71° Congresso ATI

14-16 Settembre 2016
Torino

Listening what buildings have to tell us

Manuel Gameiro da Silva
ADAI-LAETA, Departmento de Engenharia Mecânica
Universidade de Coimbra

manuel.gameiro@dem.uc.pt

My Research Framework

Laeta laboratório associado

IST idmec engenharia mecânica

FEUP idmec engenharia mecânica

EfS

ISR INSTITUTO DE SISTEMAS E ROBÓTICA UNIVERSIDADE DE COIMBRA

ADAI

GEAC

GFFD

INESC Coimbra Instituto de Engenharia de Sistemas e Computadores de Coimbra

ITeCons Instituto de Investigação e Desenvolvimento Tecnológico em Ciências da Construção

ces Centro de Estudos Sociais Laboratório Associado Universidade de Coimbra

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FEUP inegi Instituto de Engenharia Mecânica e Gestão Industrial

UNIVERSIDADE DA BEIRA INTERIOR Covilhã | Portugal

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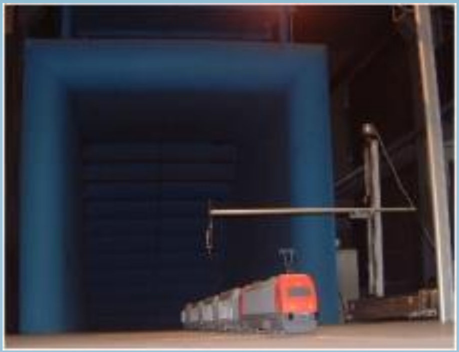
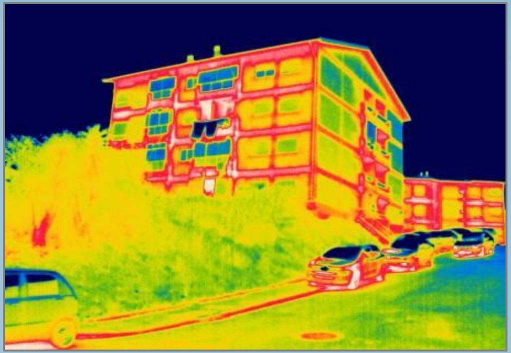
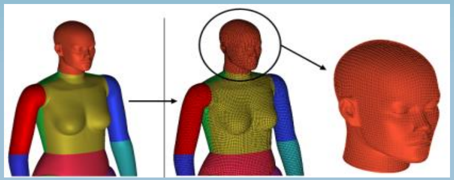
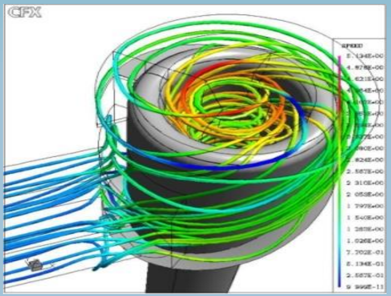
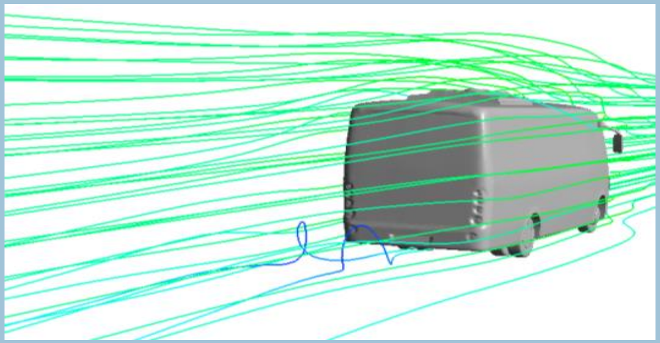
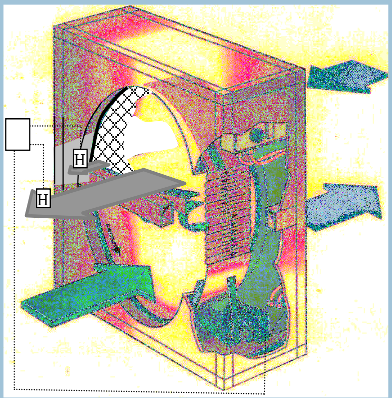
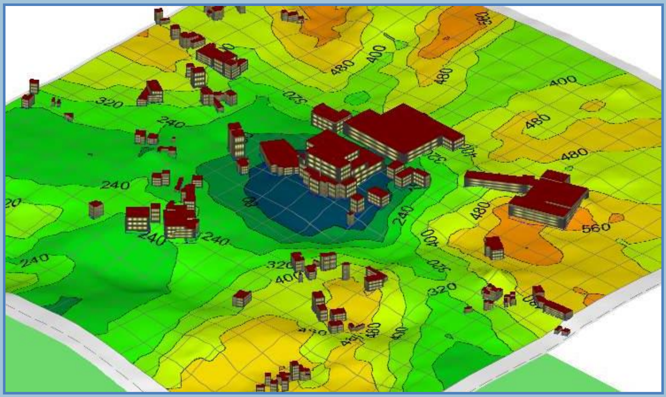
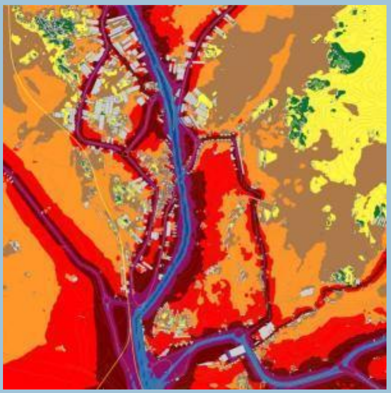
Research Group in Energy, Environment and Comfort

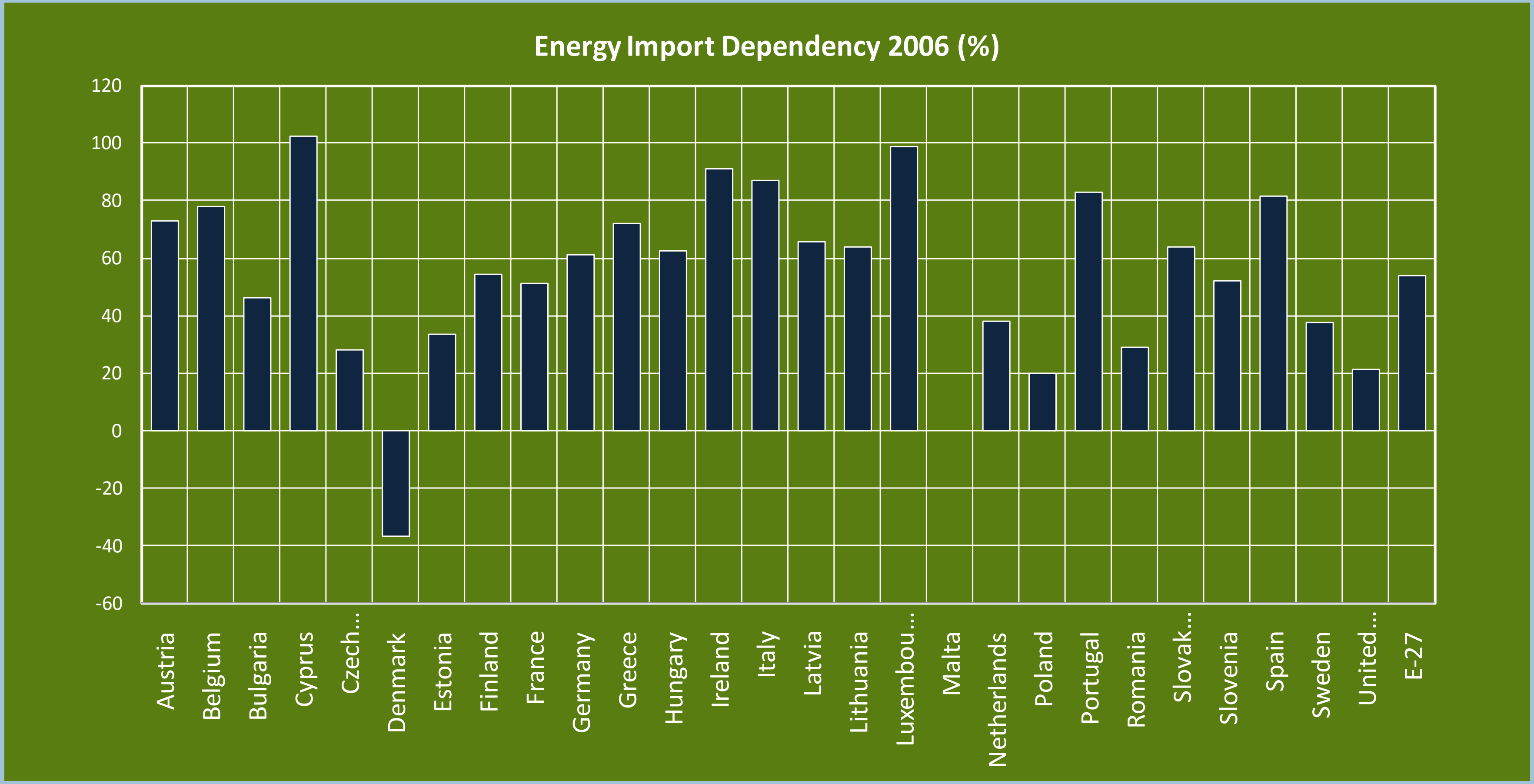







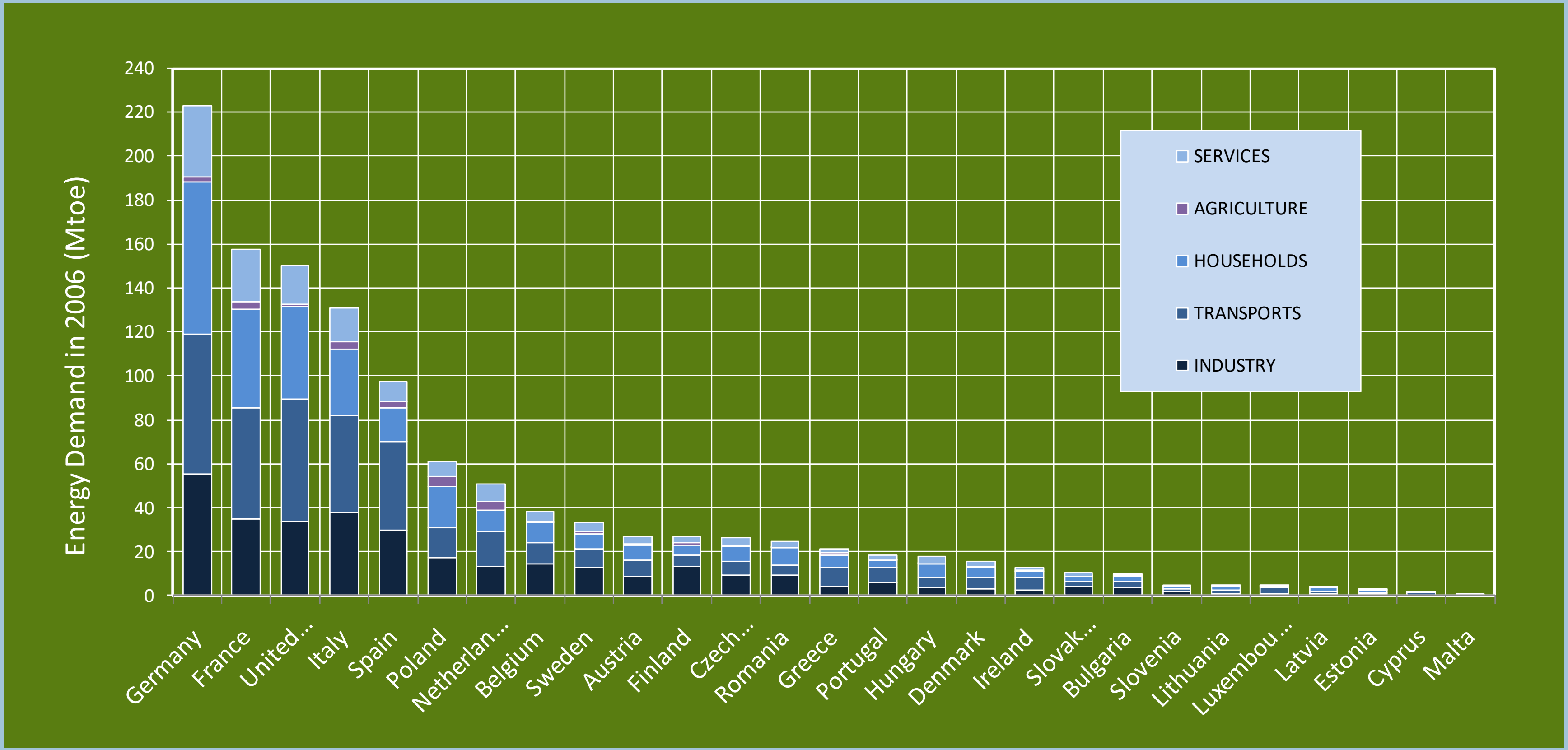


European Energy Market Analysis

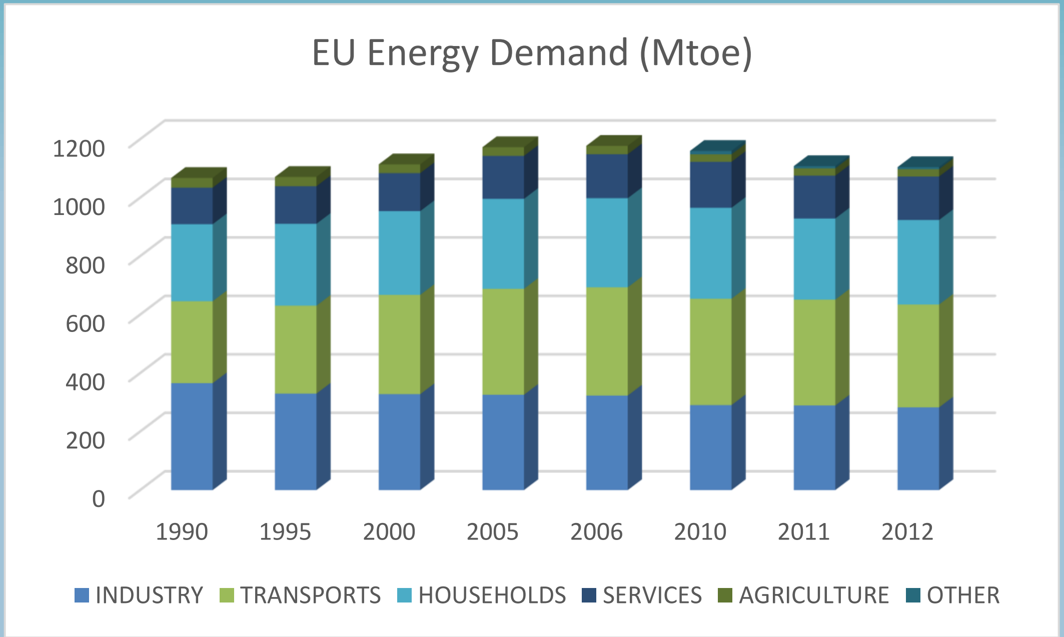


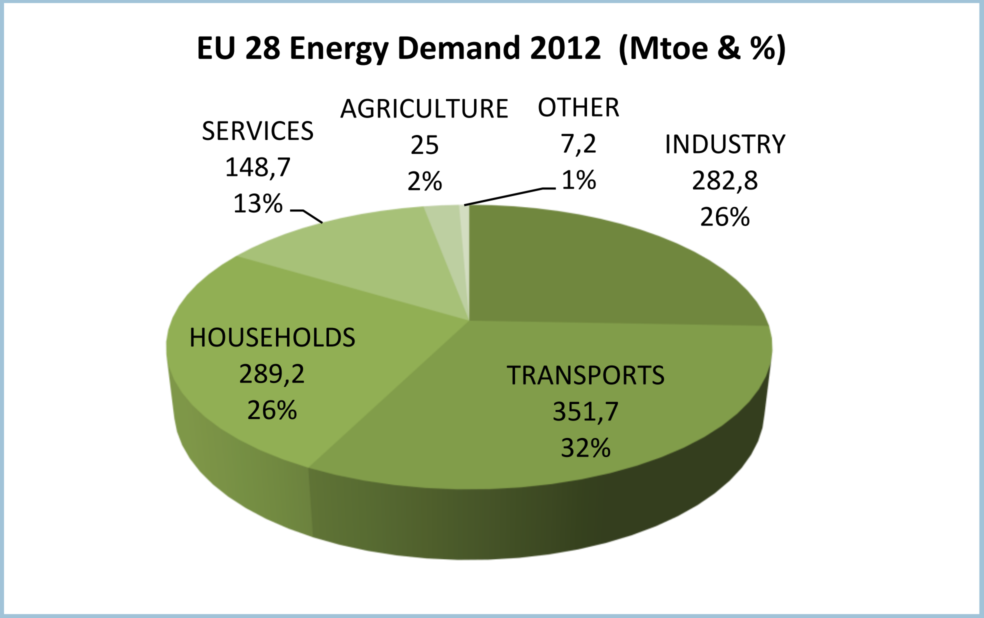
European Energy Market Analysis

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



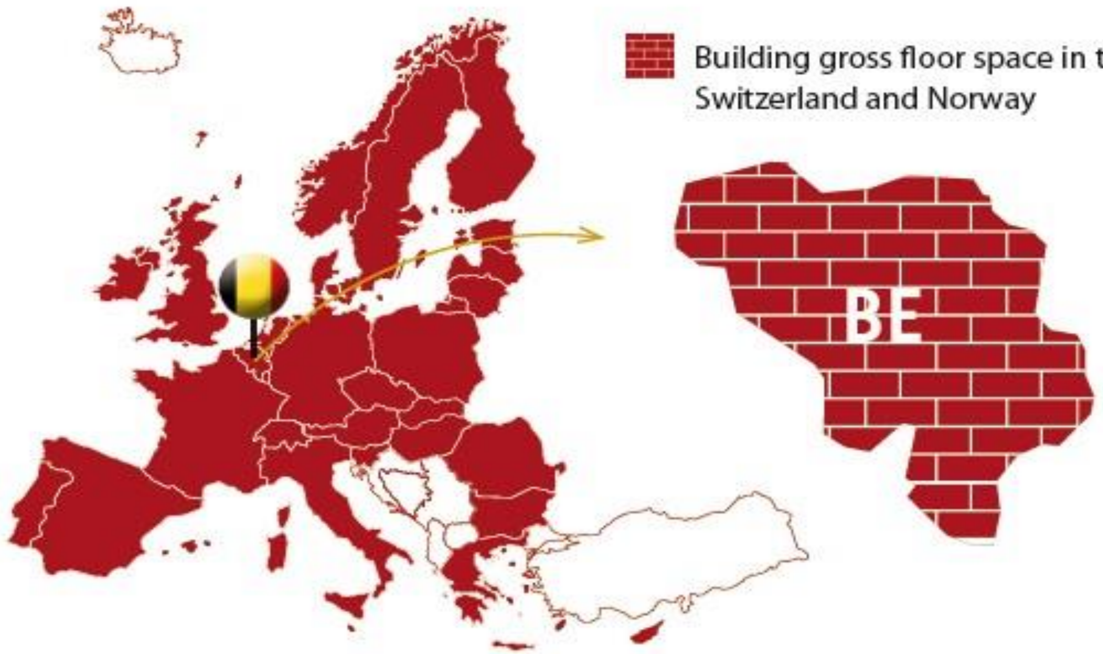
European Energy Market Analysis





Buildings in Europe

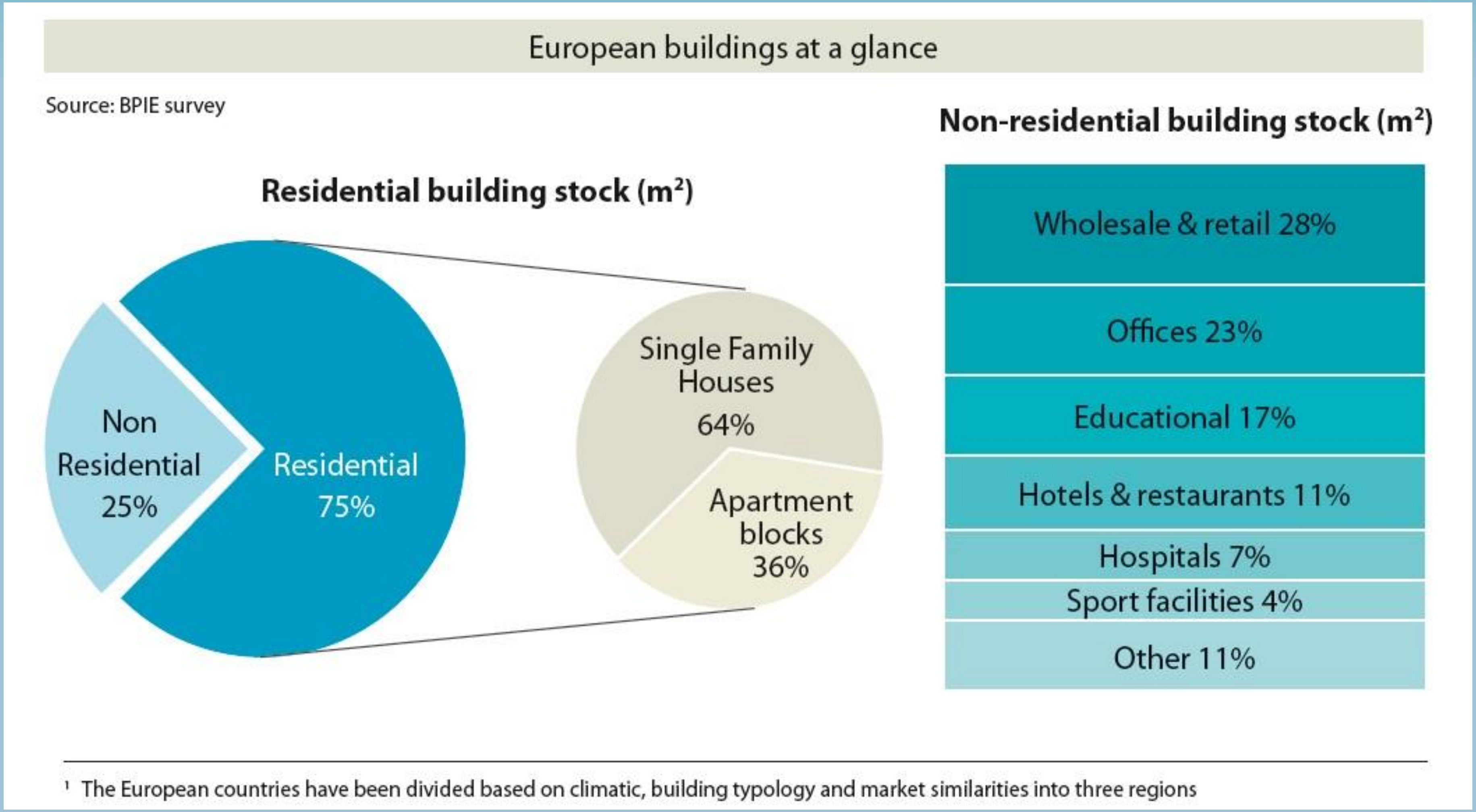
Sources: Population figures: World Bank, Eurostat. Floor spaces: EU27 - BPIE survey 2011, US - Annual Energy Outlook 2011 with projections to 2035 (US Energy Information Administration), China - Energy Efficiency in Buildings, Facts & Trends (WBCSD)



	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)*)

Buildings in Europe

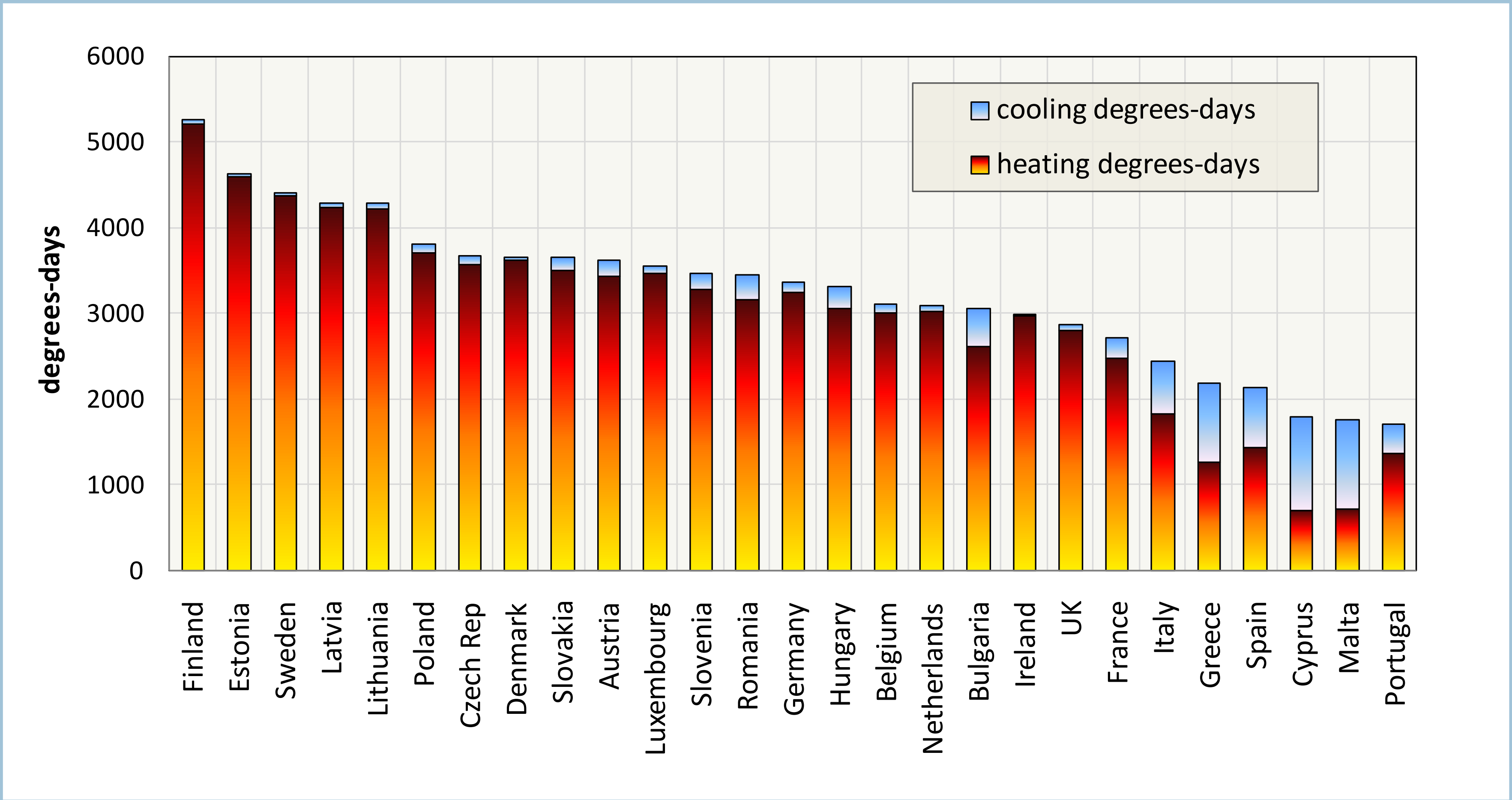


Breakdown of European building stock (*adapted from M. Economidou et al (2011)*)

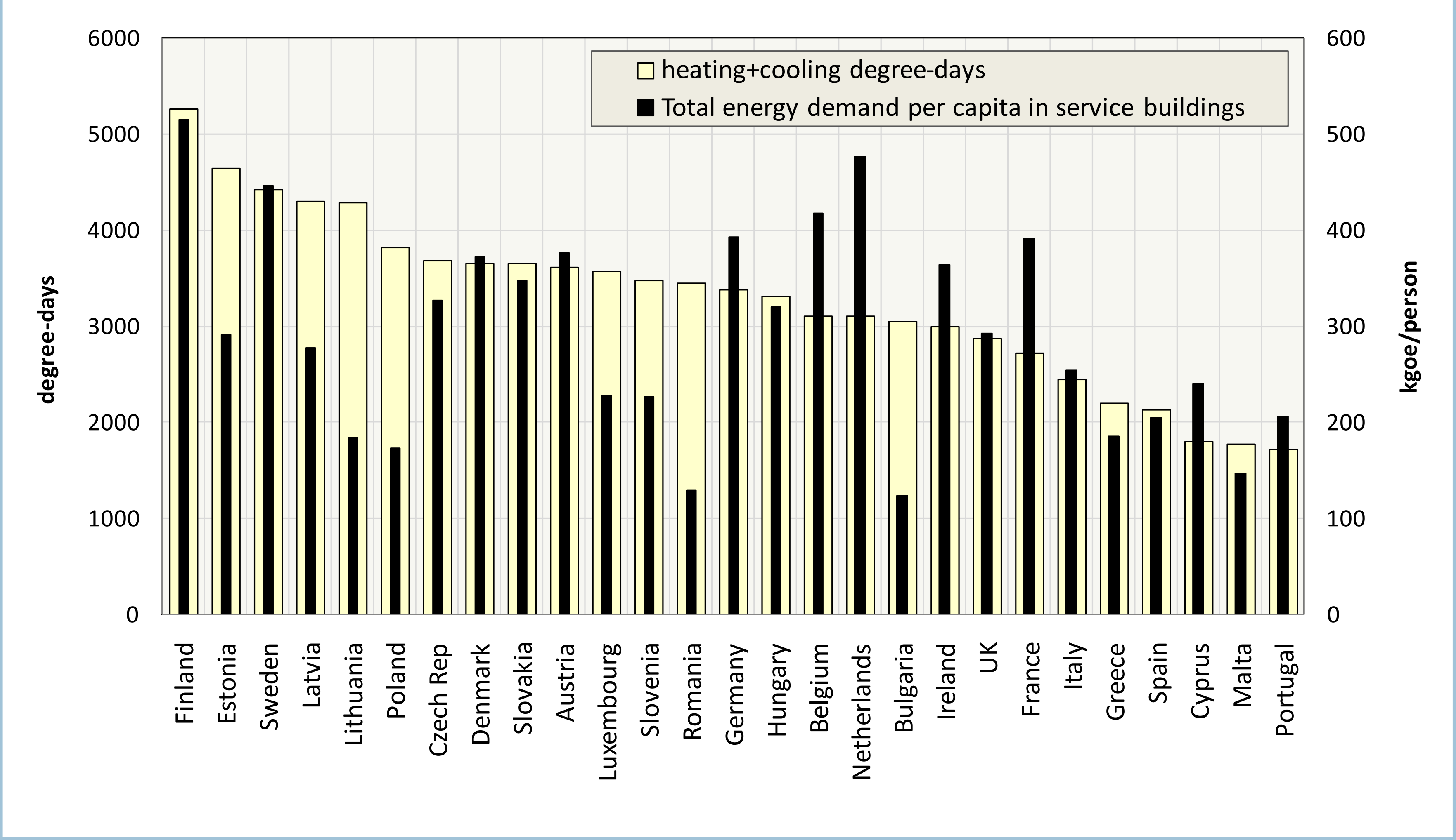
Climate Zones

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

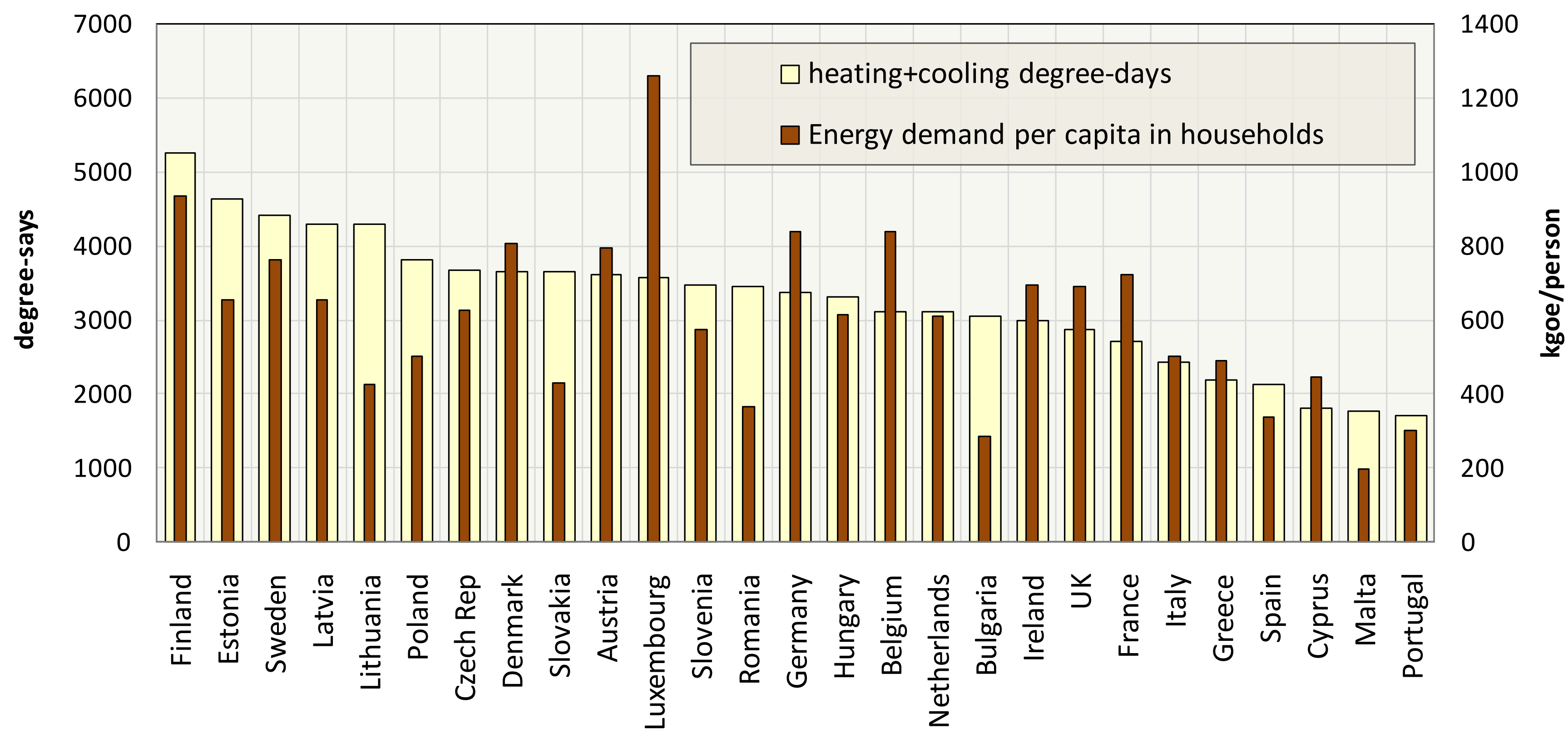
Heating and Cooling Degrees Days



Energy Demand vs H+C DD (Service Bldgs)



Energy Demand vs H+C DD (Households)

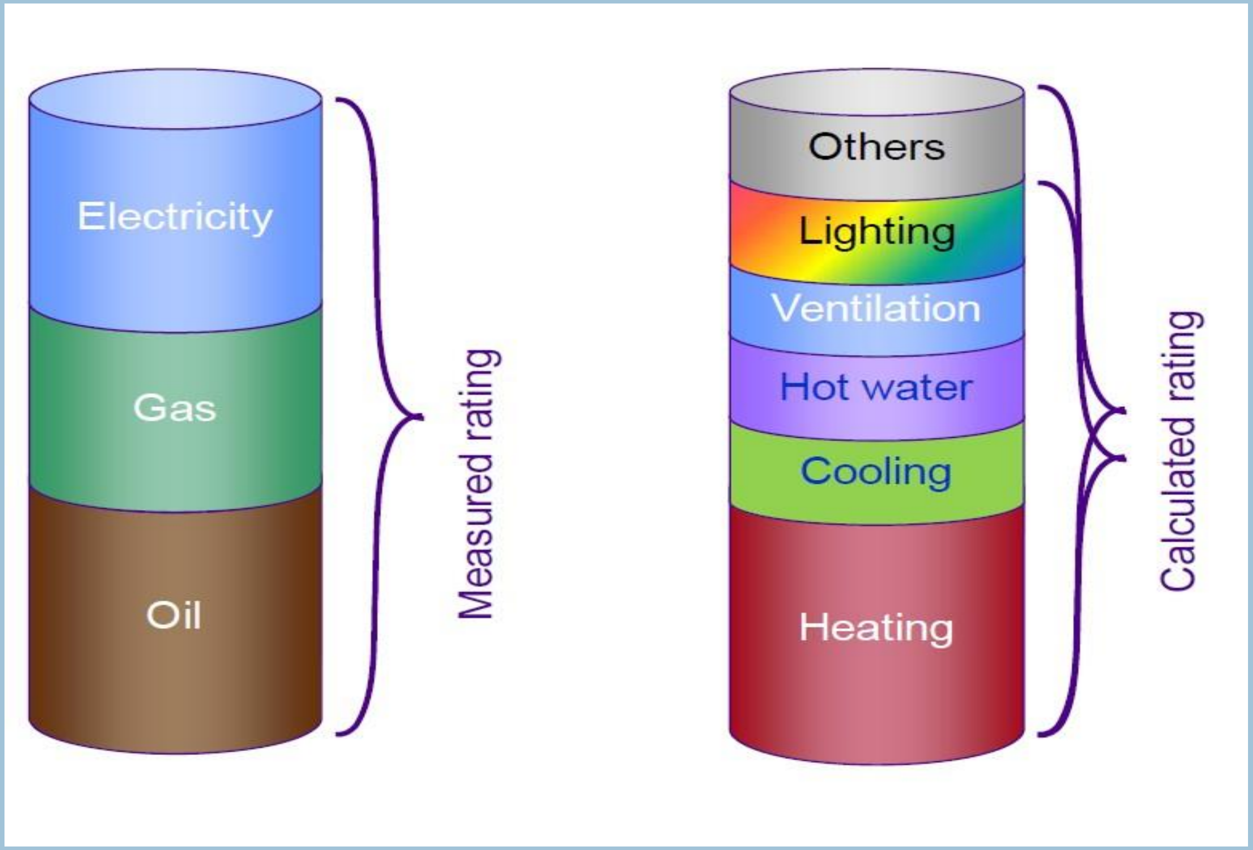


NZEB concept

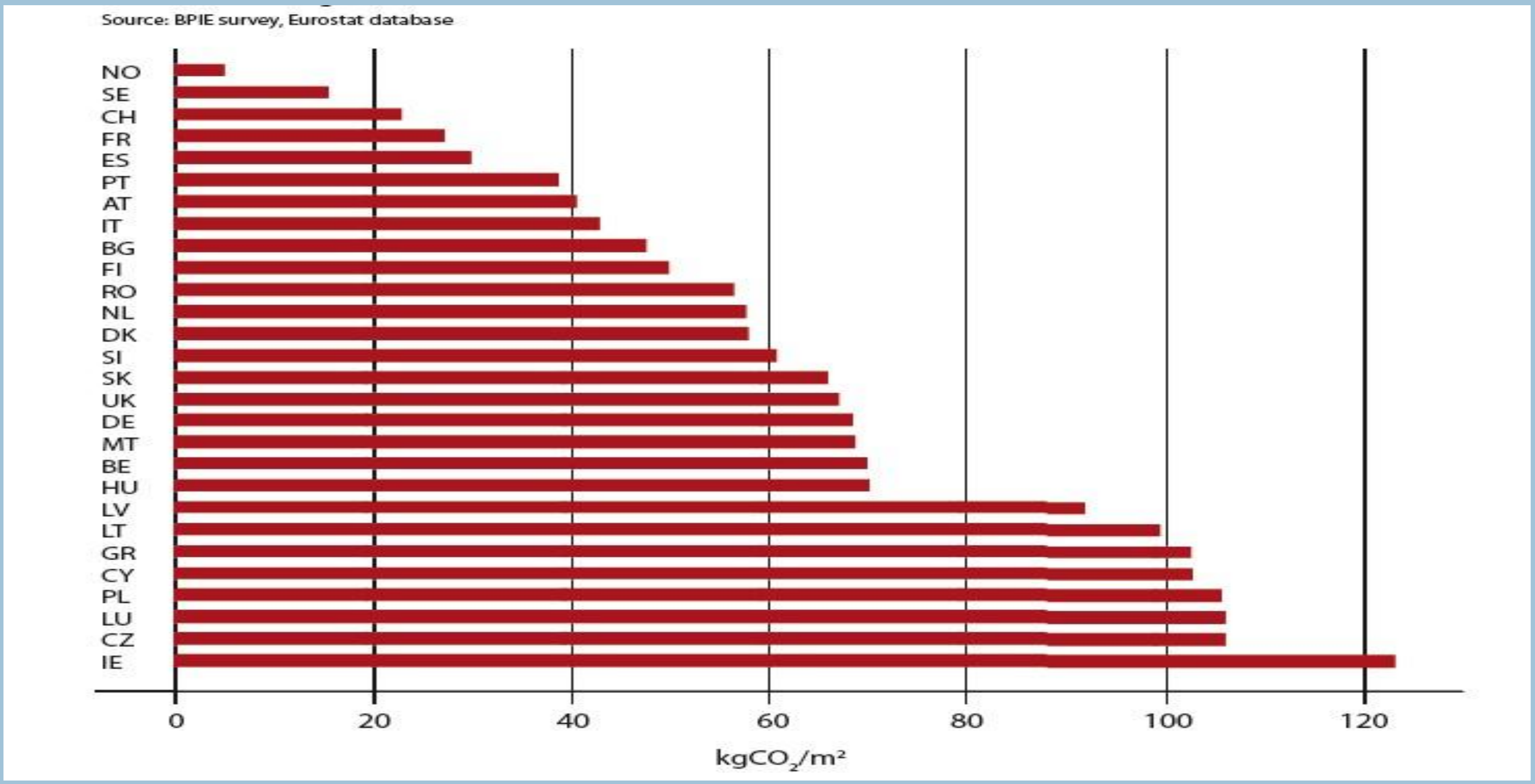
- Directive 2010/31/EU (EPBD recast) defines **NZEB as a building that has a very high energy performance**

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

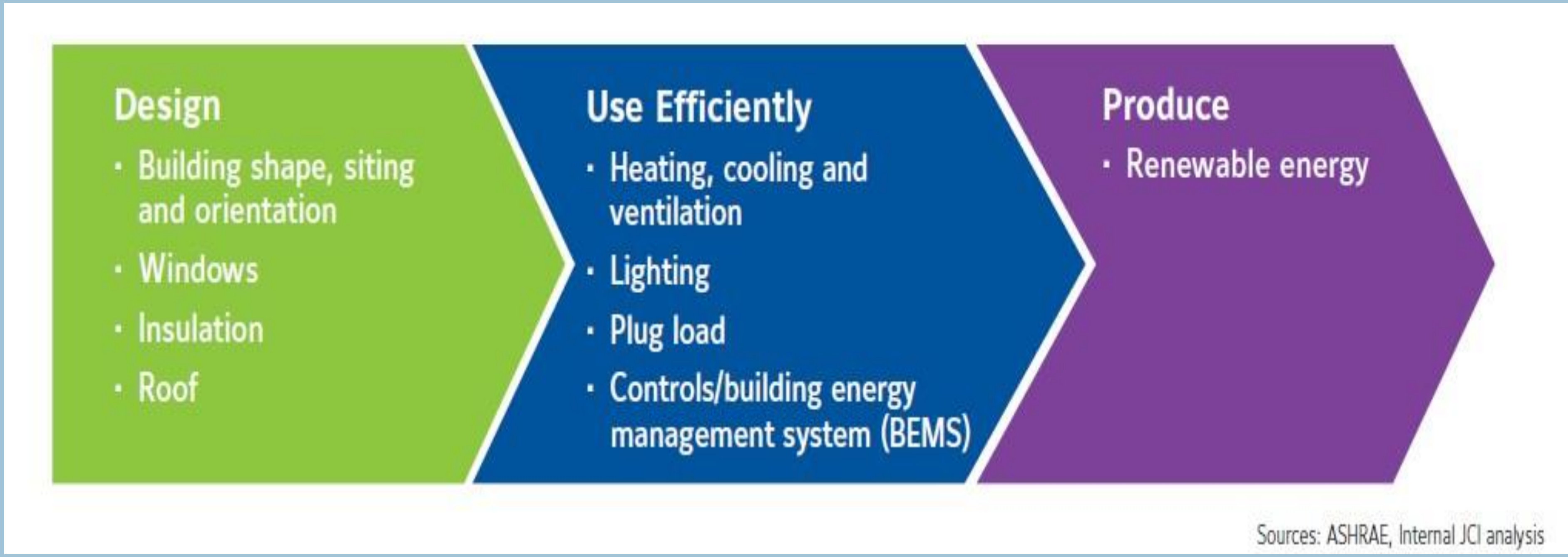
NZEB Concept



NZEB Concept



The Path to NZEBs



The Path to NZEBs

1.º Changing/Reducing traditional requirements

↓

2.º Energy Efficiency

↓

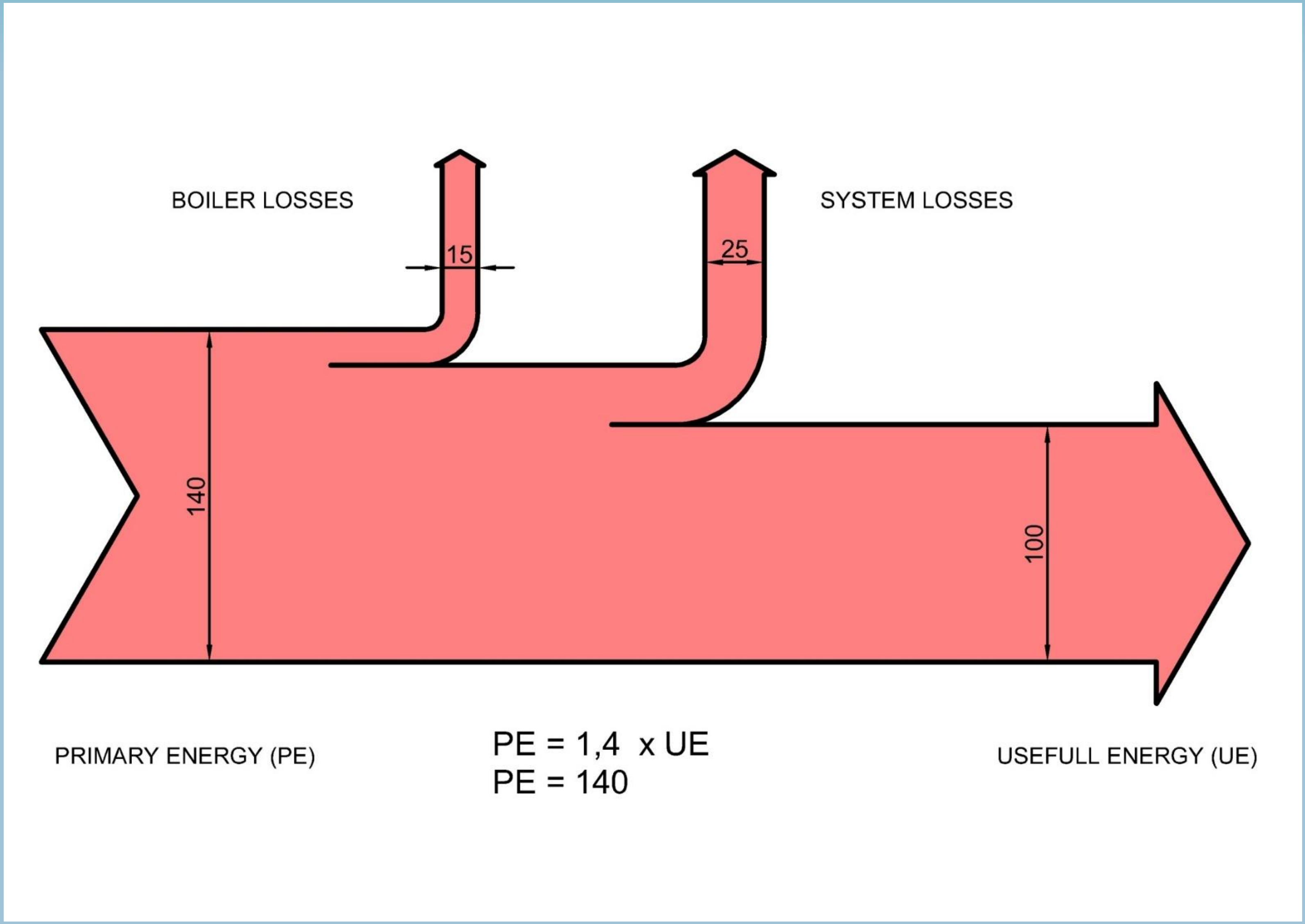
3.º Renewables

↓

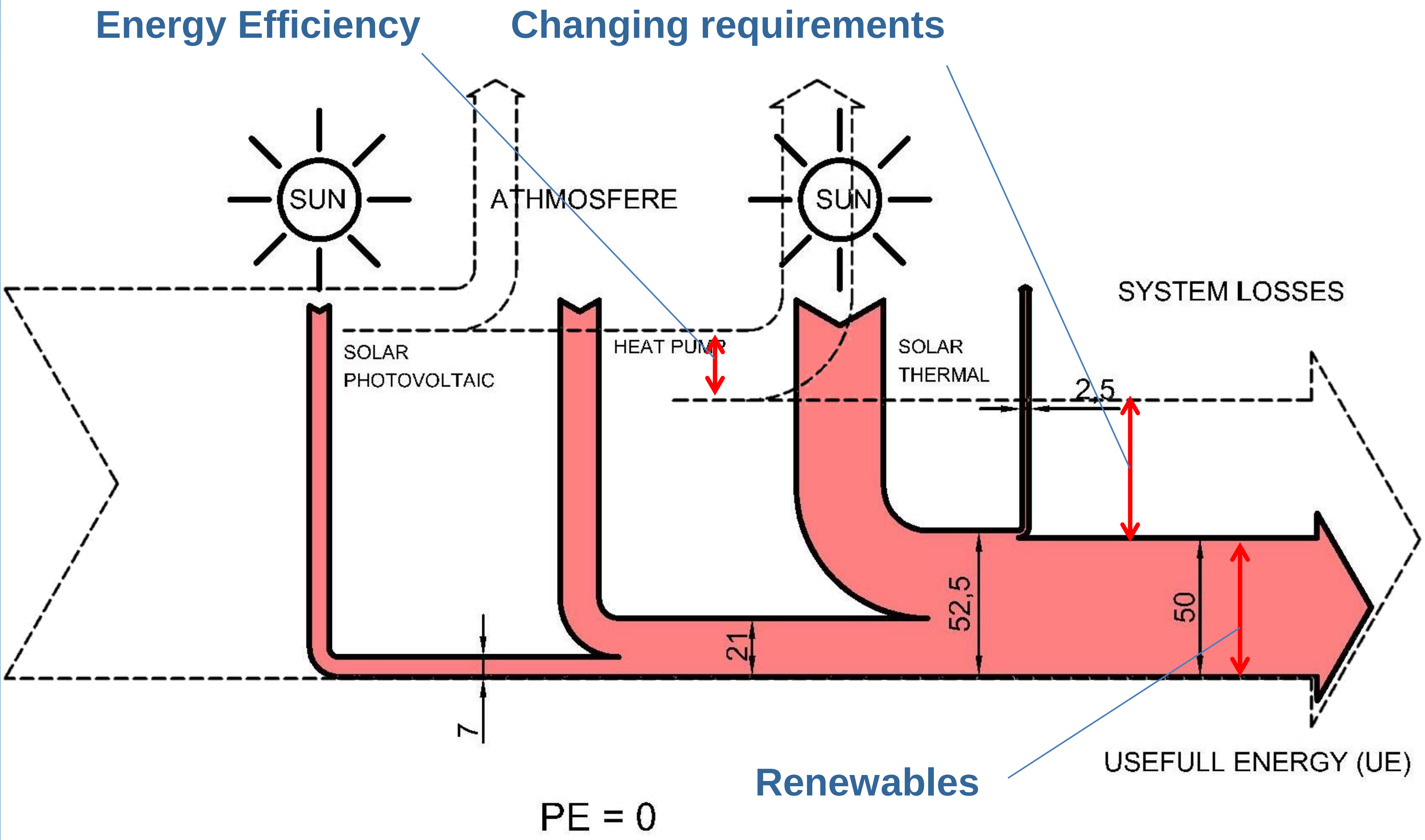
4.º Energy monitoring

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.



Monitoring Buildings. Why

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

and…

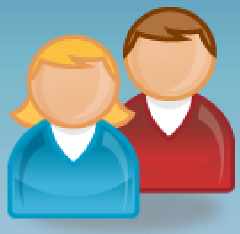
It is worthwhile and mandatory to manage Buildings and Building Systems because they represent about 40% of the energy consumptions and greenhouse gases emissions of our planet.

Monitoring Buildings. Why

but…

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.

Benefits



Energy Savings

Improvement of IEQ

Productivity of Occupants

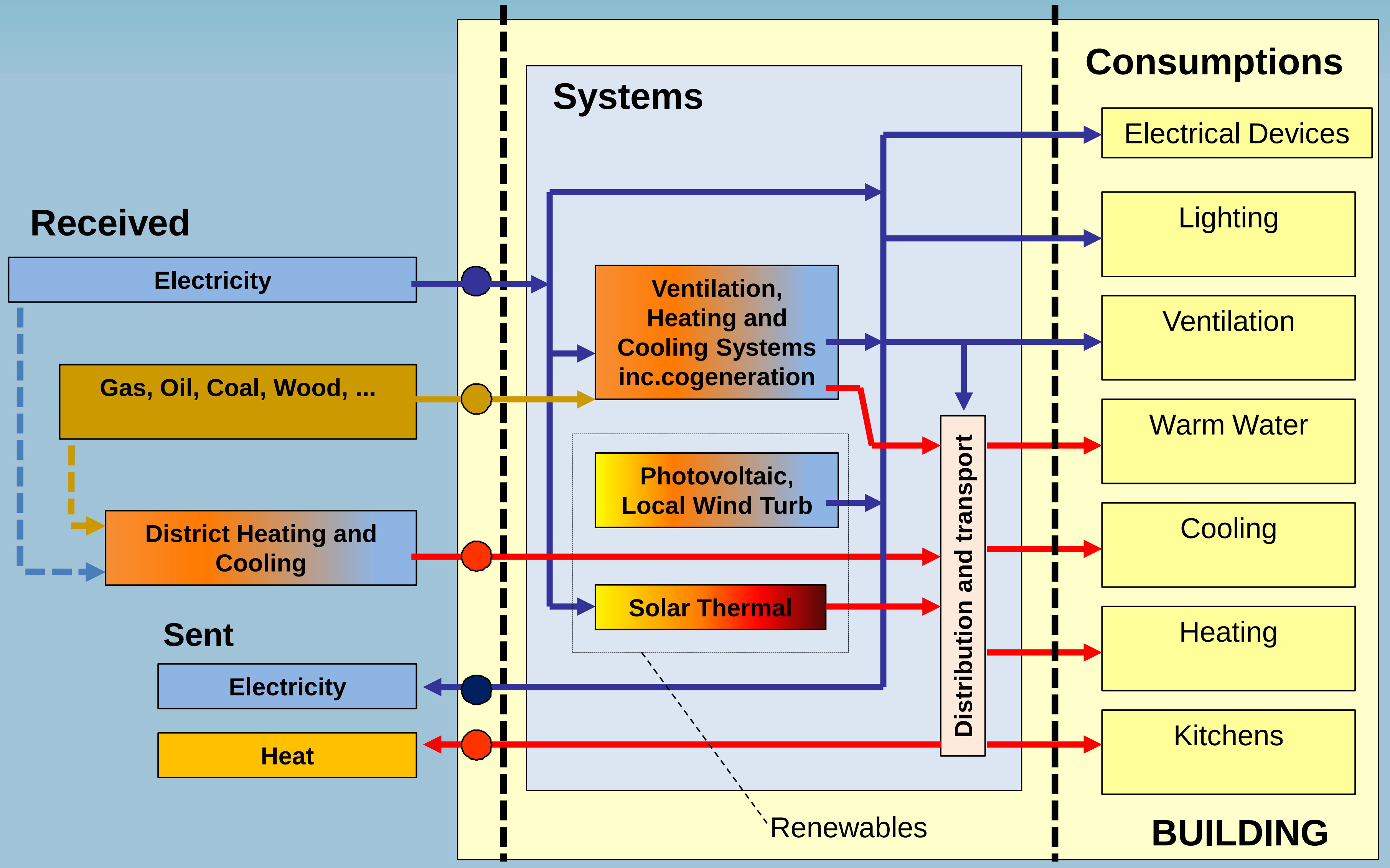
Databases and Benchmarking

Corporative Image of Companies

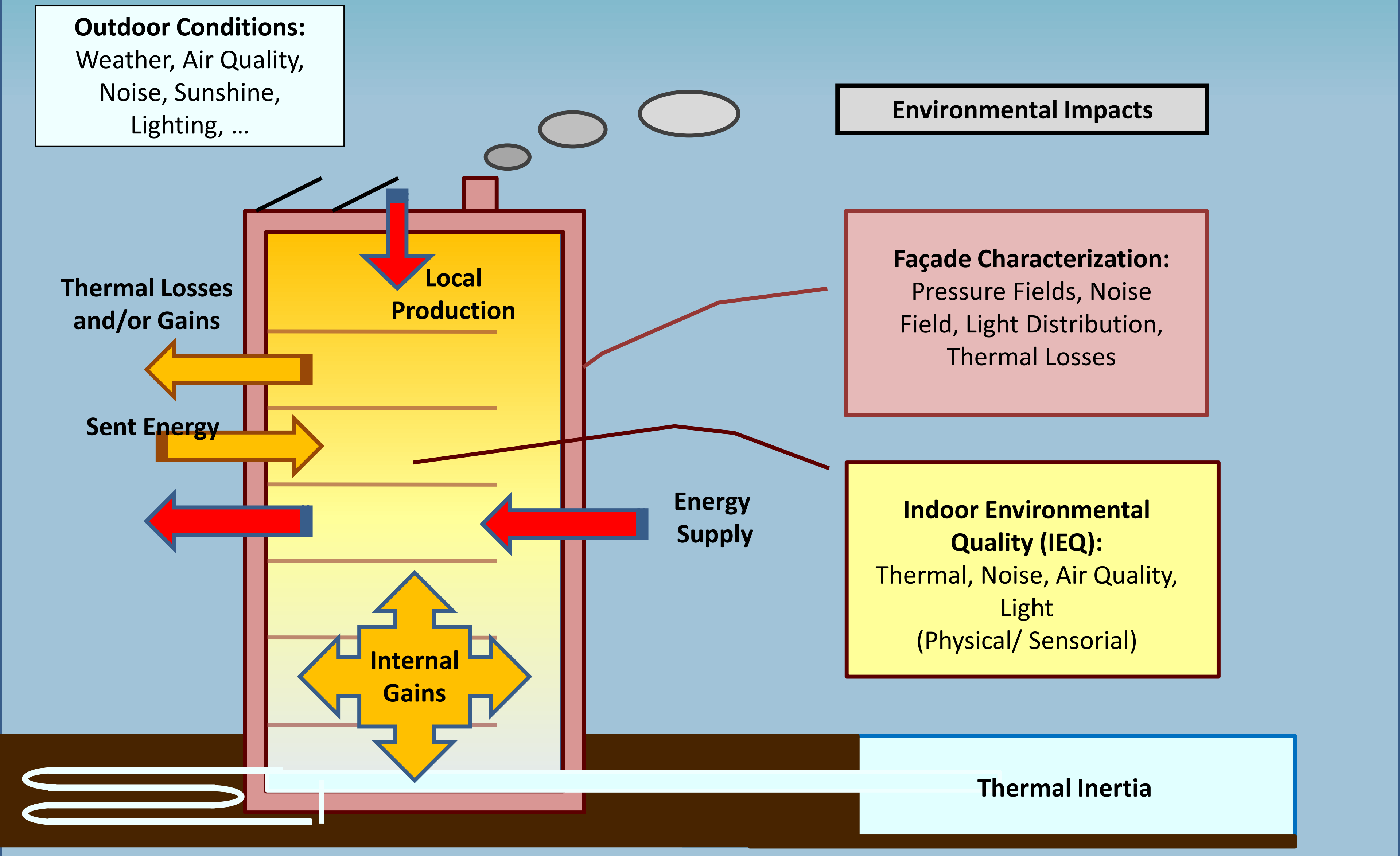
Reduction of Environmental Impacts

Interface with Building Automation System

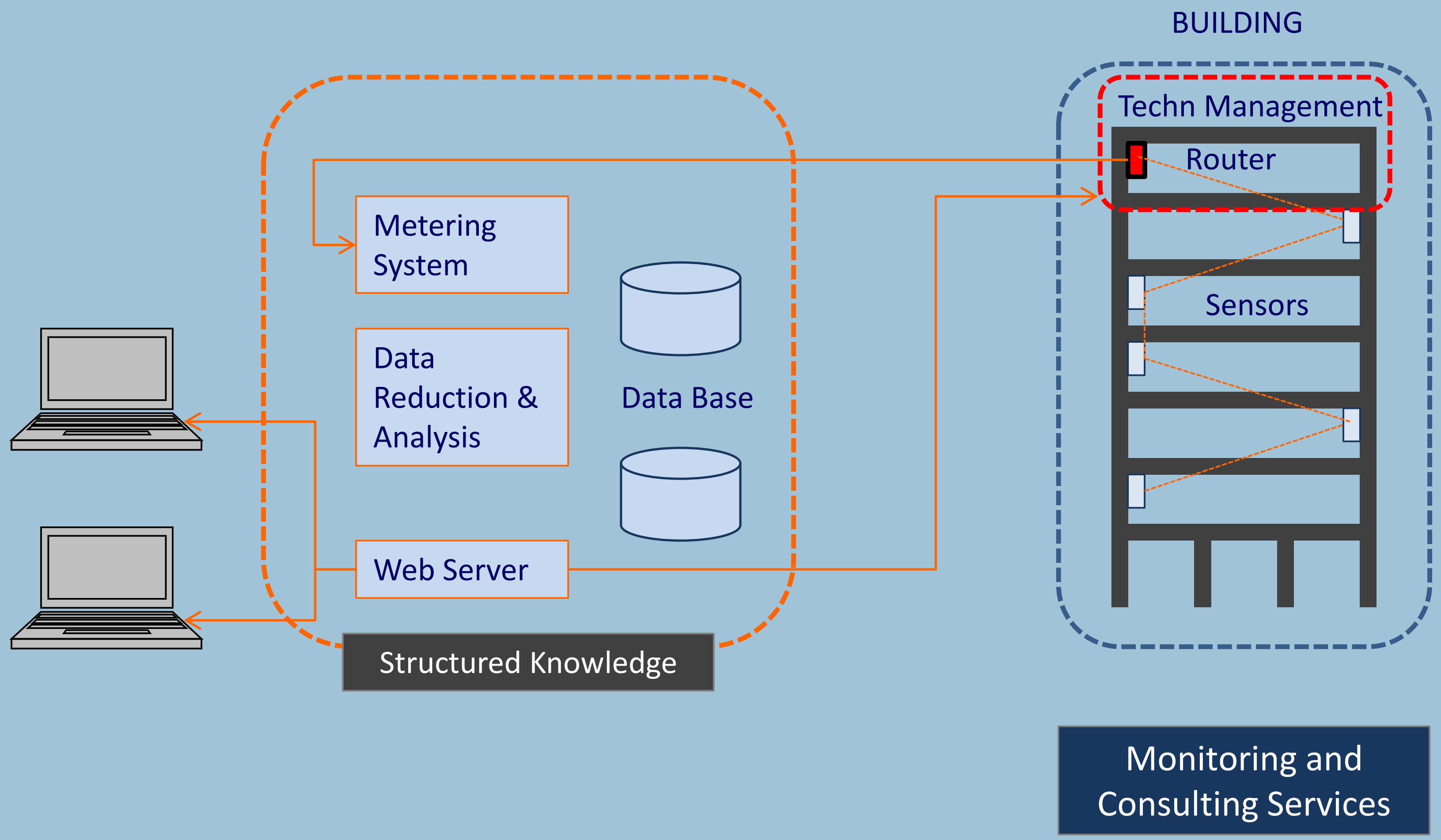
Energy Flowchart in Buildings



Relevant Parameters



Web Based Monitoring Solution Concept



1st Case Study (2008)

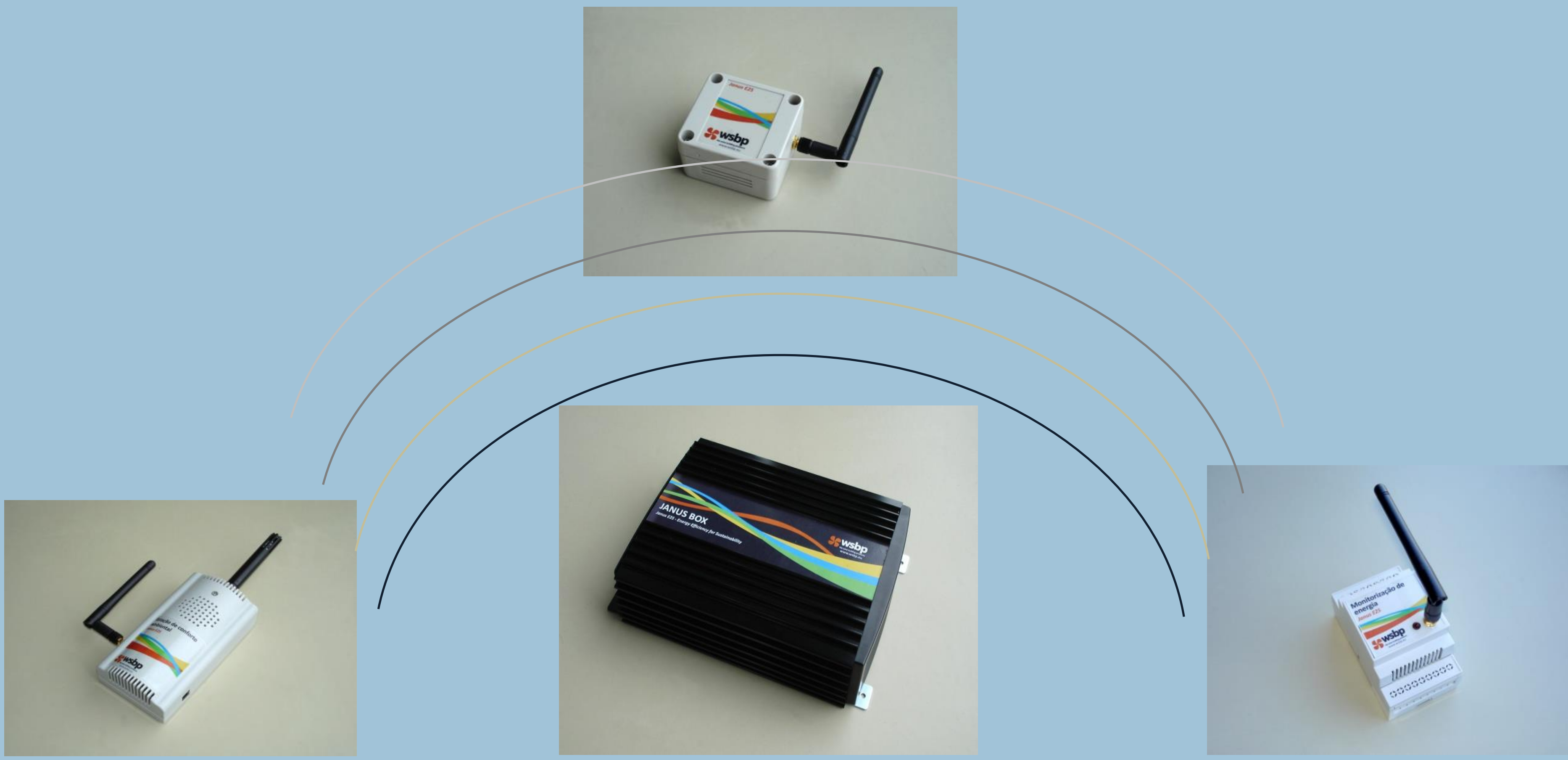
Lagoas Park

A Business Park in the municipality of Oeiras, at the metropolitan area of Lisbon, Portugal, 3 Km away from the sea coast. The building has three floors for offices (7000 m^2) and three underground floors for parking (8000 m^2)

Teixeira Duarte building

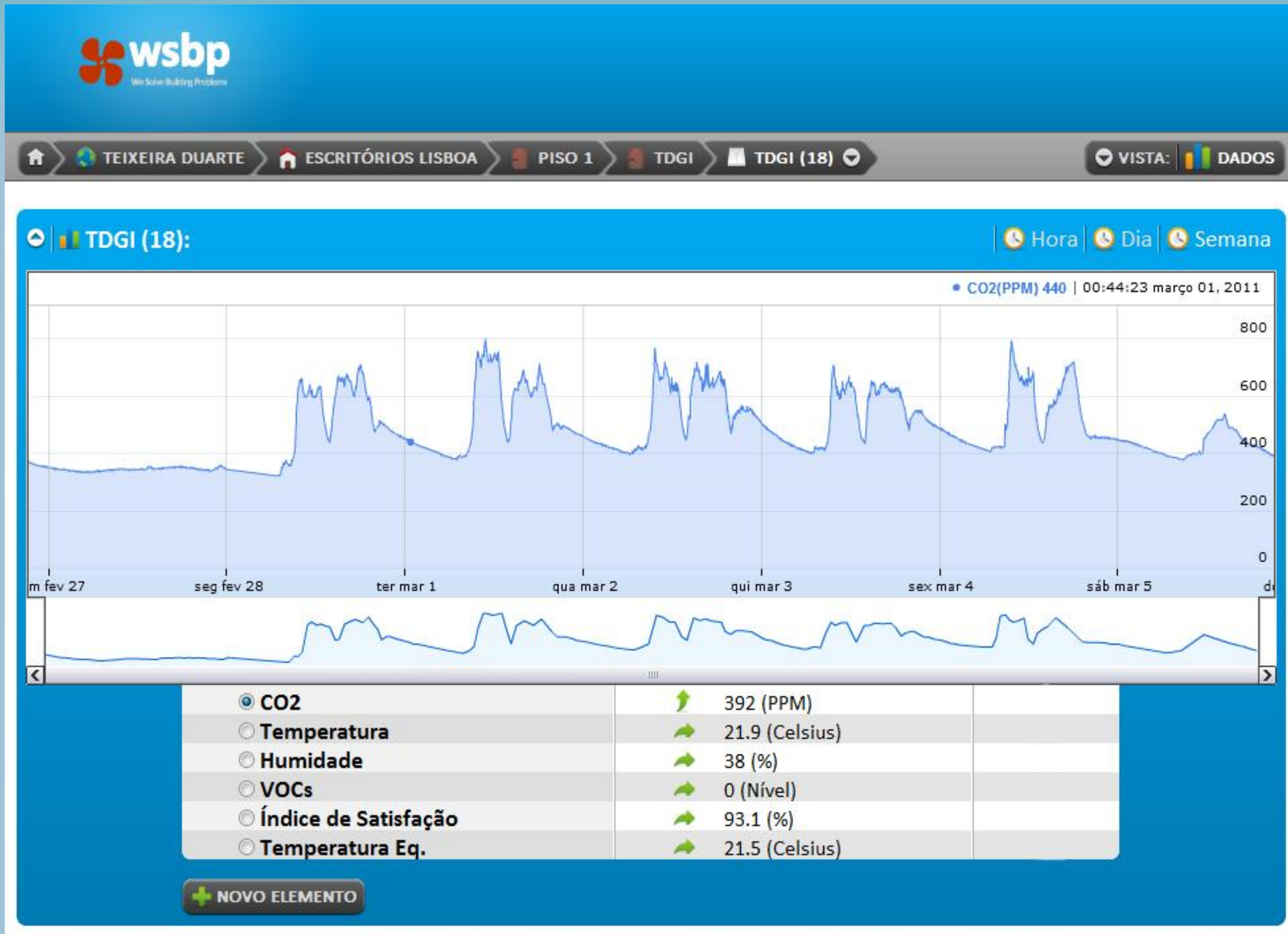
Wireless network with 49 counters for electrical energy, 15 indoor environmental quality monitoring stations (concentration of CO_2, air temperature, relative humidity, VOCs level) and one outdoor weather station

Measuring and Transmission Hardware



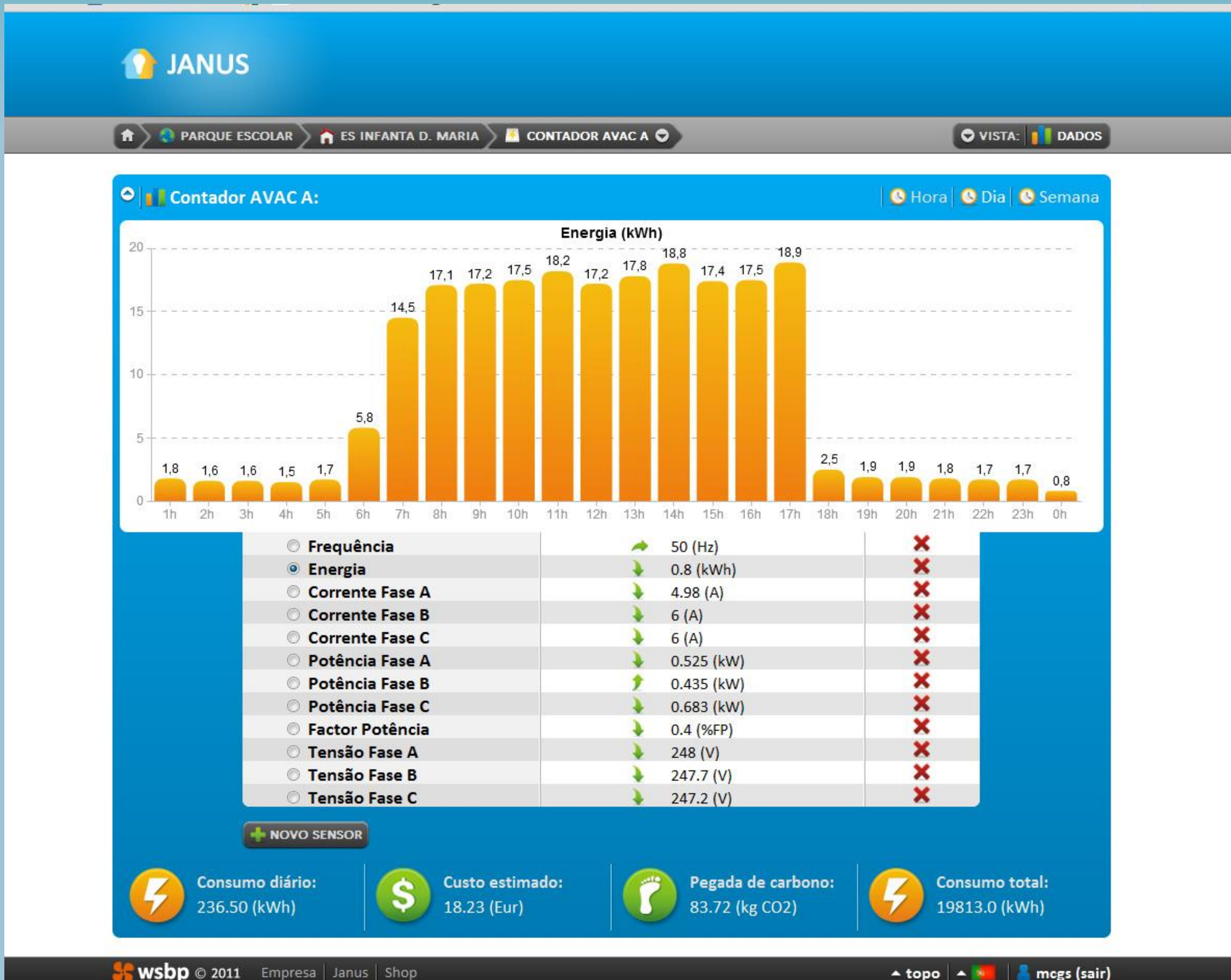
Data Broadcasting

Web Software Tool – CO_2 Data



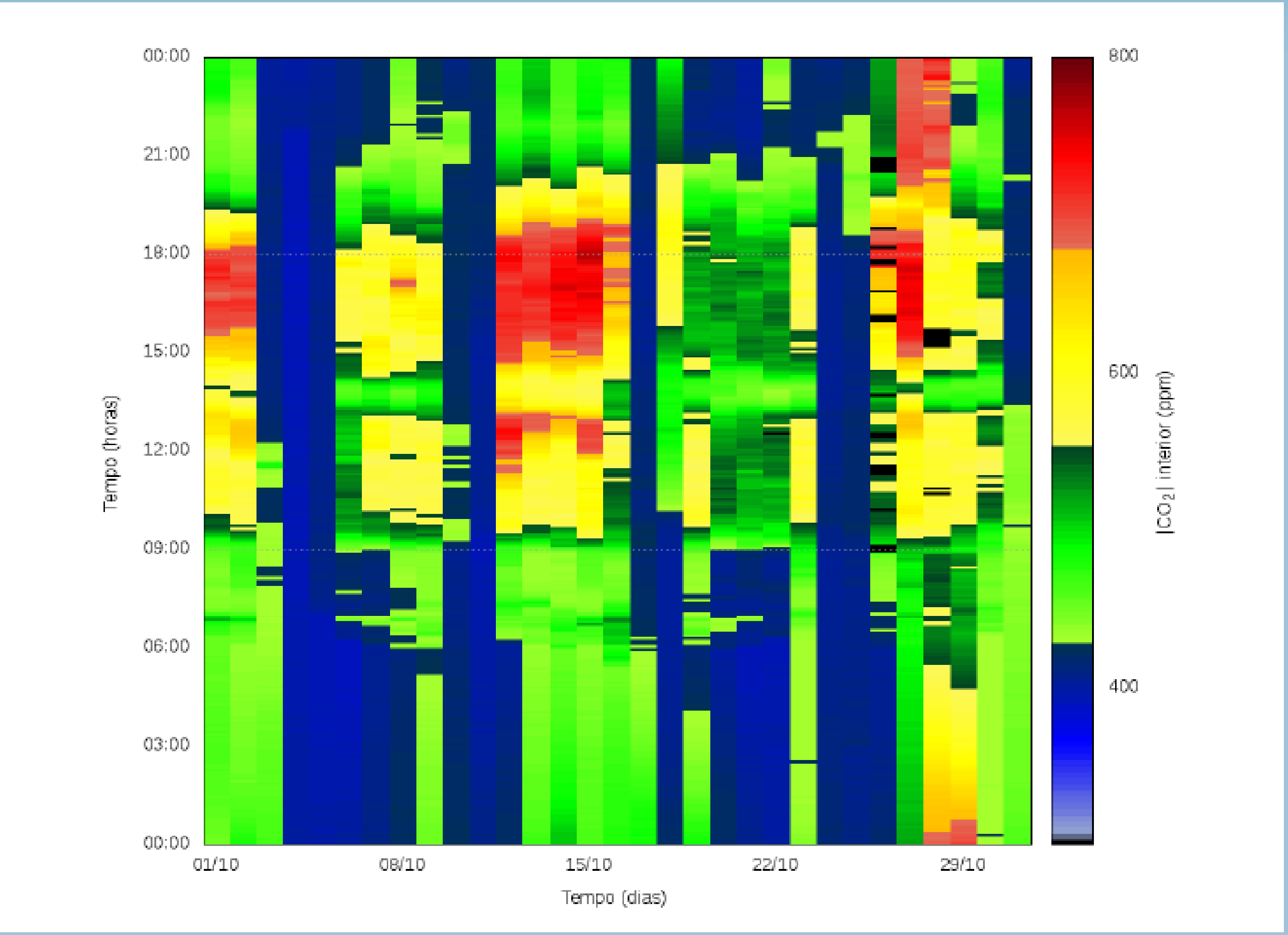
Electrical Energy Data (week graph):

Electrical Energy Data (24 h data):

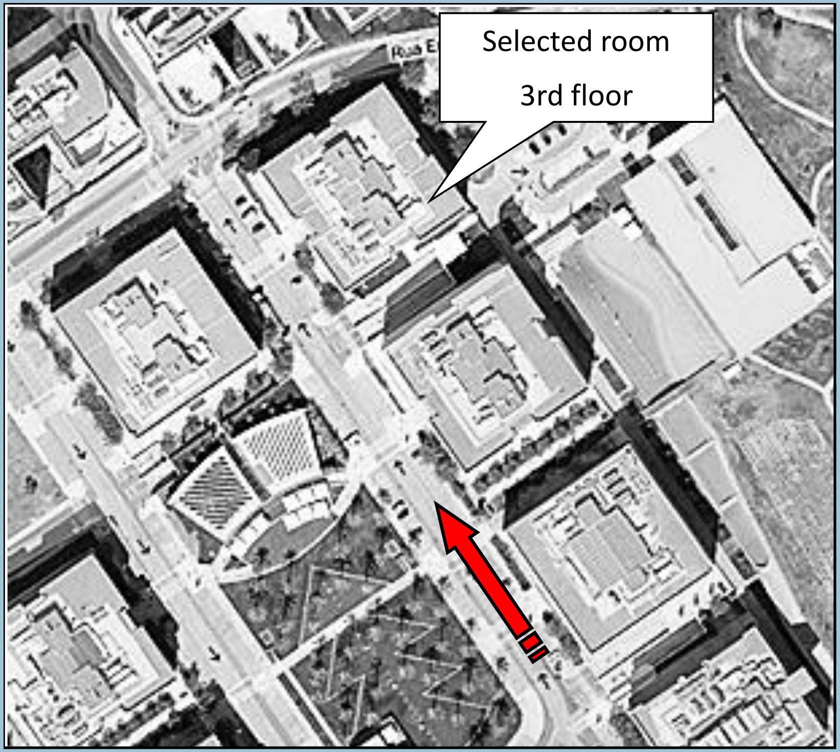


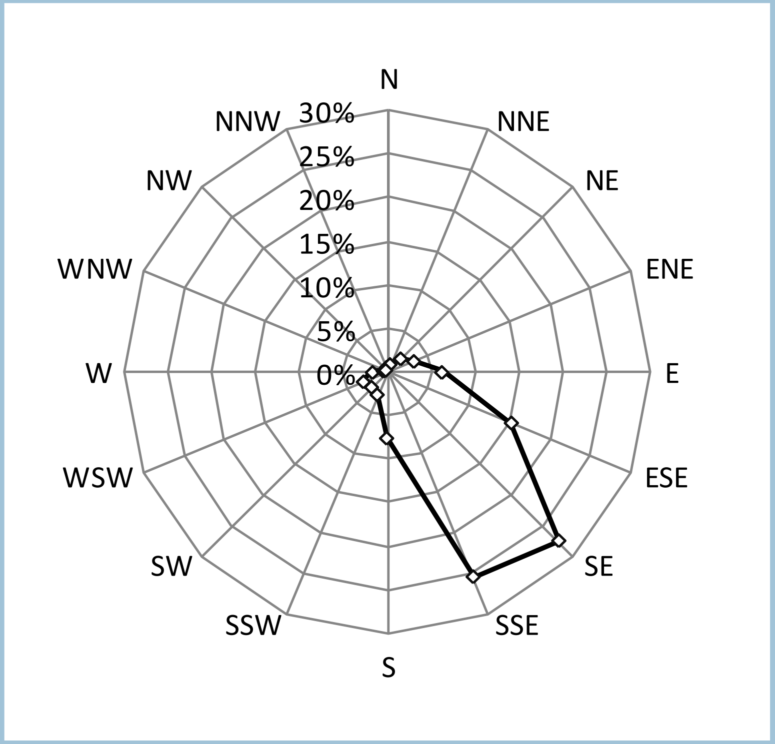
Data analysis

(Month map of CO_2 Concentration)

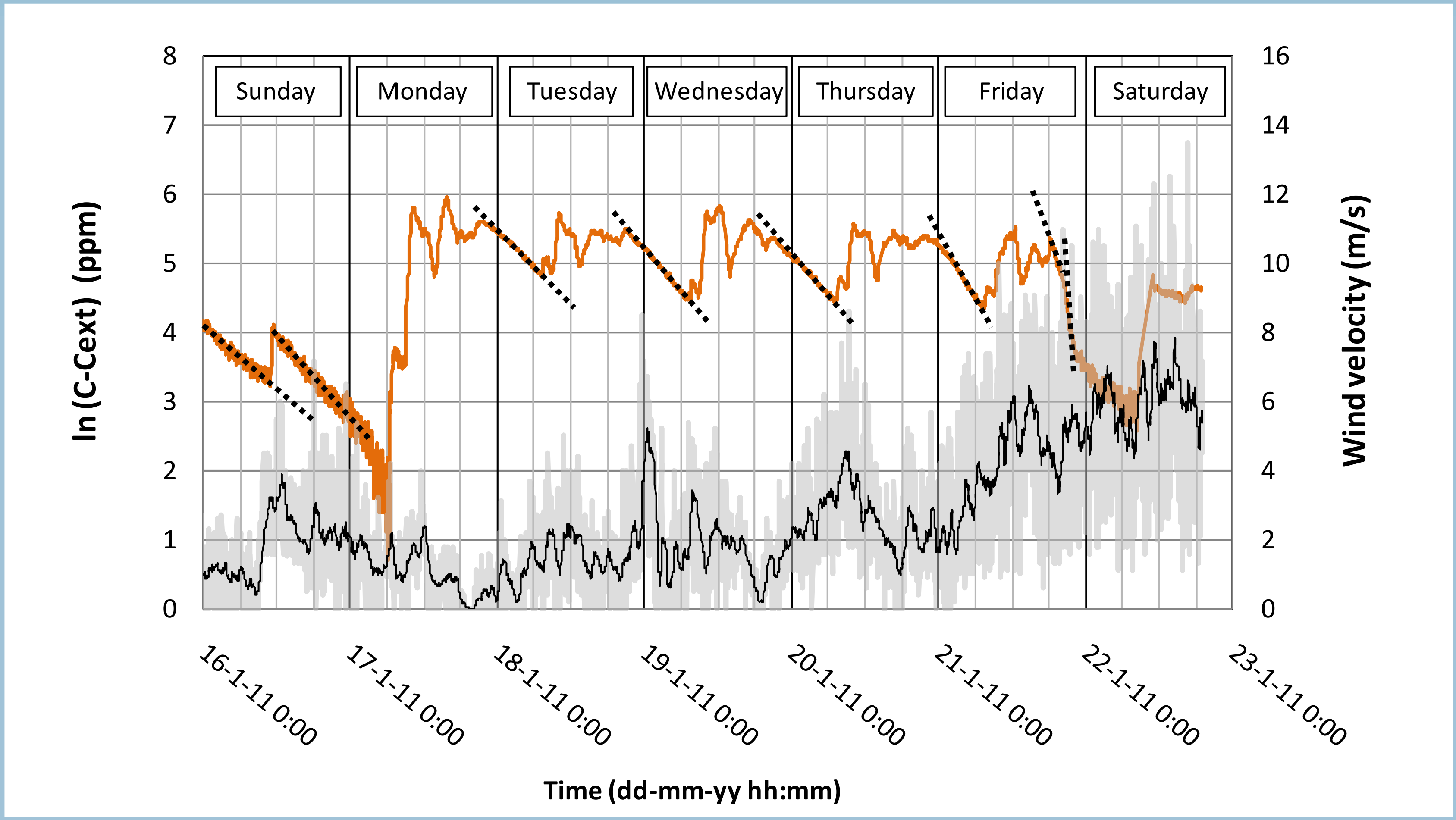


Wind Data vs Infiltration Rate

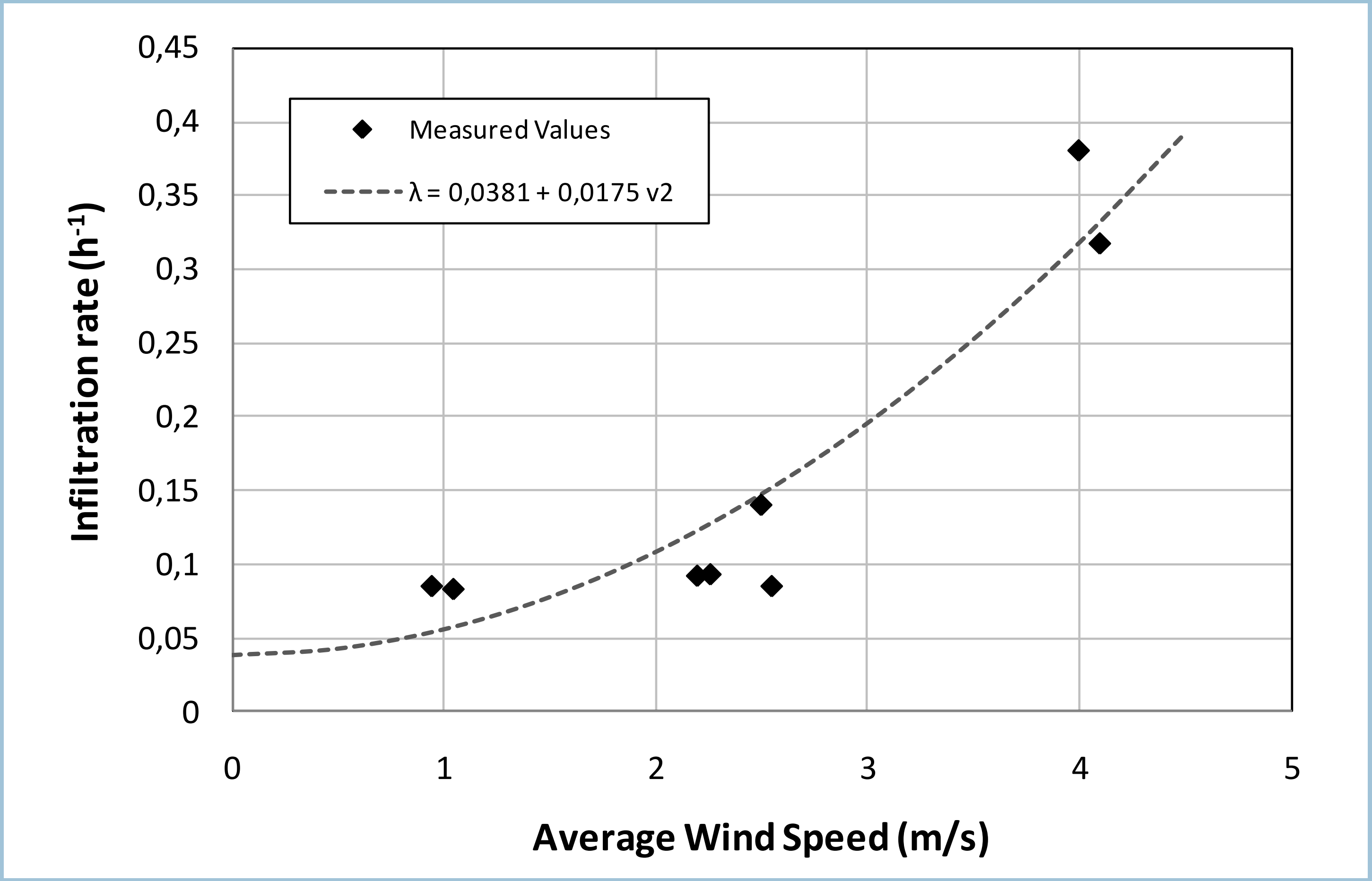




CO_2 and Wind Speed Time Series

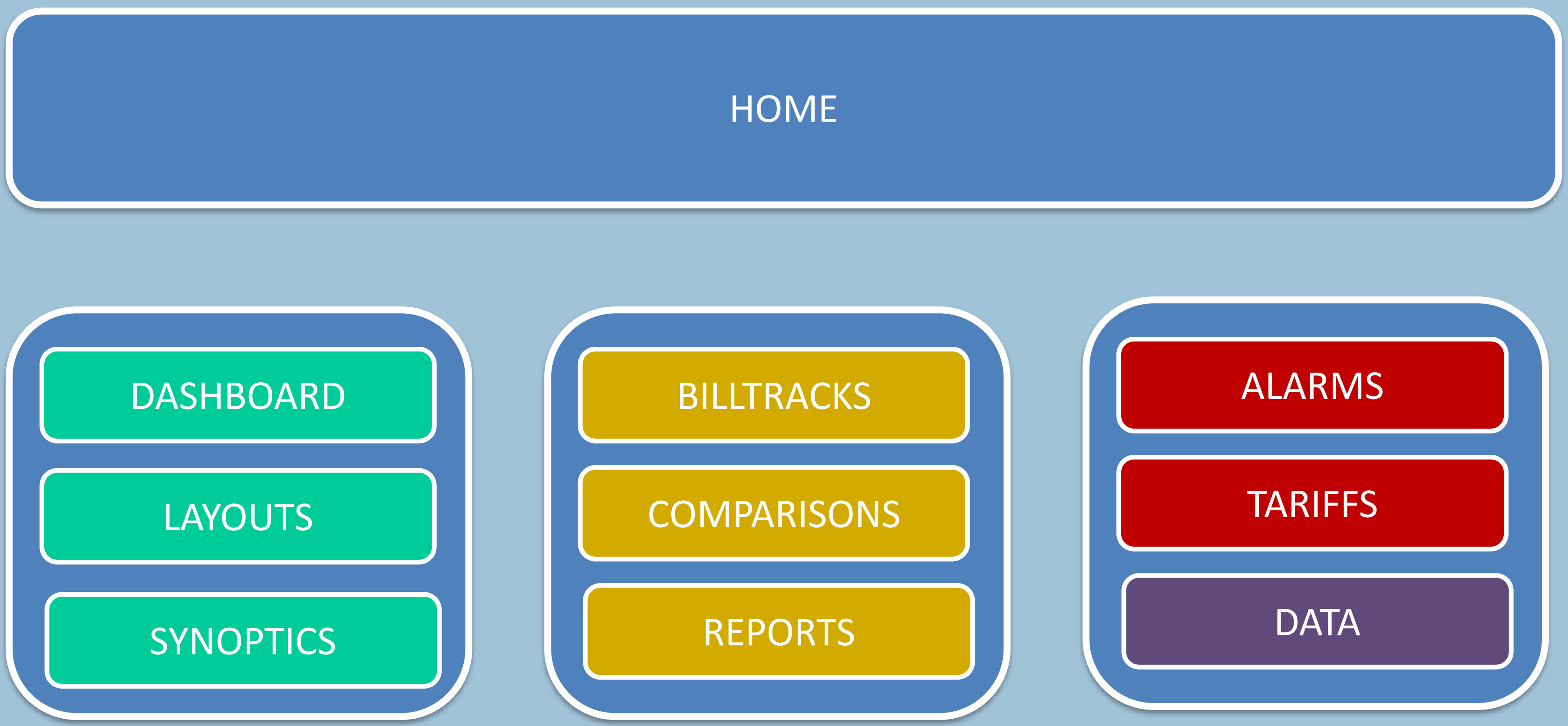


Results



0,45
0,4
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
0
1
2
3
4
5
Infiltration rate (h-1)
Average Wind Speed (m/s)
Measured Values
λ = 0,0381 + 0,0175 v2

JANUS Software Structure



HOME


Weekly Consumption
Notifications
Daily Consumption
Monthly Consumption
Menu
Anual Consumption
50%
91%
64%
51%
Consumption vs Budget
Daily Consumption
Daily Aggregate Consumption

DASHBOARD


JANUS
andreneves
BILLTRACK
COMPARISON
REPORTS
ALARMS
TARIFFS
DATA
IEQ 2 588 PPM 26,0 °C 58 % 75 %
IEQ 3 736 PPM 16,0 °C 97 % 69 %
BUILDING B
IEQ 4 654 PPM 26,0 °C 62 % 74 %
IEQ 5 906 PPM 27,0 °C 65 % 61 %
IEQ 6 760 PPM 29,0 °C 51 % 40 %
BUILDING C
IEQ 7 944 PPM 31,0 °C 45 % 18 %
IEQ 8 774 PPM 26,0 °C 29 % 83 %
IEQ 9 553 PPM 27,0 °C 62 % 62 %
Period LAST 24 HOURS
Resolution 10 MINUTES
COMPARISON +
Append Series
SUMMARY
IEQ 3, CO2
IEQ 3, CO2
PPM
800
700
600
500
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
27 Jun
01:00
02:00
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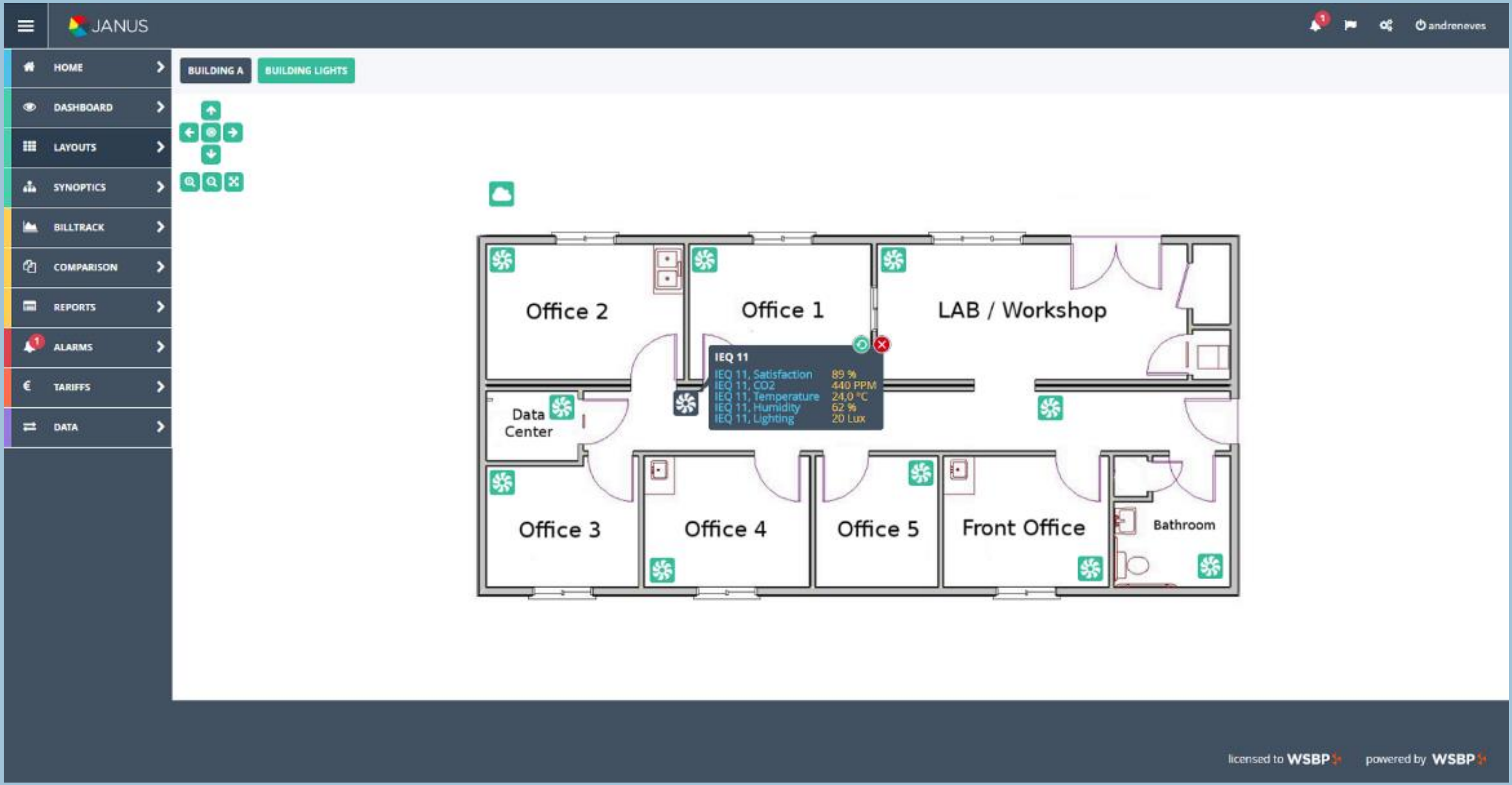
LAYOUTS



JANUS
andreneves
HOME
DASHBOARD
LAYOUTS
SYNOPTICS
BILLTRACK
COMPARISON
REPORTS
ALARMS
TARIFFS
DATA
BUILDING A
BUILDING LIGHTS
Office 2
Office 1
LAB / Workshop
IEQ 11
IEQ 11, Satisfaction 89 %
IEQ 11, CO2 440 PPM
IEQ 11, Temperature 24,0 °C
IEQ 11, Humidity 62 %
IEQ 11, Lighting 20 Lux
Data Center
Office 3
Office 4
Office 5
Front Office
Bathroom
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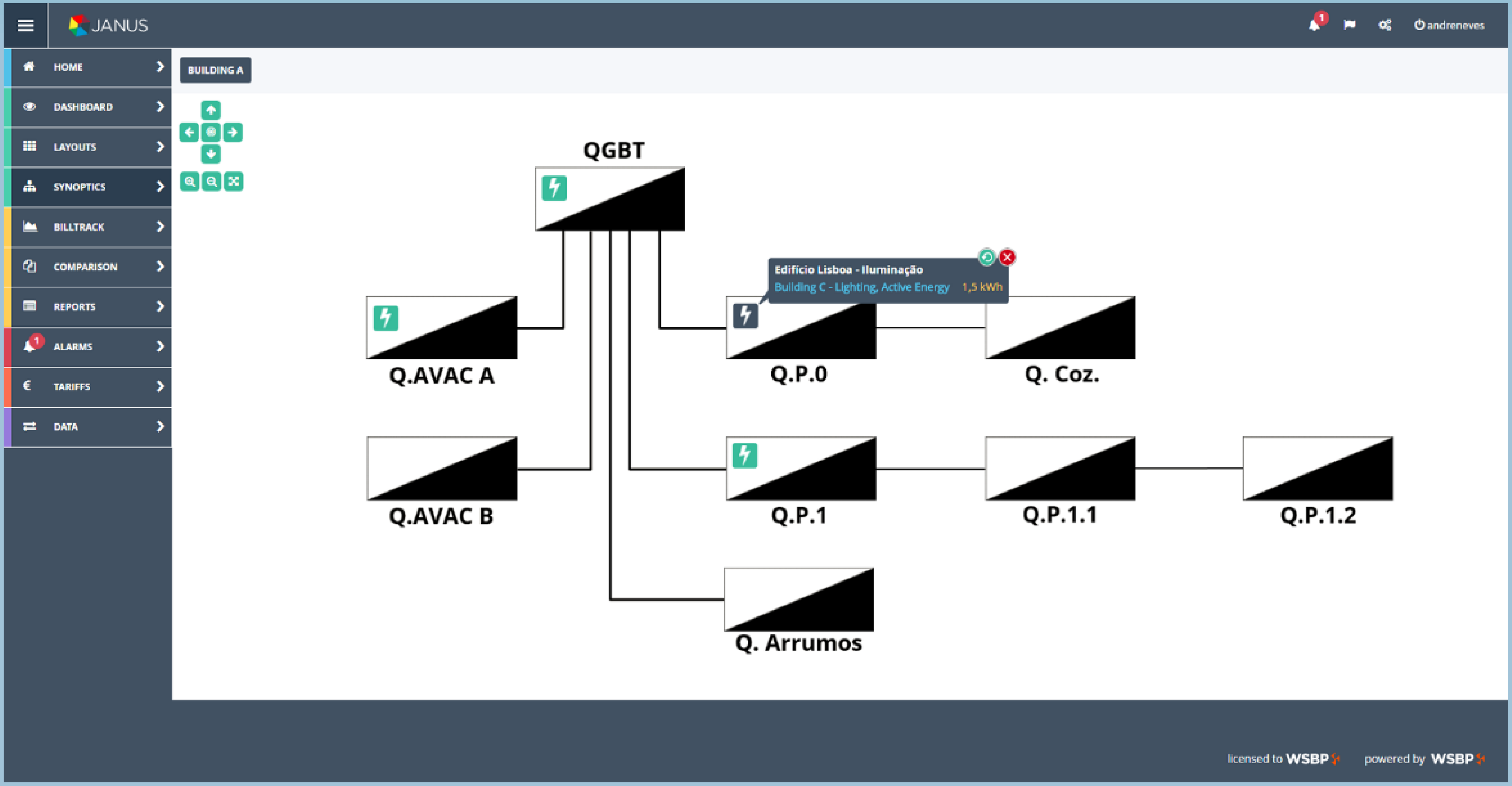
SYNOPTICS


JANUS
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HOME
DASHBOARD
LAYOUTS
SYNOPTICS
BILLTRACK
COMPARISON
REPORTS
ALARMS
TARIFFS
DATA
BUILDING A
QGBT
Edifício Lisboa - Iluminação
Building C - Lighting, Active Energy 1,5 kWh
Q.AVAC A
Q.P.0
Q. Coz.
Q.AVAC B
Q.P.1
Q.P.1.1
Q.P.1.2
Q. Arrumos
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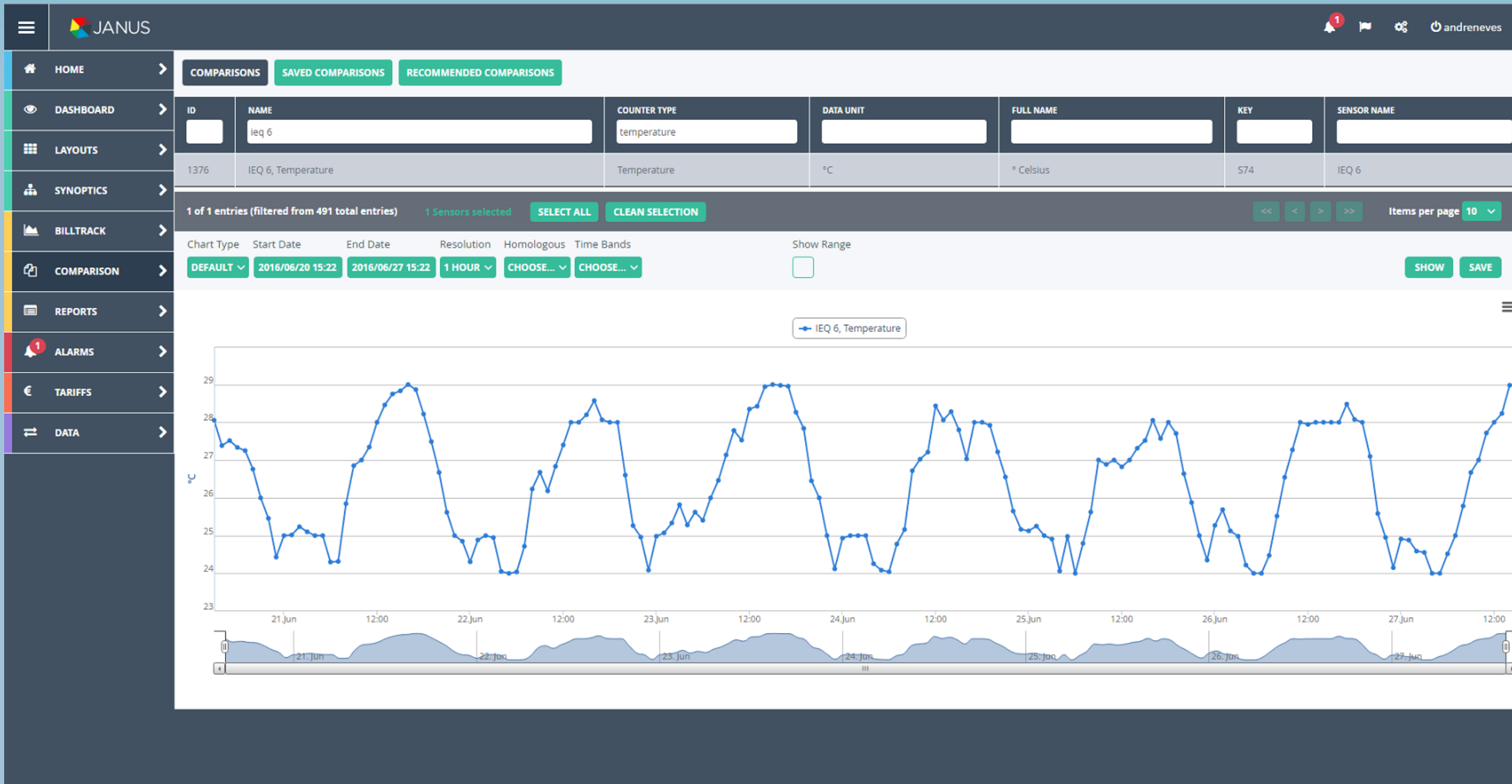
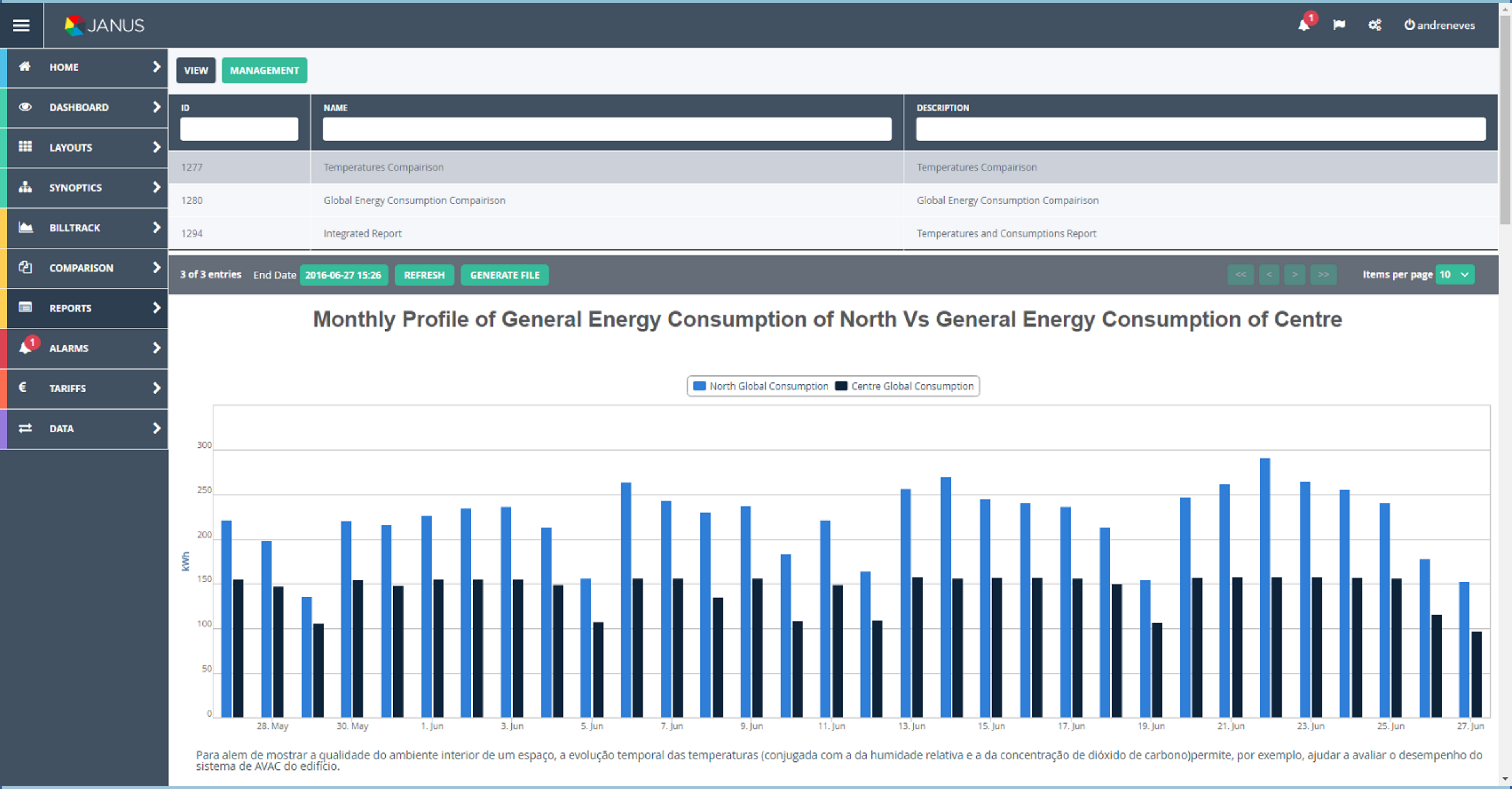
COMPARISONS



REPORTS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LAYOUTS
SYNOPTICS
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COMPARISON
REPORTS
ALARMS
TARIFFS
DATA
VIEW
MANAGEMENT
ID
NAME
DESCRIPTION
1277
Temperatures Compairison
Temperatures Compairison
1280
Global Energy Consumption Compairison
Global Energy Consumption Compairison
1294
Integrated Report
Temperatures and Consumptions Report
3 of 3 entries
End Date
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REFRESH
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10
Monthly Profile of General Energy Consumption of North Vs General Energy Consumption of Centre
North Global Consumption
Centre Global Consumption
kWh
0
50
100
150
200
250
300
28. May
30. May
1. Jun
3. Jun
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7. Jun
9. Jun
11. Jun
13. Jun
15. Jun
17. Jun
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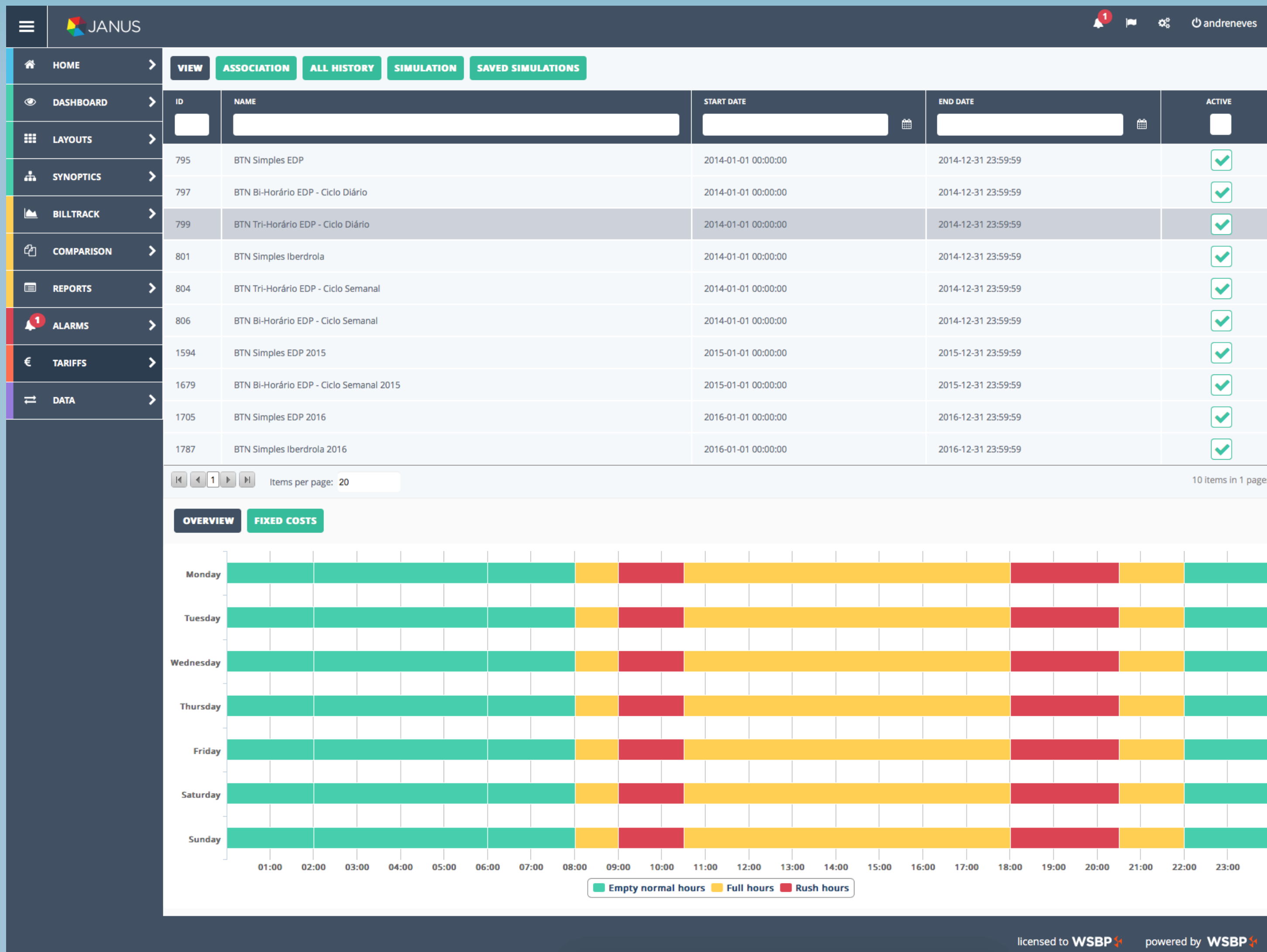
23. Jun
25. Jun
27. Jun
Para alem de mostrar a qualidade do ambiente interior de um espaço, a evolução temporal das temperaturas (conjugada com a da humidade relativa e a da concentração de dióxido de carbono)permite, por exemplo, ajudar a avaliar o desempenho do sistema de AVAC do edifício.

TARIFFS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BILLTRACK
COMPARISON
REPORTS
ALARMS
TARIFFS
DATA
VIEW
ASSOCIATION
ALL HISTORY
SIMULATION
SAVED SIMULATIONS
ID
NAME
START DATE
END DATE
ACTIVE
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797 BTN Bi-Horário EDP - Ciclo Diário 2014-01-01 00:00:00 2014-12-31 23:59:59
799 BTN Tri-Horário EDP - Ciclo Diário 2014-01-01 00:00:00 2014-12-31 23:59:59
801 BTN Simples Iberdrola 2014-01-01 00:00:00 2014-12-31 23:59:59
804 BTN Tri-Horário EDP - Ciclo Semanal 2014-01-01 00:00:00 2014-12-31 23:59:59
806 BTN Bi-Horário EDP - Ciclo Semanal 2014-01-01 00:00:00 2014-12-31 23:59:59
1594 BTN Simples EDP 2015 2015-01-01 00:00:00 2015-12-31 23:59:59
1679 BTN Bi-Horário EDP - Ciclo Semanal 2015 2015-01-01 00:00:00 2015-12-31 23:59:59
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1787 BTN Simples Iberdrola 2016 2016-01-01 00:00:00 2016-12-31 23:59:59
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10 items in 1 pages
OVERVIEW
FIXED COSTS
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
01:00 02:00 03:00 04:00 05:00 06:00 07:00 08:00 09:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
Empty normal hours
Full hours
Rush hours
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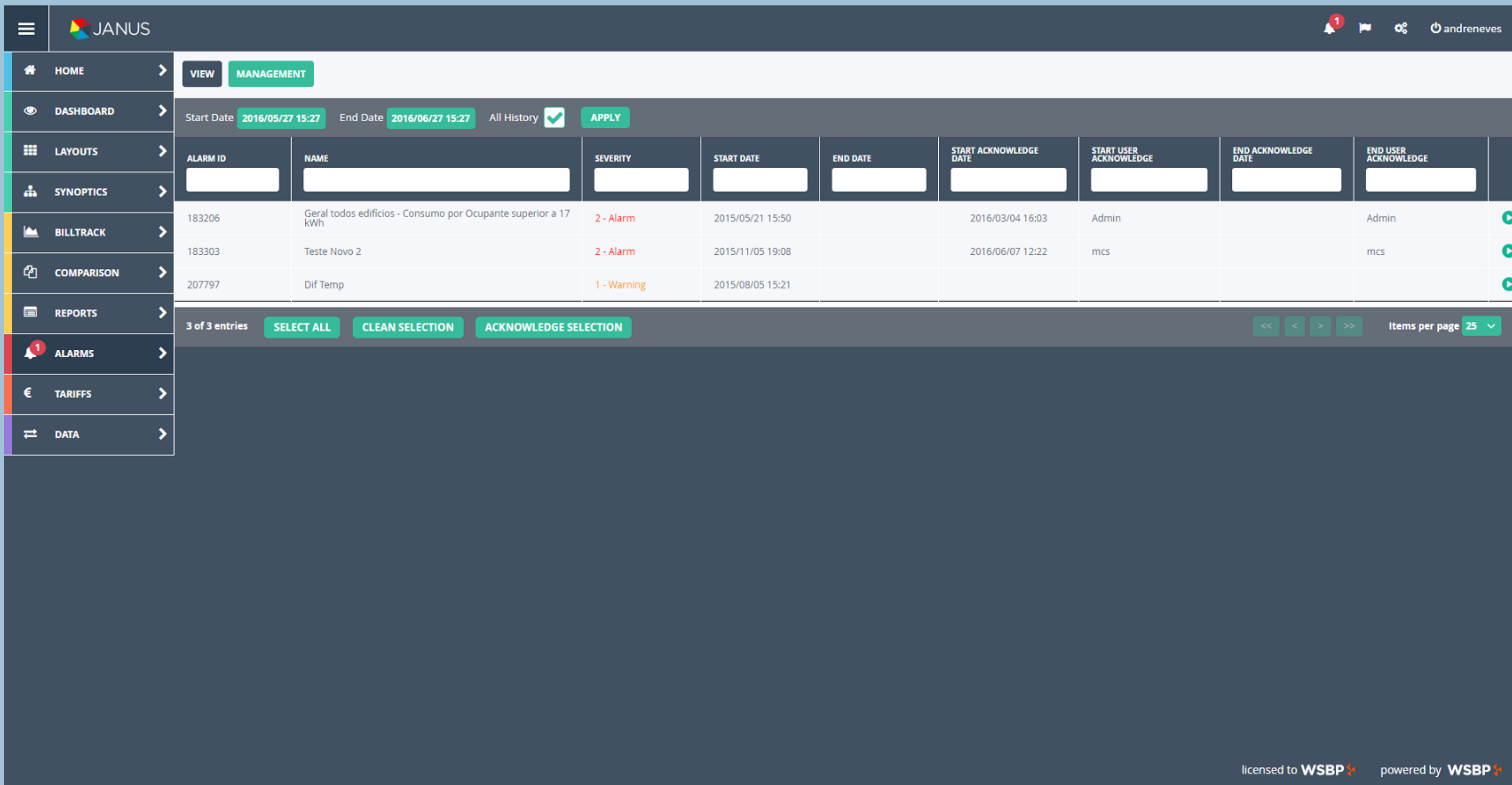
ALARMS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DASHBOARD
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BILLTRACK
COMPARISON
REPORTS
ALARMS
TARIFFS
DATA
VIEW
MANAGEMENT
Start Date 2016/05/27 15:27
End Date 2016/06/27 15:27
All History
APPLY
ALARM ID
NAME
SEVERITY
START DATE
END DATE
START ACKNOWLEDGE DATE
START USER ACKNOWLEDGE
END ACKNOWLEDGE DATE
END USER ACKNOWLEDGE
183206
Geral todos edifícios - Consumo por Ocupante superior a 17 kWh
2 - Alarm
2015/05/21 15:50
2016/03/04 16:03
Admin
Admin
183303
Teste Novo 2
2 - Alarm
2015/11/05 19:08
2016/06/07 12:22
mcs
mcs
207797
Dif Temp
1 - Warning
2015/08/05 15:21
3 of 3 entries
SELECT ALL
CLEAN SELECTION
ACKNOWLEDGE SELECTION
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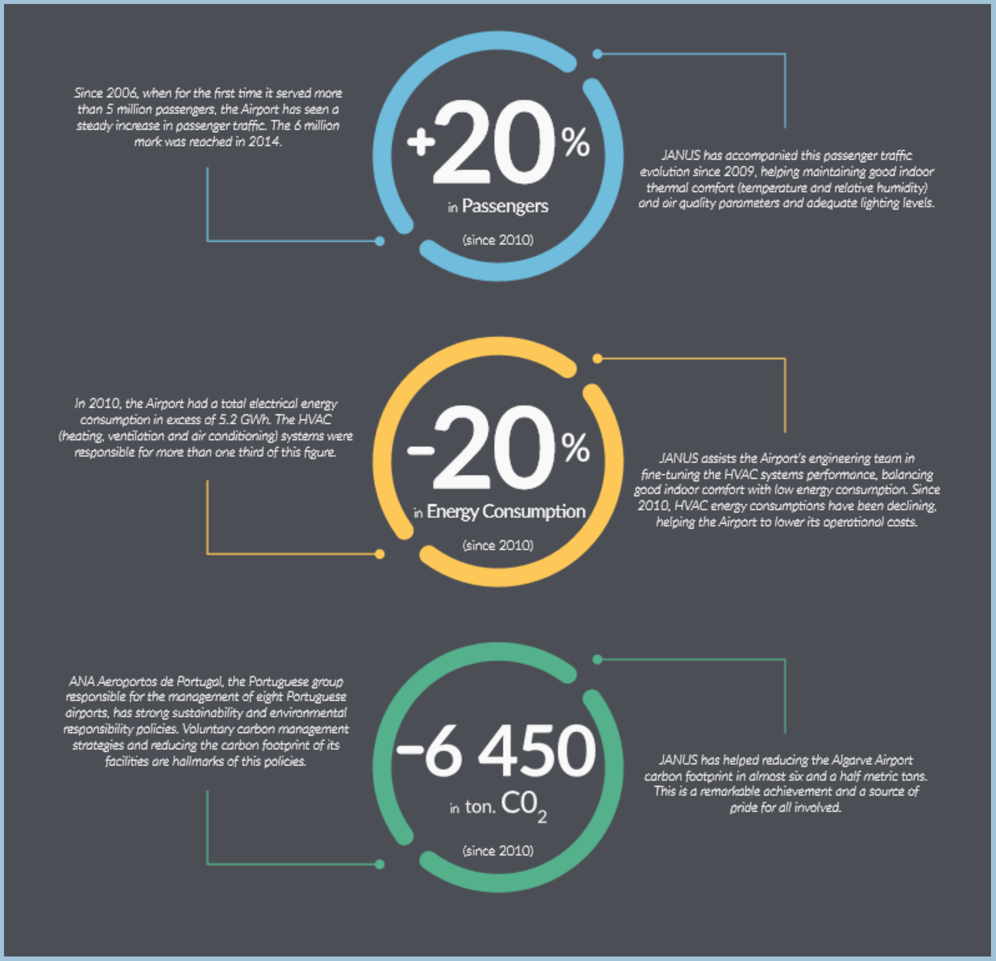
Greening Buildings

- Change of occupants habits, Redefinition of set points of indoor target conditions
- Change of control routines, Management of Solar Gains through Shadowing Solutions
- Improvement of Wall Insulation and Characteristics of Glazing Areas
- Controlled Ventilation (DCV, e. g. with CO_2 sensors or time programmed)
- Night free cooling, Tunning of Infiltration, Hybrid and Natural Ventilation
- Smart Management of Lighting (conjugation of natural and artificial lighting, low consumption lamps, occupancy sensors, etc.)
- Use of solar thermal collectors for domestic hot water and indoor environment heating
- Improvement of performance of HVAC systems. Energy recovery solutions
- Photovoltaics for electrical energy Production, Thermal Energy Storage Solutions
- Management of active and idle periods of electric devices. Reduction of stand-by consumptions

Results
Faro Airport




Ponta do Sol
Porto Novo
Mindelo
Ribeira Brava
Aeroporto Amílcar Cabral
Sal Rei
Tarrafal
Praia
São Filipe


Chegadas · Arrivals

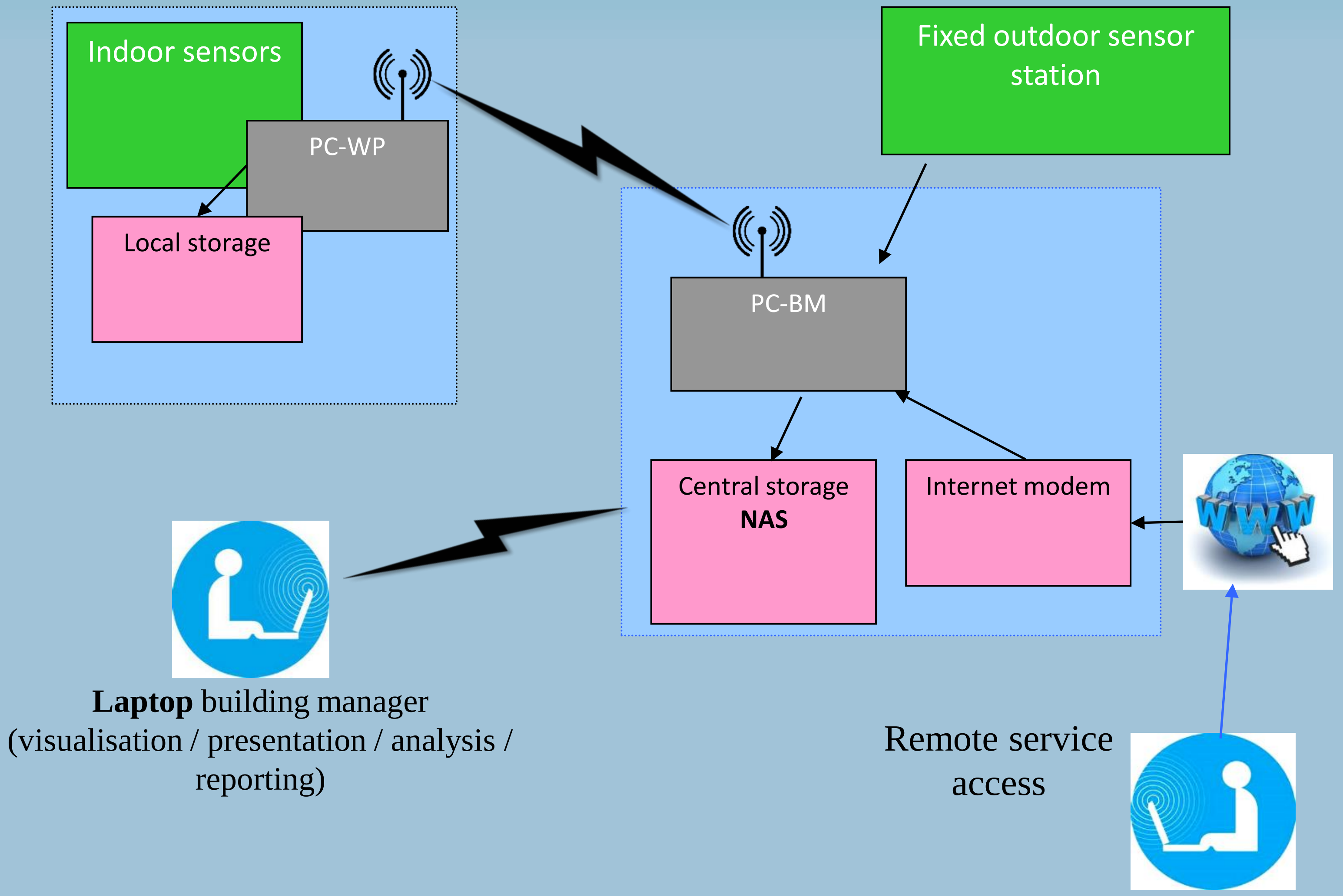

2
Sal International Airport · Sal Island, Cape Verde
Sal International Airport, or Amílcar Cabral International Airport, is the largest airport in the Cape Verde islands and one of its most important international and tourist gateways. JANUS is a recent addition to the Airport, helping in energy management and providing real-time energy monitoring since 2015.
Passenger traffic in Sal depends strongly on tourist seasons and trends. The last years, however, have seen a steady increase in passenger numbers, nearing 781 000 in 2015.
+23%
in Passengers
Jan-May 2015
Jan-May 2016
The Airtport must thus be able to adapt its HVAC (heating, ventilation and air conditioning) systems to wide demand variations. JANUS can help in identifying changing load demands and is able to trigger an alarm when it spots abnormal energy consumption patterns.
Total electrical energy consumption in 2015 topped 4.1 GWh. The HVAC and lighting systems were two of the major contributors for this figure, making them obvious targets for an early intervention.
-08%
in Energy Consumption
Jan-May 2015
Jan-May 2016
By tracking energy consumption patterns and localised energy consumption levels, JANUS was able to help the Airport's engineering and maintenance teams in quickly establishing a set of early low-investment measures to reduce energy consumptions.
Cape Verde is a group of islands with almost no natural resources and no endogenous fossil fuels. Since all fuel must be imported, energy production and availability is a critical concern for the country.
-581
in ton. $C0_2$
Jan-May 2015
Jan-May 2016
Sal International Airport is the island's most important energy consumer. JANUS help in lowering its energy consumption has a significant economic impact and helps the country to reach its target carbon emission levels.

A "low-cost" Case Study

Horst City Building

The Netherlands

A “low-cost” Case Study



Indoor WorkPlace Monitoring System

Table of WP variables

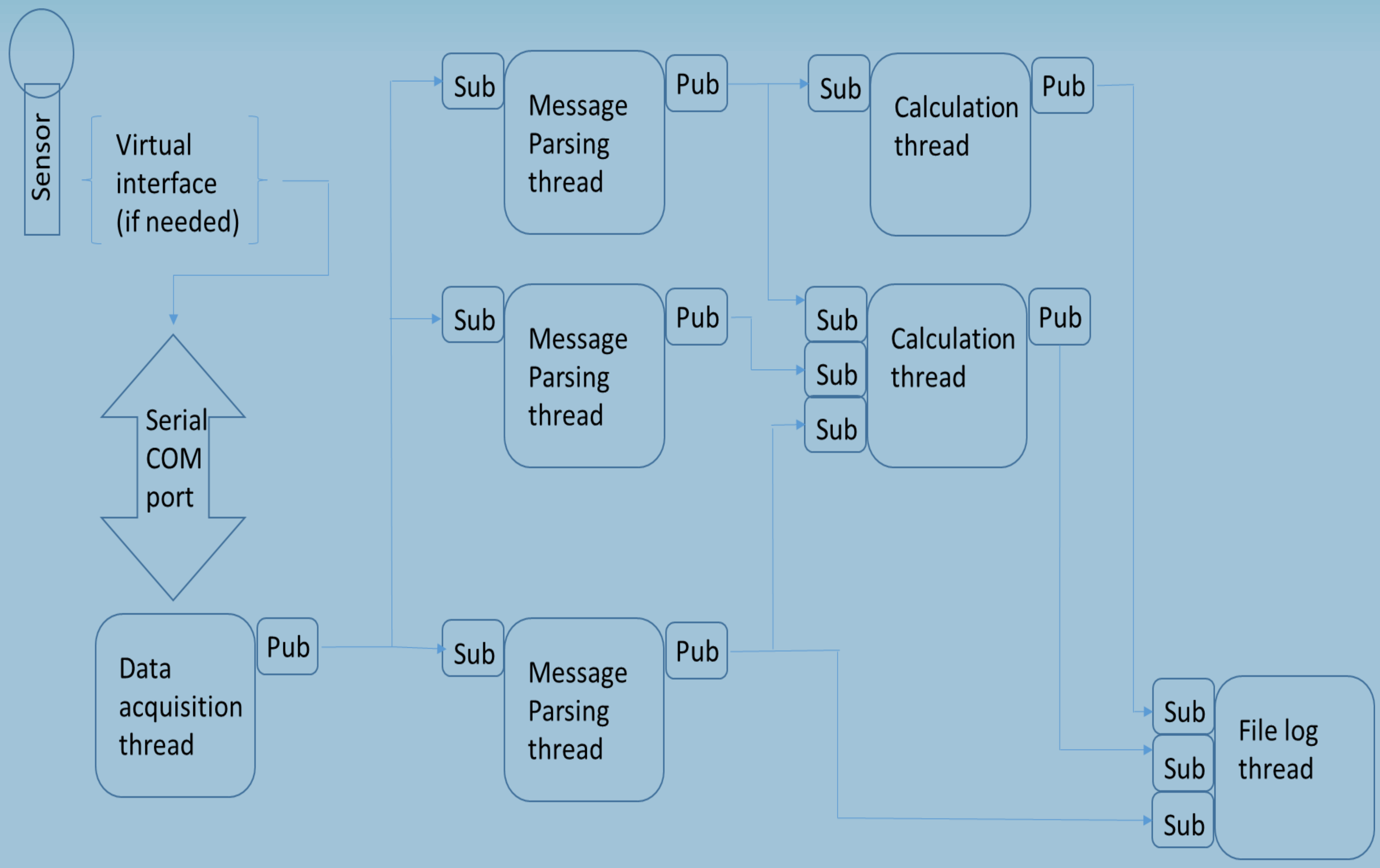
Chanel	Parameter, Units
1	Indoor Operative Temperature (°C)
2	Predicted Mean Vote - PMV 1
3	Predicted Mean Vote - PMV 2
4	Predicted Percentage of Dissatisfied - PPD 1 (%)
5	Predicted Percentage of Dissatisfied - PPD 2 (%)
6	Draught Rate (%)
7	Indoor Dew Point Temperature (°C)
8	Air Temperature Fluctuation (°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 CO_2 (ppm)
15	Indoor Concentration of CO_2 (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

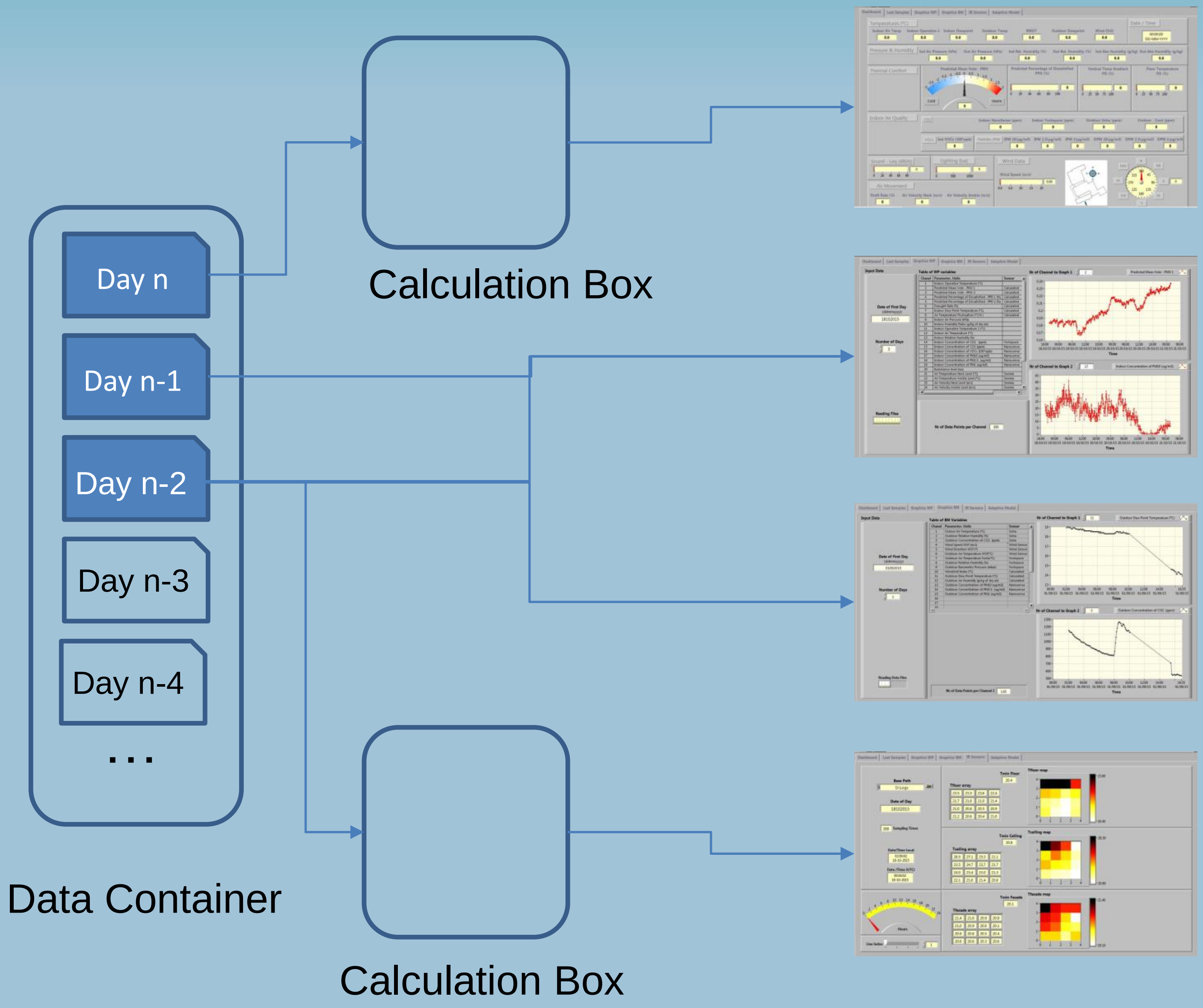
Table of BM Variables

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 – Volkerak software



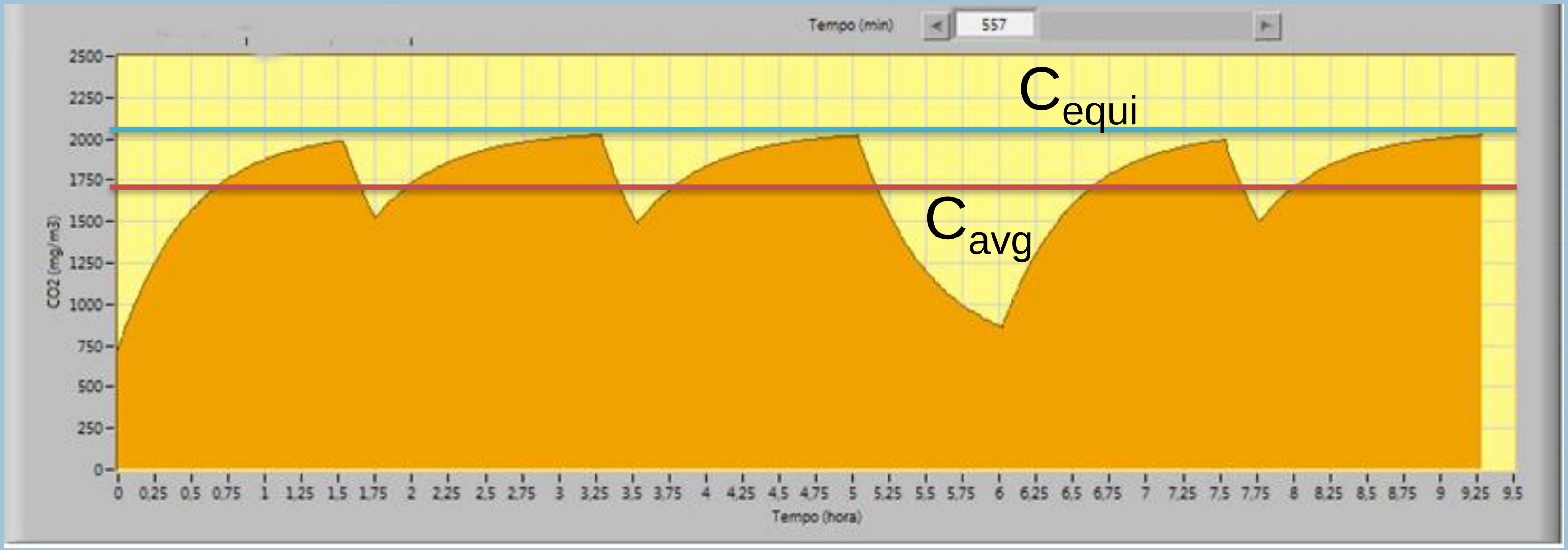
Data Viewer


Day n
Day n-1
Day n-2
Day n-3
Day n-4
. . .
Data Container
Calculation Box
Calculation Box

SIDE EFFECTS

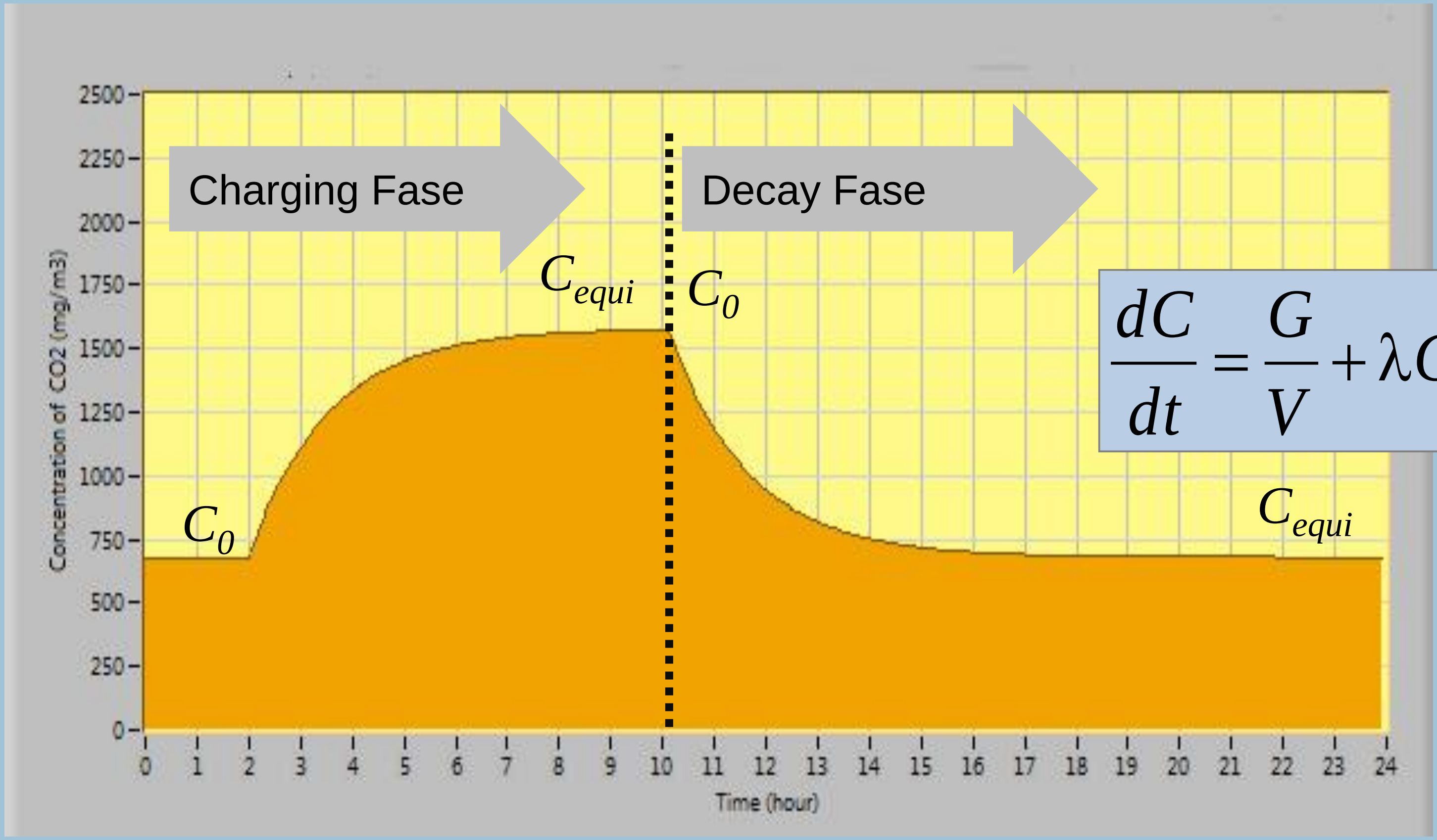
Participation in National Standards Committees

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

Basic Equations



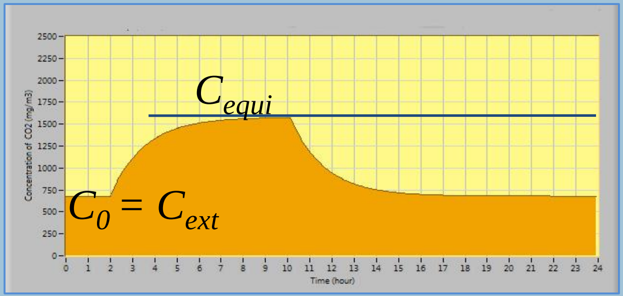
$$\frac{dC}{dt} = \frac{G}{V} + \lambda C_{ext} - \lambda C$$

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

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

Basis of the Prescriptive Methods

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



$$\frac{dC}{dt} = 0$$

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

$$C_{equi} = C_{ext} + \frac{G}{V\lambda_v}$$

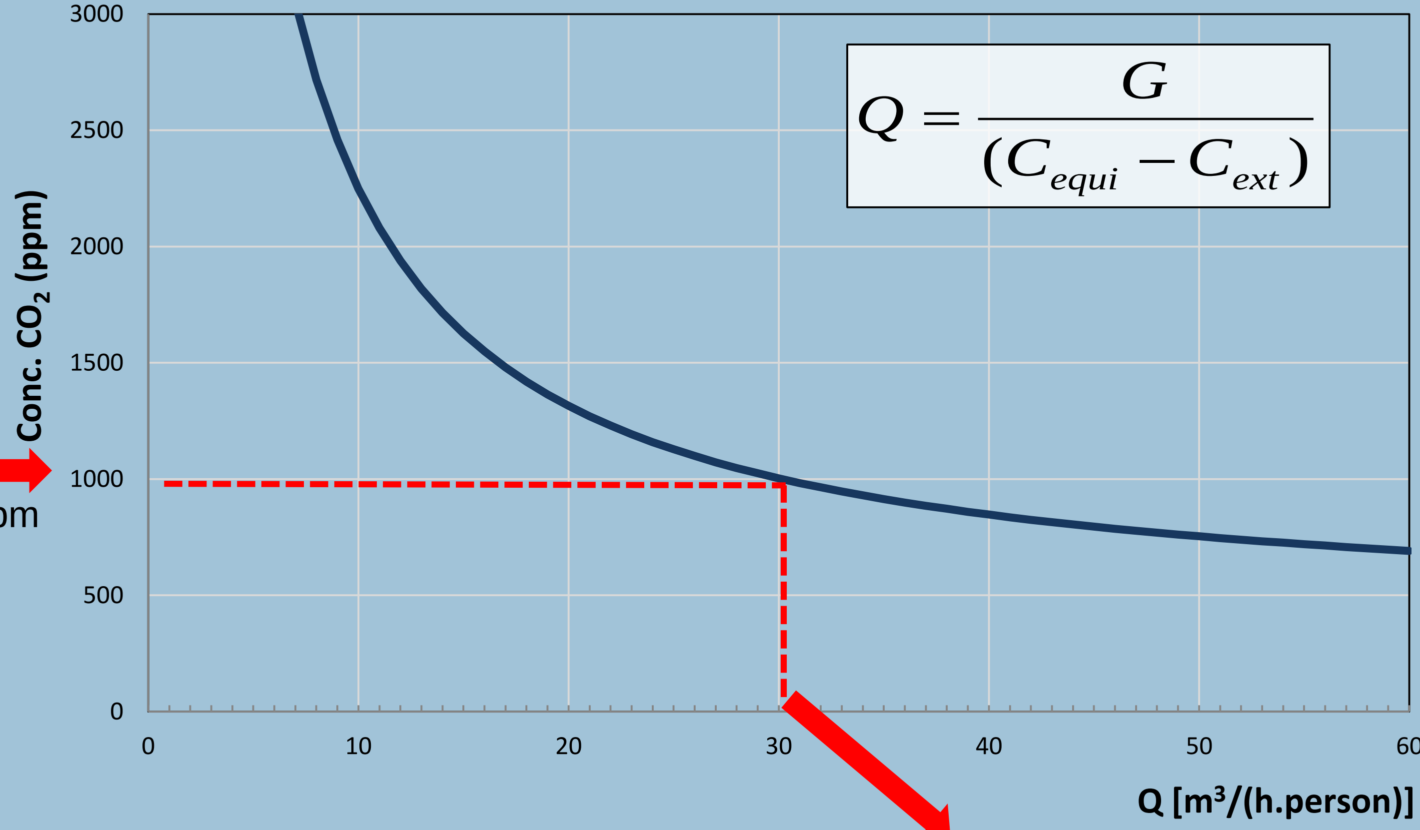
as

$$\lambda_v = \frac{Q}{V}$$

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

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

Basis of the Prescriptive Methods



C_{lim} <1000 ppm

Q > 30 m^3/(h.person)

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

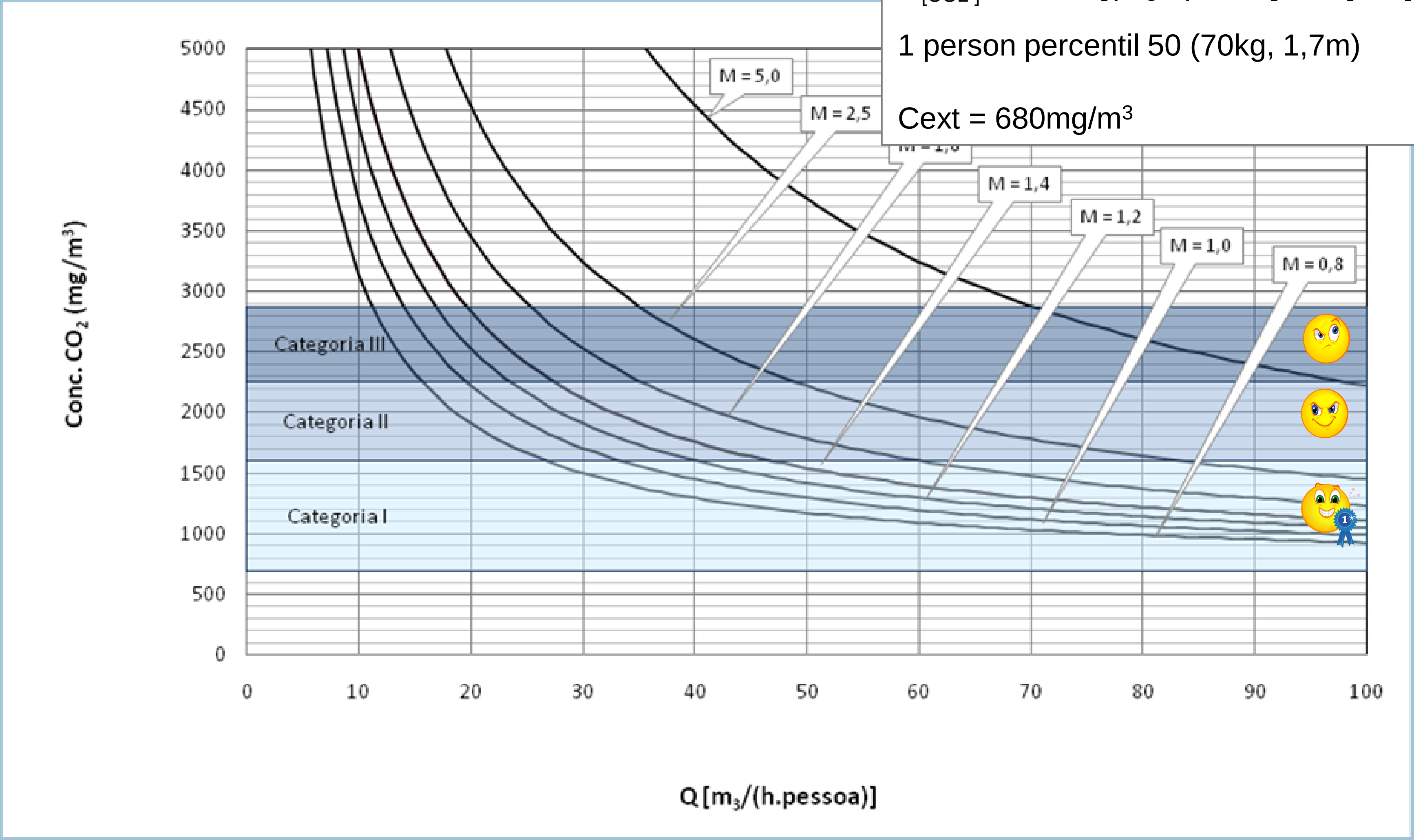
Example of a Prescriptive Method

Minimum Fresh Air Flow Rate

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

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

Cext = 680mg/m³



Example of a Prescriptive Method

Type of activity	Metabolic Rate- M (met)	Type of Space	Fresh Air Flow Rate [m^3/(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.

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

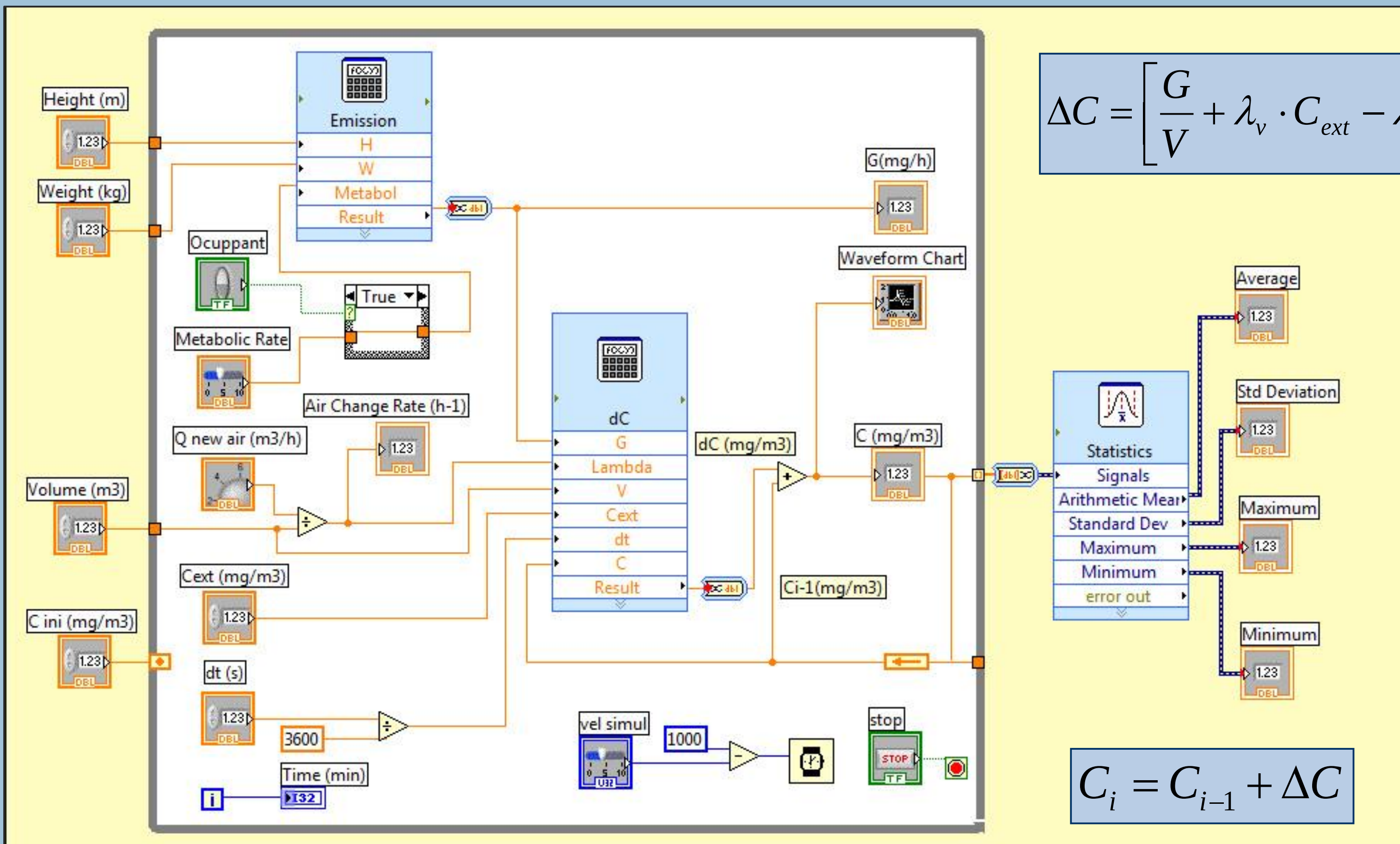
$$\Delta C = \left[\frac{G}{V} + \lambda_v \cdot C_{ext} - \lambda_v \cdot C \right] \times \Delta t$$

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

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

Analytical Method

Flowchart of Software Tool

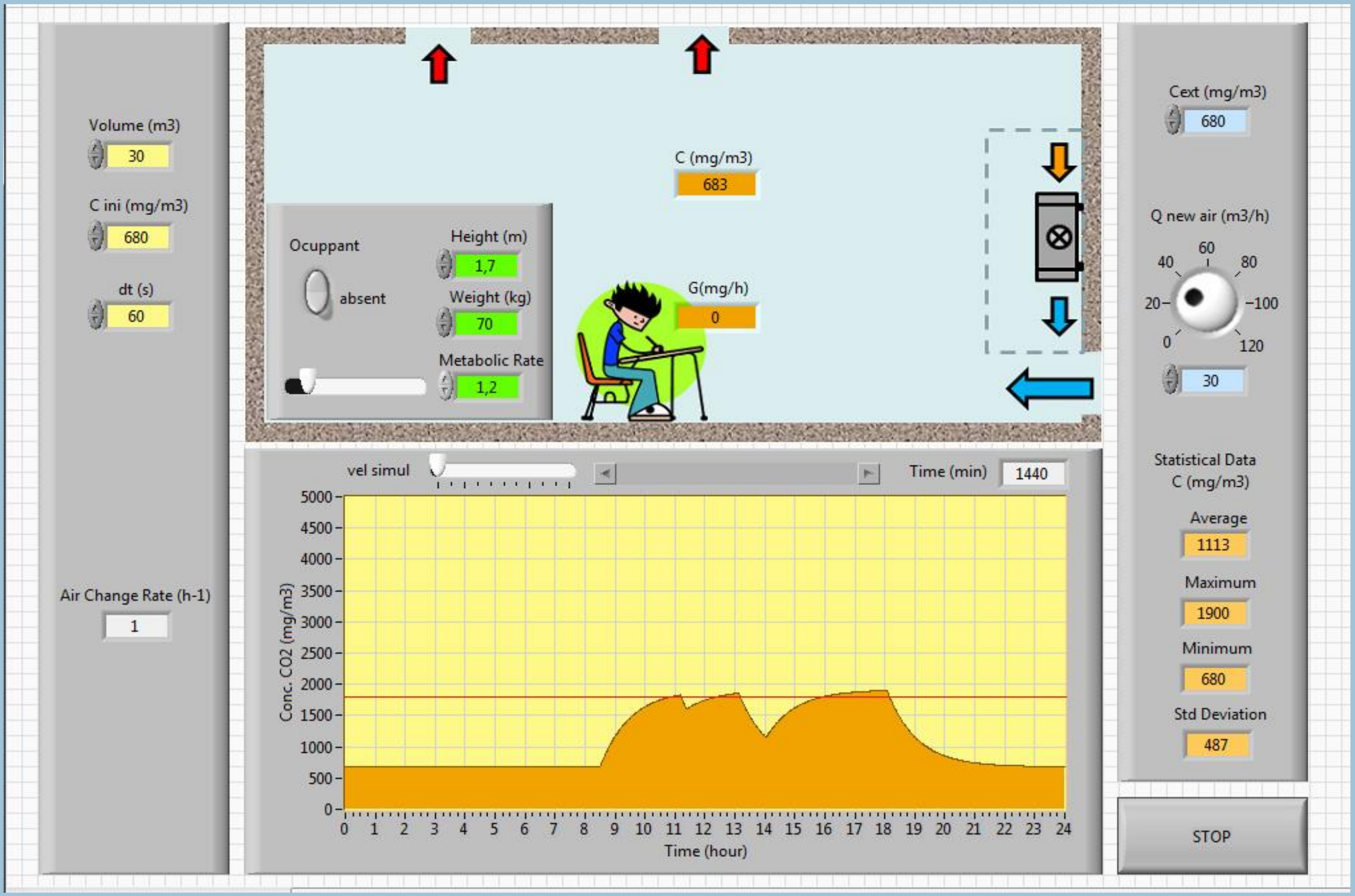


$$\Delta C = \left[\frac{G}{V} + \lambda_v \cdot C_{ext} - \lambda_v \cdot C \right] \times \Delta t$$

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

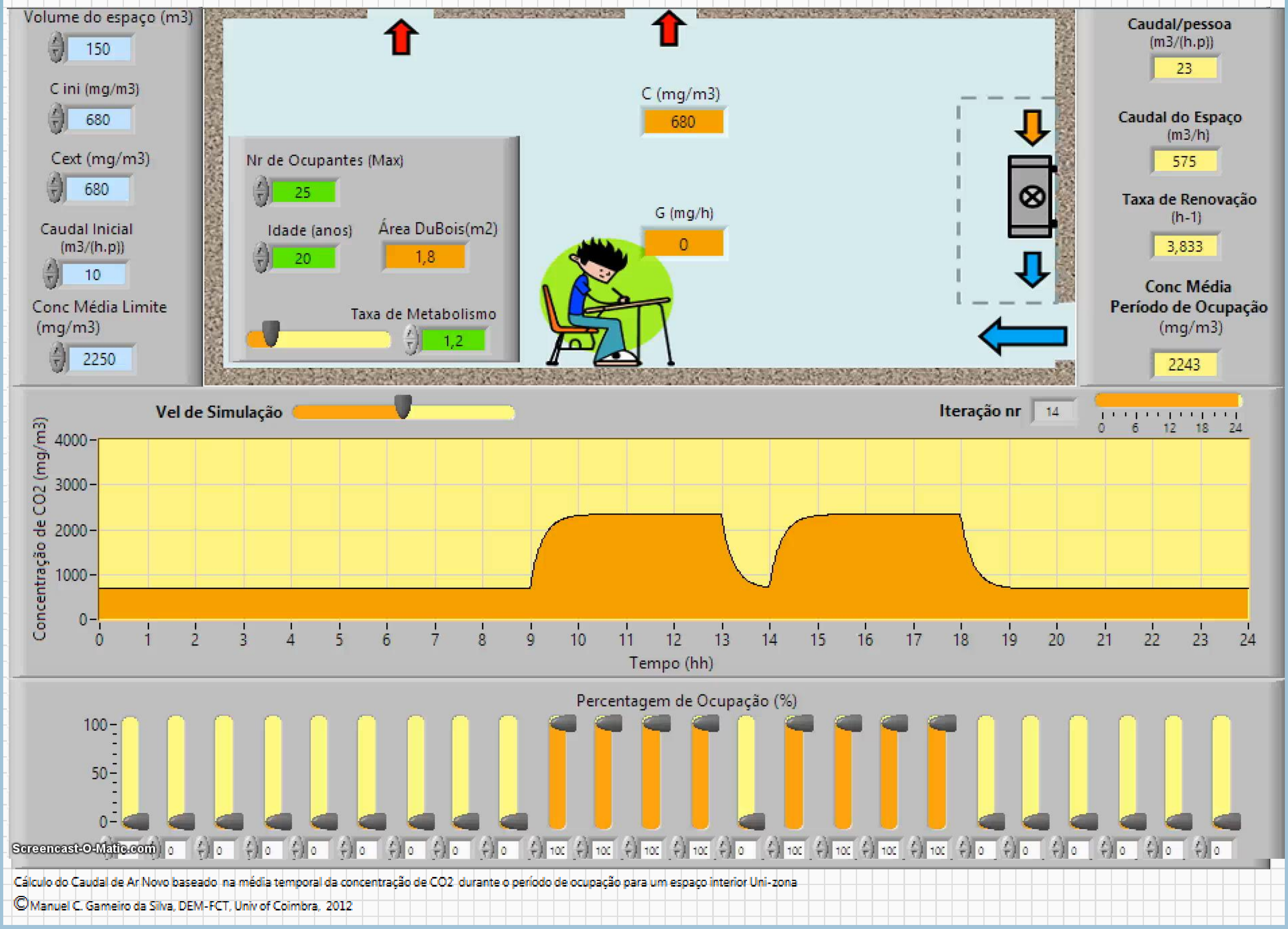
Analytical Method

Graphical Interface of Software Tool



Analytical Method

Software Tool version with Percentage of Occuppancy Input



Analytical Method

Software Tool version with Table Input Data

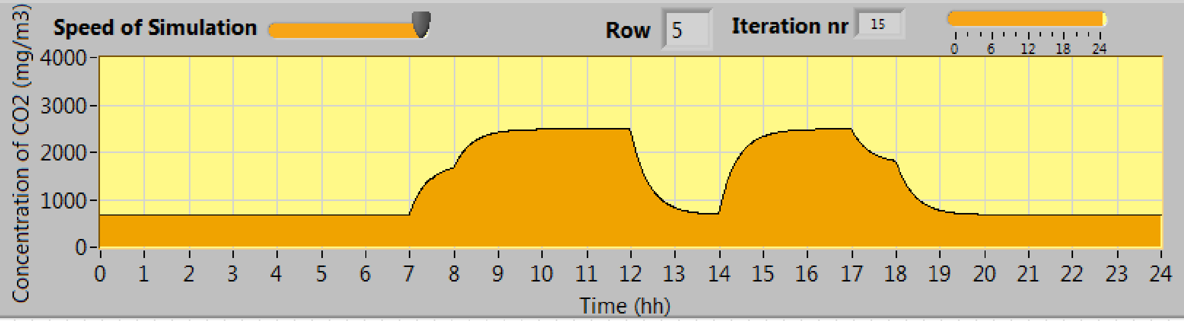
Table with Input Data

Espaço	Área (m2)	Altura (m)	.otaçãc	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

C (mg/m3)
680

G (mg/h)
0

Max Avg Conc (mg/m3)
2250



Flow Rate/person (m3/(h.p))
24

Room Flow Rate (m3/h)
576

Avg Conc Ocup Period (mg/m3)
2194

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

Dealing with Infiltration Rates

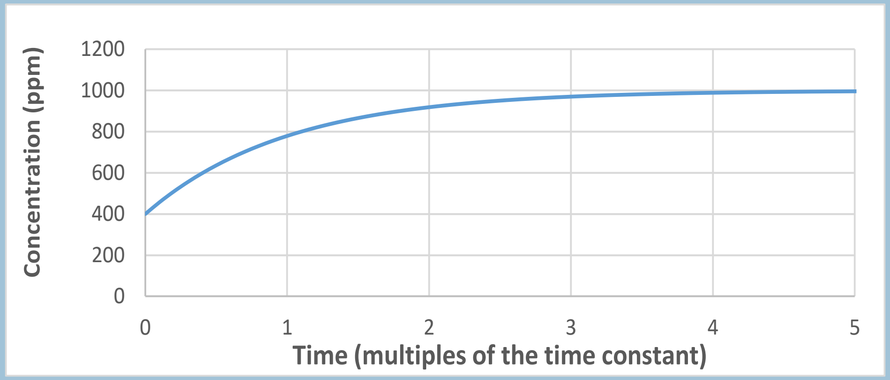
$$\frac{C(t)-C_{equi}}{C_0-C_{equi}} = e^{-\lambda t} = e^{-\frac{t}{\tau}}$$

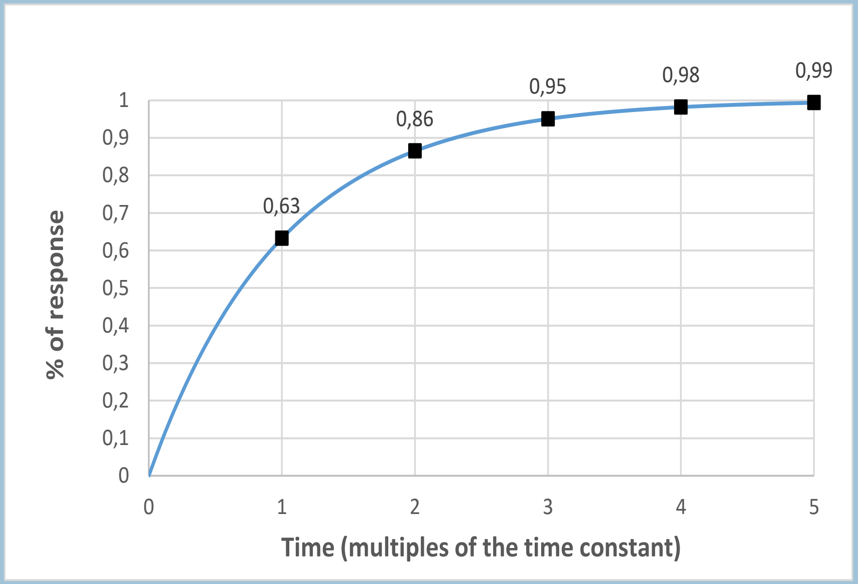
The equation governing the infiltration is an exponential function, which corresponds to the beaviour of a 1st ordem system, responding to a step input.

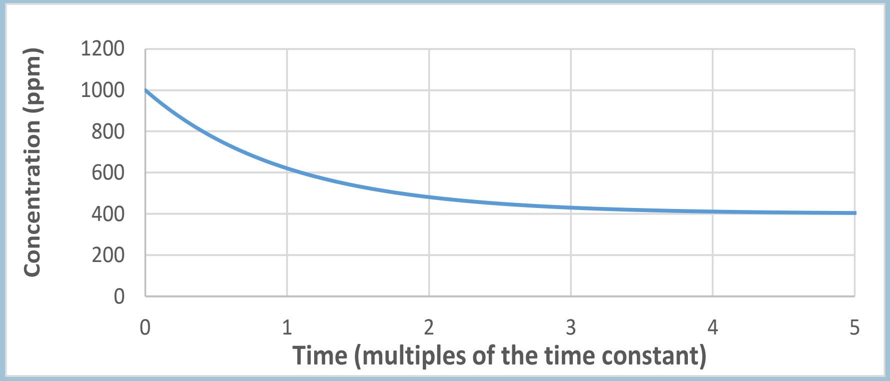
$$\lambda = \frac{Q}{V} = \frac{1}{\tau}$$

The infiltration rate $\lambda = Q/V$ is the inverse of the time constant of the system τ, which in this case, from the physical point of view, corresponds to the local mean age of the air. For instances, if we have 2 air exchanges per hour, the mean age of the air inside the compartmente is half of a hour.

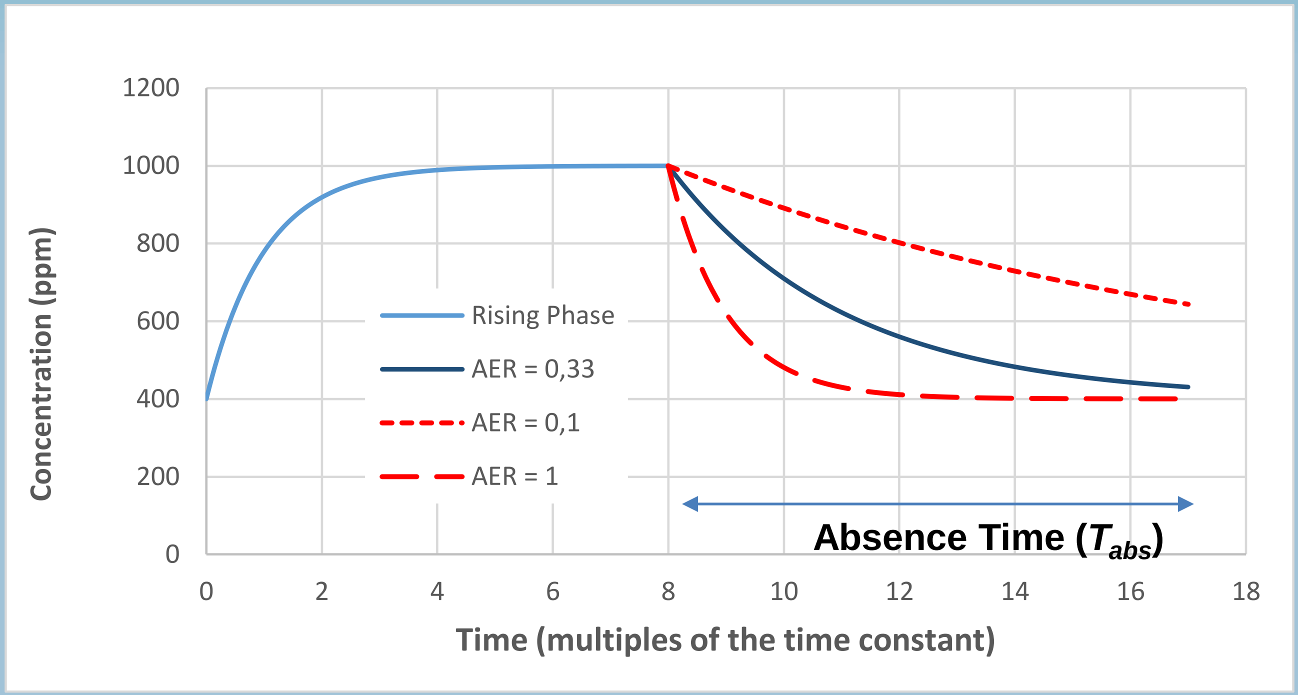
Dealing with Infiltration Rates







Dealing with Infiltration Rates



$$T_{absence} = 3\tau$$

To ensure, at least, 95% of the cleaning effect of pollutants by the infiltration

$$T_{absence} = \frac{3}{\lambda}$$

$$\lambda = \frac{3}{T_{absence}}$$

A New Method to Measure AER

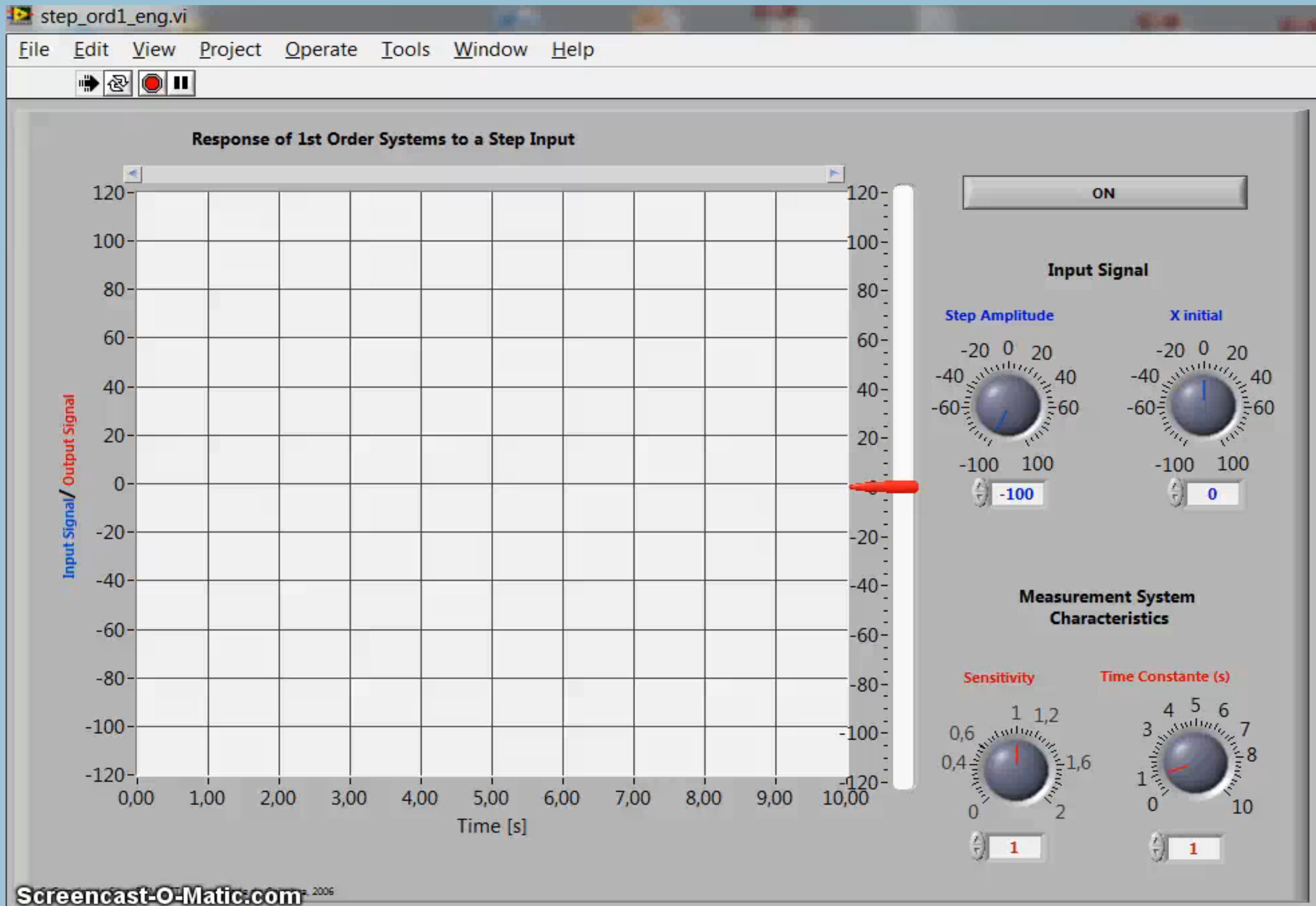
$$\tau \frac{\partial y}{\partial t} + y = K \cdot A \cdot \sin \omega t$$

$$y(t) = K \cdot C \cdot e^{-\left(\frac{t}{\tau}\right)} + \frac{K \cdot A}{\sqrt{1 + (\omega\tau)^2}} sin\left[\omega t - arctg(\omega\tau)\right].$$

Response of a first-order system to a periodic input

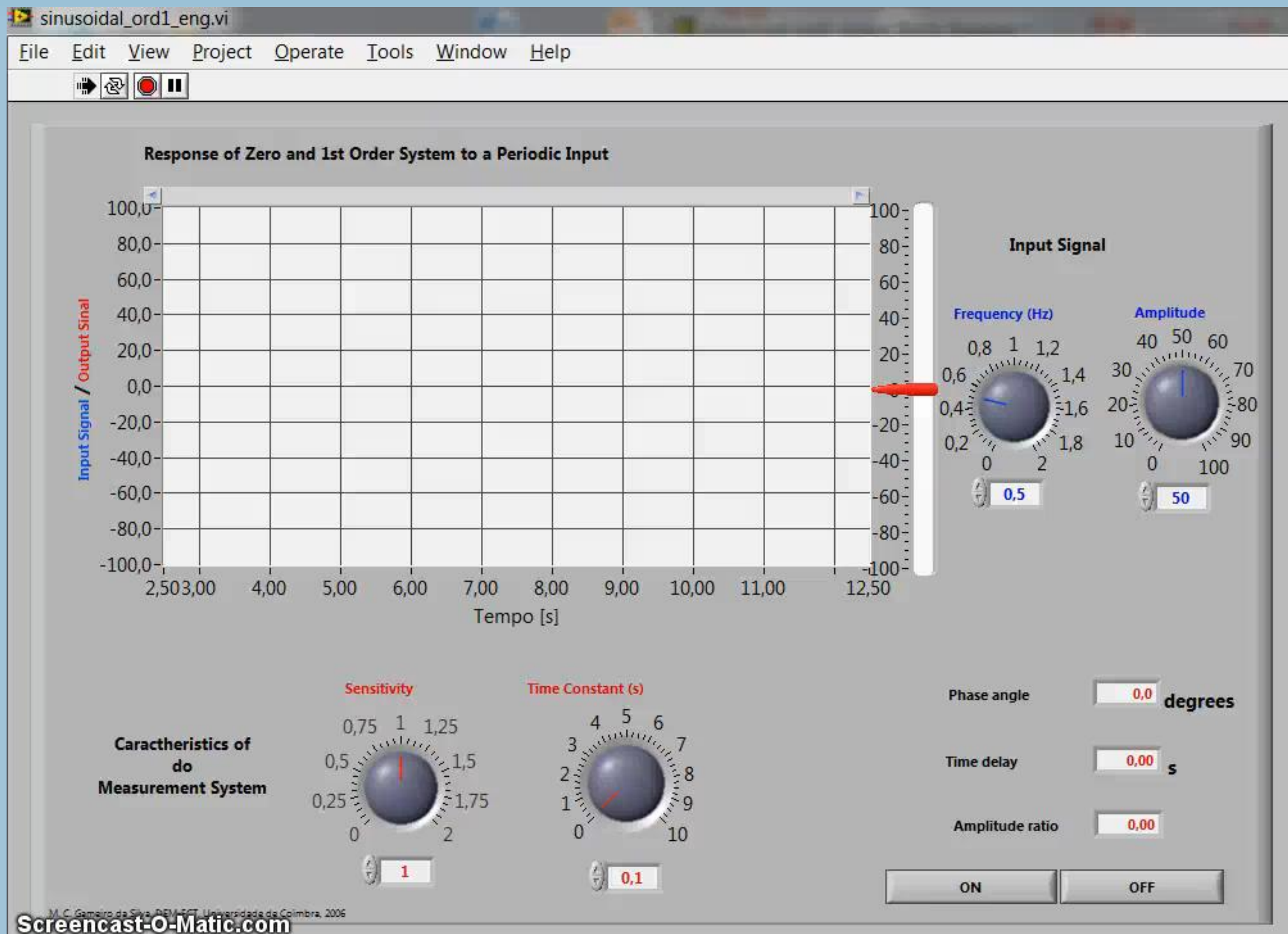
A New Method to Measure AER

Analogy with the Response of a 1st order Measuring System (STEP Input)



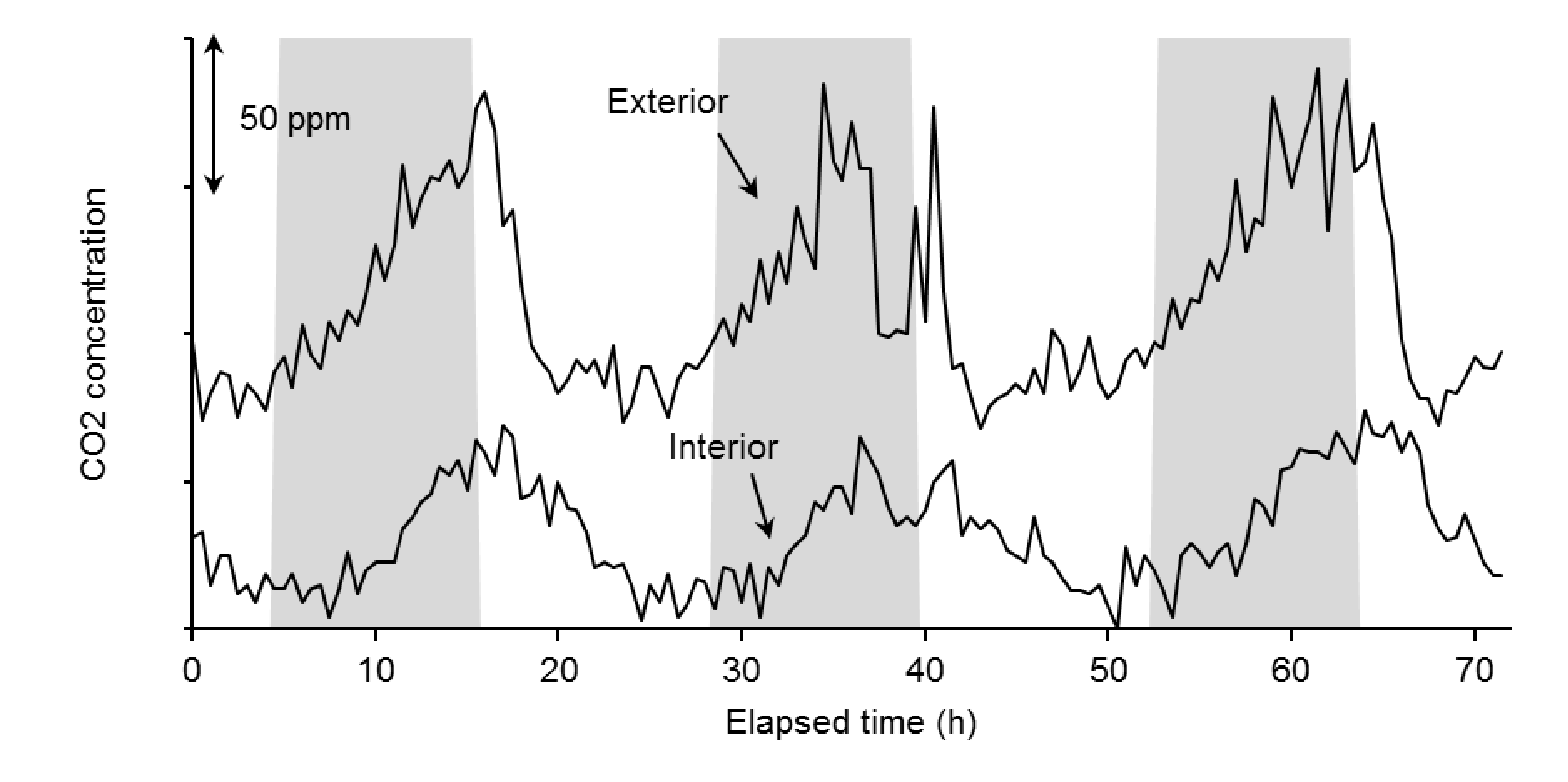
A New Method to Measure AER

Analogy with the Response of a 1st order Measuring System (Periodic Input)

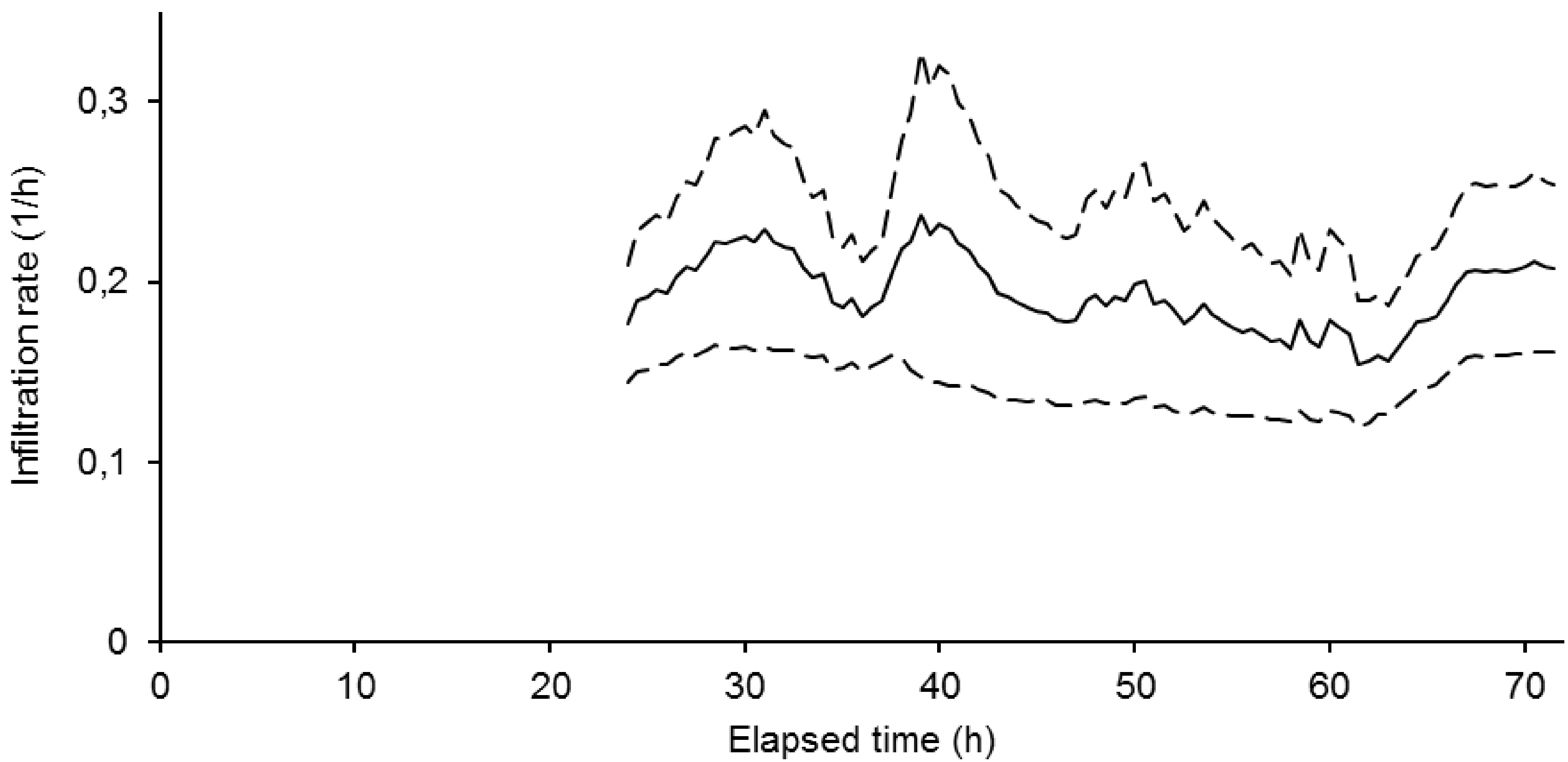


A New Method to Measure AER

Inside concentration follows outside concentration like a first order system!



Time history of AER



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Thank you very much for your attention

Muito obrigado pela vossa atenção

Grazie per l'attenzione