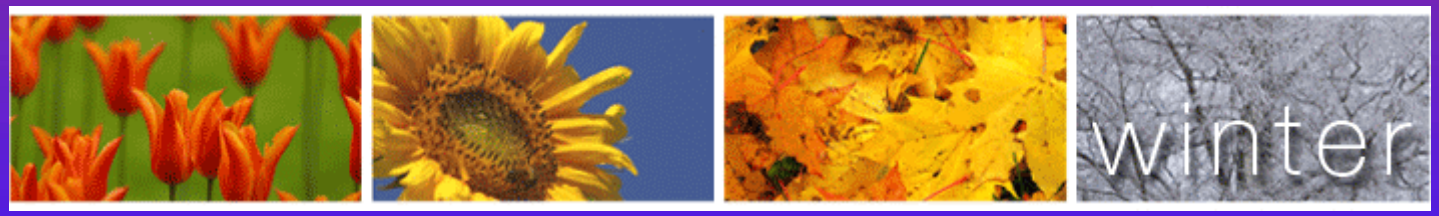
Field Test Results for a Novel Water-to-Water Propane Heat Pump System Installed in a Passive House



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Heat Pump Development – Main Goals

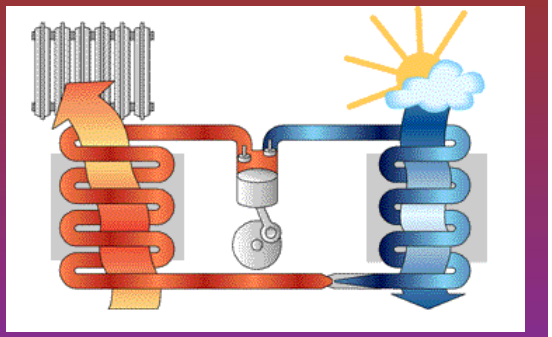
Integrated Heat Pump System for Low-Energy/Passive Houses

- System design
  - Minimize the condensation temperature/pressure during space heating, hot water heating and combined mode
  - The heat pump unit should cover the total annual heating demand in the house (space heating, DHW) – no electric reheating should be used
  - Design the heat pump according to EN 378 – equivalent to the Norwegian Refrigeration and Heat Pump Standard

- Working fluid
  - Use a natural working fluid with negligible/zero GWP and excellent thermophysical properties that leads to high energy efficiency
  - Components must be commercially available

Prototype Heat Pump System

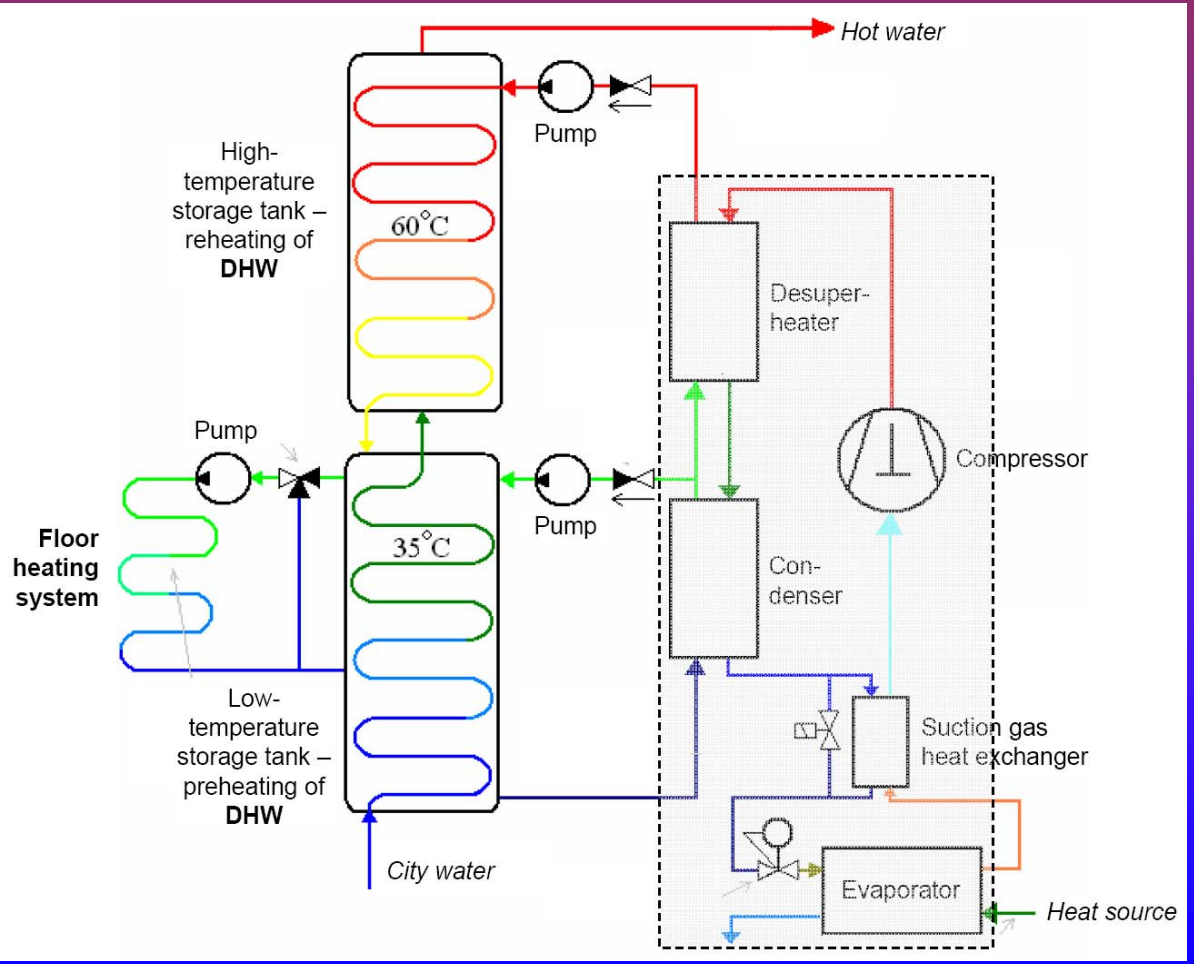
2.9 kW Heating Capacity – Components



- Water-to-water heat pump unit
  - Working fluid – **propane** (R290, C_3H_8)
  - Compressor – *Danfoss* SC15CNC, 2900 rpm, 15.28 cm^3, hermetic piston
  - Evaporator – *SWEP* brazed PHE B15-10, 0.36 m^2, height/width 6.5
  - Condenser – *SWEP* brazed PHE B15-10, 0.36 m^2, height/width 6.5
  - Desuperheater – *SWEP* brazed PHE B8-10, 0.323 m^2, height/width 4.3
  - Suction gas HX – *SWEP* brazed PHE B5-10, 0.12 m^2, height/width 2.6
  - Expansion valve – *Danfoss* TUA R22, thermostatic with internal pressure eq.
- Domestic hot water (DHW) storage – heat distribution
  - LT storage – *Laguna* 300 litre single-shell DHW) tank with integrated tube coil
  - HT storage – *Laguna* 300 litre tank buffer tank with integrated tube coil

Prototype Heat Pump System

Propane Water-to-Water Unit with LT and HT Storage Tanks



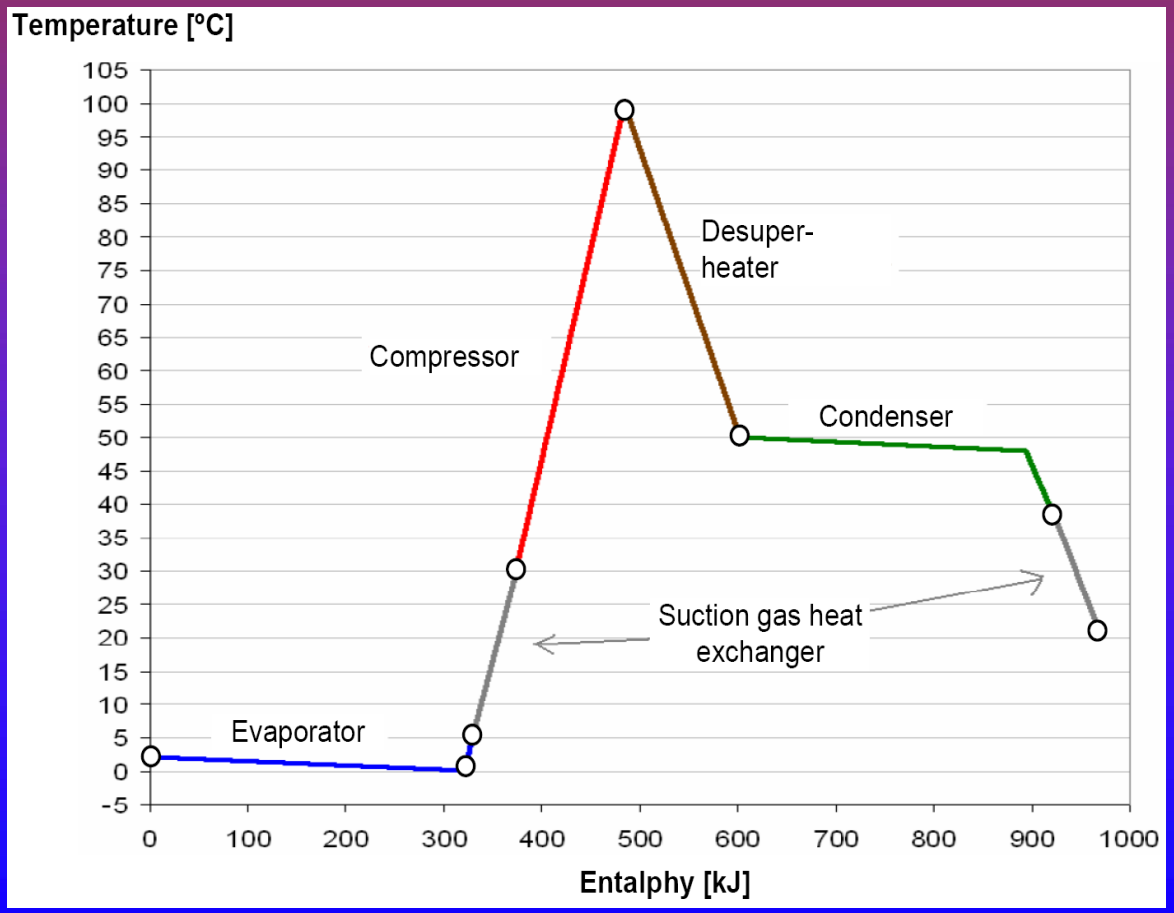
Prototype Heat Pump System

Operating Modes – Control Strategies

- Hot water mode
  - Compressor + HT pump controlled by thermostat in HT storage tank
  - Condenser and desuperheater are operative
  - Start temp. e.g. 50-55°C – stop temp. e.g. 60-65°C
- Space heating mode
  - Compressor + LT pump controlled by thermostat in LT storage tank
  - Only condenser is operative
  - Start temp. e.g. 30-35°C – stop temp. e.g. 35-40°C
- Combined mode
  - Compressor + LT and HT pumps controlled by thermostats in storage tanks
  - Condenser and desuperheater are operative

Suction Gas Heat Exchanger

Increases the Discharge Gas Temperature and the Superheat



- Example
  - t_E 0°C
  - t_C 50°C
  - Superheat 30 K
  - Δp_E 2 K
  - Δp_C 2 K
  - η_{is} 65%
  - Δh_C **70%**
  - $t_{ave\text{-}C}$ 50°C
  - Δh_{SH} **30%**
  - $t_{ave\text{-}SH}$ 75°C

Propane (R290, C_3H_8) as Working Fluid

- Highly flammable, non-toxic working fluid
  - LEL 2.1 vol%
  - UEL 9.5 vol%
  - AIT 470°C
  - Total charge approx. 250 g (> 150 g)

- Design of the heat pump unit/system
  - Indirect closed loops for heat rejection to DHW and space heating system
  - Heat pump installed in gas-tight cabinet (IP20)
  - Heat pump cabinet vented to the ambient – leak detector type NC
  - Only soldered joins for the heat pump unit inside the heat pump cabinet
  - Ex-proof low-pressure and high-pressure pressure controllers
  - Gas-tight cabinet for the electrical equipment (IP20)

Prototype Heat Pump System

Heat Pump Unit Inside Cabinet – Control Cabinet

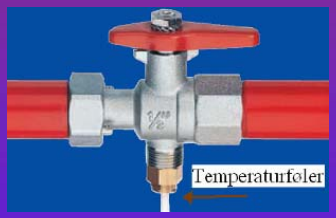
Prototype Heat Pump System

Hot Water Storage Tanks During Testing in the Laboratory

Prototype Heat Pump System

Laboratory Testing and Field Testing/Monitoring

- Heat flow meter = flow meter + temperature sensors
  - Space heating – floor heating system
  - DHW – preheating
  - DHW – reheating
- Power meter
  - Compressor
  - Compressor + pumps
- Temperature sensors
  - Heat source
  - Ambient air
  - Heat pump unit
- Calculation of Seasonal Performance Factor (SPF)
  - First results Spring 2008



Prototype Heat Pump System

Laboratory Testing According to EN 14511 – Space Heating

Heat source		Heat sink		Heating capacity [W]	COP [-]
Inlet [°C]	Outlet [°C]	Inlet [°C]	Outlet [°C]		
8.1	5.2	30.1	34.8	2281	4.2
8.1	5.3	35.7	40.0	2091	3.9
8.2	5.6	41.0	45.1	2018	3.6
10.3	7.2	30.2	35.0	2330	4.4
10.2	7.2	35.5	40.0	2197	4.1
10.1	7.2	40.6	45.2	2202	3.8
15.1	11.6	29.6	34.9	2578	4.8
15.2	11.7	34.9	40.0	2479	4.4
15.0	11.8	40.1	45.1	2406	4.1

- Carnot efficiency (η_C) excl. heat exchanger losses – approx. 0.45-0.50
- Carnot efficiency (η_C) incl. heat exchanger losses – approx. 0.30-0.40

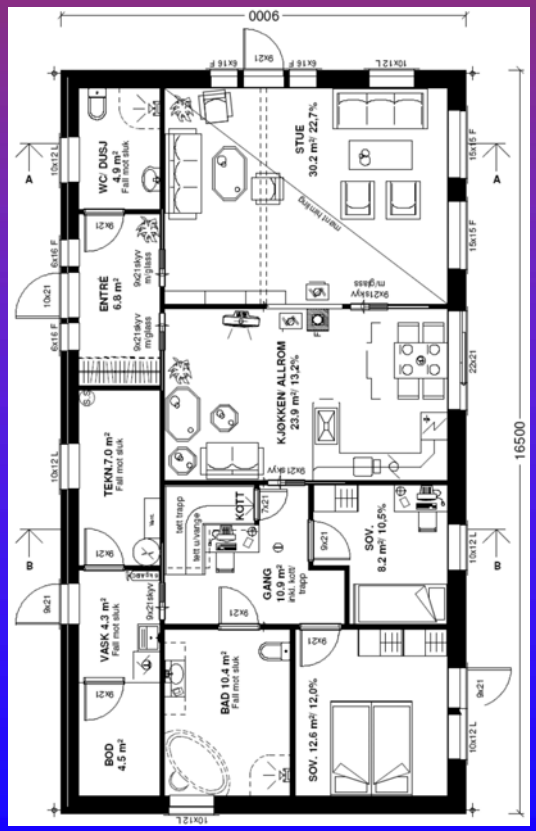
Prototype Heat Pump System

Laboratory Testing – Component Performance Evaluation

- Performance for “hot” heat exchangers and compressor
  - Condenser, desuperheater, suction gas heat exchanger – according to calc.
  - Compressor – according to calculations
- Performance for expansion valve, evaporator, flow meter
  - Expansion valve – unstable superheat control (5 – 16 K)
  - Evaporator – 50% lower heat transfer coefficient on the working fluid side due to low average liquid/vapour velocity
  - DHW flow meter – limited accuracy at low flow rates (small tapping volumes)
- Measures – expansion valve and evaporator
  - Expansion valve – use of thermal pasta between sensor and tube – OK
  - Change evaporator – use heat exchanger with smaller cross sectional area and larger thermal length (larger height/width ratio) – not likely to be done
  - Change flow meter or use complementary water meter

Installation of the Prototype System

175 m² Low-Energy/Passive House in Flekkefjord, Norway



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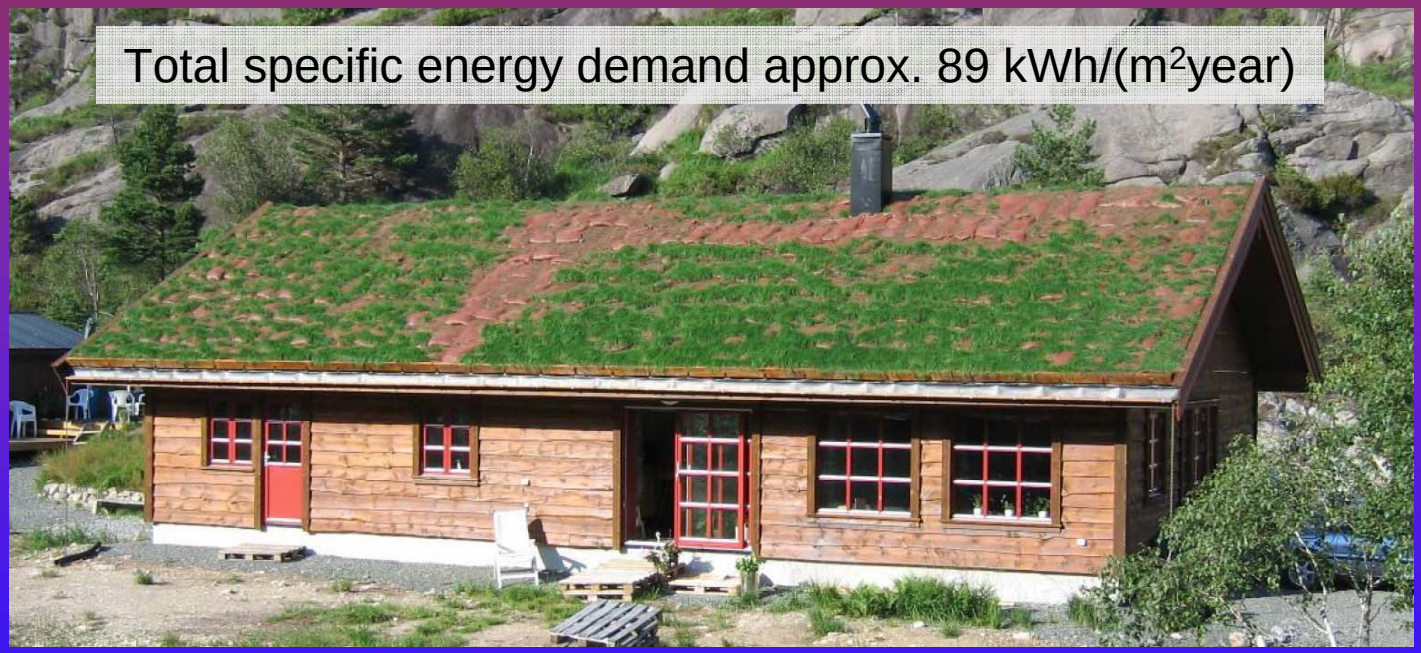
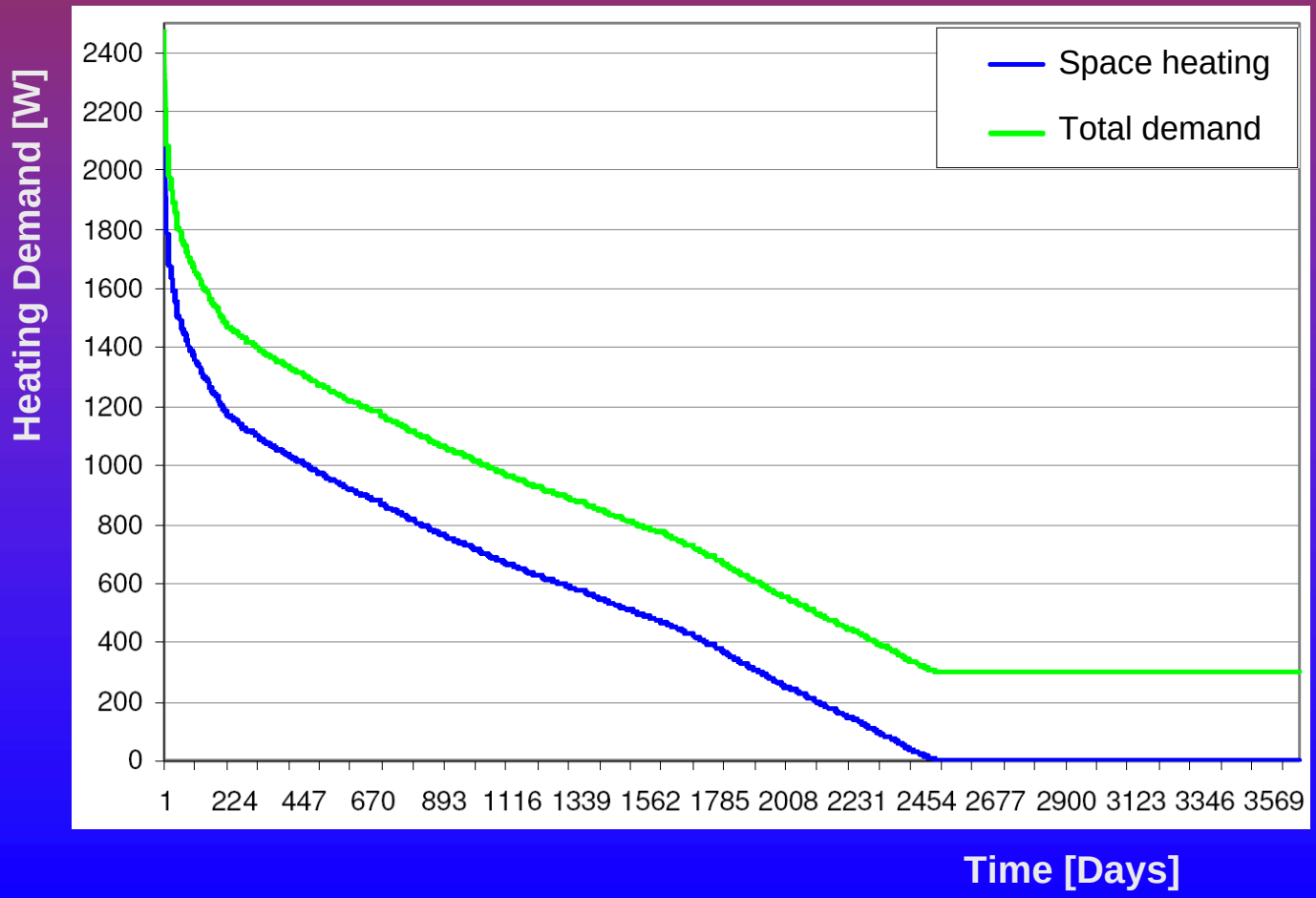


Heating demand	Power (W)	Heat (kWh/year)	Specific (kWh/m²year)
Space heating	2,400	3,800	20
Hot water heating	500	2,650	15
Total	2,900	6,450	35

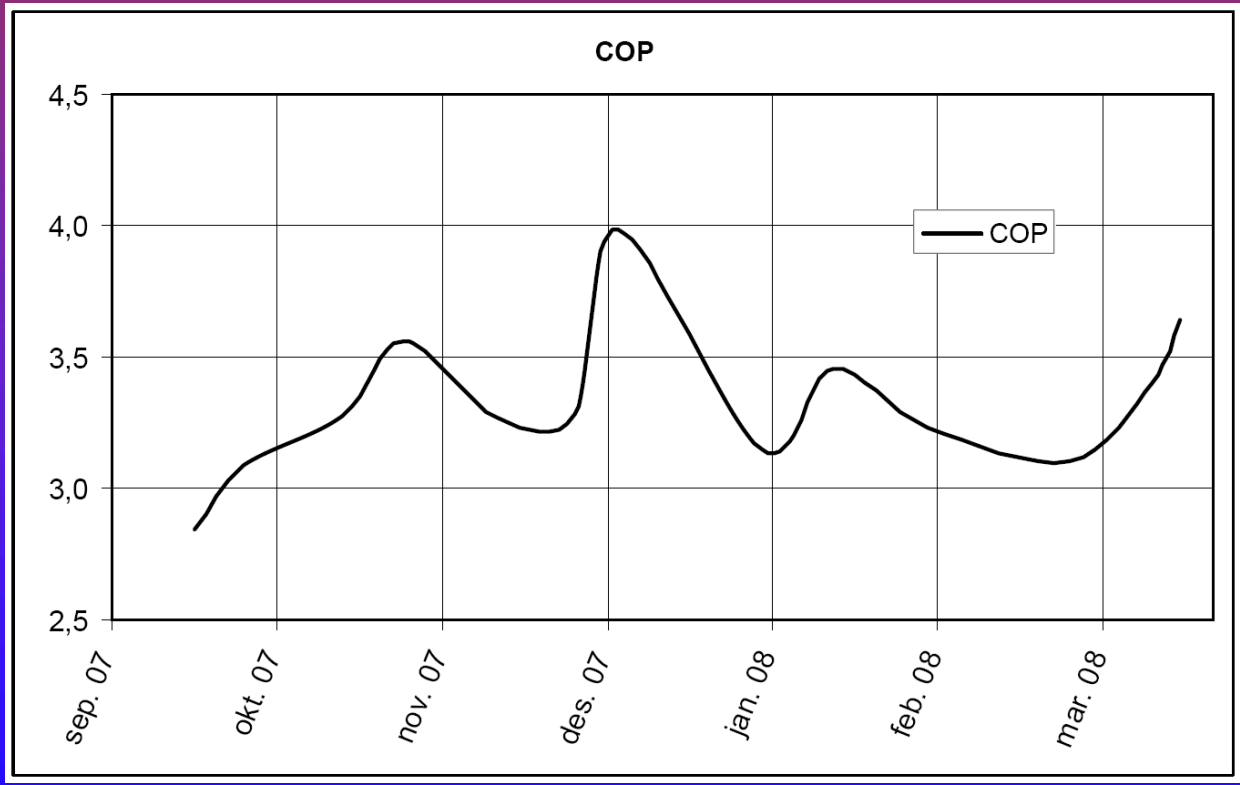
175 m² Low-Energy / Passive House

Calculated Heating Demand Duration Curve



Prototype Heat Pump System

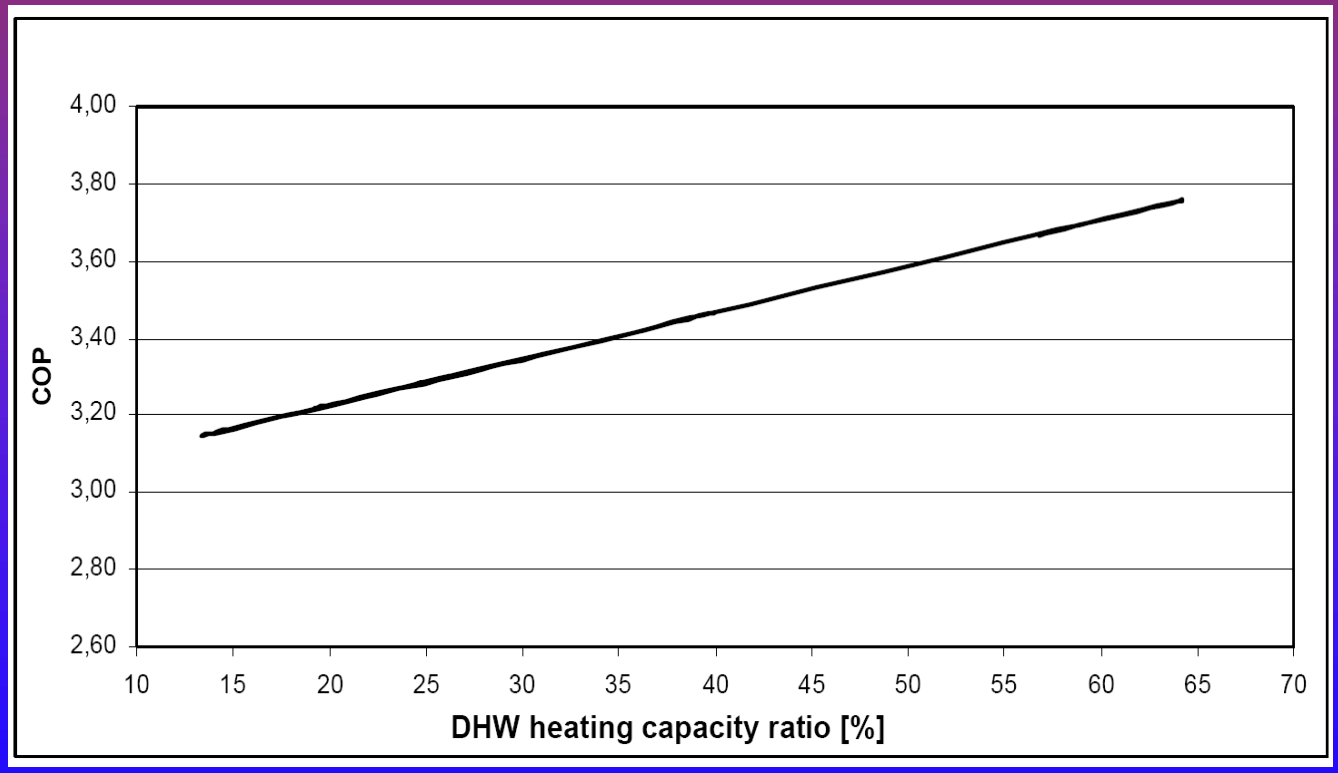
Field Testing/Monitoring in Pilot House 2007/2008



- Average weighted COP (i.e. SPF) excluding energy to pumps approx. **3.3**

Prototype Heat Pump System

Field Testing/Monitoring in Pilot House 2007/2008



- COP increases relatively linearly with increasing DHW heating capacity ratio

R290 Water-to-Water HP Prototype

Summary and Conclusions

- Integrated heat pumps using natural working fluids represent an environmentally benign technology for space heating and hot water heating in low-energy houses and passive houses
- A 2.9 kW integrated water-to-water heat pump using propane (R290) as working fluid has been designed, built and tested
  - Propane – negligible GWP, excellent thermophysical properties, flammable
  - Heat pump system optimized for high-energy efficiency at all operating cond.
  - The heat pump covers the entire heating demand – no electric reheating
- Preliminary field testing in a 175 m^2 passive house in Norway during 2007/2008 shows an average COP (SPF) of 3.3 when excluding the electric energy to the pumps
- The heat pump system will be tested during 2008/2009

Thank you for your attention!