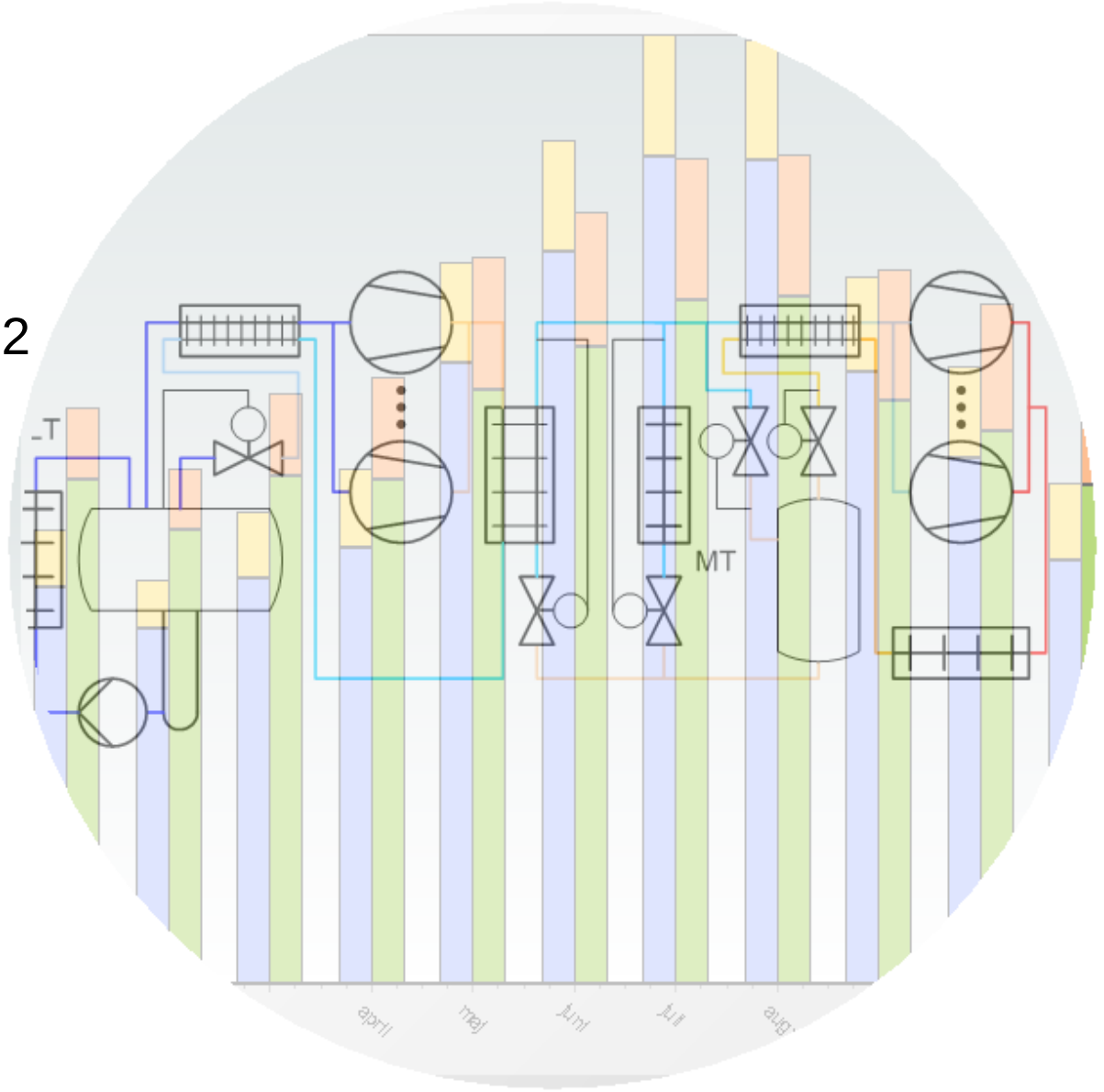
Yearly energy consumption of transcritical CO_2 plants

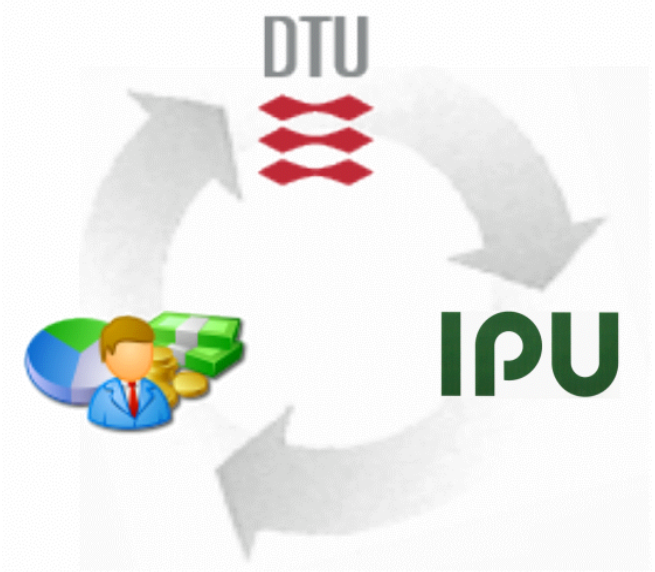
Morten Juel Skovrup

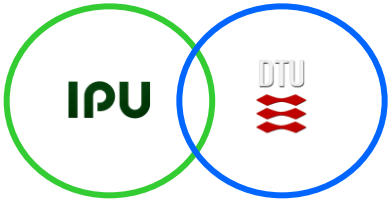
KVCA Seminar May, 2009



- A non-profit organisation at the TU of Denmark
- Research and development projects on contract

- 60 fulltime staff
- 60+ associated DTU staff
- Turnover: ~ 6 mill EUR/yr





... since 1956

Agenda

- Intro
- Simulation of yearly energy consumption
  - IPLV, SEER, ESEER…
  - Comparing different systems
- Demo Pack Calculation II
- Results
- Future…

The Project

- Calculation of yearly energy consumption is part of the project:
  - “Development and use of simulation tools for energy optimisation of refrigeration systems with CO2 as the refrigerant”
- 2007-2009
- Sponsor: ELFORSK Forskning & Udvikling i effektiv energianvendelse; danskenergi | net
- Participants:

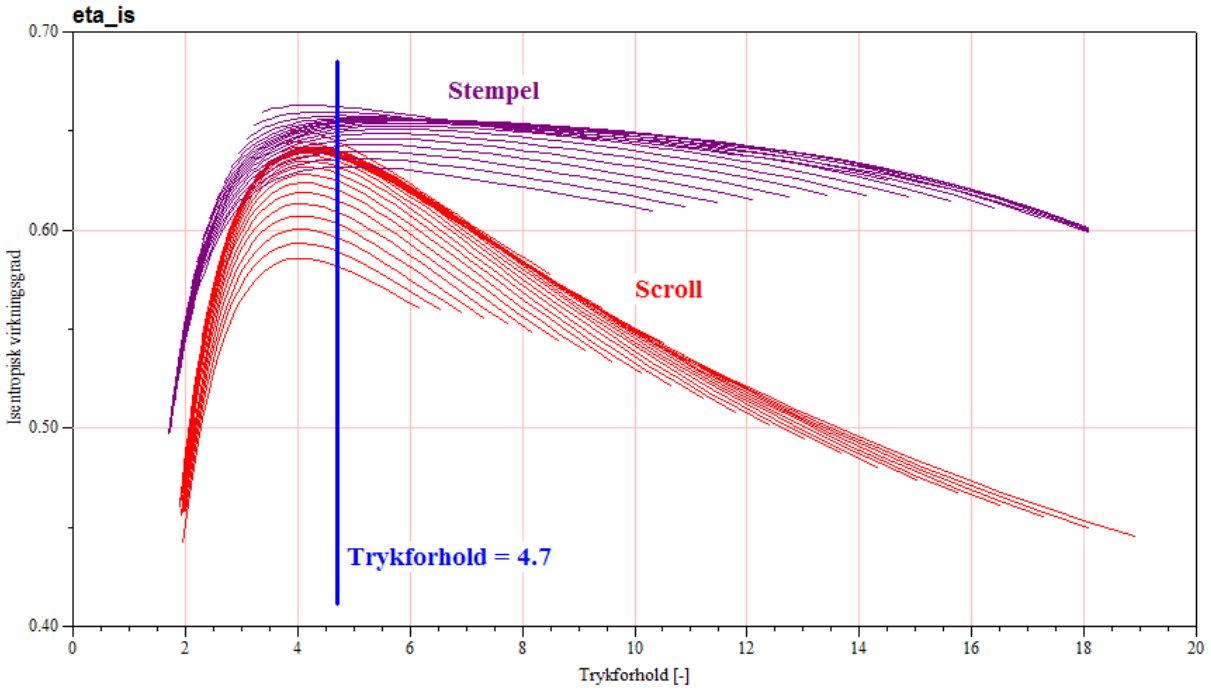
Simulation of yearly energy consumption

- Why?
  - Systems seldom runs in dimensioned condition
  - Most of the time:
    - Part load
    - Different ambient conditions

- This becomes important when:
  - You have to estimate the energy consumption of a system
  - You have to compare two alternatives
  - When technologies and/or control are evaluated:
    - Variable speed compressor
    - Variable speed fans
    - Floating head

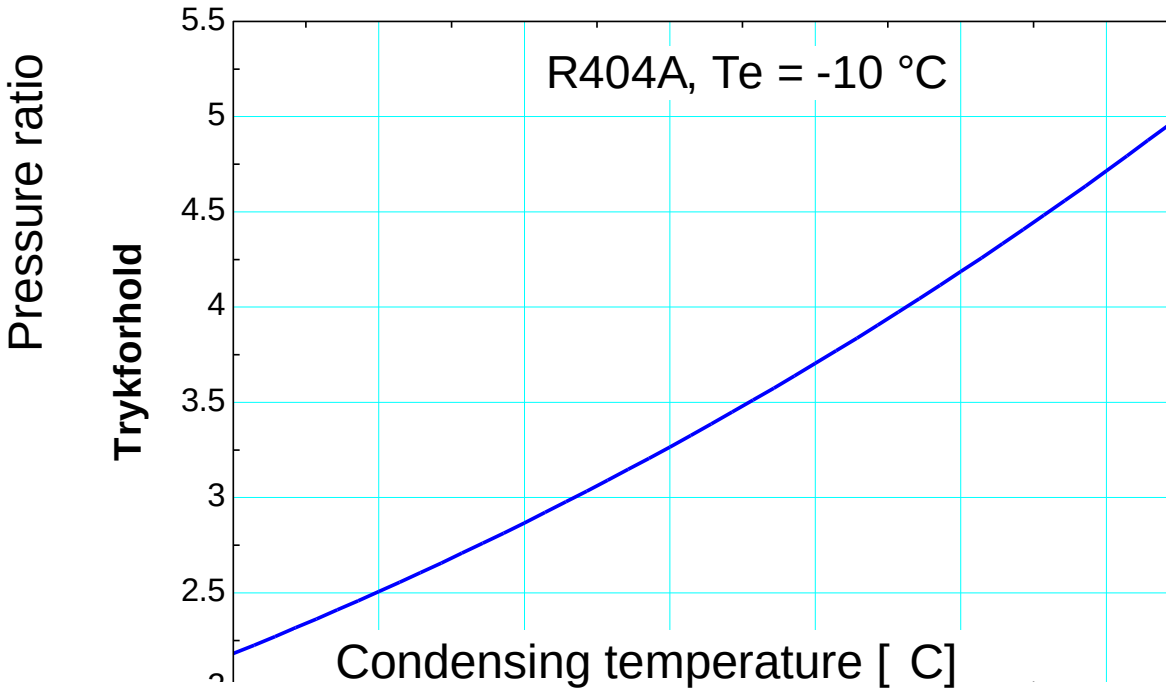
Simulation of yearly energy consumption

- Example
  - Compressor capacities are typically given at a certain rating condition:
    - For example EN12900, MBP: Te = -10, Tc = 45.
  - For R404A the gives a pressure ratio ($\frac{Pc}{Pe}$) of 4.7…



Simulation of yearly energy consumption

- The evaporation temperature is often fixed by the application; but energy can be saved by letting the condensing temperature follow the ambient…



Simulation of yearly energy consumption

- So even though you save energy by lowering the condensing temperature, the efficiency of the compressor drops of, and you don't get the full potential for savings….

- There is a need to get away from "capacities at design condition" …
  - It's notable that the efficiency for compressors often has it's maximum value at a standard dimensioning value – for example EN12900…

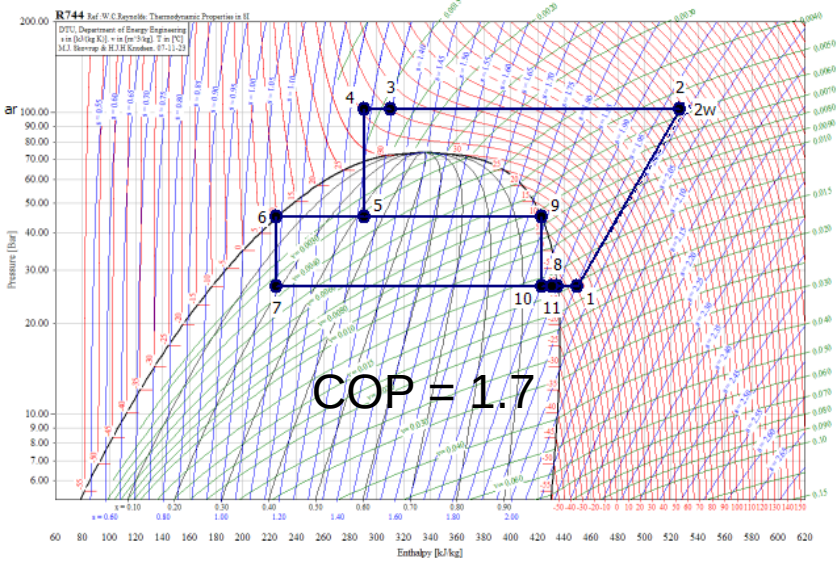
- Standards which compensate for this are being developed.

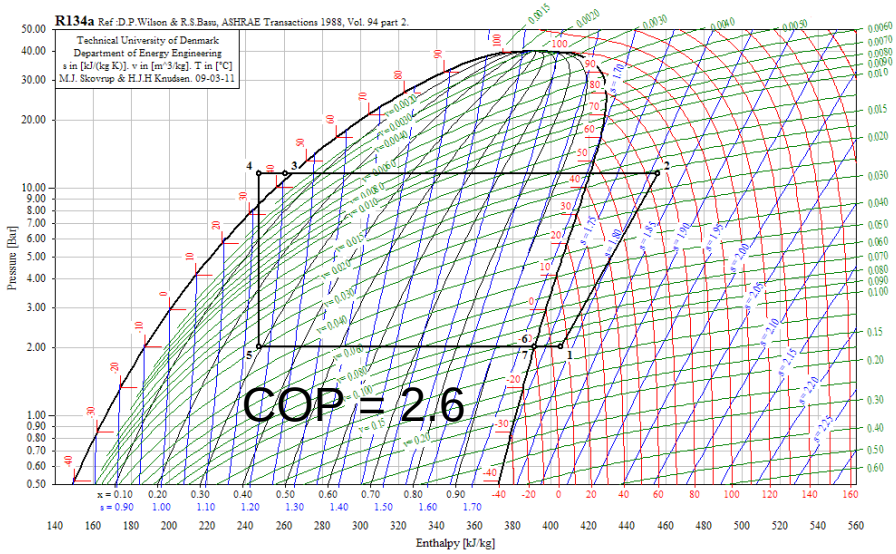
Simulation of yearly energy consumption

- All are about constructing a yearly mean COP:
  - IPLV (Integrated Part Load Value)
    - Chiller, ARI Standard 550/590
  - SEER (Seasonal Energy Efficiency Ratio)
    - AC, ARI Standard 210/240
  - ESEER (European Seasonal Energy Efficiency Ratio)
    - Eurovent
- Partly common for all:
  - Power consumption is corrected for part load. Correction based on general compressor models
  - Runtimes for part load are based on assumptions for a large geographical area (climate in Stockholm equals Barcelona)
  - Most suited for systems where measuring yearly energy consumption is impractical (and calculation not possible).

Simulation of yearly energy consumption

- Common for these methods is also that they don't apply for CO2 systems!
  - CO_2 systems runs transcritical part of the year
    - Depends very much on geographical location
  - CO_2 systems are almost always in transcritical state at usual dimensioning states
  - And if you compare a traditional system with a CO2 system at a standard dimensioning state, the traditional will almost always have a lower energy consumption:





Simulation of yearly energy consumption

- CO_2 systems also appear to have some practical advantages that are not included in IPLV, SEER and ESEER calculations:
  - CO_2 compressors are a bit more effective than traditional – but equally or more important, it looks as if the efficiency doesn't drop of as much at low pressure rations.
  - You can run with lower condensing temperatures than for traditional systems (pressure difference across expansion valve is not a problem)
  - A CO_2 condenser – at subcritical operation – is more effective than a traditional condenser. I.e. for the same costs you can run with a lower temperature difference than for a traditional condenser.
- So:
  - What you loose in transcritical operation in summer, you gain during subcritical operation in winter… depending on location… possibly… or???

Demo

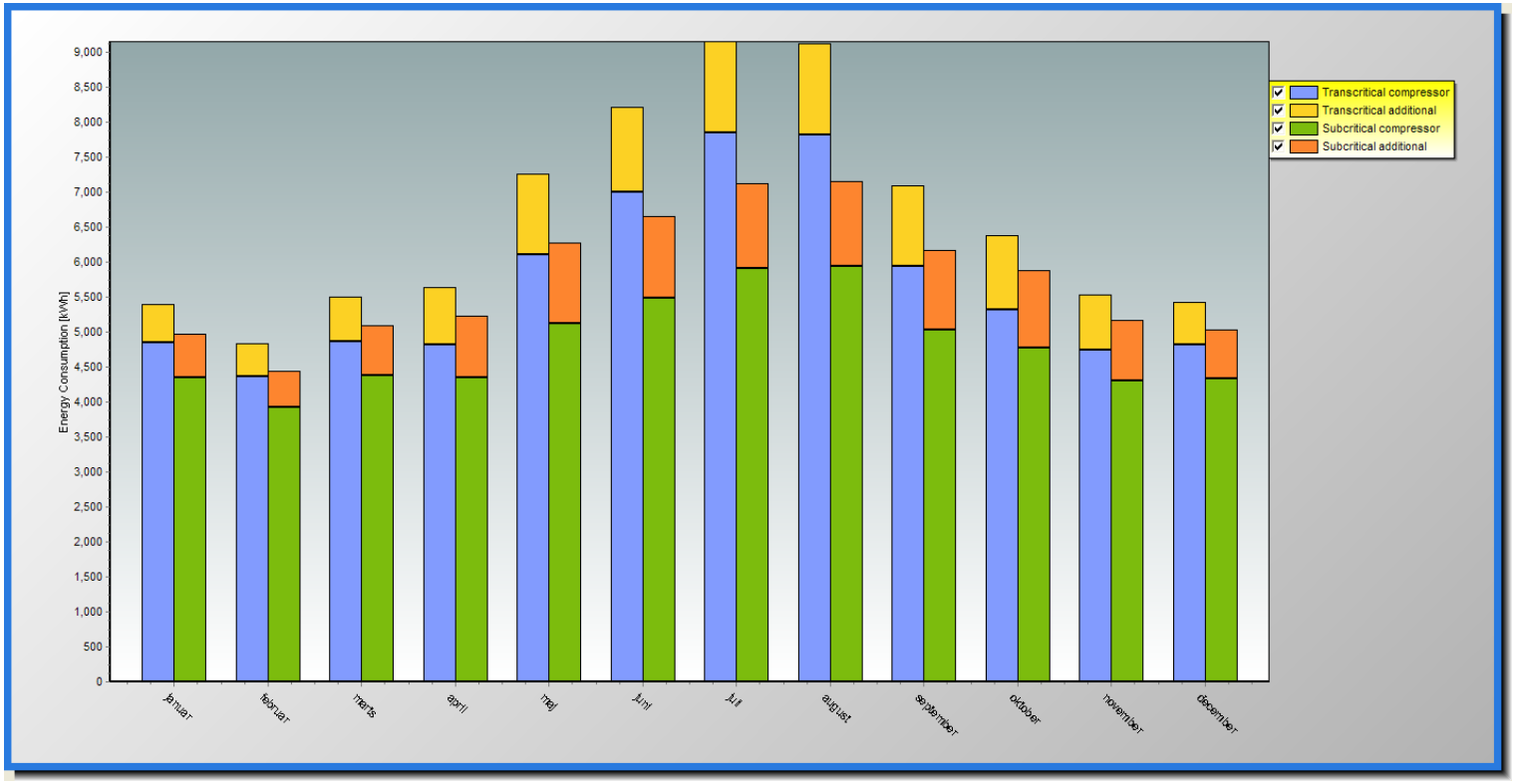
Results

- Different locations:

City	Transcritical [MWh]	Subcritical [MWh]	Savings, transcritical [%]
Stockholm	64,1	68,0	6
København	65,5	69,1	5
Amsterdam	70,6	72,0	2
Berlin	72,9	72,9	0
Paris	76,6	74,5	-3
Lyon	80,8	77,0	-5
Madrid	89,1	82,2	-8
Marseille	91,9	83,1	-11
Barcelona	93,1	83,1	-12
Rom	95,0	85,0	-12

Results

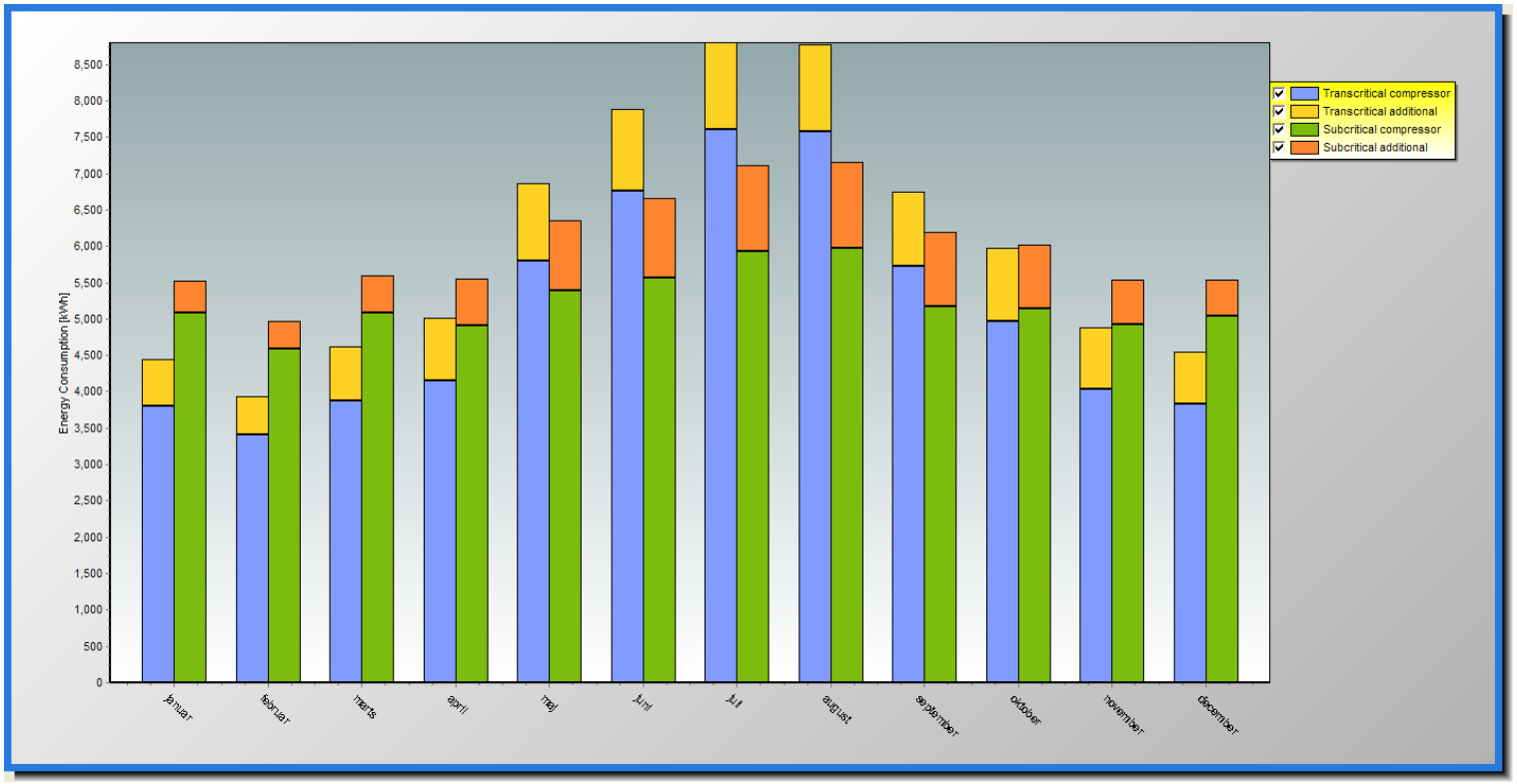
- Equal conditions and condenser size:



	Transcritical	Subcritical	Difference
Totalt energiforbrug	79,5 MWh	69,1 MWh	+ 15 %

Results

- Equal conditions and condenser size. Only difference: Tc,min,subcritical = 20 C. Tc,min,transcritical = 10 C:



	Transcritical	Subcritical	Difference
Totalt energiforbrug	72,5 MWh	72,2 MWh	0 %

Results

Life Cycle Costs | CO2 Emissions

Currency: kr

Expected average interest rate [%]: 4
Expected average inflation rate [%]: 2
Expected average energy cost [kr/kWh]: 1
Expected lifetime [years]: 10
Update

Initial cost:

	Transcritical	Subcritical
Cost of equipment [kr]	100,000	90,000
Cost of installation [kr]	60,000	60,000

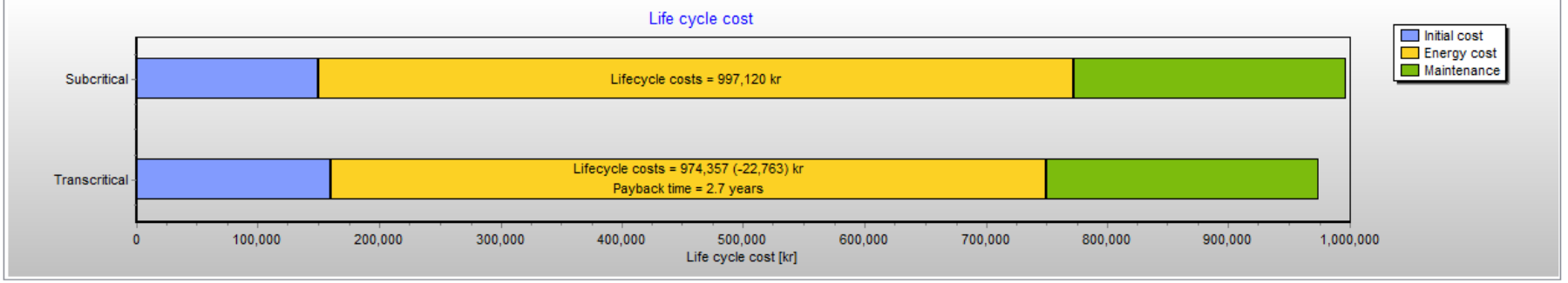
Annual operating cost:

	Transcritical	Subcritical
Energy consumption [kWh]	65473.61 (-3,640)	69113.53
Cost of maintenance [kr]	25,000	25,000

Result:

	Transcritical	Subcritical
Effective interest rate [%]	1.96	1.96
Internal rate of return [%]	34.52	-
Total annual cost [kr]	90,474 (-3,640)	94,114
Payback time [years]	2.7	-
Total initial cost [kr]	160,000 (16%)	150,000 (15%)
Present value of maintenance cost [kr]	225,026 (23%)	225,026 (23%)
Present value of energy cost [kr]	589,331 (61%)	622,094 (62%)
Life cycle cost [kr]	974,357 (-22,763)	997,120

Diagram | Plot



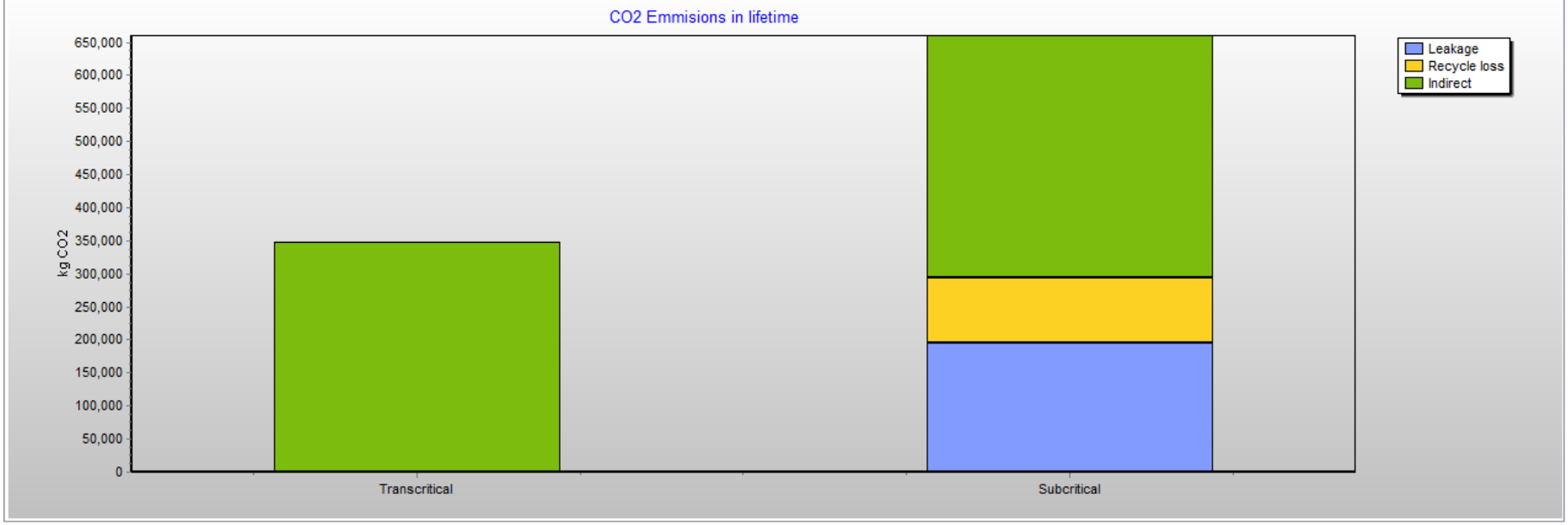
Results

Life Cycle Costs | CO2 Emissions

CO2 release, electricity generation [kg/kWh]: 0.53 Update

	Transcritical	Subcritical
Refrigerant charge [kg]	50	50
Recycle rate [%]	0.0	50
Leakage rate [%/year]	10	10

	Leakage [kg CO2]	Recycle loss [kg CO2]	Indirect [kg CO2]	Total [kg CO2]
Transcritical	50 (0.0%)	50 (0.0%)	347,010 (100.0%)	347,110
Subcritical	196,100 (29.7%)	98,050 (14.8%)	366,302 (55.5%)	660,452

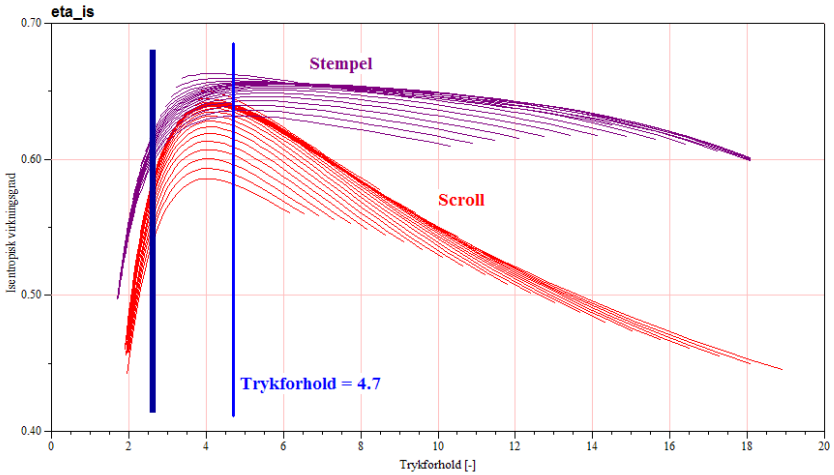


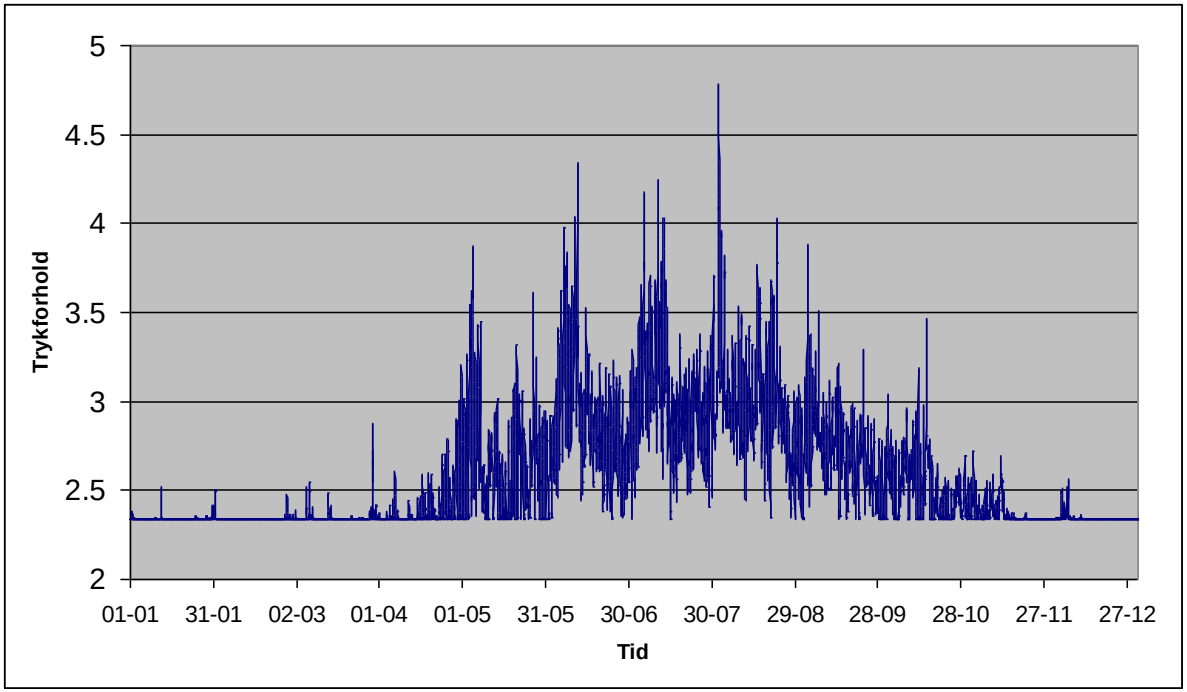
Conclusion

- In northern countries CO2 system will have at least comparable energy consumption as traditional plants…
- In southern countries energy consumption will be higher (but LC CO2 release lower)…
- In general energy consumption depends very much on component efficiencies…
- The calculation program is available at www.ipu.dk for testing (it's still a beta version though)

Conclusion

- For the simulation just performed





Mean: 2.58