Annex 61 – Technical Day

Cost-efficient Building Energy Retrofit

The Case of Karlsruhe-Rintheim

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für Wirtschaft
und Technologie

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The residential neighborhood Karlsruhe-Rintheim

- Overview -

Rintheim 2014

Heilbronner Str. 33-37
(before retrofit)

Heilbronner Str. 33-37
(after retrofit)

West facade after retrofit:

Rintheim Residential Neighborhood: Basic Data

Settlement area: 0.25 km^2 Floor Area Ratio (FAR): 0.38

45 buildings 1,308 flats 87,000 m^2 living area

ca. 3,000 tenants

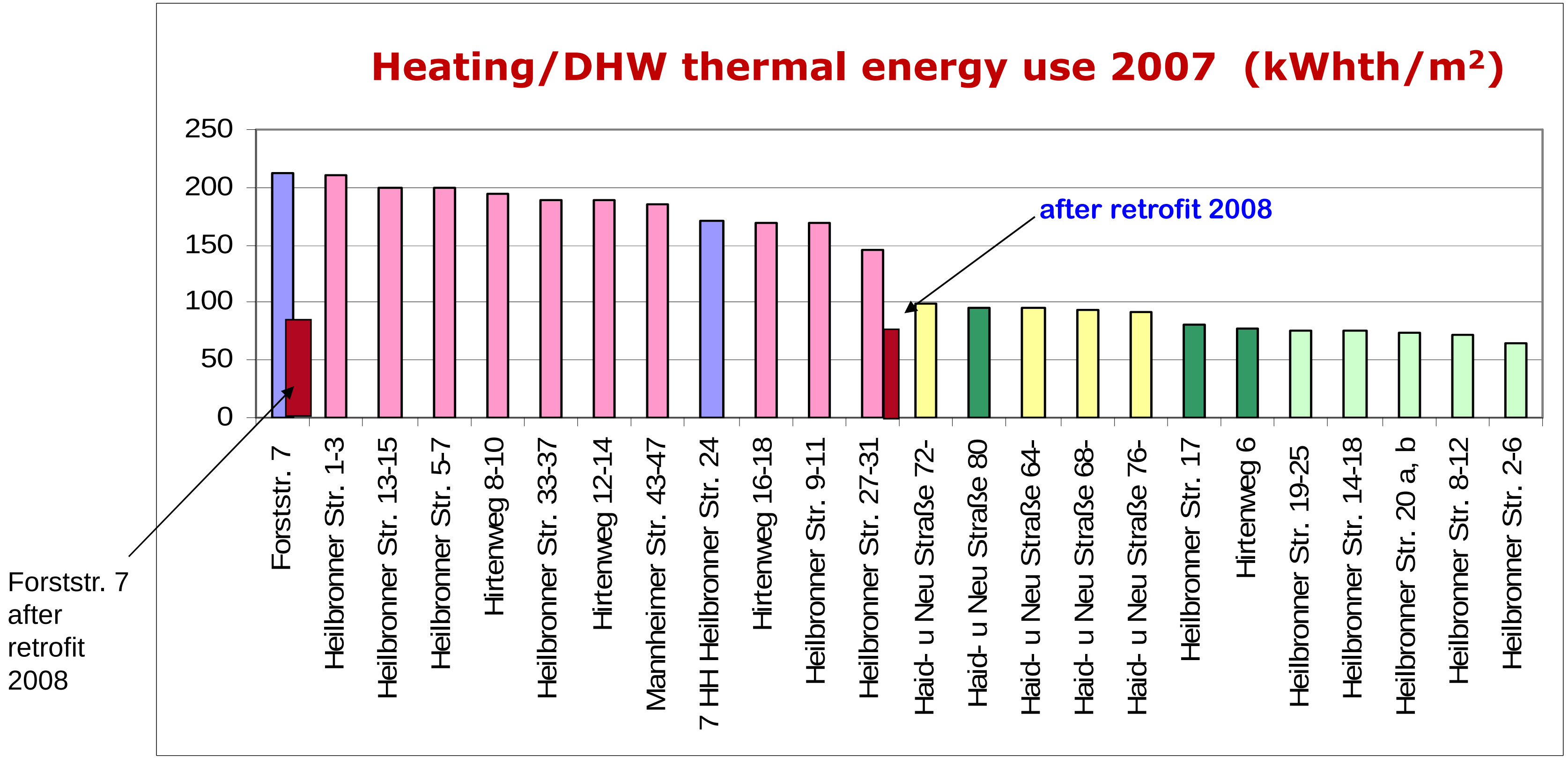
Construction: 1954 – 1956
1967 – 1971

Climate:

	Degree Days	HDD
Rintheim	3,277 Kd	**2,054 Kd**
German average	3,814	2,479

Neighborhood refurbishment project: 2008 – 2015

Retrofit costs: > 70 mio. €



- Year of construction: 1954/55, no retrofit, 4-5 storeys, individual heating
- 1974, no retrofit, 12 storeys, Gas heating plant
- 1954, partial retrofit, 4 storeys, Gas heating plant
- 1956, partial retrofit, 9 storeys, Gas heating plant
- 1955, refurbished, 4 storeys, Gas heating plant, solar collector panels for DHW

30 Buildings (VoWo):

- 16 no retrofit
- 7 partial retrofit
- 7 full refurbishment

Overall Energy Optimization:

- Minimization of total costs for energy supply by use of holistic planning approach
- Energy controlling and optimization
- Demonstration of unconventional techniques
- Evaluation of technical experiences
- proof of agreed energy goals

... the aim is to keep the resulting total rents (rent plus energy costs) as low as possible.

... before retrofit

from ....

$q_H + q_{DHW} + q_l \approx$ **170 kWh$_{th}$/m^2**

pe = 220 kWhPE/kWhEE

to

$q_H + q_{DHW} + q_l \approx$ **70 kWh$_{th}$/m^2**

pe **= 42 kWh$_{PE}$/m^2**

... after retrofit

Optimization (1)

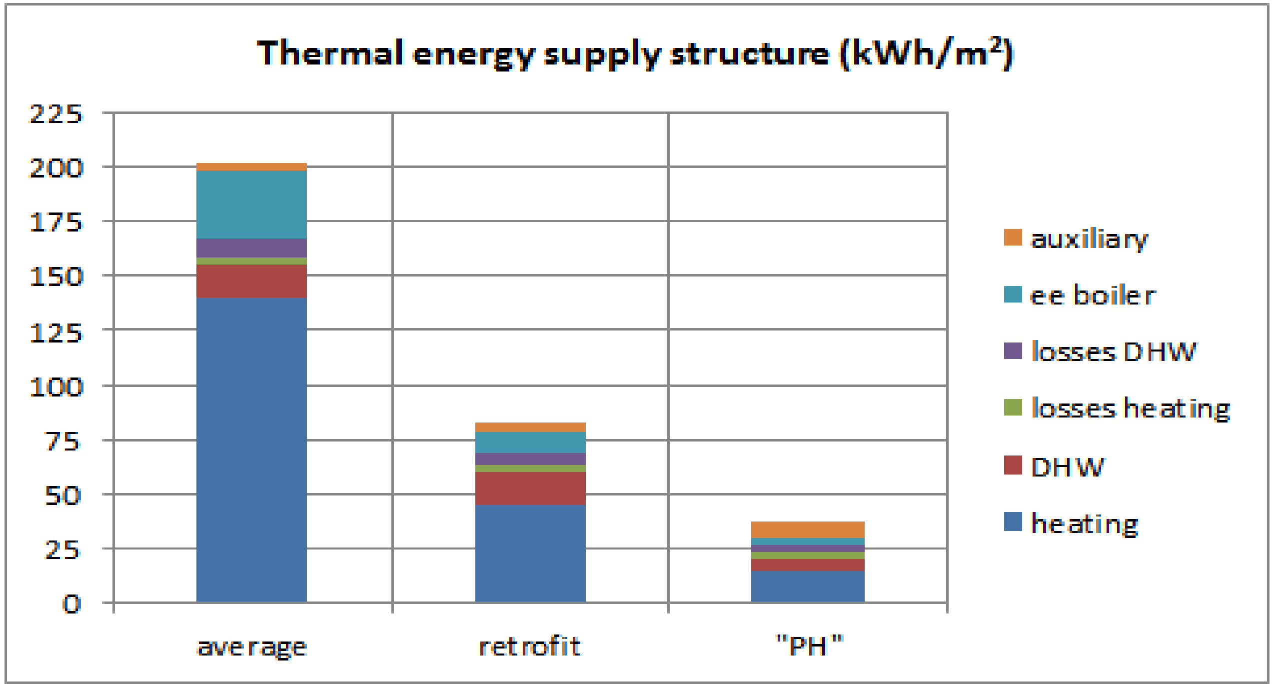
Building retrofit

Technical options in building energy conservation:

- facade insulation
- windows exchange
- distribution losses
- boiler efficiency
- ventilation heat loss recovery
- solar collectors
- heat pump

...

Example: *residential building retrofit*

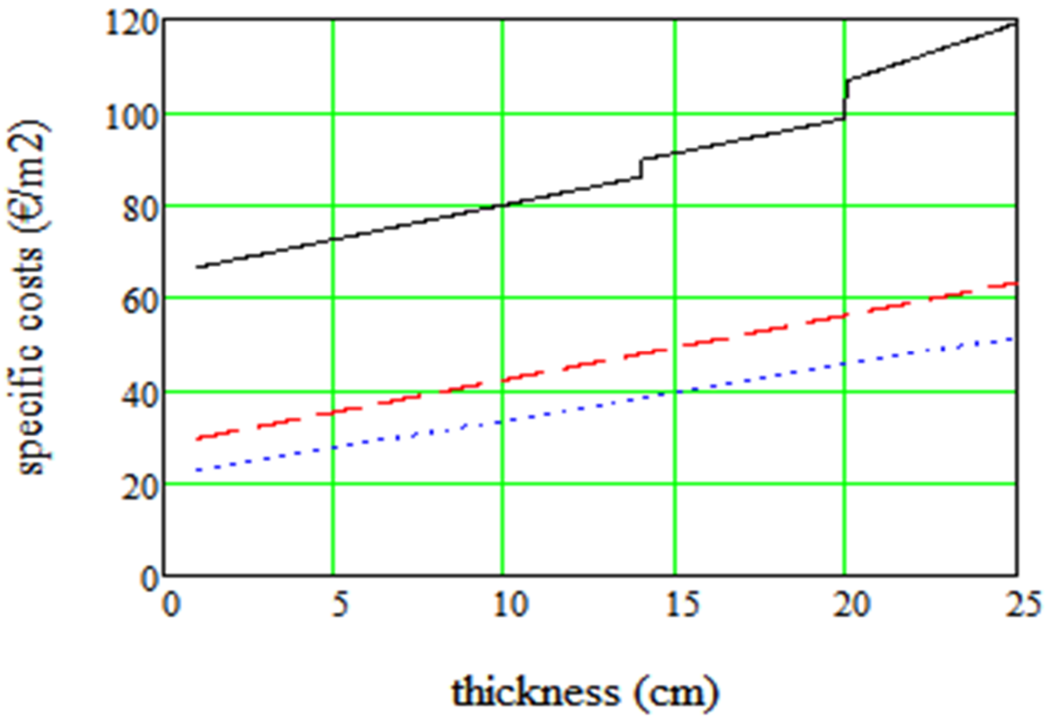


Question:

- cost efficiency?

- optimization?

Optimization: costs and benefits

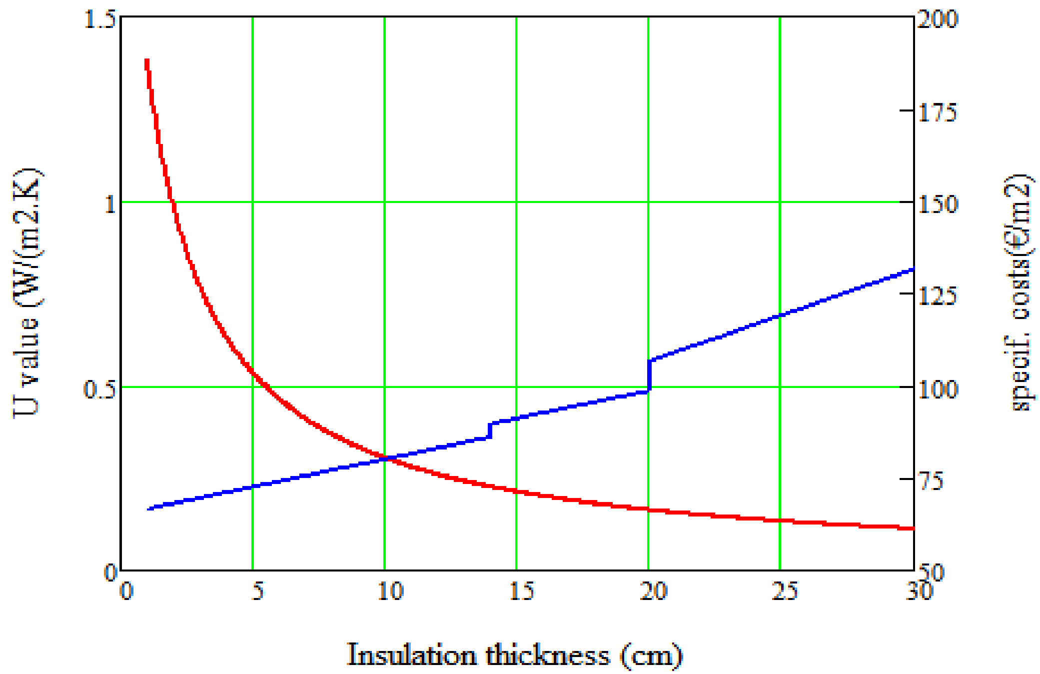


Insulation costs: (€/m²)

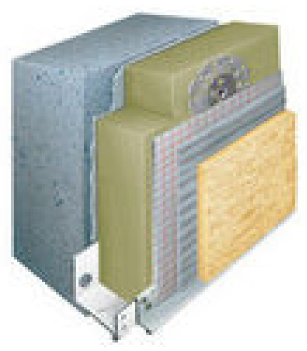
- wall
- Attic floor
- basement ceiling

Annual energy savings through wall insulation:

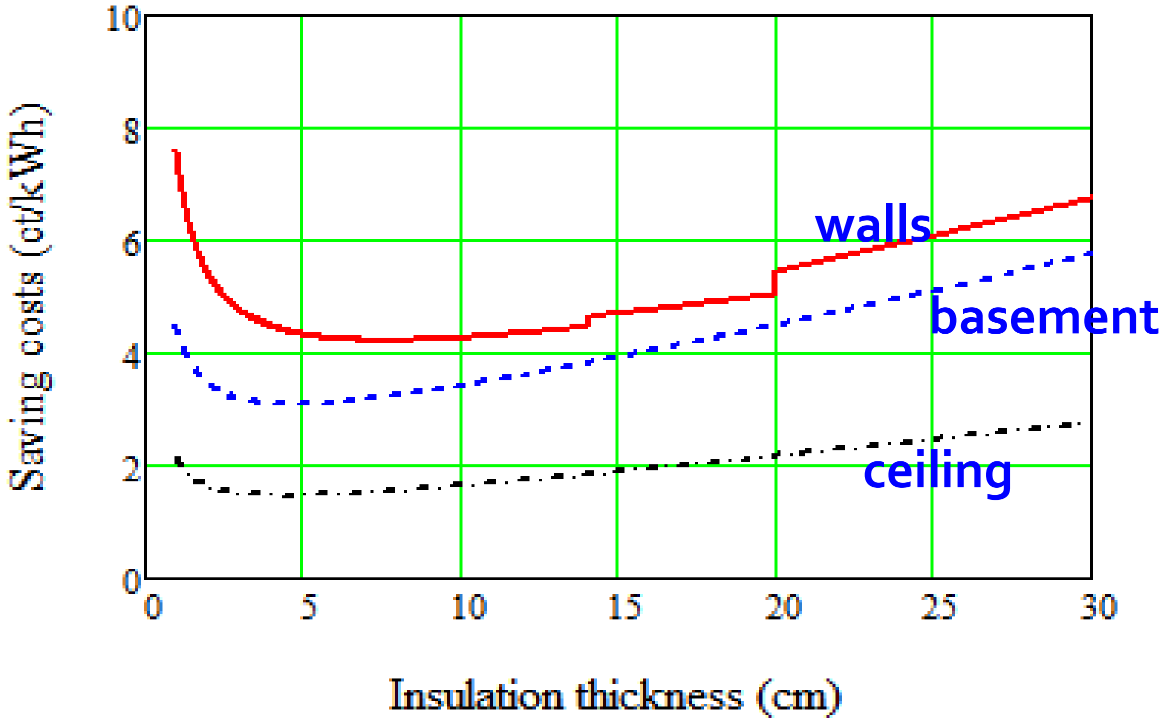
$$\Delta q_T = \frac{24}{1000}\cdot\left(U_W - U(d)\right)\cdot H_{15}$$



Wall insulation compound system:

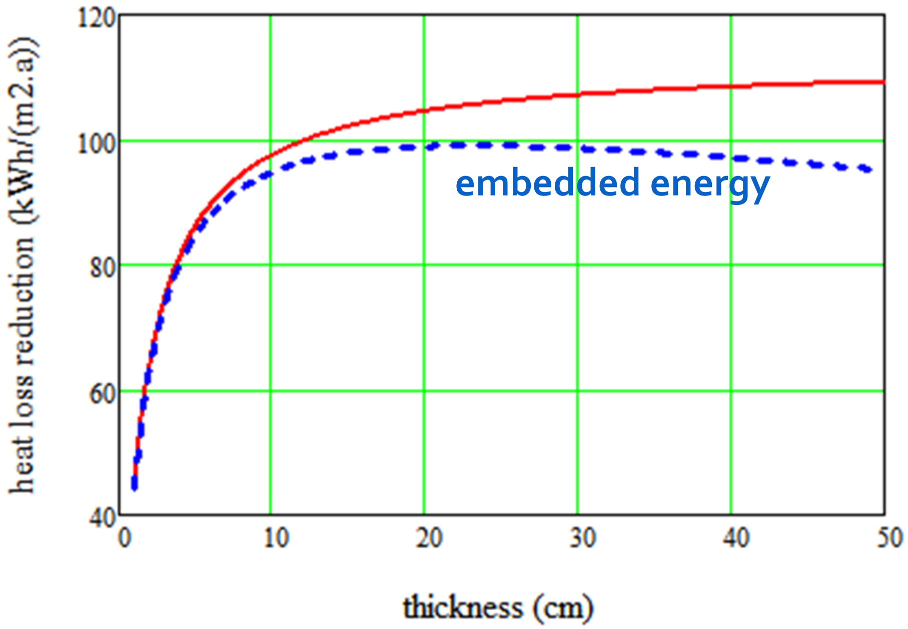


Costs to save 1 kWh of end energy (gas, oil) by envelope insulation:



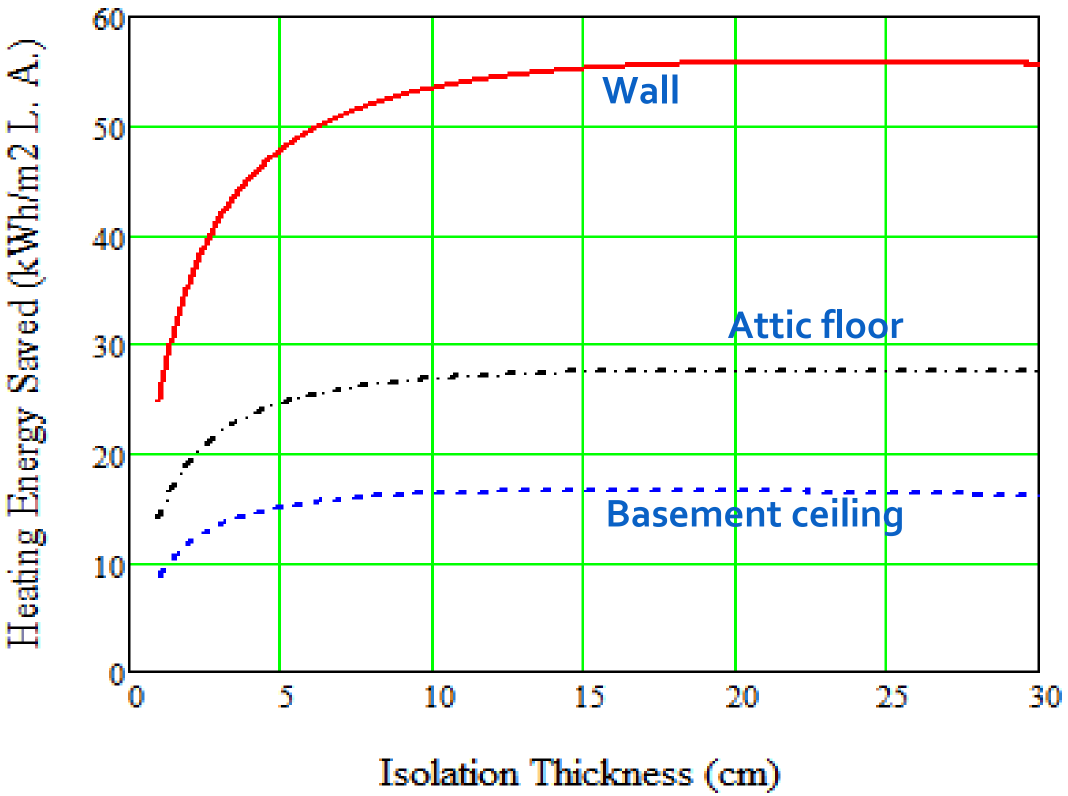
$$e(d) = \frac{1000}{24} \cdot \frac{(k \cdot d + D) \cdot a}{HDD \cdot (U_0 - U(d))} \quad [ct/kWhth]$$

HHD … degree days (KA: 2,053 Kd)



Embedded energy of
insulation materials: 300 – 1.000 kWh/m³

Envelope heat losses:
(*related to use area*)



Wall insulation:
- more expensive
- more effect

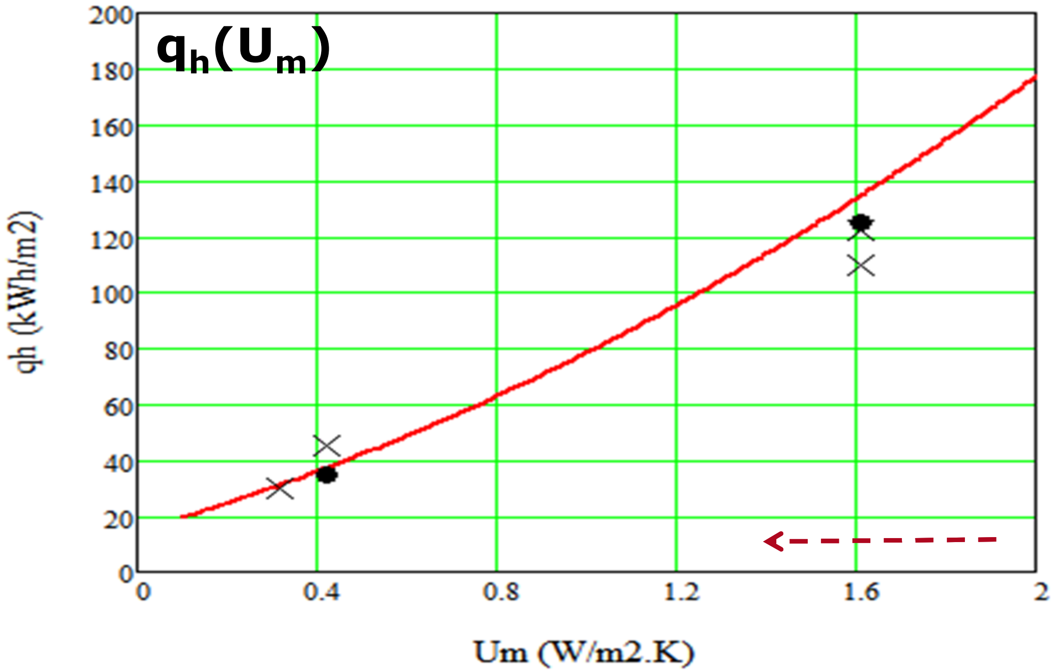
⇒ **Thickness beyond 15 – 18 cm useless!**
(climate of KA)

Annual heating demand q_h:

$$q_h = \frac{24}{1000} \cdot \frac{\left(A_{env} \cdot U_m + 0.20 \cdot V_i\right)}{A_{LA}} \cdot HDD\left(U_m\right) \quad \text{kWhth/m}^2$$

(proxy formula)

$\Delta HDD \sim 200 \cdot \Delta t_{HL}$



… continuous increase of insulation thickness
(wall, basement ceiling, attic floor)

Measured q_h values of 3 buildings before and after retrofit
(windows replacement: *double low-E panes*)

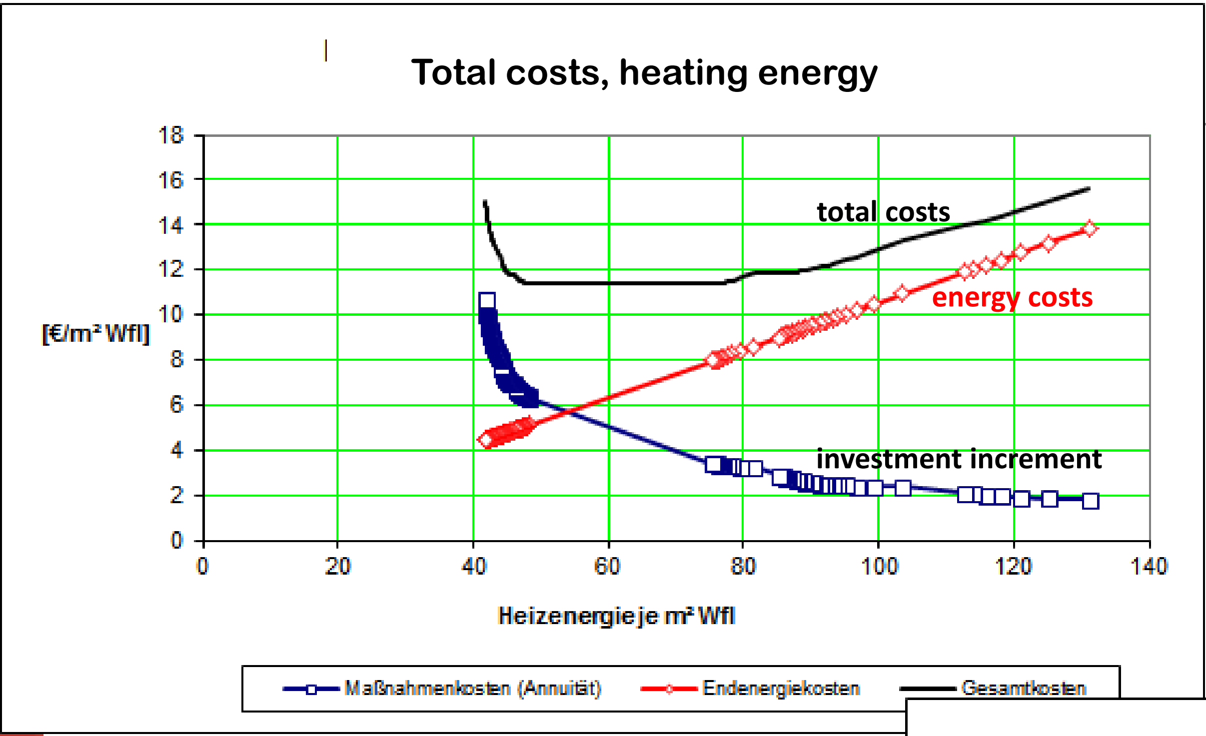
Search for *least-cost path:*

Investment with highest cost-efficiency → $min \left\{ \frac{\Delta I_A}{\Delta U_m}, \frac{\Delta I_A}{\Delta U_m}, \frac{\Delta I_A}{\Delta U_m} \right\}$

$\Delta U_{\underline{m}} \rightarrow \Delta q_h$

„V_ROM“ – model:

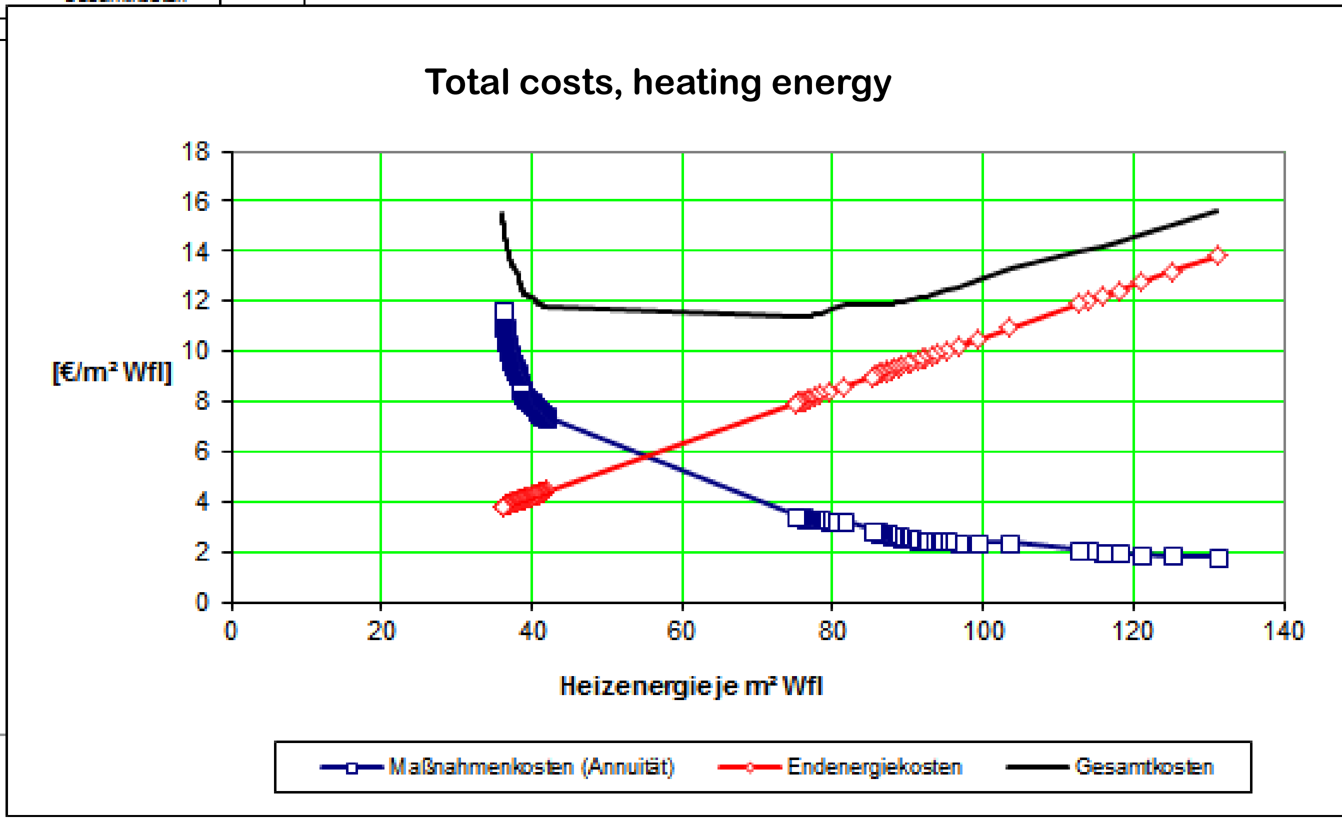
Automatic search for least-cost curve of envelope insulation



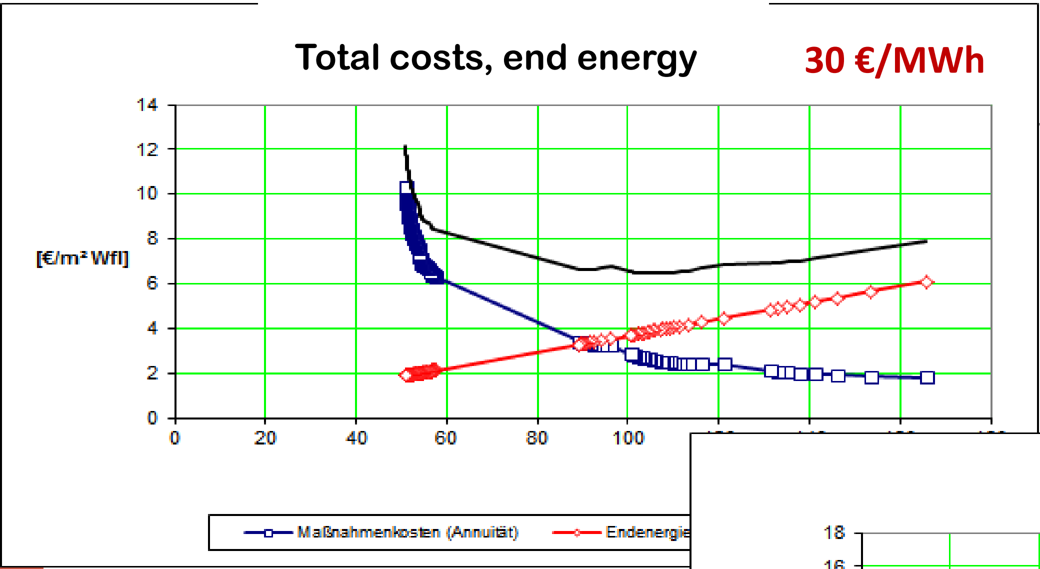
typical results of V_ROM run (here: LCA)

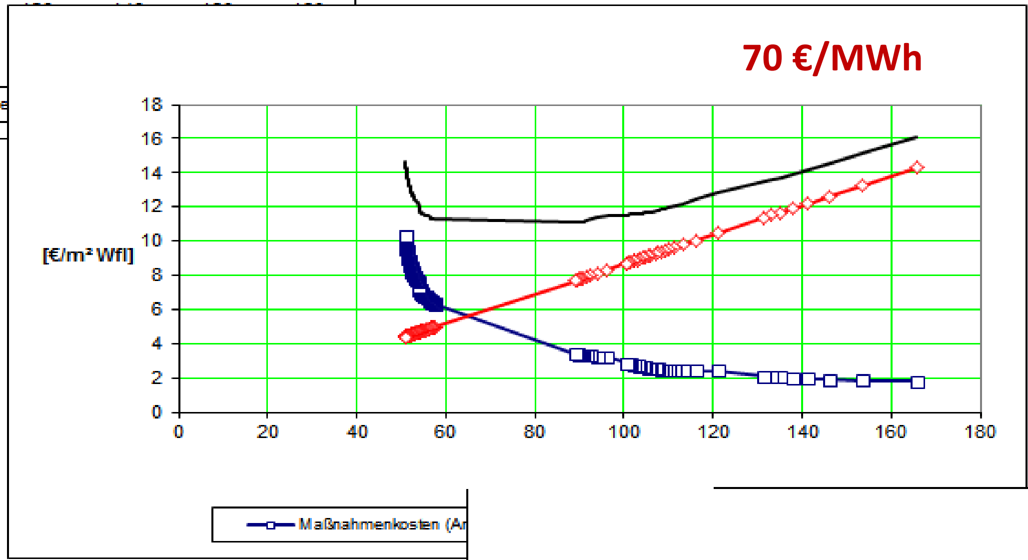
70 €/MWh_{Hi},
double-glazed lowE windows,

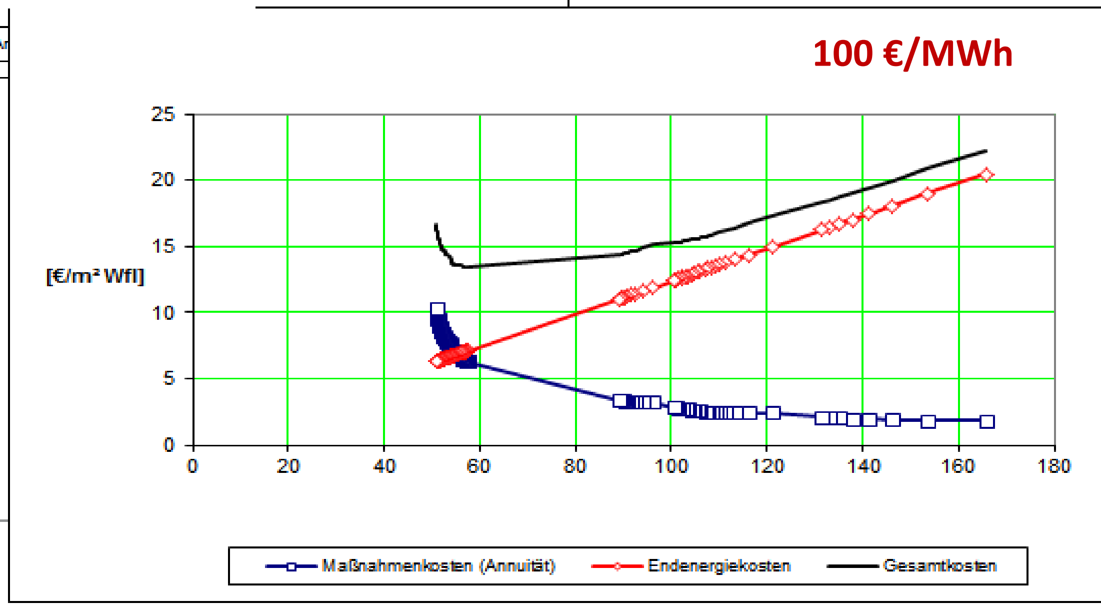
70 €/MWh_{Hi},
PH windoes



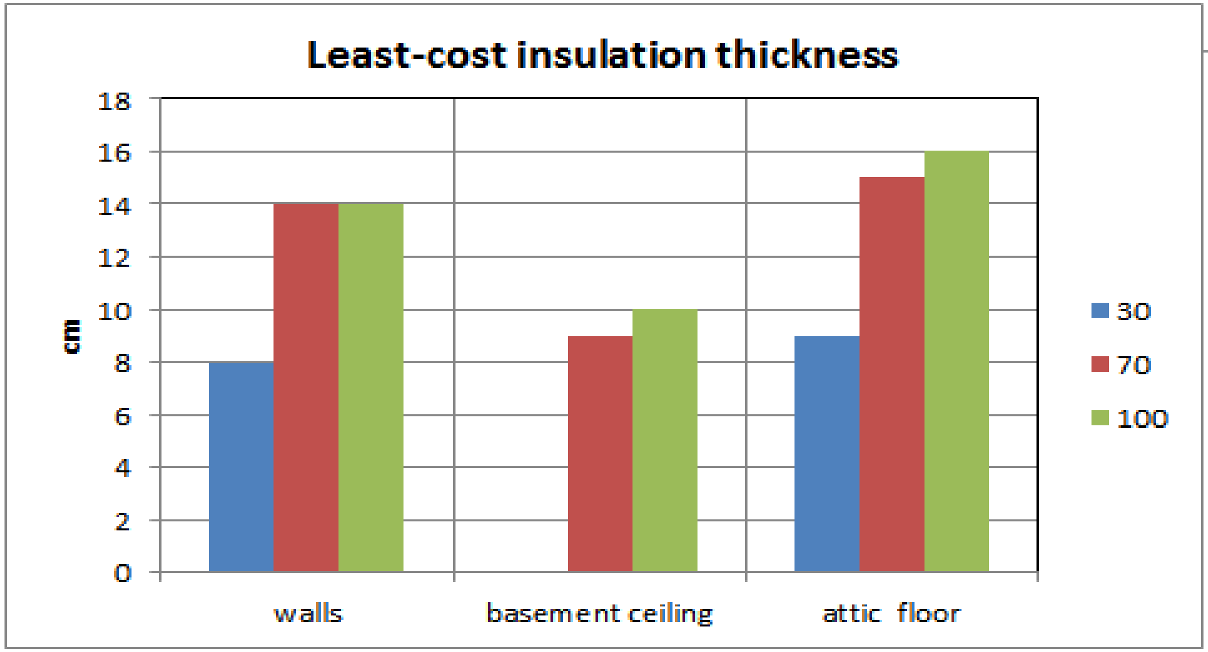
Least-cost combination: depends on energy price level



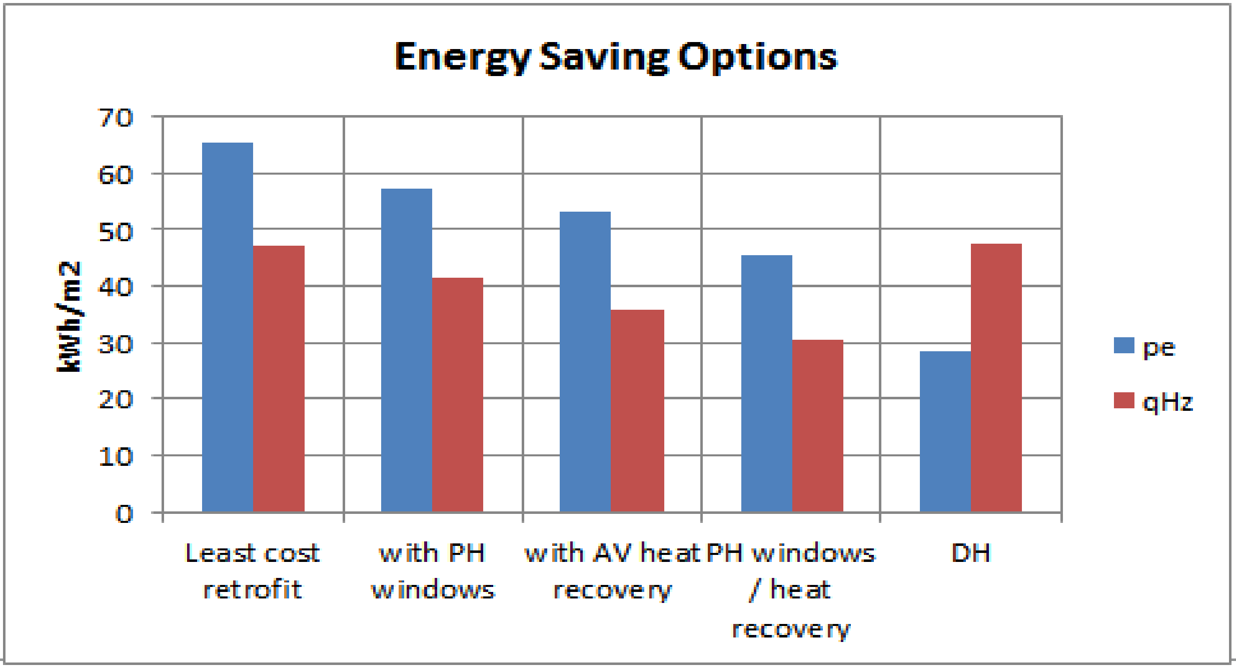




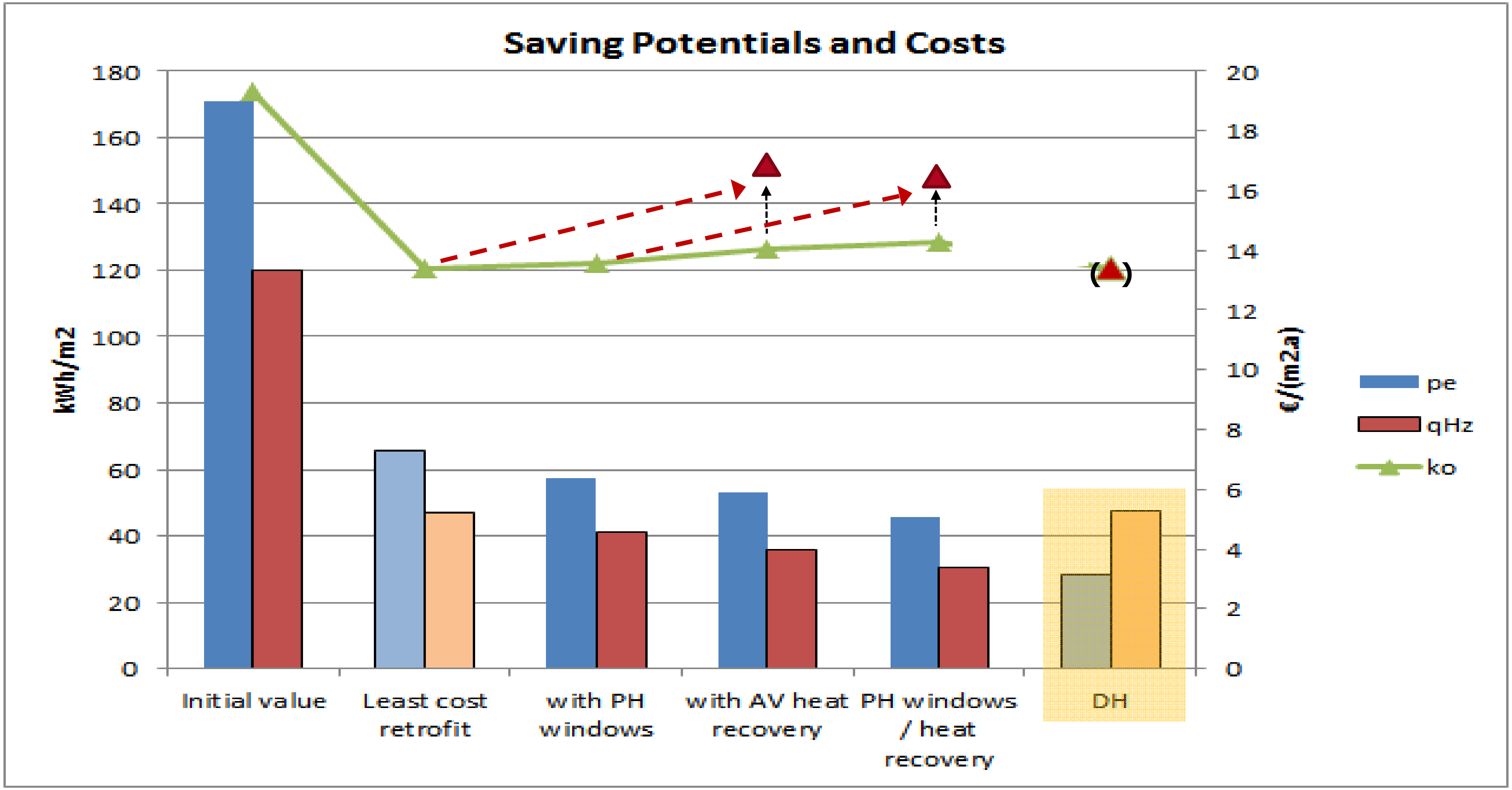
Optimized insulation thickness and energy prices



Additional saving options:



Building energy saving potentials and total costs (energy price: 100 €/MWh)



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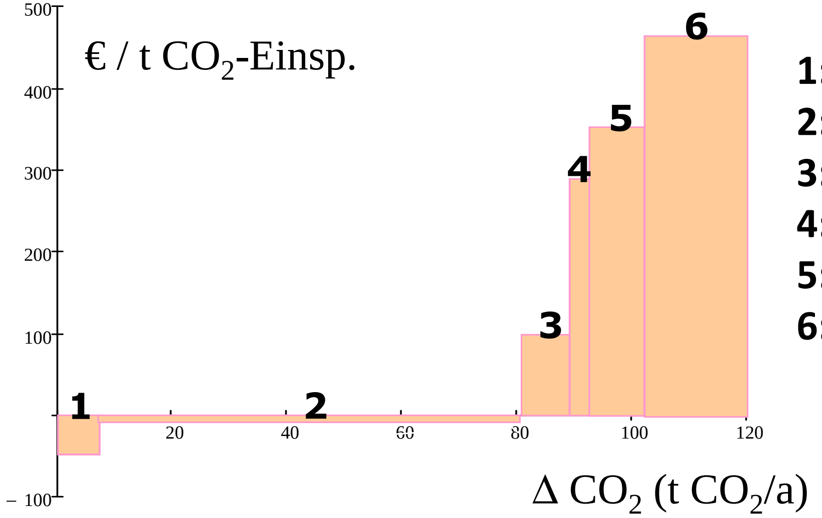
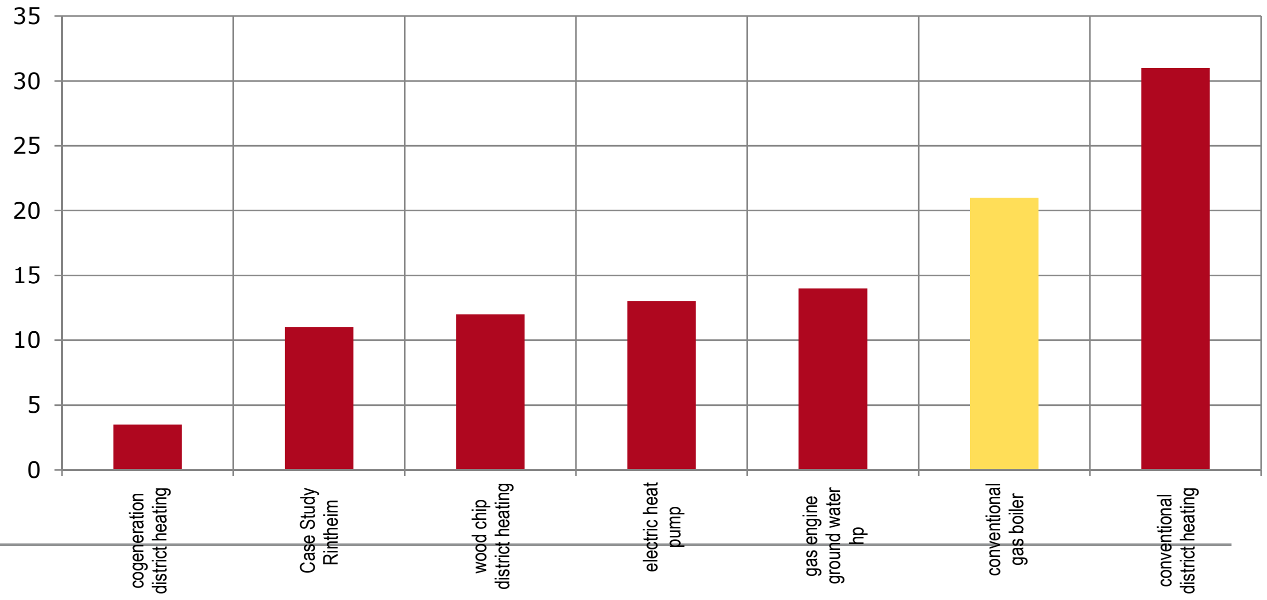
GHG savings vs additional costs:



1: room control
2: envelope retrofit (incl. windows)
3: ventilation / heat recovery
4: PV panel (6,5 kWp)
5: Solar collectors
6: Passivhaus standard

Multi-family building: 50 years, 230 kWh_{PE}/m^2
(36 flats, 9 floors)

Specific GHG emissions of DH alternatives



For economic optimization, employ neighborhood approach!
(equal savings, lesser costs)

Optimization (2)

Local District Heating

Energy Supply Concept:

DH supply (CHP plus waste heat)

Construction period: 2008-2012
lenght of DH pipes 2,6 km
costs 1,7 Mio. €

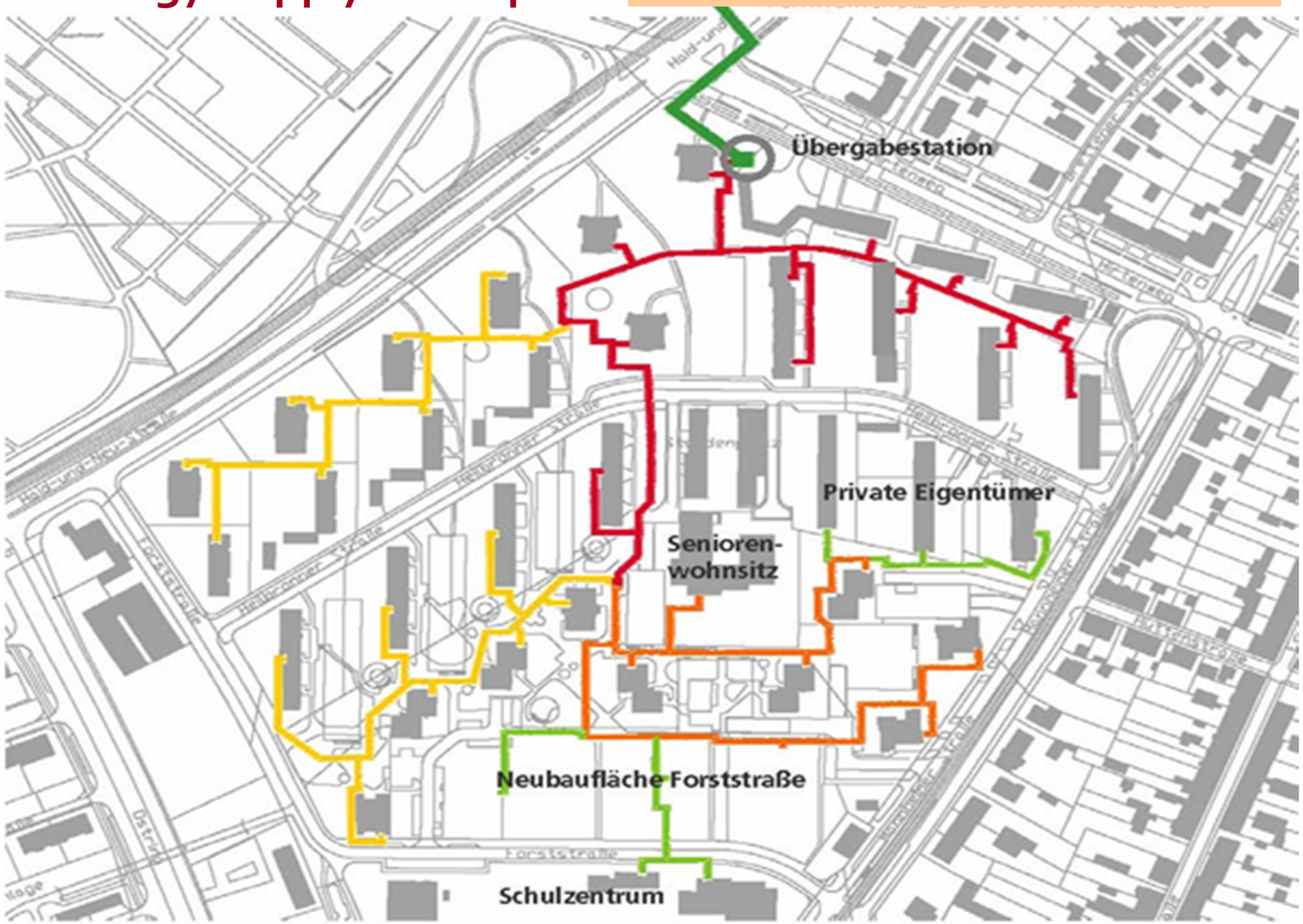
Energy demand development:

1997	14.200 MWth/a
2009	11.470 MWth/a
until 2015	6.200 MWth/a

before retrofit :
- 210 kWhPE/m²
- 42 kg CO_2/m²

after retrofit (with conv. gas):
- *103 kWhPE/m²*
- *25 kg CO_2/m²*

after retrofit (with DH)
- 41 kWhPE/m²
- 16 kg CO_2/m²



> Nahwärmenetz „Rintheimer Feld" der VOLKSWOHNUNG / KES

1. Bauabschnitt — 2. Bauabschnitt — 3. Bauabschnitt — späterer Ausbau

District Heating pipes:

∅ 50 mm

d_{insul} = 5 cm

100 cm below ground

70/40 deg. C

18 W/m total losses

Key figures and DH cost structures:

Annuity : 20 years depreciation time

grid length	L = 2.600 m		
specific costs	c_{sp} = **600 €/m**		
grid costs		$c_G = Inv \cdot ann / q_a$ =	**11,3 €/MWh**
grid losses	$v_G = 0{,}13$		
		$c_L = v_G \cdot AP$ =	**5,0**
auxiliary energy	e_A = 10 kWhel/MWhth		
		c_A =	**2,5**
maintenance	0,05 % of investment		
		c_M =	**7,7**
Overhead		c_O =	**4,0**
upfront costs		c_U =	**6,5**

Total costs of thermal energy:

c_E =	**49,6**
c_{Grid} =	**37,0**
	86,6 €/MWhth (incl. VAT)

Energy supply after full connections:

Q_a = 6.200 MWhth/a → q_a = ***2,4 MWh/m***

Energy price:

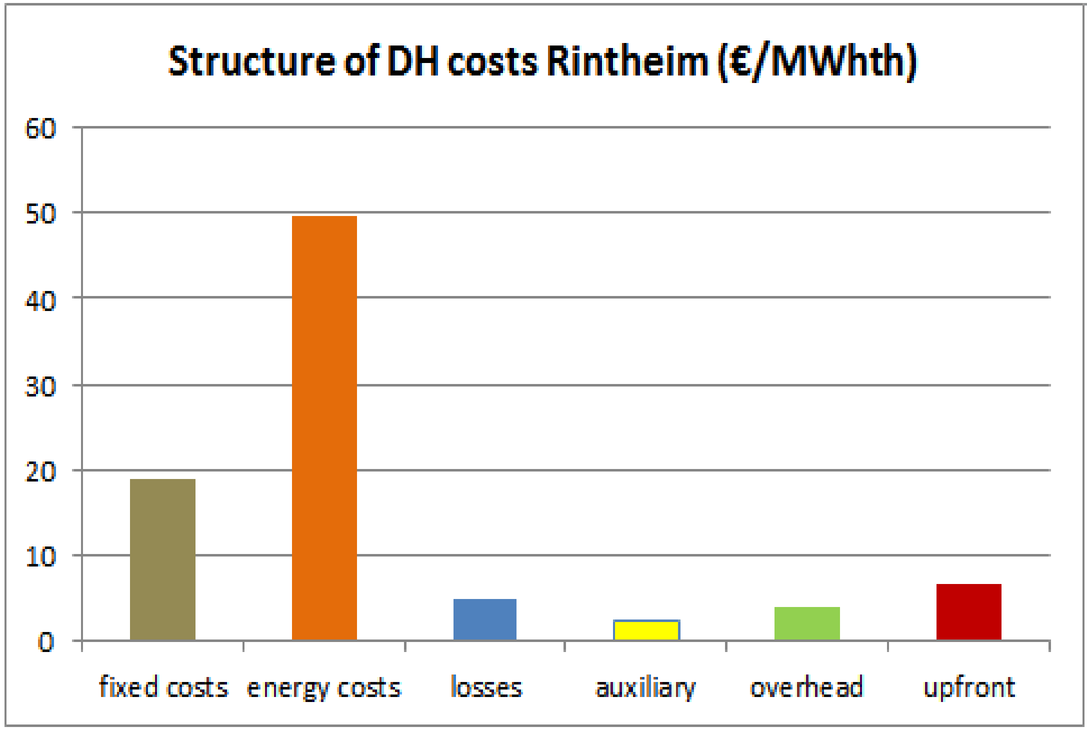
AP = 38,44 €/MWhth

LP = 21,21 €/kWth

full load hours: 1.900 h/a

→ **Energy costs:**

c_E = AP + LP/1,9 = **49,6 €/MWhth**



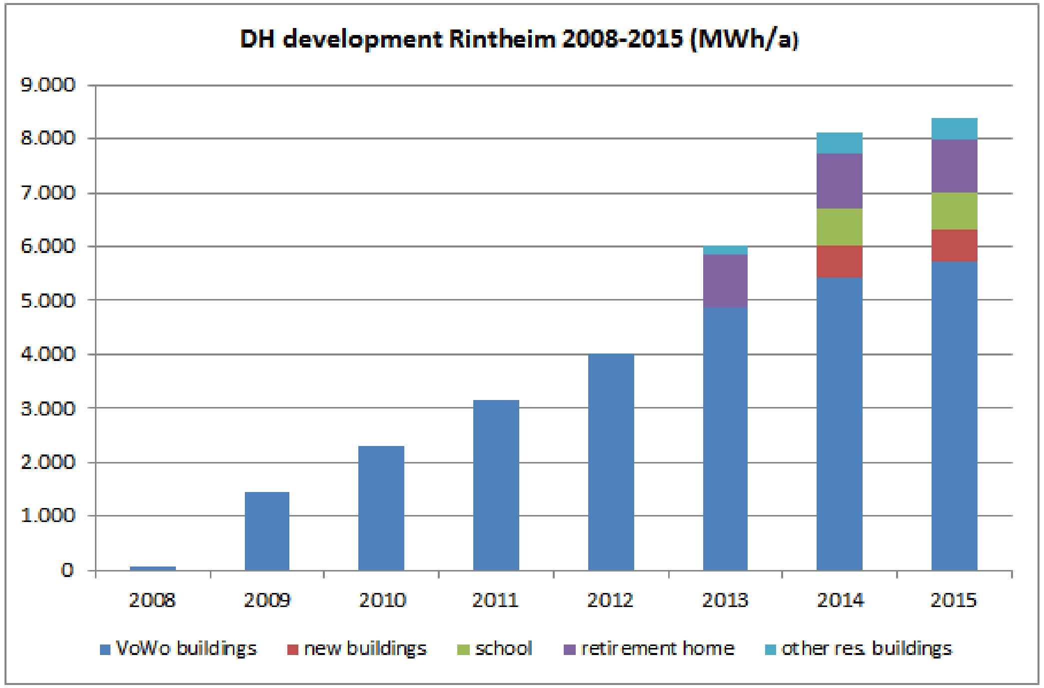
Total DH costs:

- **86,6 €/MWhth** (incl. VAT)
- 20 years depreciation time

Grid investments: Volkswohnung

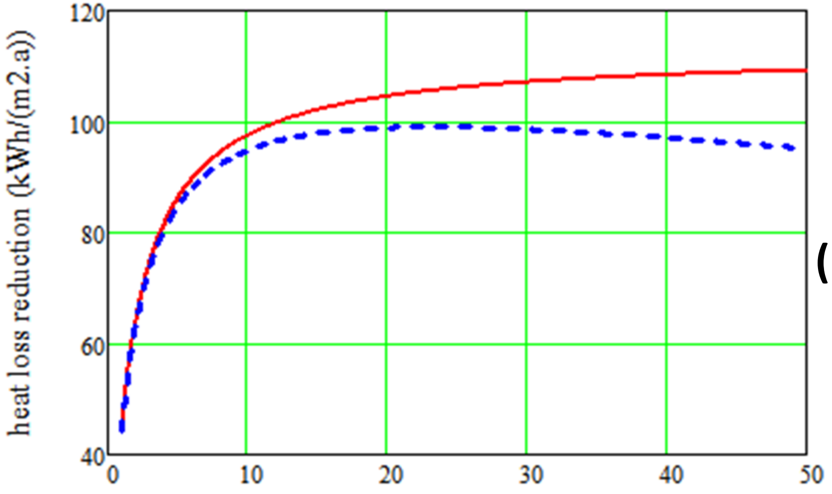
Grid operation: Stadtwerke (local utility)

DH connections during 6 years

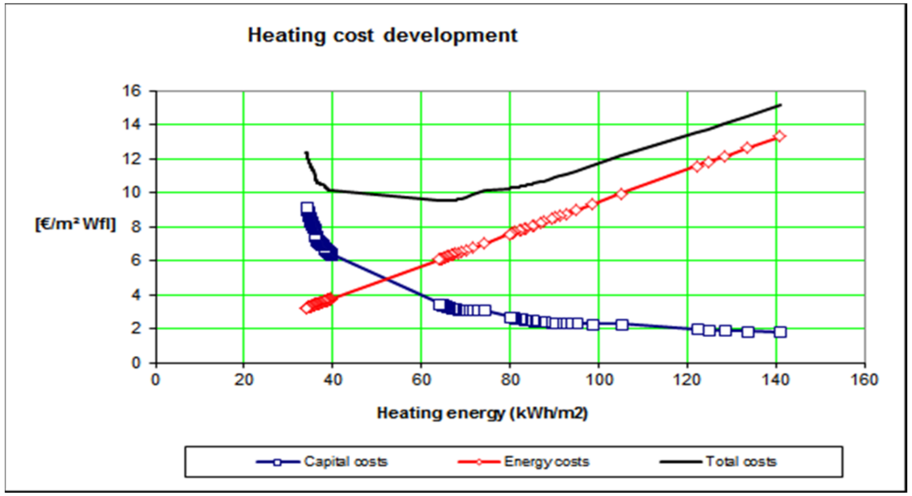


Conclusions?

Optimized insulation thickness?

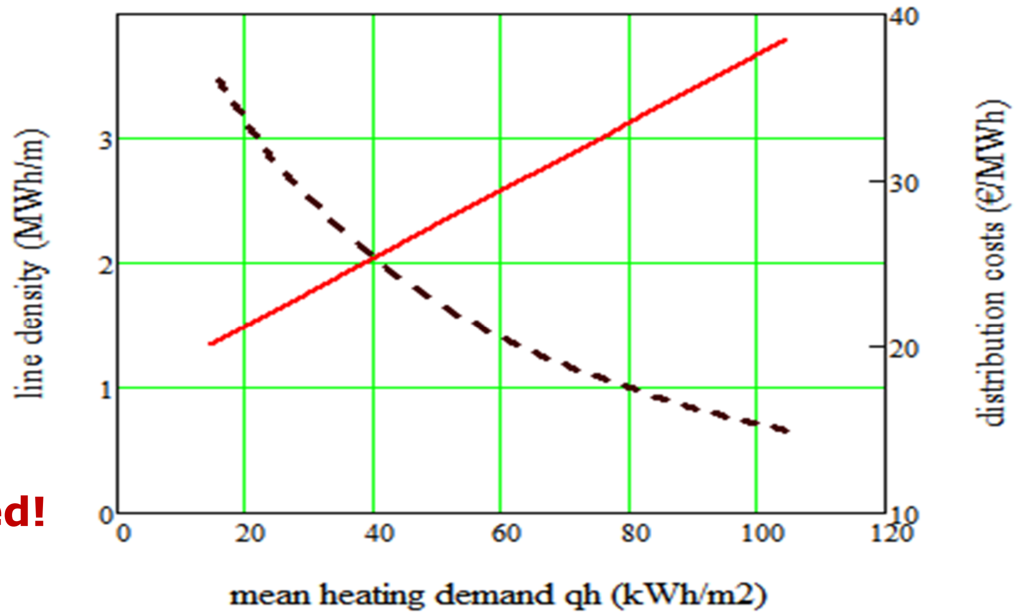


(1) Considering embedded energy, there is a limit of 20 – 30 cm (XPS foam: ~ 1,100 kWh/m³)



(2) For building insulation, there is an economic limit of 12 – 20 cm

(3) For neighbourhood scale heating schemes, there is an economic limit of energy density



Conclusion: Holistic system optimization required!

Investment cost and Return of Investment

Resulting (real) costs:

Energy retrofit investments:

- 237 €/m^2 (incl. VAT) → 1,00 €/(m^2.month)

- retrofit subsidy (KfW): 35 €/m^2 → 0,15 €/(m^2.month)

Δr = *(LCA!)* 0,85 €/(m^2.month)

Result:

	rent	thermal	total
before retrofit	4,00	1,50	5,50
after retrofit	4,85	0,53	5,38

Variation of energy costs:

(1) q_{th_old} = 170 kWh_{th}/m^2

(2) q_{th_new} = 70 kWh_{th}/m^2

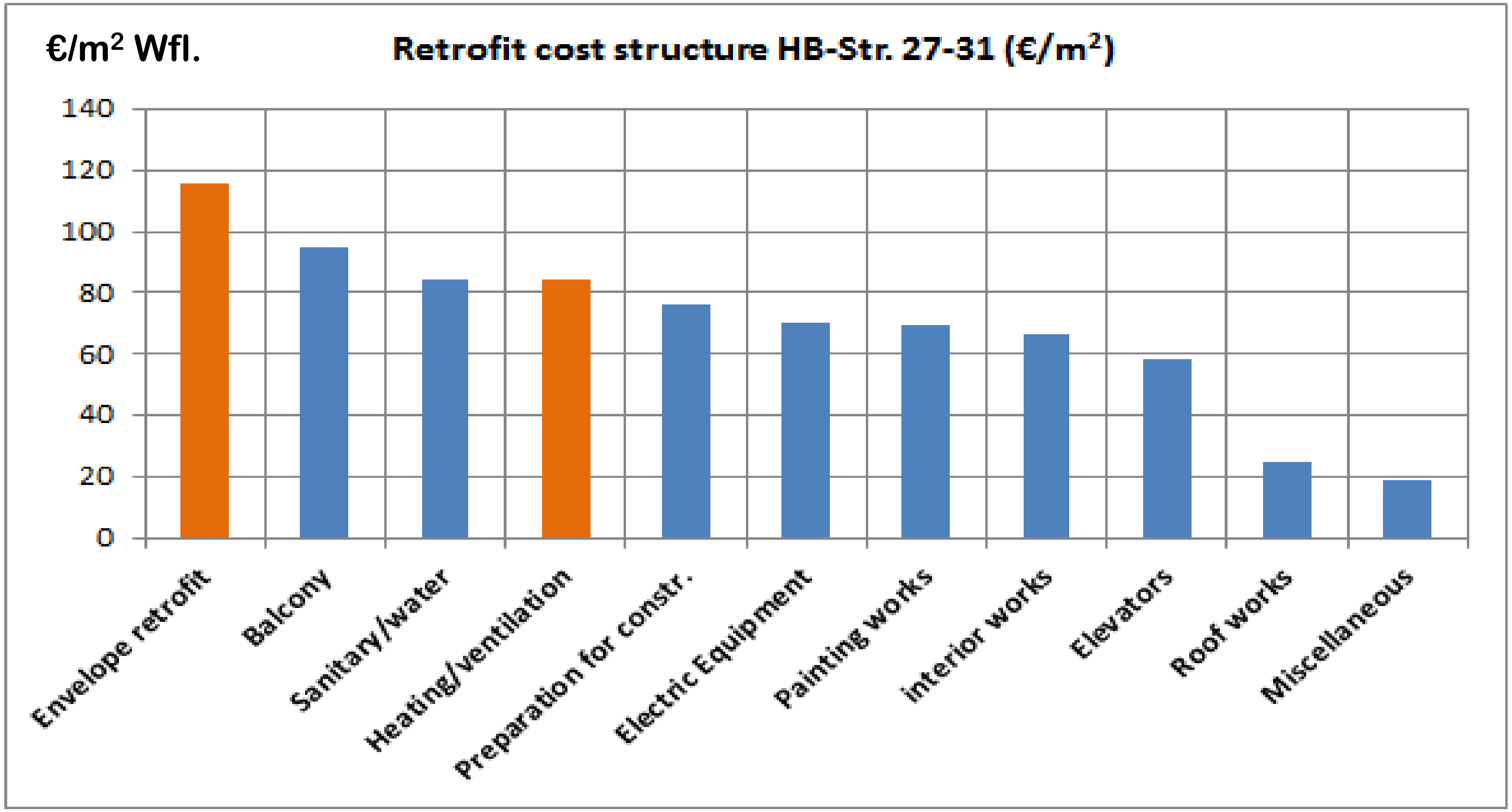
(3) energy price:

gas: 8,5 ct/kWh_{Hi}

DH: 8,7 ct/kWh_{th}

Result: Δc_E = 0,97 €/(m^2.month)

Energy Retrofit Measures:
only one part of refurbishment task!



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„Other refurbishment“:

- 338 €/m^2 → 1,42 €/(m^2.month)
- resulting new rent: 6,27 €/(m^2.month)

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Result:

	rent	thermal	total	real
before retrofit	4,00	1,50	5,50	
after retrofit	4,85	0,53	5,38	6,70

Variation of energy costs:

(1) q_{th_old} = 170 kWh_{th}/m^2

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Result: Δc_E = 0,97 €/(m^2.month)

„Other refurbishment“:

- 338 €/m^2 → 1,42 €/(m^2.month)
- resulting new rent: 6,27 €/(m^2.month)

Result depends on

- retrofit cost
- energy demand before retrofit
- energy price
- user behaviour

Energy Balance:

Global Calculation Method

Technical options for
Energy Supply Technologies

- condensing boiler
- air ventilation heat recovery
- solar collectors (detached: DHW or central)
- heat pumps (electric; gas)
- cogeneration
  - detached
  - neighborhood scale
  - district scale
- waste heat?

Cogeneration (detached, neighborhood scale, district scale):

- gas engine
- Stirling engine
- gas turbine
- ORC plant
- steam extraction
- fuel cell

Energy sources:

gas, oil, coal
nuclear
biogas, solid biomass
solar, wind

Energy Performance?

Energy Conservation measures

General Formula for

Neighborhood Primary Energy Performance pe ??

$$pe_S = (q_{th} - q_s) \cdot [e_S \cdot f_{EE} + (e_a + e_P) \cdot f_{el}] - pe_{PV}$$

Step 1: Building energy performance pe?

(1) Building thermal energy use: q_{th} [kWhth/m²]

(2) End energy performance: e_{EE} [kWhEE/kWhth]

(3) Energy carrier(s): fossil energy f_{EE} [kWhPE/kWhEE]

$$pe_{PE} = q_{th} \cdot e_{EE} \cdot f_{EE} \quad [kWhPE/m^2] \quad \rightarrow \quad \text{minimum!}$$

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Simplest example:
Performance e_{EE} of conventional / condensing gas boiler

efficiency η_B: $$\eta_B = \frac{q_{th}}{EE}$$ **[kWhth/kWhEE]**

performance e_B: $$e_B = \frac{EE}{q_{th}} = \frac{1}{\eta_B}$$ **[kWhEE/kWhth]**

	conv. boiler	condens. boiler	
η_B	0,84	0,94	kWhth/kWhEE
e_B	**1,19**	**1,06**	kWhEE/kWhth

Boiler: Primary Energy Performance e_{B_PE}

$$e_{B\_PE} = e_B \cdot f_{Gas} \; [kWhPE/kWhth]$$

(f_{Gas} = 1,10 kWhPE/kWhEE)

Building Energy Performance pe_{PE} (boiler):

$$pe_{PE} = q_{th} \cdot e_B \cdot f_{Gas} \quad [kWhPE/m^2]$$

$$q_{th} = q_h + q_{DHW} + q_{l\_h} + q_{l\_DHW} \; [kWhth/m^2]$$

q_h ... heating energy use

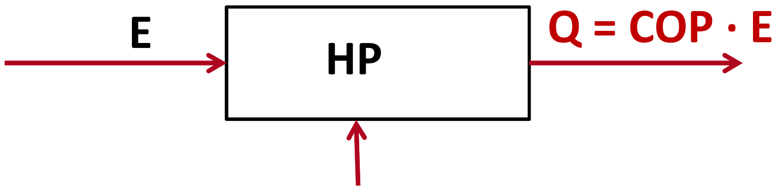
q_{DHW} ... domestic hot water use

q_{l_h} ... heating system distribution losses

q_{l_DHW} ... DHW distribution losses

Electric heat pump ***COP*** (kWhth/kWhel):

$$COP = \frac{T_c}{T_c - T_e} \cdot \eta_{HP} \quad [kWhth/kWhel]$$

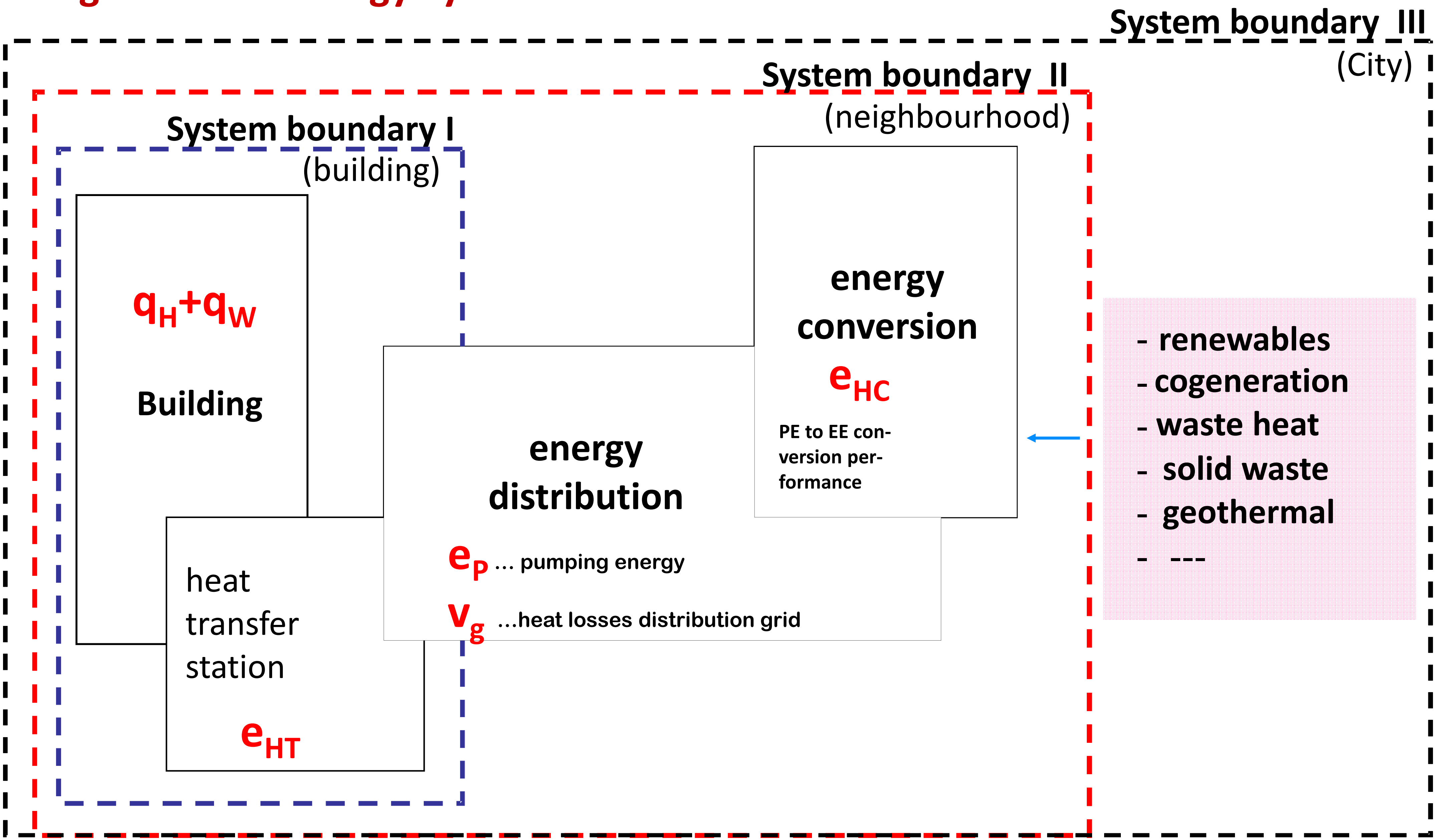


$$\rightarrow \quad e_{HP} = \frac{f_{el}}{COP} \quad [kWhPE/kWhth]$$

f_{el} ~ 2 – 2,5 kWhPE/kWhel

COP = 3,7 → e_{HP} = 2,47/3,7 = 0,67 kWhPE/kWhth

Neighborhood Energy System



Energy performance of various energy systems:

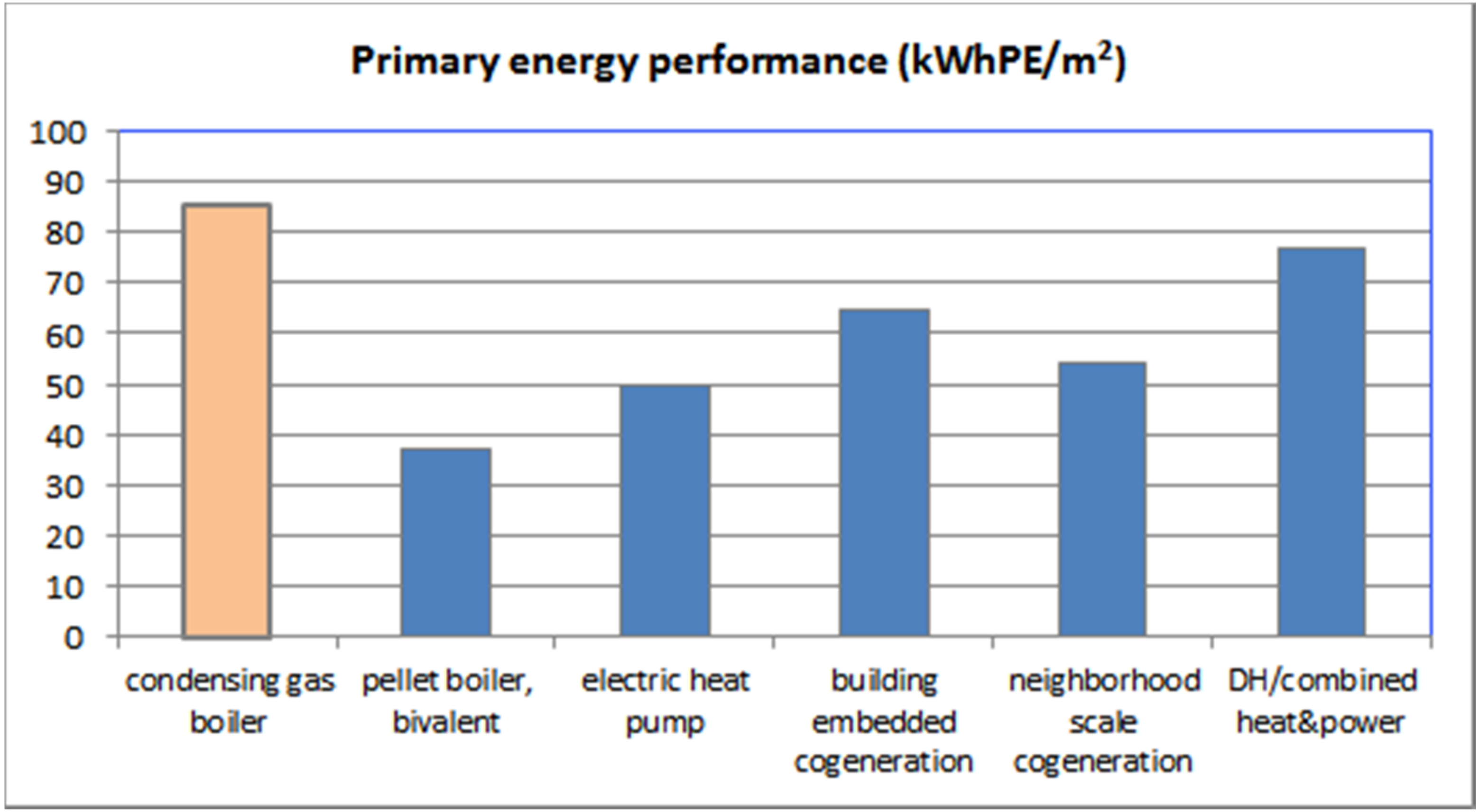
	Boiler	electric heat pump	Cogeneration unit	gas-driven heat pump	combined heat and power plant
	η_B	COP	η_{cog}, s_{cog}	η_M, s_M, ε	σ
e_S:	$e_B = \frac{1}{\eta_B}$	$e_{HP} = \frac{f_{el}}{COP}$	$\frac{1+s}{\eta_{cog}} - \frac{s}{\eta_{el}}$	$\frac{1+s}{\eta_M \cdot (1+s \cdot \varepsilon)}$	$\frac{\sigma}{\eta_{el}}$

→ **General pe formula,**
including base load / peak load,
losses, auxiliary electricity and site generation (e.g. PV):

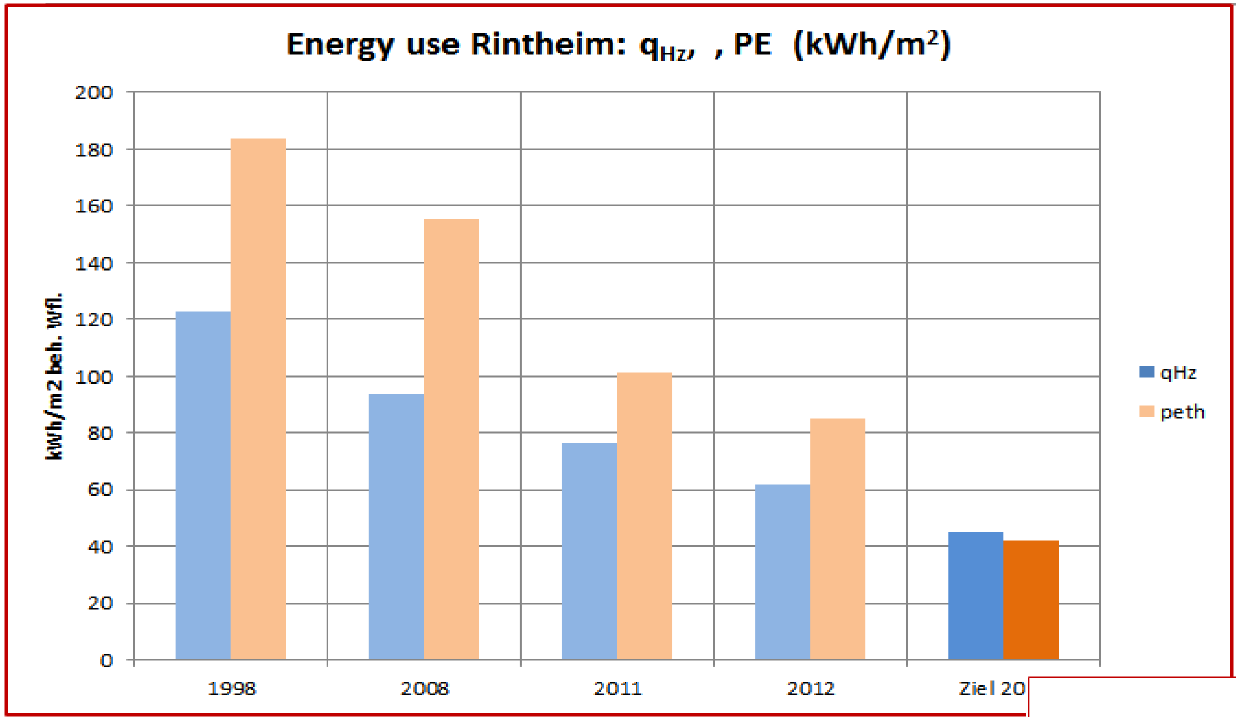
$$pe_S = (q_{th} - q_s) \cdot [e_S \cdot f_{EE} + (e_a + e_P) \cdot f_{el}] - pe_{PV}$$

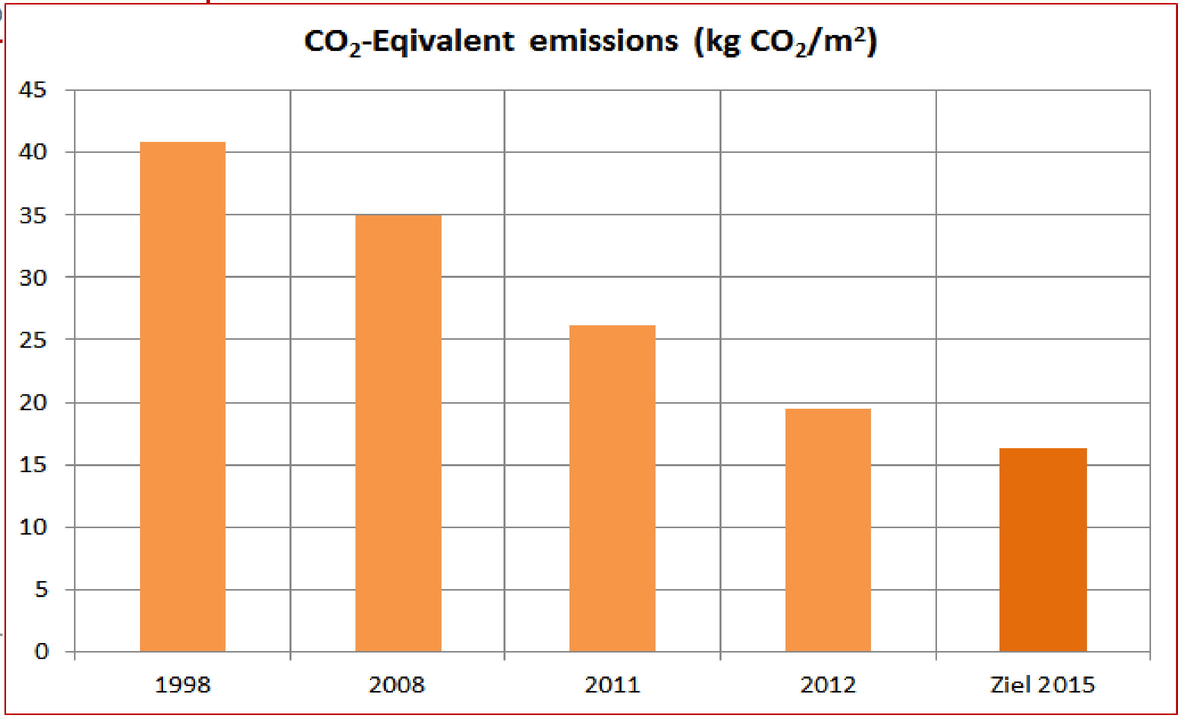
[kWhPE per m² usable building area]

Performance of various energy efficient technologies?



with q_{th} = 70 kWh/m²





Rintheim:

specific PE use, average 1998 – 2014

measured: 2008, 2011 and 2012

Key Messages (1)

(1) Calculation of energy performance:
Simple math – but consistent figures required

(2) one single formula does the job

(3) most efficient energy systems 50 % better than conventional boiler

(4) specific PE and CO_2 factors country dependent

Unconventional Technologies

Two „Pilot Buildings“

„novel techniques"??

VIP, ventil./heat rec., SC, Micro-Pumps,
HP, LT DH, cogeneration, Pellet boilers, . . .

- technologies there
- potentials high
- complexity grows
- performance??

Examples:

- earth-coupled HP: ε = 3,1 – 3,7 → > 4,0 ??
- ventil./heat rec.: $\varepsilon_{Lü}$ = 12 – 4 (??)
- SC yields : 450 - < 250 (??) kWh/m^2
- auxiliary electricity: 2 - 6 kWhel/m^2 !
- micro-pumps: $\Delta E_{el} \approx$ 80%!

Problems:

- Components → whole system optimization?
  → hydraulics, control, data logging
- optimization phase : 1 – 2 years (!)
- ***monitoring system?***

→ **goal:** - robust performance
- user acceptance

Key Messages (2)

(1) Neighborhood scale energy improvement allows energy progress similar to PassivHaus standards (ΔE > 75 %), but with lower cost

(2) In neighborhood scale refurbishment, building retrofit must be integrated with local energy system optimization

(3) Building energy retrofit must be combined with sustainable increase of neighborhood attractiveness

(4) Neighborhood scale development requires concerted action and commitments of local stakeholders

(5) Advanced technologies with high potential exist, but require

- improved system integration
- continuous controlling
- ongoing system optimization
- knowledgeable planners and service providers