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Uncertainty in modelling the energy performance of buildings and the occupants

Feedback from practical experience of models

“ You cannot be certain about uncertainty. ”

ing. Ad van der Aa
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The Netherlands
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CAUBERG-HUYGEN
RAADGEVENDE INGENIEURS BV

oplossingen zijn ons vak

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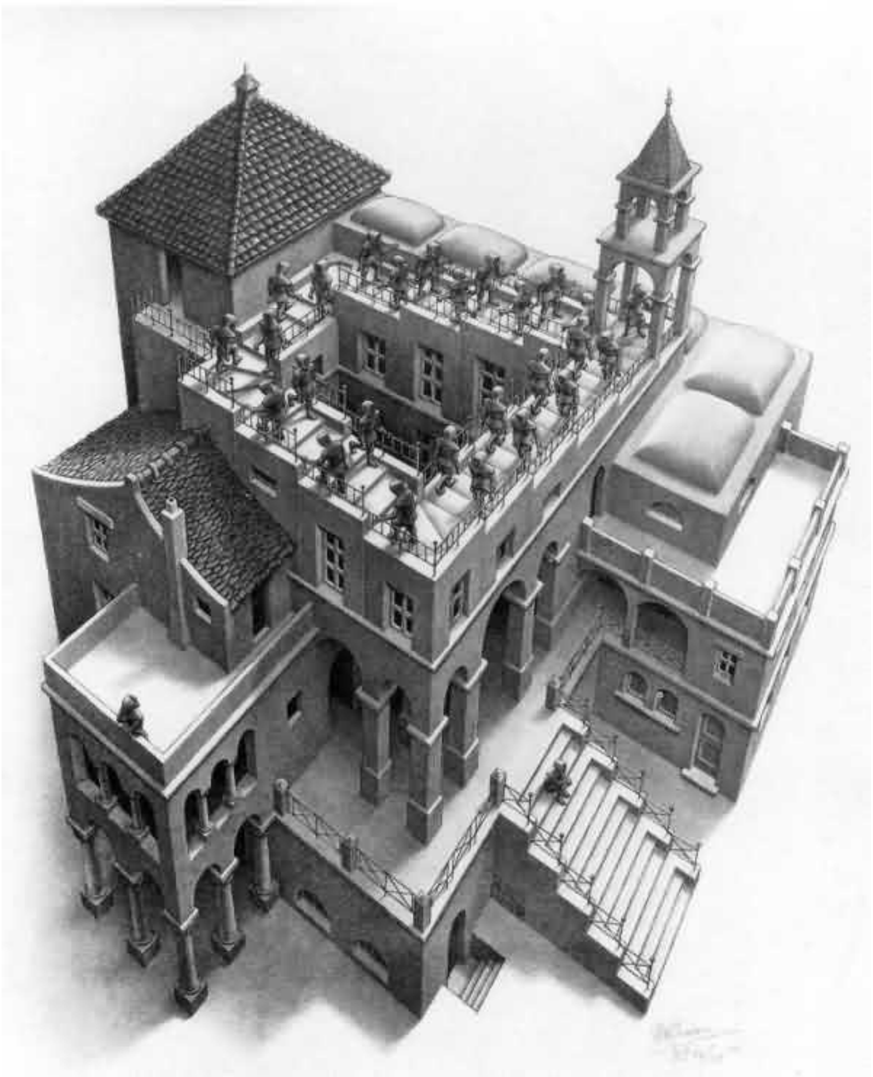
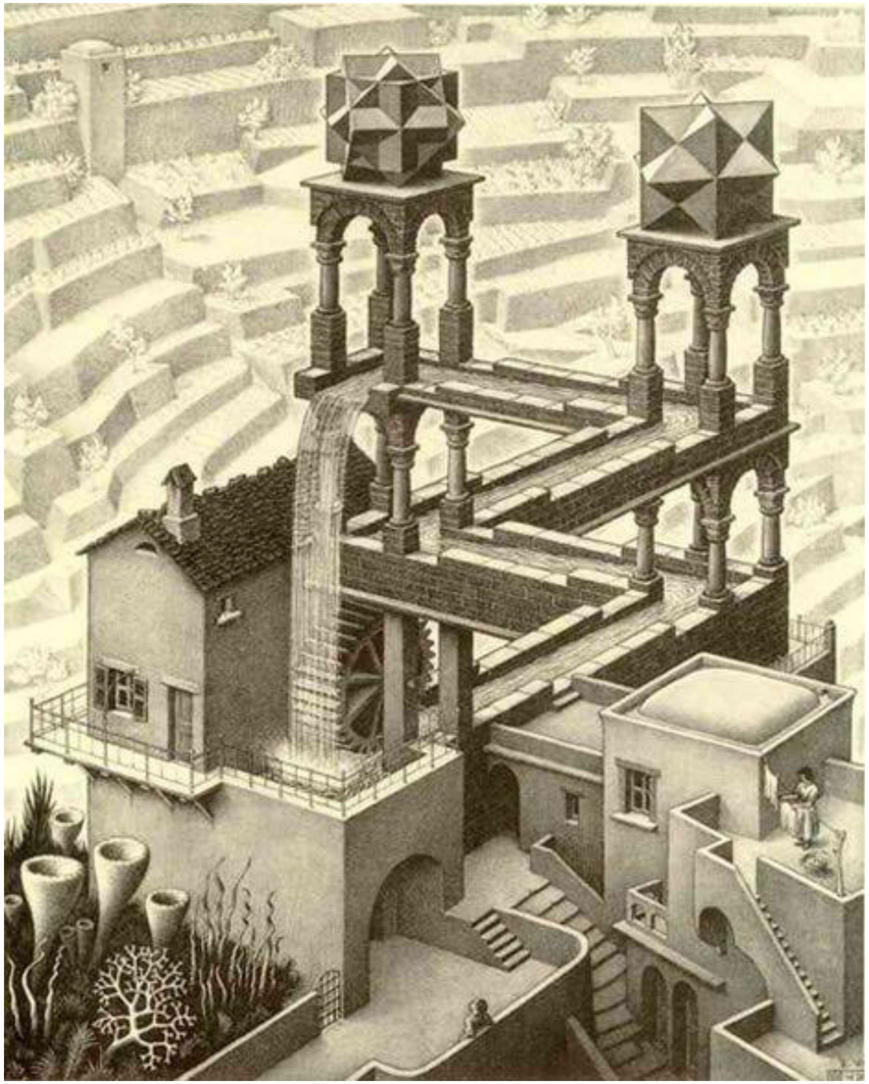
Nothing is what it seems…





Basic physics?

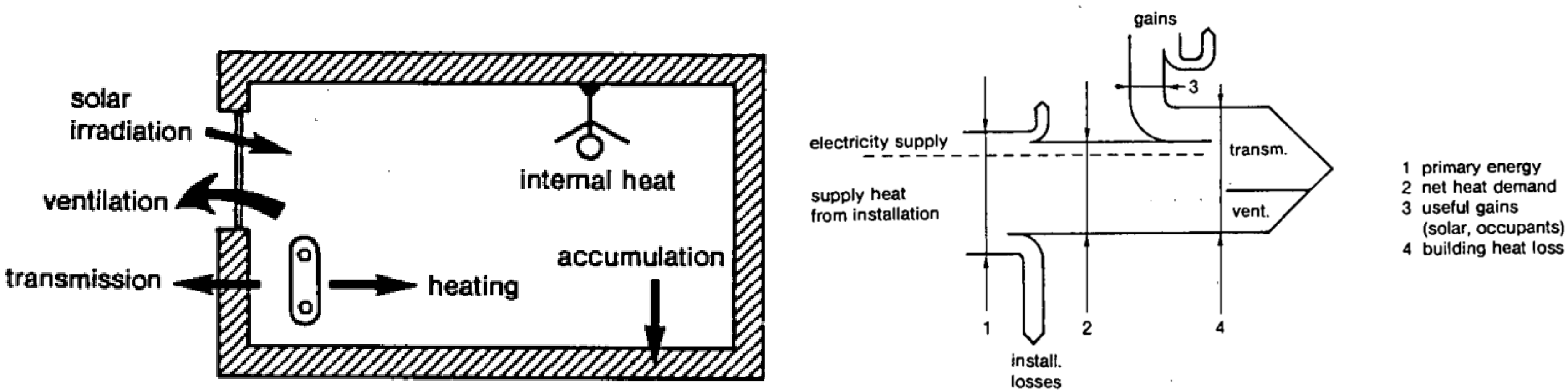


Figure 2: Apart from the efficiency of the heating installation, the heat balance of a building determines the energy consumption for space heating.

$$\phi_{HD} = \phi_L + \phi_{ACC} - \phi_G \qquad \text{(W) (1)}$$

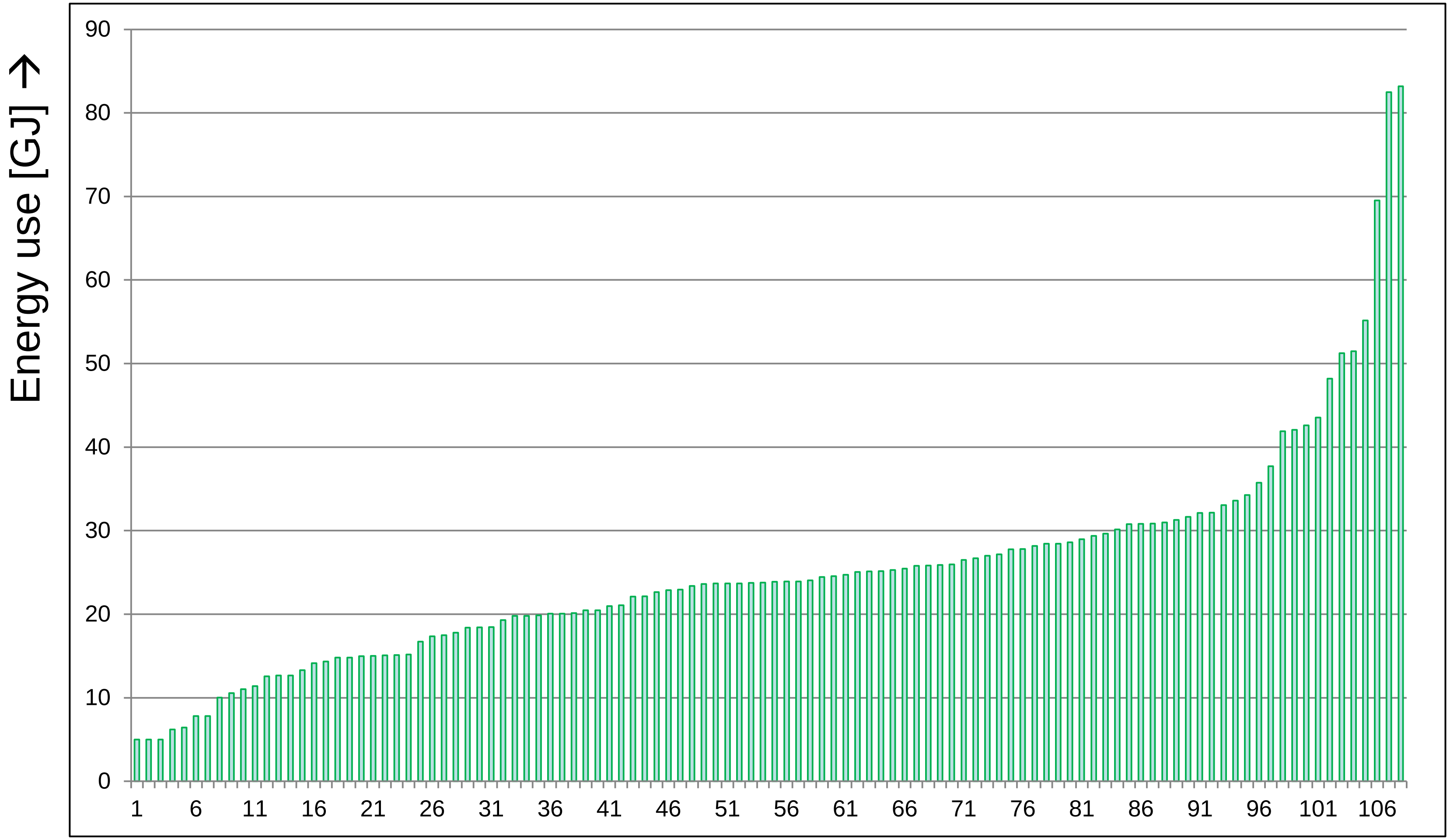
where: ϕ_{HD} = heat supplied by the heating system (W)

ϕ_L = heat losses by transmission and ventilation (W)

ϕ_{ACC} = accumulation of heat into the mass inside or surrounding the space (W)

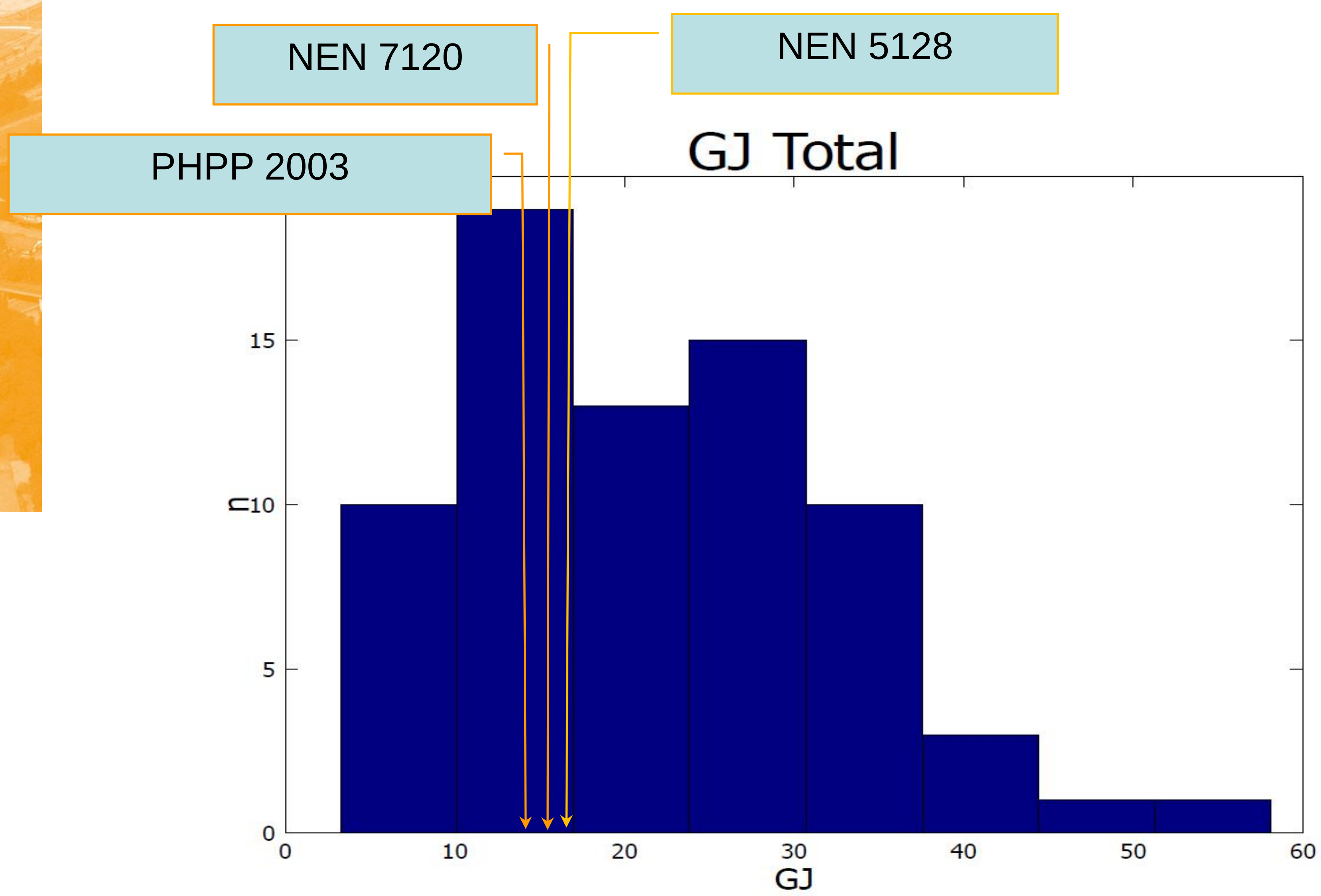
ϕ_G = heat gains from internal sources and sun (W)

Is it really that simple?

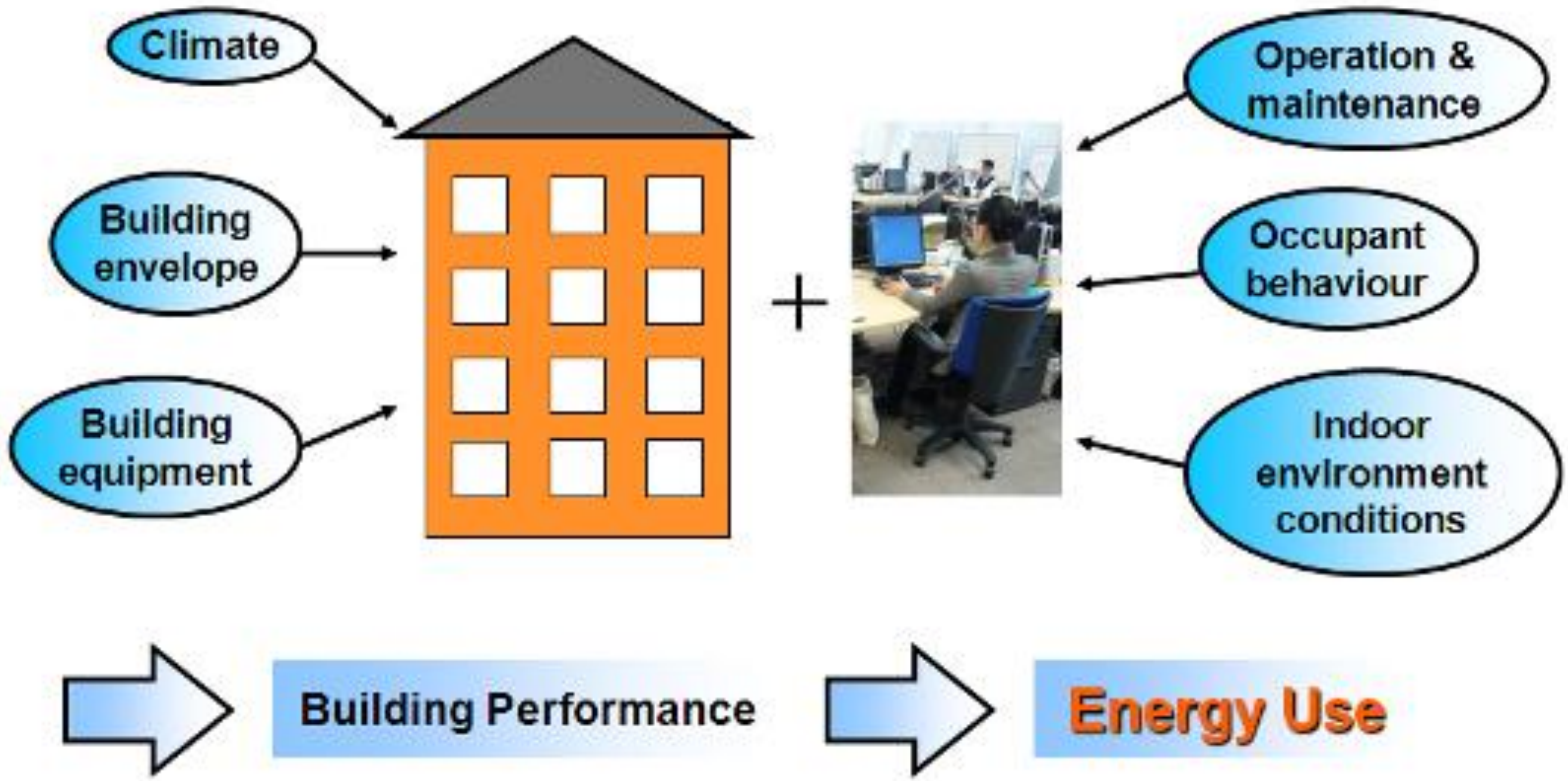


Dwelling no →

Need for better calculation methodologies?

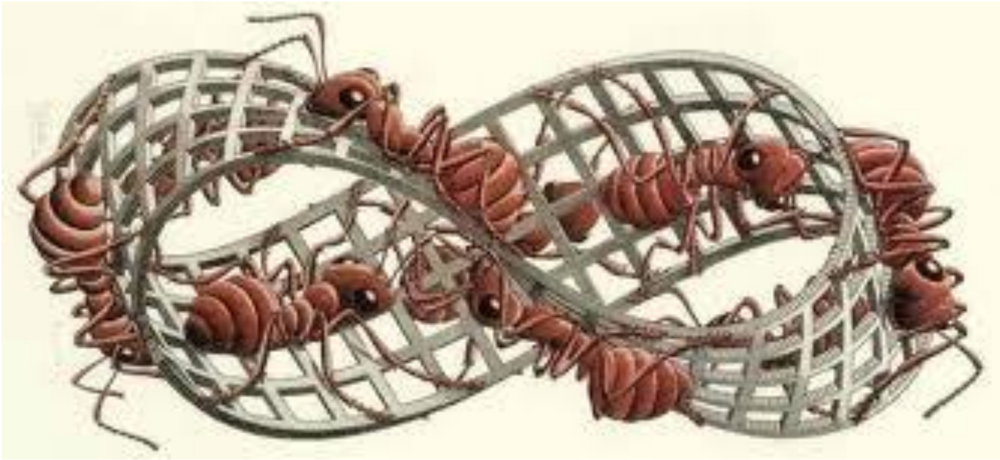


IEA Annex 53 Total energy use in buildings – influencing factors

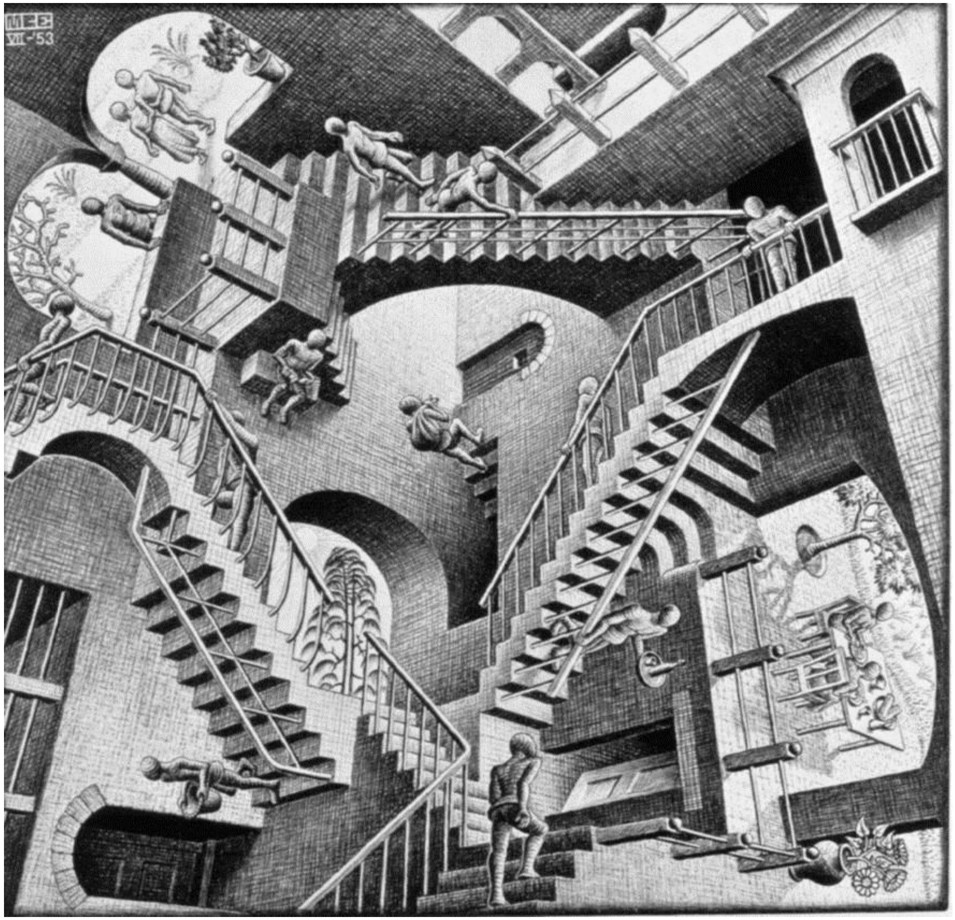


Uncertainties

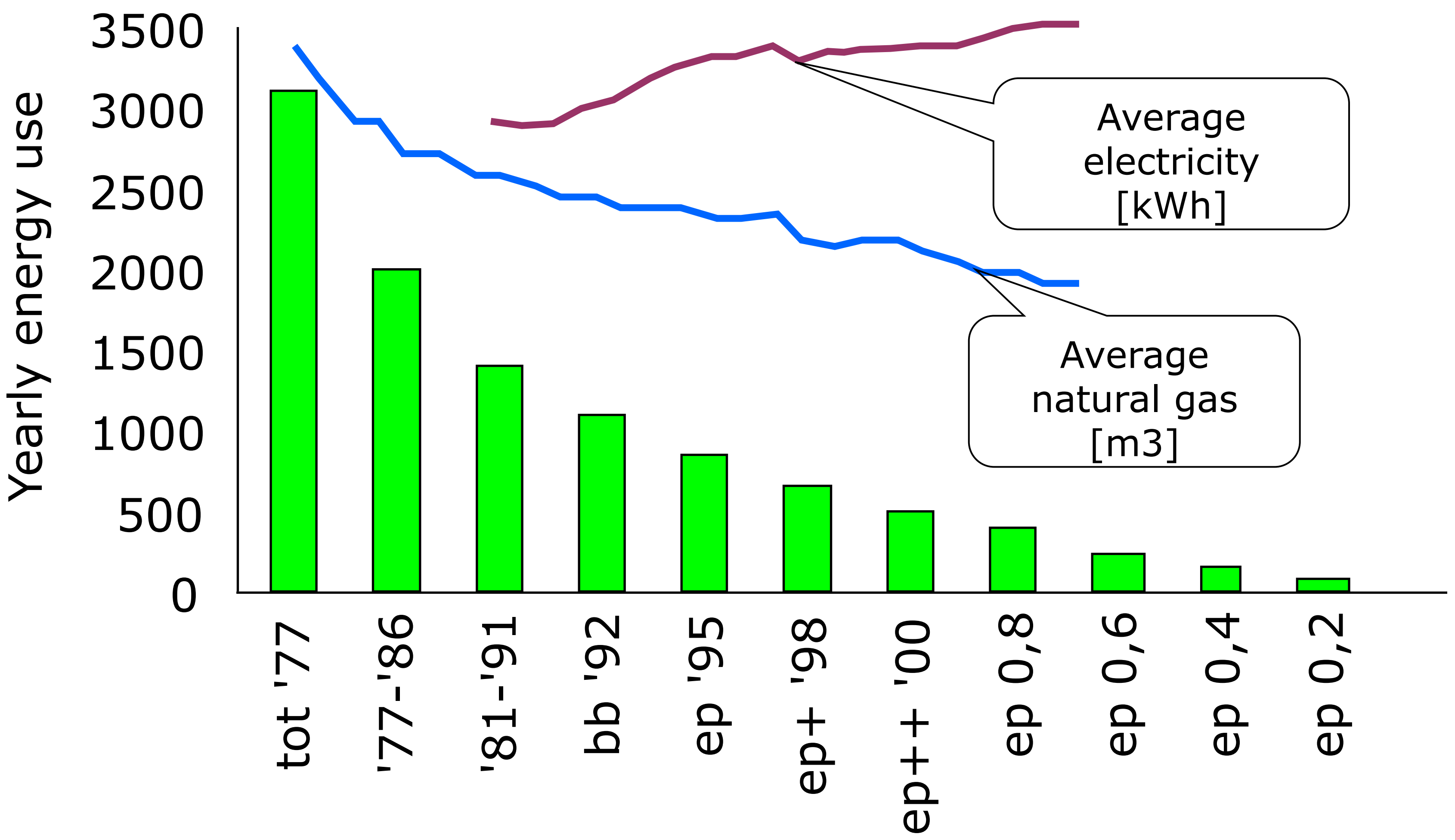
1. The energy performance regulations (EPBD)
2. The performance of buildings and equipment
3. The occupant behaviour



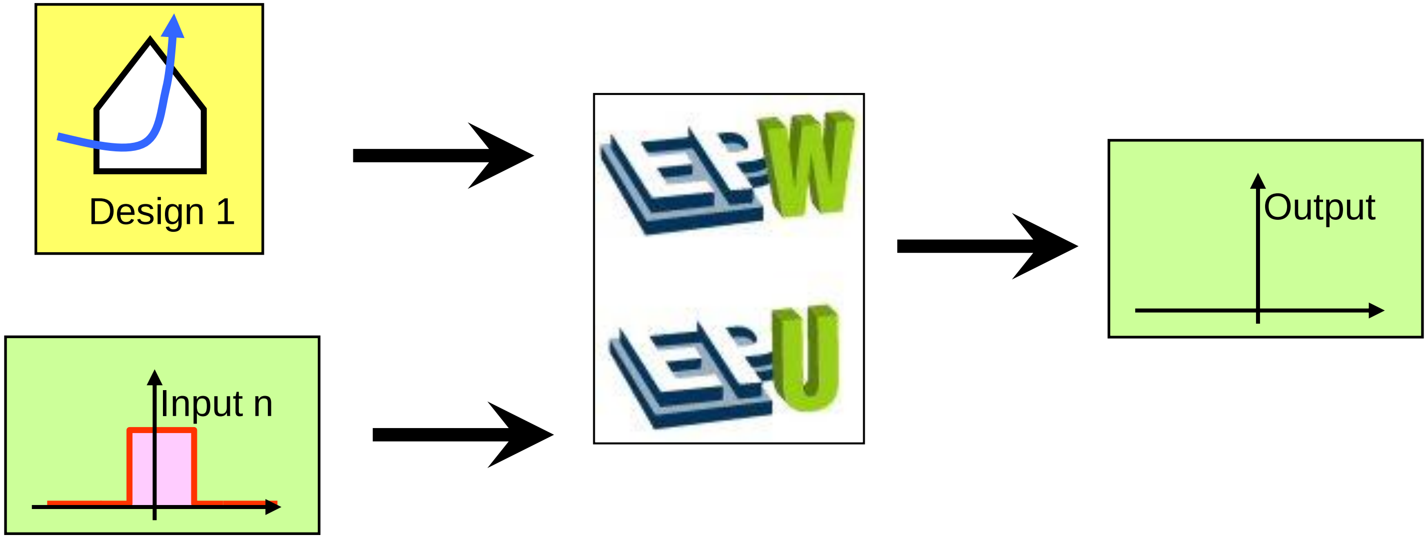
1. The energy performance regulations (EPBD)



Real energy use versus EPC

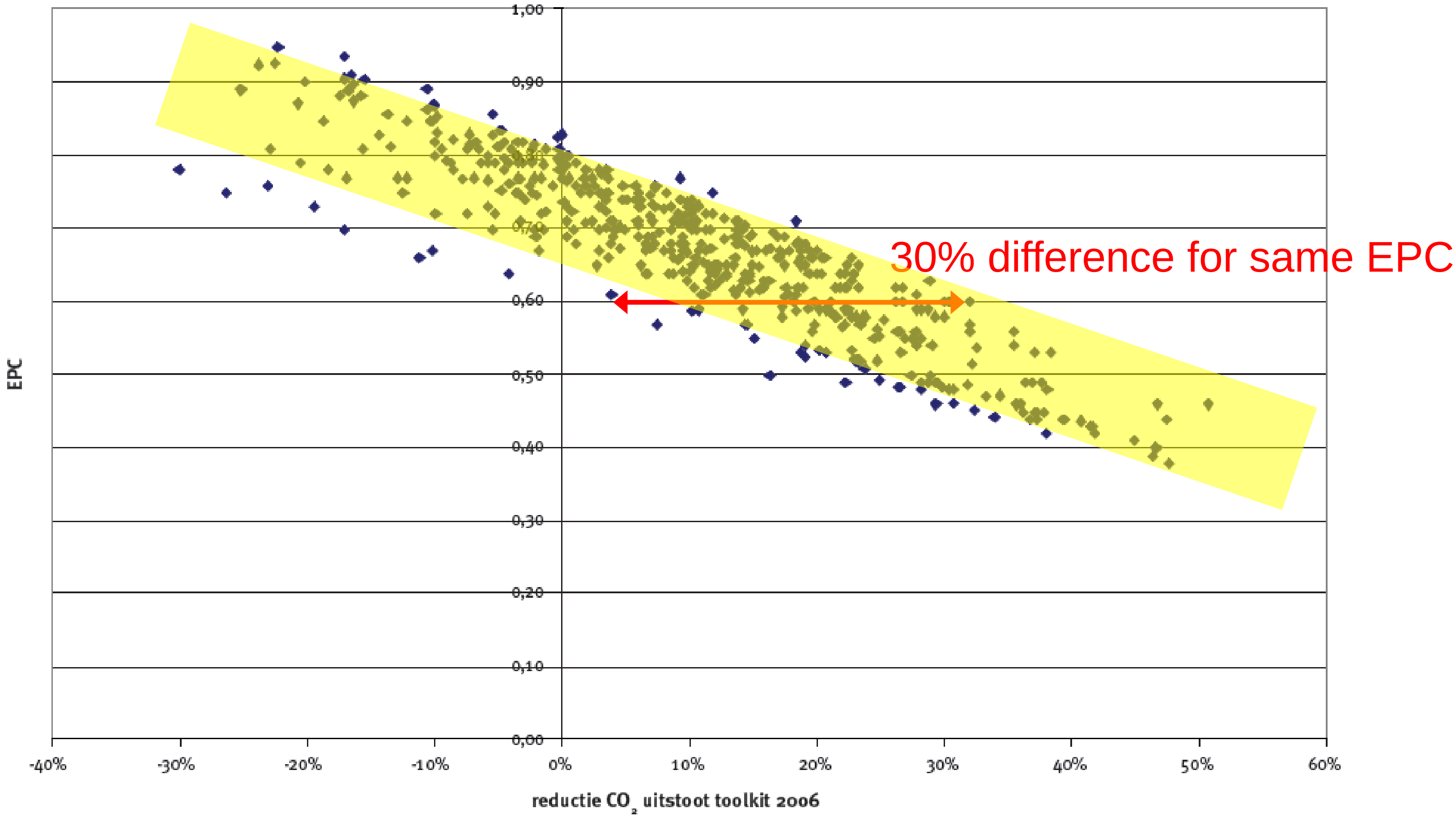


Energy performance calculation



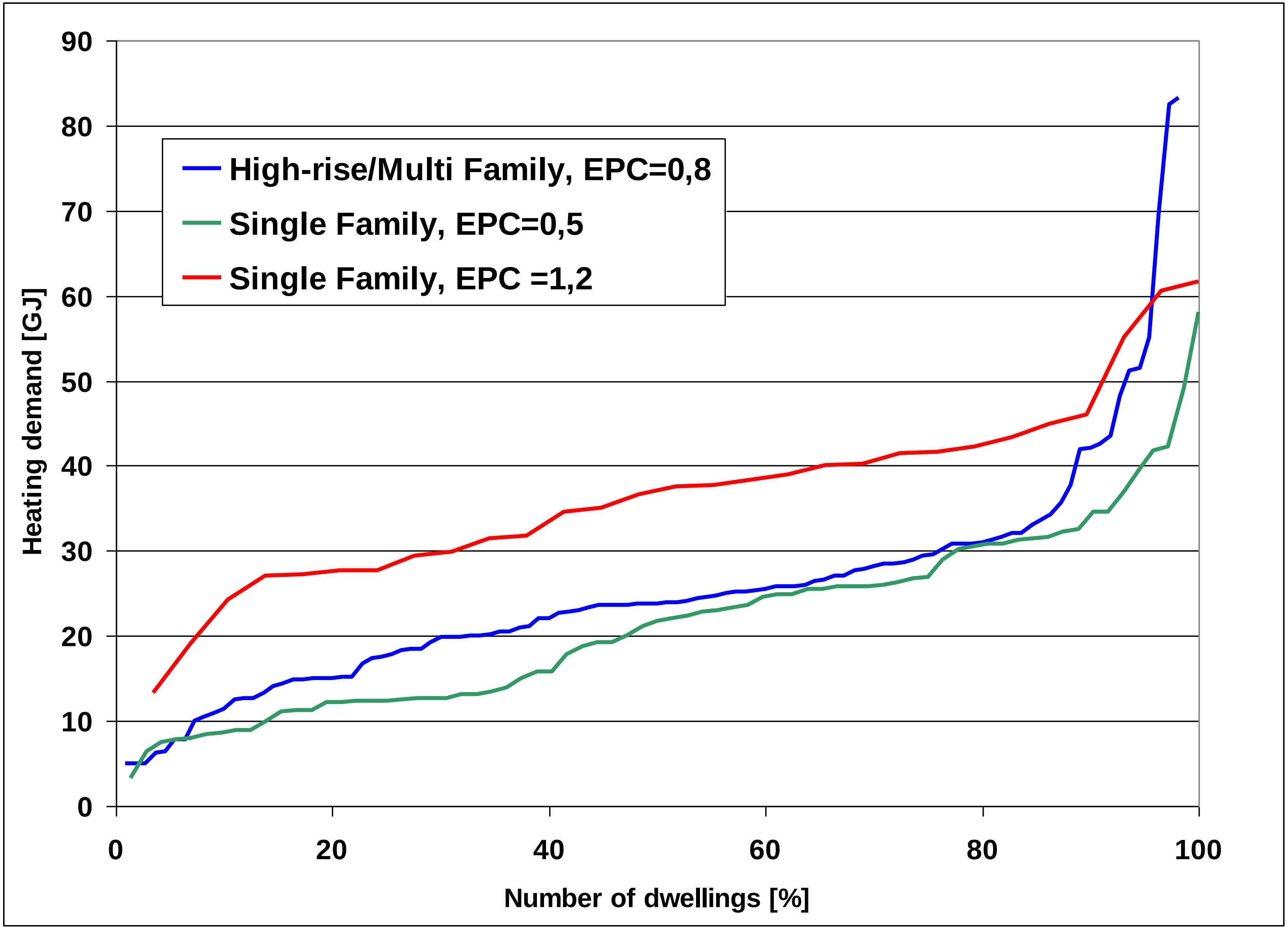
<u>Characteristics</u>
- Related to building regulations
- To obtain a building permit
- Pertaining to public law
- Control at government
- “Labeling” of buildings
- Forfaitair and sometimes arbitrary starting points
- For 1 family type, a climatic condition, etc.
- Output is dimensionless co-efficient

EPC versus CO_2-reduction



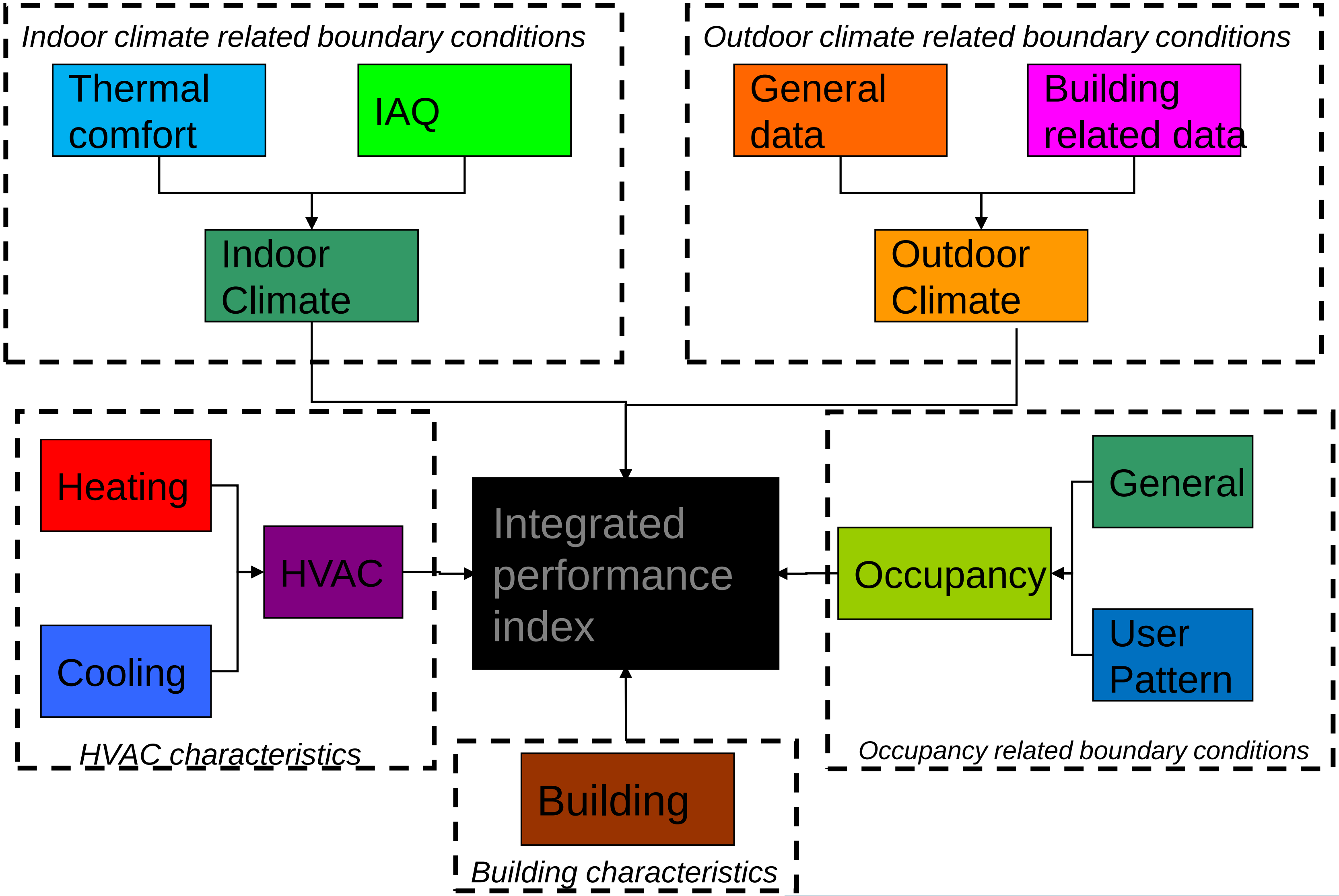
Prestaties van verschillende energieconcepten. Spreiding in CO_2-reductie bij een EPC waarde

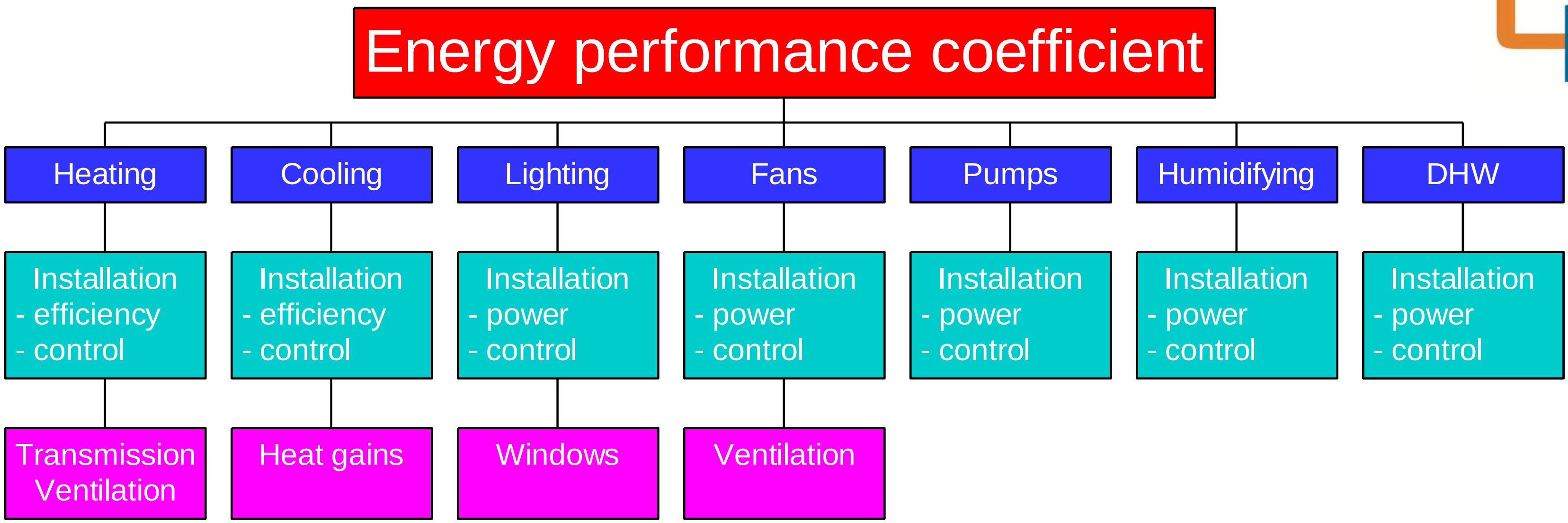
Real energy use compared to EPC



Performance calculations
Hybrid ventilation school building

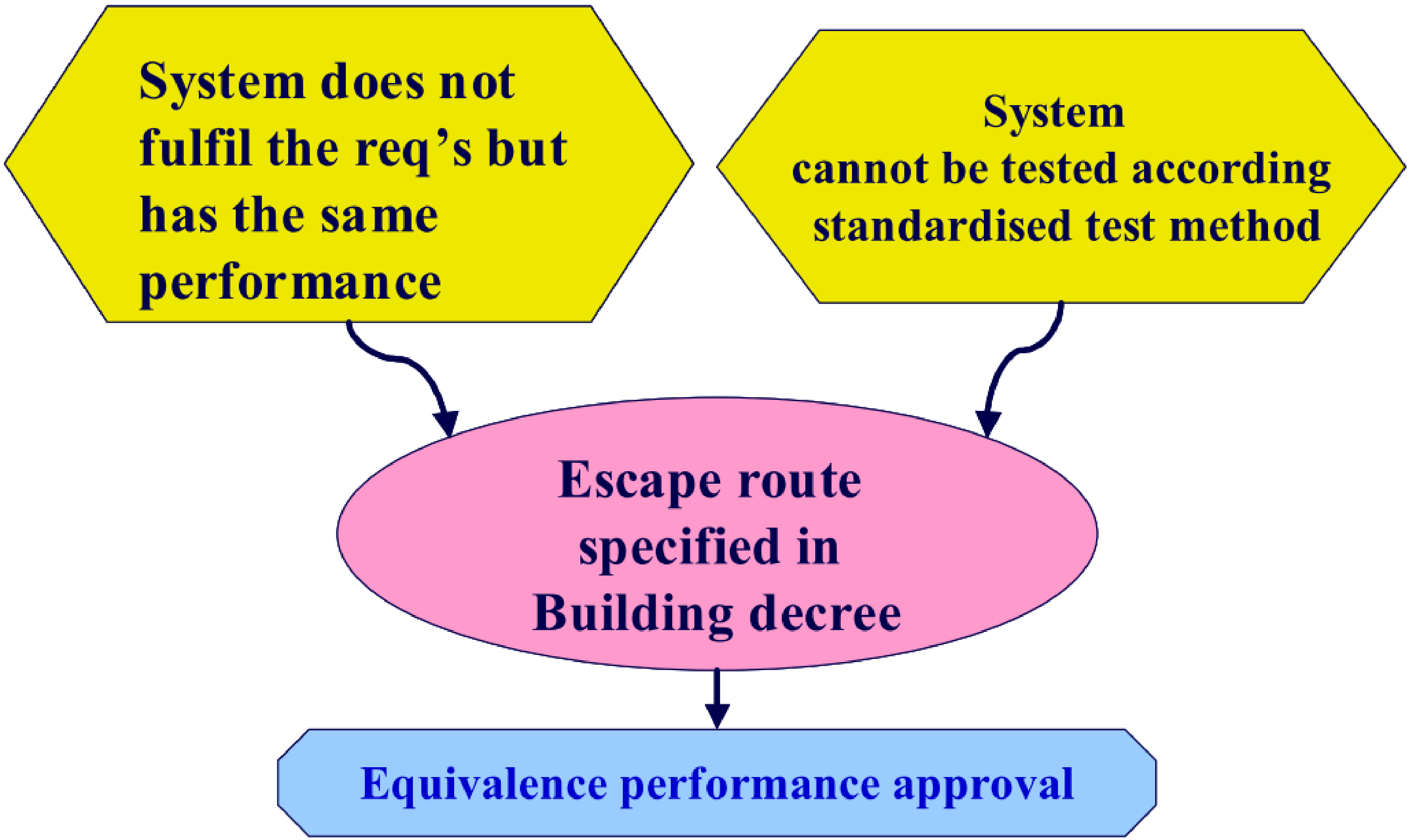
Boundary conditions for Performance Index





Measure	Calculation
U_{floor} [W/m^{2}K]	0,31
U_{roof} [W/m^{2}K]	0,37
U_{facade} [W/m^{2}K]	0,37
U_{window}[W/m^{2}K]	1,8
Shading	No
Infiltration $q_{v;10}$ [dm^3/s]	200 per 3000 m^3
Ventilation	Natural inlet / Mechanical exhaust
Fan [kW]	P_{eff}= 8,0
Heating production	Gas fired HE-boiler
HVAC system	Class I: Mech. Ventilation, radiators
DHW production	Gas fired HE-boiler
Lighting [W/m^2]	12 HF lighting + local switch
$Q_{pres,tot}/Q_{pres,acc}$	**0,98**

Principle of equivalence



Equivalent EPC

Consumption	Prim. energy [MJ]	Alteration [%]	Prim. energy [MJ]
	Mechvent		Hybvent
Heating	2,441,597	-24.3	1,848,289
Fans	228,000	-77.9	50,388
Lighting	1,229,738		1,229,738
Pumps	67,987		67,987
DHW	157,397		157,397
Qpres;total	4,124,719		3,353,799
Qpres;acc	4,193,046		4,193,046
Qpt/Qpa	**0.98**		**0.80**

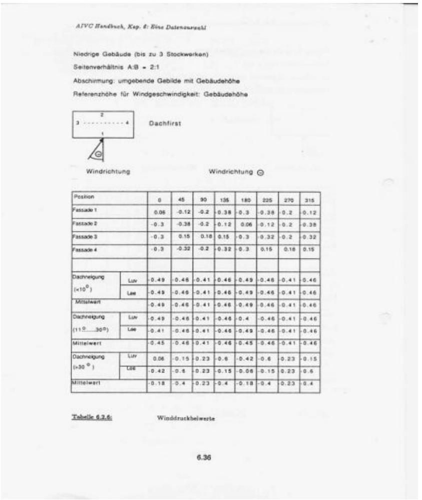
Hybrid ventilation: -20%

Boundary conditions

- Fixed parameters
  - Building characteristics
    - Thermal insulation
    - Windows
    - Air tightness
    - Thermal mass
  - Outdoor climate (SRY)
  - Internal temperature

- Variable parameters
  - Pressure distribution
  - Occupancy pattern
  - CO_2 production
  - Acceptable IAQ (CO_2)
  - Nighttemperature control
  - Internal heat production

Pressure distribution



AIVC Handbuch, Kap. 6: Eine Datenauswahl

Niedrige Gebäude (bis zu 3 Stockwerken)

Seitenverhältnis A:B = 2:1

Abschirmung: umgebende Gebilde mit Gebäudehöhe

Referenzhöhe für Windgeschwindigkeit: Gebäudehöhe

Dachfirst

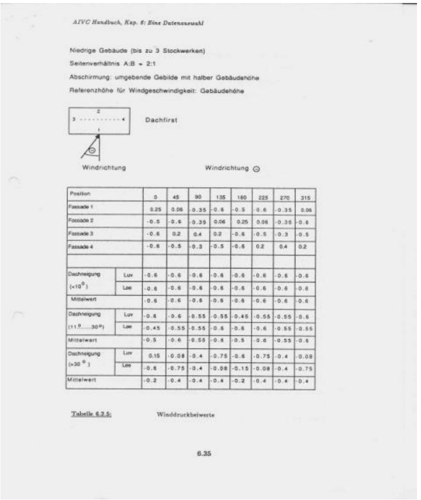
Windrichtung

Windrichtung ⊖

Position		0	45	90	135	180	225	270	315
Fassade 1		0.06	-0.12	-0.2	-0.38	-0.3	-0.38	-0.2	-0.12
Fassade 2		-0.3	-0.38	-0.2	-0.12	0.06	-0.12	-0.2	-0.38
Fassade 3		-0.3	0.15	0.18	0.15	-0.3	-0.32	-0.2	-0.32
Fassade 4		-0.3	-0.32	-0.2	-0.32	-0.3	0.15	0.18	0.15
Dachneigung (<10°)	Luv	-0.49	-0.46	-0.41	-0.46	-0.49	-0.46	-0.41	-0.46
	Lee	-0.49	-0.46	-0.41	-0.46	-0.49	-0.46	-0.41	-0.46
Mittelwert		-0.49	-0.46	-0.41	-0.46	-0.49	-0.46	-0.41	-0.46
Dachneigung (11°.....30°)	Luv	-0.49	-0.46	-0.41	-0.46	-0.4	-0.46	-0.41	-0.46
	Lee	-0.41	-0.46	-0.41	-0.46	-0.49	-0.46	-0.41	-0.46
Mittelwert		-0.45	-0.46	-0.41	-0.46	-0.45	-0.46	-0.41	-0.46
Dachneigung (>30°)	Luv	0.06	-0.15	-0.23	-0.6	-0.42	-0.6	-0.23	-0.15
	Lee	-0.42	-0.6	-0.23	-0.15	-0.06	-0.15	-0.23	-0.6
Mittelwert		-0.18	-0.4	-0.23	-0.4	-0.18	-0.4	-0.23	-0.4

Tabelle 6.2.6: Winddruckbeiwerte

6.36



AIVC Handbuch, Kap. 6: Eine Datenauswahl

Niedrige Gebäude (bis zu 3 Stockwerken)

Seitenverhältnis A:B = 2:1

Abschirmung: umgebende Gebilde mit halber Gebäudehöhe

Referenzhöhe für Windgeschwindigkeit: Gebäudehöhe

Dachfirst

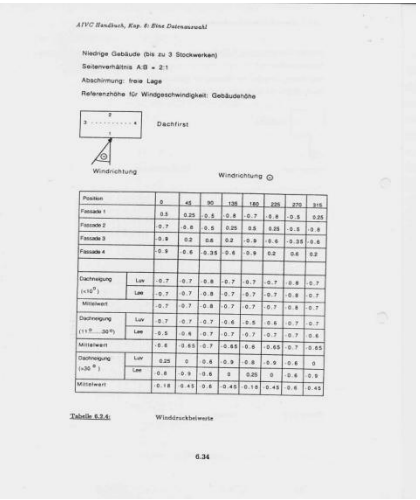
Windrichtung

Windrichtung ⊖

Position		0	45	90	135	180	225	270	315
Fassade 1		0.25	0.06	-0.35	-0.6	-0.5	-0.6	-0.35	0.06
Fassade 2		-0.5	-0.6	-0.35	0.06	0.25	0.06	-0.35	-0.6
Fassade 3		-0.6	0.2	0.4	0.2	-0.6	-0.5	-0.3	-0.5
Fassade 4		-0.6	-0.5	-0.3	-0.5	-0.6	0.2	0.4	0.2
Dachneigung (<10°)	Luv	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
	Lee	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
Mittelwert		-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
Dachneigung (11°.....30°)	Luv	-0.6	-0.6	-0.55	-0.55	-0.45	-0.55	-0.55	-0.6
	Lee	-0.45	-0.55	-0.55	-0.6	-0.6	-0.6	-0.55	-0.55
Mittelwert		-0.5	-0.6	-0.55	-0.6	-0.5	-0.6	-0.55	-0.6
Dachneigung (>30°)	Luv	0.15	-0.08	-0.4	-0.75	-0.6	-0.75	-0.4	-0.08
	Lee	-0.6	-0.75	-0.4	-0.08	-0.15	-0.08	-0.4	-0.75
Mittelwert		-0.2	-0.4	-0.4	-0.4	-0.2	-0.4	-0.4	-0.4

Tabelle 6.2.5: Winddruckbeiwerte

6.35



AIVC Handbuch, Kap. 6: Eine Datenauswahl

Niedrige Gebäude (bis zu 3 Stockwerken)

Seitenverhältnis A:B = 2:1

Abschirmung: freie Lage

Referenzhöhe für Windgeschwindigkeit: Gebäudehöhe

Dachfirst

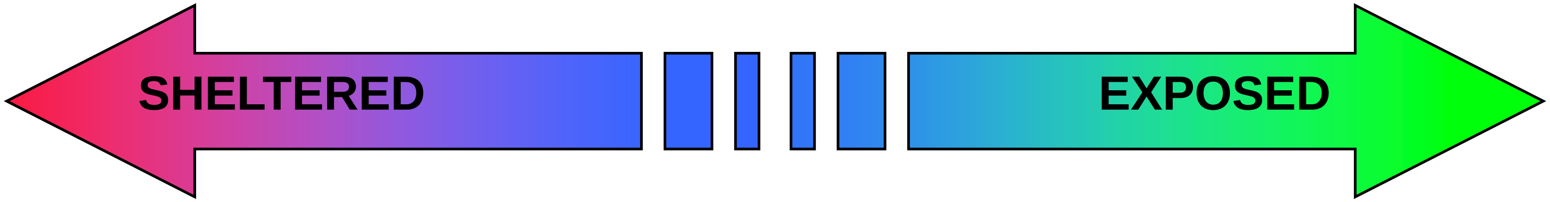
Windrichtung

Windrichtung ⊖

Position		0	45	90	135	180	225	270	315
Fassade 1		0.5	0.25	-0.5	-0.8	-0.7	-0.8	-0.5	0.25
Fassade 2		-0.7	-0.8	-0.5	0.25	0.5	0.25	-0.5	-0.8
Fassade 3		-0.9	0.2	0.6	0.2	-0.9	-0.6	-0.35	-0.6
Fassade 4		-0.9	-0.6	-0.35	-0.6	-0.9	0.2	0.6	0.2
Dachneigung (<10°)	Luv	-0.7	-0.7	-0.8	-0.7	-0.7	-0.7	-0.8	-0.7
	Lee	-0.7	-0.7	-0.8	-0.7	-0.7	-0.7	-0.8	-0.7
Mittelwert		-0.7	-0.7	-0.8	-0.7	-0.7	-0.7	-0.8	-0.7
Dachneigung (11°.....30°)	Luv	-0.7	-0.7	-0.7	-0.6	-0.5	-0.6	-0.7	-0.7
	Lee	-0.5	-0.6	-0.7	-0.7	-0.7	-0.7	-0.7	-0.6
Mittelwert		-0.6	-0.65	-0.7	-0.65	-0.6	-0.65	-0.7	-0.65
Dachneigung (>30°)	Luv	0.25	0	-0.6	-0.9	-0.8	-0.9	-0.6	0
	Lee	-0.8	-0.9	-0.6	0	0.25	0	-0.6	-0.9
Mittelwert		-0.18	-0.45	-0.6	-0.45	-0.18	-0.45	-0.6	-0.45

Tabelle 6.2.4: Winddruckbeiwerte

6.34



-26,6	HEATING [%]	-22,7
-75,8	FANS[%]	-80,0
0,79	EP[-]	0,81

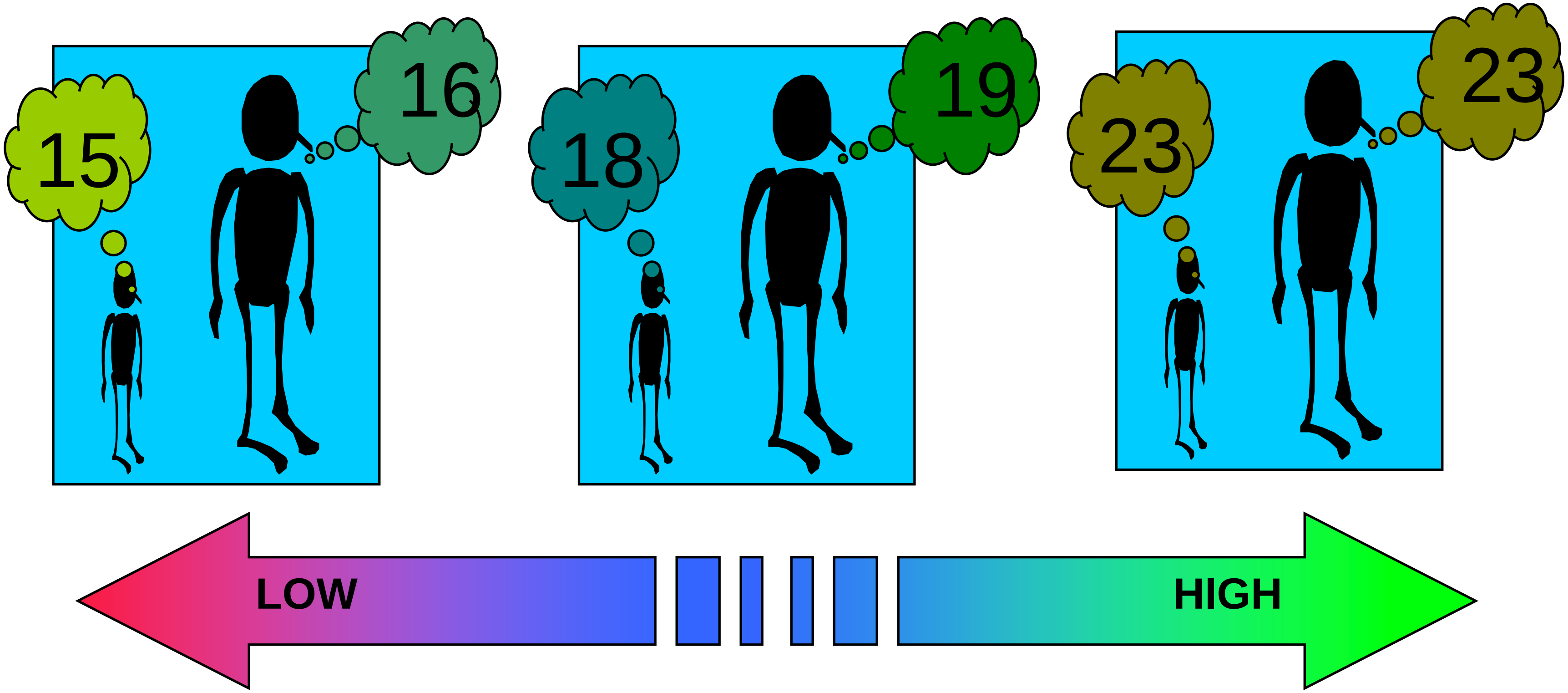
Acceptable CO_2 concentration

1500 **1300** **1000**

1500 [ppm] **1000 [ppm]**

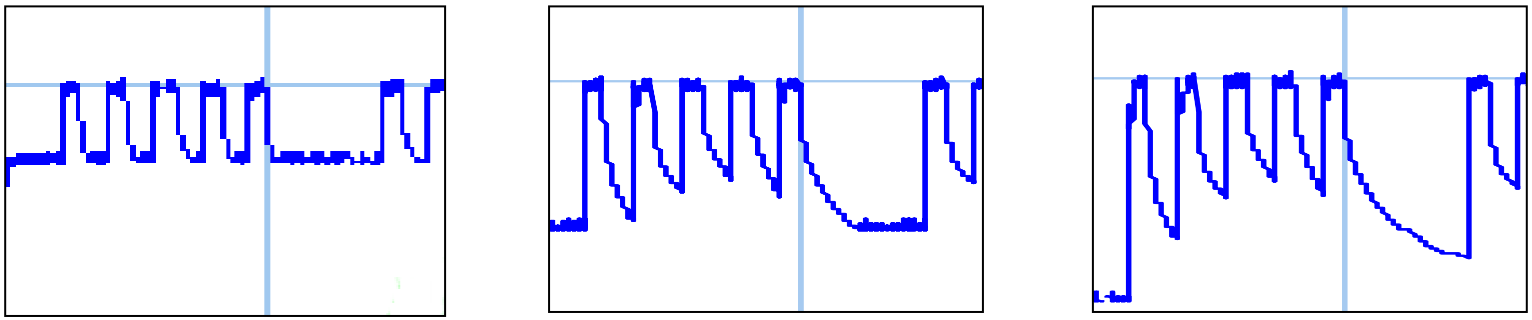
-26,9	**HEATING [%]**	**-22,4**
-87,3	**FANS[%]**	**-48,9**
0,78	**EP[-]**	**0,83**

CO_2 production



-27,5	HEATING [%]	-19,8
-86,4	FANS[%]	-63,1
0,78	EP[-]	0,83

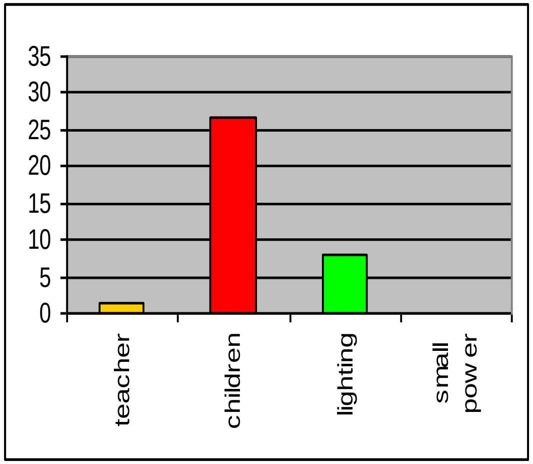
Night temperature control

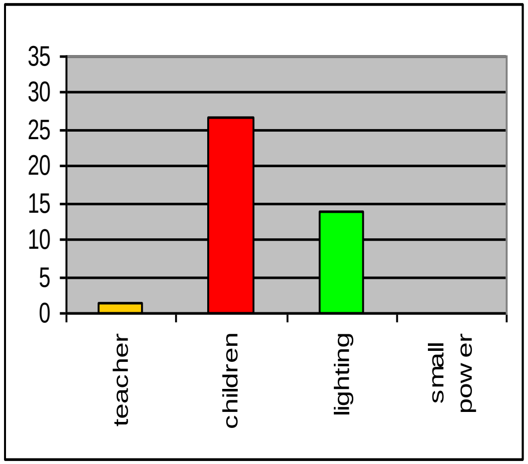


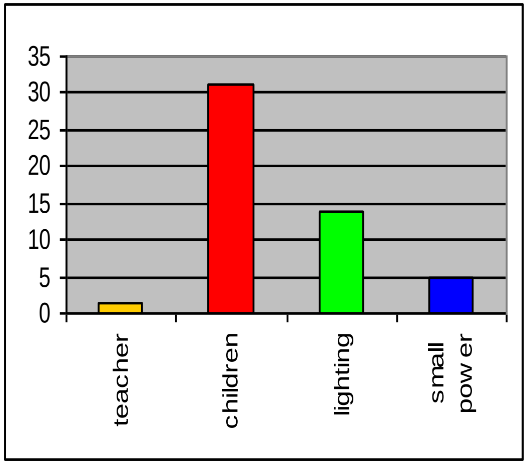
17 °C ⟷ 11 °C

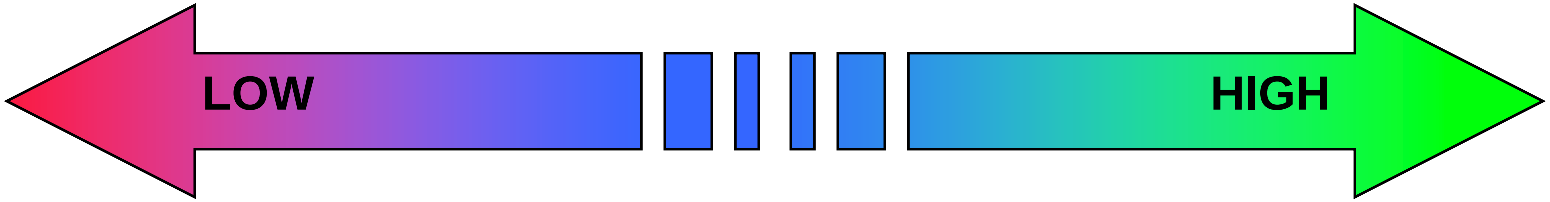
-23,1	HEATING [%]	-24,8
-77,9	FANS[%]	-77,9
0,81	EP[-]	0,80

Internal heat production









-22,5	**HEATING [%]**	**-25,3**
-80,1	**FANS[%]**	**-75,8**
0,81	**EP[-]**	**0,80**

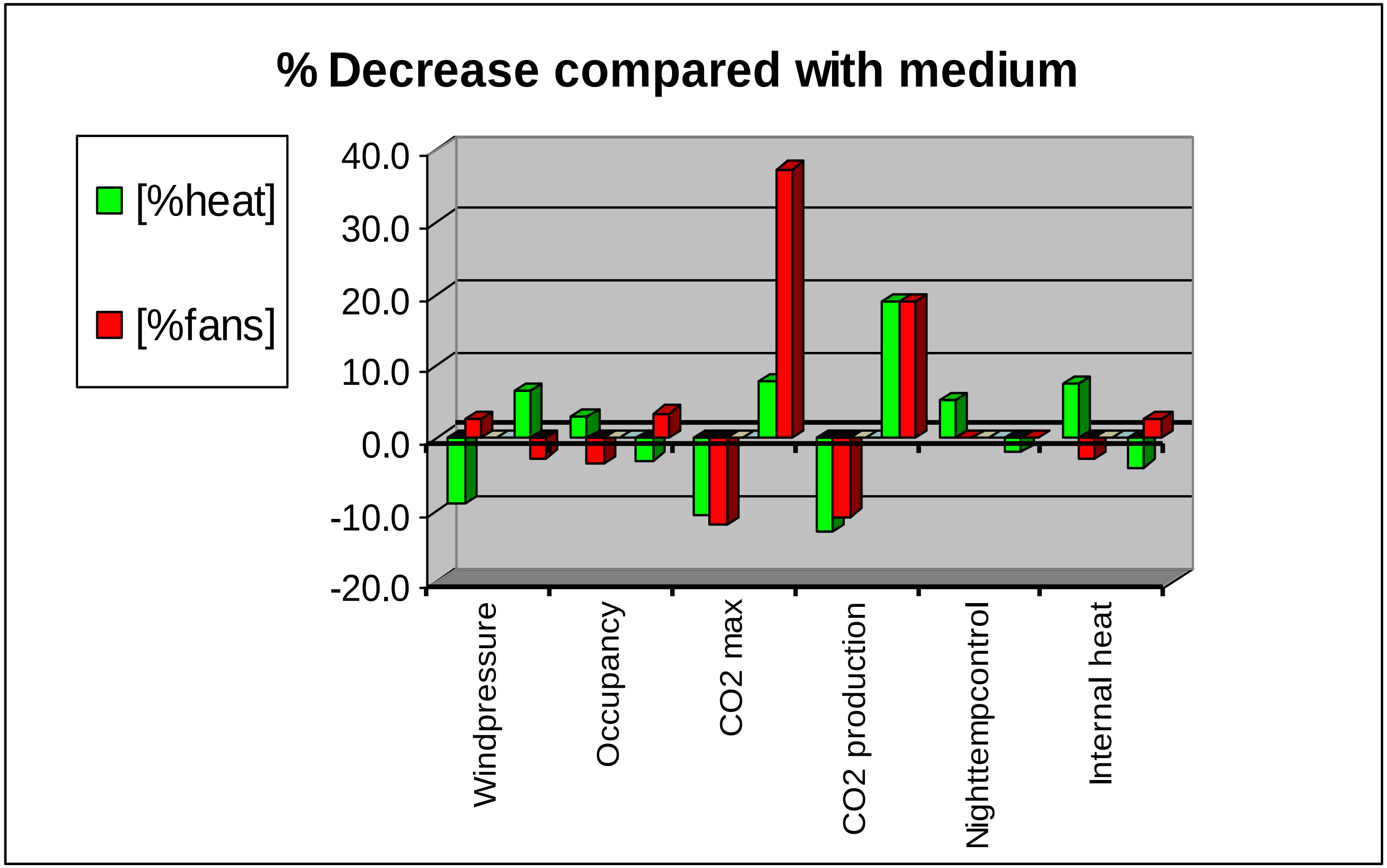
Occupancy

23+1 Occupants

25+1 Occupants

-23,6	HEATING [%]	-25,1
-80,6	FANS[%]	-75,2
0,80	EP[-]	0,80

Results versus medium

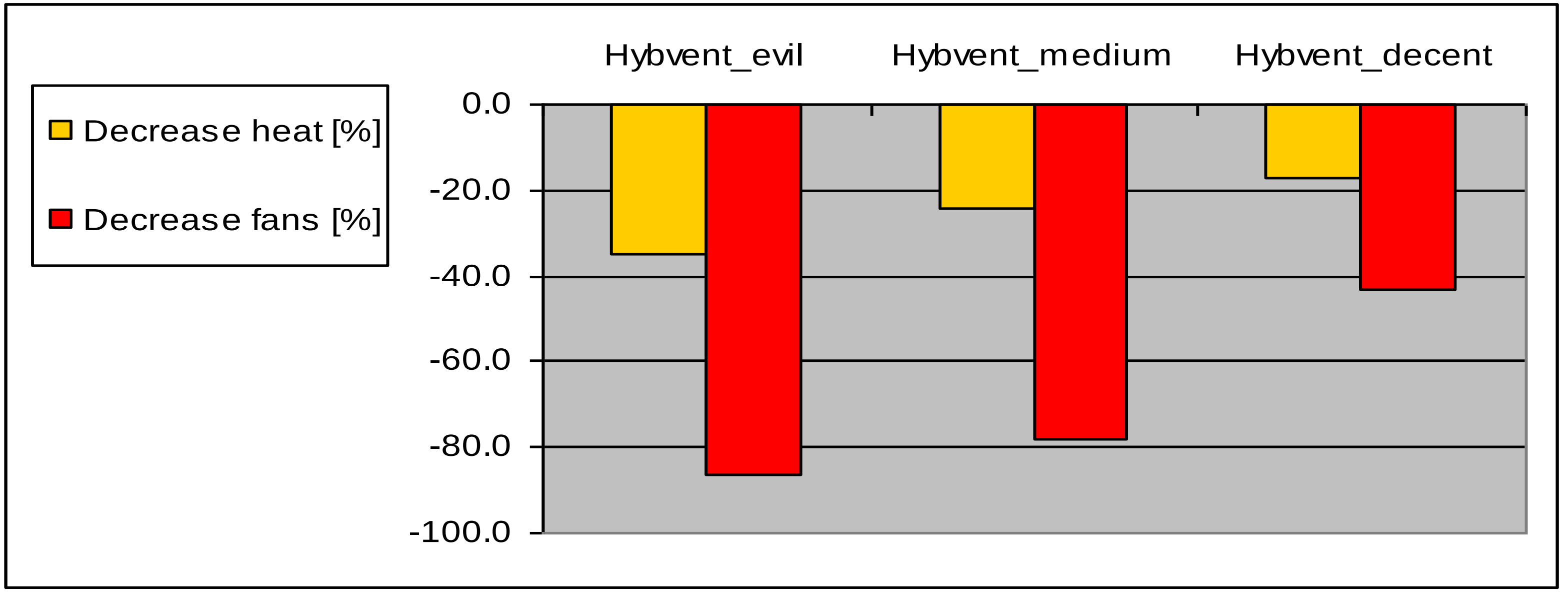


THE EXTREMES

- Evil approach
  - Sheltered
  - Occupancy high
  - Acceptable CO_2=1500 ppm
  - CO_2 production low
  - Nighttemperature low
  - Internal heat high

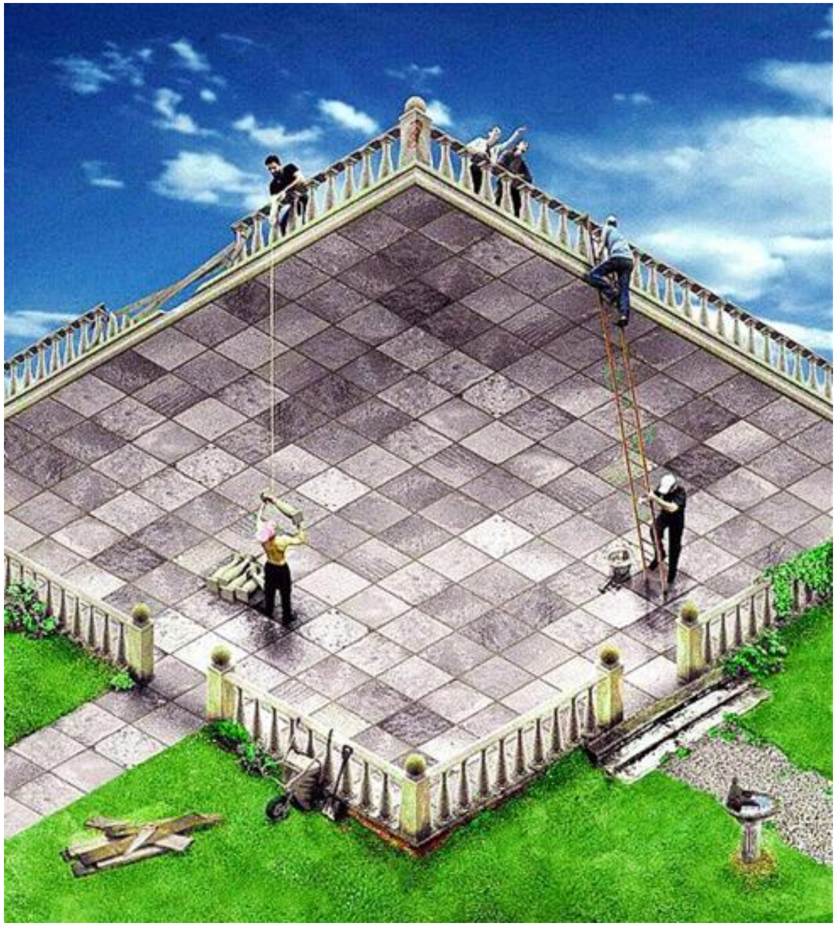
- Decent approach
  - Exposed
  - Occupancy low
  - Acceptable CO_2=1000 ppm
  - CO_2 production high
  - Nighttemperature high
  - Internal heat low

Results of extremes

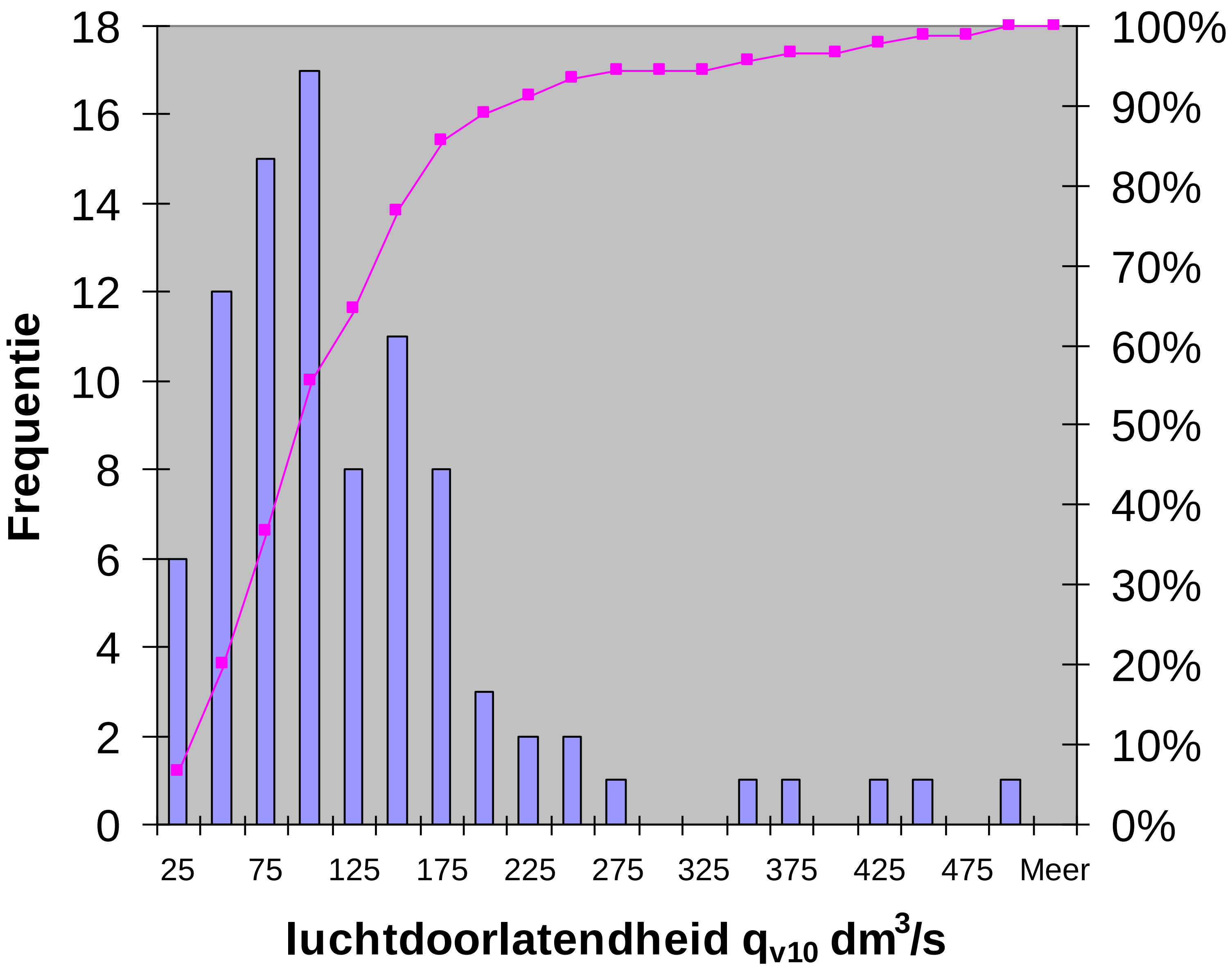


EP [-]	0,73	0,80	0,86
Savings [%]	27	20	14

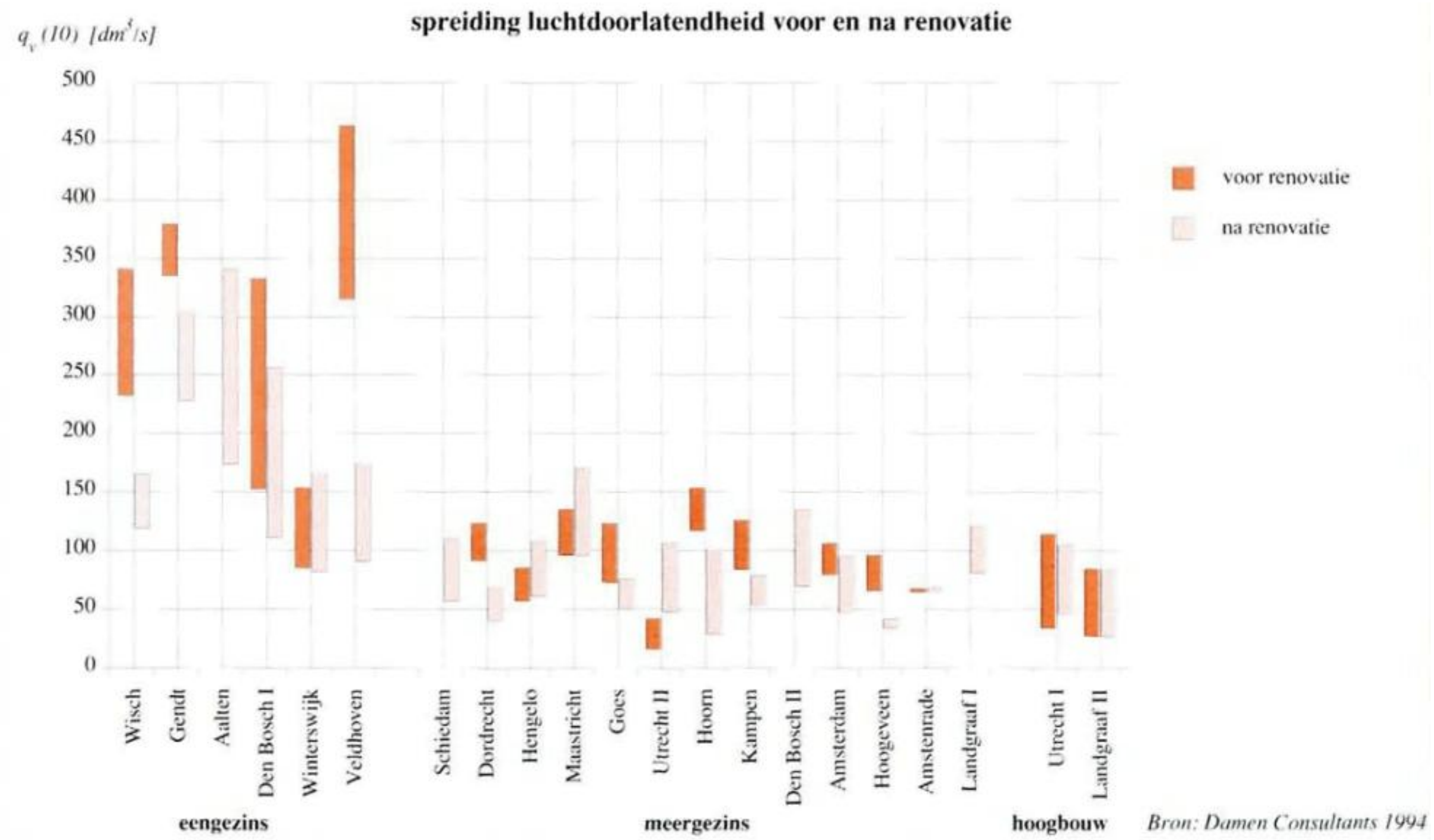
2. The performance of buildings and equipment



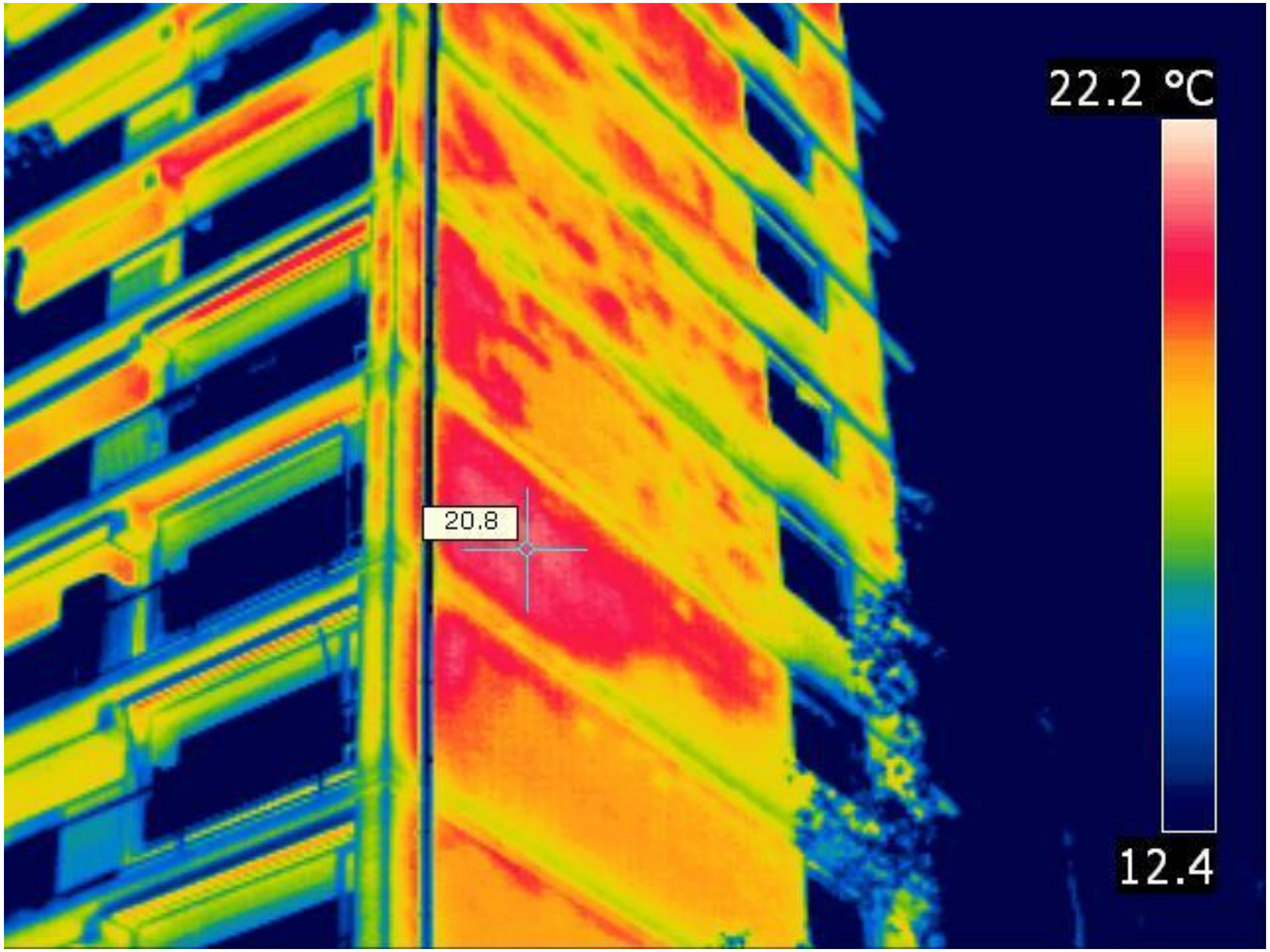
Air tightness of dwellings



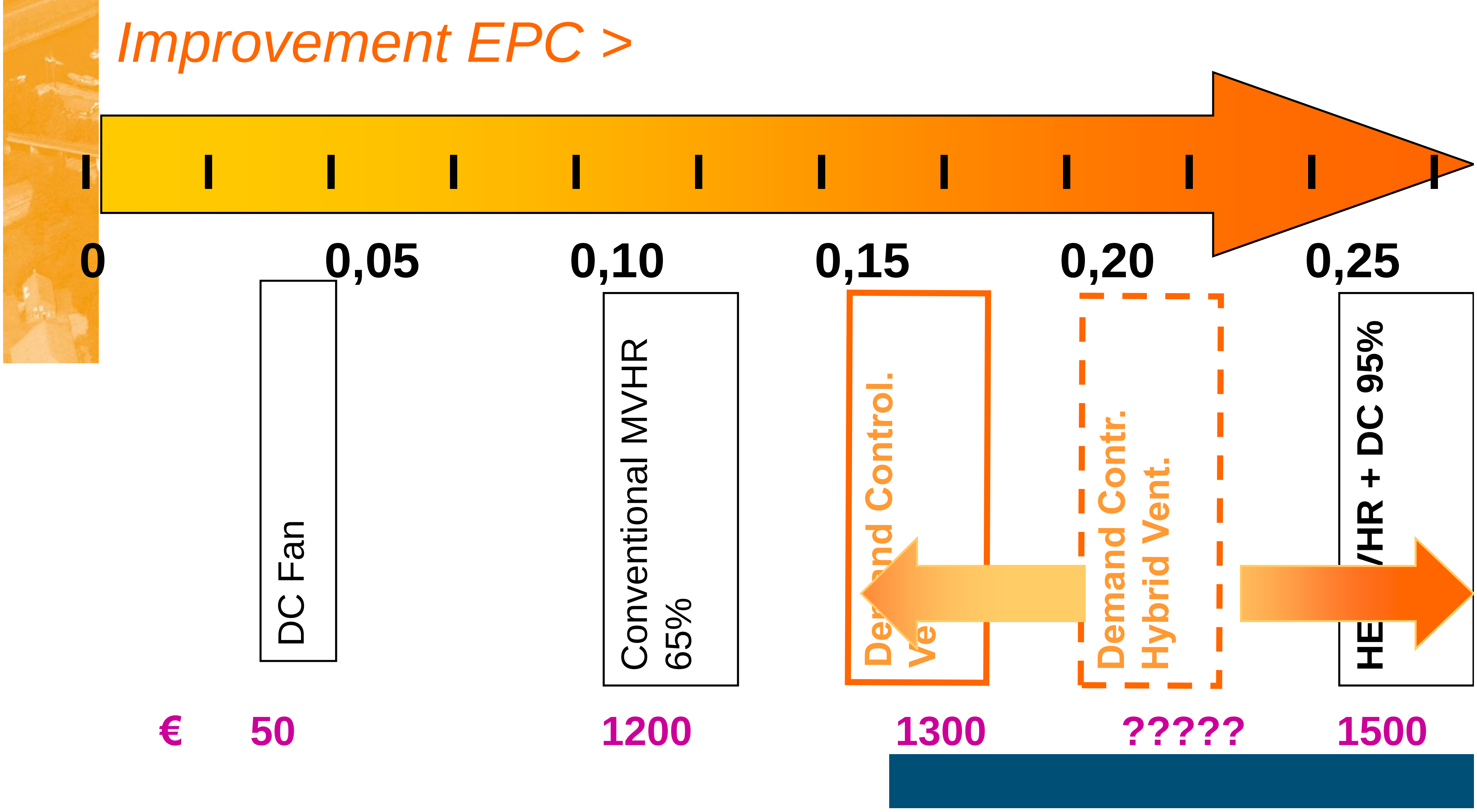
Air tightness before and after renovation



Thermal insulation



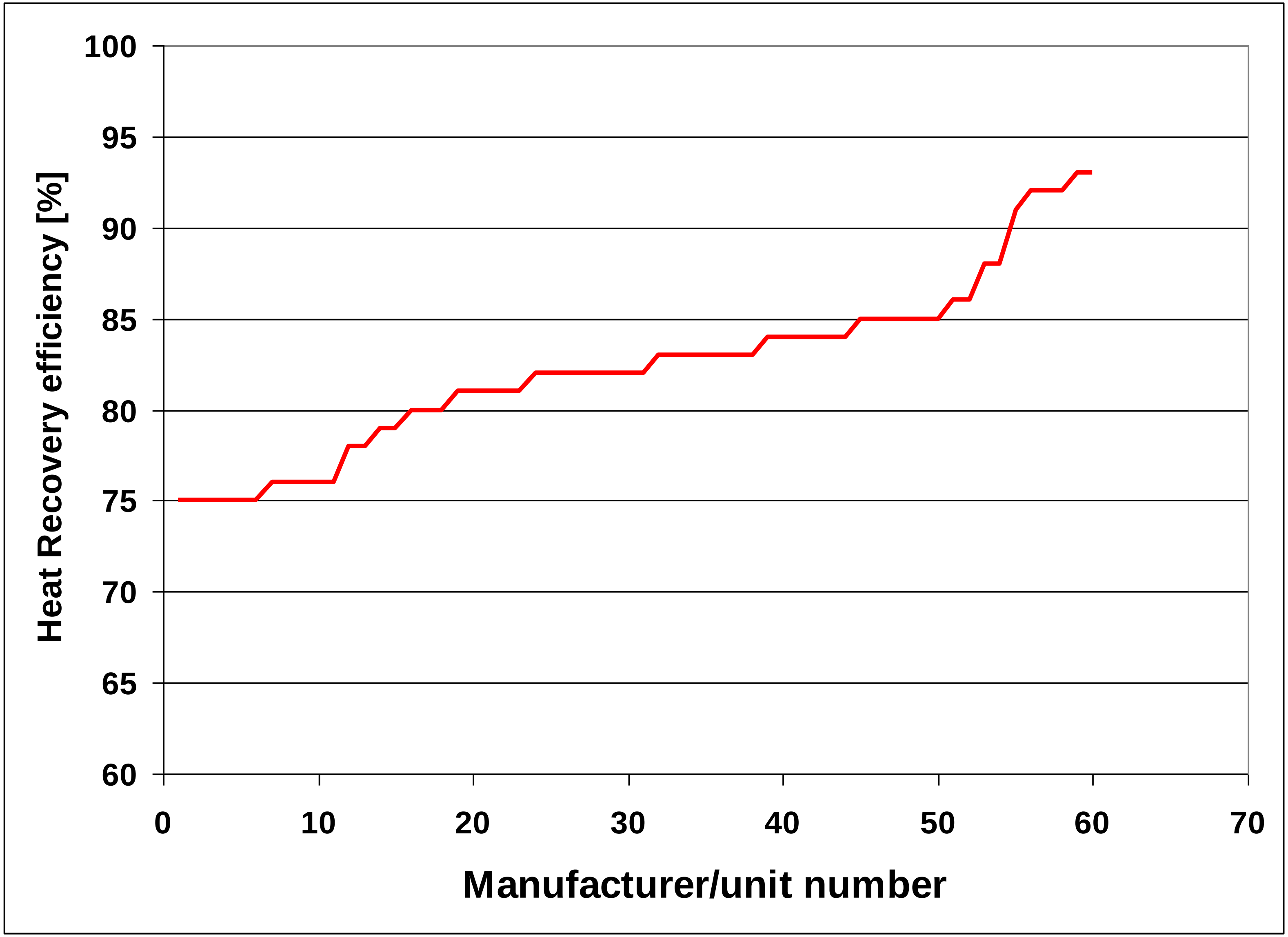
Positioning advanced ventilation in relation to the (Dutch) EPBD



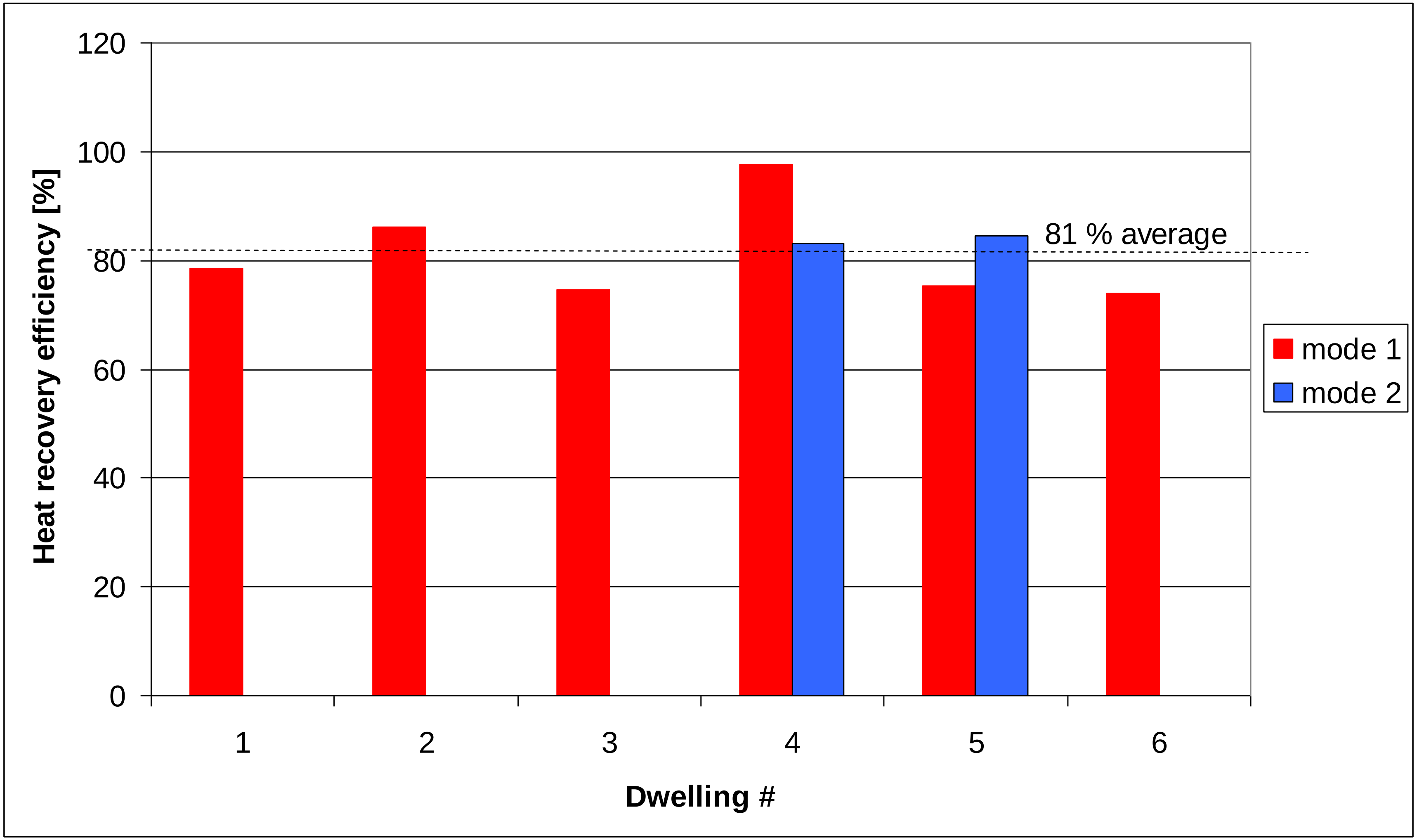
Heat recovery units (counter flow)

- EPBD default:
  previously 75%, currently 80%
- EPBD certificates: 95%
- Passive House certificates:

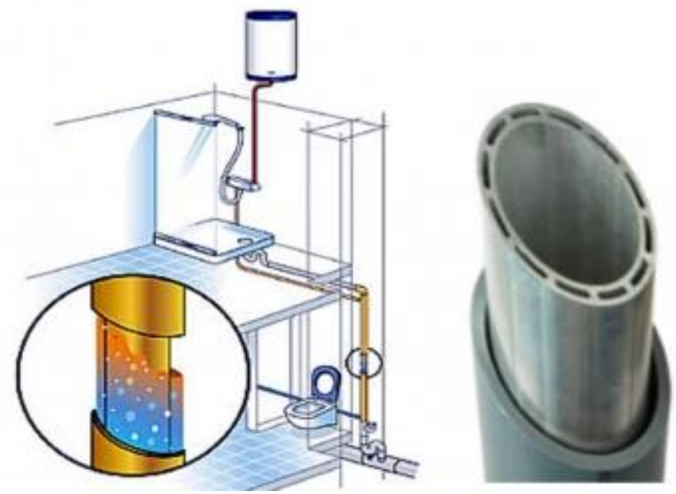
Heat recovery units, lab. measurements by PHI



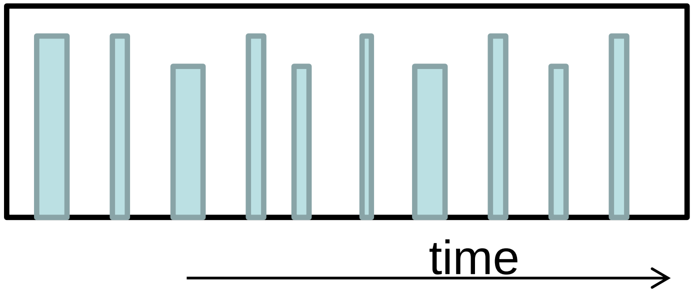
Heat recovery units, field measurements



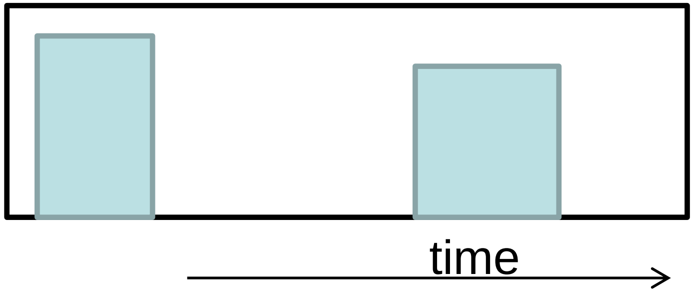
DHW heat recovery units



Pattern A



Pattern B



kiwa
Partner for progress

Kwaliteitsverklaring
douchewater-warmteterugwinapparaat
t.b.v. berekening NEN 5128
(energieprestatie voor woningen en woongebouwen
- bepalingsmethode)

Gastec Certification B.V. verklaart hierbij dat het douchewater warmteterugwinapparaat,

Type : **DSS/Bries dubbelwandige douche WTW met kunststof buitenmantel. Lengte 2,0m, diameter 63mm**

van : **Bries Energietechniek**

te : **Roden, Nederland**

doorgemeten is volgens de meetmethode ontwikkeld door Gastec Certification BV in opdracht van Novem (Juli 2003). In NEN 5128 per 21 mei 2009 (wijzigingsblad A1: 2009) zijn de tapdebieten aangepast. Het apparaat is met deze tapdebieten doorgemeten. Dit levert het volgende rendement op:

Klasse	Tapdebiet (l/min, 40°C)	Tapvolume (l)	Rendement [%]
3	9.2	73*	57.6
4,5,6	12.5	100*	56.0

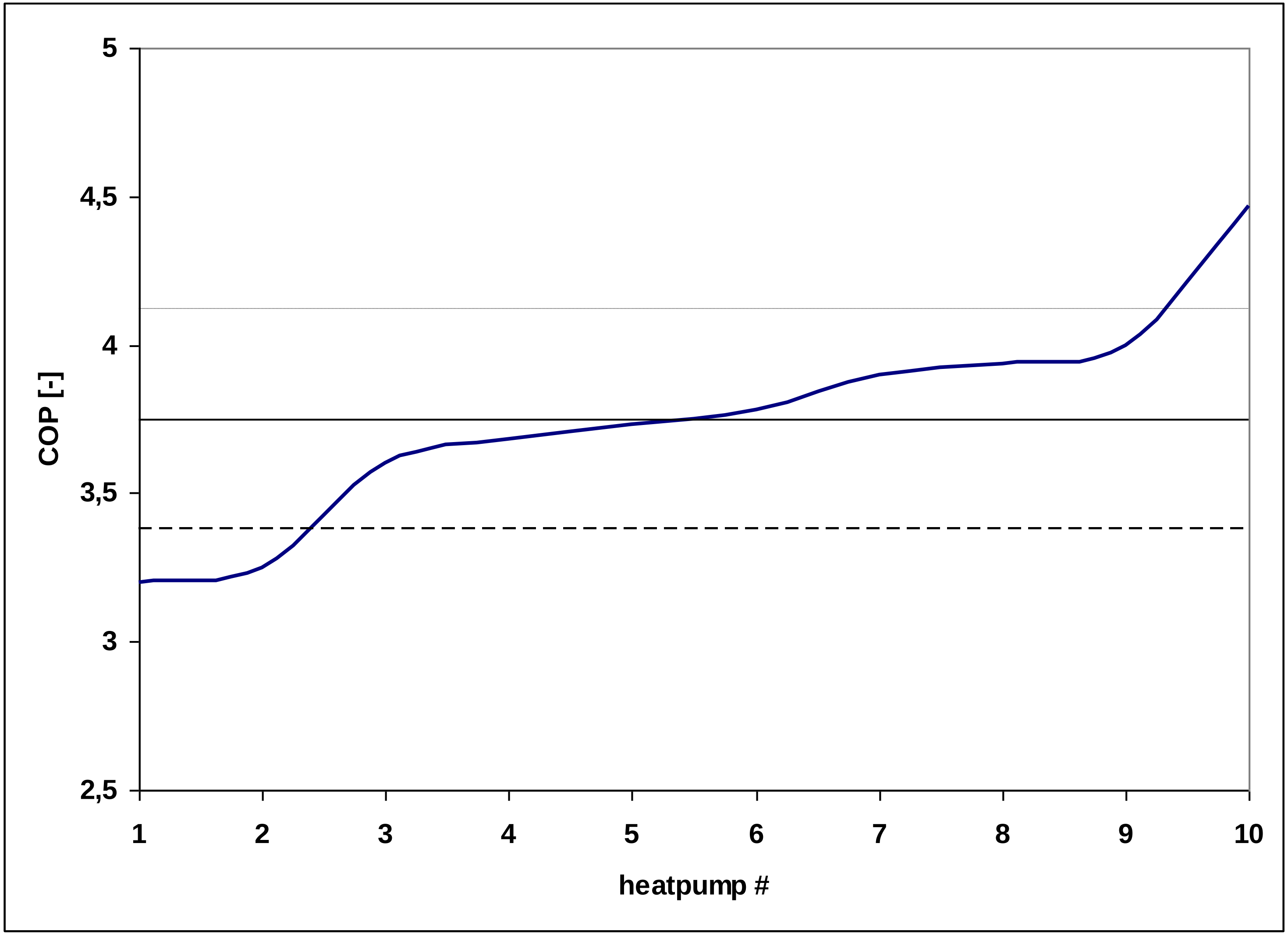
*) Het gemeten tapvolume wijkt af van het tapvolume opgegeven in NEN 5128+A1:2009.

Apeldoorn, 16 juni 2009

Ing. A.A. Slomp,
Manager Appliances,
Gastec Certification B.V.

What is it all about?

Field data (I):small heatpumps



COP of heatpumps

	COP (EPBD)	COP (EPBD& certificate)	COP (measured average)
Space-heating	4,6	6,08	
DHW	1,4 x Corr.	2,23 x Corr.	
Average	4,1 - 4,3	5,49 - 5,63	3,75± 0,5

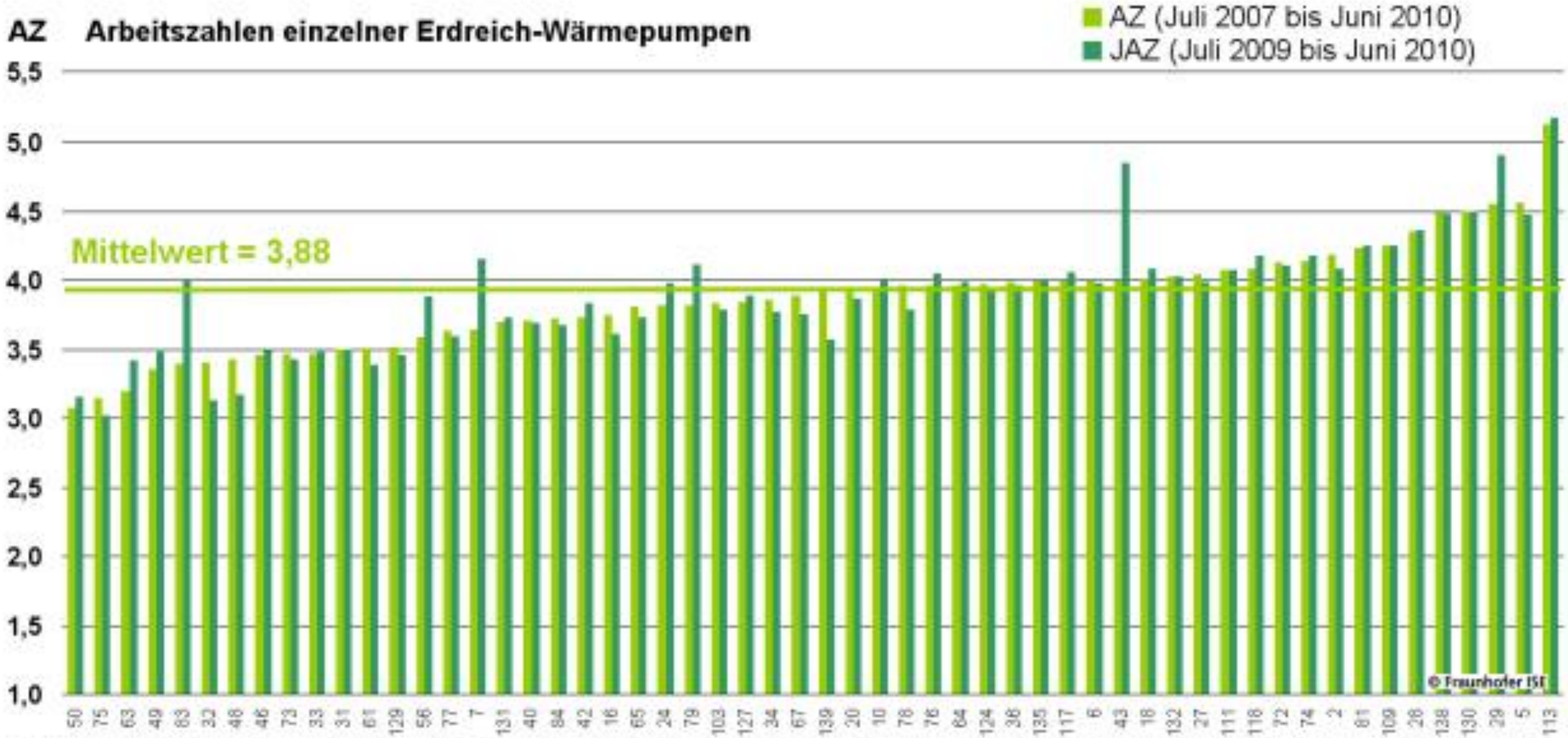
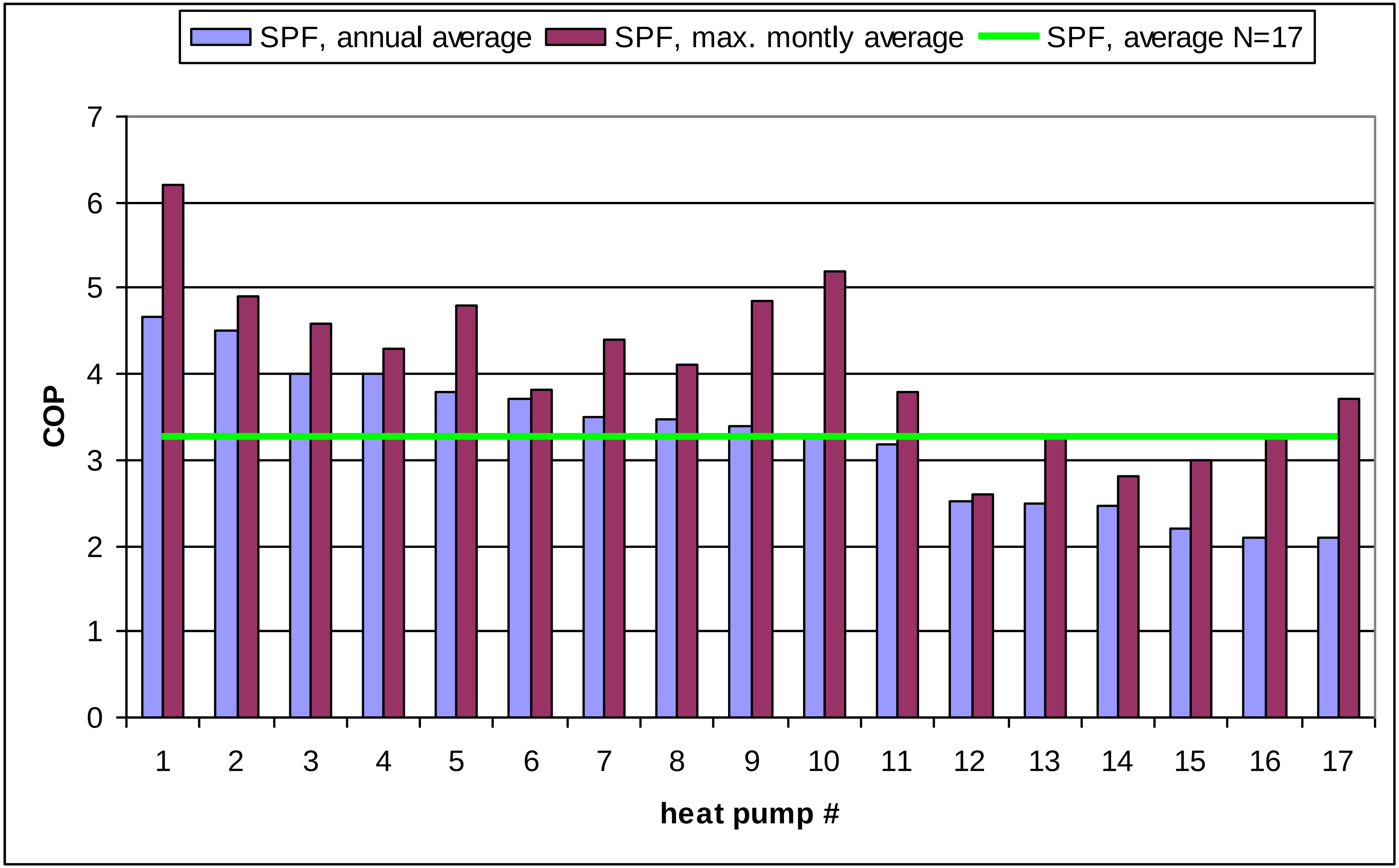


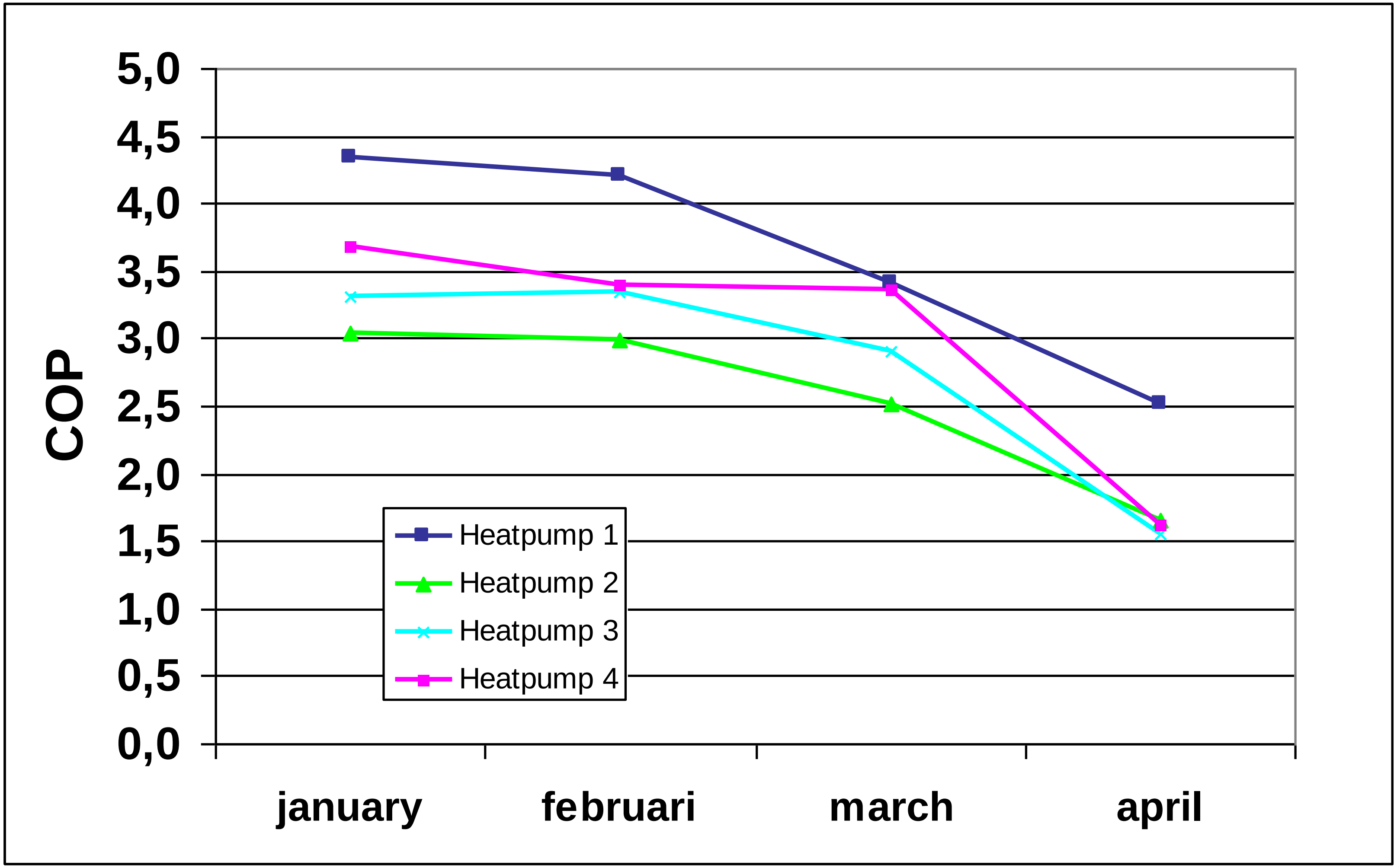
Bild 15: Arbeitszahlen von Erdreich-Wärmepumpen für die Zeiträume Juli 2007 bis Juni 2010 sowie Juli 2009 bis Juni 2010; die Anlagenbezeichnungen entsprechen den Herstellern bekannten ID-Nummern

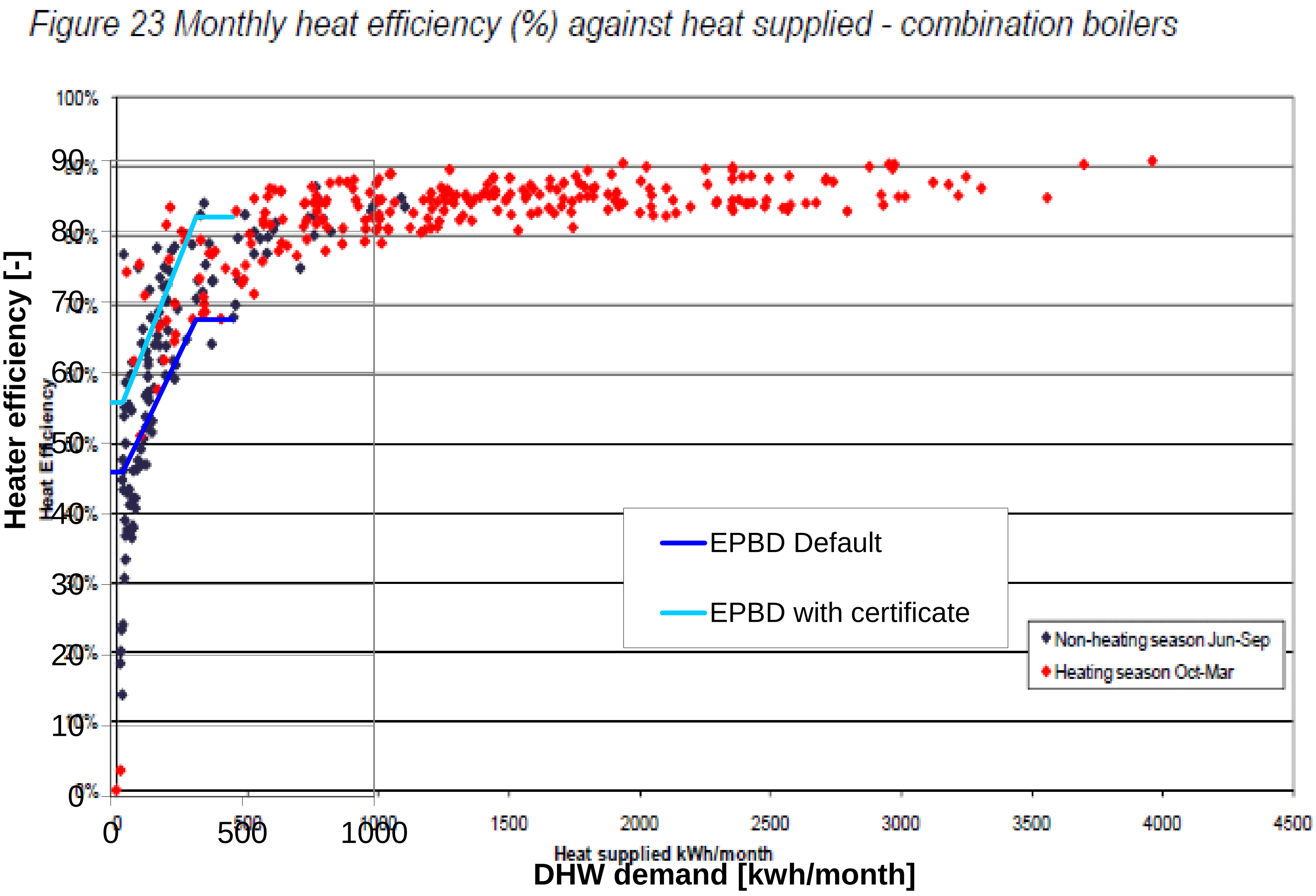
Measured field data bij Fraunhofer (Ge)

Field data (II): large heatpumps

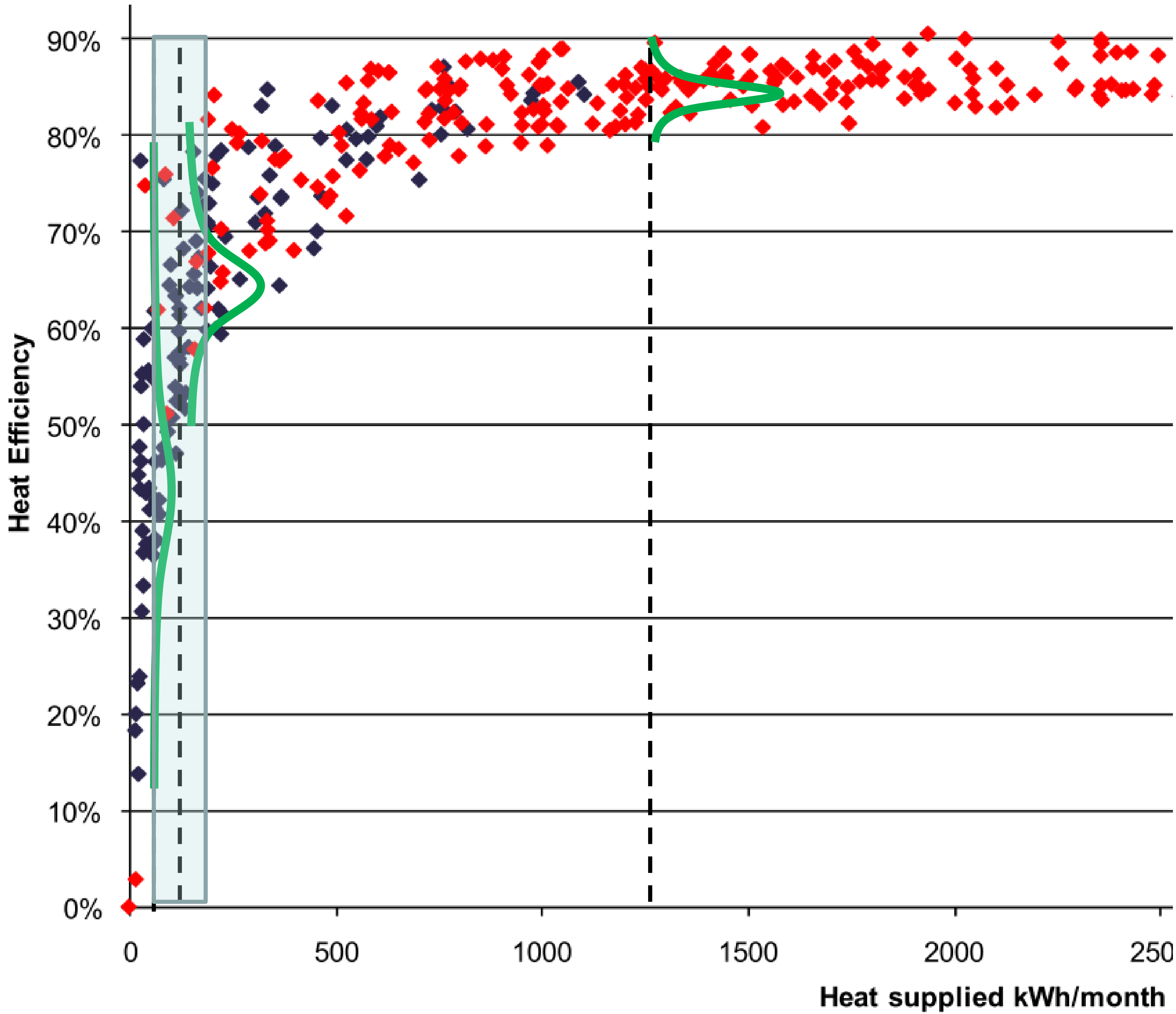


Field data large heatpumps (II)

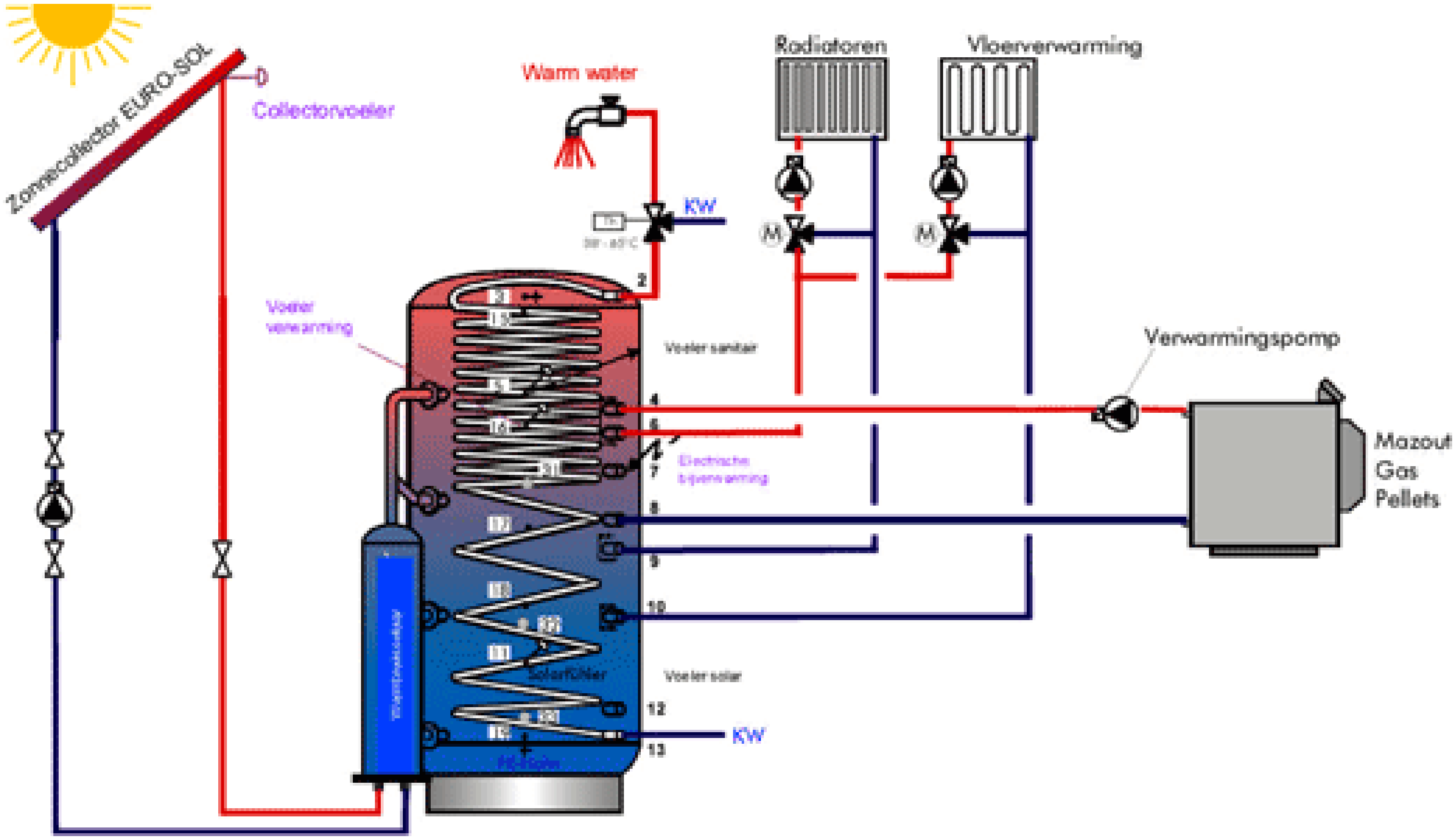




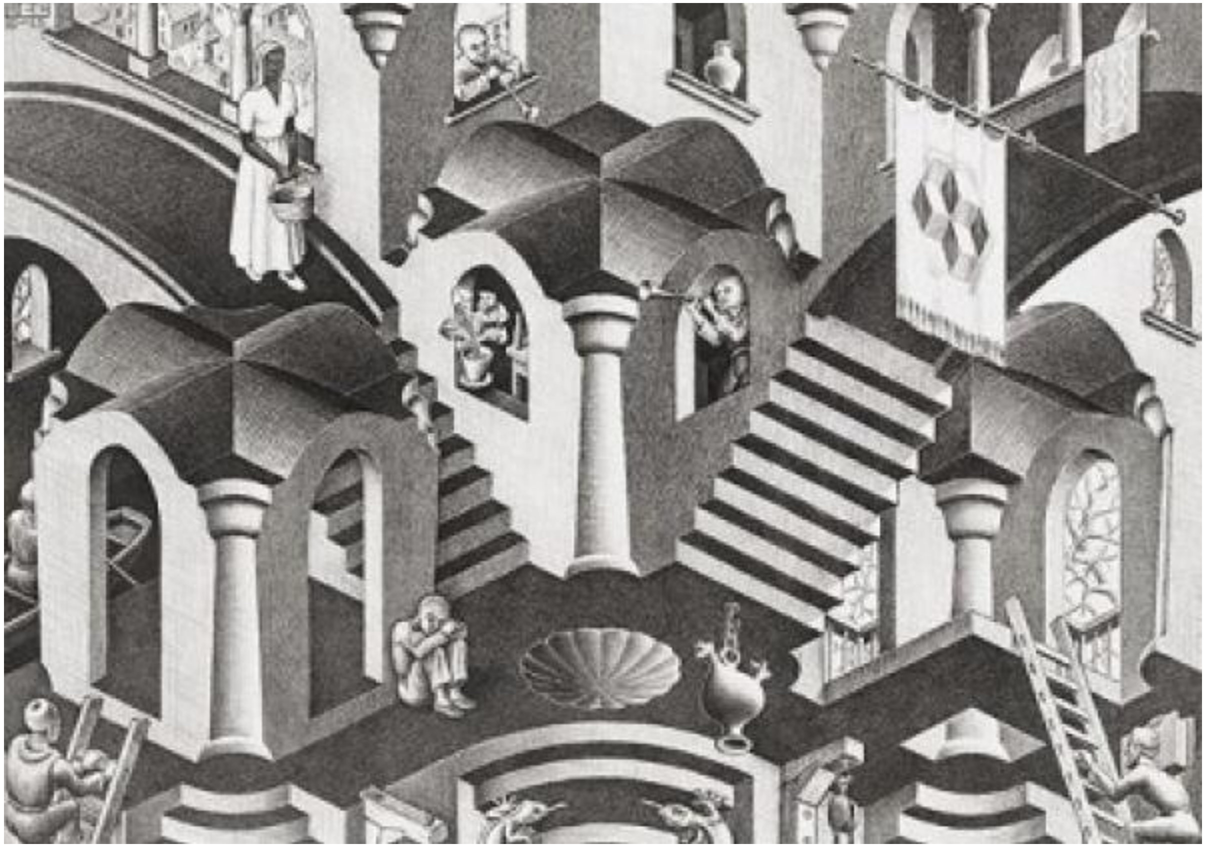
Field data on condensing gas-fired heaters bij Gastec at CRE, 2009


90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Heat Efficiency
0
500
1000
1500
2000
250
Heat supplied kWh/month

Performance of combination of technologies??



4. The occupant behaviour



The 4 stages of an occupant

1. Easy stage

2. Thermal simulation stage

3. Comfort sensing stage

4. Real occupant

Energy use and occupant behaviour

User aspects on energy use has been researched

- Social sciences
- Physics
- Economical sciences

From the social sciences several models have been developed

Exemples: Van Raaij model, NOA model

Behavioral model Van Raaij *et al.*

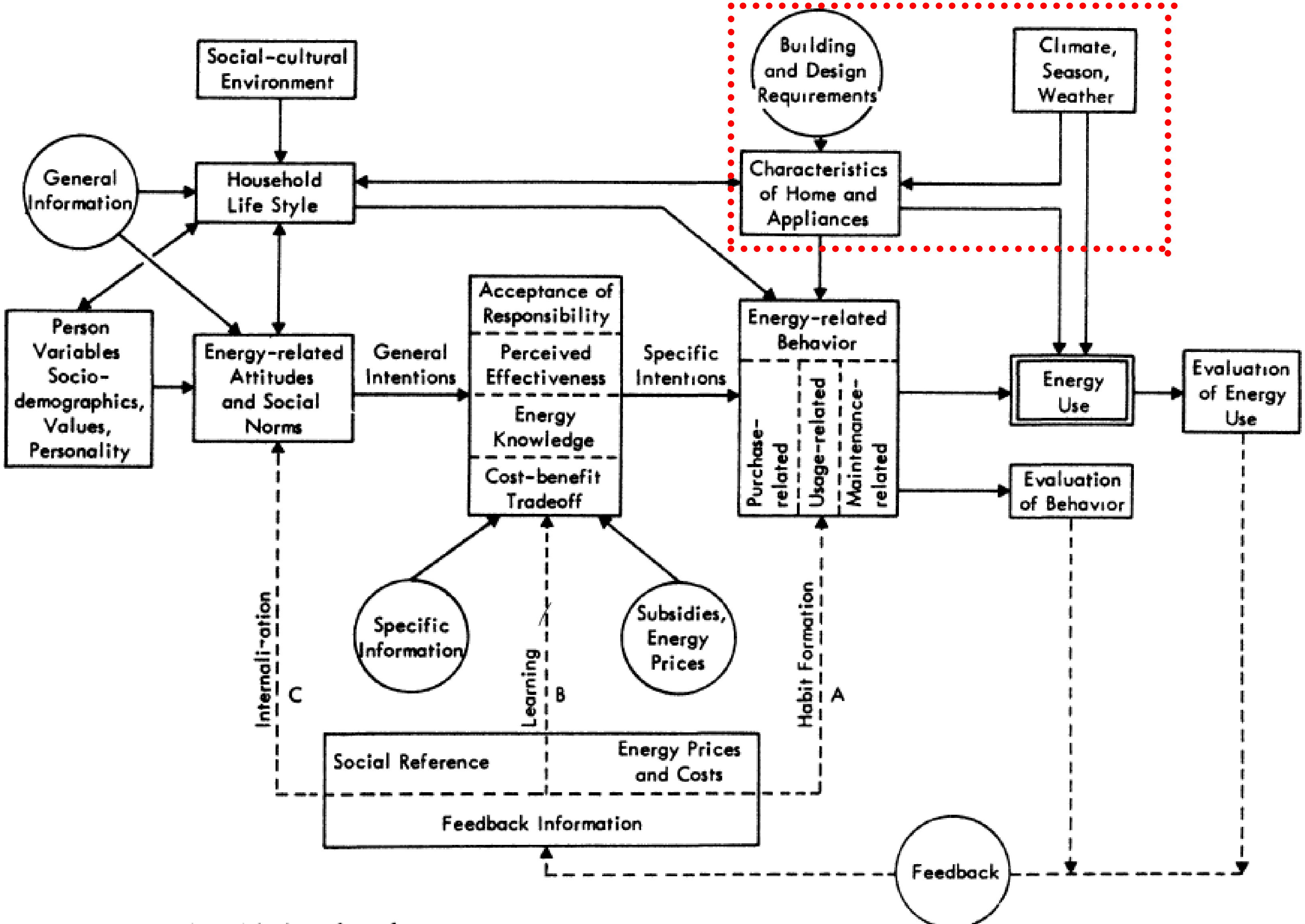
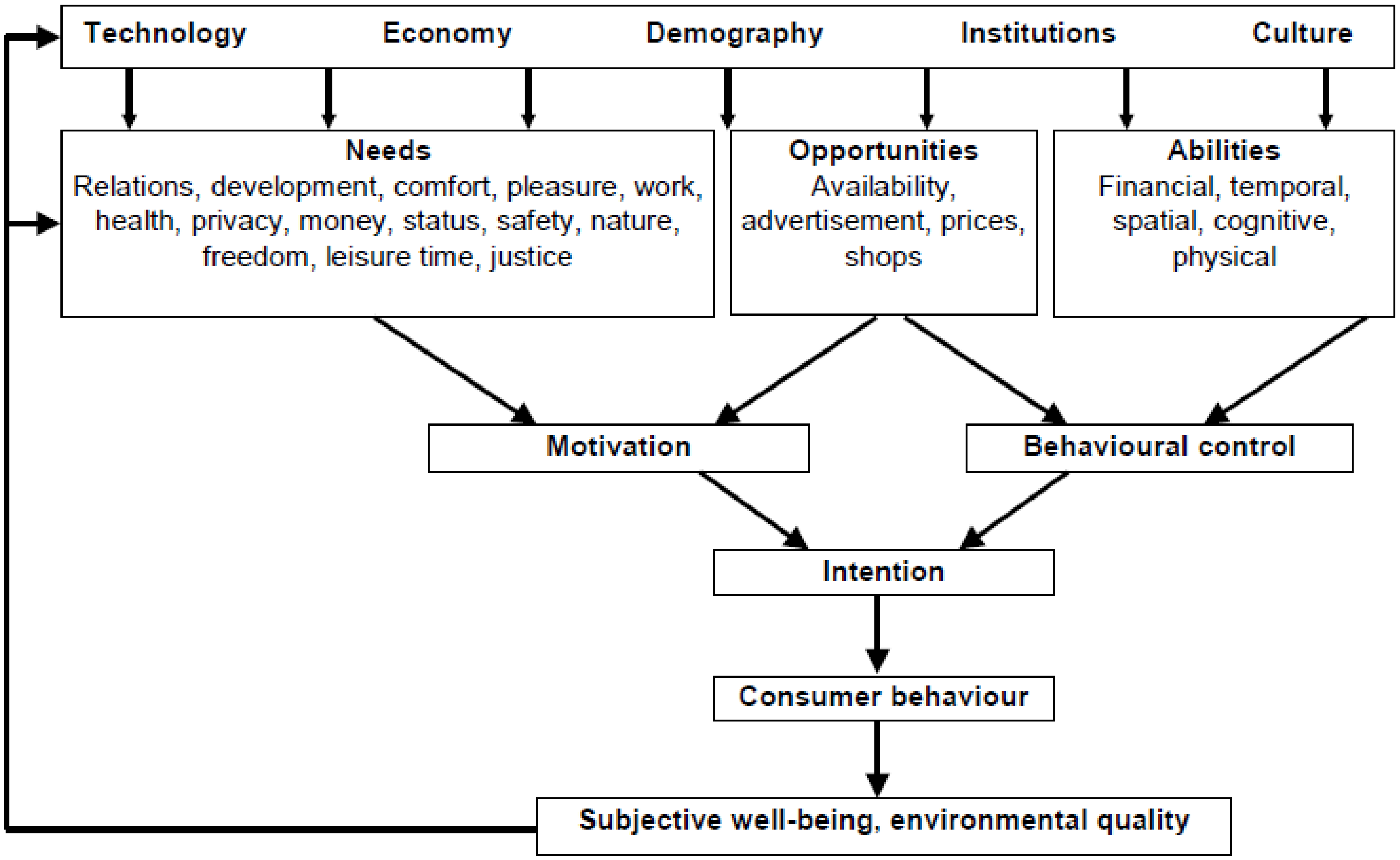


Fig. 1 A behavioral model of residential energy use

NOA-model Gatersleben & Vlek

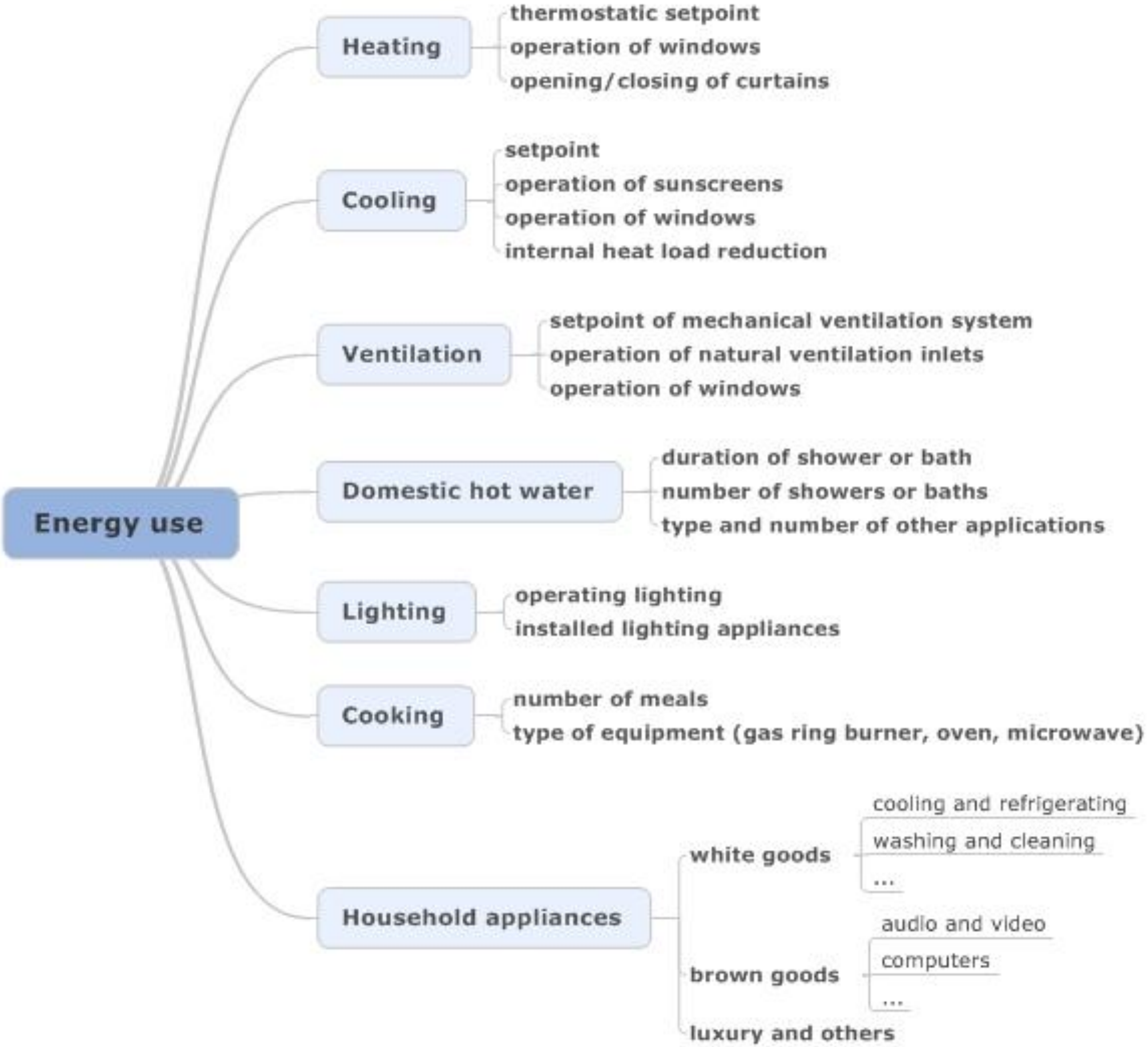


Energy behaviour in dwellings

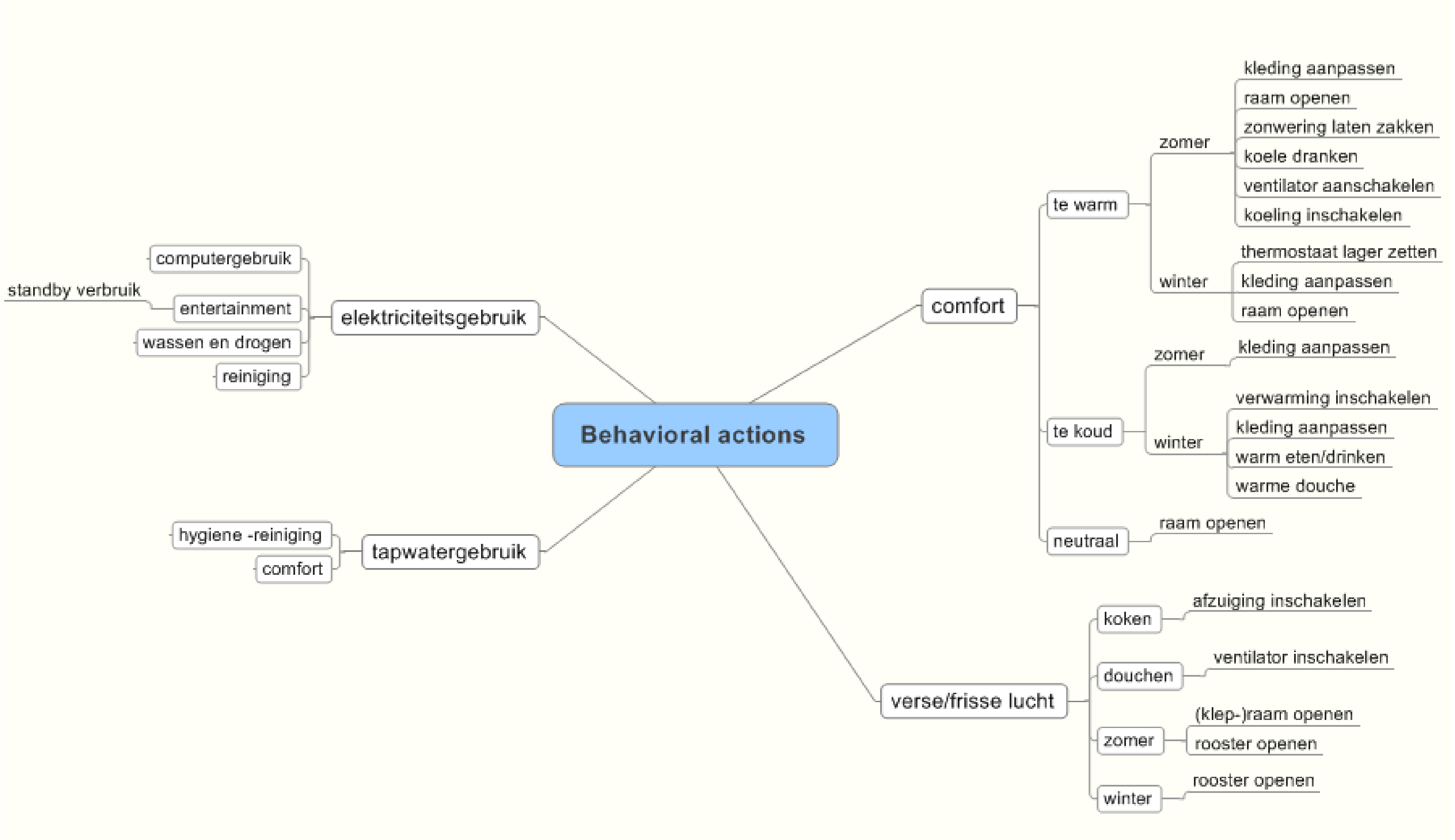
Tabel 2-17 Verklarende variabelen (naar afnemend effect) voor energiekosten

Energiekosten totaal	Kosten elektriciteit	Kosten gas en warmte
Gebruiksoppervlak	Gebruiksoppervlak	Wijze van verwarmen
Energie-index[7]	Apparaatbezit en gebruik	Gebruiksoppervlak
Wijze van verwarmen	Inkomen	Energie-index
Inkomen	Aantal kinderen	stookpatroon
Apparaatbezit en gebruik	woningtype	woningtype
Woningtype	Type huishouden	Type huishouden
Type huishouden	Wijze van verwarmen	Wijze en mate van ventileren
Stookpatroon	stookpatroon	Bouwjaar woning
Aantal buitenzijden van de woning	Aantal volwassenen	Etnische achtergrond respondent
Leeftijd (hoofd huishouden)	Etnische achtergrond respondent	Inkomen
Bouwjaar woning	Energie-index	Aantal buitenzijden van de woning
Etnische achtergrond respondent		Leeftijd (hoofd huishouden)
Wijze en mate van baden / douchen		Aantal kinderen
Wijze en mate van ventileren		
46% verklaarde variantie	33% verklaarde variantie	40% verklaarde variantie

Energy occupant behaviour



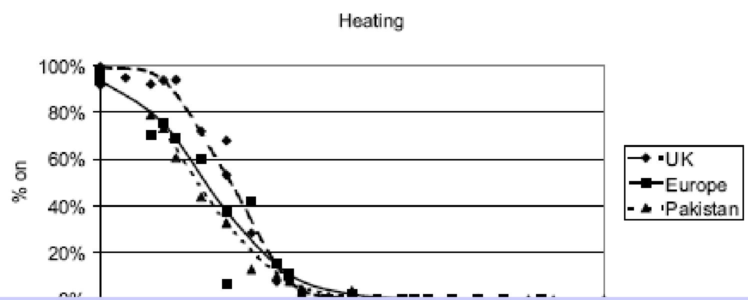
Psychological aspects



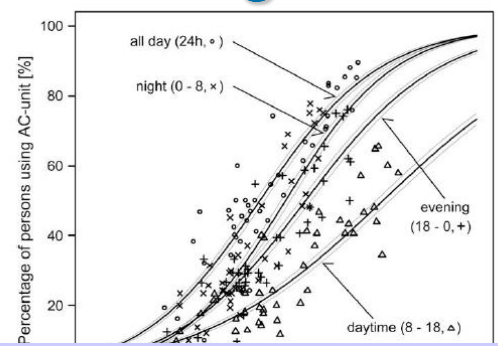
→ + group interactions

The technical approach

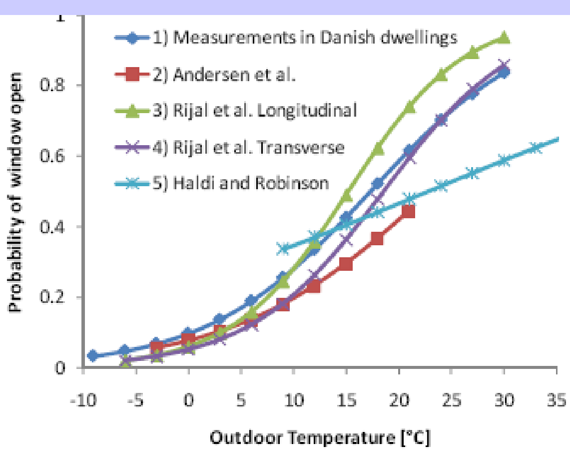
- Thermostatic setpoint

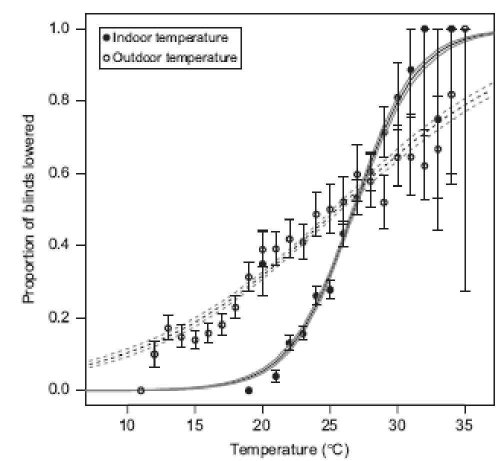


- Percentage of AC use

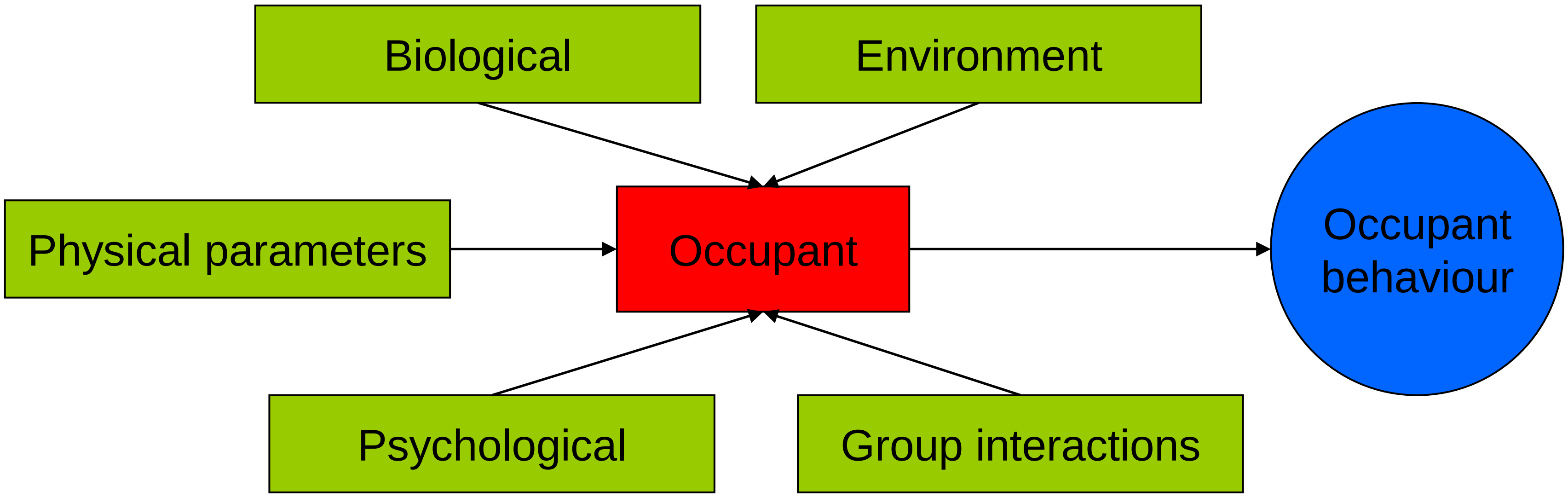


Physical parameter → *Occupant behaviour*





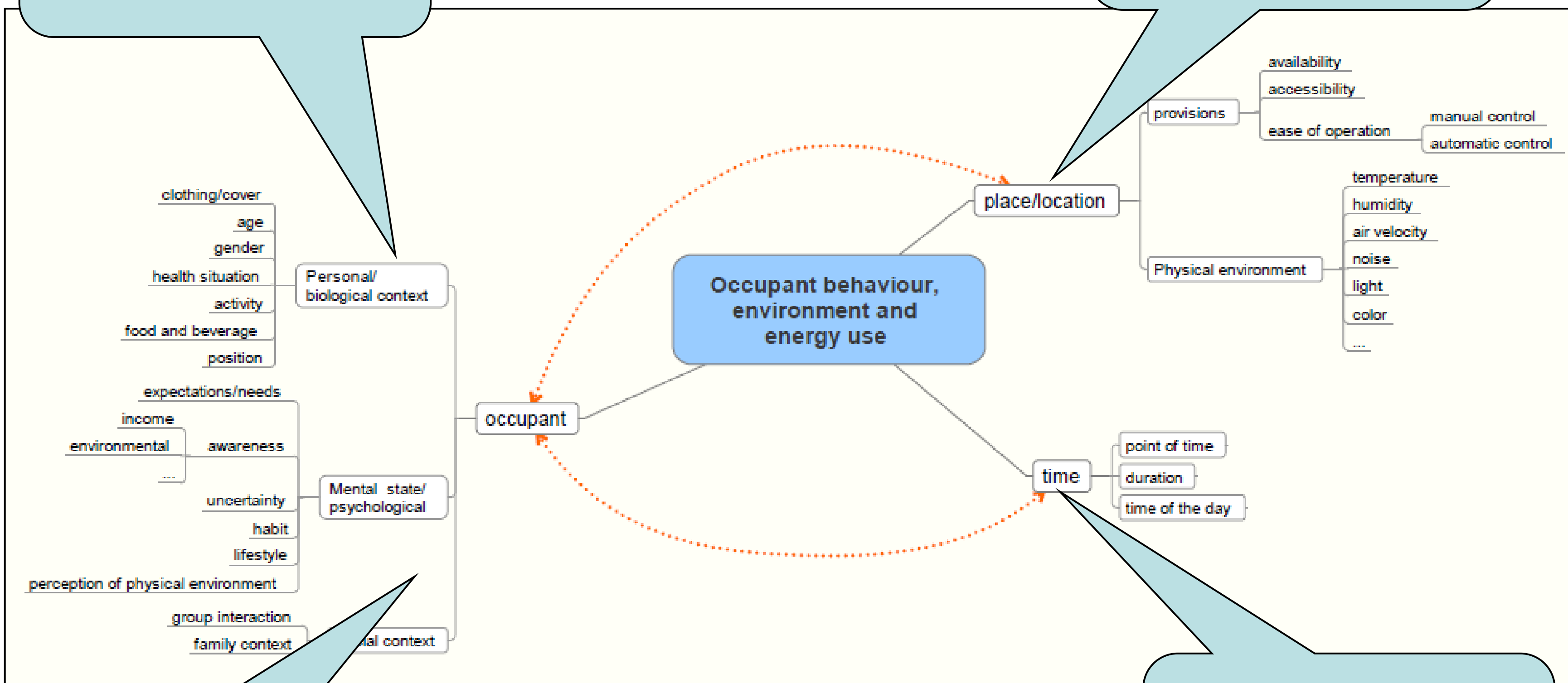
What is the complex reality?



Occupant behaviour and energy

Personal physiological comfort

Building physical characteristics and provisions



Psychological status and group interactions

Time usage research and data

Occupancy model

What type of calculation model is appropriate?

- Stochastic model, e.g. Markov-Chain Monte Carlo
- Deterministic model, e.g. occupancy profile
- Semi probabilistic/deterministic model

Occupancy

What data is available?

- Time-use survey from “The Netherlands Institute for Social Research”
- Database with 2000 respondents
- Time-interval: 15 minutes, duration: 1 week
- Activities of people have been translated in absence or presence (time and location)

Time-use survey

Microsoft Excel - Kopie van Kopie van 1_p_henk.xls

CN51 sl

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	
1	ID RP (SLEUTEL)	tbonr	100024	100033	100063	100123	100232	100429	100473	100483	100488	100598	100637	100659	100690	100715	100718	100721	10
2	Leeftijd RP	jaar	69	83	87	72	66	68	71	78	79	82	74	73	76	80	75	81	
3	Geslacht RP	m/v	v	m	v	v	v	v	v	v	v	v	v	v	v	v	v	m	v
4	Plaats huishoude	hk/phk/k/o	hk	hk	hk	hk	hk	hk	hk	hk	hk	hk	hk	hk	hk	hk	hk	hk	hk
20																			
21	Su.00		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
22	Su.00.15		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
23	Su.00.30		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
24	Su.00.45		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
25	Su.01		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
26	Su.01.15		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
27	Su.01.30		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
28	Su.01.45		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
29	Su.02		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
30	Su.02.15		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
31	Su.02.30		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
32	Su.02.45		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
33	Su.03		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
34	Su.03.15		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
35	Su.03.30		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
36	Su.03.45		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
37	Su.04		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
38	Su.04.15		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
39	Su.04.30		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
40	Su.04.45		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
41	Su.05		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
42	Su.05.15		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
43	Su.05.30		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
44	Su.05.45		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
45	Su.06		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
46	Su.06.15		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
47	Su.06.30		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
48	Su.06.45		sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
49	Su.07		sl	sl	sl	sl	pc	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
50	Su.07.15		sl	sl	sl	sl	pc	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl	sl
51	Su.07.30		sl	sl	sl	sl	pc	sl	sl	pc	pc	cook	sl	sl	cook	sl	sl	sl	sl
52	Su.07.45		sl	sl	pc	hh-d	pc	sl	sl	pc	eat	cook	sl	sl	cook	sl	sl	sl	sl
53	Su.08		hh-o	pc	pc	cook	cook	pc	sl	eat	eat	sl-s	sl	eat	cook	pc	sl	pc	pc
54	Su.08.15		hh-o	cook	hh-d	cook	eat	pc	sl	eat	eat	pc	sl	eat	hh-k	pc	sl	pc	eat
55	Su.08.30		hh-o	cook	eat	hh-d	eat	pc	sl	TV	pc	hh-d	eat	eat	hh-k	ho	sl	eat	eat
56	Su.08.45		hh-o	cook	eat	hh-k	hh-k	pc	sl	TV	nh	hh-k	eat	eat	pc	cook	sl	eat	eat
57	Su.09		hh-o	hh-d	hh-k	hh-k	nh	nh	cook	TV	nh	read	eat	pc	pc	cook	pc	read	hh-t
58	Su.09.15		hh-o	hh-k	hh-he	hh-k	nh	nh	hh-d	TV	eat	read	eat	pc	nh	hh-d	pc	read	hh-t

Data / Kopie van 1_p_henk / Data_presence / trans_BE_X / trans_BA_X / trans_KI_X / trans_LI_X / trans_

Modelling occupancy and building

Sub-selection from the Time-use data used in building model:

- Two retired persons
- Two working persons
- Family: 2 parents and 2 children

Building model:

- Reference single-family dwelling
- TRNSYS simulation
- Heating in specific room on during occupancy

Markov-Chain Monte Carlo (MCMC)

Outline of MCMC procedure for occupancy modelling

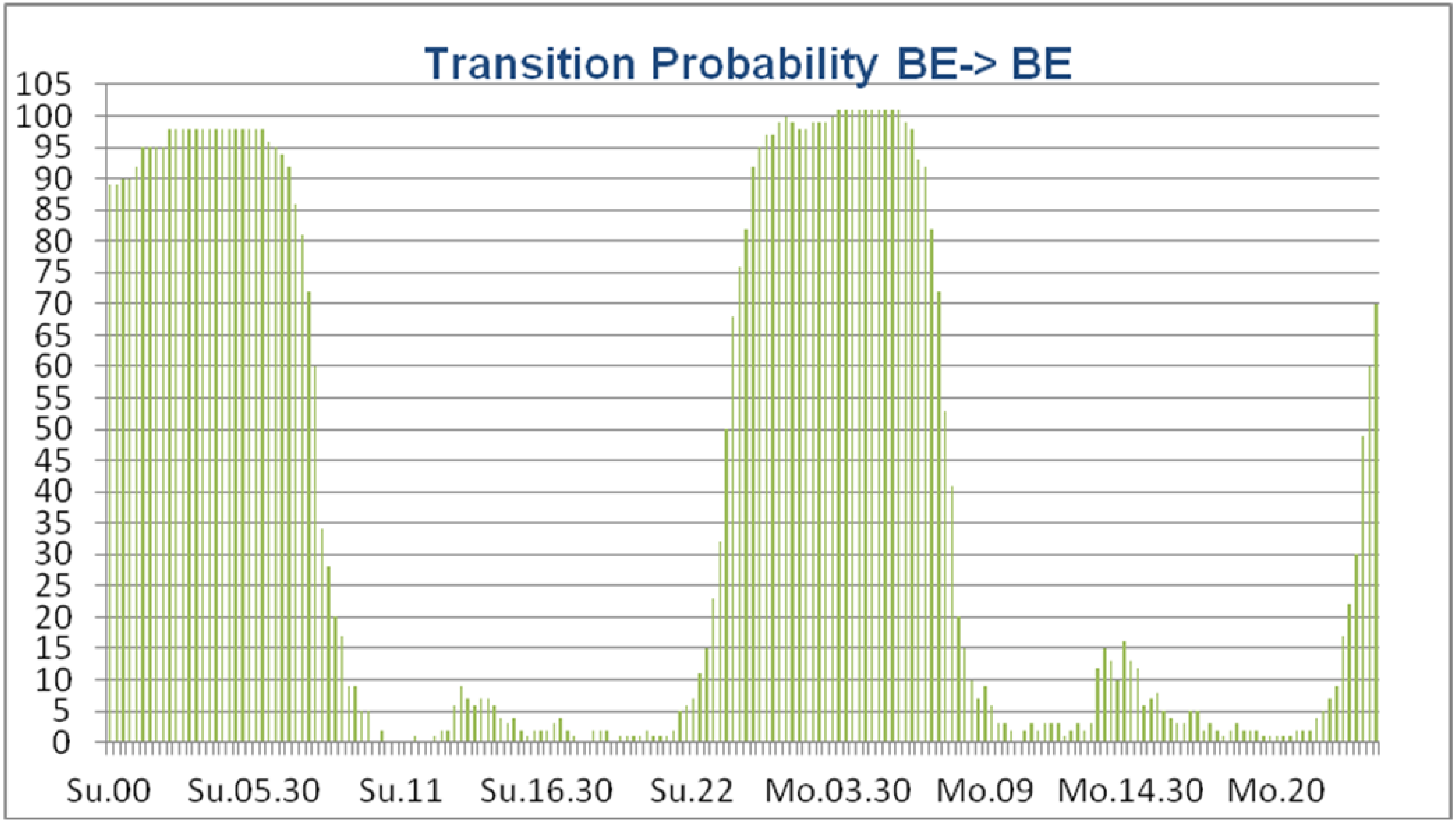
- Define 6 states: bedroom, bathroom, kitchen, living room, other, not at home
- Derive transition probabilities from one state to the other for each time step →

BE-BE	BE-BA	BE-KI	BE-LR	BE-OT	BE-NH
BA-BE	BA-BA	BA-KI	BA-LR	BA-OT	BA-NH
KI-BE	KI-BA	KI-KI	KI-LR	KI-OT	KI-NH
LR-BE	LR-BA	LR-KI	LR-LR	LR-OT	LR-NH
OT-BE	OT-BA	OT-KI	OT-LR	OT-OT	OT-NH
NH-BE	NH-BA	NH-KI	NH-LR	NH-OT	NH-NH

- Derive cumulative probabilities
- Generate random numbers and use cumulative transition probabilities to find new state

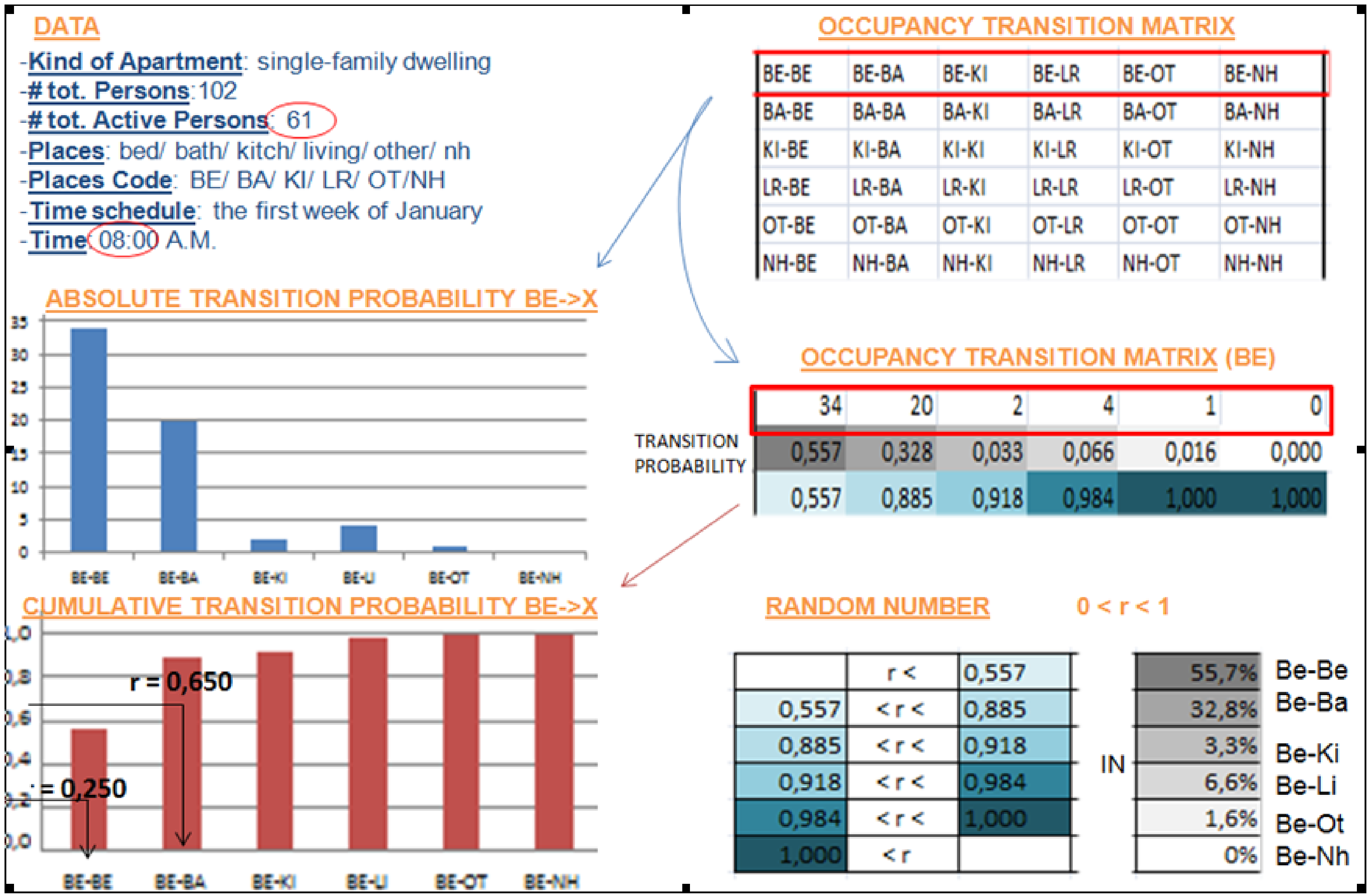
Transition probability

- Example transition probability: bedroom → bedroom



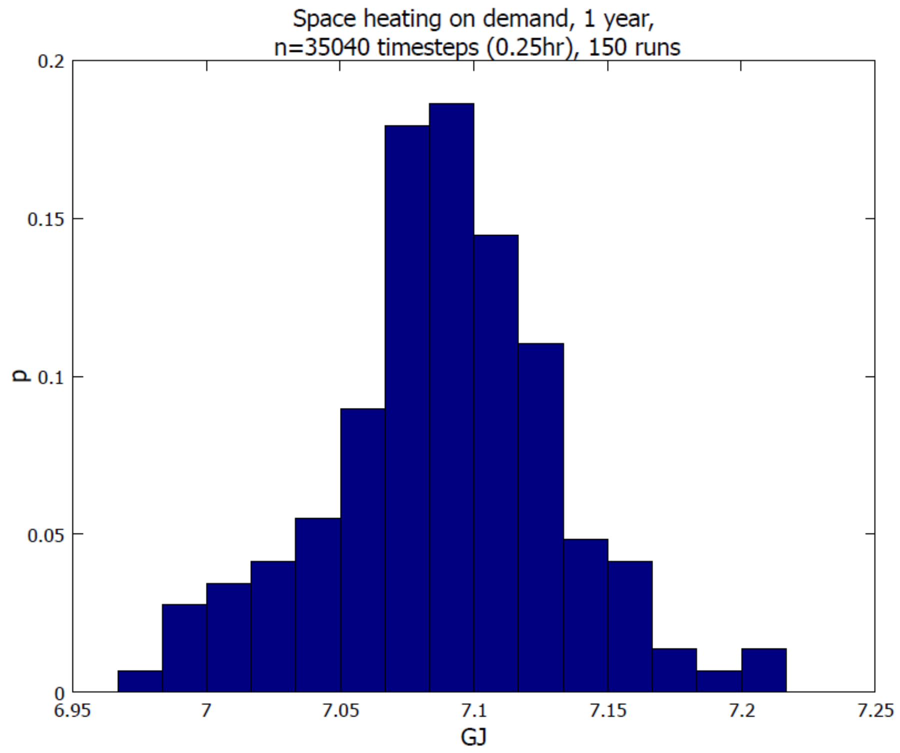
MCMC

Schematic view of MCMC procedure



MCMC results

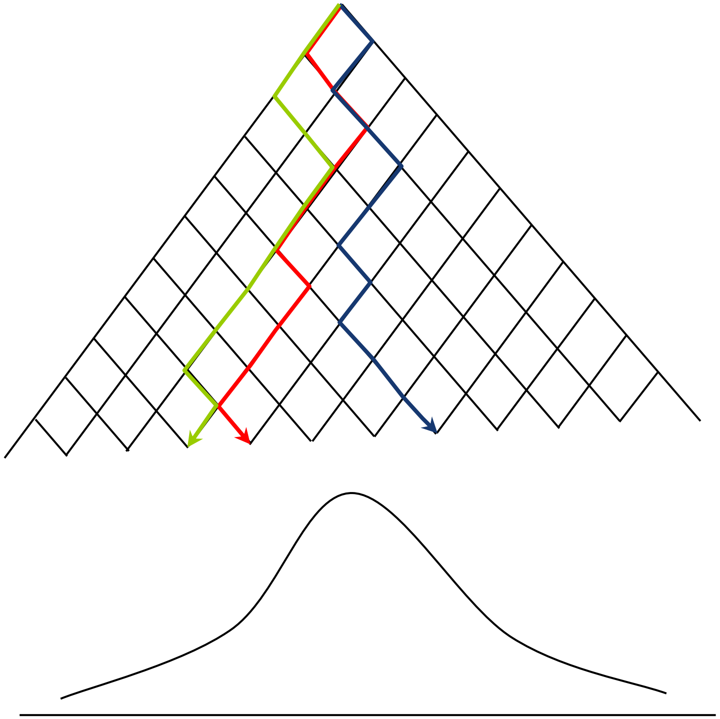
- Energy distribution, 2 working
- Complete year generated stochastically



1. Yearly heating (GJ): 7.0-7.2 GJ

MCMC

- Calculated variation in energy use is very small
- Why? Is this related to the MCMC procedure?
  → Yes



→ Extreme values are unlikely to occur

MCMC

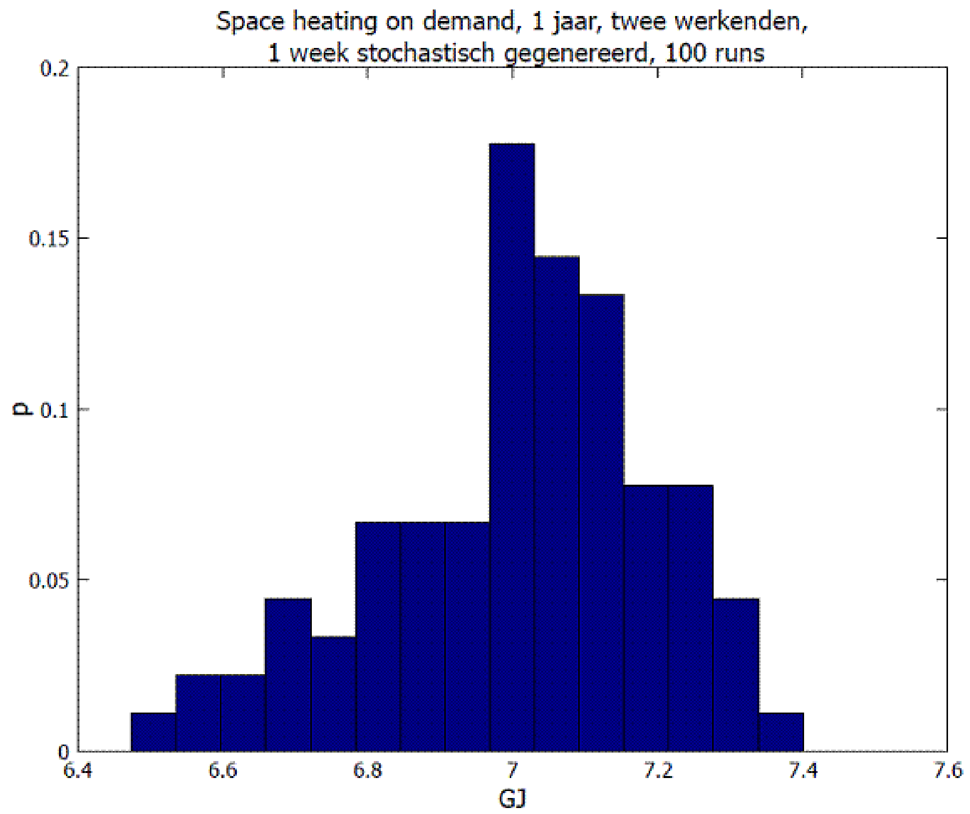
- Extreme occupancy patterns (almost always absent/present) are not likely to be generated by MCMC for a whole year

Solution?

- → generate occupancy for one week only and use this 52x for a whole year?

MCMC results

- One week generated stochastically, used 52X
- 2 working



1. Yearly heating: 7.0-7.2 GJ
2. Yearly heating: 6.5-7.4 GJ

No MCMC?

- The calculated variation in energy use has increased but is still not large
- Solution: → No MCMC?

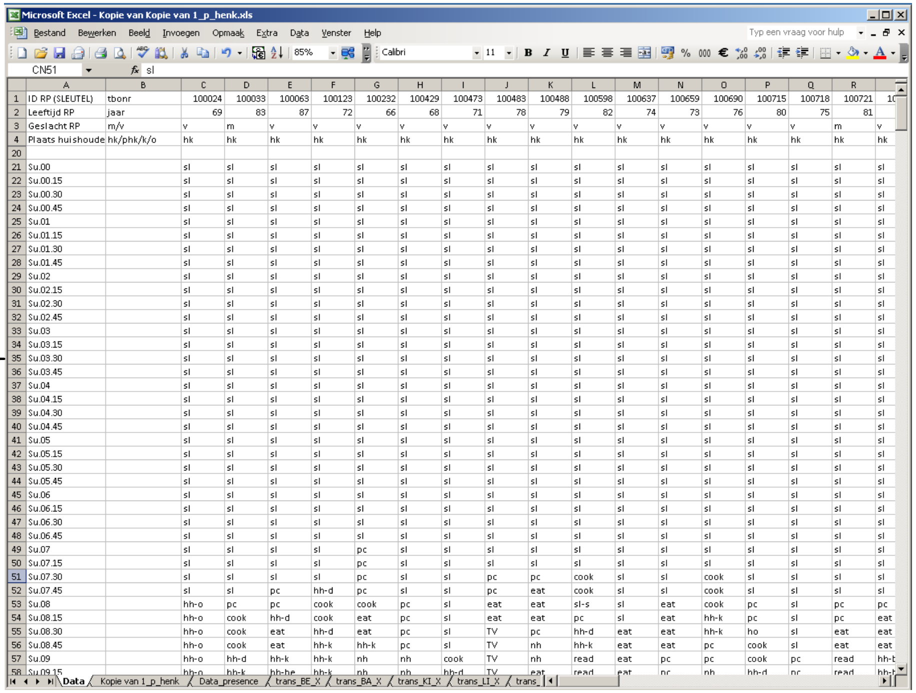
Transition probabilities in the Markov-Chain are based on occupancy patterns of 100-150 different people. → variation in occupancy will be averaged out in MCMC

Monte Carlo run for deterministic profiles?

- Randomly combine deterministic occupancy profiles.
- Do this several times
- Analyze variation in energy use

Approach

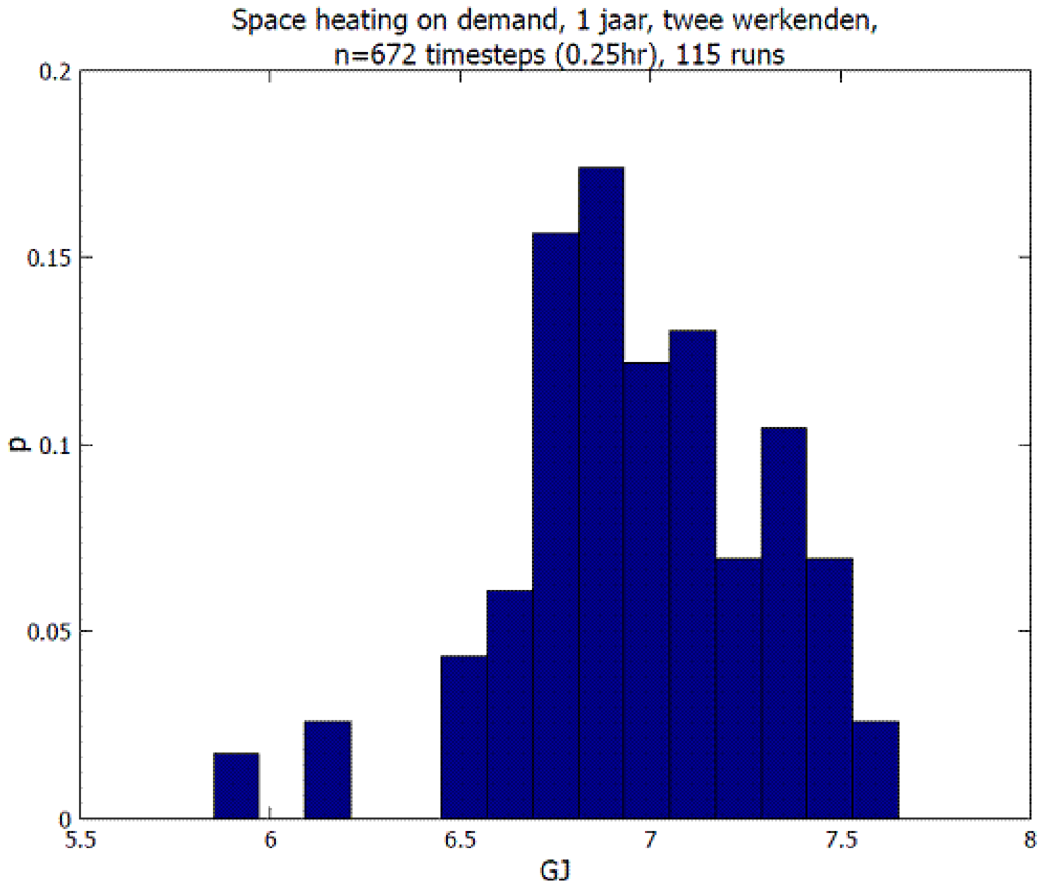
<u>Selection criteria</u>
-Household size
-Age
-Health
-Life style
-etc



Input dataset for deterministic calculations

Monte Carlo run for profiles

- Deterministic profiles have been sampled repeatedly
- 2 working



1. Yearly heating: 7.0-7.2 GJ
2. Yearly heating: 6.5-7.4 GJ
3. Yearly heating: 5.7-7.6 GJ

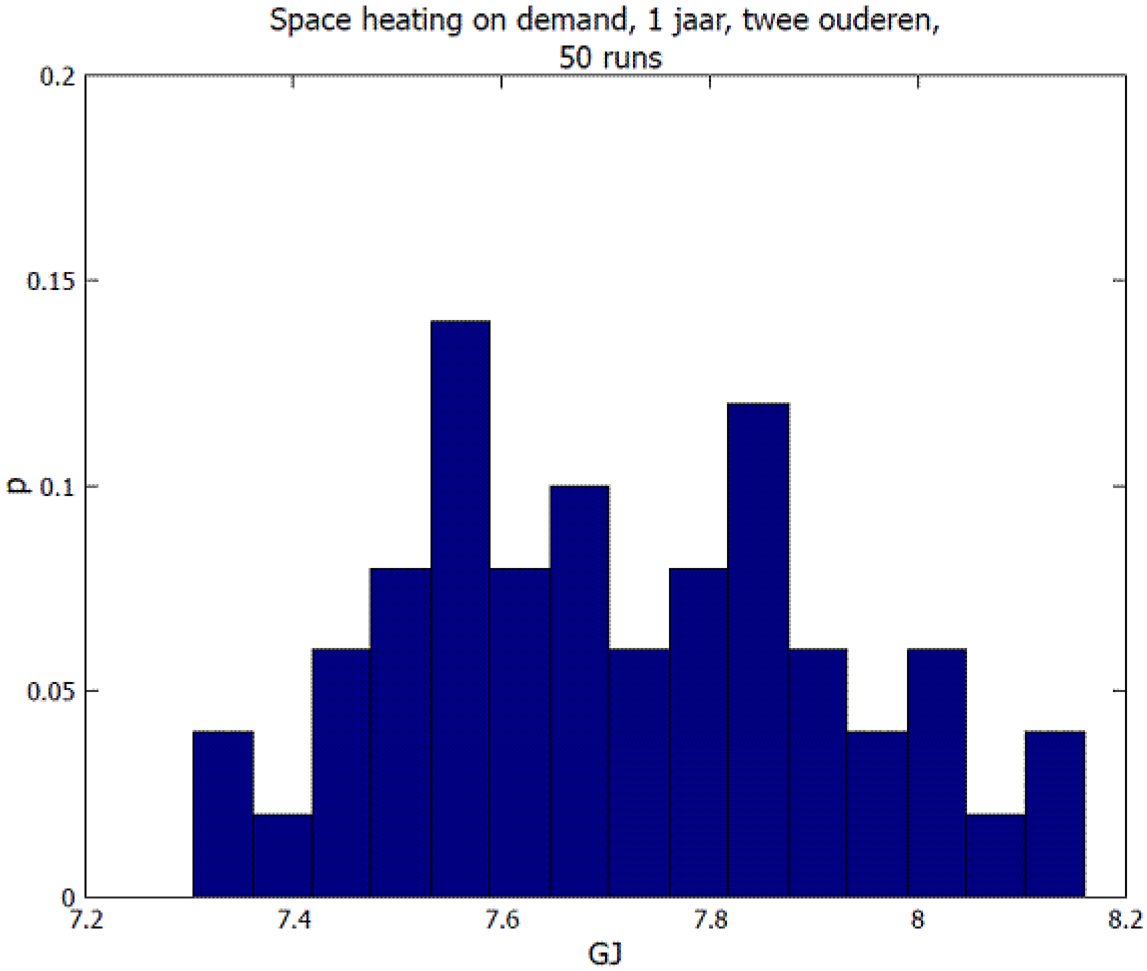
Monte Carlo run for profiles

- The calculated variation in energy use has increased
- These values make more sense

- Apply this procedure also to “2 retired persons” and “families”

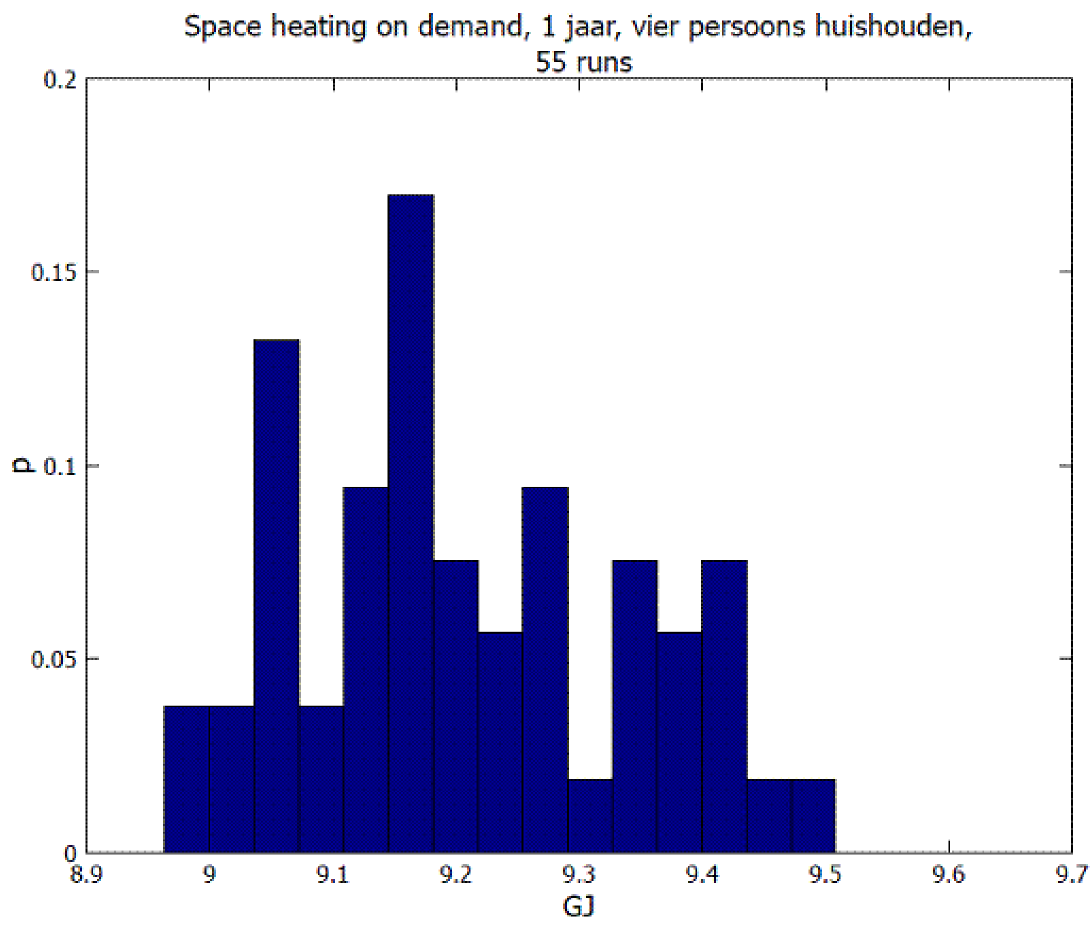
Monte Carlo run for profiles

- Deterministic profiles have been sampled repeatedly
- 2 aged people



Monte Carlo run for profiles

- Deterministic profiles have been sampled repeatedly
- Families (4p.)



Results

- Variation in heating energy

dwelling	occupancy	Yearly heating (GJ)
Single-family	2 working	5.8 – 7.7
Single-family	2 retired	7.4 – 8.2
Single-family	4p. family	9.0 – 9.5

MCMC

Schematic view of MCMC procedure

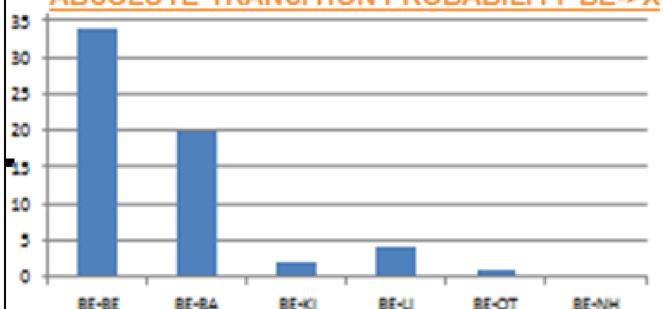
DATA

- **Kind of Apartment**: single-family dwelling
- **# tot. Persons**: 102
- **# tot. Active Persons**: 61
- **Places**: bed/ bath/ kitch/ living/ other/ nh
- **Places Code**: BE/ BA/ KI/ LR/ OT/NH
- **Time schedule**: the first week of January
- **Time**: 08:00 A.M.

OCCUPANCY TRANSITION MATRIX

BE-BE	BE-BA	BE-KI	BE-LR	BE-OT	BE-NH
BA-BE	BA-BA	BA-KI	BA-LR	BA-OT	BA-NH
KI-BE	KI-BA	KI-KI	KI-LR	KI-OT	KI-NH
LR-BE	LR-BA	LR-KI	LR-LR	LR-OT	LR-NH
OT-BE	OT-BA	OT-KI	OT-LR	OT-OT	OT-NH
NH-BE	NH-BA	NH-KI	NH-LR	NH-OT	NH-NH

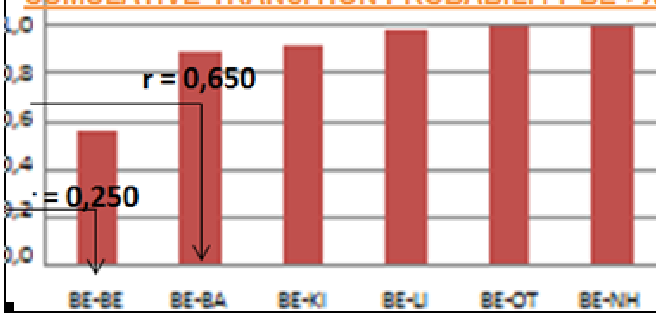
ABSOLUTE TRANSITION PROBABILITY BE->X



OCCUPANCY TRANSITION MATRIX (BE)

	34	20	2	4	1	0
TRANSITION PROBABILITY	0,557	0,328	0,033	0,066	0,016	0,000
	0,557	0,885	0,918	0,984	1,000	1,000

CUMULATIVE TRANSITION PROBABILITY BE->X

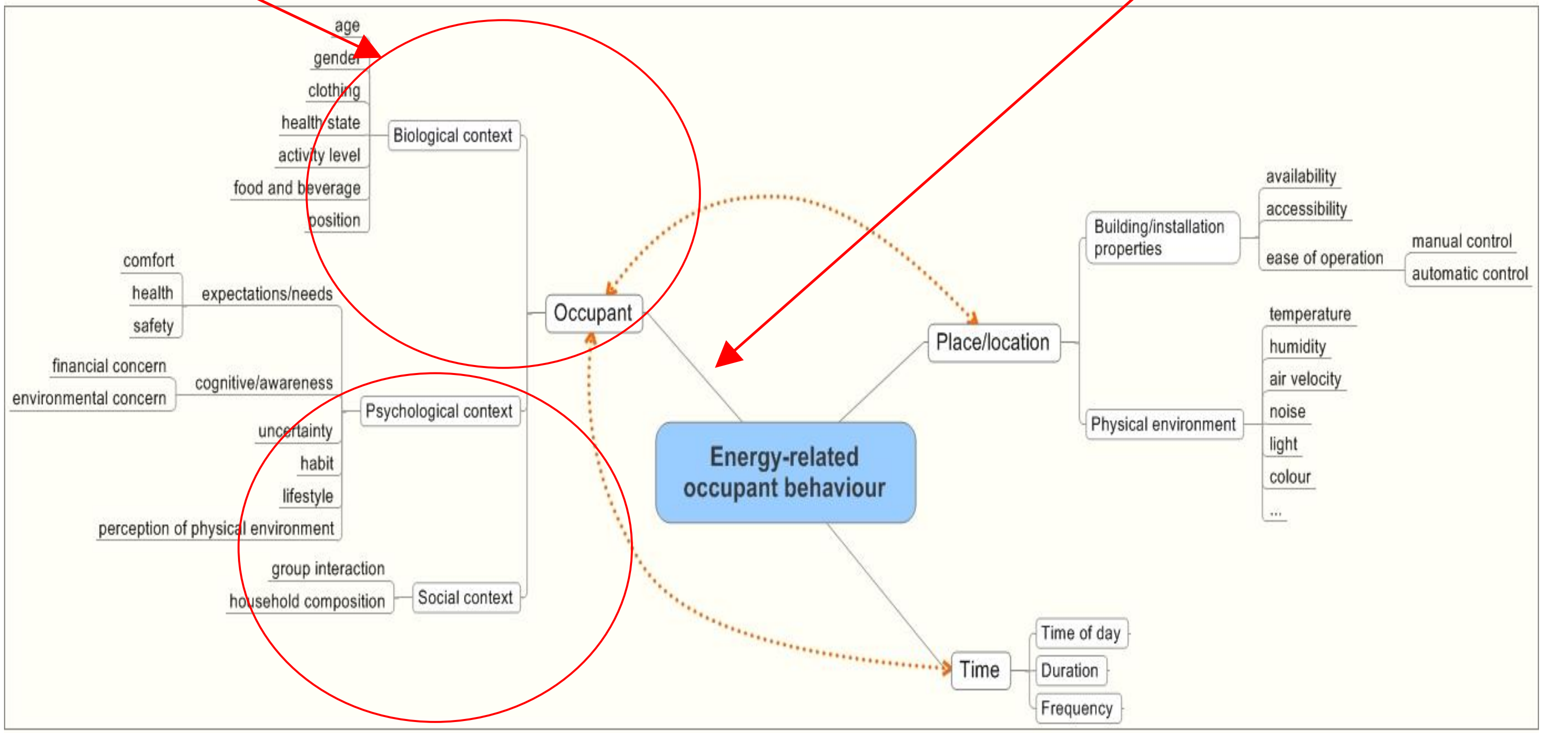


RANDOM NUMBER 0 < r < 1

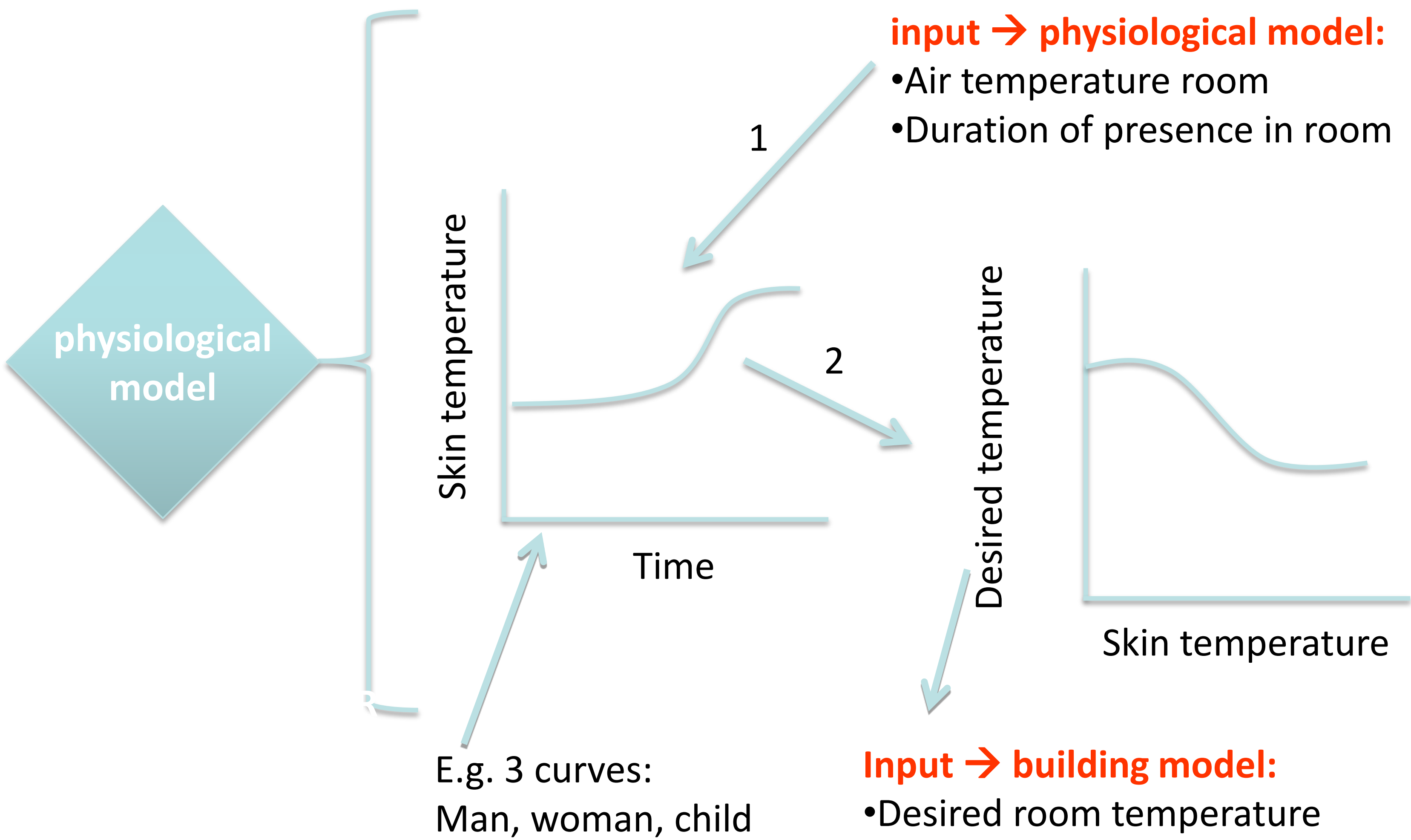
	r <	0,557		55,7%	Be-Be
0,557	< r <	0,885		32,8%	Be-Ba
0,885	< r <	0,918	IN	3,3%	Be-Ki
0,918	< r <	0,984		6,6%	Be-Li
0,984	< r <	1,000		1,6%	Be-Ot
1,000	< r			0%	Be-Nh

Next steps

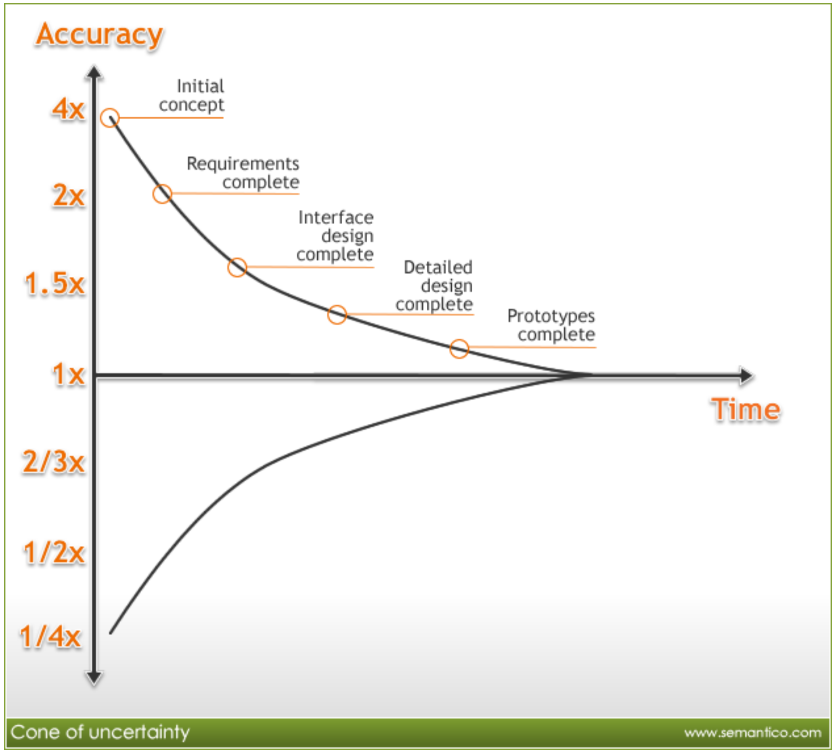
- Coupling occupancy/building model with physiological model and psychological model

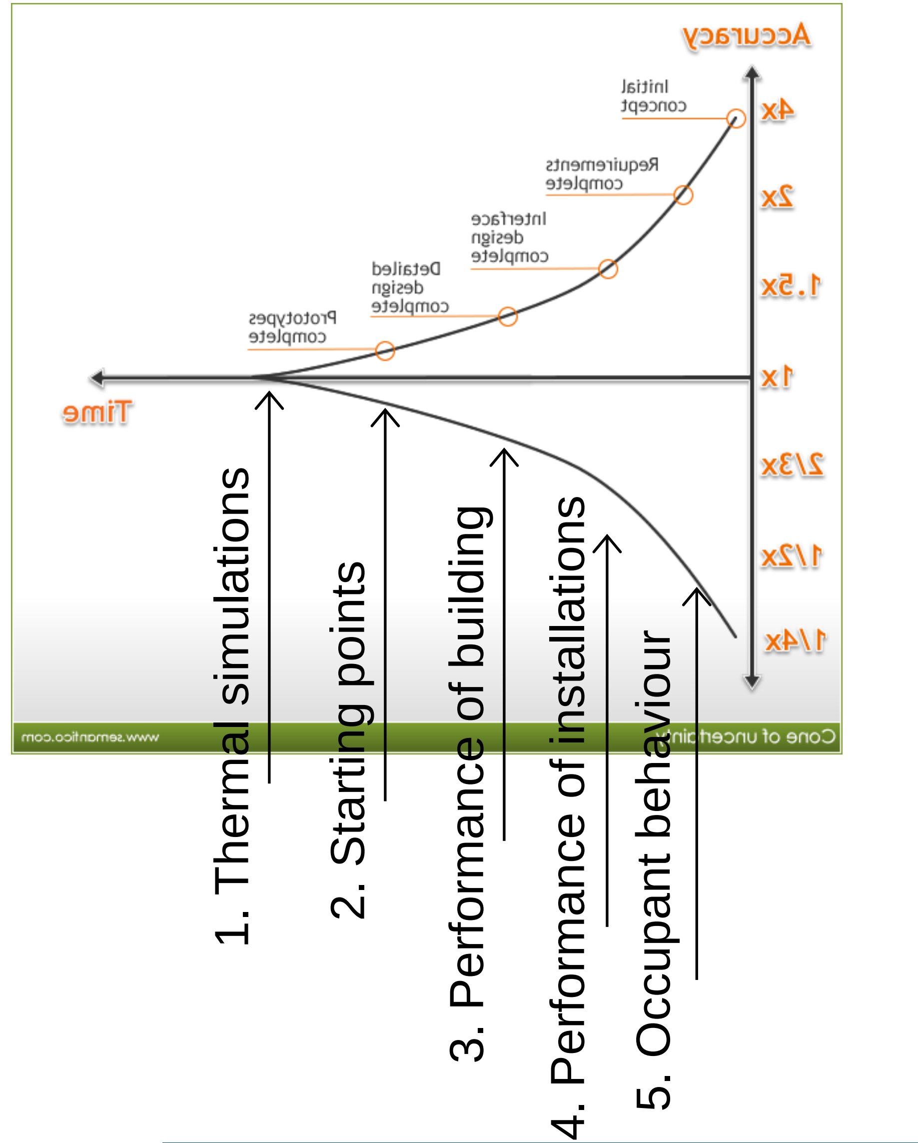


Coupling with physiological model



Cone of uncertainty

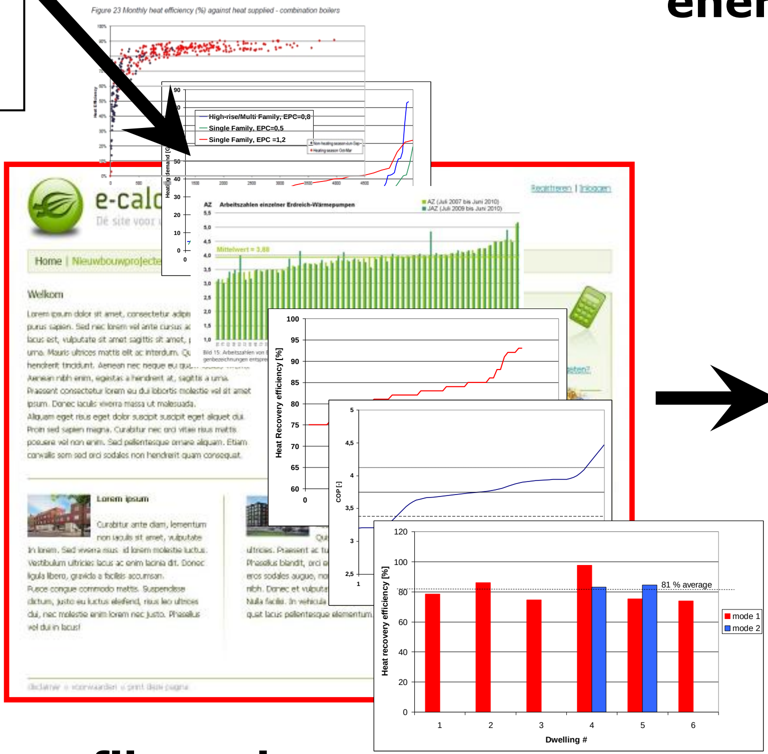




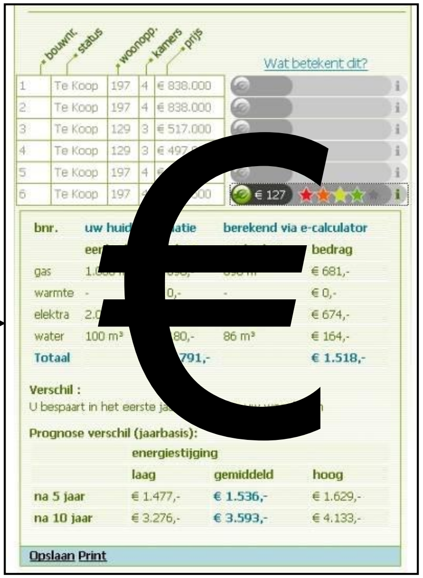
Prediction of the total energy use

Building and installation characteristics

Occupant profile and behaviour



Prediction of real total energy and distribution



From prototype to reality