Energy saving and efficiency

Eddy Janssen
Lector energy systems
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5. Pinch point analysis, industry
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Chapter 1: Scope
Chapter 1: Scope

The production of 1 kilogram beef costs:

- 15,455 liters of water
- 6.5 kilograms of crop
- 330 square meters of ground
- 16.4 kilograms of carbon dioxide

![Image of children in a polluted area]

![Image of a delivery van and airplane]
Chapter 1: Scope
Chapter 1: Scope
Chapter 1: Scope

Energy sources:

1. Fossil energy

2. Renewable energy

3. Nuclear energy
Chapter 1: Scope

Energy sources:
1. Fossil energy
2. Renewable energy
3. Nuclear energy
4. Energy saving and efficiency
Chapter 1: Scope

Step 1: minimize the demand

Step 2: use renewable sources

Step 3: efficient use
Chapter 1: Scope

Final energy consumption in Europe

Final energy consumption, by source, EU-28, 2016, (%)

- 21,6% electricity
- 39,5% petroleum products
- 22,1% natural gas
- 4% solid fuels
- 8% renewables not electricity
- 4% derived heat
- 0,4% other

Nuclear/fossil: own consumption

33,6% electricity generation, energy production and non-energy uses

Source: Eurostat
Chapter 1: Scope

Final energy consumption in Europe has received much attention to sustainable electricity... but don't forget the general picture.

Nuclear
Chapter 2: Energy conversion, basics

<table>
<thead>
<tr>
<th>École Polytechnique</th>
<th>Glasgow school</th>
<th>Berlin school</th>
<th>Edinburgh school</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sadi Carnot (1796-1832)</td>
<td>William Thomson (1824-1907)</td>
<td>Rudolf Clausius (1822-1888)</td>
<td>James Maxwell (1831-1879)</td>
</tr>
<tr>
<td>Vienna school</td>
<td>Gibbsian school</td>
<td>Dresden school</td>
<td>Dutch school</td>
</tr>
</tbody>
</table>
First law of thermodynamics: energy conservation (quantity)

system
boundary

Energy:
- mechanical
- thermal

Mass

surroundings
Chapter 2: Energy conversion, basics

Second law of thermodynamics: direction of conversion (quality)

Heat transfer
Chapter 2: Energy conversion, basics

Second law of thermodynamics: direction of conversion (quality)

Positive thermodynamic cycle = motor
(generation of mechanical energy)

\[ \eta_{\text{motor}} = \frac{Q_1 - Q_2}{Q_1} < \text{Carnot's efficiency} = \frac{T_1 - T_2}{T_1} \]

\[ \eta \uparrow \text{ if } T_1 \uparrow \text{ and } T_2 \downarrow \]
Chapter 2: Energy conversion, basics

Second law of thermodynamics: direction of conversion (quality)

Negative thermodynamic cycle
= heat transfer $\text{LT} \rightarrow \text{HT}$

$\eta_{\text{heat pump}} = \frac{Q_1}{Q_1 - Q_2} < \text{Carnot's efficiency} = \frac{T_1}{T_1 - T_2}$

$\eta_{\text{refrigerator}} = \frac{Q_2}{Q_1 - Q_2} < \text{Carnot's efficiency} = \frac{T_2}{T_1 - T_2}$

$\eta \uparrow$ if $T_1 \downarrow$ and $T_2 \uparrow$
Chapter 3: Energy conversion, technologies
Chapter 3: Energy conversion, technologies

Defrost 10 liter of soup (-18°C → +4 °C)

Primary energy consumption?

Assumption efficiency: efficiency of electricity production = 50 % or 0,5
COP of cooling = 3

- microwave: \( PE = 2 \text{ kWh} \)
- gas cooker: \( PE = 1 \text{ kWh} \)
  or on the sideboard during winter...
- outside: \( PE = 0 \text{ kWh} \)
  or on the sideboard during summer...
- refrigerator: \( PE = -0,67 \text{ kWh} \ (= -2,67) \)
Chapter 3: Energy conversion, technologies

Heating, refrigerating, free cooling, energy destruction, energy loss, heat pump, refrigeration, cogeneration, ORC, drycooler, cooling tower, absorption cooling and heating... definition, application, selection
Chapter 3: Energy conversion, technologies

Energy circle
Chapter 3: Energy conversion, technologies

Energy circle = classification of technologies for energy conversion & visualization of primary energy consumption
Chapter 3: Energy conversion, technologies

Energy circle

Structure

A: ambient
C: cooling needs
H: heat demand
E: electricity grid
F: fuel (fossil or green)
Chapter 3: Energy conversion, technologies

Energy circle

Direct heat transfer from fuel

10: boiler
11: energy destruction
12: waste of energy
Chapter 3: Energy conversion, technologies

Energy circle

Direct heat transfer from fuel: boiler
Direct heat transfer from fuel: energy destruction

heating and then cooling due to a control error
Chapter 3: Energy conversion, technologies

Energy circle

Direct heat transfer from fuel: energy loss

- Safety
- Emission
- Accident
Chapter 3: Energy conversion, technologies

Energy circle

Negative thermodynamic cycle by compression

- From LT to HT
- Using mechanical energy

1: cooling & heating

2: compression cooling

3: compression heat pump
Negative thermodynamic cycle by compression: heat pump
Chapter 3: Energy conversion, technologies

Energy circle

Negative thermodynamic cycle by compression: cooling
Chapter 3: Energy conversion, technologies

Energy circle

**Negative thermodynamic cycle by compression:**

- **E**
- **H**
- **C**
- **F**
- **A**

heating + cooling
Chapter 3: Energy conversion, technologies

Energy circle

Negative thermodynamic cycle by absorption

- From LT to HT
- Using thermal energy (HHT)

4: cooling & heating
5: absorption cooling
6: absorption heat pump
Chapter 3: Energy conversion, technologies

Energy circle

**Negative thermodynamic cycle by absorption:**

absorption cooling
(valorization of waste heat)
Chapter 3: Energy conversion, technologies

Energy circle

**Negative thermodynamic cycle by absorption:**

absorption heating

$\approx$ boiler, efficiency ...170 %
Chapter 3: Energy conversion, technologies

Energy circle

Power station

14: separated production
15: CHP (comb. heat & power)
16: ORC (Organic Rankin Cycle)
Chapter 3: Energy conversion, technologies

Energy circle

**Power station: steam turbine (35...45 %)**
Chapter 3: Energy conversion, technologies

Energy circle

Power station: gas turbine + steam turbine (50...60 %)
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Energy circle

**Power station: gas turbine + CHP (up to 90 %)**

Issues
- modulation
- temperature control
Chapter 3: Energy conversion, technologies

Energy circle

**Power station: ORC (10...20 %)**

**Organic Rankine Cycle: low temperature**

→ waste heat recovery

→ geothermal or solar energy
Chapter 3: Energy conversion, technologies

Energy circle

Direct heat transfer

7: heat recovery
8: free cooling
9: ambient heat

heat exchangers
Chapter 3: Energy conversion, technologies

Energy circle

Direct heat transfer: free cooling
Chapter 3: Energy conversion, technologies

Energy circle

Direct heat transfer: geothermal heat

district heating
Chapter 3: Energy conversion, technologies

Energy circle

Direct heat transfer: heat recovery

ventilation
Chapter 3: Energy conversion, technologies

Energy circle

heat recovery + CHP + HP

Pinch point analysis
Chapter 3: Energy conversion, technologies

Energy circle

Hybrid combinations

boiler and heat pump
Chapter 3: Energy conversion, technologies

Energy circle

Hybrid combinations

active cooling or free cooling
Chapter 3: Energy conversion, technologies

Energy circle

Hybrid combinations

active cooling or free cooling
Chapter 3: Energy conversion, technologies

Energy circle

**Hybrid combinations**

[Diagram of energy circle with nodes labeled H, C, F, and A, and arrows indicating energy flows with numbers 2, 3, 6, 7, 8, and 10.]

building our faculty
Chapter 4: Performance
Chapter 4: Performance

Ecodesign and electric motors: requirements

*Scope: electric single speed, 3-phase 50 Hz or 50/60 Hz, squirrel cage induction motor that:*
- has 2 to 6 poles
- has a rated voltage up to 1000 V
- has a rated power output between 0.75 kW and 375 kW
- is rated on the basis of continuous duty operation

This group represents **2/3 of all electrical energy used in industry.**

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>EU-standard</th>
<th>Old standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Super premium</td>
<td>IE4</td>
</tr>
<tr>
<td>Premium</td>
<td>IE3</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>IE2</td>
<td>EFF1</td>
</tr>
<tr>
<td>Standard</td>
<td>IE1</td>
<td>EFF2</td>
</tr>
<tr>
<td>Low</td>
<td>Below standard</td>
<td>No designation</td>
</tr>
</tbody>
</table>

Estimated savings in 20 year: 657 TWh or 4 powerplants of 900 MW
Chapter 4: Performance

Ecodesign and electric motors: requirements

Source: Almeida, Ferreira, Fong, & Fonseca, 2008
Chapter 4: Performance

Ecodesign and electric motors: requirements

IE efficiency classes for 4 pole motors at 50 Hz

![Graph showing IE efficiency classes for 4 pole motors at 50 Hz. The graph plots efficiency percentage on the y-axis against output kW on the x-axis. The efficiency classes IE1, IE2, IE3, and IE4 are indicated with arrows pointing to specific points on the graph for output kW values of 0.12, 0.37, 0.75, 1.5, 3, 7.5, 15, 37, 90, 160, 400, and 1000.]}
Chapter 4: Performance

Ecodesign and electric motors: requirements

<table>
<thead>
<tr>
<th>efficiency</th>
<th>purchase € net, excl tax, 2019-07</th>
<th>savings kWh/y (10%)</th>
<th>savings €/y</th>
<th>PB year</th>
</tr>
</thead>
<tbody>
<tr>
<td>kW</td>
<td>CET motoren IE2 IE3 IE4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0,75</td>
<td>IE2 0,796, IE3 0,825, IE4 0,857</td>
<td>109 250</td>
<td>290 298</td>
<td>2-3</td>
</tr>
<tr>
<td>7,5</td>
<td>IE3 0,887, IE4 0,904, IE2 0,926</td>
<td>423 1.394</td>
<td>139 173</td>
<td>0,3</td>
</tr>
<tr>
<td>75</td>
<td>IE4 0,951, IE3 0,95, IE2 0,96</td>
<td>3.732 736</td>
<td>74 72</td>
<td>2,6</td>
</tr>
<tr>
<td>355</td>
<td>IE2 0,951, IE3 0,96, IE4 0,967</td>
<td>17.224 23.463</td>
<td>307 235</td>
<td>1,4</td>
</tr>
</tbody>
</table>

optimization in partial load: https://www.automation.siemens.com/sinasave#/en/pump
Chapter 4: Performance

Ecodesign and electric motors: partial load

i.e.: Permanent Magnet Synchrone Machine

Source: UGent Campus Kortrijk

optimization in partial load: https://www.automation.siemens.com/sinasave#/en/pump
Chapter 4: Performance

Ecodesign and energy labels

- Lighting
- Heaters
- Fridges and freezers
- Vacuum cleaners
- Washing machines and driers
- Air conditioners and fans
- Televisions and TV boxes
- Kitchen appliances
- Pumps
- Transformers and converters
- Computers and servers
- Imaging equipment
- Game consoles
- Electric motors
- Tyres
- Off mode, standby and networked standby

Product label
Chapter 4: Performance
Ecodesign and energy labels

• clear indication of energy efficiency
• specific data in addition: noise emissions, water consumption
• easier for consumers when purchasing: save money and reduce greenhouse gas emissions
• encourages manufacturers to drive innovation
Chapter 4: Performance

Ecodesign and energy labels

Product label

System label

(manufacturer)
custom made, unique designs?

system label
(manufacturer)
Chapter 4: Performance
Ecodesign and energy labels

custom made, unique designs?

INDUSTRY
Pinch point analysis

BUILDINGS
Hydronic system optimisation
Chapter 5: Pinch point analysis, introduction

The heat and material balance is at this boundary

industrial process → onion diagram

Site-wide utilities
Chapter 5: Pinch point analysis, introduction

Steps (Linnhoff March): an introduction

1. Translate the process to Pinch data
2. Pinch curve and energy targets
3. Optimize utilities (energy supply like steam...)
4. Optimize the network
Pinch-analysis, step 1: Pinch data

**Red process flow**
- Start temperature: 60°C
- Supplied energy: 3200 E.U
- End temperature: 100°C

**Blue process flow**
- Start temperature: 180°C
- Supplied energy: -2000 E.U
- End temperature: 80°C

**Green process flow**
- Start temperature: 130°C
- Supplied energy: -3600 E.U
- End temperature: 40°C

**Yellow process flow**
- Start temperature: 30°C
- Supplied energy: 3240 E.U
- End temperature: 120°C
Pinch-analysis, step 1: Pinch data

**Red process flow**
Delta T
Supplied energy

**Blue process flow**
Delta T
Supplied energy
Cp (E.U / °C)

**Green process flow**
Delta T
Supplied energy
Cp (E.U / °C)

**Yellow process flow**
Delta T
Supplied energy
Cp (E.U / °C)

Sensible heat: Cp = cp x M
[kJ/kg.K] x [kg/s] = [kW/K]
Pinch-analysis, step 1: Pinch data

(a) Example Process Flow-sheet

(b) Data Extraction Flow-sheet
Pinch-analysis, step 1: Pinch data

<table>
<thead>
<tr>
<th>Stream No</th>
<th>Stream Type</th>
<th>Start Temperature (Ts) (°C)</th>
<th>Target Temperature (Tt) (°C)</th>
<th>Heat Capacity Flowrate (CP) (kW/°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hot</td>
<td>180</td>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>Hot</td>
<td>130</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>Cold</td>
<td>60</td>
<td>100</td>
<td>80</td>
</tr>
<tr>
<td>4</td>
<td>Cold</td>
<td>30</td>
<td>120</td>
<td>36</td>
</tr>
</tbody>
</table>

ΔTmin = 10°C

Hot: has to be cooled
Cold: has to be heated

CP: capacity factor [kW/K]

Utilities: Steam at 200 °C, CW at 25°C ⇒ 30°C
Pinch-analysis, step 2: Pinch curve and energy targets

A. Construction of composite curves for heating and cooling
   - TH-diagram (temperature-enthalpy change)
B. Determining the Pinch (smallest $\Delta T$) => determining the part of heat recovery

- ‘Cold’ below ‘hot’ + horizontal translation only (X-axe: $\Delta H$)
- Moving CCC left: more heat recovery, less heating and cooling, but more expensive heat exchangers.
Pinch-analysis, step 2: Pinch curve and energy targets

C. Use pinch to detect suboptimal heat recovery

- Pinch (smallest $\Delta T$), $P = U \cdot A \cdot \Delta T \Rightarrow$ **cost heat exchanger** $U \cdot A$
- Pinch divides curve:
  net heat source (Source) $\leftrightarrow$ net cold source (Sink)
C. Use pinch to detect *suboptimal heat recovery*

- **Above pinch:** requires heat input → sink
- **Below pinch:** rejects heat → source

- Heat transfer **over pinch:**
  - Above pinch:
    - requires more heat input
  - Below pinch:
    - rejects more heat
C. Use pinch to detect suboptimal heat recovery

- No heat transfer over the pinch ($\alpha$)
- No external cooling above pinch ($\gamma$)
- No external heating below pinch ($\beta$)
Pinch-analysis, step 3: Optimize utilities

- Utilities (e.g. steam, hot water, ...)
- Heating with low-grade heat (relatively low temperature)
- Cooling with low-grade cold (relatively high temperature)
Pinch-analysis, step 3: Optimize utilities

How: build a ‘Grand composite curve’

- ‘Hot’ = streams to be cooled: available at half pinch lower
- ‘Cold’ = streams to be heated: available at half pinch higher
Pinch-analysis, step 3: Optimize utilities

How: build a ‘Grand composite curve’

- $a \Rightarrow b$: move vertical over $\Delta T_{\min}/2$ until both curves hit in pinch
Pinch-analysis, step 3: Optimize utilities

How: build a ‘Grand composite curve’
- a=>b: move vertical over $\Delta T_{\text{min}}/2$ until both curses hit in pinch
- b=>c: plot difference (=$\alpha$)
Pinch-analysis, step 3: Optimize utilities

Visualize alternatives

b. Use of lower temperature heat, e.g. MP
   Use of high temperature cold, e.g. free cooling (CW)
Pinch-analysis, step 4: Optimize the network

Useful to use CHP?

3 options

Integrate across the pinch

Inappropriate Placement (a)
Pinch-analysis, step 4: Optimize the network

Useful to use CHP?

3 options

Integrate across the pinch  Integrate above the pinch

Inappropriate Placement (a)  Appropriate Placement (b)
Pinch-analysis, step 4: Optimize the network

Useful to use CHP?

3 options

Integrate across the pinch  Integrate above the pinch  Integrate below the pinch

Inappropriate Placement (a)  Appropriate Placement (b)  Appropriate Placement (c)
Useful to use HP?

3 options

Integrate Above the Pinch

Integrate Below the Pinch

Integrate Across the Pinch

Inappropriate placement

Inappropriate placement

Appropriate placement

(a)

(b)

(c)
Pinch-analysis, step 4: Optimize the network

Useful to use HP?

Only over the pinch, under condition:

- COP, depending on $\Delta T$ (left: OK; right: not OK)
Chapter 5: Performance of hydronic systems

HVAC
Heating Ventilation and Air Conditioning

District heating
Chapter 5: Performance of hydronic systems

Problem 1:
slow process:
- low energy price
- how to estimate the saving potential

huge challenge:
- climate change
- energy poverty
Chapter 5: Performance of hydronic systems

Problem 2:

good compents + bad design

= sub optimal systems
Chapter 5: Performance of hydronic systems

Problem 3:

- Competents: mass product requires optimization
- Industry: excellent working process is the core business
- Buildings: - every building is original
- - bad commissioning
Chapter 5: Performance of hydronic systems

Problem 3:

- Industry:

- Buildings:
Chapter 5: Performance of hydronic systems

Hydronic systems in buildings & industry: hysopt

Equilibrium: \[ P_{\text{out}} = P_{\text{in}} \]

Equations of a heat exchanger:

\[ P_{\text{out}} = U \cdot A \cdot \text{LMTD} \]

\[ P_{\text{in}} = V \cdot \rho \cdot c \cdot \Delta T \]

\( T_{\text{rad, su}} \) = T radiator supply

\( T_{\text{ro}} \) = T room

\( T_{\text{rad, re}} \) = T radiator return

(logarithmic mean temperature difference)
Chapter 5: Performance of hydronic systems

Hydronic systems in buildings & industry: hysopt

\[\text{Power regulation} \]

\[P_{\text{out}} = U \cdot A \cdot \text{LMTD}\]

\[P_{\text{in}} = V \cdot \rho \cdot c \cdot \Delta T\]
Chapter 5: Performance of hydronic systems

Hydronic systems in buildings & industry: hysopt

Characteristics heat exchanger

\[ T_{\text{rad, su}} = \text{variabel} \]
\[ V = \text{constant} \]

\[ T_{\text{ro}} \]

\[ V = \text{variabel} \]
\[ T_{\text{rad, su}} = \text{constant} \]

\[ T_{\text{rad, re}} \]

\[ P_{\text{out}} \]

\[ 0 \% \]
\[ 100 \% \]

\[ T_{\text{ro}} = 20 \, ^{\circ}\text{C} = \text{constant} \]
\[ n = 1,3 \]

\[ 20 \]
\[ 75 \]
\[ 75/65/20 \]

\[ \Delta T = 20 \, \text{K} ; T_{\text{rad, su}} = \text{constant} \]

\[ V \]

\[ (\text{m}^3/\text{s}) \]

\[ 20 \% \]
\[ 100 \% \]
Chapter 5: Performance of hydronic systems

Hydronic systems in buildings & industry: hysopt

How to realise:

\[ T_{rad,su} = \text{variabel} \quad V = \text{constant} \]

\[ T_{rad,re} \]

\[ V = \text{variabel} \quad T_{rad,su} = \text{constant} \]

\[ T_{rad,re} \]
Chapter 5: Performance of hydronic systems

Hydronic systems in buildings & industry: hysopt

Before 2013

Full variable control

Now

1: boiler

2: mixing valve

3: thermostatic radiator valve

3: valve + actuator
Chapter 5: Performance of hydronic systems

Hydronic systems in buildings & industry: hysopt

Model is assembled form hydraulic base circuits
Design faults are signalled automatically
Simulation of the return temperature (left) and the flow rate (right) before and after the low loss header.
Chapter 5: Performance of hydronic systems

Hydronic systems in buildings & industry: hysopt

Behaviour of the controlled riser temperature according to the position of the 3-way valve (scatter plot)
Chapter 5: Performance of hydronic systems

Hydronic systems in buildings & industry: hysopt

Example of a model shared in the hysopt inspiration library
Chapter 5: Performance of hydronic systems

Hydronic systems in buildings & industry: hysopt

increased scale and complexity
Chapter 5: Performance of hydronic systems

Hydronic systems in buildings & industry: hysopt

increased scale and complexity
increased scale and complexity $\rightarrow$ increased savings by hysopt
Chapter 6: Energy monitoring

understanding follow up adjustment

encrease energy performance and reduce energy cost
Summary and conclusion

• energy saving, especially heat deserves extra attention

• keep attention for details, i.e. expansion vessels are related with corrosion prevention, noise reduction and energy efficiency

• increasing complexity, optimization through simulation

• education and training of technicians and designers

• technology cannot solve everything, adjust your lifestyle...

• who will pay for this: ted talk washing machines

watch: www.youtube.com/watch?v=6s qpntxljCw
And don’t forget: collaboration and peace