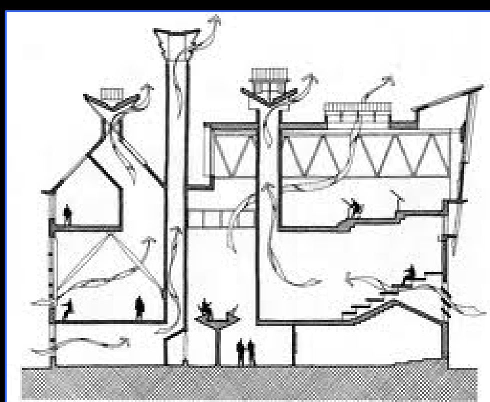
Comfort Performance of Residential Wind Towers in Sydney

Dr Mahsan Sadeghi – University of Sydney ➔ Renson
Dr Graeme Wood – CPP ➔ Arup
Prof Richard de Dear – University of Sydney

WIND TOWER COOLING SYSTEM IN VERNACULAR ARCHITECTURE

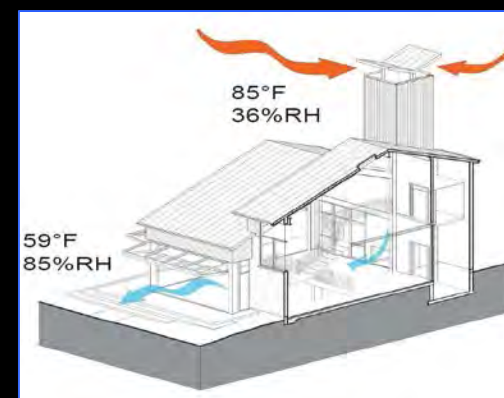
The wind tower (a.k.a. *baudgir* or wind catcher in Persian) has been used as a passive cooling system throughout Persia and neighbouring countries since 1300 BC (Roaf, 1988)

WIND TOWER IN CONTEMPORARY ARCHITECTURE



Queen's building at De Montfort University, UK
Source: http://walkingarchitecture.co.uk

Jubilee Campus at Nottingham University, UK
Source: http://newsofthesouth.com



Carnegie Centre for Ecology in Stanford University, USA
http://www.carboun.com/tag/wind-tower

RESEARCH CONTRIBUTION

- Most previous researchers have used the wind tunnel method to study wind tower ventilation impact on a single room, ignoring effects of…
  - Whole building
  - urban context
- Previous research has used indoor air change rate or air speed as dependent variable, ignoring impacts on occupant thermal comfort
- To date no wind tower research has been done in Australian residential context

RESEARCH QUESTIONS

- Can wind towers provide thermal comfort benefits in the humid sub-tropical Australian metropolitan residential context?
- How does the pressure difference generated by the wind tower ventilation translate into air movement within the occupied zone of a medium density apartment?
- How do the comfort benefits of a wind tower compare with conventional through-window cross ventilation?

RESEARCH METHODS

Wind Tunnel Experiments

- 1- Pressure distribution measurement over the building
- 2- calculating the pressure coefficient differences between the openings (in/out)
- 3- Calculating the indoor air movement

Case Study Sydney

- 1- applying Sydney 2013 TMY file into the wind tunnel analyses
- 1- Calculating the velocity coefficient based on outdoor wind speed and direction
- 2- Calculation indoor air speed hourly in 6 hot/warm months

Indoor Thermal Comfort Analyses

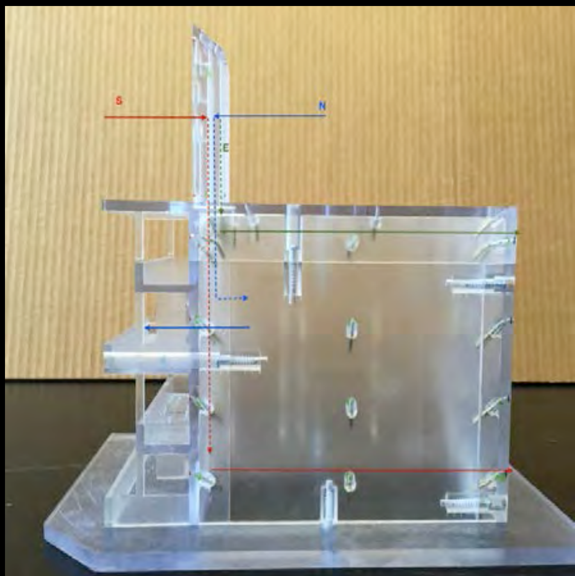
- 1- SET* simulation hourly for six hot/warm months of the 2013 year
- 2- calculating ΔSET* as the impact of the increased Vi in compare with the cross ventilation
- 3- Calculation of indoor thermal comfort improvement in degree hours

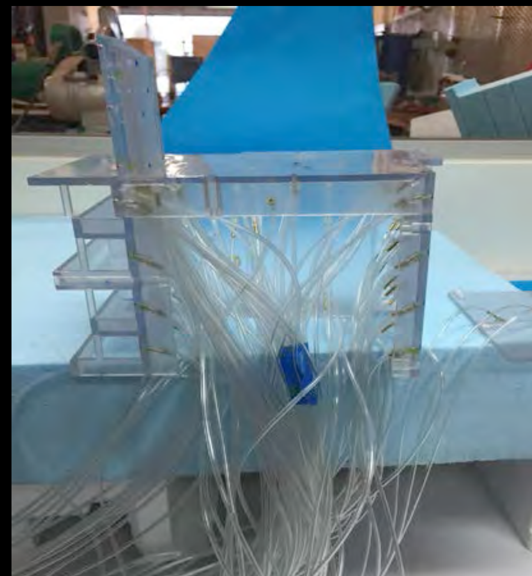
Apartment Building Design

Climate Change Adaptation Research Facility (NCCARF, 2013)

The apartment building design adopted in this study is typical of the medium–density apartment development being widely forecast to increase in popularity in many Australian cities by 2030 (NCCARF, 2013).

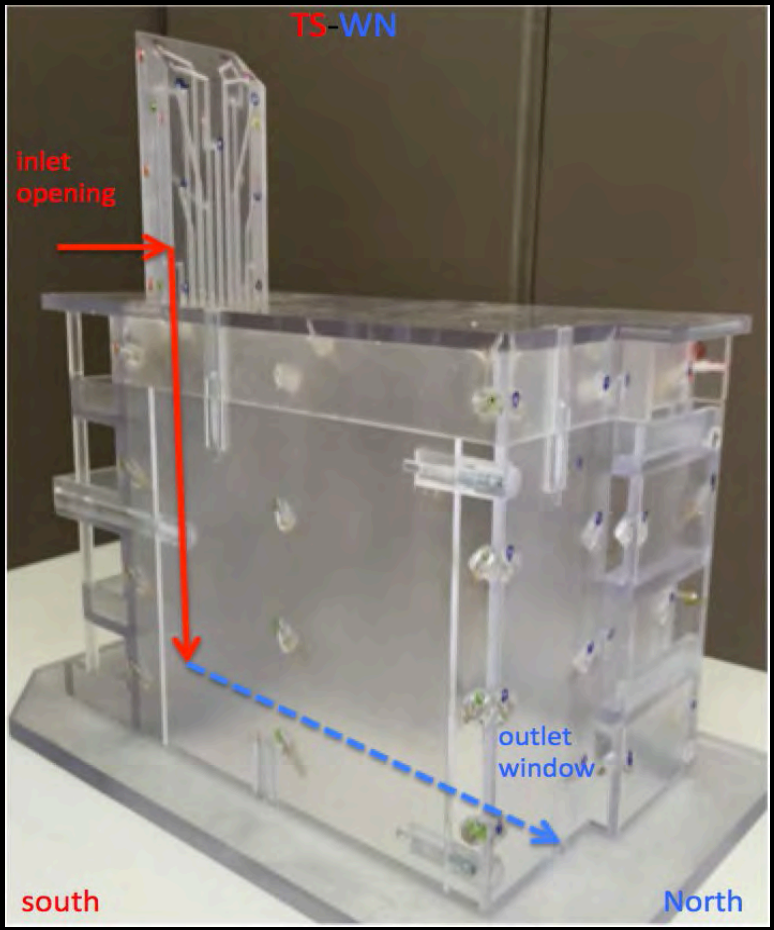
WIND TUNNEL SET UP WITH SCALE MODEL

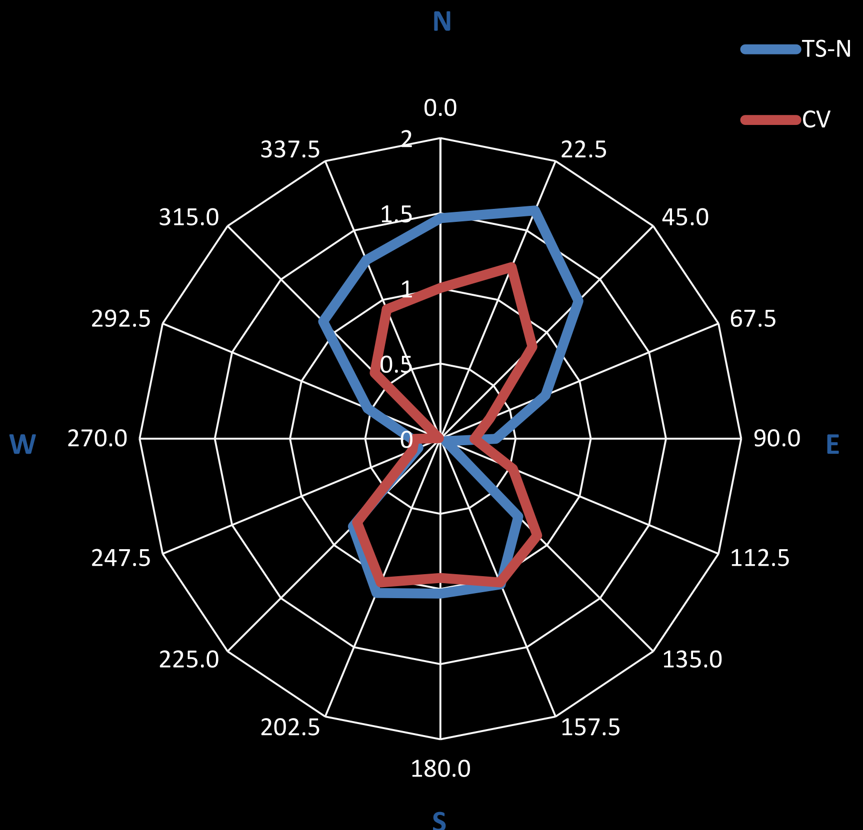




Sealed model at 1:100 scale with 299 pressure taps spread over 5 facades

Mean pressure coefficient difference, ΔCP (n.d.) across the openings





Average pressure coefficient difference between tower openings in south the building windows in north facade (TS-N) compared with the window cross ventilation(CV)

DERIVATION OF MEAN INDOOR AIR SPEED

Air changes per hour

- ACH = $\sqrt{\Delta Cp}$ * Ve * Ao/Volume / $\sqrt{\text{total energy loss coefficient}}$ * 3600

Airflow rate per hour (m^3/h)

- Air changes per hour * room volume

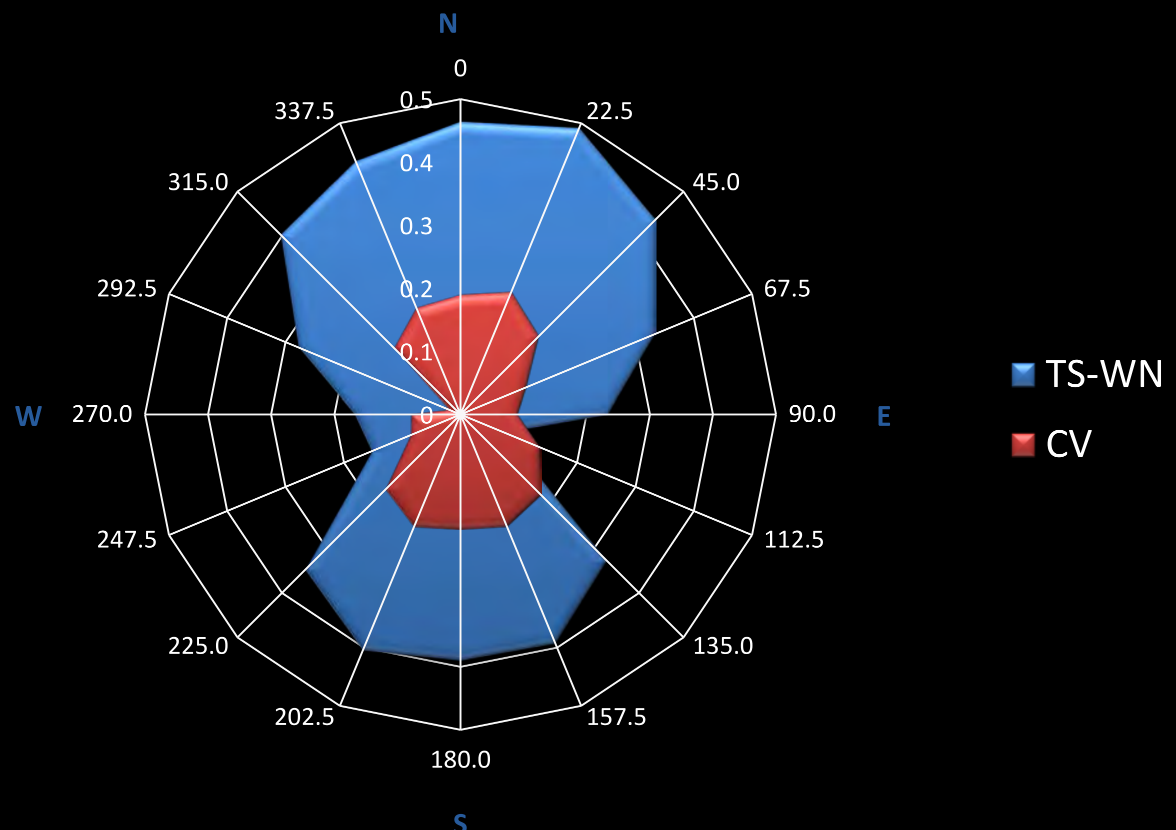
Indoor Air Speed (m/s)

- Vi = airflow/3600/Ar

where,
ΔCp = pressure coefficient differential (n.d.)
Ve = mean exterior velocity at building height (m/s)
Ao = area of openings on windward building façade (m)
Total Energy Loss coefficient= entry loss + exit loss + bend losses + friction loss (n.d.)
Vi = indoor air speed (m/s)
Ar = Room cross-sectional area (m^2)

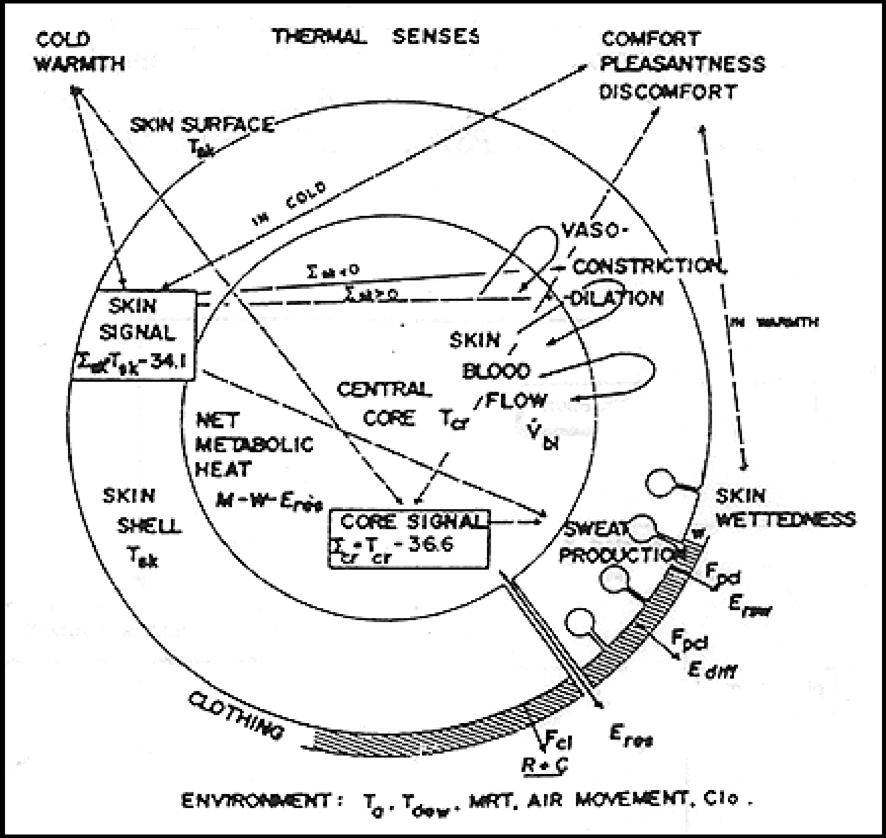
Air speed (m/s) within the occupied zone

- Most conservative design in first floor
- Tower opening 3 m^2
- Tower opening height: 0.75 m over roof in center (shortest height)



Mean indoor air speed in Jan 2013 via wind tower south opening & north window(TS-WN)
Benchmarked against through-window ventilation (CV)

CALCULATING COMFORT BENEFITS OF INCREASED INDOOR AIR MOVEMENT



Gagge, Nishi *et al.*'s 2-node model and Standard Effective Temperature (SET*)

Inputs include…

- Air temperature
- Mean radiant temperature
- Humidity
- Air speed
- Clo
- Met

RESULT AND DISCUSSION

THERMAL COMFORT ANALYSES, SET*

Aim: To evaluate thermal comfort benefits of increased indoor air speed generated by wind tower on thermal comfort (6 warmest months)

- Outdoor air temperature & humidity: TMY 2013
- Operative temperature: EnergyPlus simulations
- Metabolic rate: assumed 1.1 met
- Clothing: assumed 0.5 clo (typical summer residential)
- Indoor air speed: simulated wind tunnel analyses

- Cooling potential of the wind tower $\Delta SET^* = (SET^*_{cv}) - (SET^*_{wt})$

- Hourly indoor SET* for the six hot/warm months, In wind tower ventilation & cross ventilation modes

- $\Sigma\Delta SET^*$ = 1,726 degree hours free cooling compared to the through-window cross ventilation

CONCLUSION

- Wind towers represent an ancient yet still useful passive comfort technology
- They can source ***more*** and ***healthier ventilation air*** beyond the polluted urban canyon
- They represent a **zero carbon**, ***healthy comfort*** alternative to the current default option of mechanical cooling solution for ventilation in medium density residential developments along busy transport corridors

Recommended criteria for thermal comfort and indoor air quality in International standards (ASHRAE-ISO-CEN)

Professor Bjarne W. Olesen, Ph.D., FASHRAE
bwo@byg.dtu.dk
Society President
International Center for Indoor Environment and Energy
Technical University of Denmark

INDOOR ENVIRONMENT

- THERMAL
- AIR QUALITY
- ACOUSTIC
- LIGHT

EVALUATION OF THE INDOOR ENVIRONMENT

- DESIGN LEVEL
- COMMISSIONING
- TESTING
- COMPLAINTS

STANDARDS

- **ISO EN 7730-2005**
  - Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort effects.
- **ASHRAE 55-2016**
  - Thermal environment conditions for human occupancy
- **ASHRAE 62.1 and 62.2 -2016**
  - Ventilation and indoor air quality
- **EN15251**
  - Indoor environmental input parameters for design and assessment of energy performance of buildings- addressing indoor air quality, thermal environment, lighting and acoustic
- **EN 13779**
  - Ventilation for non-residential buildings - performance requirements for ventilation and room-conditioning systems

International Standards
Indoor Environmental Quality

- **prEN16798-1 and ISO 17772-1:**
  - Indoor environmental input parameters for the design and assessment of energy performance of buildings.
- **TR16798-2 and ISO TR 17772-2:**
  - Guideline for using indoor environmental input parameters for the design and assessment of energy performance of buildings.
- **EN 16798-3 and TR 16798-4**
  - Ventilation for non-residential buildings - performance requirements for ventilation and room-conditioning systems

MODERATE ENVIRONMENTS

- GENERAL THERMAL COMFORT
  - PMV / PPD, OPERATIVE TEMPERATURE
- LOCAL THERMAL DISCOMFORT
  - Radiant temperature asymmetry
  - Draught
  - Vertical air temperature difference
  - Floor surface temperature

THERMAL COMFORT

- OPERATIVE TEMPERATURE
- $-0,5 < PMV < +0,5$; $PPD < 10$ %
- SPACES WITH MAINLY SEDENTARY OCCUPANTS :
  - SUMMER CLOTHING 0,5 clo
  - ACTIVITY LEVEL 1,2 met
- 23 °C < t_o < 26 °C.

GENERAL THERMAL COMFORT

- Personal factors
  - Clothing
  - Activity
- Environmental factors
  - Air temperature
  - Mean radiant temperature
  - Air velocity
  - Humidity

Categories

Cate-gory	Explanation
I	High level of expectation and also recommended for spaces occupied by very sensitive and fragile persons with special requirements like some disabilities, sick, very young children and elderly persons, to increase accessibility.
II	Normal level of expectation
III	An acceptable, moderate level of expectation
IV	Low level of expectation. This category should only be accepted for a limited part of the year

Recommended categories for design of mechanical heated and cooled buildings

Category	Thermal state of the body as a whole	
	PPD %	Predicted Mean Vote
I	< 6	-0.2 < PMV < + 0.2
II	< 10	-0.5 < PMV < + 0.5
III	< 15	-0.7 < PMV < + 0.7
III	< 25	-1.0 < PMV < + 1.0

Evaluation standard for indoor thermal environment in civil buildings Chinese standard

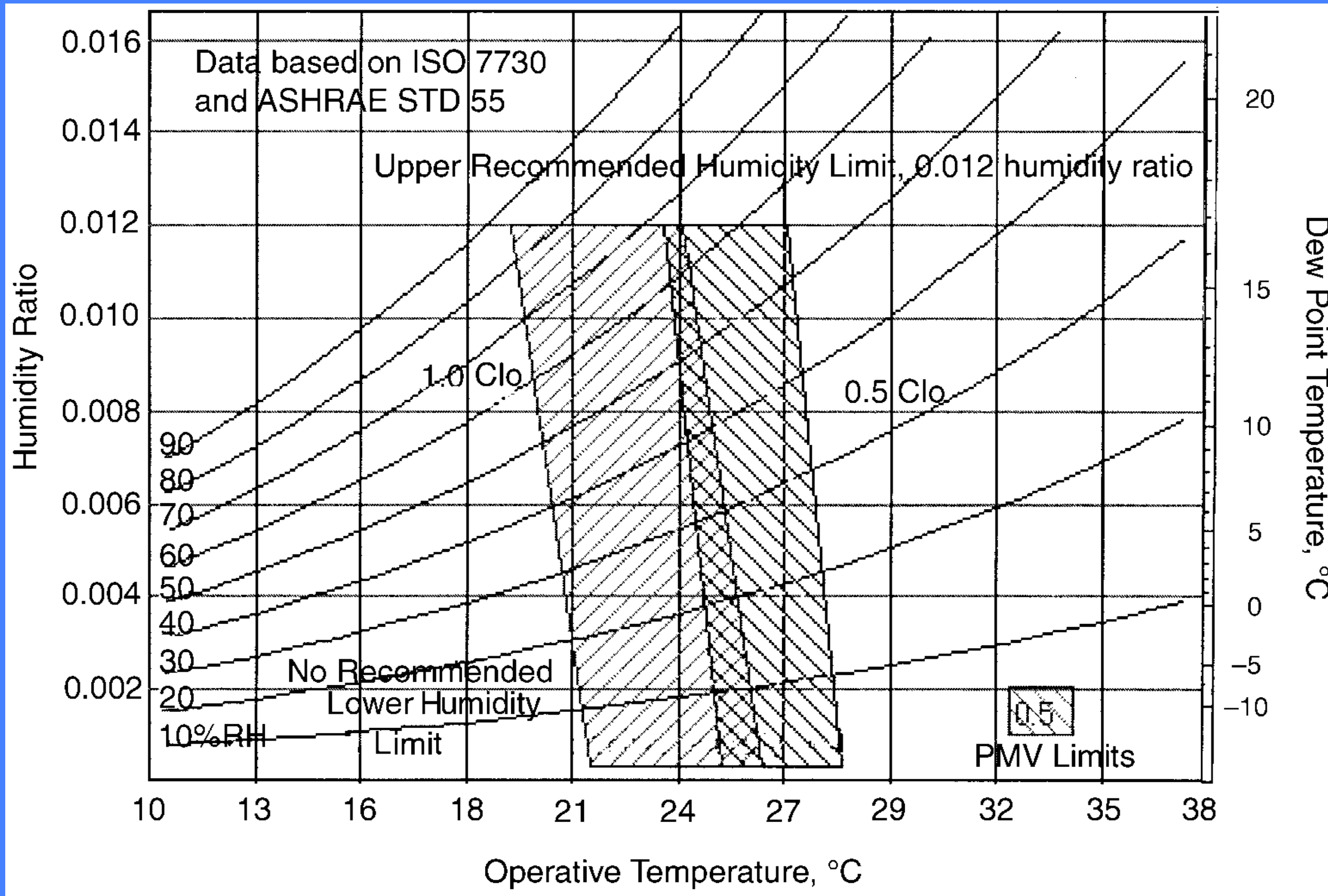
Table 4.2.4-1 overall thermal comfort index value

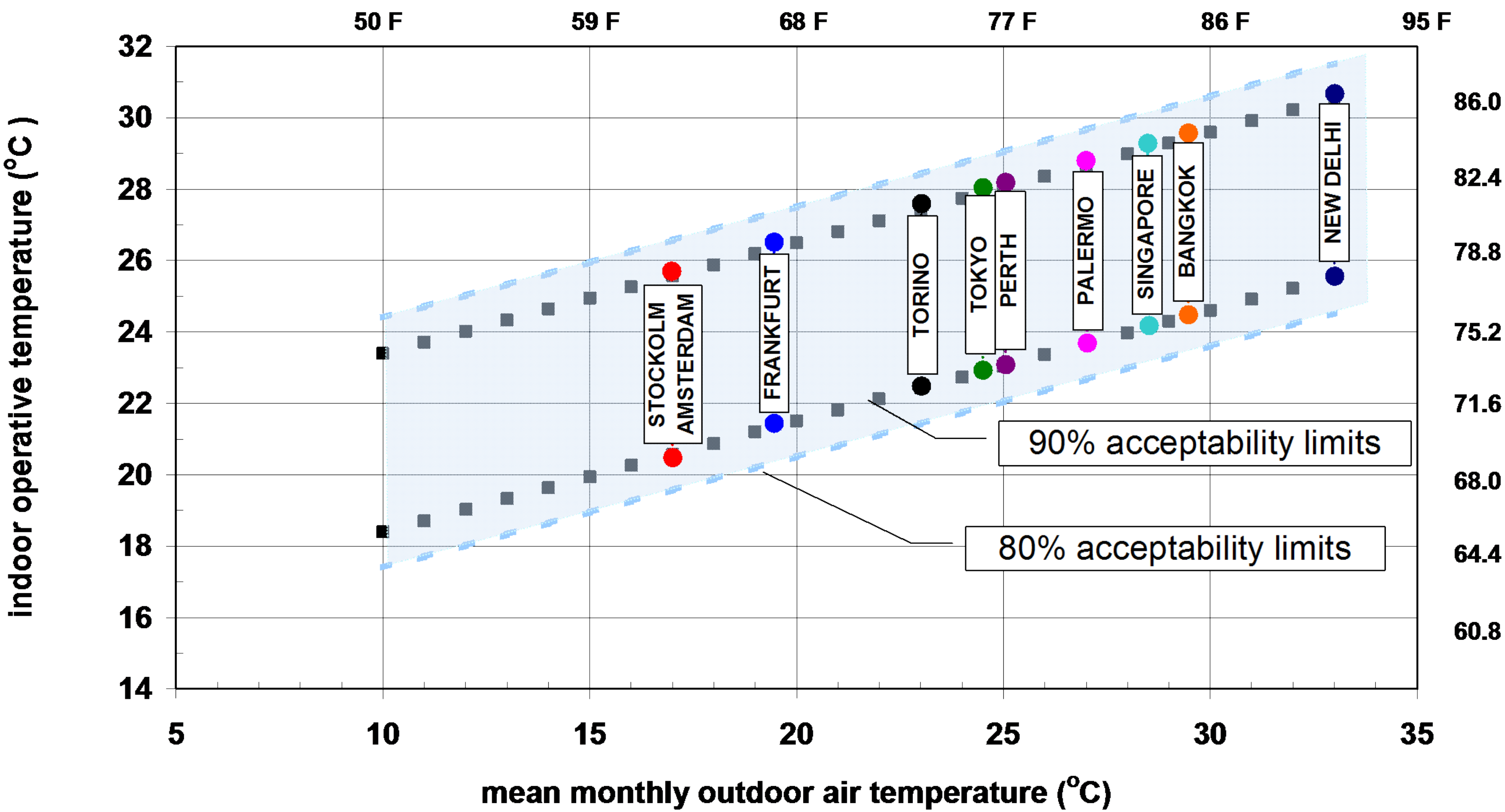
Grade	Overall thermal comfort index	
I	PPD≤10 %	-0.5≤PMV≤+0.5
II	10%<PPD≤25 %	-1≤PMV<-0.5or+0.5<PMV≤+1
III	PPD>25%	PMV<-1 or PMV>+1

Temperature ranges for hourly calculation of cooling and heating energy in three categories of indoor environment

Type of building/ space	Category	Operative Temperature for Energy Calculations °C	
		Heating (winter season), ~ 1,0 clo	Cooling (summer season), ~ 0,5 clo
Offices and spaces with similar activity (single offices, open plan offices, conference rooms, auditorium, cafeteria, restaurants, class rooms, Sedentary activity ~1,2 met	I	21,0 – 23,0	23,5 - 25,5
	II	20,0 – 24,0	23,0 - 26,0
	III	19,0 – 25,0	22,0 - 27,0
	IV	17,0 – 26,0	21,0 - 28,0

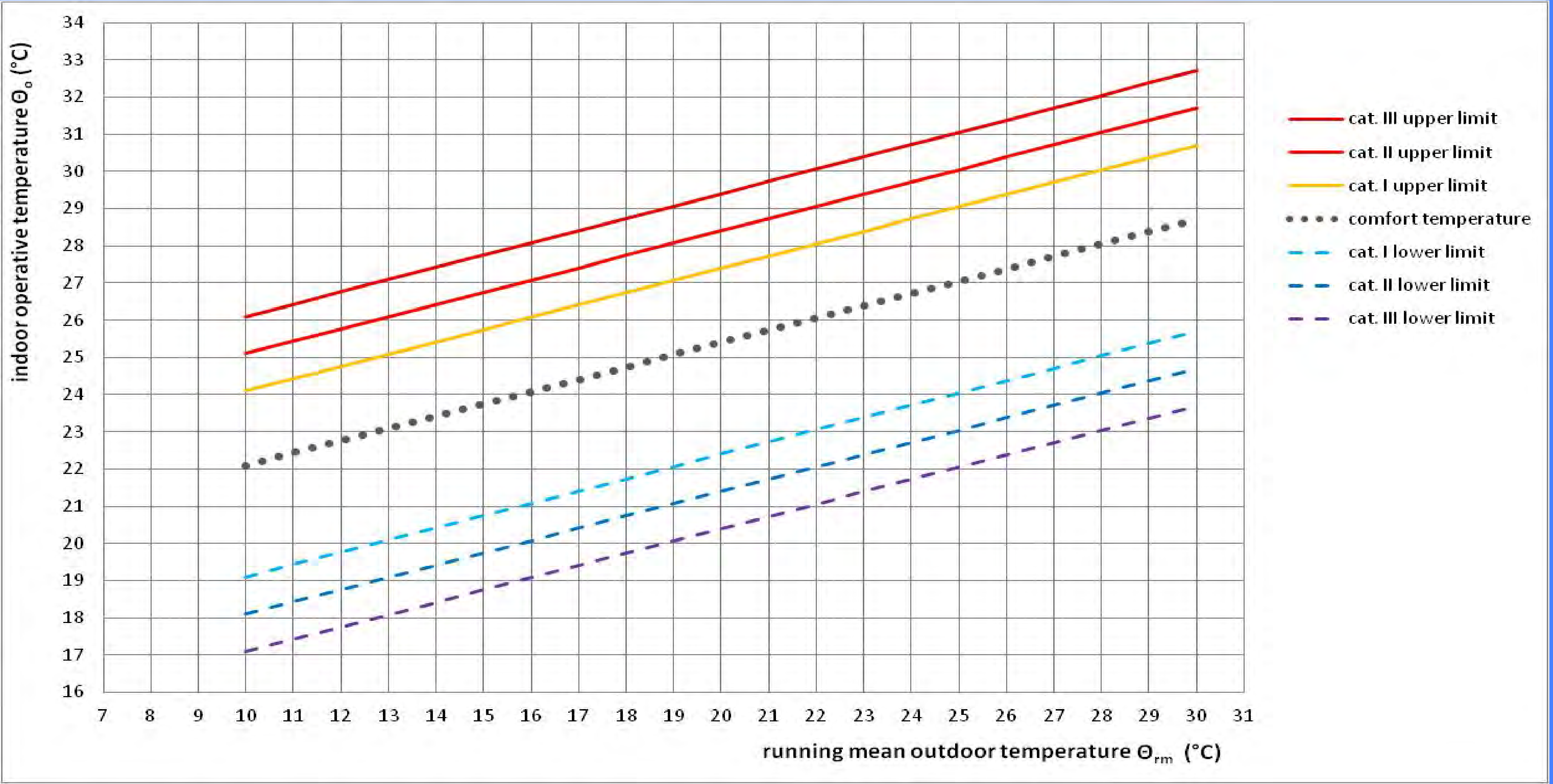
Humidity limits according to ASHRAE-55-2016





50 F
59 F
68 F
77 F
86 F
95 F
32
30
28
26
24
22
20
18
16
14
86.0
82.4
78.8
75.2
71.6
68.0
64.4
60.8
indoor operative temperature (°C)
STOCKOLM
AMSTERDAM
FRANKFURT
TORINO
TOKYO
PERTH
PALERMO
SINGAPORE
BANGKOK
NEW DELHI
90% acceptability limits
80% acceptability limits
5
10
15
20
25
30
35
mean monthly outdoor air temperature (°C)

ISO DIS 17772-1



$$\Theta_{rm} = (\Theta_{ed\,-1} + 0{,}8\ \Theta_{ed\,-2} + 0{,}6\ \Theta_{ed\,-3} + 0{,}5\ \Theta_{ed\,-4} + 0{,}4\ \Theta_{ed\,-5} + 0{,}3\ \Theta_{ed\,-6} + 0{,}2\ \Theta_{ed\,-7})/3{,}8$$

Natural ventilated buildings- without mechanical cooling

- activity levels lie most of the time in the range of 1,2 - 1,6 met
- clothing insulation can be varied according to momentary preferences from 0,5 to 1,0 clo
- access to operable windows
- less than 4 persons per room
- such as dwellings and office buildings.

GENERAL THERMAL COMFORT

- AIR VELOCITY
  - Draught
  - Preferred air velocity at increased temperature
  - Direction of air velocity
  - Large individual differences
  - Personal control (fans, windows)

ASHRAE 55-2016

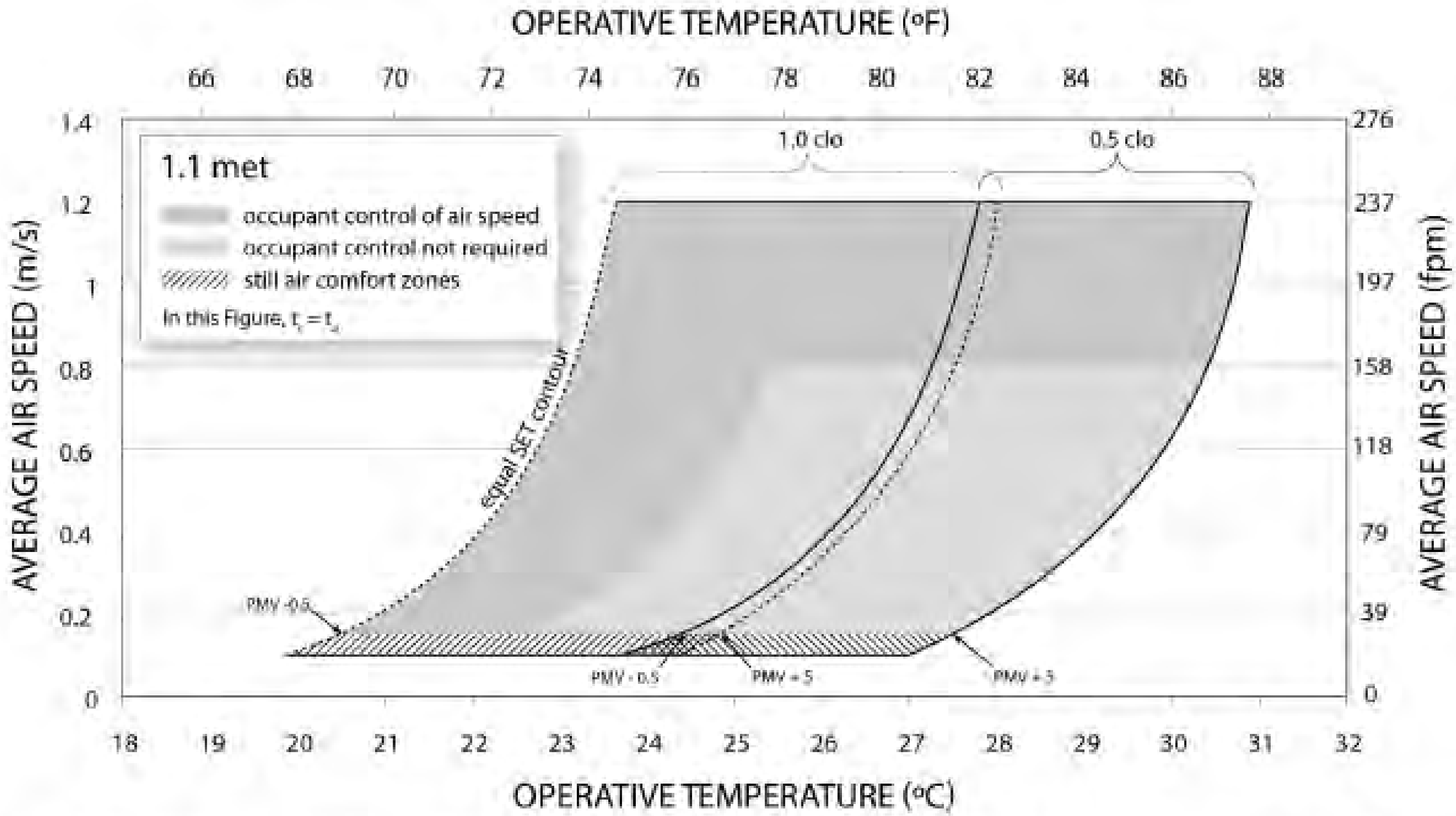


FIGURE 5.3.3A Acceptable ranges of operative temperature (t_o) and average air speed (V_a) for the 1.0 and 0.5 clo comfort zone presented in Figure 5.3.1.1, at humidity ratio 0.010.

LOCAL THERMAL DISCOMFORT

- FLOOR SURFACE TEMPERATURE
- VERTICAL AIR TEMPERATURE DIFFERENCE
- DRAUGHT
- RADIANT TEMPERATUR ASYMMETRI

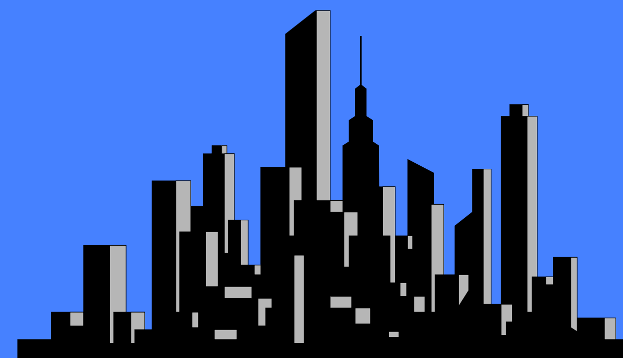
CRITERIA FOR INDOOR AIR QUALITY ~VENTILATION RATES

- COMFORT (Perceived Air Quality)
- HEALTH
- PRODUCTIVITY
- ENERGY

Concept for calculation of design ventilation rate

People Component

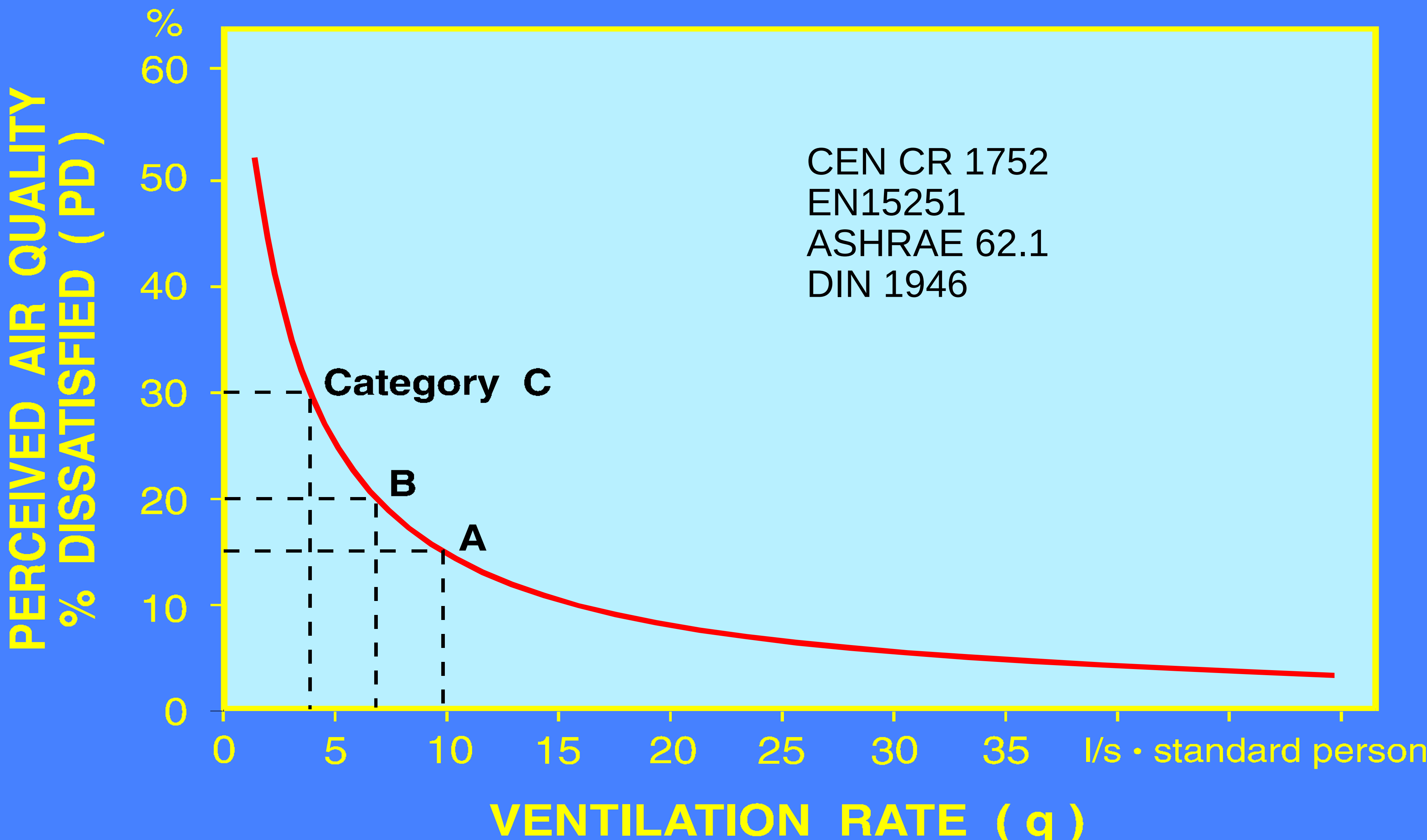
Building Component



Breathing Zone Outdoor Airflow

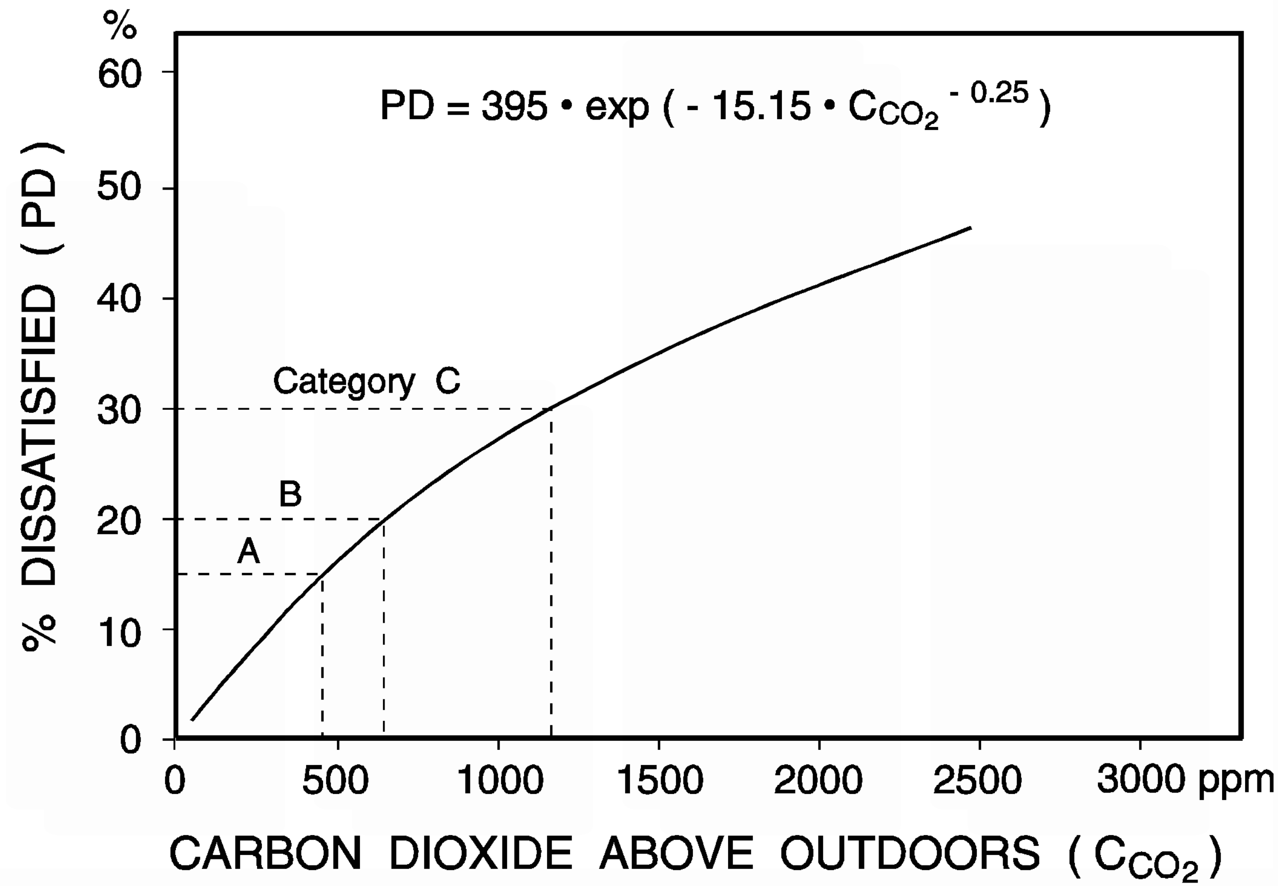
$$V_{bz} = R_p P_z + \sout{R_s S_d} + R_a A_z$$

- R_p: Minimum l/s/Person
- P_z: Number of People
- ~~R_s: Ventilation per Smoker~~
- ~~S_d: Number of Smokers~~
- R_a: Minimum l/s/m²
- A_z: Building Area



PERCEIVED AIR QUALITY
% DISSATISFIED (PD)
%
60
50
40
30
20
10
0
CEN CR 1752
EN15251
ASHRAE 62.1
DIN 1946
Category C
B
A
0
5
10
15
20
25
30
35
l/s • standard person
VENTILATION RATE (q)

CO2 as reference



ASHRAE 62.1

TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p	Area Outdoor Air Rate R_a	Notes	Default Values		Air Class
				Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)	
	cfm/person	cfm/ft^2		#/1000 ft^2	cfm/person	
Office Buildings						
Office space	5	0.06		5	17	1
Reception areas	5	0.06		30	7	1

MINIMUM VENTILATION RATES IN BREATHING ZONE

						Default Values		
Occupancy Category	People Outdoor Air Rate R_P		Area Outdoor Air Rate R_A		Notes	Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)	
	cfm/person	L/s•person	cfm/ft^2	L/s•m^2		#/1000 ft^2 (#/100 m^2)	cfm/person	L/s•person
Correctional								
Cell	5	2.5	0.12	0.6		25	10	4.9
Day room	5	2.5	0.06	0.3		30	7	3.5
Guard stations	5	2.5	0.06	0.3		15	9	4.5
Booking/waiting	7.5	3.8	0.06	0.3		50	9	4.4
Educational Facilities								
Daycare (through age 4)	10	5	0.18	0.9		25	17	8.6
Classrooms (ages 5-8)	10	5	0.12	0.6		25	15	7.4
Classrooms (age 9 plus)	10	5	0.12	0.6		35	13	6.7
Lecture classroom	7.5	3.8	0.06	0.3		65	8	4.3
Lecture hall (fixed seats)	7.5	3.8	0.06	0.3		150	8	4.0
Art classroom	10	5.0	0.18	0.9		20	19	9.5

Basic required ventilation rates for diluting emissions (bio effluents) from people for different categories

Category	Expected Percentage Dissatisfied	Airflow per non-adapted person l/(s.pers)
I	15	10
II	20	7
III	30	4
IV	40	2,5*

*The total ventilation rate must never be lower than 4 l/s per person

ASHRAE Standard 62.1 : Adapted persons 2,5 l/s person (Cat. II)

Design ventilation rates for diluting emissions from buildings

Category	Very low polluting building l/(s m^2)	Low polluting building l/(s m^2)	Non low-polluting building l/(s m^2)
I	0,5	1,0	2,0
II	0,35	0,7	1,4
III	0,2	0,4	0,8
IV	0,15	0,3	0,6
Minimum total ventilation rate for health	4 l/s person	4 l/s person	4 l/s person

Example on how to define low and very low polluting buildings

SOURCE	Low emitting products for low polluted buildings	Very low emitting products for very low polluted buildings
Total VOCs TVOC (as in CEN/TS 16516)	< 1.000 µg/m³	< 300 µg/m³
Formaldehyde	< 100 µg/m³	< 30 µg/m³
Any C1A or C1B classified carcinogenic VOC	< 5 µg/m³	< 5 µg/m³
R value (as in CEN/TS16516)	< 1.0	< 1.0

Total ventilation rate

$$q_{tot} = n \cdot q_p + A_R \cdot q_B$$

$$q_{supply} = q_{tot} / \varepsilon_v$$

- Where
- ε_v = the ventilation effectiveness (EN13779)
- q_{supply} = ventilation rate supplied by the ventilation system
- q_{tot}= total ventilation rate for the breathing zone, l/s
- n = design value for the number of the persons in the room,
- q_p = ventilation rate for occupancy per person, l/s, pers
- A_R= room floor area, m^2
- q_B = ventilation rate for emissions from building, l/s,m^2

Example of design ventilation air flow rates for a single-person office of 10 m^2 in a low polluting building (un-adapted person)

Cate-gory	Low-polluting building l/(s*m^2)	Airflow per non-adapted person l/(s*person)	Total design ventilation air flow rate for the room l/s	l/(s*person)	l/(s* m^2)
I	1,0	10	20	20	2
II	0,7	7	14	14	1,4
III	0,4	4	8	8	0,8
IV	0,3	2,5	5,5	5,5	0,55

Type of building/ space	Occu-pancy person/m²	Cate-gory CEN	Occupants only l/s person		Additional ventilation for building (add only one) l/s·m²			Total l/s·m²	
			ASH-RAE Rp	CEN	CEN low-polluting building	CEN *Non*-low-polluting building	ASH-RAE Ra	CEN Low Pol.	ASH-RAE
Single office (cellular office)	0,1	A	2,5	10	1,0	2,0	0,3	2	0,55
		B		7	0,7	1,4		1,4	
		C		4	0,4	0,8		0,8	
Land-scaped office	0,07	A	2,5	10	1,0	2,0	0,3	1,7	0,48
		B		7	0,7	1,4		1,2	
		C		4	0,4	0,8		0,7	
Confe-rence room	0,5	A	2,5	10	1,0	2,0	0,3	6	1,55
		B		7	0,7	1,4		4,2	
		C		4	0,4	0,8		2,4	

$1\ l/s\ m^2 = 0.2\ cfm/ft^2$

The design *zone outdoor airflow* (*Voz*)

The outdoor airflow that must be provided to the zone by the supply air distribution system, shall be determined in accordance:

$$Voz = Vbz/Ez$$

ASHRAE 62.1

TABLE 6-2
Zone Air Distribution Effectiveness

Air Distribution Configuration	E_z
Ceiling supply of cool air	1.0
Ceiling supply of warm air and floor return	1.0
Ceiling supply of warm air 15°F (8°C) or more above space temperature and ceiling return.	0.8
Ceiling supply of warm air less than 15°F (8°C) above space temperature and ceiling return provided that the 150 fpm (0.8 m/s) supply air jet reaches to within 4.5 ft (1.4 m) of floor level. Note: For lower velocity supply air, E_z= 0.8.	1.0
Floor supply of cool air and ceiling return provided that the 150 fpm (0.8 m/s) supply jet reaches 4.5 ft (1.4 m) or more above the floor. Note: Most underfloor air distribution systems comply with this proviso.	1.0
Floor supply of cool air and ceiling return, provided low- velocity displacement ventilation achieves unidirectional flow and thermal stratification	1.2
Floor supply of warm air and floor return	1.0
Floor supply of warm air and ceiling return	0.7
Makeup supply drawn in on the opposite side of the room from the exhaust and/or return	0.8
Makeup supply drawn in near to the exhaust and/or return location	0.5

HEALTH CRITERIA FOR VENTILATION ISO 17772-1 and prEN16798-1

Minimum 4 l/s/person

Indoor Air Quality Procedure

The required ventilation rate is calculated as:

$$Q = \frac{G}{(C_i - C_o) \cdot E_v}$$ l/s

where G = Total emission rate mg/s

C_i = Concentration limit mg/l

C_o = Concentration in outside air mg/l

E_v = Ventilation effectiveness

EPA Ambient-Air Quality Standards Contaminant	Long Term Concentration Averaging µg/m³	ppm		Short Term Concentration Averaging µg/m³	ppm	
Sulfur dioxide	80	0.03	1 year	365[a]	0.14[a]	24 hours
Particles (PM 10)	50[b]	—	1 year	150[a]	—	24 hours
Carbon monoxide				40,000[a]	35[a]	1hour
Carbon monoxide				10,000[a]	9[a]	8 hours
Oxidants (ozone)				235[c]	0.12[c]	1 hour
Nitrogen dioxide	100	0.055	1 year			
Lead	1.5	—	3 months[d]			

a Not to be exceeded more than once per year.
b Arithmetic mean.
c Standard is attained when expected number of days per calendar year with maxi-mal hourly average concentrations above 0.12 ppm (235 μg/m³) is equal to or less than 1, as determined by Appendix H to subchapter C, 40 CFR 50.
d Three-month period is a calendar quarter.

WHO guidelines values for indoor and outdoor air pollutants

Pollutant	WHO Indoor Air Quality guidelines 2010	WHO Air Quality guidelines 2005
Benzene	No safe level can be determined	-
Carbon monoxide	15 min. mean: 100 mg/m^3 1h mean: 35 mg/m^3 8h mean: 10 mg/m^3 24h mean: 7 mg/m^3	-
Formaldehyde	30 min. mean: 100 $\mu g/m^3$	-
Naphthalene	Annual mean: 10 $\mu g/m^3$	-
Nitrogen dioxide	1h mean: 200 $\mu g/m^3$ Annual mean: 40 mg/m^3	-
Polyaromatic Hydrocarbons (e.g. Benzo Pyrene A B[a]P)	No safe level can be determined	-
Radon	100 Bq/m^3 (sometimes 300 mg/m^3, country-specific)	-
Trichlorethylene	No safe level can be determined	-
Tetrachloroethylene	Annual mean: 250 $\mu g/m^3$	
Sulfure dioxide	-	10 min. mean: 500 $\mu g/m^3$ 24h mean: 20 mg/m^3
Ozone	-	8h mean:100 $\mu g/m^3$
Particulate Matter PM 2,5	-	24h mean: 25 $\mu g/m^3$ Annual mean: 10 $\mu g/m^3$
Particulate Matter PM 10	-	24h mean: 50 $\mu g/m^3$ Annual mean: 20 $\mu g/m^3$

INDIA-Indoor Environmental Quality

Table3 Threshold values for indoor air quality parameters

Parameters	Units	Classification		
		Class A	Class B	Class C
CO_2	ppm	Ambient + 350	Ambient + 500	Ambient + 800
PM 2.5	μg/m^3	<15	<25	<60
PM 10	μg/m^3	<50	<100	<100
CO	ppm	<9	<9	< 9
TVOC	μg/m^3	<200	<400	<600
CH_2O	μg/m^3	<30	<100	-
SO_2	μg/m^3	<40	<80	-
NO_2	μg/m^3	<40	<80	-
O_3	μg/m^3	<50	<100	-
Total Microbial Count	CFU/m^3	Indoor ≤ ambient	Indoor ≤ ambient	-
User Satisfaction	%	90	80	-

Residential buildings

Category	Total ventilation including air infiltration (1)		Supply air flow per. person (2)	Supply air flow based on perceived IAQ for adapted persons (3)		Supply air flow Bed room level (l/s) (4)		Exhaust air flow, l/s peak or boost flow for high demand		
	l/s,m²	ach	l/s*per	q_p l/s*per	q_B l/s,m²	Master bed-room l/s	Other bed-room l/s	Kit-chen (3a)	Bath-rooms (3b)	Toilets (3c)
I	0,49	0,7	10	3,5	0,25	20	10	28	20	14
II	0,42	0,6	7	2,5	0,15	14	8	20	15	10
III	0,35	0,5	4	1,5	0,1	8	4	14	10	7
IV*	0,23	0,4				5*	2,5*	10	6	4

ASHRAE 62.2 Residential

$$Q_{tot} = 0.15A_{floor} + 3.5(N_{br} + 1) \qquad \text{(SI)} \quad (4.1b)$$

where

Q_{tot} = total required ventilation rate, L/s

A_{floor} = dwelling-unit floor area, m^2

N_{br} = number of bedrooms (not to be less than 1)

Occupant density:
Two persons (studio, one-bedroom
Plus one person i.e. plus 3.5 L/s for
each additional bedroom

TABLE 4.1b (SI) Ventilation Air Requirements, L/s

	Bedrooms				
Floor Area, m^2	**1**	**2**	**3**	**4**	**5**
<47	14	18	21	25	28
47–93	21	24	28	31	35
94–139	28	31	35	38	42
140–186	35	38	42	45	49
187–232	42	45	49	52	56
233–279	49	52	56	59	63
280–325	56	59	63	66	70
326–372	63	66	70	73	77
373–418	70	73	77	80	84
419–465	77	80	84	87	91

Example criteria for personalized systems

Aspect	Requirement
'Temperature' control winter	At workstation level, the (operative/equivalent) temperature is adjustable with a response speed of at least 0,5 K/minute within a range of 5 K, from 18 °C to 23 °C.
'Temperature' control summer	At workstation level, the (equivalent) temperature is adjustable (with a response speed of at least 0,5 K/minute within a range of 5 K, from 22 °C to 27 °C.
Fresh air supply control	Local fresh air supply (per workstation) is adjustable from around 0 to at least 7 l/s.
Delivered air quality	For requirements related to air cleaning technology: see Annex K.
Installation noise	Noise level – with the personalized system in the highest setting – should not be higher than 35 dB(A).

This is a topic under IEA -EBC Annex 69 "Thermal Comfort"

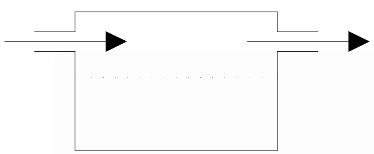
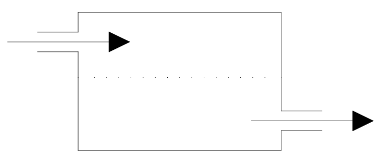
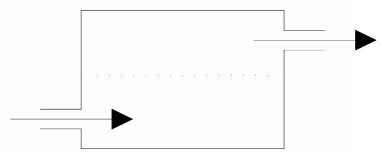
Air Distribution Effectiveness

$$\varepsilon_V = \frac{C_E - C_S}{C_I - C_S}$$

CEN Report CR 1752 (1998)

Concentrations:

- C_E **exhaust air**
- C_S **supply air**
- C_I **breathing zone**

Mixing ventilation		Mixing ventilation		Displacement ventilation		Personalized ventilation	
							
T supply - T inhal °C	Vent. effect. -	T supply - T inhal °C	Vent. effect. -	T supply - T inhal °C	Vent. effect. -	T supply - T room °C	Vent. effect. -
< 0	0,9 - 1,0	< -5	0,9	<0	1,2 - 1,4	-6	1,2 - 2,2
0 - 2	0,9	-5 - 0	0,9 - 1,0	0-2	0,7 - 0,9	-3	1,3 - 2,3
2 - 5	0,8	> 0	1	>2	0,2 - 0,7	0	1,6 - 3,5
> 5	0,4 - 0,7						

COMFORT-PRODUCTIVITY
Building costs

People	100
Maintenance	10
Financing	10
Energy	1

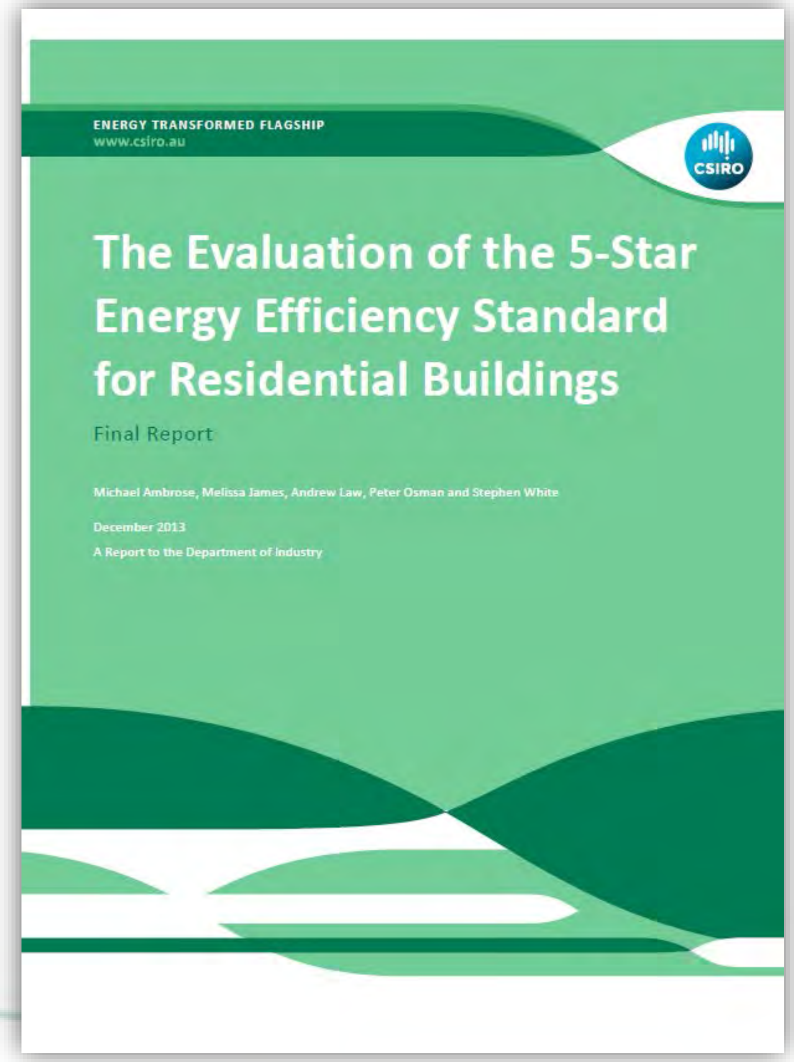
This clearly show that buildings are for people not for saving energy

Managing Summer Cooling Loads in Code Compliant Australian Housing

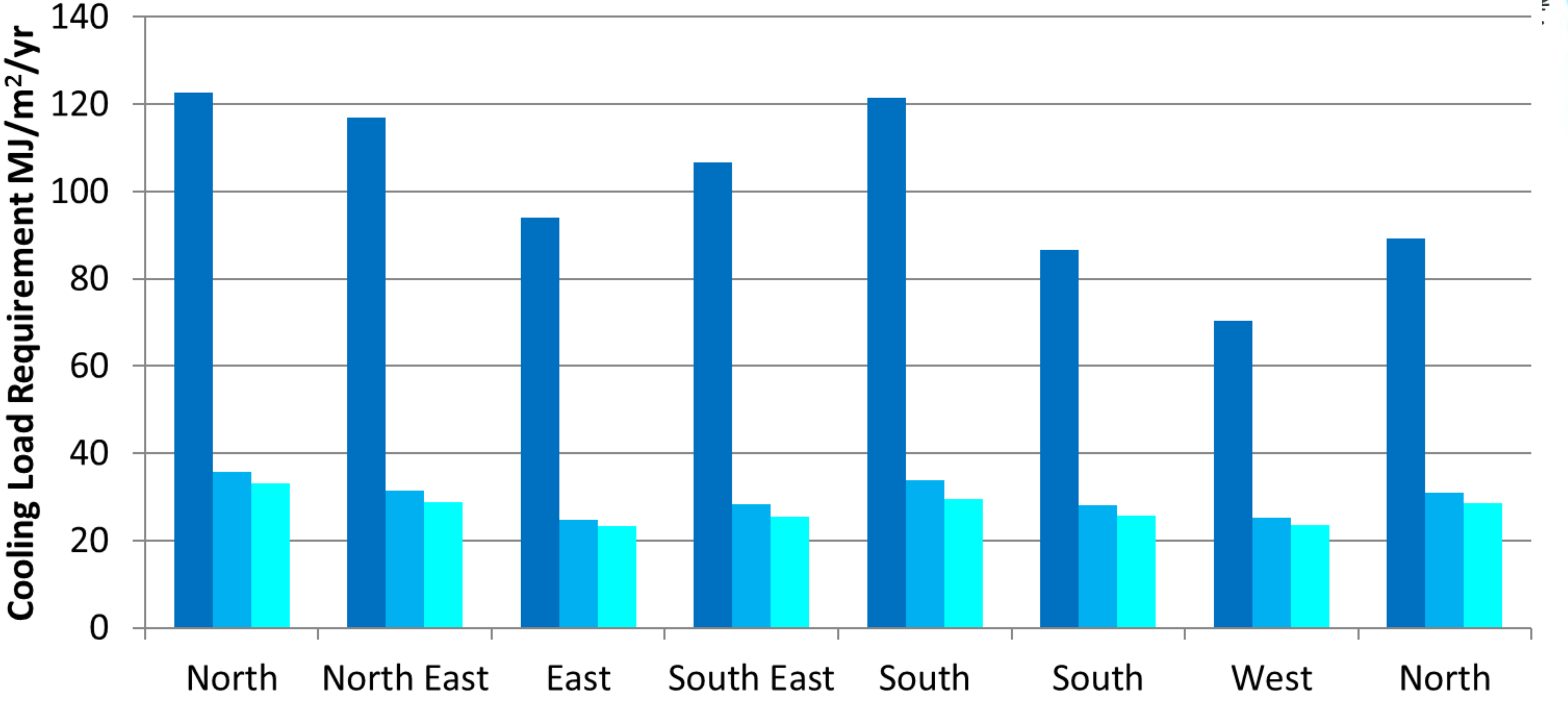
A Cost Benefit Analysis for Mass Market Implementation of Purge Ventilation Technologies

The Issue

"The average cooling energy use in summer was greater in (…) higher-rated houses in Brisbane and Melbourne. (…) However, it is not clear whether this was due to (…) behavioural factors (…) [including] **the extent of window opening and closing during summer.**"



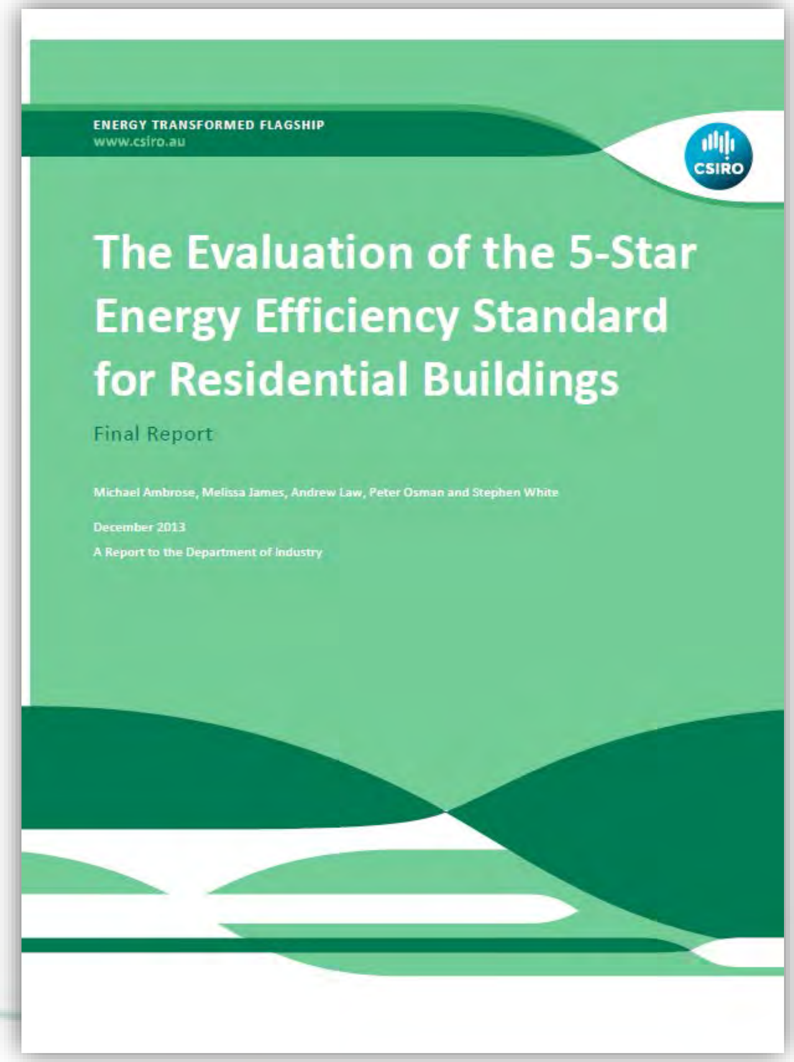
When Windows Remain Shut



- Do not operate windows
- Operate windows as assumed by regulatory software
- Guaranteed with purge ventilation technology

Expectations Vs Reality

"The unexpected trend appears to be that energy consumption increases with star rating."



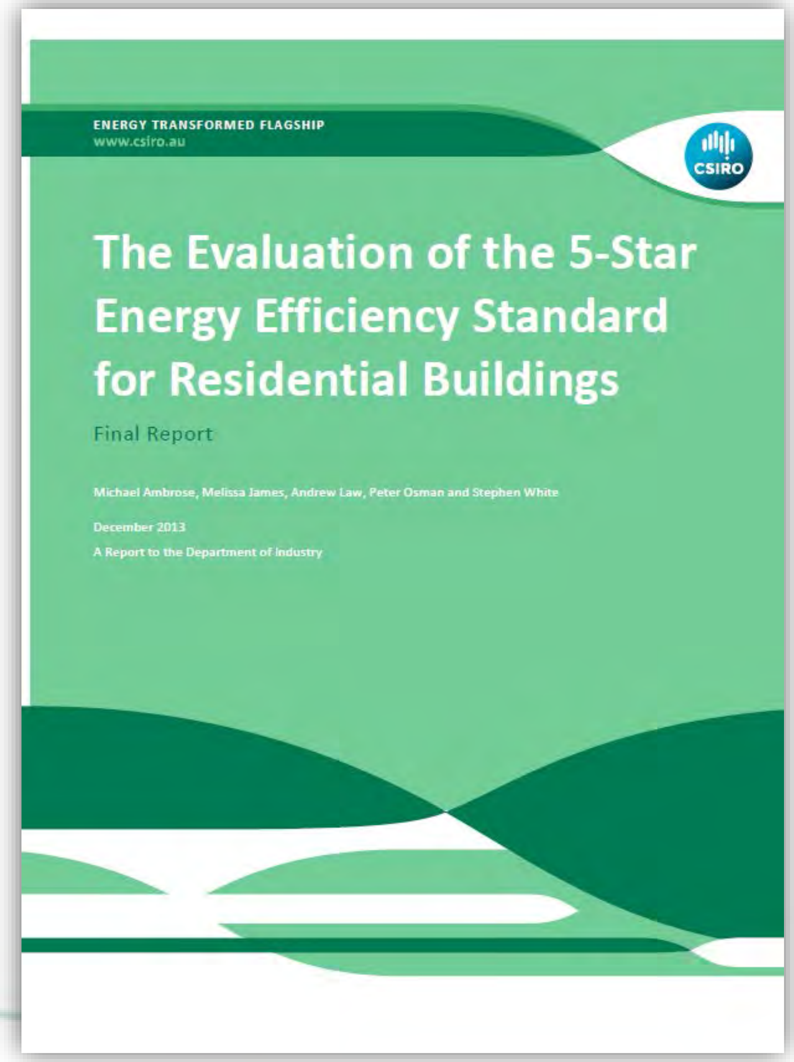
Exacerbated Cooling Loads

In **Brisbane** cooling loads increased on average by

31%

Compered to lower-rated houses

Ambrose, James, Law, Osman, & White, 2013, CSIRO (2013)


ENERGY TRANSFORMED FLAGSHIP
www.csiro.au

CSIRO

The Evaluation of the 5-Star Energy Efficiency Standard for Residential Buildings

Final Report

Michael Ambrose, Melissa James, Andrew Law, Peter Osman and Stephen White

December 2013

A Report to the Department of Industry

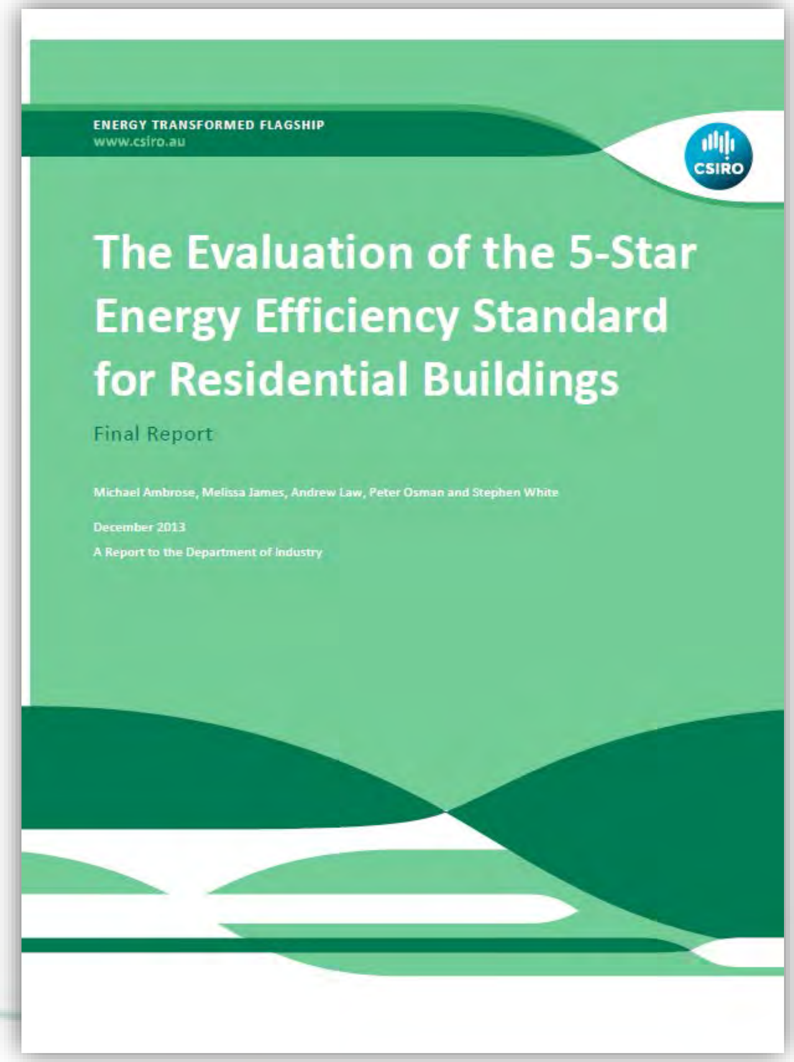
Exacerbated Cooling Loads

In **Melbourne** cooling loads increased on average by

38%

Compered to lower-rated houses

Ambrose, James, Law, Osman, & White, 2013, CSIRO (2013)


ENERGY TRANSFORMED FLAGSHIP
www.csiro.au

CSIRO

The Evaluation of the 5-Star Energy Efficiency Standard for Residential Buildings

Final Report

Michael Ambrose, Melissa James, Andrew Law, Peter Osman and Stephen White

December 2013

A Report to the Department of Industry

Reducing Stars Is Not An Option

– Increase R-Values

– Reduce U-Values

– Shading

– Seal it Tight

– Ventilate Right

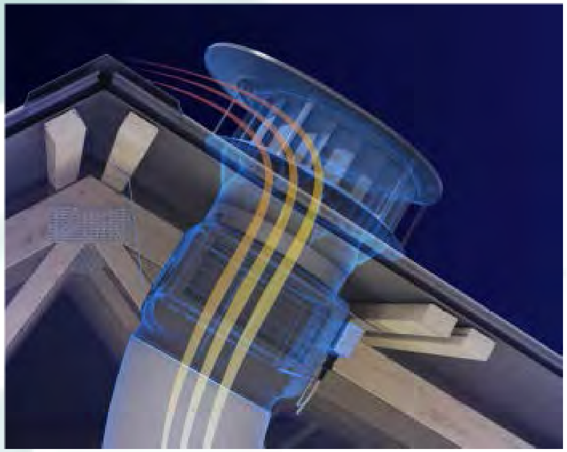
NatHERS Inputs

"Data input assumptions to the NatHERS methodology may not adequately represent typical end user behaviour [...]. If an air conditioner is turned off in summer and the house is shut up (e.g. if people are away from home), then stored heat is likely to build up in the fabric of the house. This may not be being adequately accounted for in the current data input assumptions."

Ambrose, James, Law, Osman, & White, 2013, CSIRO (2013)

Smart Purge Ventilators

Centrifugal Roof Mounted
Hybrid: Wind & Powered



Axial Roof Space
Powered

Engineering Terminology; Economy Cycle, Economiser

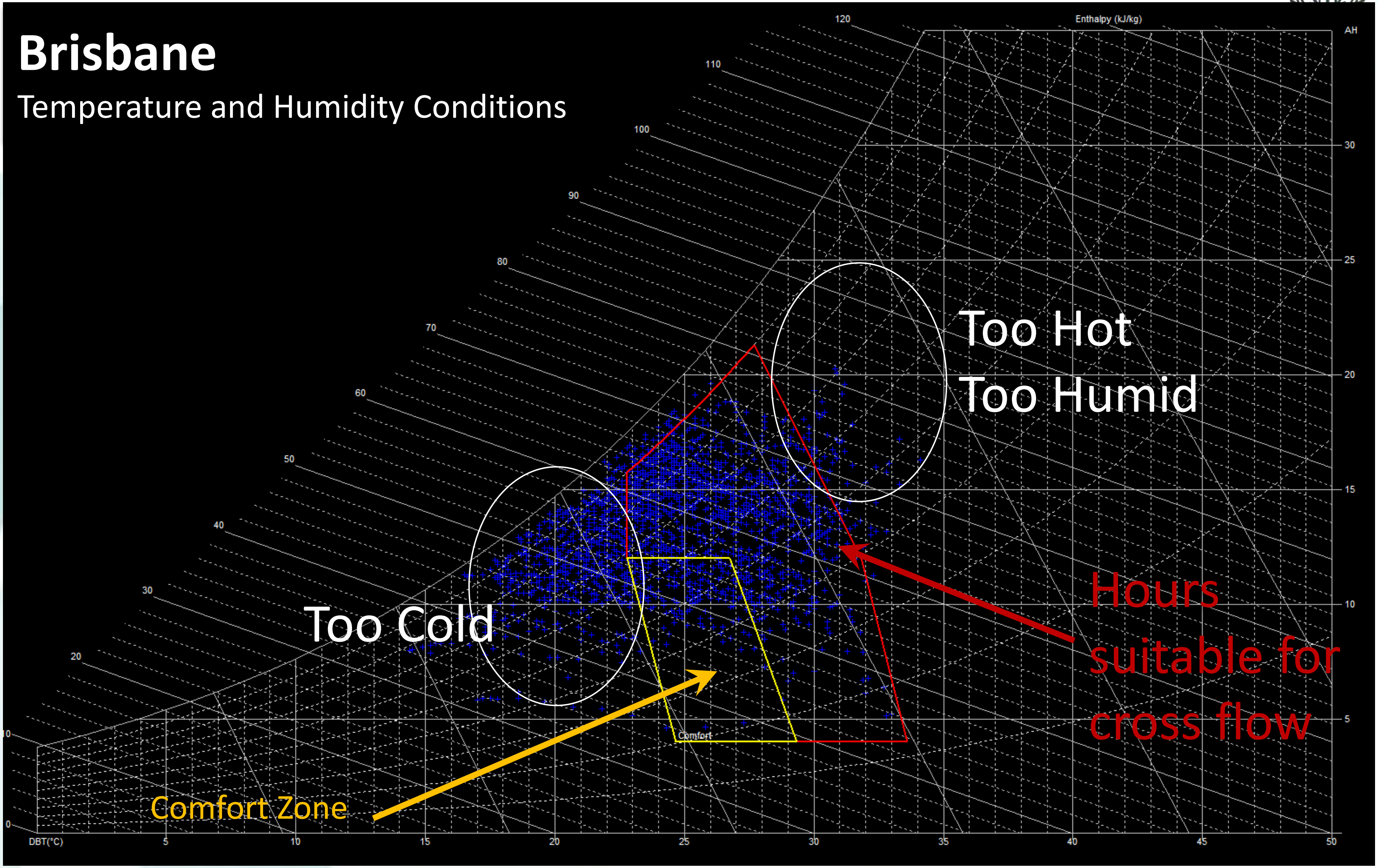
To be Successful

- The technology needs to be "smart"
  - An automated response to indoor and outdoor temperature conditions in relation to occupant comfort, and
  - Must communicate with the air conditioning system to prevent the two technologies opposing each other and delivering perverse energy outcomes.

Note:

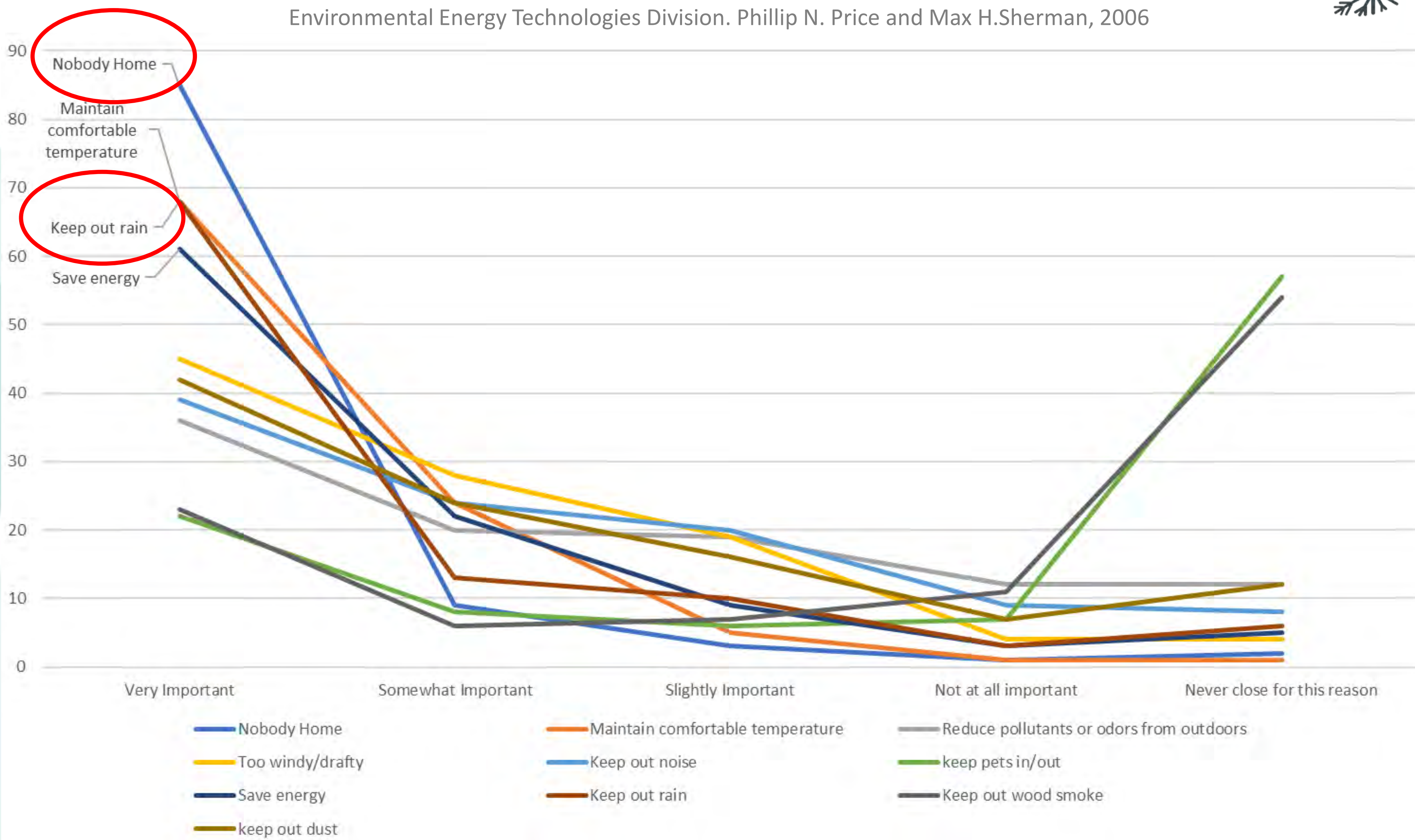
1. Must have sufficient air inlets relative to the air tightness of the house.
2. Noise levels need to be considered.

The Lost Opportunity



International Research

Ventilation Behaviour and Household Characteristics in New California Houses. LBNL Environmental Energy Technologies Division. Phillip N. Price and Max H.Sherman, 2006

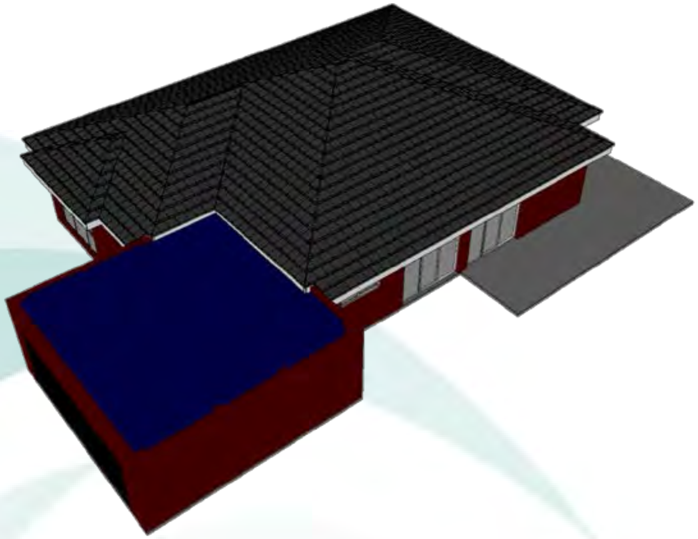


N=1448

This Analysis

- Compares Purge Ventilation with:
  1. Full use of windows for ventilative cooling as per NatHERS assumptions
  2. Windows operated effectively to achieve only 50% of the cooling savings as predicted in the NatHERS scheme
  3. Windows never opened and a full reliance on mechanical air conditioning for cooling

BCR Quantification



Single Storey

Double Storey

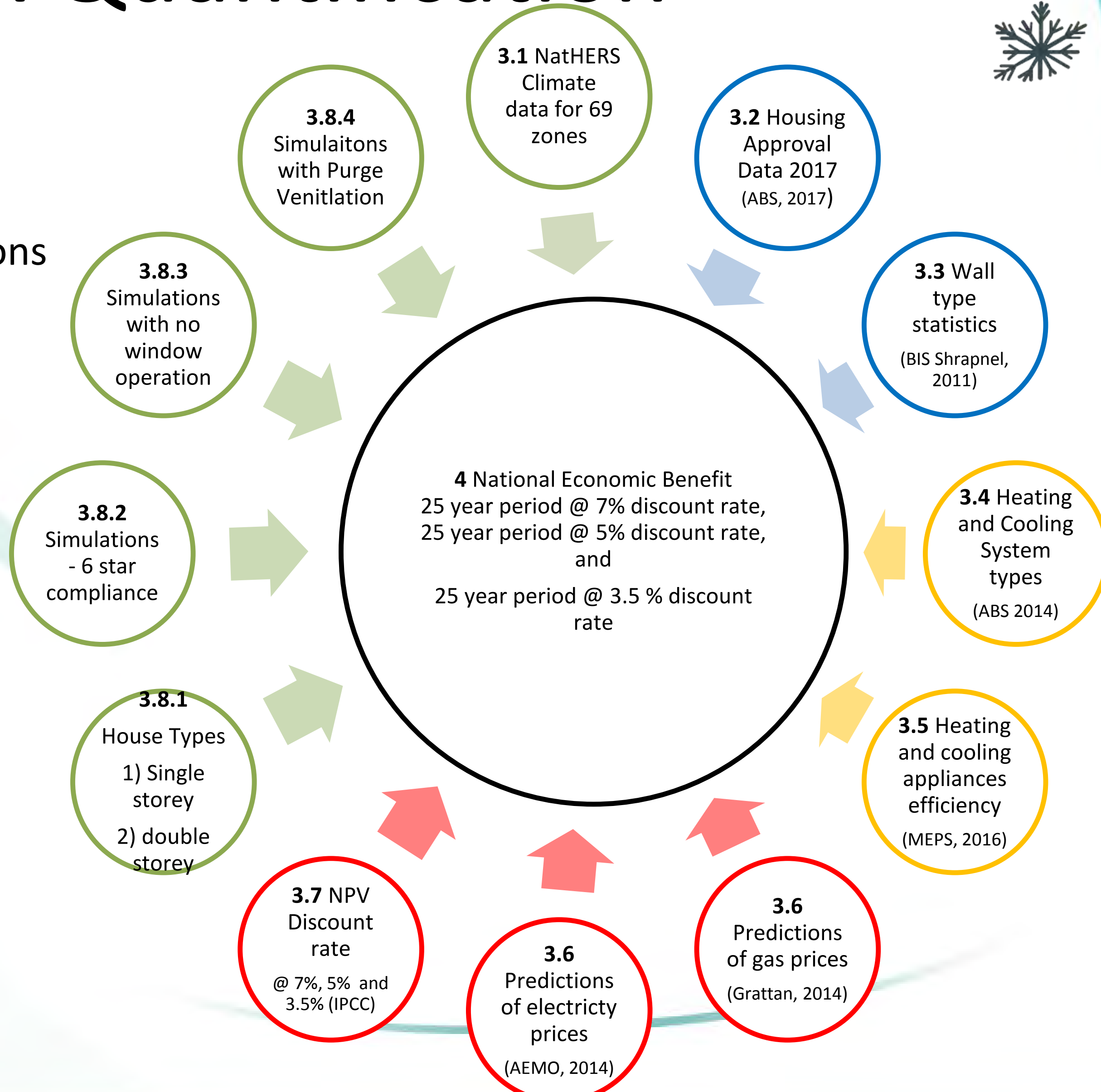
BCR Quantification

NatHERS Load Calculations

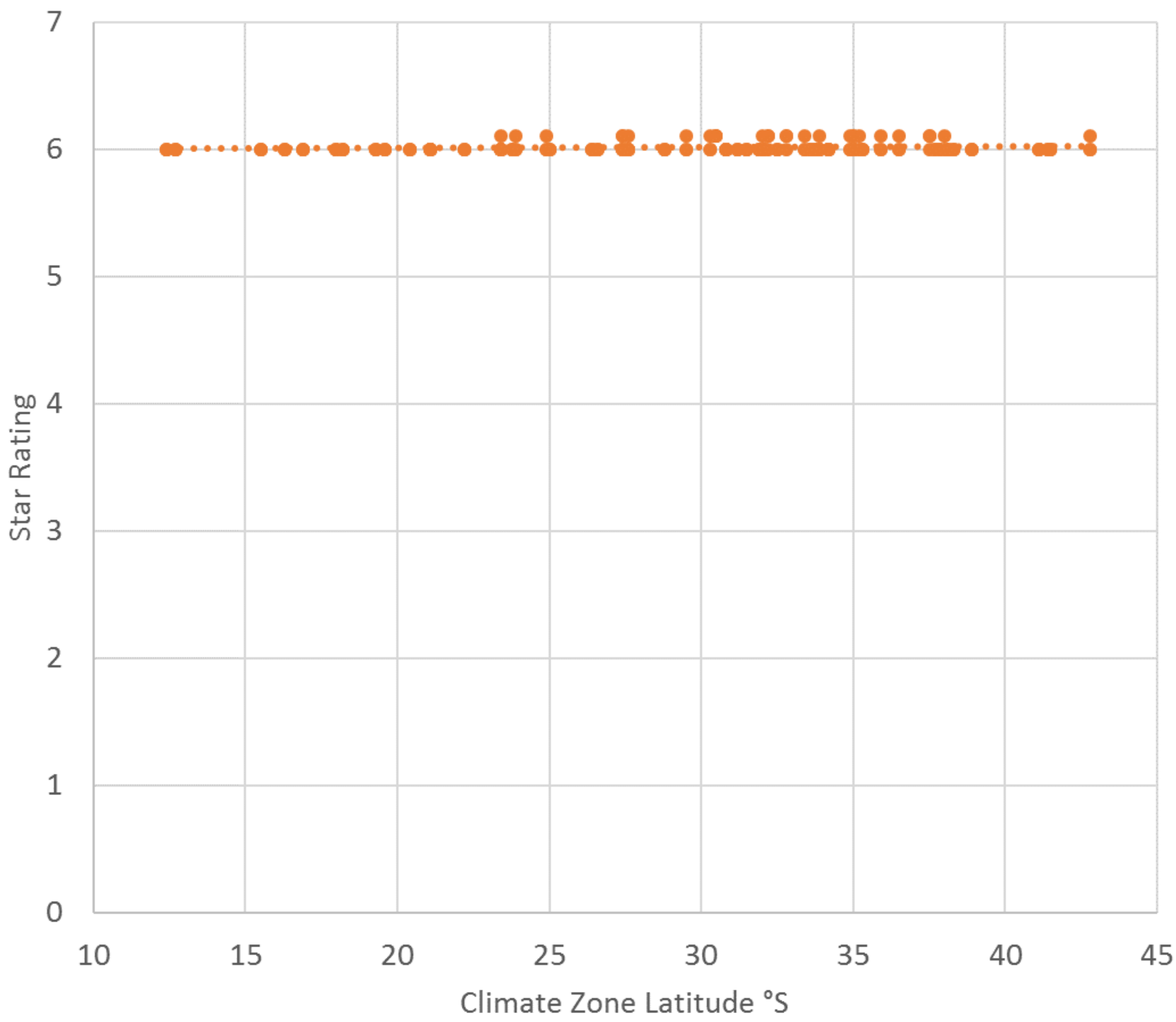
National Energy Load
(Housing Data)

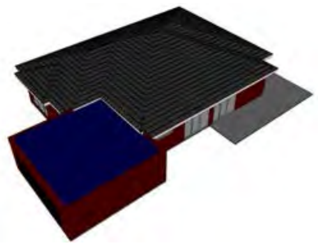
Fuel Consumption
(HVAC Appliances)

NPV Calculation
Fuel Prices & Discount

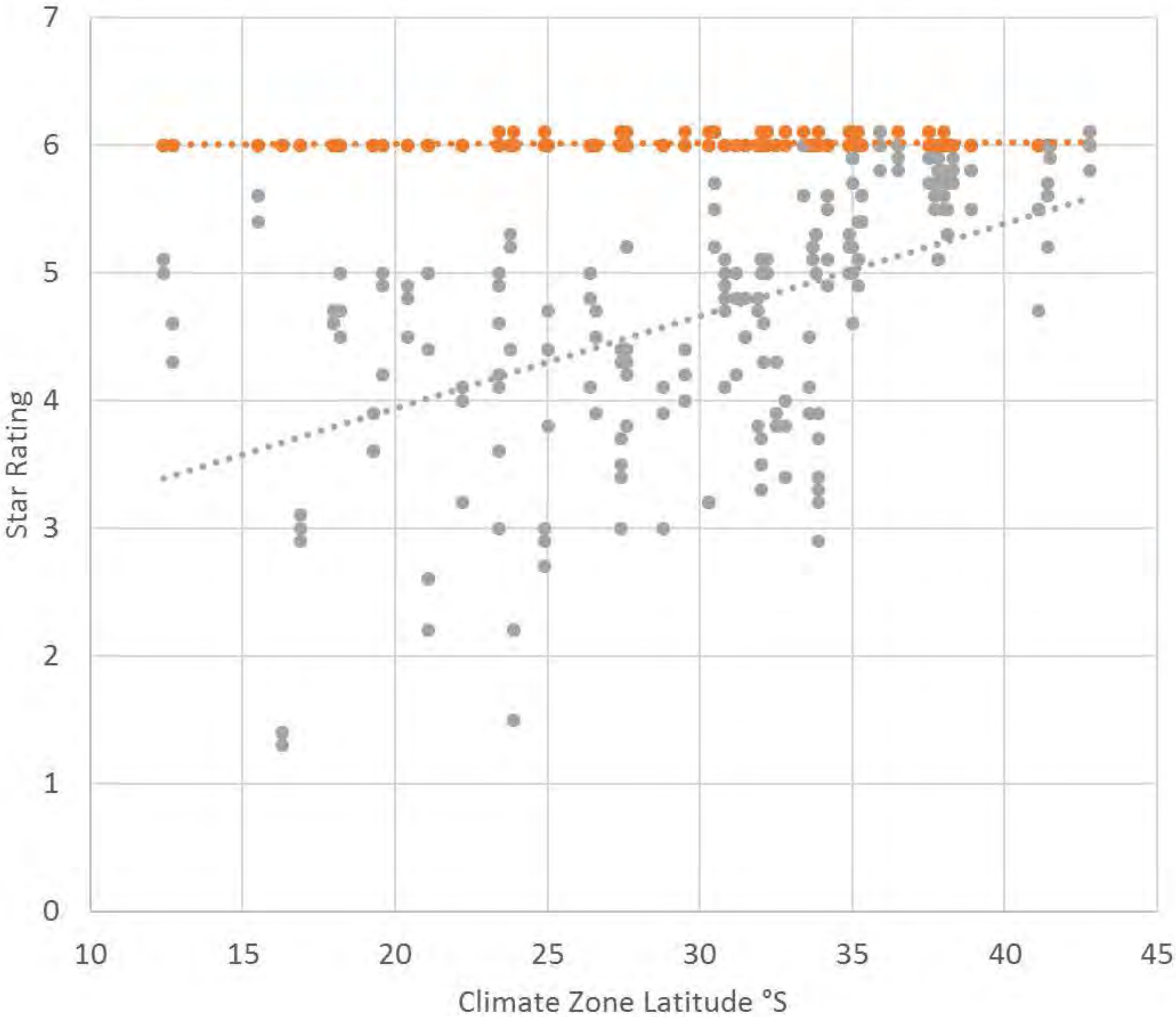


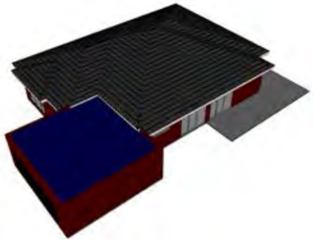
NatHERS Load Calculations



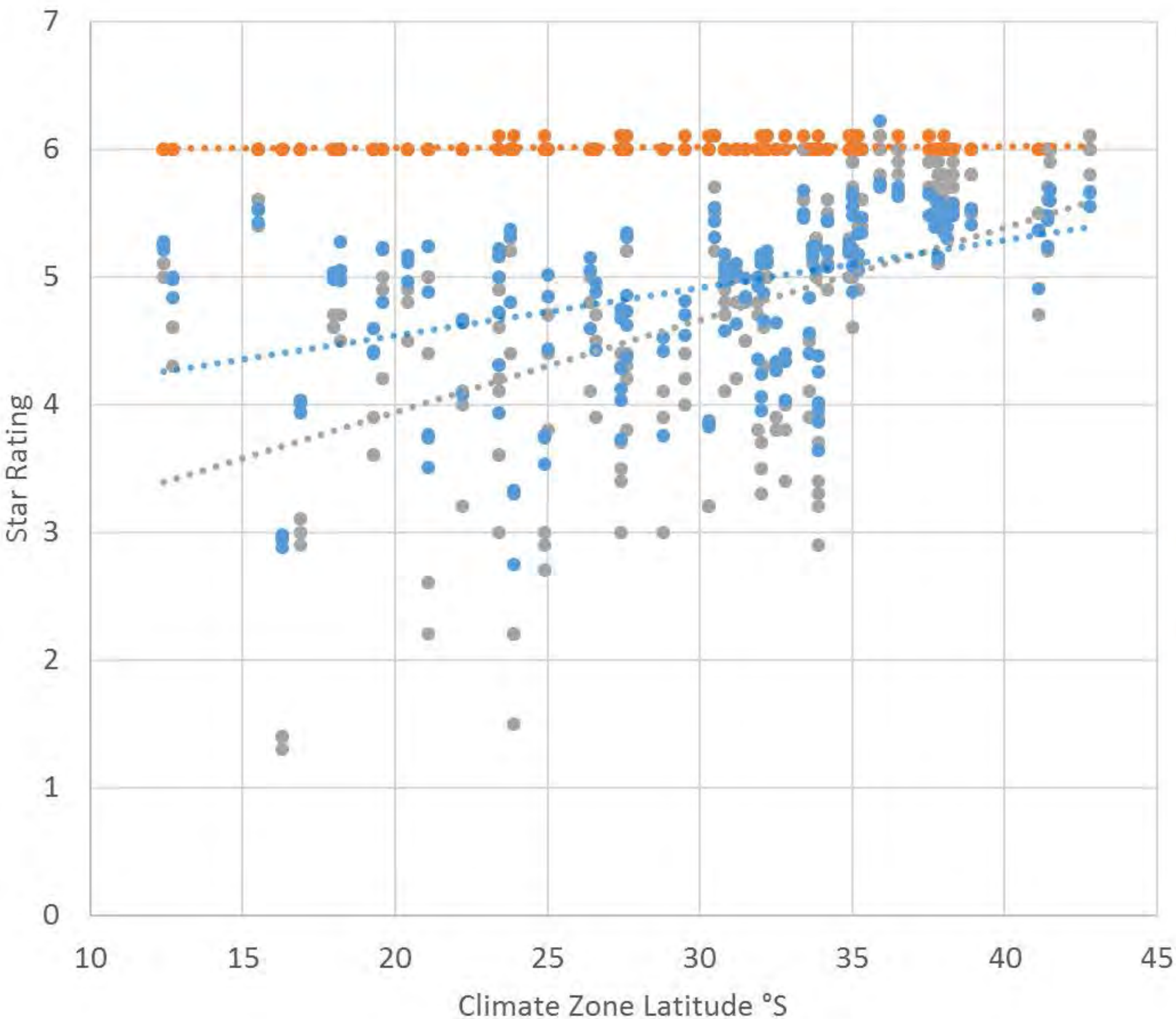


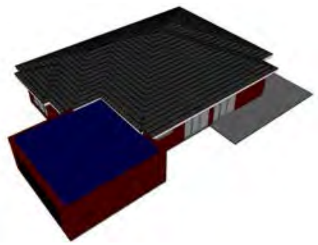
NatHERS Load Calculations



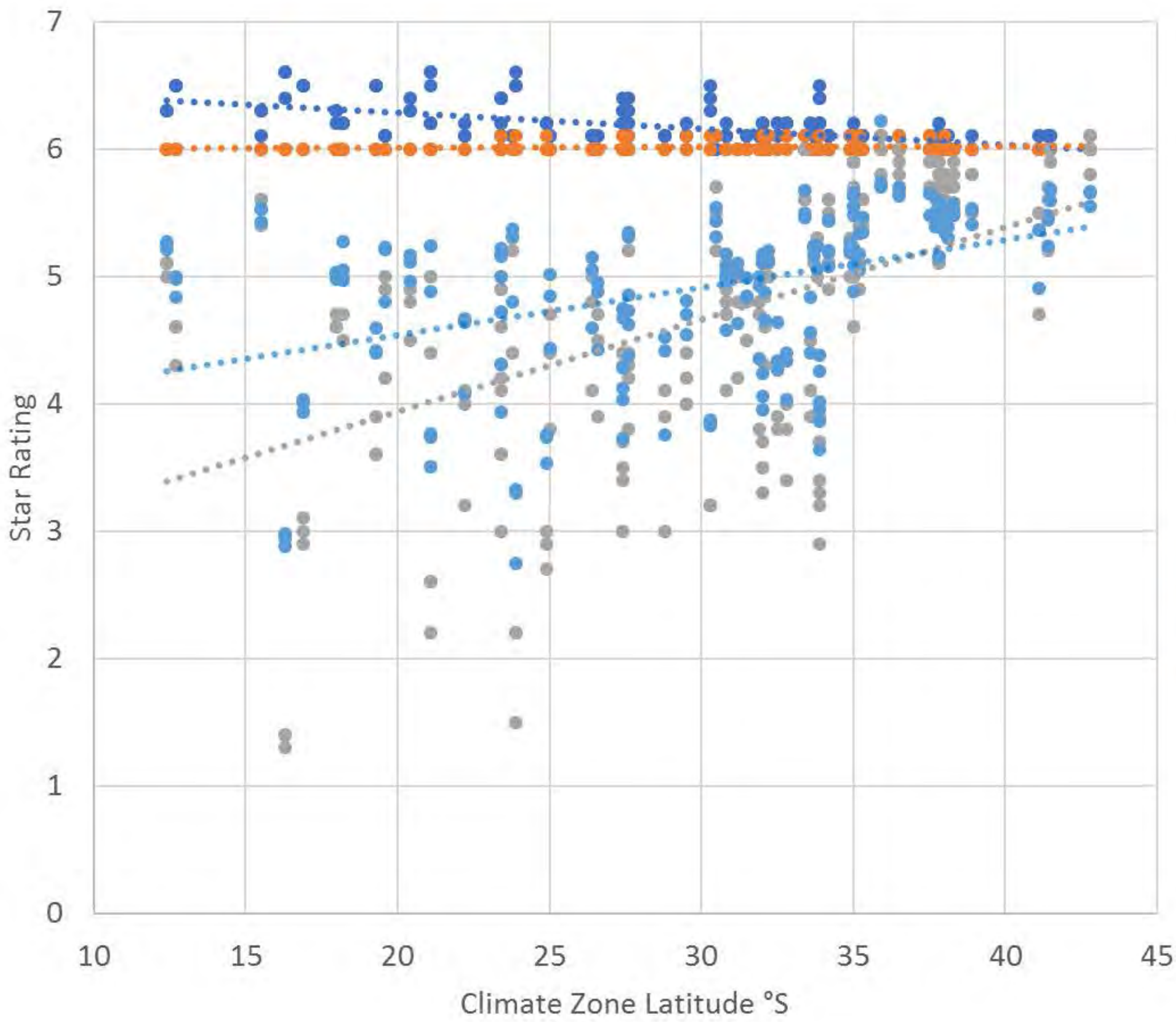


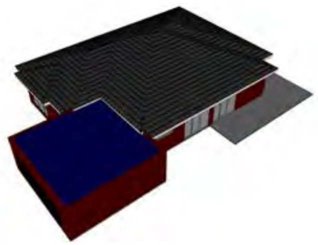
NatHERS Load Calculations





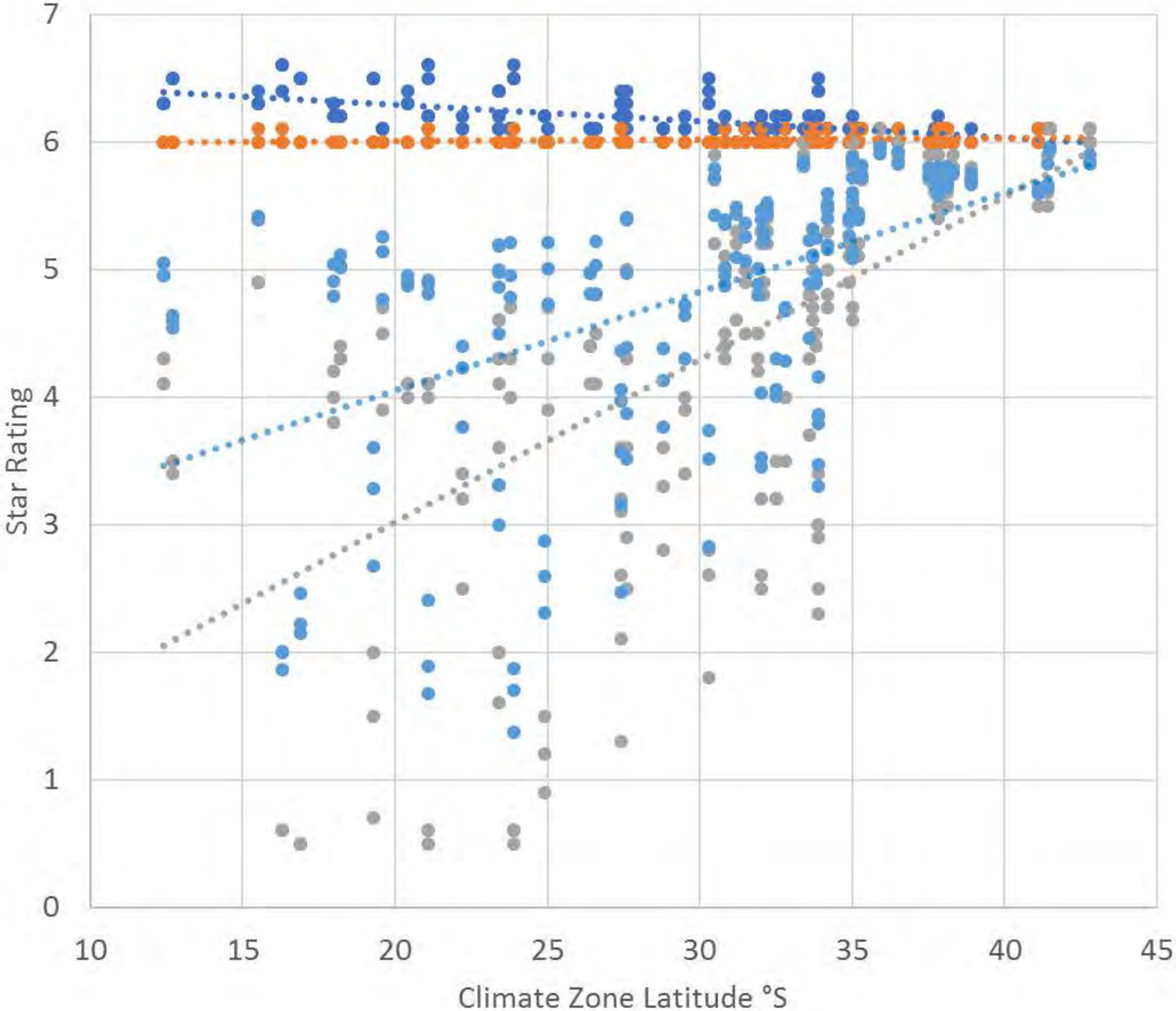
NatHERS Load Calculations





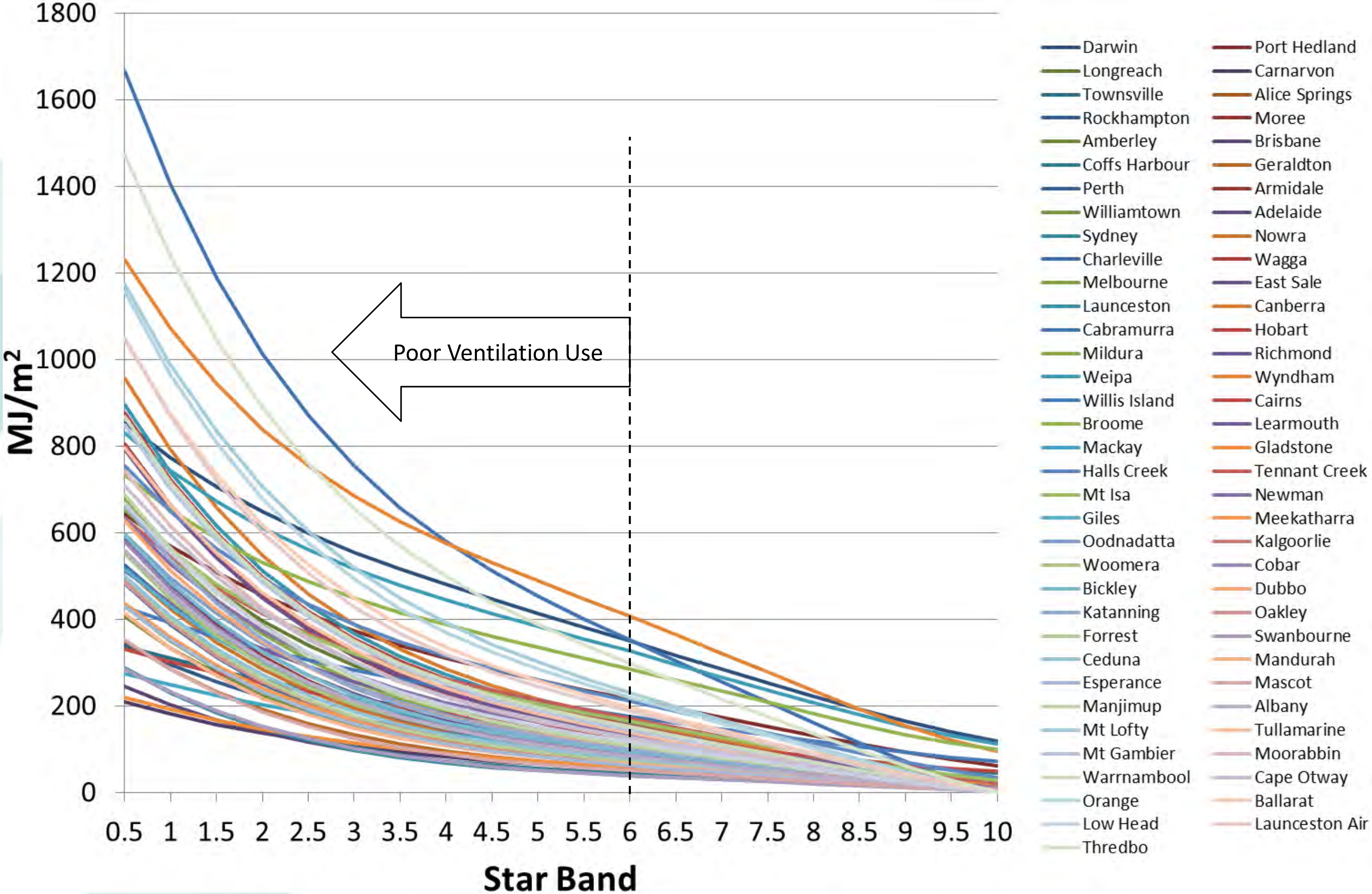
Calculated using a modified Chenath engine as derived for "Potential Benefit of Odyssey System for House Cooling System. CSIRO, Dong Chen, 2017"

NatHERS Load Calculations



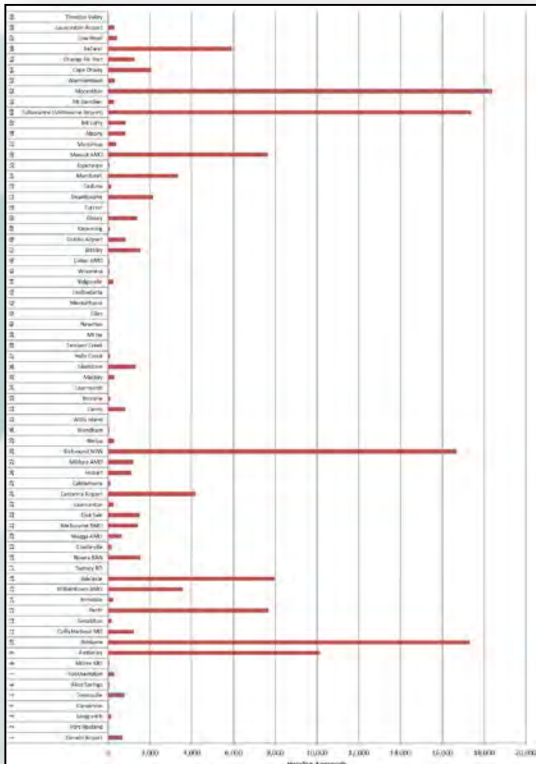
Calculated using a modified Chenath engine as derived for "Potential Benefit of Odyssey System for House Cooling System. CSIRO, Dong Chen, 2017"

Star Vs Energy



Benefit

- Housing Approvals



- Heating and Cooling

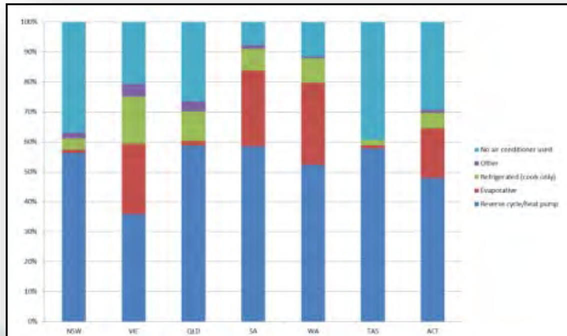


Figure 10 Type of cooling system by household, ABS 2014

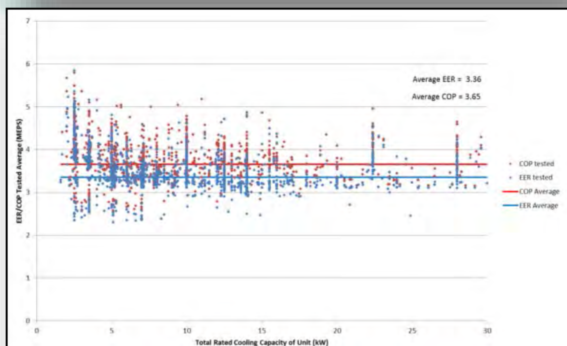
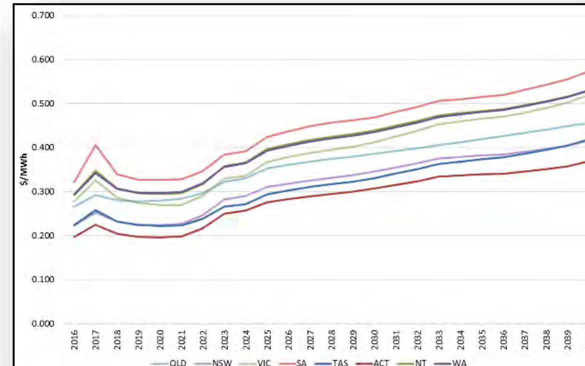
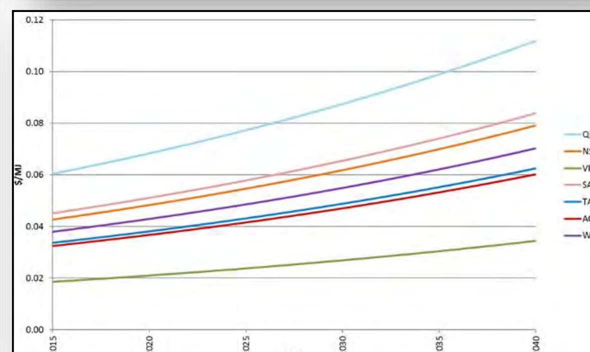


Figure 11 Average COP and EER of MEPS Air Conditioners (0 - 30kW)

- Energy and Gas



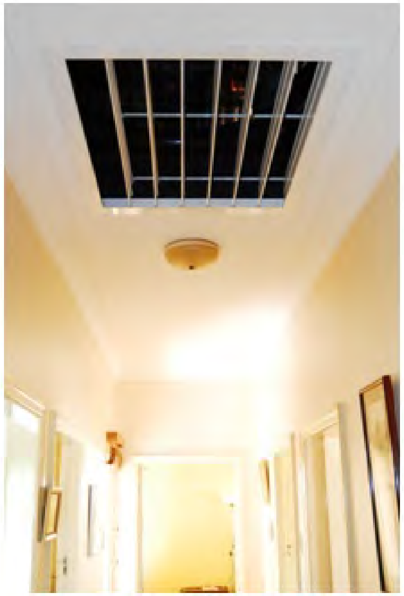


Costs

Centrifugal Roof Mounted

$2400 Fully Installed

Axial Roof Space



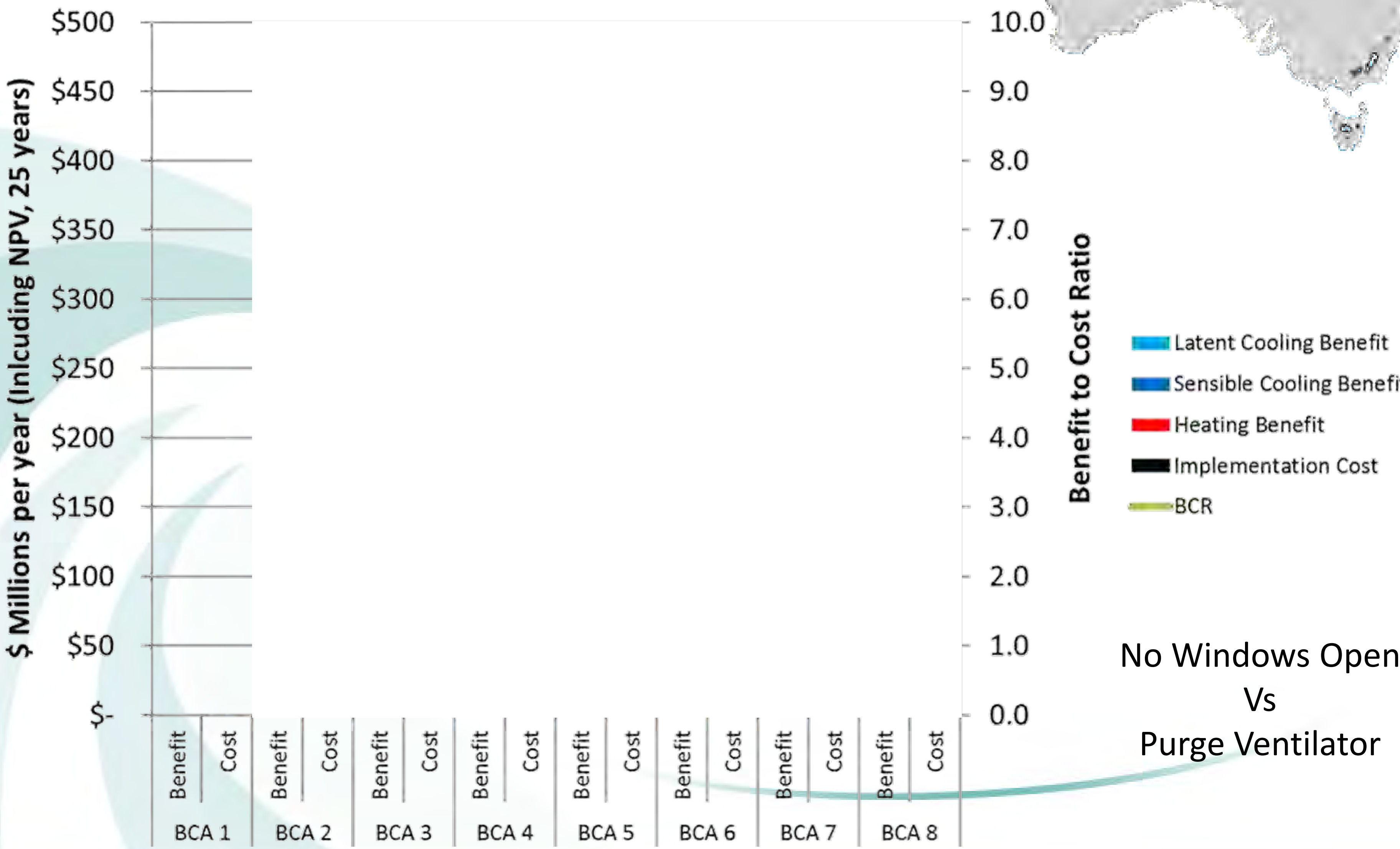
$3600 Fully Installed

Average $3000 per unit

Climatic Humidity

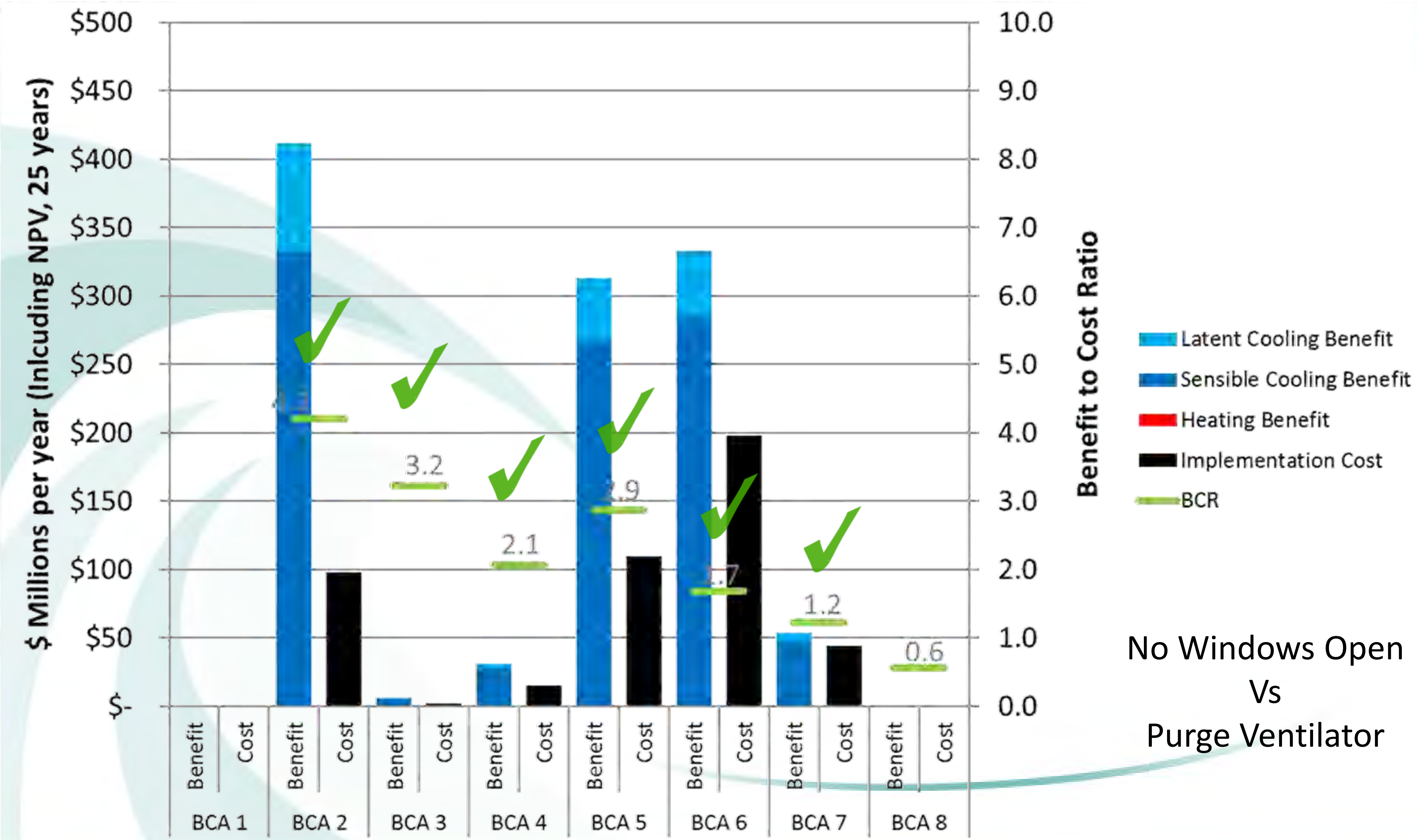
Photo: Heath Bussell, QBCC Cairns Regional Service Centre

BCR – 5% Discount



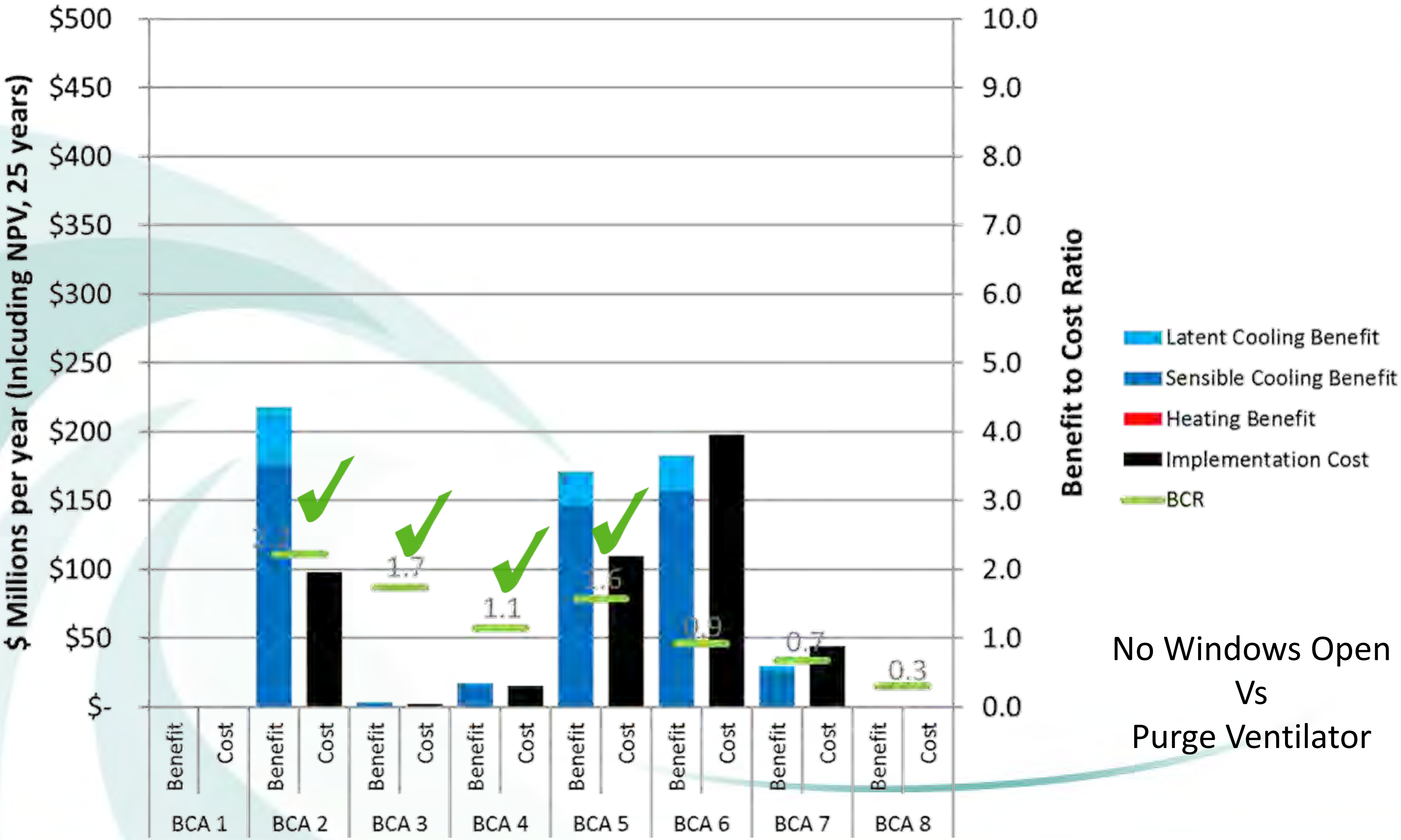
No Windows Open
Vs
Purge Ventilator

BCR – 3.5% Discount - IPCC



No Windows Open
Vs
Purge Ventilator

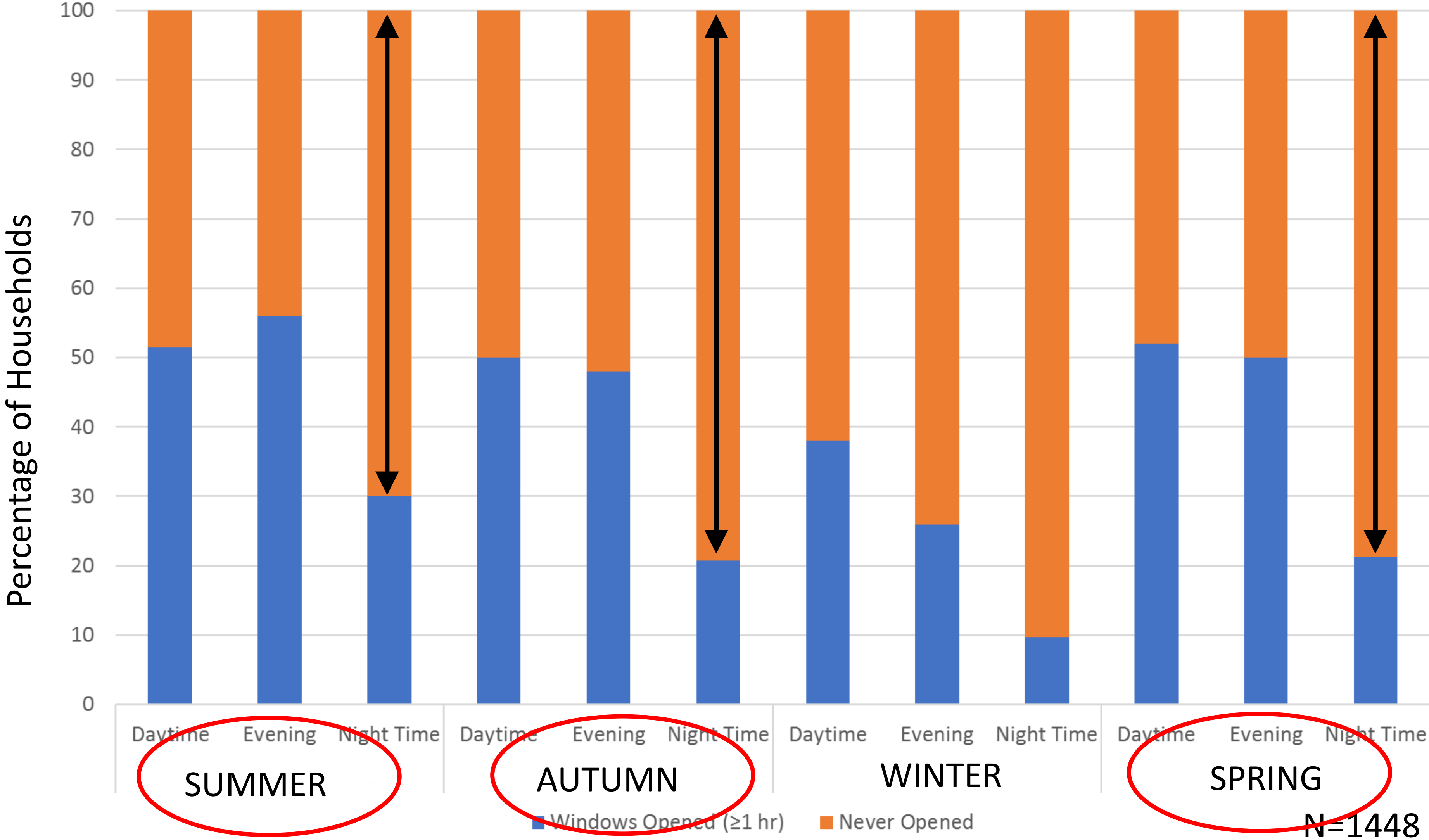
BCR – 7% Discount OBPR



No Windows Open
Vs
Purge Ventilator

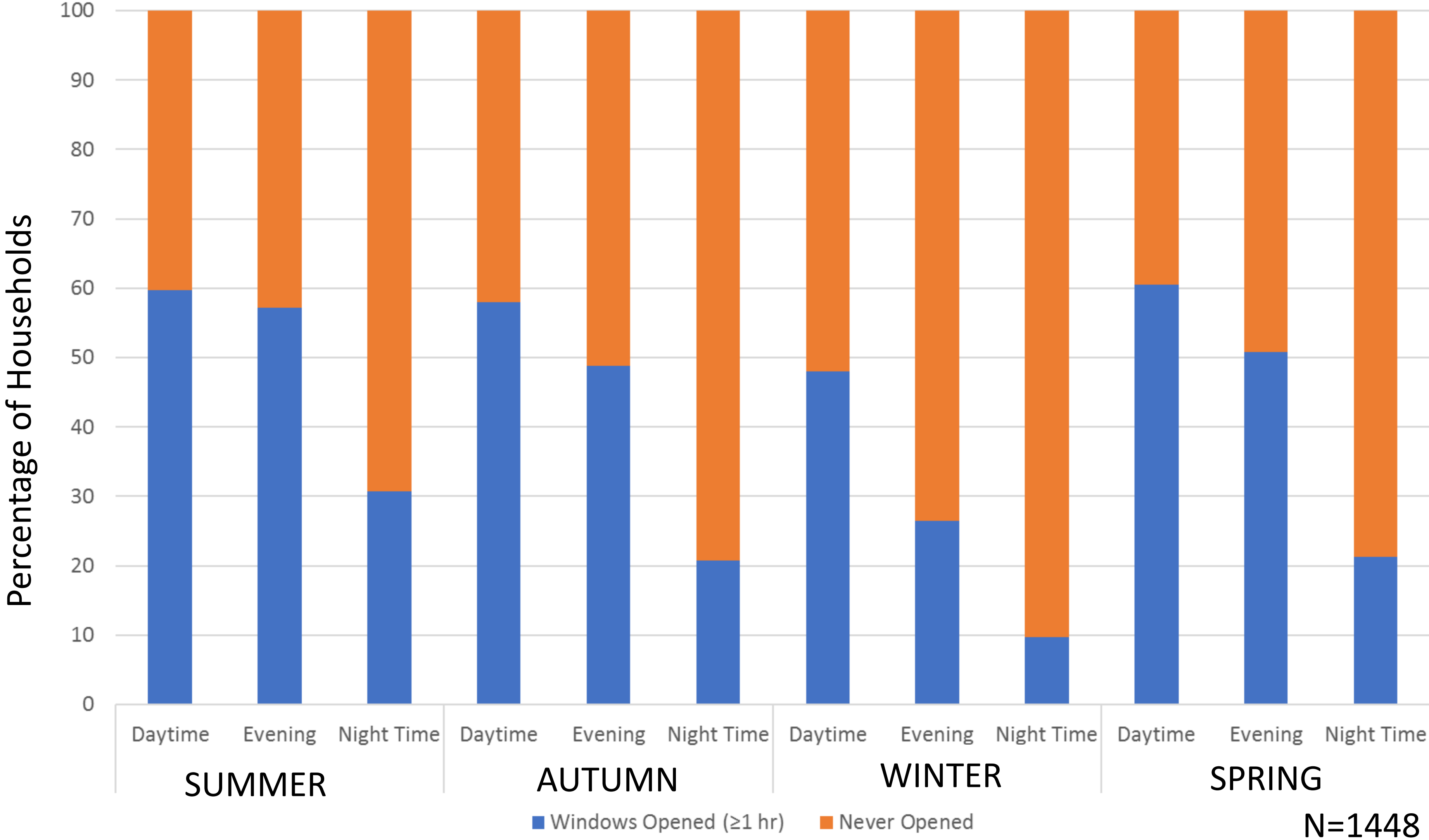
Window Operation Week Days

Calculated from: Ventilation Behaviour and Household Characteristics in New California Houses. LBNL Environmental Energy Technologies Division. Phillip N. Price and Max H.Sherman, 2006

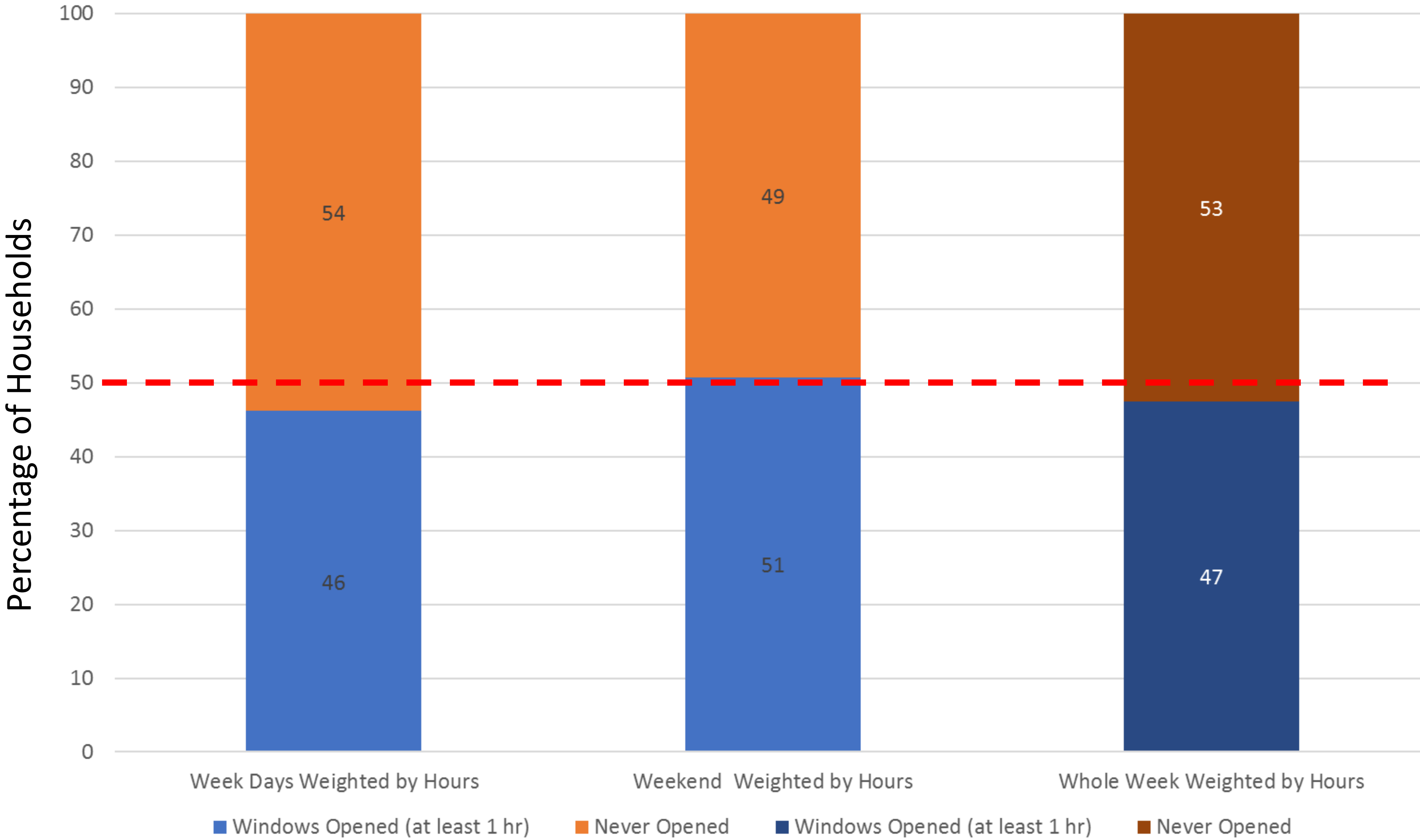


Window Operation Weekends

Calculated from: Ventilation Behaviour and Household Characteristics in New California Houses. LBNL Environmental Energy Technologies Division. Phillip N. Price and Max H.Sherman, 2006

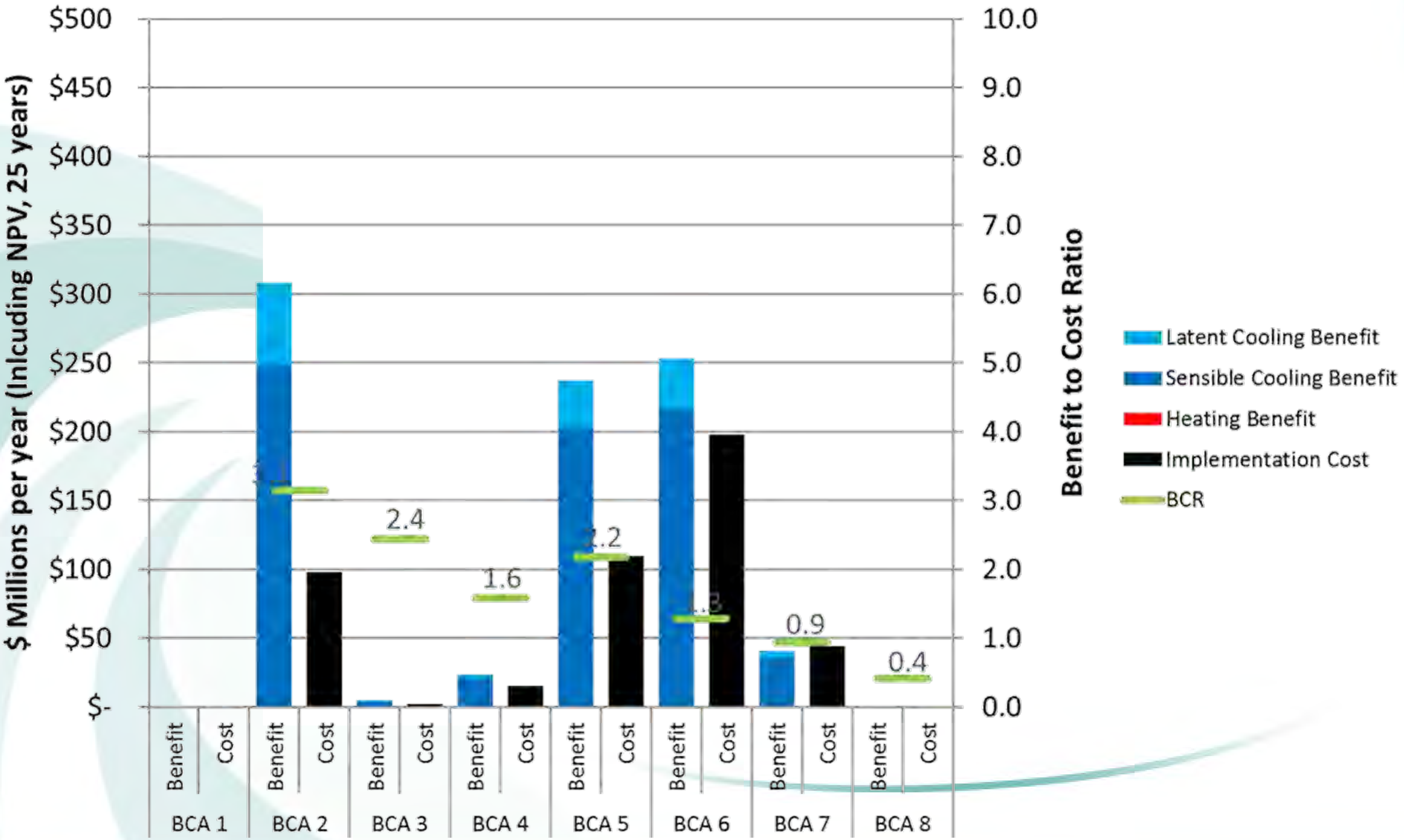


Averages

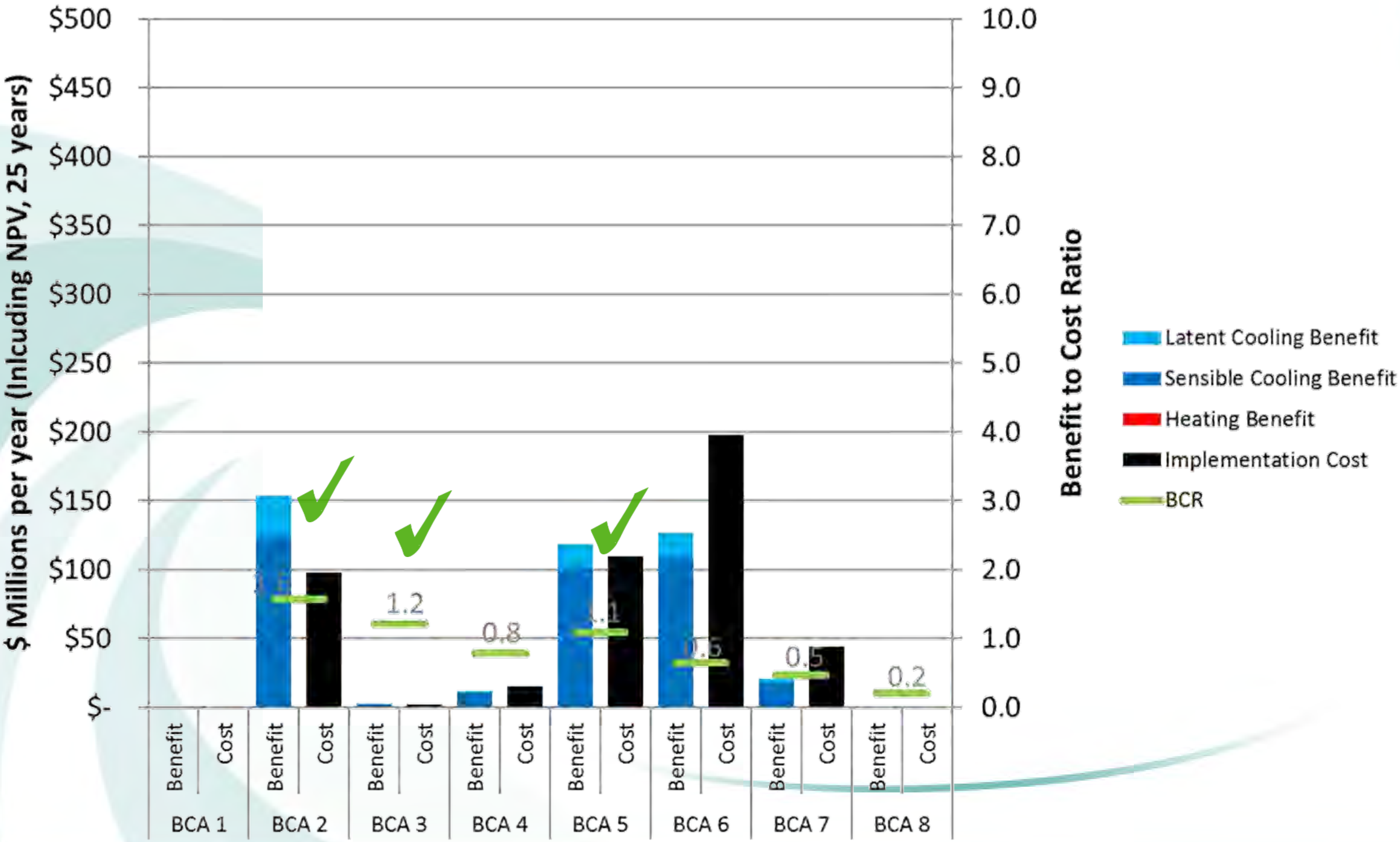


Percentage of Households
100
90
80
70
60
50
40
30
20
10
0
54
46
49
51
53
47
Week Days Weighted by Hours
Weekend Weighted by Hours
Whole Week Weighted by Hours
Windows Opened (at least 1 hr)
Never Opened
Windows Opened (at least 1 hr)
Never Opened

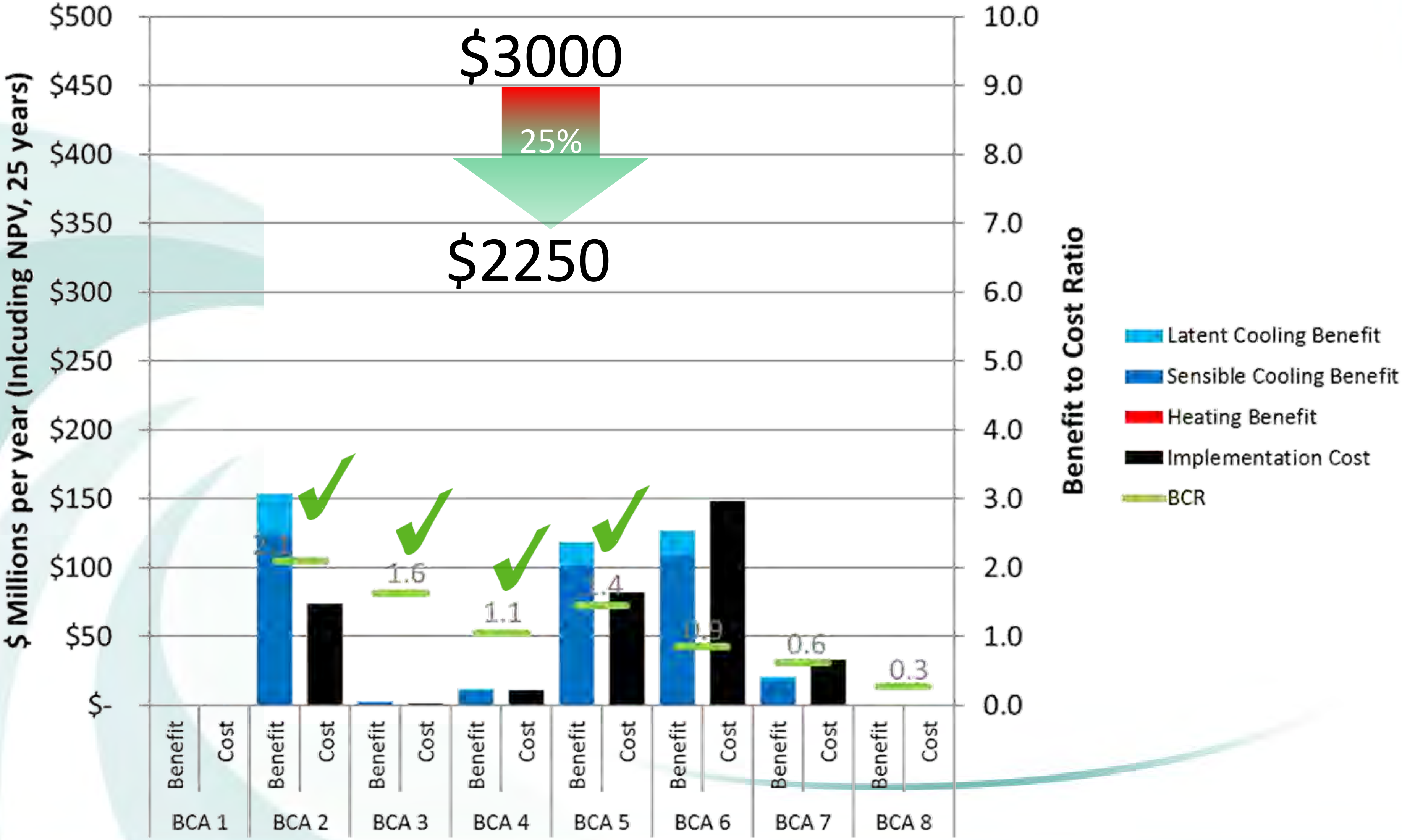
BCR – 5% Discount



50% Benefit Achieved

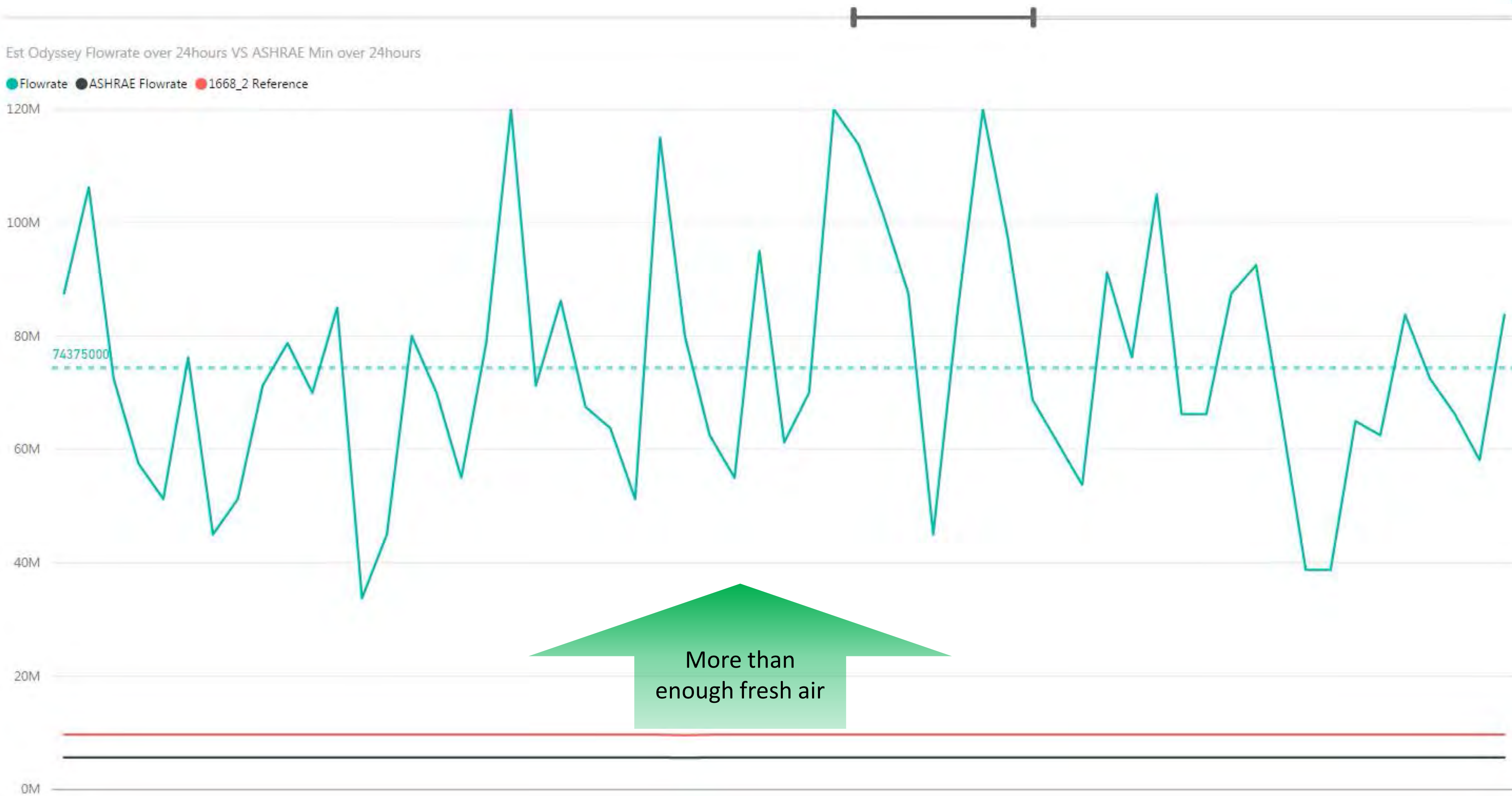


25% Reduction in Cost



Fresh Air - Summer

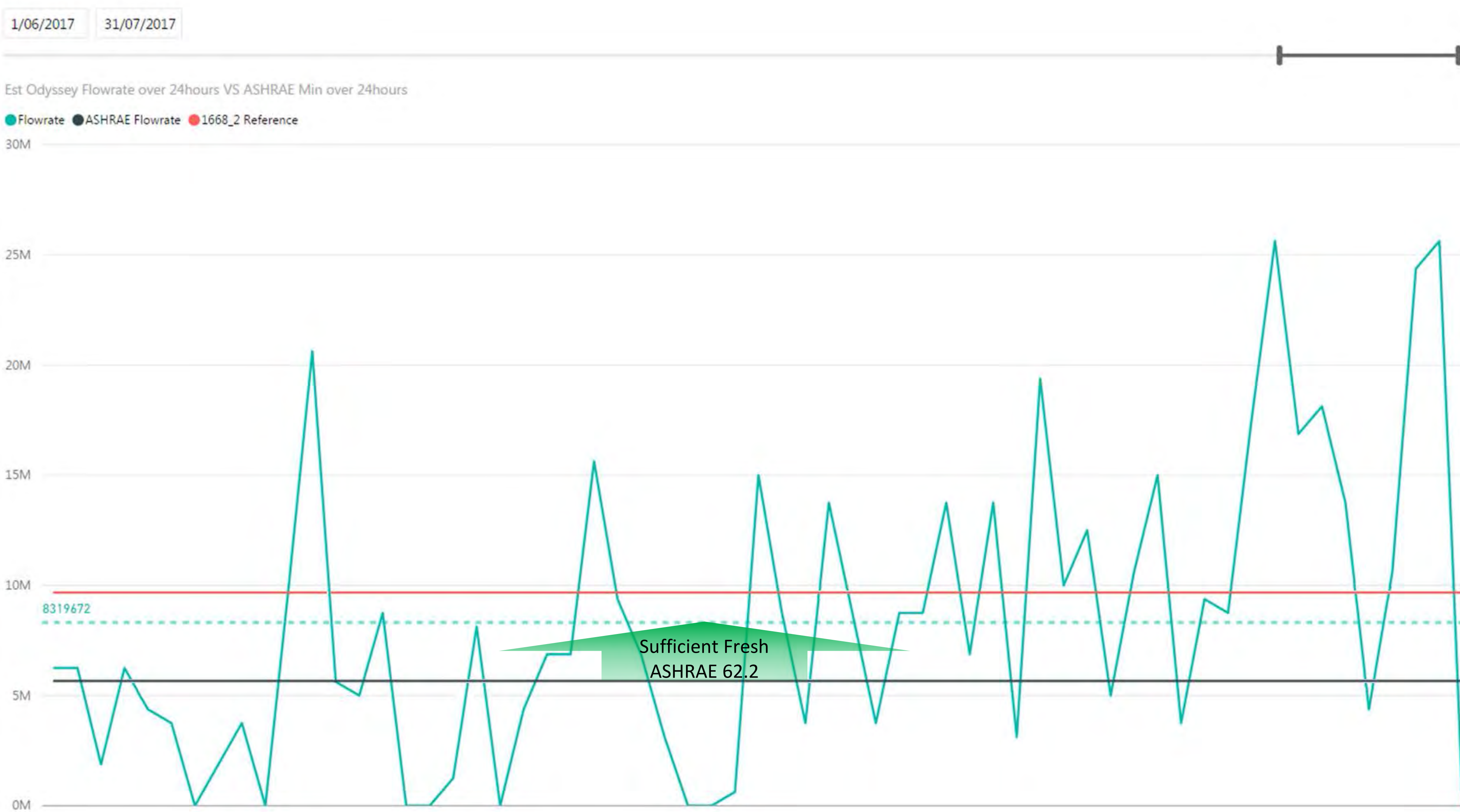
(Summer flow rates – Sydney Retrofit House)



1st Jan 28 Feb

Fresh Air - Winter

(Winter flow rates – Sydney Retrofit House)



1st Jun

31St Jul

"I think the value of beauty and inspiration is very much underrated, no question. But I want to be clear. I'm not trying to be anyone's saviour. [...] I'm just trying to think about the future and not be sad."

Elon Musk | TED2017

Future Cooling Needs of Buildings
The Role of Ventilation

Mat Santamouris – UNSW Sydney Australia

The Air Conditioning Market

PENETRATION OF AIR CONDITIONING

The world air conditioning market has exceeded 100 billion US$ presenting a total increase close to 7 % compared to the previous year.

Almost 128,5 million units have been sold worldwide.

Most of the increase occurred in China and the Asia - Pacific zone where the global sales of air conditioning correspond almost 58 % of the world market.

China and Japan represent almost 83% of the total market in this area while important growth rates are observed in Myanmar, Vietnam, Hong Kong and Malaysia.

Cooling Energy Consumption

World Cooling Energy Consumption

1,25 PWh

Residential : 55 %

Commercial : 45 %

World Residential Energy : 23,7 PWh

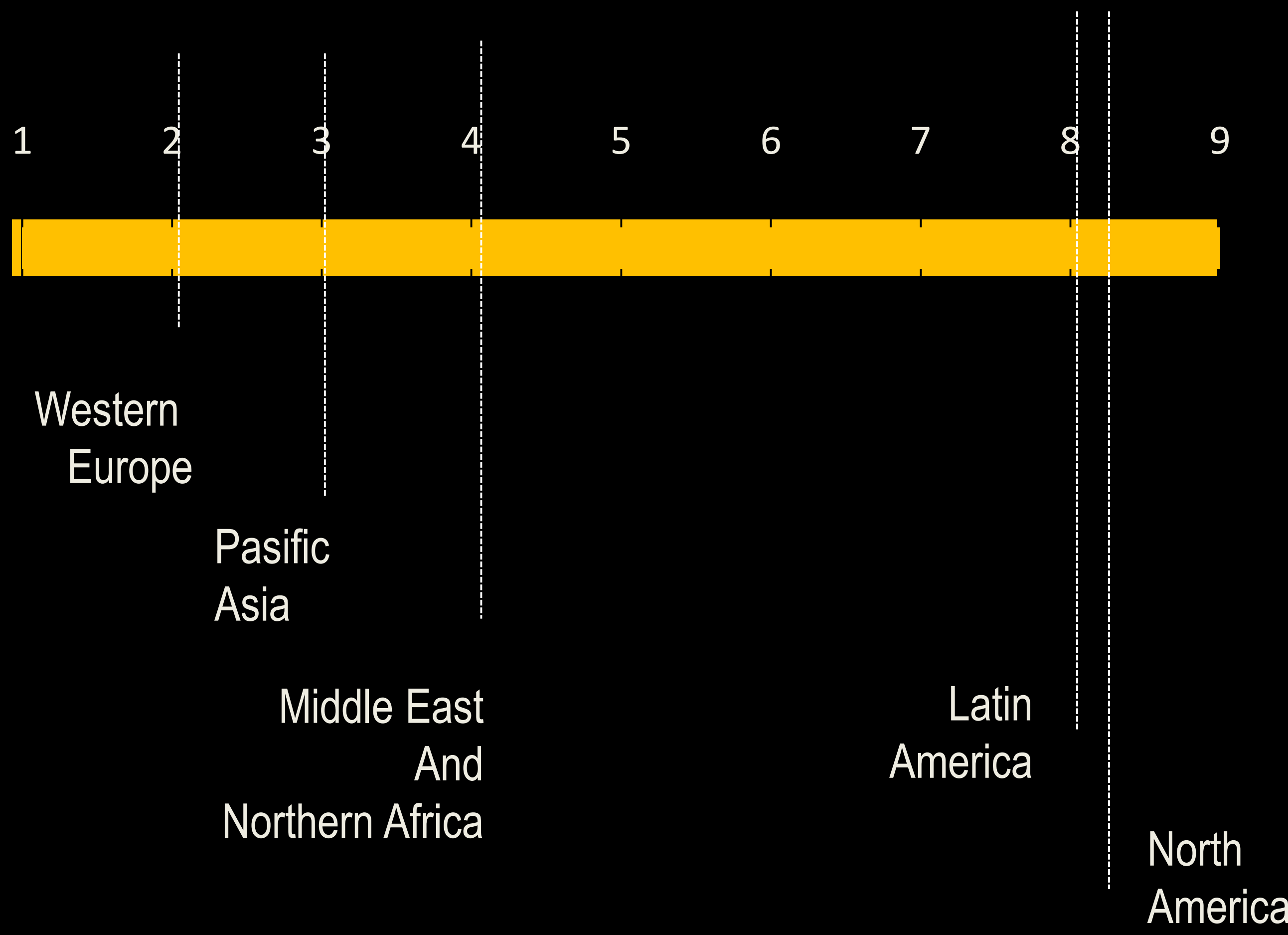
Cooling : 0,68 PWH or 2,9 %

World Commercial Energy : 8,4 PWh

Cooling : 0,56 PWH or 6,7 %

Cooling Energy Consumption

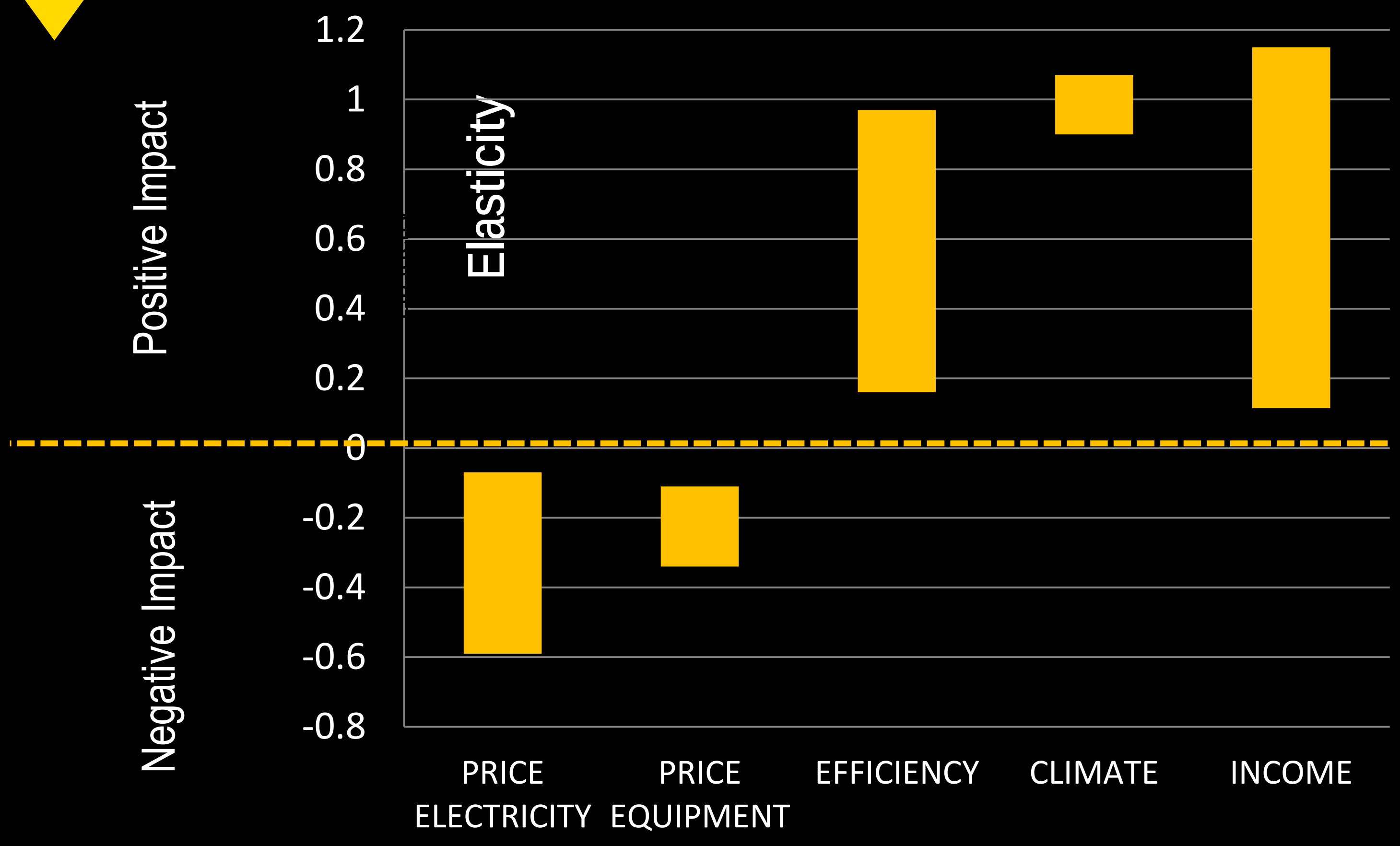
Energy Intensity Residential Sector (kWh/m2)



Drivers Affecting Air Conditioning

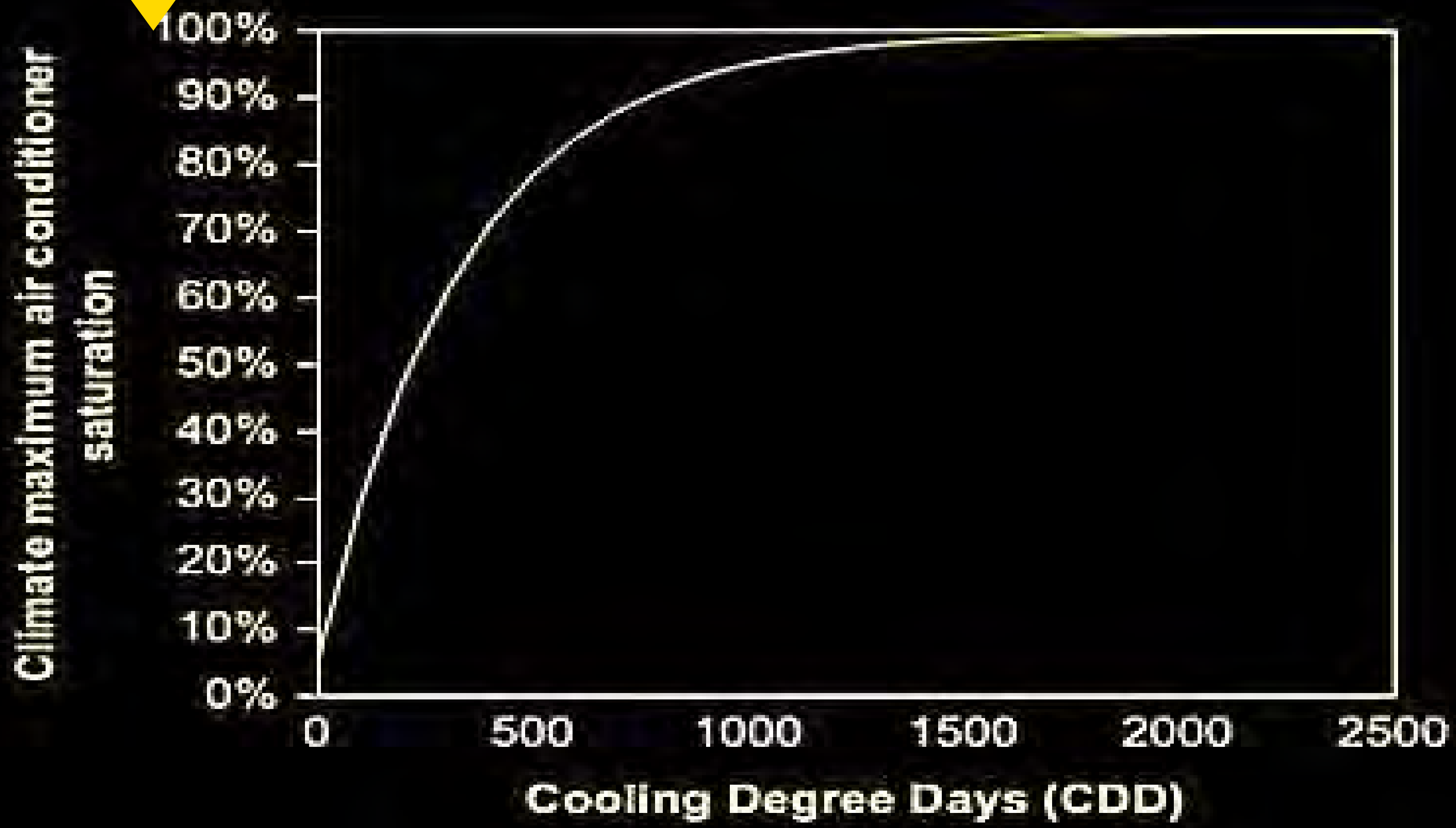
Drivers Affecting Air Conditioning

Range of Air Conditioning Elasticities



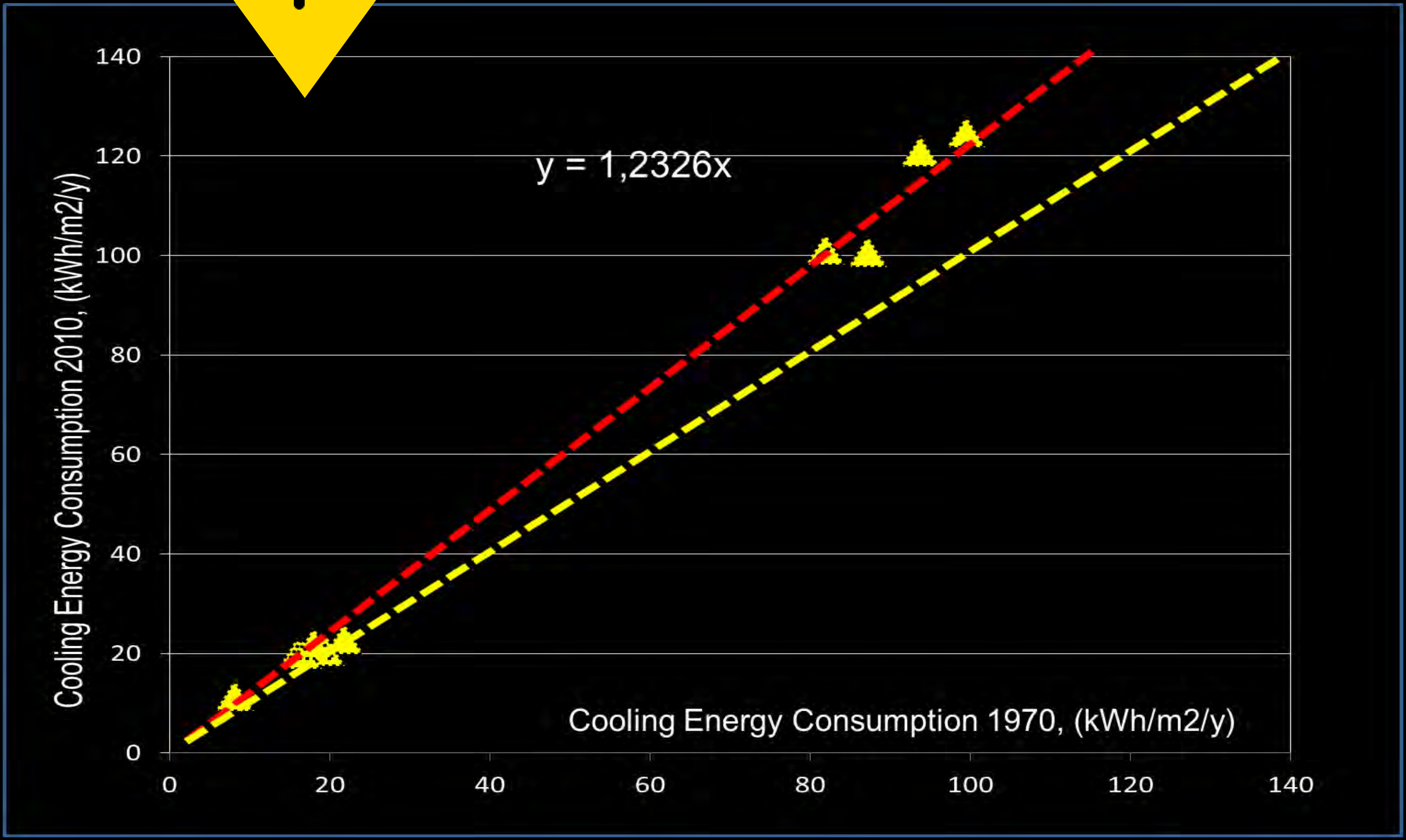
The Potential Impact of Climate Change

Air Conditioning Penetration depends on the Cooling Degree Days



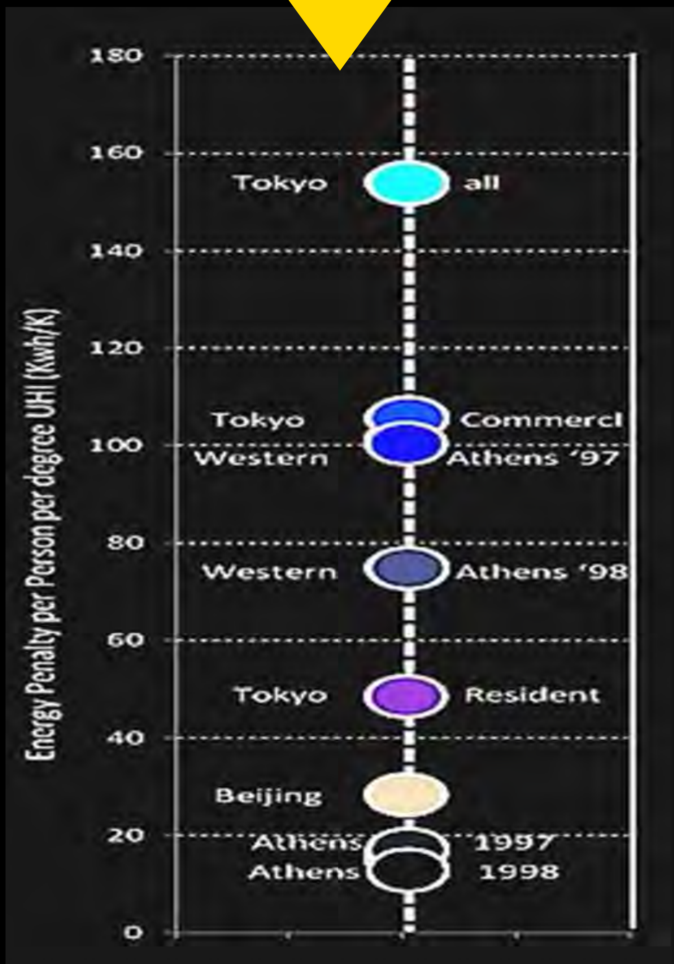
The Potential Impact of Climate Change

Existing Increase of the Cooling Load of Individual Buildings



The Potential Impact of Climate Change

Existing Increase of the Cooling Load of Buildings because of the Urban Heat Island



Global Energy Penalty per Person and per degree of the UHI intensity, GEPPI

It has the same characteristics as the GEPP index while it includes the local UHI intensity as additional information.

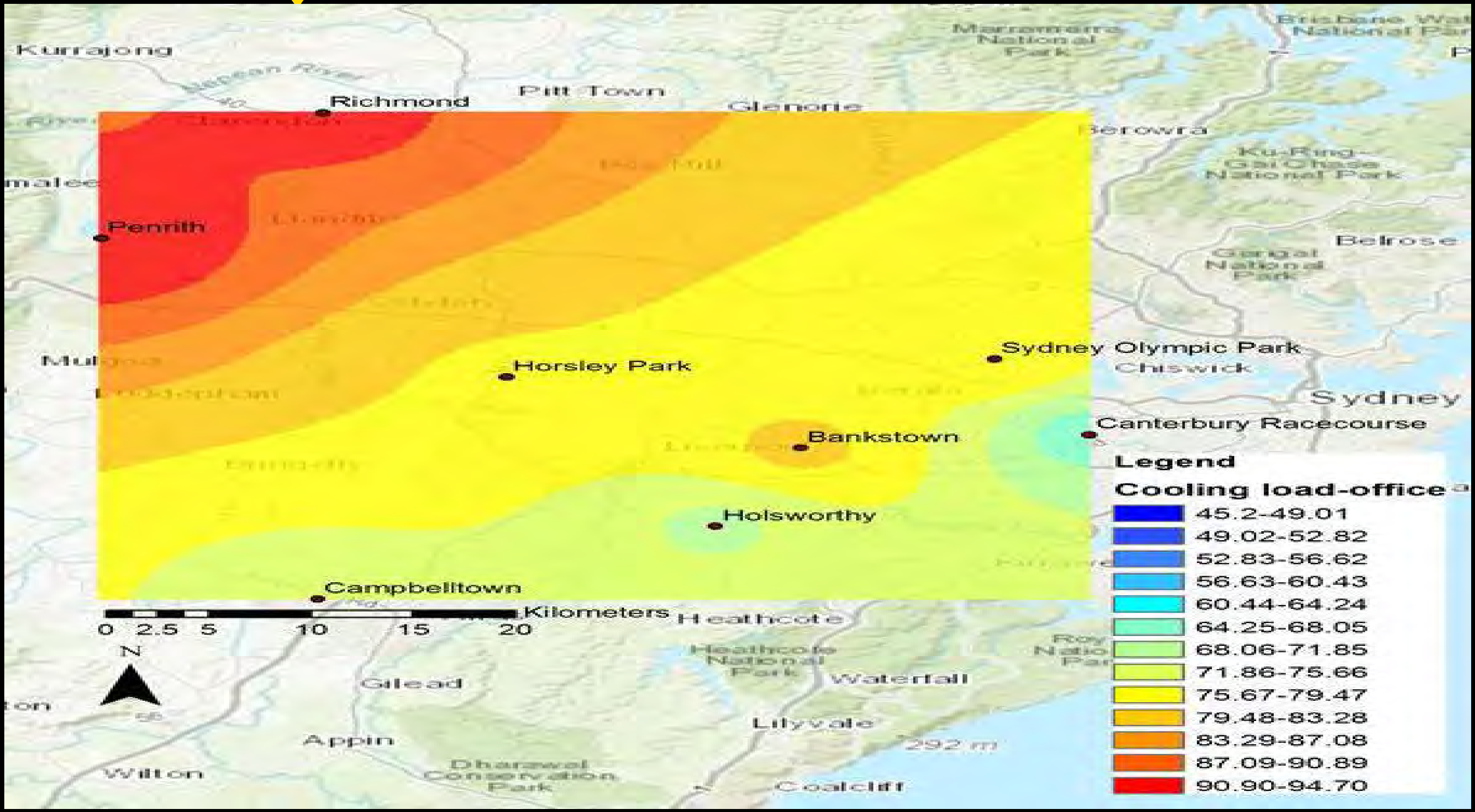
Values of GEPPI varied between 15 kWh/k for the Municipality of Athens to 154 kWh/K for Tokyo.

UHI triggers an average Global Energy Penalty per Person and per degree of the UHI intensity, GEPPI, close to

68 kWh/p/K.

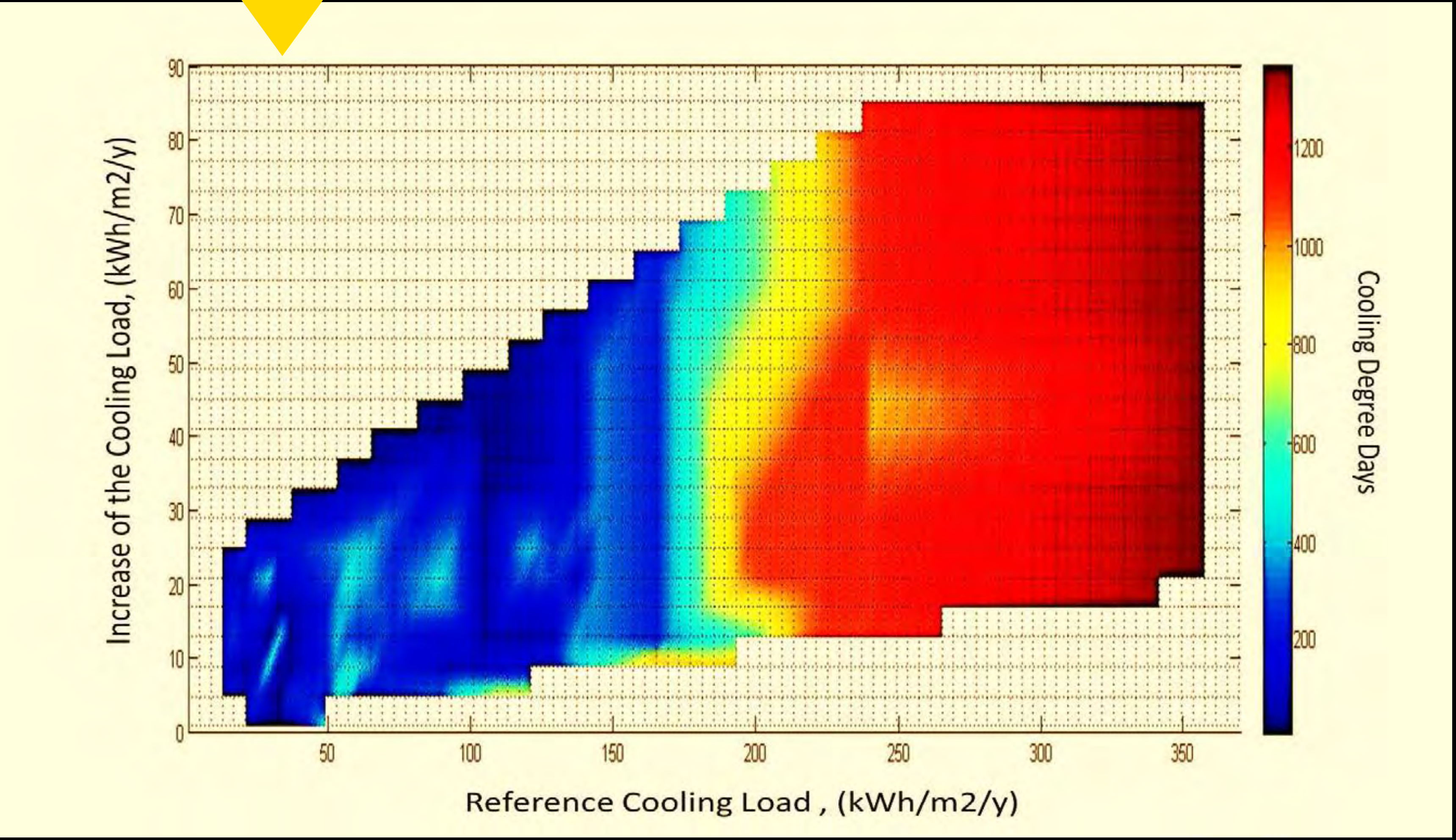
The Impact of Climate Change

Future Increase of the Cooling Degree Days



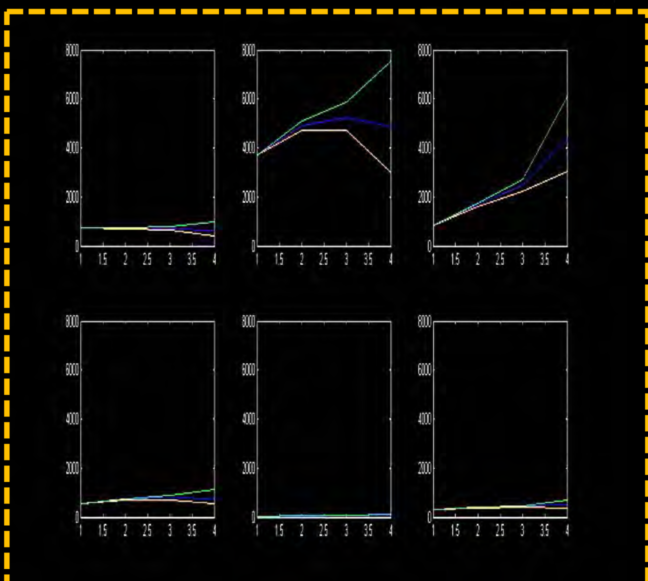
The Potential Impact of Climate Change

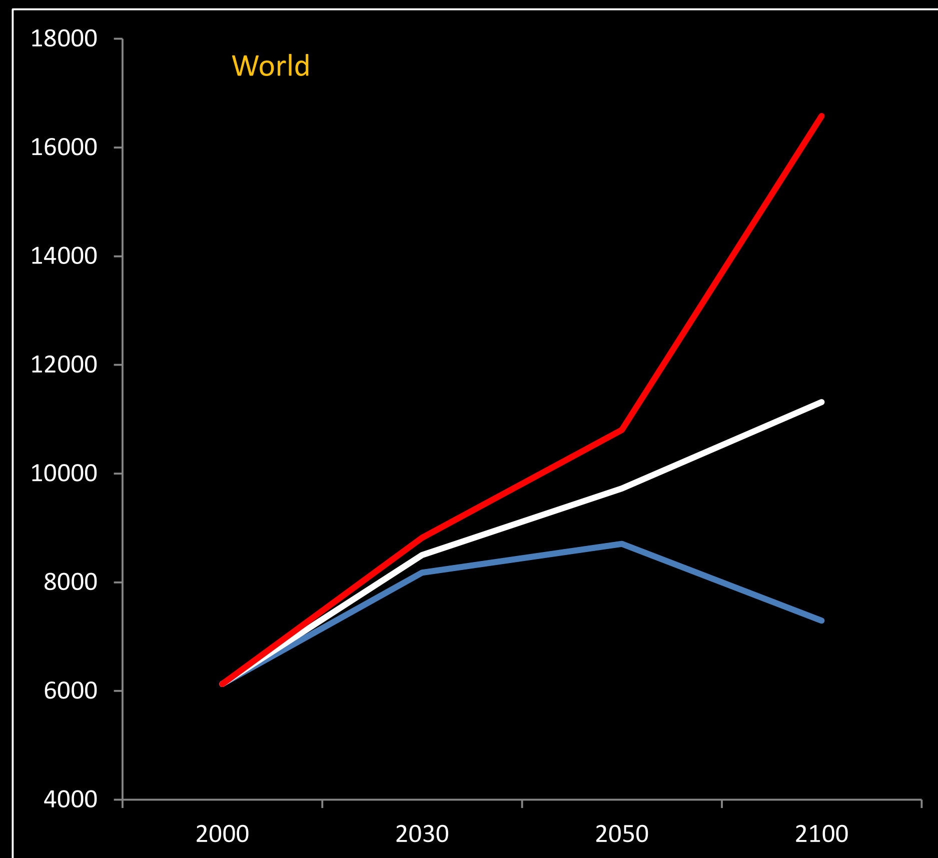
Existing Increase of the Cooling Load of Individual Buildings from 144 Case studies around the World



The Potential Impact of Population Increase

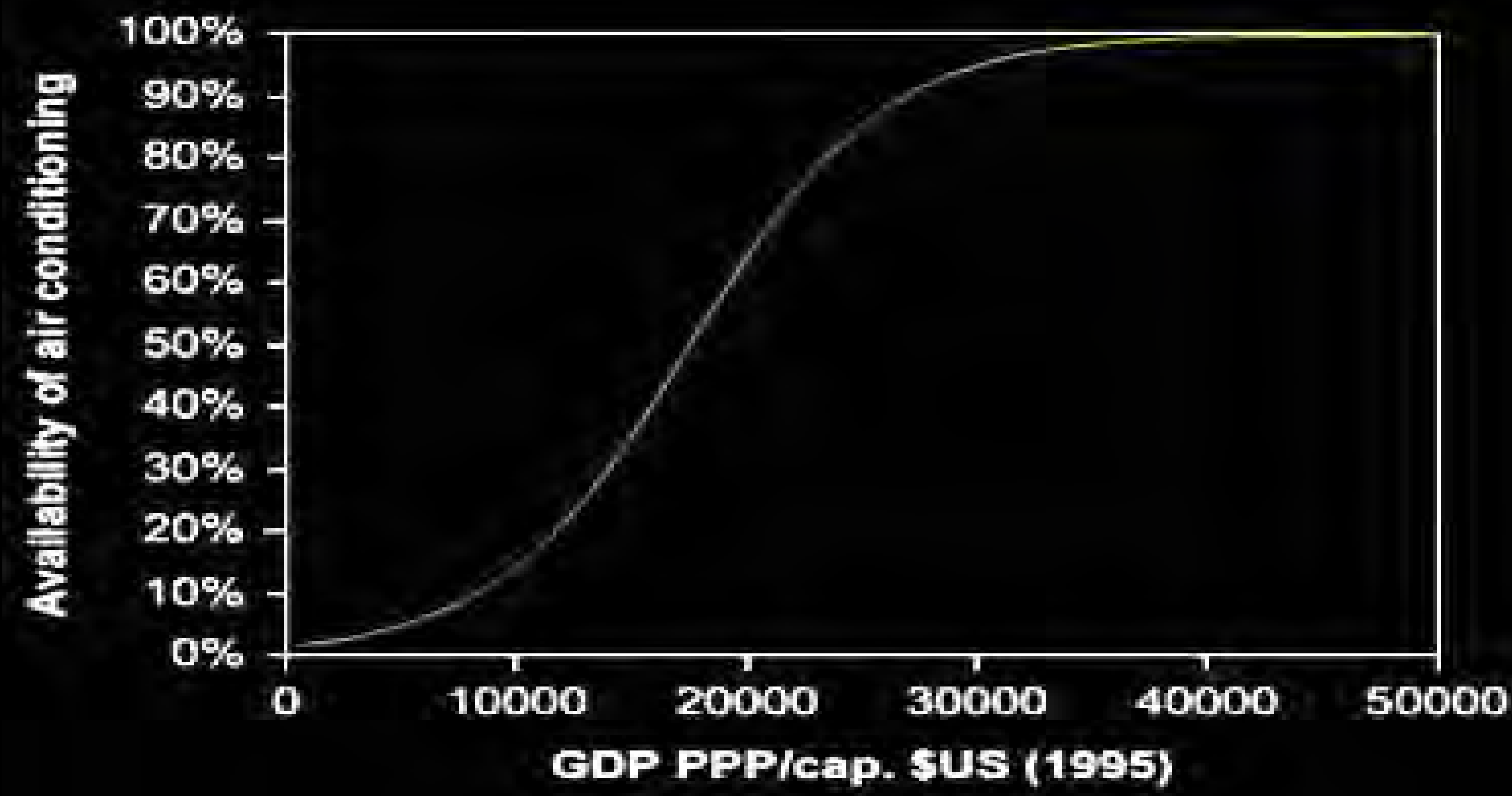
Forecasts of the United Nations about the Future Population





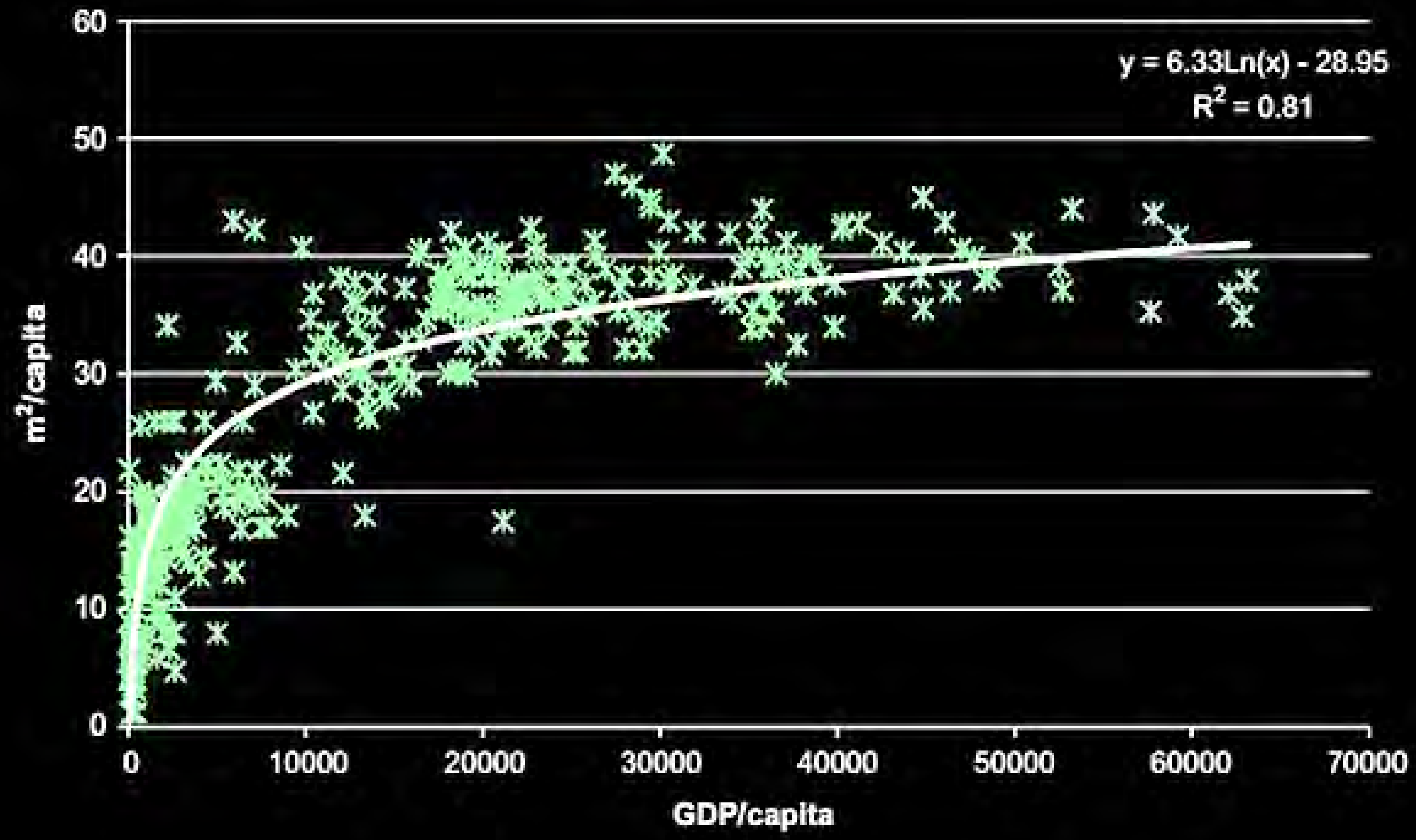
The Potential Impact of Increased Income

Air Conditioning Penetration depends on the Income Levels



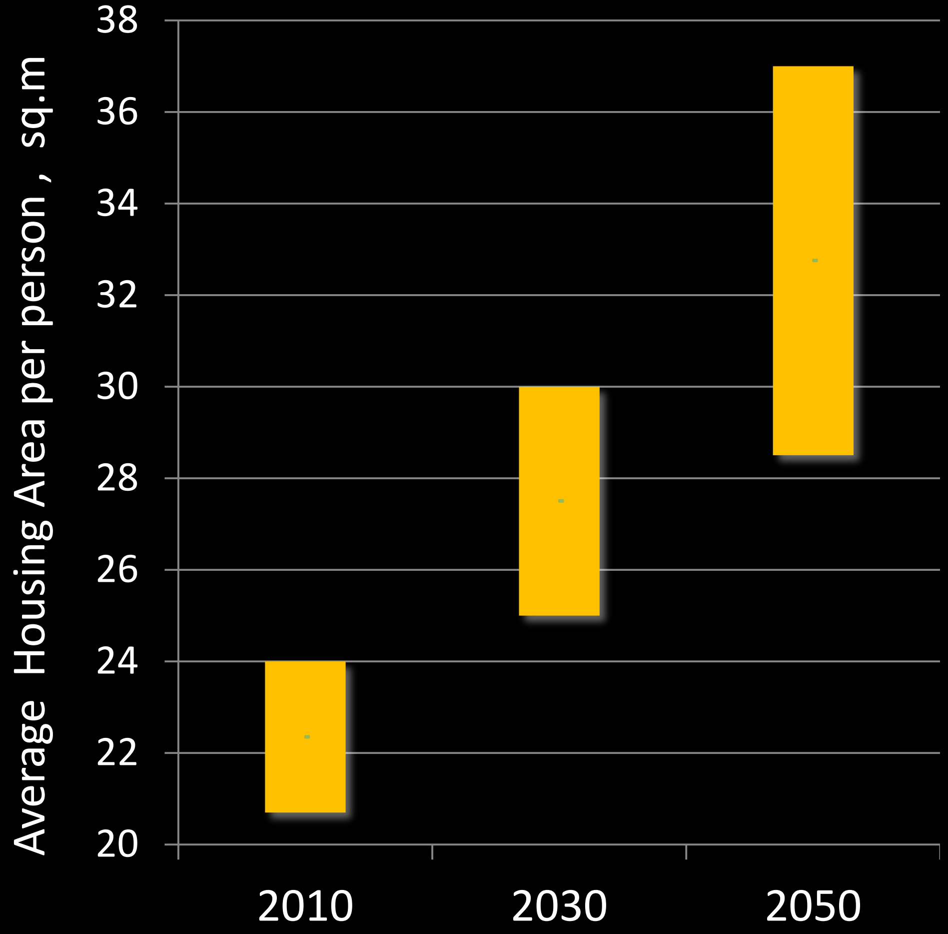
The Potential Impact of Increased Income

Air Conditioning Penetration depends on the Income Levels



The Potential Impact of Housing Size

How much the Future Size of Houses will be ?



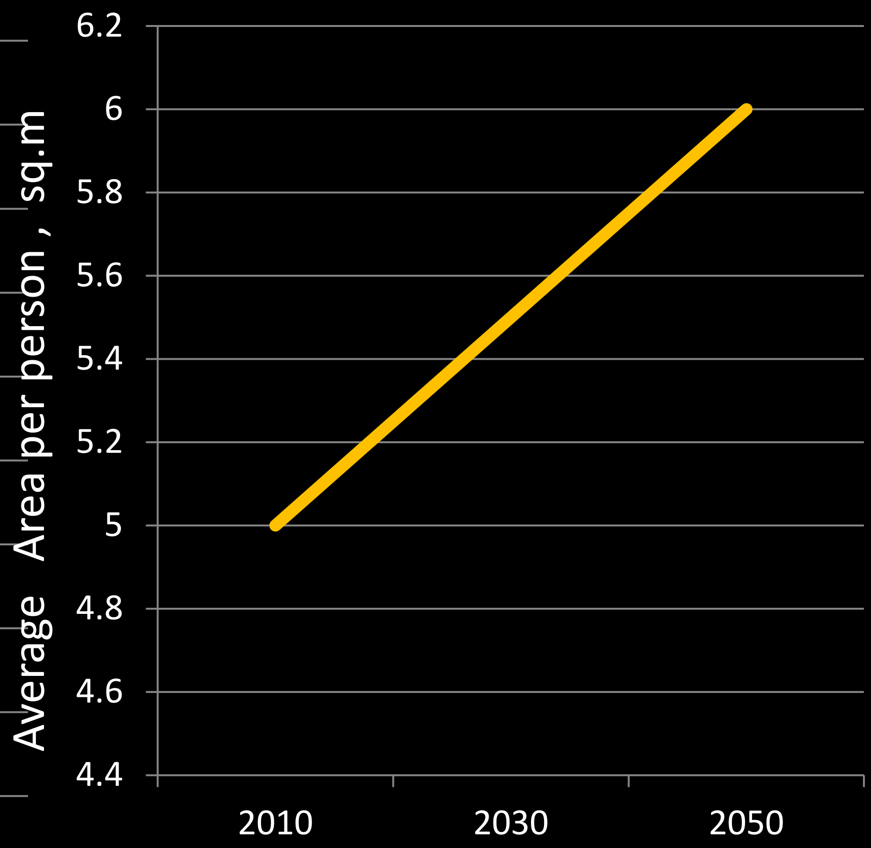
The expected increase of the total residential area between 2005 and 2050 is close to 500%

The Potential Impact of Building Size

How much the Future Size of Commercial buildings will be ?

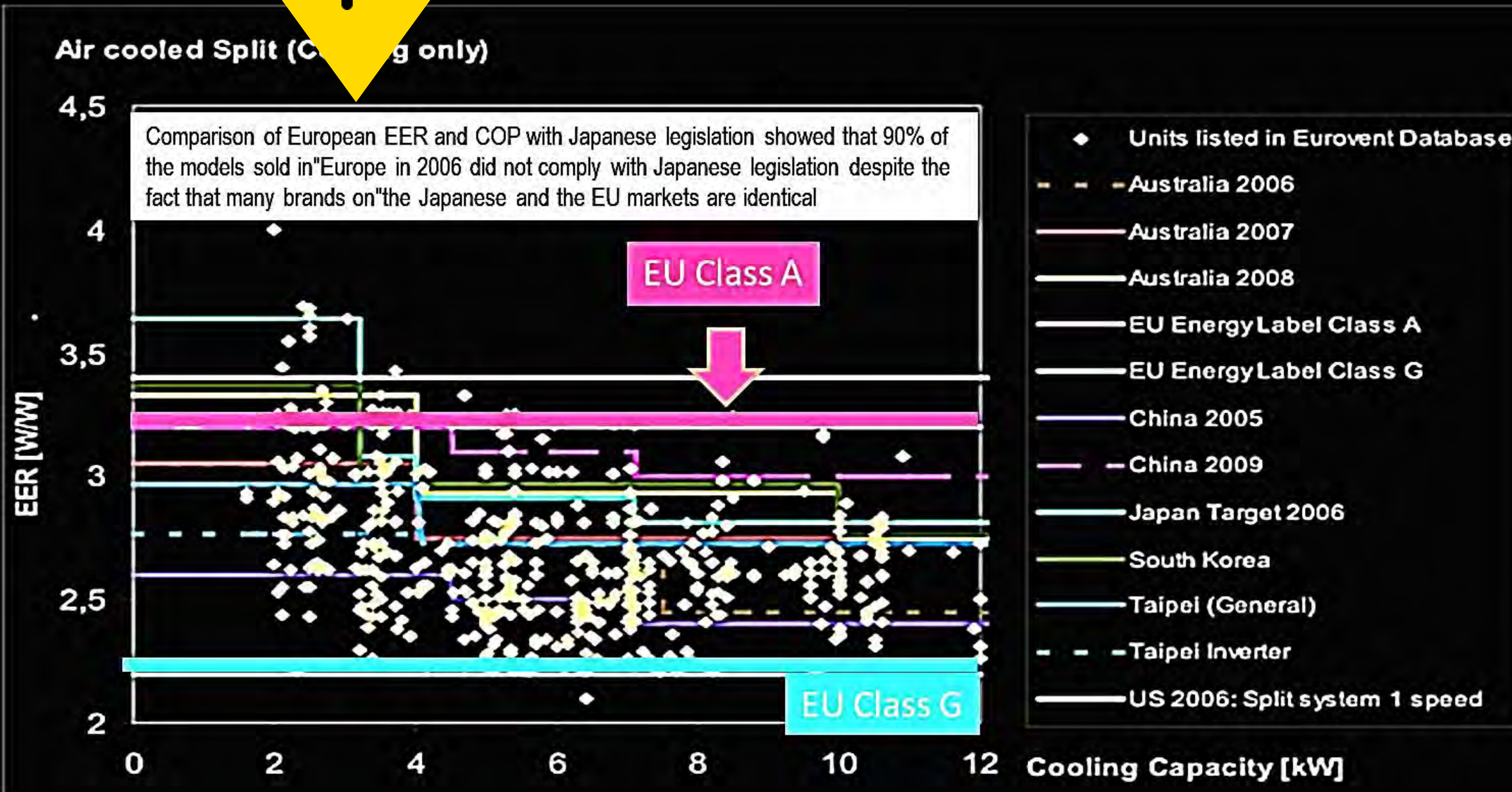
The highest increase rate of the commercial floor area between 2005 and 2050, is expected in North Africa and Middle East area, (549 %), the Central and Eastern Europe, (483 %), and South Asia, (471 %).

The smaller increase is expected in North America, (51 %).



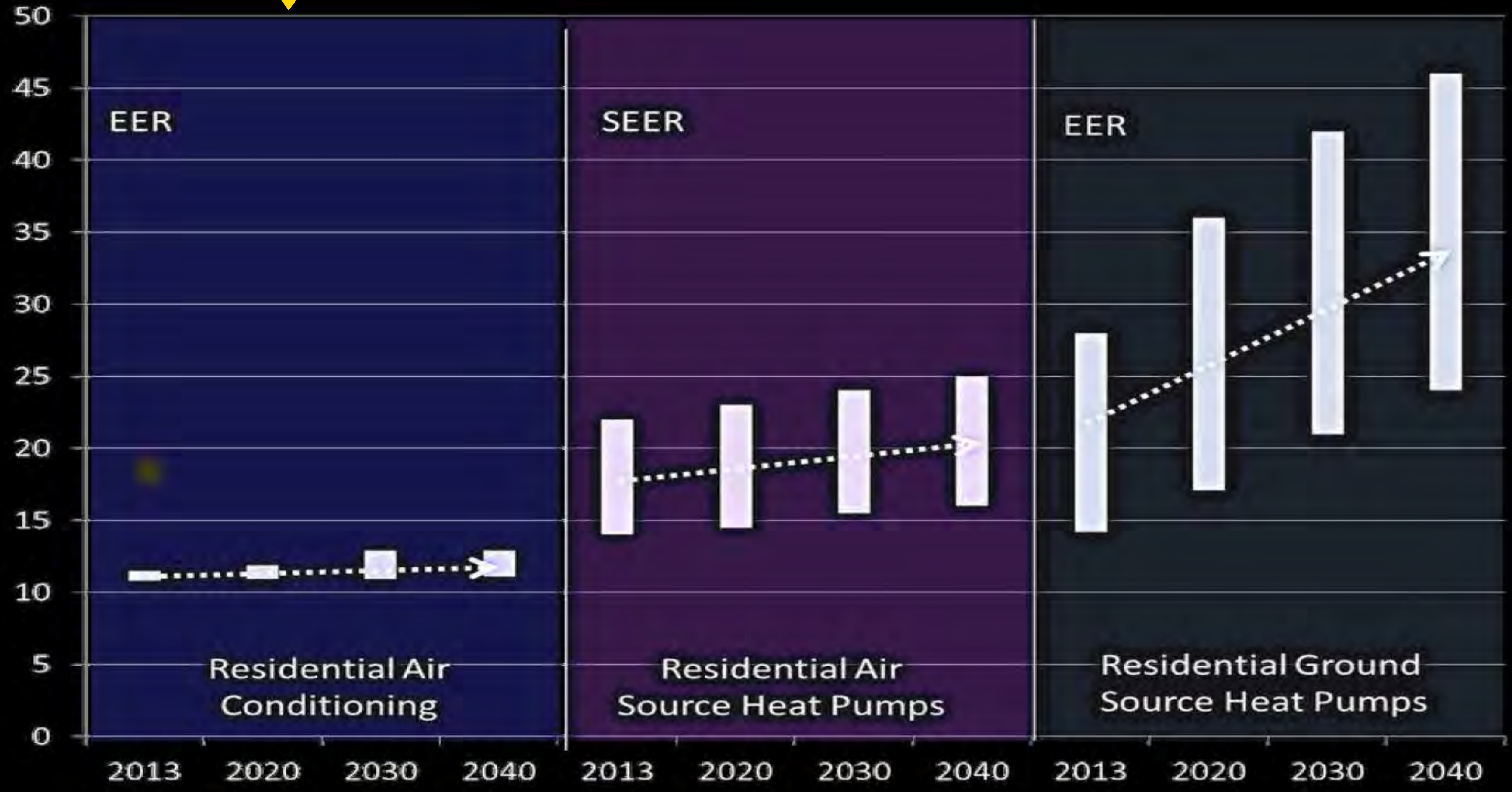
The Impact of Advanced AC Technology

The Actual Efficiency of Air Conditioning



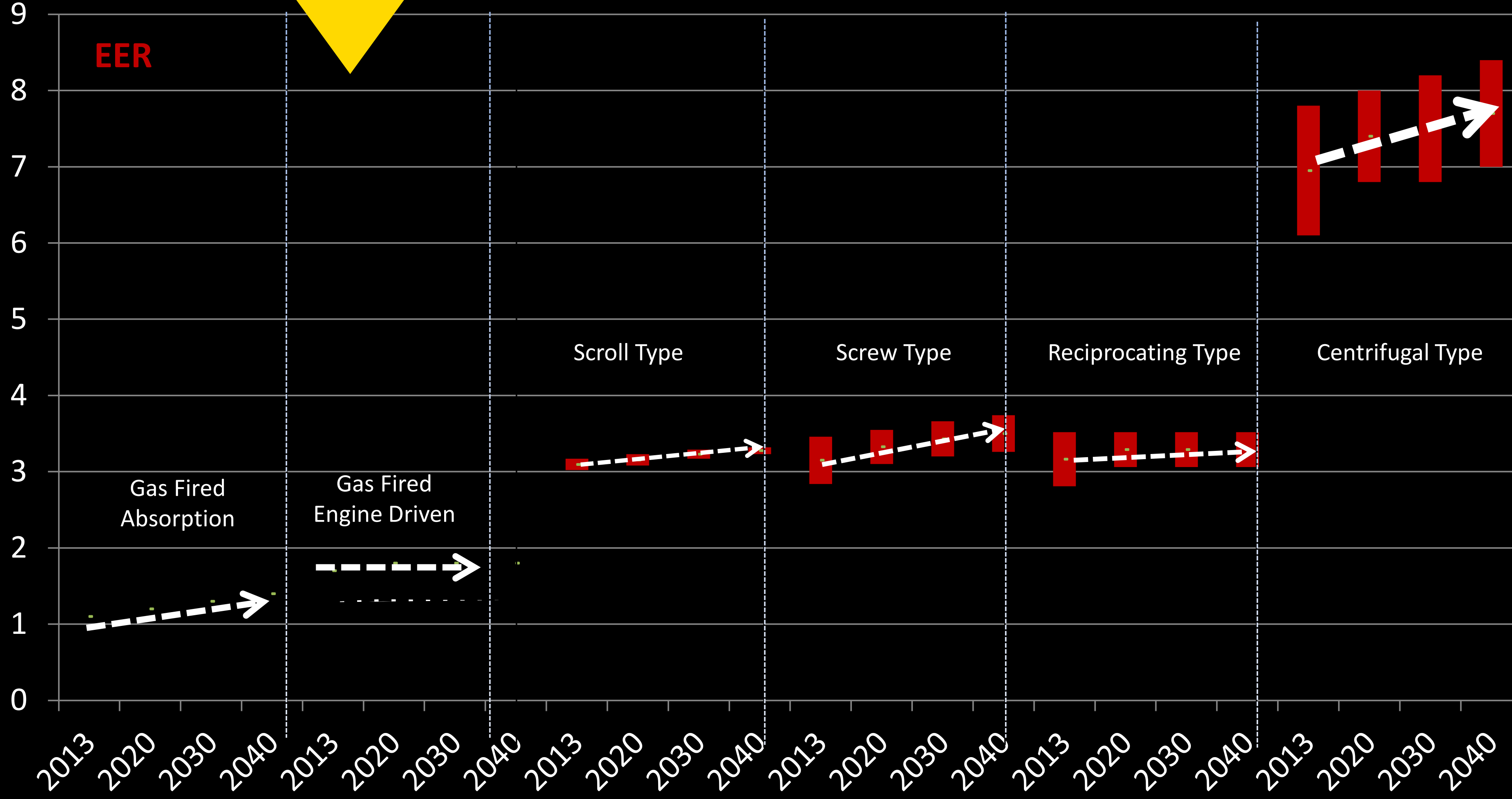
The Impact of Advanced AC Technology

The Future Efficiency of Air Conditioning



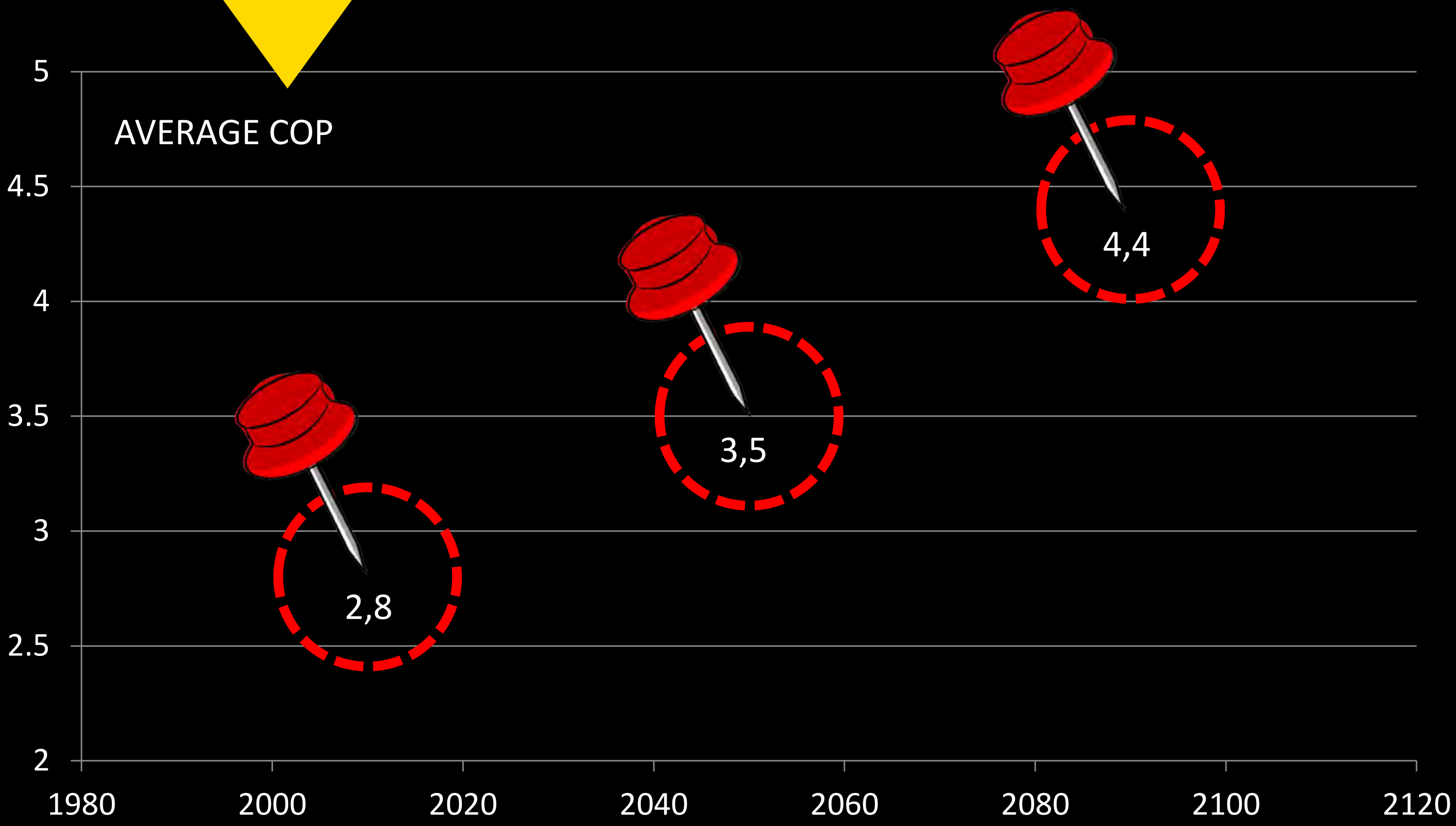
The Impact of Advanced AC Technology

The Future Efficiency of Air Conditioning



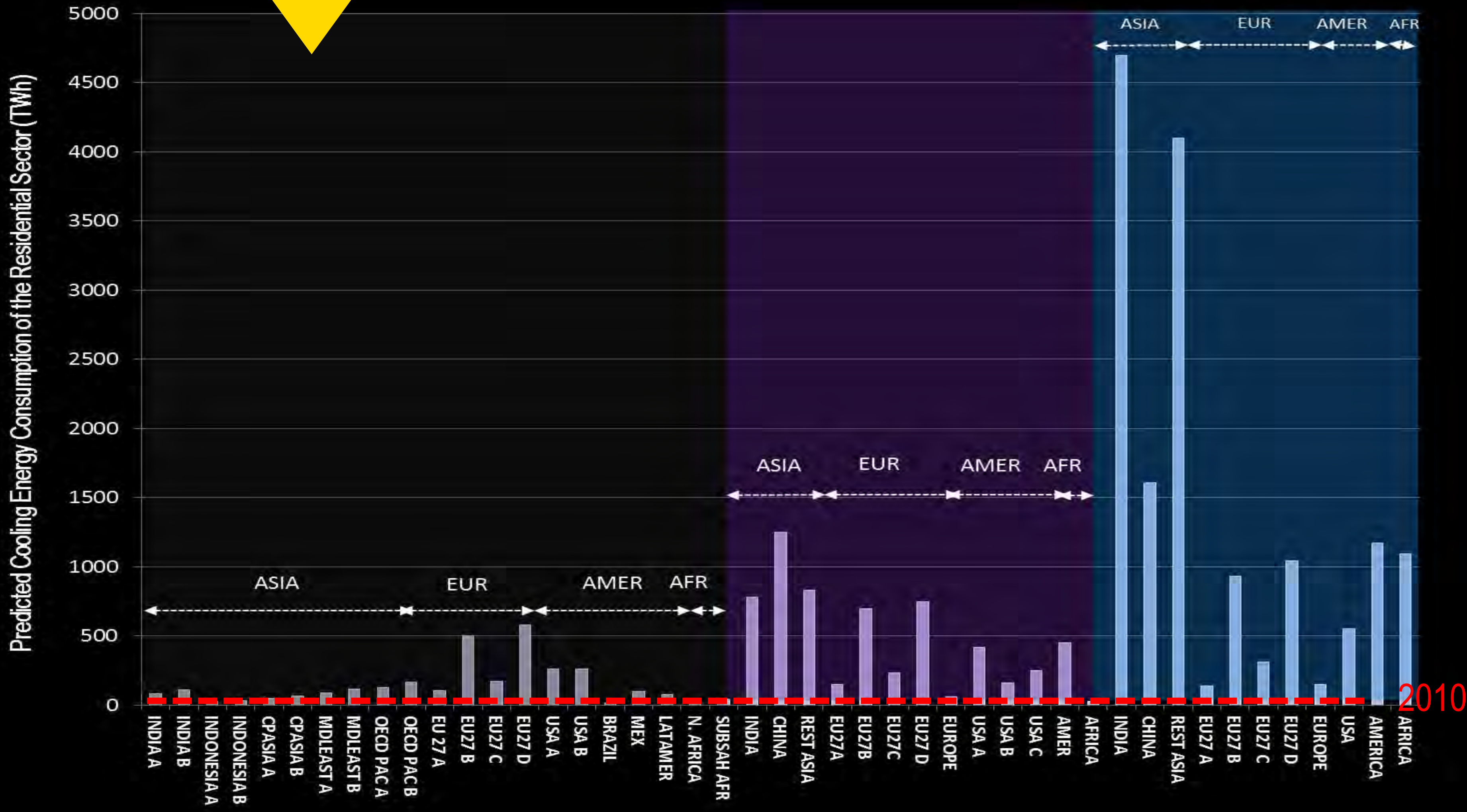
The Impact of Advanced AC Technology

The Future Efficiency of Residential Air Conditioning



The Impact of Advanced AC Technology

The Future Consumption of Residential Air Conditioning



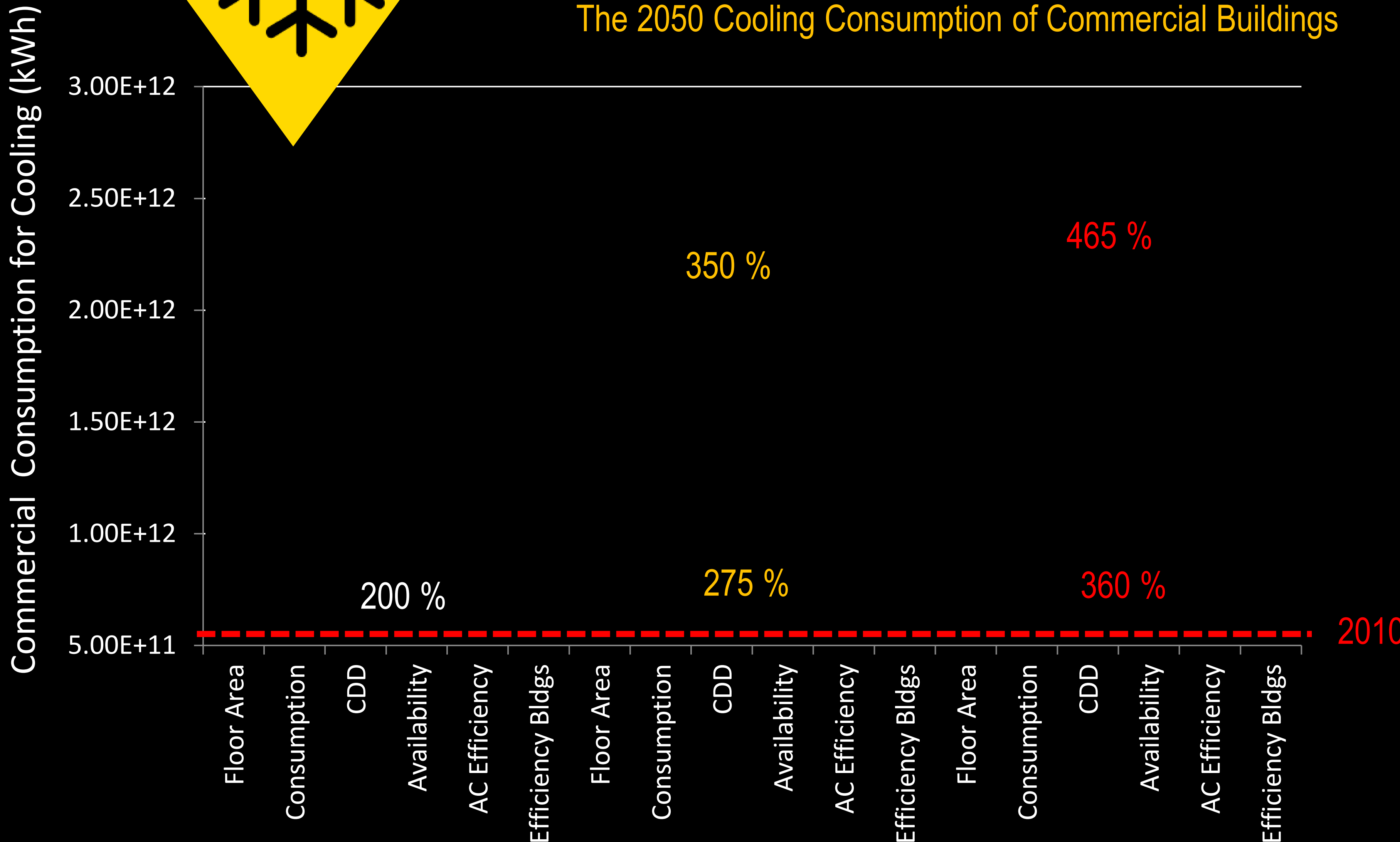
The Future Consumption of Air Conditioning

The 2050 Cooling Consumption of Commercial Buildings

	Low Development Scenario	Average Development Scenario	High Development Scenario
Floor Area, (m2)	8E10	9,9E10	1,2E11
Cooling Consumption , (kWh/m2)	13	14	15
Temp Increase (K)	0-1	1-2	2-3
Increase of AC penetration (%)	10	20	30
Increase of AC Efficiency (%)	4	12	20
Improve Energy Performance Bldngs (%)	10	20	30

The Future Consumption of Air Conditioning

The 2050 Cooling Consumption of Commercial Buildings



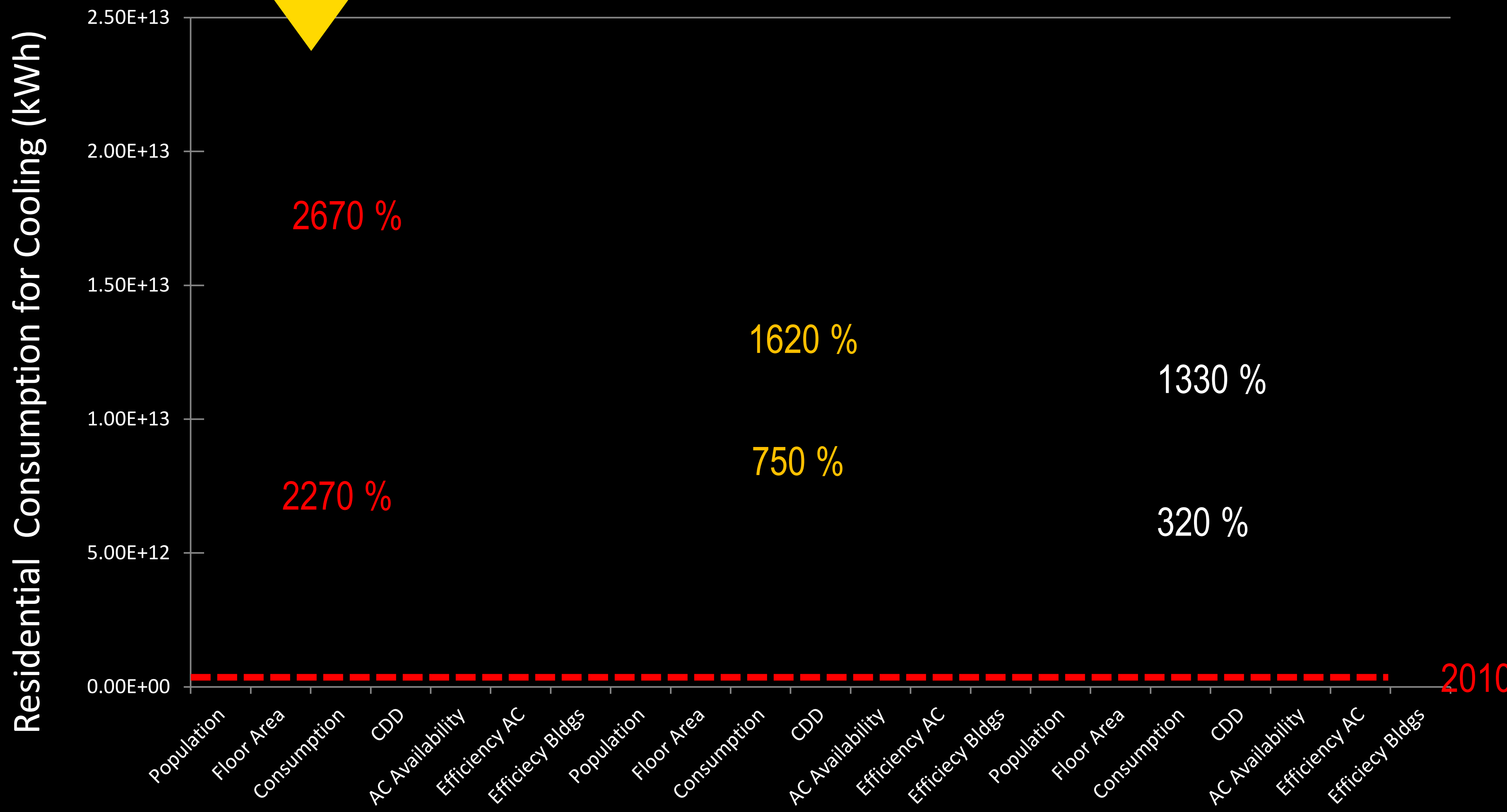
The Future Consumption of Air Conditioning

The 2050 Cooling Consumption of Residential Buildings

	Low Development Scenario	Average Development Scenario	High Development Scenario
Floor Area, (m2/p)	28,5	30	37
Cooling Consumption , (kWh/m2)	3,7	4,1	5
Temp Increase (K)	0-1	1-2	2-3
Increase of AC penetration (%)	137	375	762
Increase of AC Efficiency (%)	4	12	18
Improve Energy Performance Bldngs (%)	10	20	30
Population	8,7	9,7	10,8

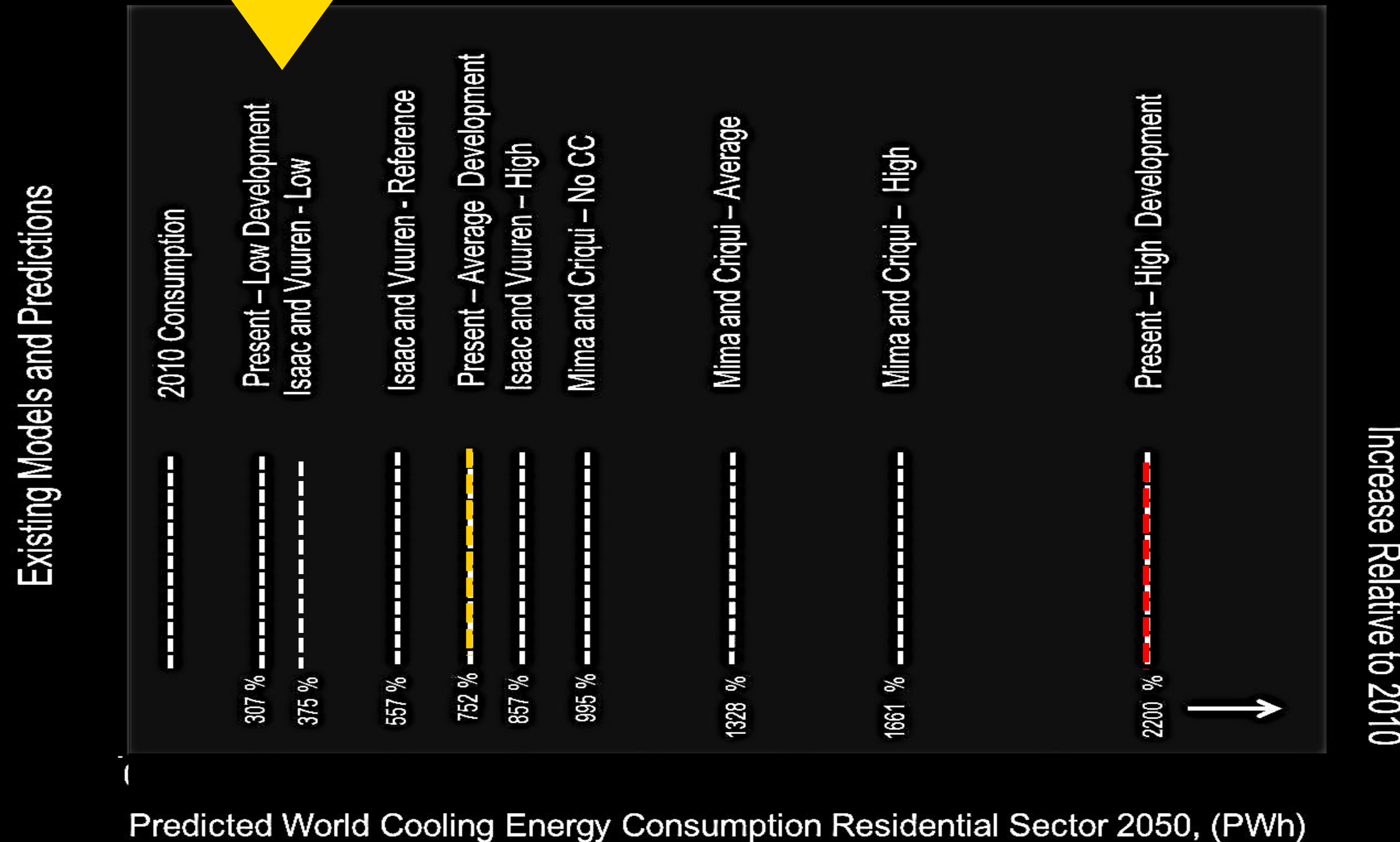
The Future Consumption of Air Conditioning

The 2050 Cooling Consumption of Residential Buildings



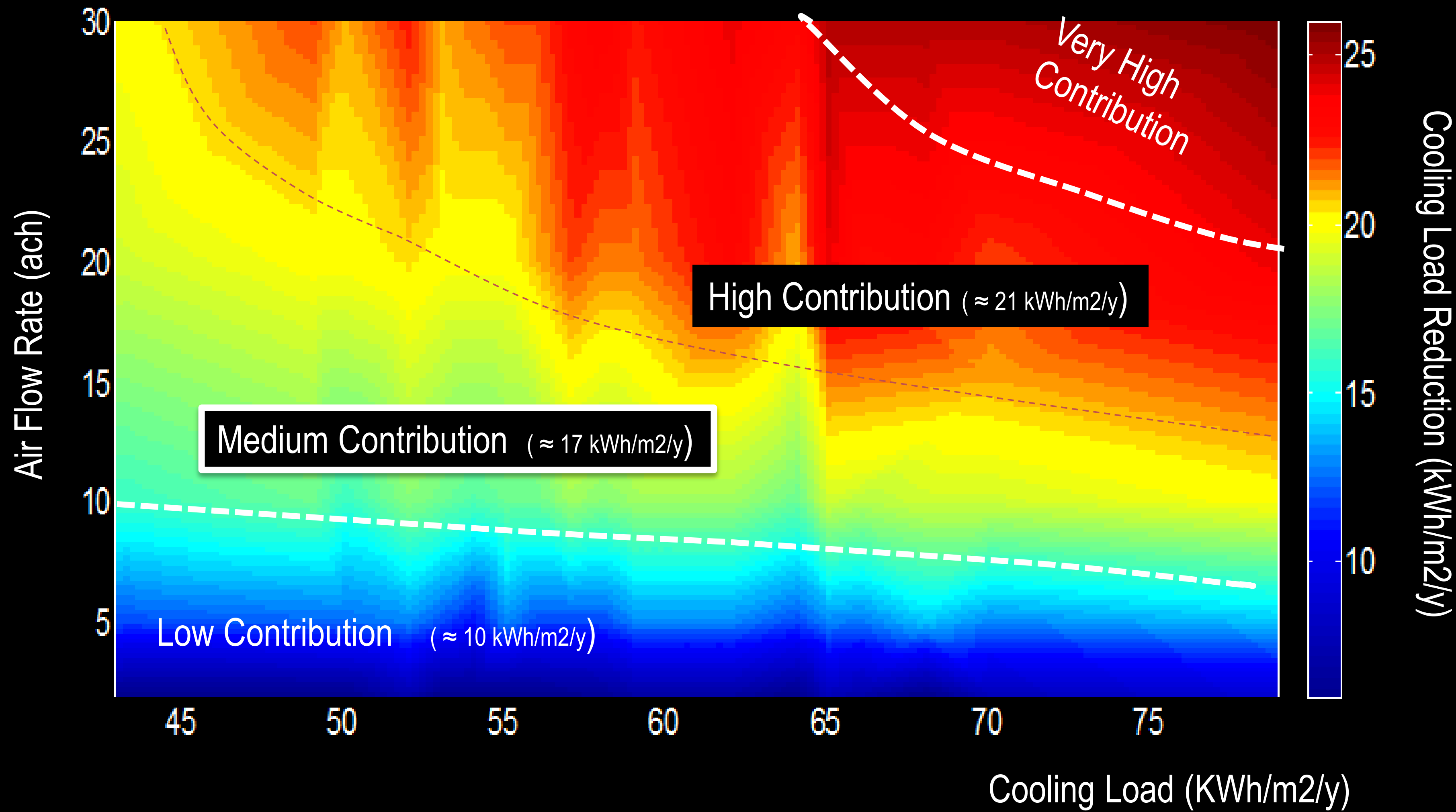
The Future Consumption of Air Conditioning

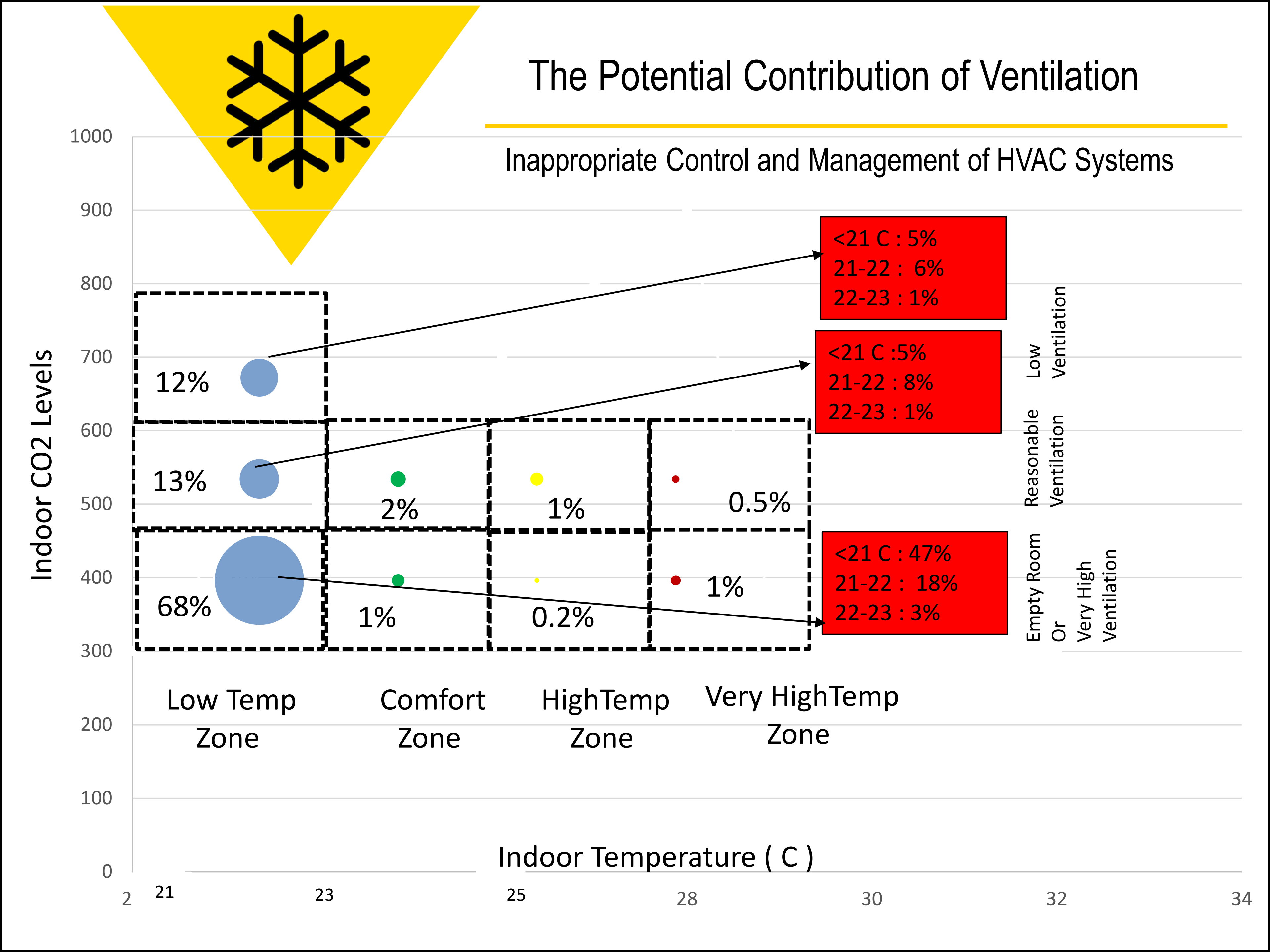
The 2050 Cooling Consumption of Residential Buildings



The Potential Contribution of Ventilation

The Theoretical Contribution of Night Ventilation




The Potential Contribution of Ventilation
Inappropriate Control and Management of HVAC Systems
Indoor CO2 Levels
1000
900
800
700
600
500
400
300
200
100
0
12%
13%
68%
2%
1%
1%
0.2%
0.5%
1%
<21 C : 5%
21-22 : 6%
22-23 : 1%
<21 C :5%
21-22 : 8%
22-23 : 1%
<21 C : 47%
21-22 : 18%
22-23 : 3%
Low Ventilation
Reasonable Ventilation
Empty Room Or Very High Ventilation
Low Temp Zone
Comfort Zone
HighTemp Zone
Very HighTemp Zone
Indoor Temperature (C)
2
21
23
25
28
30
32
34

The Air Conditioning Market

CONCLUSIONS

Local and Global Climate Change, increase of the world's population and potential economic growth result in significant increase of the energy demand for cooling.

While, in 2010, the global cooling consumption of the residential sector represented almost 4,4 % of the total heating and cooling needs of buildings, it is expected to increase up to 35 % in 2050 and 62 % in 2100.

In parallel, although the heating energy demand is expected to remain constant or slightly decrease in the future, the total heating and cooling consumption of residential buildings may increase up to 67 % in 2050 and 166 % in 2100 compared to the 2010 levels intensifying the global energy and environmental problems

The Air Conditioning Market

CONCLUSIONS

Higher energy consumption for cooling is strongly associated with a very significant increase of the peak electricity demand that oblige utilities to build additional power plants to satisfy the extra needs for electricity.

Significant future investments to increase the power capacity may raise the cost of electricity and put in strength the health and the quality of life of the low income and vulnerable population

Cooling the Future

CONCLUSIONS

To face the problem of the future growth of the cooling energy needs and of the associated increase of climatic vulnerability, three major clusters of policy actions may be identified and proposed:

Actions Aiming to Mitigate the Global and Local Climate Change. Decrease of the greenhouse gas emissions and counterbalance of the urban heat island may significantly limit the amplitude of the temperature increase and the strength of the energy impact of the climatic change.

Policies aiming to reduce the sources and enhance the sinks of temperature anomaly, like the use of clean fuels and mainly of renewable sources for power generation, higher energy efficiency, rationalization of the energy demand, intelligent and efficient use of energy, smart and resilient technologies for cities, green energy distribution systems, in association with urban mitigation technologies like cool and green materials and reduction of the anthropogenic heat, could seriously reduce the future demand for cooling, and protect the vulnerable population during the extreme climatic events.

Cooling the Future

CONCLUSIONS

Actions aiming to adapt the Building Sector and improve its Energy Performance.

A massive energy rehabilitation of the existing building stock requires a further reduction of the cost of the energy efficient building technologies.

Given the actual technological status, the necessary investments to reduce drastically the global building energy consumption in the world, are tremendous.

It is characteristic that only in Europe, the necessary investments to achieve an almost 80 % reduction of the building energy needs by 2050 are between 16-24 trillion Euros.

In parallel, the unprecedented urbanization and the increase of the population asks for the construction of billions of new buildings mainly in less developed, quite poor zones of the planet that unfortunately suffer the more the consequences of the climate change.

It is very crucial all these new buildings present significantly low energy consumption through the use of reduced cost energy efficiency technologies.

Cooling The Future

CONCLUSIONS

Actions aiming to Improve the Efficiency of Mechanical Air Conditioning and Alternative Cooling Technologies.

Although, the efficiency of the mechanical air conditioning systems has improved impressively, it is not sufficient to counterbalance the tremendous increase of the future cooling demand.

Breakthrough cutting edge technologies have to be developed through intensive scientific and industrial research.

In parallel, the performance of the alternative cooling dissipation technologies associated with the use of low temperature environmental sinks has to improve further in order to provide low cost and reliable coverage of a fraction of the cooling needs.

NEW METHOD TO TEST AIRTIGHTNESS OF NEARLY ZERO ENERGY DWELLINGS

Wouter Borsboom, TNO
Timothy Lanooy, ACIN
Wim Kornaat, TNO
Willem de Gids, VentGuide

TNO innovation for life

VLA Vereniging Leveranciers Luchttechnische Apparaten

UNETO-VNI

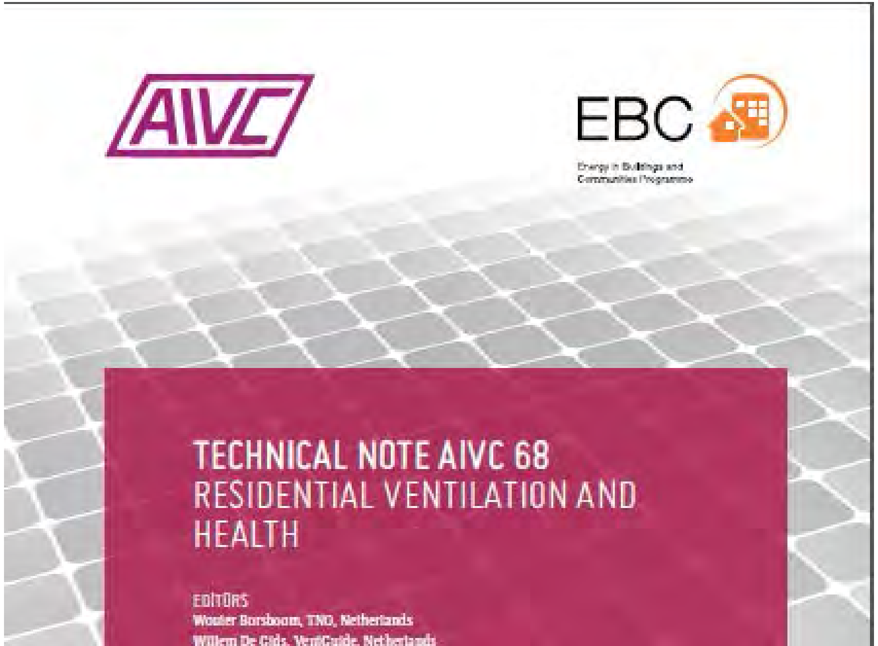
TKI URBAN ENERGY Topsector Energie

Rijksdienst voor Ondernemend Nederland

ACIN INSTRUMENTEN BV

WOUTER BORSBOOM, TNO

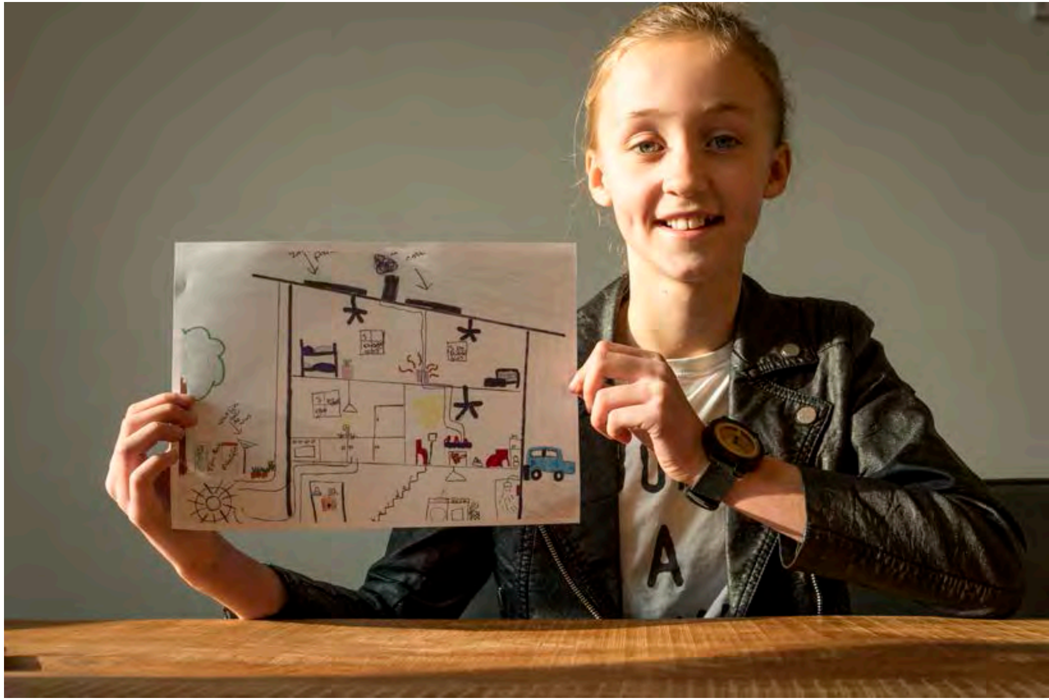
Business consultant, energy built environment.



Example nearly zero energy dwelling: Rc=5-6, N50 ach 0.8, heat recovery, heat pump, PV -> can be built without subsidies

WHAT SHOULD A HEALTHY ENERGY EFFICIENT DWELLING OFFER?

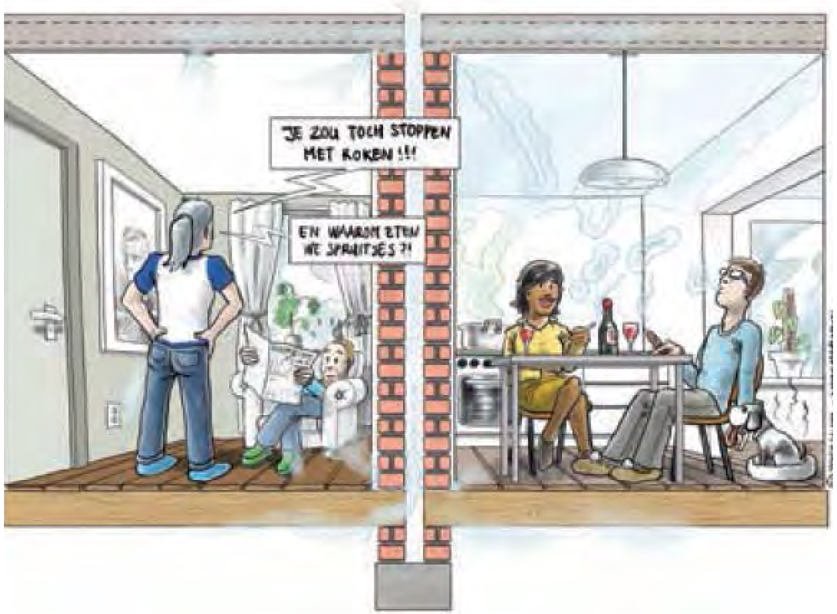
- A dwelling with sufficient ventilation
- A cool house in the summer
- A dwelling with less exposure to conterminants



GOOD PERFORMANCE OF VENTILATION NEEDS AIRTIGHT DWELLINGS

- Airtightness at least N50 < 4
- High preformance dwelling are mostly airtight **N50 < 1 to**:
  - **Reduce the installed capacity** heating / cooling
  - **Reduce energy demand** Heating & Cooling

Darling, you told me that you stopped smoking..

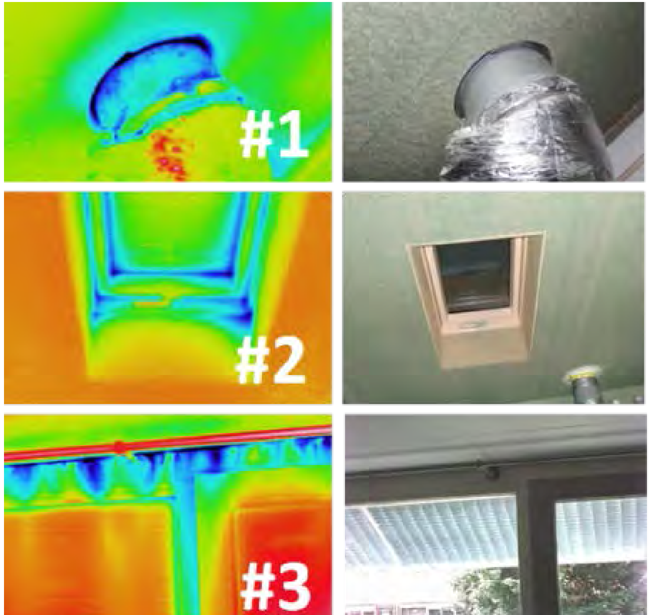


Bron: Willem Koppen, Koppen Bouwexperts

PROBLEMS IN QUALITY CONTROL

- Specified airtightness is not met in many cases
- **Effects**:
  – **Roomset points is not met** through insufficient capacity
  – **Thermal comfort**
    · temperature control
    · draught
  – **Reduced indoor air quality** trough advantitious ventilation
  – **Increased energy bill** through extra heating and cooling demand
  – Example renovation: **design ach 3, but realized ach 15**

Top 3 air-leakages in 13 nearly zero energy dwellings



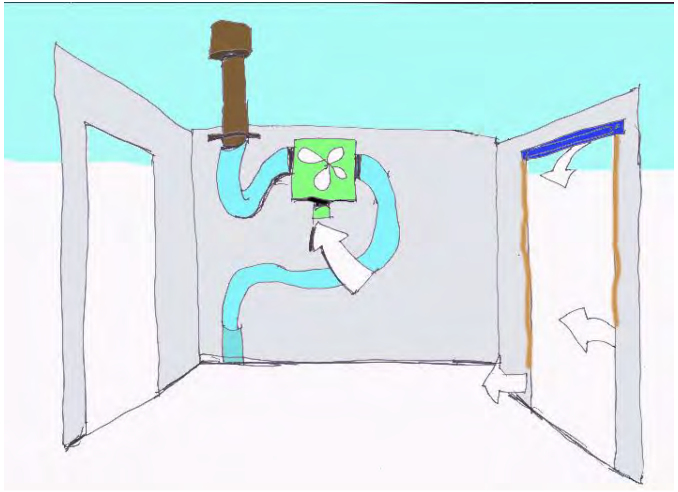
NEED FOR 100% QUALITY CHECKS AIRTIGHTNESS

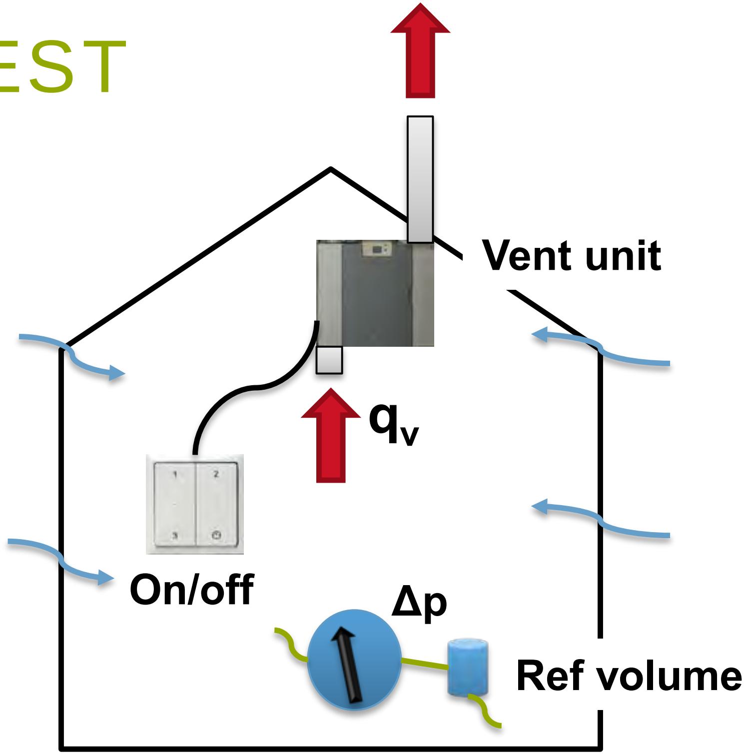
- Both new and retrofitted dwellings
- Meet European Carbon reduction targets
- Last week in the Netherlands **statement** “healthy living without gas heating” by the **building industry,** 21 companies and associations to perform a **100% check of airtightness** and ventilation and **N50 < ach 1,5**

QUICK & SIMPLE AIRTIGHTNESS TEST

Reason of the research:
The association of manufactors of ventilation systems and installers joint forces: The challenge is to make **an airtightness test method suitable for all kind of craftsmen and inspectors.**

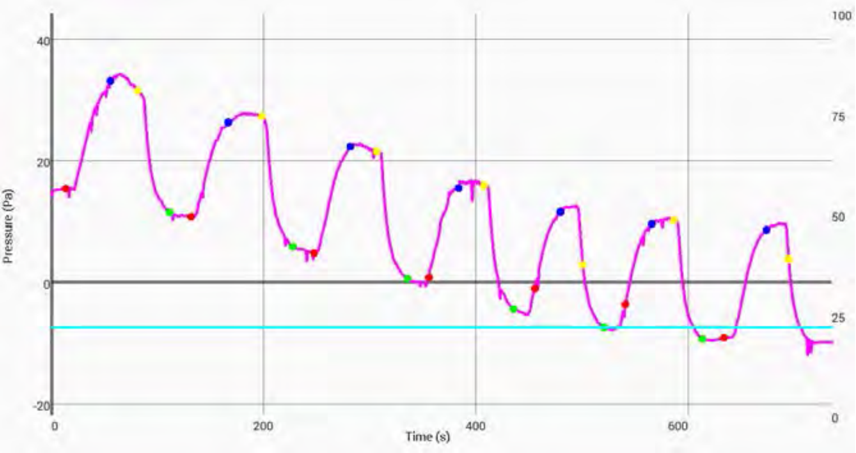
PRINCIPLE OF THE TEST



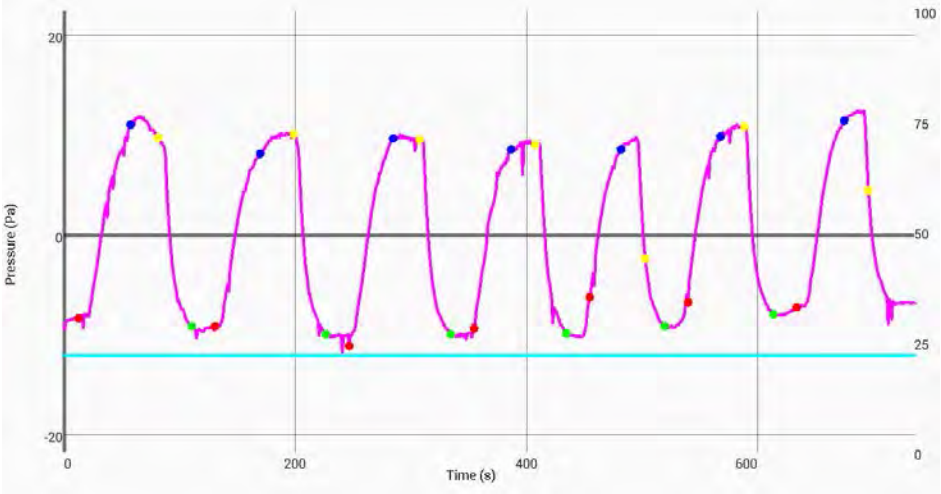


EXAMPLE TEST SIGNAL

- Measurement signal



- Corrected signal



PRACTICAL ISSUES

- Mechanical exhaust or supply, natural inlet or range hood
  – Closed grills

  or

- Balanced ventilation with heat recovery
  – Switch off the supply or exhaust and block it

SCOPE OF THE METHODOLOGY

- Required airtigthness **N50 < 4**
- Sufficient **mechanical flow > 20 l/s** to have a pressure of > 10 Pa
  - **Whole house ventilation** (20-70 l/s)
  - Or a **range hood**

Every country has it’s own rules how the measurements take place. For instance how to handle fire place, open gas boilers etc.

TNO innovation for life

LABORATORY CALIBRATIONS

Calibrated opening	q_v, blower door (l/s)	n (-)	$q_{v,system}$ (l/s)	$q_{v,new}$ (l/s)	$q_{v,new}$ (l/s)	Δq_v (l/s)	Δq_v (%)
			±1.0 l/s	*n measured*	$n = 0.66$		
Closed	17.0	0.68	49.0	18.6±0.5	19.1±2.8	1.6	9.4
	16.1	0.70	48.5	17.6±0.4	18.9±2.8	1.5	9.3
12.5	30.5	0.62	48.5	30.7±1.3	29.8±2.6	0.2	0.7
	34.6	0.58	48.5	32.4±1.6	30.8±2.7	-2.2	-6.4
25	44.7	0.58	48.5	47.5±1.5	47.3±1.8	2.8	6.3
	51.7	0.53	48.5	42.9±9.3	41.7±11.4	-8.8	-17.0
50	86.7	0.53	48.5	77.7±10.1	86.0±16.0	-9.0	-10.4
	77.7	0.52	48.5	66.6±26.5	72.5±38.5	-11.1	-14.3
	77.7	0.52	65.0	72.8±3.4	74.9±4.6	-4.9	-6.3
	77.7	0.52	104.0	79.3±2.6	73.7±4.9	1.6	2.1
75	101.7	0.51	49.0	82.5±18.6	96.2±30.2	-19.2	-18.9
	101.2	0.51	65.5	97.9±15.1	110.1±23.8	-3.3	-3.3
	101.2	0.51	104.5	106.9±6.7	107.6±8.7	5.7	5.6
	101.2	0.51	104.5	101.5±6.9	100.6±8.9	0.3	0.3

fixed and assumed *n*

LABORATORY CALIBRATIONS

Calibrated opening	q_v, blower door (l/s)	*n* (-)	$q_{v,system}$ (l/s)	$q_{v,new}$ (l/s)	$q_{v,new}$ (l/s)	Δq_v (l/s)	Δq_v (%)
			±1.0 l/s	*n measured*	*n* = 0.66		
Closed	17.0	0.68	49.0	18.6±0.5	19.1±2.8	1.6	9.4
	16.1	0.70	48.5	17.6±0.4	18.9±2.8	1.5	9.3
12.5	30.5	0.62	48.5	30.7±1.3	29.8±2.6	0.2	0.7
	34.6	0.58	48.5	32.4±1.6	30.8±2.7	-2.2	-6.4
25	44.7	0.58	48.5	47.5±1.5	47.3±1.8	2.8	6.3
	51.7	0.53	48.5	42.9±9.3	41.7±11.4	-8.8	-17.0
50	86.7	0.53	48.5	77.7±10.1	86.0±16.0	-9.0	-10.4
	77.7	0.52	48.5	66.6±26.5	72.5±38.5	-11.1	-14.3
	77.7	0.52	65.0	72.8±3.4	74.9±4.6	-4.9	-6.3
	77.7	0.52	104.0	79.3±2.6	73.7±4.9	1.6	2.1
75	101.7	0.51	49.0	82.5±18.6	96.2±30.2	-19.2	-18.9
	101.2	0.51	65.5	97.9±15.1	110.1±23.8	-3.3	-3.3
	101.2	0.51	104.5	106.9±6.7	107.6±8.7	5.7	5.6
	101.2	0.51	104.5	101.5±6.9	100.6±8.9	0.3	0.3

fixed and assumed *n*

LABORATORY CALIBRATIONS

Calibrated opening	q_v, blower door (l/s)	*n* (-)	$q_{v,system}$ (l/s)	$q_{v,new}$ (l/s)	$q_{v,new}$ (l/s)	Δq_v (l/s)	Δq_v (%)
			±1.0 l/s	*n measured*	*n* = 0.66		
Closed	17.0	0.68	49.0	18.6±0.5	19.1±2.8	1.6	9.4
	16.1	0.70	48.5	17.6±0.4	18.9±2.8	1.5	9.3
12.5	30.5	0.62	48.5	30.7±1.3	29.8±2.6	0.2	0.7
	34.6	0.58	48.5	32.4±1.6	30.8±2.7	-2.2	-6.4
25	44.7	0.58	48.5	47.5±1.5	47.3±1.8	2.8	6.3
	51.7	0.53	48.5	42.9±9.3	41.7±11.4	-8.8	-17.0
50	86.7	0.53	48.5	77.7±10.1	86.0±16.0	-9.0	-10.4
	77.7	0.52	48.5	66.6±26.5	72.5±38.5	-11.1	-14.3
	77.7	0.52	65.0	72.8±3.4	74.9±4.6	-4.9	-6.3
	77.7	0.52	104.0	79.3±2.6	73.7±4.9	1.6	2.1
75	101.7	0.51	49.0	82.5±18.6	96.2±30.2	-19.2	-18.9
	101.2	0.51	65.5	97.9±15.1	110.1±23.8	-3.3	-3.3
	101.2	0.51	104.5	106.9±6.7	107.6±8.7	5.7	5.6
	101.2	0.51	104.5	101.5±6.9	100.6±8.9	0.3	0.3

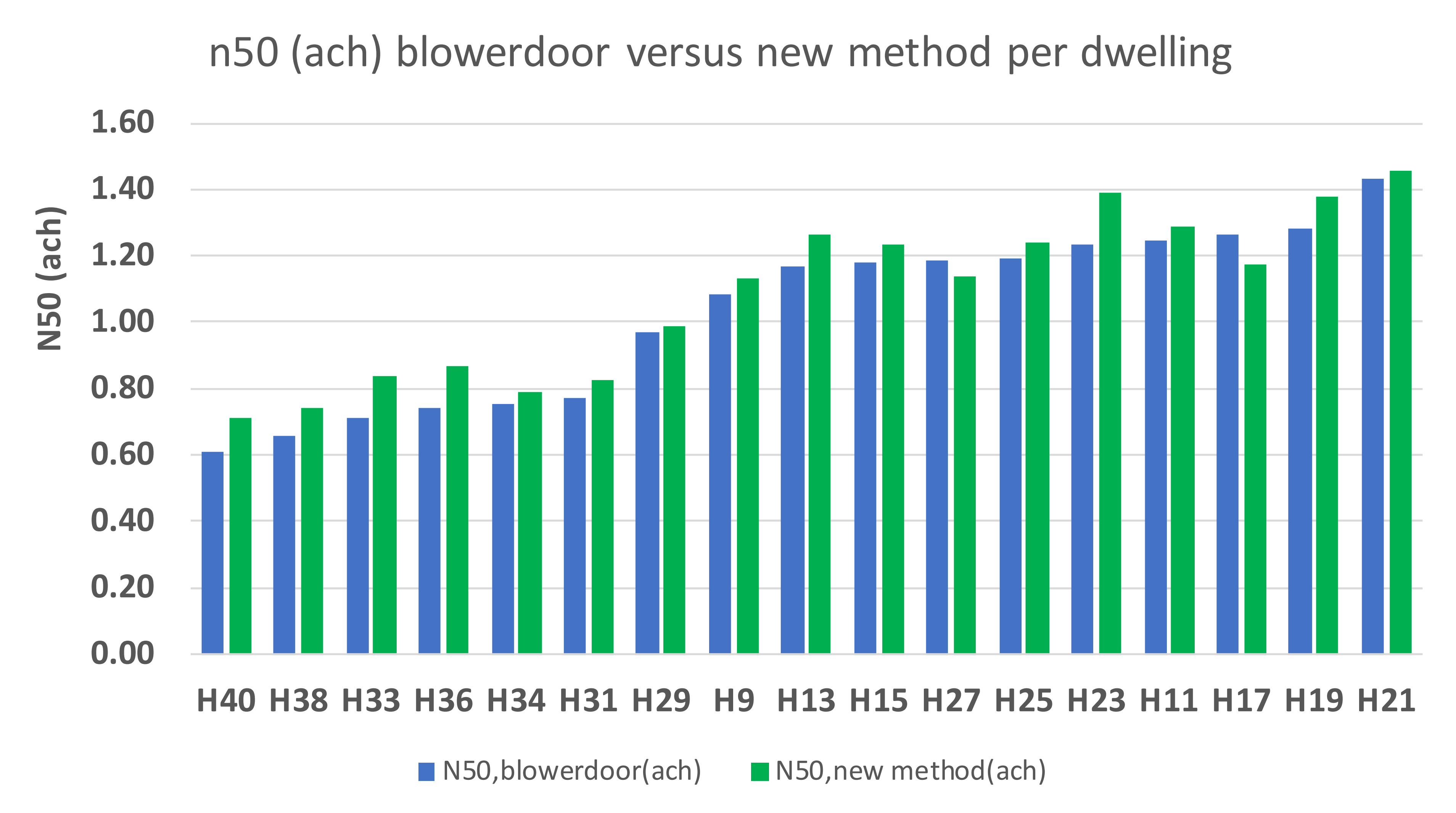
fixed and assumed *n*

LABORATORY CALIBRATIONS

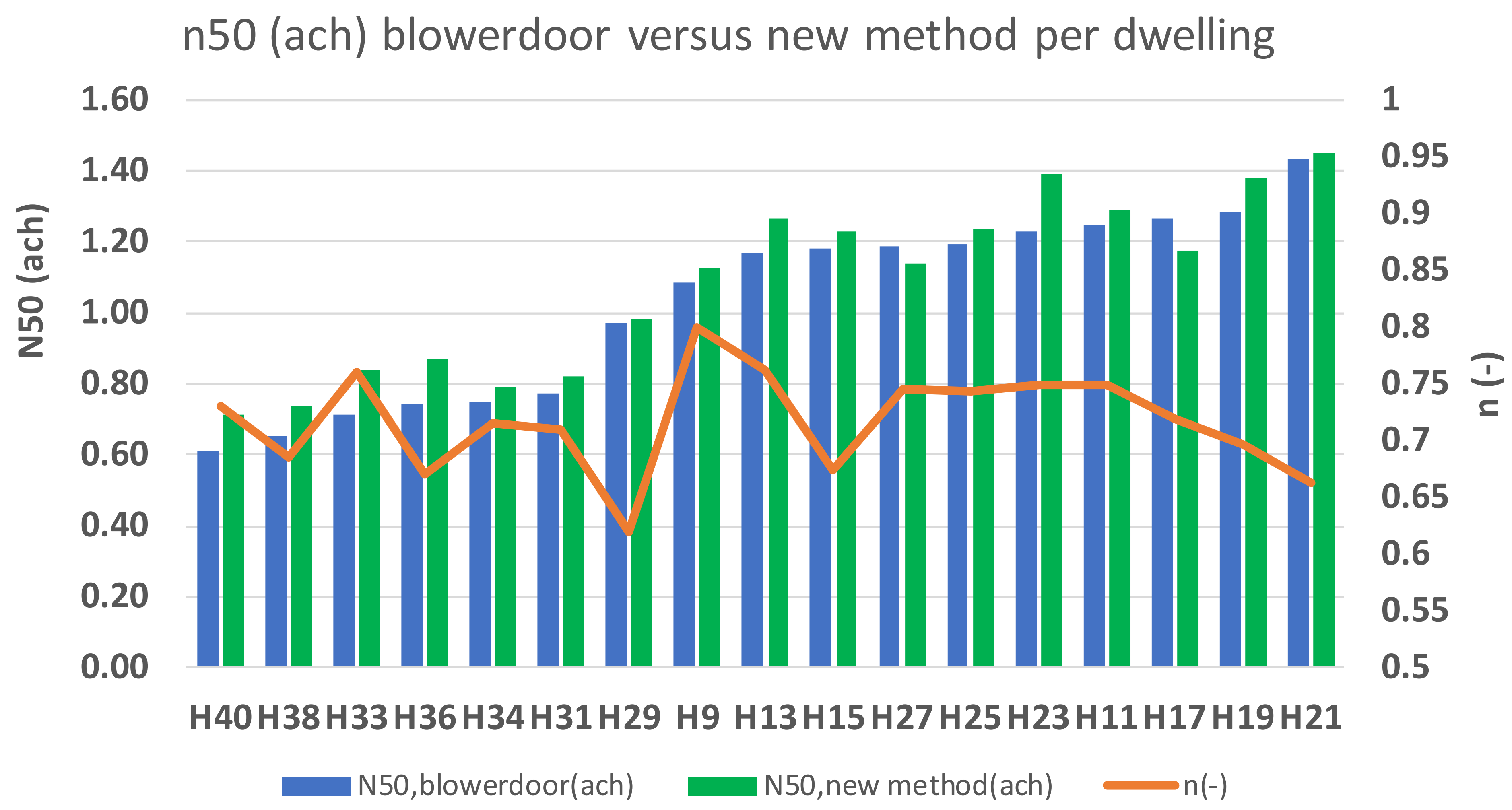
Calibrated opening	q_v, blower door (l/s)	*n* (-)	$q_{v,system}$ (l/s)	$q_{v,new}$ (l/s)	$q_{v,new}$ (l/s)	Δq_v (l/s)	Δq_v (%)
			±1.0 l/s	*n measured*	*n* = 0.66		
Closed	17.0	0.68	49.0	18.6±0.5	19.1±2.8	1.6	9.4
	16.1	0.70	48.5	17.6±0.4	18.9±2.8	1.5	9.3
12.5	30.5	0.62	48.5	30.7±1.3	29.8±2.6	0.2	0.7
	34.6	0.58	48.5	32.4±1.6	30.8±2.7	-2.2	-6.4
25	44.7	0.58	48.5	47.5±1.5	47.3±1.8	2.8	6.3
	51.7	0.53	48.5	42.9±9.3	41.7±11.4	-8.8	-17.0
50	86.7	0.53	48.5	77.7±10.1	86.0±16.0	-9.0	-10.4
	77.7	0.52	48.5	66.6±26.5	72.5±38.5	-11.1	-14.3
	77.7	0.52	65.0	72.8±3.4	74.9±4.6	-4.9	-6.3
	77.7	0.52	104.0	79.3±2.6	73.7±4.9	1.6	2.1
75	101.7	0.51	49.0	82.5±18.6	96.2±30.2	-19.2	-18.9
	101.2	0.51	65.5	97.9±15.1	110.1±23.8	-3.3	-3.3
	101.2	0.51	104.5	106.9±6.7	107.6±8.7	5.7	5.6
	101.2	0.51	104.5	101.5±6.9	100.6±8.9	0.3	0.3

fixed and assumed *n*

FIELD MEASUREMENTS

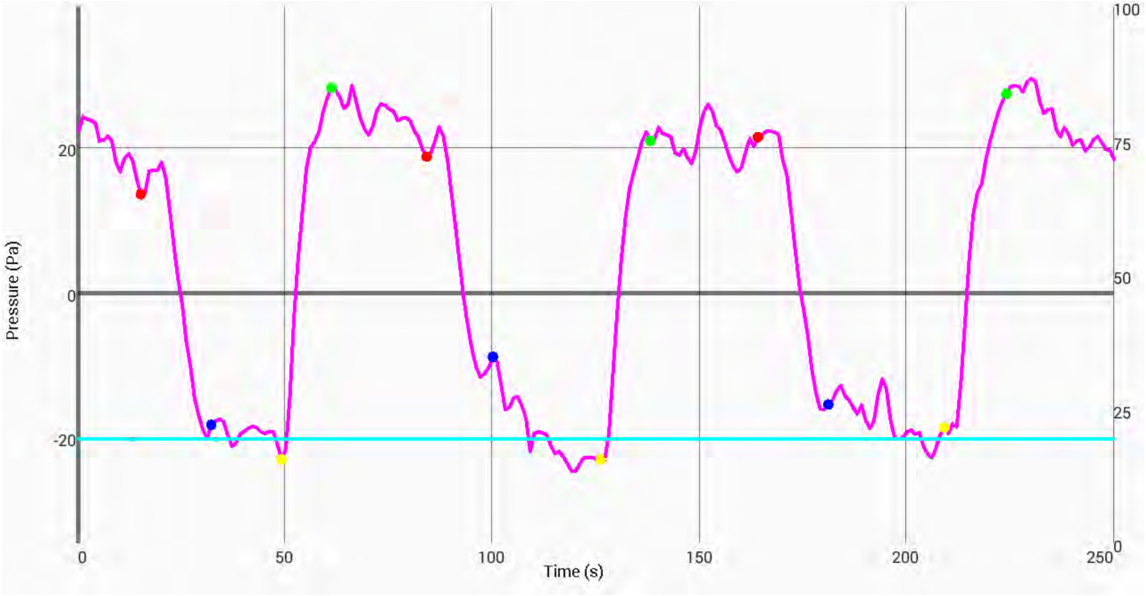


n50 (ach) blowerdoor versus new method per dwelling
N50 (ach)
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
H40
H38
H33
H36
H34
H31
H29
H9
H13
H15
H27
H25
H23
H11
H17
H19
H21
N50,blowerdoor(ach)
N50,new method(ach)



n50 (ach) blowerdoor versus new method per dwelling
N50 (ach)
n (-)
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
H40 H38 H33 H36 H34 H31 H29 H9 H13 H15 H27 H25 H23 H11 H17 H19 H21
N50,blowerdoor(ach)
N50,new method(ach)
n(-)

MEASURING AT HIGH WIND SPEED



$q_{v,10}$ new = 34.2 l/s (N50=1,1)

Blowerdoor fan off 40 Pa

$q_{v,10}$ blower = 31.6 l/s at another day

RESULTS FIELD STUDIES

- **Flow** was **more difficult to measured** in the **field** studies due to summing up of flow of different outlets. A fault in the flow has a strong impact in overall accuracy
- Room for improvement to **calculate pressure difference**
- Average **difference** between blower door and new test methode up about 10%, max 20%

DISCUSSION

- Advantages
  – **Quick**, about 20 minutes
  – **Compact** can be placed in a bag pack
  – **Simple**
  – **Inaccuracy < 20%**

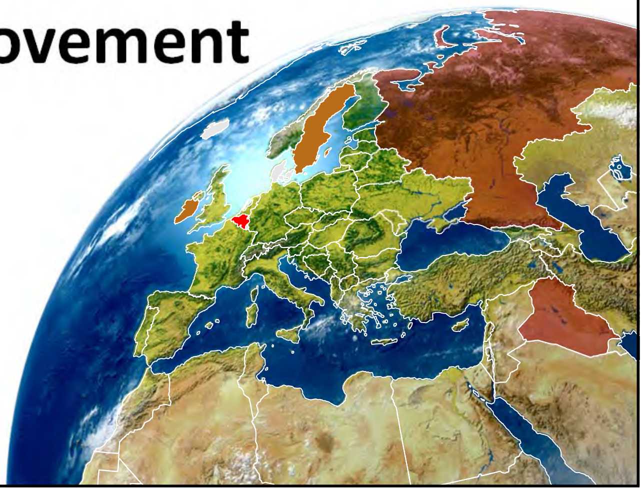
- Disadvantages
  – **Flow coefficient needs multiple** measurements with different flows
  – **Less visual impression smoke test** in cases with lower pressure
  – When ventilation flow is not measured by the ventilation unit, **multiple measurements of flows through valves leading to lower accuracy**

THANKS FOR YOUR ATTENTION

Contact:
Wouter Borsboom
wouter.borsboom@tno.nl

TNO innovation for life

Ventilation and airtightness: European experiences of on-site performances and approaches for improvement



Peter Wouters

Manager INIVE EEIG

International Network for Information
on Ventilation and Energy Performance

INIVE

You expect a reliable label

… **and you expect a good quality**

You expect a reliable label

… **and you expect a good quality**

… **and you expect a good quality**

You expect the presence of a ventilation system

… **and you expect good performances (air flow, acoustics, IAQ, energy, …)**

EU QUALICHeCK project (2014-2017)

QUALICHeCK project had 2 objectives…

- *To set up a series of actions which should result in more attention and practical initiatives for* ***actual compliance with the claimed energy performance for new and renovated buildings***

  i.e. 'Boundary conditions which force people to do what they declare';

- *To set up a series of actions, which should result in more attention and practical initiatives for* ***achieving a better quality of the works****,*

  i.e. 'Boundary conditions which stimulate and allow the building sector to deliver good quality of the works'.

QUALICHeCK
Towards better quality and compliance

QUALICHeCK products and outcomes

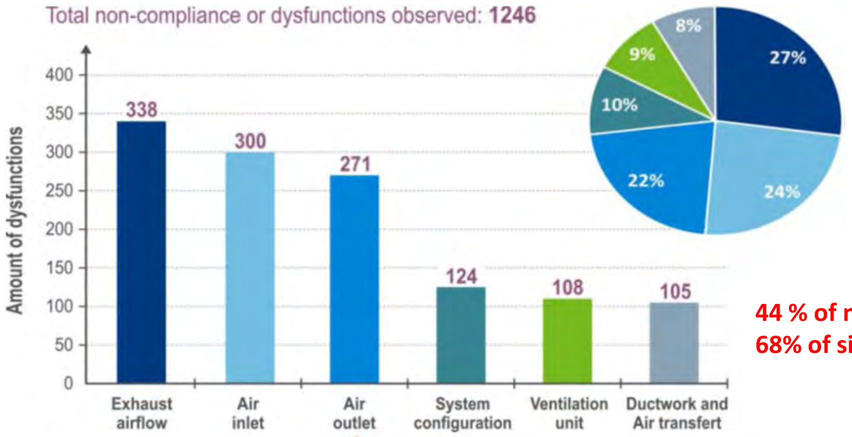
1. **About the status on the ground…**
2. **About interesting approaches…**
3. **About guidance for improvements**

4 focus areas in QUALICHeCK

- Transmission characteristics
- Ventilation and airtightness
- Sustainable summer comfort techniques
- Renewables in multi-energy systems

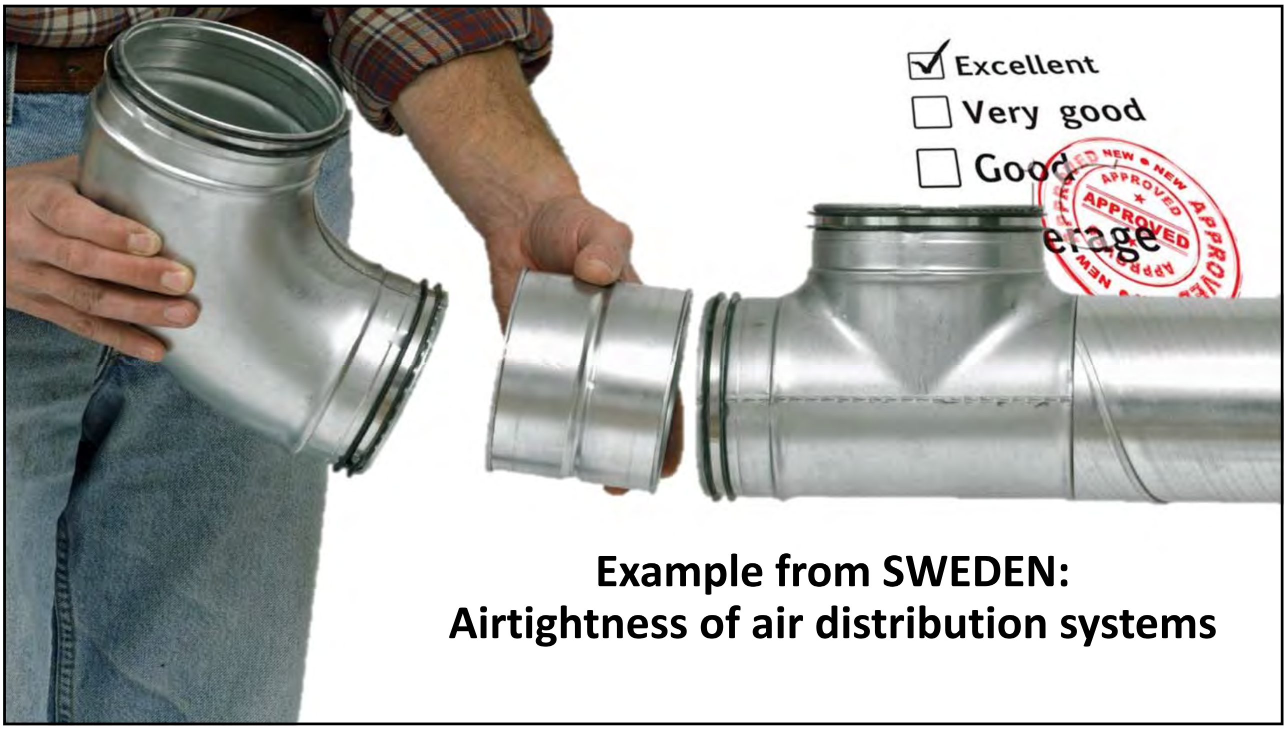
QUALICHeCK
Towards better quality and compliance

Example from FRANCE:
Quality of ventilation systems in 1.287 new dwellings



44 % of multi-family dwellings don't comply
68% of single-family dwellings don't comply

QUALICHeCK
Towards better quality and compliance



Example from SWEDEN:
Airtightness of air distribution systems

QUALICHeCK products and outcomes

- 2 booklets
- 3 global reports
- 2 source books
- 9 country reports
- 54 fact sheets
- 6 newsletters
- 16 webinars
- 4 conferences
- 4 focused technology workshops
- 9 national roadshows
- 3 special issues of REHVA Journal
- …

www.qualicheck-platform.eu

QUALICHeCK
Towards better quality and compliance

Source book on quality of the works

Aim:

To give guidance towards better frameworks for quality of the works

Factsheets


baubook – EASILY ACCESSIBLE PRODUCT INFORMATION FOR EPC CALCULATION PROVIDED BY THE AUSTRIAN DATABASE

Providing the necessary product data for calculating Energy Performance Certificates (EPCs) is one of the main purposes of the Austrian baubook database. In addition, Life Cycle Assessment (LCA) data and other information about building products are included into the database to facilitate the holistic evaluation of buildings and building components as part of voluntary Sustainable Building Assessment Schemes. This fact sheet presents the baubook database and its functionalities; it provides detailed information about the process to ensure quality of data that can be used as input data for various calculation procedures.

Since 2008, the online product database baubook has offered easily accessible input data needed for the calculation of EPCs (Energy Performance Certificates) according to the Energy Performance of Buildings Directive 2010/31/EU (EPBD) and for the voluntary assessment of the environmental impact of buildings in Austria[1]. The product data are declared by the manufacturer. Prior to publication, all information is checked by qualified persons. In order to ensure highest accessibility, the data are transferred to EPC software programs which are approved for calculating and issuing EPCs in Austria, but also to other software programs and platforms applied for voluntary building assessments.

The data necessary for the calculation of building energy performance are expanded by additional product information about the ecological performance (Life Cycle Assessment (LCA) data, indoor quality data, …) and technical adjectives. Thus, baubook provides a central product database, containing ecological and energy-related data, and the basic data required to calculate EPC and LCA for buildings. This makes it useful for architects, consultants, developers and construction industry managers looking for tools assisting them in planning and building energy-efficient and ecological buildings.

In Austria, the regulatory background for EPCs is defined by the nine federal provinces because the EPBD is transposed and implemented on the regional level. Thanks to coordination between the federal provinces, the method for calculating EPCs is harmonised to a high degree, though not identical [3, 4]. Declaration of EPC input data for products is based on European Standards, but there are still Austrian standards [5, 6, 7] which have to be considered. Therefore, product information and test certificates developed for other countries cannot be used in all cases in Austria, but have to be issued once again taking into account specific Austrian requirements. This poses an economic challenge especially for small markets such as the Austrian one.

What is a factsheet?

Short document on a specific topic

Fact Sheets by topic

TECHNOLOGIES / ASPECTS	Transmission Characteristics	Ventilation and Airtightness	Sustainable Summer Comfort Technologies	Renewables in Multi-Energy Systems
Status on the Ground	X	X	X	X
Compliant and Easily Accessible EPC Input Data	X	X	X	X
Quality of the Works	X	X	X	X
Compliance Frameworks	X	X	X	X

QUALICHeCK
Towards better quality and compliance

AIVC　EBC

International Energy Agency
Towards compliant building airtightness and ventilation systems
AIVC Contributed Report 16

Energy in Buildings and Communities Programme
June 2017

This report was produced in collaboration with QUALICHeCK

EBC is a programme of the International Energy Agency (IEA)

QUALICHeCK Towards better quality and compliance

fact sheet #07

2015.12

Author
Sandrine Charrier (Cerema), Adeline Bailly (Cerema), François Rémi Carrié (ICEE)

Technology	Aspect	Country
Ventilation and airtightness	Compliance frameworks	France

BUILDING AIRTIGHTNESS IN FRANCE: REGULATORY CONTEXT, CONTROL PROCEDURES, RESULTS

Since 2006, there has been a significant reward in the French energy regulations for good airtightness, which has been combined with a minimum requirement for residential buildings in the 2012 version of the regulation. Airtightness test results show that the average building airtightness performance has improved by nearly 50% in single- and multi-family buildings since 2006 and now stabilises below the minimum requirements around q_{50} = 2.8 m^3/h per m^2 of envelope area, excluding lowest floor (or about n_{50} = 1.8 h^{-1}).

	Minimum requirement	Possible values in case of Quality Management (QM) approach (multiples of 0,1 $m^3/h/m^2$	Default value
Single-family buildings	0.6 (3.2)	0.3-0.6 (1.6-3.2)	
Multi-family buildings	1.0 (5.4)	0.3-1.0 (1.6-5.4)	
Non-residential buildings		0.3-1.7 (1.6-9.2) or 0.3-3.0 (1.6-16.2) depending on building type (QM no longer applicable as of July 2015)	1.7 (9.2) or 3.0 (16.2) depending on building type

Table 1: Airtightness levels in the 2012 French regulation in m^3/h per m^2 of envelope surface area at 4 Pa. Approximate corresponding values at 50 Pa are shown in parenthesis.

OPTION 1: systematic test by certified tester
OPTION 2: Quality management approach (see other factsheet)

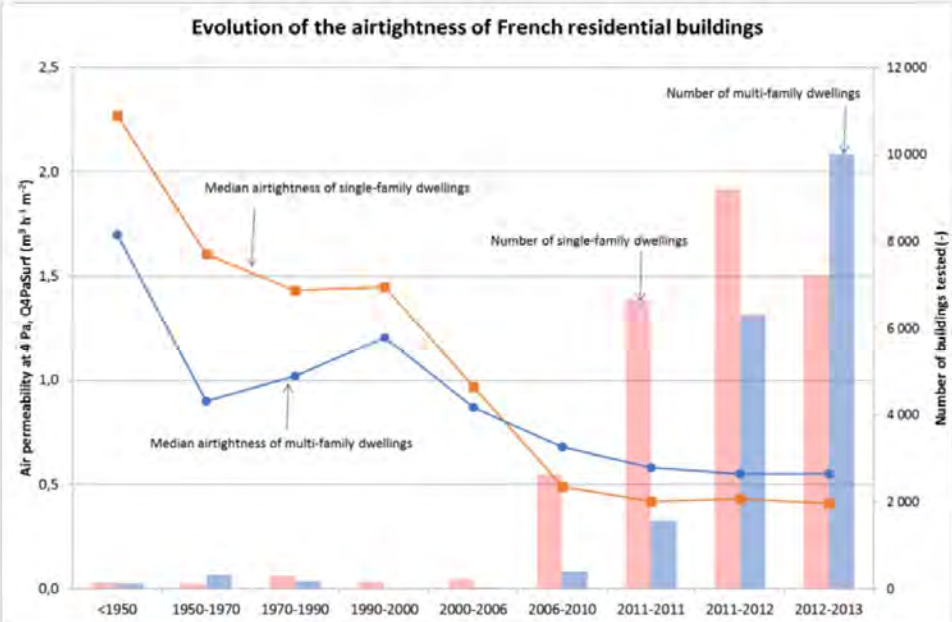


Figure 1: Specific building air leakage rate at 4 Pa performance depending on the construction year of measured buildings

QUALICHeCK Towards better quality and compliance

fact sheet #01

2015.1

Authors
François Rémi Carrié (ICEE) and Sandrine Charrier (CEREMA)

Technology	Aspect	Country
Ventilation and airtightness	Quality of the works	France

BUILDING REGULATIONS CAN FOSTER QUALITY MANAGEMENT: THE FRENCH EXAMPLE ON BUILDING AIRTIGHTNESS

The French regulation includes an alternative route to systematic building airtightness testing to justify for a given airtightness level. This route was developed to push professionals to revisit their methods for implementing building airtightness solutions and to include specific quality requirements. At the end of 2014, 81 such quality management approaches have been approved representing a production of about 15.500 buildings per year.

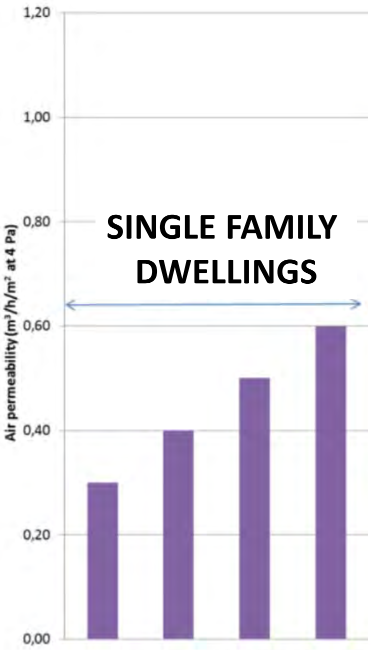


Figure 1: Possible values of maximum air permeability guaranteed by the applicant in single-family dwellings and multi-family buildings.

Type of buildings	Production	Sample size
Single-family dwellings	Nprod ≤ 500 Nprod > 500	Ntests = 5 +10 % Nprod Ntests = 55 + 5 % (Nprod - 500)
Other buildings	Nprod ≤ 50 Nprod > 50	Ntests = 30 % Nprod Ntests = 15 +15 % (Nprod - 50)

Table 2: Minimum sample size for the QM approach in the 2012 French regulation

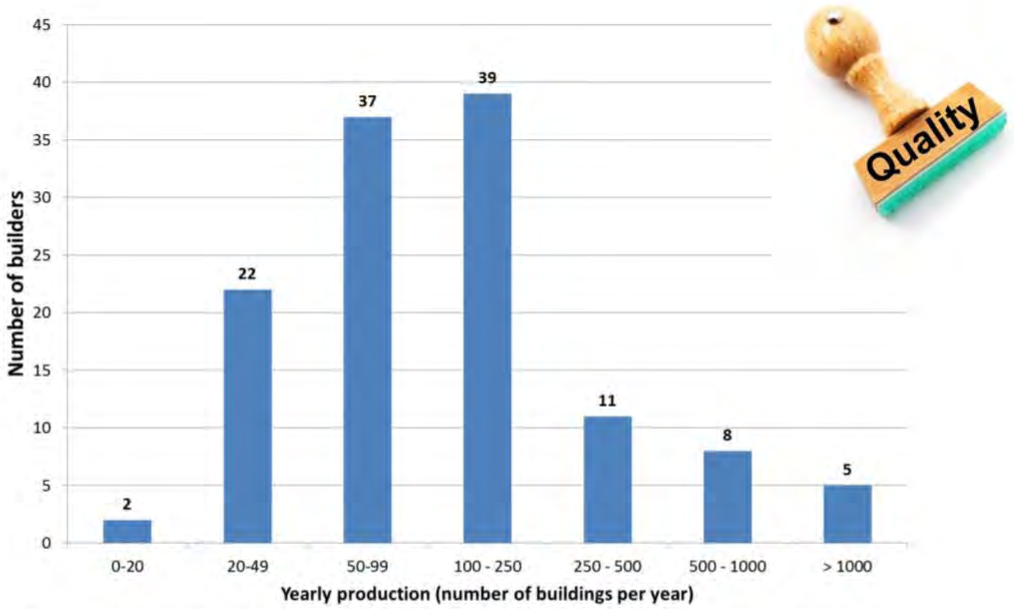


Figure 1: Distribution of builders applying the approach according to their yearly production

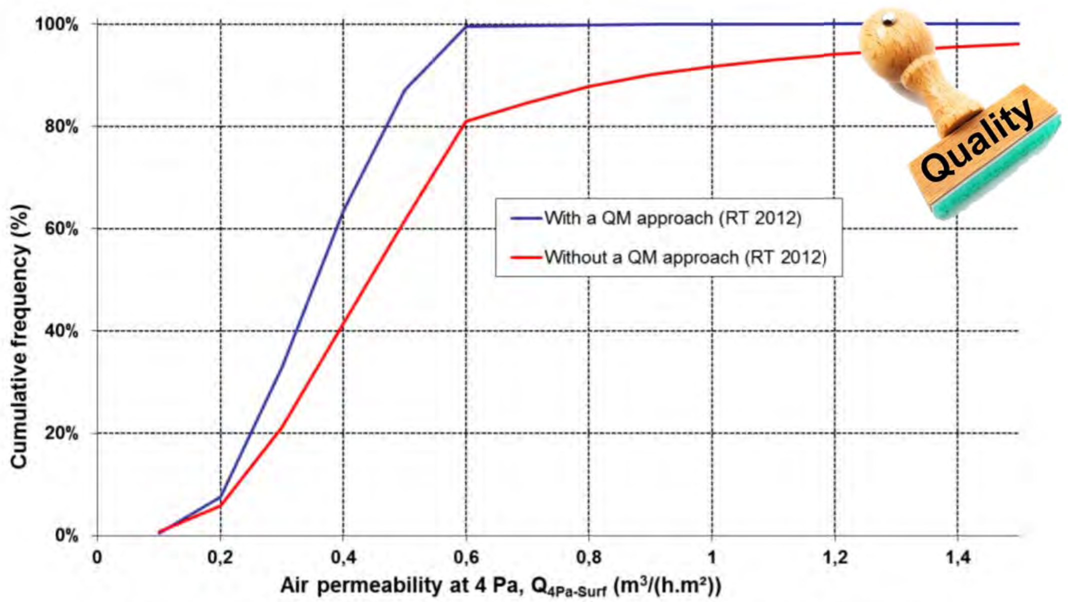


Figure 5: Distribution of measured airtightness of houses with and without implementation of a certified QM approach.

Level of complexity (dark orange = simplest)	
Potential for replication (dark orange = best)	

Prerequisite:
Substantial reward for good airtigh in EP calculation

Hints	Pitfalls
✓ Stress the benefits of QM approaches to secure airtightness level and comply with the regulation among stakeholders ✓ Discuss options with stakeholders ✓ Progressively increase QM requirements ✓ Ensure fair evaluation of the applications ✓ Conduct in situ controls ✓ Carefully estimate the minimum size of the sample to be measured	✓ Resources for examining applications ✓ Proof of application of standard drawings is not sufficient, some measurements must be done

Table 5: Overall hints and pitfalls to avoid when developing such an approach

QUALICHeCK Towards better quality and compliance — fact DATABASE

Authors
François Durier (CETIAT), Laure Mouradian (CETIAT), Fabrice Lamarre (Uniclima)

Technology	Aspect	Country
Ventilation and air tightness	Compliant and easily accessible EPC input data	France

FRENCH VOLUNTARY SCHEME FOR HARMONISED PUBLICATION OF VENTILATION PRODUCT DATA

A voluntary scheme defining the data to be announced in the product documentation has been launched in 2012 by Uniclima, the French association of ventilation product manufacturers. It ensures that product characteristics are provided under a harmonised form (same physical quantity, unit and assessment method), and facilitates access to relevant input data for the energy performance calculation of a building. The scheme contributes to enhancing the compliance of published data.

QUALICHeCK Towards better quality and compliance

fact

Author
Samuel Caillou (BBRI)

Technology	Aspect	Country
Ventilation and airtightness; Transmission characteristics; Sustainable summer comfort	Compliant and easily accessible EPC input data	Belgium

VOLUNTARY SCHEME AND DATABASE FOR COMPLIANT AND EASILY ACCESSIBLE EPC PRODUCT INPUT DATA IN BELGIUM

The "EPB product database" in Belgium is an effective scheme to improve the compliance and easy access to product characteristics used as input data for the Energy Performance Certificate (EPC) calculation. The acceptance of this scheme by the market has been successful for many years. The present factsheet explains this Belgian scheme and tries to identify the reasons for its success and the prerequisites for the implementation of similar schemes in other countries.

QUALICHeCK Towards better quality and compliance

fact sheet #06

2015.11

Author
François Rémi Carrié (ICEE), Sandrine Charrier (CEREMA) and Adeline Bailly (CEREMA)

Technology	Aspect	Country
Ventilation and airtightness	Compliance frameworks	France

REGULATORY COMPLIANCE CHECKS OF RESIDENTIAL VENTILATION SYSTEMS IN FRANCE

Regulatory compliance checks on samples of residential ventilation systems are operational in France. The analysis of their results shows a significant rate of non-compliance with the ventilation regulation (rate on the order of 50%).

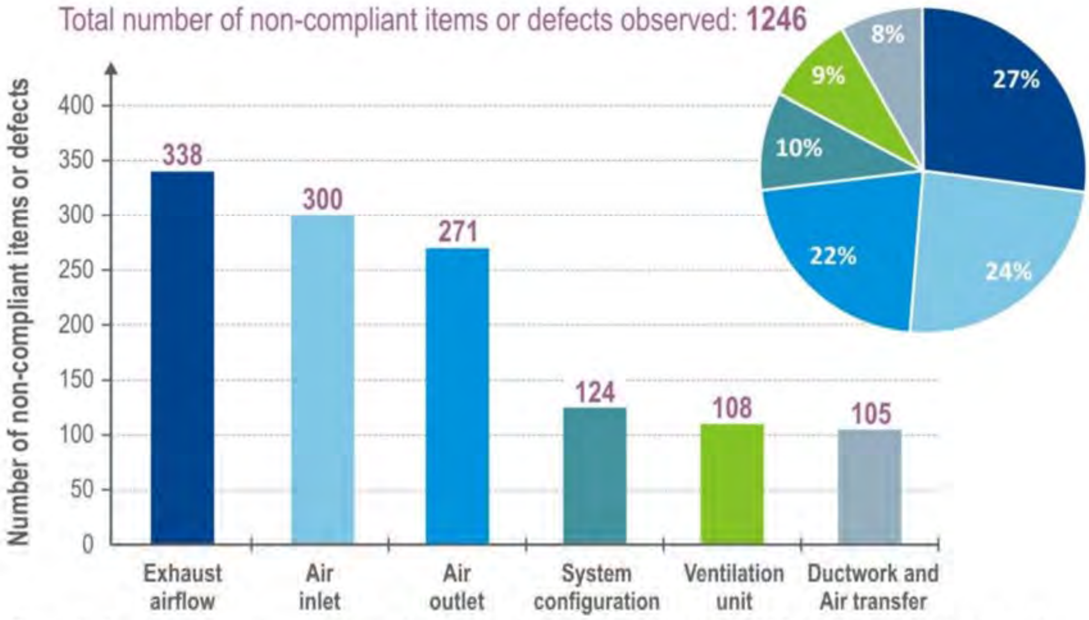


Figure 1: Number of non-compliance or defects per category in a sample of 1287 dwellings, see Jobert and collaborators (2012, 2013)

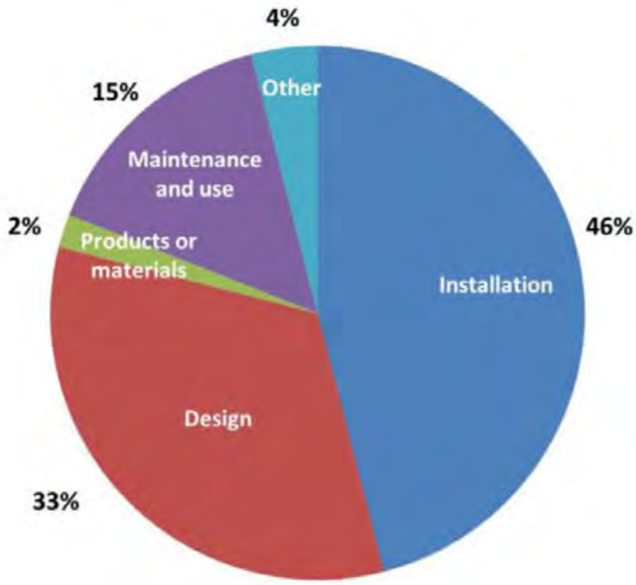


Figure 2: Origin of defects observed in residential ventilation systems in France (Sycodes, 2012)

QUALICHeCK
Towards better quality and compliance

fact sheet #55

2017.02

Authors
Samuel Caillou, Paul Van den Bossche (BBRI)

Technology	Aspect	Country
Ventilation	Compliance frameworks	Belgium

BELGIAN/FLEMISH EVALUATION SCHEME FOR VENTILATION SYSTEMS

Since many years, several monitoring studies have shown that the quality and compliance of installed ventilation systems can be low. The recently developed Evaluation scheme in Belgium tries to tackle this problem, thanks to the mandatory Ventilation Performance Report of all new ventilation installations, to be delivered by a Ventilation Reporter recognised by a Third-Party control organisation. This factsheet describes the approach of this scheme, including the penalty scheme and the role of the actors involved.

Figure 1: Principles of the evaluation scheme for ventilation in Belgium

Quality frameworks in Flemish Region(Belgium)

- **Insulation of existing cavity walls**
  - Operational since July 2012
  - About 90.000 buildings done since then
- **Internal insulation of external walls**
  - Only by "competent" contractors
- **External insulation**
  - In preparation

DRIVER: SUBSIDIES

- **Building airtightness**
  - For new buildings since January 2015
  - If not done in quality framework: use of default value
- **Residential ventilation**
  - For building permits after January 1 2016
  - If not done in quality framework: air flow rate = 0 m^3/h

DRIVER: ENERGY LEGISLATION

Practical information on airtightness and ventilation quality frameworks

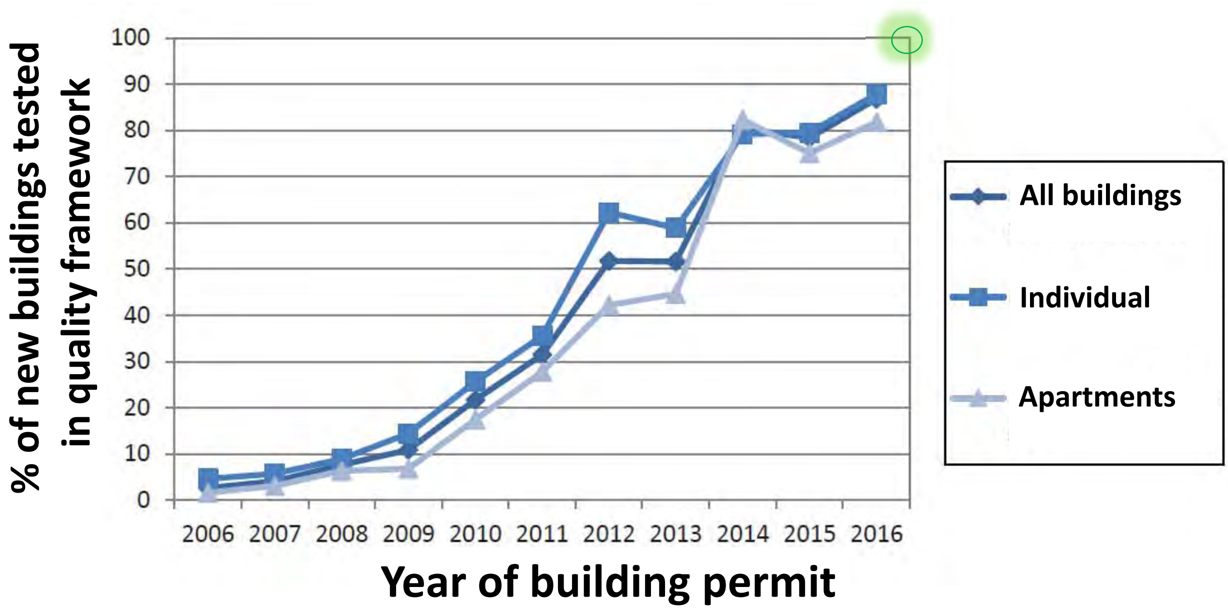
- Quality framework for **building airtightness**:
  - About 3 years of experience

- Quality framework for **residential ventilation:**
  - For new buildings with building permit after January 2016
  - In practice limited number of dossiers

Quality framework for airtightness testing

Context:

- **NOT** mandatory
- BUT if done outside quality framework: use of default value
  - 12 m³/h.m² of building envelope
- In practice: will become standard practice with increasing requirements on energy efficiency
  - → See next slide



Who can do a test?

- **No requirement of independence**
  - Contractor can test his own building
- **Proof of competence:**
  - Theoretical exam
  - Practical exam

Control by third party organisation

- **Desktop checks**
  - **10 %** of submitted reports are checked
- **In situ checks**
  - **10 %** of tests are checked on-site
    - Or during the test itself
      - Appropriate equipment? Preparation of building? Testing and reporting
    - Or after test (based on SMS message)
      - Is there a reliable reporting?

SMS procedure

- **SMS 1**: If airtightness tester believes a test is possible:
  - SMS 1: dossier number + estimated time of finishing test
- **SMS 2**: If test is finalised:
  - SMS 2: measured result

- BCCA actions in case on-site check are the requirements:
  - Within 5 minutes: an SMS indicating that an inspector will come on site
  - Within 20 minutes: inspector must be on-site

Desktop checks – BCCA statistics for 2017

- About 6.200 buildings tested
- How many checks: **10,1% of reports** (631 checks)
- At least one check for each testing company : 152 companies were checked **(100%)**

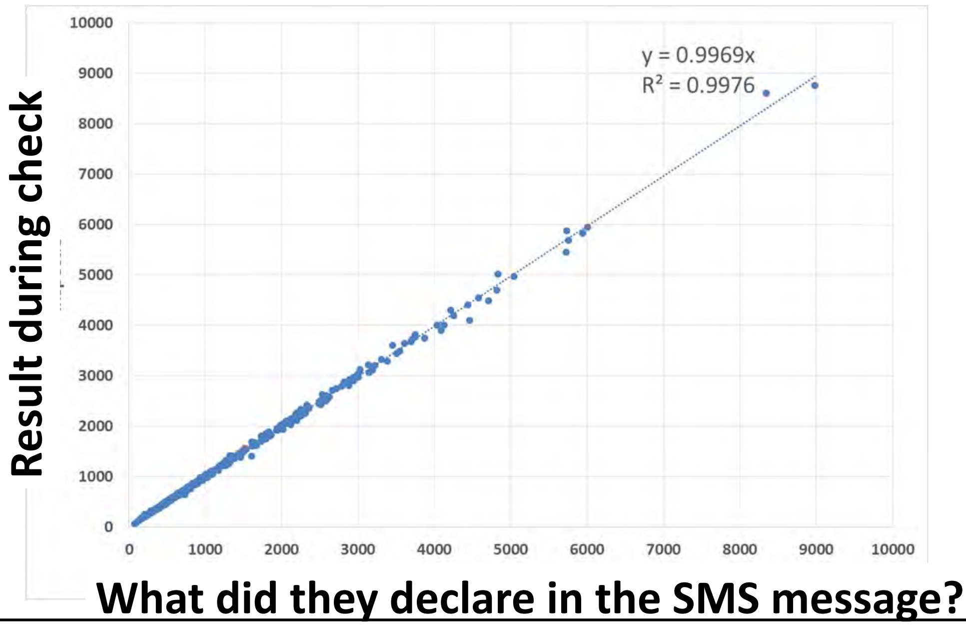
In situ checks – BCCA statistics for 2017

- Checks: **10,2% of reports** (634 inspections)
  - 66% after sending of SMS
  - Also during weekend

- **Duration of inspection?**
  - Average duration of inspection: 21,5 minutes
  - Average waiting time for inspection to arrive: 2,8 min

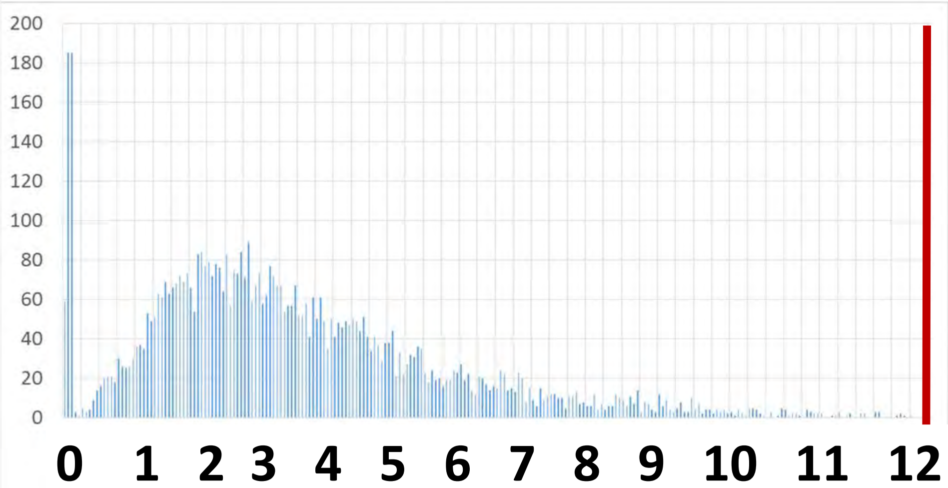
→ Since 10% of tests are checked: average time 'loss': about 2.5 minutes

In situ checks– statistics 2017 – 634 inspections



In situ checks – statistics 2017

Distribution of results (m³/h.m² at 50 Pa)



BCCA

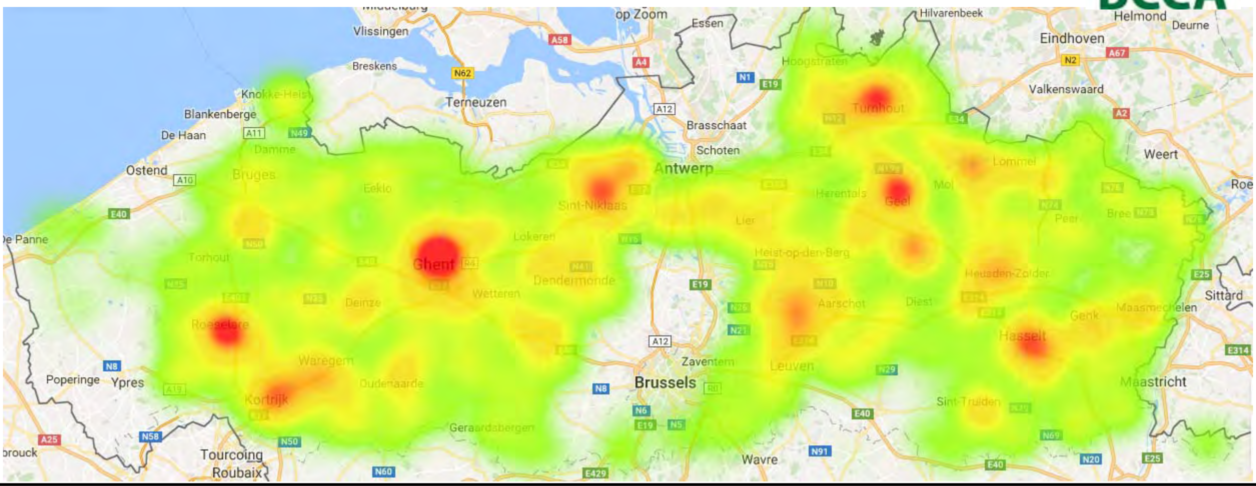
In situ checks – statistics 2017

BCCA

In situ checks – statistics 2017

Location of airtightness testing

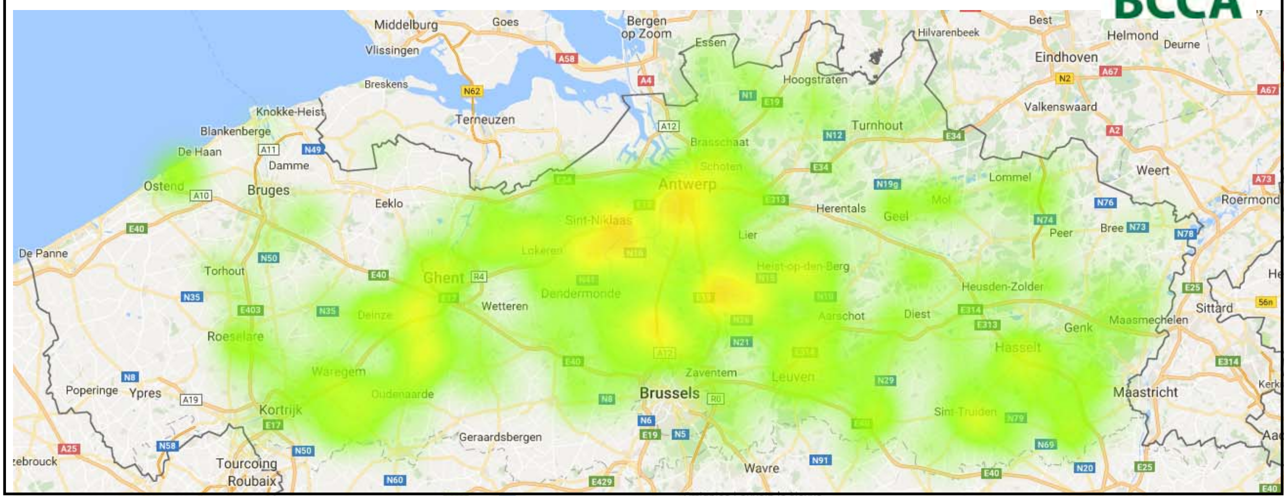
BCCA



In situ checks – statistics 2017

Location of in situ checks

BCCA



Characteristics Flemish VENTILATION quality framework

- Mandatory scheme in context of requirements for new buildings
- Major elements:
  - **"Competent" person(s)** must execute a number of activities
    - Ventilation pre-design concept
      - Major objective: inform the building owner
    - Ventilation performance report
      - Declaration of performances of ventilation system
  - **Desktop checks** – 10%
  - **In situ tests** – 10%

Competence: Online exams

	# of persons
Coordinator	**686**
Designer	**800**
Rapporteur supply openings	**737**
Rapporteur transfer openings	**999**
Rapporteur exhaust openings	**648**
Rapporteur mechanical ventilation	**784**

Competence: Practical tests

Rapporteur mechanical ventilation: about 350 persons

Conclusions

- Is is not evident to assume that:
  - everybody is following the regulations
  - Everybody reports correctly

- There are various interesting approaches for achieving better compliance