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Buildings: Energy, Environment and Health

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Energy Framework for Europe

EUROPEAN COMMISSION

Directorate-General
for Energy
and Transport

Estimated energy saving potential in end-use sectors

Sector	Energy consumption 2005 (Mtoe)	Energy consumption 2020 (business-as-usual) (Mtoe)	Energy saving potential 2020 (Mtoe)	Energy saving potential 2020 (%)
Households (residential)	280	338	91	27
Commercial buildings (tertiary)	157	211	63	30
Transport	332	405	105	26
Manufacturing industry	297	382	95	25

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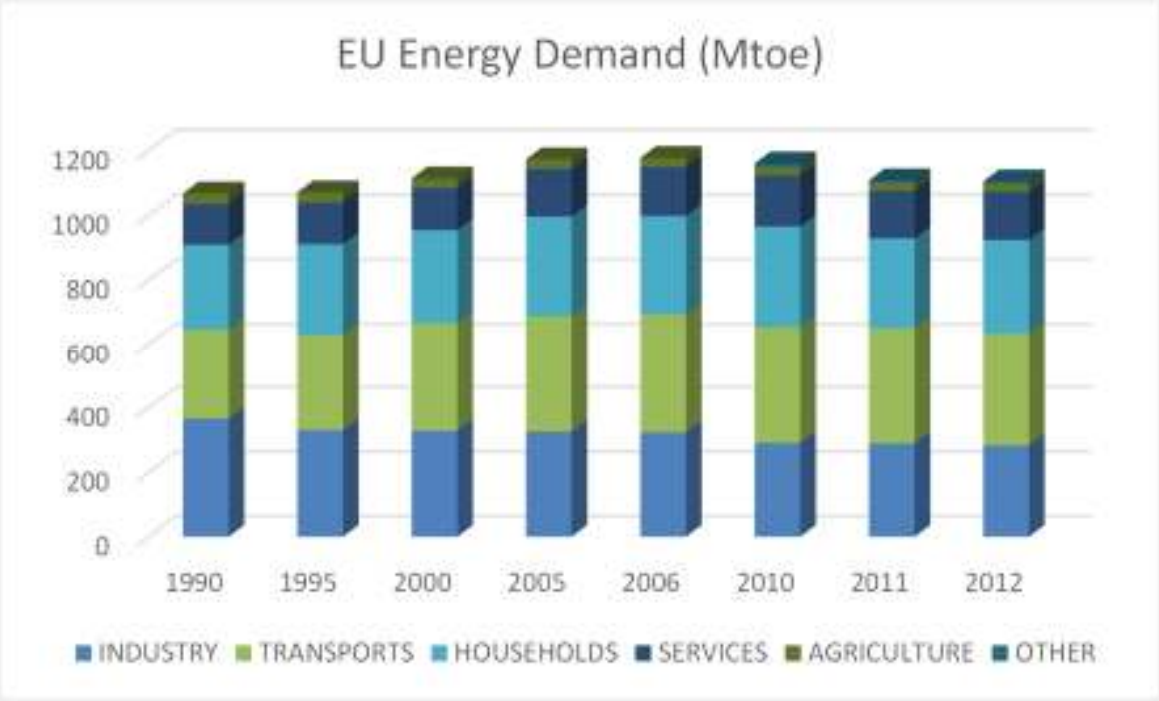
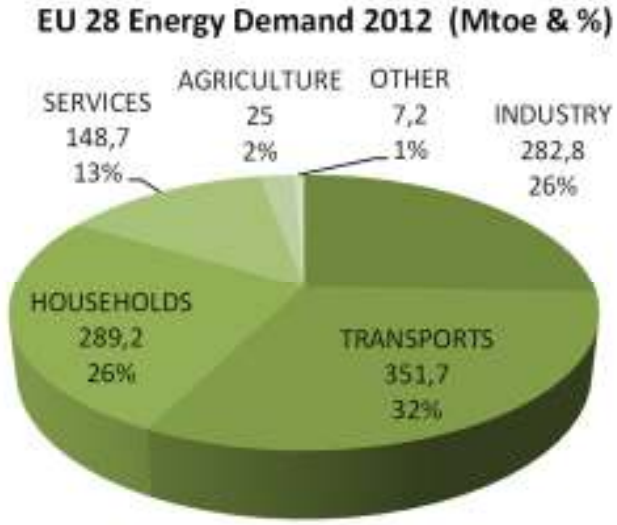
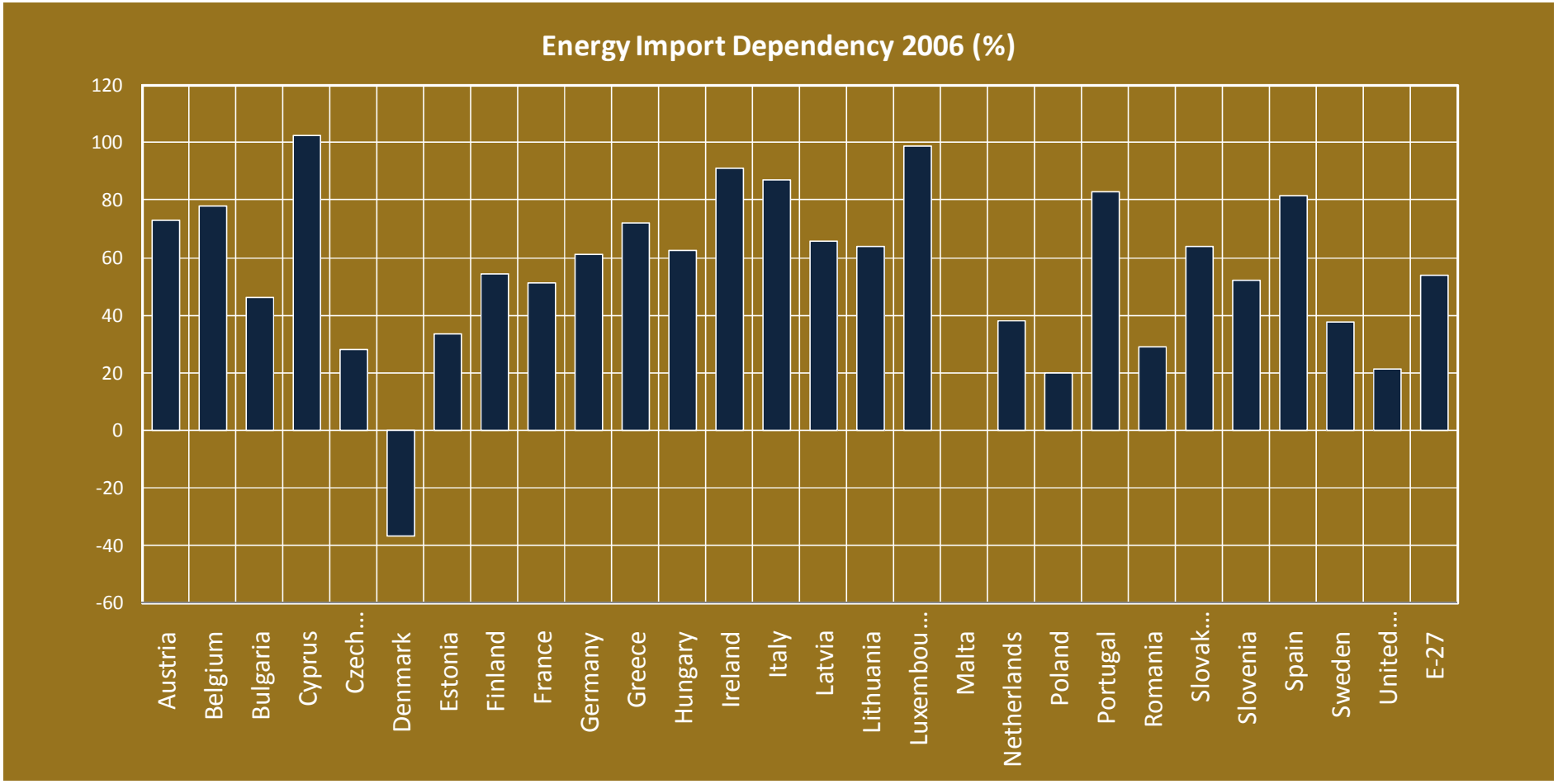
Energy Framework for Europe



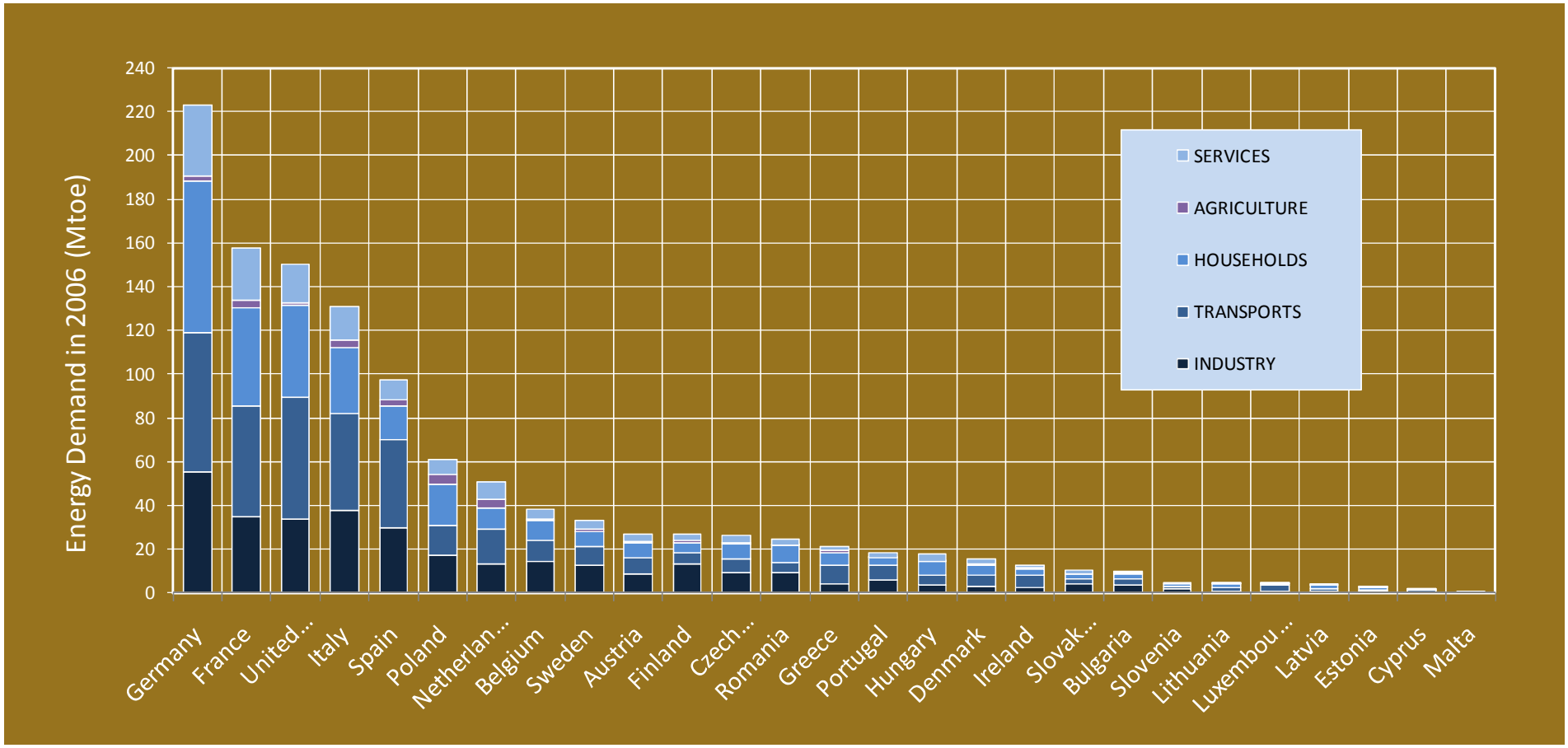


Energy Framework for Europe

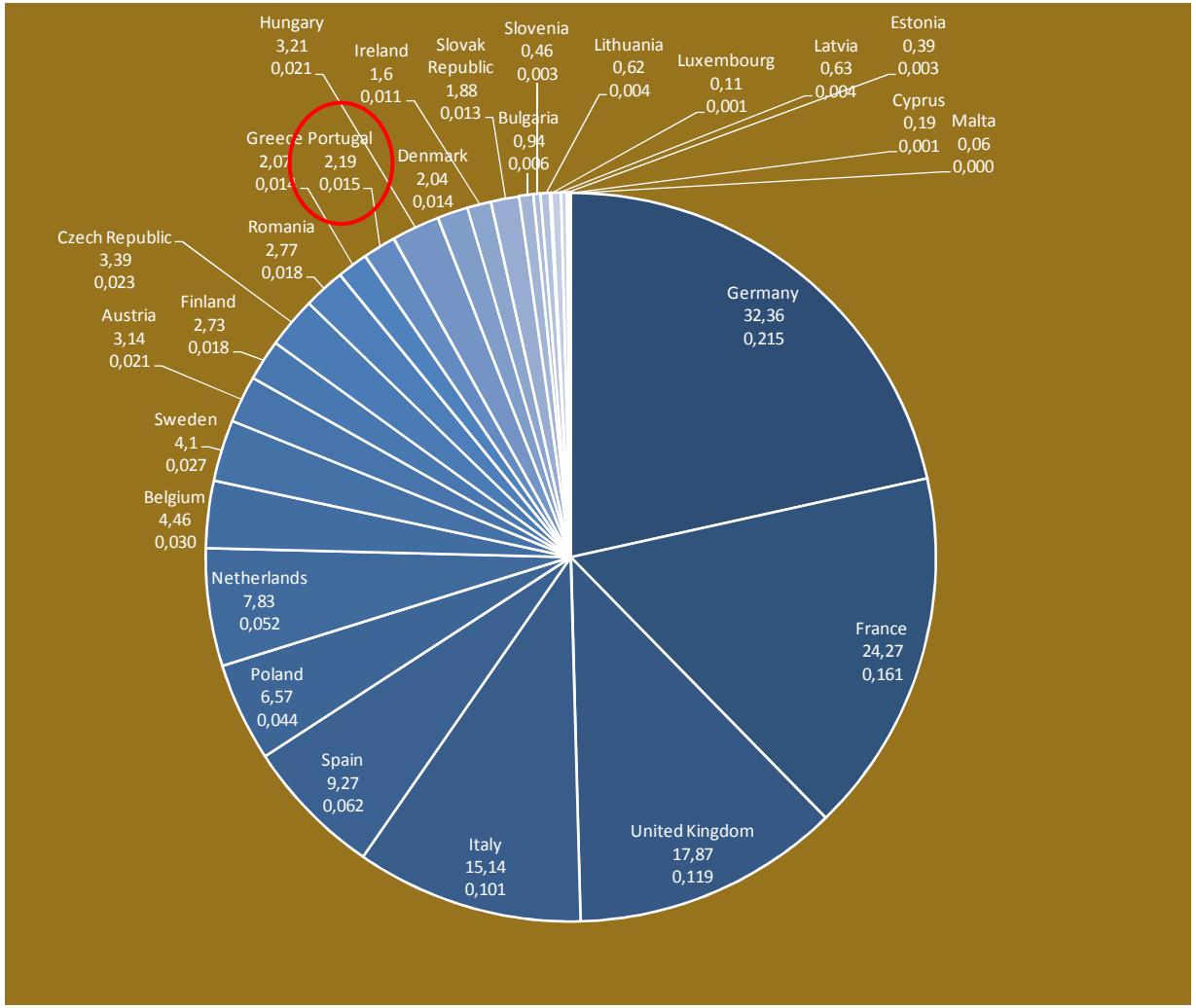


Energy Framework for Europe

Total Energy Demand (Mtoe & %) for the countries of EU-27 (2006)

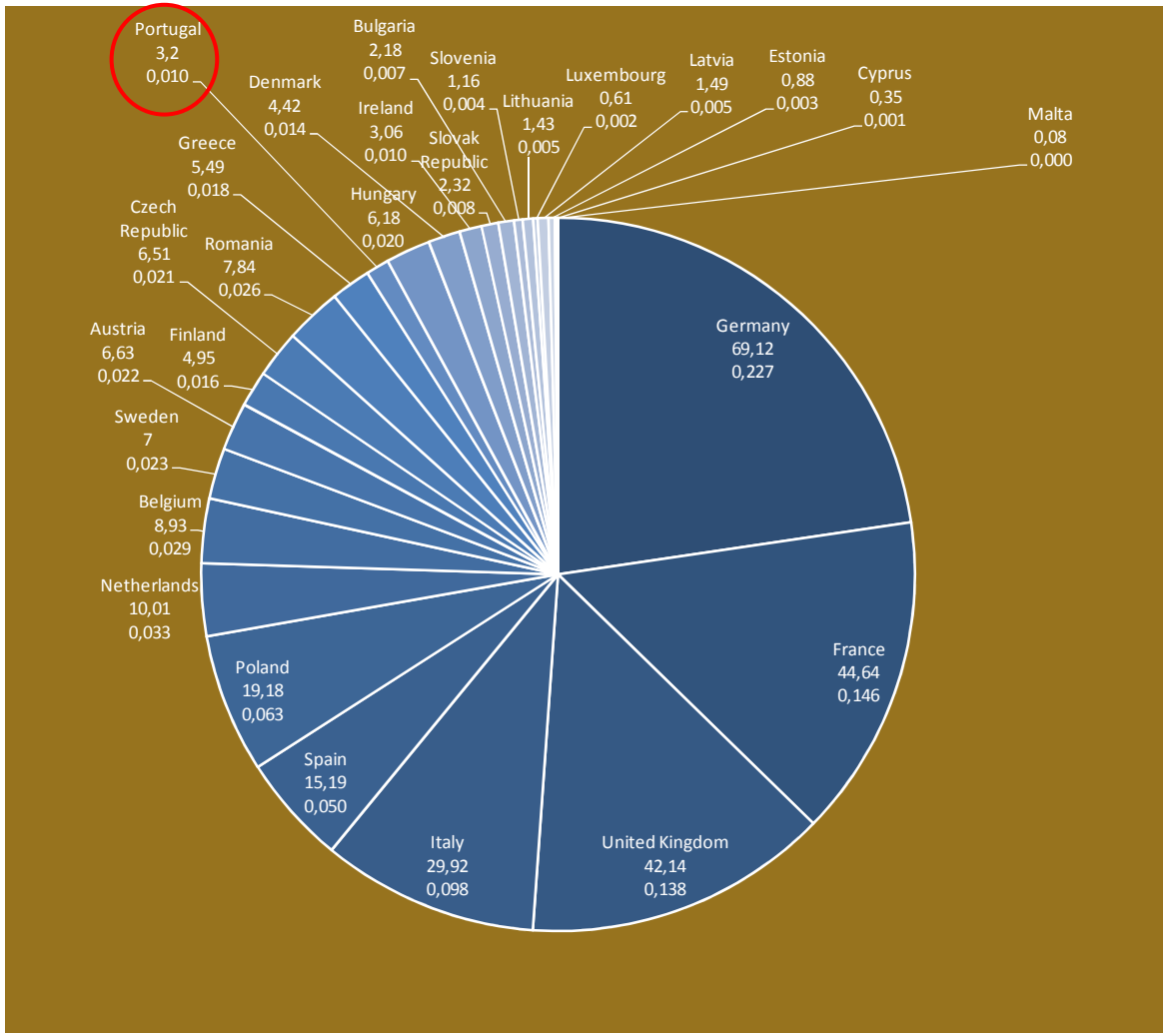


Buildings in Europe



Energy Demand in Services (Mtoe & %)
for the countries of EU-27(2006)

Buildings in Europe



Energy Demand in Households (Mtoe & %) for the countries of EU-27(2006)

Buildings in Europe

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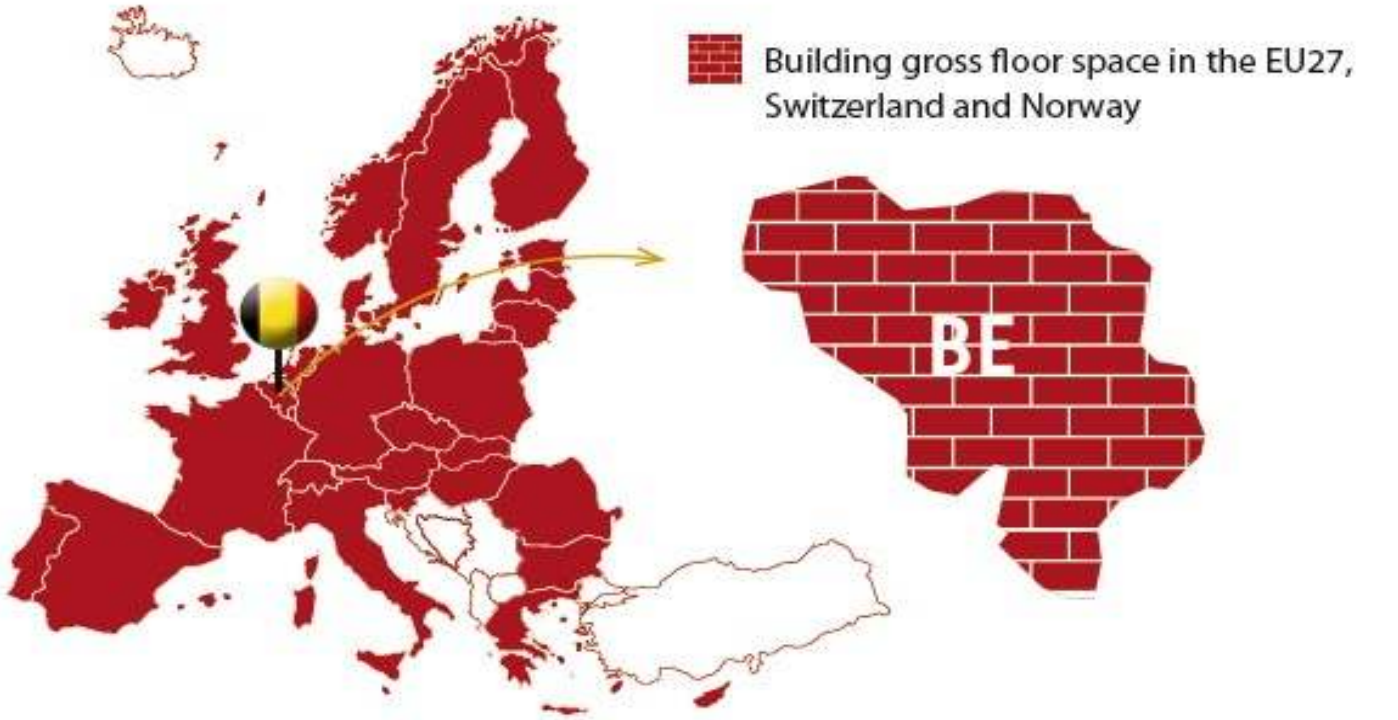
Sources: Population figures: World Bank, Eurostat. Floor spaces: EU27 - BPIE survey 2011, US - Annual Energy Outlook 2011 with projections to 2035 (US Energy Information Administration), China - Energy Efficiency in Buildings, Facts & Trends (WBCSD)



	Population (2010)	Land area (km²)	Building Floor Space	
EU27	501 million	4,324,782	24 billion m²	47 m²/person
US	309 million	9,826,675	25 billion m²	81 m²/person
China	1338 million	9,598,080	35 billion m²	26 m²/person

The size of building stock in Europe (*adapted from M. Economidou et al (2011)*)

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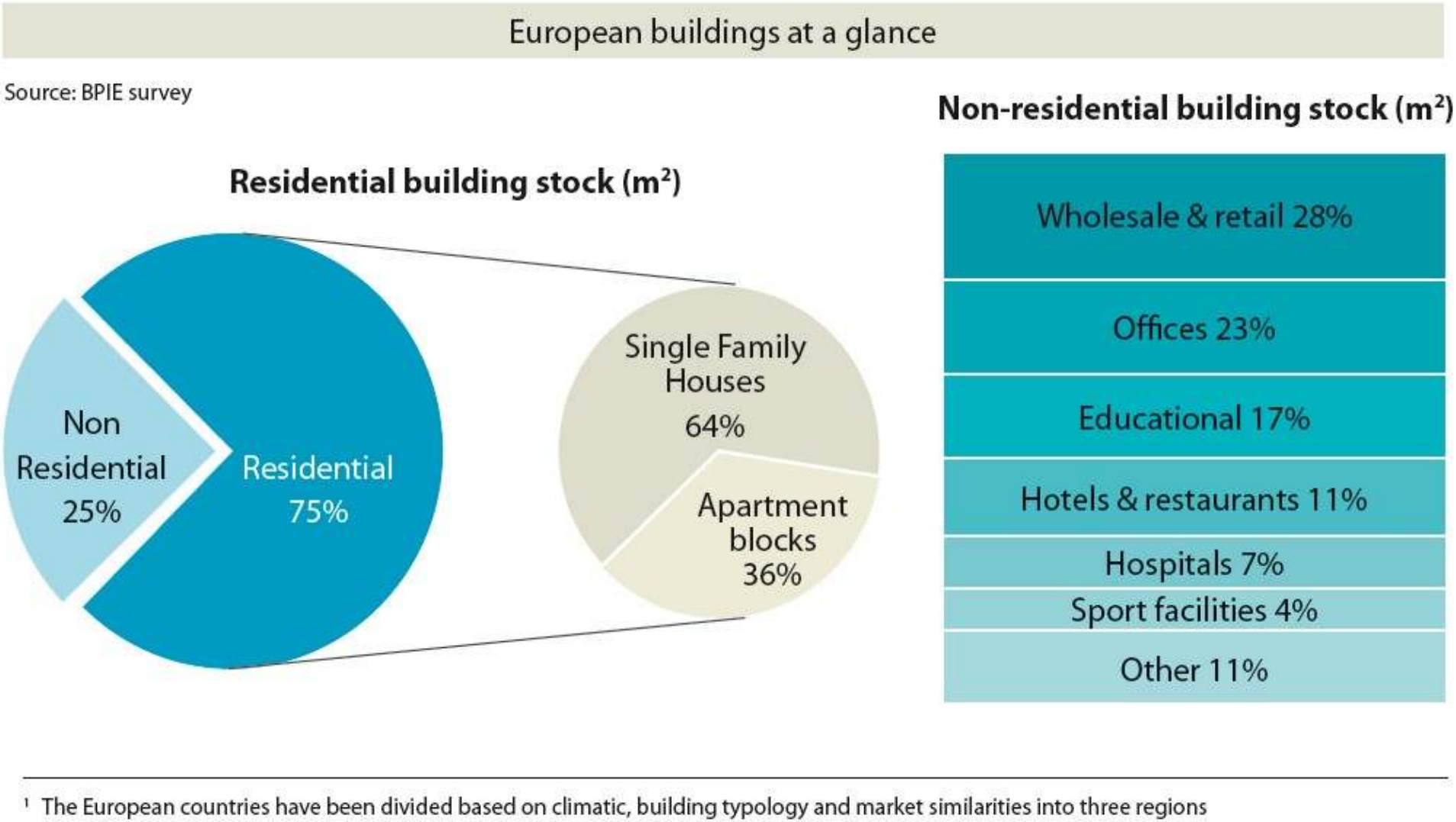
Buildings in Europe



Breakdown of European building stock (*adapted from M. Economidou et al (2011)*)

Climate Zones

ECOFYS Climate zones suitable for ranking of technology options and comparison of building performance

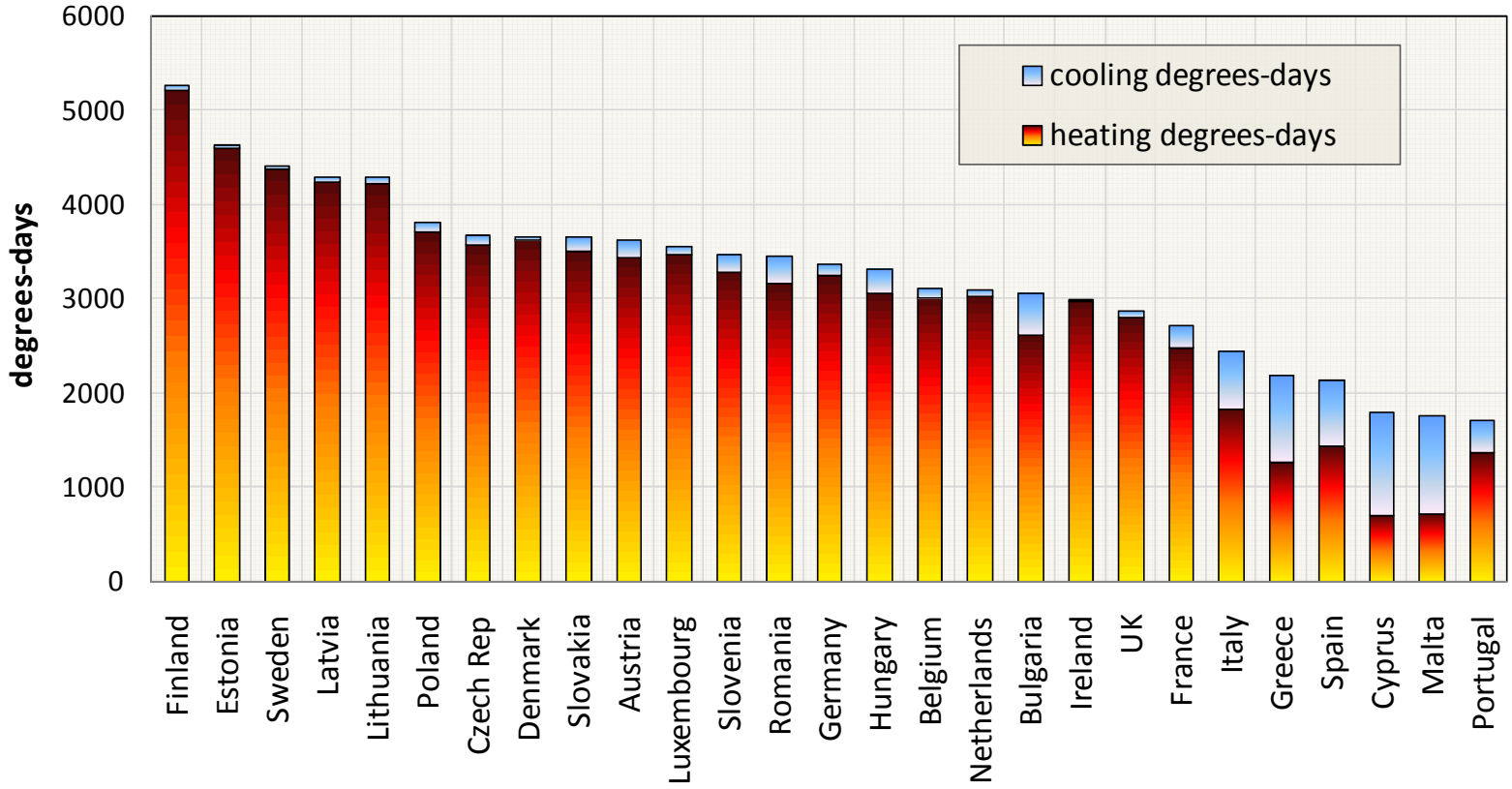
Heating and Cooling Days

The best indicators to synthesize in a quantified way the greater or lesser harshness of weather conditions, respectively in situations of cold and heat, are **heating degree days** (HDD) and **cooling degree days** (CDD)

Are defined as the annual sum of daily differences between the mean outside temperature of the day and a reference temperature at which it would be not necessary to use systems either heating or cooling to maintain comfort conditions inside a building.

Normally, reference temperatures are not the same for HDD and CDD

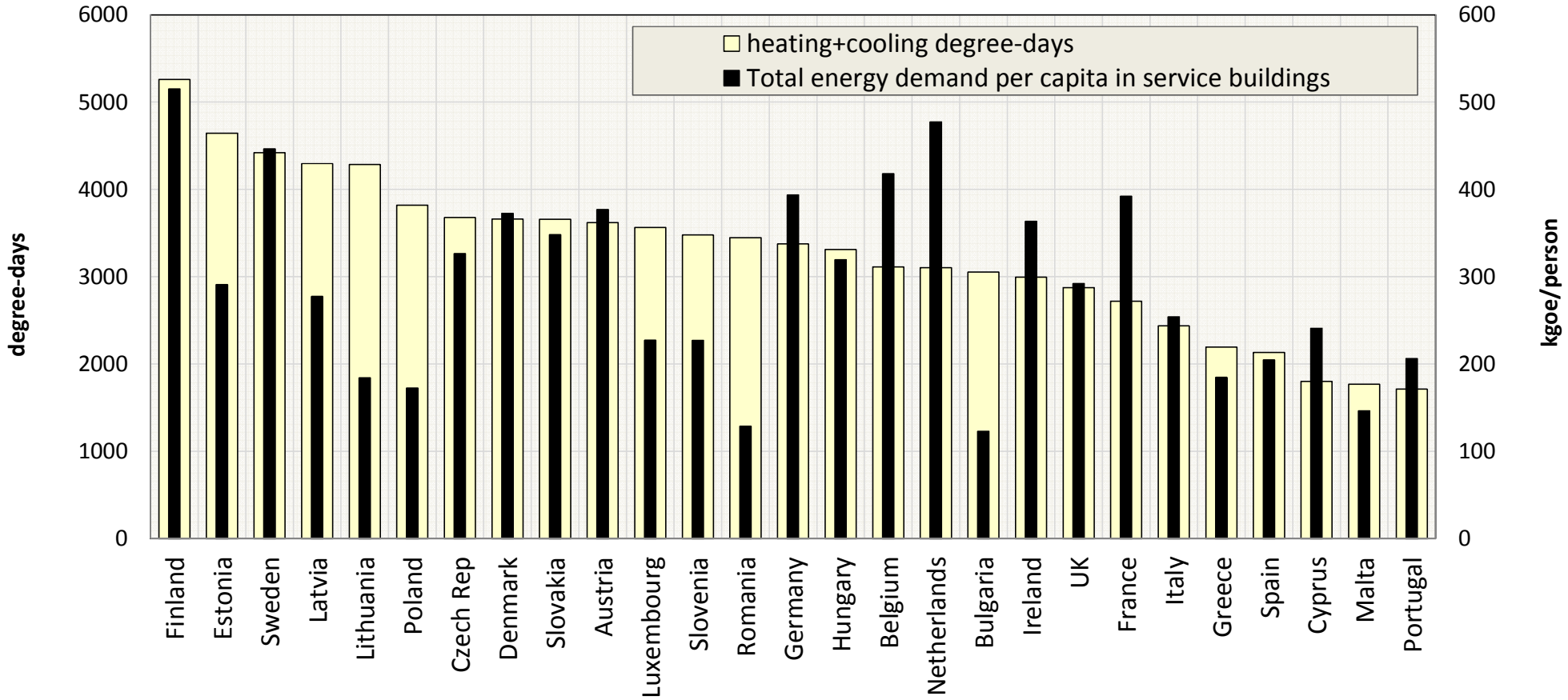
Heating and Cooling Days



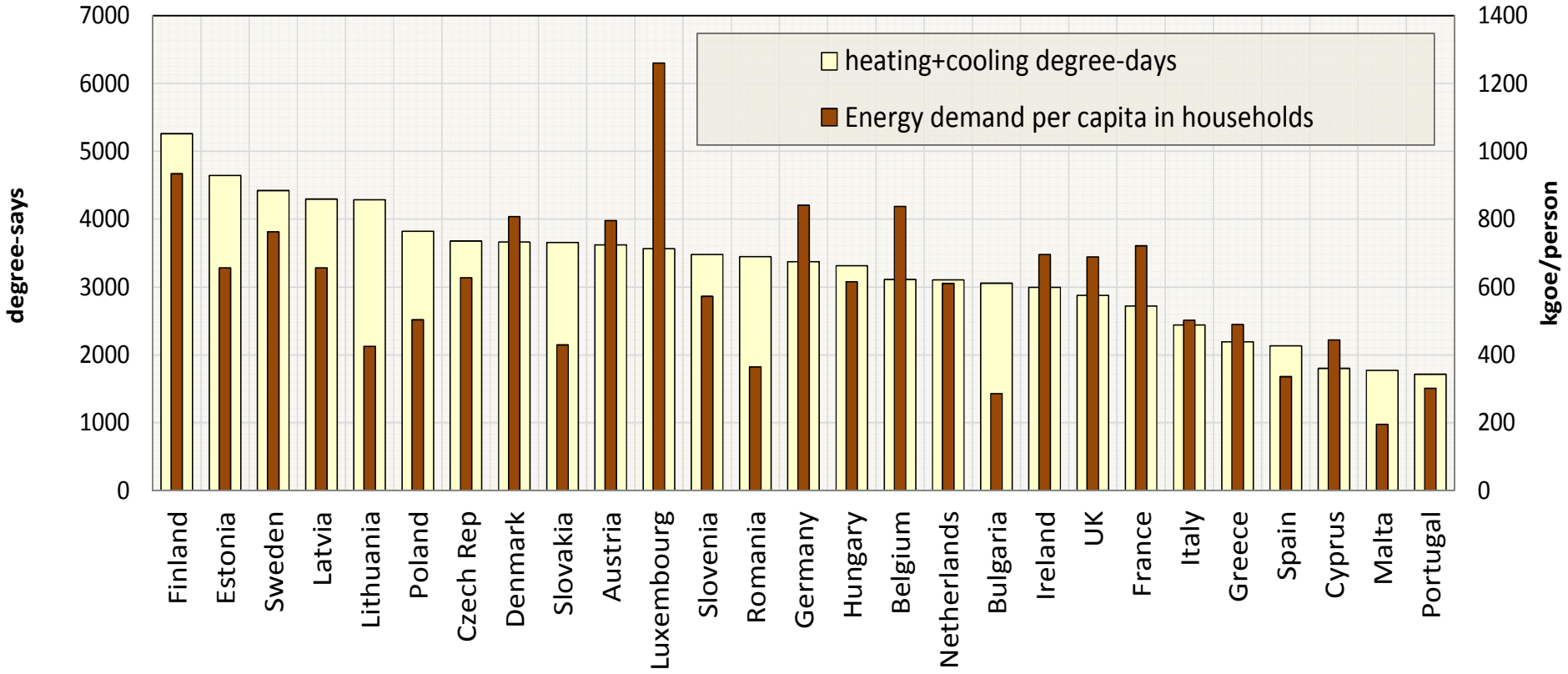
Heating and Cooling degrees-days for the European countries (T_{ref} = 17ºC)

Source: **Heating and Cooling Degree Days, Kevin Baumert and Mindy Selman, World Resources Institute, 2003**

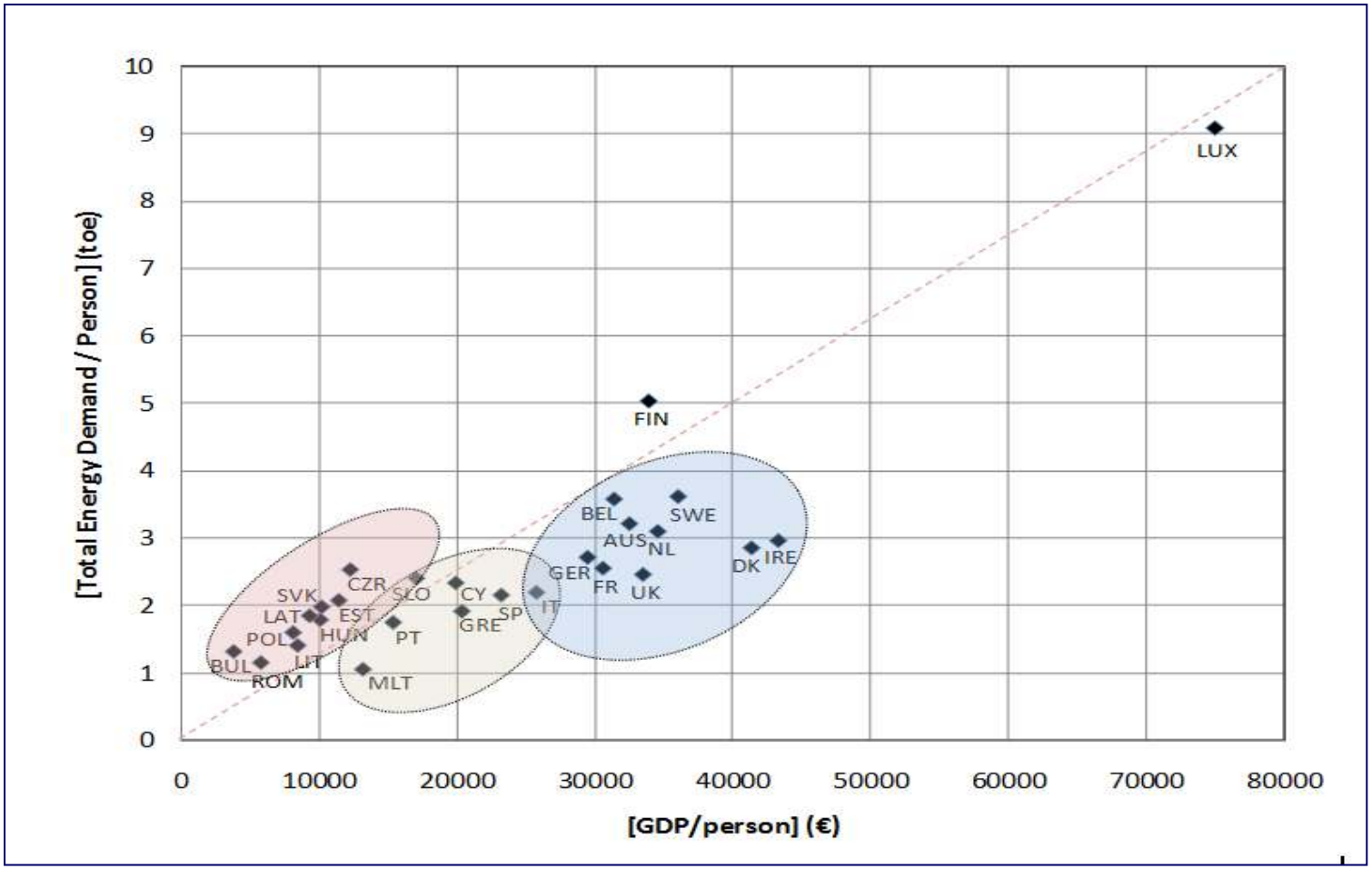
Total Energy Demand vs HDD+CDD



Total Energy Demand vs HDD+CDD

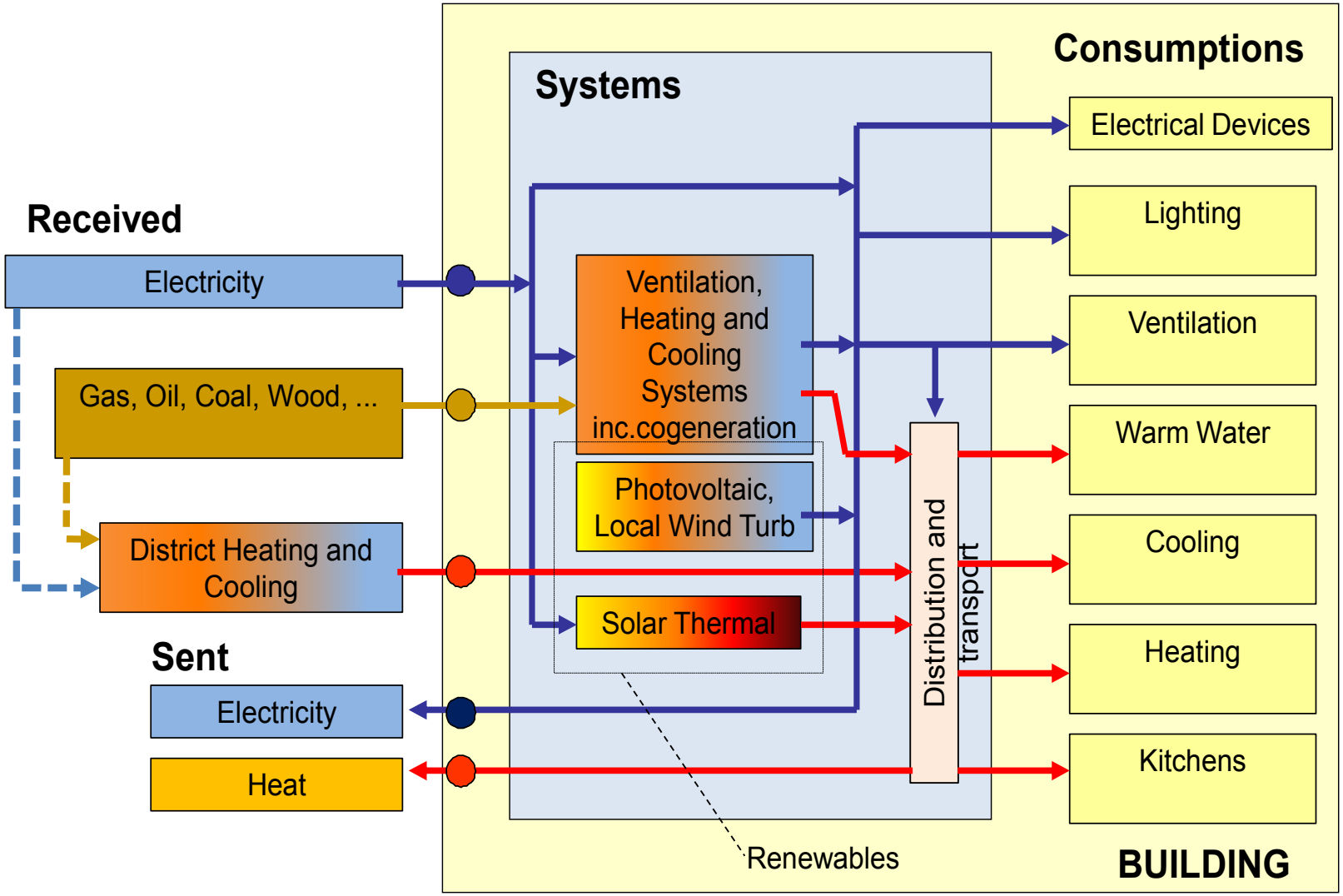


Energy Intensity of EU



Energy Intensity of the Economies of the EU-27 countries (2006)

Energy Fluxes in a Building



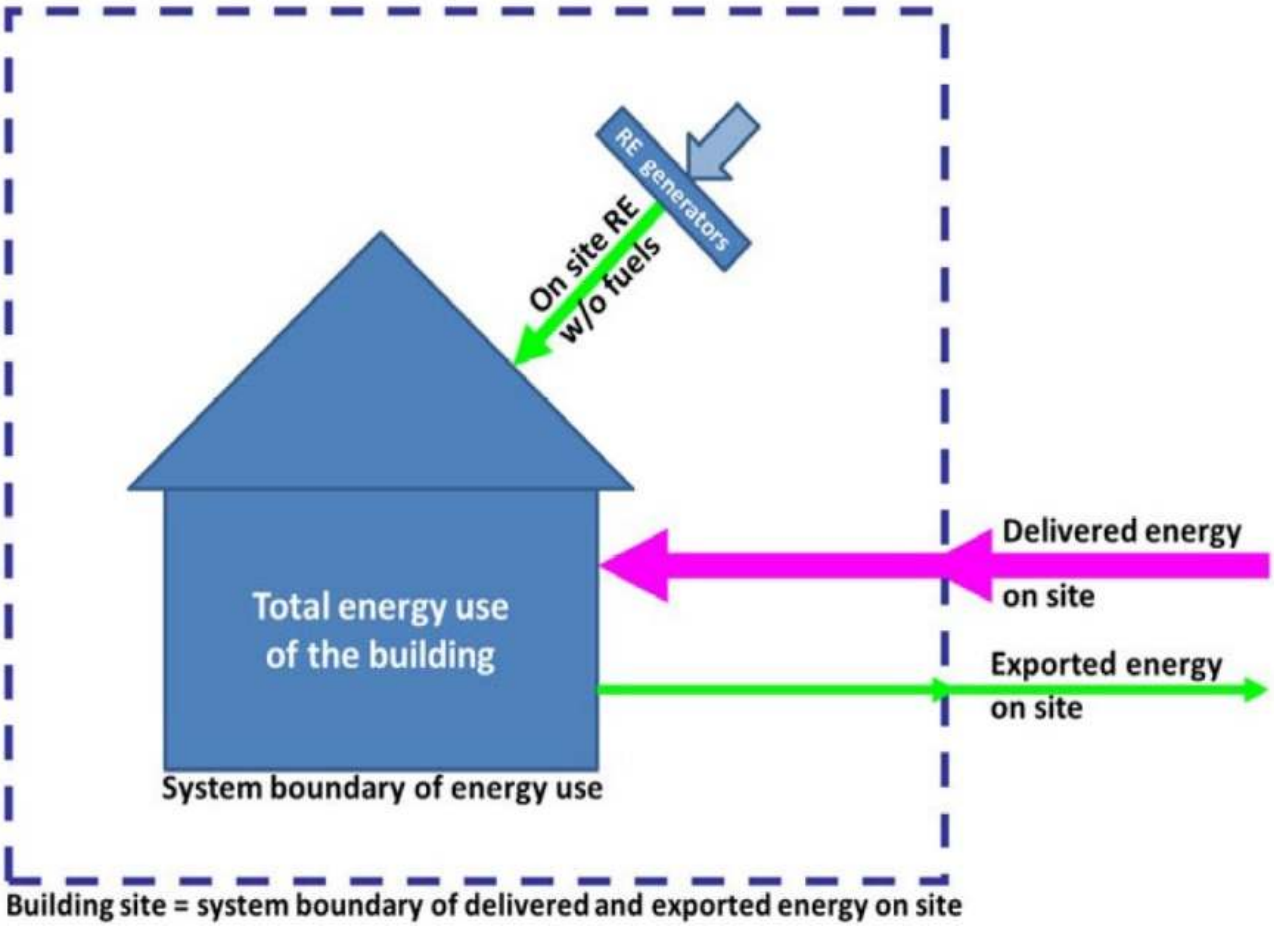
NZEB concept

Directive 2010/31/EU (EPBD recast) defines **NZEB as a building that has a very high energy performance**

The nearly zero or very **low amount of energy required should be covered to a very significant extent by energy from renewable sources**

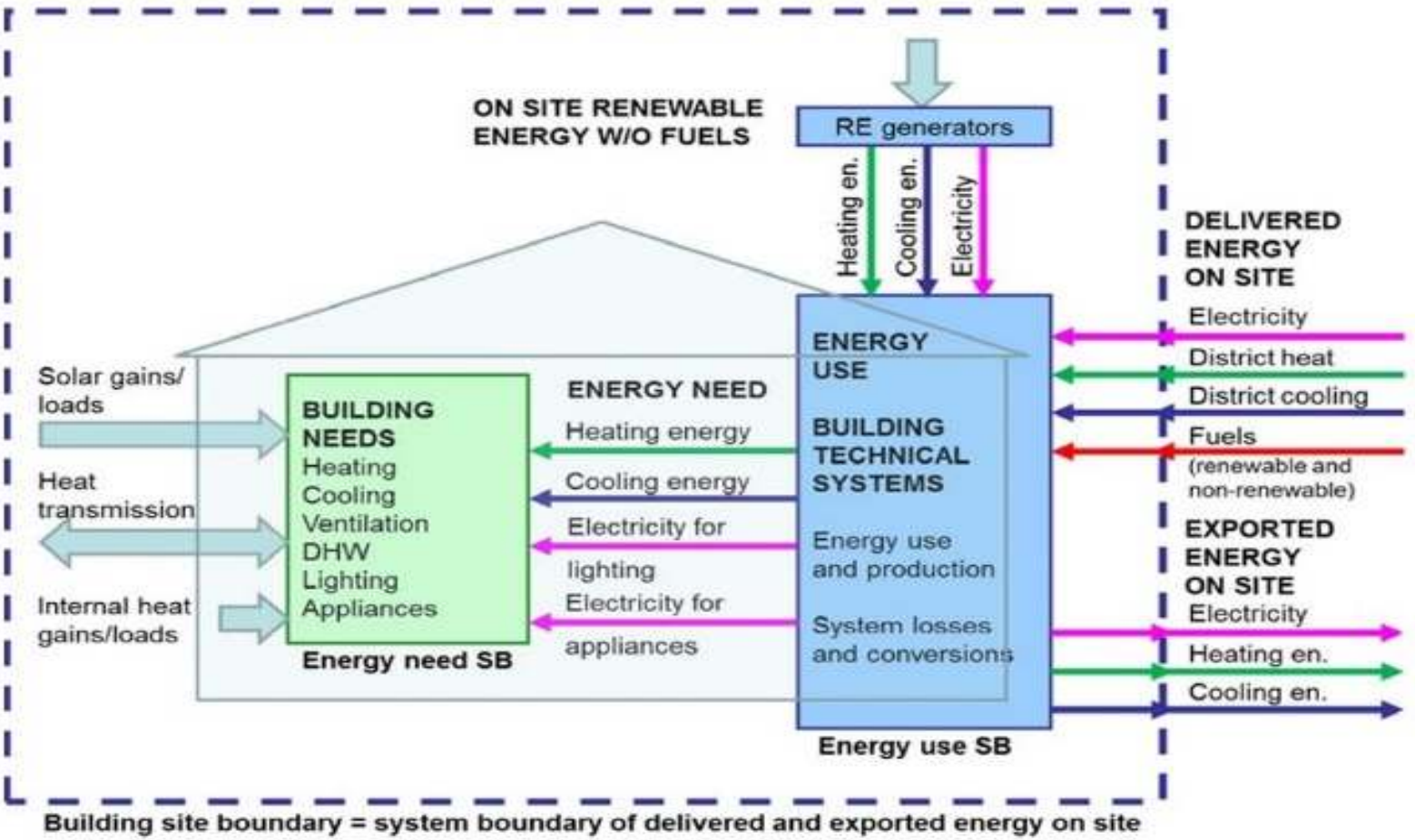
The energy performance of a building shall be expressed in a transparent manner and shall include **an energy performance indicator** and a **numeric indicator of primary energy use**, based on primary energy factors per energy carrier

System Boundaries of a NZEB



Definition of the system boundary for the case of on-site renewable production. *Adapted from Rehva (2013)*

System Boundaries of a NZEB



Definition of the system boundary for the case of on-site renewable production. *Adapted from Rehva (2013)*

The Path to NZEBs

Sources: ASHRAE, Internal JCI analysis

The Path to NZEBs

1.º Changing/Reducing traditional requirements

↓

2.º Energy Efficiency

↓

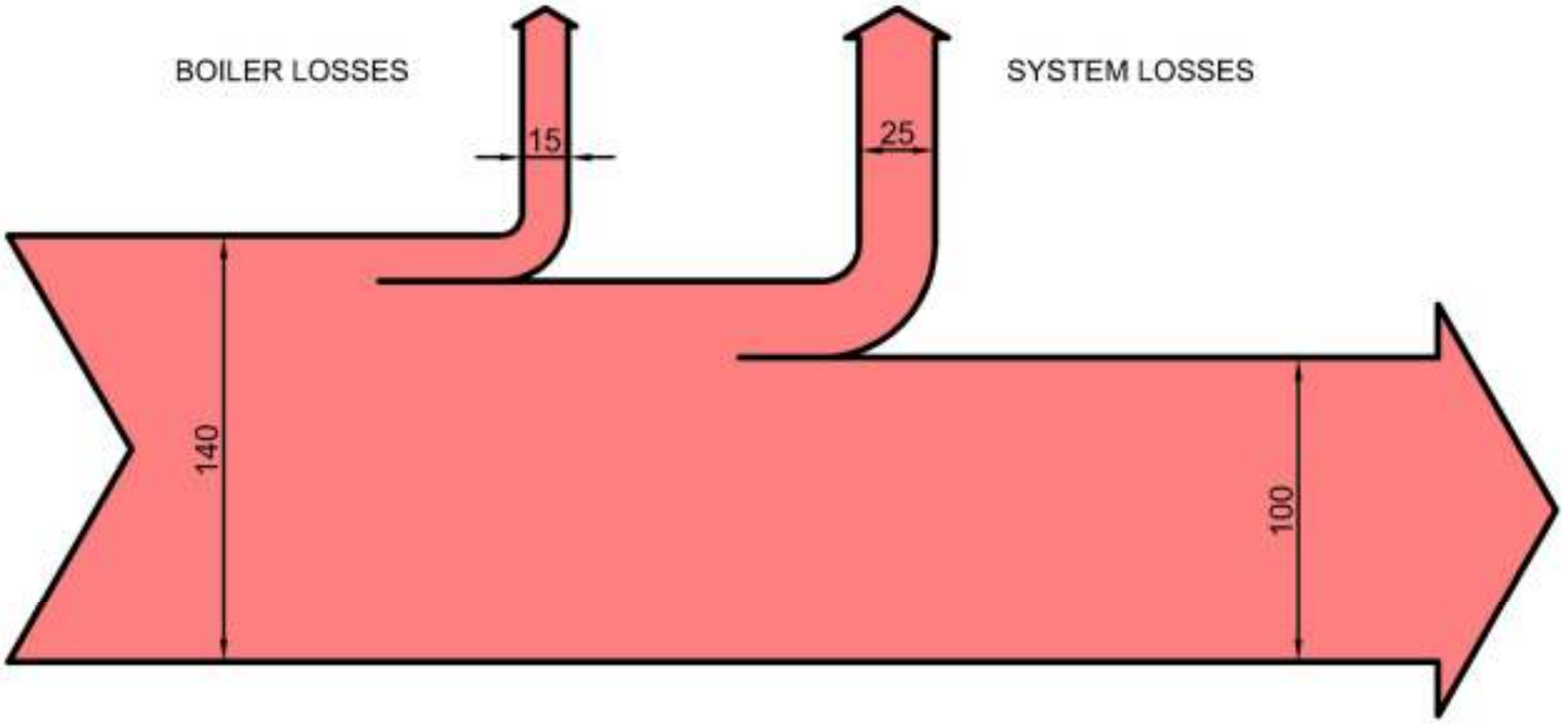
3.º Renewables

↓

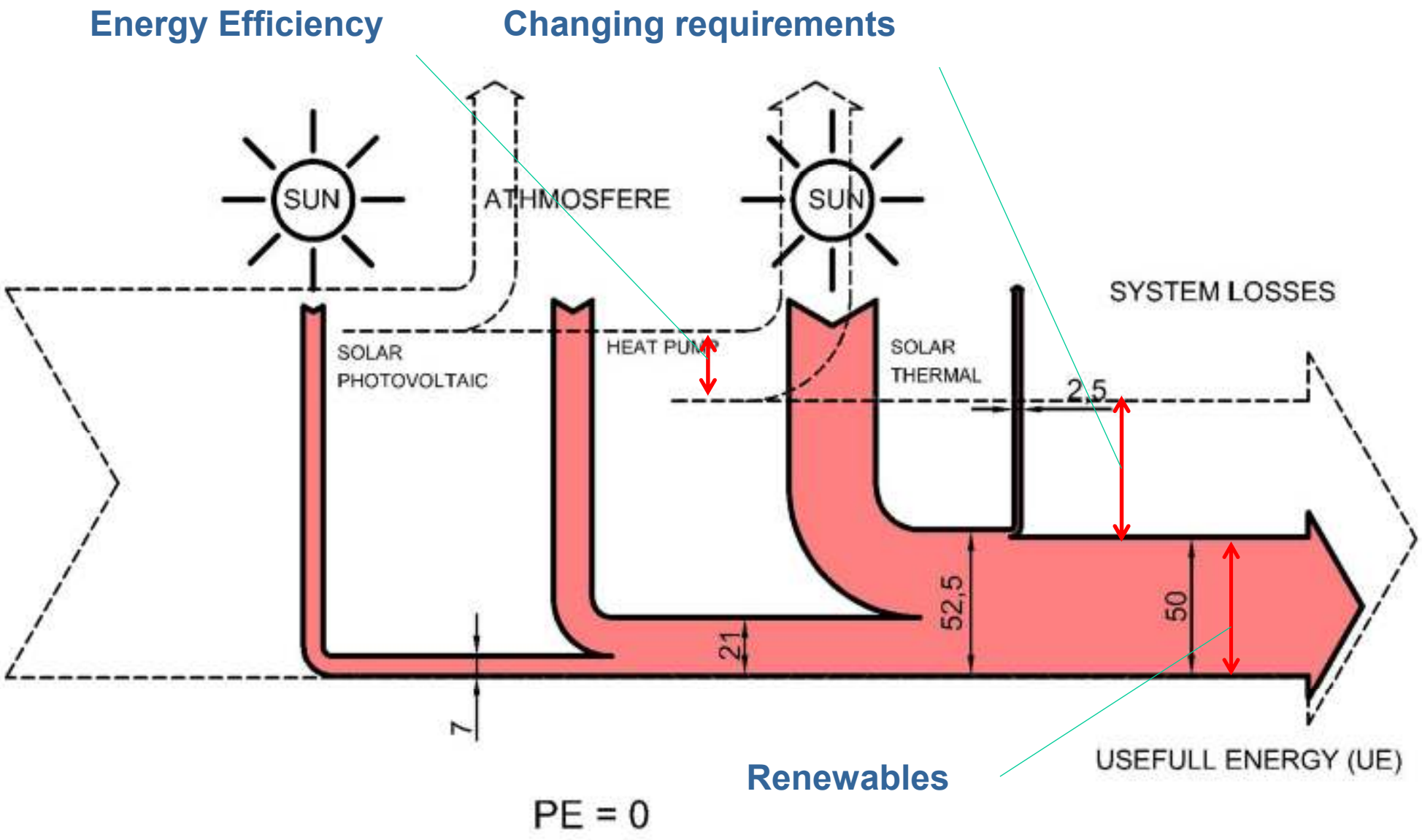
4.º Energy monitoring

Domestic Hot Water (DHW) Example.

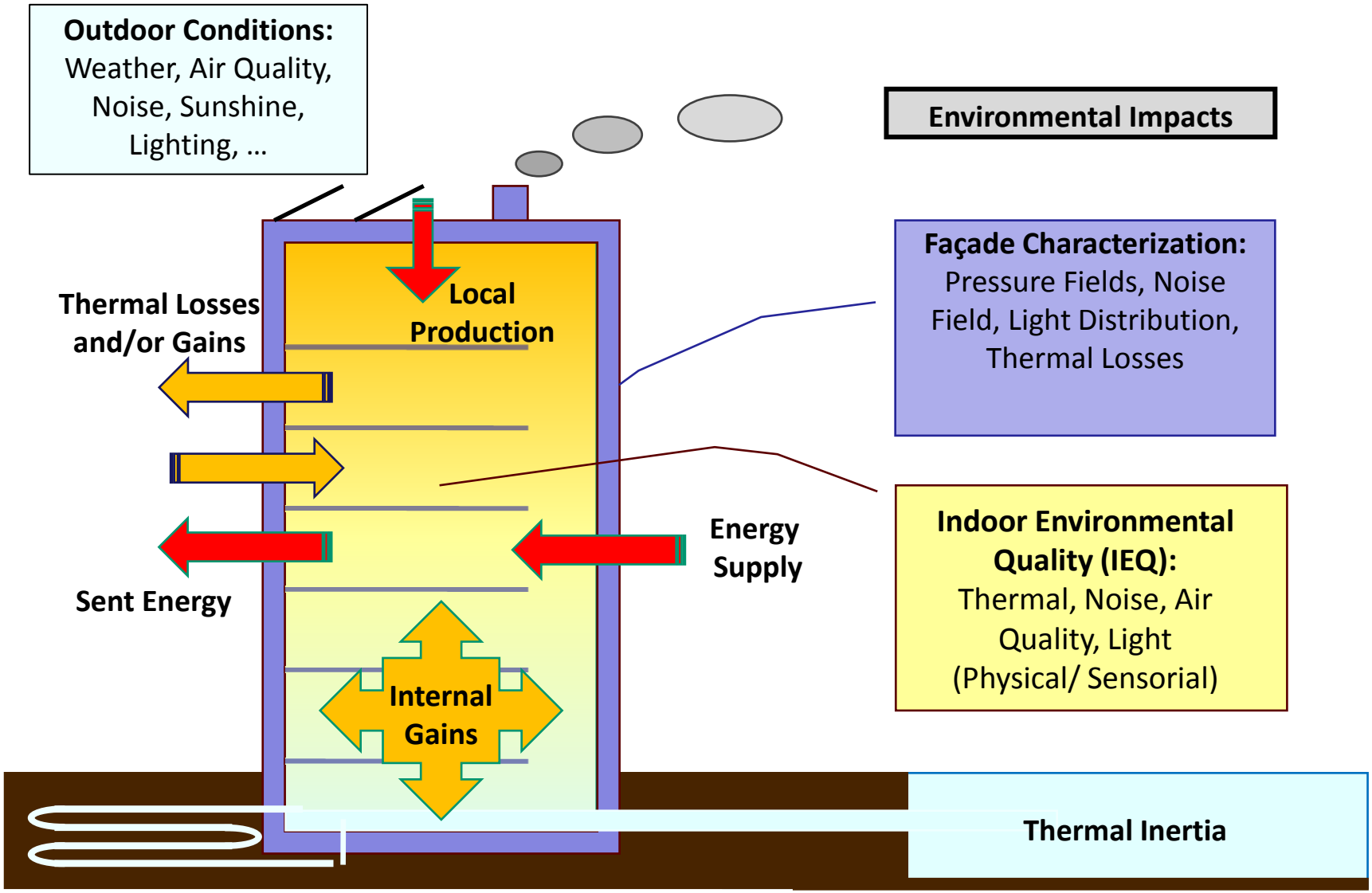
Existing DHW system serving showers in a gymnasium, using a gas boiler to produce DHW



Domestic Hot Water (DHW) Example.



Relevant Parameters



Thermal Comfort Requirements

Heat Balance of the Human Body

Metabolic Heat Production (**M**)

Wet and Dry Heat Exchanges in Respiration (**Res**)

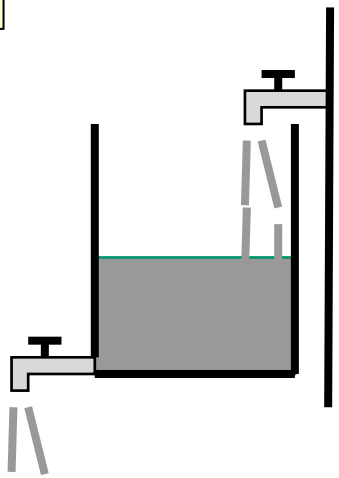
External Mechanical Work (**W**)

Radiation Exchanges with Surroundings (**R**)

Evaporation Losses in Sweating and Perspiration (**E**)

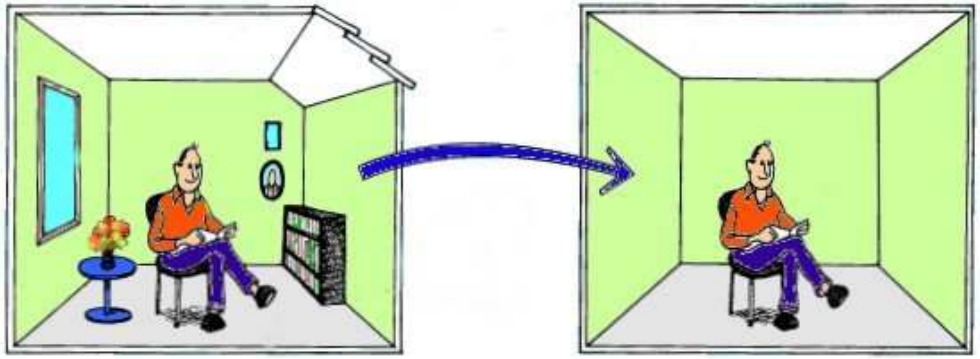
Convection Exchanges with air Layers (**C**)

Conduction to or from clothing (**K**)



$$S = M - W \pm R \pm C \pm K - E \pm Res$$

Thermal Environment Indices



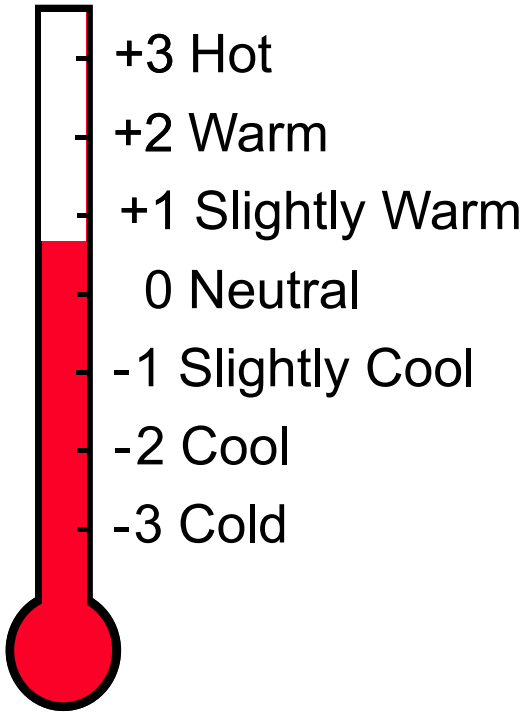
<u>Operative Temperatura</u> (t_o)
Uniform temperature of a black imaginary enclosure where the occupant exchanges the same amount of heat, by convection and radiation, as in the real one.

<u>Equivalent Temperature</u> (t_e)
Uniform temperature of an imaginary enclosure , with null air velocity, where the occupant exchanges the same amount of sensible heat as in the real one.

<u>Efective Temperature</u> (ET*)
Uniform temperature of an imaginary enclosure with a 50% relative humidity, where the occupant exchanges the same amount of heat aby radiation, convection and evaporation as in the real one

Fanger's Model (PMV and PPD, ISO 7730:2005)

$$PMV = (0{,}303e^{-0{,}036*M} + 0{,}028)*[(M-W) - H - E_c - C_{res} - E_{res}]$$



Fanger's Model (PMV and PPD, ISO 7730:2005)

$$PMV = (0{,}303e^{-0{,}036*M} + 0{,}028)*[(M-W) - H - E_c - C_{res} - E_{res}]$$

$$PMV = (0{,}303e^{-2{,}100*M} + 0{,}028)*[(M-W)$$

Human vote model

Heat Generation

$$- 3{,}96*10^{-8}*f_{cl*}[(t_{cl}+273)^4 - (t_r+273)^4] - f_{cl}*h_c*(t_{cl}-t_a)$$

H1: Radiation

H2: Convection

$$- 3{,}05*10^{-3}*[5733 - 6{,}99*(M-W)-p_a] -0{,}42*[(M-W)-58{,}15]$$

E_{c1}: Perspiration

E_{c2}: Sweating

$$- 0{,}0014*M*(34 - t_a) - 1{,}7*10^{-5}*M*(5867-p_a)]$$

Breathing (sensible)

Breathing (latent)

Calculation Tool (PMV and PPD, ISO 7730:2005)

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Model for the calculation of thermal comfort indices PMV and PPD (ISO 7730 - Fanger's method)

Input Data	
M (met) =	1,2
W (met) =	0
I cl (clo) =	0,5
Ta (ºC) =	22,0
Tr (ºC) =	22,0
pa (Pascal) =	1587
Va (m/s) =	0,10

M (W/m²) =	69,8
W (W/m²) =	0
Icl (m² ºC/W) =	0,0775

Control of Iterative Method	
$(Tcl-Tcl_{ini})$ =	0,00

Enable Macros
After introducing data,
Press Run Button.
After calculation, $(Tcl - Tcl_{ini})$ must be equal to 0.

Run

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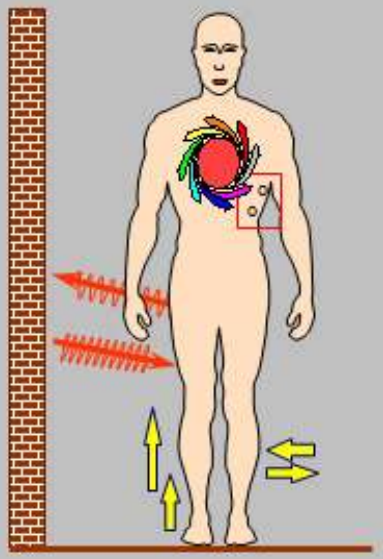
Intermediate Calculations

T skin =	33,7	ºC		
hc natural conv =	3,865	max hc =	3,865	(W/m² ºC)
hc forced conv =	3,826			
Tcl =	29,0	ºC		
fcl (Icl<0.5 clo) =	1,100	min fcl =	1,100	(m² ºC/W)
fcl (Icl>0.5 clo) =	1,100			



Heat Fluxes		
perspiration	11,16	(W/m²)
sweating	4,88	(W/m²)
breathing (latent)	5,08	(W/m²)
breathing (sensible)	1,17	(W/m²)
radiation	32,23	(W/m²)
convection	29,57	(W/m²)
Total Flux (Q)	84,10	(W/m²)
Balance [(M-W) - Q]	-14,32	(W/m²)

Output Data

PMV =	-0,75
PPD (%) =	16,9

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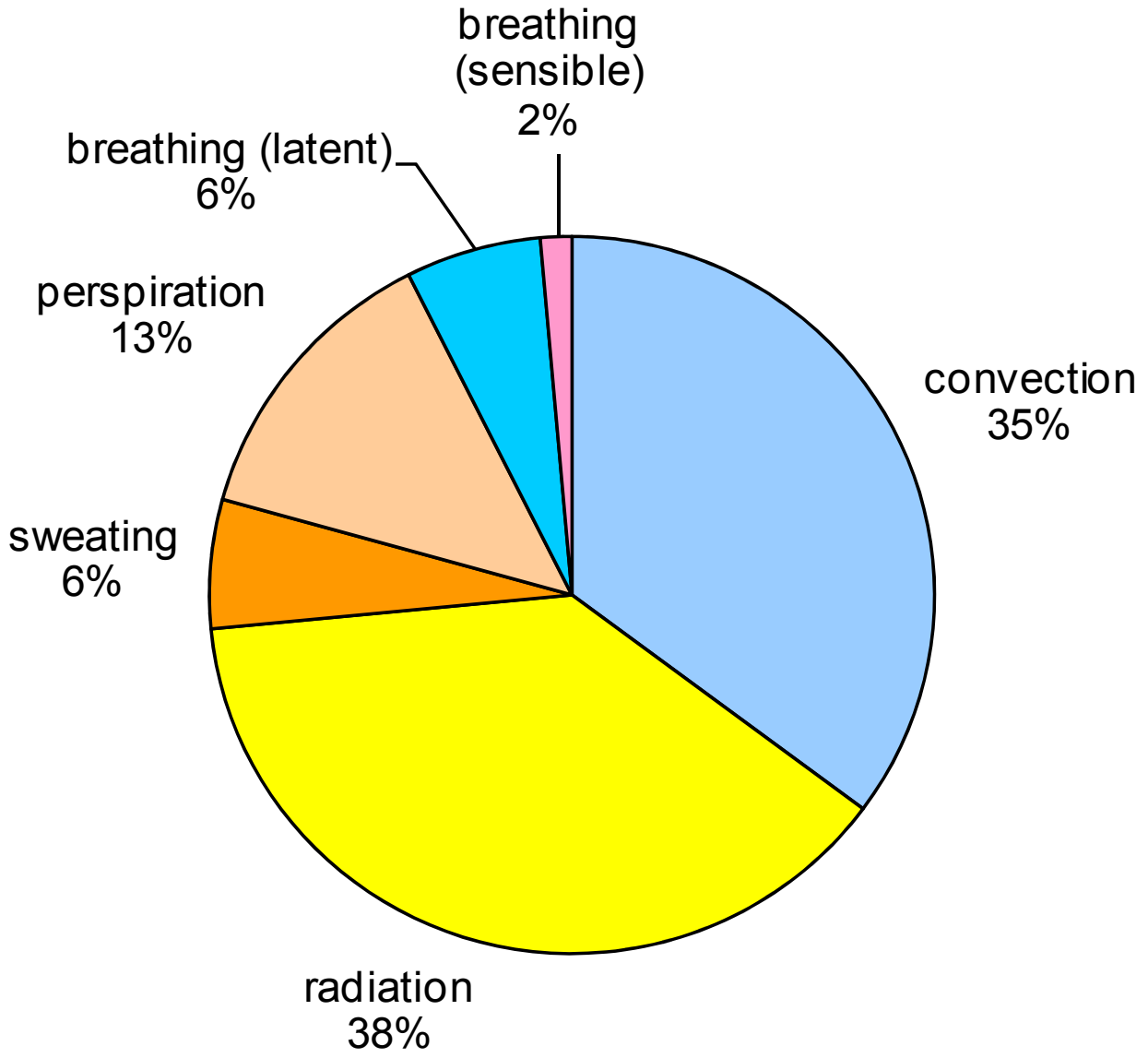
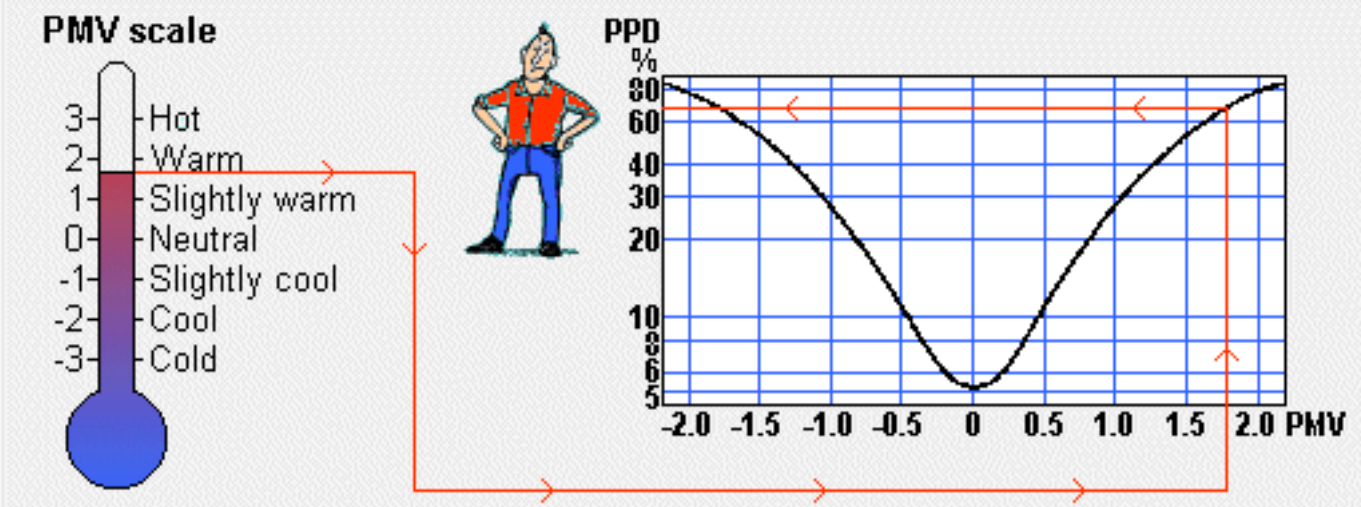
Breakdown of human body energy losses (PMV and PPD, ISO 7730:2005)



PPD Index (Predicted Percentage of Dissatisfied)

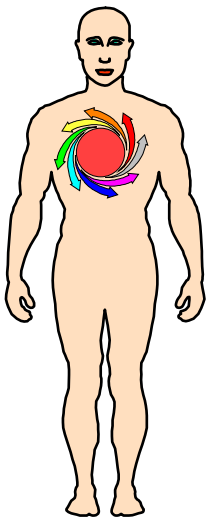


$$PPD = 100 - 95 \cdot e^{-(0.03353 \cdot PMV^4 + 0.2179 \cdot PMV^2)}$$

- PMV-index (Predicted Mean Vote) predicts the subjective ratings of the environment in a group of people.

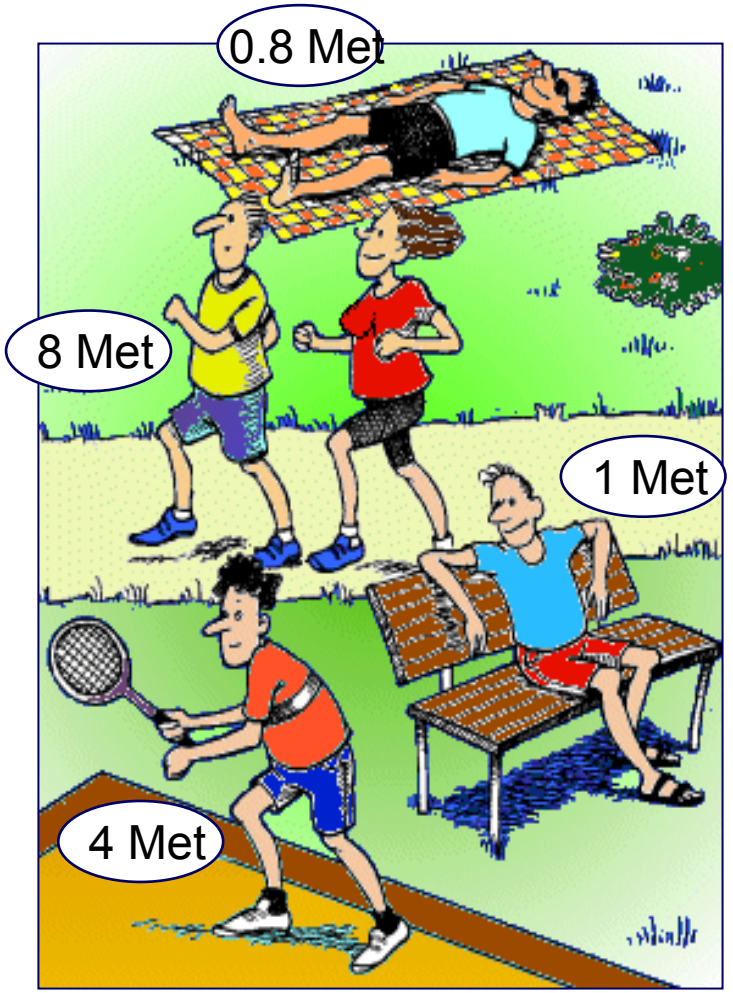
- PPD-index predicts the number of dissatisfied people.

Metabolic Heat Production



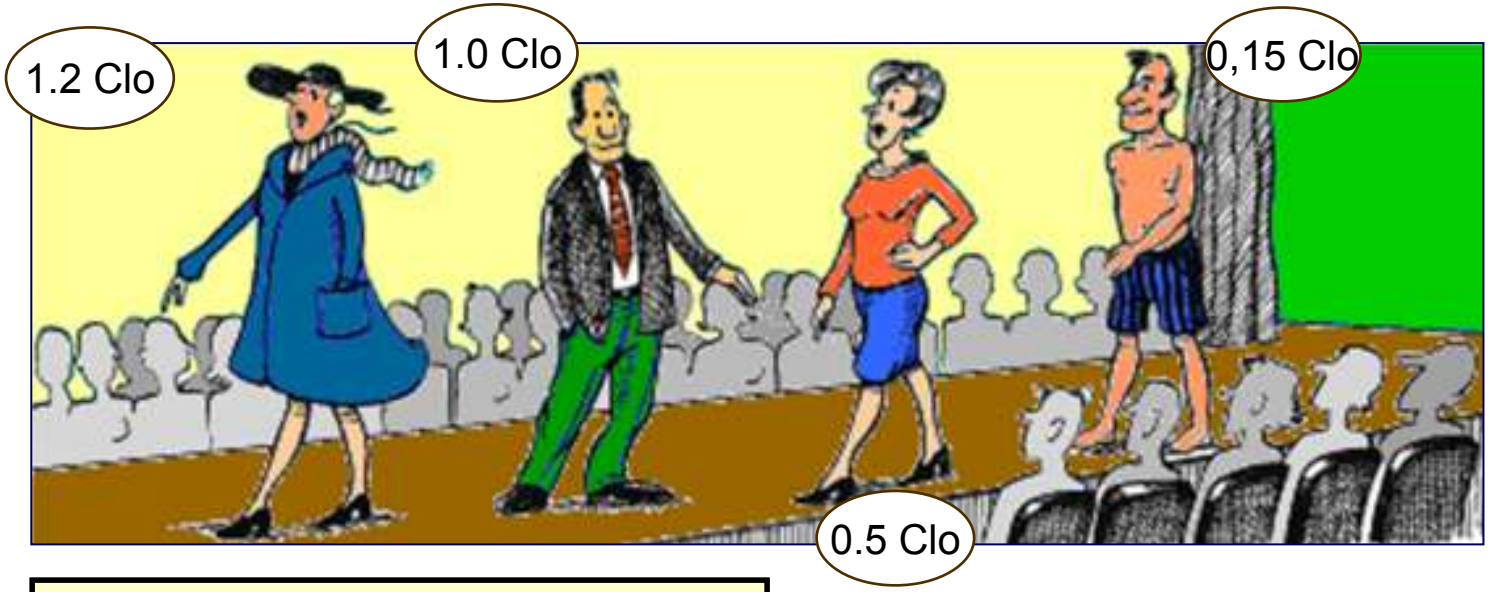
1 Met = 58.15 W/m^2

Activity	Metabolic Rates [M]	
Reclining	46 W/m^2	0.8 Met
Seated relaxed	58 W/m^2	1.0 Met
Clock and watch repairer	65 W/m^2	1.1 Met
Standing relaxed	70 W/m^2	1.2 Met
Car driving	80 W/m^2	1.4 Met
Standing, light activity (shopping)	93 W/m^2	1.6 Met
Walking on the level, 2 km/h	110 W/m^2	1.9 Met
Standing, medium activity (domestic work)	116 W/m^2	2.0 Met
Washing dishes standing	145 W/m^2	2.5 Met
Walking on the level, 5 km/h	200 W/m^2	3.4 Met
Building industry	275 W/m^2	4.7 Met
Sports - running at 15 km/h	550 W/m^2	9.5 Met



$$S = M - W \pm R \pm C \pm K - E \pm Res$$

Insulation of Clothing

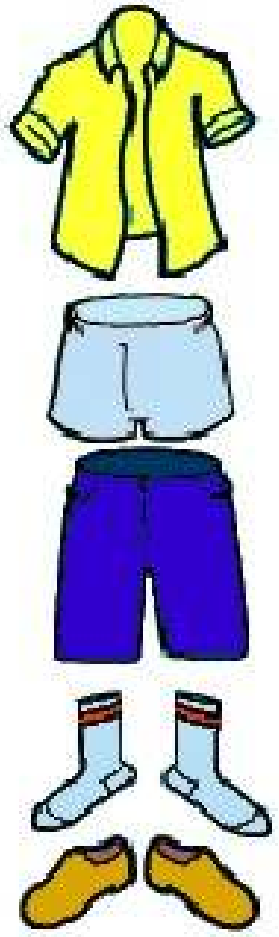


$$1Clo = 0.155 m^2 {}^{o}C / W$$

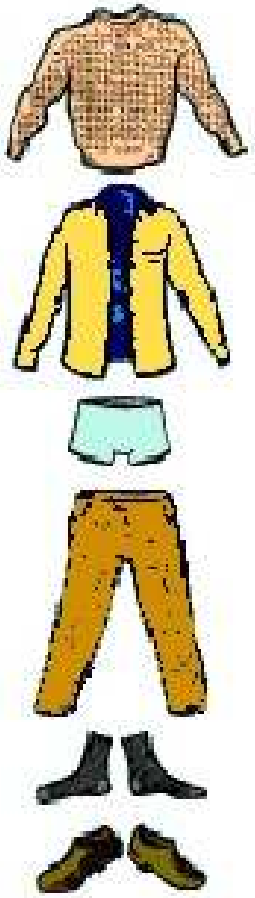
Clothing	Clo	m²ºC/W
Jacket	0.35	0.054
Coat	0.70	0.109
Trousers	0.25	0.039
Skirt	0.18	0.028
Short skirt	0.10	0.016
Shirt	0.25	0.039
Light shoes	0.02	0.003
Boots	0.10	0.016

Insulation of Clothing

Insulation for the entire clothing: $I_{cl} = \sum I_{clu}$



0.19 + 0.04 + 0.11 + 0.02 + 0.02 = 0.38



0.28 + 0.25 + 0.04 + 0.25 + 0.05 + 0.04 = 0.91

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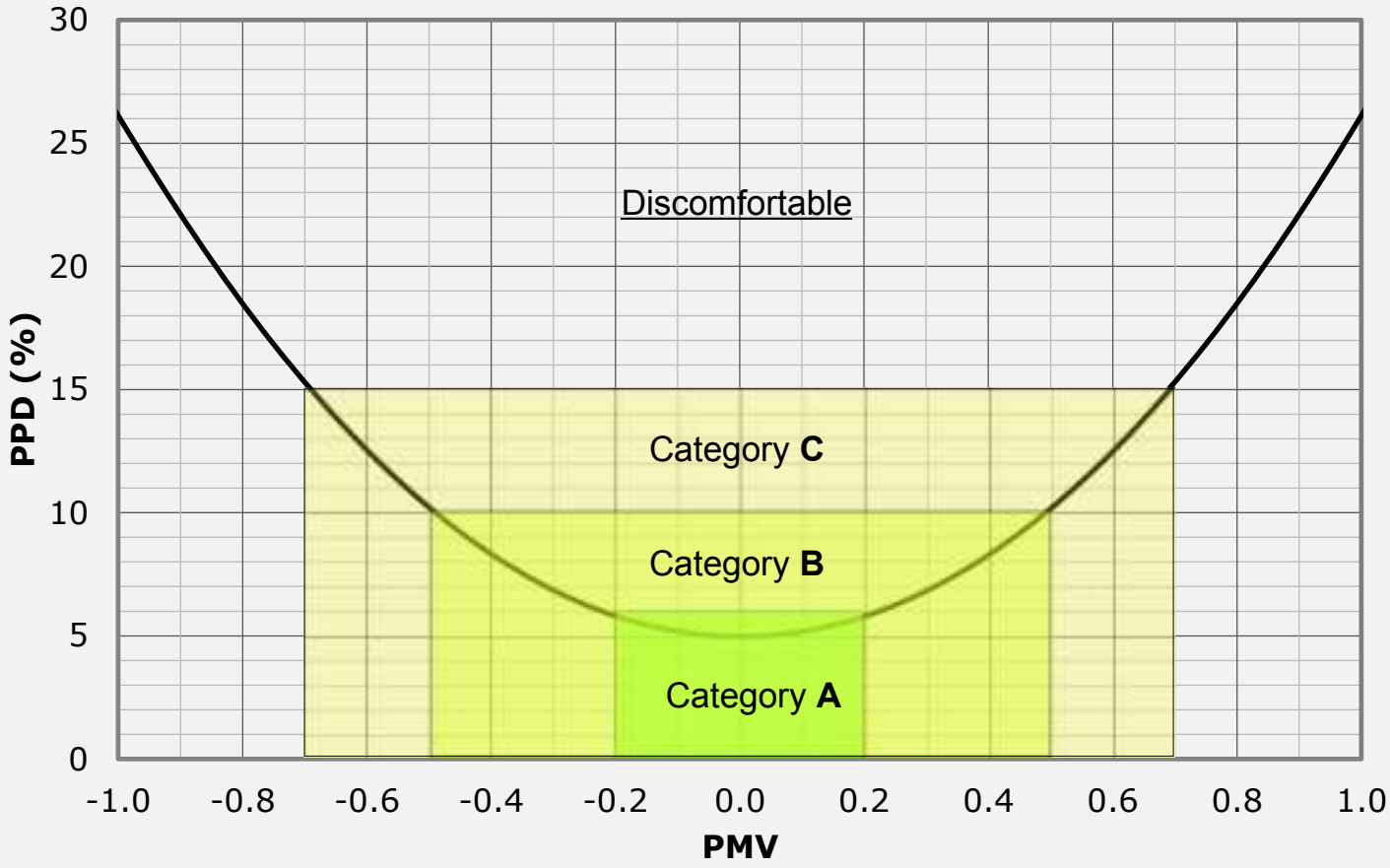
Thermal Comfort of the Human Body as a Whole – ISO 7730:2005

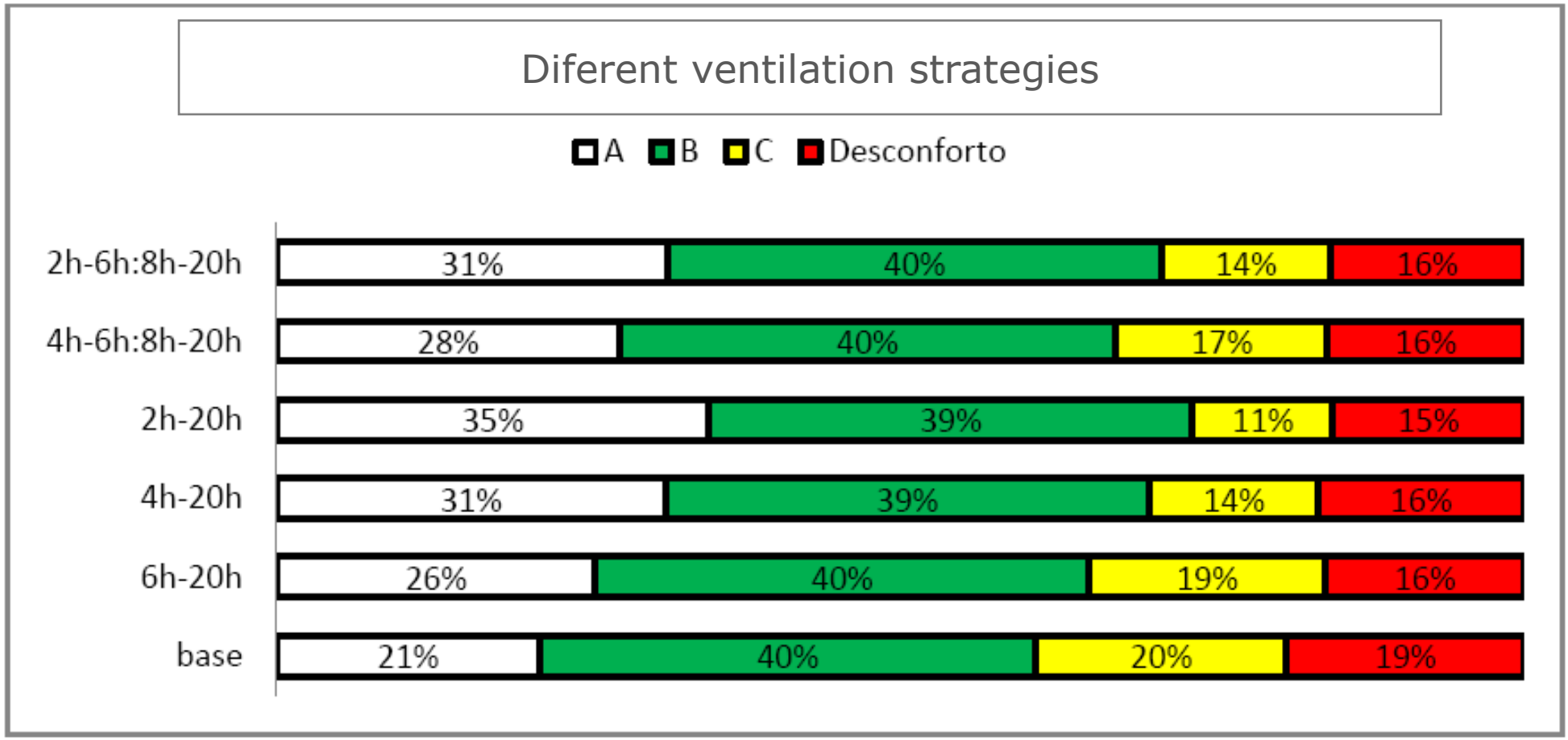
Table A.1 — Categories of thermal environment

Category	Thermal state of the body as a whole		Local discomfort			
	PPD %	PMV	DR %	PD % caused by		
				vertical air temperature difference	warm or cool floor	radiant asymmetry
A	< 6	– 0,2 < PMV < + 0,2	< 10	< 3	< 10	< 5
B	< 10	– 0,5 < PMV < + 0,5	< 20	< 5	< 10	< 5
C	< 15	– 0,7 < PMV < + 0,7	< 30	< 10	< 15	< 10

Thermal Comfort of the Human Body as a Whole – ISO 7730:2005

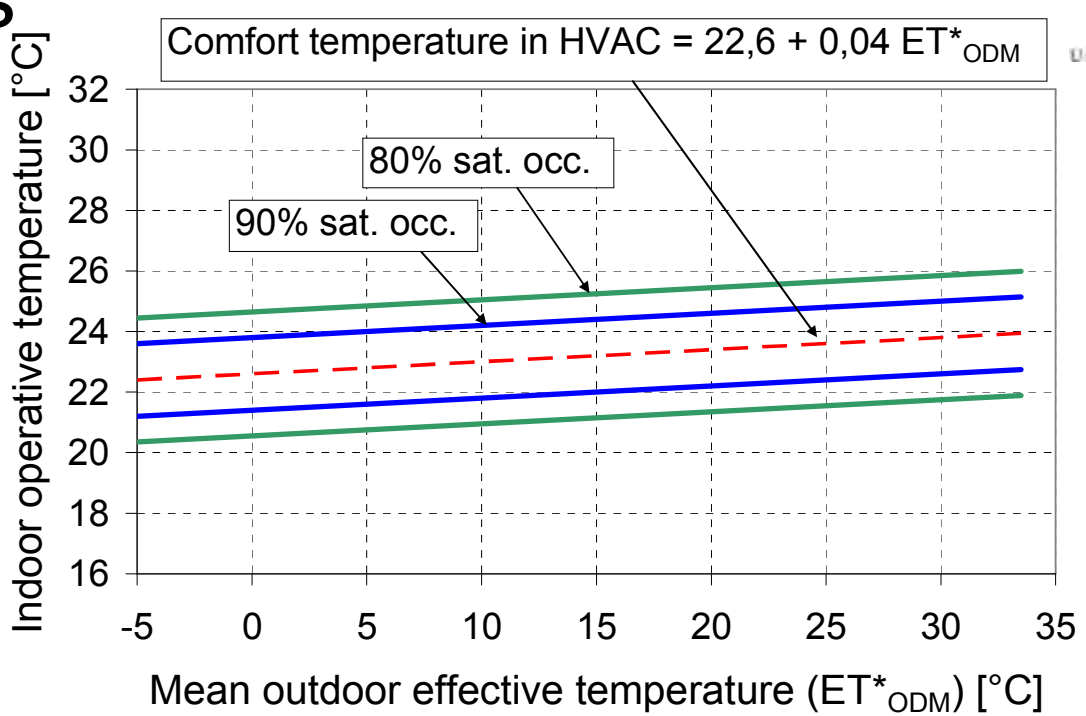


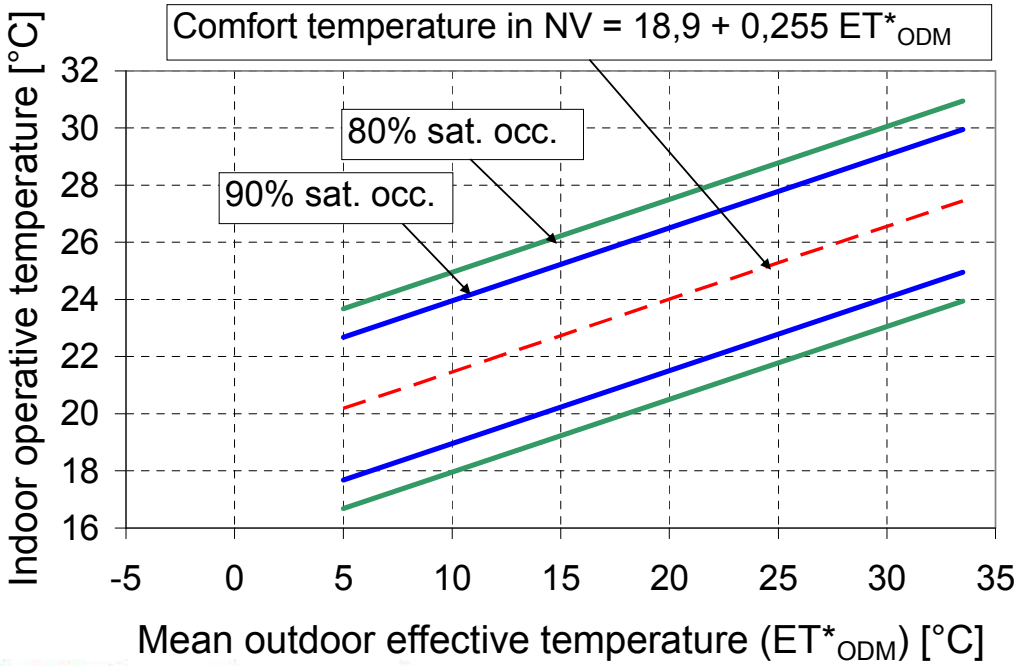
Yearly distribution of comfort categories for a classroom - occupation period



Adaptive Models

Adaptive Models

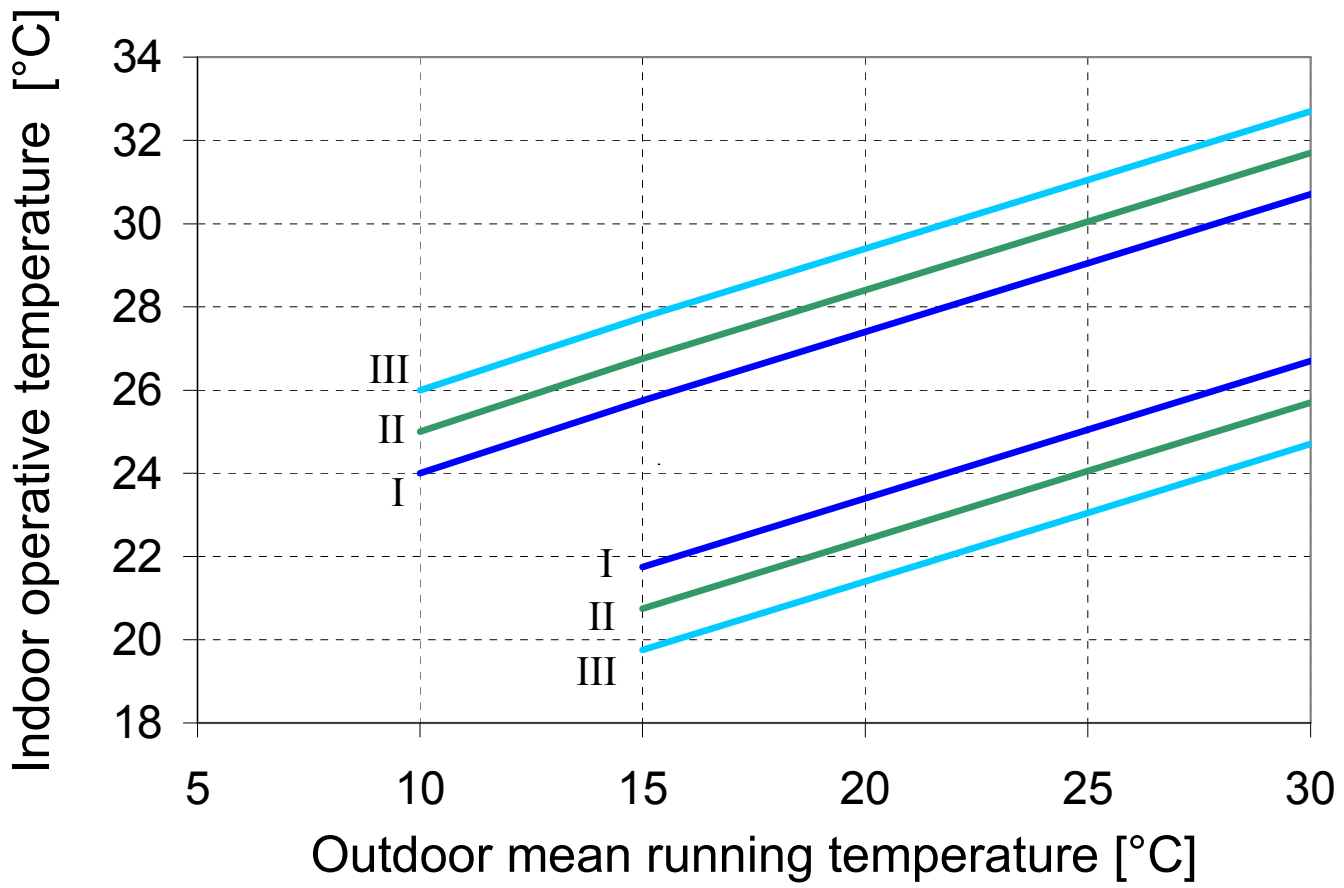




Acceptability ranges for 90% and 80% satisfied occupants for fully mechanically controlled (HVAC) and for naturally ventilated (NV) environments

Adaptive Models

Indoor operative temperature vs outdoor mean running temperature for buildings without mechanical cooling systems



$$t_{ORM(n)} = (1 - \alpha)\,(t_{OMD(n-1)} + \alpha\, t_{OMD(n-2)} + \alpha^2\, t_{OMD(n-3)} + \ldots.)$$

$t_{ORM(n)}$ running mean temperature in the day n
$t_{ODM(n)}$ outdoor daily mean temperature in the day n

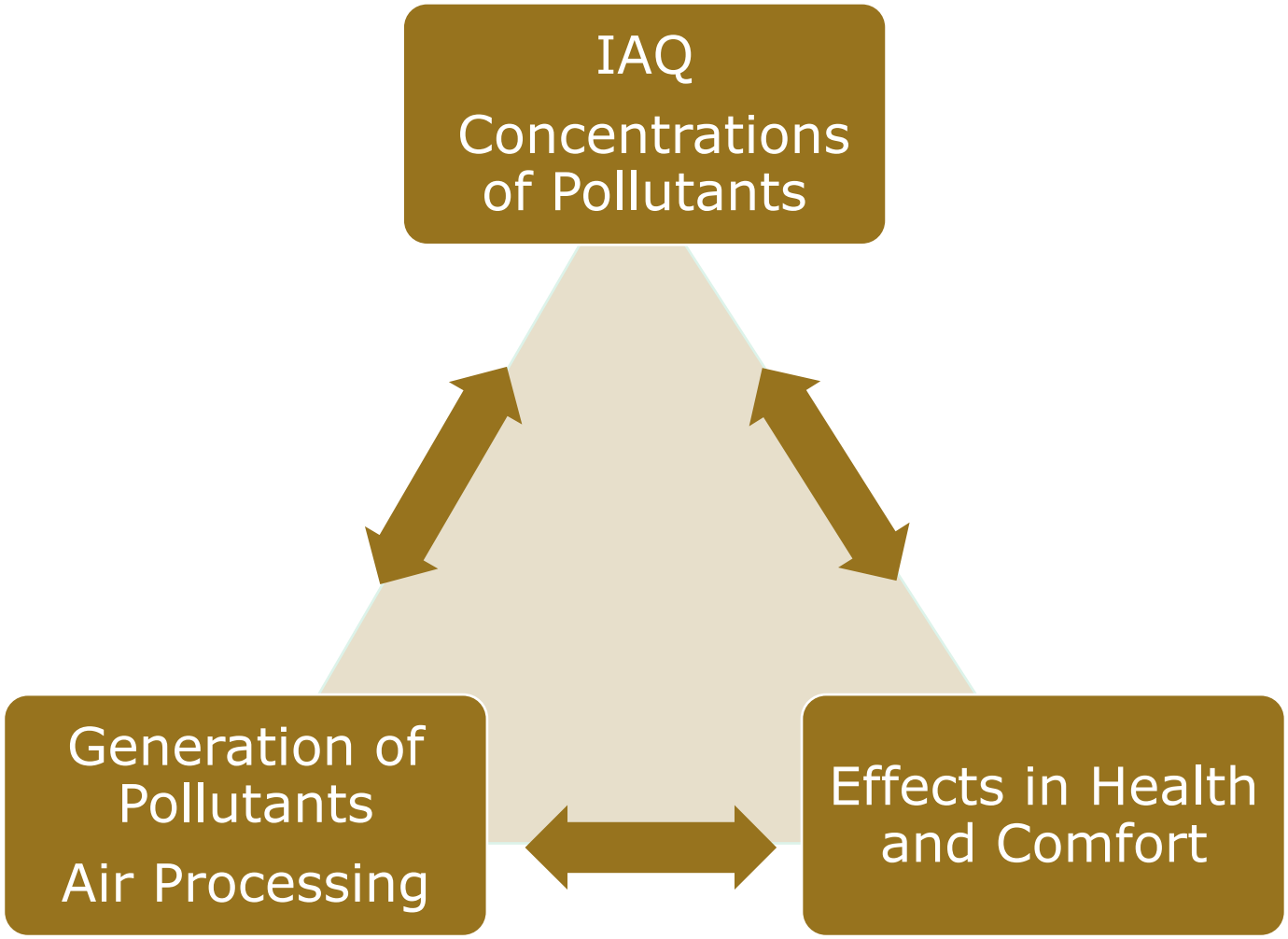
Indoor Air Quality

An indicator of the types and amounts of pollutants in the air that might cause discomfort or risk of adverse effects on human or animal health, or damage to vegetation

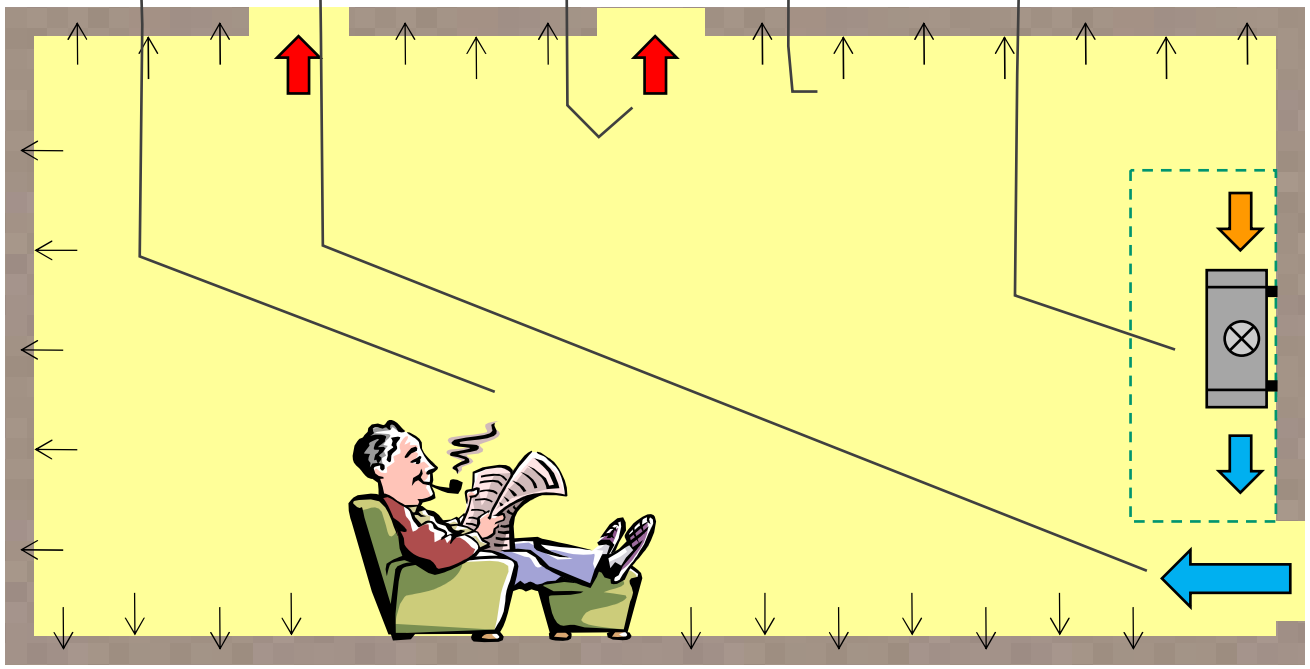
Air quality is usually referenced to the concentration in air of one or more pollutants. For many pollutants, air quality is expressed as an average concentration over a certain period of time, e.g., $\mu g/m^3$ averaged over 8 hours

(*In ISIAQ Glossary of Indoor Air Sciences, 1st ed, 2006)*

IAQ Triangle

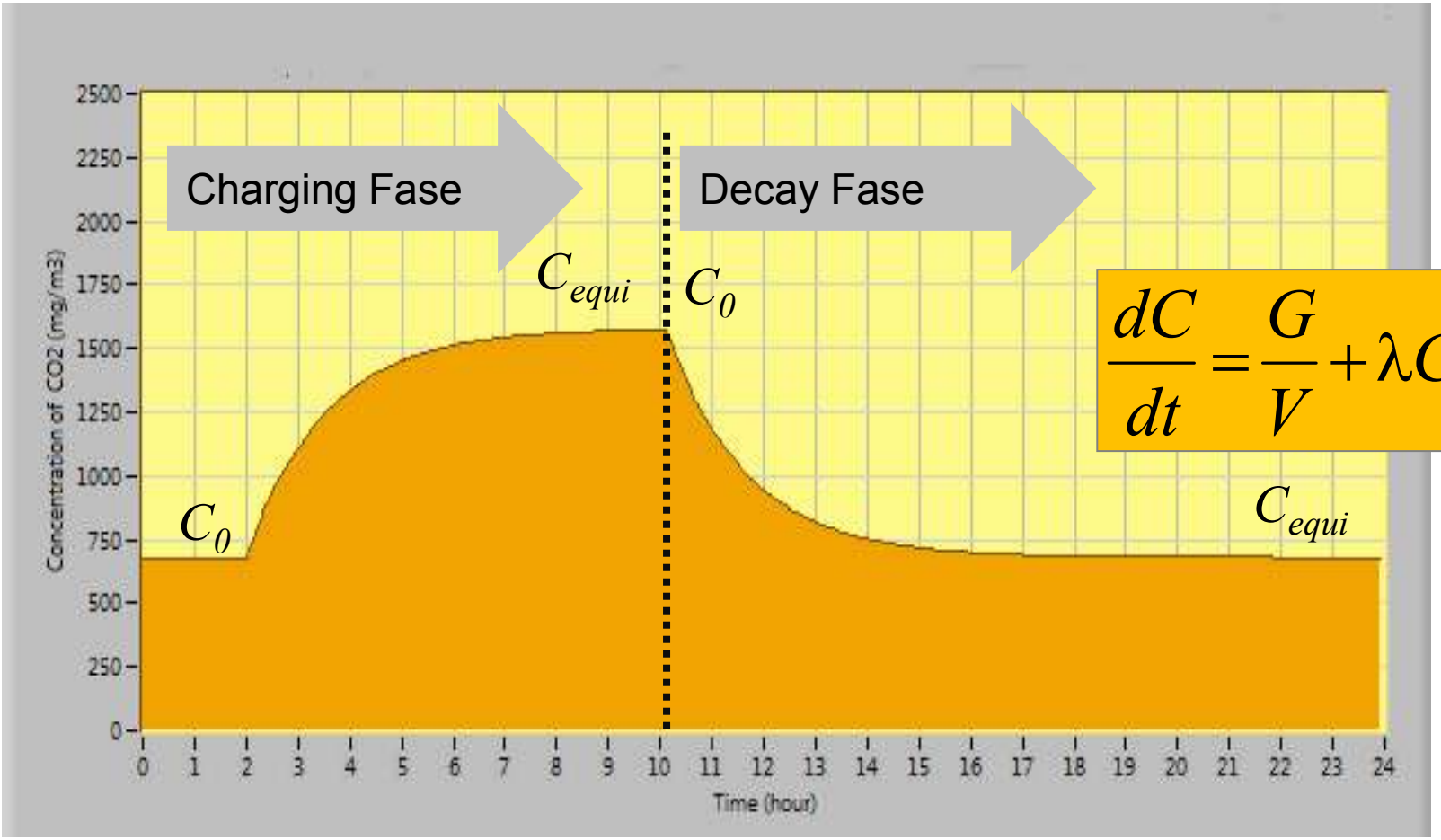


$$\frac{dC}{dt} = \frac{G}{V} + \lambda_v C_{ext} - \lambda_v C(t) - v_d \frac{S}{V} - \frac{Q_{ac}}{V} C \varepsilon_{ac}$$



Variation of Concentration = Emitted Pollutants + Pollutants entering − Pollutants leaving − Poluentes deposited or absorpted − Removed pollutants

Basic Equations

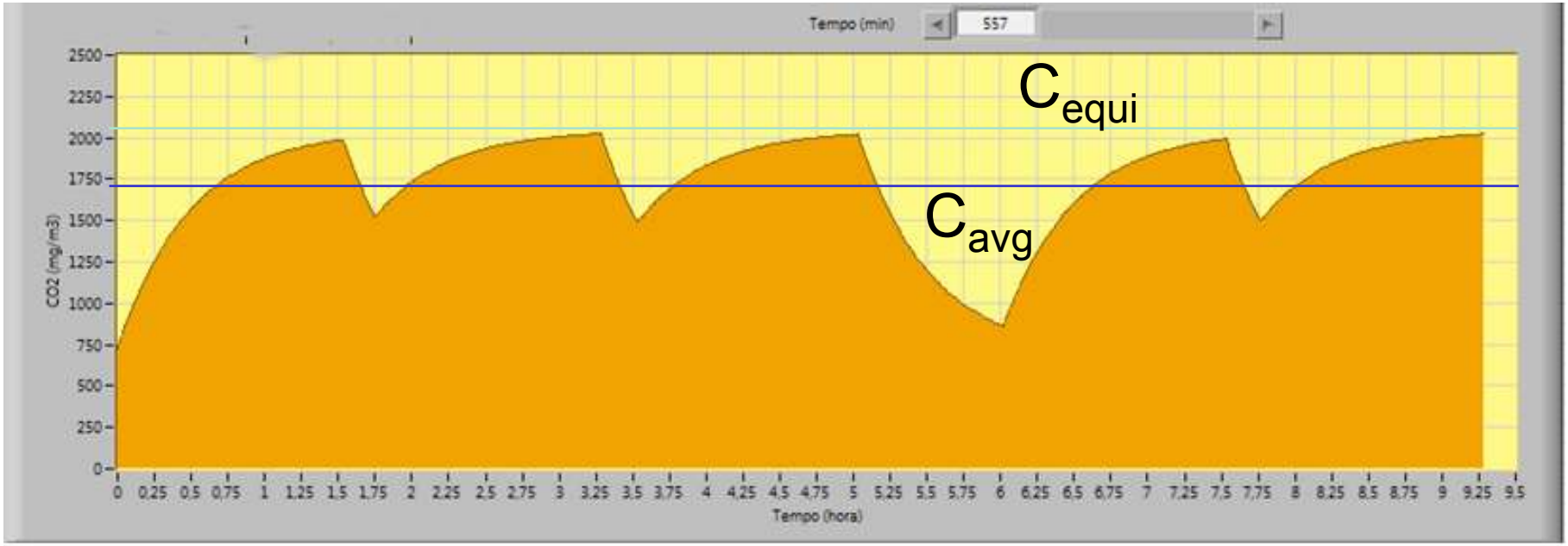


$$\frac{dC}{dt} = \frac{G}{V} + \lambda C_{ext} - \lambda C$$

$$\frac{C(t) - C_{equi}}{C_0 - C_{equi}} = e^{-\lambda t}$$

$$C_{equi} = C_{ext} + \frac{G}{Q}$$

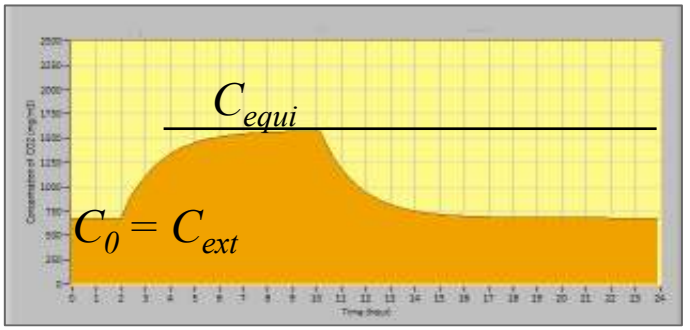
Definition of Ventilation Requirements



Parameter	Condition	Method
Fresh Air Flow Rate or Air Exchange Rate	$C_{equi} < C_{ref}$	Prescriptive
	$C_{avg} < C_{ref}$	Analytical

Basis of the Prescriptive Methods

$$\frac{dC}{dt} = \frac{G}{V} + \lambda_v (C_{ext} - C(t))$$

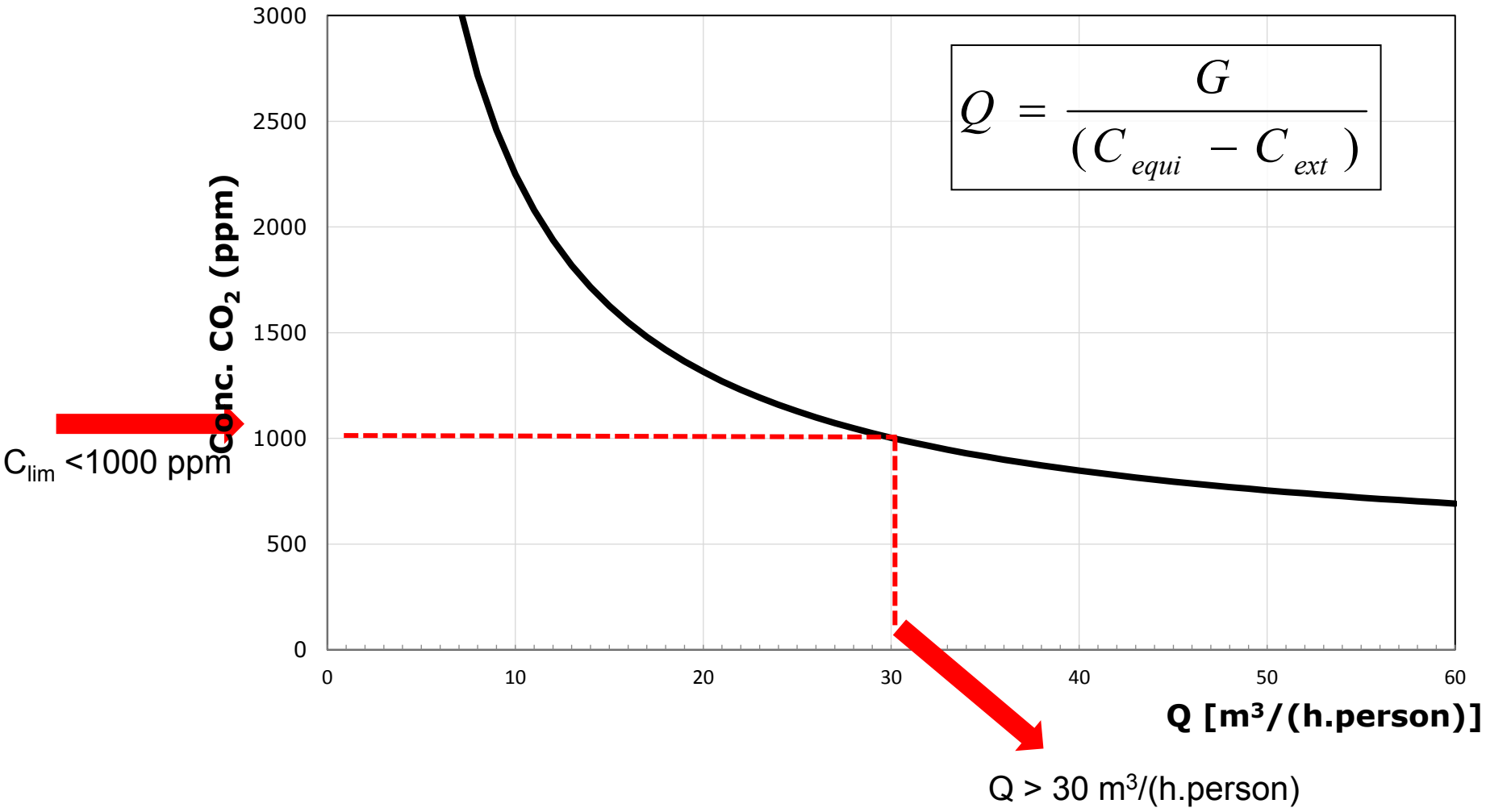


$$\frac{dC}{dt} = 0 \quad \Rightarrow \quad 0 = \frac{G}{V} + \lambda_v (C_{ext} - C_{equi})$$

$$C_{equi} = C_{ext} + \frac{G}{V\lambda_v} \qquad \text{as} \qquad \lambda_v = \frac{Q}{V}$$

$$C_{equi} = C_{ext} + \frac{G}{Q} \quad \Rightarrow \quad Q = \frac{G}{(C_{equi} - C_{ext})}$$

Basis of the Prescriptive Methods



NOTE: Curve for the CO_2 generation of CO_2 of a standard person (P50%) with 1.2 met matabolic rate

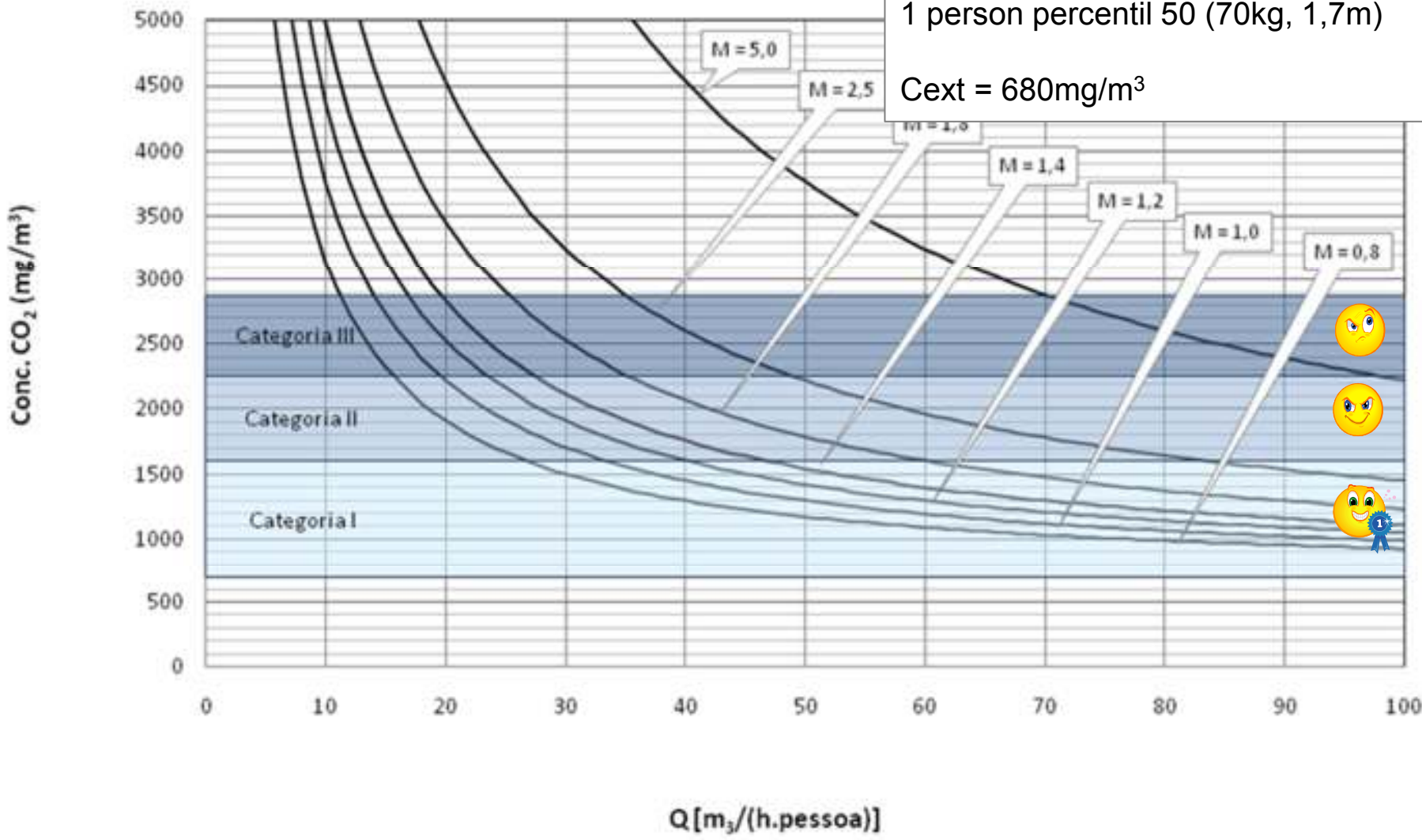
Example of a Prescriptive Method

Minimum Fresh Air Flow Rate

$G_{[CO2]}$= 30833 [(mg/h) / met] x M [met]

1 person percentil 50 (70kg, 1,7m)

Cext = 680mg/m^3



Example of a Prescriptive Method

Type of activity	Metabolic Rate- M (met)	Type of Space	Fresh Air Flow Rate [m³/(hora.person)]
Sleeping	0,8	Bedrooms, Dormitories, etc.	16
Resting	1	Resting rooms, Waiting Rooms, Conferene Rooms, Auditoriums	20
Sedentary	1,2	Offices, Libraries, Schools	24
Moderate	1,75 (1,4 a 2,0)	Laboratories Ateliers, Drawing Rooms, Cafés, Bars,	35
Slightly High	2,5 (2,0 a 3,0)	Dance Floors, Gymnasium rooms, Ballet rooms	49
High	5,0 (3,0 a 9,0)	Bodybuilder rooms, Sport facilities, etc	98

$$Q[m^3/(h.person)] = 20 \times M(met)$$

Analytical Method

It is performed a simulation of the time evolution of the concentration during the occupancy period, using a finite diferences equation, to calculate the dose at which occupants are exposed.

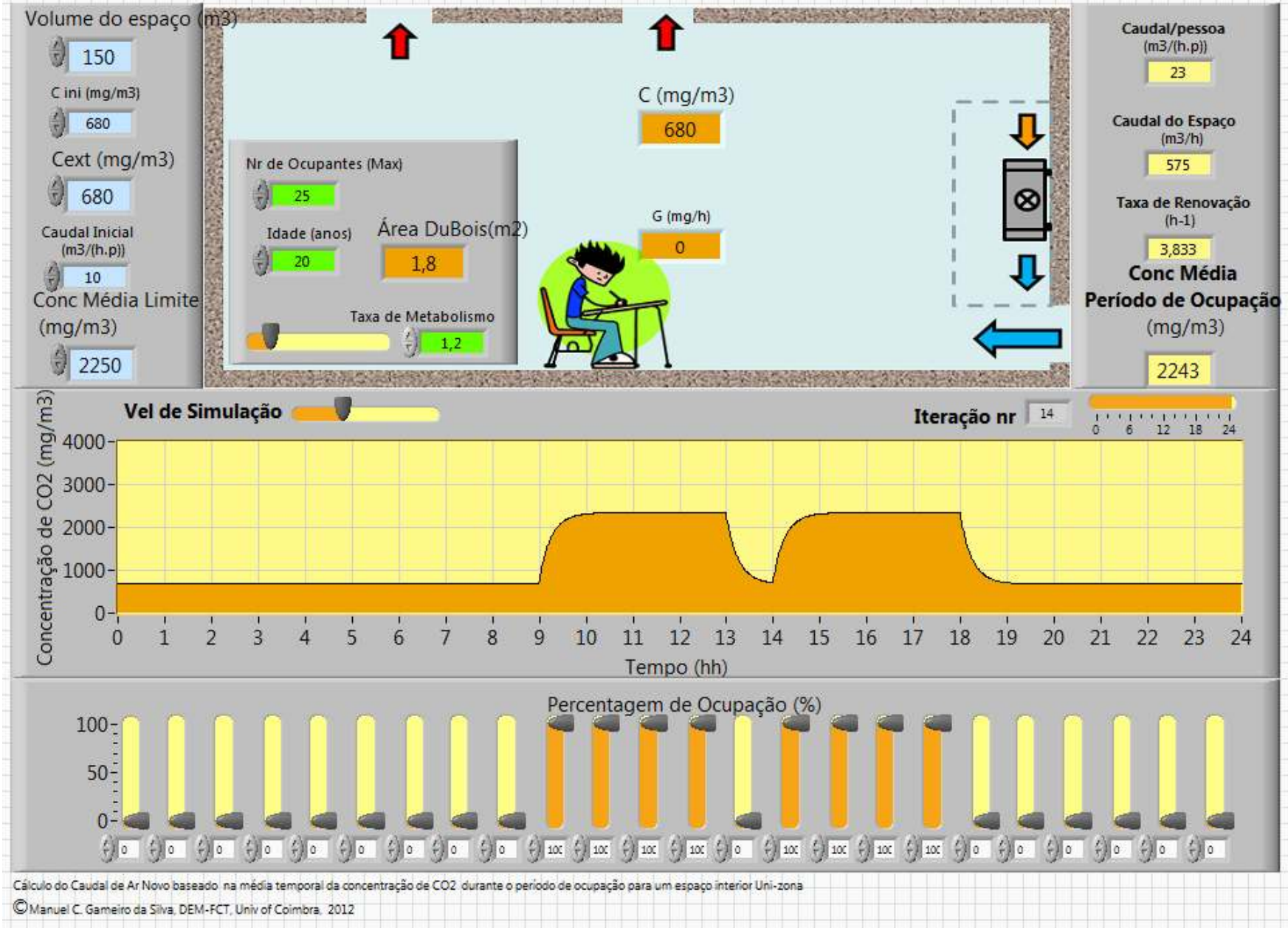
$$\frac{dC}{dt} = \frac{G}{V} + \lambda C_{ext} - \lambda C \quad \Rightarrow \quad \Delta C = \left[\frac{G}{V} + \lambda_v \cdot C_{ext} - \lambda_v \cdot C \right] \times \Delta t$$

$$C_i = C_{i-1} + \Delta C$$

Category	Daily Average Concentrations	
	CO_2	
Special Req	1600 mg/m^3	900 ppm
Normal	2250 mg/m^3	1250 ppm

Analytical Method

Software Tool version with Percentage of Occuppancy Input



Analytical Method

Software Tool version with Table Input Data

Table with Input Data

Espaço	Área (m2)	Altura (m)	Lotaçã	Metab	Idade	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14	H15	H16	H17	H18	H19	H20	H21	H22	H23	H24
1	50	3	25	58	18	0	0	0	0	0	0	0	60	100	100	100	100	0	100	100	100	40	0	0	0	0	0	0	0
2	60	3	50	58	15	0	0	0	0	0	0	0	80	100	100	100	100	0	100	100	100	40	0	0	0	0	0	0	0
3	70	3	60	65	18	0	0	0	0	0	0	0	60	100	100	100	100	0	100	100	100	40	0	0	0	0	0	0	0
4	80	3	30	70	18	0	0	0	0	0	0	0	70	100	100	100	100	0	100	100	100	40	0	0	0	0	0	0	0
5	80	3	24	70	18	0	0	0	0	0	0	0	60	100	100	100	100	0	100	100	100	100	60	0	0	0	0	0	0

Results of Fresh Air Flow Rate per Room

Espaço	Área (m2)	Altura (m)	Lotação	Metabolismo	Idade	Caudal/ocup (m3/h)	Caudal Total (m3/h)
1	50	3	25	58	18	19	475
2	60	3	50	58	15	19	950
3	70	3	60	65	18	22	1320
4	80	3	30	70	18	23	690
5	80	3	24	70	18	24	576

Monitoring Buildings. Why

"If you don't measure it, you can't manage it"

Buildings and Building Systems are too much complicated to understand with simple one-shot measurements, on account of the large number of relevant parameters with strong time and space variability.

Case Study

Horst City Building

The Netherlands

Indoor WorkPlace Monitoring System

Table of WP variables

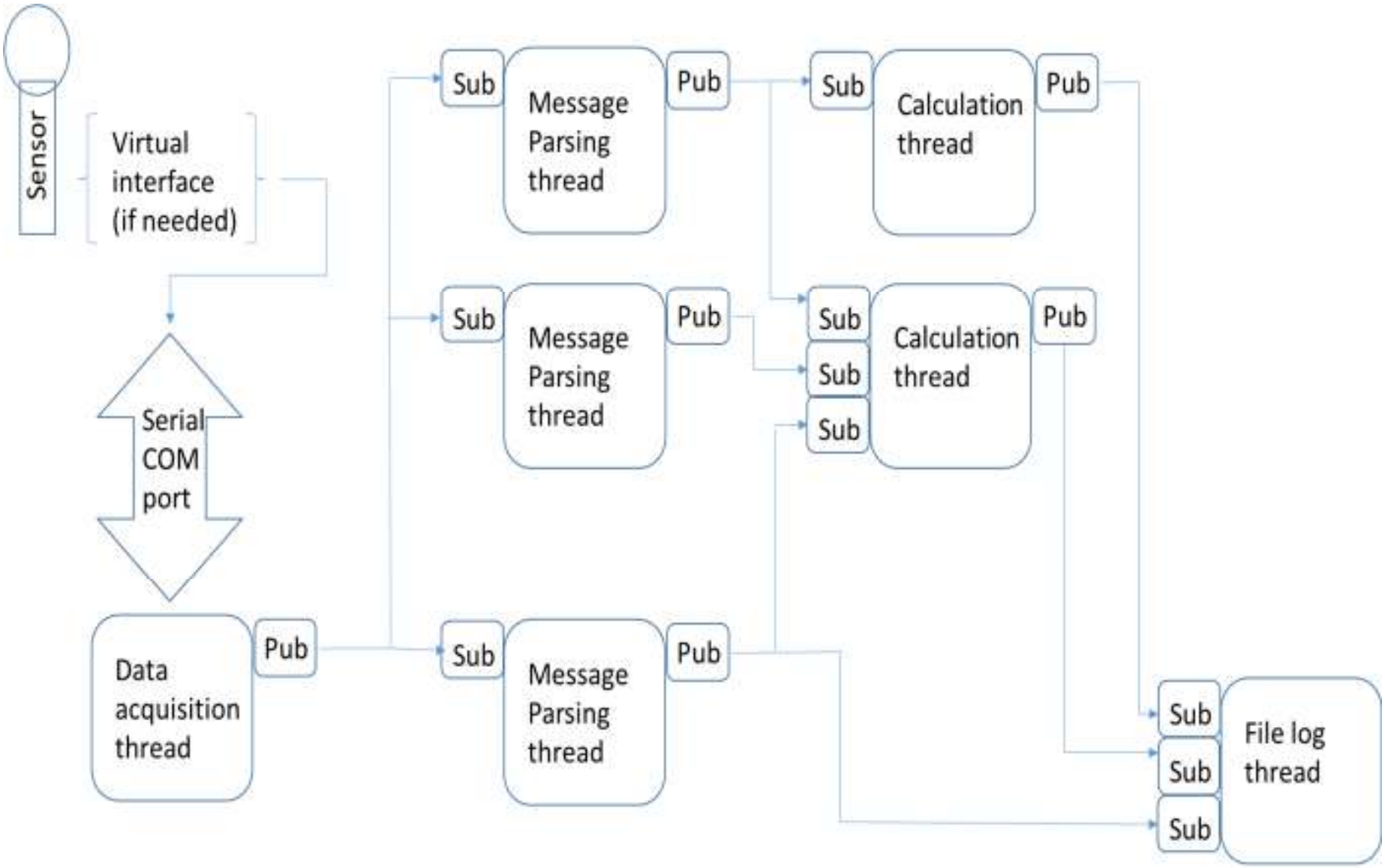
Chanel	Parameter, Units
1	Indoor Operative Temperature (°C)
2	Predicted Mean Vote - PMV 1
3	Predicted Mean Vote - PMV 2
4	Predicted Percentage of Dissatisfied - PPD 1 (%)
5	Predicted Percentage of Dissatisfied - PPD 2 (%)
6	Draught Rate (%)
7	Indoor Dew Point Temperature (°C)
8	Air Temperature Fluctuation (°C/h)
9	Indoor Air Pressure (hPa)
10	Indoor Humidity Ratio (g/Kg of dry air)
11	Indoor Operative Temperature 2 (°C)
12	Indoor Air Temperature (°C)
13	Indoor Relative Humidity (%)
14	Indoor Concentration of CO2 (ppm)
15	Indoor Concentration of CO2 (ppm)
16	Indoor Concentration of VOCs (100*ppb)
17	Indoor Concentration of PM10 (ug/m3)
18	Indoor Concentration of PM2.5 (ug/m3)
19	Indoor Concentration of PM1 (ug/m3)
20	Iluminance level (lux)
21	Air Temperature Neck Level (°C)
22	Air Temperature Anckle Level (°C)
23	Air Velocity Neck Level (m/s)
24	Air Velocity Anckle Level (m/s)

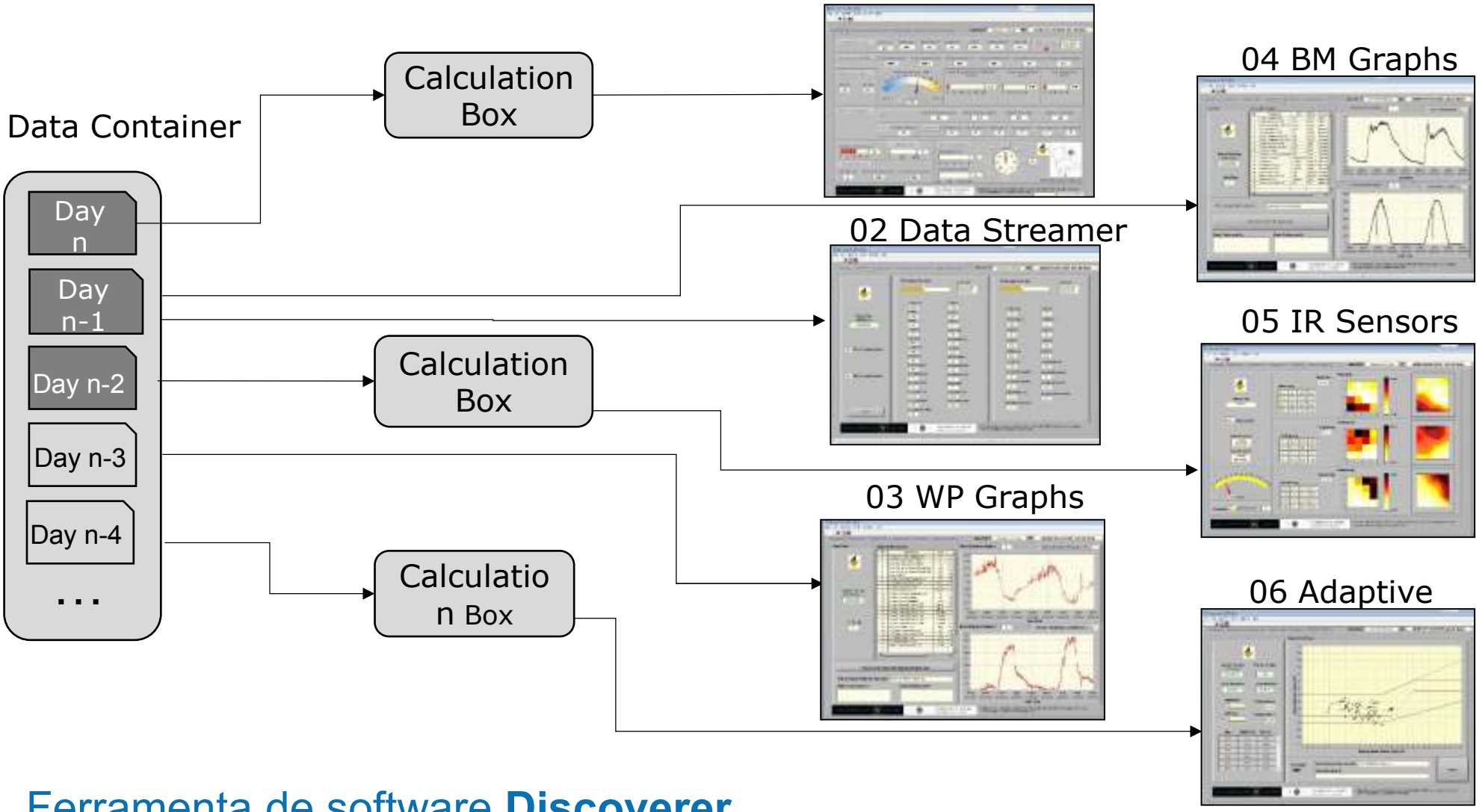
Outdoor Measured Values

Table of BM Variables

Chanel	Parameter, Units
1	Outoor Air Temperature (°C)
2	Outdoor Relative Humidity (%)
3	Outdoor Concentration of CO2 (ppm)
4	Wind Speed WST (m/s)
5	Wind Direction WST (°)
6	Outdoor Air Temperature WST(°C)
7	Outdoor Air Temperature Yocto(°C)
8	Outdoor Relative Humidity (%)
9	Outdoor Barometric Pressure (mbar)
10	Windchill Index (°C)
11	Outdoor Dew Point Temperature (°C)
12	Outdoor Air Humidity (g/kg of dry air)
13	Outdoor Concentration of PM10 (ug/m3)
14	Outdoor Concentration of PM2.5 (ug/m3)
15	Outdoor Concentration of PM1 (ug/m3)

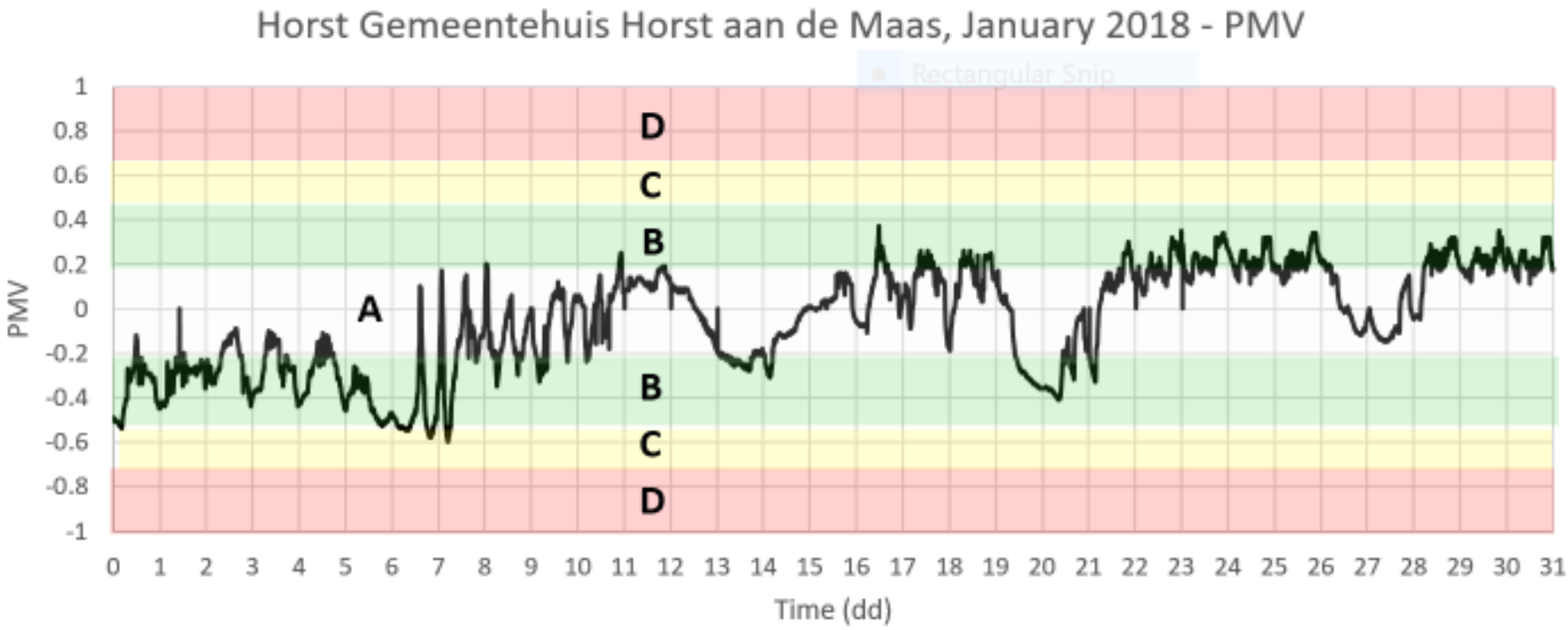
Data Acquisition



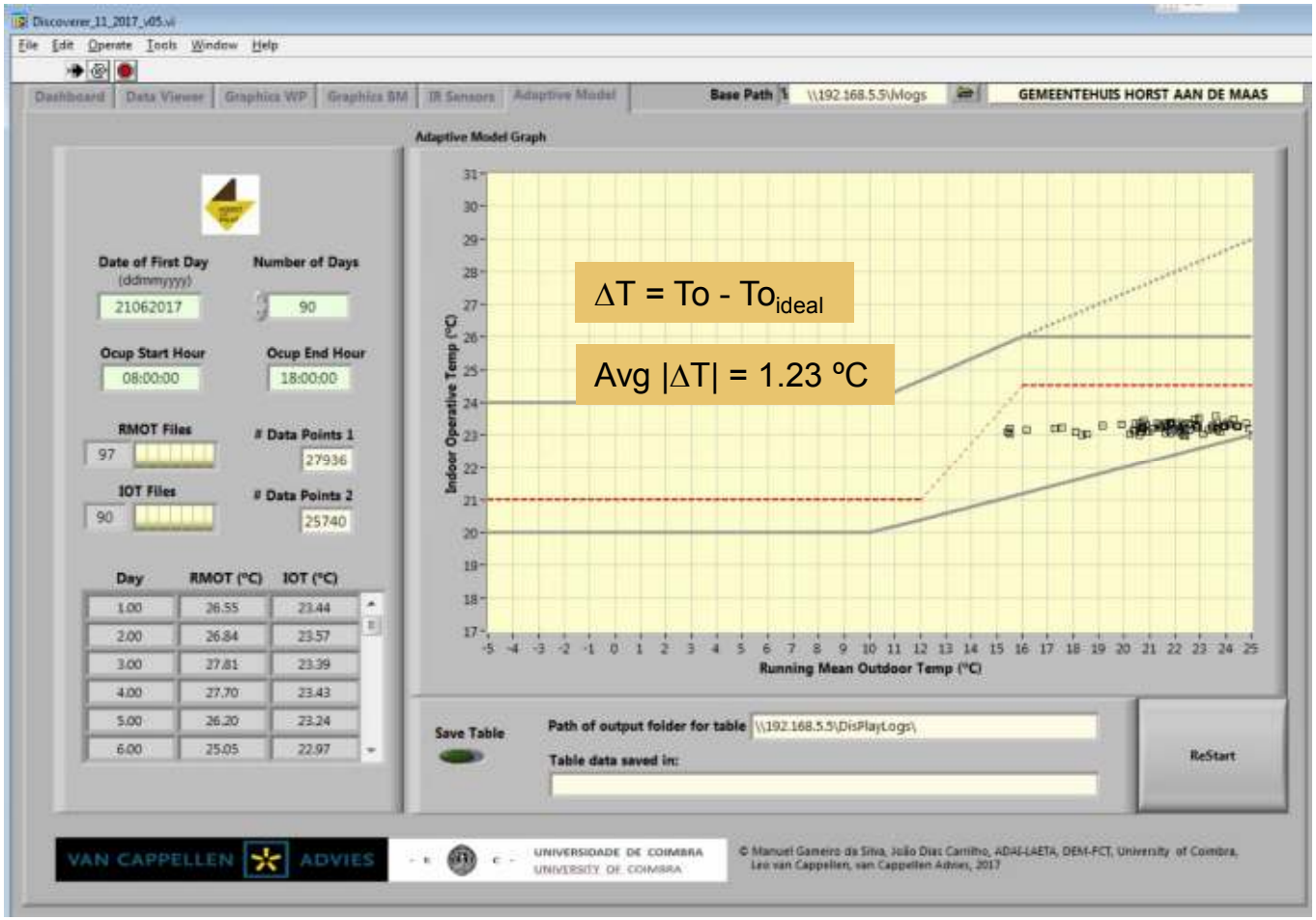


Ferramenta de software **Discoverer**

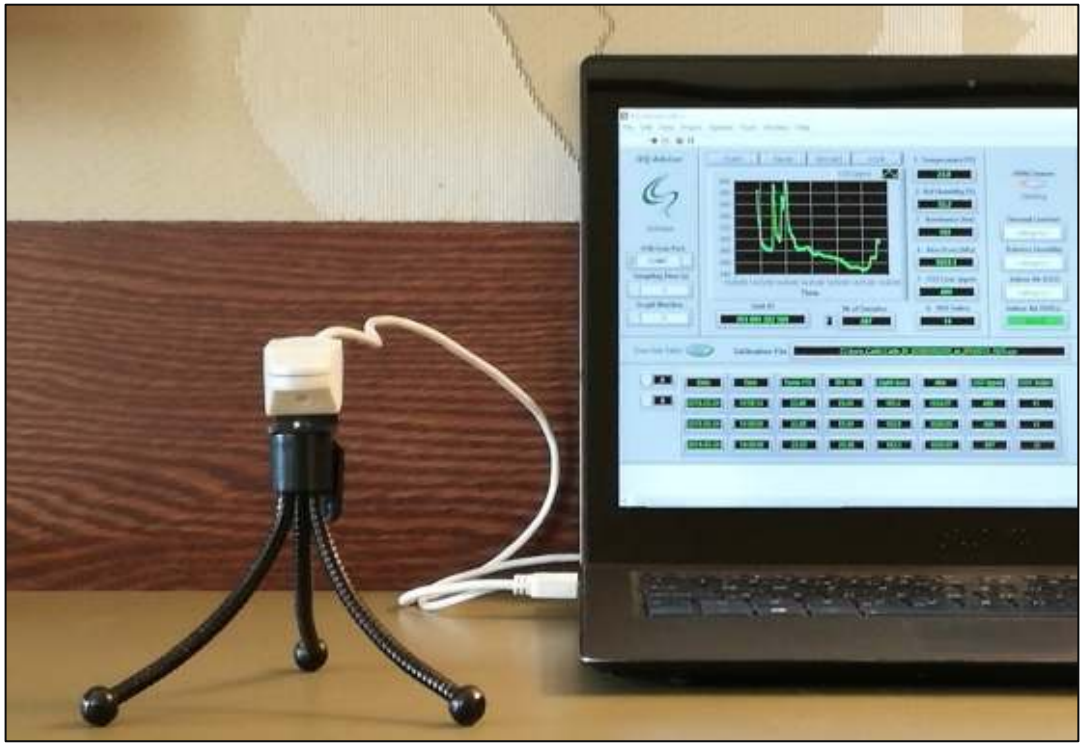
Avaliação de longo termo do Conforto Térmico



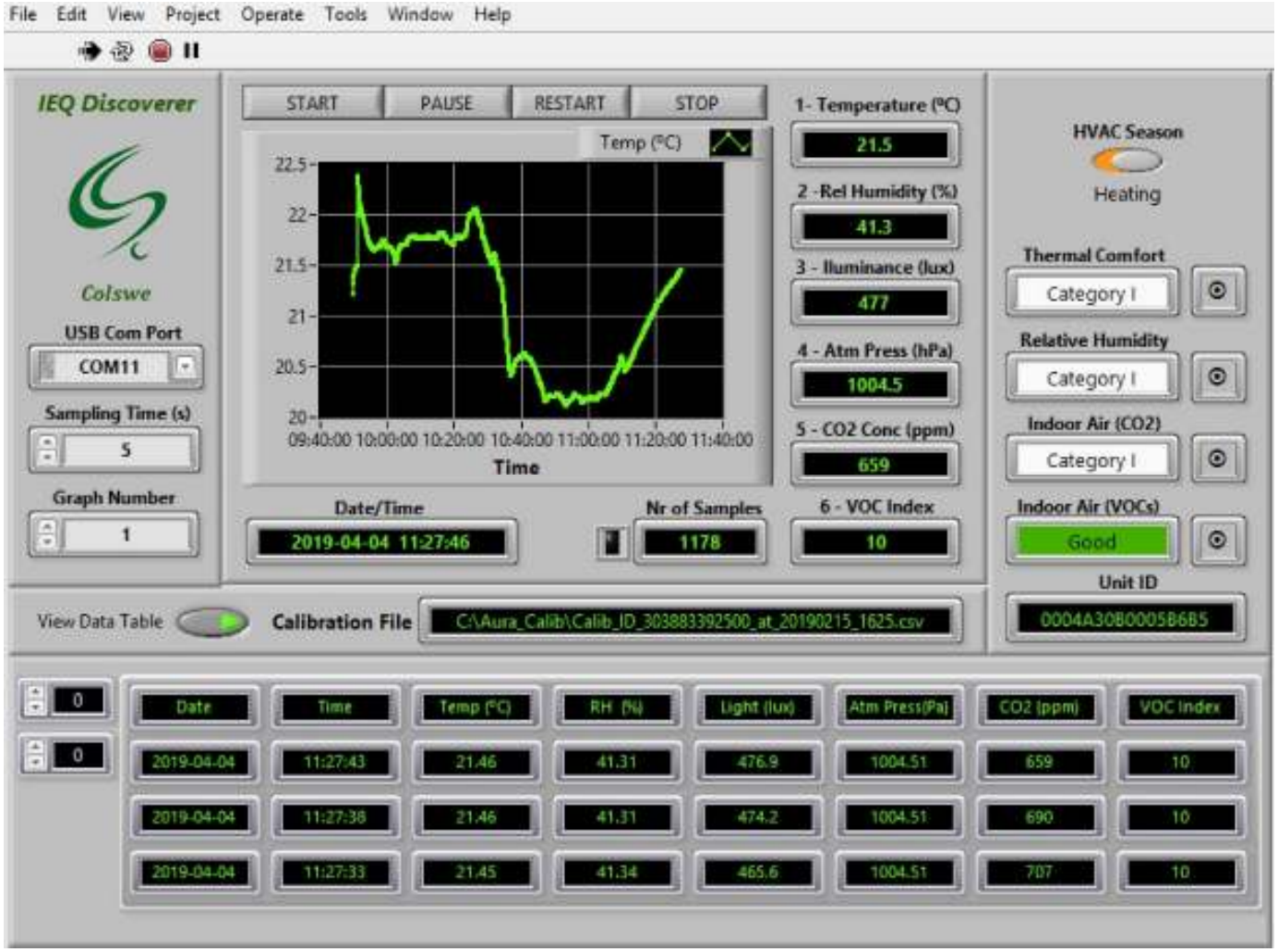
Modelo Adaptativo de Conforto Térmico



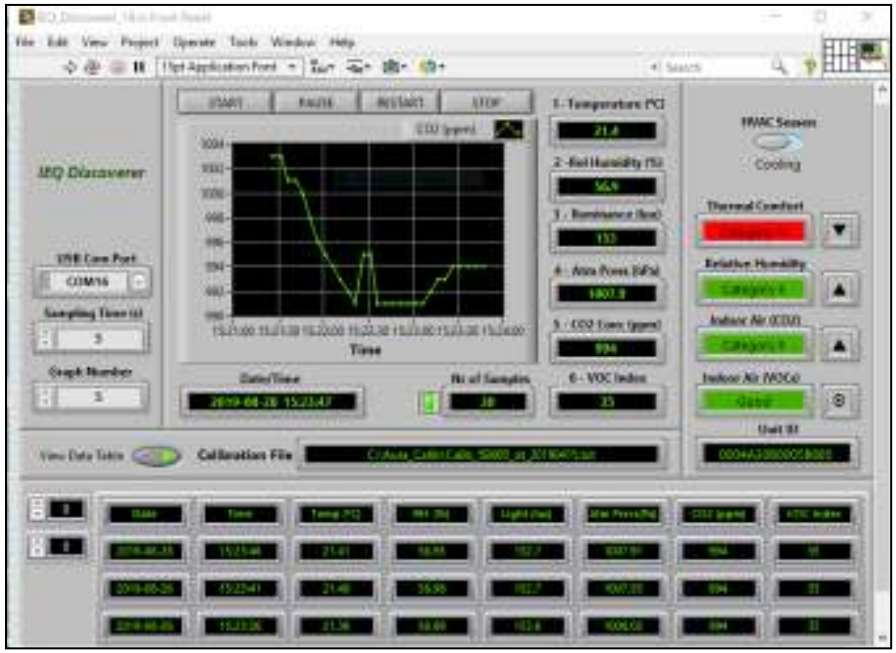
IEQ Multiprobe + IEQ Discoverer App



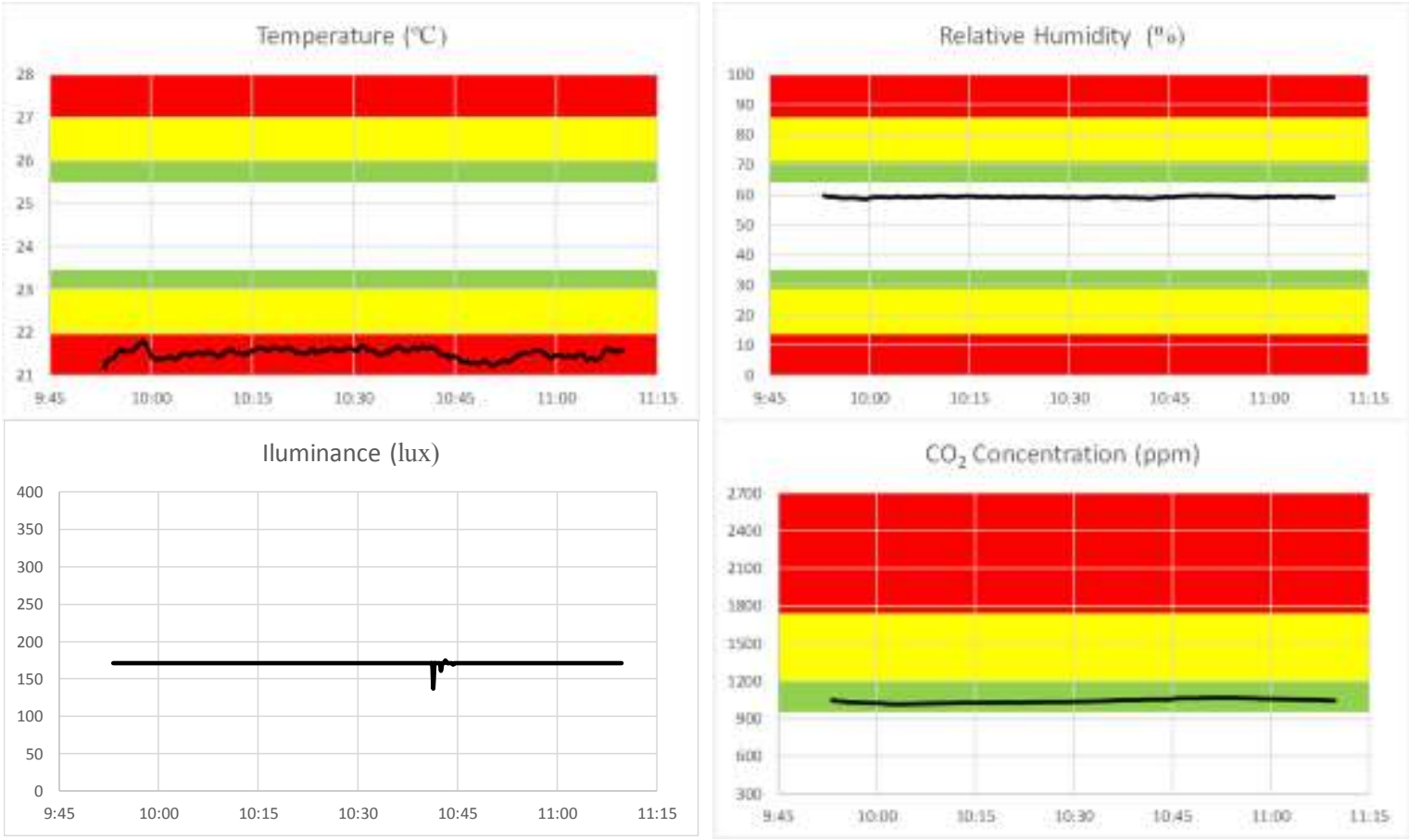
IEQ Discoverer App



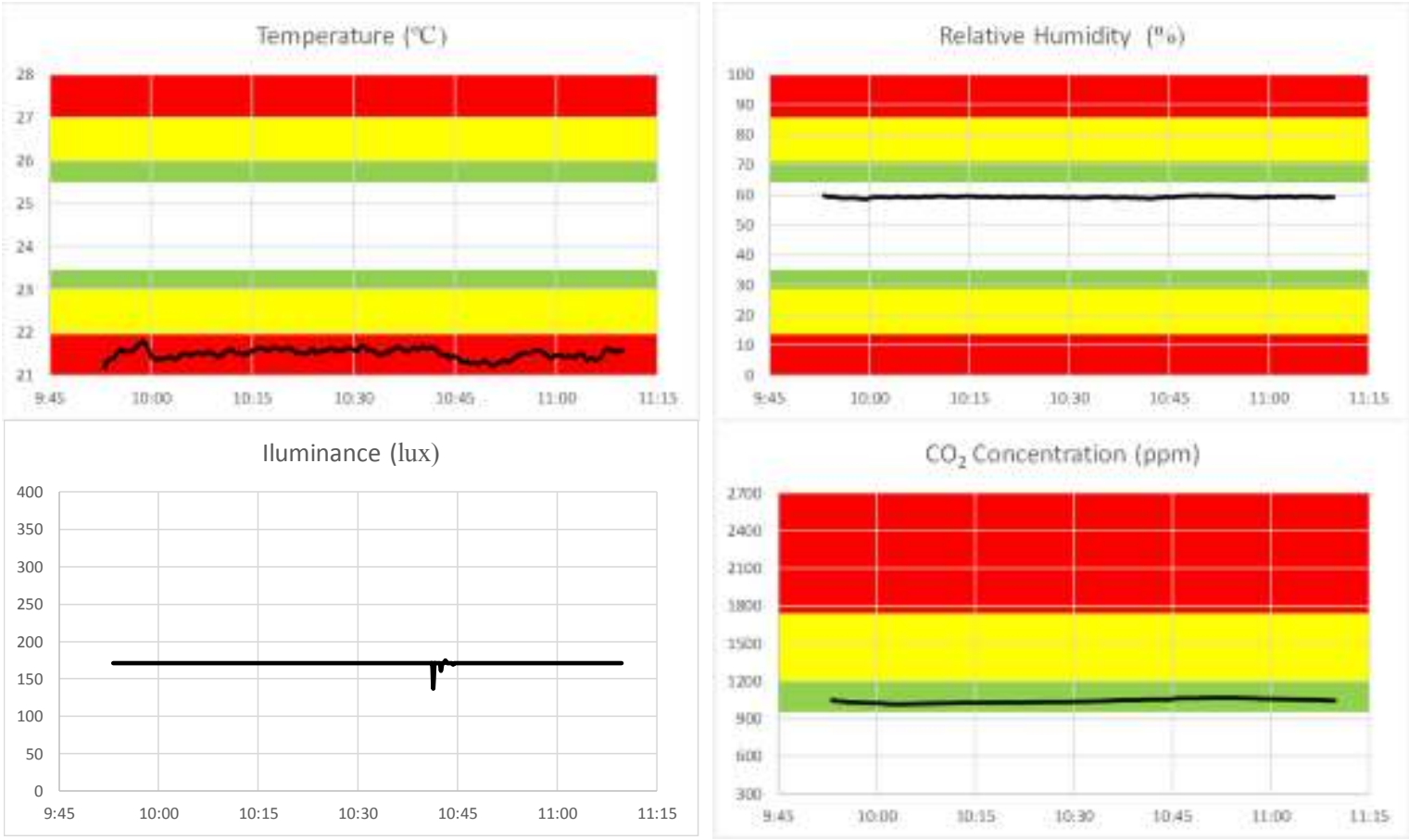
Caso de Estudo: Centro de Eventos Puerta de Oro, Auditório Barranquilla, 2019-08-28



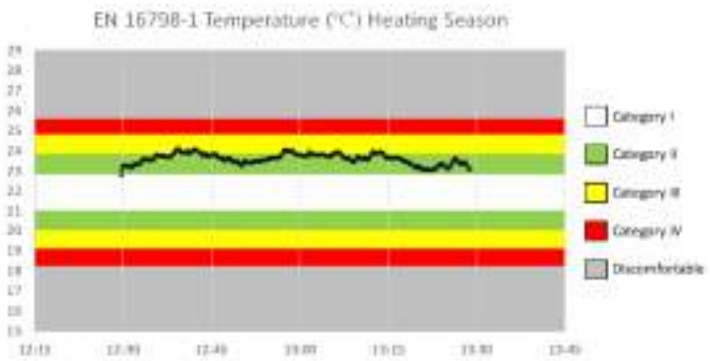
Caso de Estudo: Centro de Eventos Puerta de Oro, Auditório Barranquilla, 2019-08-28

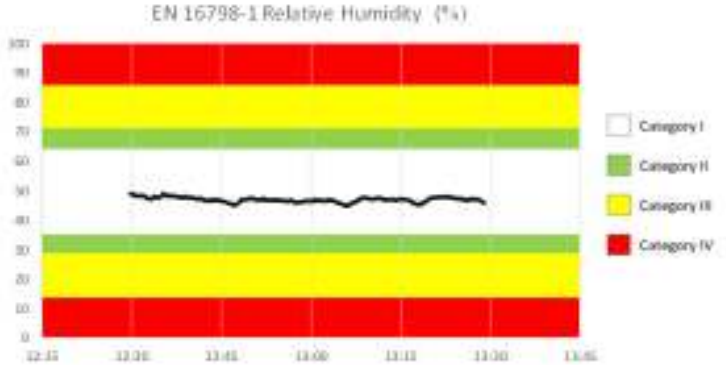


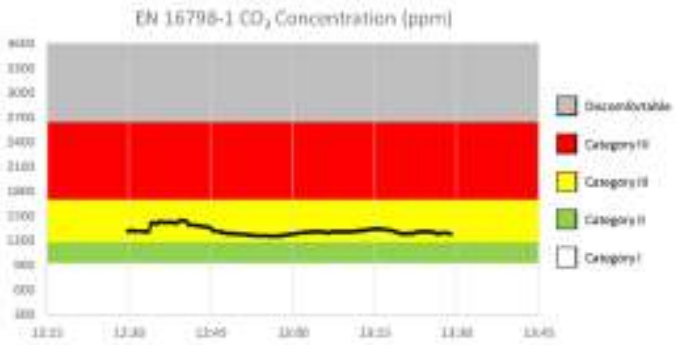
Caso de Estudo: Centro de Eventos Puerta de Oro, Auditório Barranquilla, 2019-08-28

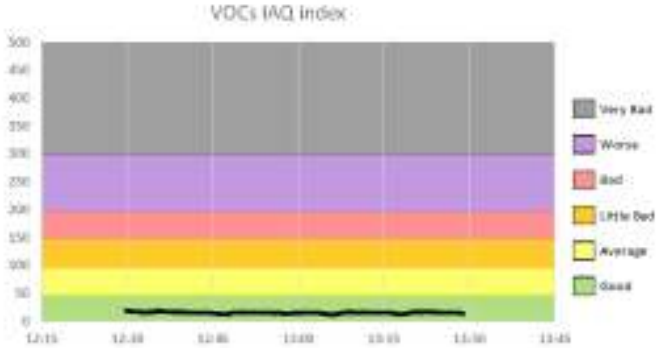


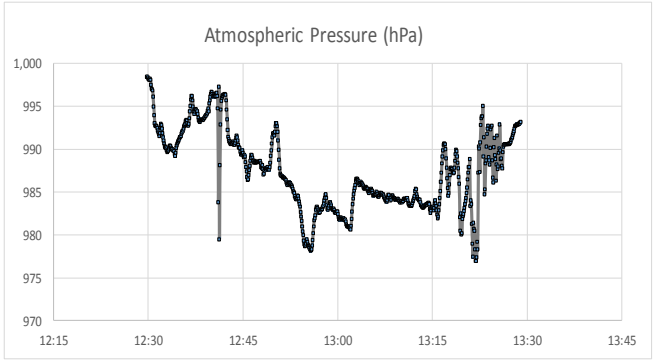
Caso de Estudo: TGV_8446_Poitiers_Paris_2019-11-07



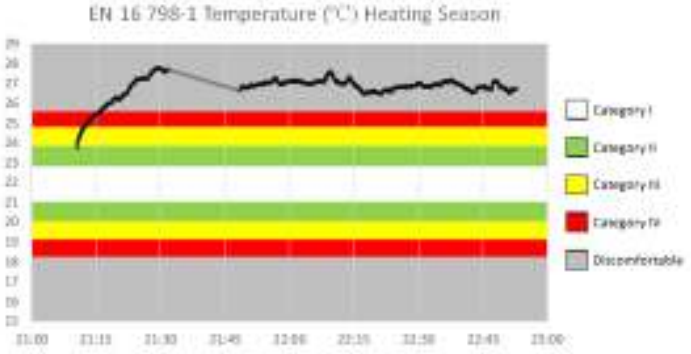


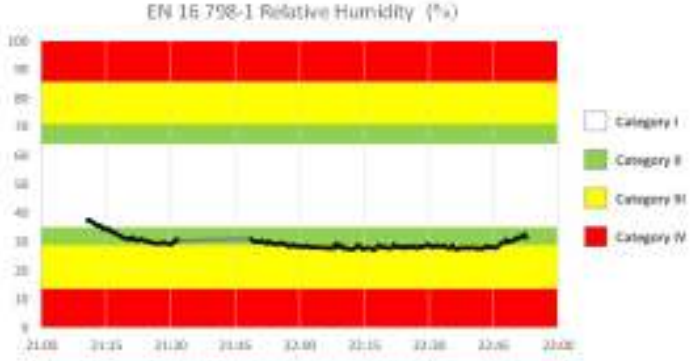


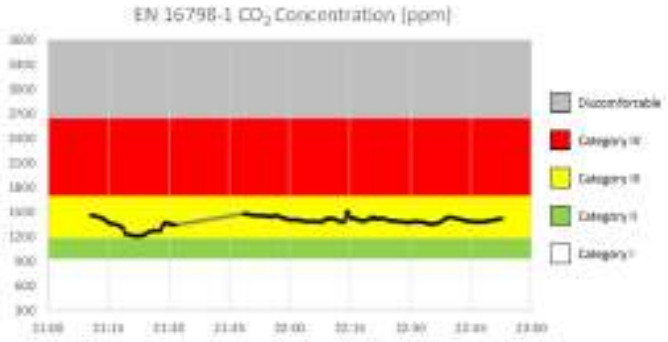


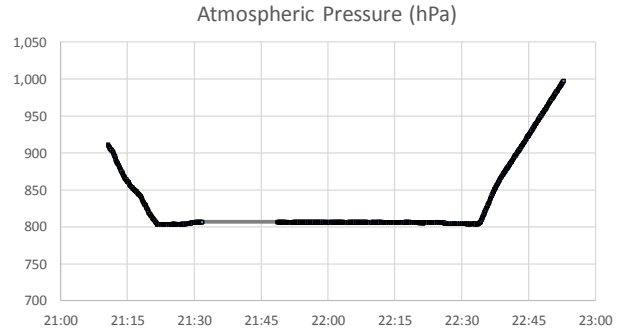


Caso de Estudo: TP_449_Paris_Lisboa_Airbus_A320_2019-11-08









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Thank you very much for your attention

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Questions