Cost optimal opaque thermal insulation in buildings without overheating or cooling
(e.g. transalpine Europe)

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Overview

- **analytical deduction**
- graphical illustrations of principle
- numeric examples

Analytical deduction (1): energy

- heat flux

$$q = U \cdot (\theta_{int} - \theta_e)$$

- annual flux

$$Q_a = U \cdot \sum_m \left[(\theta_{int,set,H} - \theta_{e,m}) \cdot t_m\right] = \frac{1}{R} \cdot \sum_m \left[(\theta_{int,set,H} - \theta_{e,m}) \cdot t_m\right]$$

Analytical deduction (2): energy cost

- net present energy cost

$$f_2 = NPEC = \frac{Q_a}{\eta_{sys}} \cdot C \cdot PWF$$

- or

$$f_2 = NPEC = \frac{\alpha}{R} = \alpha \cdot U \quad with\ \alpha = \frac{\sum_m \left[(\theta_{\mathrm{int},set,H} - \theta_{e,m}) \cdot t_m \right]}{\eta_{sys}} \cdot C \cdot PWF$$

- with

$$PWF = \sum_{j=1}^{N} \frac{(1+i)^{j-1}}{(1+d)^{j}} = \begin{cases} \frac{1}{d-i}\left[1 - \left(\frac{1+i}{1+d}\right)^{N}\right] & \text{if } i \neq d \\ \frac{N}{1+i} & \text{if } i = d \end{cases}$$

Analytical deduction (3): lowest life cycle cost

- total net present cost

$$f_3 = f_1 + f_2$$

- optimum point

$$\frac{df_3}{dR} = 0 \Rightarrow \frac{df_1}{dR} = -\frac{df_2}{dR}$$

Climate dependency

$$f_1 = c_1 + c_2\left(R - R_b\right)$$

$$\frac{df_1}{dR} = c_2 \qquad \text{and} \qquad \frac{df_2}{dR} = -\frac{\alpha}{R^2}$$

$$R_{opt} = \sqrt{\frac{\alpha}{c_2}} \propto \sqrt{DD}$$

$$DD = \sum_m \left[(\theta_{\text{int},set,H} - \theta_{e,m}) \cdot t_m\right] \Big/ 0.0864$$

Unheated spaces

$$b_U = \frac{(\theta_{\text{int}} - \theta_U)}{(\theta_{\text{int}} - \theta_e)}$$

$$f_4 = NPEC_U = \frac{1}{R} \frac{\sum_m \left[b_U \cdot (\theta_{int,set,H} - \theta_{e,m}) \cdot t_m \right]}{\eta_{sys}} \cdot C \cdot PWF = \frac{b_U \cdot \alpha}{R}$$

$$\frac{df_4}{dR} = -\frac{b_U \cdot \alpha}{R^2}$$

$$R_{opt,U} = \sqrt{\frac{b_U \cdot \alpha}{C_2}}$$

Some ext'l verification of the outcomes

- cost optimal studies for EPBD reporting:
  - BE-FL: based on full EPB calculations: same results
  - DK: based on (same?) degreeday method: same results
- set of annual eurima ecofys studies (~10 years ago)
  - most likely also based on the DD method (but nowhere explicitly mentioned (?))
  - several identical conclusions throughout the report

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- **graphical illustrations of principle**
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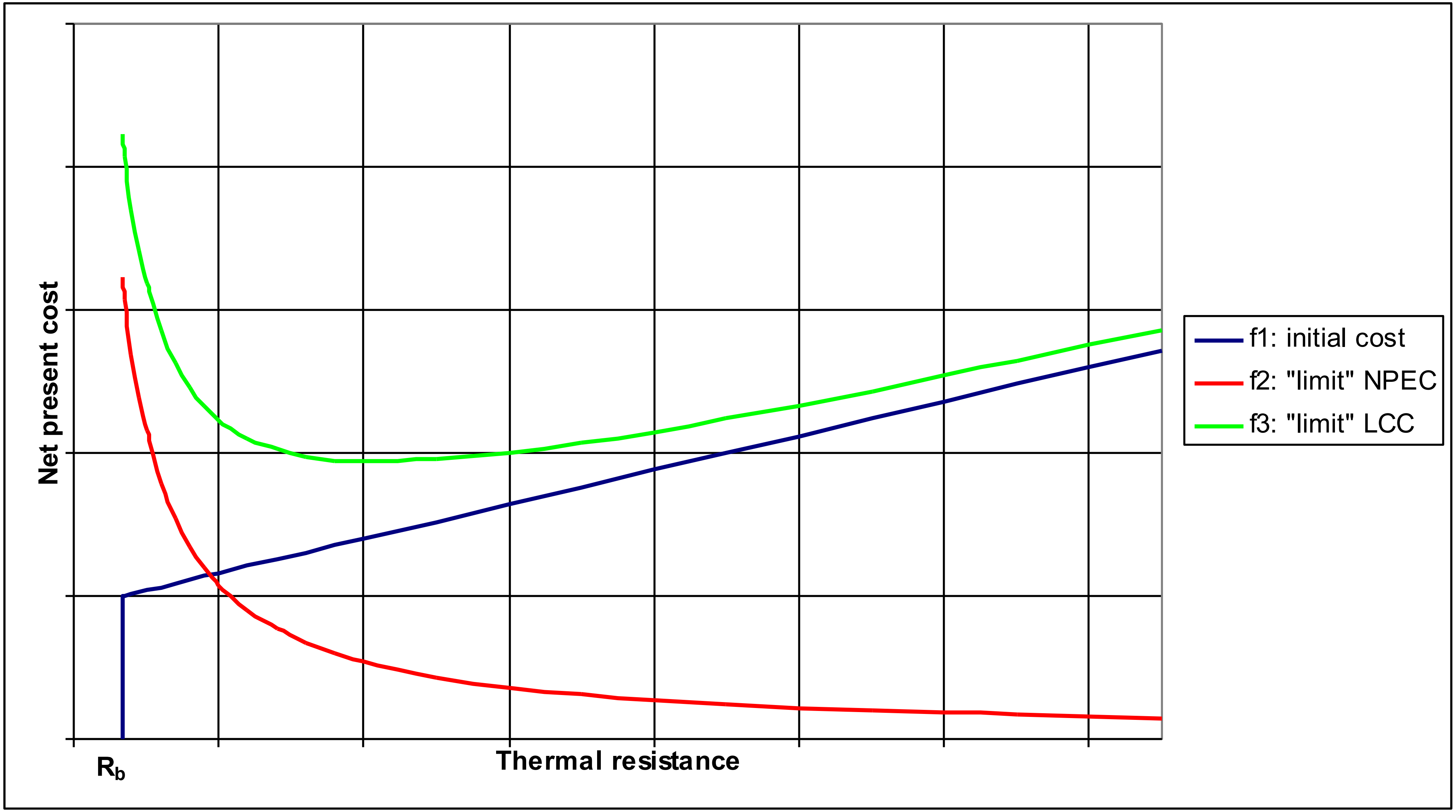
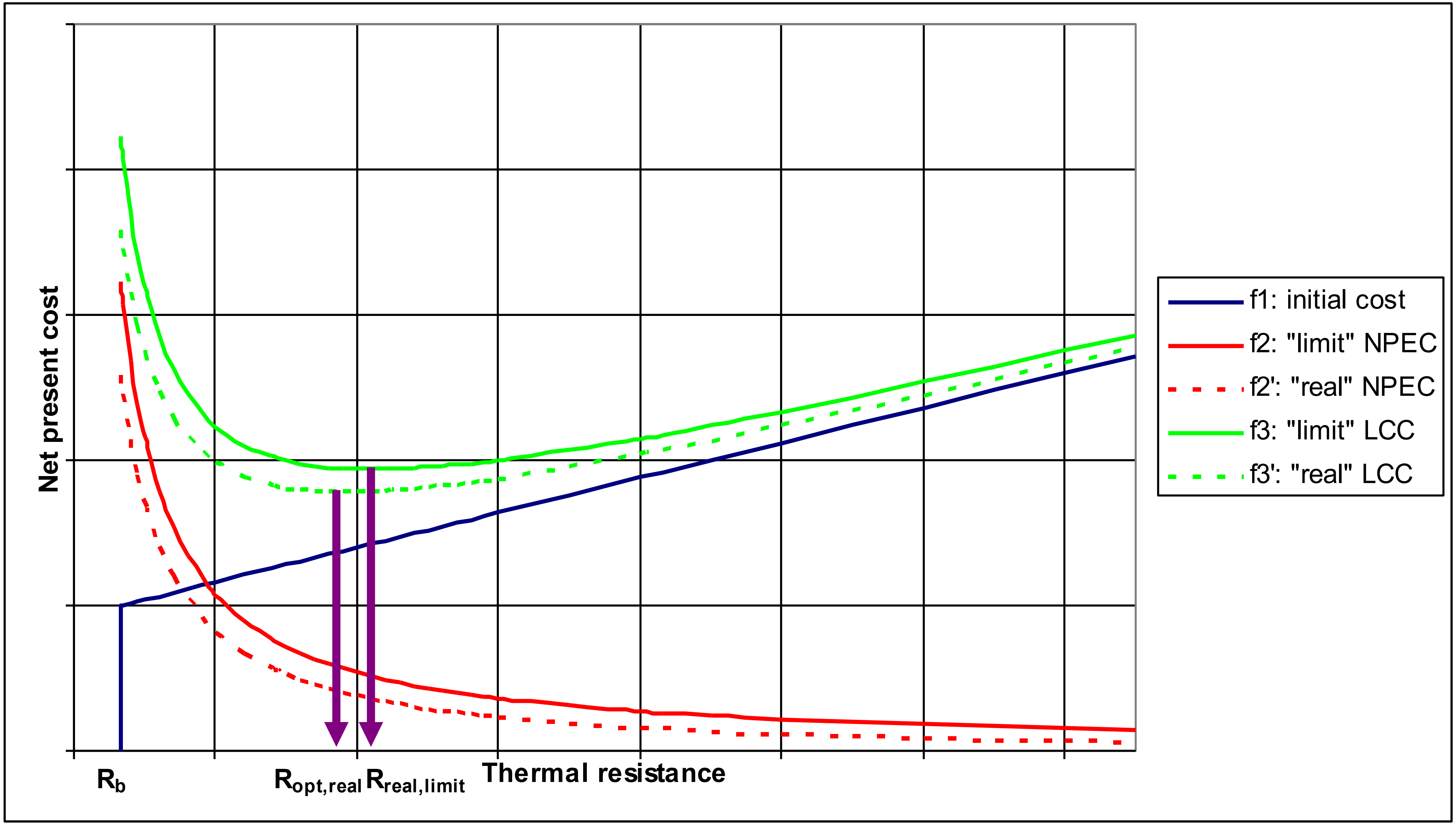
Without thermal gains



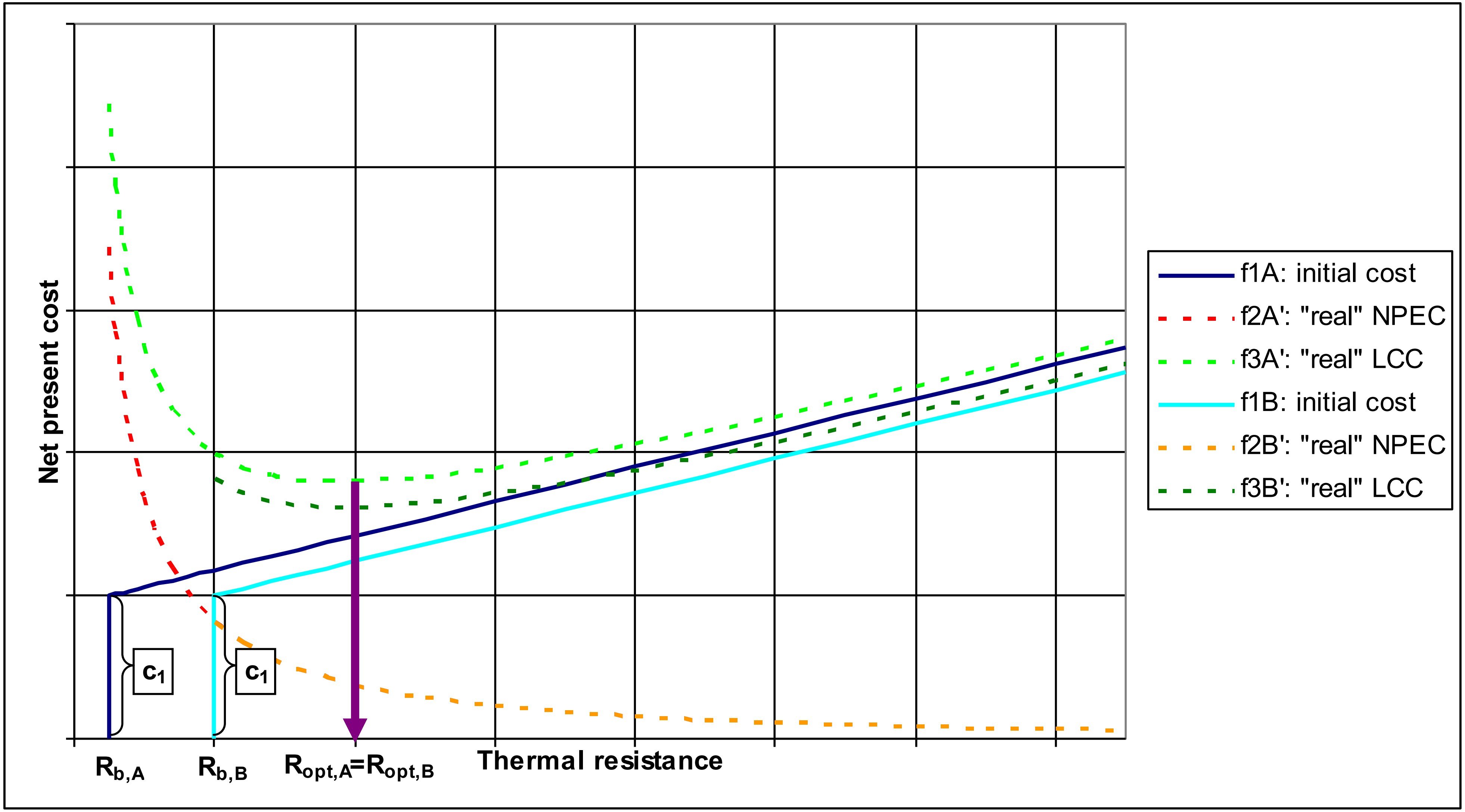
With thermal gains



Effect of smaller heating systems

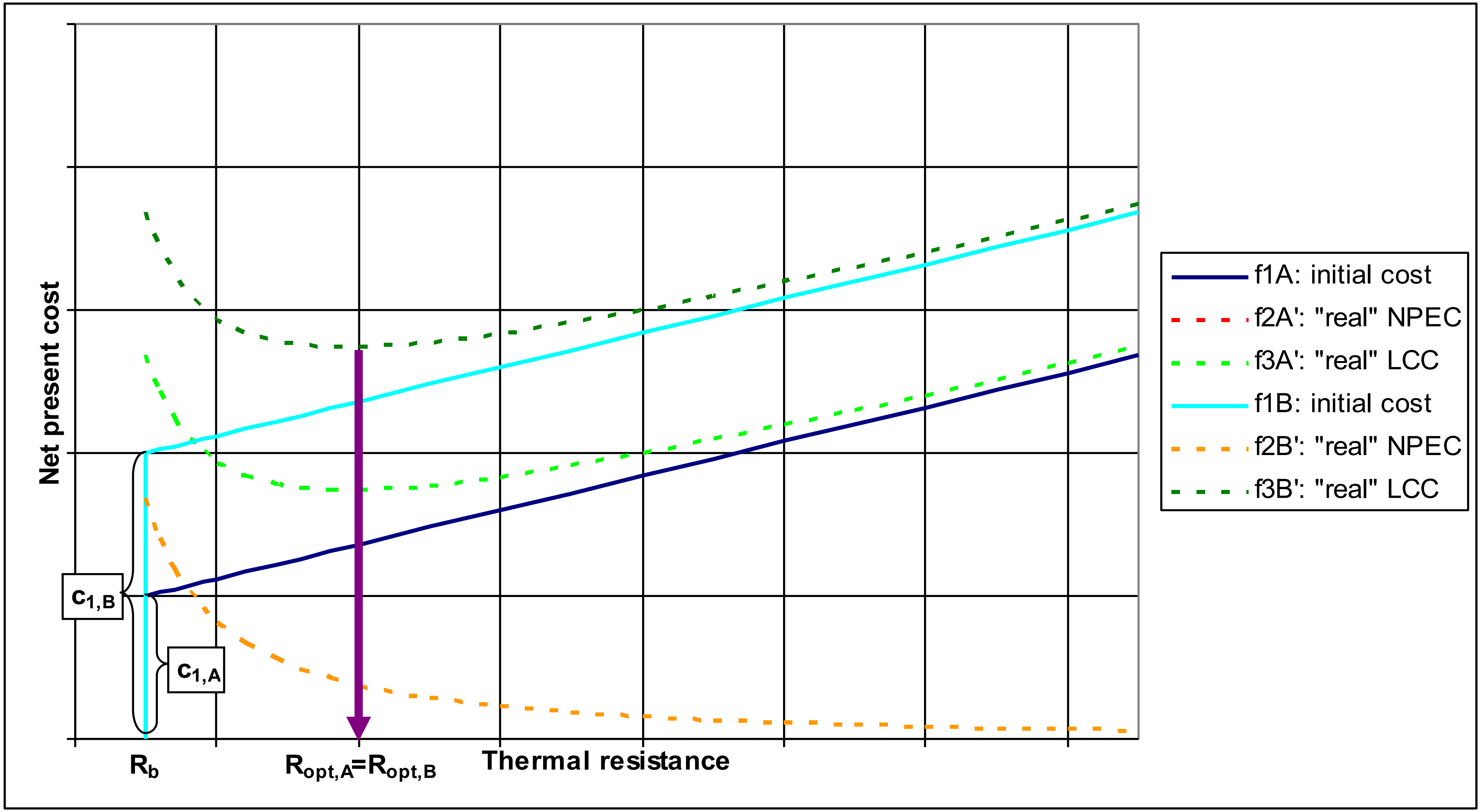
- emitters: often not a large initial cost, so not much savings possible
- heat generator:
  - some cost reduction possible in originally uninsulated buildings
  - otherwise: size often determined by the hot water power needs, so no further downsizing possible

Influence of the basic resistance of the component



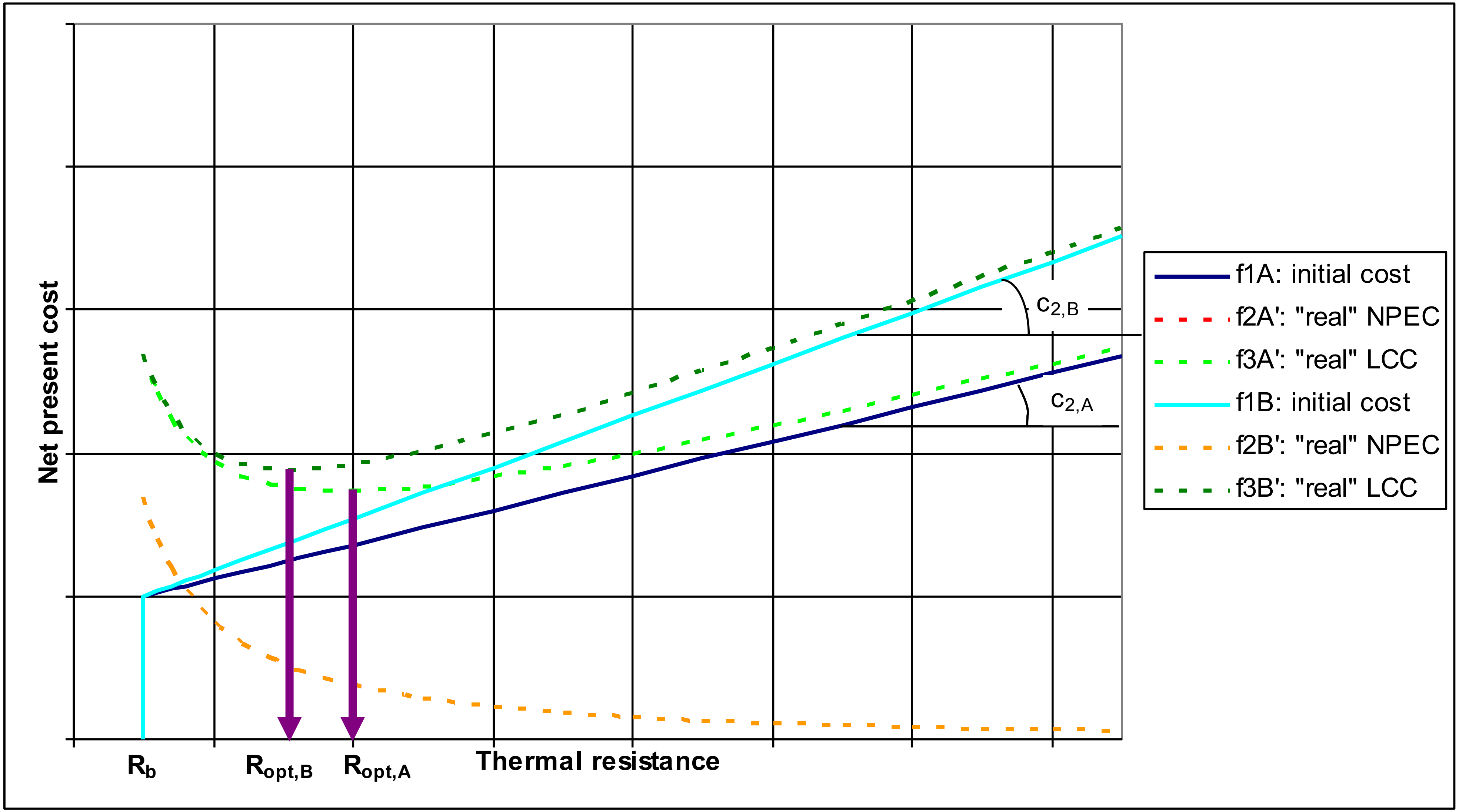
Conclusion: the initial basic resistance (Rb) does not influence the optimal final resistance

Influence of the initial minimum cost of applying insulation



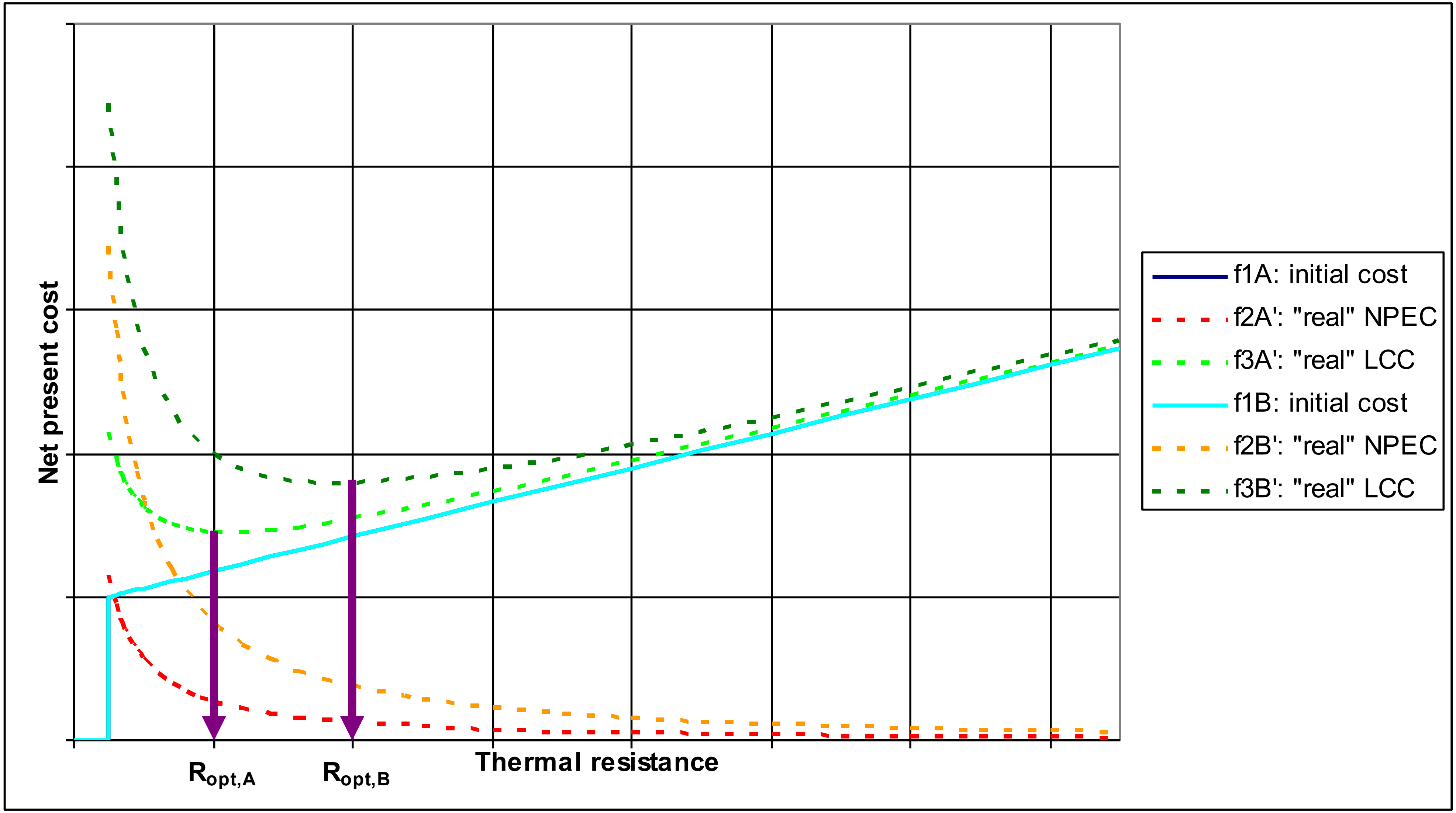
Conclusion: the initial starting cost of applying insulation does not influence the optimal final resistance

Influence of the marginal cost of extra insulation



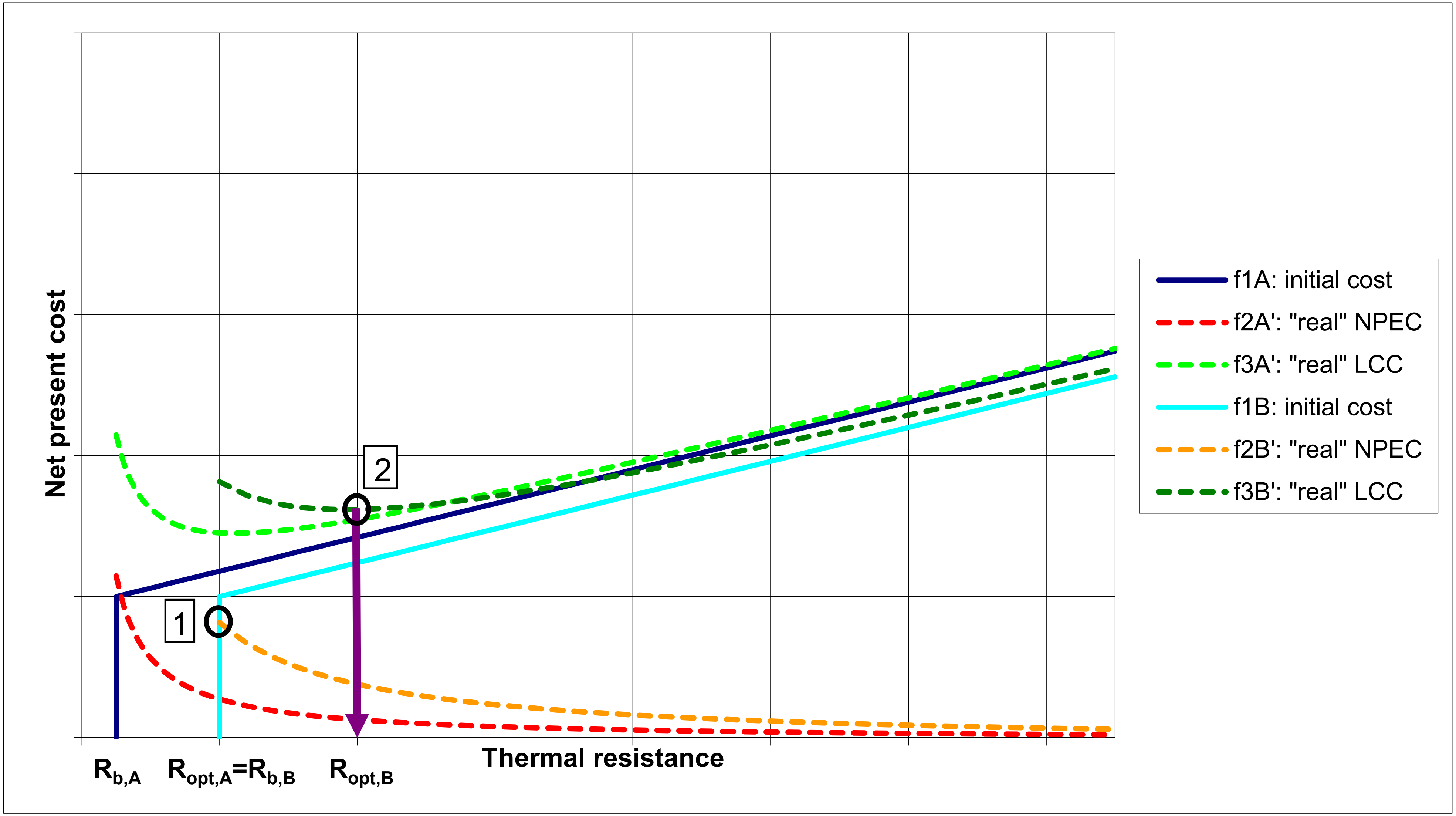
Conclusion: the marginal insulation cost affects the optimal resistance strongly

Influence of the energy price



Conclusion: volatile energy prices of the day don’t seem a sound basis for long term decisions

Upgrading of a moderately insulated component



Conclusion: a (high) initial incremental cost can render a 2nd round of insulation uneconomic

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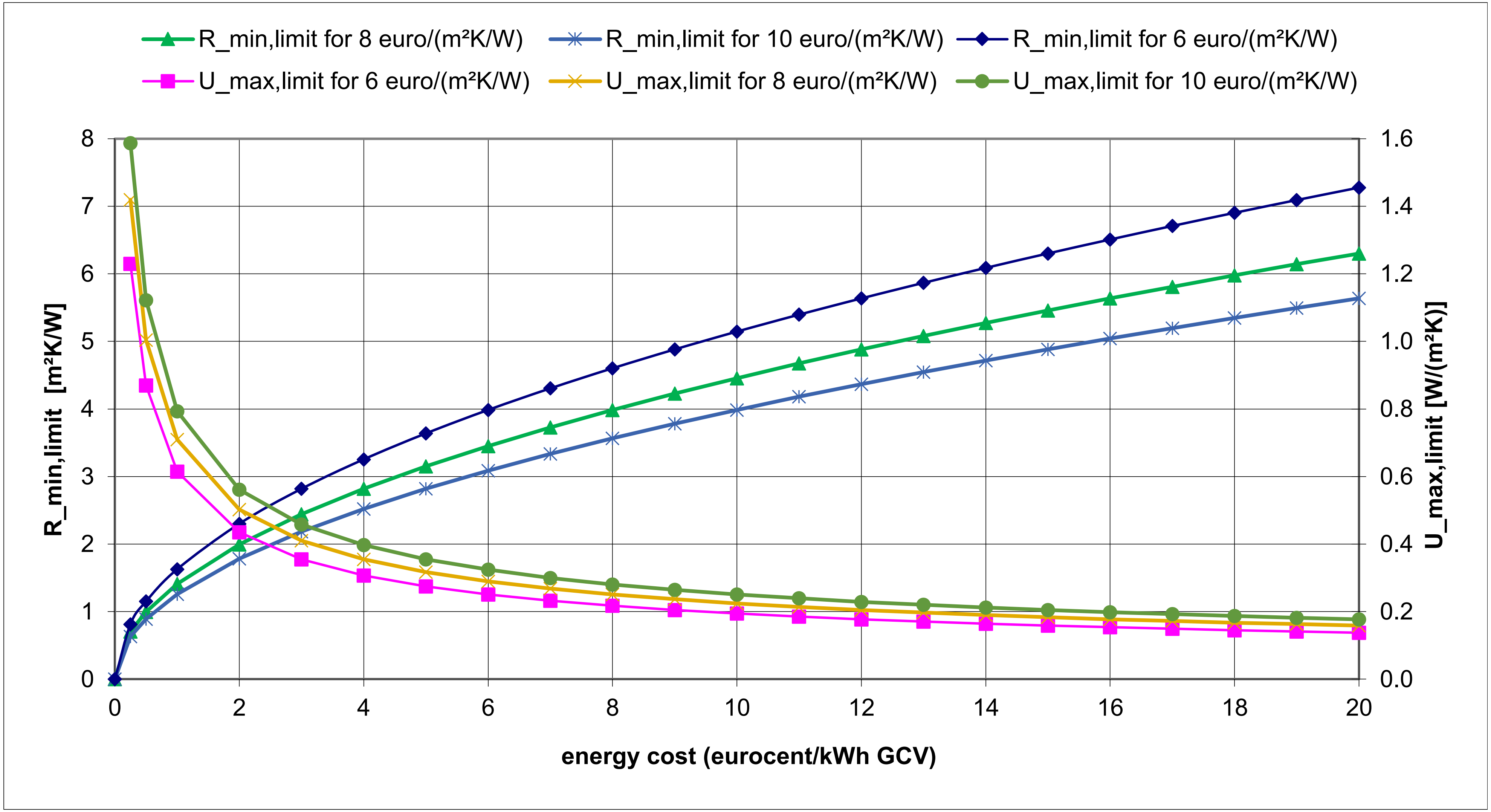
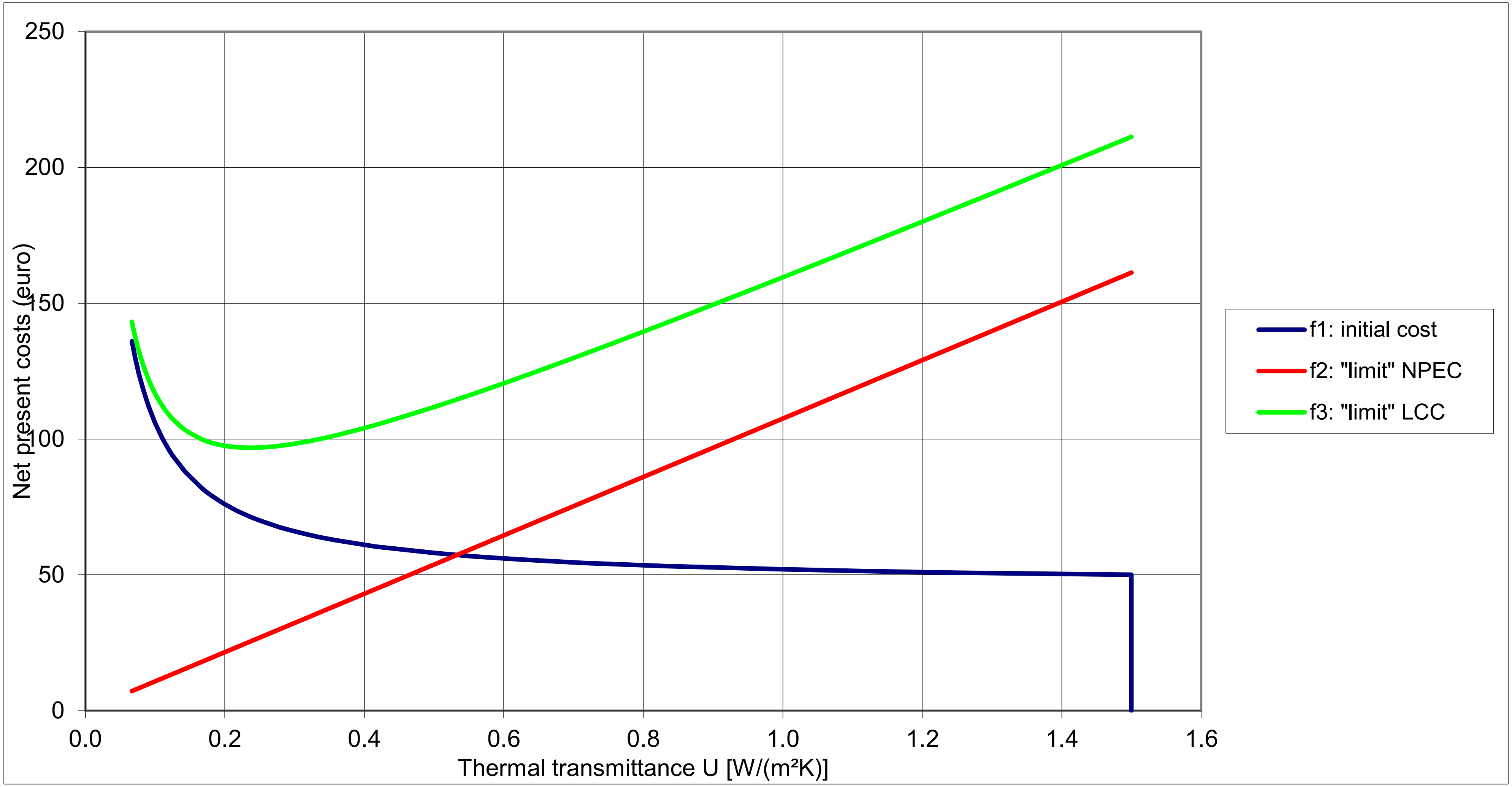
Dependence on energy cost

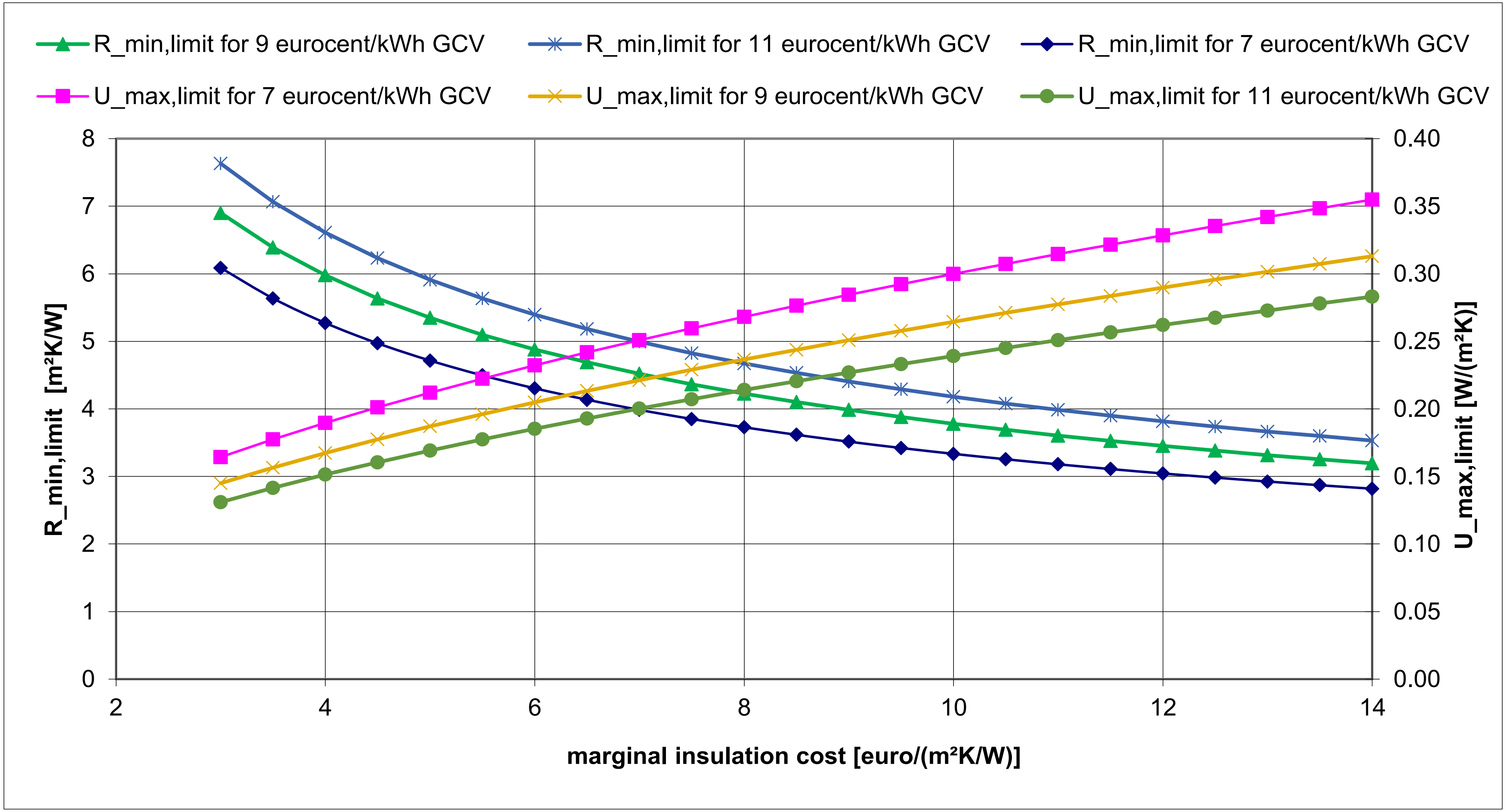


Conclusion: even if energy cost were 3x times present value (20 iso 7 c/kWh) no PH U-values of 0.10-0.12 W/(m²K)

Other representation: as function of U iso R

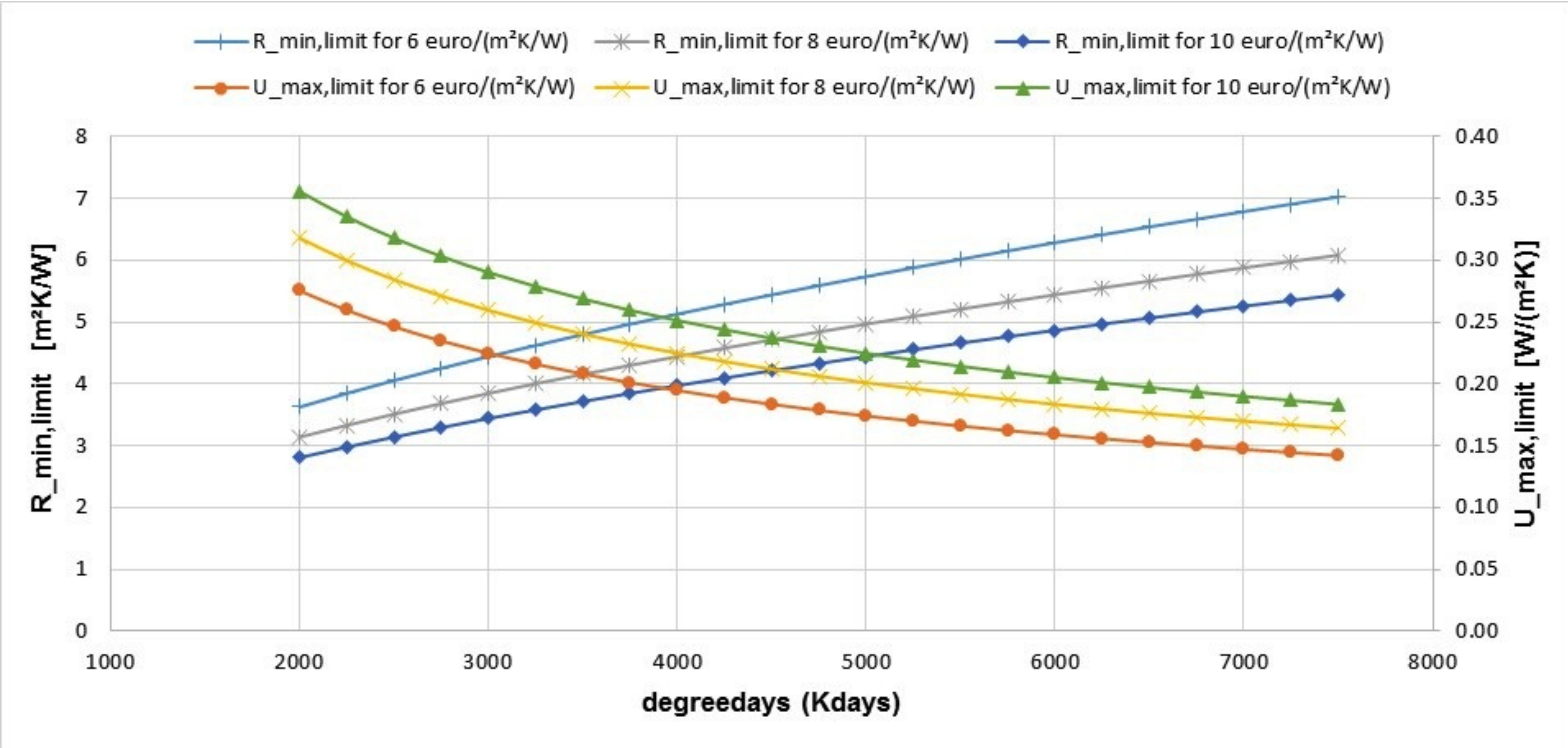


Dependence on c_2



Question: what is historic trend of insulation material cost?

Dependence on degreedays



Resistance inversely proportional to square root of DD (see analytical deduction slide)

Conclusions (1)

Simple degree day method good approximation to determine optimal insulation.

- The optimal resistance is independent of the value of the basic resistance R_b of an opaque building element (i.e. the resistance at starting point before any insulation is added).
- The optimum is also independent of the initial incremental cost associated with starting to apply insulation.
- The optimum mainly depends on the marginal cost (including secondary costs) of adding extra resistance.

Conclusions (2)

- The optimum does not increase linearly with the severity of the climate, but proportionally with only the square root of the climate severity (expressed in terms of degree-days).
- For unheated adjacent spaces, the optimum doesn't decrease linearly with smaller b-factor (i.e. the temperature reduction factor) but proportionally with only the square root of the b-factor.
- The internal and solar gains shift the economically optimal resistance to a somewhat lower value, but generally speaking the difference is probably small (unless the buildings would tend towards very low heating needs such as in passive houses or equivalent).

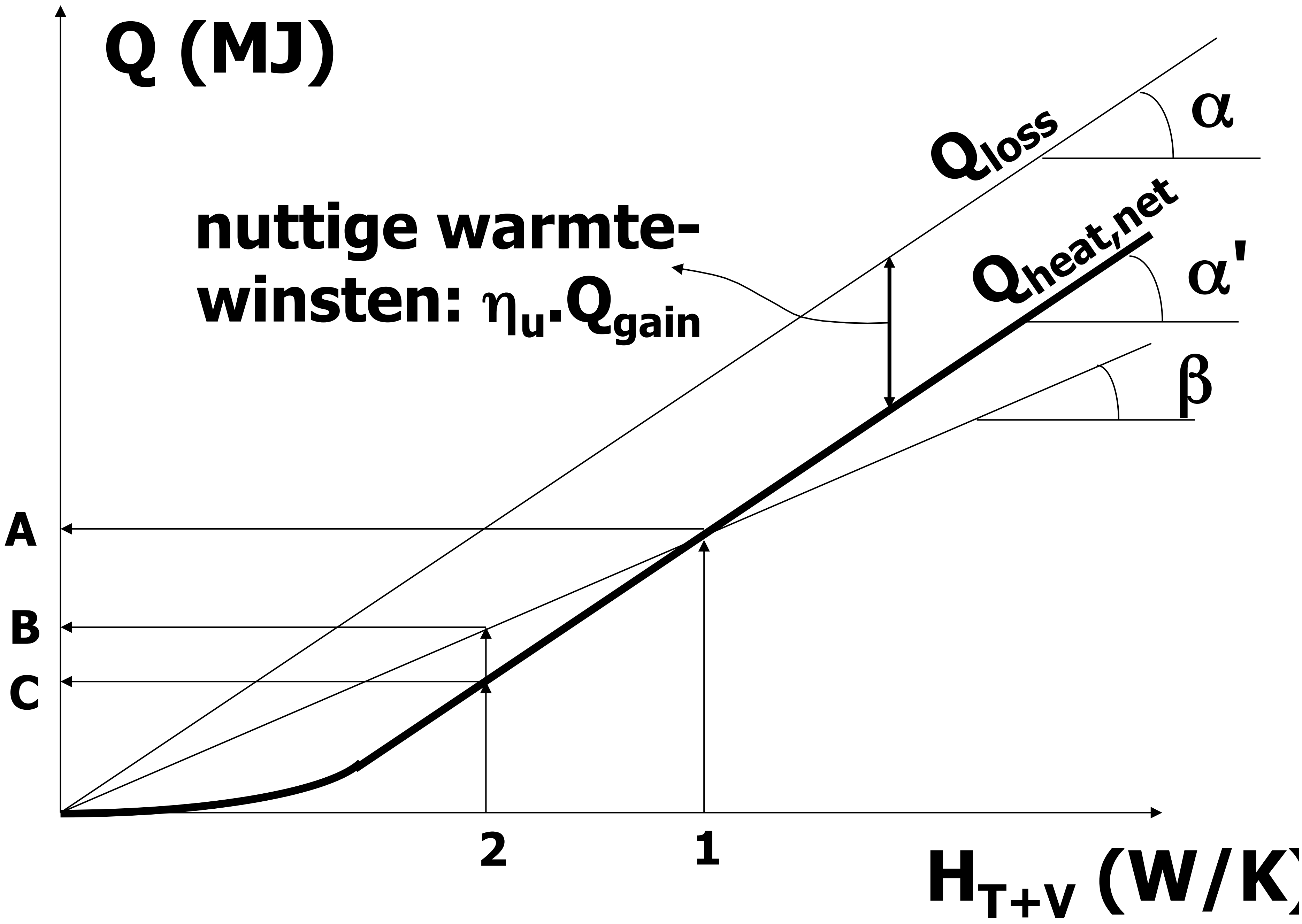
Informal session, this afternoon @ 16:30

**<u>Setting EPB requirements:
new (EN) ISO 52003 & 52018 standards, and beyond</u>**

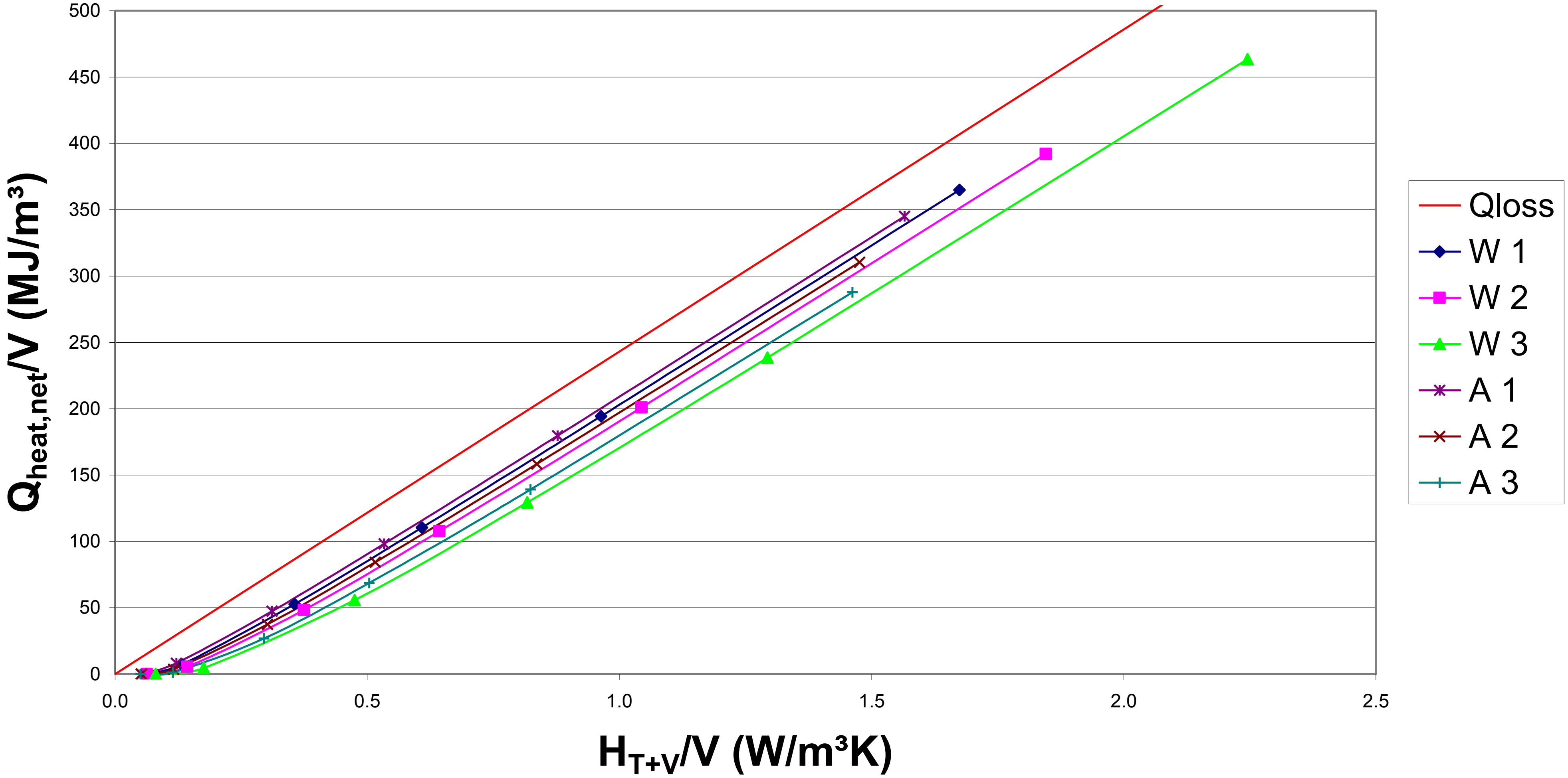
- ❖ Which objectives are pursued?
- ❖ Which mix of EPB features to set requirements?
- ❖ For which indicators?
- ❖ Which strictness?
- ❖ And especially the important issue of tailoring requirements to each individual building.

Questions

- position vis-à-vis post insulation of cavities in brick walls?
  - U-value from … 1.5-1.8 … to … 0.5-0.65 … W/m²K: still much more (2-3 x) than the cost optimum of new elements
  - external insulation not cost effective (5+ times more expensive) + different visual aspect
  - impact on residual energy consumption of a fully renovated building stock on RE demand
- how to deal with PH-insulation apparently never becoming economic?
  - abandon economic behaviour and go for the (reasonable) "full" technical potential? (PH)
  - economic perspective is only …30… years into the future, but envelope insulation is for building lifetime (… 100 … years)
- …?



Q (MJ)
Q loss
Q heat,net
α
α'
β
nuttige warmte-
winsten: η u .Q gain
A
B
C
2
1
H T+V (W/K)



500
450
400
350
300
250
200
150
100
50
0
0.0
0.5
1.0
1.5
2.0
2.5
$Q_{heat,net}/V$ (MJ/m³)
H_{T+V}/V (W/m³K)
Qloss
W 1
W 2
W 3
A 1
A 2
A 3