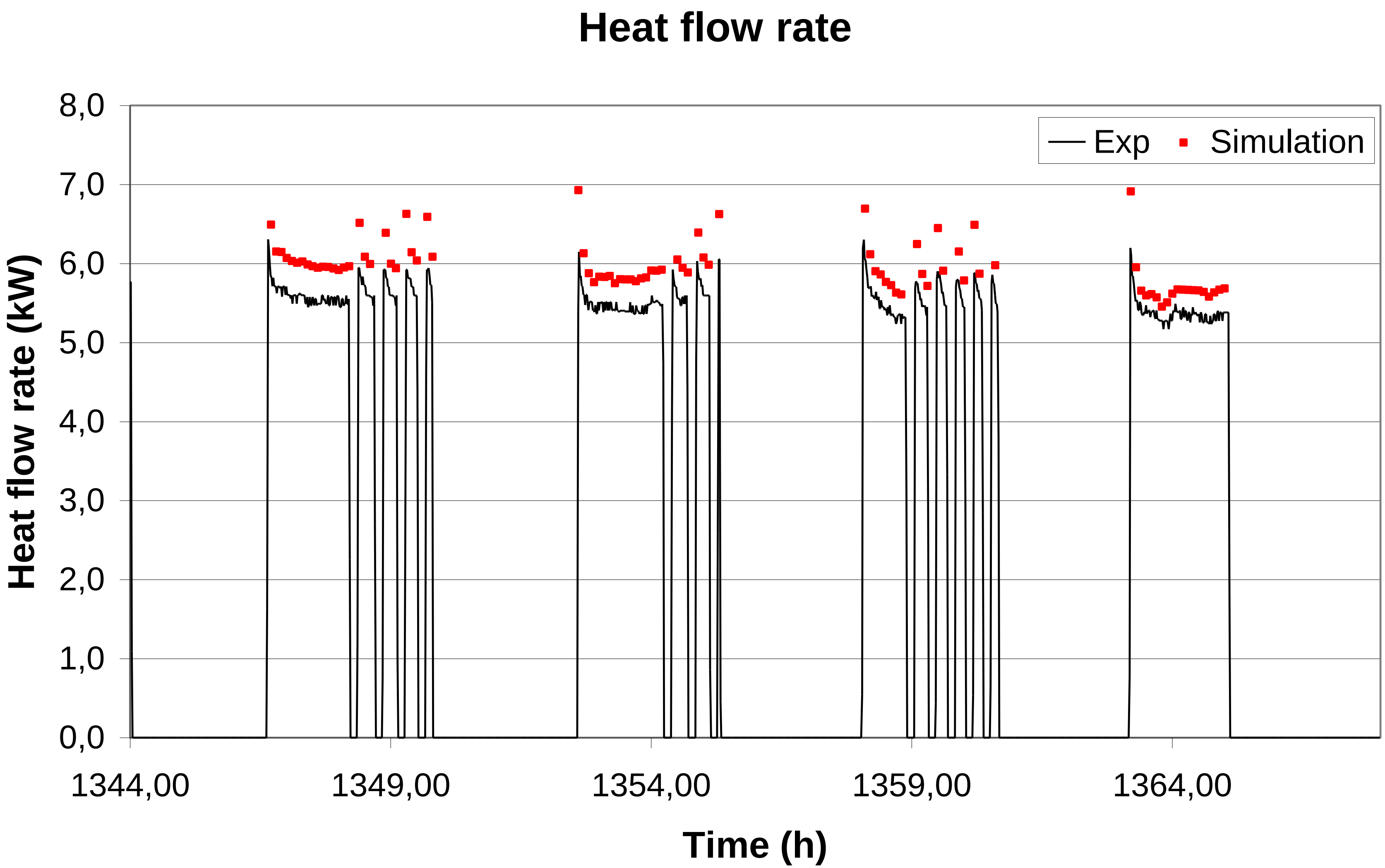
Simulation conditions

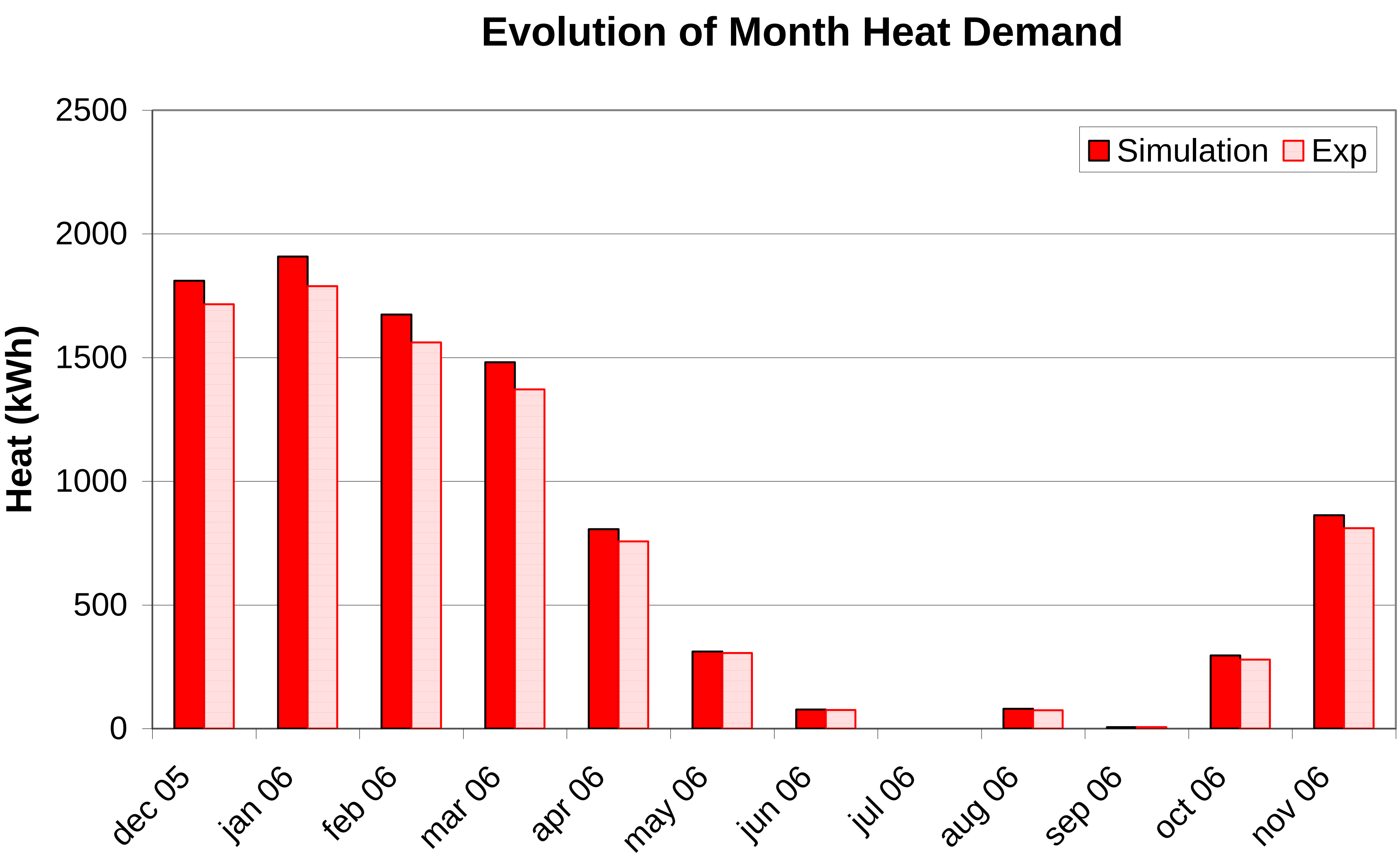
- differential equations solved every 6 minutes for one year

- Heat pump set on at the same time as measured experimentally: allows the computation of the indoor temperature and of the heat delivered to the dwelling as well as the electrical consumption

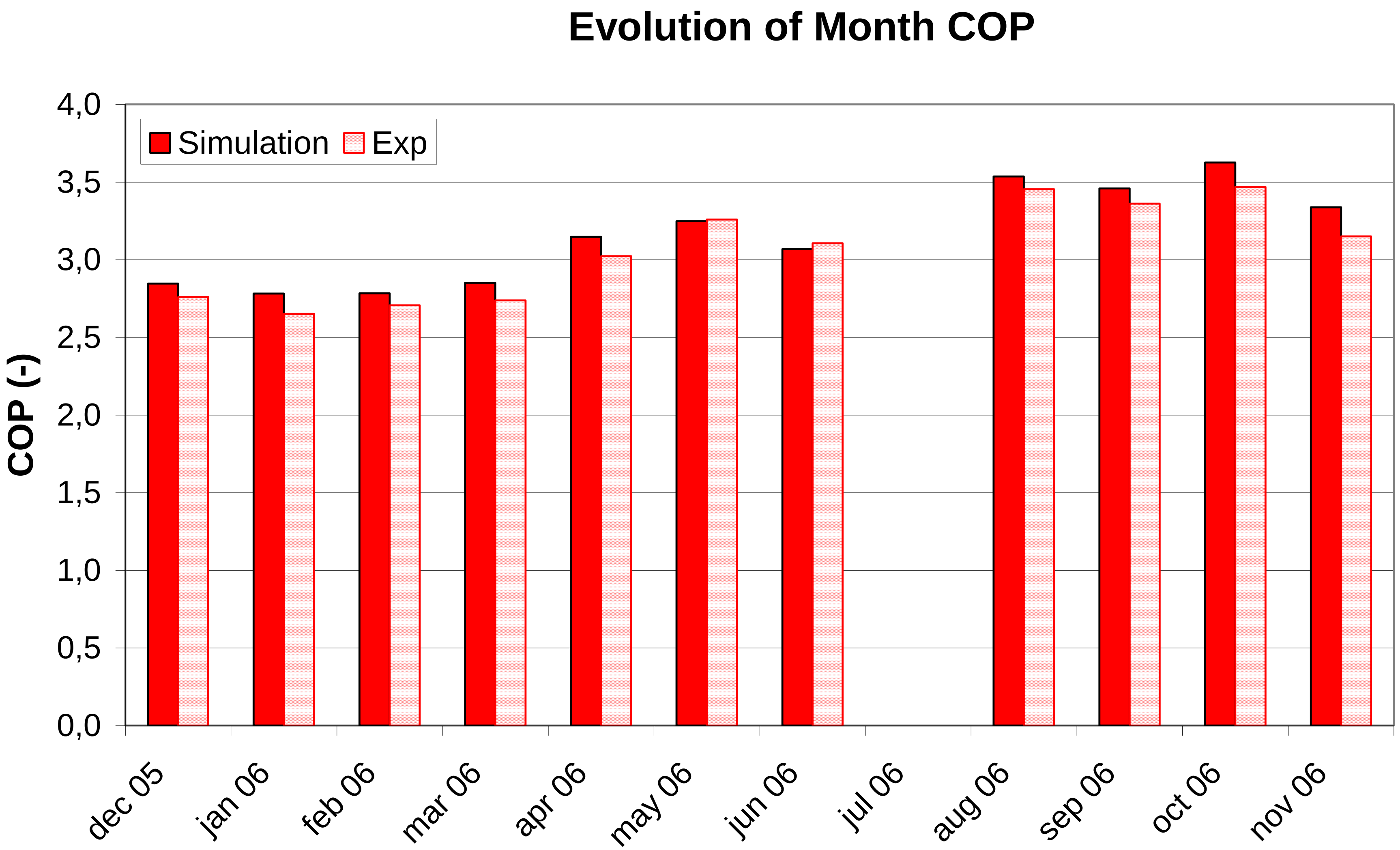



Mass flow rate
Mass flow rate (kg/s)
0,050
0,045
0,040
0,035
0,030
0,025
0,020
0,015
0,010
0,005
0,000
1344,00
1349,00
1354,00
1359,00
1364,00
Time (h)
Exp
Simulation


Heat flow rate
8,0
7,0
6,0
5,0
4,0
3,0
2,0
1,0
0,0
Heat flow rate (kW)
Exp
Simulation
1344,00
1349,00
1354,00
1359,00
1364,00
Time (h)



Evolution of Month Heat Demand
Heat (kWh)
2500
2000
1500
1000
500
0
Simulation
Exp
dec 05
jan 06
feb 06
mar 06
apr 06
may 06
jun 06
jul 06
aug 06
sep 06
oct 06
nov 06


Evolution of Month COP
Simulation
Exp
COP (-)
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
dec 05
jan 06
feb 06
mar 06
apr 06
may 06
jun 06
jul 06
aug 06
sep 06
oct 06
nov 06

V. System Simulation

Heat pump			
	Heat (kWh)	Electricity (kWh)	COP (-)
Exp (dec 05 - nov 06)	8743	3103	2,82
Sim (dec 05 - nov 06)	9312	3185	2,92
NBN 62-002	9778	-	-
EPB Belgium	14201	-	-

Primary Energy (EPB Belgium)				
	Heat (kWh)	E primary (kWh)	E ref (kWh)	E level (-)
Flemish Region	14201	20471	28721	0,71
Walloon Region	14201	20471	34209	0,60

VI. Conclusions

Simulation:

- Improvement of the calculated heat flow rate (heat pump parameters)

- Multizone building model

Heat pump:

- Add model for the static air heat exchanger

Primary Energy Consumption:

- Try better heat pumps (variable speed compressor)

- Try other heat pumps (ground-coupled, …)