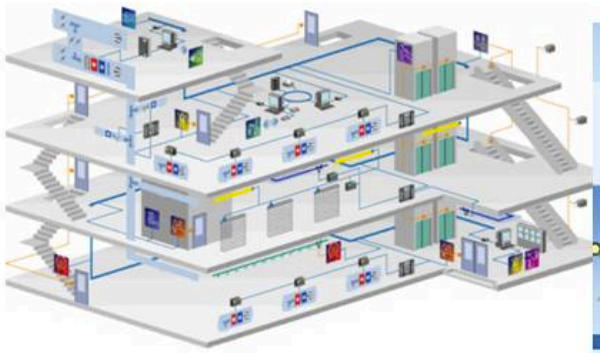
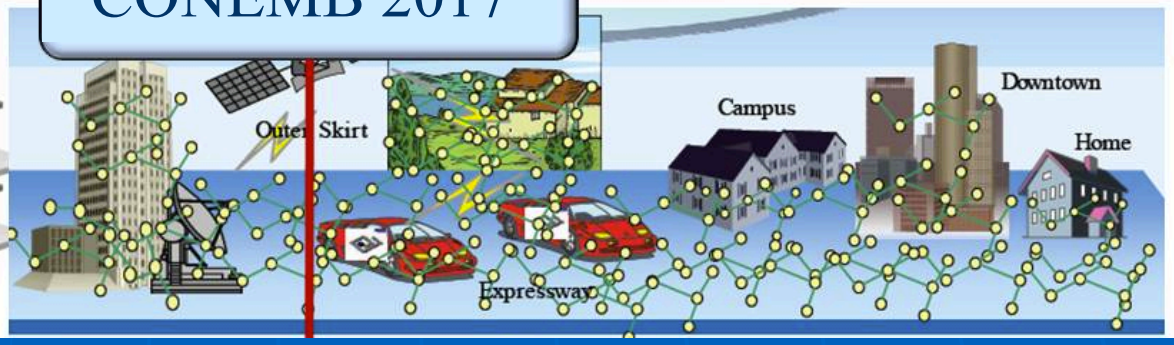


CONEMB 2017



- Intelligent Building Automation -

"the search for the ZEB"

Prof. Adolfo Bauchspiess

LARA- Automation and Robotics Laboratory
Departamento de Engenharia Elétrica
Universidade de Brasília - Brazil

Summary

Concepts:

- Sub-systems
- Segments
- Technologies
- Where can you work?
- Ambient Intelligence

Some Research Projects

- Energy Saving
- Thermal Comfort
- User tracking
- nZEB

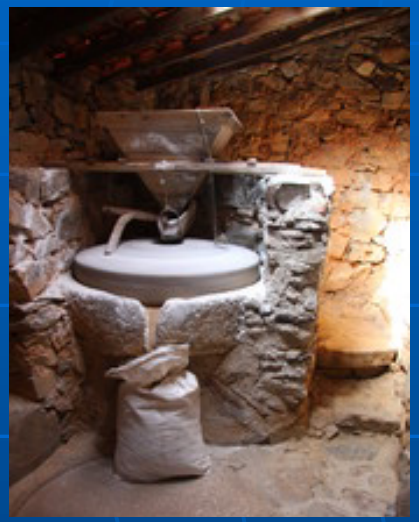
Perspectives

Intelligent Building Automation

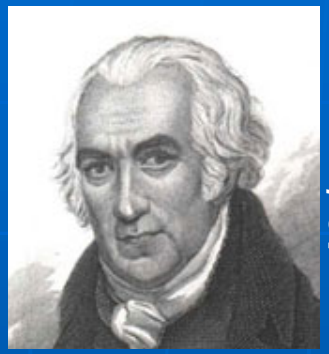
#trend_topics

- *Building Automation*
- *Artificial Intelligence*
- *Ambient Intelligence*
- *Ubiquitous Systems*
- *Assisted Living*
- *Cyber Physical Systems*
- *nZEB*
- ***Smart*** *Environments / Buildings / Campus / Cities*

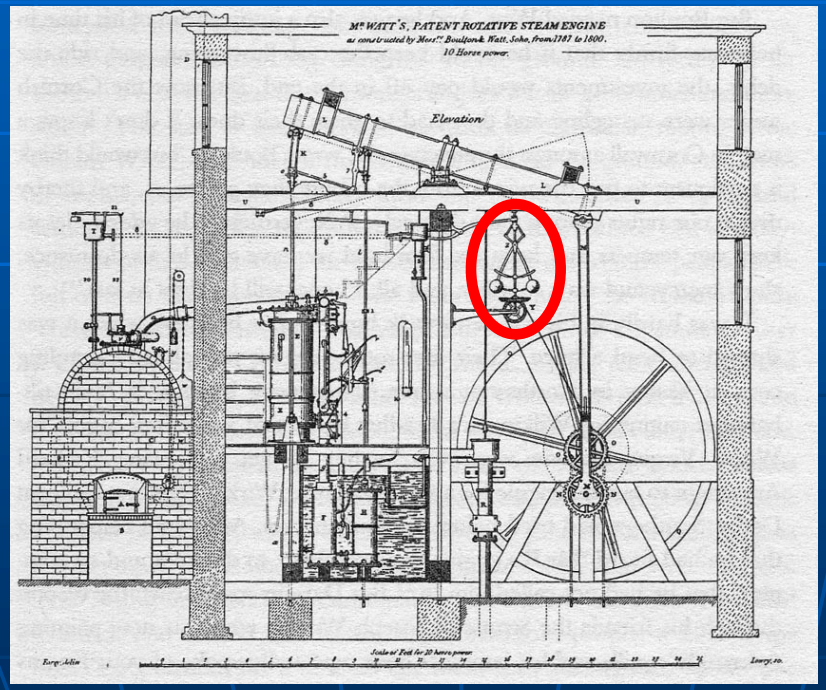
Automation – The Beginning

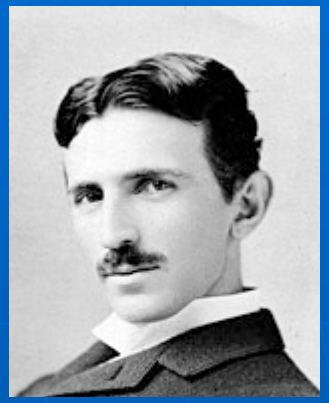


Flour mill
Work of 10 men
Xth century

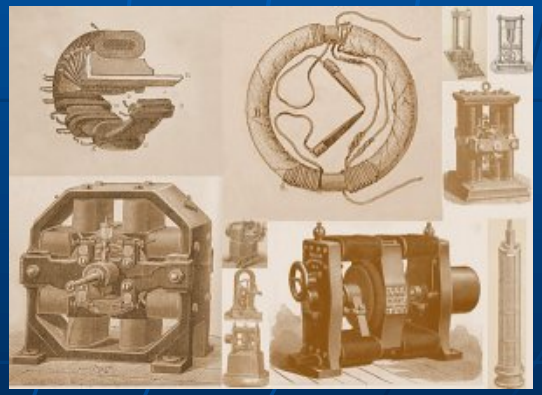


James Watt -1775
Steam Engine
Flyball governor



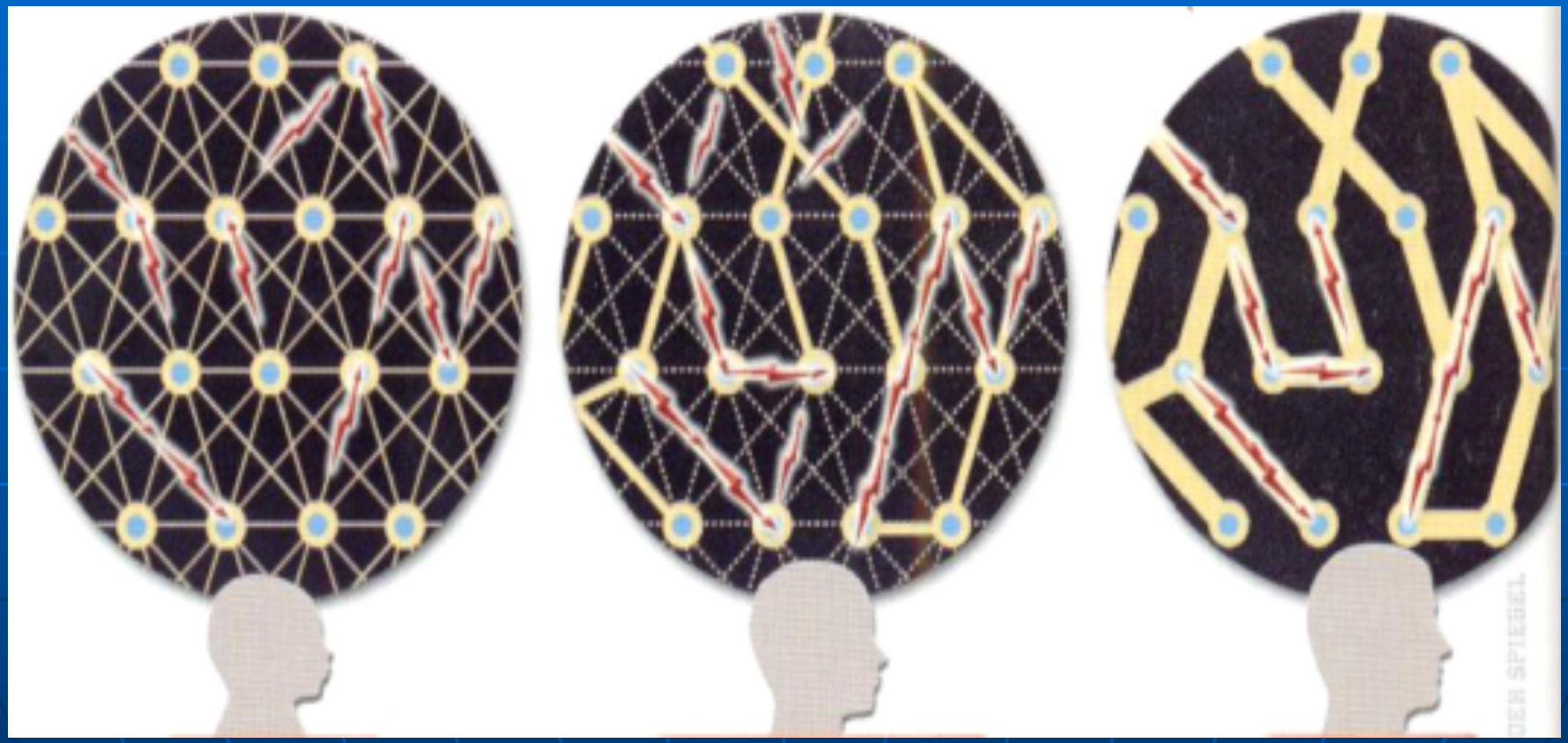


Tesla (⋆1856 †1943)
Multiphase Systems
AC Motor



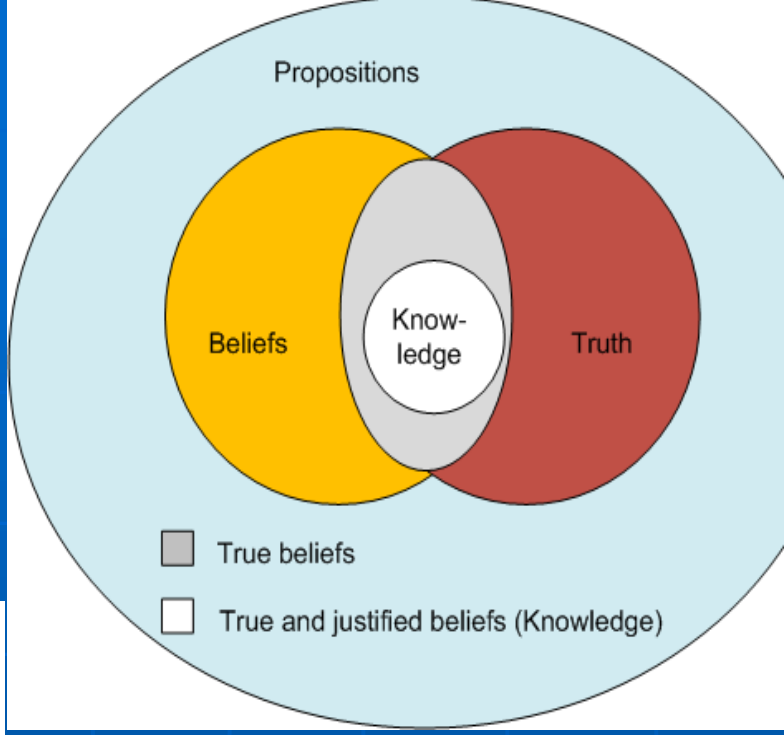
Intelligent Systems - The Brain as model !!

Build Neuron Synaptic *Connections* - Learning!

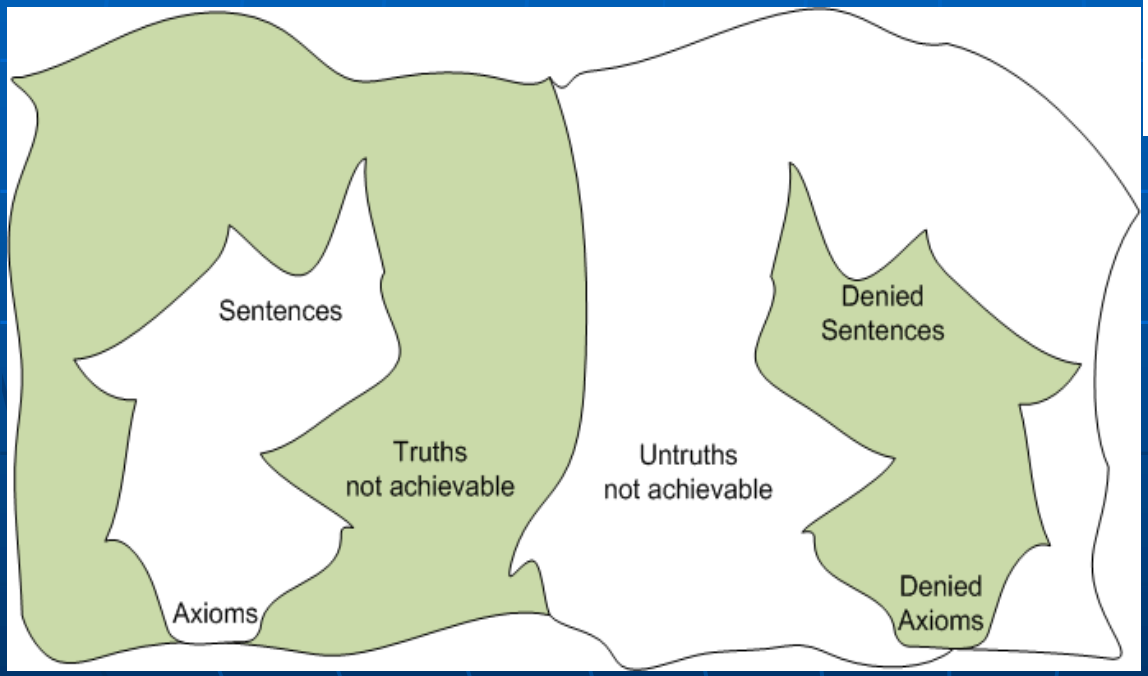


0-2 years | 2 years to puberty | Adult

“Philosophy of Knowledge”



Gödel's incompleteness theorems, 1931



“Heuristics”
A way that works,
but you do not know way.

“Sub-optimal solutions”
The brain is ***expert*** in finding good heuristics!

Artificial Intelligence?

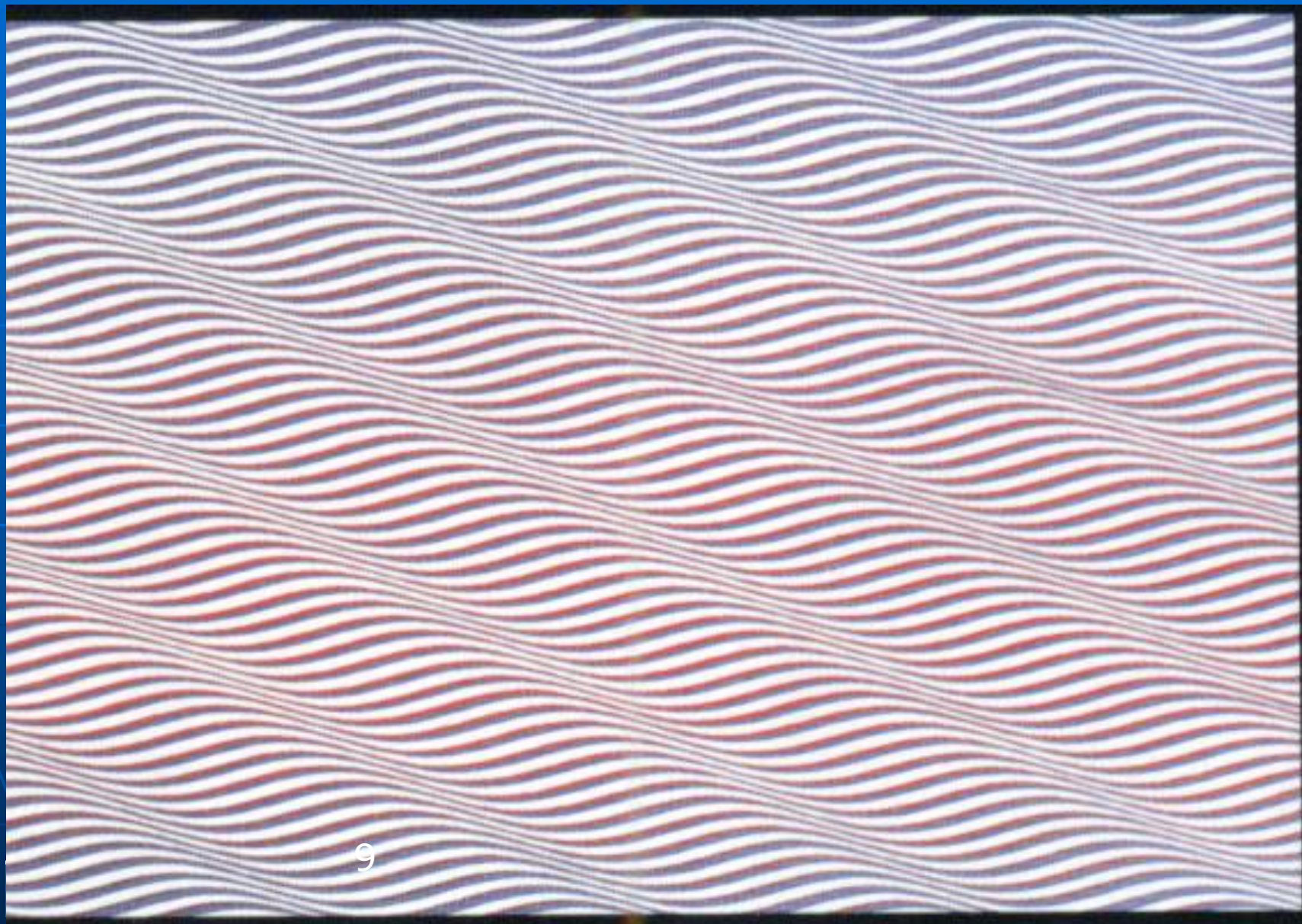
From Natural Intelligence to Artificial Intelligence

Ex. – Dislexia?

I cnduo't bvleiee taht I culod aulaclty uesdtannrd waht I was rdnaieg. Unisg the icndeblire pweor of the hmuan mnid, aocdcrnig to rseecrah at Cmabrigde Uinervtisy, it dseno't mttaer in waht oderr the lterets in a wrod are, the olny irpoamtnt tihng is taht the frsit and lsat ltteer be in the rhgit pclae. The rset can be a taotl mses and you can sitll raed it whoutit a pboerlm. Tihs is bucseae the huamn mnid deos not raed ervey ltteer by istlef, but the wrod as a wlohe. Aaznmig, huh? Yaeh and I awlyas tghhuot slelinpg was ipmorantt! See if yuor fdreins can raed tihs too.

Giant x 3D Ilusion?

Waves?



Simpathic?

GRIMASSE STEHT KOPF

Auf den ersten Blick scheint das Foto von Margaret Thatcher nicht ungewöhnlich. Das ändert sich, wenn Sie das Bild auf den Kopf stellen. Der verblüffende Effekt tritt auf, weil Augen und Mund auf dem Foto um 180 Grad gedreht sind – und damit genau die Merkmale, auf die das Gesichtserkennungsprogramm des Hirns besonders sensibel anspricht.

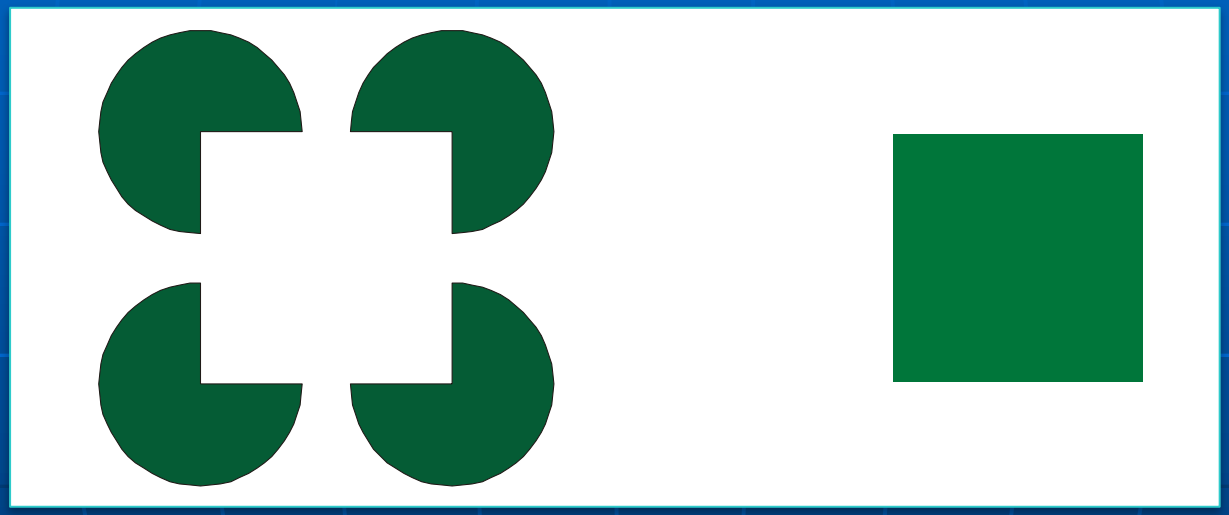
EMILE LUIDER / RAPHO / AGENTUR FOCUS (L.); PERCEPTION (R.)

Antipathic?


GRIMASSE STEHT KOPF
Auf den ersten Blick scheint das Foto von Margaret Thatcher nicht ungewöhnlich. Das ändert sich, wenn Sie das Bild auf den Kopf stellen. Der verblüffende Effekt tritt auf, weil Augen und Mund auf dem Foto um 180 Grad gedreht sind – und damit genau die Merkmale, auf die das Gesichtserkennungsprogramm des Hirns besonders sensibel anspricht.
EMILE LUIDER / RAPHO / AGENTUR FOCUS (L.); PERCEPTION (R.)

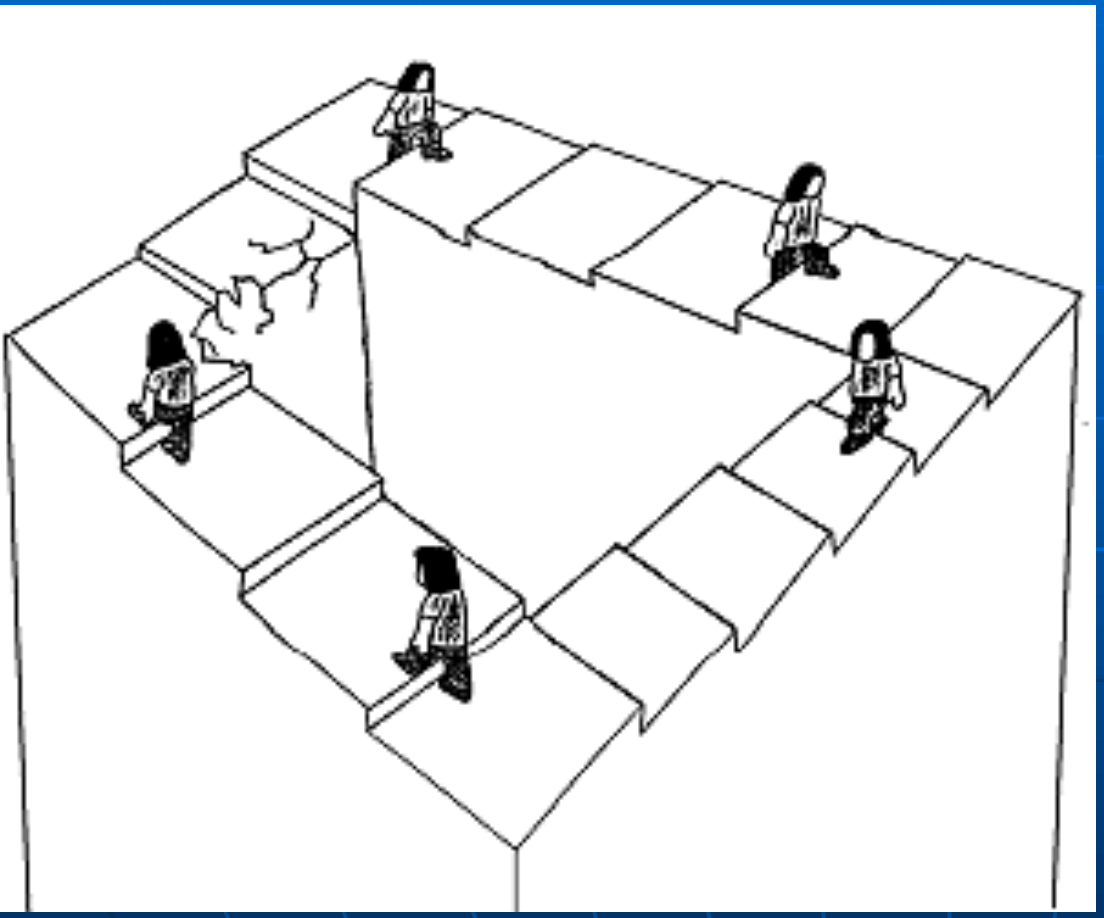
- Incomplete pattern -
Brain Interpolation!

-Perception



The Kanizsa square, 1976

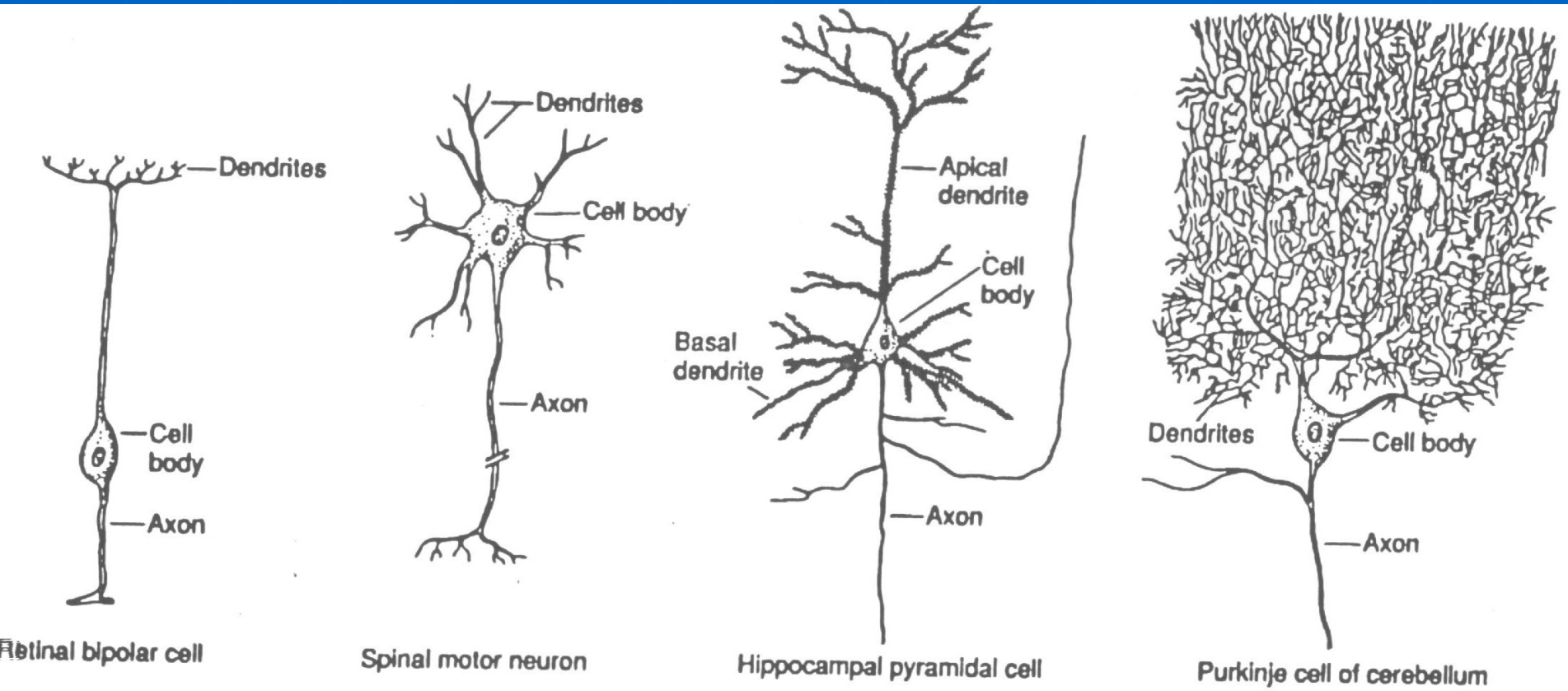
“Local Coherency –Global Paradox"



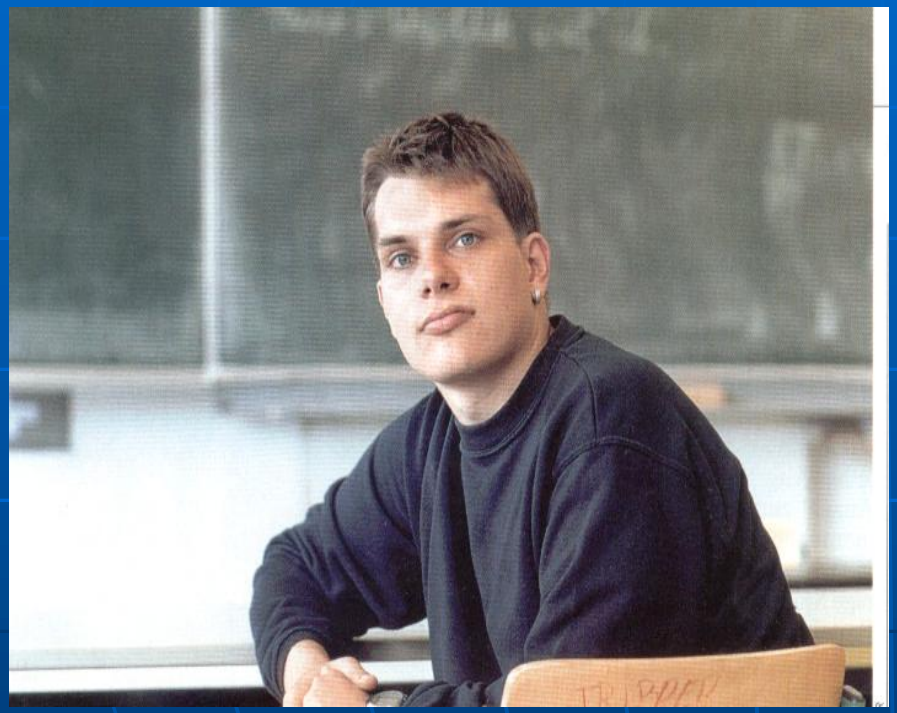
Sandro delPrete. Enigmas Visuais. Rio de Janeiro, 2004, p. 45

Biological Fundaments

Some kinds of neurons



Epilepsy Patient –
without left brain hemisphere since 12 years age



Leben ohne links

Seit zwölf Jahren lebt Philipp Dörr mit einem halben Großhirn. Trotzdem spielt er Schach, liest Goethe und taucht – ein verblüffendes Beispiel für die Wandlungsfähigkeit des Denkorgans.

Living connected

http://perso.limsi.fr/jps/enseignement/examsma/2004/BHATTI/

Ambient Ingelligence

"Provide services to the users of an ambient through an almost invisible wireless sensor and actuator network"

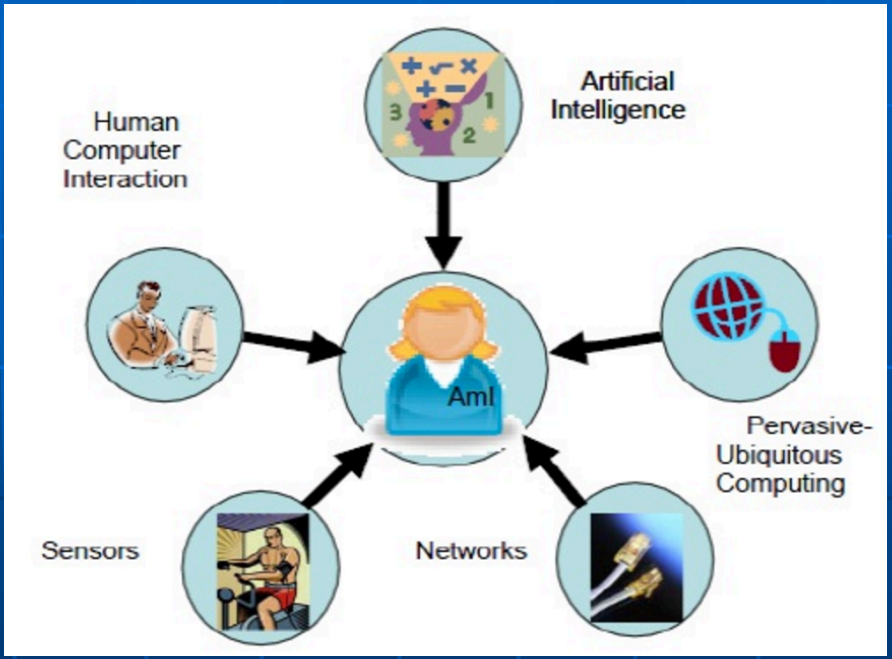
Summary

1 – Concepts

2 – Projects

- Energy saving
- Comfort
- User Tracking

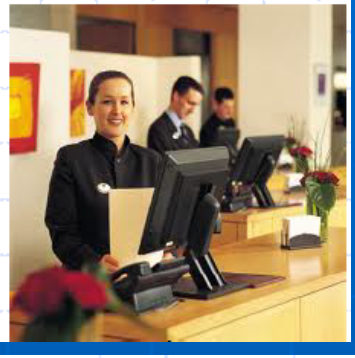
3 – Perspectives



Building Automation - Segments

- ✓ Schools
- ✓ Hospitals
- ✓ Hotels
- ✓ Pharmaceutical
- ✓ Commercial
- ✓ Airports
- ✓ Stadiums
- ✓ Domotics
- ✓ …

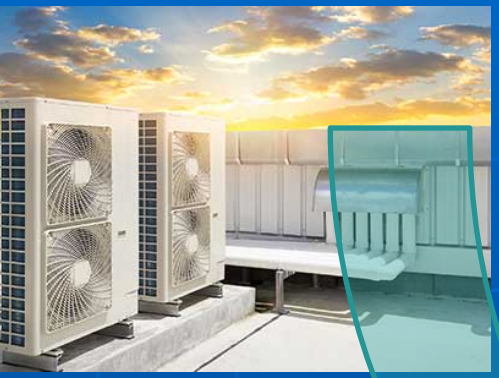








Sub-Systems



- ✓ HVAC
- ✓ Illumination
- ✓ Fire
- ✓ Energy Management
- ✓ Back-Up Power Gen.
- ✓ CC-TV
- ✓ Access Control
- ✓ Elevator/Escalator
- ✓ …

Building Automation- Objetives

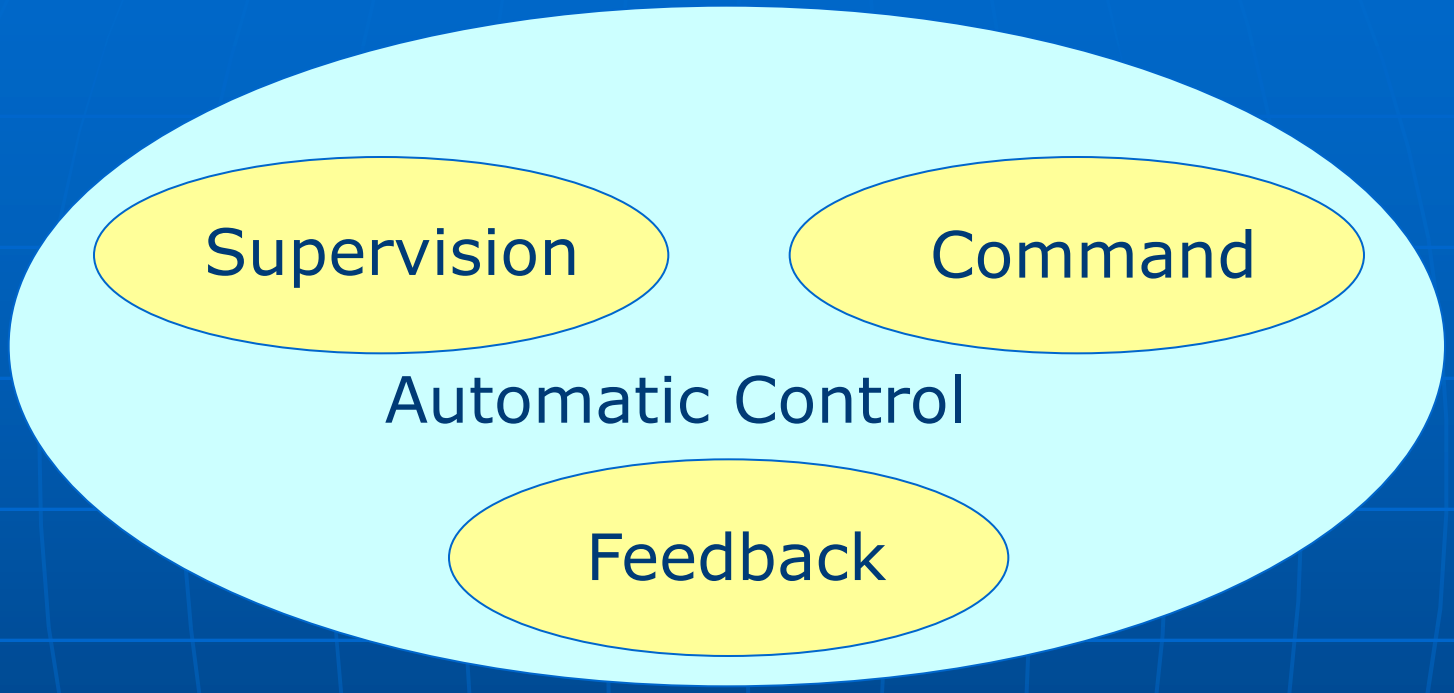
- Security
  - Access Control
  - CC-TV
  - Fire Detection
- Comfort (Productivity)
  - temperature, humidity,… (PMV)
  - illumination,
  - waiting time for elevators, …
- Health issues
  - air quality (renovation, filters…)
  - CO_2
- Energy Saving

Building Automation- Technologies

- Supervision, Control, Data Acquisition (SCADA)
- Human-Machine Interface (HIM)
- Programmable Logical Controllers (PLC)

- Network
  - Cabled
  - PLC
  - Wireless

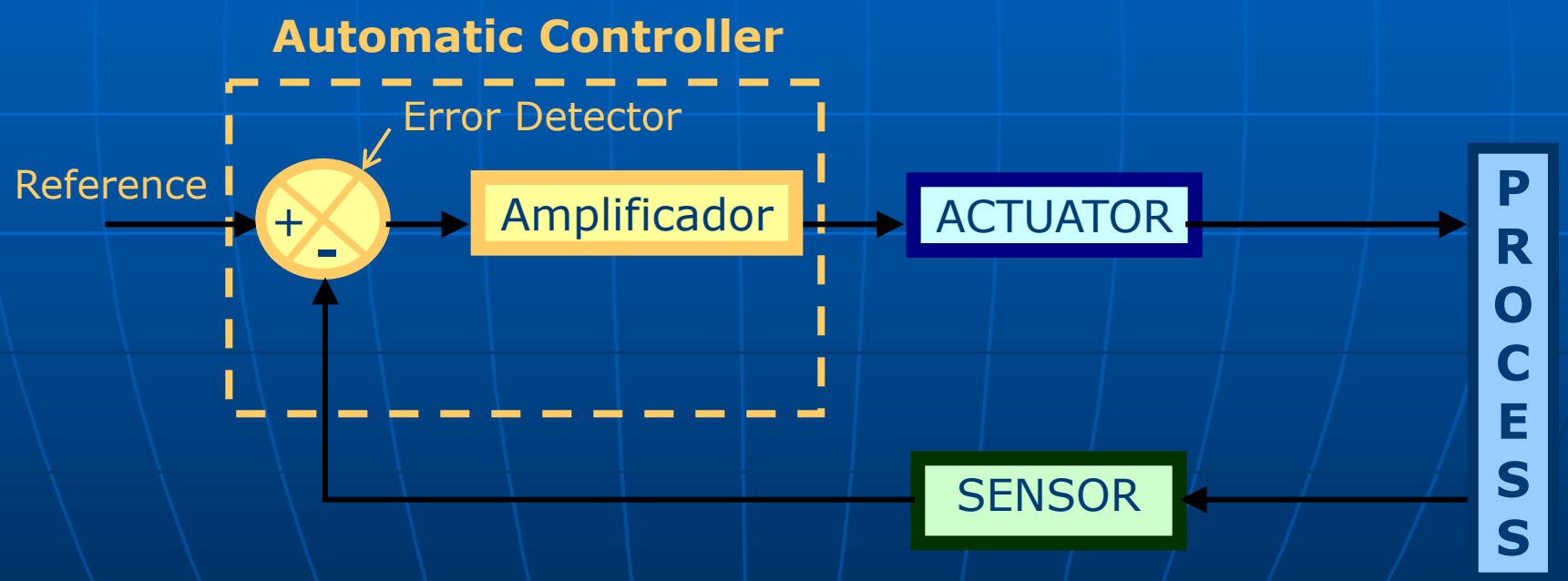
- Devices
  - Modularity (Easy to expand)
  - Interoperability


Supervision
Command
Automatic Control
Feedback

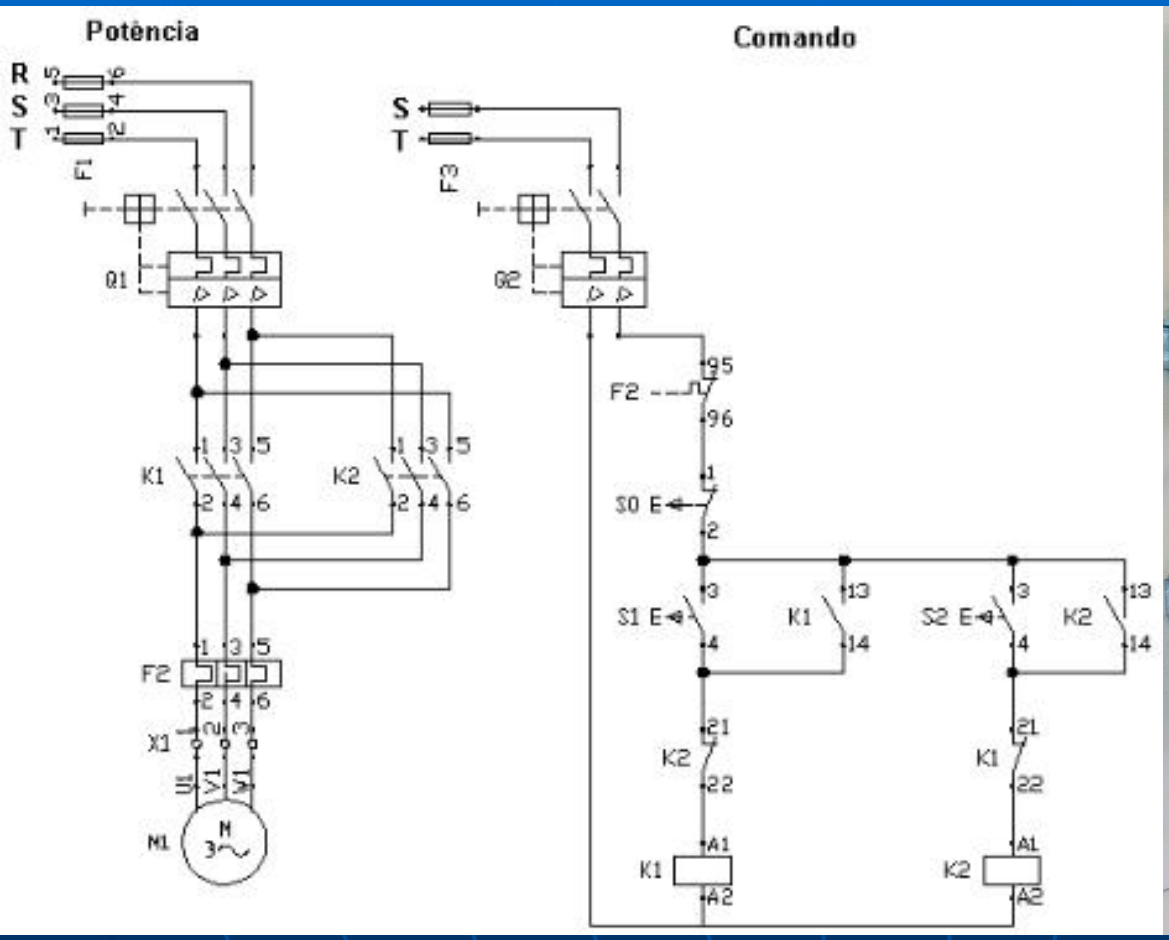
Automatic Control

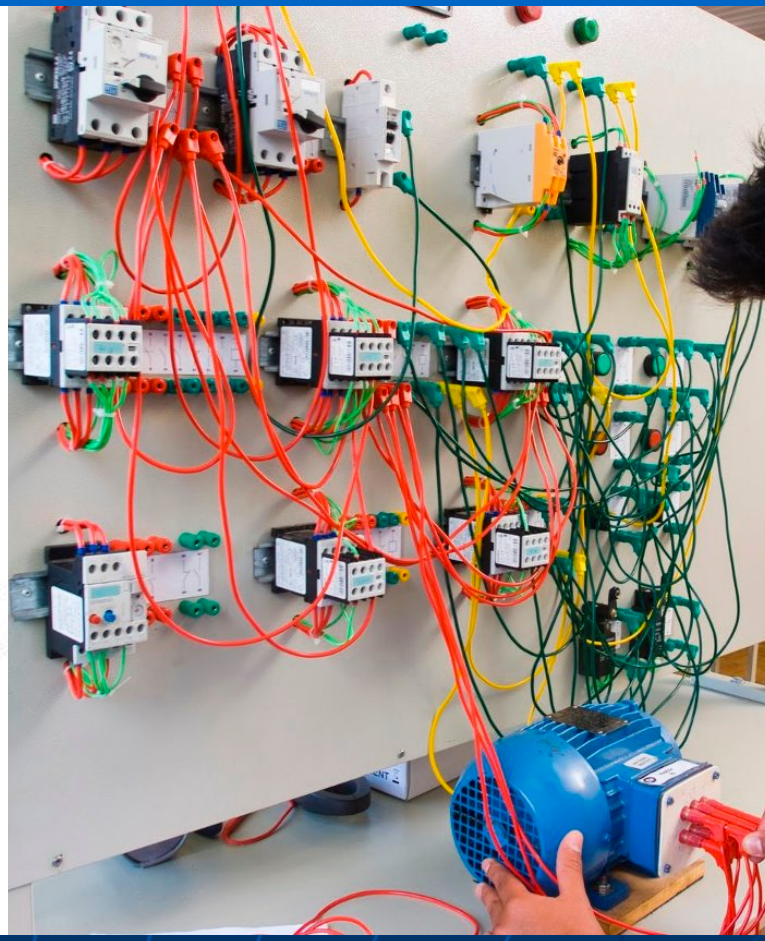
Keep a process variable at the reference value

"Compare reference and measured value then act"



Relay-Logic

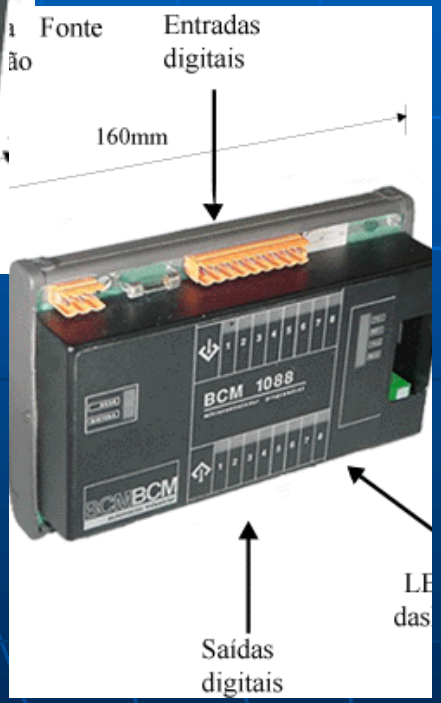

Potência
Comando
R
S
T
F1
Q1
K1
K2
F2
X1
M1
S
T
F3
Q2
F2
95
96
S0 E
S1 E
S2 E
K1
K2
A1
A2

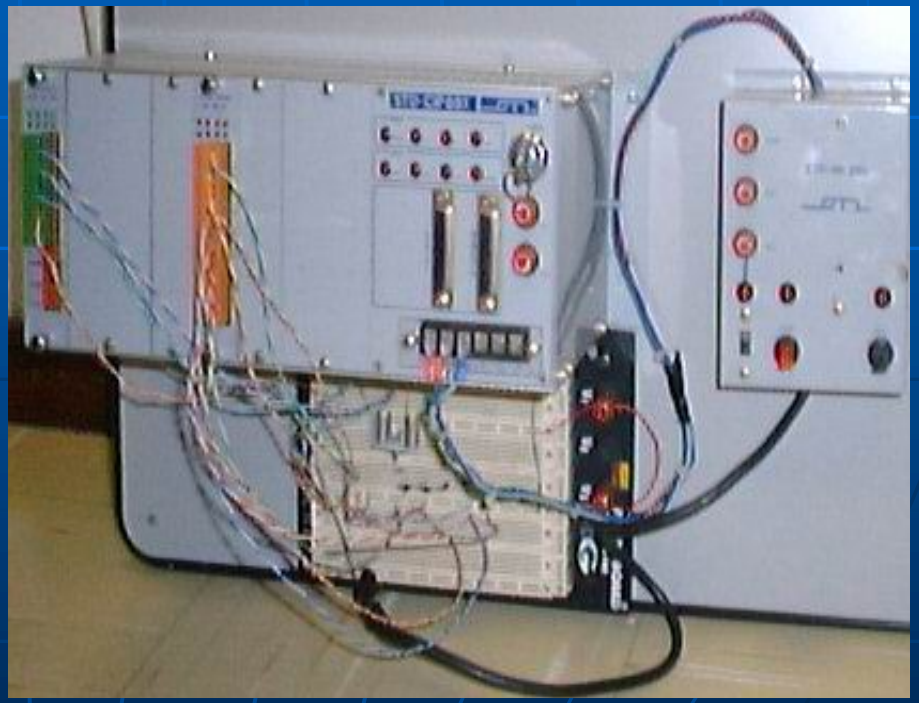


Some PLCs.br

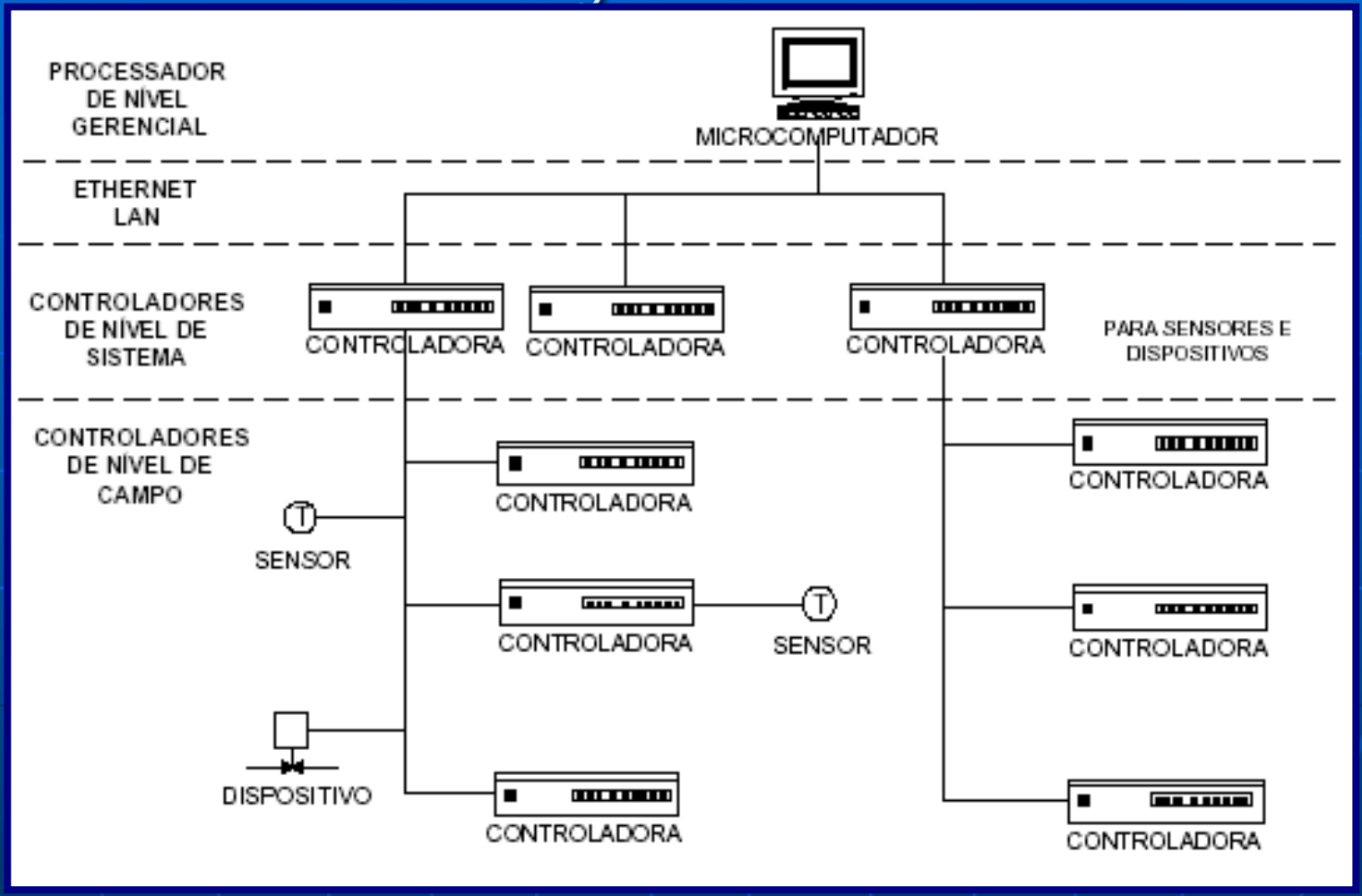

483,0mm


180mm


Fonte
Entradas digitais
160mm
BCM 1088
Saídas digitais



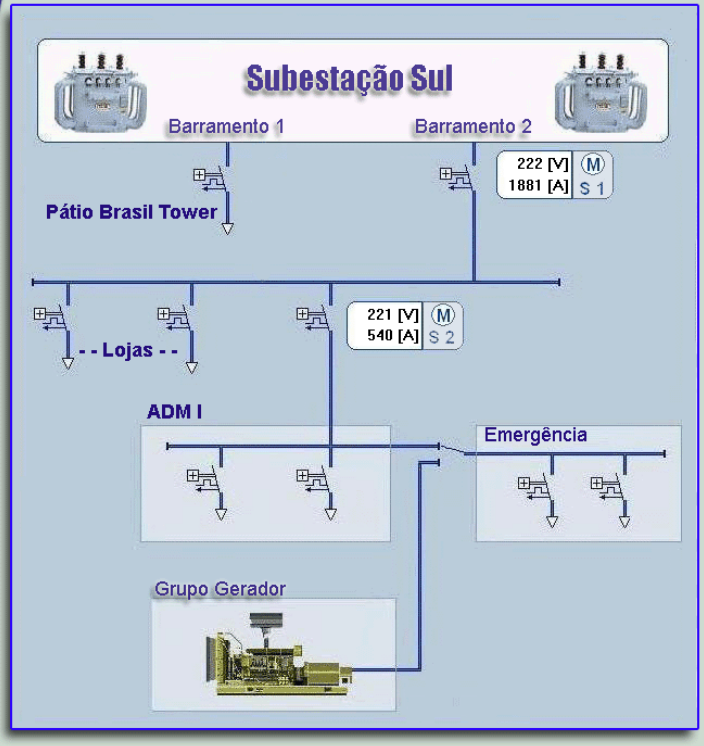
Automation System

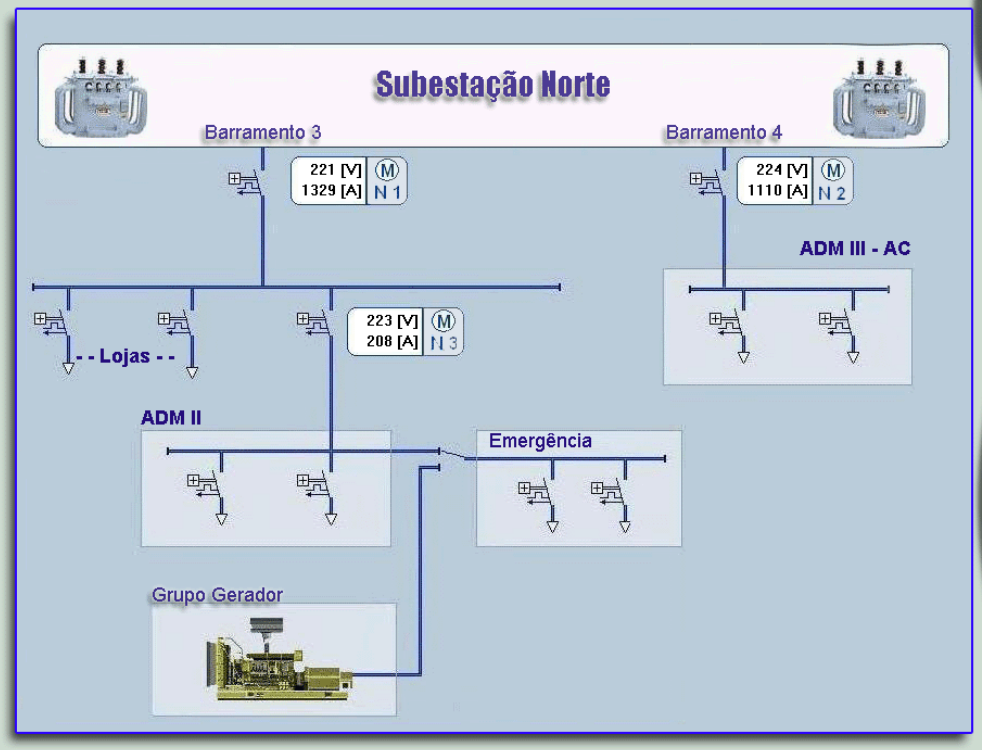


Energia Elétrica - Circuitos Alimentadores

PÁTIO BRASIL SHOPPING

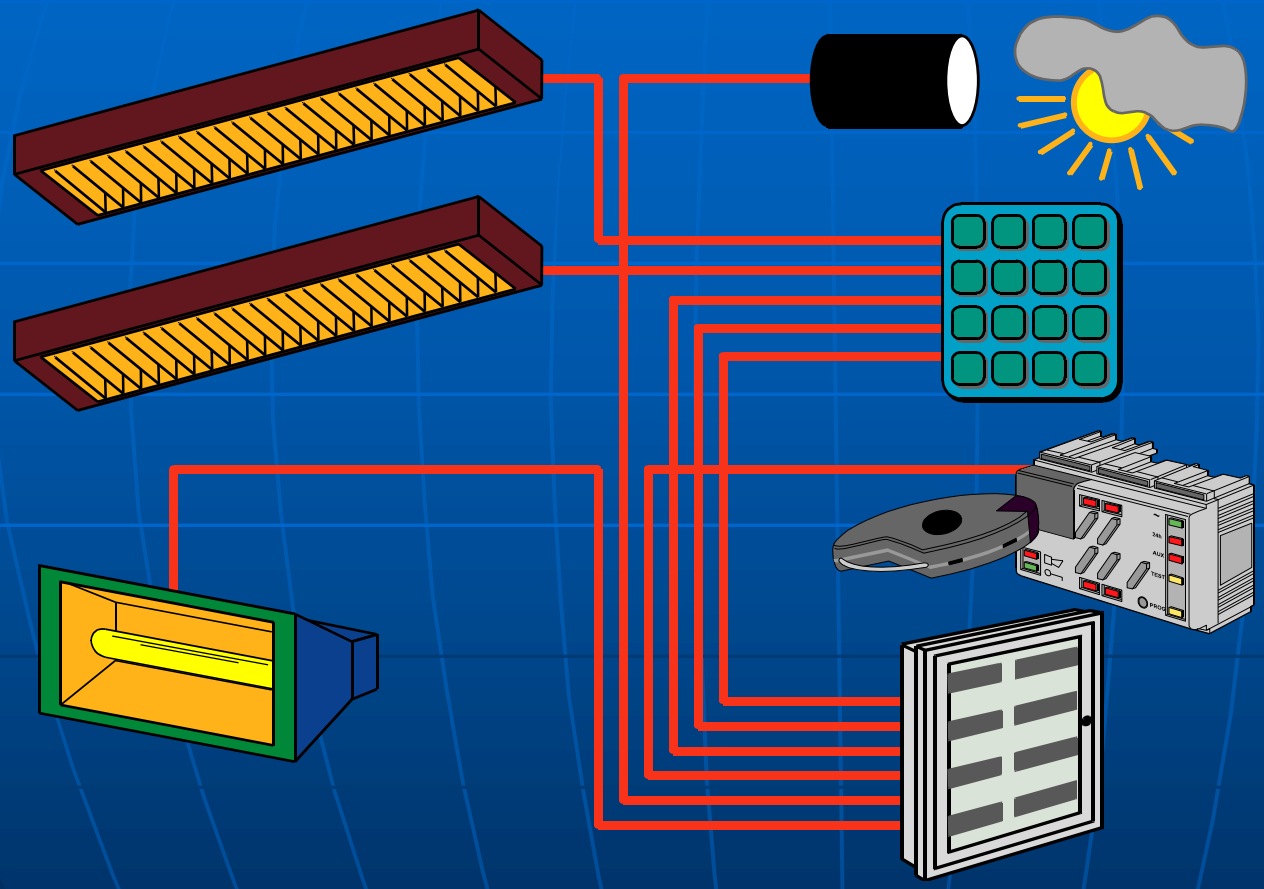
PRINCIPAL



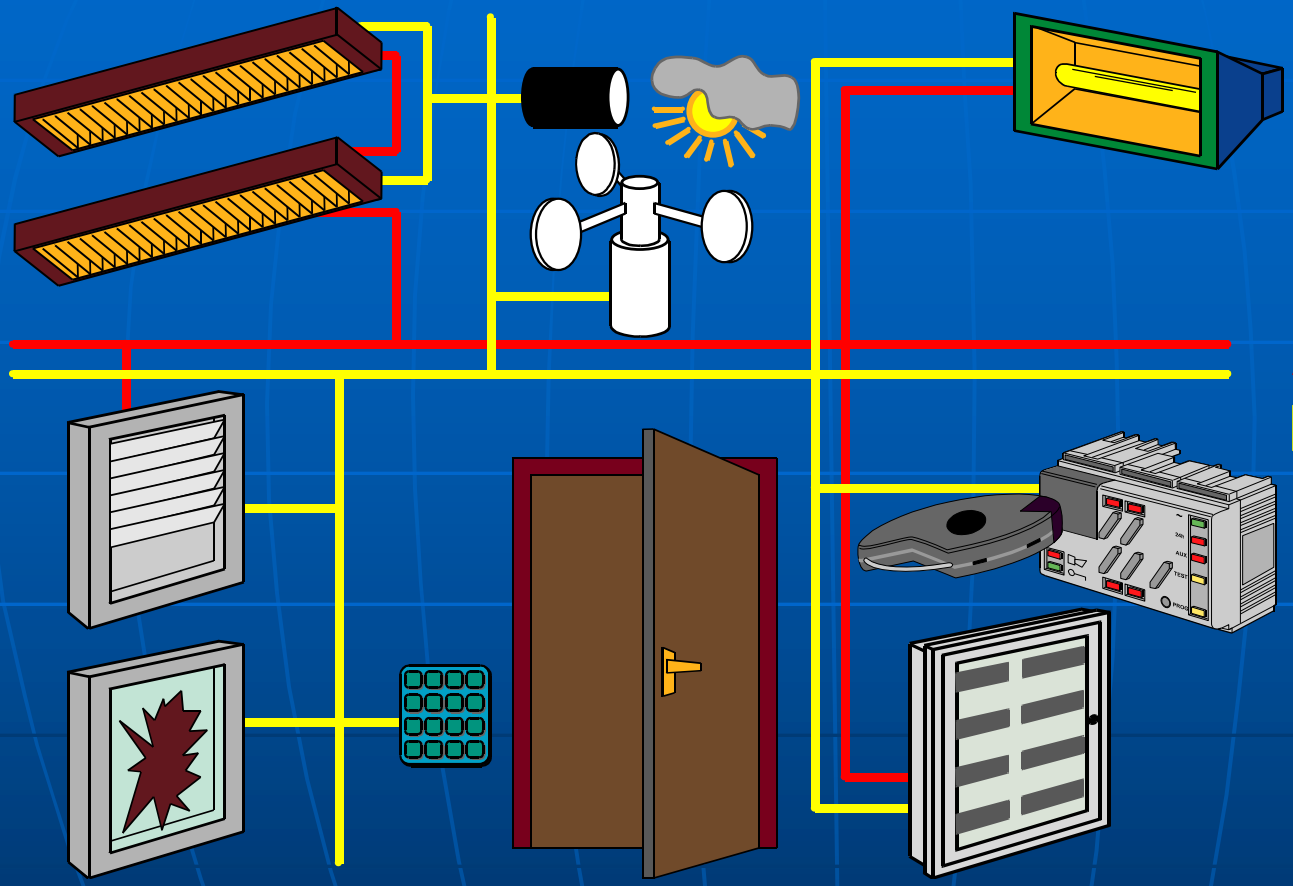


	Alimentador Sul - M S1				ADM I - Medidor M S2				Alimentador Norte - M N1				ADM II - Medidor M N3				ADM III (AC) - Medidor M N2			
	[V]	[A]	FP	[kW]	[V]	[A]	FP	[kW]	[V]	[A]	FP	[kW]	[V]	[A]	FP	[kW]	[V]	[A]	FP	[kW]
FASE R	220	1930	0,89	378130	220	589	0,83	107742	220	1027	0,80	180481	221	211	0,95	44343	224	1090	0,97	236051
FASE S	222	1841	0,88	358394	222	519	0,80	92869	221	1436	0,91	288350	224	184	1,00	41140	224	1161	0,95	248133
FASE T	222	1872	0,88	364930	222	511	0,79	89937	222	1526	0,90	305239	223	227	0,97	48998	225	1080	0,95	229506
MÉDIA	222	1881	0,88	101455	221	540	0,81	290548	221	1329	0,88	774071	223	208	0,97	134481	224	1110	0,96	713690

Traditional Connection



Bus Connection

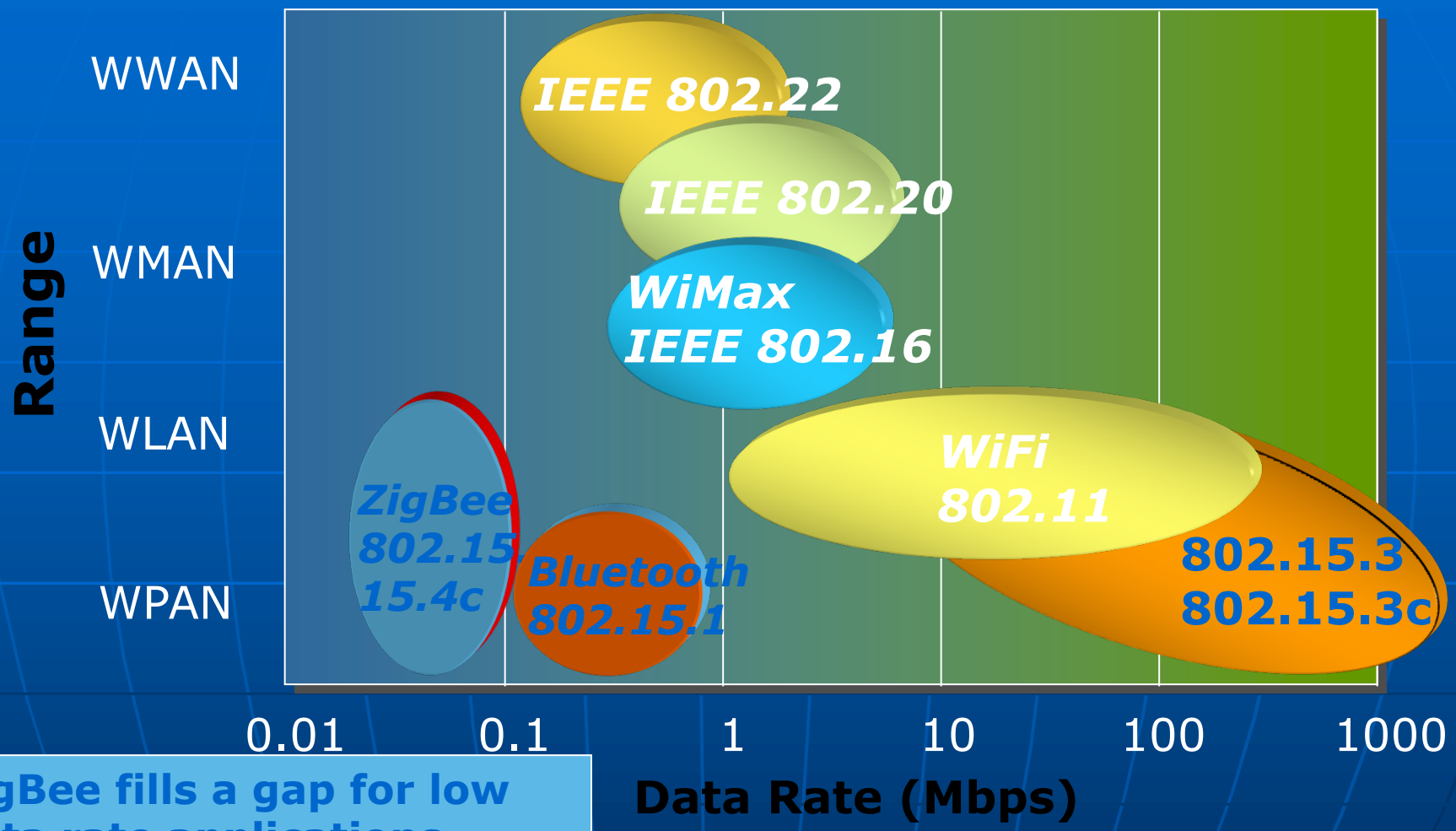


AC power line

Bus line

...wireless

The IEEE 802 Wireless Space



ZigBee fills a gap for low data rate applications

ZigBee Applications

BUILDING AUTOMATION

security
HVAC
AMR
lighting control
access control

CONSUMER ELECTRONICS

TV
VCR
DVD/CD
remote

PERSONAL HEALTH CARE

patient monitoring
fitness monitoring

PC & PERIPHERALS

mouse
keyboard
joystick

TELECOM SERVICES

m-commerce
info services
object interaction
(Internet of Things)

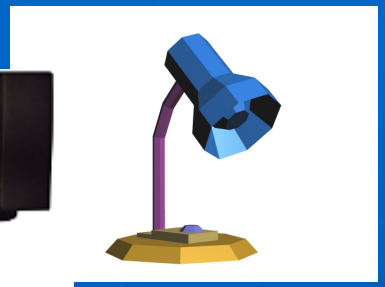
INDUSTRIAL CONTROL

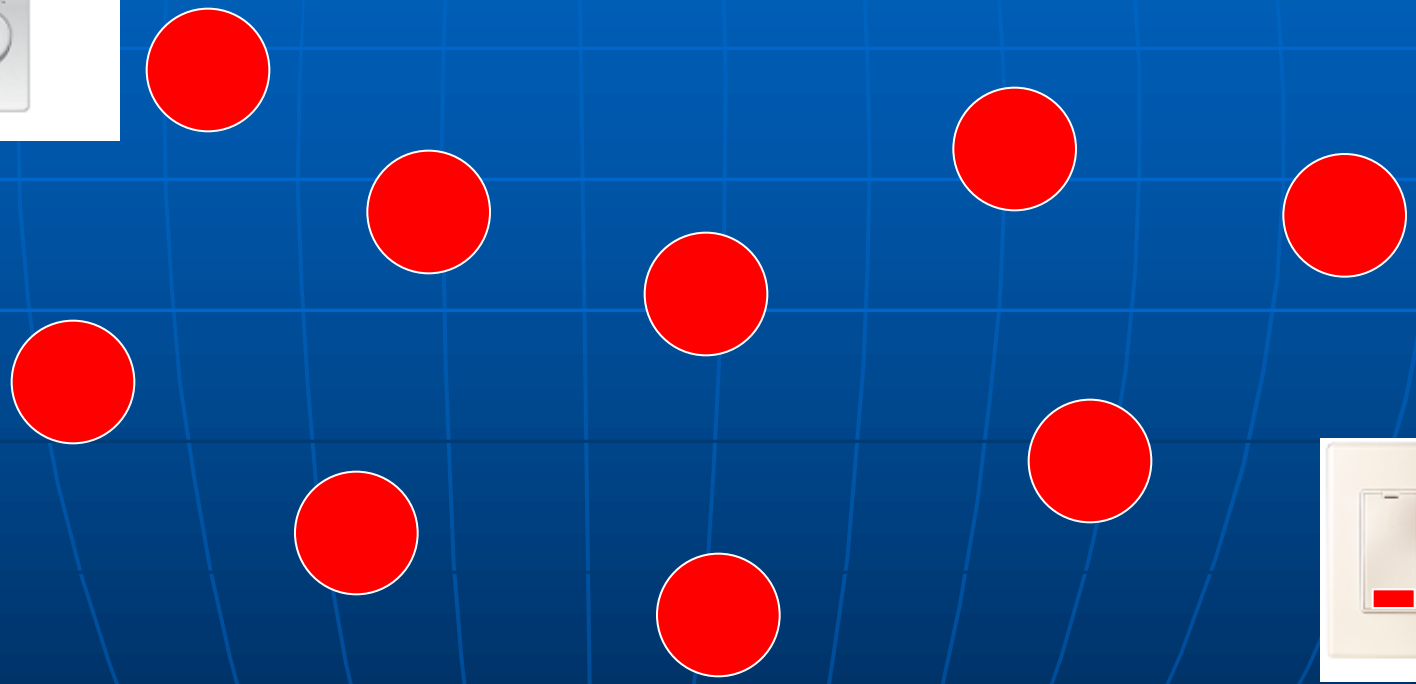
asset mgt
process control
environmental
energy mgt

HOME CONTROL

security
HVAC
lighting control
access control
irrigation

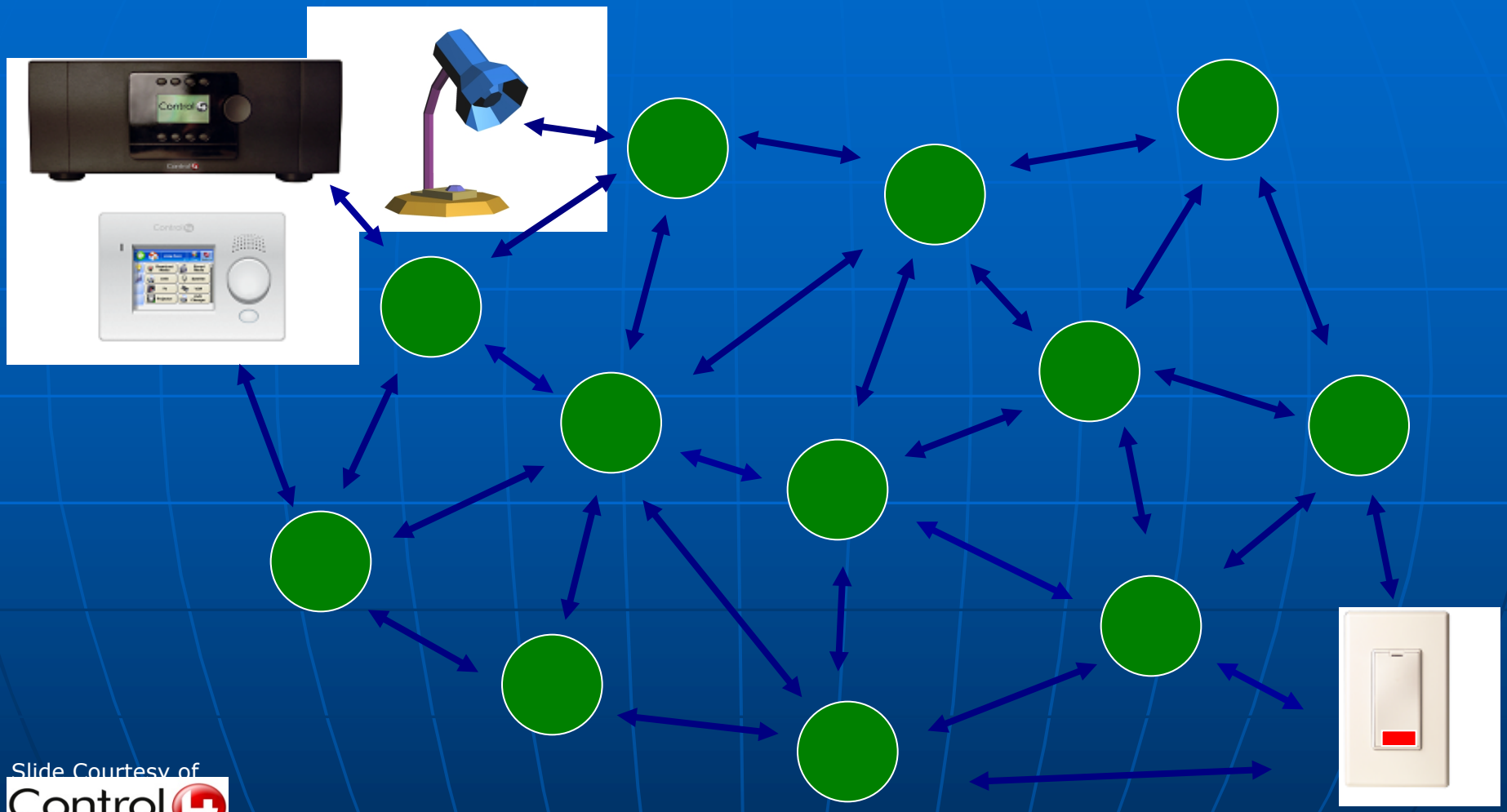
ZigBee Mesh Networking





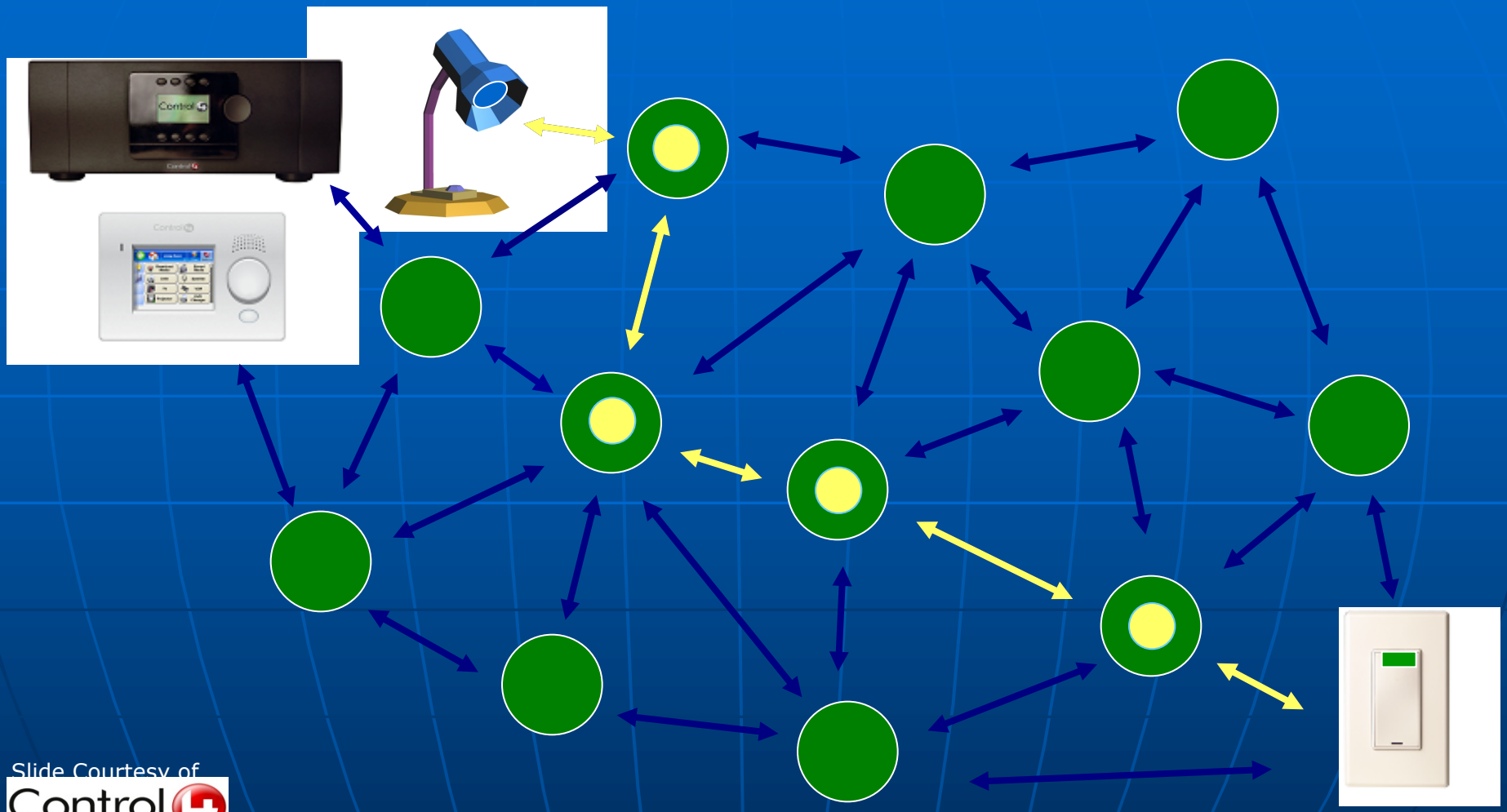
Slide Courtesy of

ZigBee Mesh Networking



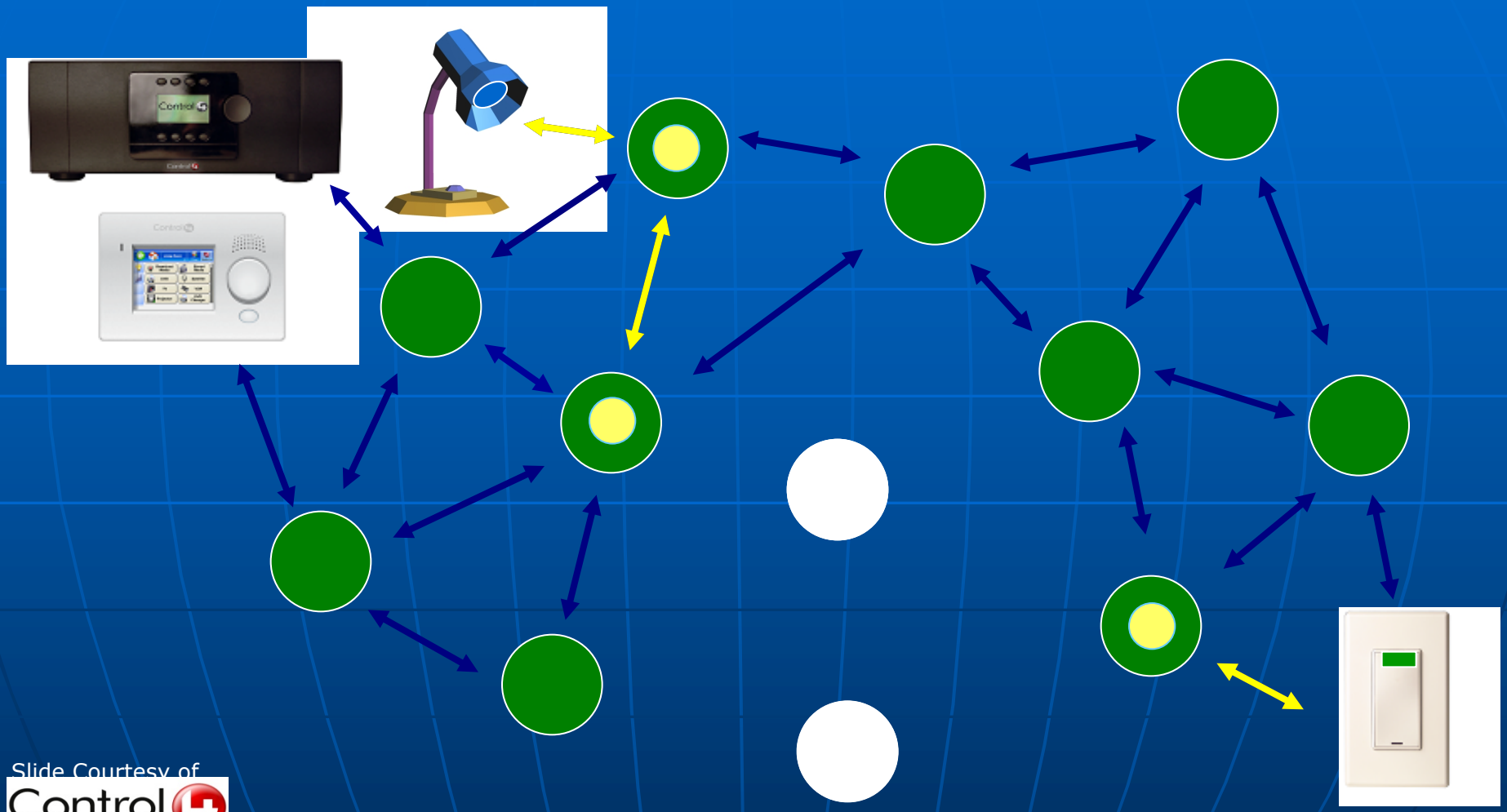
Slide Courtesy of

ZigBee Mesh Networking



Slide Courtesy of

ZigBee Mesh Networking



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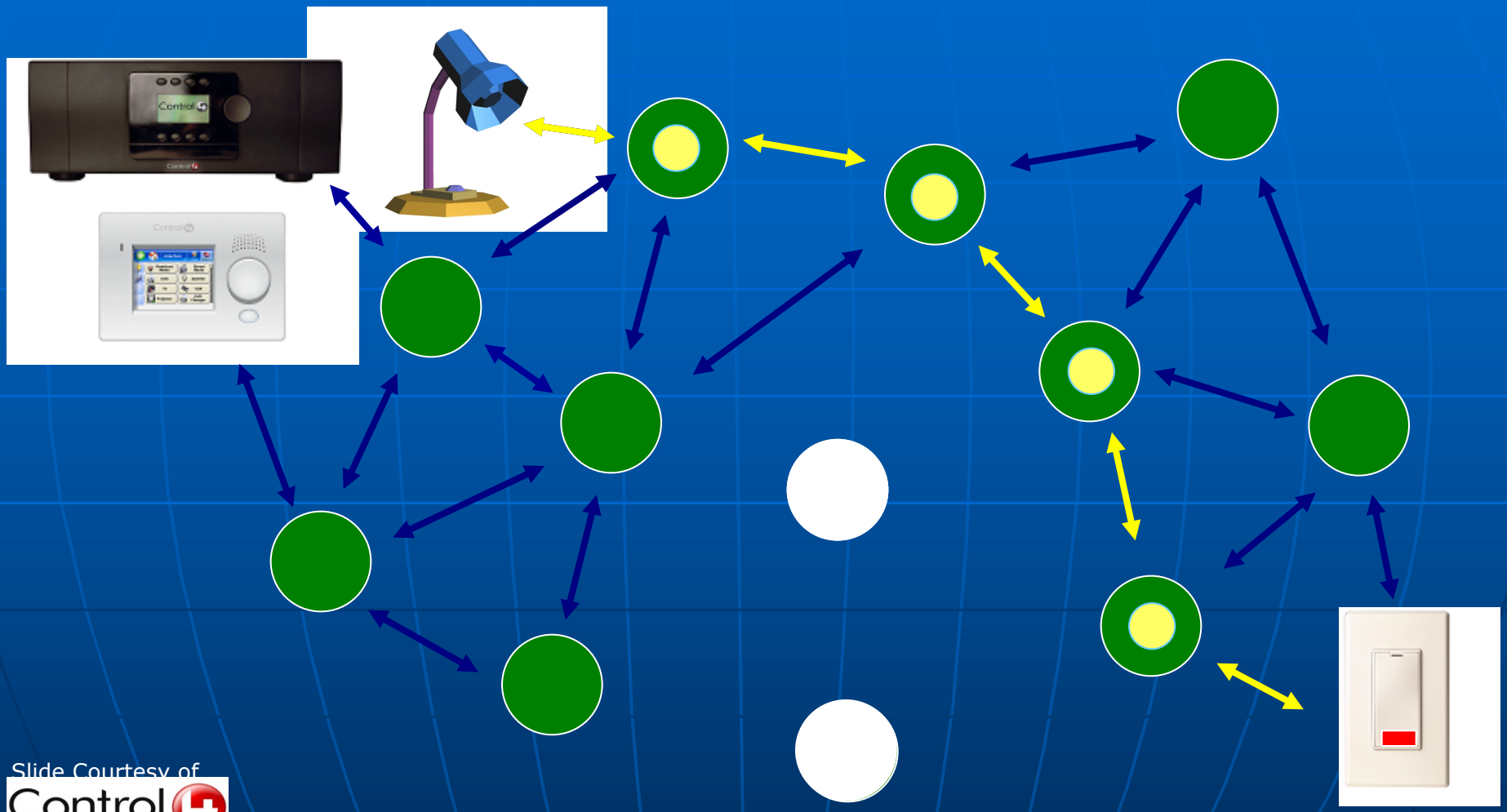
ZigBee Mesh Networking



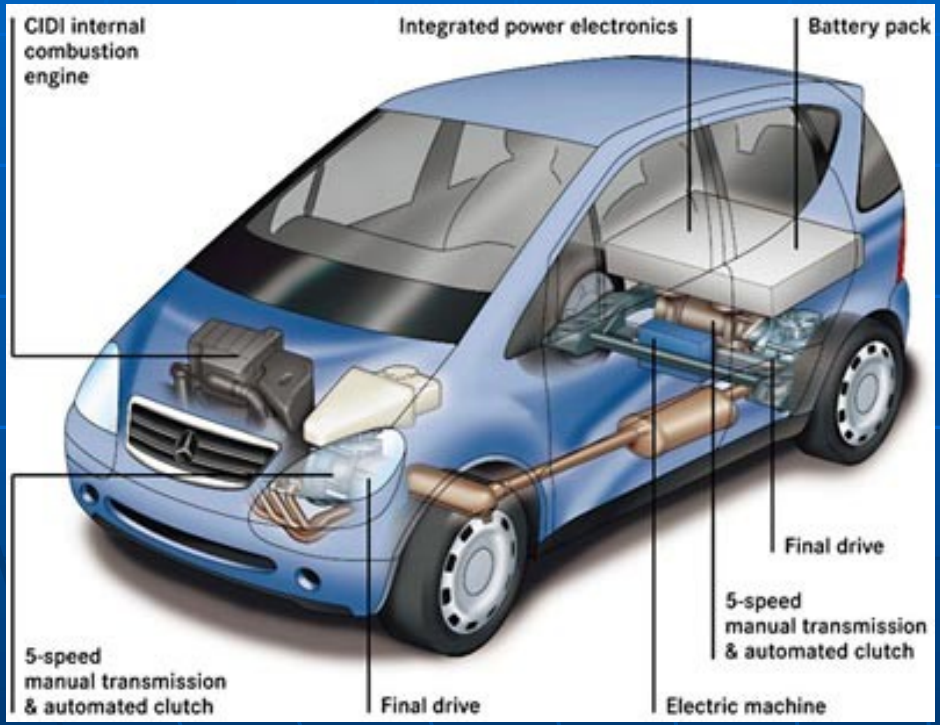
Slide Courtesy of

Control 4

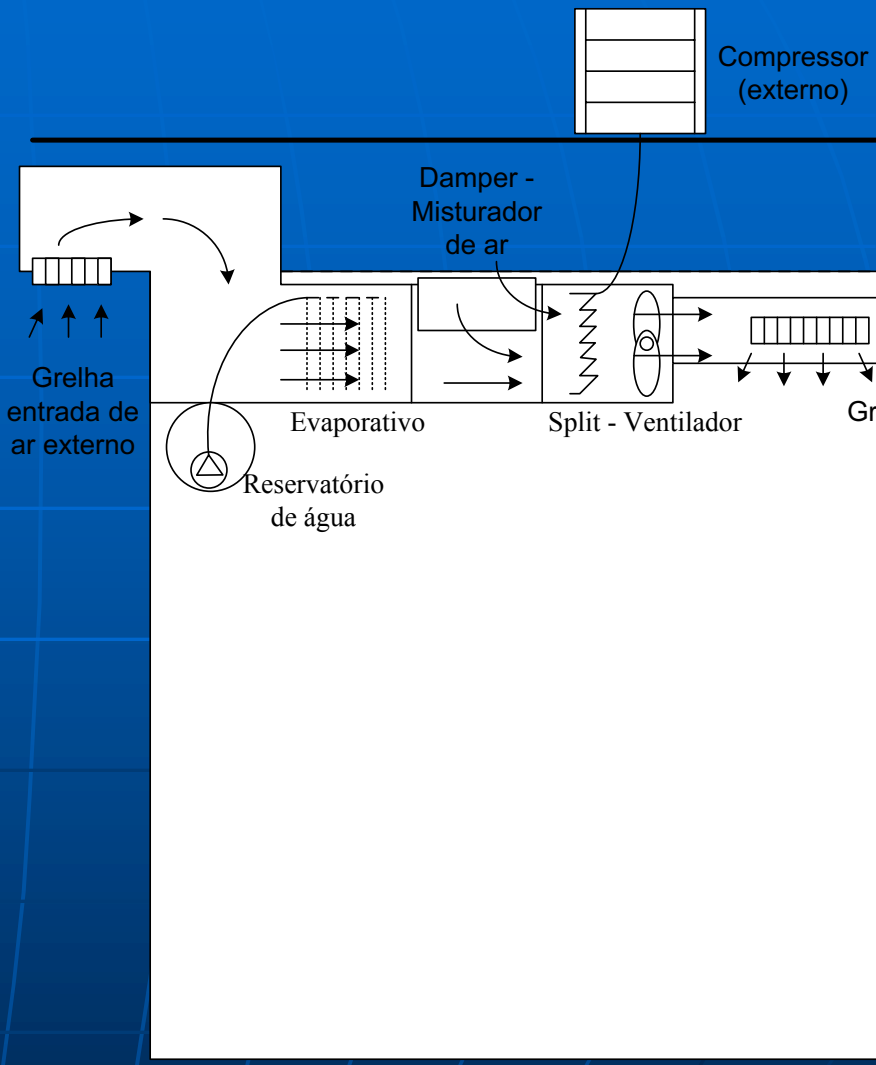
LARA

Energy Saving:

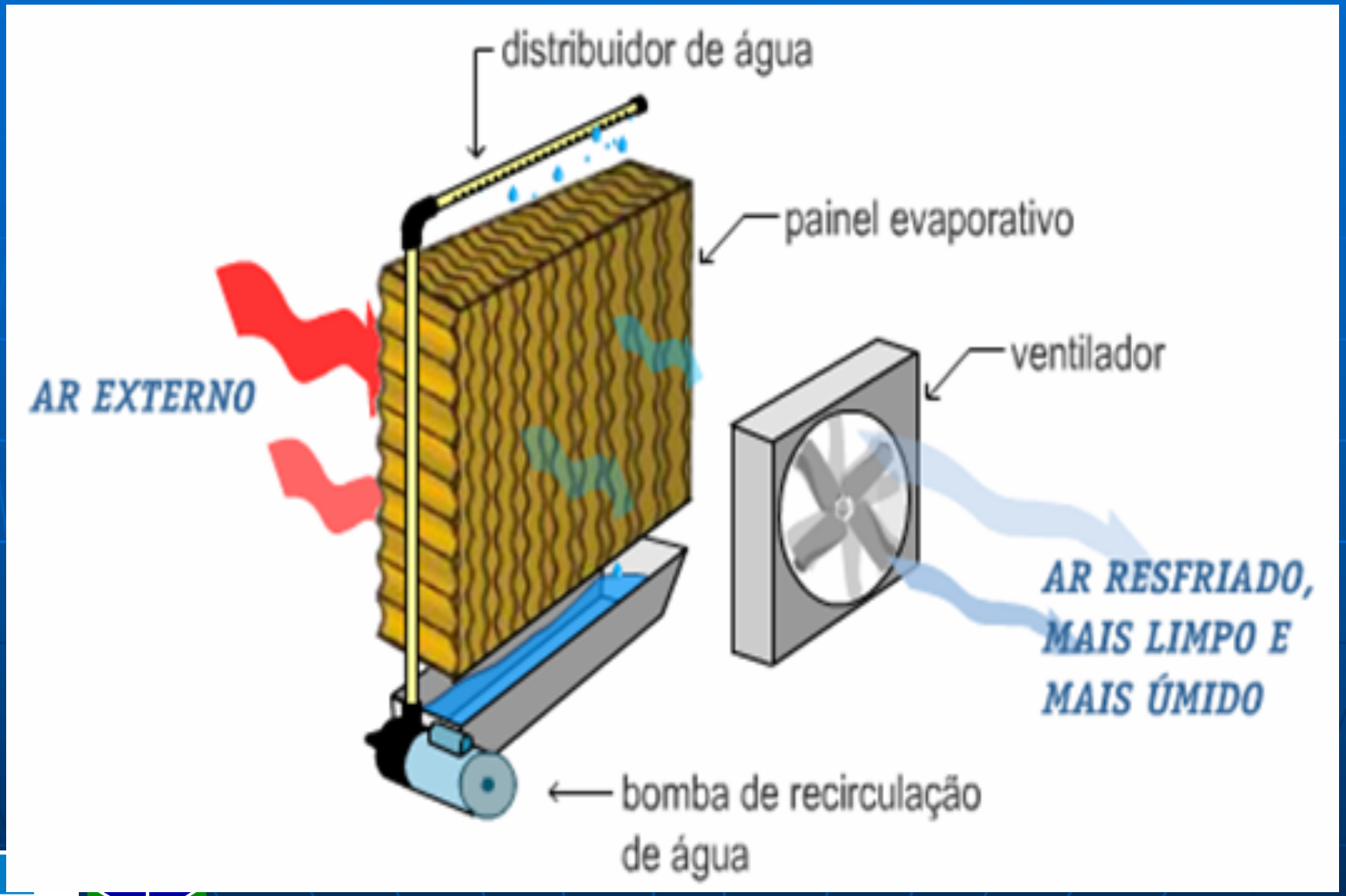
Hybrid Car



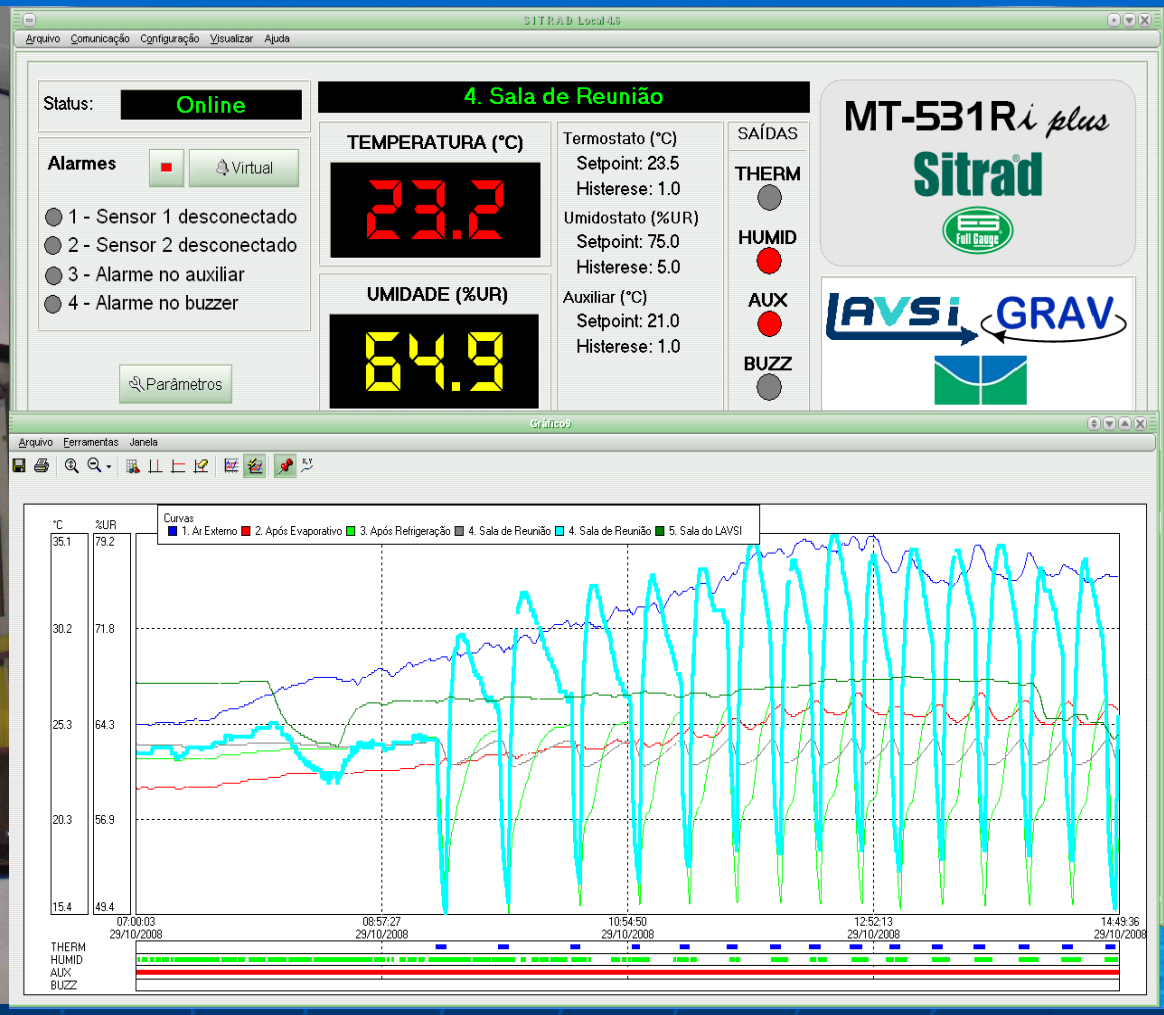
Hybrid Air Conditioner



Fundamentos – Resfriamento evaporativo



Hybrid Climatization: Evaporative-Conventional



M.Sc José Luis Olmos Flores, 2009

Análise de dados – Tela do *Software Sitrad*

SITRAD Local 4.6

Arquivo Comunicação Configuração Visualizar Ajuda

Status: **Online**

4. Sala de Reunião

Alarmes Virtual

- 1 - Sensor 1 desconectado
- 2 - Sensor 2 desconectado
- 3 - Alarme no auxiliar
- 4 - Alarme no buzzer

Parâmetros

TEMPERATURA (°C): 21.2

UMIDADE (%UR): 58.4

Termostato (°C)
Setpoint: 22.5
Histerese: 1.0

Umidostato (%UR)
Setpoint: 65.0
Histerese: 5.0

Auxiliar (°C)
Setpoint: 20.0
Histerese: 1.0

SAÍDAS: THERM, HUMID, AUX, BUZZ

MT-531Ri plus
Sitrad
Full Gauge

LAVSI GRAV

Unidade em destaque: 4. Sala de Reunião

Cadastrados: 5
Em Operação: 5

Histórico | Agenda | Desligar

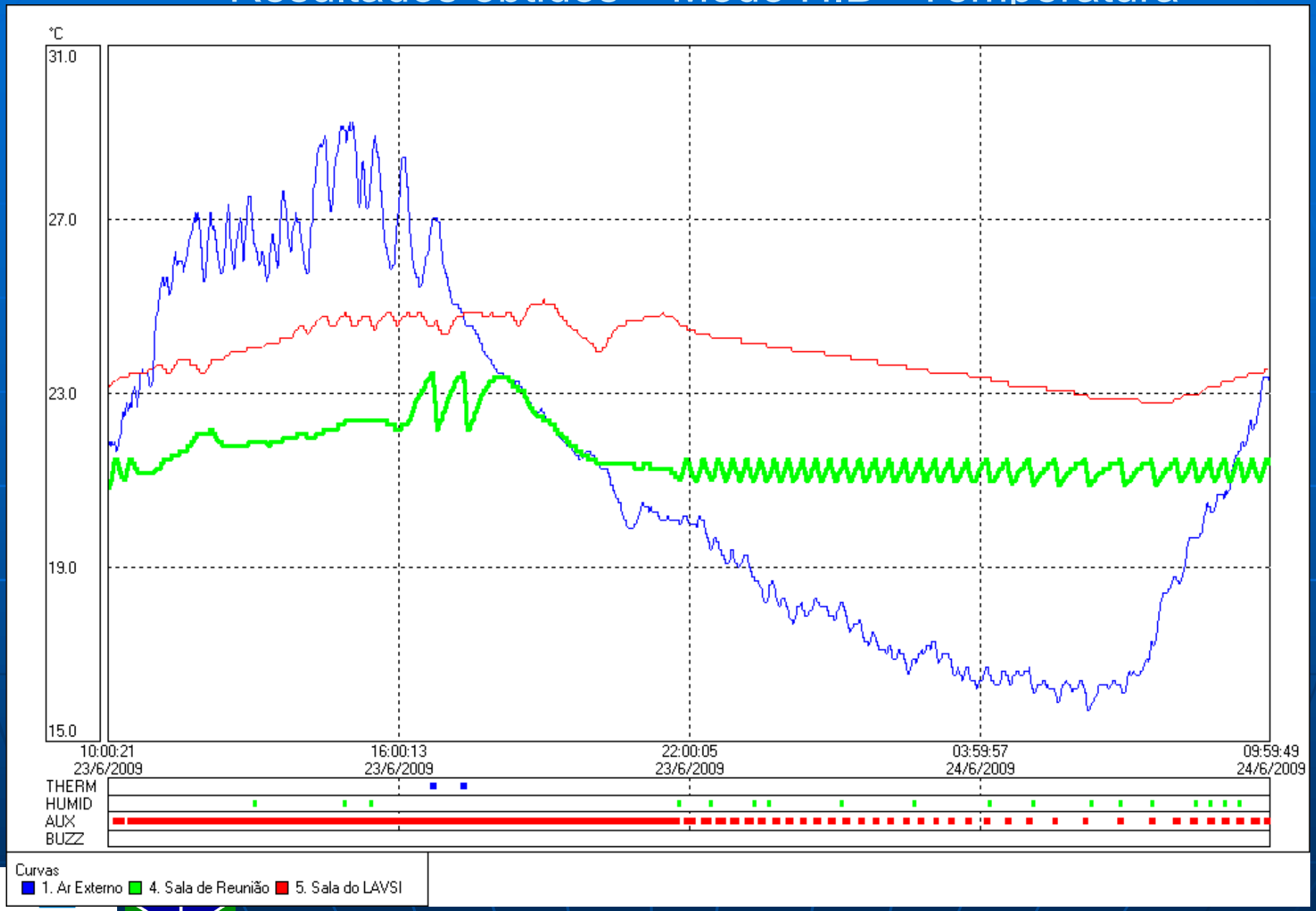
MT-531Ri plus

End	Descrição	Temper.	Umidade	THERM	HUMID	AUX	BUZZ	Alarmes	Status
001	1. Ar Externo	23.9	40.6	Desl	Desl	Desl	Desl	- - - -	Online
002	2. Após Evaporativo	18.5	79.3	Desl	Desl	Desl	Desl	- - - -	Online
003	3. Após Refrigeração	19.8	64.2	Desl	Desl	Desl	Desl	- - - -	Online
004	4. Sala de Reunião	21.2	58.4	Desl	Desl	Lig	Desl	- - - -	Online
005	5. Sala do LAVSI	23.4	53.2	Desl	Desl	Desl	Desl	- - - -	Online

Espaço livre em (C:) : 132.83 GB | Tamanho do banco de dados: 1.05 MB

Iniciar | Sitrad Local | José Luis - documentos | Relatórios 22052009 ...

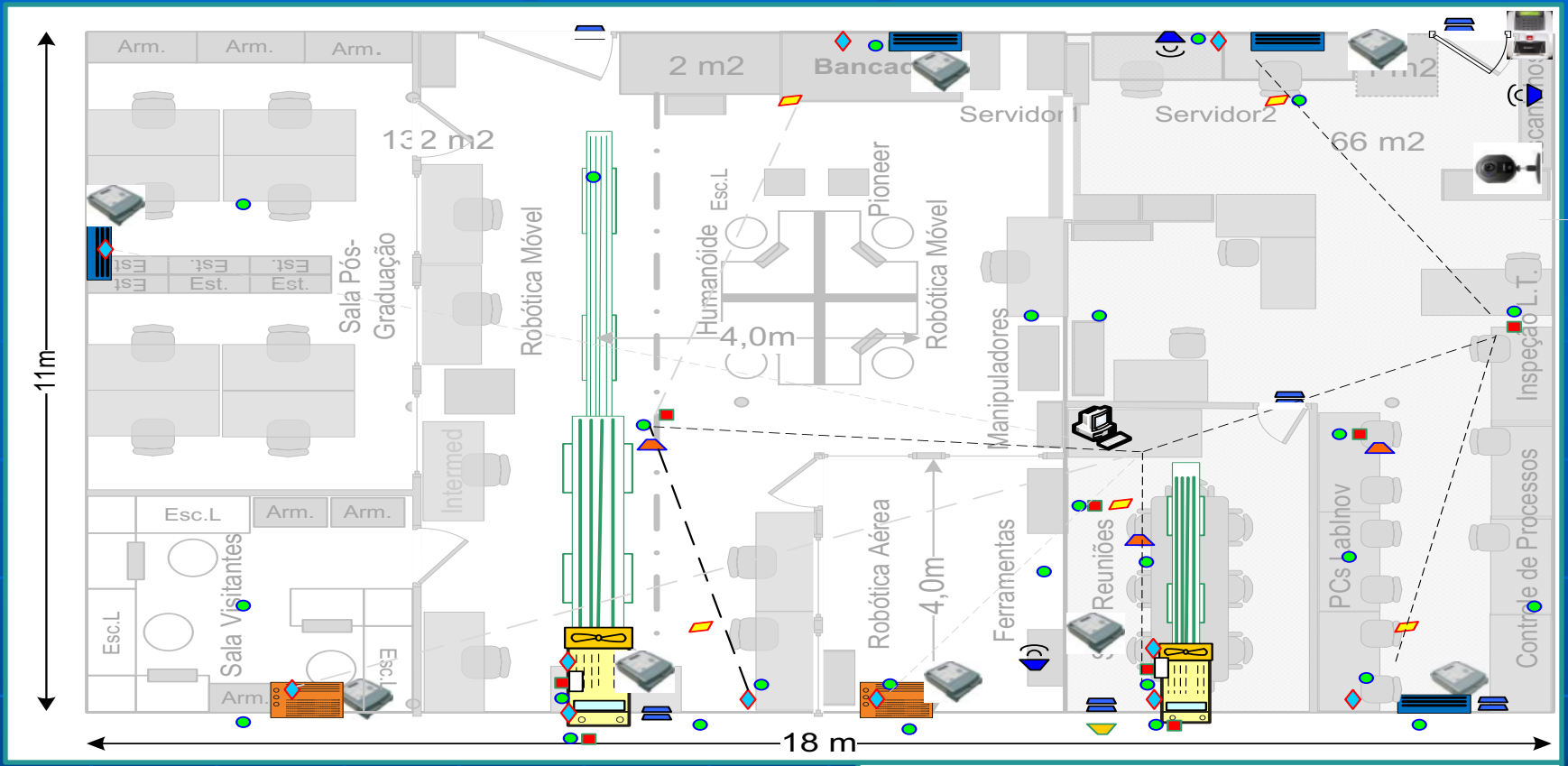
Resultados obtidos – Modo HIB - Temperatura



Análise de dados – Consumo de energia elétrica – 24 h.

Modo de Operação	Tempo operação Ventilador	Tempo operação Bomba	Tempo operação Compressor	Consumo total de Energia	Observações
DESL	00h00m00s	00h00m00s	00h00m00s	**0,17 kWh**	Muito Baixo
VENT	22h15m45s	00h00m00s	00h00m00s	**2,23 kWh**	Normal
EVAP	13h52m54s	00h29m42s	00h00m00s	**1,36 kWh**	Normal
REF	22h58m08s	00h00m00s	01h49m57s	**5,92 kWh**	Alto
HIB	14h56m31s	00h28m40s	00h09m02s	**1,95 kWh**	Normal

Intelligent Building Automation



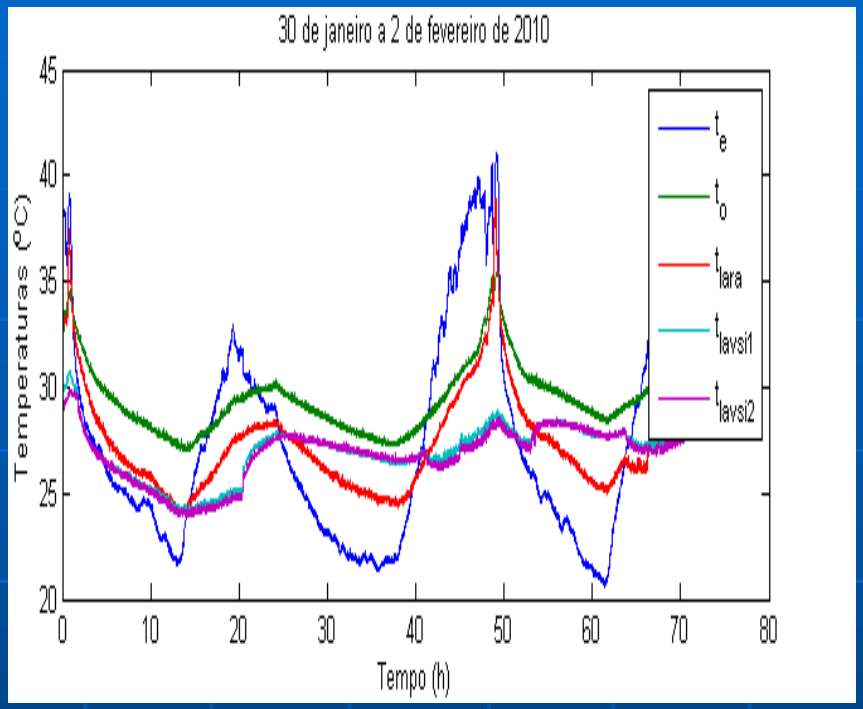
Laboratório de Automação e Robótica - ENE/UnB

- Sensor de Temperatura
- Sensor de Umidade
- Anemômetro
- Sensor Radiação Térmica Média
- Piranômetro
- Atuador Ar Cond.
- Detector de Presença
- Detector Porta/Janela aberta
- Medidor de Energia
- Camera de Vigilância
- Controle de Acesso
- BAS - Building Automation System

mobile Thermal Comfort sensor module

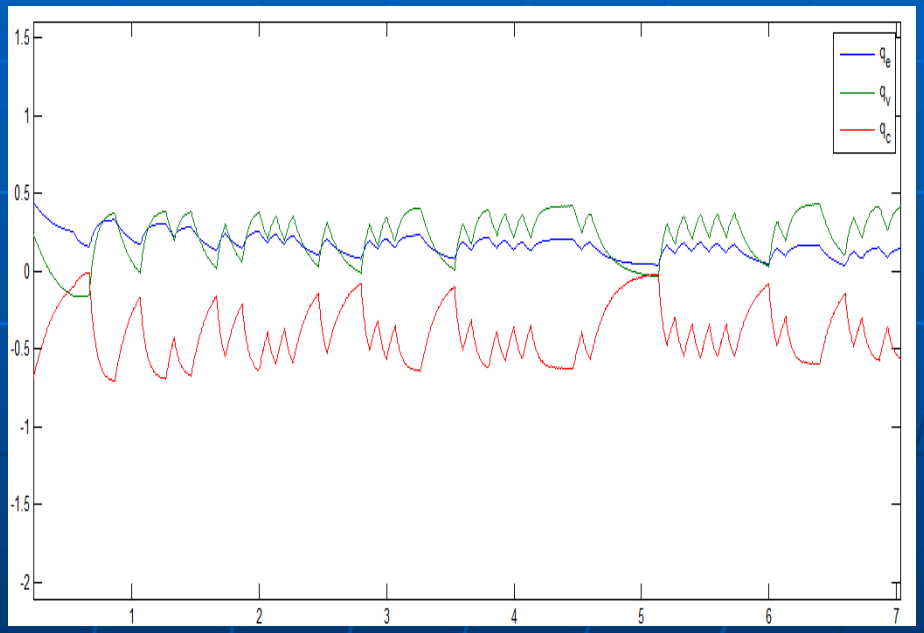
LARA/UnB - First-Principles Identification

M.Sc. Flávio Augusto R. de Oliveira, 2010



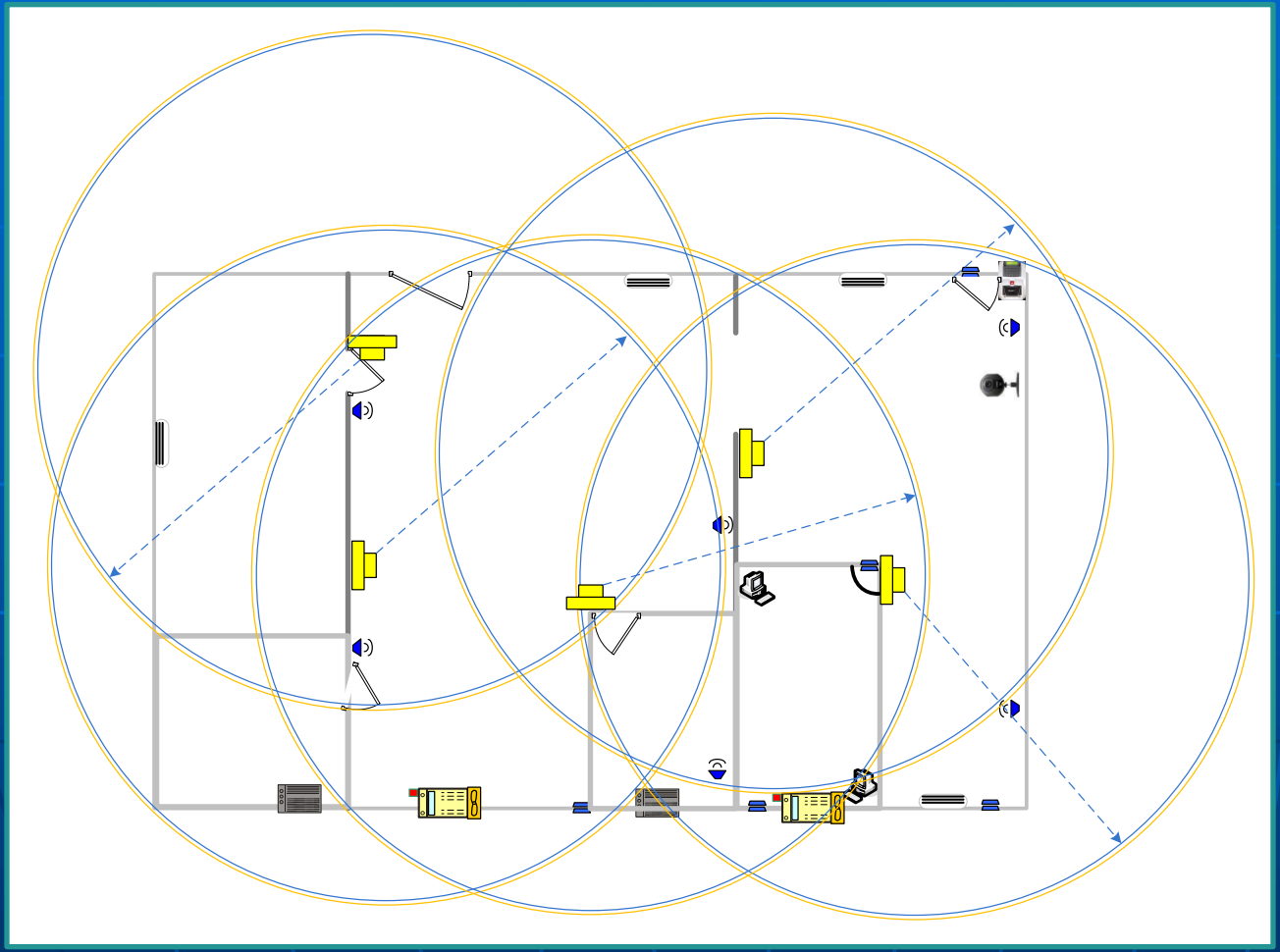
Measured identification data

I	e	v	c
a_i	220	321.3	175.4
K_i	0.035	0.095	0.241



Estimated heat and colling flow

RFID occupancy identification for thermal load estimation



Eng. Josué Souza & Eng. Ariel Souza, 2011

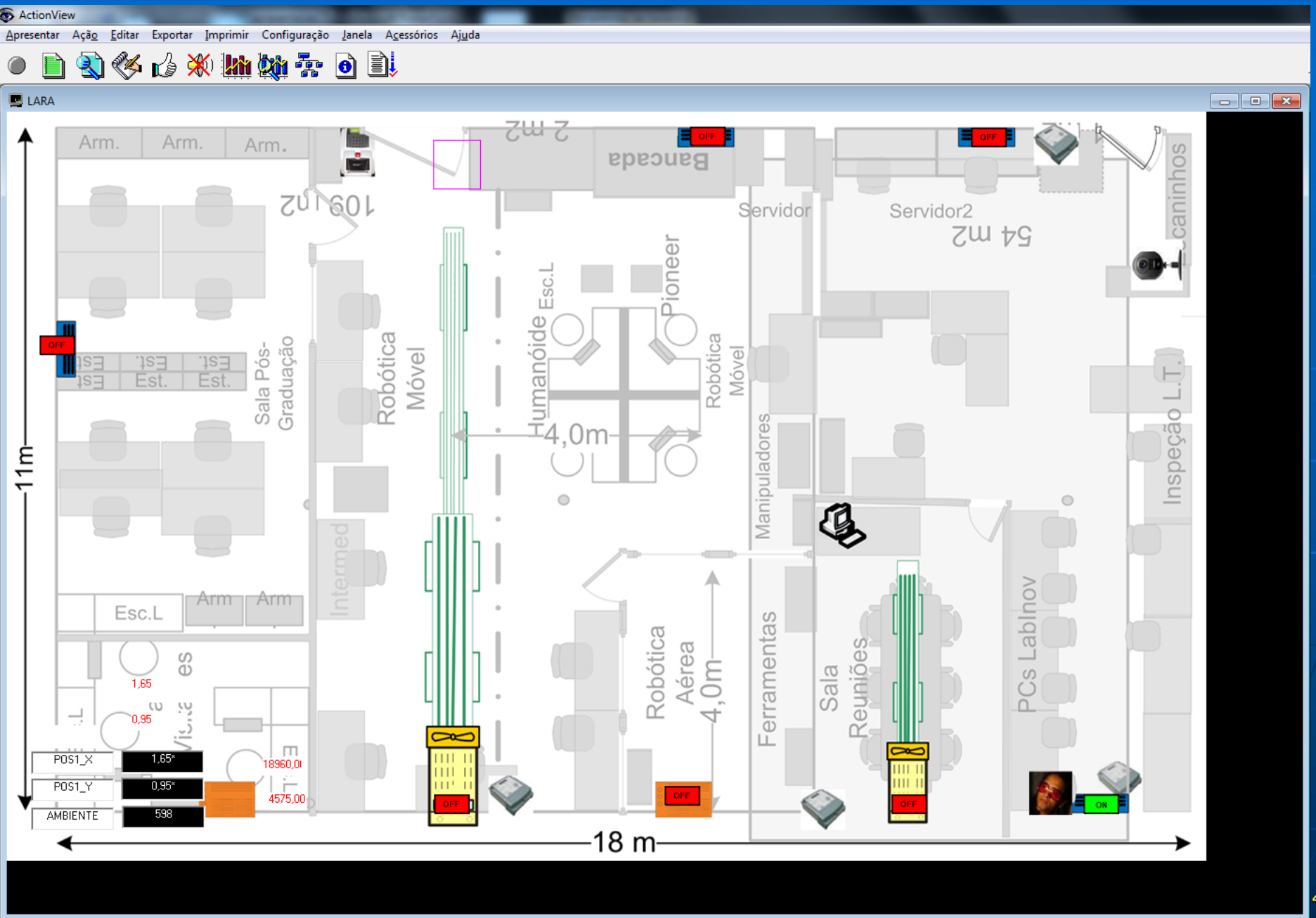
Active Tags

- Battery
- Microcontroller
- Motion Detector

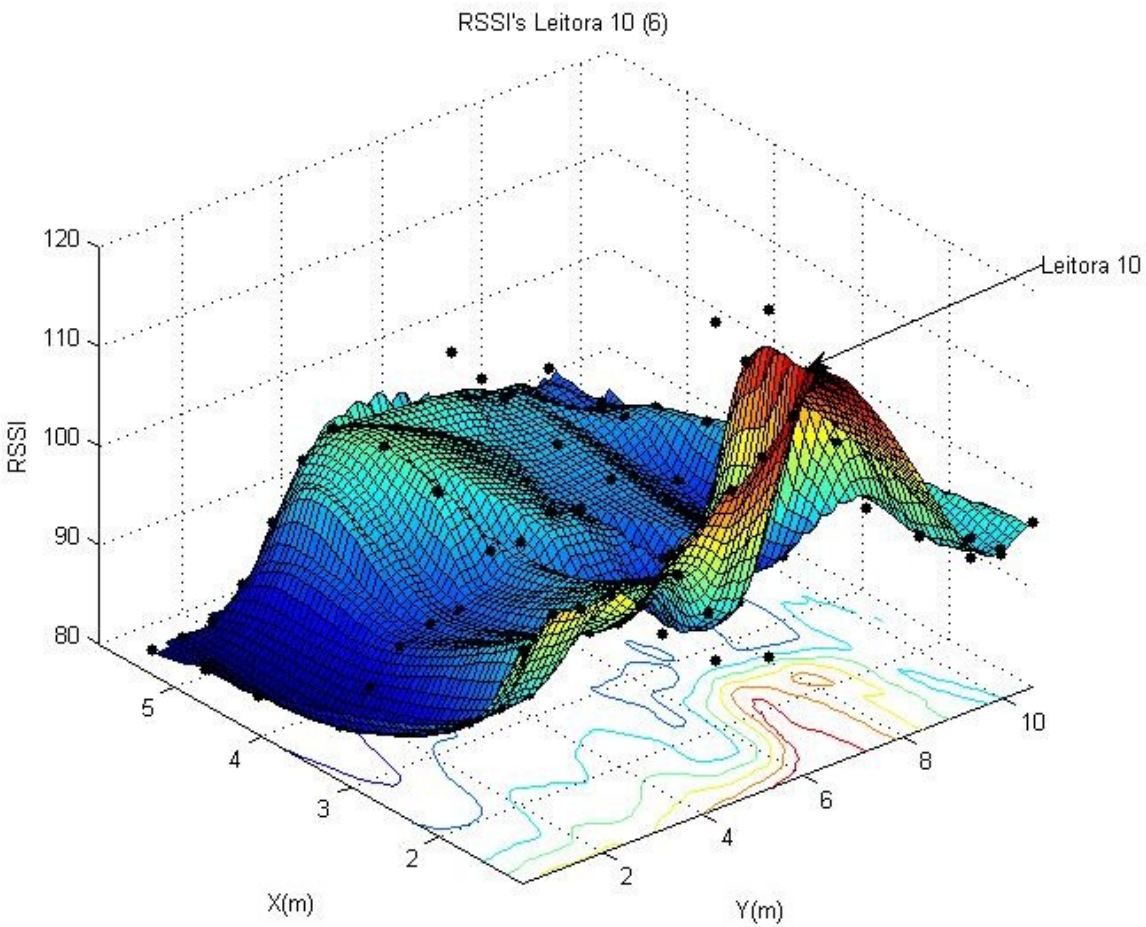
Send 39 bytes; used in this work:

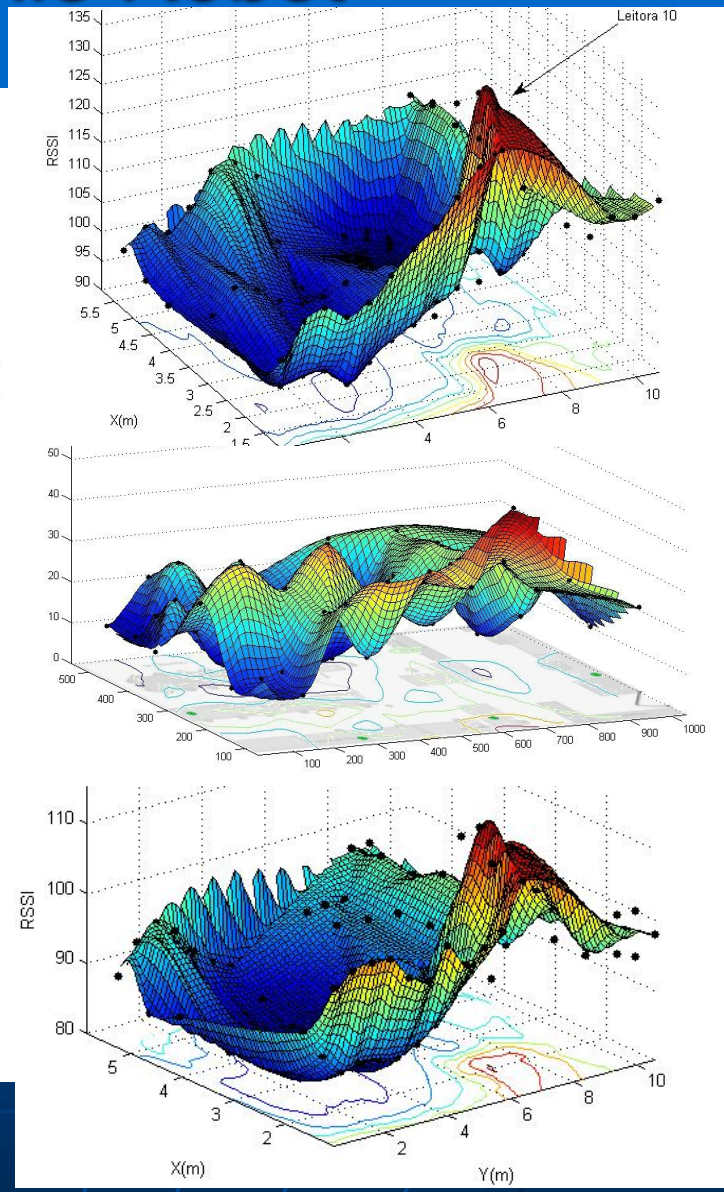
TagID	• Unique tag Identity
Age	• Tag age, since assembled
RSSI	• Received Signal Strength Indicator
Interval	• Interval: 1.5 s (motion)/ 30 s (rest)

Actionview Runtime Screen



RSSI Mapping –
Data collected by Aramis Mobile Robot





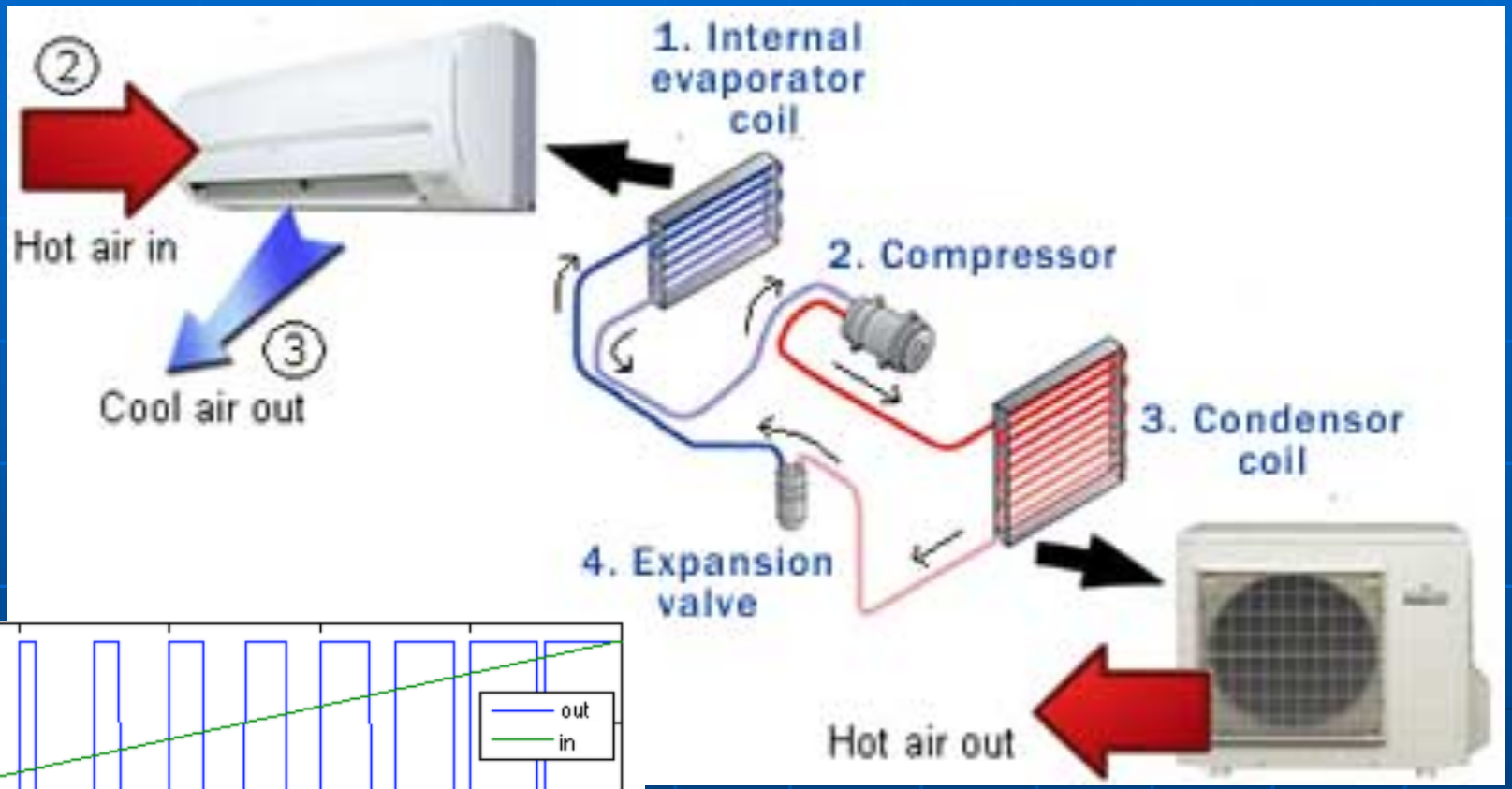
Energy Saving of Adaptive Thermal Control for PWM Driven Air-Conditioners

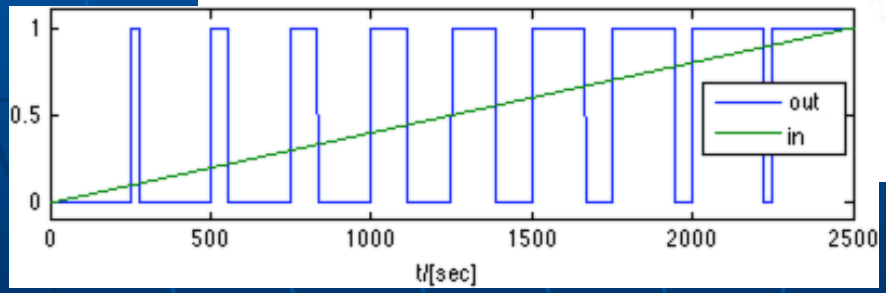
Enga. Marcella Cortat Campos Melo
Eng. Heyder Antonio Silva de Araújo
2014

- Variable Dynamics
  - Occupancy
  - External Temperature/Humidity
  - Activity
  - Season/Clothing

- Adaptive approach
  - Process Instrumentation
  - Recursive Identification

PWM for split air conditioner



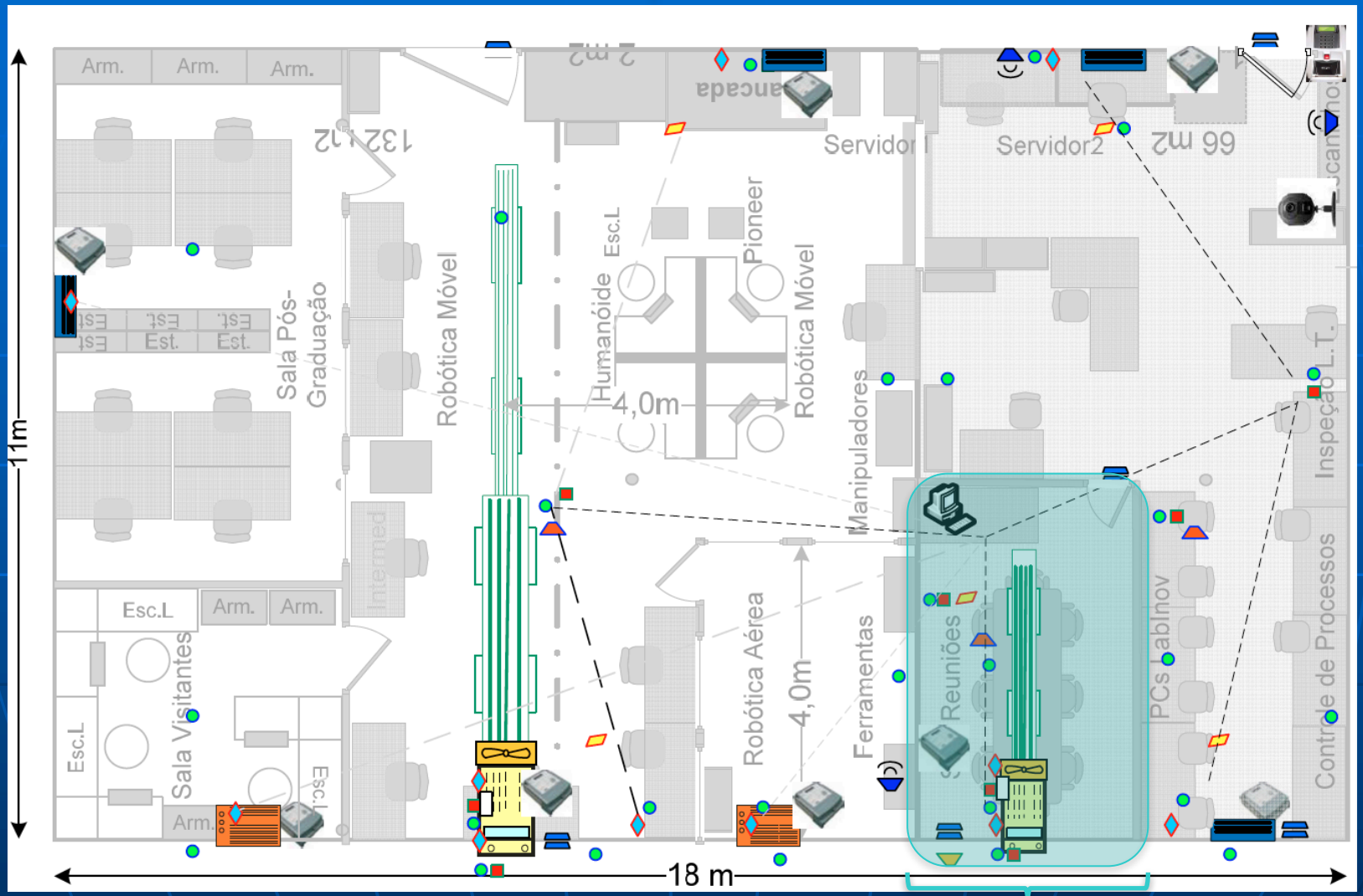


PWM *duty cycle* = 220 *s*

(adapted from airintelligence.co)

Adapitve Control
TEST ENVIRONMENT

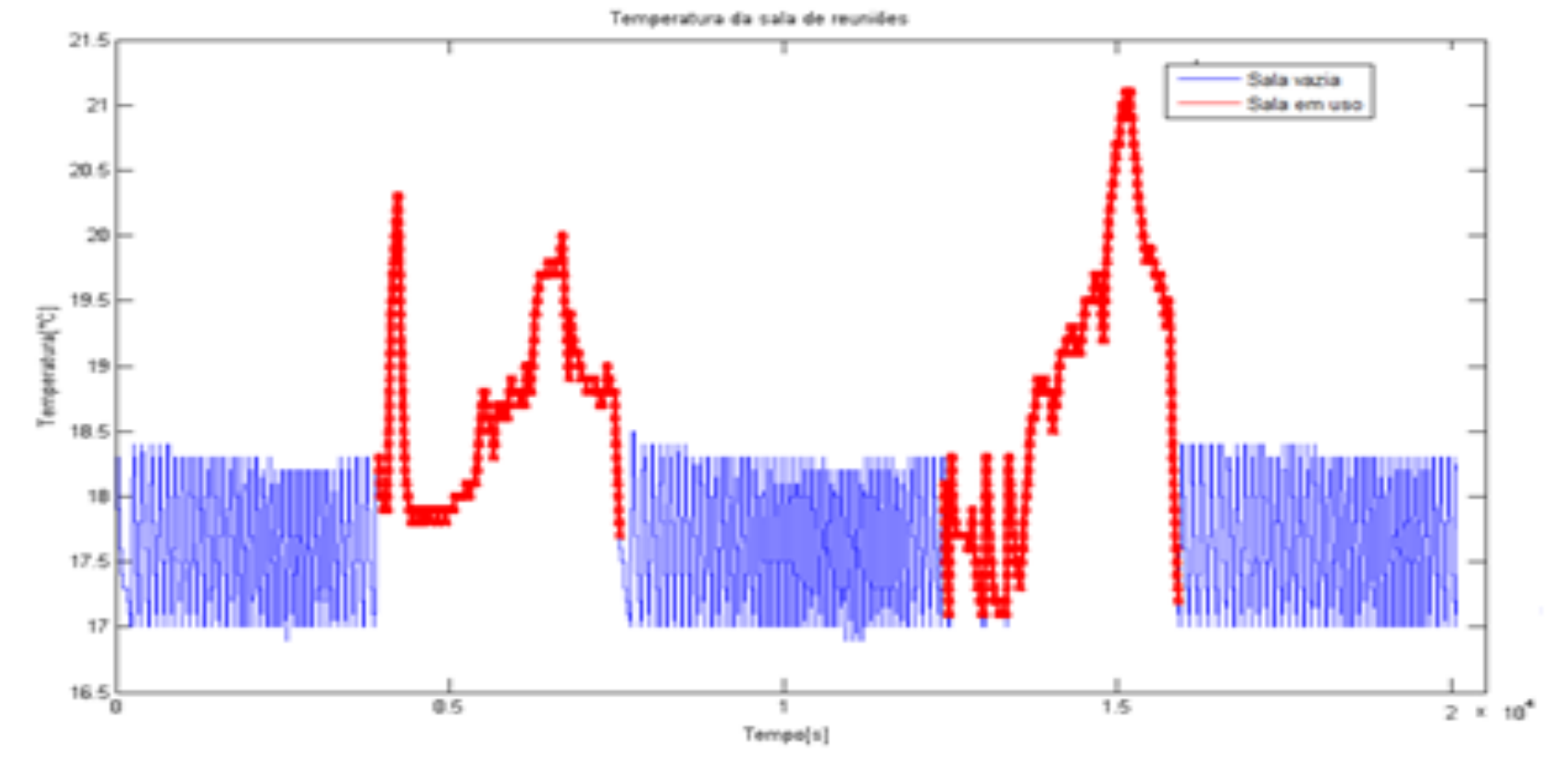
LARA/UnB
Brasília-BRAZIL



Meeting Room

Temperature of the meeting room
- On-Off controller -

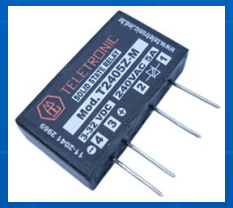
People entering/leaving the room are a major disturbance (**red**)

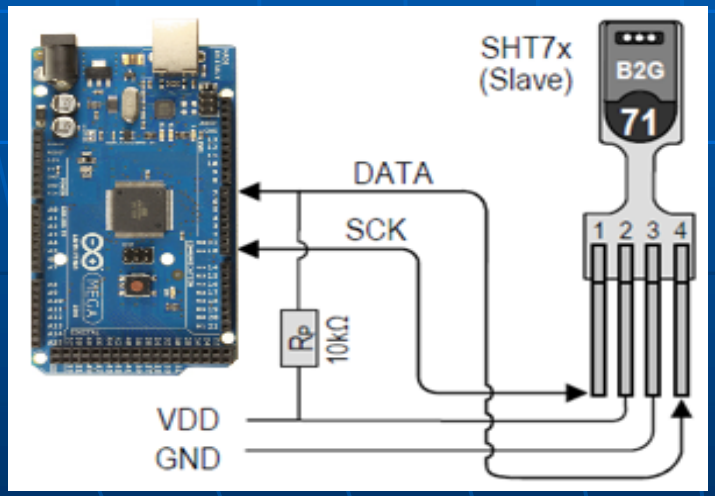


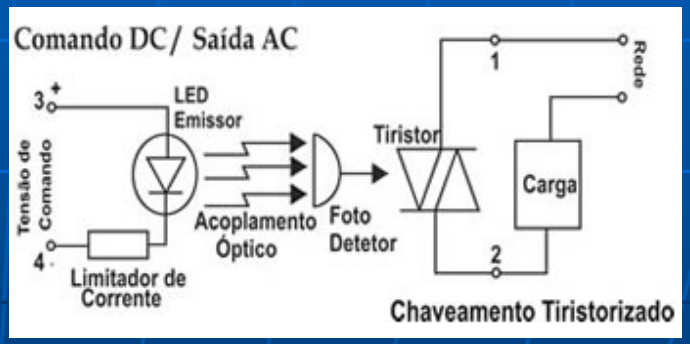
Instrumentation

- Sensirion® SHT71
  - I²C Communication
  - Power Suply: 2,4 V a 5,5 V
  - 8 to 14 bits A/D
- Arduino ATmega1280
- IEEE 802.15.4 (ZigBee) - Xbee Shield

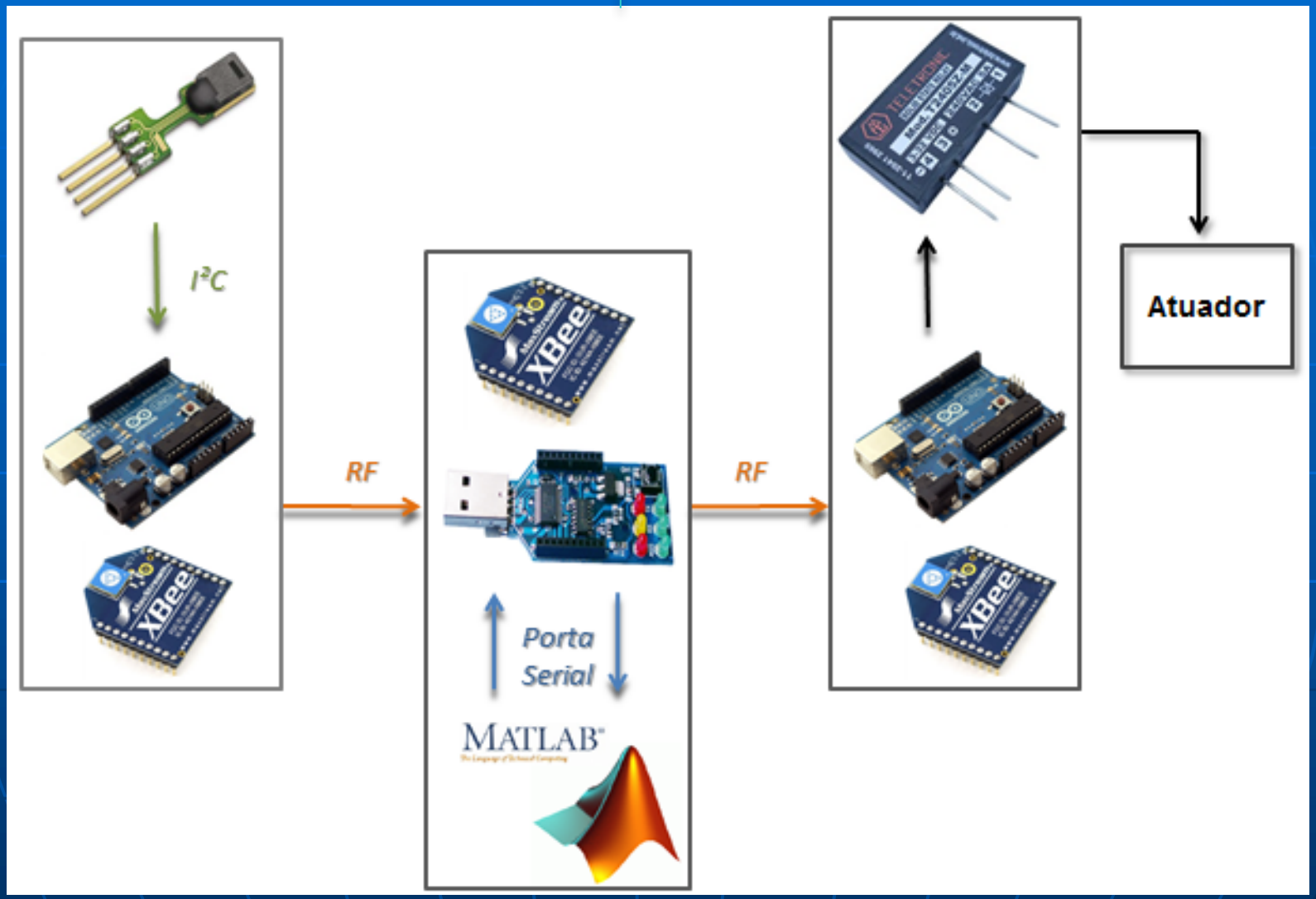
- Solid State Rele T2405Z-M







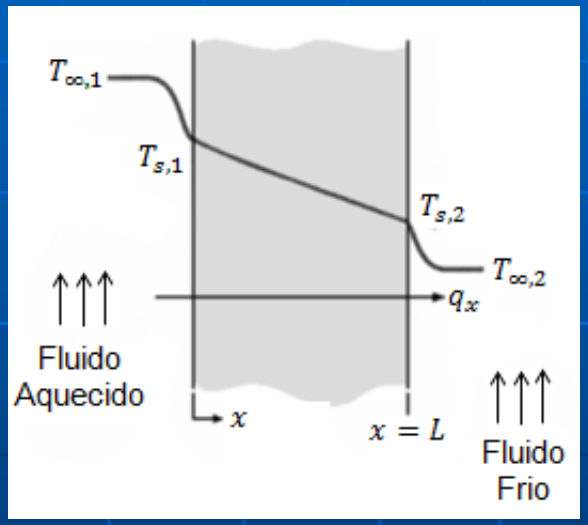
ZigBee Automation NETWORK

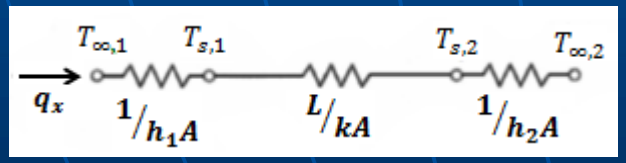


First Principles Modelling

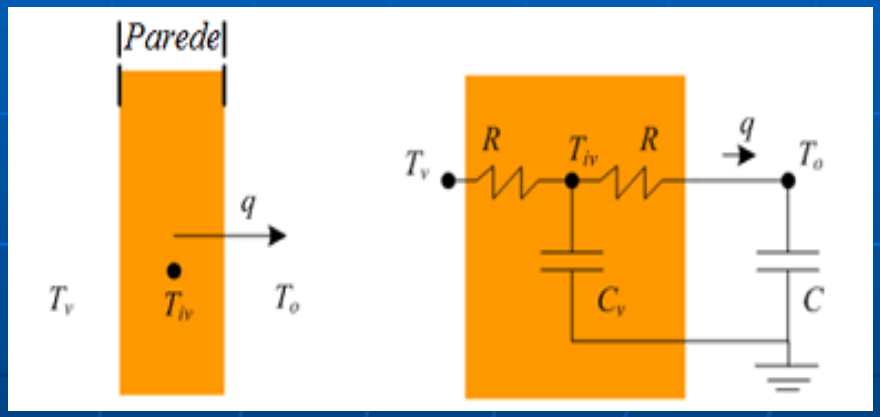
Recursive Identification needs a Structure for the Model -> Gray Box

Temperture along a Wall:



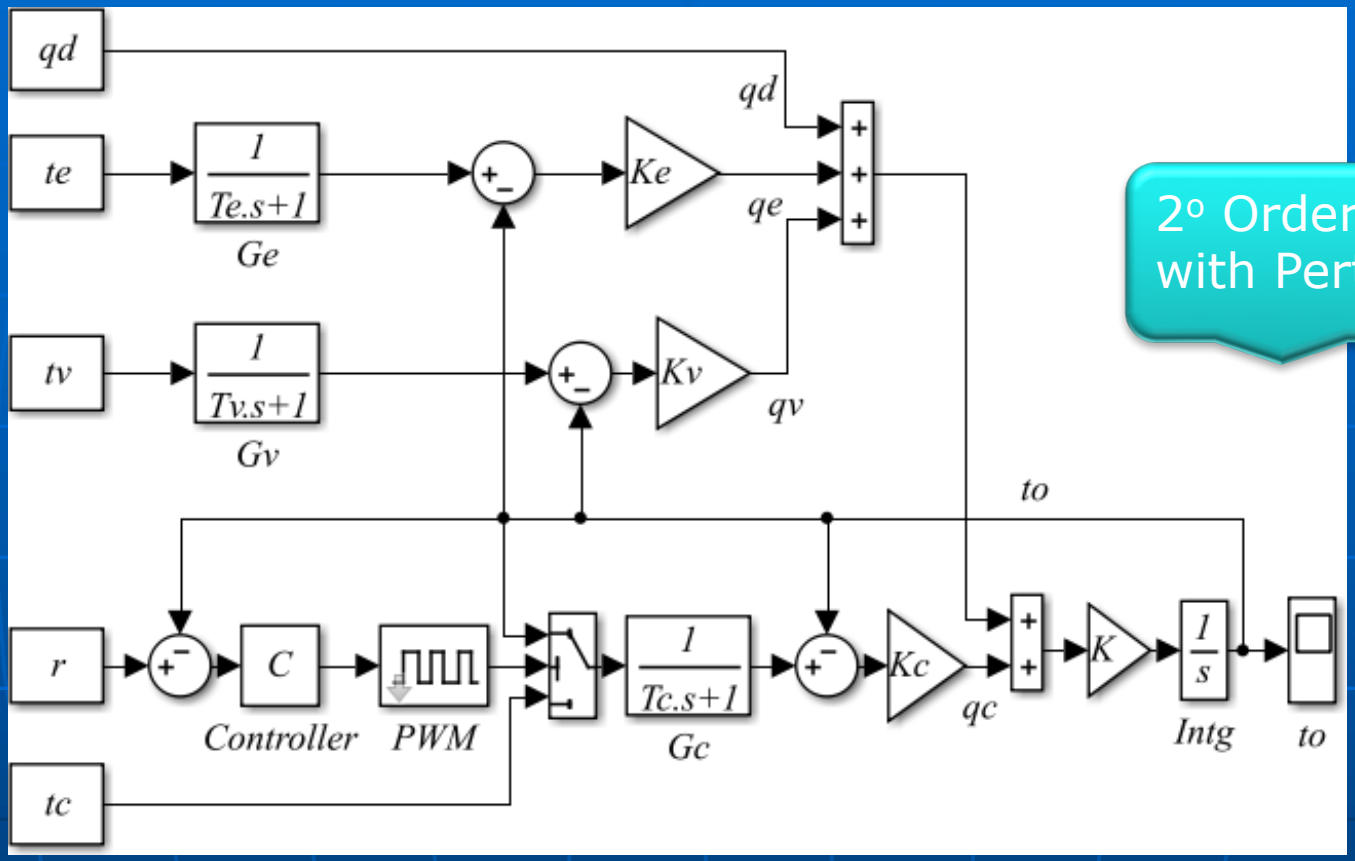


Thermal flow simplifications:



Wall analog Model

FIRST-PRINCIPLES BASED MODEL



2º Order Dynamics with Perturbations

Temperatures: *r* - reference, *y* - controlled, *te* - external, *tv* -vicinity, *tc* - cooler
Time constants: *Te* , *Tv* , *Tc* . Gains: *Ke* , *Kv* , *Kc* , *K*
Heat flows: *qe* , *qc* , *qv* , *qd*

- Recursive Identification
  - Min. parameter variance
  - No bias
  - Plasticity

$$y(k) = \psi_k^T(k-1)\boldsymbol{\theta_k} + \xi(k)$$

Regressors (measurements)

Parameter vector

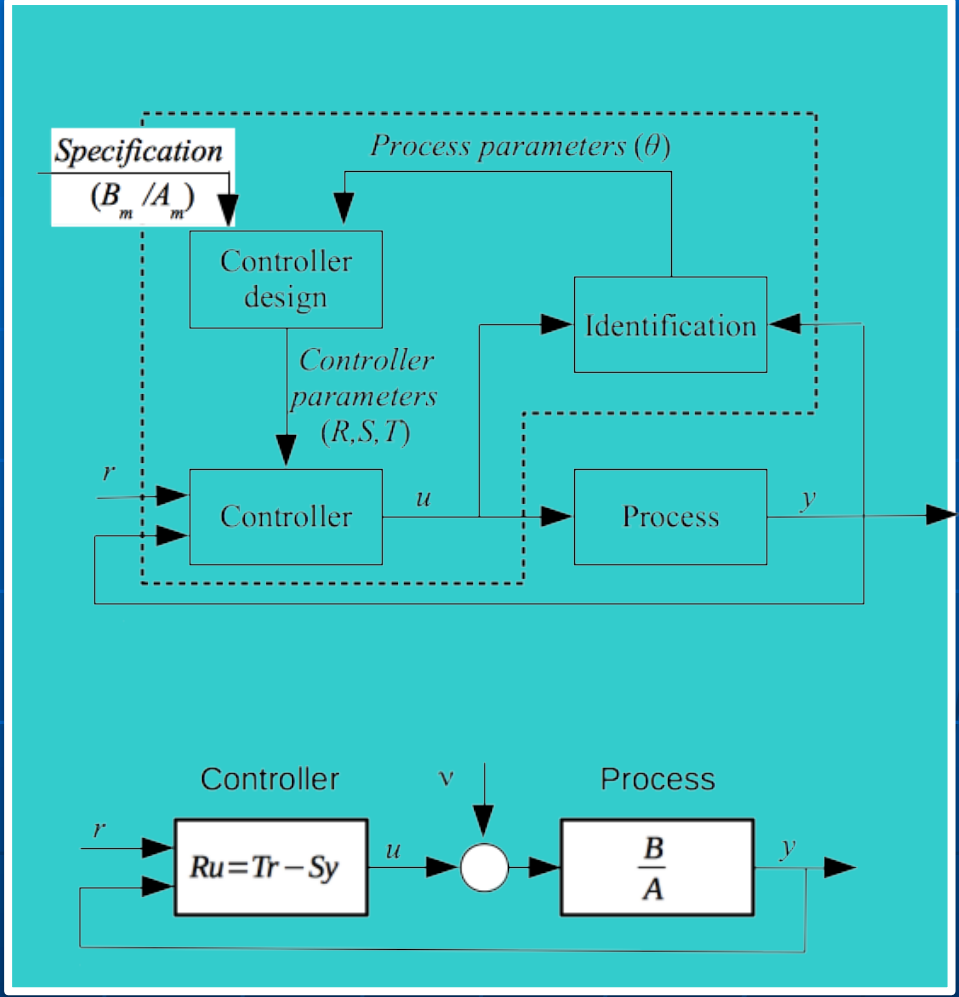
Residue

P = covariance matrix
λ = forgetting factor
y-$\psi\boldsymbol{\theta}$ = innovation
K = update gain

$$\begin{cases} K_k = \dfrac{P_{k-1}\psi_k}{\psi_k^T P_{k-1}\psi_k + \lambda}; \\ \boldsymbol{\theta_k} = \boldsymbol{\theta_{k-1}} + K_k[y(k) - \psi_k^T\boldsymbol{\theta_{k-1}}]; \\ P_k = \dfrac{1}{\lambda}\left(P_{k-1} - \dfrac{P_{k-1}\psi_k\psi_k^T P_{k-1}}{\psi_k^T P_{k-1}\psi_k + \lambda}\right). \end{cases}$$

- Adaptive Control
  - Direct or ***Indirect***

- Design Techniques:
  - Model Reference (MRAC)
  - ***Self-Tuning Regulator (RST)***
  - Dual Control
  - Gain Scheduling

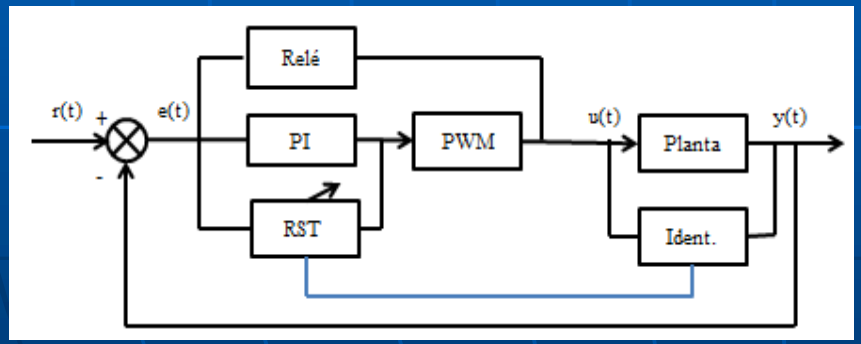


Self-tuning RST controller - pole placement design

CONTROLLERS

- On-Off Control

$$\begin{cases} 1 \ if \ \ y_{ref} - y < 1{,}0 \\ 0 \ if \ \ y_{ref} - y > 0{,}0 \end{cases}$$



- PID Control

Empiric Tuning by Chien, Hrone e Reswick, 1952.
where T_p is the time constant and τ is the deadtime.

Tipo de Contro-lador	Servo - 20% overshoot		
	K_p	T_i	T_d
P	$0.7T_p/\tau$	-	-
PI	$0.6T_p/\tau$	τ	-
PID	$0.95T_p/\tau$	1.4τ	0.47τ

$$D_{PI}(z) = \frac{-0.41424(z - 0.9975)}{z - 1}$$

– Adaptive Control (Aström and Wittenmark, 95)

Model with input noise $A(k)y(k) = B(u(k) + v(k))$

Pole assignment controller $Ru(k) = Tr(k) - Sy(k)$ R, S, T – *to be designed.*

$$y(k) = \frac{BT}{AR + BS} r(k) + \frac{BR}{AR + BS} v(k) \qquad A_c = AR + BS$$

Identified Model

$$G(z) = \frac{b_0 z + b_1}{z^2 + a_1 z + a_2} z^{-d}$$

Reference Model

$$A_m y_m(k) = B_m r(k)$$

Control Law

...

$$u(k) = f[u(k-1), y(k-2), y(k-1), y(k), r(k), b_2, b_1, a_2, a_1, a_0, b_{m2}, b_{m1}, a_{m2}, a_{m1}, a_{m0}]$$

MEETING ROOM

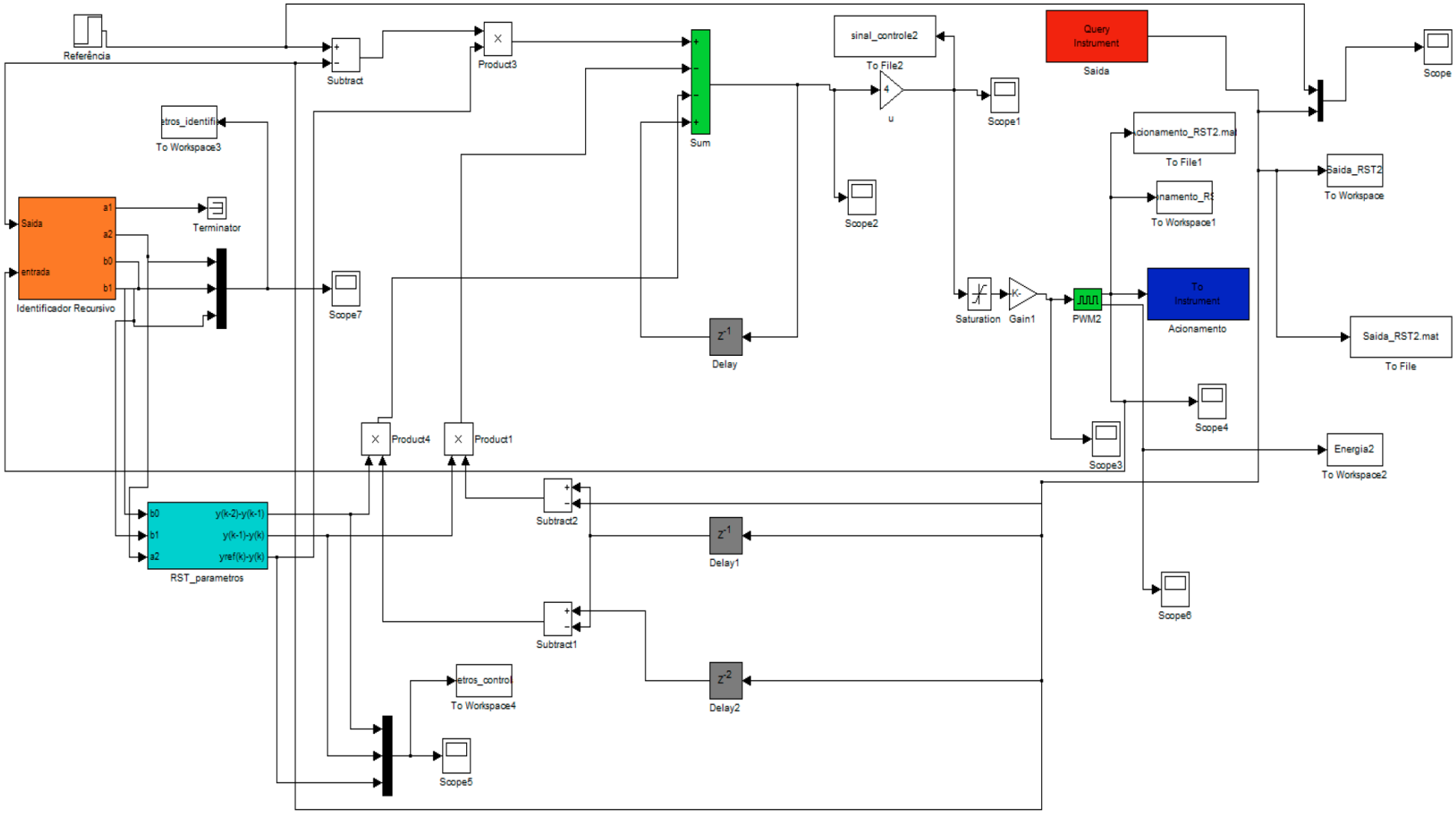
– Identification

- Model: $$G(z) = \frac{b_0 z + b_1}{z^2 + a_1 z + a_2} z^{-d}$$
- Regressor Vector: $$\psi(k) = [y(k-1)\ y(k-2)\ u(k-5)\ u(k-4)]$$
- Parameter Vector: $$\theta(k) = [\theta_1\ \theta_2\ \theta_3\ \theta_4]^T$$

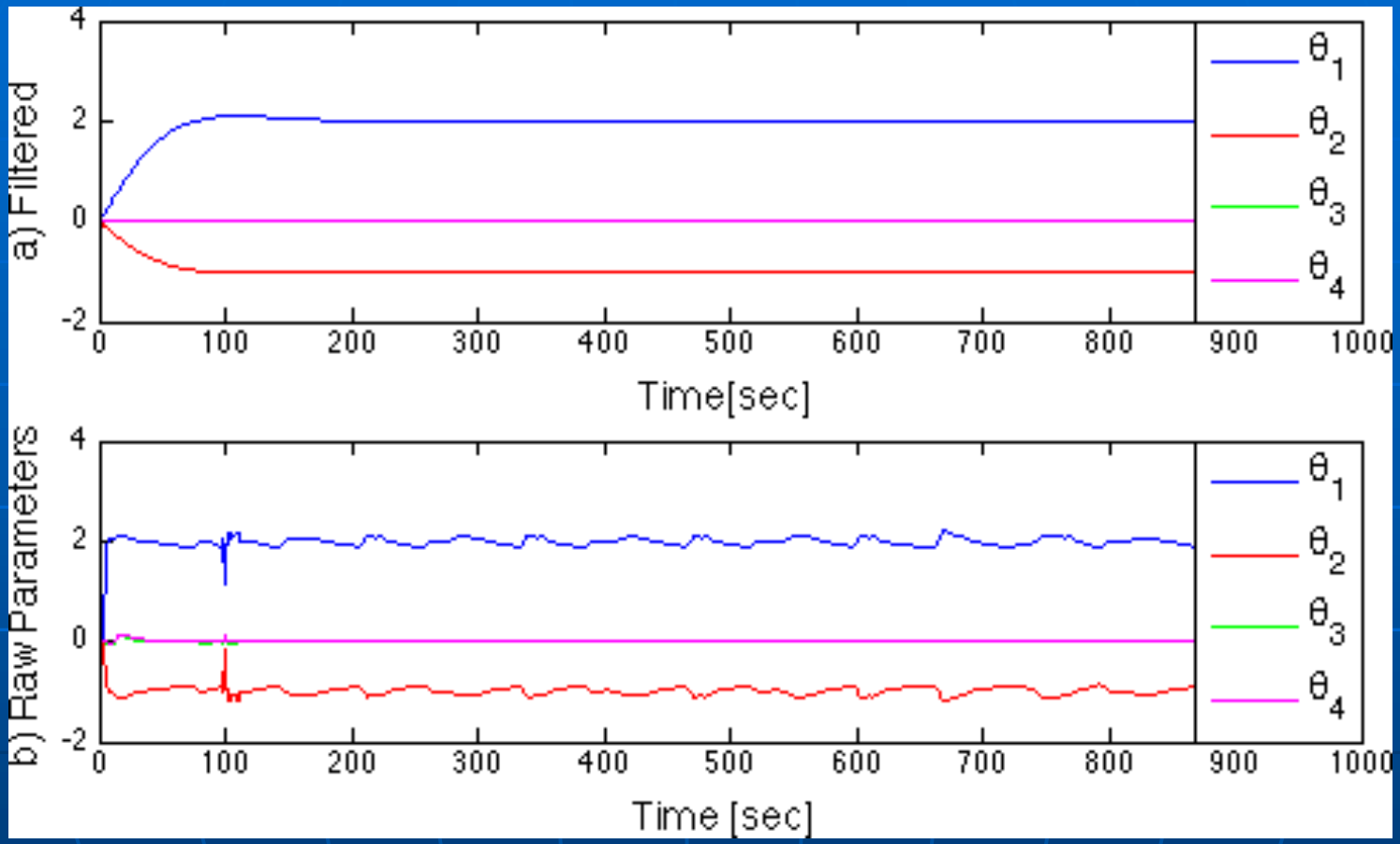
$$G(z) = \frac{-0.0219z + 0.0154}{z^2 - 1.918z + 0.919} z^{-3} \qquad G_m(z) = \frac{0.0925z}{z^2 - 1.0088z + 0.08738} z^{-3} \quad (\approx 5x\ faster\ than\ G(z))$$

(typical 91% fit)

RST Adaptive Controller

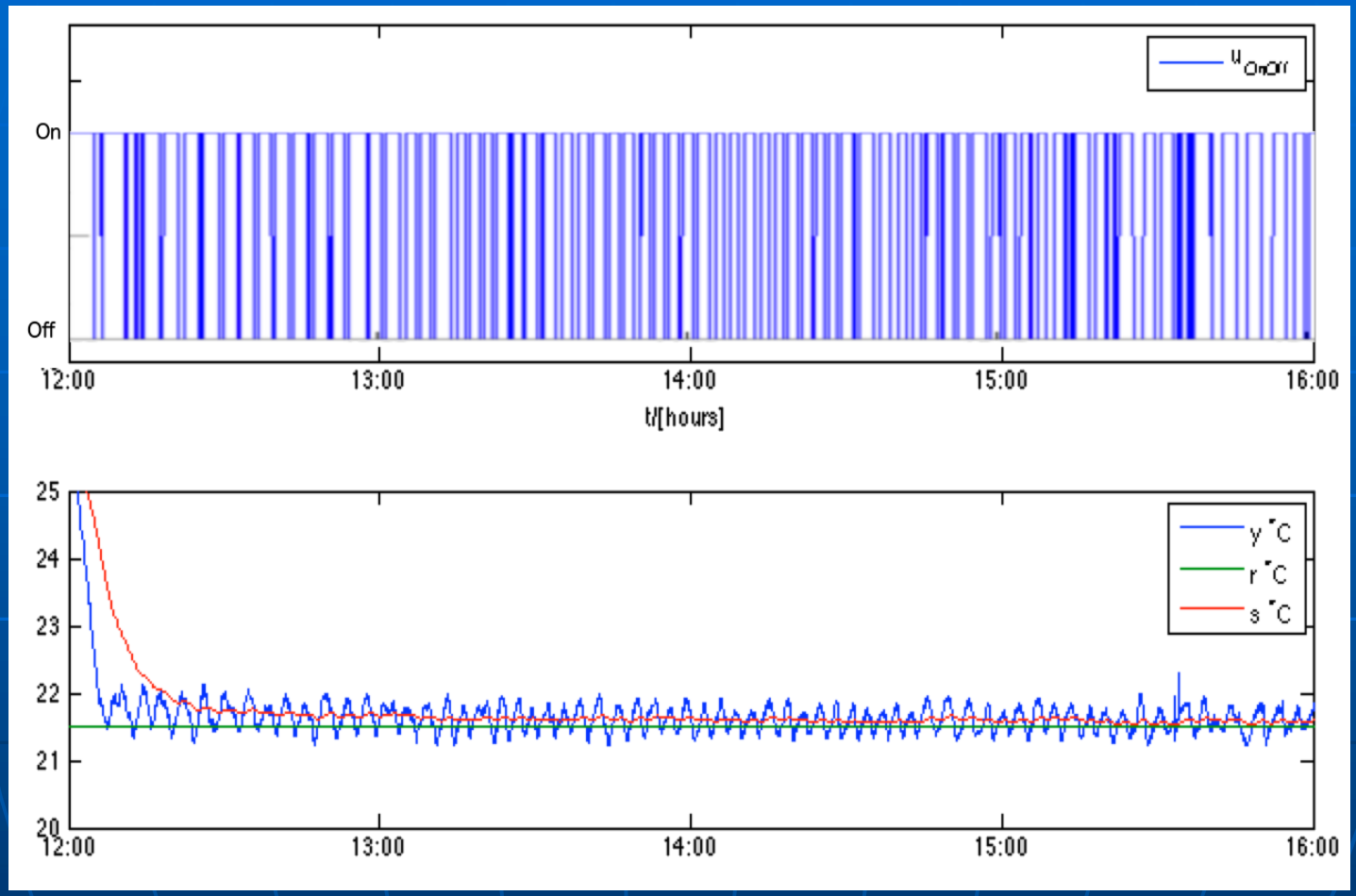


IDENTIFICATION



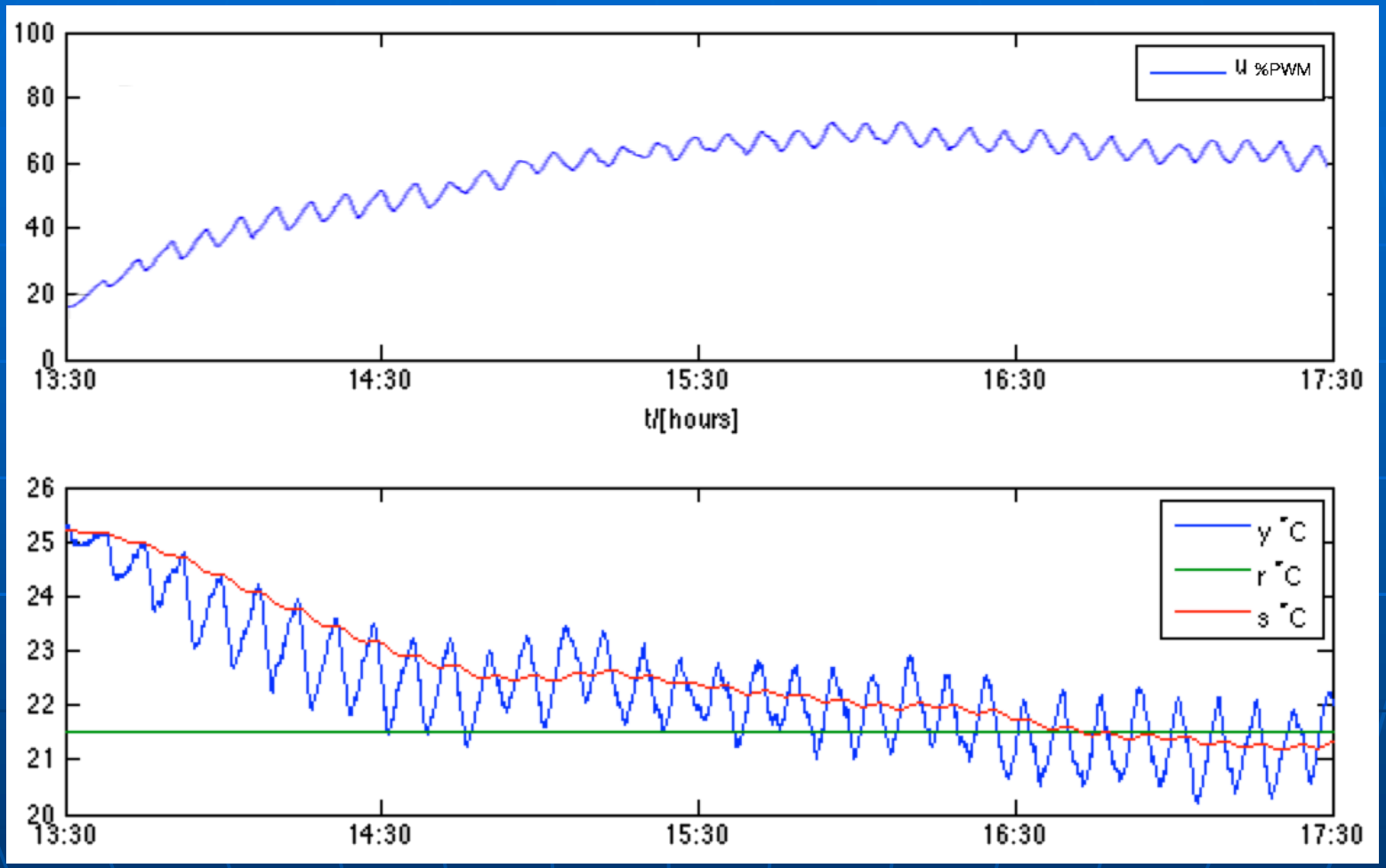
Estimated model parameters:
a) smooth filtered parameters, b) raw estimated model parameters.

ON-OFF



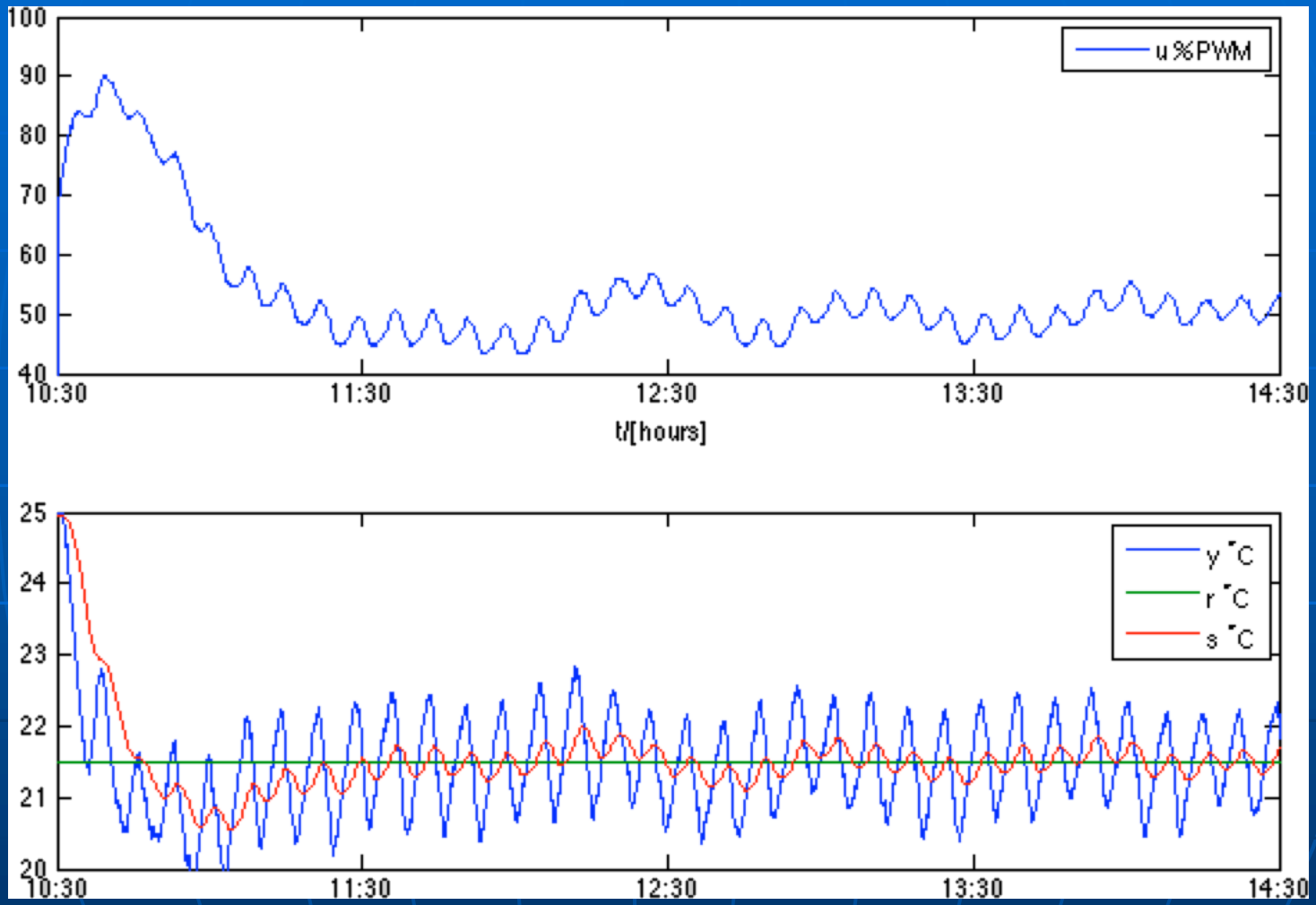
On-Off controller, variable thermal load.

PI



PI controller, variable thermal load.

RST



RST controller, variable thermal load.

ERROR - ENERGY

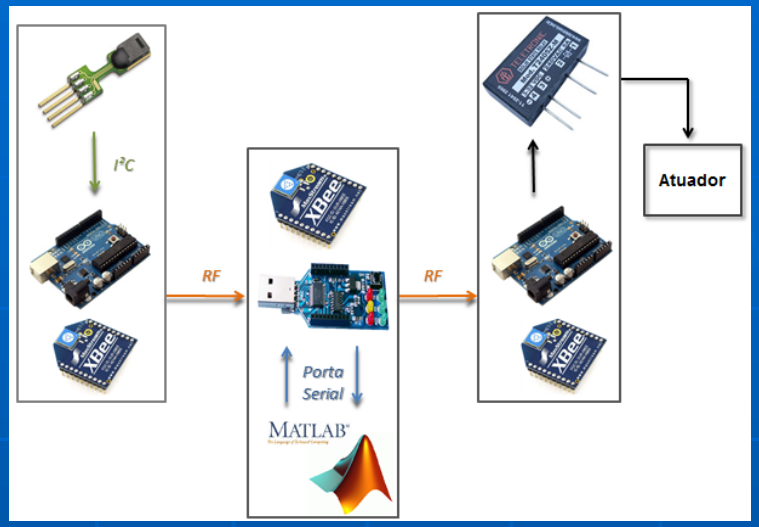
Table 1 - Controller Comparison – RMS error and Energy, 8-hour runs.

Thermal Load	ON-OFF Controller		PI Controller		Adaptive Controller	
	Error [RMS]	Energy [kWh]	Error [RMS]	Energy [kWh]	Error [RMS]	Energy [kWh]
Constant	0.14	6.69	1.55	3.12	0.53	3.42
Variable	0.12	7.89	1.18	4.84	0.43	4.63

Constant thermal load - empty meeting room's door kept closed.

Variable thermal Load - occupancy change:
meetings, studying, and vacancy periods.
Opening of the door -> large heat flow (process parameters change).

Better ADAPTIVE!

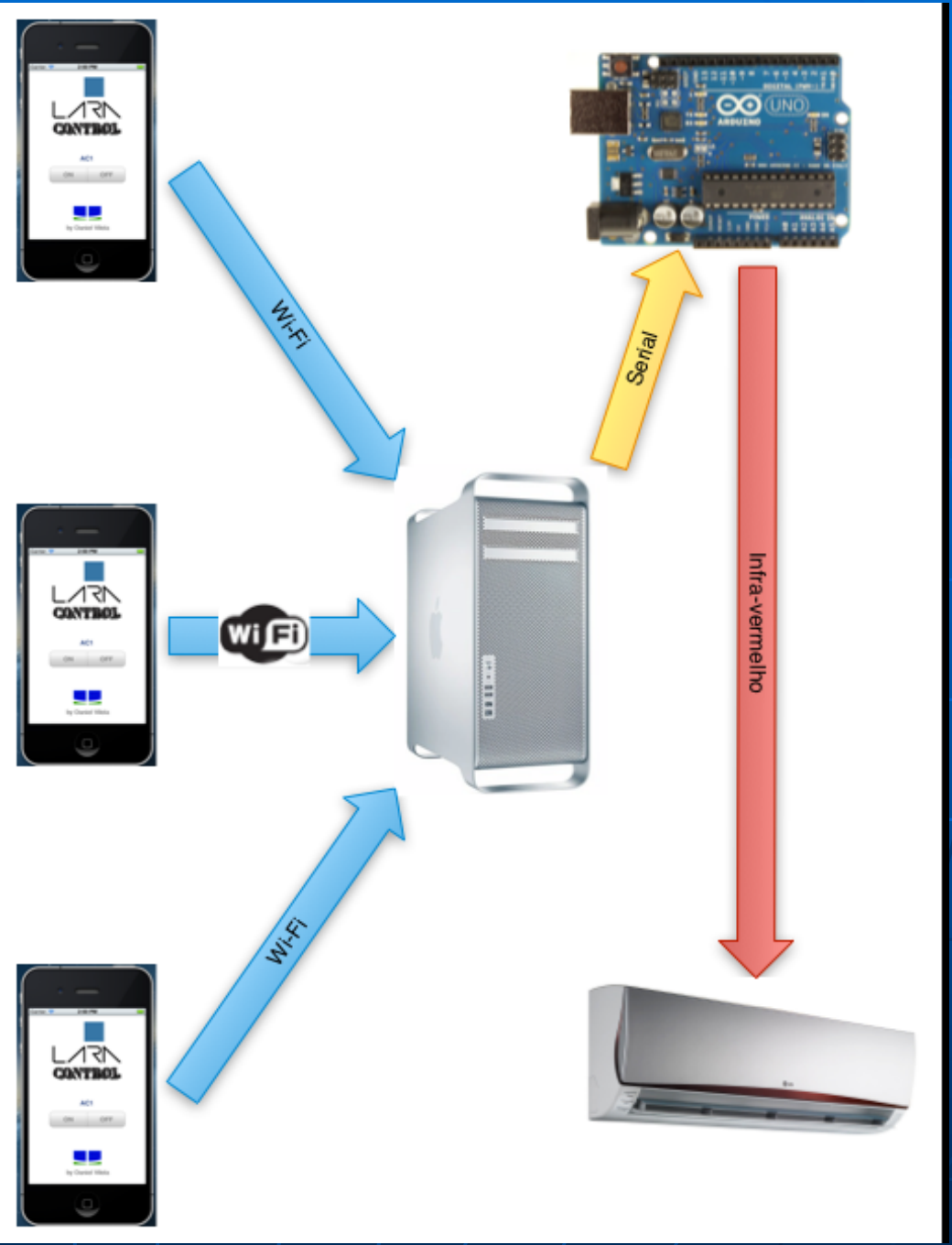


- On-Off controller
  - consumes the most energy
- PI controller
  - Has a better following of the set point (thermal comfort)
  - Slow to reach the set point
- Adaptive controller: model based building climatization:
  - Lowest energy consumption (quick pay back)
  - Good thermal comfort
  - Extra hardware and software necessary

Building Automation

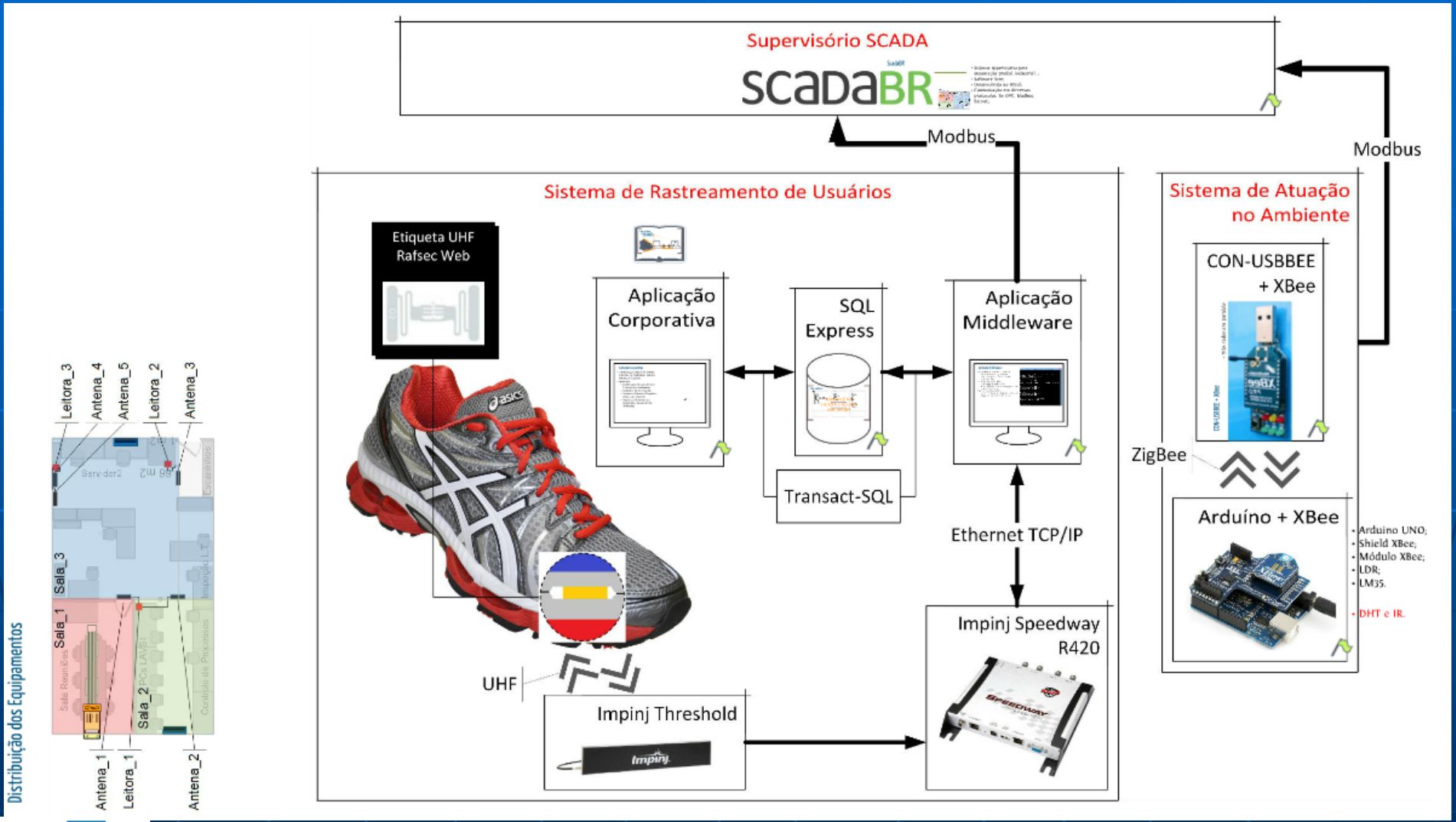
iPhone
WiFi
Arduino
ZigBee
Infra-Red
Split Air- Cond.

(Daniel Vilela, 2012)



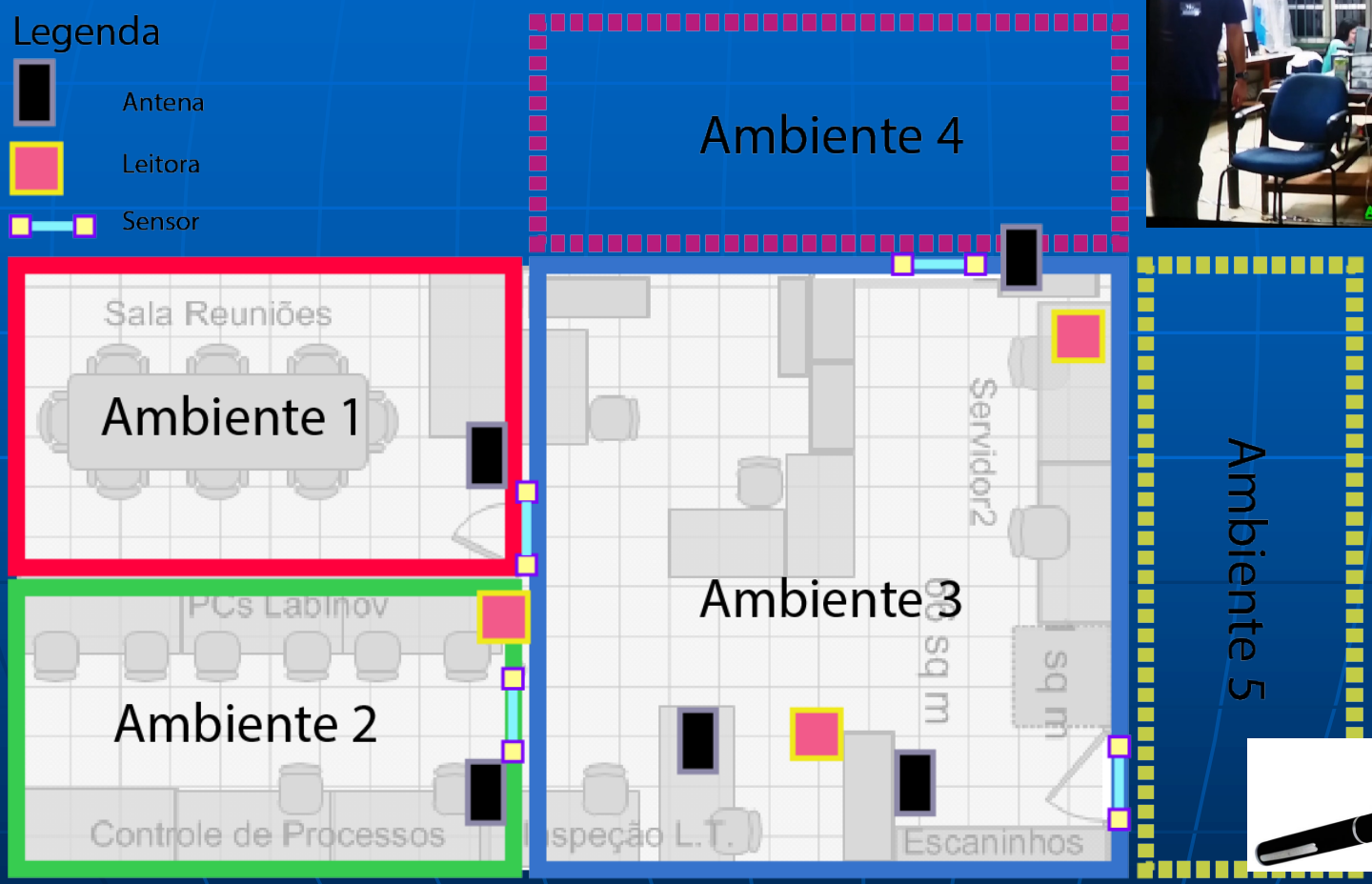
Passive RFID user tracking in building automation

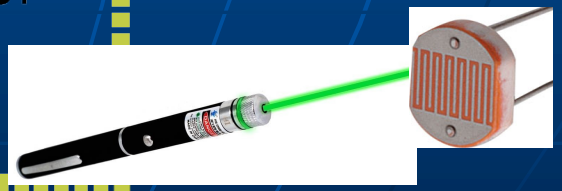
(Frederico Rocha e Filipe Oliveira, 2013)



Occupancy by Passive RFID + Laser Beam

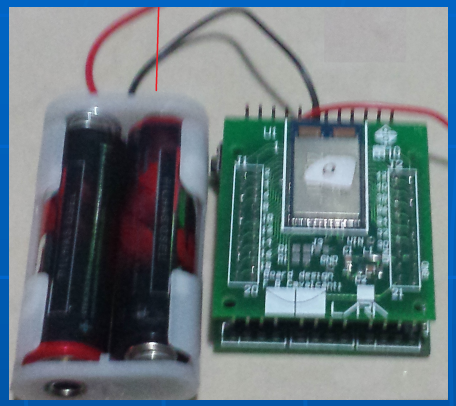
TG2015 Mecatrônica
Renata C.M. Chupel e Raissa A. Alves



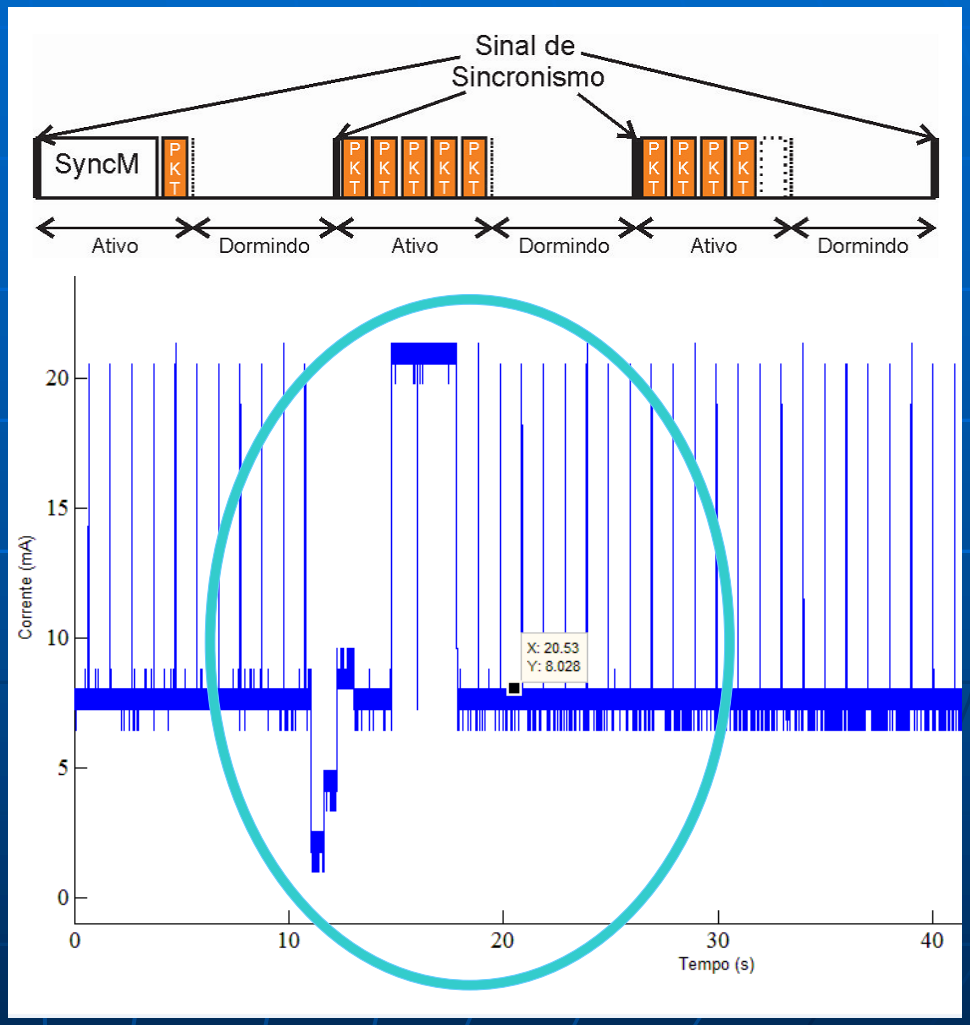


DyTEE MAC/UnB – Dynamic Timed Energy Efficient

MSc Vinícius Guimarães, 2014



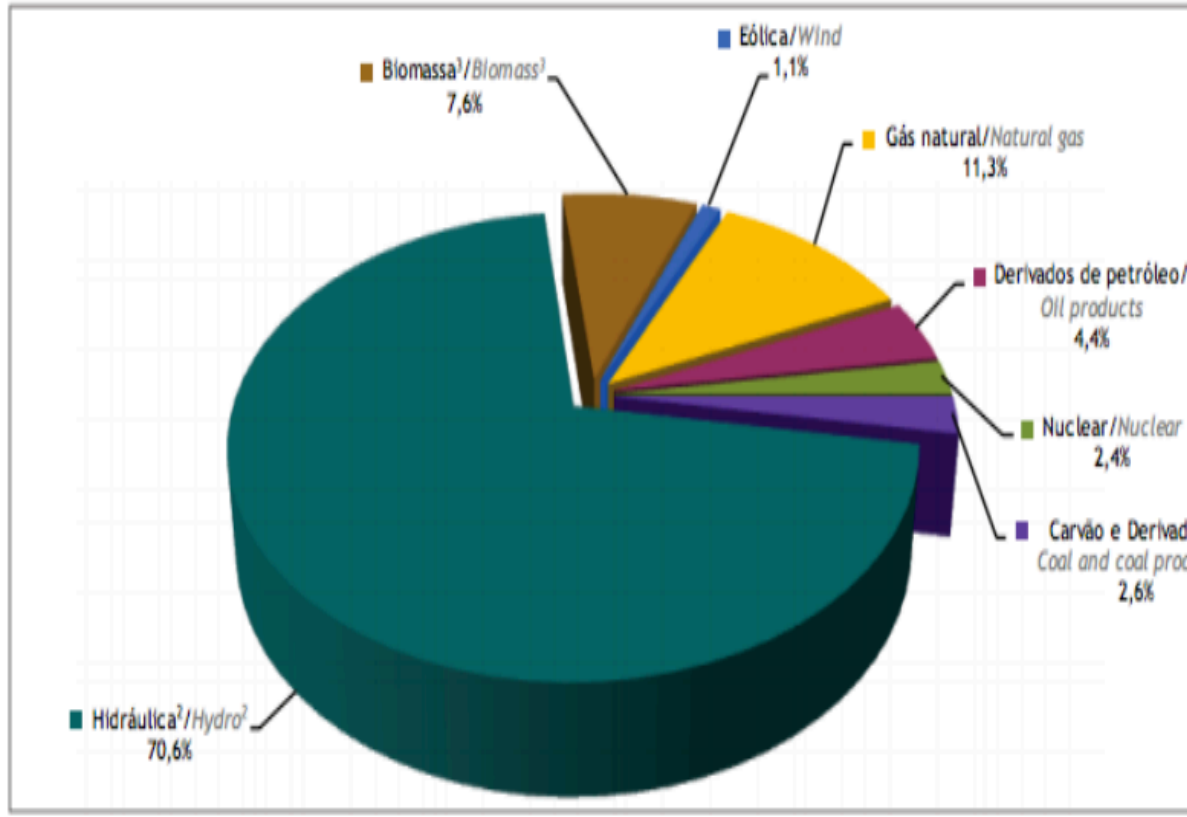
Sensor Node



DyTEE

IEEE 802.15.4

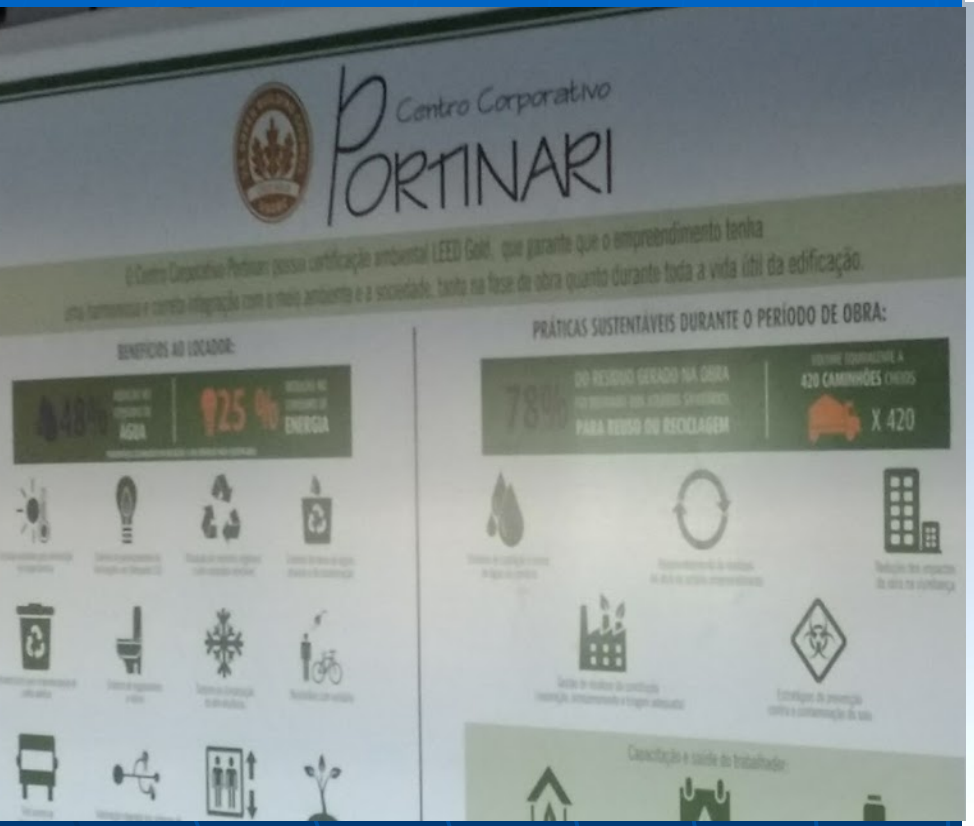
Energy Efficiency - Labeling of Buildings



Composição da matriz energética brasileira (EPE, 2013).

“Green Buildings”

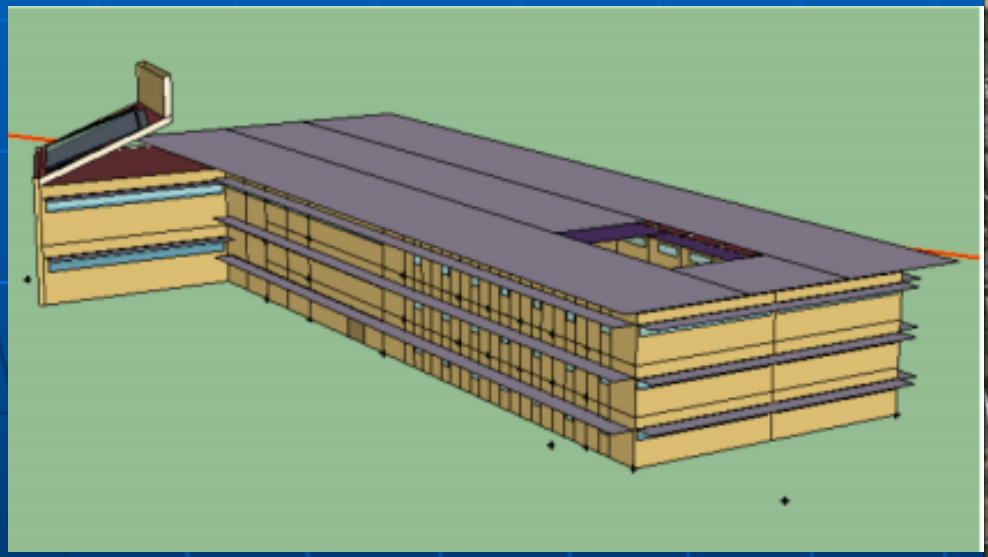
“Green Buildings”



2.2 million +

square feet is LEED certified every day with more than 90,000 projects using LEED.

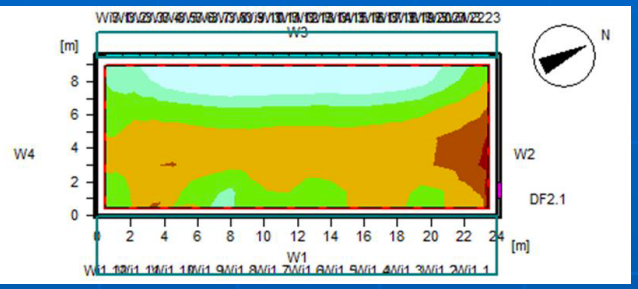
nZEB – FAU/ENM/ENE-UnB

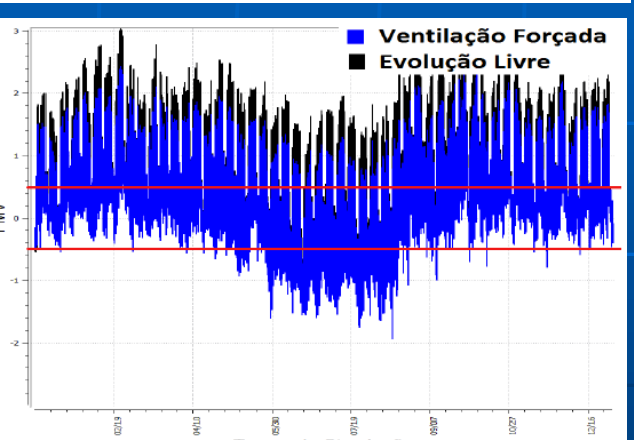


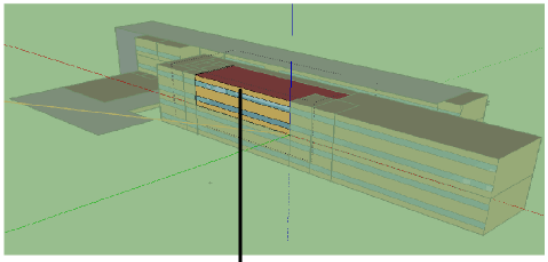
Brick, 2014

UnB nZEB Study

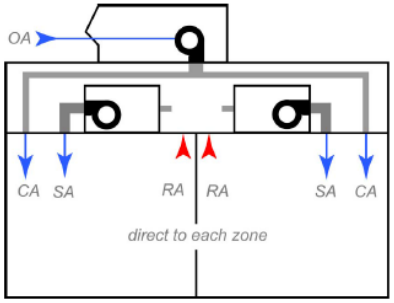
- Thermal Zone
- Forced Ventilation
- Solar colector
- Ground Heat
- Biogas
- Photovoltaic
- Dedicated Outdoor Air System

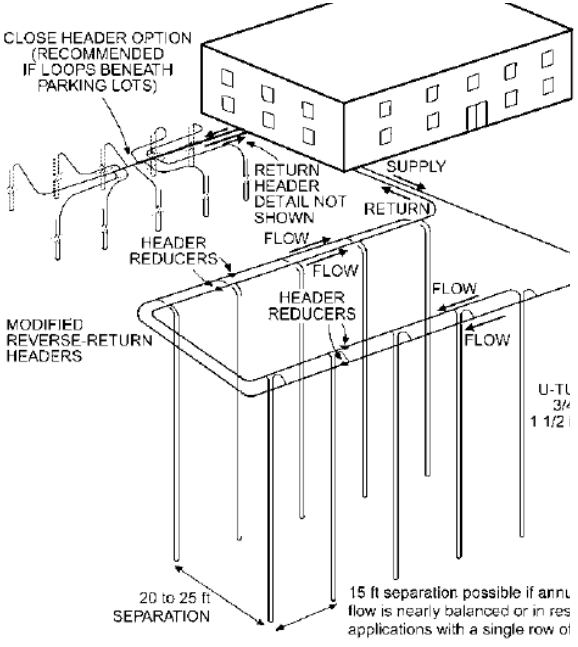


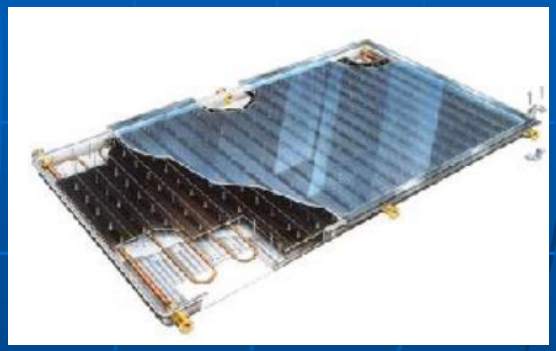


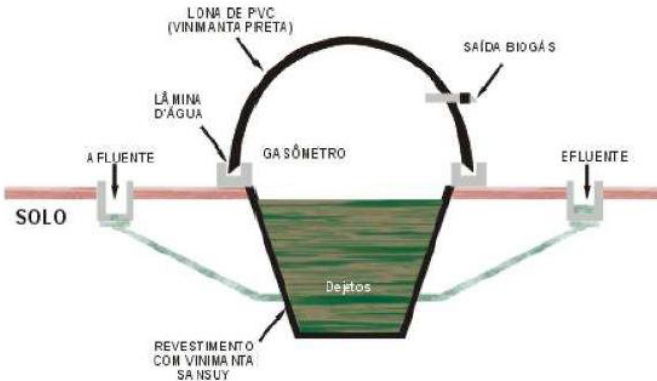


LABORATÓRIO_1° PAVIMENTO









nZEB - UnB

CC - Estratégias energéticas

Legenda

01. Elementos de proteção solar calculados para cada fachada.

02. Melhor aproveitamento da iluminação e ventilação naturais.

03. Espaços verdes, que reduzem o efeito da ilha de calor.

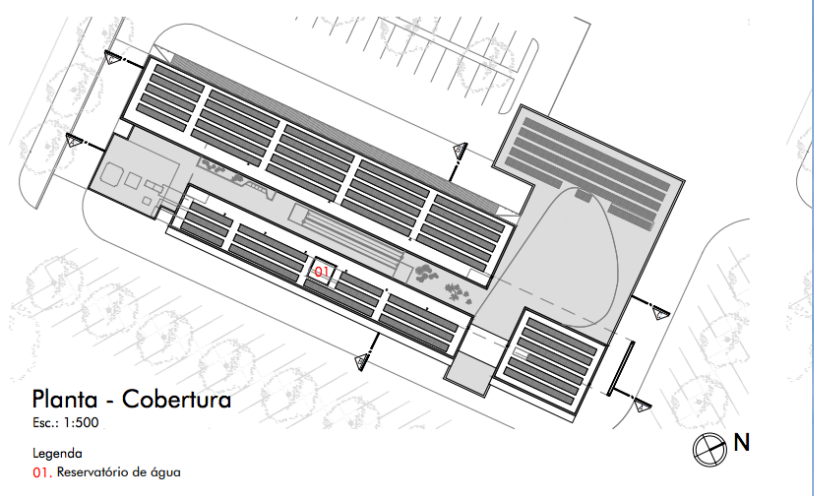
04. Elevada inércia térmica das fachadas.

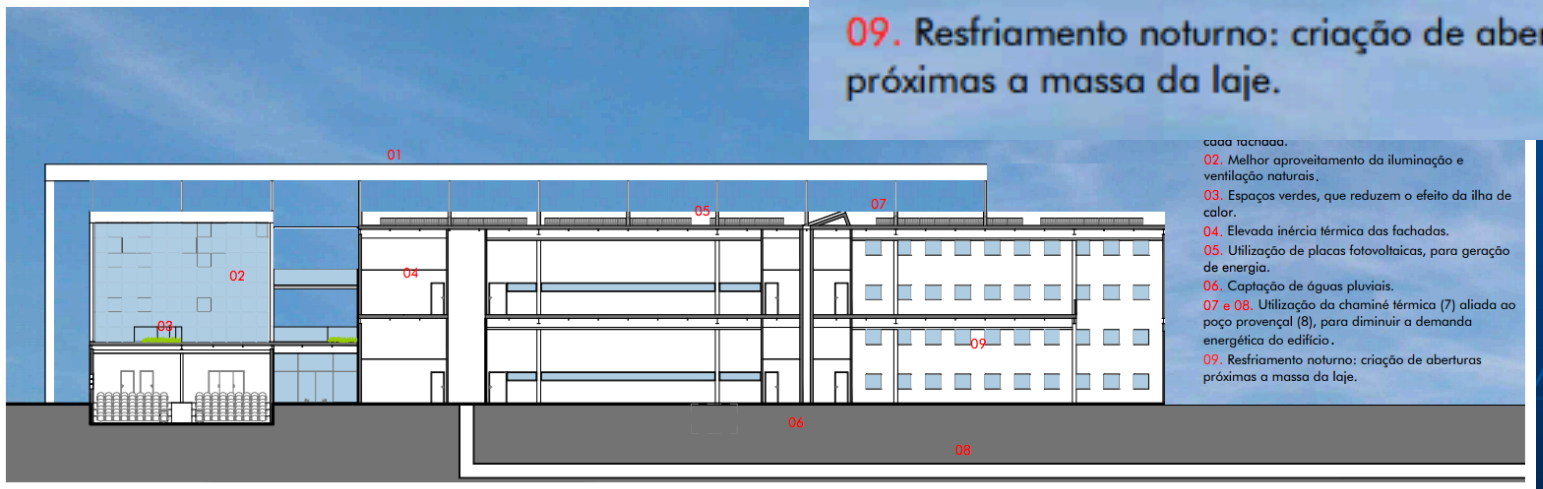
05. Utilização de placas fotovoltaicas, para geração de energia.

06. Captação de águas pluviais.

07 e 08. Utilização da chaminé térmica (7) aliada ao poço provençal (8), para diminuir a demanda energética do edifício.

09. Resfriamento noturno: criação de aberturas próximas a massa da laje.





cada fachada.
02. Melhor aproveitamento da iluminação e ventilação naturais.
03. Espaços verdes, que reduzem o efeito da ilha de calor.
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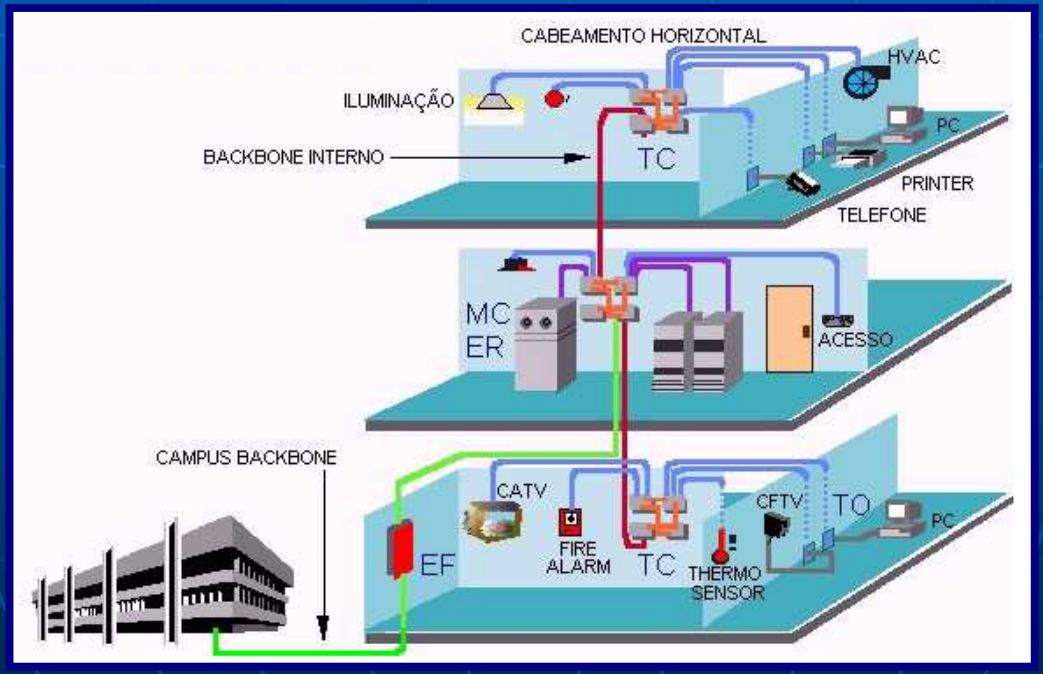
Building Automation – Where to work

- Design
- Specification
- Execution
- Supervision
- Comissioning
- Operation
- Maintanance
- Consulting

The “near” future

- Energy Efficiency Labeling of Buildings
- nearly Zero Energy Building - nZEB
- Assisted Living
- Virtual Campus
- Ambient Intelligence



Prof. Adolfo Bauchspiess

Short C.V.

– *SENAI/1982 – Eletricista de Dispositivos de Comandos Elétricos*

– *UnB/1986 - Eng. Elétrica*

  – *Estágios: Telebrasília (1984), Prólogo (1985), Novadata (1986)*

- Engenheiro: Novadata Sistemas e Computadores Ltda (1986-1990)

– *UnB/1990 - Mestre Eng. Elétrica*

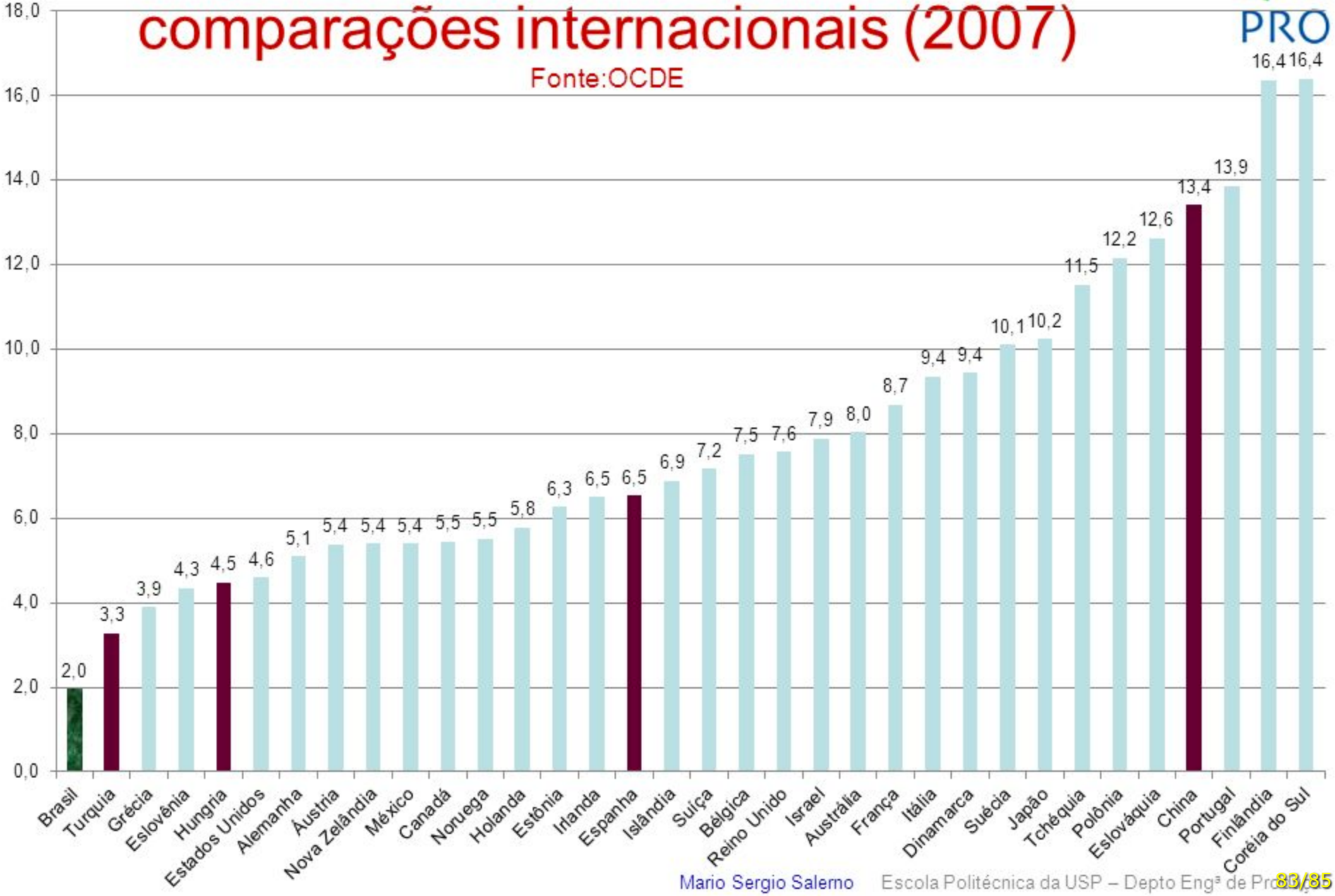
– *Erlangen-Alemanha/1995 – Dr.-Ing.*

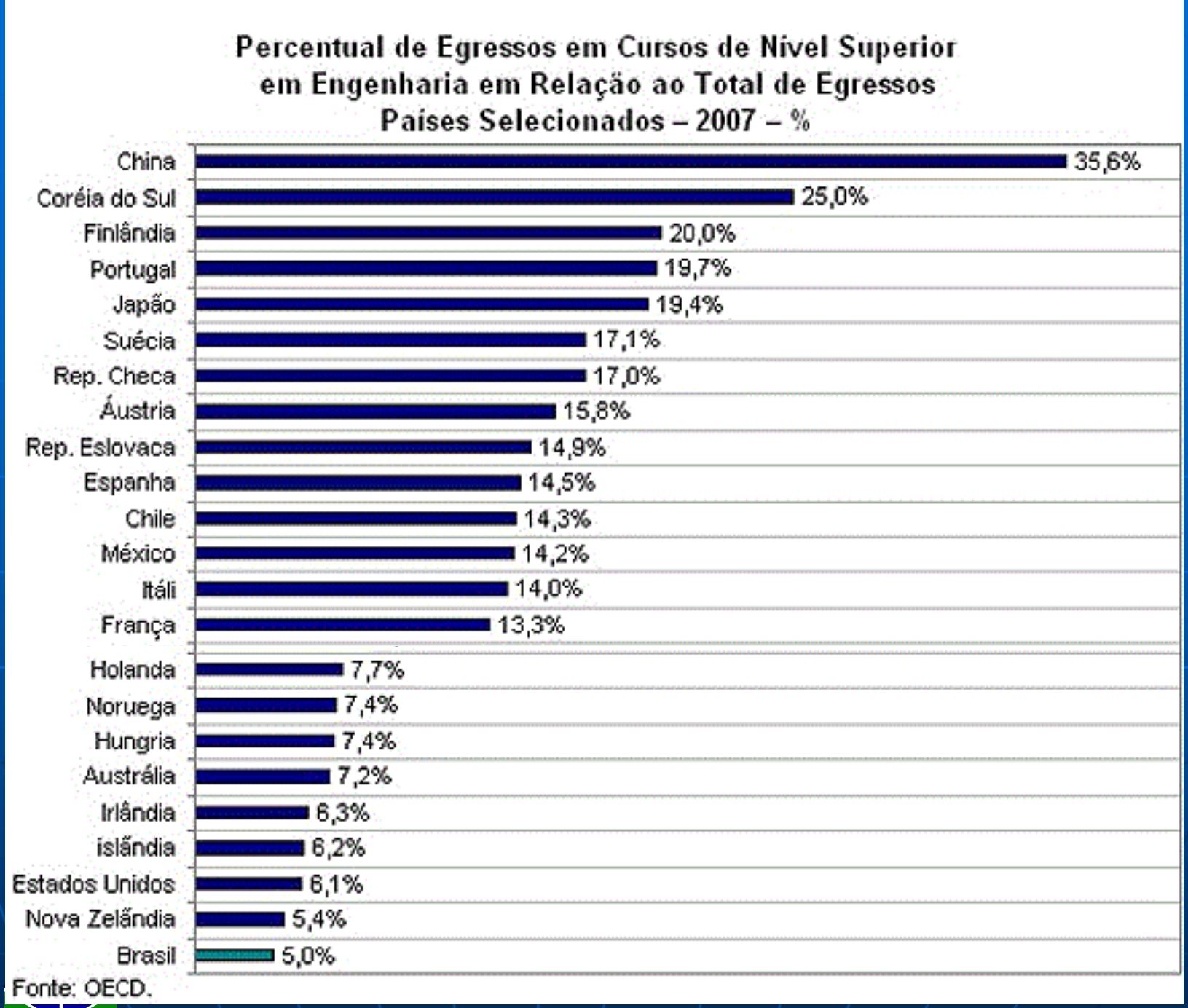
– *ENE/UnB 1995 ... - Prof. Controle & Automação*

  - *Pós-Doc (Aachen/1997, Kaiserslautern/2005-2006, Santa Barbara/2014)*
  - *Projetos: FAP-DF, CNPq, CAPES, FINEP*
  - *Erasmus Mundus – Kaiserslautern*
  - *Coordenador Eng. Mecatrônica UnB 2015/17*

Engenheiros/ 10.000 habitantes
comparações internacionais (2007)

Fonte:OCDE




Percentual de Egressos em Cursos de Nível Superior
em Engenharia em Relação ao Total de Egressos
Países Selecionados – 2007 – %
China 35,6%
Coréia do Sul 25,0%
Finlândia 20,0%
Portugal 19,7%
Japão 19,4%
Suécia 17,1%
Rep. Checa 17,0%
Áustria 15,8%
Rep. Eslovaca 14,9%
Espanha 14,5%
Chile 14,3%
México 14,2%
Itáli 14,0%
França 13,3%
Holanda 7,7%
Noruega 7,4%
Hungria 7,4%
Austrália 7,2%
Irlândia 6,3%
islândia 6,2%
Estados Unidos 6,1%
Nova Zelândia 5,4%
Brasil 5,0%
Fonte: OECD.

Thank You!

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adolfobs@ene.unb.br