Motivation
Sustainable heat supply using Heat Pumps

■ “Heat pumps as the primary key technology for sustainable heat supply of the building stock”

heat pump ≠ zero emissions or environmental impact

Direct emissions
≡ Refrigerant leakage during operation (GWP > 0)

Indirect emissions
≡ Power demand
≡ Production
≡ Disposal

Others
≡ Ozone Depletion
≡ Photochemical Ozone Formation
≡ ...

Lifetime of a heat pump

Manufacture
Utilization
Disposal

Production of materials and refrigerant
Leakage and energy demand
Refrigerant and materials

Questions:
1. Which factor dominates the environmental impact?
2. How to measure the environmental impact?
Motivation
Ecologic Assessment Methods

1. Which factor dominates the environmental impact?
2. How to measure the environmental impact?

≡ Four common assessment methods from the literature

**SCOP**
- (only efficiency focused)
  - Includes grid emissions (indirect)

**TEWI**
- (only utilization phase)
  - Includes grid emissions + emissions due to refrigerant (GWP)

**LCCP**
- (whole lifetime)
  - Includes TEWI + emissions of production and disposal

**LCA**
- (whole lifetime)
  - Includes LCCP + other aspects of environmental impact

Research and calculation effort
Investigate the Environmental Impact of Heat Pump Systems

Study Setup

- Comparing assessment methods
  - Focus on the choice of refrigerant
    - Mixture ODP > 0
    - | Refrigerant | GWP (ODP) |
      |-------------|-----------|
      | R436A       | 3         |
      | R32         | 675       |
      | R1270       | 2         |
      | R290        | 3         |
      | R22         | 1760 (0.055) |
      | R410A       | 1920      |
      | R454C       | 146       |
      | R134a       | 1300      |
      | R404A       | 3940      |
      | R1234yf     | 4         |

- Case study using simulations
  - Heat pump with internal heat exchanger (ihx-flowsheet)
    - Shifting the amount of superheat into ihx
  - Model approaches
    - Minimum temperature difference in the heat exchanger ($\Delta T_{\text{min}} = 2K$)
    - Isenthalpic expansion valve
    - No pressure losses and heat losses to the surroundings
    - Loss-based compressor model (reciprocating compressor)
Investigate the Environmental Impact of Heat Pump Systems

### Study Setup

- **Comparing assessment methods**
  - Focus on the choice of refrigerant

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- **Case study using simulations**
  - Building located in Aachen with a radiator system [4]
    - $\dot{Q}_{\text{nom}}$: 9.7 kW with $T_{\text{supply}}(T_{\text{amb}} = -10^\circ\text{C})$: 55°C

  - Ecologic assessment approaches
    - 20 years of lifetime
    - 2 % leakage rate [2]
    - 20 % End of life leakage
    - German grid emissions [1] (annual reduction described by function)
Investigate the Environmental Impact of Heat Pump Systems
Comparing Assessment Methods: SCOP

- Using clustered days for calculating the SCOP \(^5\)

- Small differences between best-performing refrigerants (R436A \(\rightarrow\) R290: \(-2.2\%\))

- Mixture R436A highest SCOP

- 3 of 4 best-performing refrigerants are low GWP refrigerants
Investigate the Environmental Impact of Heat Pump Systems
Comparing Assessment Methods: TEWI

- Convert SCOP in emissions (based on German power grid)
- Additionally calculation of emissions due to refrigerant (GWP) \([6]\)

Emissions due to energy demand (grid emissions) dominates total emissions → high impact of SCOP

No significant impact of refrigerant for low-GWP refrigerants → R436A is still the refrigerant of choice
Investigate the Environmental Impact of Heat Pump Systems

Comparing Assessment Methods: LCCP

- **LCCP** includes TEWI + emissions due to production *cradle to grave*
- Same values for material production for all refrigerants

- Impact of material production minor influence (< 1%)
- Production of R22 includes high emissions (energy intensive and by-products with high GWP)
Investigate the Environmental Impact of Heat Pump Systems
Comparing Assessment Methods: LCA

- Includes several aspects of the environmental impact
- Calculation LCA value by weighting all aspects

- Acidification and POF caused by power demand → no significant changes to LCCP
- ODP has a great impact on LCA value (e.g.: R22)
Investigate the Environmental Impact of Heat Pump Systems
Comparing Assessment Methods: LCA

1. Which factor dominates the environmental impact?
3. What effort is sufficient?

Main factors:
- Energy demand
- GWP of refrigerant
- ODP of refrigerant

Under certain regulations (low GWP, no ODP)
evaluation based on SCOP sufficient
Conclusions and Further Work

■ Key findings:

➢ Energy demand is the dominating factor for impact assessment
  → System efficiency essential for sustainability

➢ Global Warming Potential of refrigerant influence the assessment
  → Regulations already focus on this topic (GWP < 150)
  → Low impact on choice since low GWP refrigerants show high efficiency

➢ ODP has drastically influence on the LCA
  → Regulations already focus on this topic (no ODP allowed)

■ Further Work:
  ≡ Expand the LCA [2]
    → very low data
  ≡ System analysis
    → including further system components + control

Manufacture  Utilization  Disposal
Thank you for your attention!

Sebastian Ostlender, M.Sc.
T +49 241 80-49807
F +49 241 80-49769
sebastian.ostlender@eonerc.rwth-aachen.de

Christoph Höges, M.Sc.
T +49 241 80-49598
F +49 241 80-49769
christoph.hoeges@eonerc.rwth-aachen.de
References


References