Evaluation of different heat pump systems for sanitary hot water production using natural refrigerants

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Heat pumps dedicated to produce DHW have some characteristics that make its design different from the most common heat pumps for heating applications:

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- The water temperature range is higher than heating applications.
- The demand is very irregular showing peaks along the day.
- The water temperature lift is larger than heating applications.
The refrigerant cycle

Subcritical

Transcritical
Subcritical systems

- Systems working with low subcooling.
- Sometimes, in order to have a good efficiency, maintain the temperature lift small.
- The water tank is heated progressively up to the service temperature.
- It is not able to produce instantly water at the desired temperature.

Used Refrigerants

- Refrigerants used nowadays: R134a, R410a.
- No major problems to substitute these refrigerant by R290 (R600 will require a system redesign).
Subcritical systems

- Systems working at constant subcooling.
- In order to have a good efficiency, maintain the temperature lift small.
- The water tank is heated progressively up to the service temperature.
- It is not able to produce instantly water at the desired temperature.


Charge of the system is lower than 0.3 kg
Transcritical systems

- R744 working in transcritical conditions
- Able to produce water at high temperature and high temperature lift with high efficiency.
- Tank function: reduction heat pump size in order to response to the demand peaks
Commercially available systems

Direct tank heating Indirect tank heating

- Efficiency of wrapped tank is significantly lower.
- Direct tank heating is cheaper.
- Subcritical system presents a better COP in wrapped tanks.
- Indirect tank heating do not show significant differences between both systems.
- R744 is more sensible to proper tank stratification.

Development of a new heat pump system able to control subcooling in order to adapt it to the water temperature lift maximizing the efficiency.


Heating water at 60ºC
Subcooled Heat Pump

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Subcooled heat pump

Heating water at 60ºC
Heat pump comparison

- Air to water heat pump


- Steady state analysis
- Dynamic system analysis
Heat pump comparison

- Air to water heat pump


- Steady state analysis

\[
\text{Relative COP dif} = \frac{COP_{R744} - COP_{R290}}{COP_{R290}}
\]

Negative means difference favorable for R290
Heat pump comparison

Water profile demand

<table>
<thead>
<tr>
<th>Location</th>
<th>User</th>
<th>Refrigerant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helsinki (cold climate)</td>
<td>Hospital</td>
<td>R290</td>
</tr>
<tr>
<td></td>
<td>School</td>
<td>R744</td>
</tr>
<tr>
<td>Athens (warm climate)</td>
<td>Hospital</td>
<td>R290</td>
</tr>
<tr>
<td></td>
<td>School</td>
<td>R744</td>
</tr>
<tr>
<td>Strasbourg (medium climate)</td>
<td>Hospital</td>
<td>R290</td>
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<tr>
<td></td>
<td>School</td>
<td>R744</td>
</tr>
</tbody>
</table>

Stratified water tank

Water mass flow rate [kg/h · person]
<table>
<thead>
<tr>
<th>Location</th>
<th>Refrigerant</th>
<th>User</th>
<th>SPF</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Hospital</td>
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<tr>
<td>Helsinki</td>
<td>R744</td>
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<td>Hospital</td>
<td>3.93</td>
</tr>
<tr>
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<td>R744</td>
<td>Hospital</td>
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<td>R290</td>
<td>School</td>
<td>4.03</td>
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<tr>
<td>Strasbourg</td>
<td>R744</td>
<td>School</td>
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<tr>
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<td>R290</td>
<td>Hospital</td>
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<tr>
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<td>R744</td>
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</tr>
<tr>
<td>Athens</td>
<td>R744</td>
<td>School</td>
<td>3.98</td>
</tr>
</tbody>
</table>

- R290 heat pump improves COP compared to R744 in medium and soft climates.
- R290 heat pump is more sensible to the given profile.
Other possibilities

Energy recovery applications

Variable volumen tank

Graph showing COP vs. water inlet temperature with different refrigerants.
Other possibilities

- Energy recovery applications

12% of improvement of the variable volumen system vs stratified system
Natural refrigerants working in subcritical and transcritical conditions can be used effectively to satisfy the DHW demand.

In 1 family houses R290 is a good candidate to substitute R134a systems without losing efficiency.

For large systems where legionella regulation is important R744 has been used when efficiency is crucial.

Subcritical heat pumps working with an adapted subcooling control can also be an efficient solution for these type of systems.

R290 as a natural refrigerant in this type of heat pumps could have comparable or even higher SPF than R744 heat pumps.

For energy recovery applications the subcooled heat pump system with a proper water storage system could improve significantly the energy efficiency of these systems.

R290  R744
Thanks for your attention!

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COP/COPr134a for heating water from 10ºC-60ºC and several refrigerants

Heat pump comparison

- Air to water heat pump


- Steady state analysis
- Dynamic system analysis

COP vs Ambient temperature and Condenser water inlet temperature.
- Compare R134a subcritical with R744 transcritical
- Assumes compressor technologies existing at that time.
- Heat exchangers adapted to each refrigerant.
- Heating water until 45ºC


- Stratified systems have a better performance than no stratified systems.
- R744 shows better performances overall in summer time if the system is designed properly.
- The differences for R744 will increase if water is heated at higher temperatures.
Introduction

Final energy consumption in the residential sector. (EEA)

45% buildings

20-30% in buildings in DHW

Demand in DHW is almost constant

Reduction in Heating demand

Heat pumps can contribute very significantly to the emissions derived from this source:

- Autonomous systems.
- They can be considered as renewable.
- They can be used to recover heat from other sources.