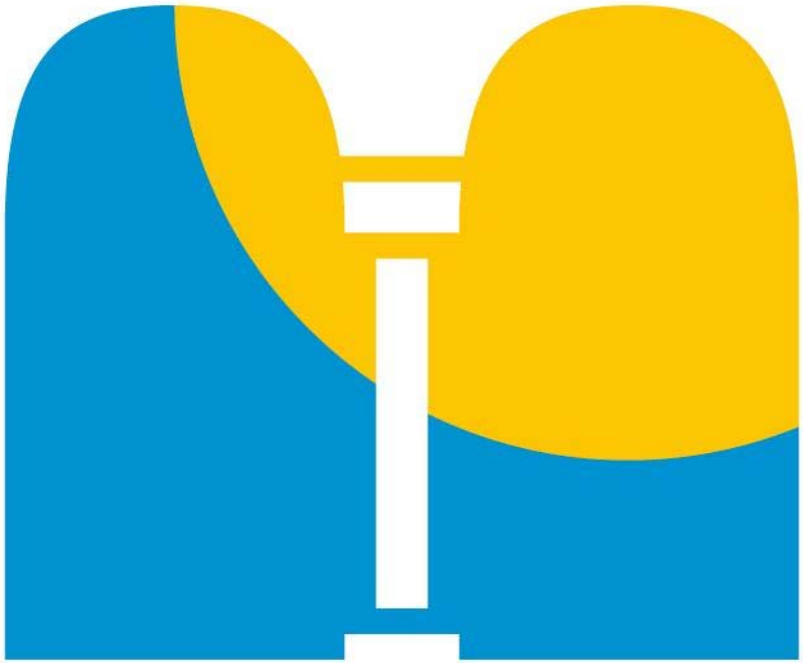

D8.9 Educational Material for University Studies

Densely Instrumented Physical Infrastructures for Energy-Efficient Building

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Guiding principle

Presentation 2
Author: Giacomo Paci
Partner: Università degli Studi di Bologna, Dipartimento DEIS (UNIBO)
University course: Advanced school on ICT for future energy systems
Date: 2012/09/13
Place: Università degli Studi di Trento
Title of the lesson: Densely Instrumented Physical Infrastructures for Energy-Efficient Building
Description of the contents: The lesson regards the basic concept of energy savings of historic building and living comfort, with a particular attention of monitoring instrument and control concept.
Name of the file: WP8_D8.9_20131007_UNIBO-Presentation 2

European residential units overview

European residential units overview

- In Europe 26.5% of energy consumption is due to households
  - Appliances (Oven, fridge, washing machine, etc.)
  - Heat ventilation, Air conditioning (HVAC)
  - Lighting
  - Hot water
- 55 million dwellings dating from before 1945 with more than 120 million Europeans living there
- 150 towns and urban fragments are declared World Cultural Heritage site
- Tourism is 5.5% of EU gross domestic product (GDP) and is strongly related to cultural heritage

Energy Efficient Building

Energy Efficient Building

- Energy Efficient Building
  - Any type of building that from design, technologies and building products uses less energy, from any source, than a traditional or average contemporary building.
- Green Building
  - Structure and using process that is environmentally responsible and resource-efficient throughout a building's life-cycle: from siting to design, construction, operation, maintenance, renovation, and demolition.
- Passive House
  - Any type of building that from design, technologies and building products uses on average zero energy from power grids to deliver adequate living comfort and services.

Living Comfort

Living Comfort

- Comfort
  - sense of physical or psychological ease, often characterized as a lack of hardship.

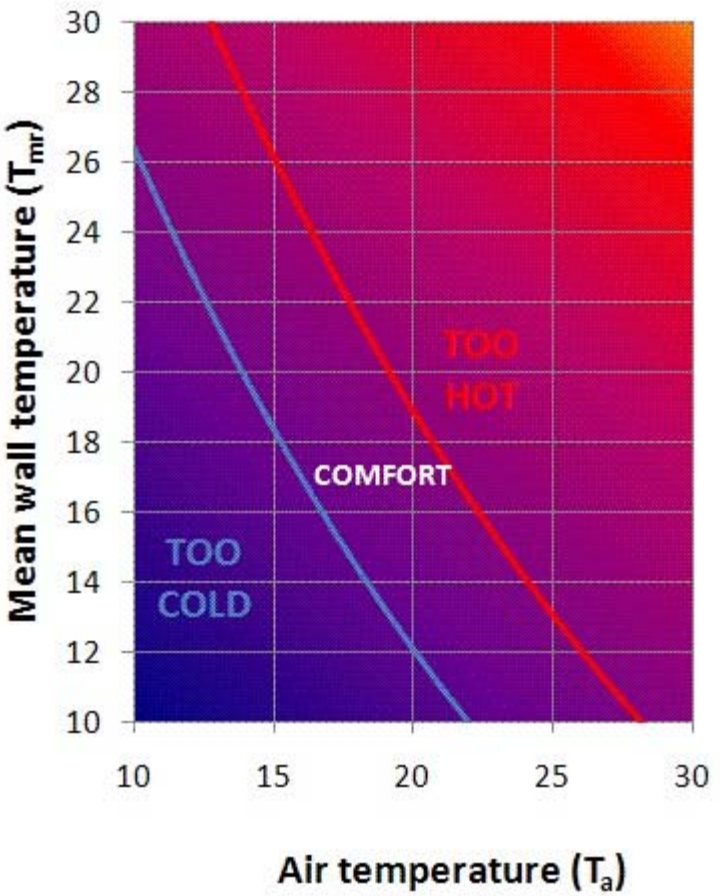
- Living comfort is characterized by:
  - Temperature
  - Humidity
  - Lighting
  - Noise
  - Air quality

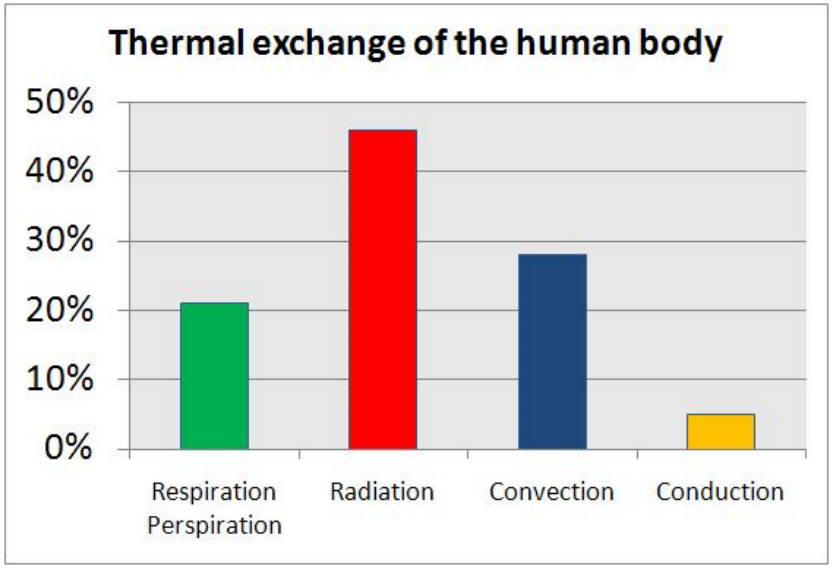
Then the physical quantities that we have to monitoring and control in the most efficient way to have an energy efficient building are the ones that characterize the living comfort plus the direct energy consumption due to appliances

Living Comfort

- Temperature

Bedford Bachman graph

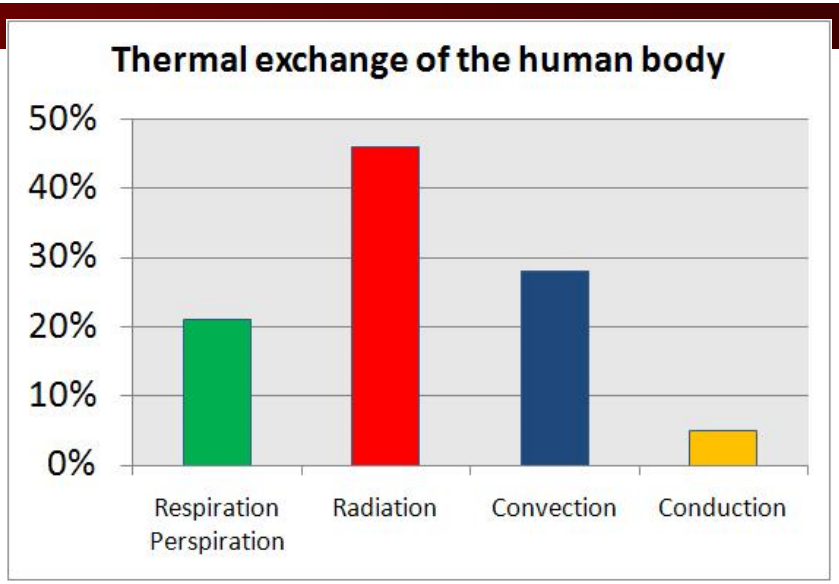




- The human exchange 45% of heat due to radiation
- The human exchange 55% of heat due to respiration, perspiration, convection, conduction
- Then the thermal comfort is strongly correlated to the wall temperature due to radiation thermal exchange

Living Comfort

- Humidity



- The perspiration capability to exchange heat is related to the relative humidity percentage. However the human body thermal exchange due to perspiration is less then 20% of the total amount.
- For humans relative humidity below 25% feels uncomfortable dry. Relative humidity above 60% feels uncomfortable wet. Human comfort requires the relative humidity to be in the range 25 - 60% RH
- Relative humidity above 70% (and even lower at special conditions) may for normal living conditions cause condensation on cold surfaces - causing mold, corrosion and moisture related deterioration.
- To low relative humidity may cause problems with static electricity, cracking of paint and shrinkage of wood furniture and wood floors.

Living Comfort

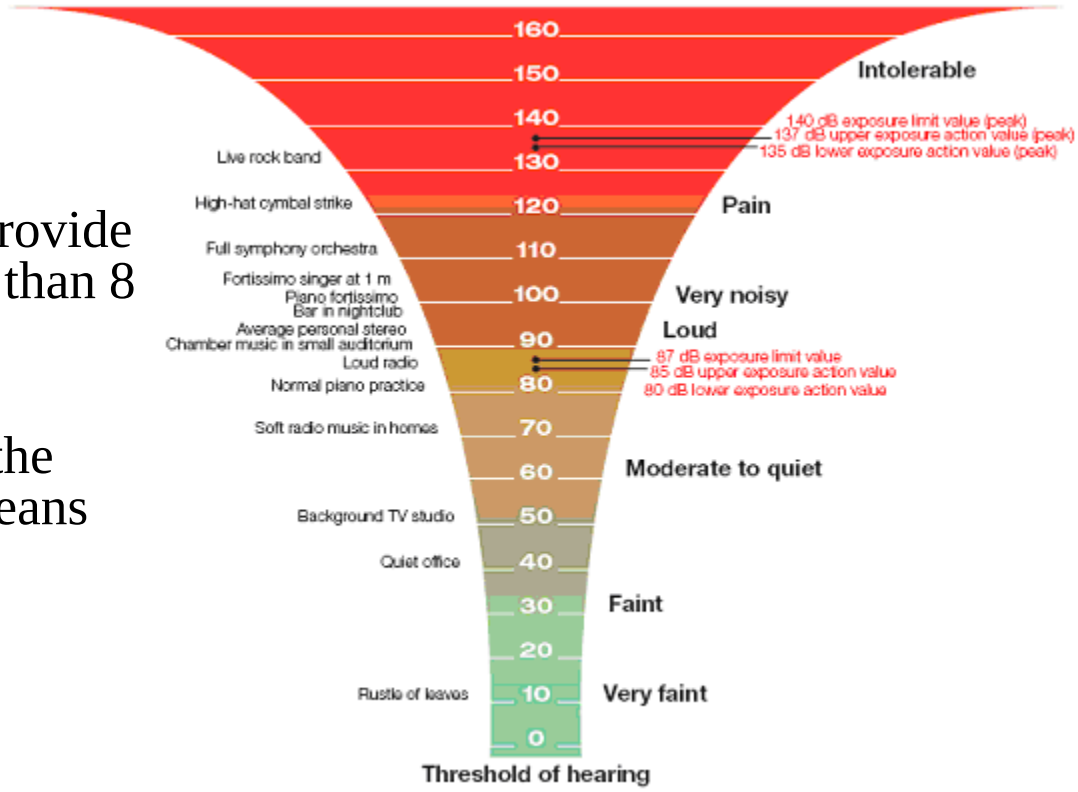
- Lighting

- Human needs at least 50 lux in a room to be comfortable during leisure time
- Corridor, toilet usually have 80 lux
- Working place as office has typically 320-500 lux
- The light intensity required by humans change with the activity

Illuminance	Example
10^{-4} lux	Total starlight, overcast sky
0.002 lux	Moonless clear night sky with airglow
0.01 lux	Quarter moon
0.27 lux	Full moon on a clear night
1 lux	Full moon overhead at tropical latitudes
3.4 lux	Dark limit of civil twilight under a clear sky
50 lux	Family living room
80 lux	Hallway/toilet
100 lux	Very dark overcast day
320-500 lux	Office lighting
400 lux	Sunrise or sunset on a clear day
1,000 lux	Overcast day; typical TV studio lighting
10,000 – 25,000 lux	Full daylight (not direct sun)
32,000 – 130,000 lux	Direct sunlight

Living Comfort

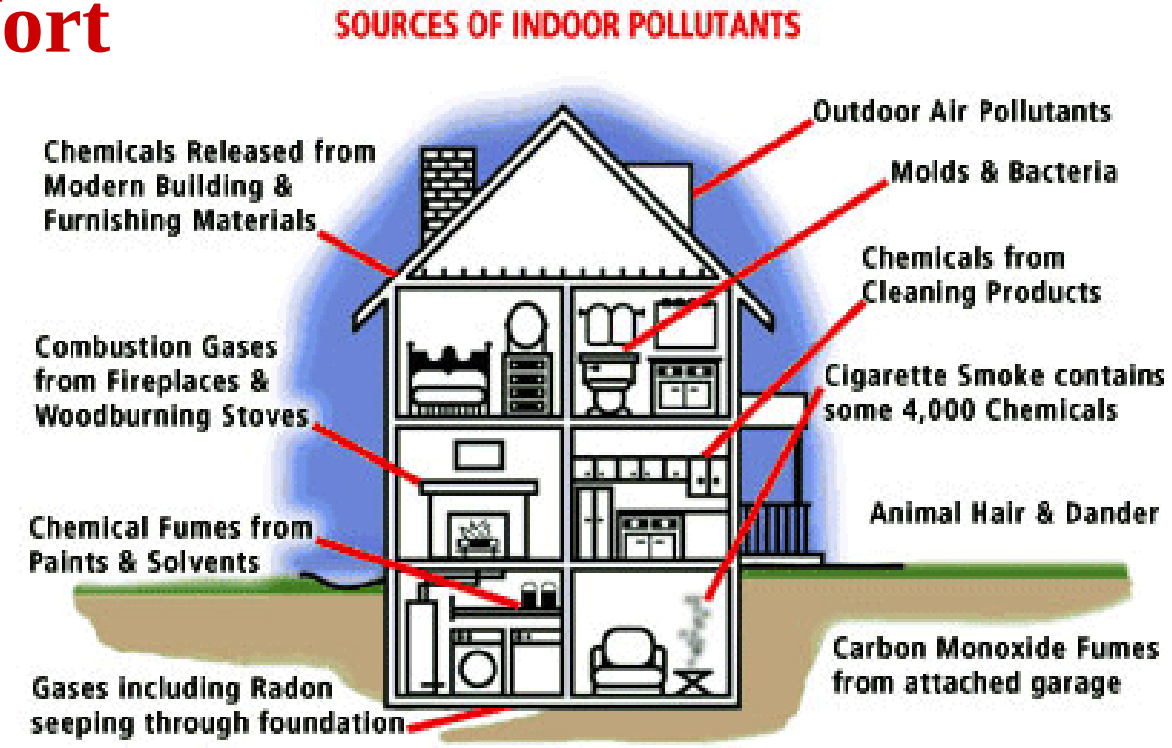
- Noise
  - Louder noise than 85dB can provide hearing damage if listen more than 8 hours
  - The word **noise** may be from the Latin word **nauseas**, which means disgust or **discomfort**.



Average Noise level	Time taken to receive a dose equivalent to the upper exposure action value (85 dB)
85 dB	8 hours
95 dB	45 minutes
100 dB	15 minutes
105 dB	5 minutes
110 dB	Under 2 minutes
115 dB	Under 30 seconds

Living Comfort

- Air quality



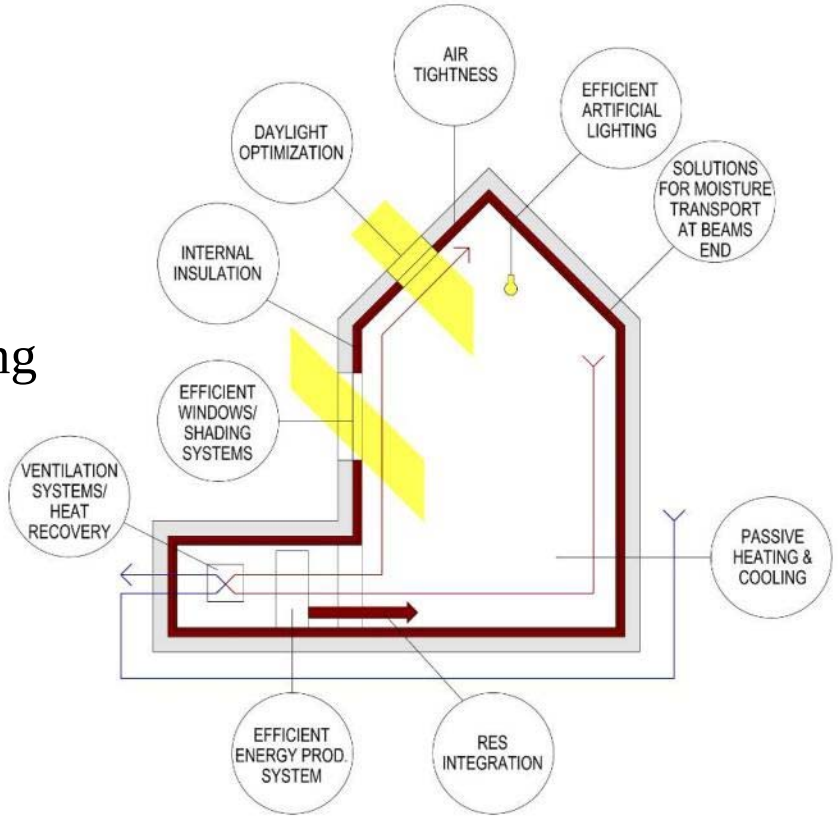
- CO^2 - Humans consume oxygen producing carbon dioxite that in an higher concentration can grow drowsy, get headaches, or function at lower activity levels. CO^2 should less than 600ppm above outdoor level.

- VOCs – Volatile organic compounds are emitted as gases from certain solid and liquid as furniture, paints, cigarette smoke, clothes etc. VOCs include a variety of chemicals, some of which may have short- and long-term adverse health effects.

Design Energy Efficient building

Design Energy Efficient building

- An energy efficient building design have to address:
  - Internal insulation
  - Efficient windows/shading system
  - Daylight optimization
  - Air tightness
  - Artificial lighting
  - Moisture transport at beams end
  - Passive – active heating and cooling
  - Ventilation system
  - Heat recovery
  - Efficient energy production
  - Resource integration
  - Thermal mass
  - Local climate



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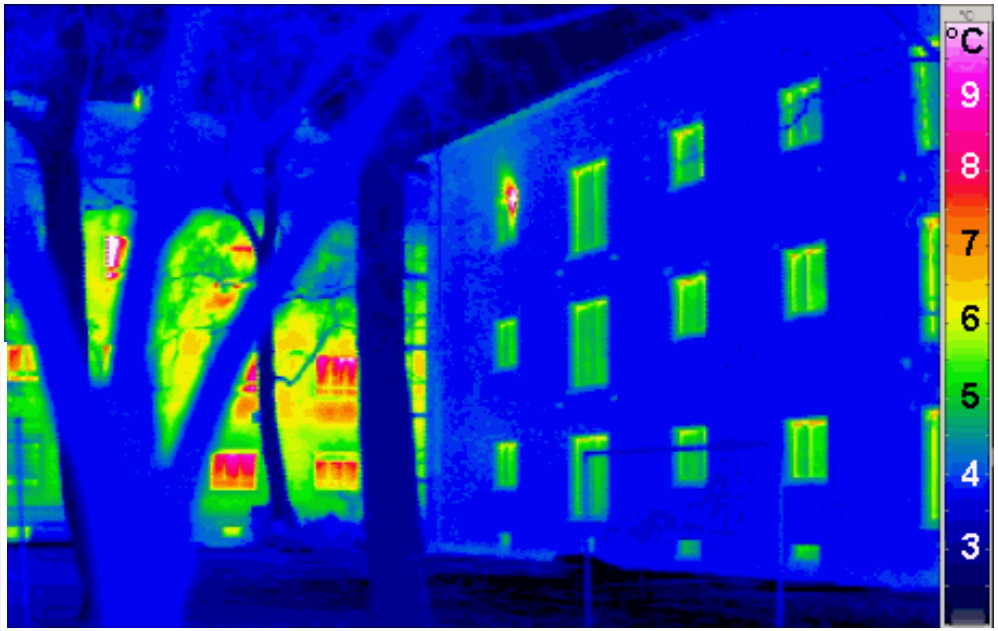
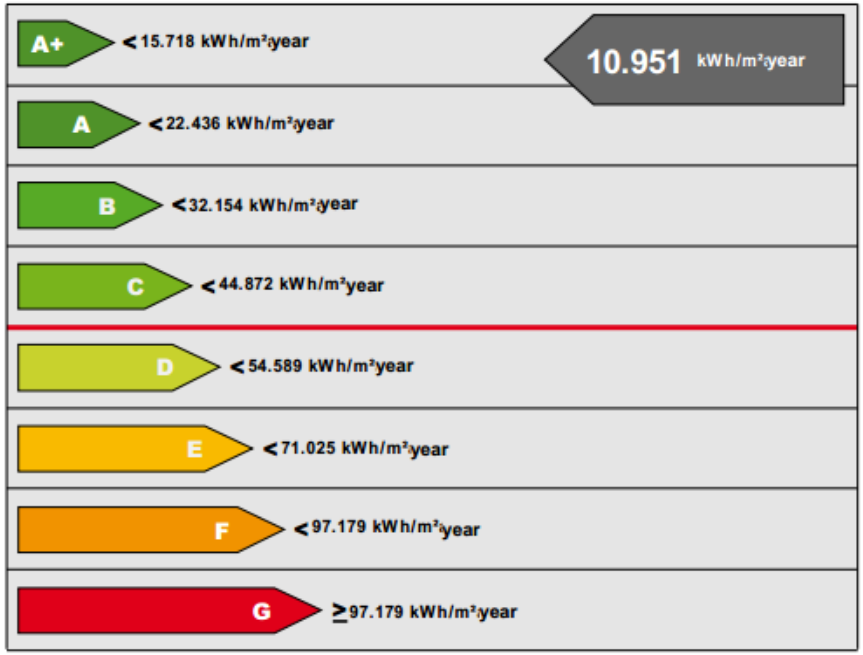
Design Energy Efficient building

- An energy efficient building design have to address:
  - Internal insulation

Super insulation permits the drastically reduction of the heating and cooling dissipation throw the wall





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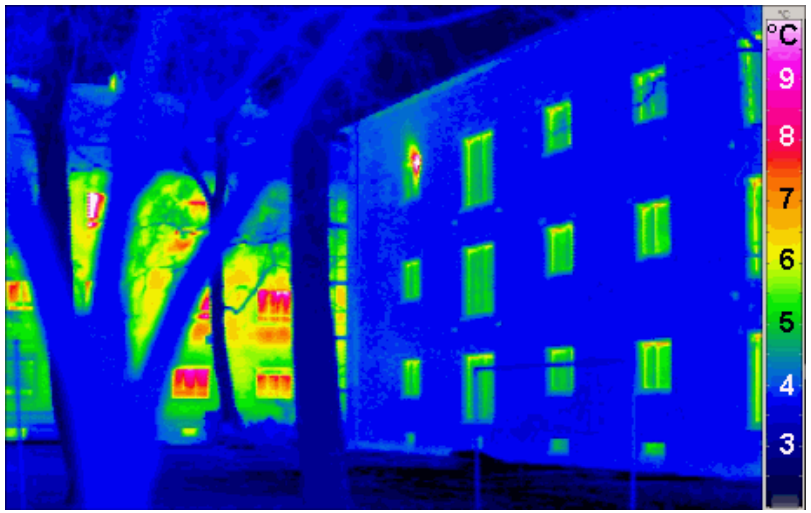
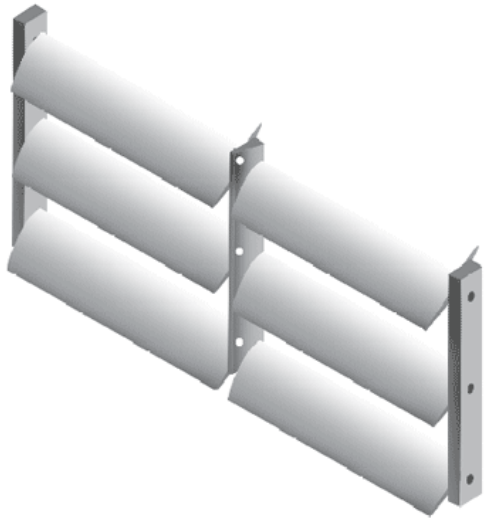
Design Energy Efficient building

- An energy efficient building design have to address:
  - Efficient windows/shading system
  - Daylight optimization



A good shadowing system can reduce the overheating during summer keeping the right daylight level



Windows are usually the critical part of thermal exchange between indoor and outdoor

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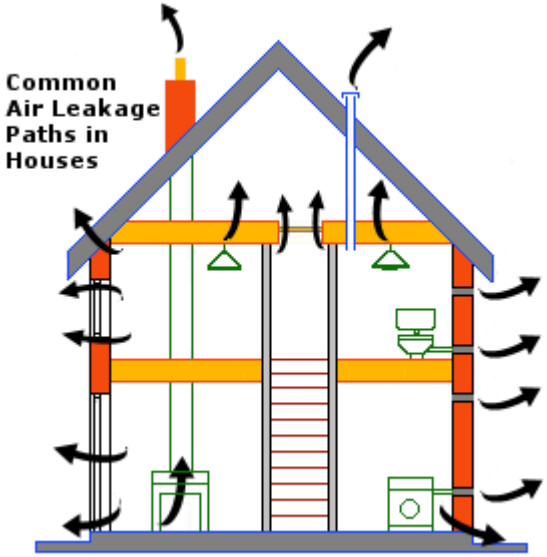
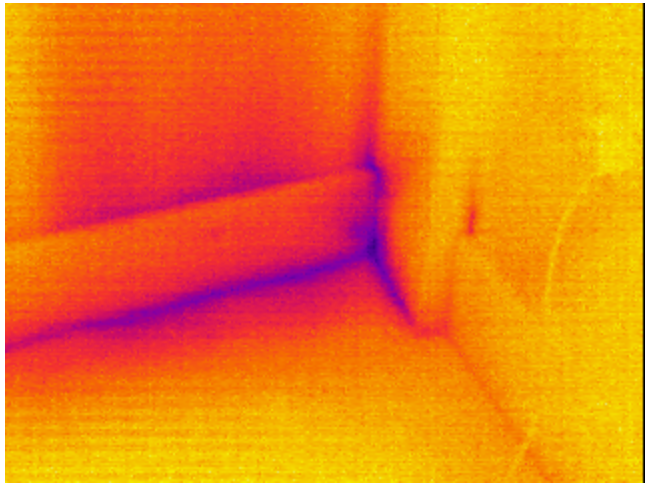
Design Energy Efficient building

- An energy efficient building design have to address:
  - Air tightness



The air leakage paths increase the thermal transportation among the building and the surrounding environment



Increase the air tightness avoid the heat to flow in rooms that usually are not heated (e.i. Garret, underground, etc)

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Design Energy Efficient building

- An energy efficient building design have to address:
  - Artificial lighting

The artificial lighting should provide the right amount of lux respect the activity that will be performed in the room

The artificial light intensity can change during the day in function of the sun light intensity (e.i. corridors)

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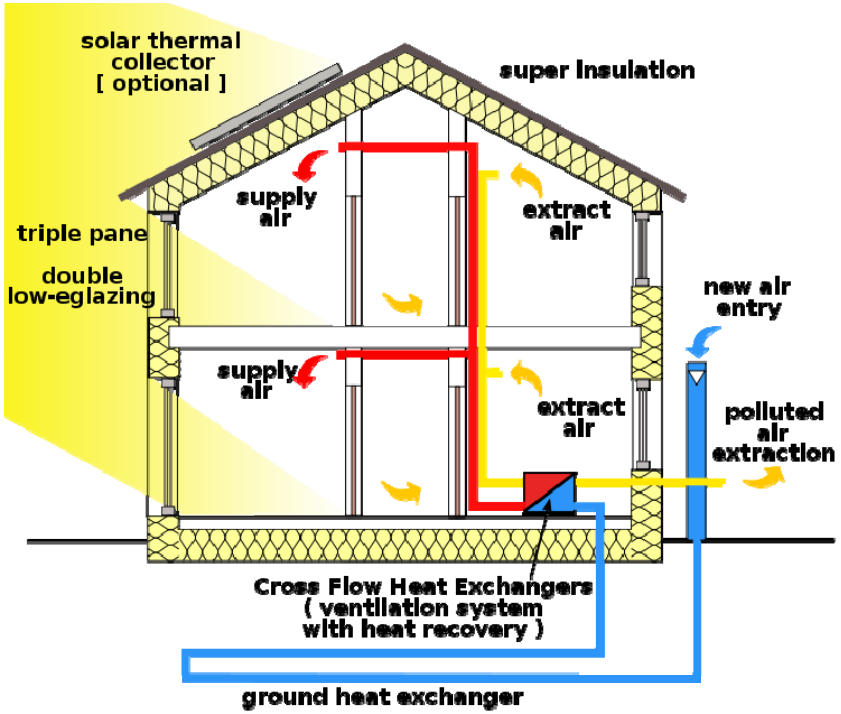
Design Energy Efficient building

- An energy efficient building design have to addresses:
  - Active heating and cooling
  - Ventilation system
  - Heat recovery
    - Due to heat exchangers
  - Efficient energy production
    - Solar, geothermic
  - Resource integration
    - Energy from power grid



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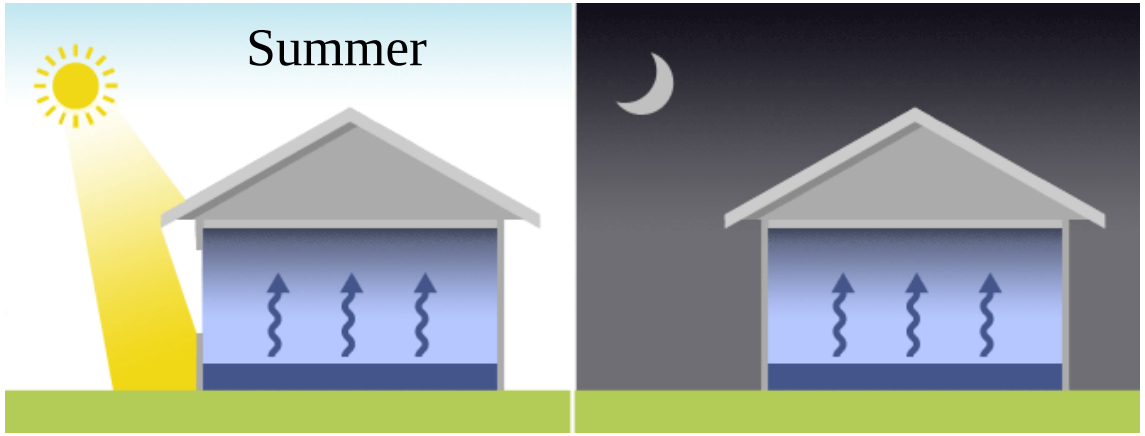
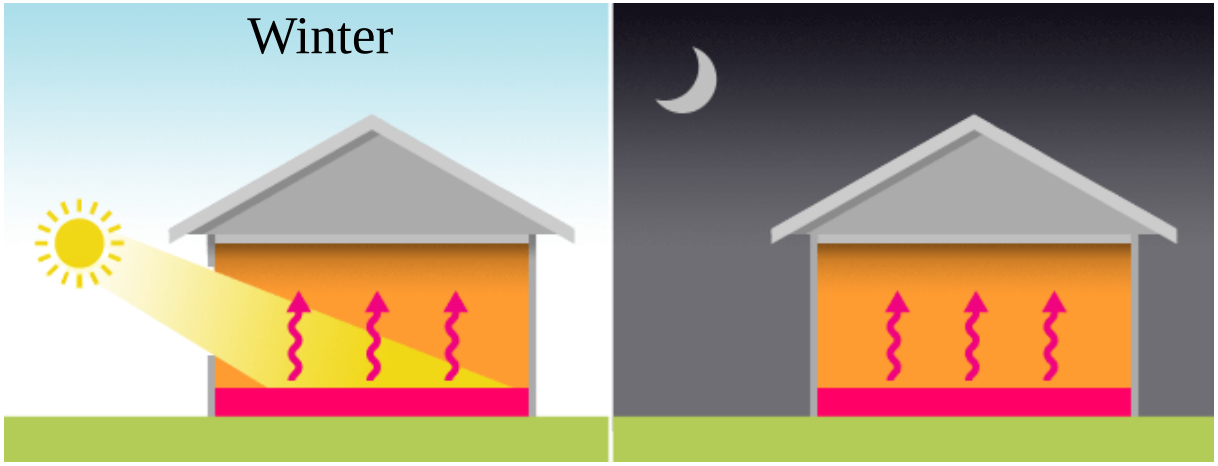
Design Energy Efficient building

- An energy efficient building design have to address:
  - Passive heating and cooling
  - Thermal mass





Thick brick walls are good thermal mass

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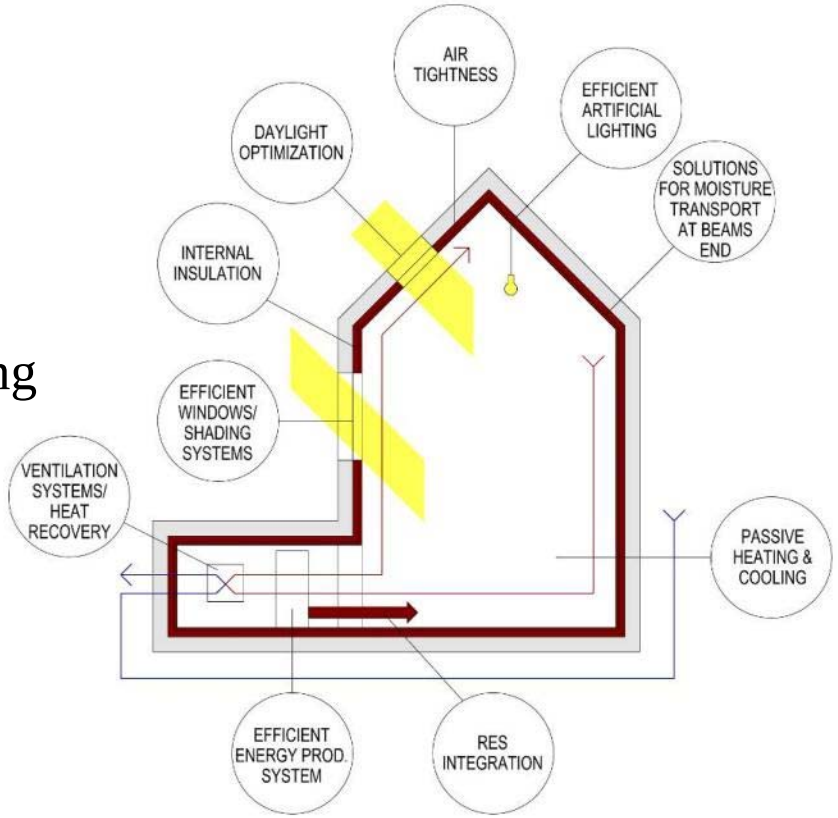
Design Energy Efficient building

- An energy efficient building design have to address:
  - Internal insulation
  - Efficient windows/shading system
  - Daylight optimization
  - Air tightness
  - Artificial lighting
  - Moisture transport at beams end
  - Passive – active heating and cooling
  - Ventilation system
  - Heat recovery
  - Efficient energy production
  - Resource integration
  - Thermal mass
  - **Local climate**



Almost the above items are correlated to local climate

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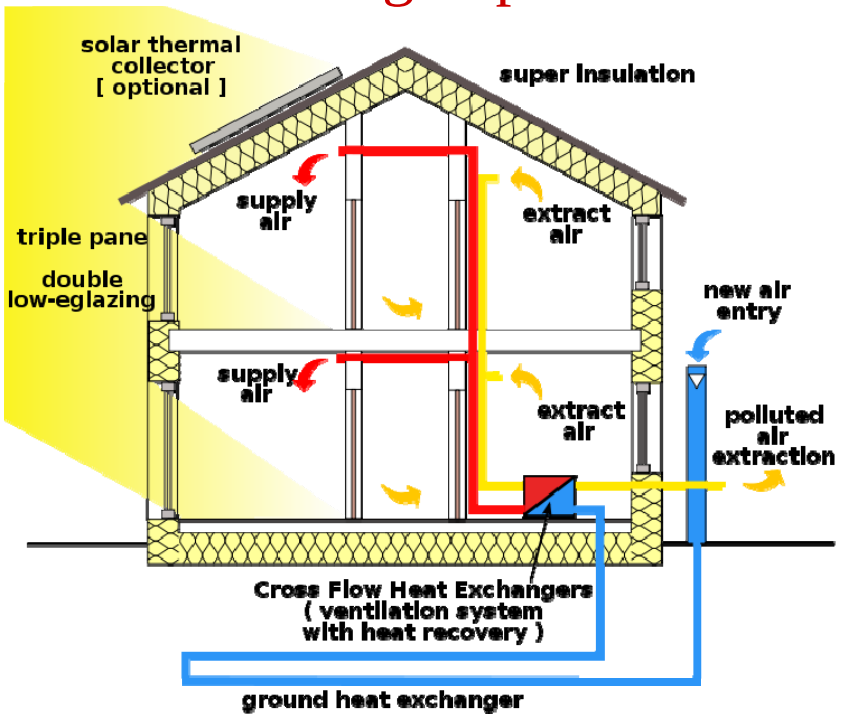
Design Energy Efficient building

- The designers collect information about local climate and simulate the future new building to predict its energy behavior



- However the complexity of the systems require a densely instrumented monitoring and controlling system to perform the best energy management

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Design Energy Efficient building

- Monitoring
  - Air temperature
  - Wall temperature
  - Humidity
  - Light intensity
  - Air velocity
  - Air quality
  - Human presence
  - Windows state
  - Doors state
  - Electric power consumption
- The monitoring should be performed at each room with one or more acquisition points

- Controlling
  - Artificial lighting
  - Heating
  - Cooling
  - Ventilation
  - Shadowing
  - Energy production
  - Resource integration
  - Energy usage
- The controlling can be applied either to few or all of the above items

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Design Energy Efficient building

- Building management system (BMS)
  - The building management system is the central unit that collects data from the **monitoring** system and performs several actions with the **controlling** system to preserve the users **comfort** and **energy efficiency**
  - The BMS runs complex algorithms to increase the energy efficiency
  - The BMS has usually remote connection to perform remote control and analysis of the building

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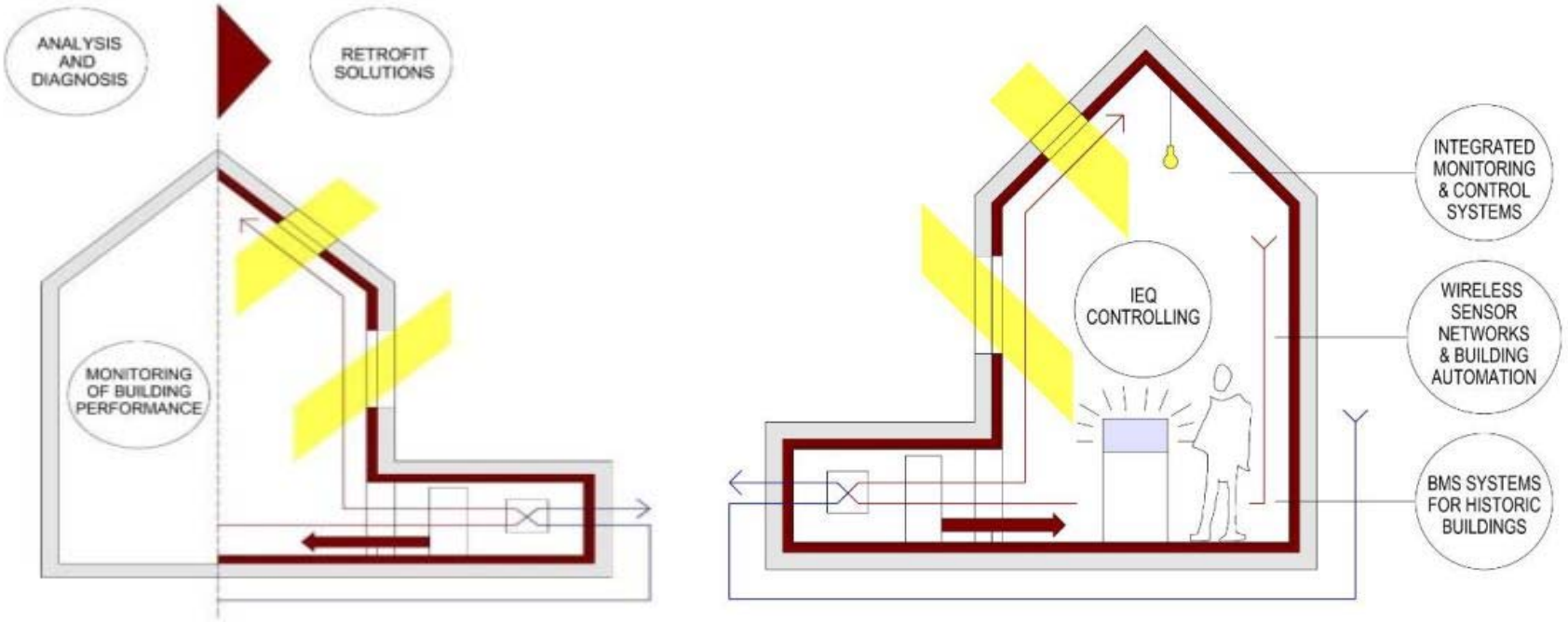
Design Energy Efficient building

- Refurbishment case!
  - In Europe there are 55million dwellings dating from before 1945 possible subject of refurbishment



- The designer have to know the building performance to plan the retroffiting solutions to increase the energy efficiency and preserve the building cultural heritage

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Design Energy Efficient building

- Monitoring system used as performance building meter under usage condition
- Need to monitoring
  - Air temperature
  - Wall temperature
  - Humidity
  - Light intensity
  - Air velocity
  - Air quality
  - Human presence
  - Windows state
  - Doors state
  - Electric power consumption
- To estimate
  - Thermal loss
  - Air leakage paths
  - Thermal mass
  - Sun overheating
  - Poor ventilation
  - Bad air quality
  - Energy usage
  - Passive ventilation
- Usually this kind of monitoring systems are wireless to reduce the installation cost avoiding mansonery and cable placement

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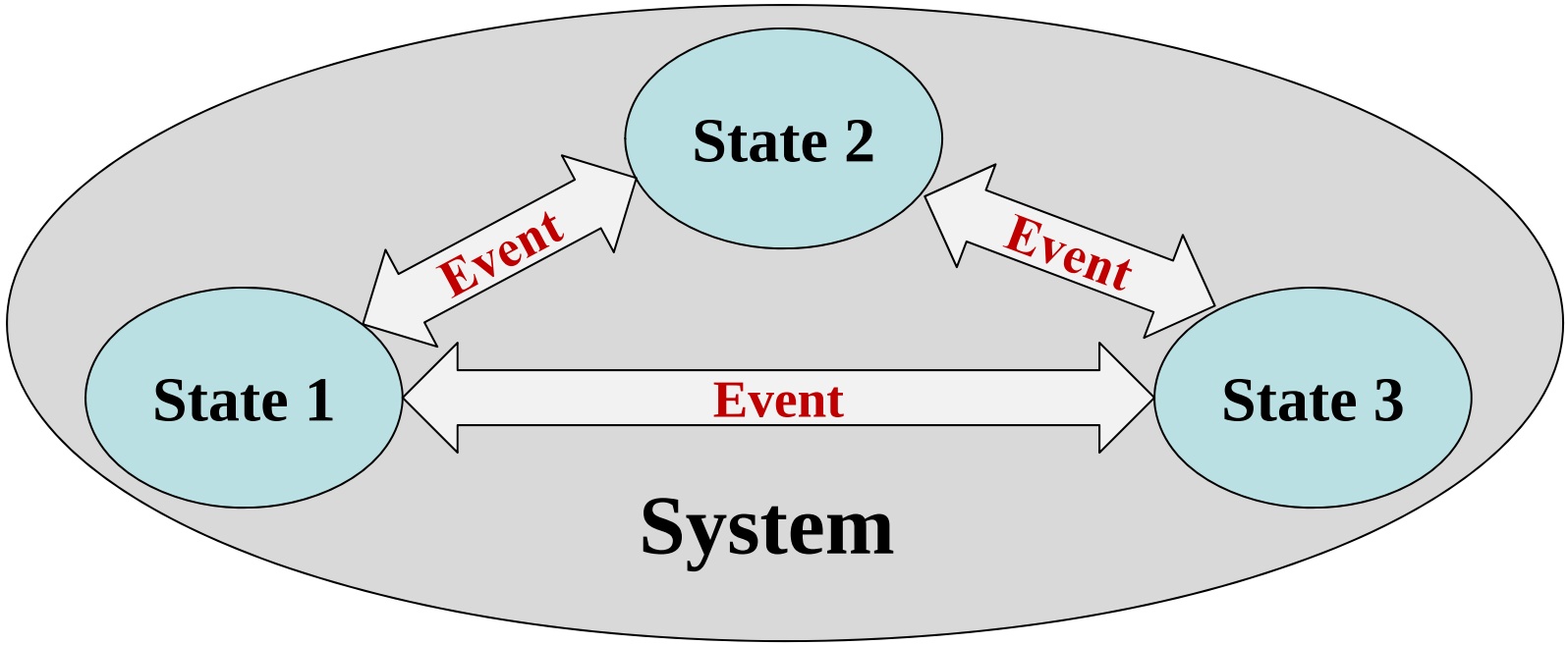
Monitoring and control concept

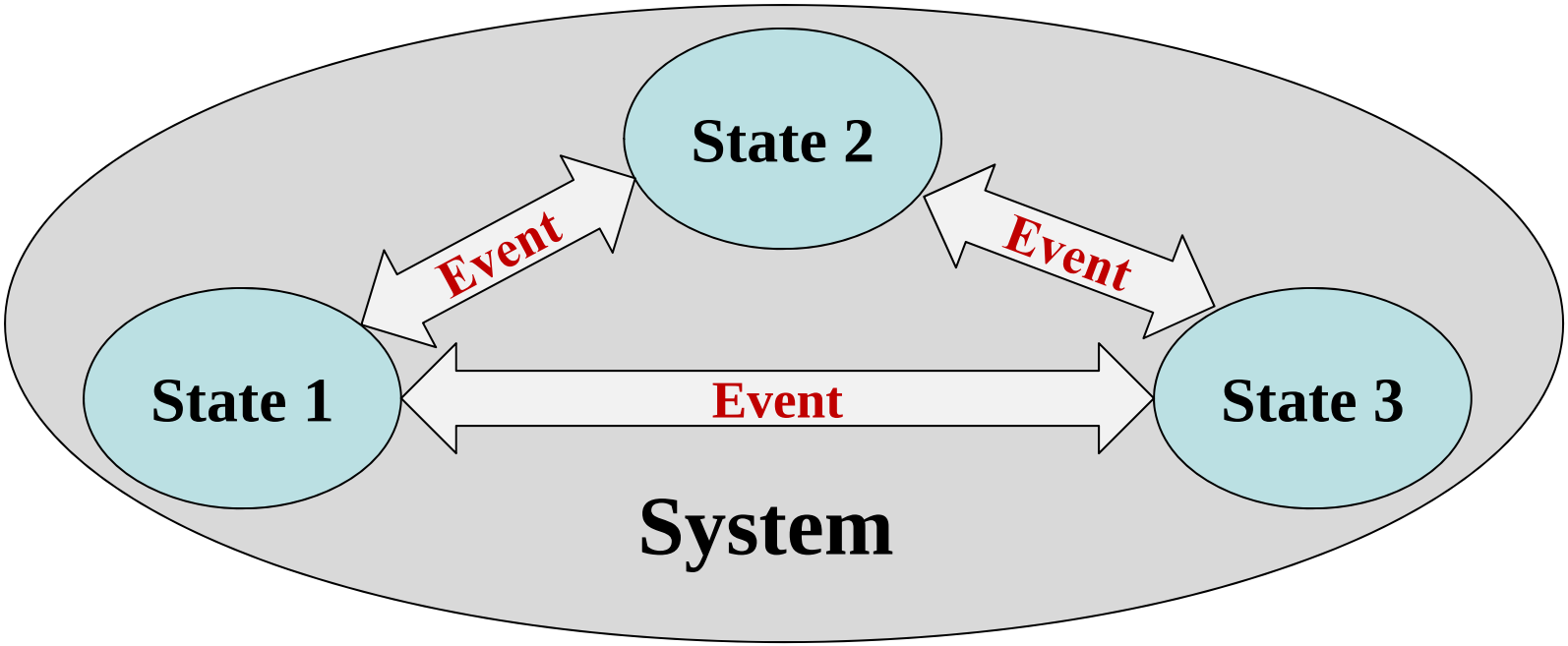
Monitoring and control concept

- To monitor or monitoring generally means to be aware of the state of a system
  - A system can be described as a collection of states
  - Each state is described by a batch of conditions
  - The change of state is typically triggered by an event
  - The monitoring aims to detect the system status



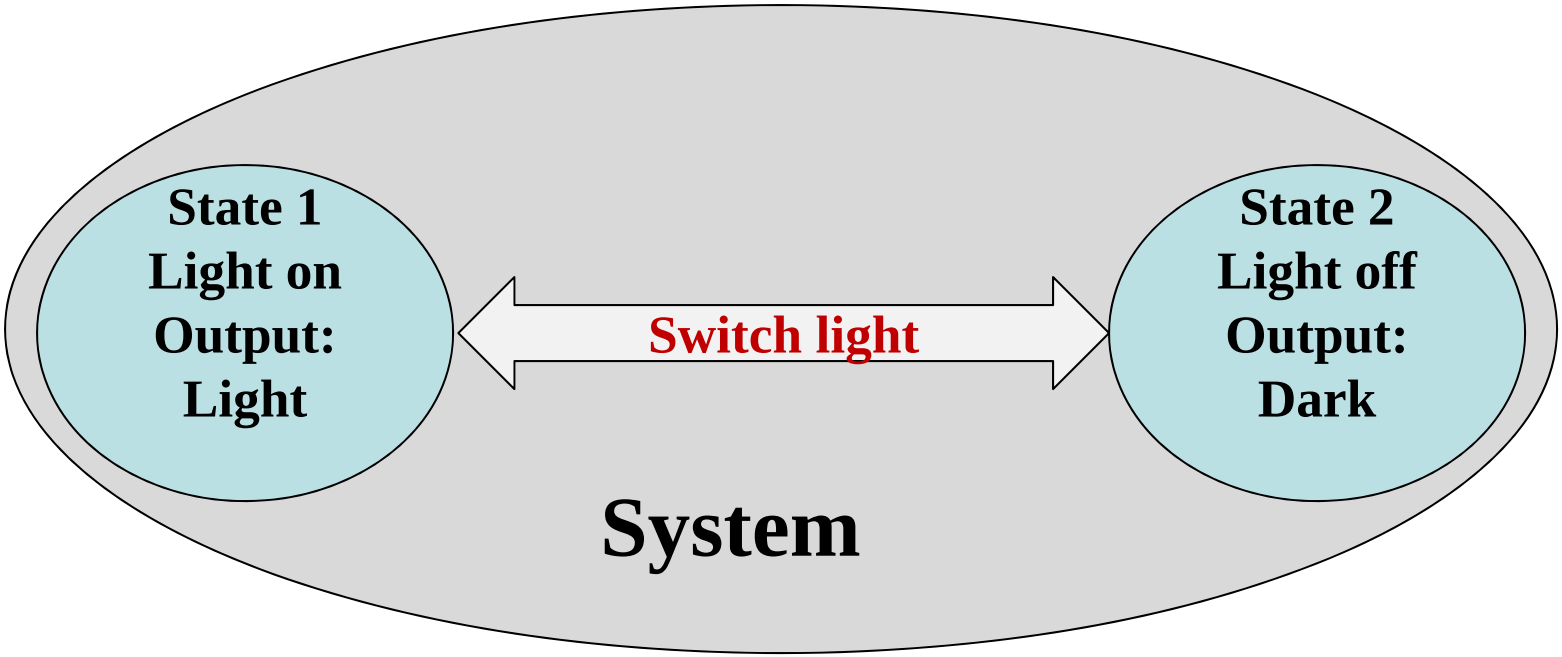
Monitoring and control concept

- To control generally means to force a system to reach a predefined state
  - The control can trigger events (called input) to reach the desired state
  - An output of a system is a condition that we want to control
  - A system is fully controllable if the triggered events can bring the system to have the desired output

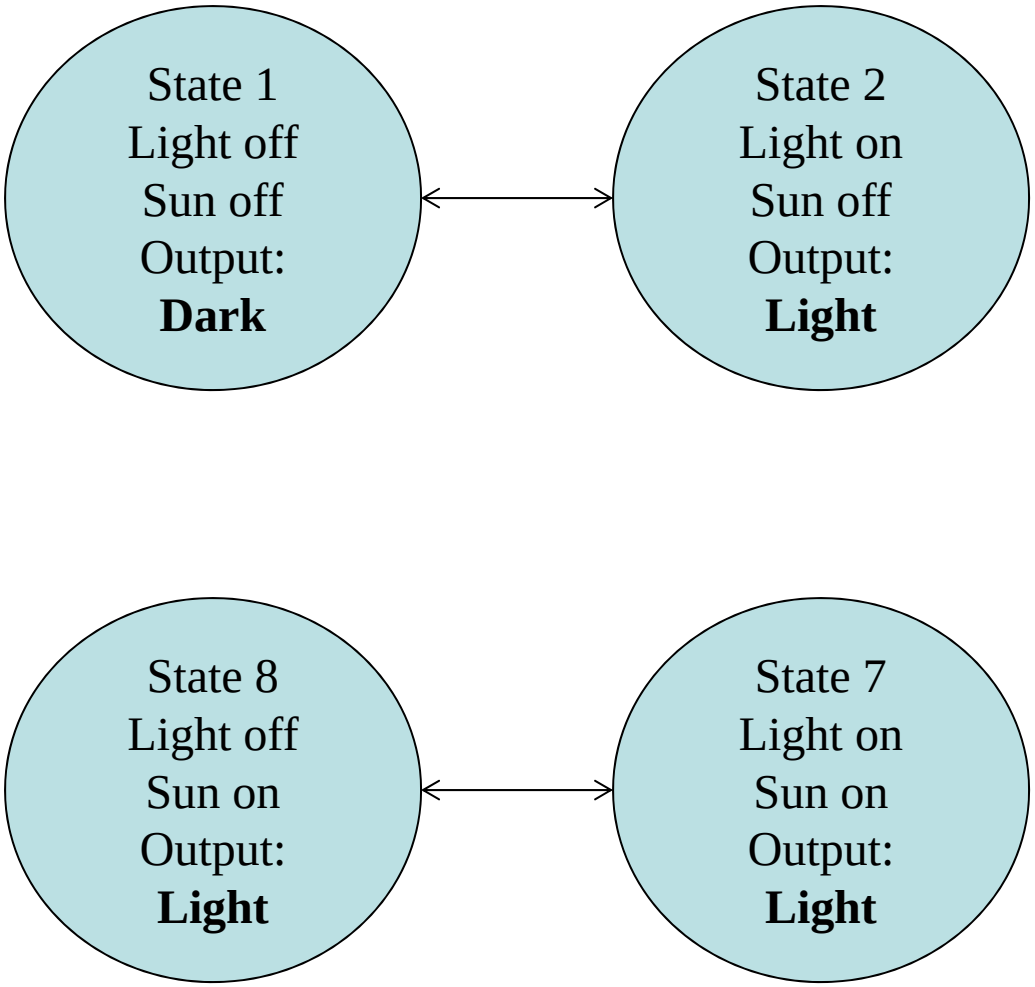


Monitoring and control concept

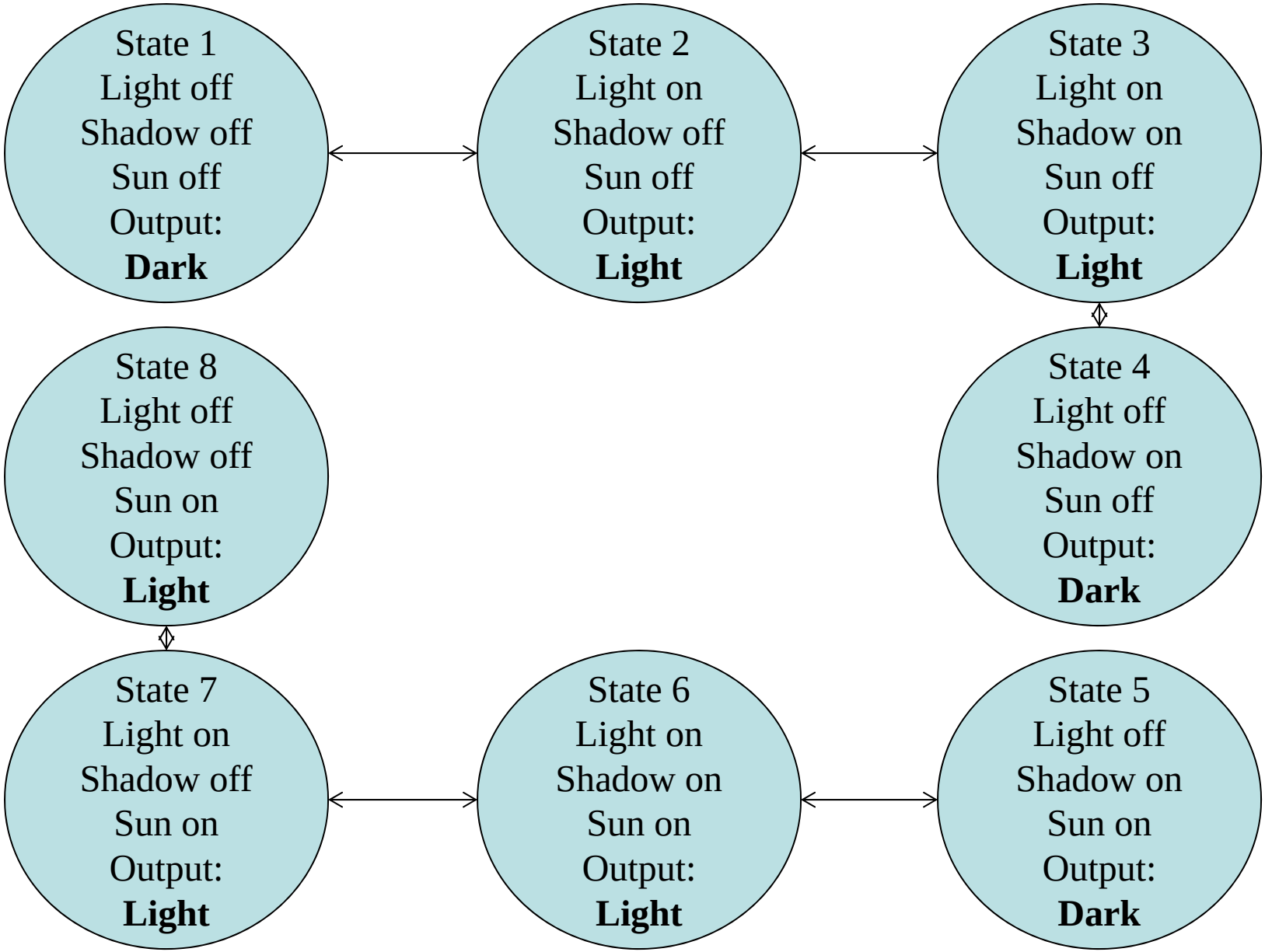
- Example: Lighting control
  - In a room without windows it is possible to control the lighting acting only to the light switch (fully controllable)
  - In a room with windows we can not control the lighting only acting to the light switch (the system is partially controllable)
  - Adding the possibility to act to the shadowing we can completely control the system



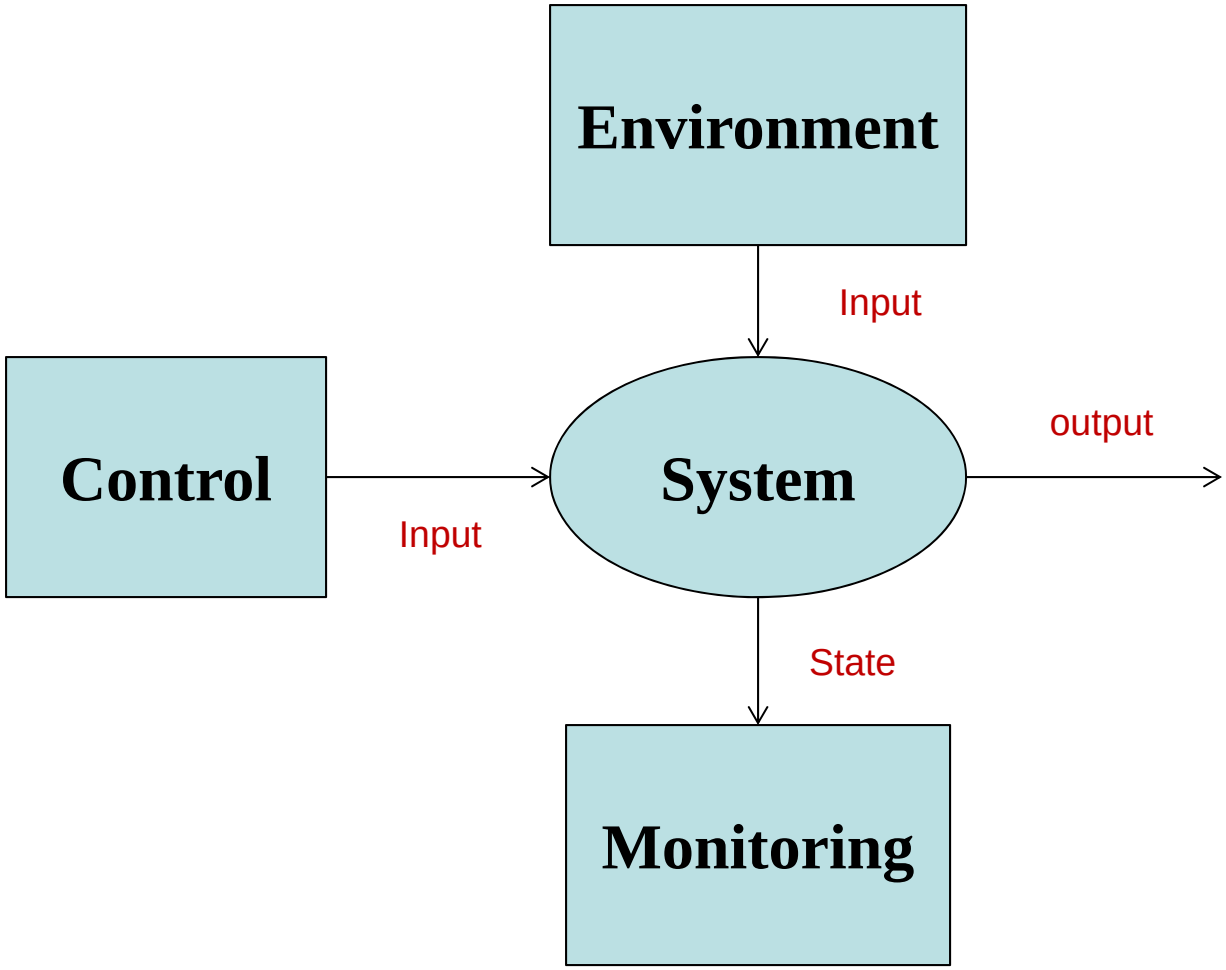
Monitoring and control concept



Monitoring and control concept

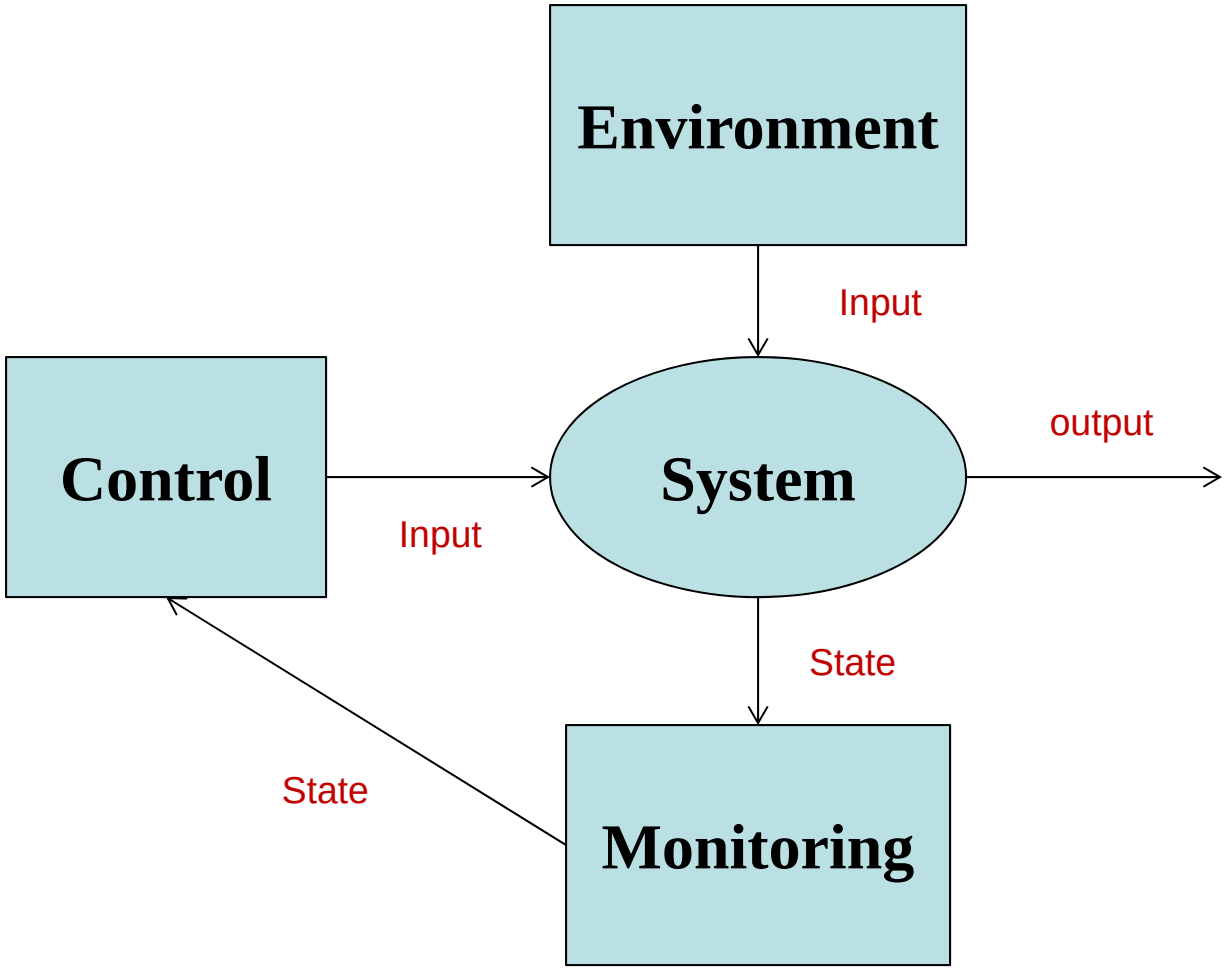


Monitoring and control concept



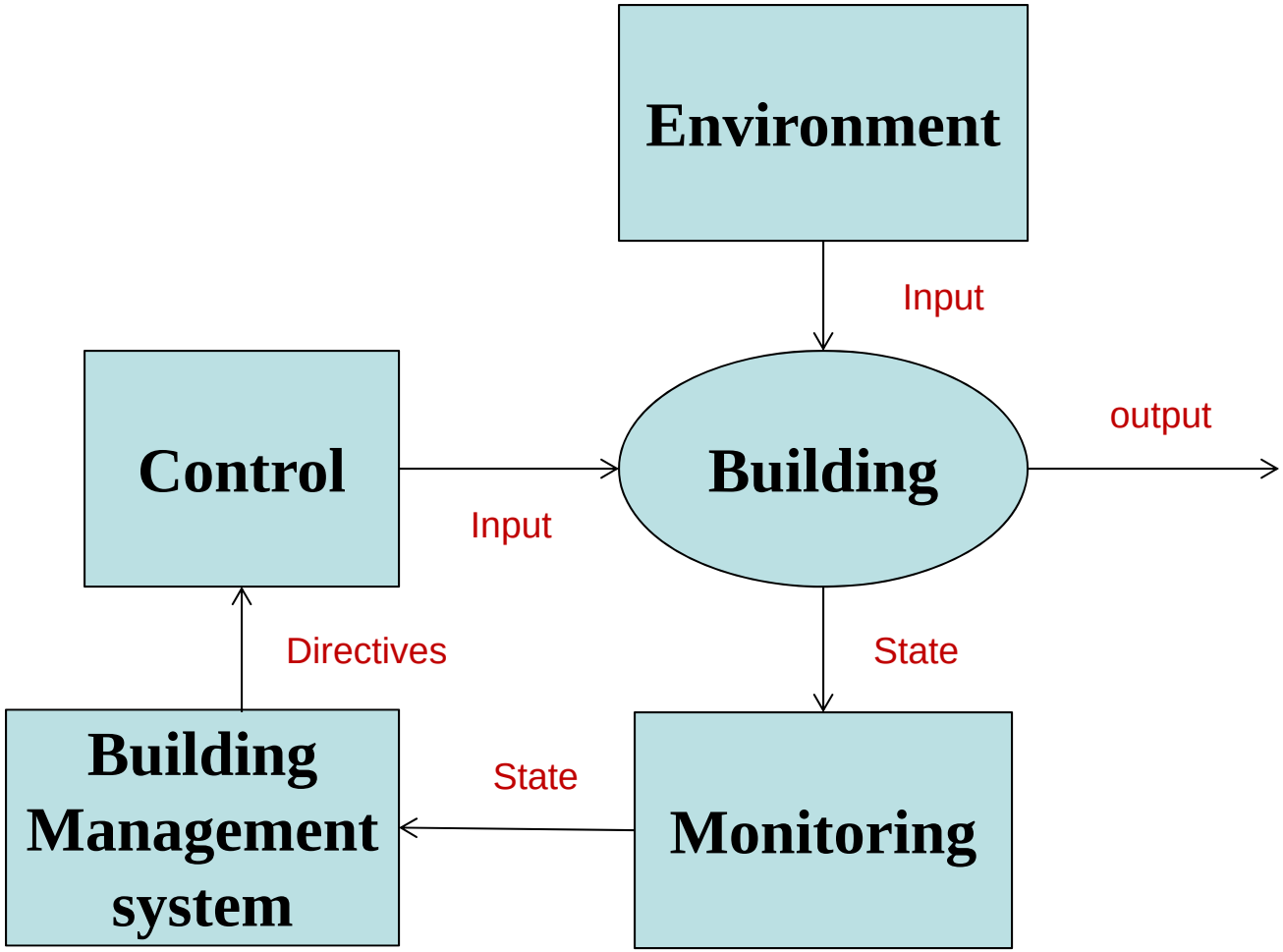
- Open loop control system

Monitoring and control concept



- Closed loop control system

Monitoring and control concept

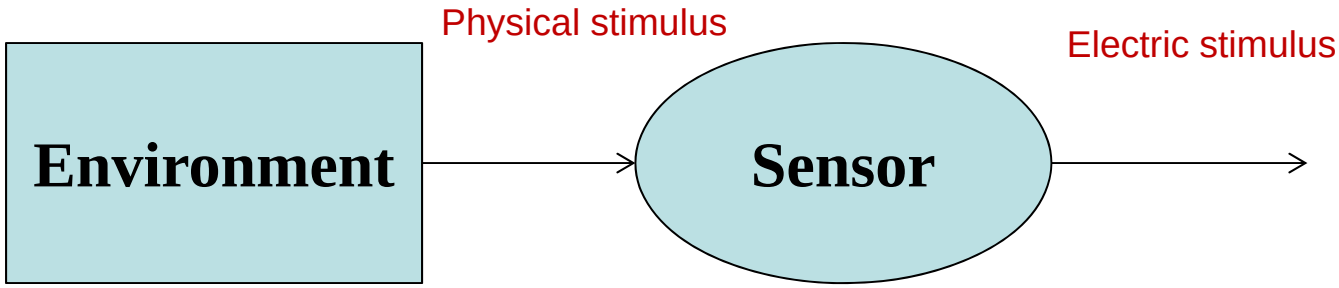


- Smart building: monitoring and control

Sensors

Sensors

- Sensor is a device that convert a physical stimulus (as heat, light, sound, pressure, magnetism, or a particular motion) to an electric stimulus



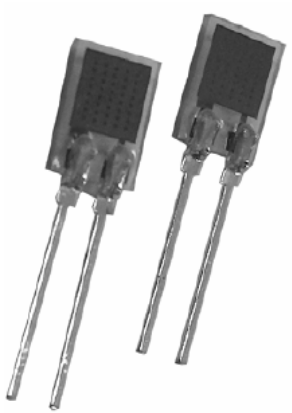
- The electric stimulus could be:
  - Voltage (e.i. Light sensors, microphone, gas sensors)
  - Current (e.i gas sensors, current sensors)
  - Resistance (temperature sensors, gas sensors, pressure sensors)
  - Capacitance (humidity sensors, acceleration sensors)
  - Frequency (velocity sensors, wind sensors)
- The sensor could need power supply or not
  - Microphone (self powered)
  - Temperature (need power supply)

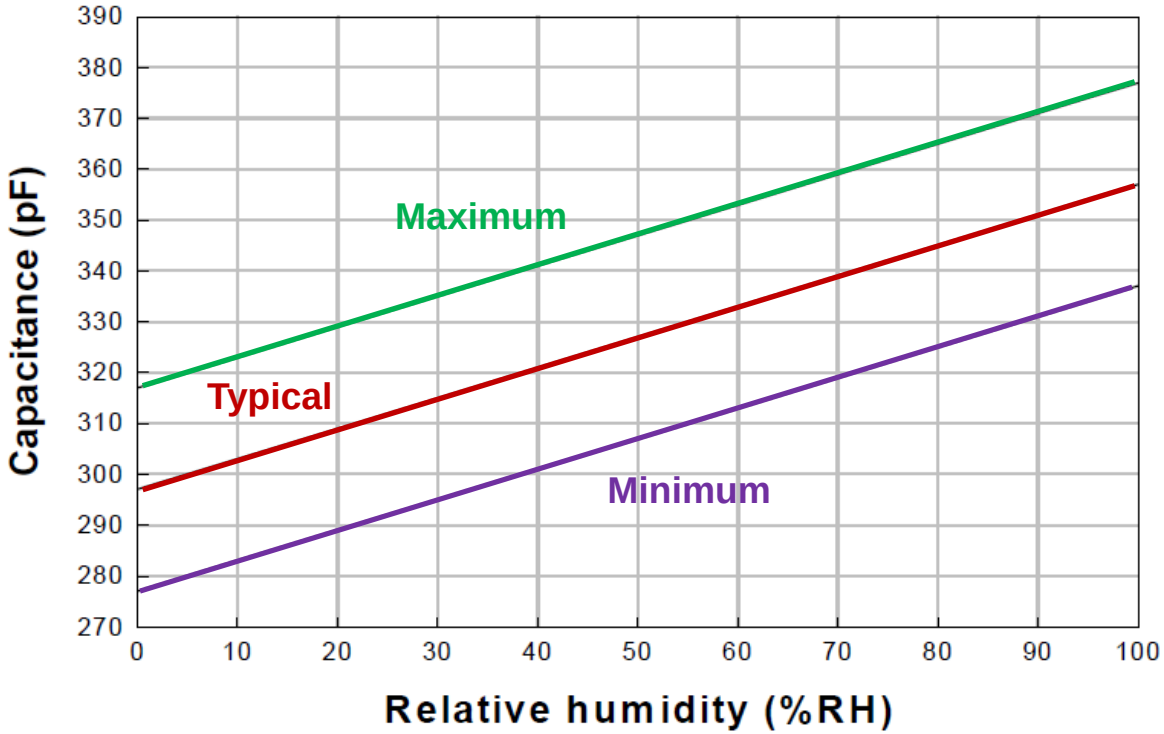
Sensors

- Sensor characteristics
  - Conversion characteristics, the function that convert the physical entity amount in the electrical stimulus amount (linear, quadratic, un linear etc.)
  - Sensitivity, the capability to convert a certain amount of physical entity in a corresponding electrical amount.
  - Range, the maximum and minimum amount of physical quantity that the sensor can detect.
  - Resolution, is the degree to which repeated measurements under unchanged conditions show the same results
  - Accuracy, is the degree of closeness of measurements to the physical entity true value.
  - Tolerance, is the degree to which repeated measurements under unchanged condition with different entity of the same sensor show the same results. (Usually due to production variability)
  - Response time, the time required to the sensor to go at equilibrium with the surrounding environment.
  - Reading time, the time required to the sensor to collect the measurement

Sensors

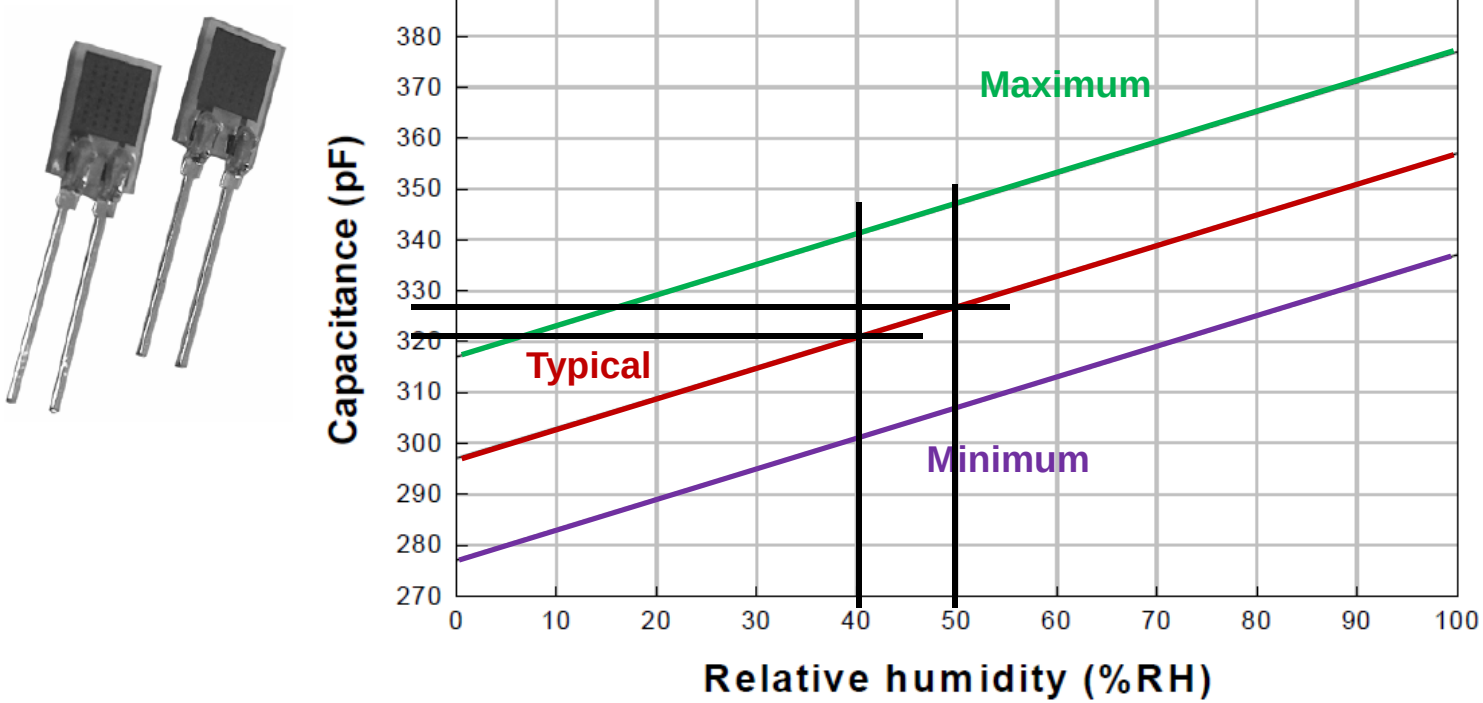
- Sensor characteristics example
  - Conversion characteristics, the function that convert the physical entity amount in the electrical stimulus amount (linear, quadratic, un linear etc.)
- Humidity sensor (linear)





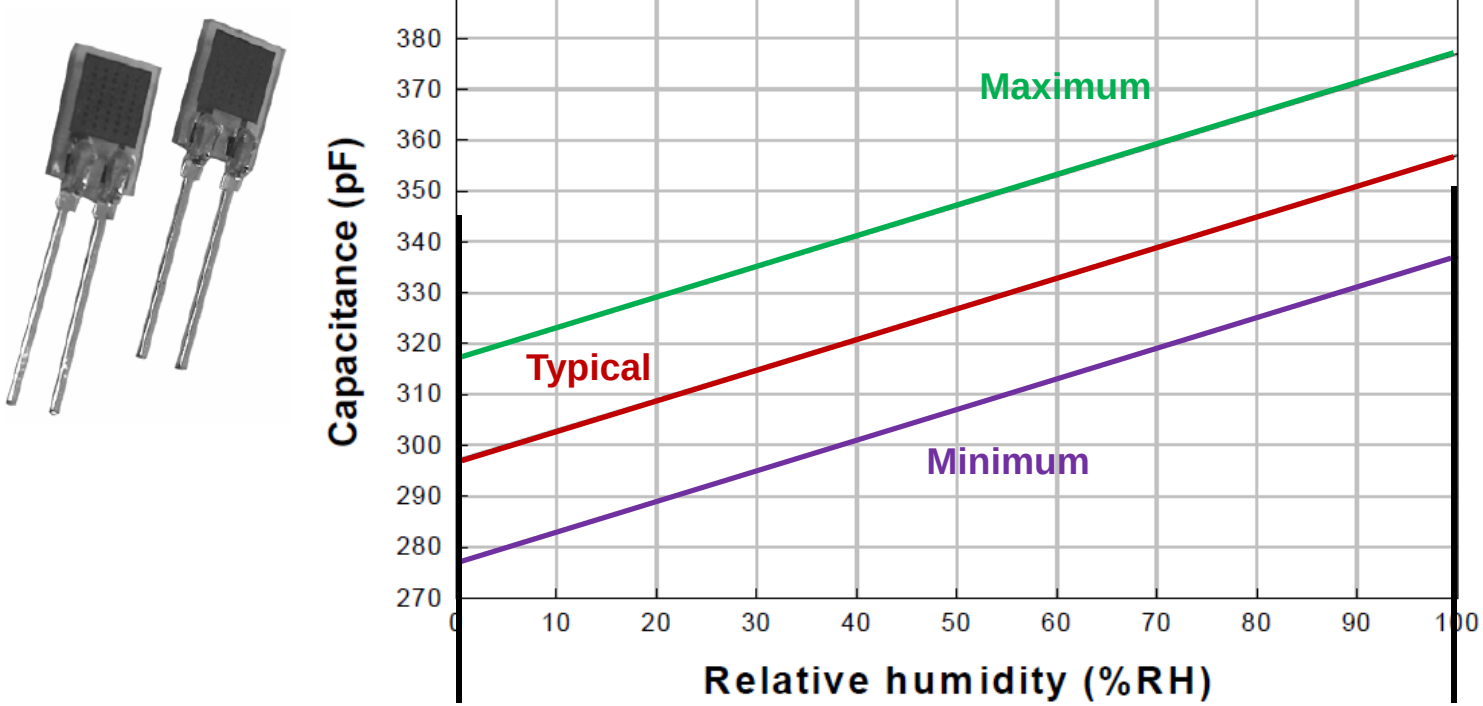
Sensors

- Sensor characteristics example
  - Sensitivity, the capability to convert a certain amount of physical entity in a corresponding electrical amount.
- Humidity sensor: 0.6 pF/%RH



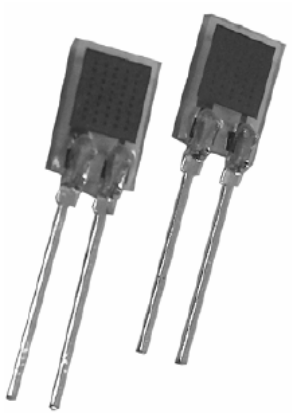
Sensors

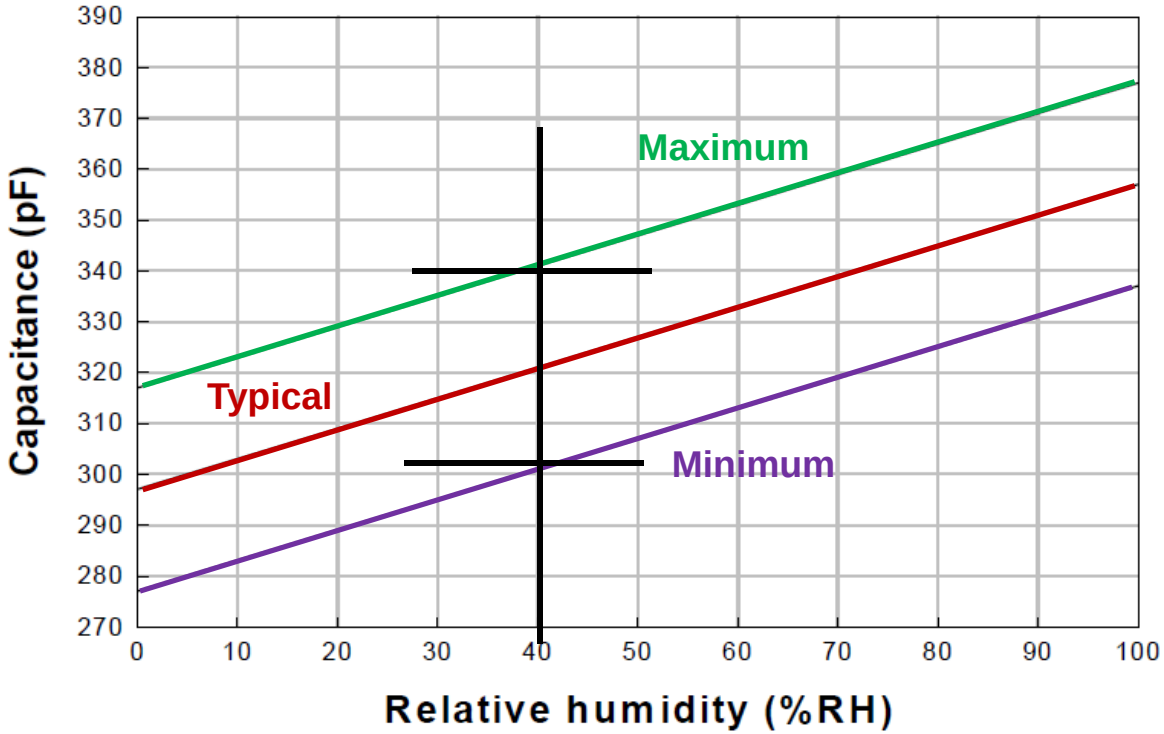
- Sensor characteristics example
  - Range, the maximum and minimum amount of physical quantity that the sensor can detect.
- Humidity sensor: 0 to 100% RH



Sensors

- Sensor characteristics example
  - Tolerance, is the degree to which repeated measurements under unchanged condition with different entity of the same sensor show the same results. (Usually due to production variability)
- Humidity sensor: ±20pF





Sensors

- Sensor characteristics example
  - Response time, the time required to the sensor to go at equilibrium with the surrounding environment.
- Humidity sensor: 15sec

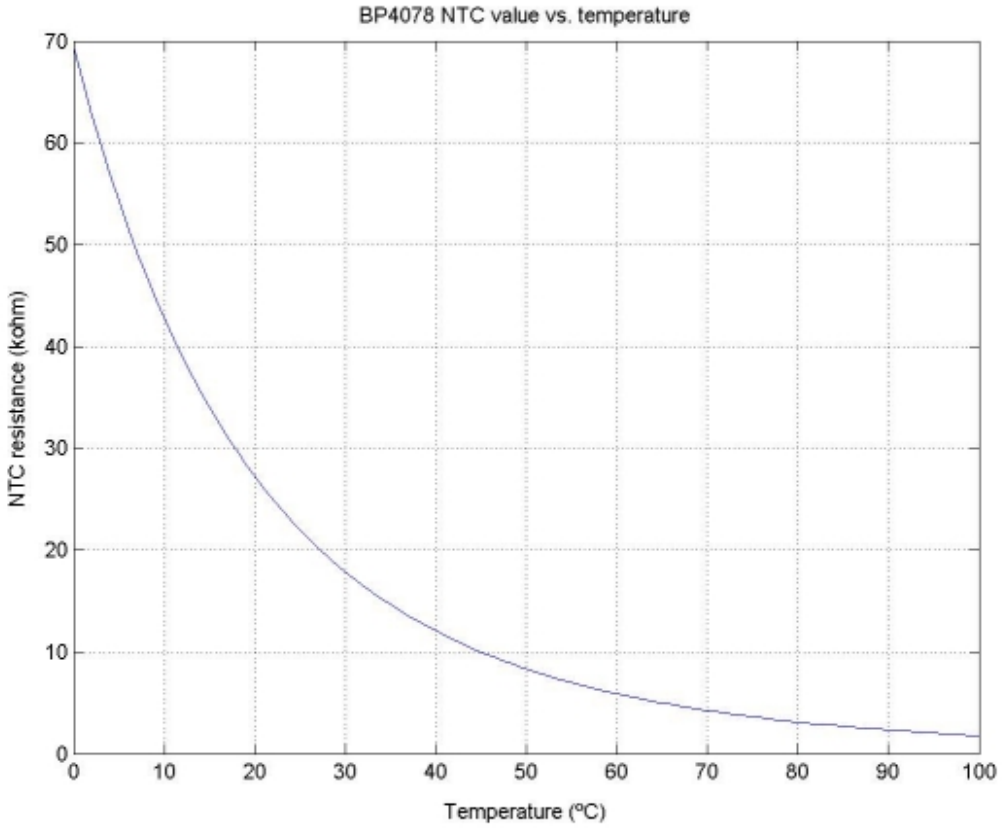
SPECIFICATIONS (T_A= 25 °C [77 °F], Input Voltage = 1 V_{RMS}, Frequency = 20 kHz)

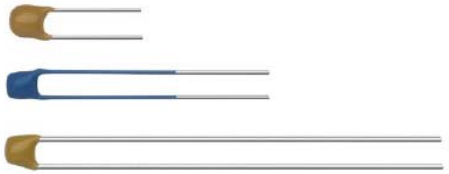
Characteristic	Min.	Typ.	Max.	Unit	Note
Normal capacitance	310	330	350	pF	at 55% RH
Sensitivity	0.55	0.60	0.65	pF/%RH	10% RH to 95% RH
Humidity hysteresis	–	±2	–	%RH	–
Linearity	–	±2	–	%RH	–
Response time	–	15	–	sec	30% RH to 90% RH
Temperature coefficient	0.15	0.16	0.17	pF/°C	5 °C to 70 °C [41 °F to 158 °F]
Long-term stability (drift)	–	0.2	–	%RH/year	–
Operating temperature range	-40 [-40]	–	120 [248]	°C [°F]	–
Operating humidity range	0%	–	100%	RH	–
Operating frequency range	1	–	100	kHz	–

- Note: the measurement can be affected from others physical quantity. The humidity sensor is sensitive to the temperature!
- Note: the humidity sensor is affected by log term stability drift due to wear out process.

Sensors

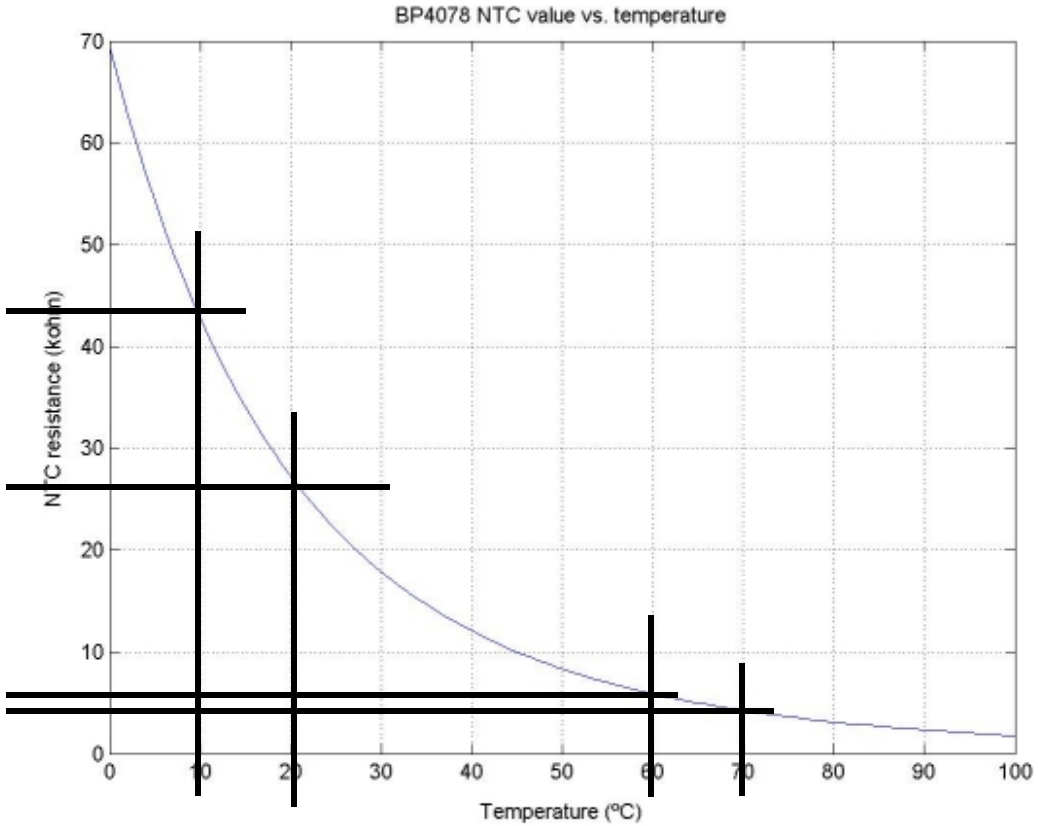
- Sensor characteristics example
  - Conversion characteristics, the function that convert the physical entity amount in the electrical stimulus amount (linear, quadratic, un linear etc.)
- Temperature sensor NTC (no linear)

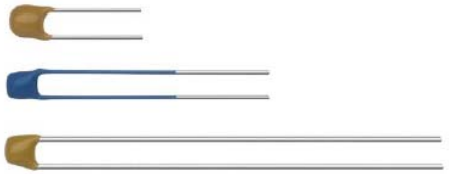




Sensors

- Sensor characteristics example
  - Sensitivity, the capability to convert a certain amount of physical entity in a corresponding electrical amount.
- Temperature sensor NTC: change with the temperature





Sensors

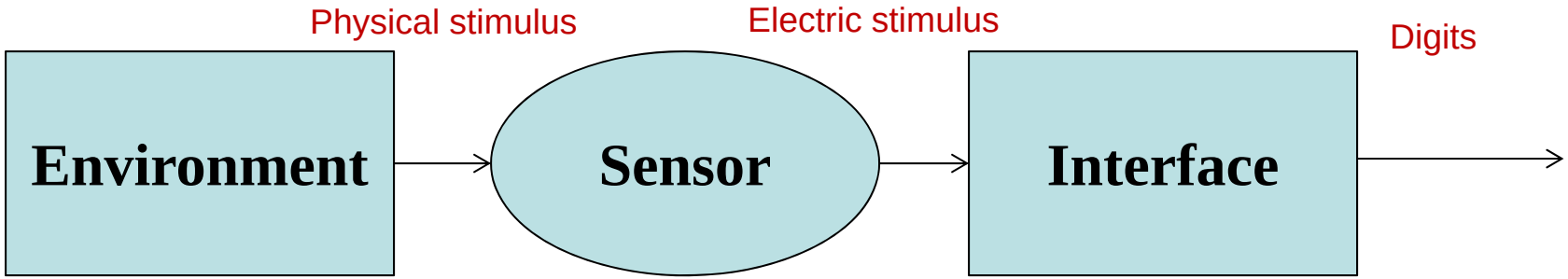
- Sensor characteristics example
  - Resolution, is the degree to which repeated measurements under unchanged conditions show the same results
  - Accuracy, is the degree of closeness of measurements to the physical entity true value.
- Temperature sensor digital (Sensirion SHT21)

Parameter	Condition	min	typ	max	Units
Resolution [1]	14 bit		0.01		°C
	12 bit		0.04		°C
Accuracy tolerance [2]	typ		±0.3		°C
	max	see Figure 3			°C
Repeatability			±0.1		°C
Operating Range	extended [4]	-40		125	°C
		-40		257	°F
Response Time [7]	τ 63%	5		30	s
Long Term Drift			< 0.04		°C/yr

Sensors interfacing and data acquisition

Sensors interfacing and data acquisition

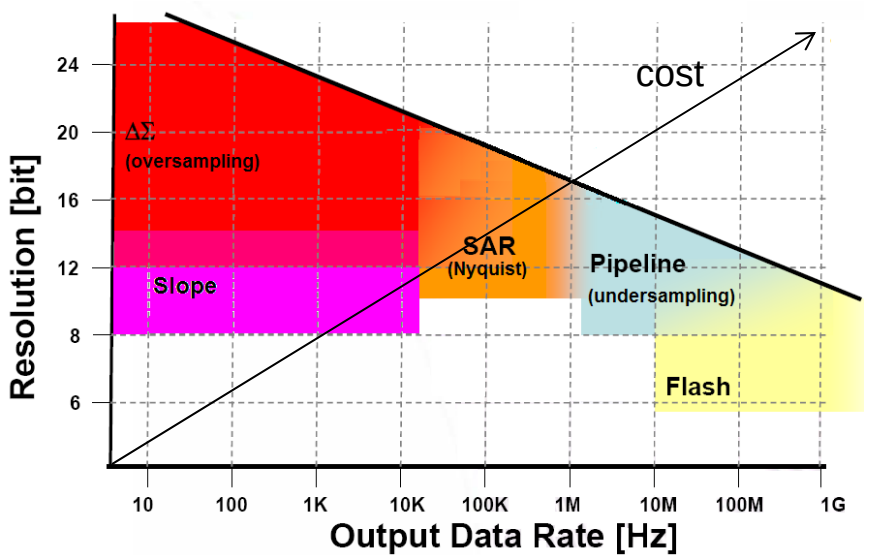
- Sensor interface is usually an electronic circuit that provides the power supply to the sensor (if needed); filters the signals to eliminate unwanted noise; amplifies the signal and converts it in a form more suitable to be transmitted.

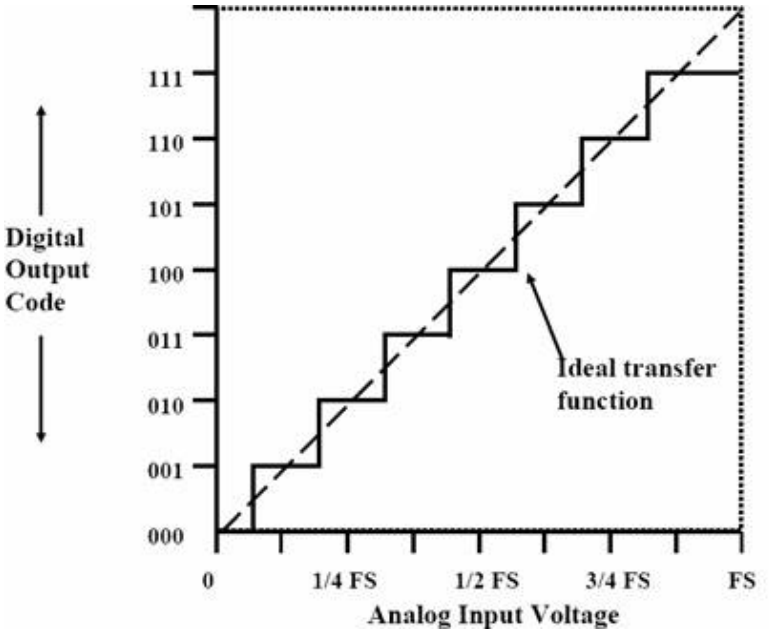


- The interface:
  - It is usually responsible of the sensor resolution, which is essentially due to the signal noise ration capability of the circuit.
  - More close is the interface to the sensor and better signal noise ratio it is possible to achieve at minor cost.
  - The modern interfaces have an Analog to Digital Converter (ADC) that convert the electric signal in binary code string.
  - If the sensor and the interfacing with ADC are built in the same package than it is a digital sensor. (e.i. SHT21)
  - Digital sensors usually provides directly the measure of the physical quantity not the measure of the electric quantity

Sensors interfacing and data acquisition

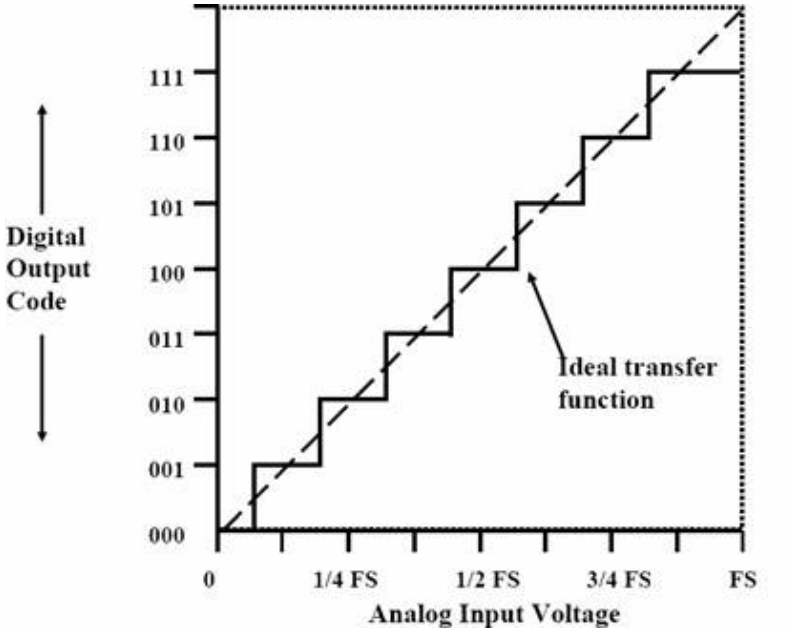
- Analog to Digital Conversion (ADC)
  - Analog to Digital converter is a circuit that typically translate a voltage in a binary digital string (or binary number)
  - The ADC main characteristics are:
    - Resolution, how many binary digits has the output string
    - Sample rate, how many string can the ADC take at each second





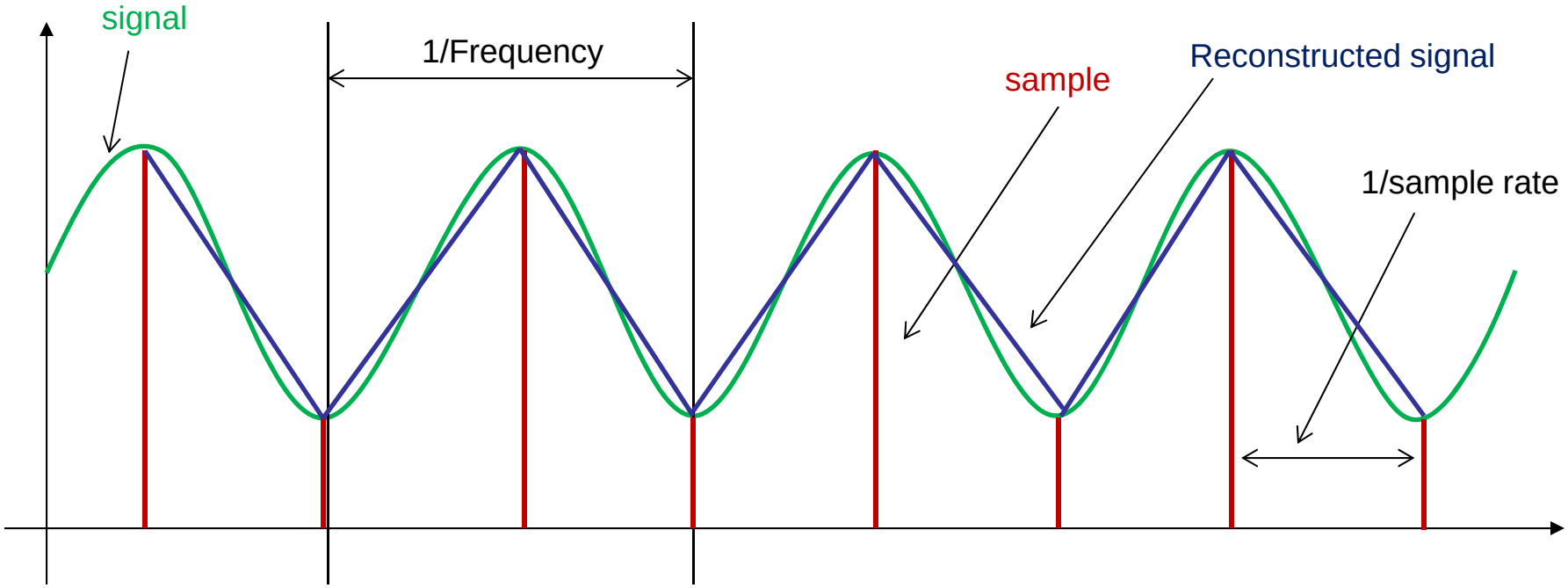
Sensors interfacing and data acquisition

- Analog to Digital Conversion (ADC) resolution
  - An ADC can represent the entire range of signal input using the number of binary digits express in the resolution. Than if we have a 8 bits ADC it means that the entire range is divided in $2^8 = 256$ segments (signal quantization). Therefore the smallest number representable is a 1/256 of the maximum value.
  - E.i. If we have a linear temperature sensor raging from 0 to 100ºC and we interface it with an 8 bit ADC, the minimum detectable temperature variation would be 100/256=0,39ºC
  - The ADC resolution typically range from 8 bit to 24 bit



Sensors interfacing and data acquisition

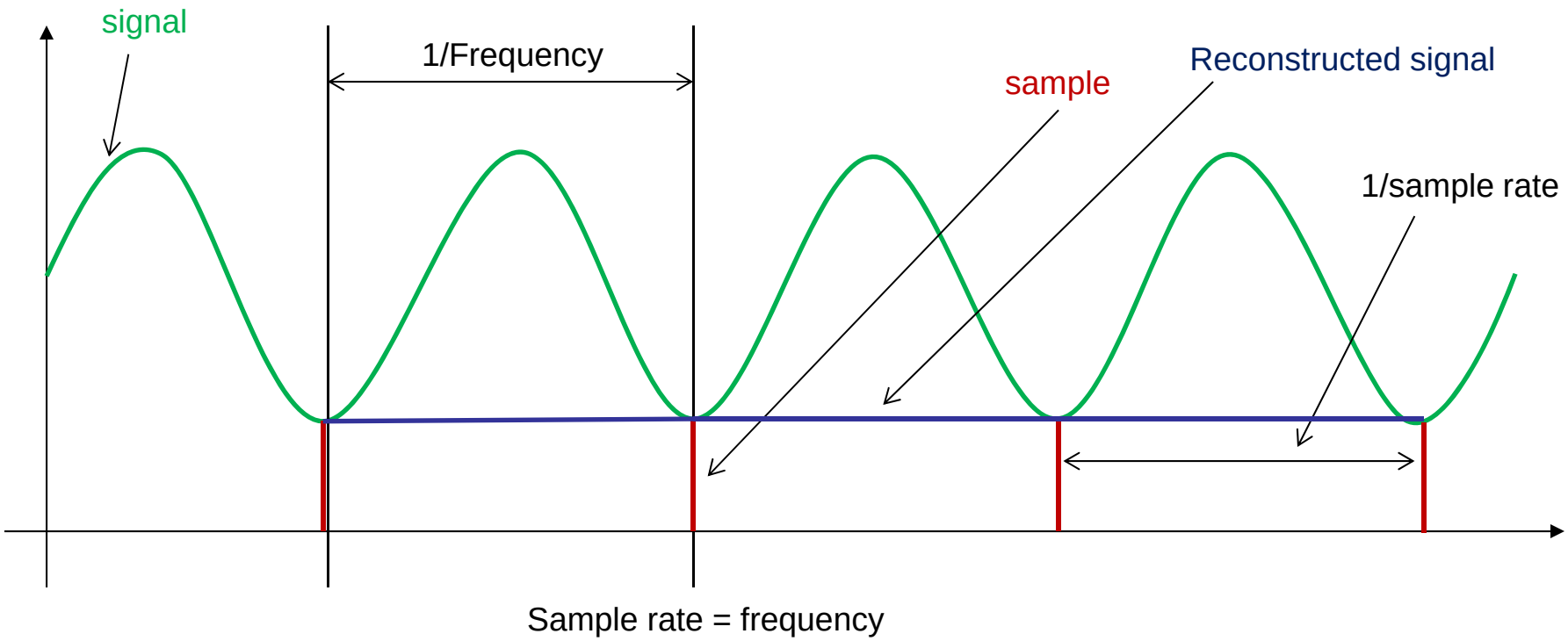
- Analog to Digital Conversion (ADC) sample rate
  - The sample rate is important to have da correct temporal representation of the signal
  - The Shannon theory explain that a signal as to be converted in digital form with at least double sample rate of the maximum frequency
  - E.i. music is sampled at 44,1Khz because we can hear till 20Khz



Sample rate = 2 * frequency

Sensors interfacing and data acquisition

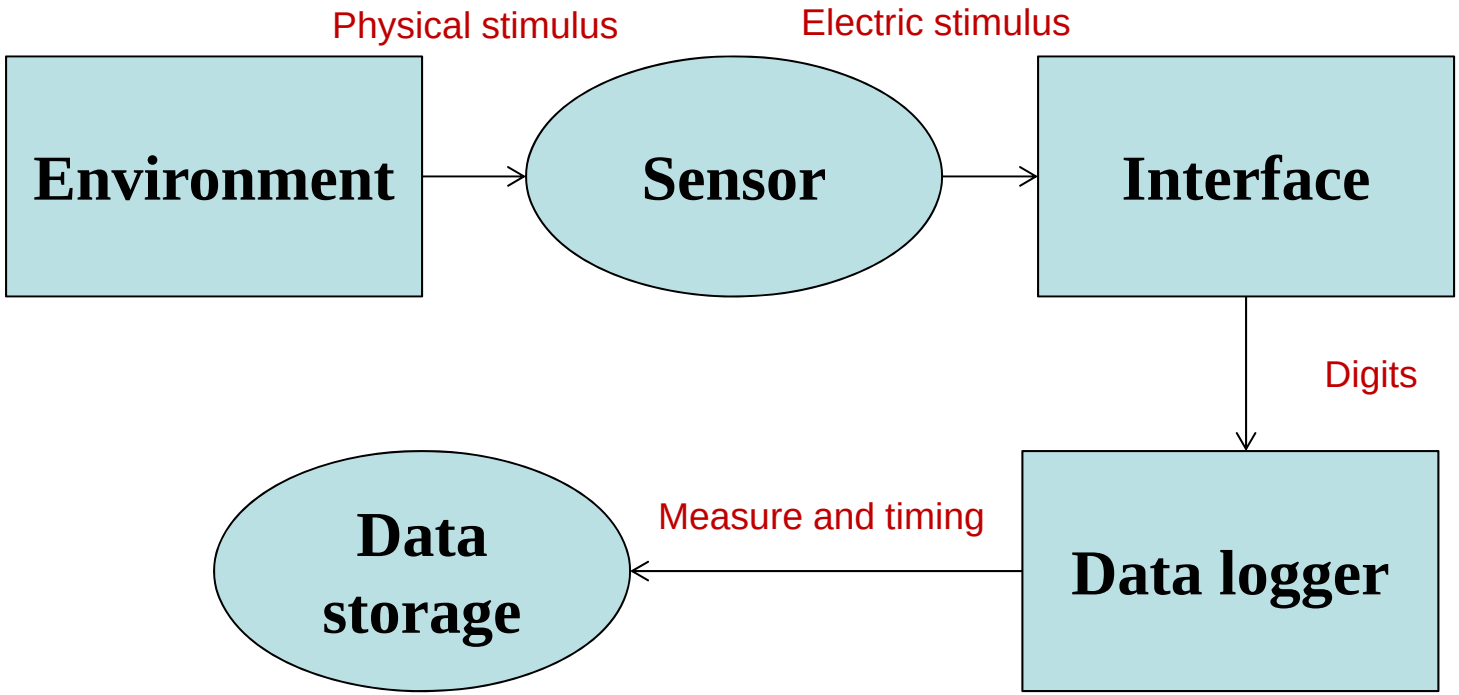
- Analog to Digital Conversion (ADC) sample rate



Sample rate = frequency

Sensors interfacing and data acquisition

- Data logger



- A data logger collect the sensor information in a data storage with the timing information of the acquisition
  - Off the shelf there are data logger that have analog and digital interfaces to collect data from digital and analog sensors.
  - The analog interface main component is ADC, then it is characterized by digital resolution and sample rate as the ADC.

Sensors interfacing and data acquisition

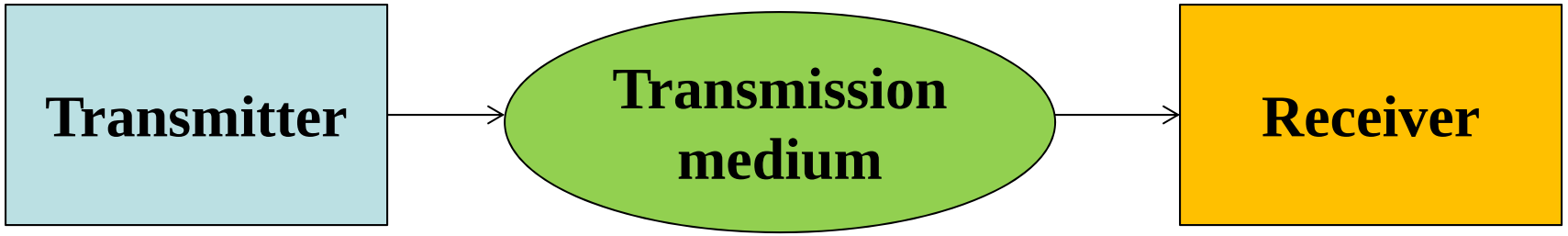
- Commercial data logger

  - There are commercial data logger with analog channel design to measure electric quantity as voltage, current, resistance, capacitance, etc.
  - Most of the data loggers can be connected to a PC to program them and to show the data collected to the user
  - Moreover there are software to elaborate the data in the way to obtain directly the value of the measured physical entity

Data transmission

Data transmission

- Transmission is the process to send information from a transmitter to a receiver throw a communication channel



- Transmitter is the electronic circuits that convert the digital data to a energy waves able to propagate throw the transmission medium (modulation)
- Receiver is the electronic circuits that convert the energy waves present in the transmission medium to a digital data (Demodulation)
- Transceiver is a transmitter and receiver in the same electronic circuit
- Data transmissions speed is characterized by the bit per second (bps), a byte is composed of eight bits.

Data transmission

- Transmission medium is the physical material that permit the propagation of energy waves.
  - Data transmission typically use electromagnetic waves able to propagate in: Air, cables, optic fiber.
- Transmission media usually used are:
  - Air: Radio communication with a modulation that permit the division of the media with several radio channels. Each channel has is own carrier wave at fixed frequency.
  - Cables: communication with a modulation that can divide the media with one or several radio channels.
    - The cable can have two or more wires. Two wires make a transmission line.
    - If a communication is done with one transmission line is called serial.
    - If a communication is done with more transmission lines is called parallel.
  - Power line: The power line is used as transmission line with more than one radio channels; the AC power goes in the lower frequency channel meanwhile the information goes to the higher frequency channel

Data transmission

- Transmission can be:

- Simplex one user to one or more users (television, Radio).
  - It use one radio channel and/or one transmission line

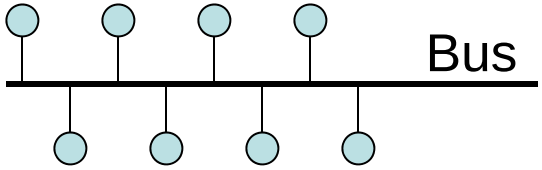
- Half duplex bidirectional but one user at time (Walkie - talkie).
  - It use one radio channel and/or one transmission line

- Full duplex bidirectional two user contemporarily (telephone).
  - It use two radio channel and/or two transmission line

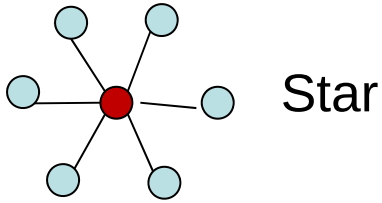
Network infrastructure and protocol

Network infrastructure and protocol

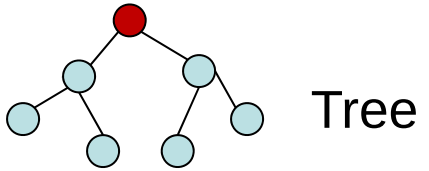
- Network is a collection of transceiver interconnected each others
- The network can have different topology
- Bus topology
  - Each transceiver is connected to the same transmission line and can communicate with every other transceiver



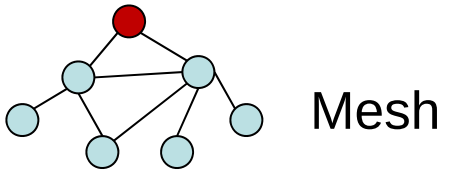
- Star topology
  - Each transceiver is connected to a dedicated transmission line and can communicate directly only with the center star transceiver



- Tree topology
  - Each transceiver (called also node) is connected to more dedicated transmission lines and can communicate directly with their parent and children



- Mesh topology
  - Each transceiver (called also node) is connected to a more dedicated transmission line and can communicate directly with several nodes

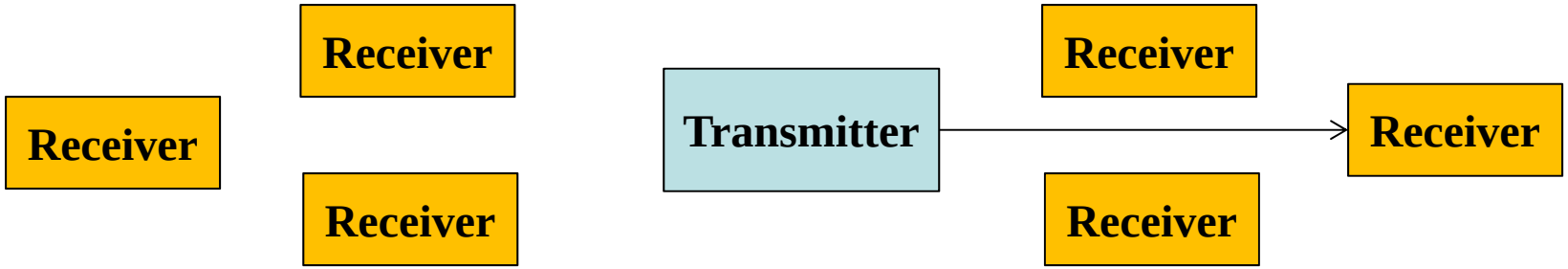


Network infrastructure and protocol

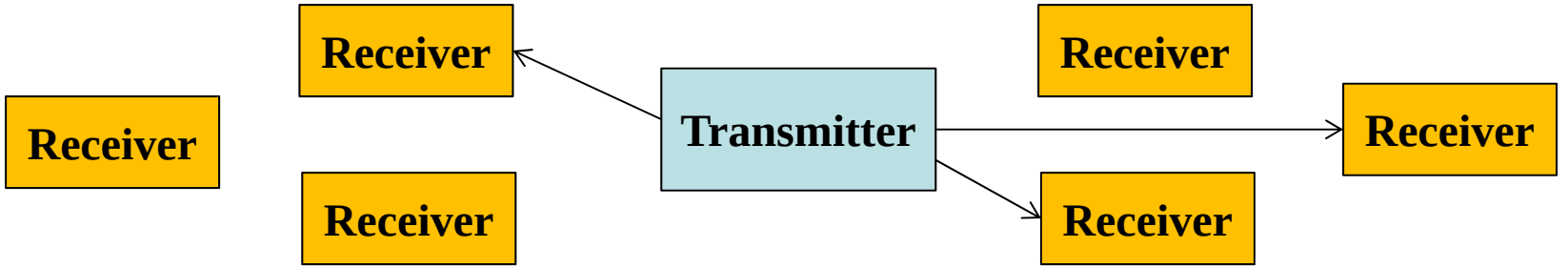
- Protocol is a collection of rules that each components of the network should respect to permit the communication and the execution of the services that the network will provide
- The protocol define:
  - Transmission data packet, that contain addressing information, command and data.
  - Commands (to manage and control the network)
  - Addressing rules
  - Network services
  - Network hierarchy
  - Modulation type
  - Physical characteristic of the transmission
  - The transmission medium

Network infrastructure and protocol

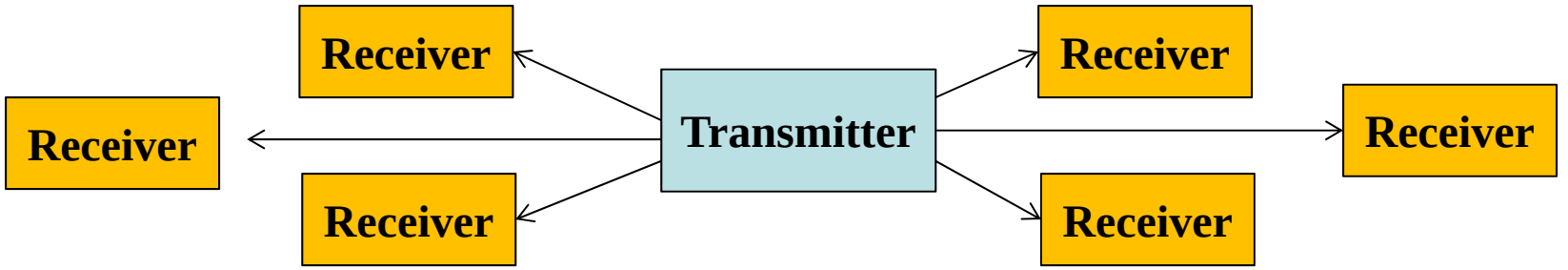
- Routing and addressing can be:



- Unicast one user to one in a network (point to point)



- Multicast one user to many users (point to multipoint)



- Broadcast one to all (point to all)

X10

X10

- Standard introduced by the Pico Electronics in the 1975 with the aim to integrate at low cost lighting devices with controls devices.
- Use power line transmission.
- Still highly used, especially in the USA.

- It is typically constituted by a *Controller* and a certain amount of receivers, connected to power plugs.

- The transmission is typical unidirectional from the Controller to the receivers.

- The protocol has been extended for bidirectional communication but there are not many device able to do that (called Two-way)

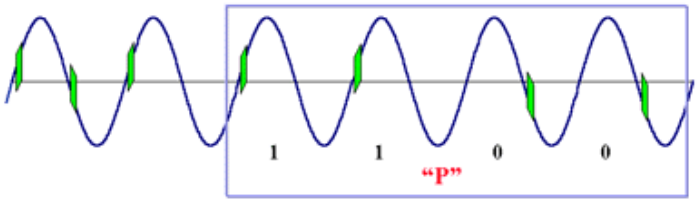
- It is possible to build a network up to 256 receivers.

X10

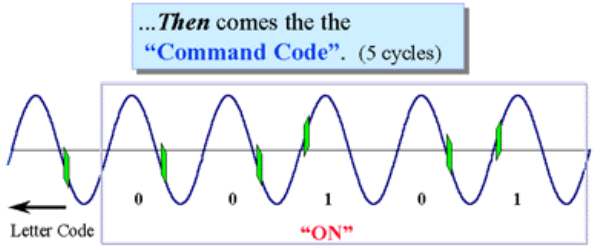
- Most used controller is the Marmitek CM11
- The data packet is composed by a start code and addressing field
- The start code is 1110.
- The addressing is composed by an house code and key code.
- The key codes can be an unit code or function code

HOUSE CODES					KEY CODES					
	H1	H2	H4	H8		D1	D2	D4	D8	D1
A	0	1	1	0	1	0	1	1	0	0
B	1	1	1	0	2	1	1	1	0	0
C	0	0	1	0	3	0	0	1	0	0
D	1	0	1	0	4	1	0	1	0	0
E	0	0	0	1	5	0	0	0	1	0
F	1	0	0	1	6	1	0	0	1	0
G	0	1	0	1	7	0	1	0	1	0
H	1	1	0	1	8	1	1	0	1	0
I	0	1	1	1	9	0	1	1	1	0
J	1	1	1	1	10	1	1	1	1	0
K	0	0	1	1	11	0	0	1	1	0
L	1	0	1	1	12	1	0	1	1	0
M	0	0	0	0	13	0	0	0	0	0
N	1	0	0	0	14	1	0	0	0	0
O	0	1	0	0	15	0	1	0	0	0
P	1	1	0	0	16	1	1	0	0	0
					All Units Off	0	0	0	0	1
					All Lights On	0	0	0	1	1
					On	0	0	1	0	1
					Off	0	0	1	1	1
					Dim	0	1	0	0	1
					Bright	0	1	0	1	1
					All Lights Off	0	1	1	0	1
					Extended Code	0	1	1	1	1
					Hail Request	1	0	0	0	1
					Hail Acknowledge	1	0	0	1	1
					Pre-Set Dim	1	0	1	X	1
					Extended Data (analog)	1	1	0	0	1
					Status=on	1	1	0	1	1
					Status=off	1	1	1	0	1
					Status Request	1	1	1	1	1

X10

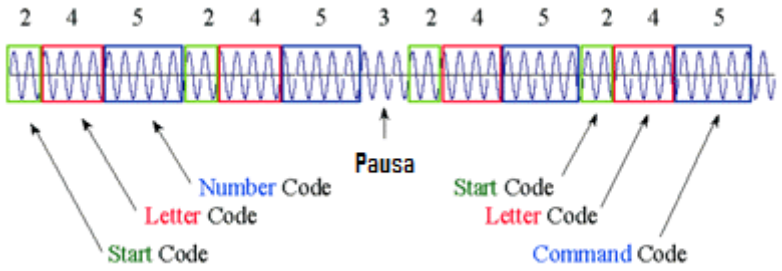


A = 0110	E = 0001	I = 0111	M = 0000
B = 1110	F = 1001	J = 1111	N = 1000
C = 0010	G = 0101	K= 0011	O = 0100
D = 1010	H = 1101	L = 1011	P = 1100



On = 00101	All Lts On = 00011	Bright = 01011
Off = 00111	All Units Off = 00001	Dim = 01001

....and there are 9 other commands but they are rarely used.



X10

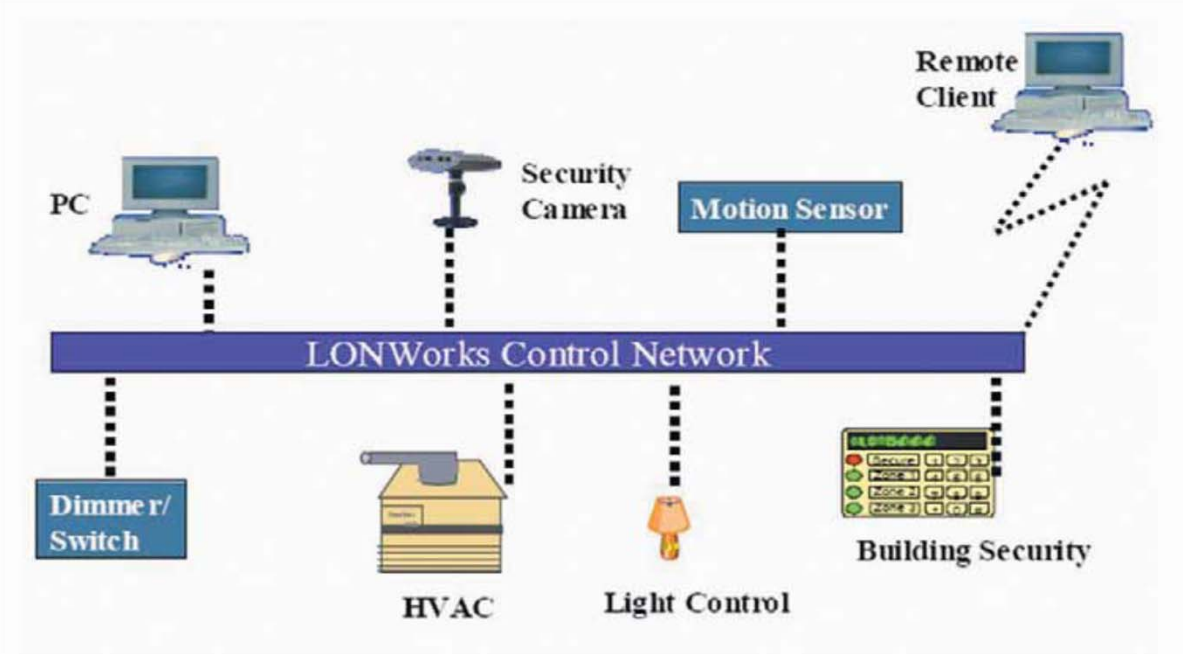
- The producer offer devices that the address can be configure with a mechanical switch, or with proprietary bus commands.

Drawback

- Not compability between X10 for the USA market and the Eurpean market
- Low data rate
- Attenuation due to older appliance (as CRT monitor)
- Crosstalking between two near X10 network
- Sensitivity to the discharge lamps noise

LonWork

LonWork



- LonWork has been developed by Echelon as a communication technology that use the same protocol to interconnect devices connected to a different transmission medium, as twisted pair, power line, optic fiber and TCP/IP.
- Lon means Local Operating Network and identify network for transmit sensor and actuators status and data.

LonWork

- The comunication is based to the protocol LonTalk, which address different media
- LonWork rapidally spreaded in the building automation for HAVC (heating, ventilation, air conditioning), lighting, access control and fire allarm.
- LonWork has gained consideration in industrial sector and for the realizzation of smart metering
- In the last years LonWork is used for managing energy efficiency in smart building and reduce the mainteinance building cost

LonWork

- The fundamental concept of the LonWork is to put the intelligence directly where the function is implemented, than in the sensors and actuators.

- The LonWork network is based upon three fundamental units:
  - LONTalk
  - Neuron Chip
  - LSN (Lonwork netowork service) that is the network operative system.

- Neuron chip is the Lonwork transceiver that automatically manage the protocol and permit an easy realization of lonwork device. Then a producer can realize a Lon device using the neuron chip without know anything about the Lon protocol.

LonWork

Off the shelf are present LonWork trasceiver for:

- twisted pair cables
- Power line
- Radio transceiver for 400-470Mhz and 900Mhz

- Lonwork can manage huge network and provide a network infrastructure to realize all type off addressing (unicast, multicast, broadcast)

- The data packet is light and there is a priority police to permit the delivery in time of urgent data.

LonWork

- The addressing is divided in domain, sub network, nodes to simplify the routing. Can be defined
- 2^{48} Domain
- 127 sub-network in a domain
- 127 nodes in each sub-network.

- LonWork has network variables, that can be configure at installation time. It is possible to associate to a sensor output a variable which could be readed by an actuator automatically, using the binding process. The tool ICELAN provide all the support to do that.

KNX

KNX

- KNX is based up three precedent European standard.
- It is suitable for the creation of smart building thank its capability to exchange information between switch, actuators, motors and HVAC.

- KNX use different transmission media as:
  - Twisted pair
  - Powerline
  - RF at 868Mhz

- The communication it is based to data points.
- A data point is a control variable of the system.
- A data point is inside a group object that is the functional system unit

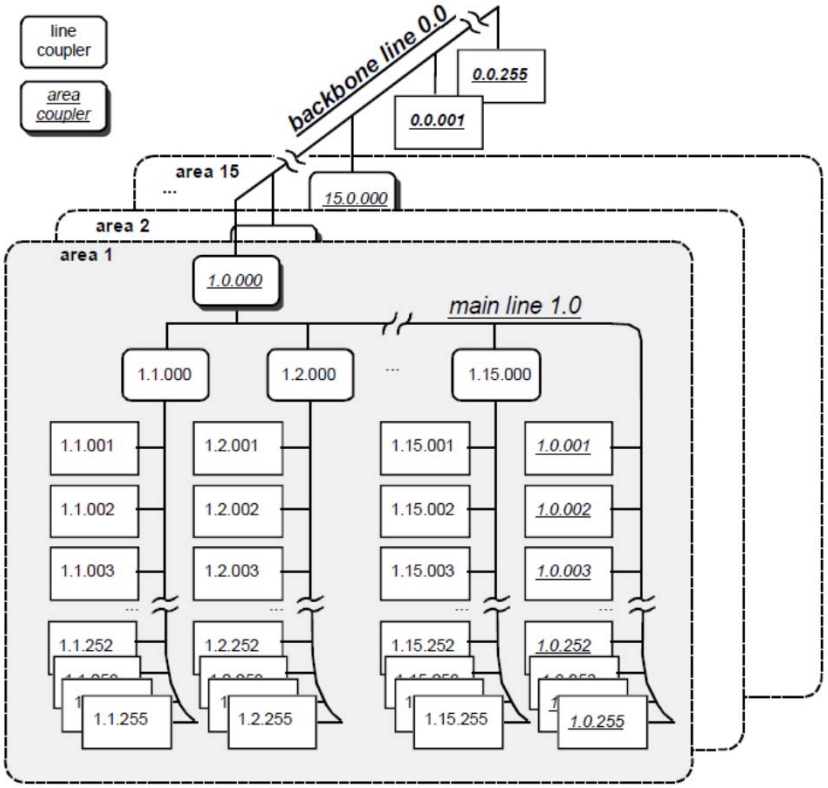
KNX

- A device can read and write a data point.
- Then if a switch can write is status and a relay actuator can read the value, than the actuator can know when turn on or off the light in relation of the switch state.

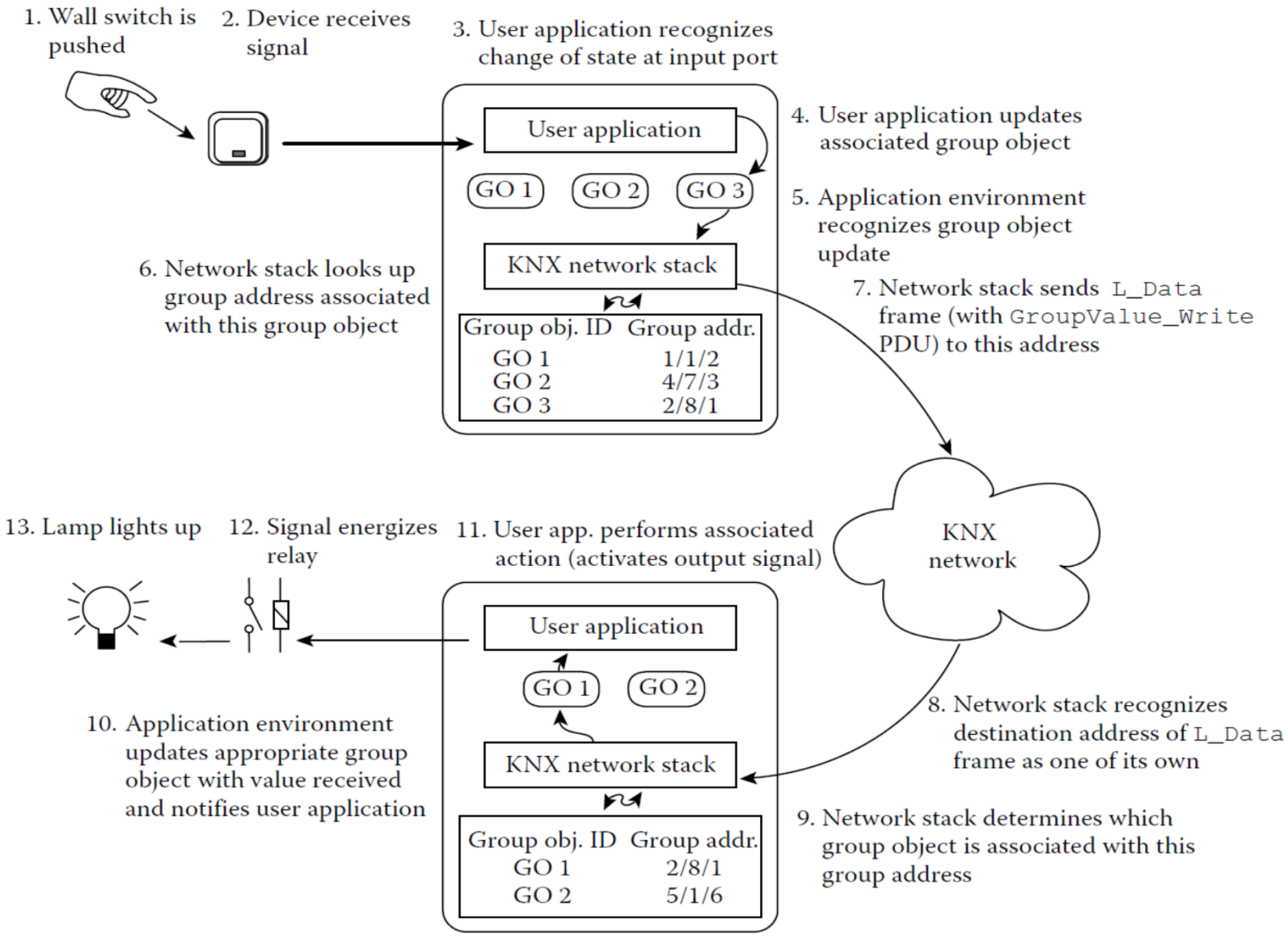
- KNX is the bridge to permit the single node to write and read datapoints, creating the system

KNX

- Each device must have a logical address that identify univocally the device.
- The logical address is compose: 255 devices in 15 main lines, insides at 15 areas and everything connected with the backbone line.
- The group object has its own object address
- More group object can be associated to the same object address (multicast)
- Group address the same structure of logical address

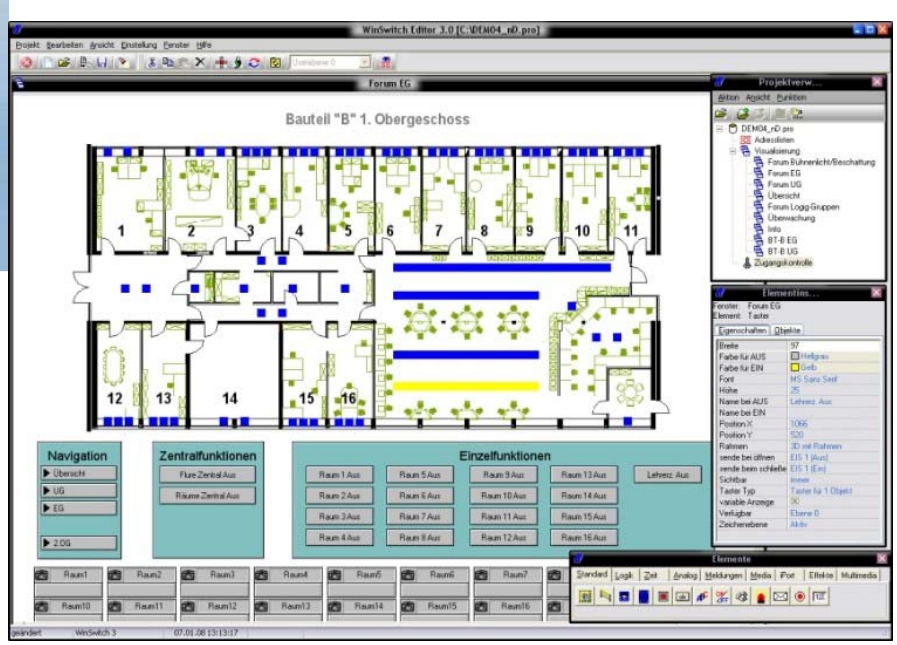


KNX


1. Wall switch is pushed
2. Device receives signal
3. User application recognizes change of state at input port
User application
GO 1
GO 2
GO 3
KNX network stack
Group obj. ID Group addr.
GO 1 1/1/2
GO 2 4/7/3
GO 3 2/8/1
4. User application updates associated group object
5. Application environment recognizes group object update
6. Network stack looks up group address associated with this group object
7. Network stack sends L_Data frame (with GroupValue_Write PDU) to this address
KNX network
8. Network stack recognizes destination address of L_Data frame as one of its own
9. Network stack determines which group object is associated with this group address
User application
GO 1
GO 2
KNX network stack
Group obj. ID Group addr.
GO 1 2/8/1
GO 2 5/1/6
10. Application environment updates appropriate group object with value received and notifies user application
11. User app. performs associated action (activates output signal)
12. Signal energizes relay
13. Lamp lights up

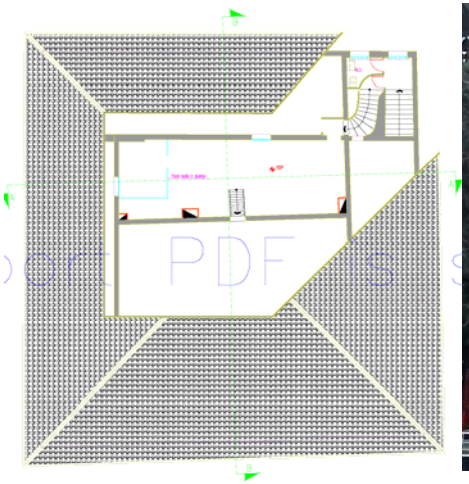
KNX

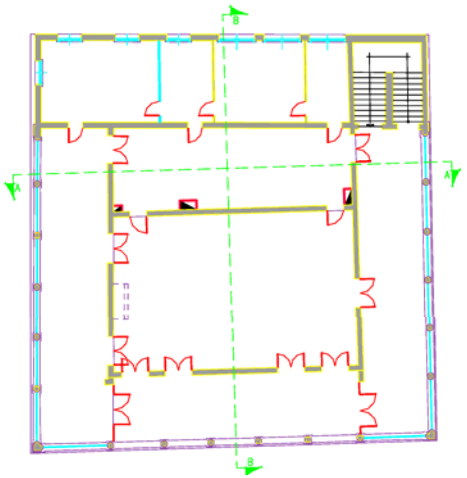
- In the market there are a lot of KNX devices, as sensors, actuators,
- Supervisor systems

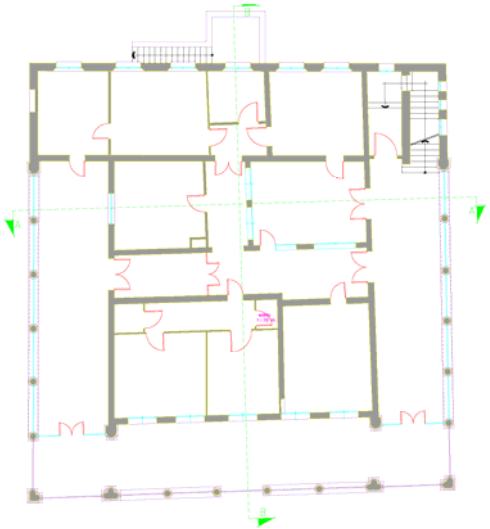


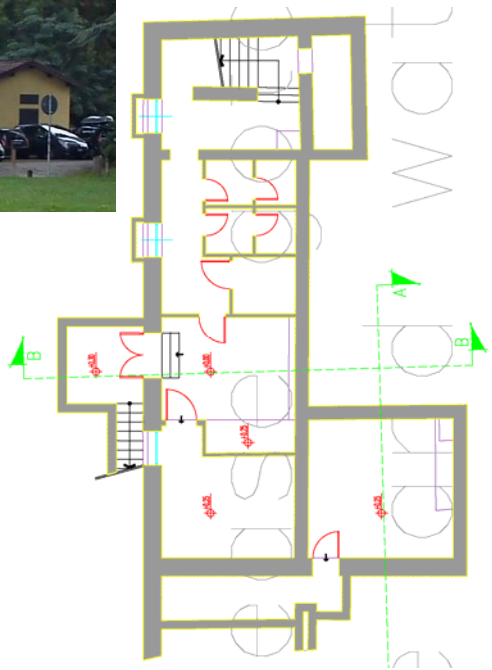
Monitoring infrastructure Deployment case

Case study









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Wireless sensor node used

- 32Mhz 32Mbit microprocessor
- 2.4Ghz radio transceiver
- Zigbee Pro compliant
- Aggressive power management (sleep mode 8µA) for long battery life
- MicroSD card for local data logging
- On board sensors
  - Temperature (0.01°C resolution)
  - Humidity (0.04°C resolution)
  - Light sensor (0.23 lx resolution)
  - 3-axis accelerometer (1mg resolution)
  - Gas sensor interface (10% resolution)
    - VOC, CO, NHx, O3, NH4
- Analog input with 12bit resolution and 300khz sample rate
- 10 digital input/output
- 1 UART (convertible to RS232, RS422, USB)
- 1 I2C (used to communicate with IC sensors)
- 1 SPI (used to communicate with fast IC sensors and external Analog Digital converter)
- 3V 1.5W fully controlled DC output power supply for both external sensors and expansion board

Ad hoc developed wireless protocol

Main characteristics

- WSN fully configurable with multi-hop radio link capable to operate for years.
- Each device can be configured either by USB or remotely with radio link to:
  - Set the device ID, PAN ID, radio channel
  - Check the list of neighbor device with radio link quality
  - Select the network parent device in order to build up a network custom tree
  - Check sensor state (disable/enable), sample time and batteries voltage, check network parameters.
- The network coordinator uses the USB to:
  - Set each node sensor state (enable/disable)
  - Set sample time
  - Provide data collected from every device connected to the network
  - Set date

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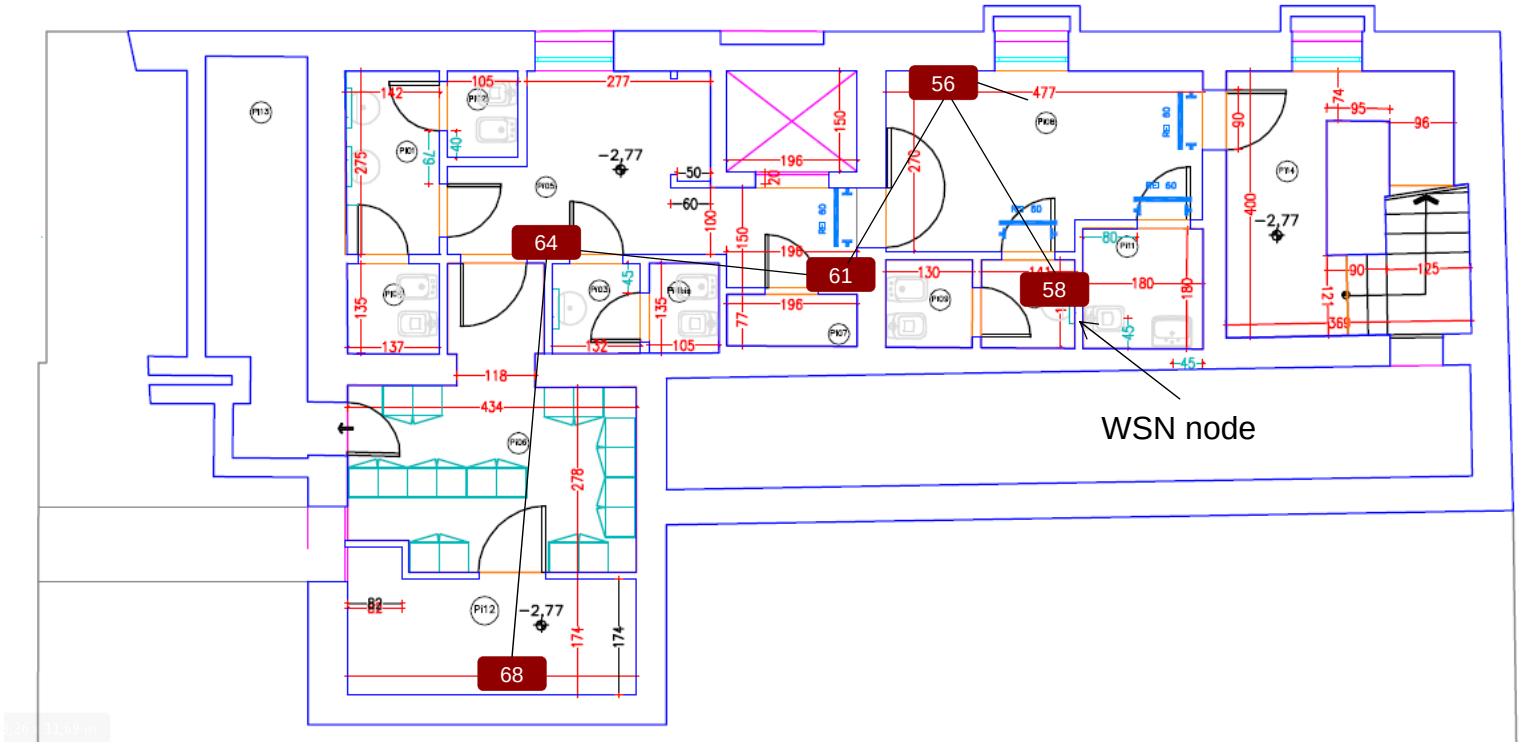
Deployment

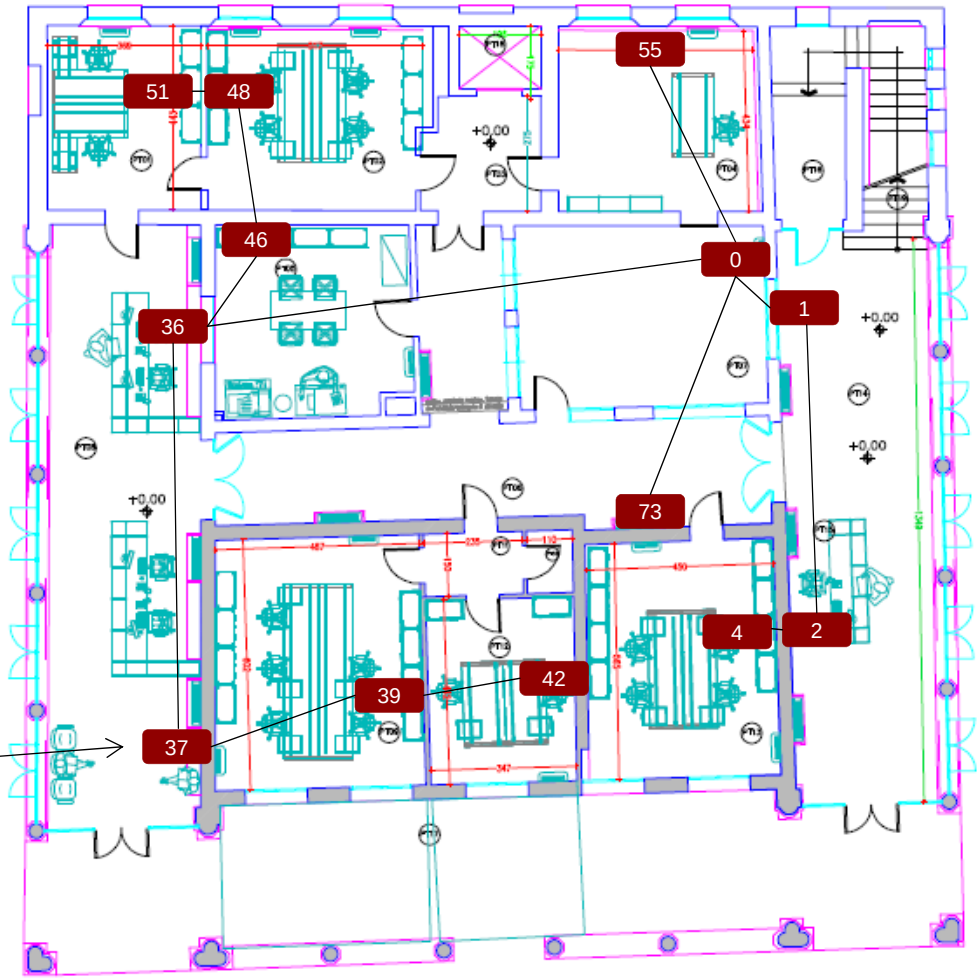


ID	Address
56	11
58	89
61	8a
64	451
68	2289

Underground floor

Deployment

Ground floor



WSN node

ID	Address
0	0
1	1
2	9
4	49
36	3
37	19
39	c9
42	649
46	1a
48	d1
51	689
55	2
73	7

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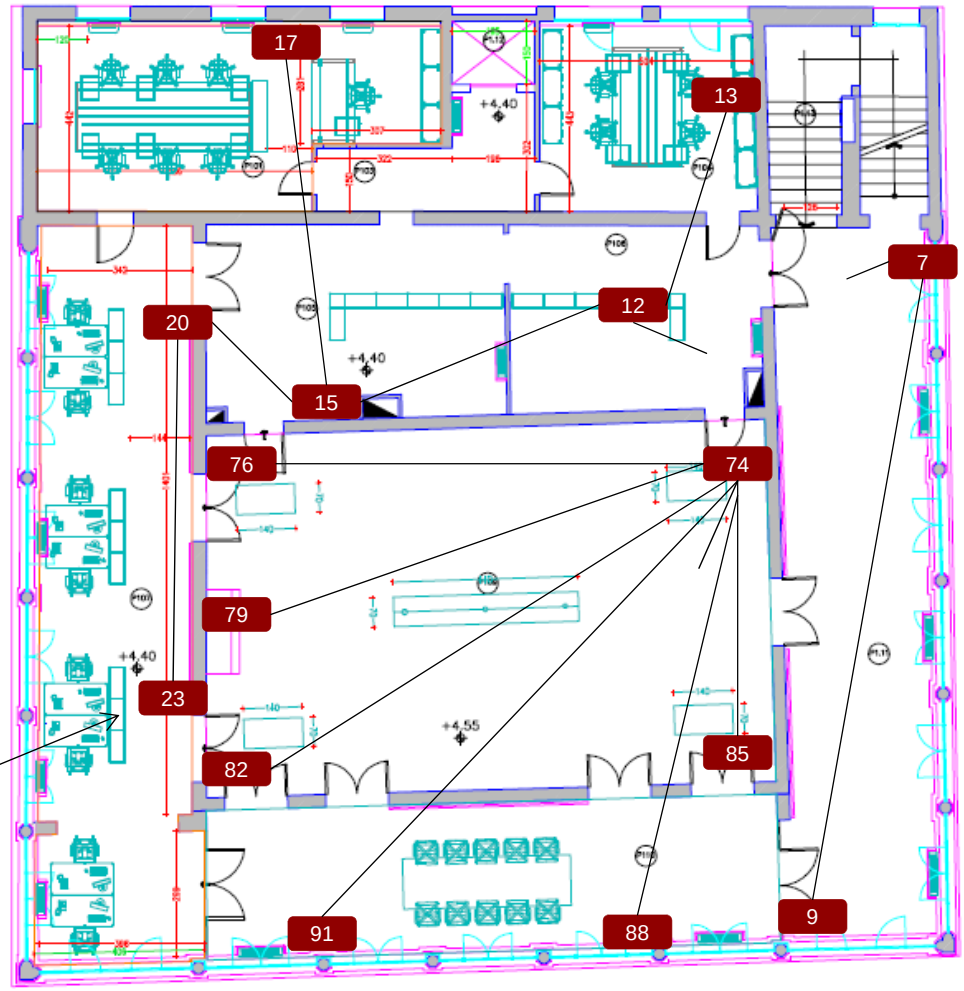
Deployment

First floor



ID	Address
7	a
9	51
12	4
13	21
15	22
17	111
20	112
23	891
74	39
76	1c9
79	1ca
82	1cb
85	1cc
88	1cd
91	1ce

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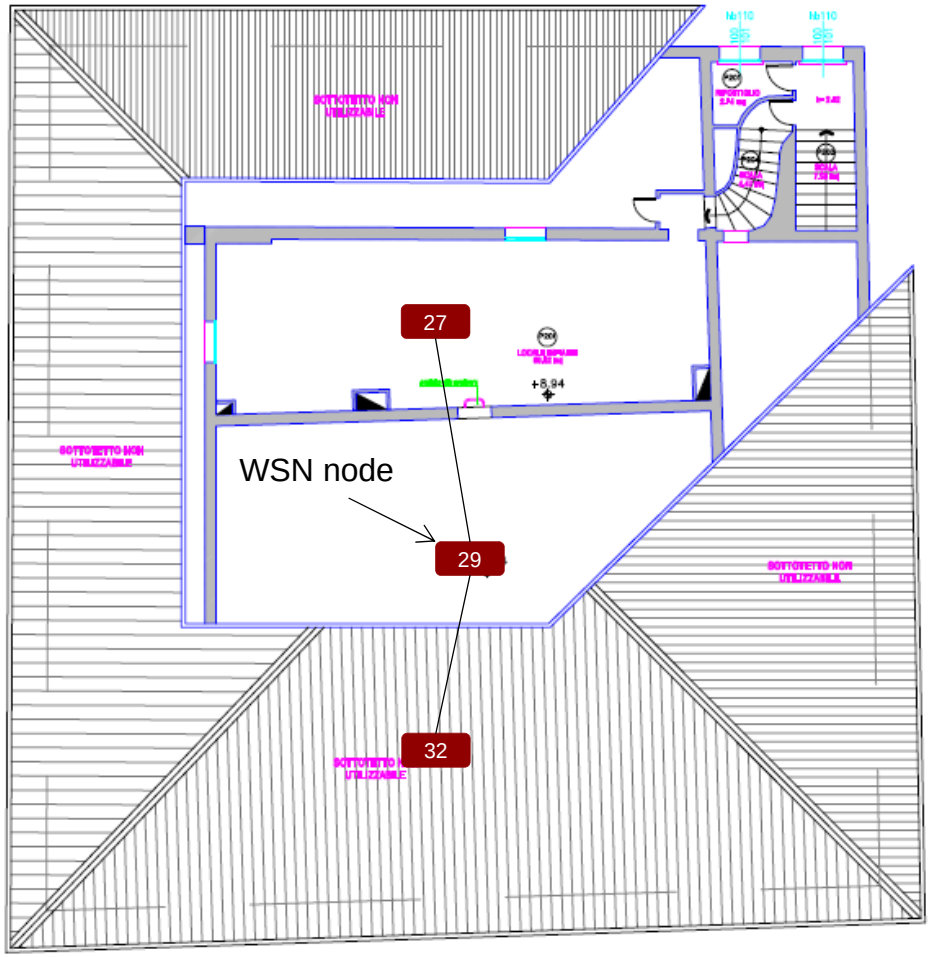
Deployment

Attic floor



ID	Address
27	23
29	119
32	8c9

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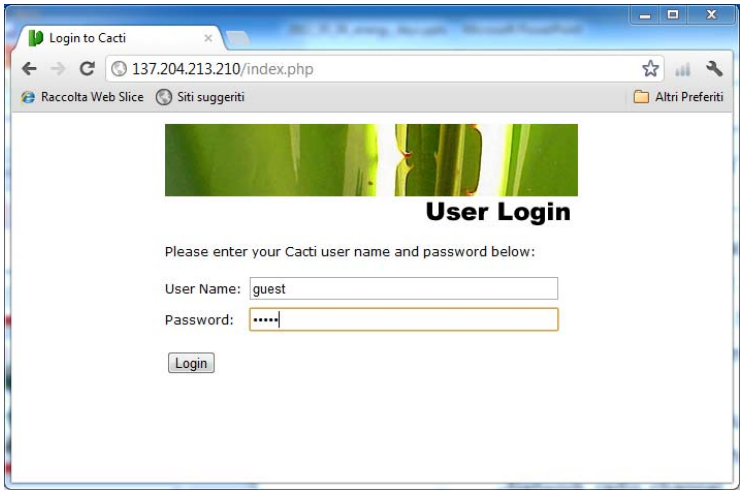
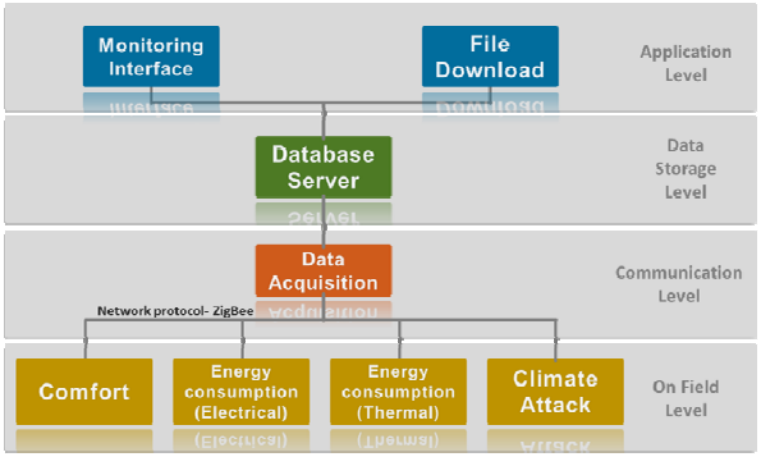
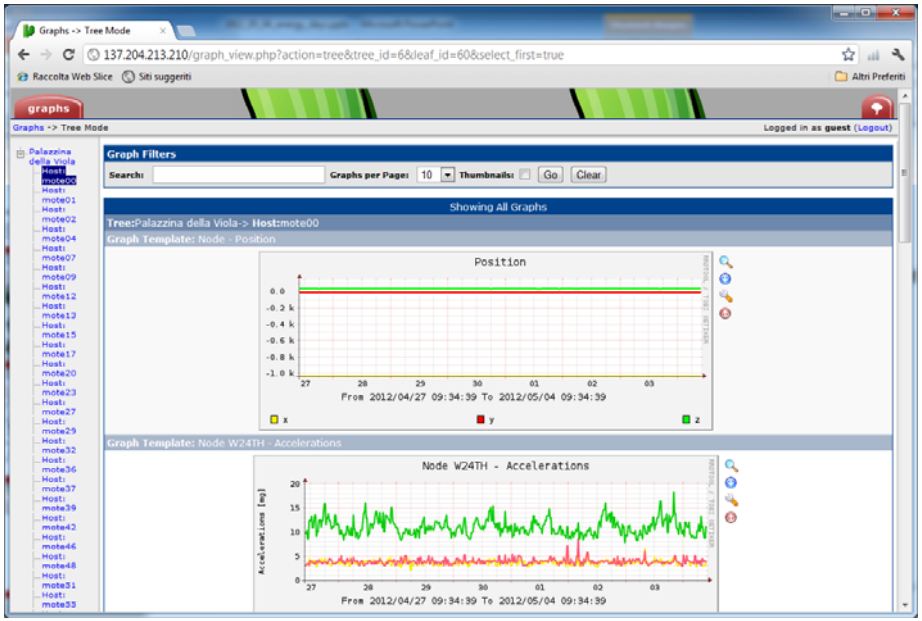
User Interface developed



The data are sent to a web server.
The web server is accessible at the page:
137.204.213.210
User:guest
Password:guest





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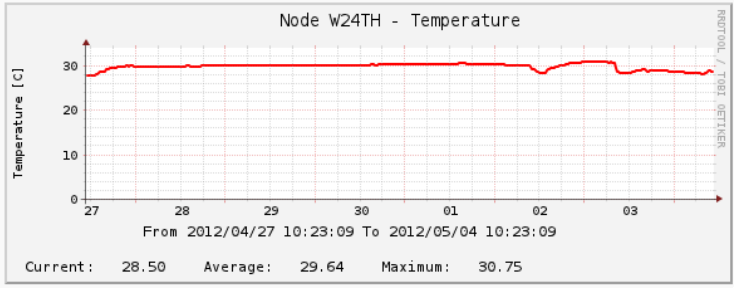
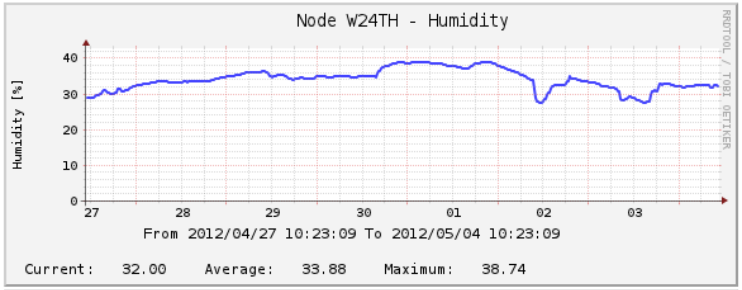
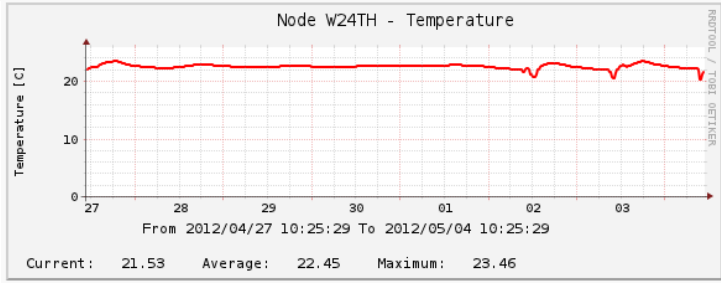
Data collected sample

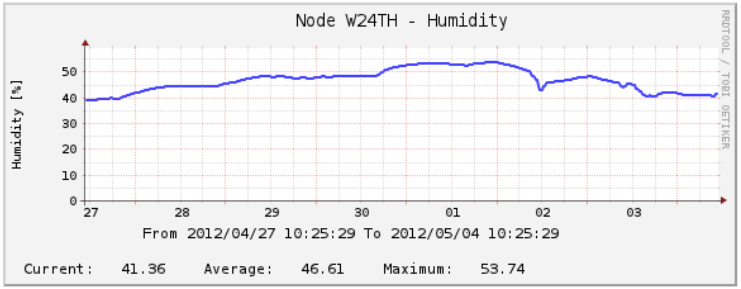
- Underground



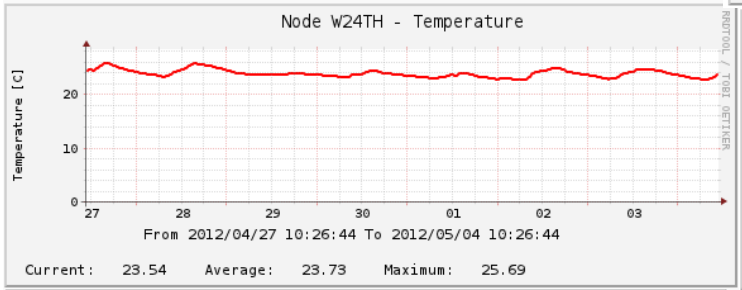


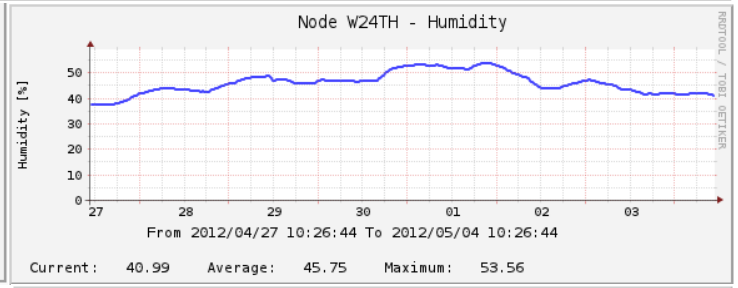
- Ground floor



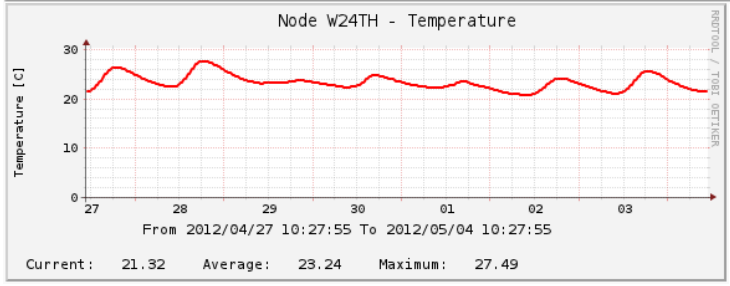


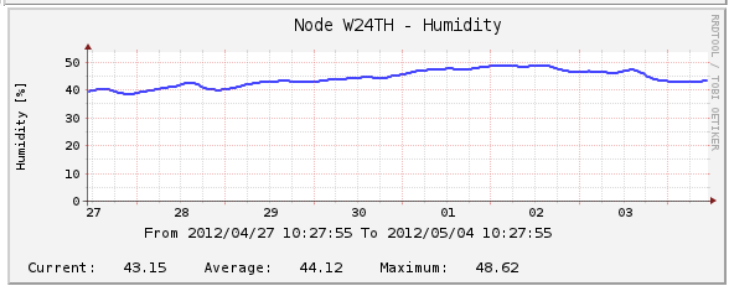
- First floor





- Attic floor





Advanced school on ICT for FUTURE ENERGY SYSTEMS

Densely Instrumented Physical Infrastructures for Energy-Efficient Building

Ing. Giacomo Paci
Micrel Lab
DEIS - Università di Bologna

giacomo.paci@unibo.it

Wireless Sensor Node

- 32Mhz 32Mbit microprocessor, 128KB RAM, 512KB FLASH
- 2.4Ghz radio transceiver (IEEE802.15.4 compliant)
- Aggressive power management (sleep mode 8µA) for long battery life (last for years)
- MicroSD card for local data logging
- On board sensors
  - Temperature (0.01°C resolution; -40 to +90 °C range)
  - Humidity (0.04°C resolution; 0 to 100%rh range)
  - Light sensor (0.23 lx resolution; 0 to 100,000lx range)
  - 3-axis accelerometer (1mg resolution; 0 to 6g)
  - MOX Gas sensor interface (10% resolution)
    - VOC, CO, NHx, O3, NH4 (from few ppm)
- Analog and Digital input/output aviable (RS232, RS422, USB, UART, SPI, I2C etc)
- 3.3V 1.5W fully controlled DC output power supply for both external sensors and expansion board
- Energy scavenger connectivity (solar cell, vibration, wind generators)

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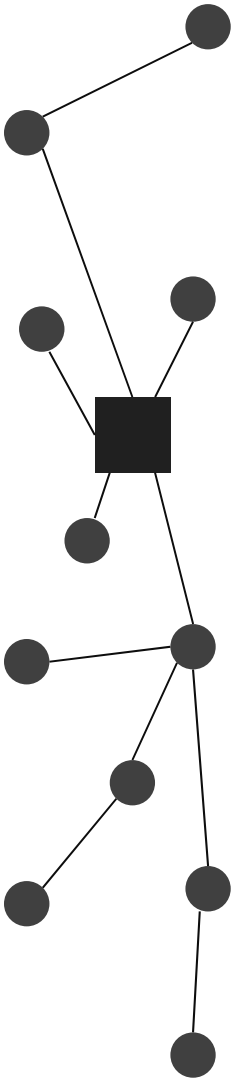
Wireless Stack



Developed Wireless Sensor Network Stack is:

- IEEE802.15.4 compliant
- Star and Tree topologies based
- Sleepy router based (permitting a tree network to last for years with the same batteries)
- Connectable via USB, Bluetooth, WiFi, UMTS
- Fully programmable by the end user:
  - Network radio channel
  - Network PAN ID
  - Sensors sample rate (from 10 sec to 36 hours)
  - Sensors select
  - Network topology
  - Real Time clock set
  - SD card local data logging (to a CVS file)

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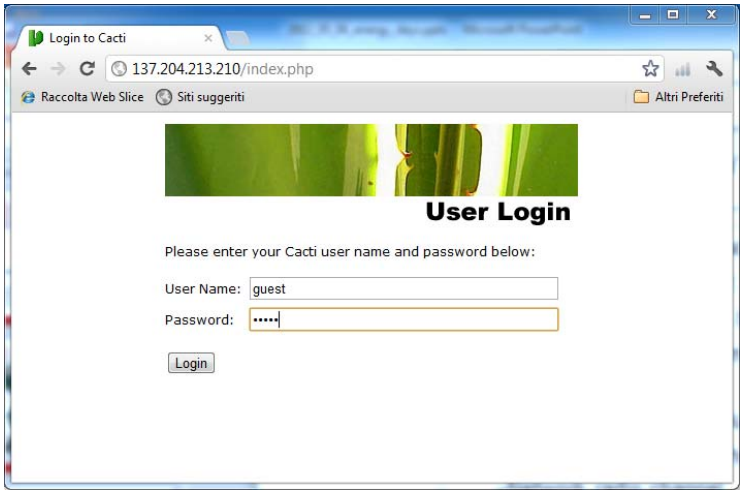
User Interface



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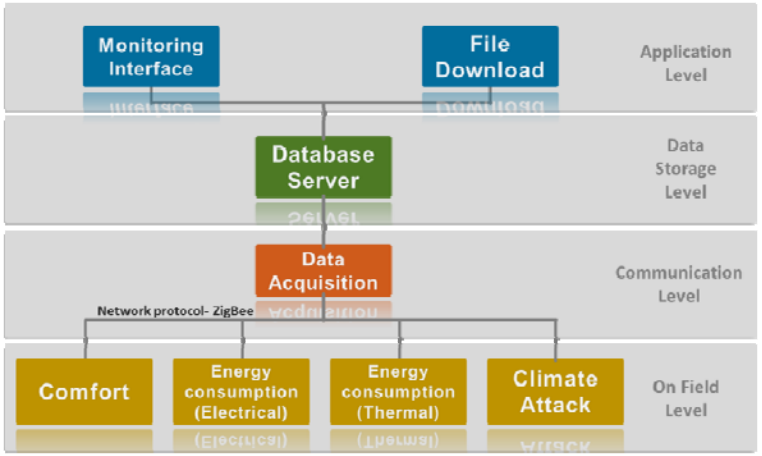

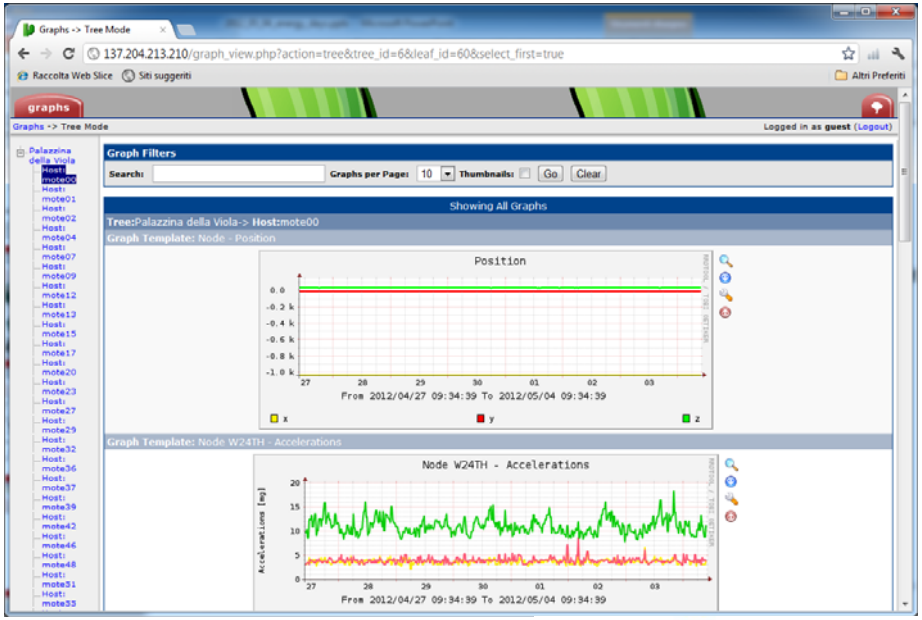

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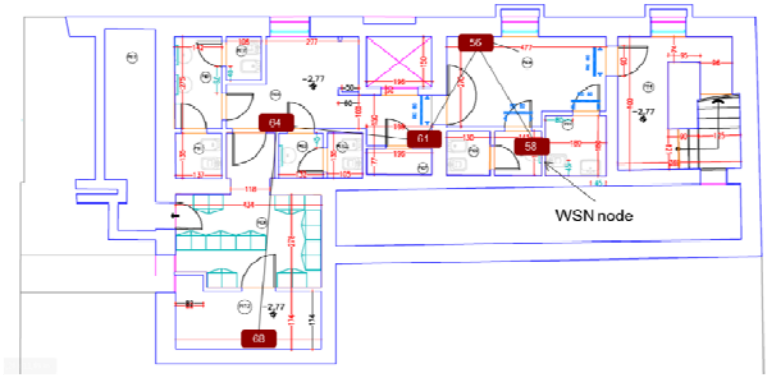
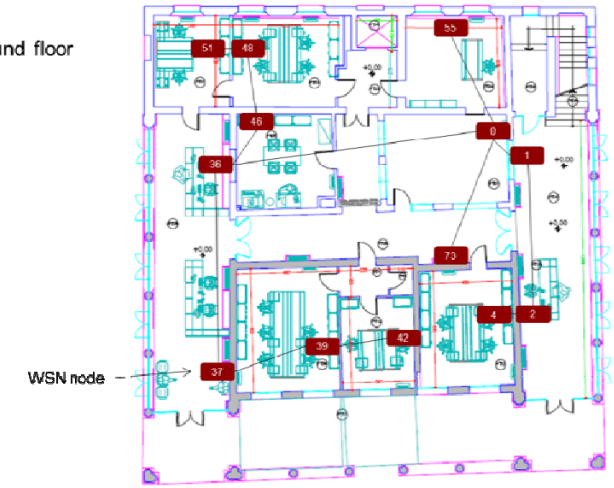


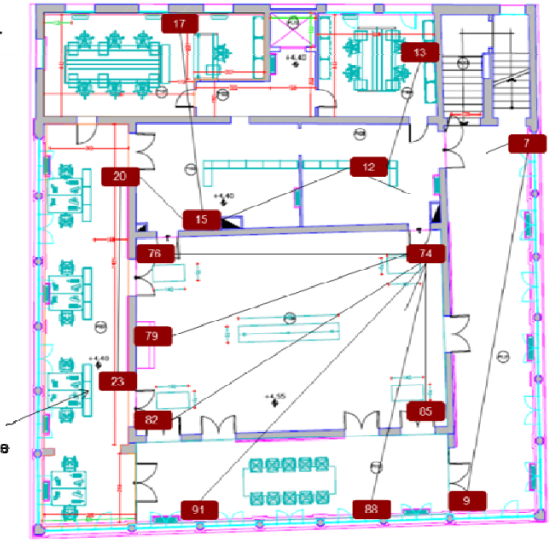
Underground floor

Installed 36 wireless data-loggers.
Collected 144 sensors' data.
Expected life time, 2 years without batteries replacement

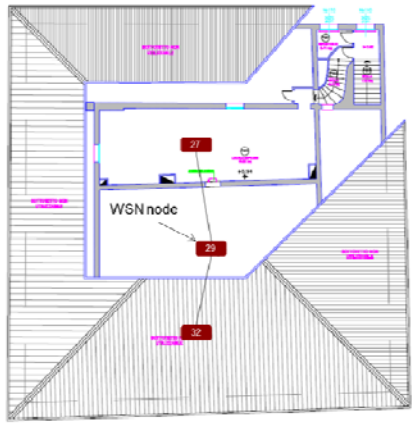
Ground floor



First floor



Attic floor



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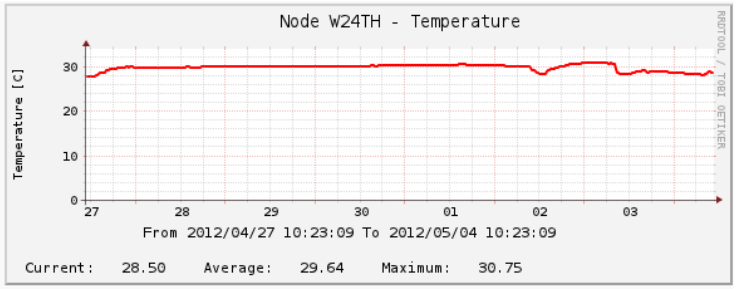
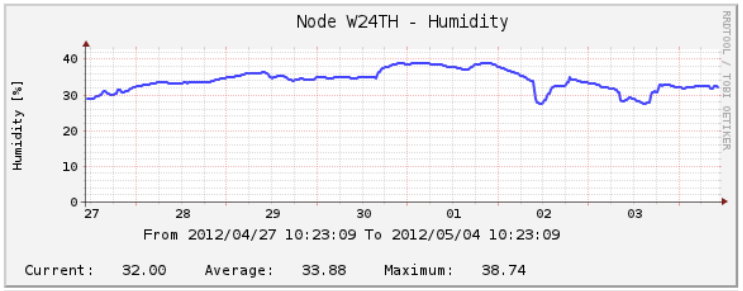
EFFICIENT ENERGY FOR EU CULTURAL HERITAGE

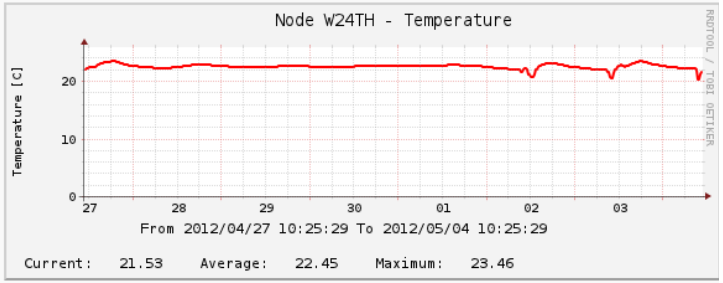
Palazzina Della Viola

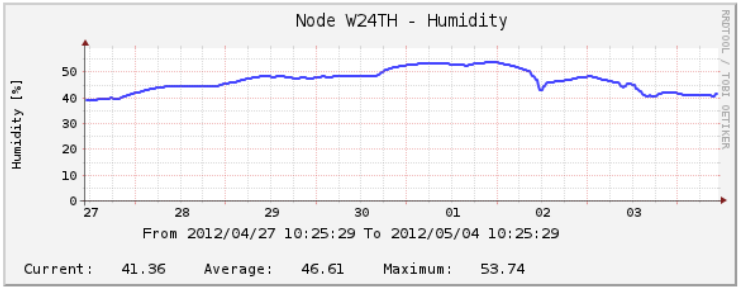
- Underground



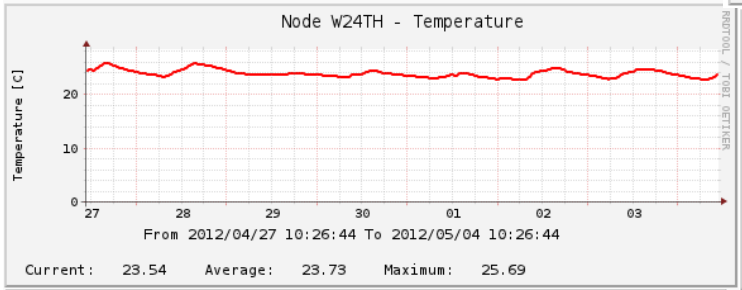


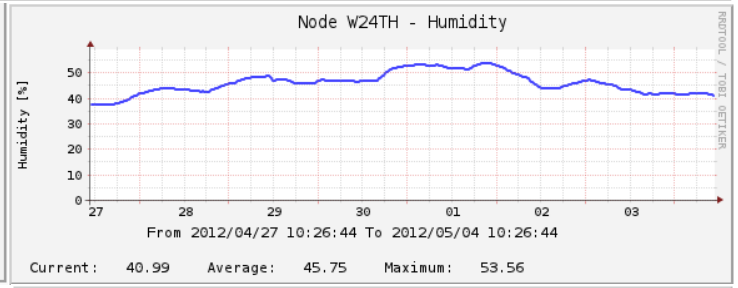
- Ground floor





- First floor





- Attic floor