Evaluation of building envelope retrofit techniques for reducing energy needs for space cooling

from COOLING to COMFORT with KC2

Intelligent Energy Europe

Sustainable summer COMFORT (rather than COOLING)

Sustainable summer comfort can be defined as:

- Achieving summer comfort conditions (explicitly defined, see next slides)
- with minimal use of "resource energy" (CEN Overall energy use, primary energy and CO2 emissions)
- and with environmentally non-harmful materials

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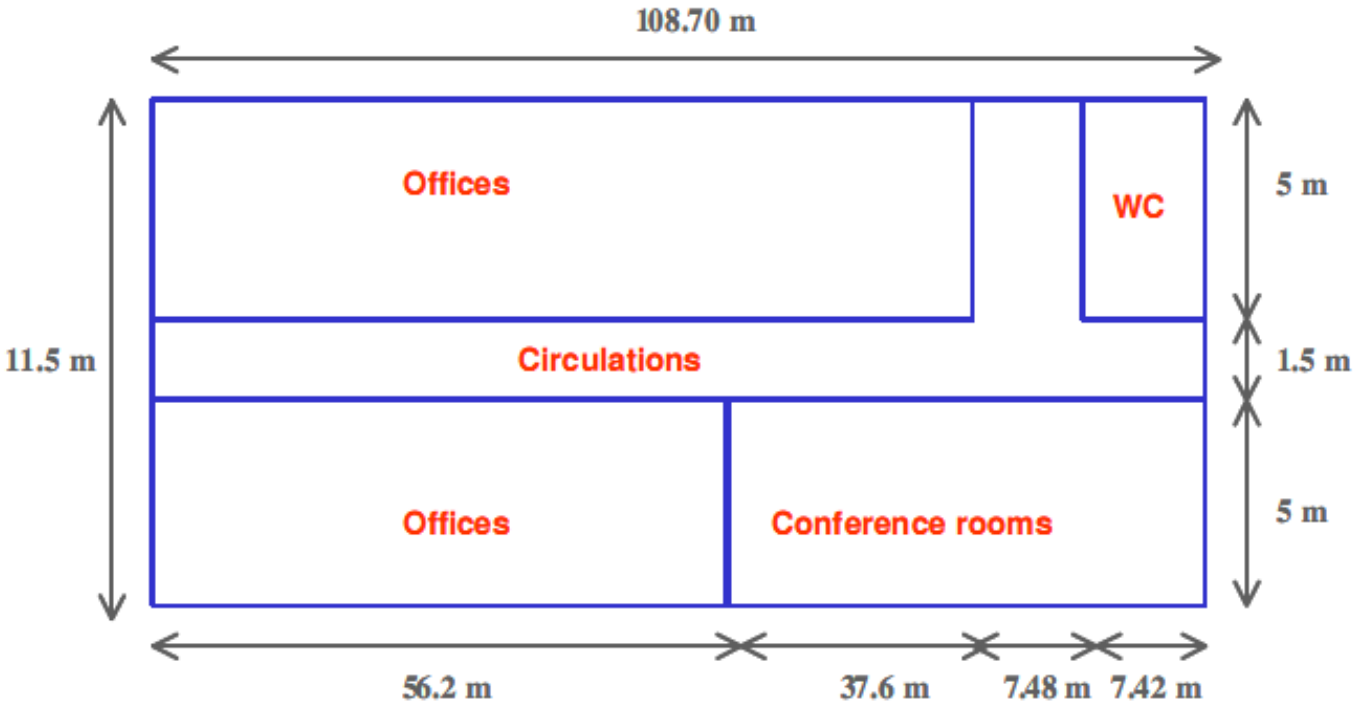
Summary

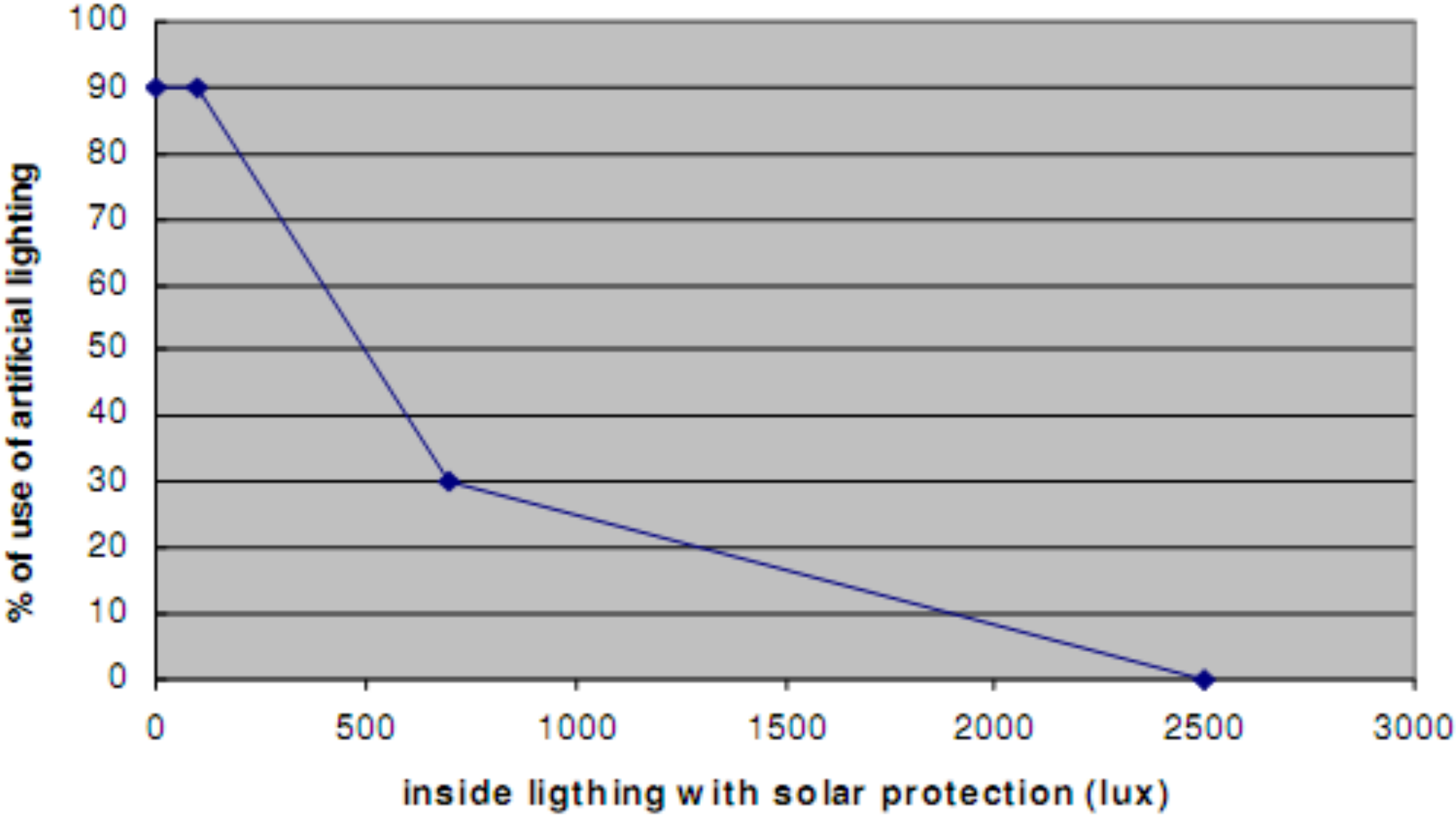
- a methodology for bottom-up assessment of the energy savings related to “sustainable summer comfort” solutions;
- reference base case building typologies in 5 European climates,
- dynamic simulations to calculate the reductions in the energy need for cooling by specific retrofit actions
- situations where mechanical cooling can be avoided are evaluated using the Adaptive Comfort model, according to the norm EN15251.
- case studies of buildings with good summer comfort and low energy consumption performances
- case studies of “comfort policies” adopted by public and private bodies

- Office 1 has 12 identical floors of 1250 m². The glazed area corresponds to 45 % of the total vertical surface.
- Office 2 is a suburban building (1008 m²) with two floors. The glazed area corresponds to 30 % of the t

otal vertical s



Reference case: use of artificial lighting



Reference case: use of internal blinds

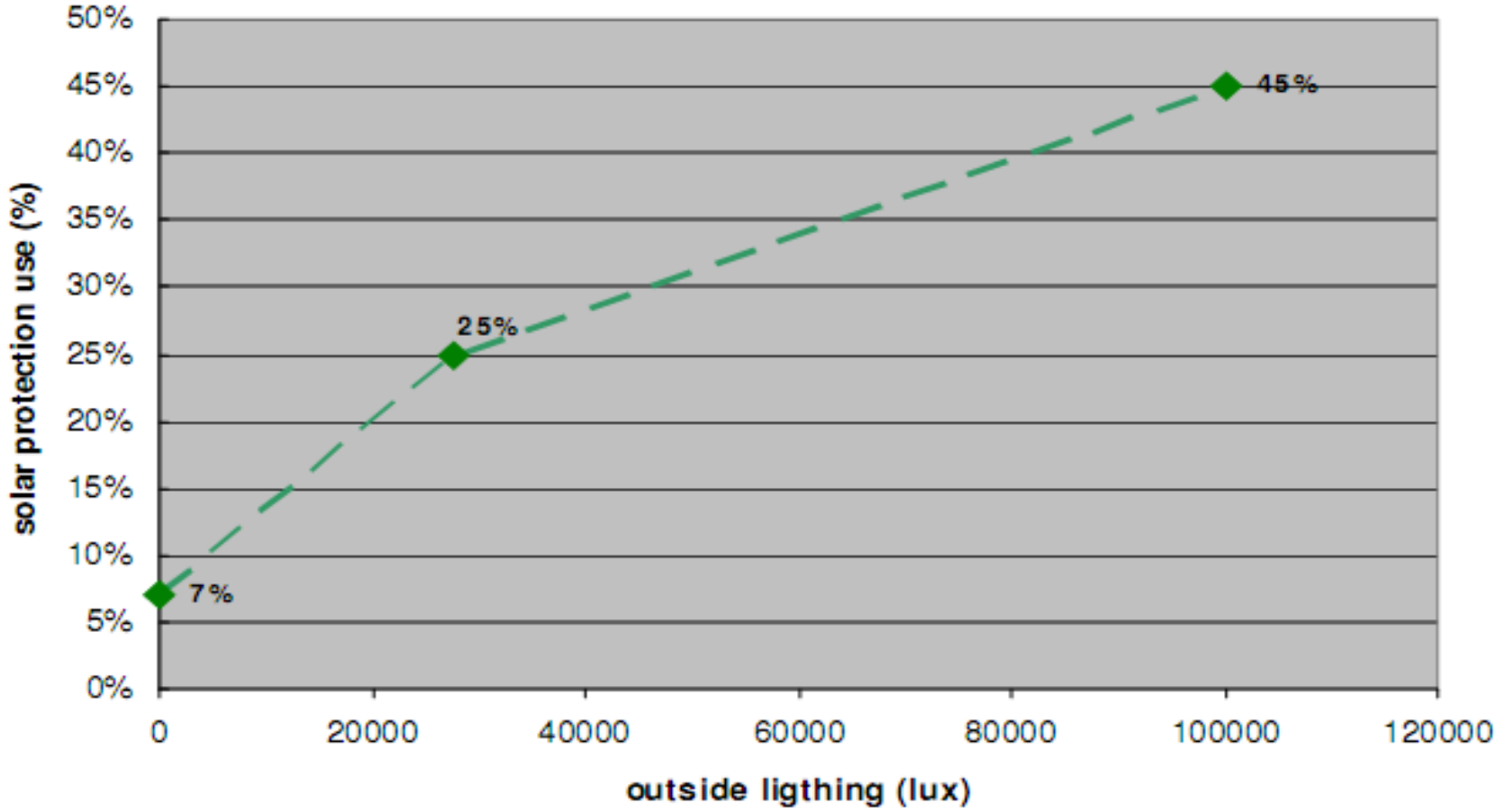


Figure 22. Average use of solar protection

the window to be opened or closed. The probability for a window to be opened is given according to the outdoor temperature (T_{out}) by the following equation [Nicol, 2004]:

$$p=\frac{\exp(0.104T_{out}-2.31)}{(1+\exp(0.104T_{out}-2.31))}$$

It is also assumed that occupants only open the windows when the operative temperature is higher than 24°C and that the probability of window opening is set at 10 % when the outdoor temperature is higher than 28 °C.

EEI actions to be studied	Offices	Retails	Flats
Install an external movable screen blind	X		X
Install an external movable screen blind with radiation control	X		X
Install an external movable Venetian blind	X		X
Install an external movable Venetian blind with radiation control	X		X
Install an external window awning		X	
Install efficient windows	X	X	X
Treat wall and roofs with special paintings	X		X
Insulate the roof	X		X
Install Phase Change Material (PCM) plasterboard	X	X	X
Use energy efficient office equipment	X		
Install energy efficient lightings and ballasts	X	X	
Install automatic night-time operable openings	X		
Install automatic day and night time operable openings	X		
Install extraction system for night-time ventilation	X		
Install extraction system for day and night-time ventilation	X		
Use an existing ventilation system at full speed for night-time ventilation	X	X	
Use an existing ventilation system at full speed for day and night-time ventilation	X		X

O. Fanger on his model

P. Ole Fanger*, Jørn Toftum

In non-air-conditioned buildings in warm climates, occupants may, however, perceive the warmth as being less severe than the PMV predicts. This is mainly caused by low expectations, but a metabolic rate that is estimated too high under warm conditions also contributes to explain the difference.

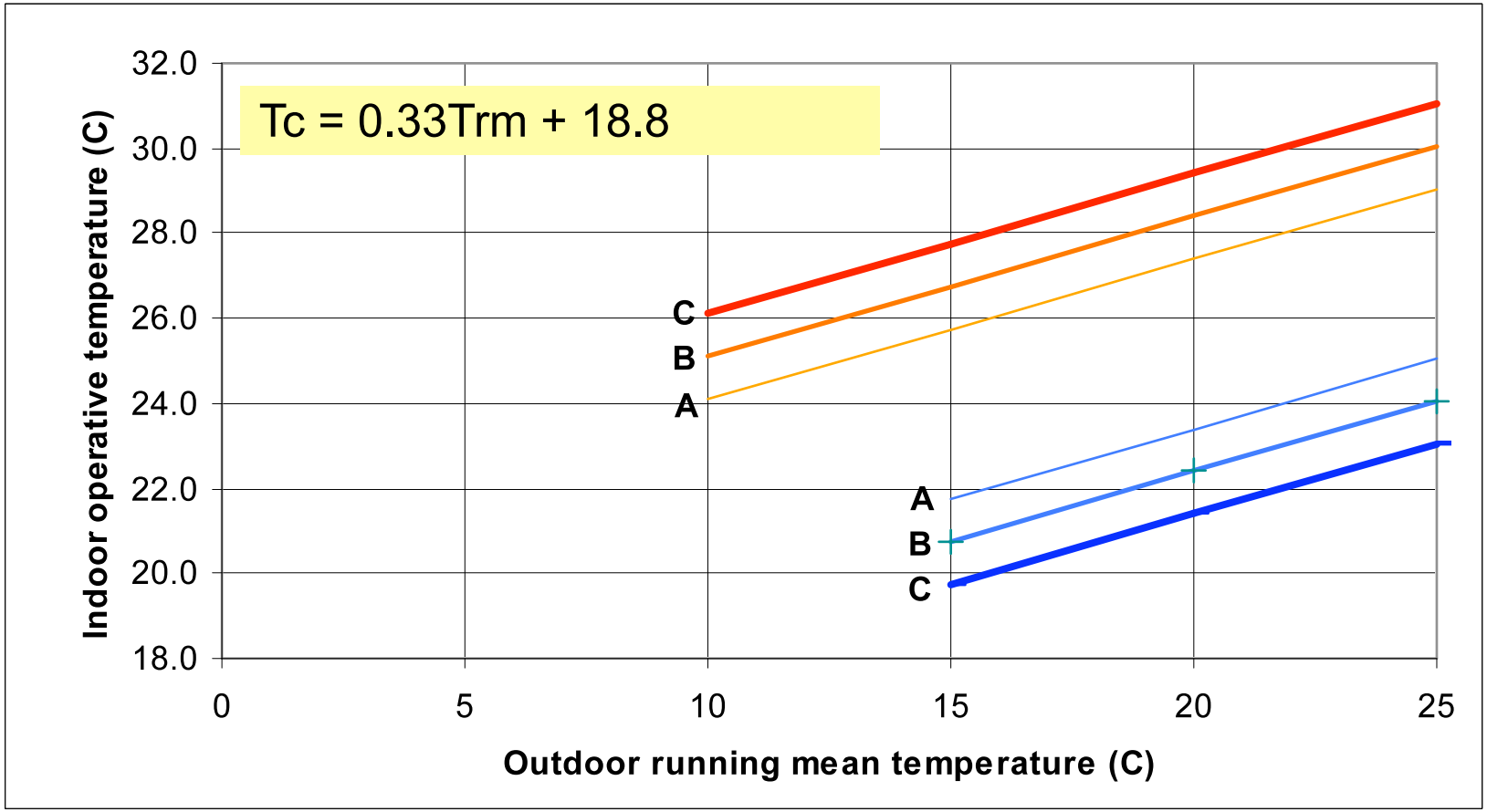
An extension of the PMV model that includes an expectancy factor is proposed for use in non-air-conditioned buildings in warm climates.

Expectancy factor: (0,5 to 1)

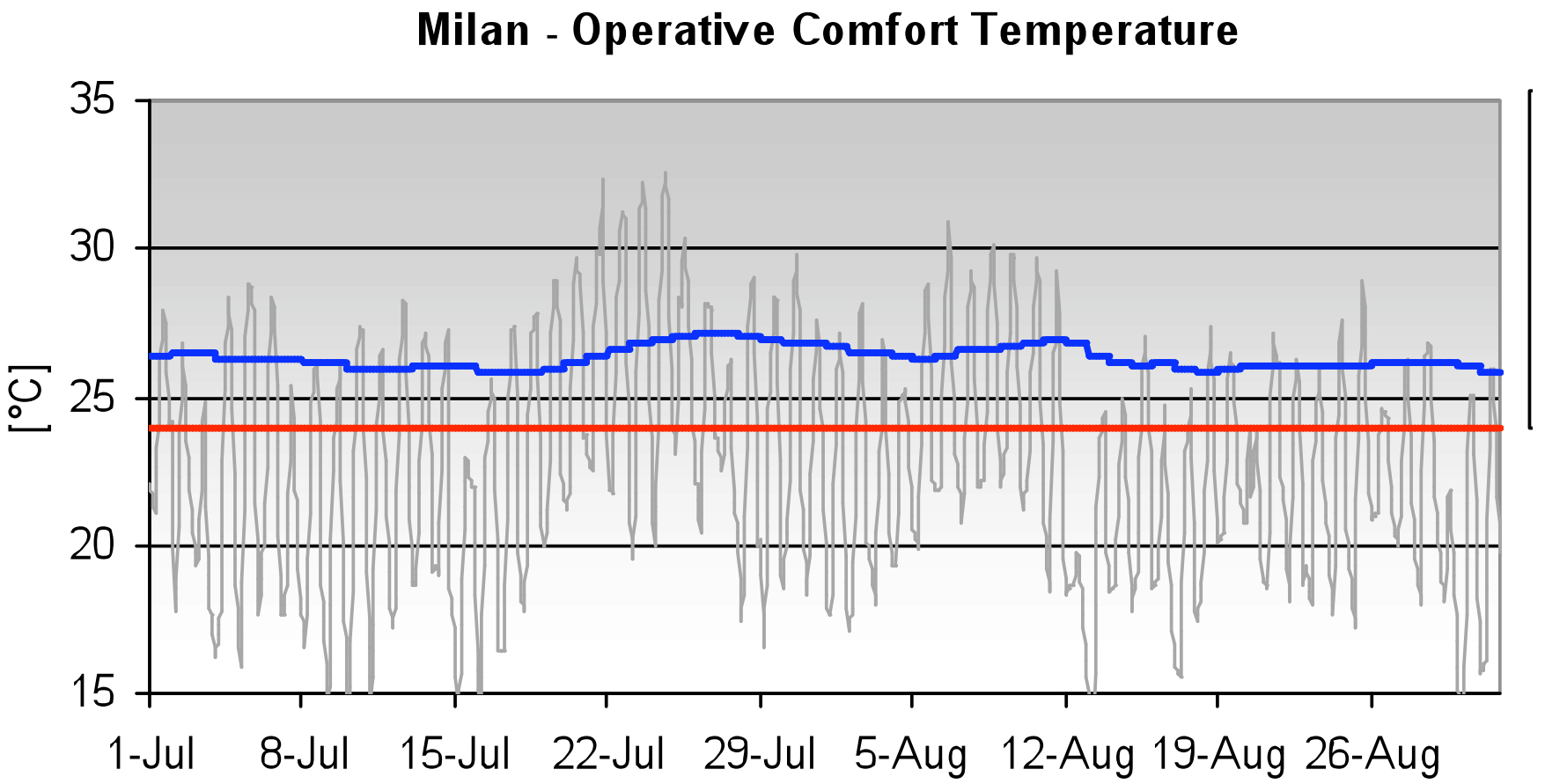
EN 15251 – Comfort categories

- Non mechanically cooled buildings:

Building Category	Adaptive Range
I	± 2°C
II	± 3°C
III	± 4°C



Adaptive vs Fanger (Milan)



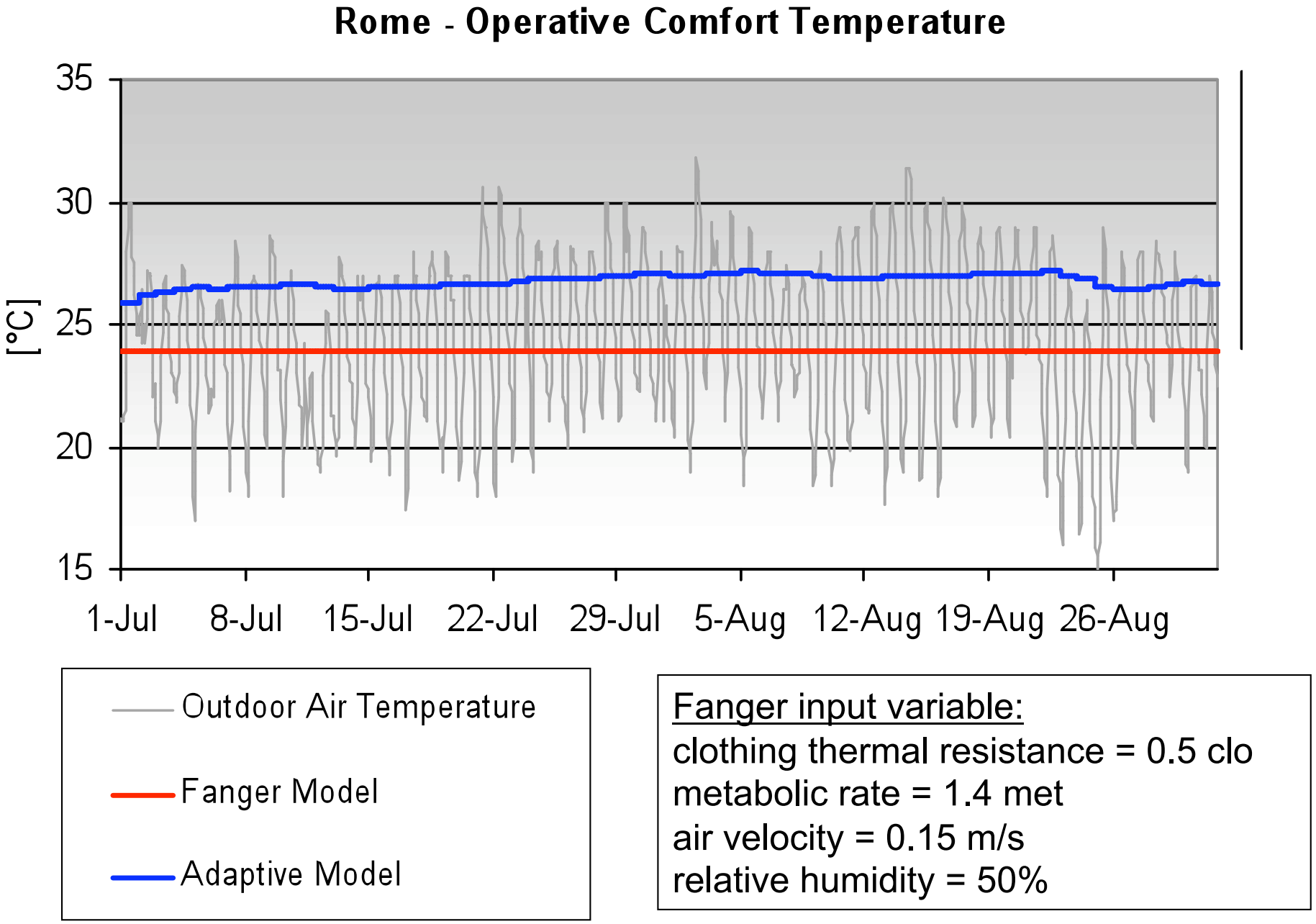
Outdoor Air Temperature

Fanger Model

Adaptive Model

Fanger input variable:
clothing thermal resistance = 0.5 clo
metabolic rate = 1.4 met
air velocity = 0.15 m/s
relative humidity = 50%

Adaptive vs Fanger (Rome)



Fanger input variable:
clothing thermal resistance = 0.5 clo
metabolic rate = 1.4 met
air velocity = 0.15 m/s
relative humidity = 50%

Long term discomfort indexes (EN15251)

- the "percentage outside the range" method requires to calculate the number or % of occupied hours when the PMV or the operative temperature is outside a specified range.
- In the "degree hours criteria" : the time during which the actual operative temperature exceeds the specified range during the occupied hours is weighted by a factor which is a function of by how many degrees the range has been exceeded.
- The weighing factor, wf= 0 for $\Theta_{o,limit,\ lower} < \Theta o < \Theta_{o,limit,upper}$ (e.g. 23,0°C < Θo < 26,0°C corresponding to –0,5 < PMV < 0,5 as specified in Annex A for offices, category II, summer).
- The weighing factor, wf, is calculated as $wf = \Theta_o - \Theta_{o,limit,}$ when otside limits
- For a characteristic period during a year, the product of the weighting factor and time is summed..
- Warm period: ∑wf· time for Θo > Θo,limit,upper
- Cold period: ∑wf· time for Θo < Θo,limit,lower

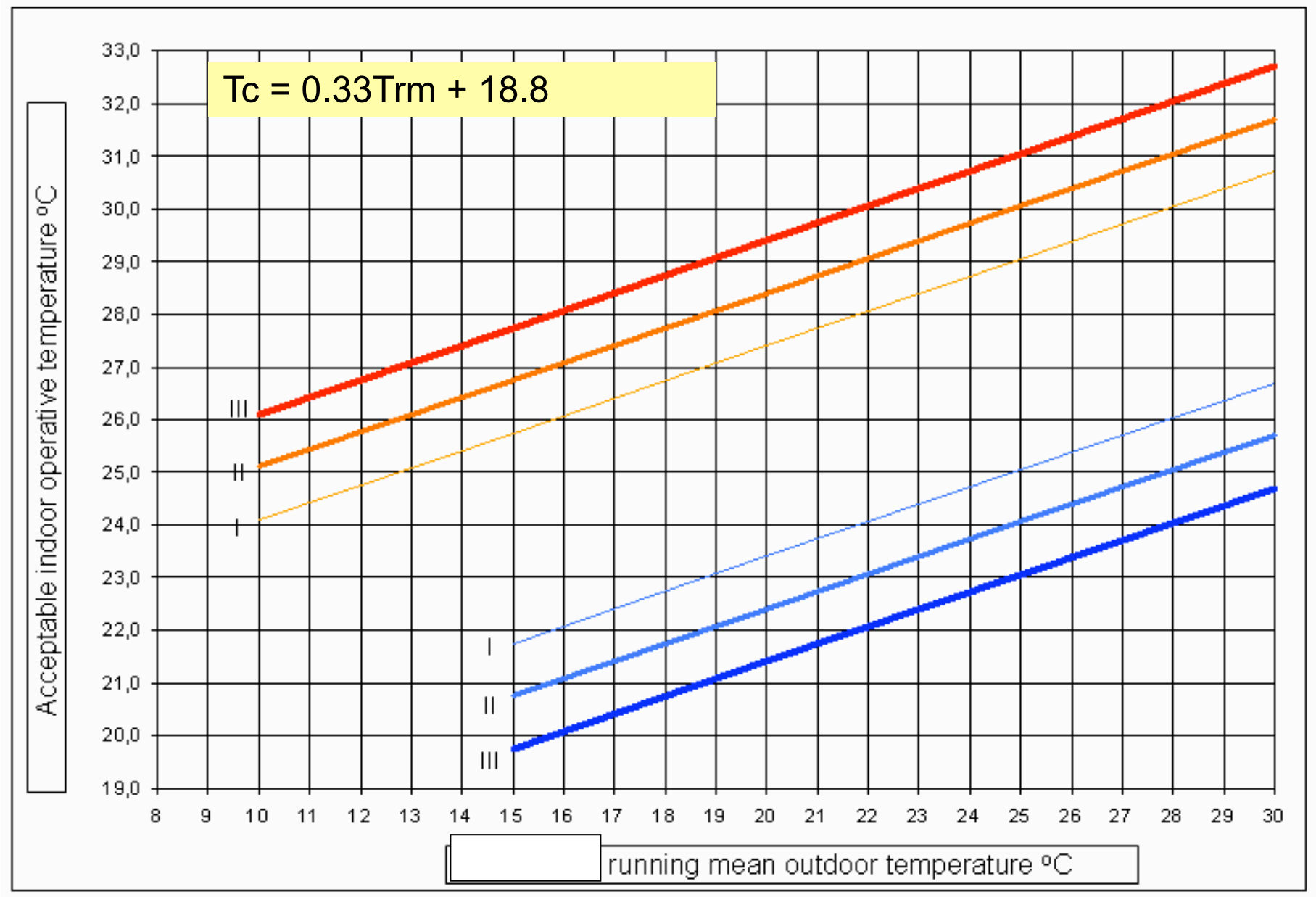
The following long-term indices are used here:

- Percentage outside range based on a maximum operative temperature of 26 °C (default value in the standard for Category II)
- Degree hours based on a maximum operative temperature of 26 °C (default value in the standard for Category II)

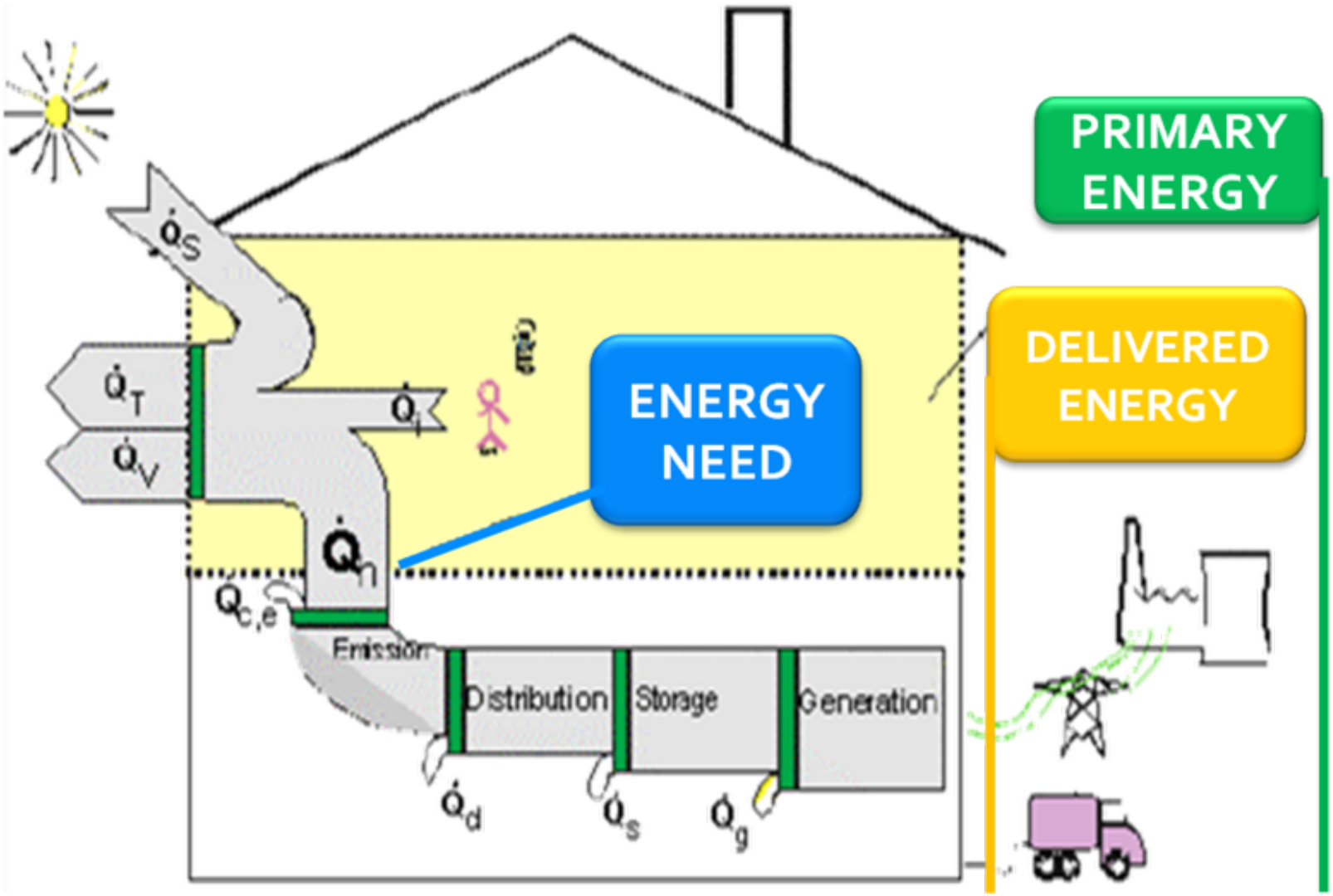
- Percentage outside range based on the adaptive comfort (Category II)
- Degree hours based on the adaptive comfort range (Category II)

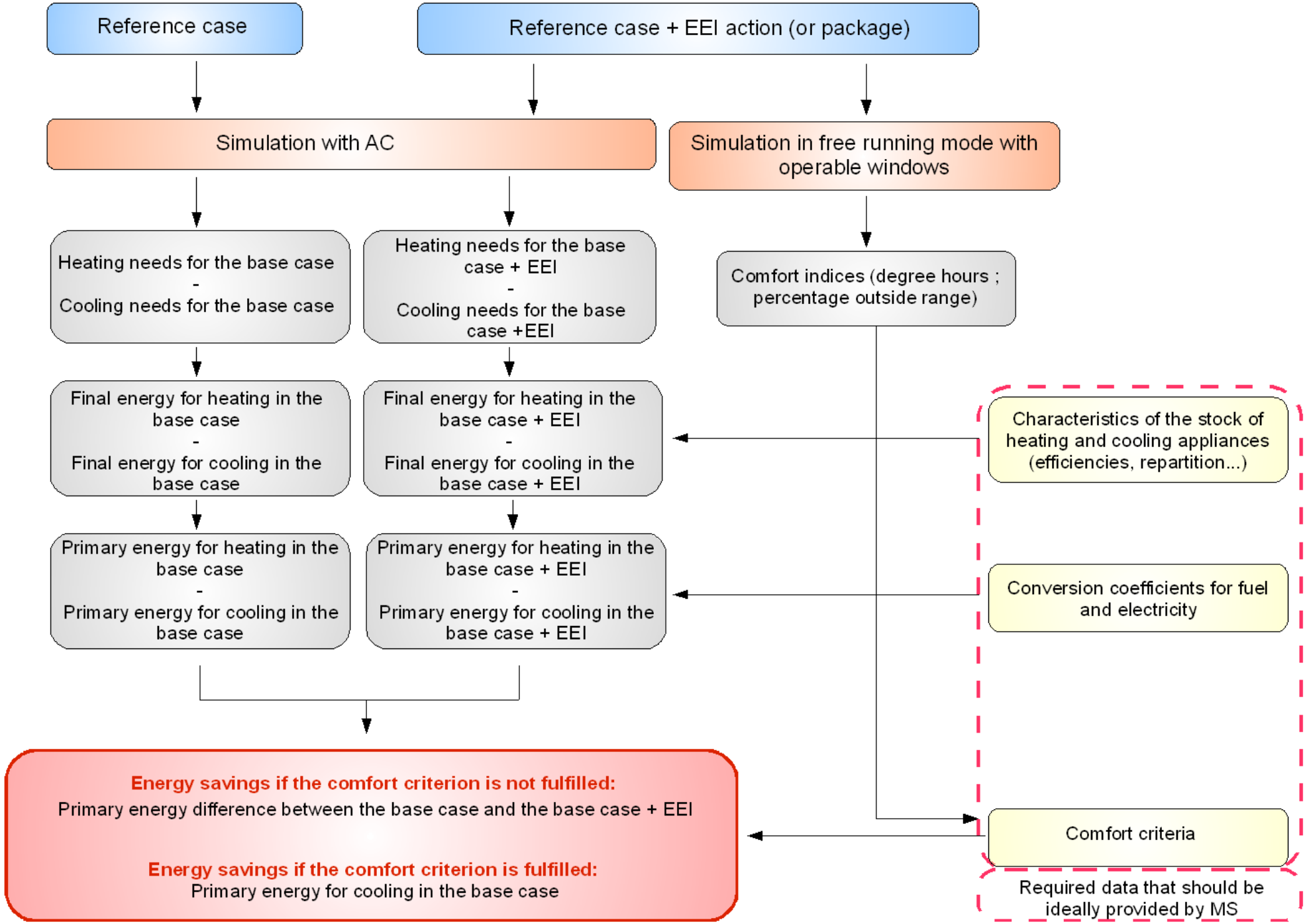
- Our default assumption is that a building is comfortable if the percentage of time outside comfort zone is lower than 5 % over the year.

EN15251: Temperature limits in Free Running Buildings



DLGS 192/2005 + DLGS 311/2006 (and EN NOMENCLATURE on energy levels!)

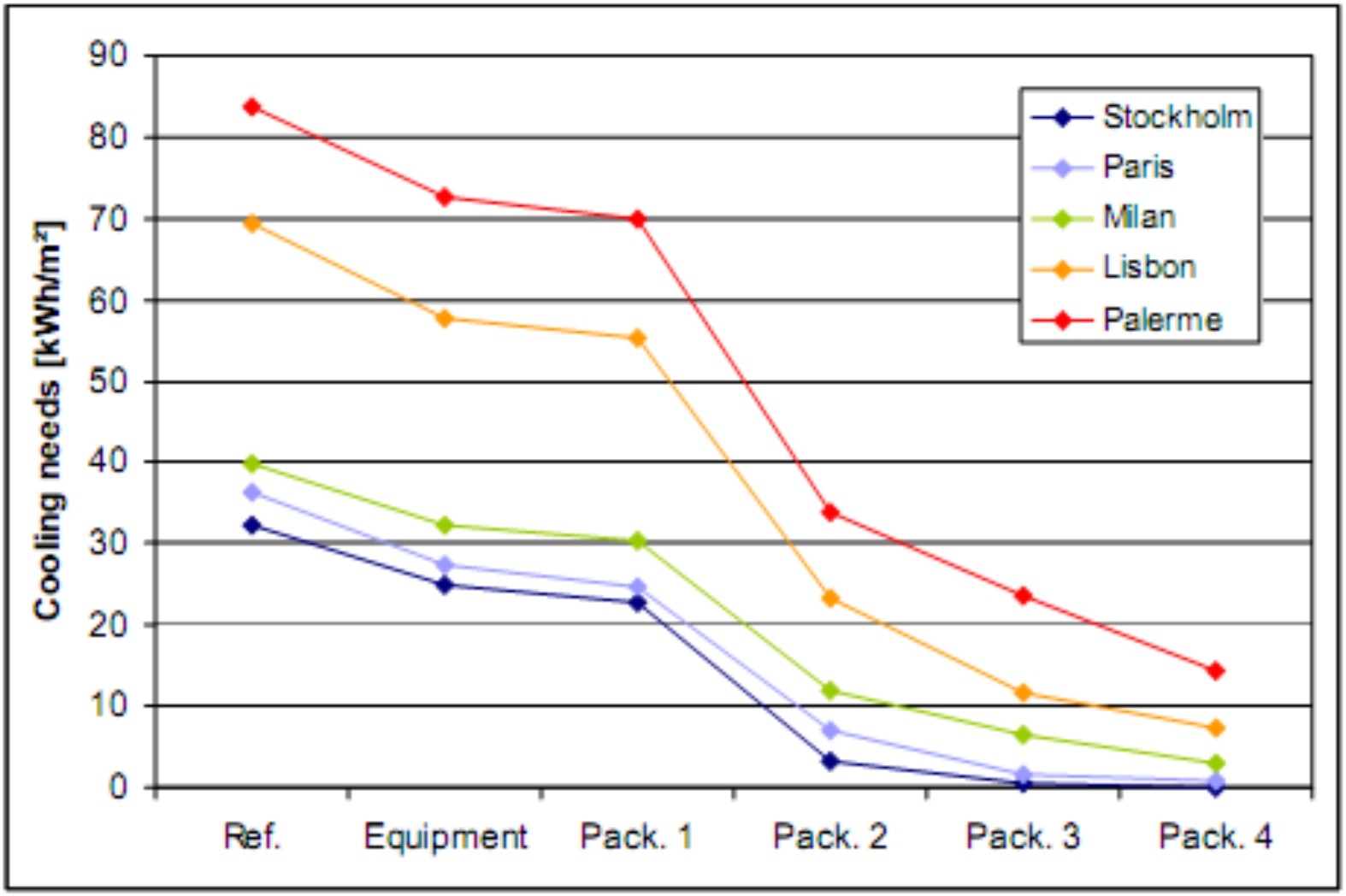



Reference case
Reference case + EEI action (or package)
Simulation with AC
Simulation in free running mode with operable windows
Heating needs for the base case - Cooling needs for the base case
Heating needs for the base case + EEI - Cooling needs for the base case +EEI
Comfort indices (degree hours ; percentage outside range)
Final energy for heating in the base case - Final energy for cooling in the base case
Final energy for heating in the base case + EEI - Final energy for cooling in the base case + EEI
Characteristics of the stock of heating and cooling appliances (efficiencies, repartition...)
Primary energy for heating in the base case - Primary energy for cooling in the base case
Primary energy for heating in the base case + EEI - Primary energy for cooling in the base case + EEI
Conversion coefficients for fuel and electricity
Energy savings if the comfort criterion is not fulfilled:
Primary energy difference between the base case and the base case + EEI
Energy savings if the comfort criterion is fulfilled:
Primary energy for cooling in the base case
Comfort criteria
Required data that should be ideally provided by MS

Packages of actions

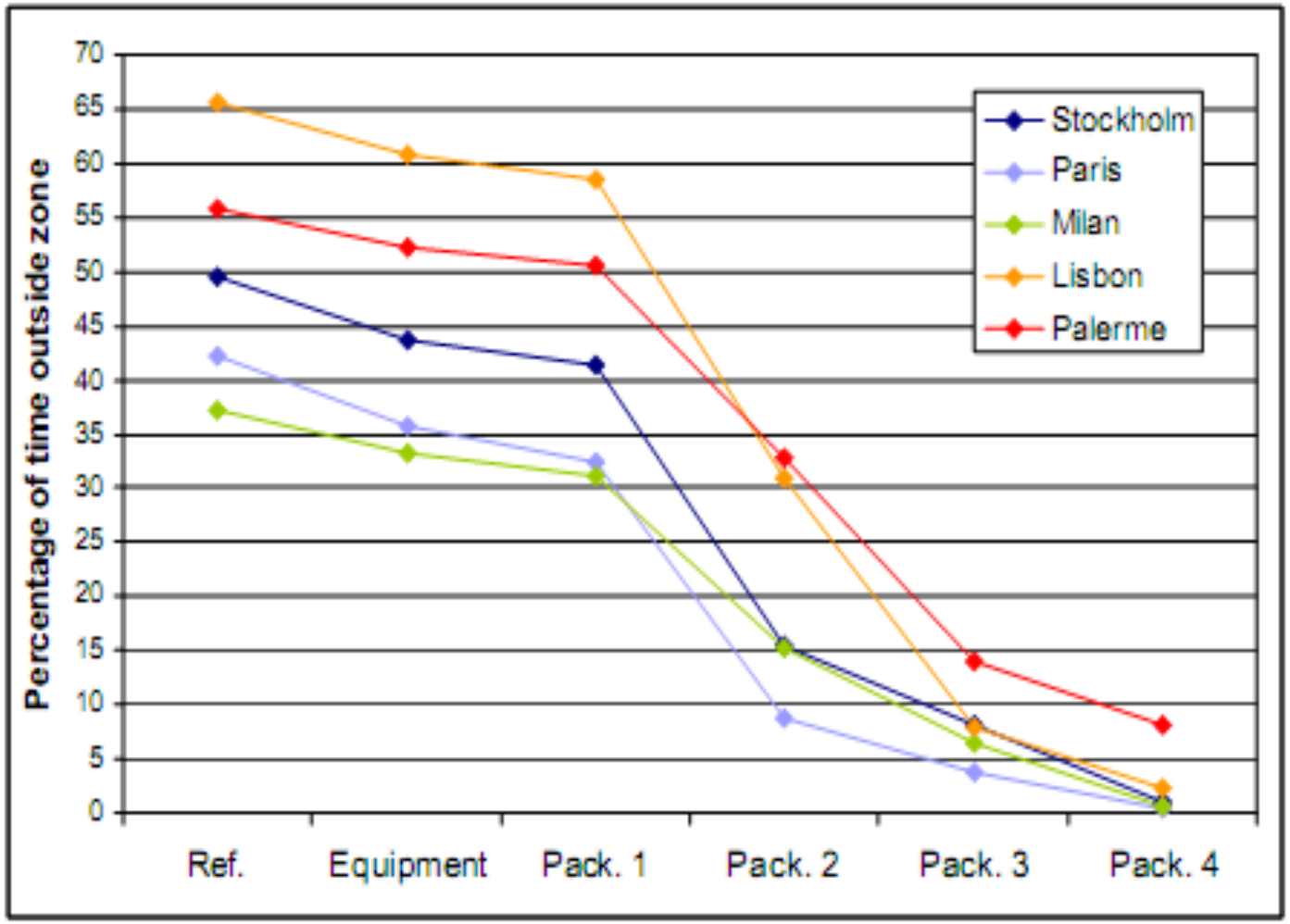
Table 15. Description of packages of EEI actions to be studied for office buildings

EEI actions	Pack. 1	Pack. 2	Pack. 3	Pack. 4
Install an external screen blind				
Install an external screen blind (radiation control)				
Install an external Venetian blind				
Install an external Venetian blind (radiation control)		X	X	X
Install efficient windows				X
Treat wall and roofs with special paintings				
Insulate the roof				X
Use energy efficient office equipment	X	X	X	X
Install energy efficient lightings and ballasts	X	X	X	X
Night-time free cooling Install automatic operable openings				
Day and night time free cooling Install automatic operable openings			X	X
Install extraction system for night-time ventilation				
Install extraction system for day and night-time ventilation				

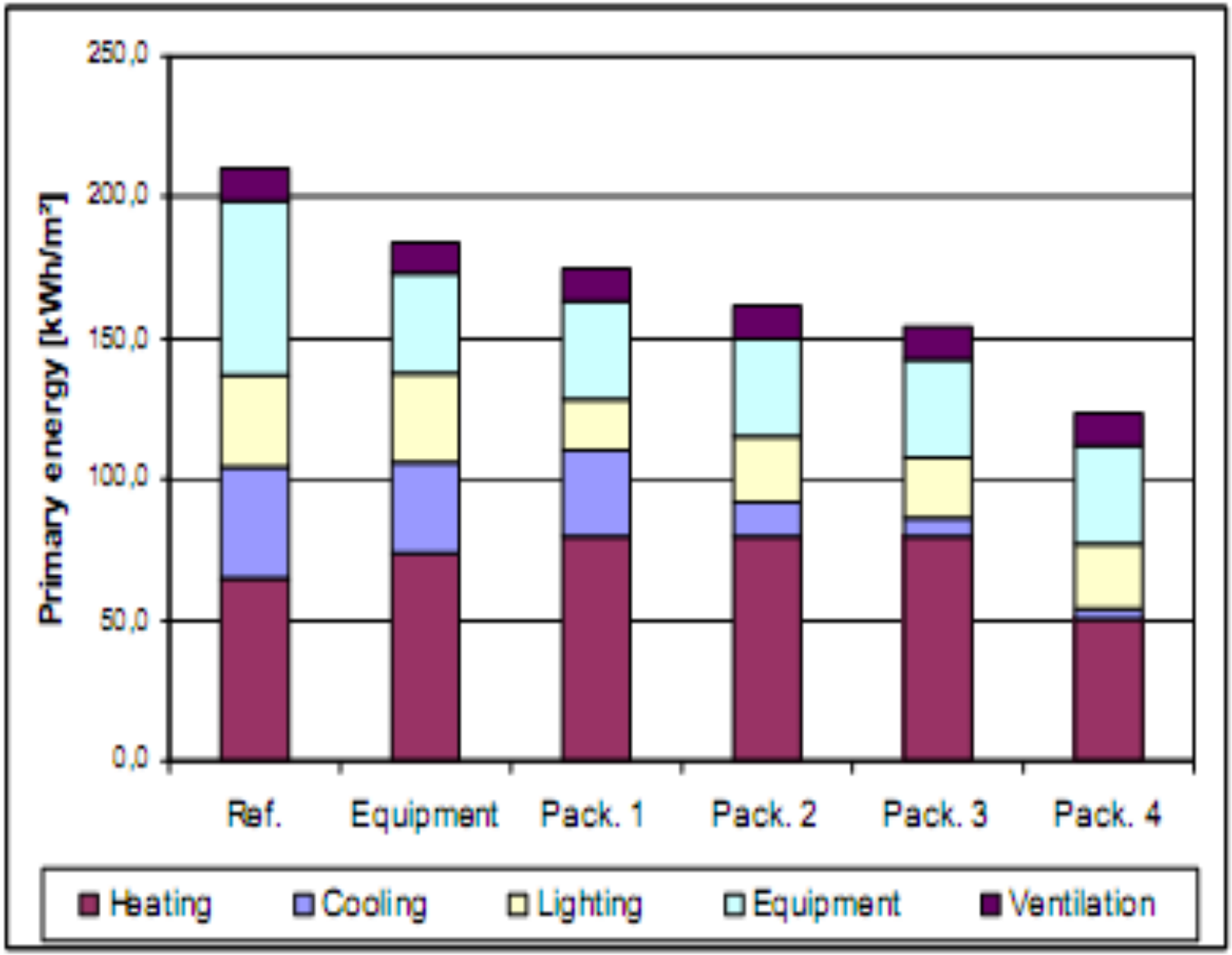


Evolution of cooling needs for the different packages studied in Office 2

Office 2.
Percentage of hours outside the adaptive comfort ran ge - Category II (existing buildings, disfavoured room).



Primary energy consumption per end use

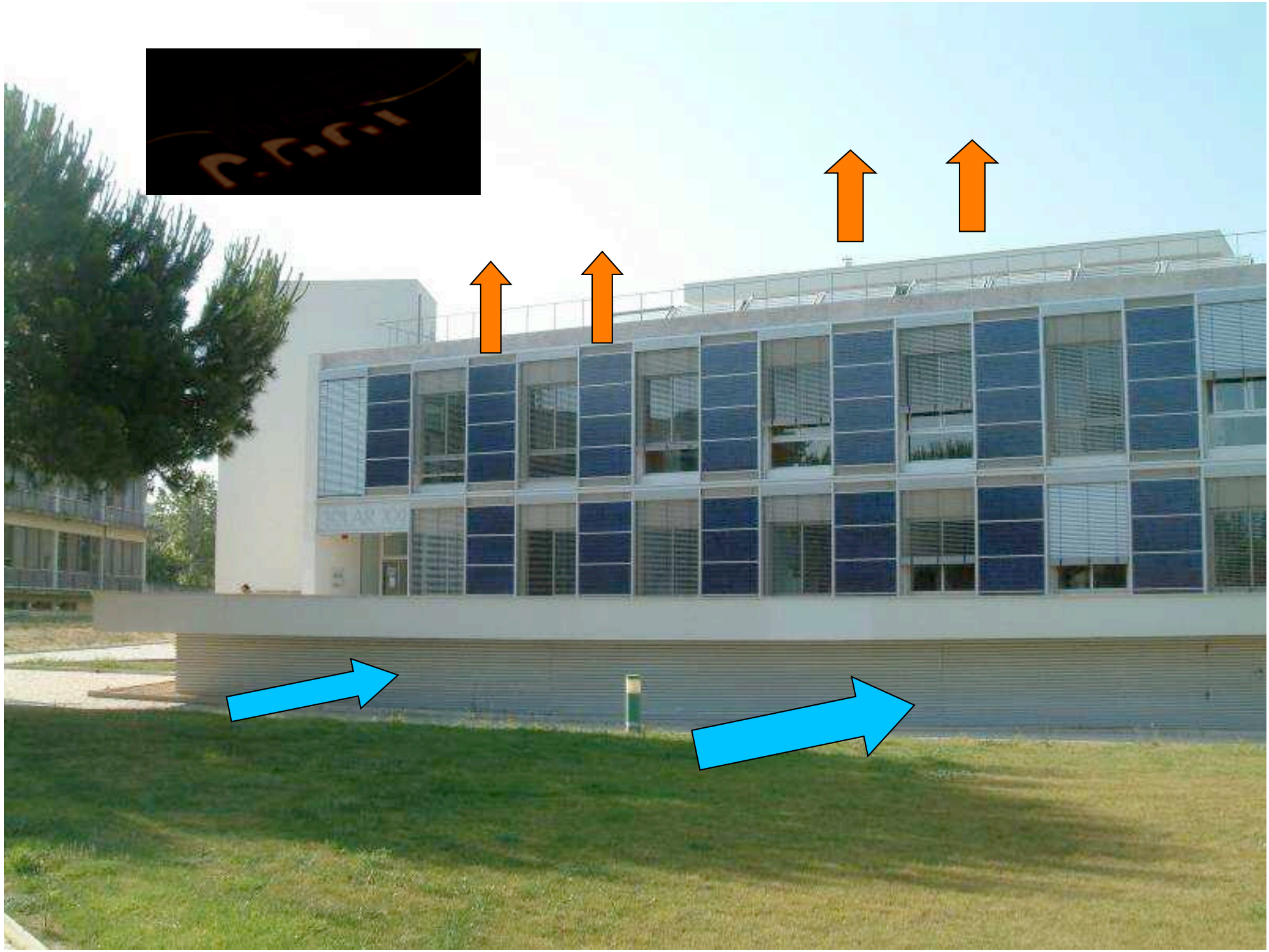


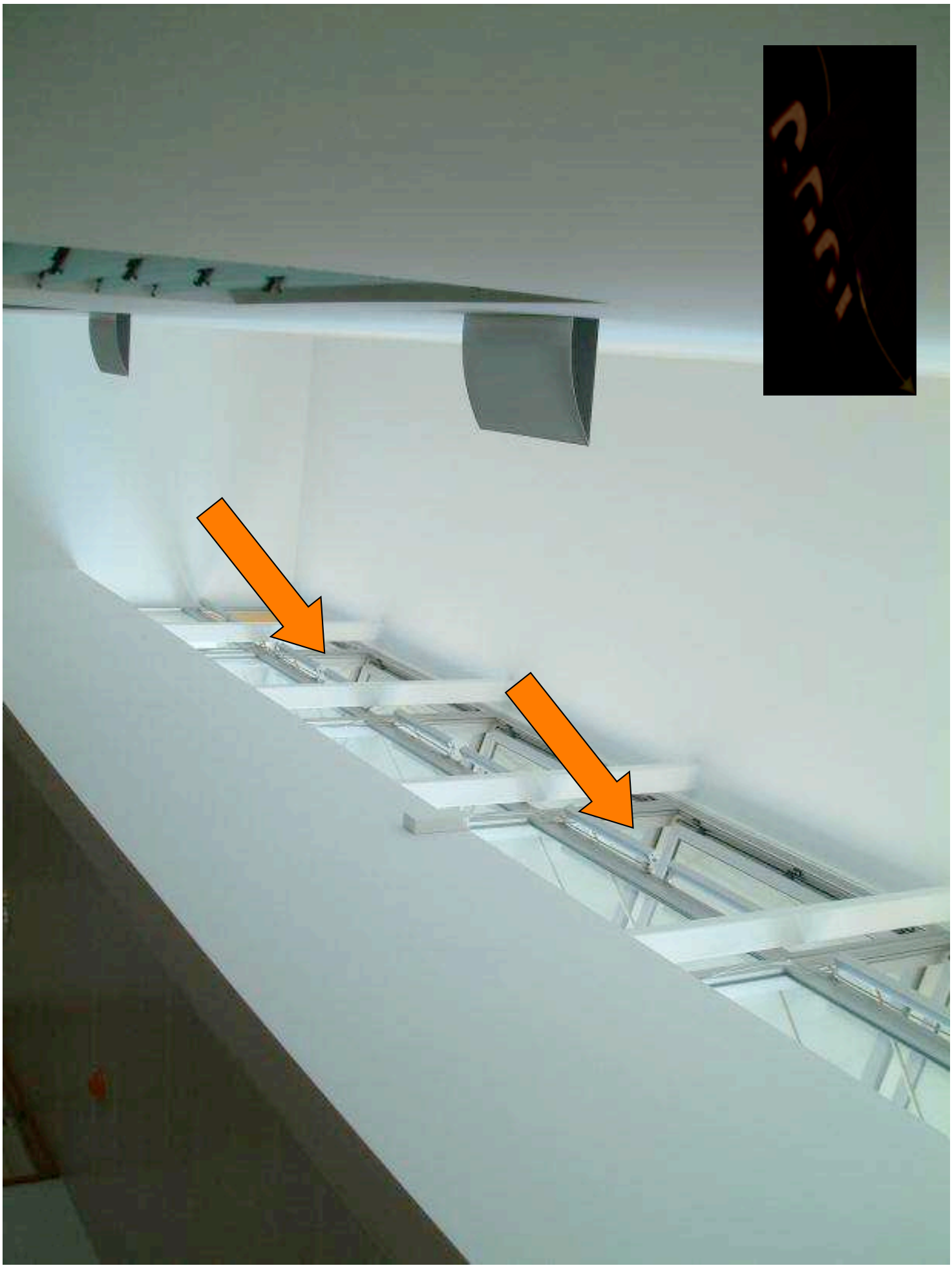
	EEI actions and packages	Comfort index in NV buildings [%]	Unitary savings (fuel) - [kWh/m²]	Unitary savings (electricity) – [kWh/m²]	Unitary savings (primary energy) [kWh/m²]
Milan	Screen blind - Manual control	37,1	-4,7	3,2	3,4
	Screen blind - Radiation control	32,3	-0,4	6,2	15,0
	Venetian - Manual control	29,3	-6,3	4,2	4,3
	Venetian - Radiation control	30,8	-0,5	2,9	6,8
	Efficient windows	26,5	7,1	5,6	21,0
	Treat walls and roofs	29,3	-9,1	7,0	8,3
	Insulate the roof	26,5	32,2	0,9	34,4
	Energy efficient equipments	50,3	-13,0	31,4	65,5
	Efficient lighting	33,3	-7,7	14,3	28,1
	Free cooling (night)	35,4	0,0	8,1	20,3
	Free cooling (night/day)	27,6	0,0	12,3	30,6
	Mechanical ventilation for cooling (night)	17,1	0,0	1,6	4,1
	Mechanical ventilation for cooling (night/day)	27,6	0,0	4,5	11,2
	Package 1	31,2	-58,8	109,7	236,3
	Package 2	15,2	-70,6	118,2	257,1
	Package 3	6,5	-70,6	128,1	281,7
	Package 4	0,7	-66,1	134,4	379,4

	EEI actions and packages	Comfort index in NV buildings [%]	Unitary savings (fuel) - [kWh/m²]	Unitary savings (electricity) – [kWh/m²]	Unitary savings (primary energy) [kWh/m²]
Palerme	Screen blind - Manual control	55,8	-2,1	7,0	15,4
	Screen blind - Radiation control	49,5	-0,2	12,8	31,7
	Venetian - Manual control	45,5	-3,0	9,1	19,8
	Venetian - Radiation control	47,6	-0,3	8,7	21,4
	Efficient windows	41,4	4,0	9,3	27,4
	Treat walls and roofs	50,5	-5,3	14,7	31,3
	Insulate the roof	41,4	7,0	1,9	11,8
	Energy efficient equipments	70,9	-4,2	34,5	82,1
	Efficient lighting	52,2	-2,2	13,6	31,7
	Free cooling (night)	54,2	0,0	10,6	26,6
	Free cooling (night/day)	48,2	0,0	17,7	44,2
	Mechanical ventilation for cooling (night)	31,7	0,0	0,7	1,8
	Mechanical ventilation for cooling (night/day)	47,5	0,0	4,9	12,3
	Package 1	50,6	-58,8	112,3	267,9
	Package 2	32,8	-70,6	132,6	318,4
	Package 3	14,0	-70,6	147,4	355,4
	Package 4	8,0	-66,1	153,4	388,0

Ten steps to achieve sustainable summer comfort

1. Comfort objectives explicitly defined
2. Site layout
3. Reduce heat gains at the envelope boundary
4. Control heat transfer through the structure
5. Reduce internal heat gains
6. Allow for local and individual adaptation
7. Passive cooling (e.g. night ventilation, ground cooling)
8. Solar cooling
9. Efficient conventional active cooling
10. Operation, maintenance and monitoring





NOS

Office building in Austria

Year of construction	2003
Type of construction	Light outer construction with heavy components inside
Function	Office building plus a cefeteria and a loading/parking space inside
Location	Austria, 48°05' north, 13°51' east, 370 m above sea level, countryside
Main technologies for cooling	Mass activation, night ventilation, water to ground heat exchanger,
Energy distribution system	Heating and cooling panels, floor heating
Heated/cooled building area	1215 m^2

Energy performances

- During the cooling period the measured cooling demand was 6,4 kWh/m²a and the maximal cooling load was 11 W/m². The summer results can be seen as a successful integration of load reduction (daylight, controlled shading) and passive cooling (ground to water heat exchanger, night ventilation).
- The heating demand was measured to 20 kWh/m²a and the maximal heat load was 13 W/m² for the winter operation

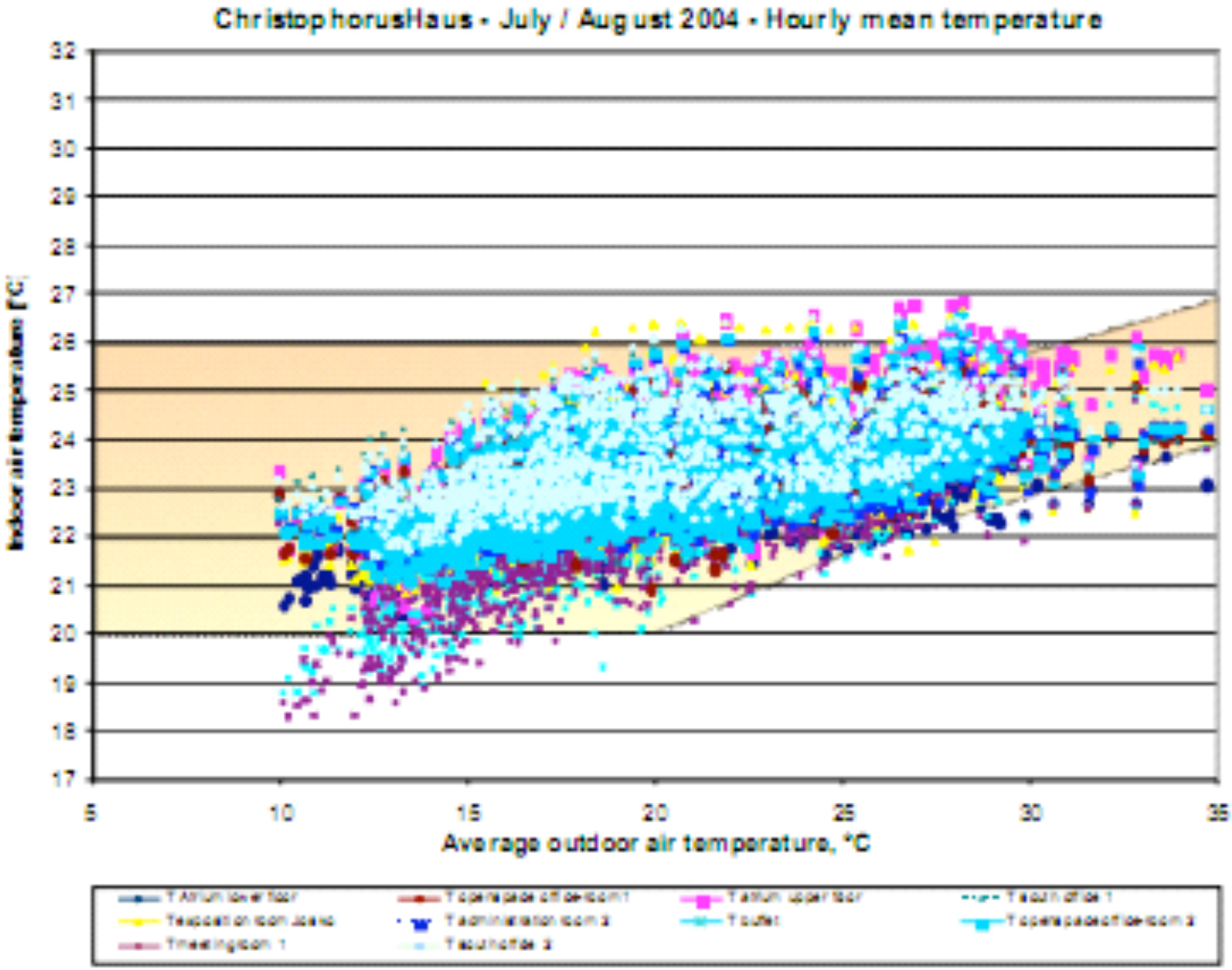


Figure 4. Mean indoor hourly temperature in different areas of the ChristophorusHaus building and the mean outdoor temperature – July / August 2004)

Allow for local and individual adaptation

-
-
-
-

“Code of conduct” at Middlebury College (Vermont, USA, 2003 onward)

- the college:
- commits to give priority to heat load reducing mechanisms before introducing mechanical cooling;
- encourages individual adaptation during heat wave periods (e.g. relaxed dress codes, use of ceiling fans, adaptation of the working schedule to avoid working during hotter hours etc.);
- gives exact guidance on the use of mechanically cooled spaces.

Other “comfort policy” examples

- Sidney University
- Coolbiz in Japan
- United Nations
- ENI and SanPaolo in Italy

A guideline to sustainable summer comfort in service buildings
ustainable comfort ?
ce examples
about cooling
& Experts
eep Cool
nks
Building Owner
O&M Personnel
Technical Consultant
Building User
Checklist - what to do
Benefits of sustainable cooling
You are a Building Owner
6 steps to achieve sustainable summer confort:
The 6 steps include defining thermal comfort needs, reducing internal and external heat loads.
Follow the instructions given below:
1. Define the thermal comfort objectives
2. Reduce internal heat loads
3. Reduce external loads
Summary
Detailed info
Solar gains
Heat transfer
Links/Documents
4. Use passive means to remove energy from the building
5. Consider active solar assisted cooling plants
6. If necessary, consider efficient conventional active cooling systems
www.keepcool.info

DPR 24/02/2009 : FIRST REQUIREMENTS ON SPACE COOLING IN ITALY

4. In every site where monthly average solar irradiance on horizontal plane is higher then 290 W/m^2:
   i. External opaque vertical walls, exposed from east to west, must have or a **thermal mass per unit of front area** higher then 230 kg/ m^2 **or periodic thermal transmittance** (or transfer admittance) lower then 0,12 W/m^{2}K $Y_{ie} = -\left.\frac{\varphi_i}{\theta_e}\right|_{\theta_i=0}$
   ii. External opaque horizontal component must have **periodic thermal transmittance** (or transfer admittance) lower then 0,20 W/m^{2}K

5. It is possible to reach periodic thermal transmittance limits covering roof with vegetation

DPR 24/02/2009 : FIRST REQUIREMENTS ON SPACE COOLING IN ITALY

6. to favour **natural ventilation** of the whole building using in the best way the external ambient conditions and disposition of indoor spaces. If it is not possible, mechanical ventilation systems can be installed

7. **External shading systems** are compulsory. If they are not cost-effective, they can be omitted if glazed surfaces are characterized by a **solar factor** not higher then 0,5

DPR 24/02/2009 : FIRST REQUIREMENTS EVER ON SPACE COOLING IN ITALY – maximum energy need

TYPE OF BUILDING	MAXIMUM LEGAL VALUE FOR SPACE COOLING	CLIMATIC ZONES
Residential	40 kWh/m^2	A - B
	30 kWh/m^2	C - D - E - F
Non residential	14 kWh/m^3	A - B
	10 kWh/m^3	C - D - E - F

THANK YOU

end-use Efficiency Research Group (eERG) - Politecnico di Milano

Lorenzo Pagliano

www.eerg.it

eERG
end-use Efficiency Research Group
Gruppo di ricerca sull'efficienza negli usi finali dell'energia

Aiming at a correct definition of comfort, “avoiding unnecessary energy consumption”

Main changes achieved in the new standard EN15251

F.Nicol, L.Pagliano +European Environmental Citizens' Organisation for Standardisation (ECOS)

Subjective Comfort Survey (ASHRAE scale)

Used for interviews and base for both the Famger nad Adaptive Comfort models

How do you feel?

+3 Hot

+2 Warm

+1 Slightly warm

0 Neutral

-1 Slightly cool

-2 Cool

-3 old

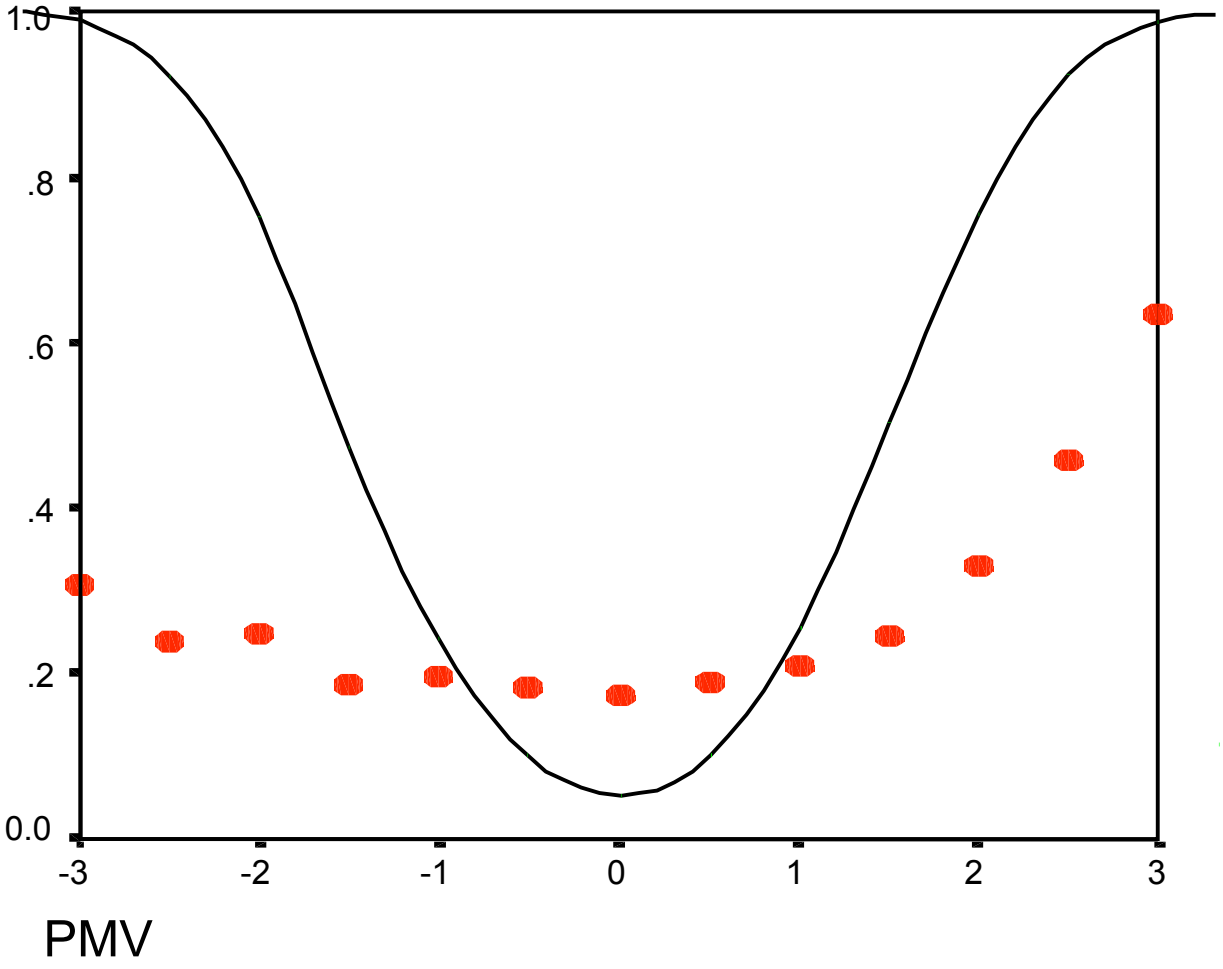
FANGER Comfort Model

- interviews in controlled chambers after 3 hours stay in stationary conditions. and simultaneous measurements of :
  - air temperature,
  - mean radiant temperature,
  - relative air velocity,
  - relative humidity,
  - activity (metabolic rate),
  - clothing (thermal resistance).
- Used to produce a correlation
- which allows to calculate from values of air temperature etc in a given situation the Predicted Mean Vote (on the ASHRAE scale -3 to +3) or PMV
- **The Predicted Mean Vote** can also be reformulated as **Predicted Percentage of Dissatisfied** PPD
- Remember Validity conditions!!!!

Recommended categories for design of mechanical heated and cooled buildings in ISO 7730 (proposed for prEN13251)

Category	Thermal state of the body as a whole	
	PPD %	Predicted Mean Vote
A	< 6	-0.2 < PMV < + 0.2
B	**< 10**	**-0.5 < PMV < + 0.5**
C	< 15	-0.7 < PMV < + 0.7
D	> 15	PMV<-0.7; or +0,7<PMV

Predicted Percentage of Dissatisfied (PPD) vs Actual Percentage of Dissatisfied (APD) in real buildings



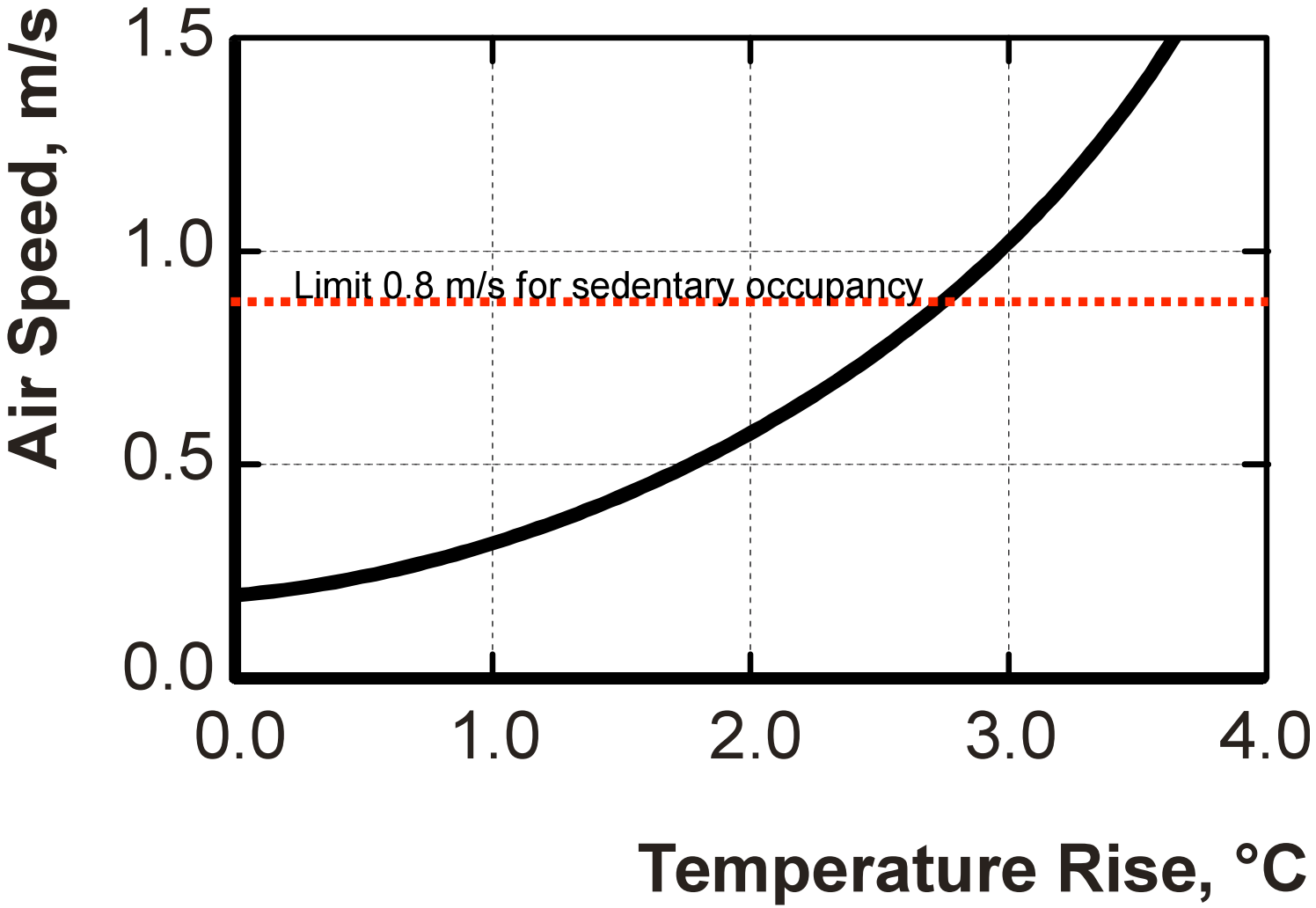
- Based on data of ASHRAE RP-884 database, 15000 interviews in 160 bldngs

PPD (ISO 7730)

APD (votes -3,-2,2,3) from ASHRAE database 884

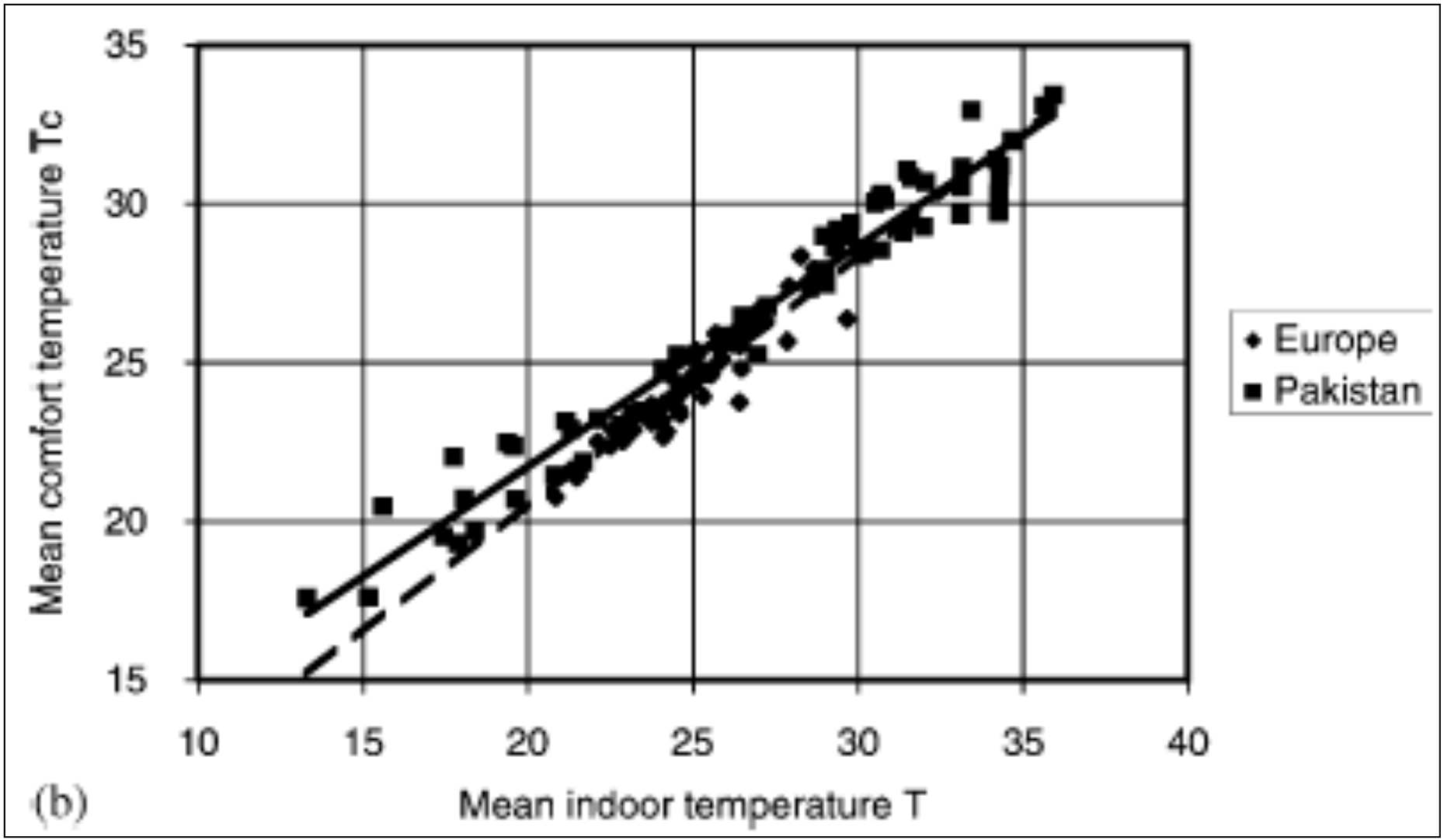
Allowance for air movement

ASHRAE Standard 55, EN ISO 7730, then also in EN15251:



Critical issues about PMV

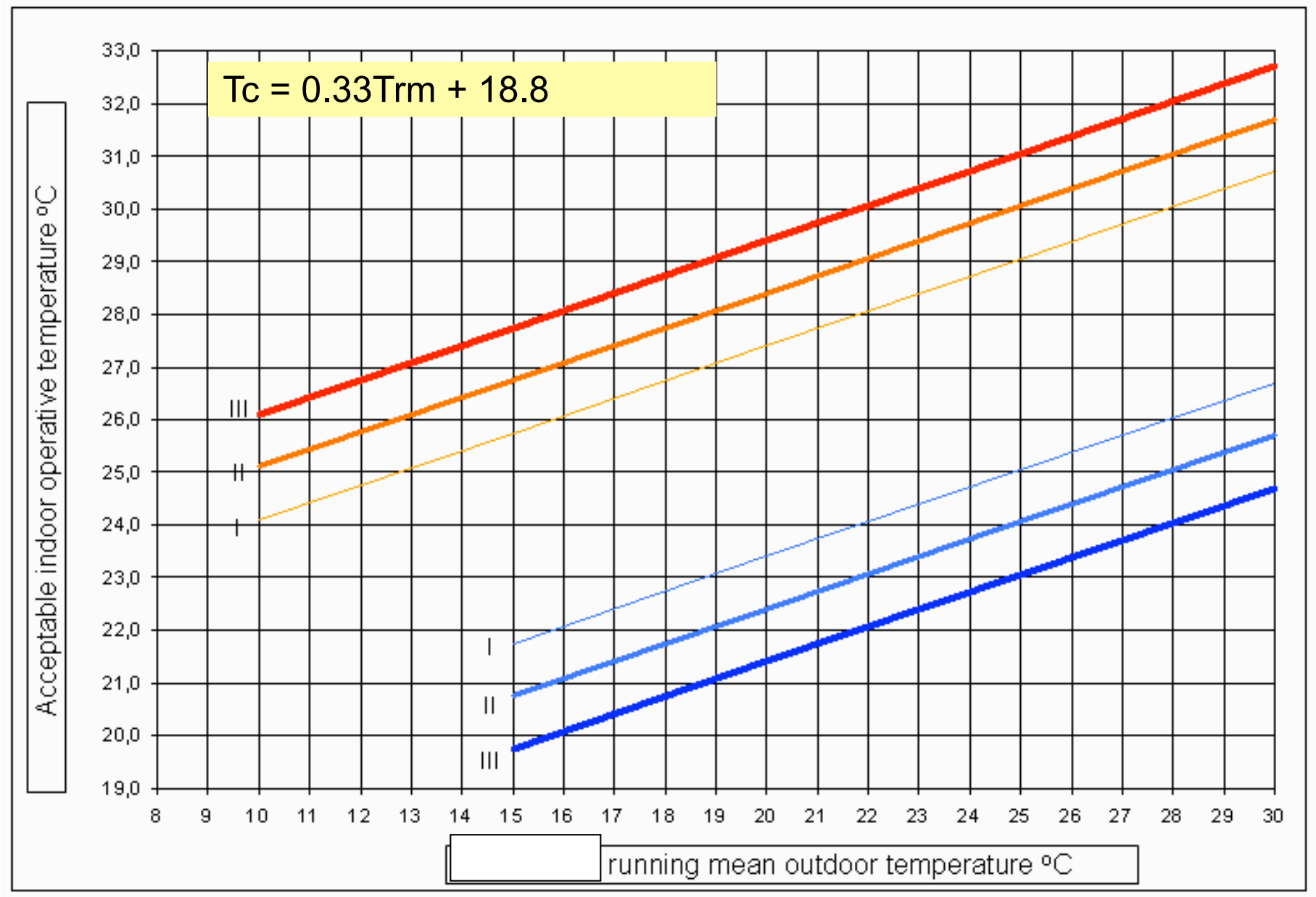
- INDOOR comfort temperature (responses of occupants) vs measured INDOOR comfort temperature



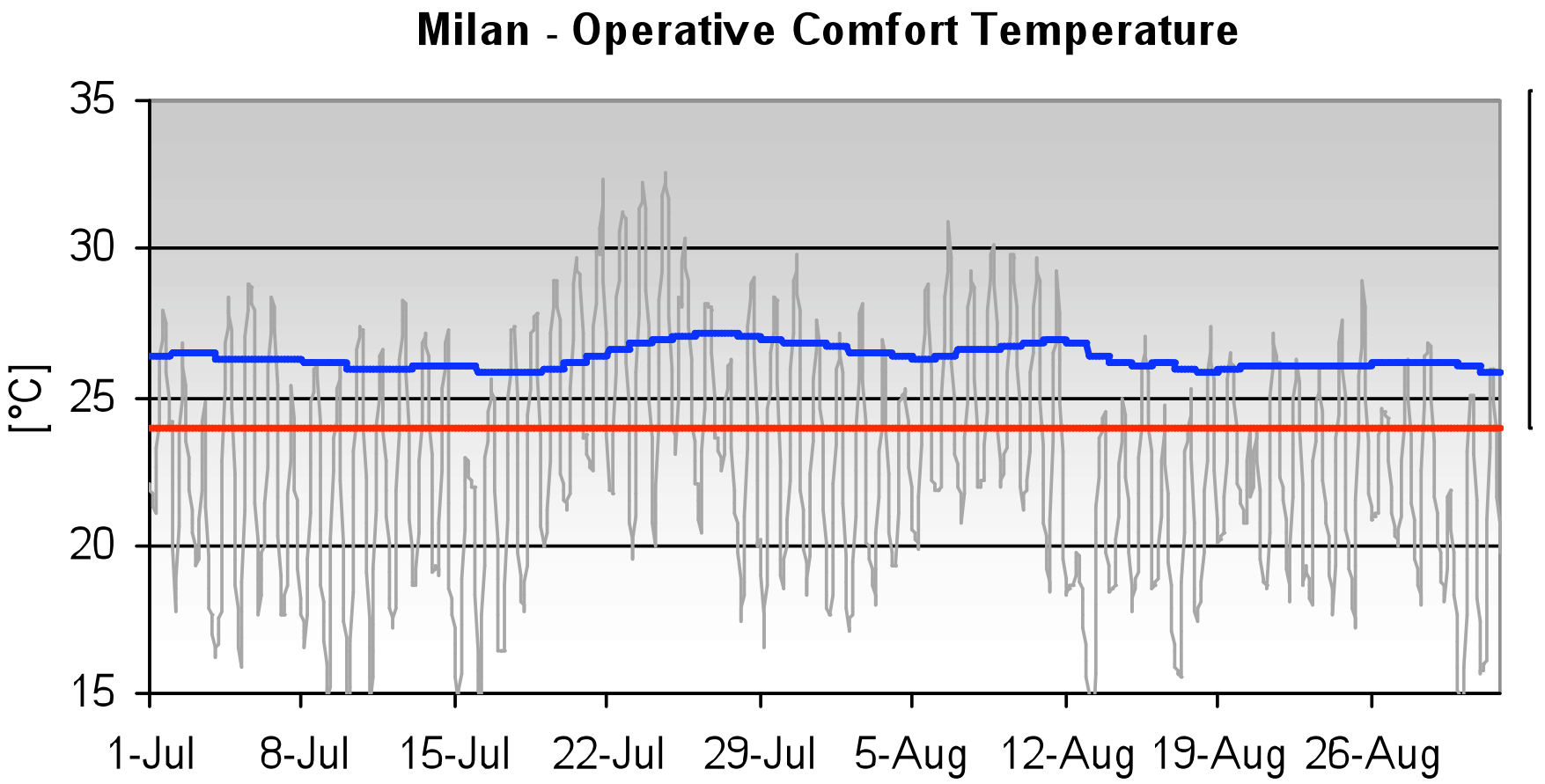
ADAPTIVE COMFORT MODEL (Humprey&Nicol 1972) in EN 15251

- The Adaptive Approach has been developed from field-studies of people in daily life.
- people in daily life are not passive, but tend to make themselves comfortable, by making adjustments (adaptations) to their clothing, activity and posture.
- The ‘adaptive opportunity’ may be provided, for instance, by fans or openable windows in summertime ...
- Dress codes will also have consequences for thermal design, ... and ... for energy consumption.

EN15251: Temperature limits in Free Running Buildings



Adaptive vs Fanger (Milan)



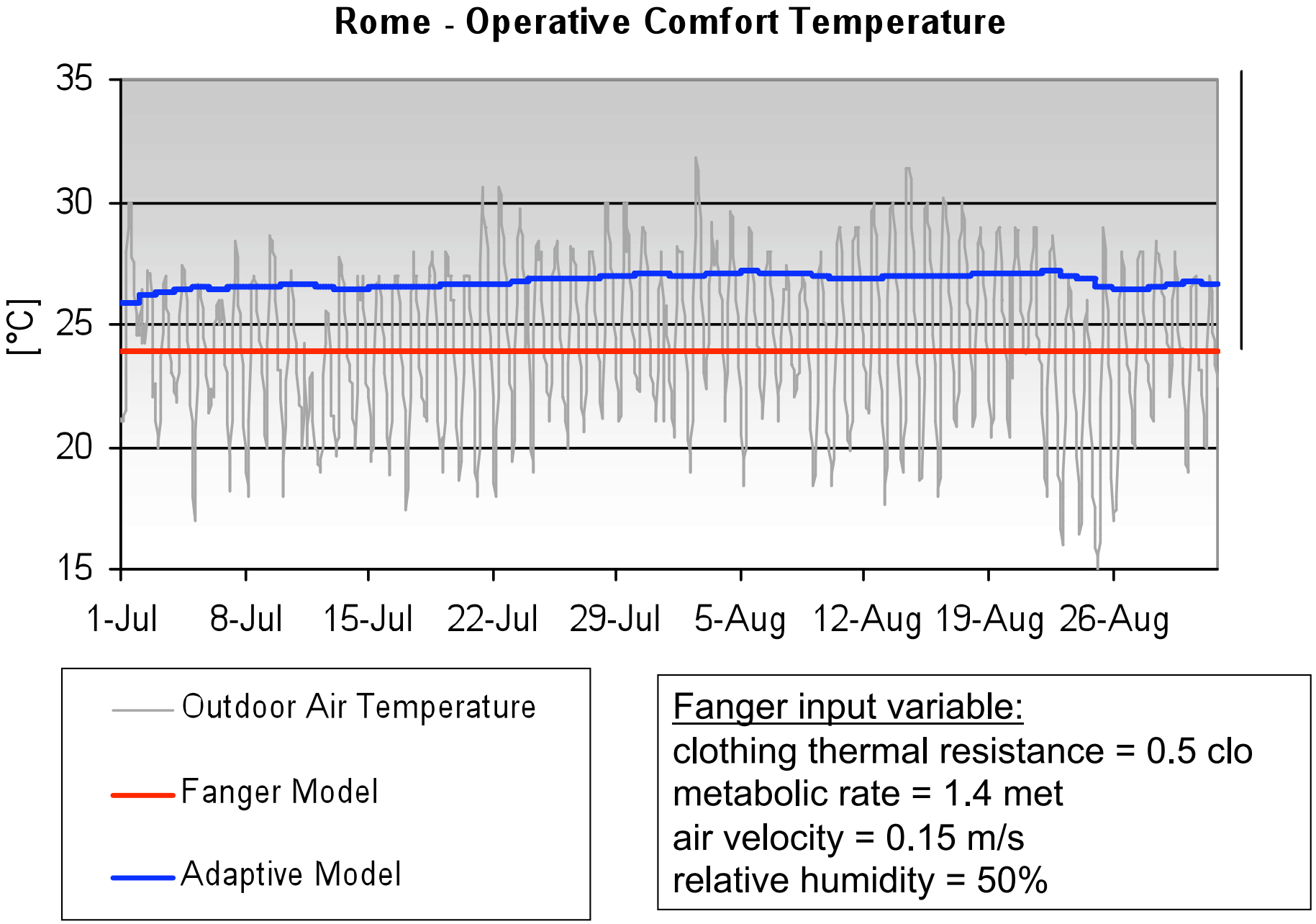
Outdoor Air Temperature

Fanger Model

Adaptive Model

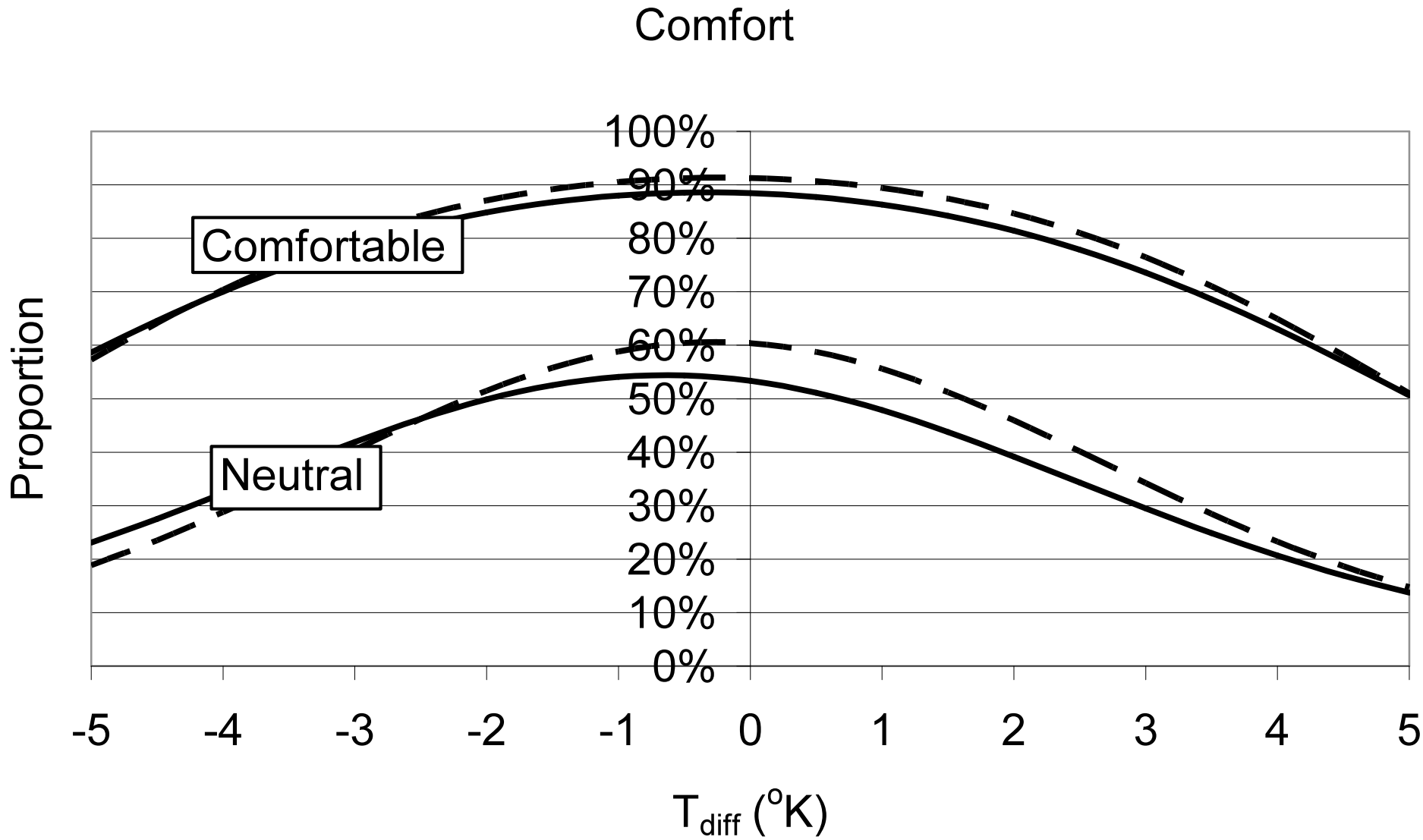
Fanger input variable:
clothing thermal resistance = 0.5 clo
metabolic rate = 1.4 met
air velocity = 0.15 m/s
relative humidity = 50%

Adaptive vs Fanger (Rome)



Fanger input variable:
clothing thermal resistance = 0.5 clo
metabolic rate = 1.4 met
air velocity = 0.15 m/s
relative humidity = 50%

COMFORT IN BUILDINGS



prEN15251: Temperature limits in Free Running Buildings (1)

Category	Suggested acceptable range
I	± 2K
II	± 3K
III	± 4K
IV	

Selected policy recommendations (1)

- Building code and Energy certification: they should explicitly deal with net useful energy demand for cooling
- Inspection of AC systems: energy advice should not relate to the mechanical AC system only but should also include actions for the reduction of the net useful energy demand for cooling

Selected policy recommendations (2)

- Enact legislation and incentives schemes to take full stock of the possibilities offered by the Adaptive model in characterising comfort in non-mechanically cooled buildings
- take full stock of the flexibility present in the Fanger model and its application in ISO 7730 (in mechanically cooled buildings).
- Include a description of comfort models in the curricula for designers and training courses for professionals who will be charged of providing the building energy certification.

Selected policy recommendations (3)
Research strategy

- Include in the "European Strategic Energy Technology Plan (SET-Plan)“ a focus on sustainable summer comfort issues (e.g. through the formation of a European technology platform for envelope and passive cooling technologies);

- Increase the share of demonstration, dissemination and monitoring activities. Promote large, well designed monitoring campaigns

- Promote empirical studies on comfort perception in real, occupied buildings, (mechanically cooled buildings, buildings that apply passive cooling technologies and in hybrid buildings)

Keepcool 2

- More direct activity in promoting pilots
- More industry networking and market transformation (packaged solutions)
- Evaluation of savings by envelope and passive cooling technologies (library of measures) to be used for implementation of the EEESD
- Integrated solutions for Public Procurement

Comprehensive evaluation of the national EEAP-s with respect to measures that reduce energy consumption for cooling and information exchange between member countries

on this issue;

- Development of guidelines for public procurement that take into account energy savings

from sustainable summer solutions and compilation of best practice examples relating to

the integration of energy efficiency issues – in this case of sustainable summer aspects

– into public building administrations;

- Making available simplified procedures to evaluate the energy savings related to sustainable

summer comfort (approach for a bottom-up assessment).

prEN15251: INTRODUCTION

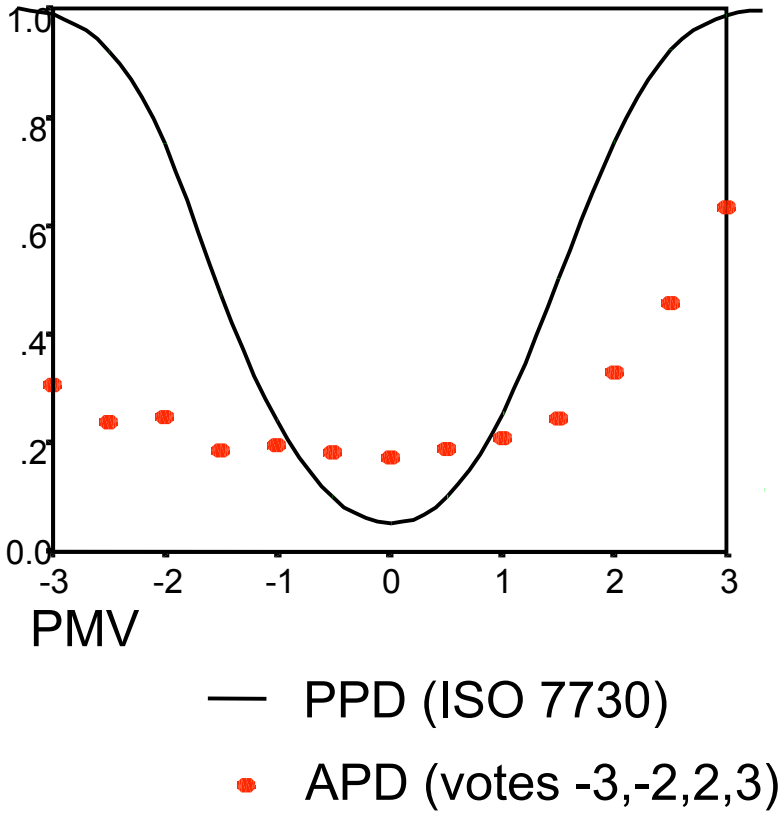
- European Energy Performance of Buildings Directive: *"the displaying of officially recommended indoor temperatures, together with the actual measured temperature, should discourage the misuse of heating, air-conditioning and ventilation systems. This should contribute to avoiding unnecessary use of energy and to safeguarding comfortable indoor climatic conditions (thermal comfort) in relation to the outside temperature".*
- The European Standard prEN15251 *(Indoor environmental input parameters for design and assessment of energy performance of buildings)* defines minimum standards for the internal environment in buildings to complement the EPBD. A major consideration of the prEN is to ensure a correct definition of thermal comfort.

prEN15251: NV and AC Buildings

- International Standard EN ISO 7730 (2006) makes no allowance for differences in comfort conditions in naturally ventilated (NV) and mechanically cooled (AC) buildings.
- prEN15251 makes a distinction between buildings which are HC and those which are FR. Thus NV buildings will be HC during the heating season and FR during the summer; AC buildings are HC throughout the year. In Standard prEN15251, the comfort zone for HC buildings is defined as in EN ISO 7730 (2006).

prEN15251: Examples of 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
IV	> 15	PMV<-0.7; or +0,7<PMV



prEN15251: Evaluation of thermal conditions for compliance

- There are two methods suggested in the prEN for evaluating the thermal comfort conditions:
  - Percentage outside range: the proportion of the occupied hours during which the temperature lies outside the acceptable zone.
  - Degree hours criterion: The time during which the actual operative temperature exceeds the specified range during occupied hours is weighted by a factor depending on the number of degrees by which the range has been exceeded.
- Acceptability of the space on the 'percentage' criterion is on the basis that the temperature in the rooms representing 95% of the occupied space is not more than 3% (or 5% - to be decided) of the occupied hours a day, week, month or year, outside the limits of the specified category. Acceptability for the degree hours criterion are still to be decided.

CONCLUSION

- The proposed new European Standard prEN 15251 has been framed to allow the natural variability of the indoor climate in free running buildings to be matched to the natural ability of people in well designed buildings with adequate occupant control, to change their room conditions to suit their needs.

- This will mean that buildings can be designed which are both comfortable and can make full use of passive, low energy cooling and heating technologies.

AKNOWLEDGMENTS

- Evidence supporting the use of the Adaptive Comfort Model, simulations on its application and considerations on categories have been developed, summarised in the appropriate language and formally brought to the attention of the drafting group of prEN 15251 by the authors. This was done within the work programme of the EIE projects KeepCool and Passive-on, and by means of ECOS, European Environmental Citizens' Organisation for Standardisation, which has Associate status with CEN. Some National Standardisation Bodies supported the presentation of parts of the amendments proposed. We would like to acknowledge the role of Prof Michael Humphreys in developing many of the ideas presented.

- www.energimyndigheten.se

Modification to PMV proposed by Fanger

P. Ole Fanger*, Jørn Toftum

In non-air-conditioned buildings in warm climates, occupants may, however, perceive the warmth as being less severe than the PMV predicts. This is mainly caused by low expectations, but a metabolic rate that is estimated too high under warm conditions also contributes to explain the difference.

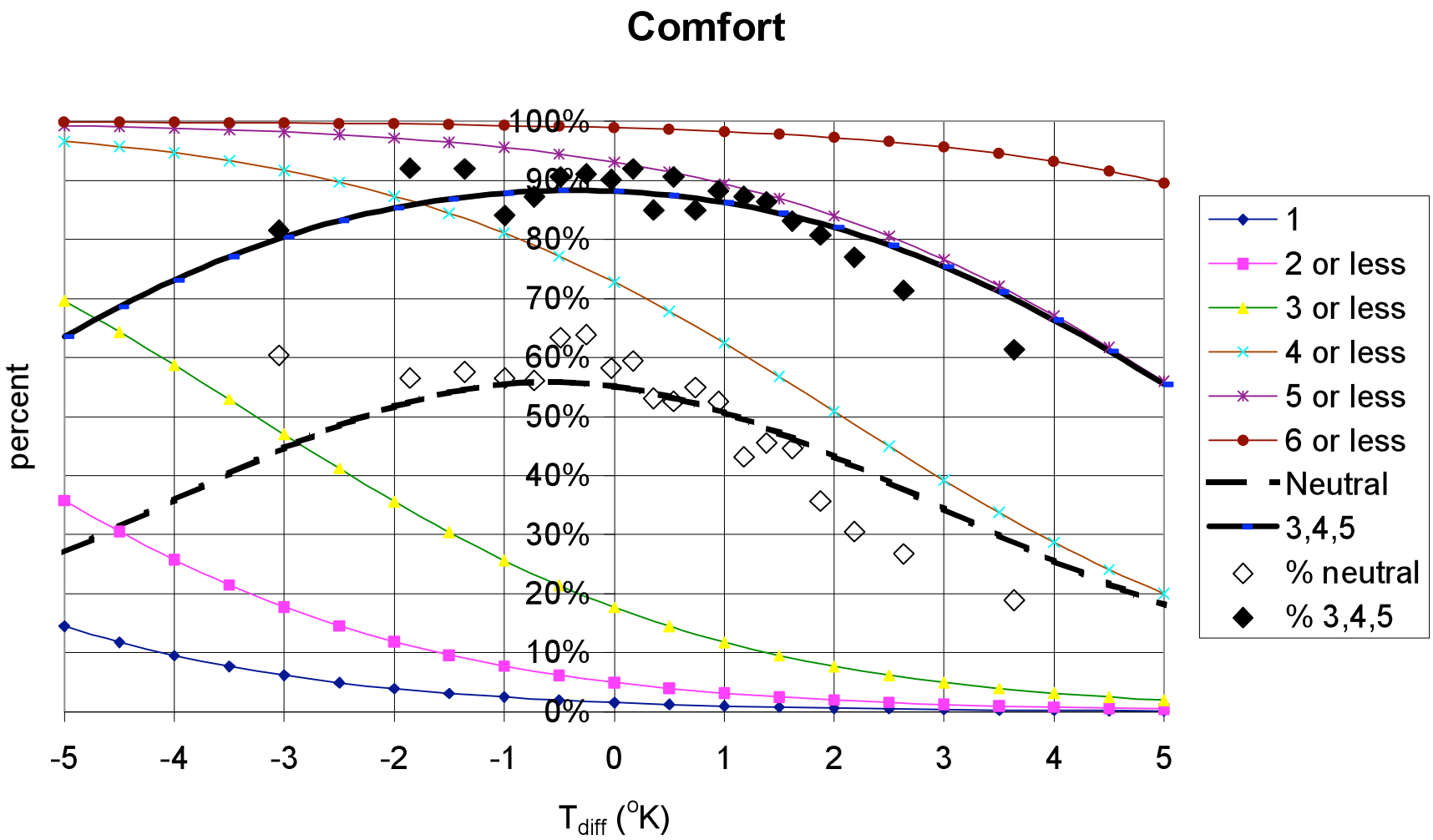
An extension of the PMV model that includes an expectancy factor is proposed for use in non-air-conditioned buildings in warm climates.

Expectancy factor: 0,5 to 1 : a change of a factor two

ADAPTIVE APPROACH (3)

- Clothing and other adjustments in response to day-on-day changes in temperature, will occur when a building is responding to weather and seasonal changes. These will occur quite gradually and can take a week or so to complete. So it is desirable that the day-to-day change in mean indoor Operative temperature during occupied hours should not occur too quickly for the adaptive processes to keep pace.
- During the summer months many buildings in Europe are free-running. The temperatures in such buildings will change according to the weather outdoors, as will the clothing of the occupants. Even in air-conditioned buildings the clothing has been found to change according to the weather. As a result the temperature people find comfortable indoors also changes with the weather. Thus the temperature people find comfortable can vary quite considerably depending on the climate, but any change should occur sufficiently slowly to give building occupants time to adapt.

Expected discomfort



Conclusions

- PrEN15251 allows for a variation in comfort temperature in buildings which are not mechanically cooled.
- The comfort temperature can be calculated from the running mean of the outdoor temperature.
- The level of discomfort is a function of the difference between comfort temperature and operative temperature

Policy suggestions

Conclusions

- There is no temperature at which everyone will feel comfortable,
- Minimum discomfort will be experienced within 2^{o}K of the comfort temperature.
- An allowance can be made for air movement

OUTLINE

EN 15251 (on the base of data from SCATS and other surveys of thermal comfort):

- Defines an adaptive comfort temperature for European office workers in free running buildings.
- Defines comfort categories (in terms of use of the building, and range of PMV or operative temperature).
- Provides examples of adaptive comfort temperatures in different climates.

ISO 7730: Validity conditions

- The index shall be used only for values of PMV between -2 and +2 and when the six main parameters are within the following intervals.:
  - Air temperature: 10 °C < *ta* < 30 °C;
  - Radiant mean temperature: 10 °C < *tmr* < 40 °C;
  - Air velocity: *va* < 1 m/s;
  - Activity between 0.8 and 4 met (46 to 232 W/m2)
  - Clothing between 0 and 2 clo (0 m2 K/W and 0,310 m^2 K/W