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Different Path to Low Energy Homes – How Low Can You Go?

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ACI – Home Performance Conference

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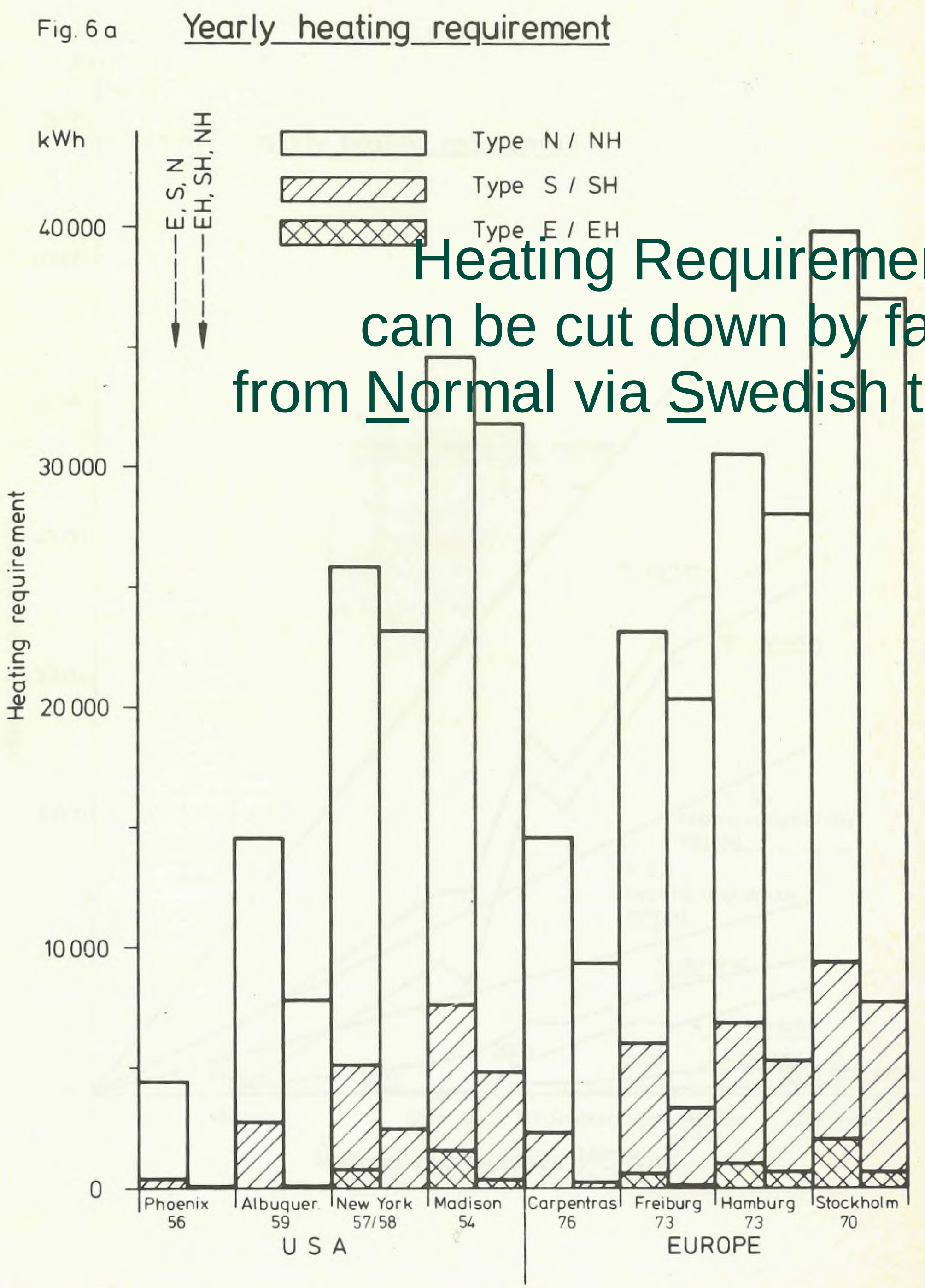
How Low Can We Go?

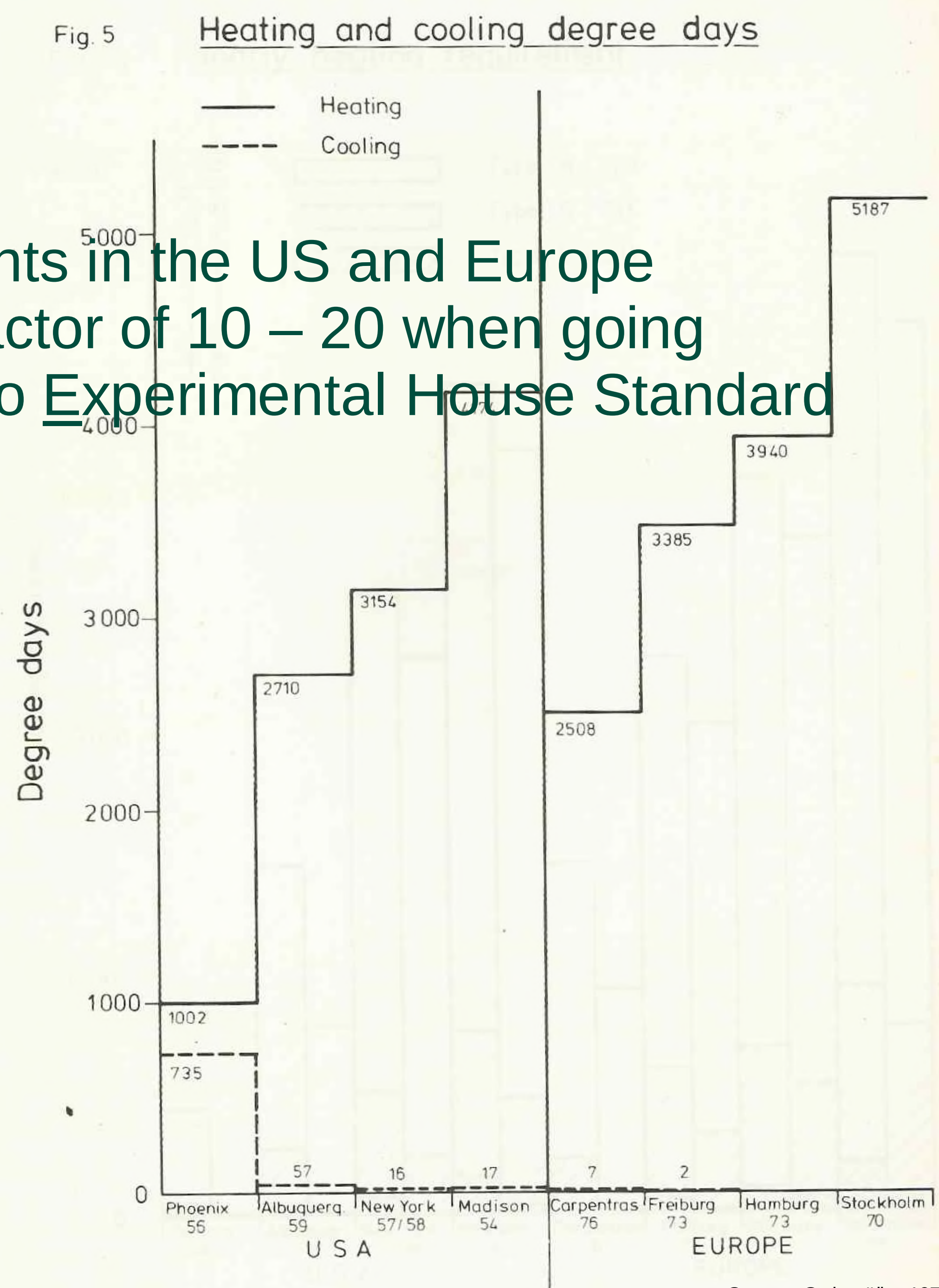
Philips Experimental House -
First (Ultra-)Low-Energy House in Germany, Aachen 1974 ff

- Super insulation: U-Value 0.14 W/m^2K (R~40)
- Efficient Window Systems: (coated double) + shutters
- Controlled ventilation, 90% air-to-air-heat recovery plus soil heat exchanger
- Heating demand 20 - 30 $kWh/(m^2a)$ i.e. 2 – 3 $kWh/(ft^2a)$ or 7 – 10 $kbtu/(ft^2a)$
- Renewable Energies
- Theory-Experiment Comparisons
- Parameter Studies US & Europe …

Source: Hörster, Steinmüller (PFA)

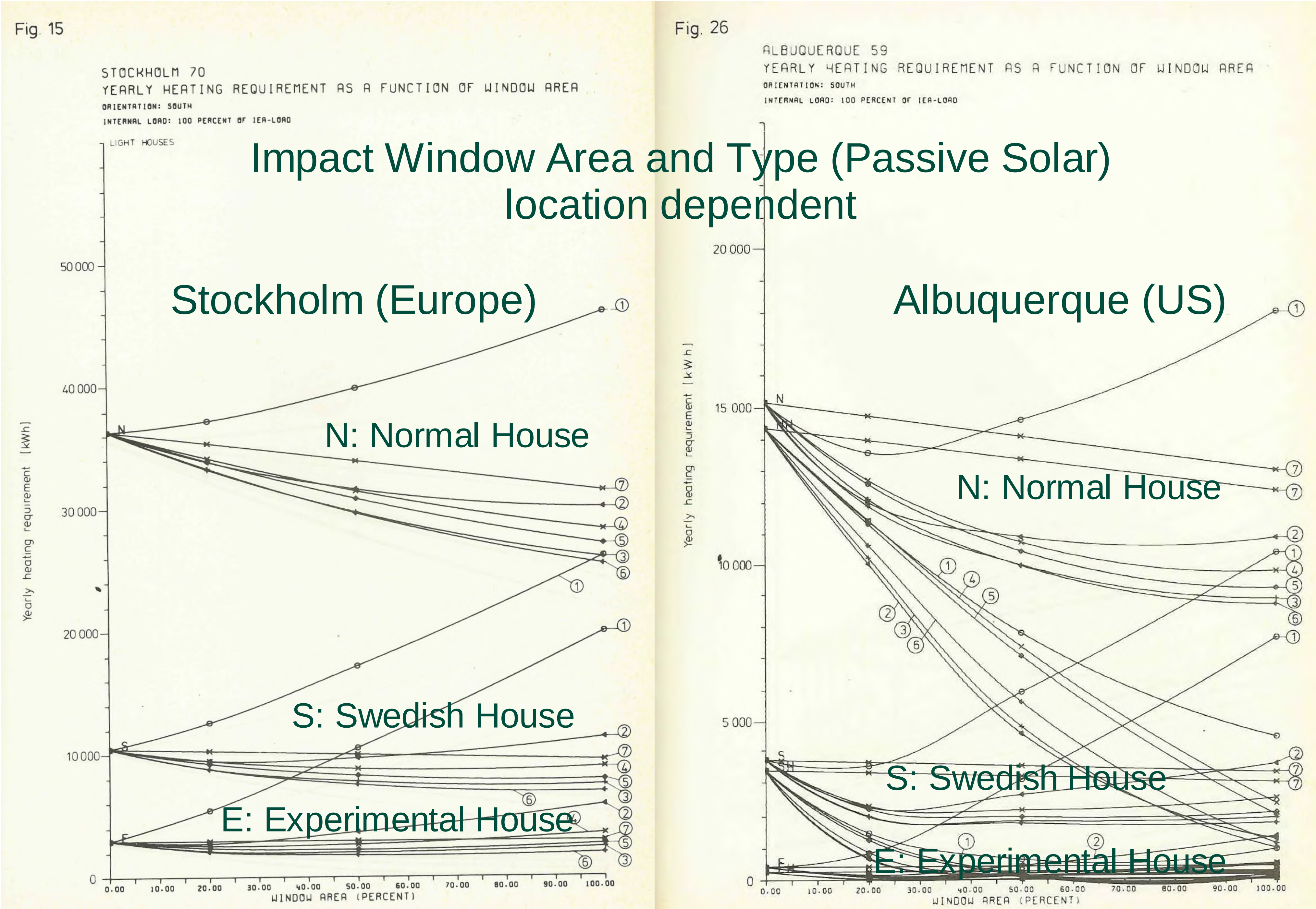
Heating Requirements in the US and Europe can be cut down by factor of 10 – 20 when going from Normal via Swedish to Experimental House Standard





Source: Steinmüller 1979

Impact Window Area and Type (Passive Solar) location dependent



Source: Steinmüller 1979

➔We can reach … “Zero-Energy Homes”

… and by collecting regenerative energy we can arrive at

“Plus-Energy-Homes”

How Low Should We Go?

Sustainability Limit

for Energy Related CO_2-Emissions

Global limit:

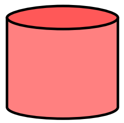
10 billion tons per year

Population 2050:

10 billion people

means →

max. 1 ton



per capita and year

The Situation

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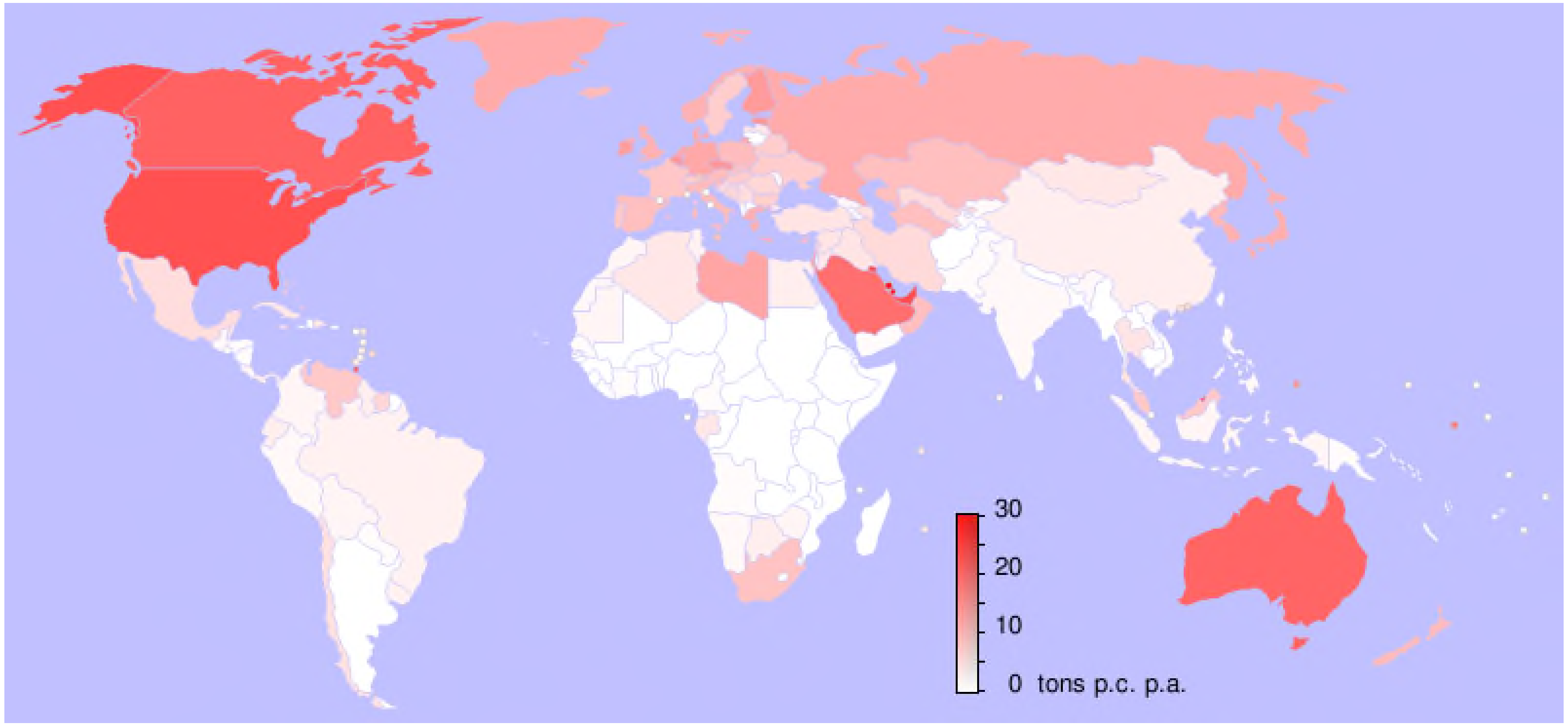
CO_2-Emissions in tons p.p. p.yr. across the world



Source: Wikipedia, Licenced under GNU-Condition -

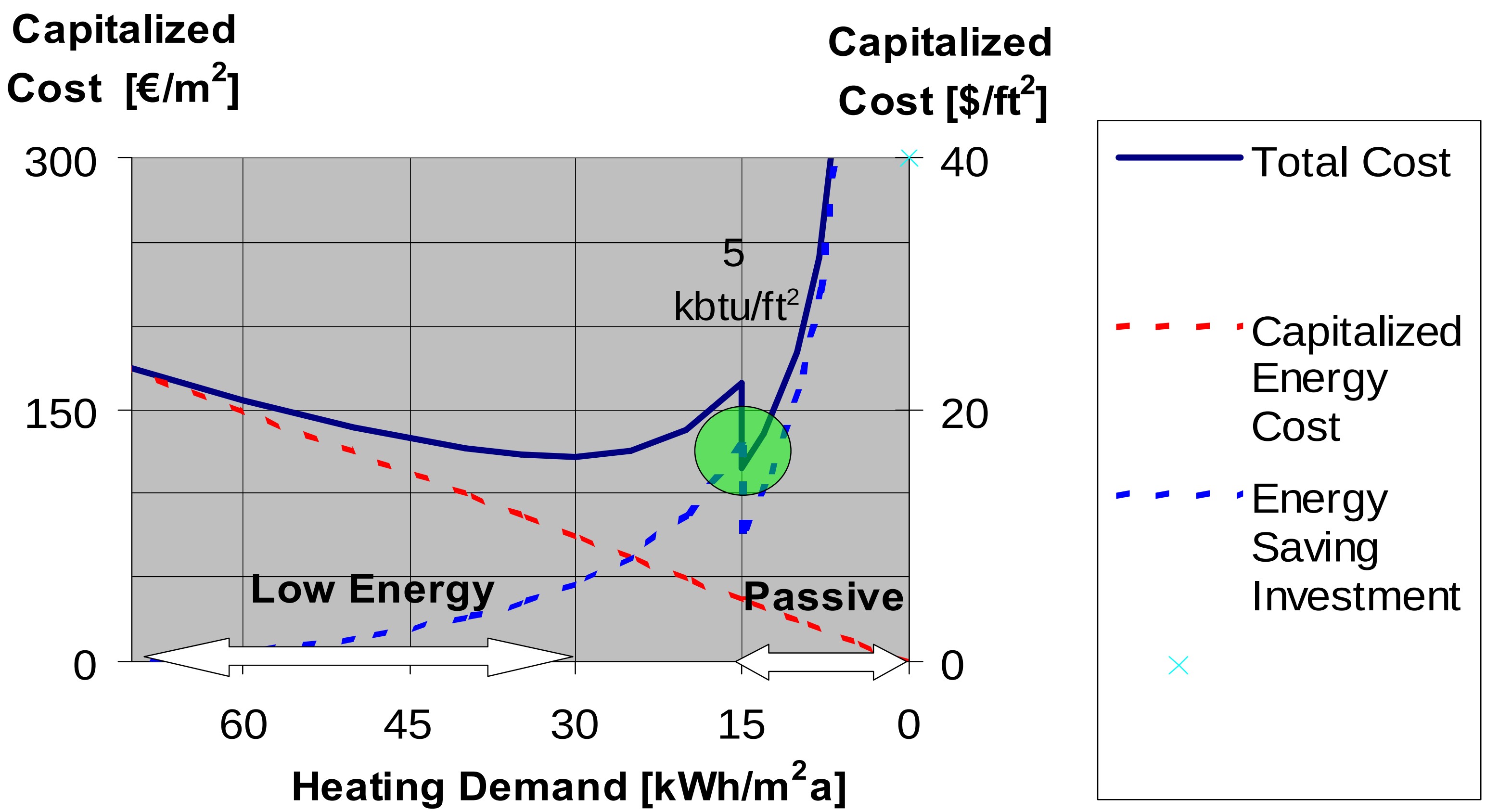
The Implication

Energy-related CO_2-emissions have to be reduced

by at least a factor of 10 in the western world! …

How Low Can We Go Economically …?

The Passive House Idea:
Improve Envelope, Simplify Active System, Get New Optimum



… Leads to Passive House – Formal Definition

Central Requirement:

- Maximum Heating Load at Climate Extreme <= 10 W/m^2 (~ 1 W/ft^2)
  - allows omission of traditional heating system

Secondary Requirements:

- Maximum Annual Heating Demand <= 15 kWh/m^2a (~ 5 $kBtu/ft^2a$)
  - for south oriented buildings in Central Europe

- Overall Primary Energy Consumption <= 120 kWh/m^2a (~ 40 $kBtu/ft^2a$)
  - Including household appliances
  - To be lowered in the future

Source: PHI

Passive House – Principles

- Highly Efficient Building Envelope
  - Highly insulated components: U-factors < 0.15 W/(m^2K) *(i.e. ~ R40),* Avoidance of thermal bridges
  - Energy-efficient windows: U-factors < 0.80 W/(m^2K) *(~ R7),* solar heat-gain coefficients ~ 50%, southern orientation (if possible) and shade provisions
  - Air-tightness: infiltration rate < 0.6 per hour in pressure test at 50 Pa *(i.e. CFM50 < 200 ft^3/min for a 2000 ft^2 home)*
  - Compact form
- Highly Efficient Air and Heat Supply
  - No separate traditional heating system necessary
  - Energy-efficient ventilation: Highly efficient heat recovery from exhaust air > 80%
  - Hot water supply using regenerative energy sources
- Energy-saving household appliances

Source: PHI

Darmstadt-Kranichstein
First Passive House in Europe/Germany 1991

- Super insulated House in a Row
  - Insulation: 10 - 18 inches, U-Value 0.1 bis 0.14 W/(m²K) → R40 to R60
  - Optimized triple panes windows with insulated frames, south oriented
  - Ventilation with heat recovery
- Rest Energy Demand
  - Heating: 12 kWh/(m²a)
  - Hot water: 8 kWh/(m²a)
  - Household appliances: 11 kWh/(m²a)
- Covered by
  - Vacuum collectors
  - Gas condensing furnace

Source: Feist (IWU, PHI)

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Wiesbaden-Lummerlund
First Passive House & Low Energy-Settlement in Europe 1997

- 46 Houses in a Row,
  - 50% Passive
  - 50% Low Energy
  - Building cost: 90 - 100 €/ft²
- Scientific Evaluation
  - Inhabitants highly satisfied
  - Passive Houses preferred to low energy ones
- ➢ Passive Houses enable sustainable life-style
  - Energy reduction factor 10
  - Economically attractive
  - Comfortable, healthy indoor climate
  - No sacrifices, but new degrees of freedom

Source: IWU, Rasch

Passive
Single Family
Home

Bodensee

BKI 6100-414
313 €/m^3
12 $/$ft^3$

Quelle: BKI

Passive
Single Family
Home

Ludwigsburg

BKI 6100-411
378 €/m^3
14,5 $/$ft^3$

Quelle: BKI

Passive
Single Familiy
Home

Karlsruhe

BKI 6100-321
427 €/m^3
16 \$/ft^3

Quelle: BKI

Passive
Single Family
and Small Office
Building

Oldenburg

BKI 1300-099
295 €/m^3
11 \$/ft^3

Quelle: BKI

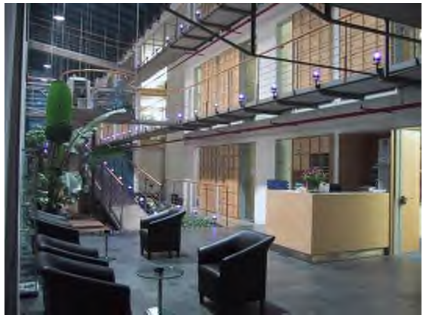
Passive
Multi Family
Building

Freiburg

BKI 6100-432
279 €/m^3
11 $/$ft^3$

Quelle: BKI





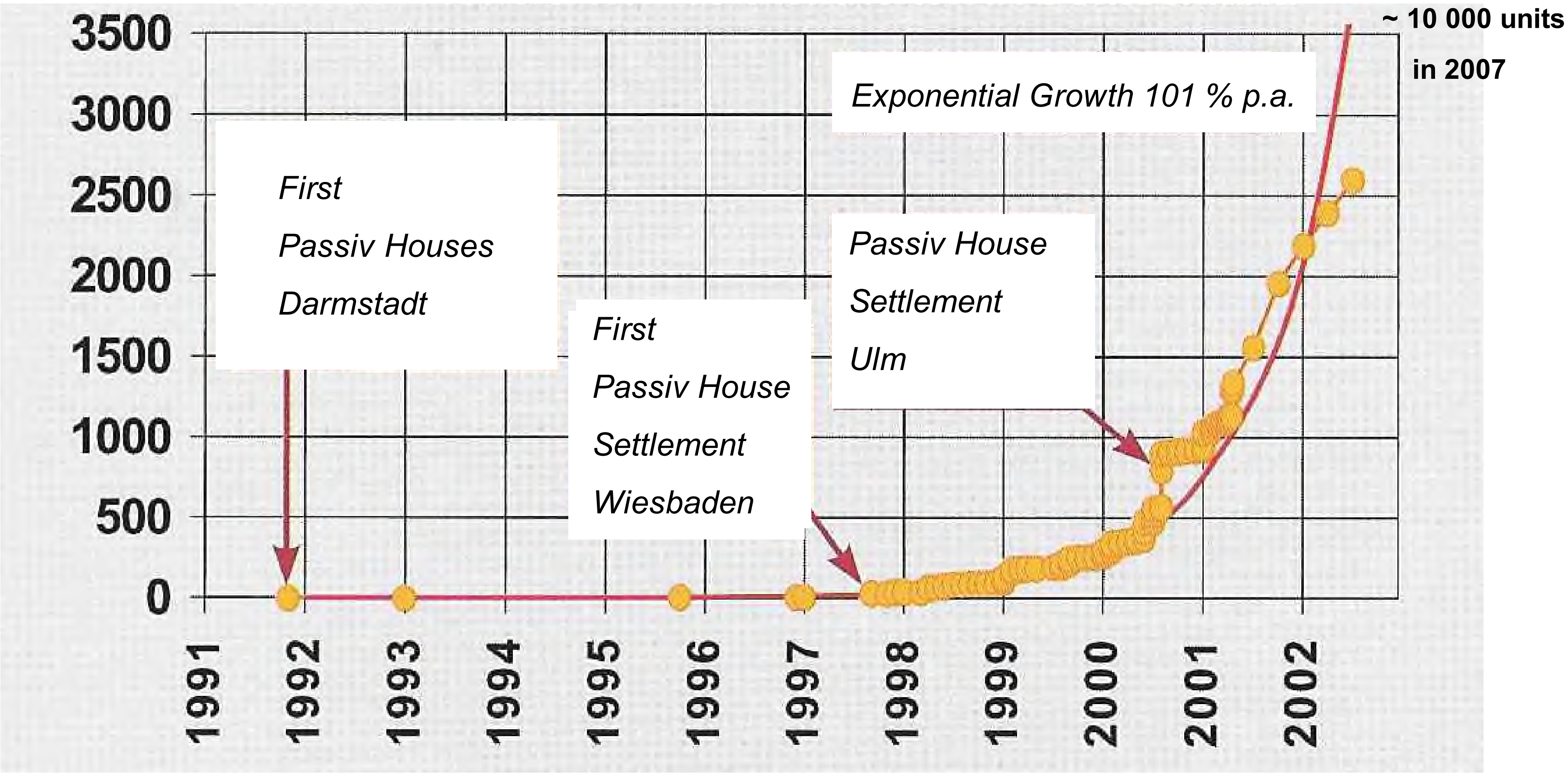






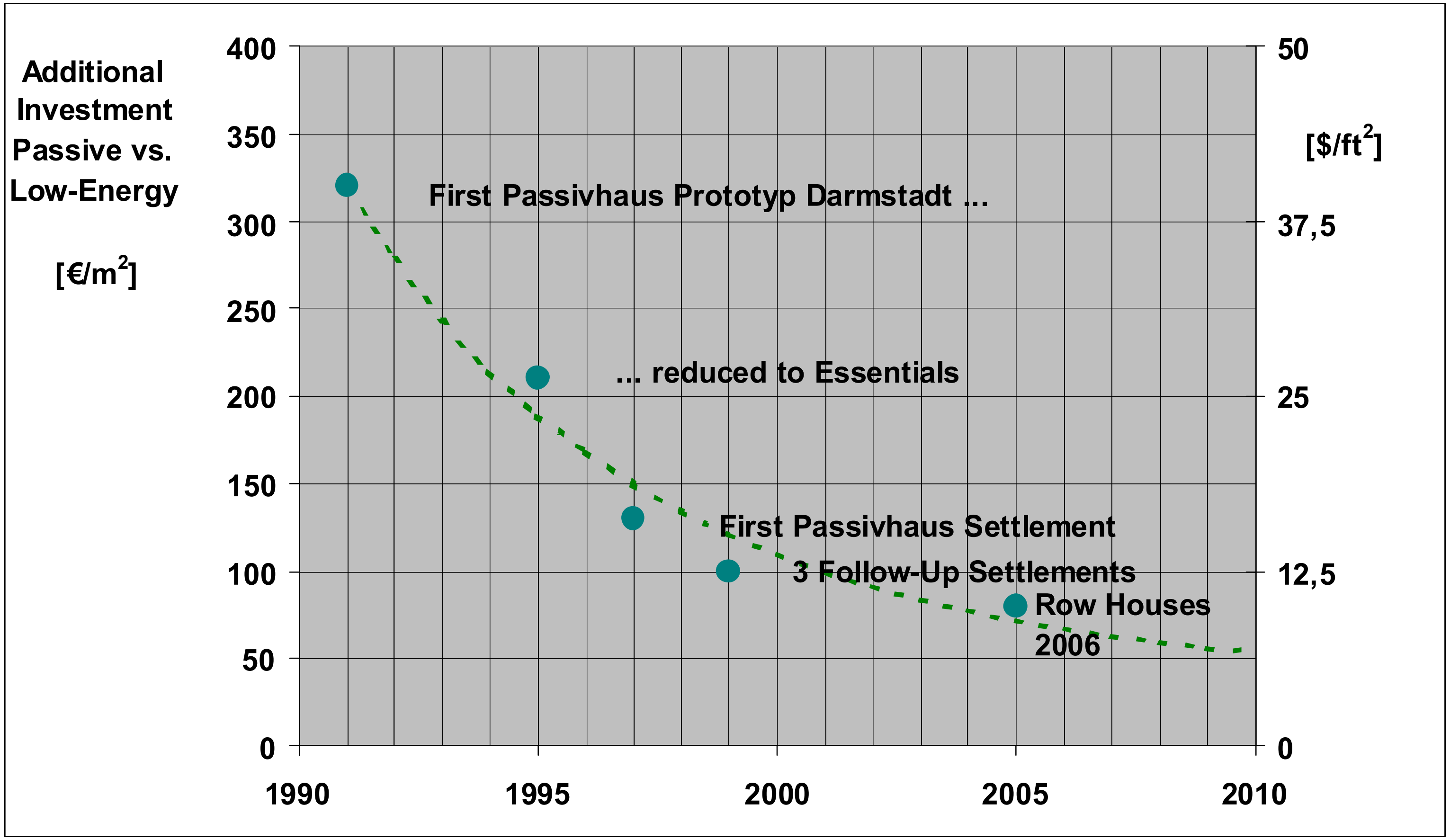
Source: BKI, BSMC, SurTec

Number of Passive House Units Grow …



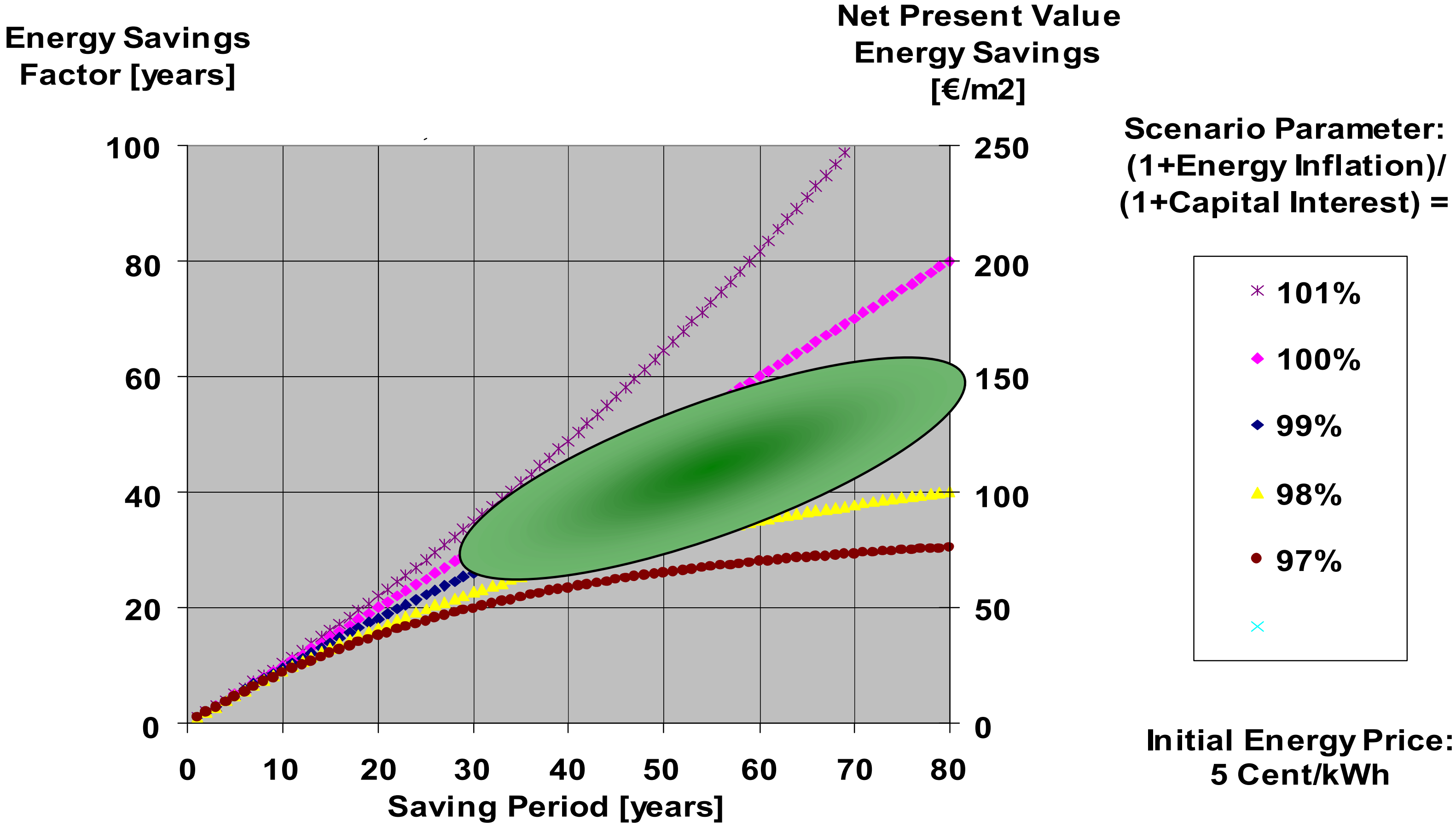
Source: PHI

.... Additional Investment → 50 €/m² (6 $/ft2)



Source: W.Feist, PHI

Energy Savings well above 50 €/m² (6$/ft²)



Economics in more detail …

Calculate/estimate the **Net Present Value „NPV"** of energy savings occuring in the future ... by determining the **NPV of one Unit of Energy** first of all ...

$$\textbf{NPV} = E_0 \sum_{t=0}^{n-1} q_{eK}^{\ t} = \mathbf{E_0} * (\mathbf{q_{ek}}^{\mathbf{n}} - 1)/(q_{ek} - 1) = E_0 * \textbf{NPV1}$$

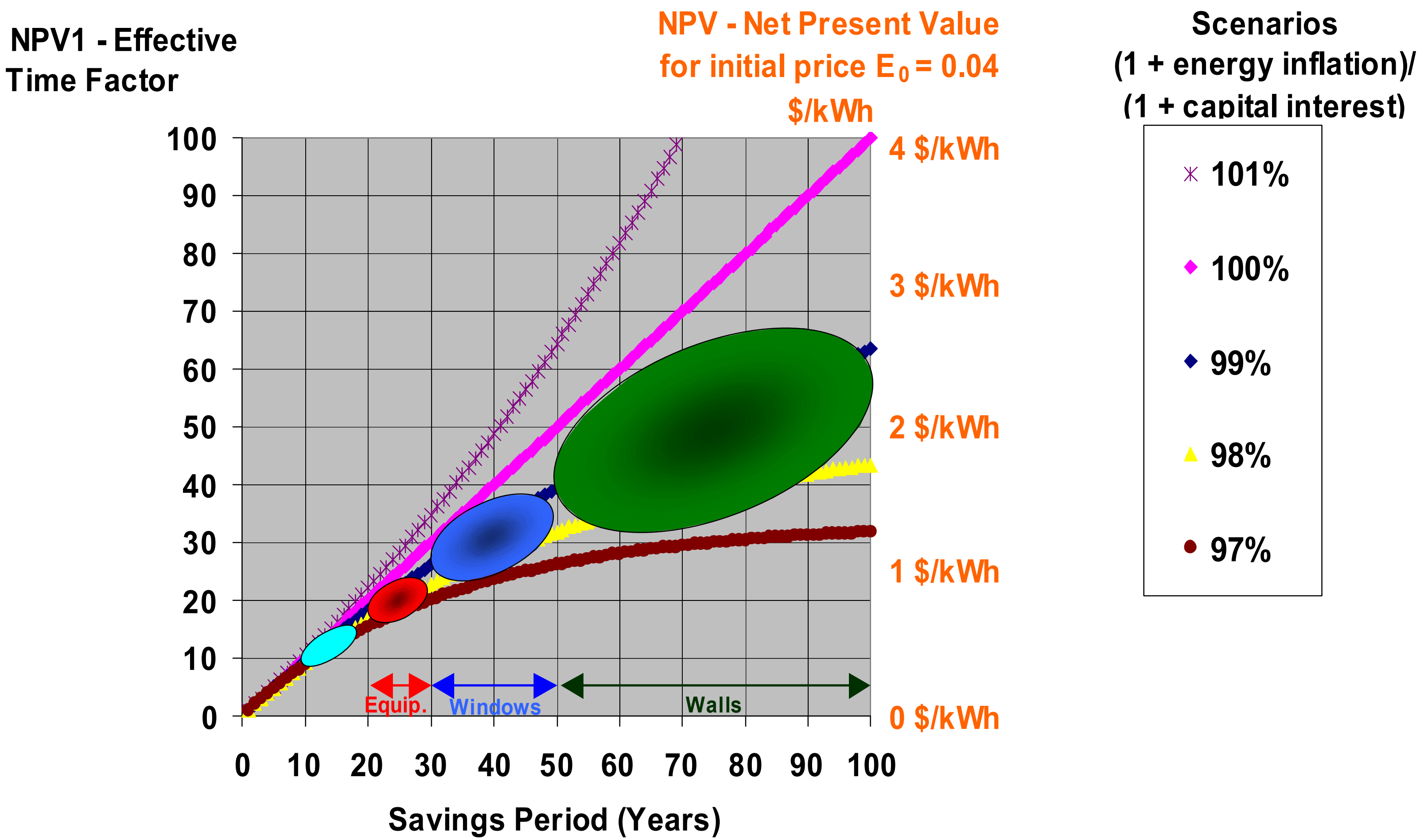
which fundamentally depends on three parameters:

(1) $\mathbf{E_0}$ = initial energy price
(2) **n** = saving period
(3) $\mathbf{q_{eK}}$ = (1 + energy inflation)/(1+ capital interest)

whereby the dependencies of the future can be lumped into

$$\textbf{NPV1} = (\mathbf{q_{ek}}^{\mathbf{n}} - 1)/(q_{ek} - 1)$$ (effective „time factor")

NPVs for one Unit of Energy for Different Scenarios ...



Next Steps:

- Multiplying these NPVs by the number of energy units saved
  - yields the total NPV of Energy Savings …
  - yields statement about economic feasibility when compared to investment …

- Maximizing NPV of Energy Savings minus Investment Cost
  - yields the "ecomomic optium" …

Optimum R-Value:

The optimum heat resistance is given by:

$\mathbf{R_{opt}}$	=	$\sqrt{\mathbf{NPV1}} * \mathbf{F}$	where	($\mathbf{U_{opt}} = 1/\ \mathbf{R_{opt}}$ optimum U-Value)
NPV1	=	s.o. net present value factor		
F	=	$\sqrt{(E_0 * H)/(\lambda * \eta * P_0)}$		

whereby F is determined by the following parameters (typical values in brackets):

E_0	=	Energy price per kWh time 0	(e.g. 0,04 $/kWh)
P_0	=	var. insulation cost per m and m^2 at time 0	(e.g. 100 $/ m^3)
H	=	effective heating degree hours in kh/yr	(e.g. 84 kh/yr)
η	=	efficiency of heating plant	(e.g. 84%)
λ	=	thermal conductivity of insulation in W/m	(e.g. 0,04 W/mK)

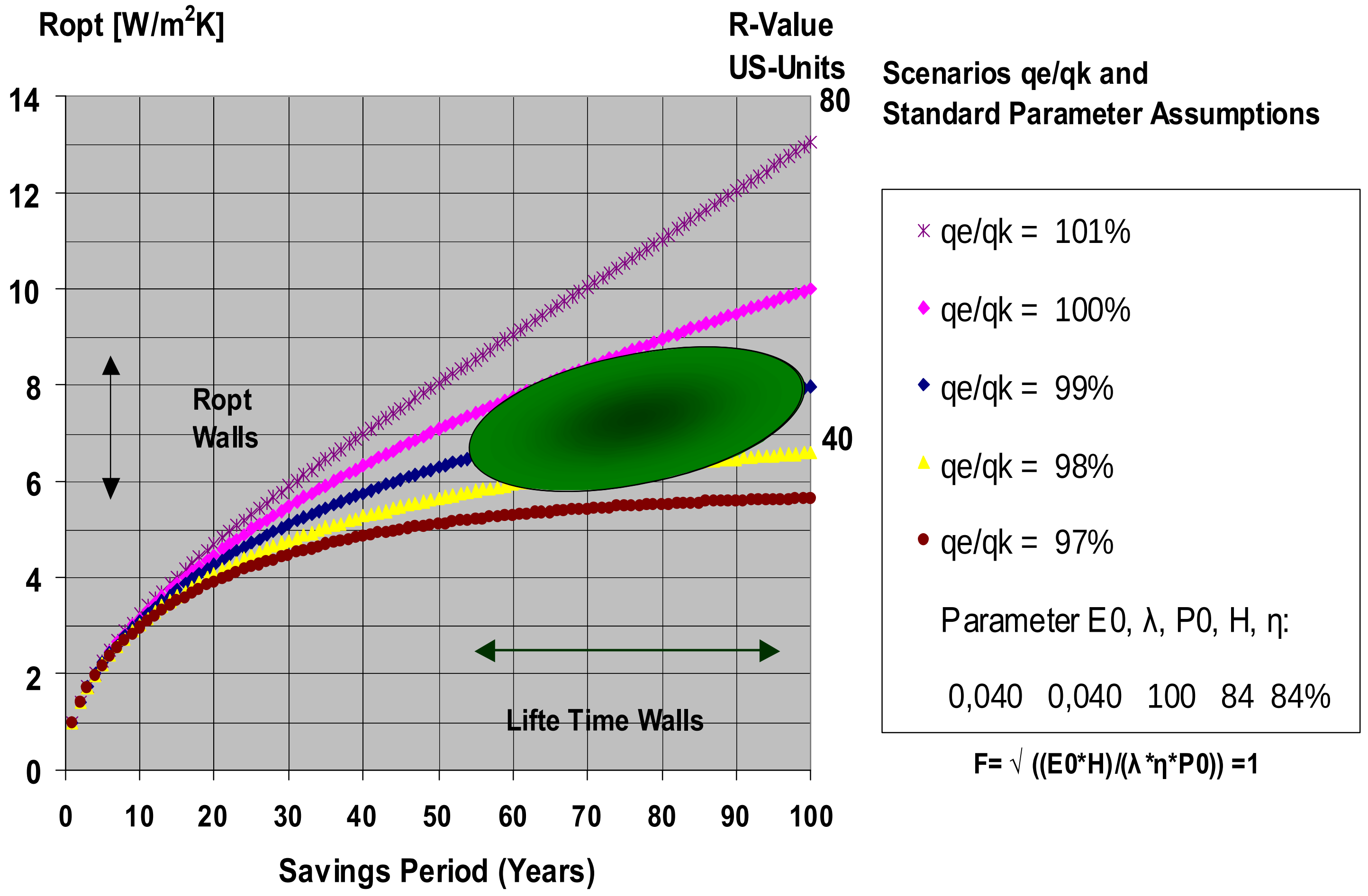
For these typical values F = 1 in international units and F= 5,7 in common US-Units

This is a powerful formula
for quickly estimating parameter effects on insulation optimum
(incl. climate!)

Note: square root softens underlying effects by ~1/2

Thus:
if climate 50% different
→ optimum only changes by 25%!

Optimum R-Value for Different Scenarios ...



Conclusions ...