PERFORMANCE EVALUATION OF A HEAT PUMP WATER HEATER BY MEANS OF THERMODYNAMIC SIMULATION

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The external air Heat Pump Water Heater (HPWH): «An efficient and renewable individual sanitary hot water production system»

- **Thermal storage tank**: 200-300l
- **Auxiliary heater**: (1800-2000W)
- **Low capacity external air R134a heat pump**: (1800-2800W)
- **Normative COP**: < measured performances than expected by LCIE
- **HPWH Optimization**
- **Detailed performance analysis**
EXPERIMENTAL STUDY

- Water mass flow meter
- External air
- Ambient air
- Refrigerant mass flow meter
- Temperature probes
  - $T_{t,in}$
  - $T_{t,out}$
  - $T_{air,in}$
  - $T_{air,out}$
  - $T_{air,surf}$
  - $T_{e,in}$
  - $T_{e,ou}$
  - $T_{e,surf}$
  - $T_{HP,in}$
  - $T_{HP,ou}$

Dimensions:
- 60cm x 137cm
- 17cm
NUMERICAL MODELING
Using Modelica/Dymola language

Tank model

Heat pump model

Object based Heat Pump modeling (Dymola + TLK-TIL+ Builtsys), **neglecting**:
- Oil flow and accumulation
- Evaporator collectors and distributors
- Frost build-up
MODEL AND EXPERIMENTAL DATA COMPARISON

Mean error: 18 W (<5%)

Mean error: 0.12 K
Max error: 1.4 K

COP calculation phase

Mean error: 1.66 K
Max error: 4.8 K

Mean error: 2.9 K
Max error: 5.8 K

Experimental instabilities!

Mean error: 4 W (<1%)
Mean error: 18 W (<5%)

Tap Water Mass Flow Rate (l/h)

Exp. Electric Power (W)
Model Electric Power (W)
ANNUAL SIMULATIONS WITH VARIOUS CLIMATES

- Climatic impact influence shaded by other losses and phenomena: $2.00 < \text{COP} < 2.15$
  - Importance of standby heat losses: 19.6 % of total thermal energy produced
- COP Paris $\approx$ COP Strasbourg $\approx$ COP Karlsruhe
  - Auxiliary only used for low air temperatures and high water tank temperatures
  - Negligible impact of defrosting cycles

**Improvement potentials:**
- Storage efficiency ?
- Thermodynamic cycle ?
- Control ?
IMPROVING HPWH DESIGN

Storage efficiency on a normative COP

- **COP increase of 12%** with a void insulated (0.004W/(m.K)) tank

- **Ideal normative COP increase with perfect stratification:** + 3%
  - The mixing induced by the cold water jets affect stratification hence the condensing pressure
  - But need to perform annual study for better quantification
Thermodynamic cycle improvement
On single 10°C – 55°C heat ups
full factorial analysis

- low COP improvement potential: 4.2%
- Low water side convective heat transfer (200-300 W/m²K vs. 2500 W/m²K on refrigerant side)
- No interest from a techno-economic nor environmental stand point
IMPROVING HPWH CONTROL: HPWH SMART CONTROL ALGORITHM

- Rule based control strategy for load shifting
  - Providing fixed thermal capacity with the inverter based on historical daily consumption logs
  - Time of Use tariffs vs. Day periods prioritization based on day-1 forecast cost function

- Benefits hoped:
  - Lower tank temperature restart
  - Less unnecessary tank heat losses
  - Tariff/performance optimization
IMPROVING HPWH CONTROL: HPWH SMART CONTROL

- **Control strategy**
  - Control A: fixed speed hysteresis control
  - Control B: variable speed hysteresis control with fixed capacity PID
  - Control C: Variable speed + smart control

- **Impact on energy performance:**
  - Average COP C/A + 11%
  - Reduction of standby heat losses
  - Better start-up conditions: low tank temperature
  - No Auxiliary use and less on/off restart
IMPROVING HPWH CONTROL: HPWH SMART CONTROL

Impact on the comfort and energy bill

- Reducing energy bill in average by 20%
  - Improving energy performance and valorizing TOU period better

- Increasing discomfort
  - Especially in highly variable daily draw-off profiles
  - Need for a boost function – available with the inverter

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<th>Tapping profile</th>
<th>Discomfort Rate (nb of events)</th>
<th>Cost (euros/y)</th>
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<table>
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<th>Average daily volume [40°C l/day]</th>
<th>Std. deviation [40°C l/day]</th>
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A detailed HPWH model was validated experimentally (<5% error) able to perform standard test sequences
No strong improvement potential was found on the basic design of the HPWH cycle
A simple rule based control scheme allows to reduce the bill by up to 20%

Perspectives
- Optimize the HPWH thermodynamic cycle
- Strengthen the actual parametric study
- Develop optimal HPWH control algorithms
Thank you

Further questions:
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ANNEX 1 – HPWH PERFORMANCE AS A FUNCTION OF BOUNDARY CONDITIONS