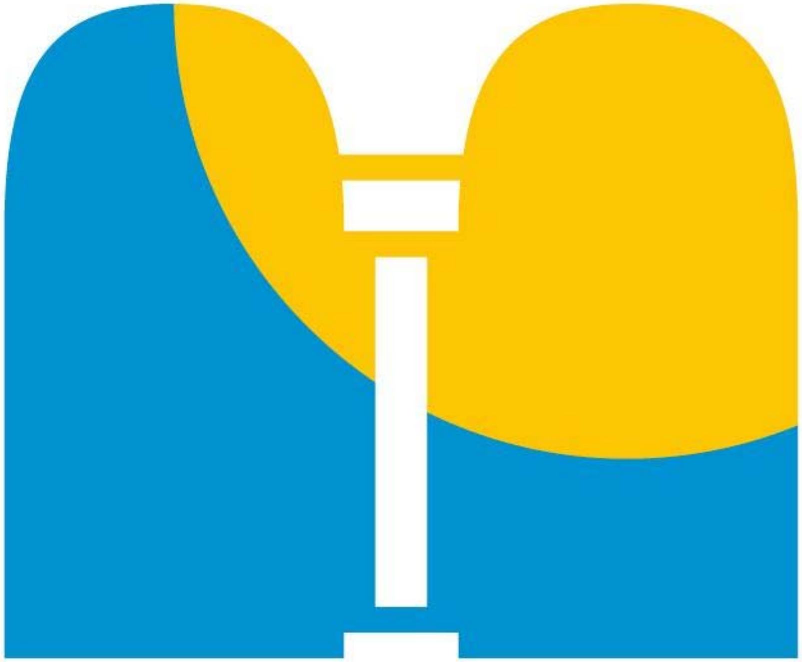


EFFICIENT ENERGY FOR EU CULTURAL HERITAGE

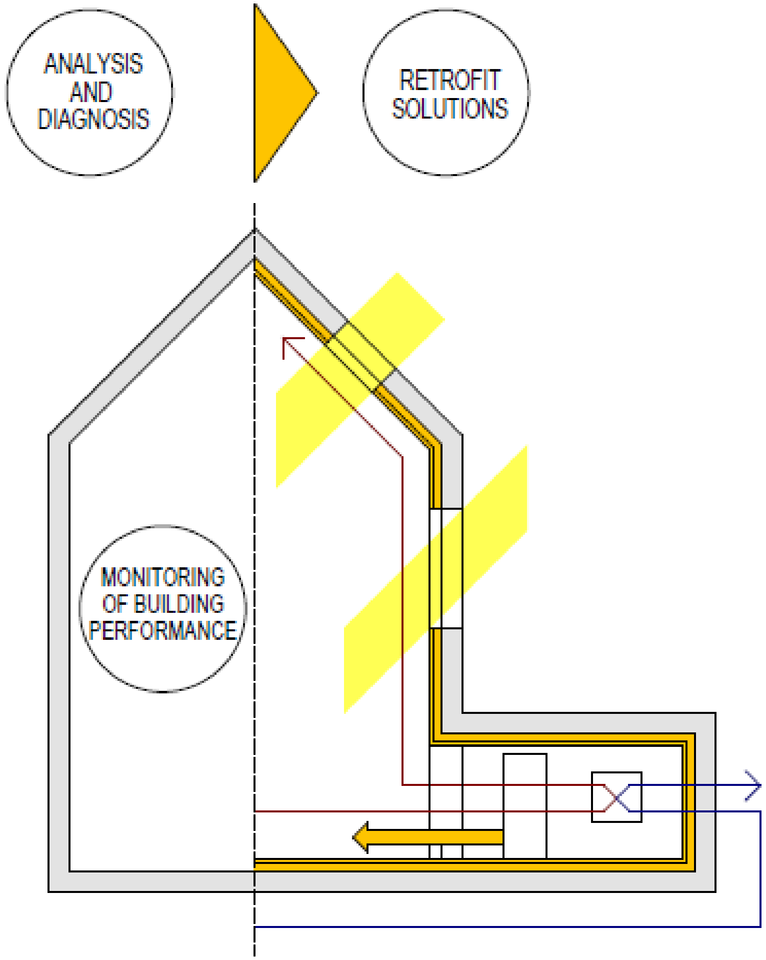
Analysis & diagnosis

Camilla Colla, UNIBO
Enrico Esposito, Artemis
Simone Reeb, UNISTUTT
Alexandra Troi, EURAC

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 260162

SEVENTH FRAMEWORK PROGRAMME

Holistic approach



Beside the ambitious target to minimise the primary energy consumption in historic buildings preservation tasks are of main importance. Thus before any building measure, a complete survey on the historic building treated has to be undertaken. Starting with the description of the history of the building, a complete data uptake of the substance especially with respect to the historic (traditional) materials and constructions has to be undertaken. As historic buildings since ever defended the waste of energy, the historic strategies of energy ‘management’ have to be investigated. This demands a multidisciplinary approach of specialised teams. Here only profound historical science, art history, material science, architecture and engineering knowledge combined with modern analysis and documentation techniques assure best results.

Basic principles

„Heritage“ & „energy“ analysis go hand in hand

heritage value

energy

damage

materials

(original) energy systems

(original) use & function

hidden structures

Information sources

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dialogue with conservator

visual inspections

historic documents & photos

NDT or MDT
(Non or Minor Destructive Testing)

calculation & simulation

Monitoring

Outline

- Monitoring aspects & sensors
  [Simone Reeb, University of Stuttgart]
- Methods & tools for complete diagnosis (IR, flux meters, T & RH monitoring)
  [Enrico Esposito, Artemis]
- Methods & tools for complete diagnosis (air pressure test, IR, GPR, psychrometric maps, air fluxes, light distribution, micro-climate, vibration monitoring)
  [Camilla Colla, University of Bologna]
- Example: Public Weigh House | Bozen/Bolzano
  [Dagmar Exner, EURAC]
- „Raumbuch“ integrated with energy aspects – a tool to support the multidisciplinary approach

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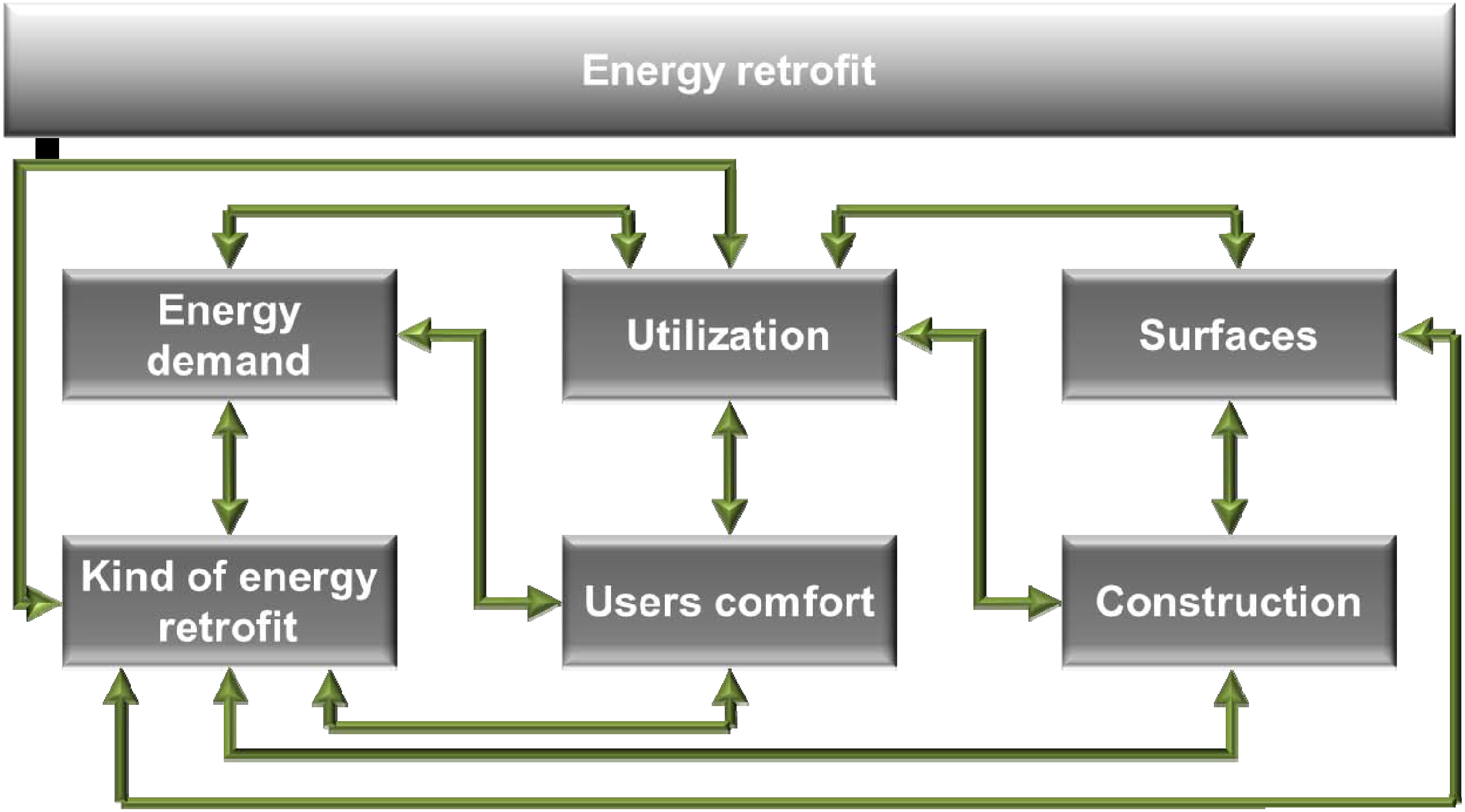
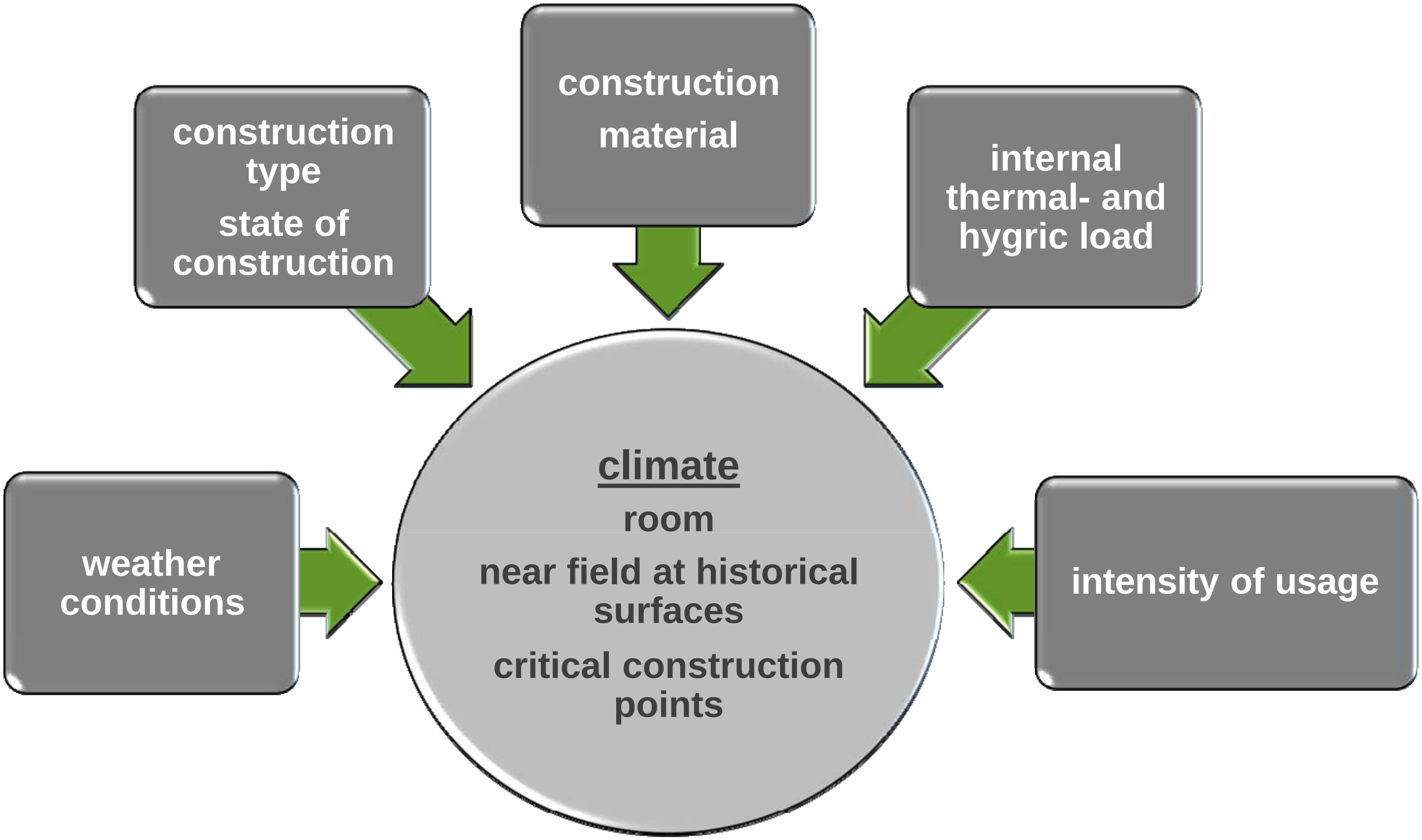
Monitoring aspects & sensors

ENERGY AND HISTORIC BUILDINGS

Interactions



Influences of the room climate



construction type

state of construction

construction material

internal thermal- and hygric load

weather conditions

intensity of usage

climate

room

near field at historical surfaces

critical construction points

Tasks of monitoring

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Design a sensor network to capture all relevant parameters:

- Room climate / users comfort
- climate related stress at historical surfaces
- thermal and hygrical situation inside the construction
- Collect energy consumption

→ Evaluation of energy and physical situation of the building

→ Adjustment and optimization of operation of HVAC systems with the right of energy and the monument preservation

Monitoring of the energy consumption and the user comfort State acquisition

of the construction and the historic surfaces

BASICS OF MONITORING

Necessary informations to develop a monitoring concept

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1. Recording of the constructional design details, the existing technical facilities, any existing historic surfaces of the building and potential problems such as salt loads, etc.

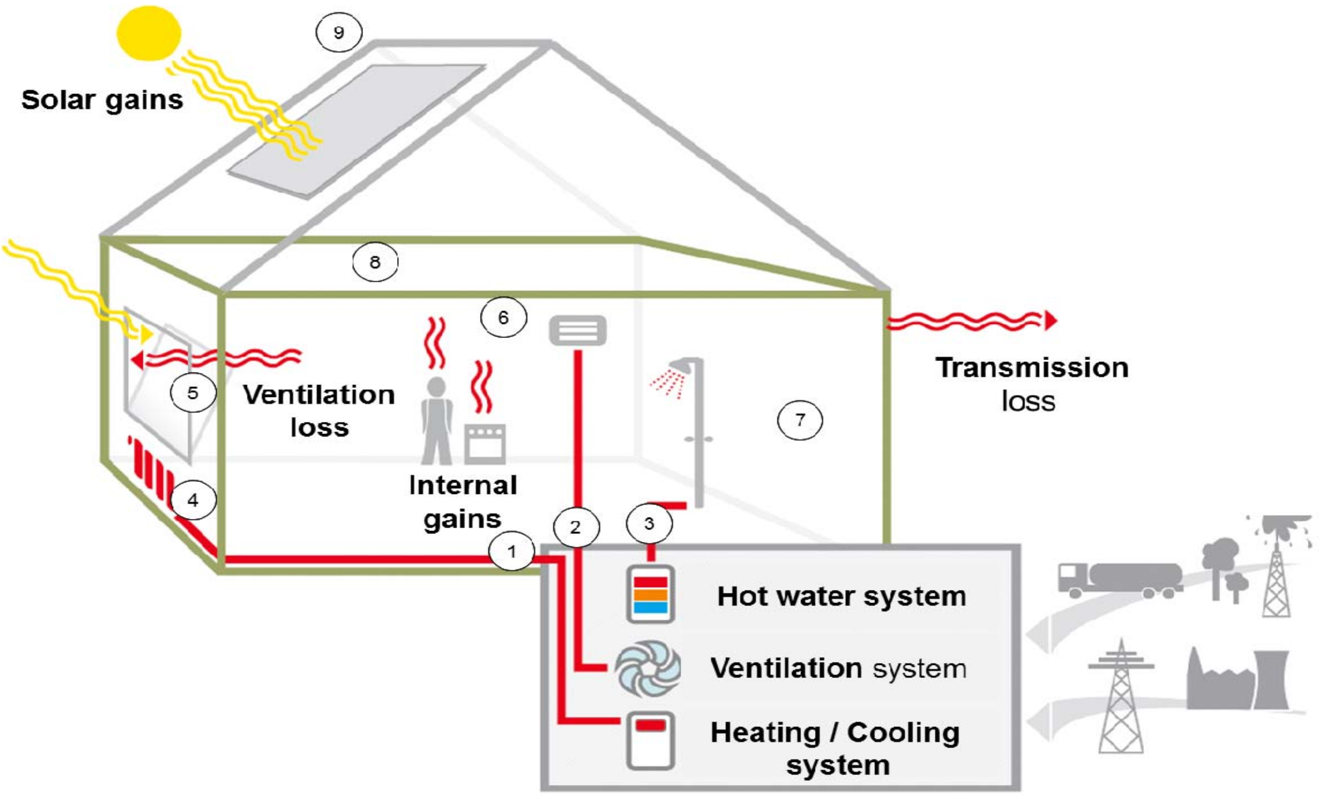
2. Determination of previously possible measurement of energy consumption (heat meters, costing, bills etc.)

3. Detecting any existing measurements related to indoor climate, outdoor air or near field climate on critical design details and historical surfaces

4. Provision of existing investigations for all buildings, e. g. for example, material-technical analysis, etc.

5. As a part of the research project proposed energetic improvements

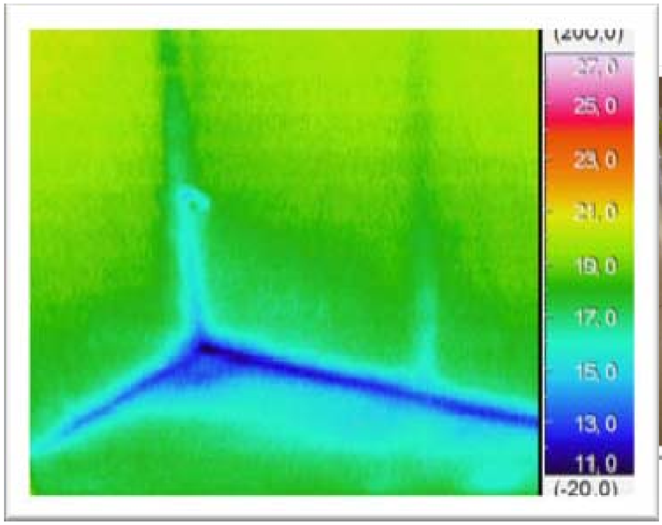
Basics of monitoring
Energy and comfort monitoring



1 **Energy demand – heating / cooling system (kWh)**
2 **Power consumption – ventilation system (kWh)**
3 **Energy demand – hot water system (kWh)**
4 **Energy demand – radiator (kWh)**
5 **Status windows and doors (open/closed/tiled)**
6 **Room climate (°C / RH /CO_2)**
7 **Surface temperature (°C)**
8 **Lighting (lux)**
9 **Weatherstation (°C / RH / Wind / Global radition)**

Basics of monitoring
Historical surfaces and critical construction points

- critical climate fluctuations at historical surfaces caused by technical systems, e.g. heating, cooling, ventilating, humidify and dehumidify
- extremely complex exposures in the context of transient hygrothermal conditions can appear in the near field area of material layers



Interaction - Climate and historical surfaces / critical construction points

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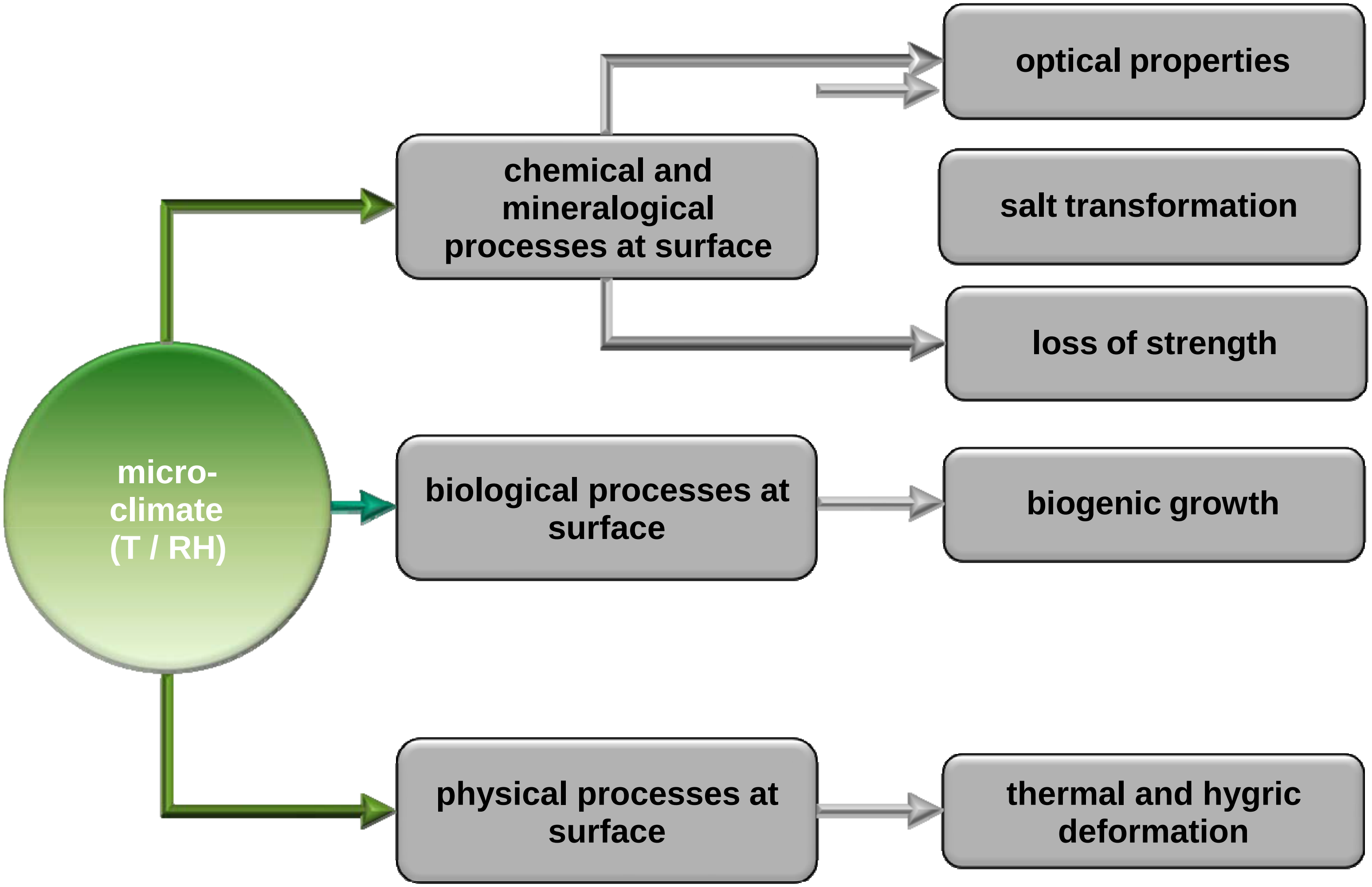


micro-climate (T / RH)

chemical and mineralogical processes at surface

optical properties

salt transformation

loss of strength

biological processes at surface

biogenic growth

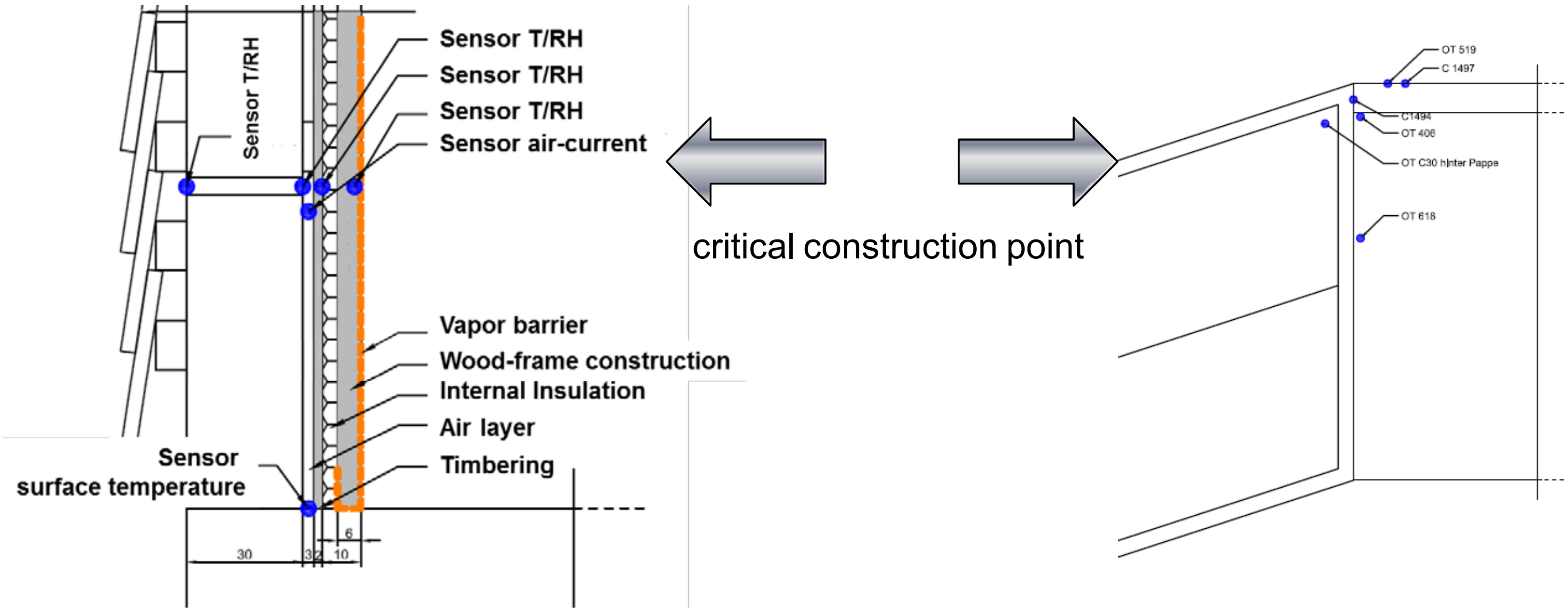
physical processes at surface

thermal and hygric deformation

Arrangement of sensors at inside insulation - example

Measuring the climatic conditions by:

- Surface-temperature
- Temperature and relative humiditiy at different room positions
- Temperature and relative humidity at surfaces and inside construction



critical construction point

Measuring tasks of the monitoring

Energy demand Comfort / Utilization	Critical construction points Historical surface
heating system cooling system ventilation system electrical system hot water system domestic electricity	near field climate surface temperature Dew-point moisture content
room climate surface temperature air-current CO_2-level light conditions	near field climate surface temperature air-current moisture content thermal- and hygric deformation

additional analysis: infrared thermography, blower-door-test, etc.

MONITORING AND SIMULATION

Monitoring and simulations tools

A prerequisite for the planning of energetic refurbishment of historical buildings is the evaluation of the planned measures in the context of different simulation calculations.

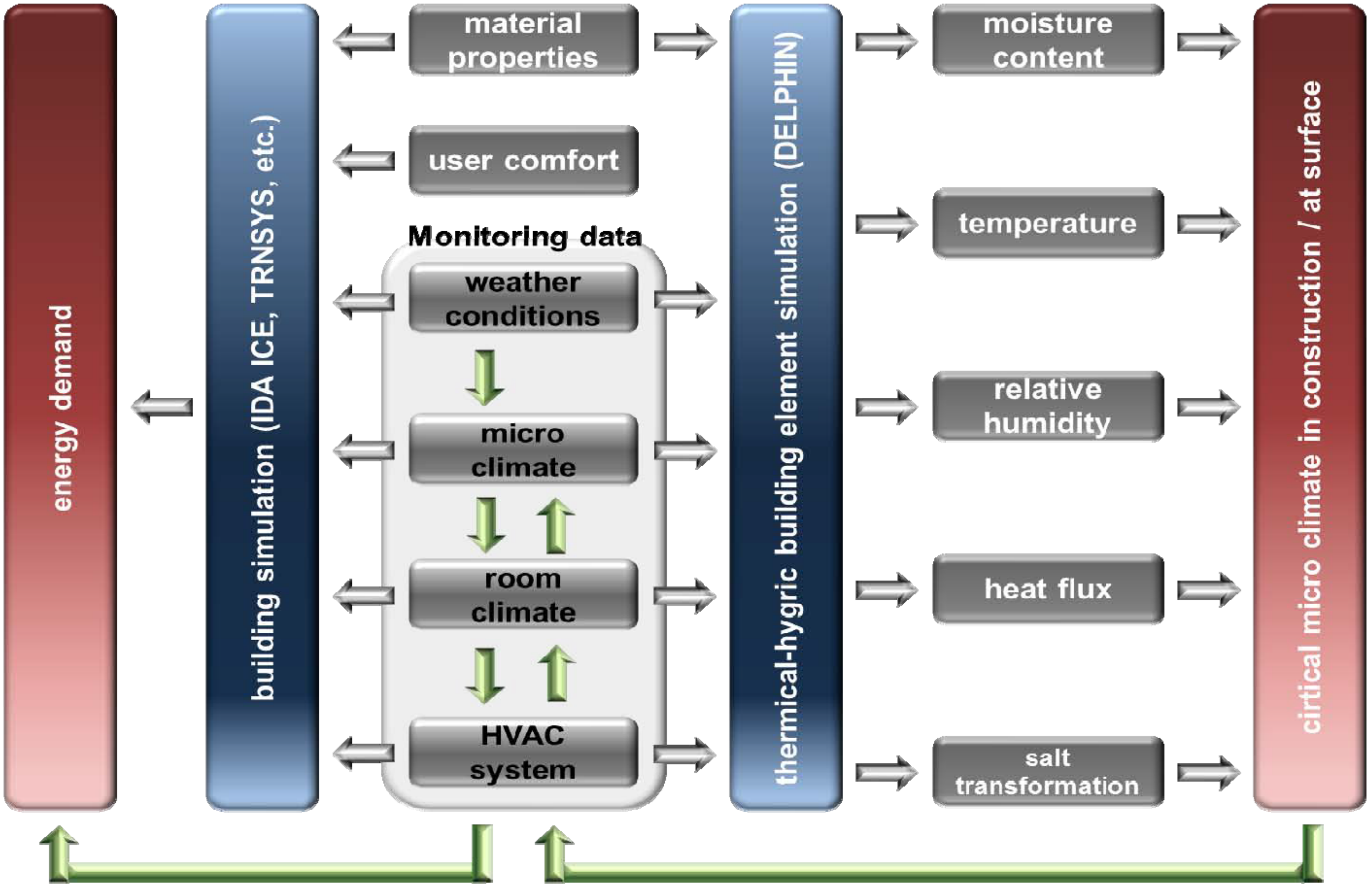
Goals of comercial simulation tools:

Building simulation	**Optimization the energy demand and technical systems**
Thermal-hygrical	**thermal-hygrical conditions inside the construction**

Only meaningful results can be achieved with historic buildings, if:

Building simulation + thermal-hygrical simulation

Interaction
Monitoring and simulation



energy demand

building simulation (IDA ICE, TRNSYS, etc.)

material properties

user comfort

Monitoring data

weather conditions

micro climate

room climate

HVAC system

thermical-hygric building element simulation (DELPHIN)

moisture content

temperature

relative humidity

heat flux

salt transformation

critical micro climate in construction / at surface

Monitoring concept and simulationtools

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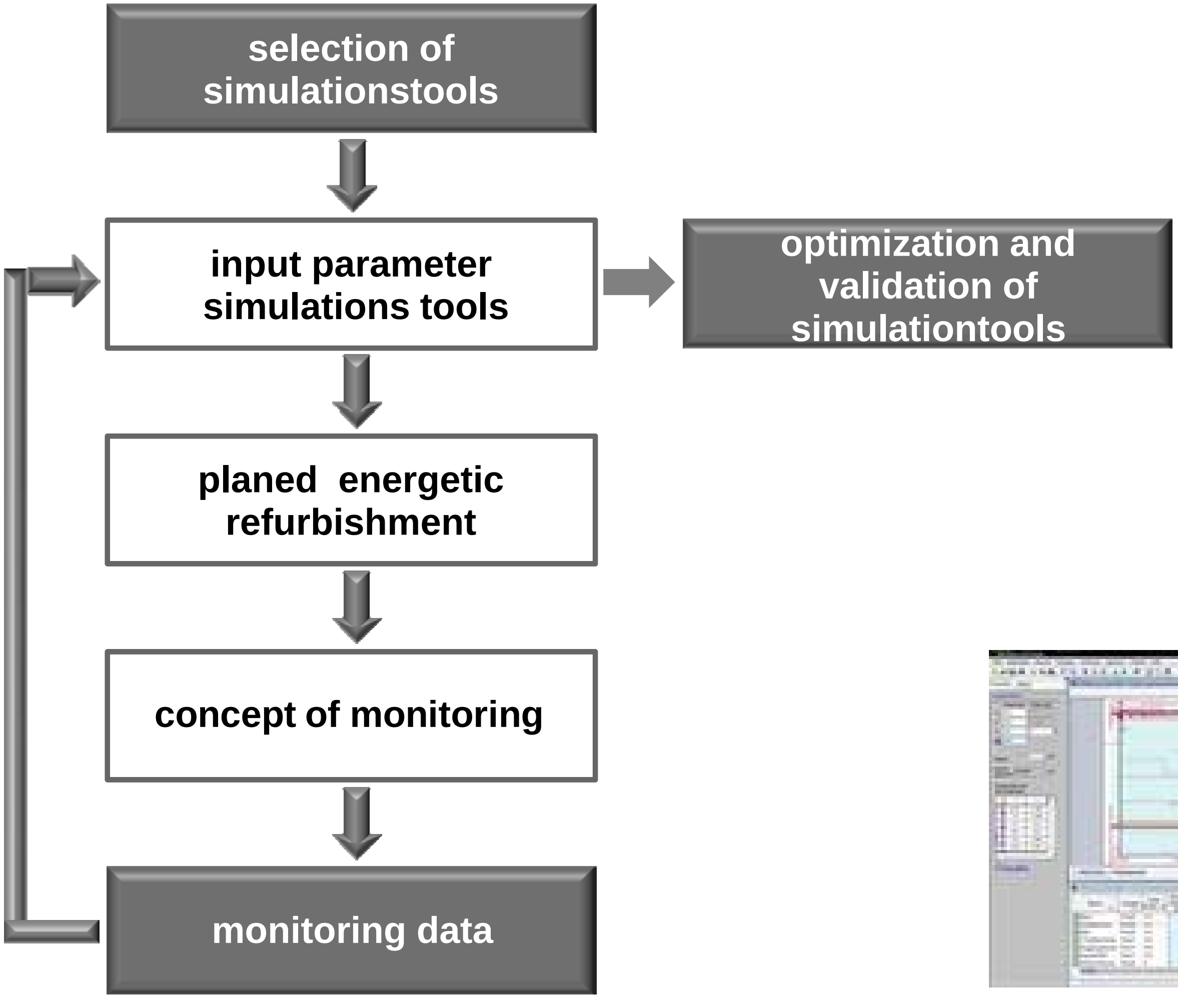


selection of simulationstools

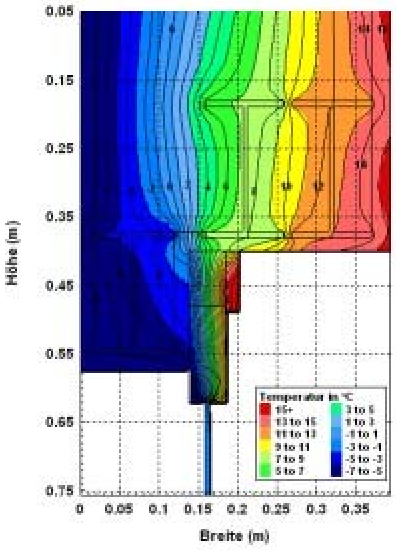
input parameter simulations tools

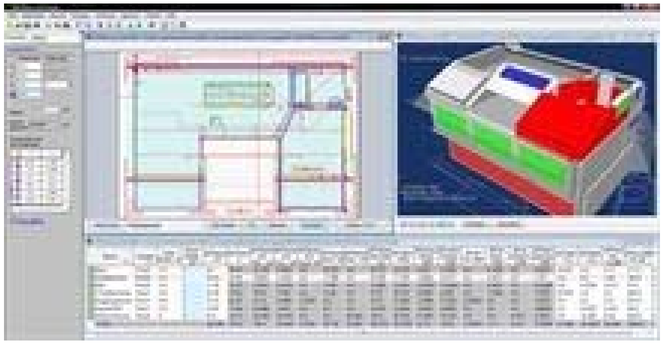
optimization and validation of simulationtools

planed energetic refurbishment

concept of monitoring

monitoring data





EURAC research
Universität Innsbruck
Universität Stuttgart
CARTIF
Bartenbach LichtLabor
Artemis

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METERS AND SENSORS

Basics of installing meters

- The allocation of most meters in the building to be examined depends on the existing technical systems and their accessibility.

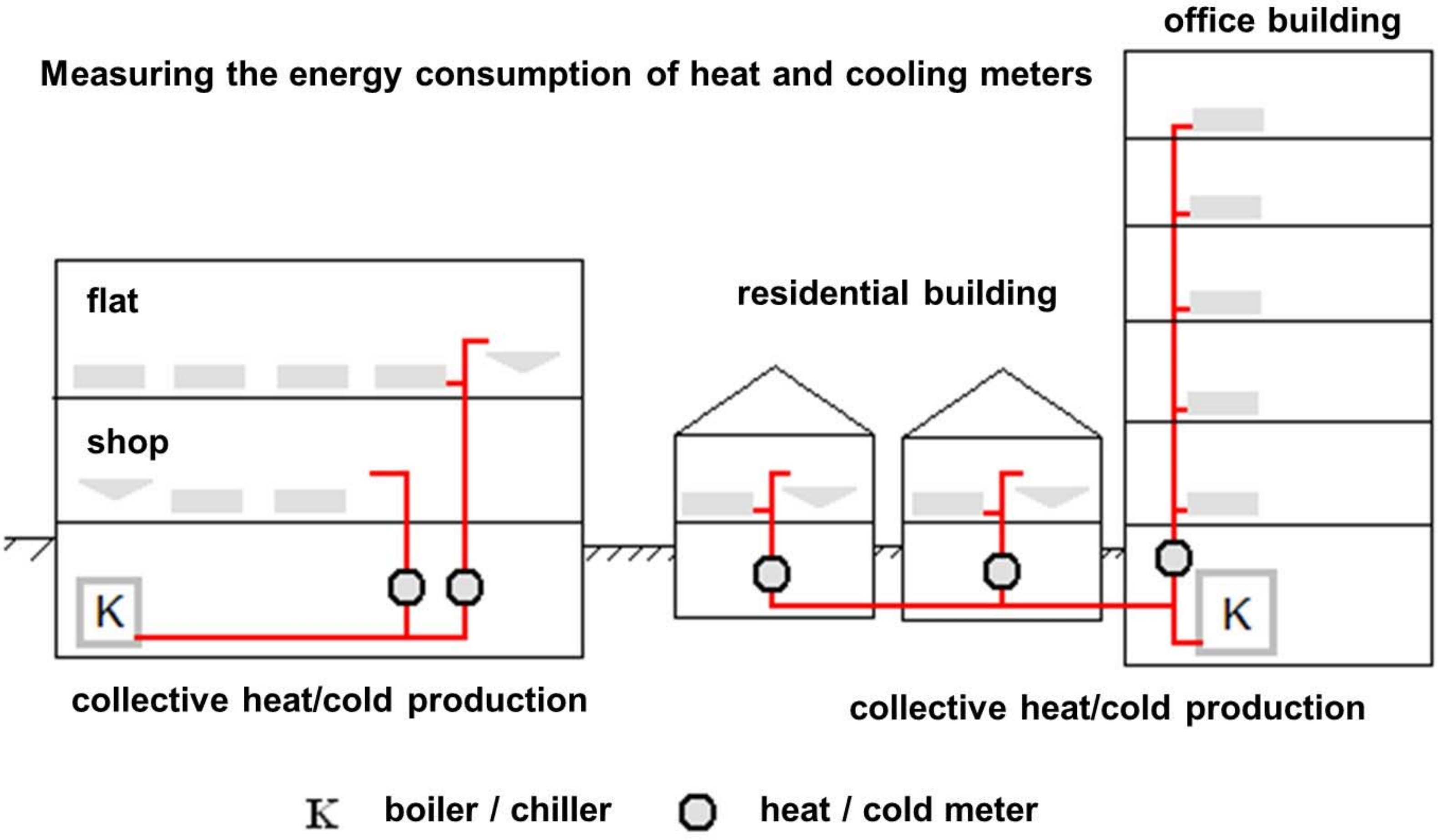
- As part of the energy monitoring it would be desirable that the energy consumption is detected in very small units, i. e. in individual rooms. As this is often, due to different conditions, not possible, they should be installed at least one counter

of the total consumption for this kind of energy and if feasible for each unit seperate meters.

- Invasive meters are commercially available and must be fitted by technically competent companies.

- The costs of the different meters depends on their configuration, i.e. manually readable, with electrical interface. The estimate costs for the professional installation depends on the country-specific costs.

Example for installing meters



Measuring the energy consumption of heat and cooling meters

Basics of heat meters

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Heat meters are devices that are installed into the supply repectively return line from a radiator, a room, an apartement or a house and they determine the amount of heat consumed. The amount of heat consumed is calculated by the counter. For this, the temperature difference between flow and return line and the flow rate are measured.

From the amount of water per unit time, the temperature difference and the konwn heat capacity of water, the measuring device is able to calculate the current heating power i. e. the energy delivered per unit time. This measure variable is integrated over time by the calorimeter, so that any point in time the previously consumed heat energy is known. The heat energy is measured in mega watt hours (MWh) or

kilo-watt hours (kWh).

Heat meters

Heat meter (invasive)

Heat meter non-(invasive)

For the use of monitoring the heat-measuring device(s) should be equipped with elecrical interfaces, so that the measuring values can be recorded and archived in real time.

The choice of the electrical interface used in this context depends on the possibility of the implemented in an existing or prospective monitoring concept.

Cold meters

Cold meter (invasive)

Cold meter non-(invasive)

With the aid of an air conditioner primarily ambient air is cooled. For this purpose, the air conditioning removes thermal energy. Cooling meters, which determine the energy, do not differ from heat meters in principle.

However, cold meters work as opposed to heat meters in a significantly reduced temperature range of 3 C to 20 C and at small temperature differences of up to 20 kelvin.

Even in cold meters,the energy consumption in megawatt hours (MWh) or kilowatt hours (kWh) specified.

Water meters

Water meter (invasive) with pulse output

Water meters are measuring instruments for determing of total or individual consumption in buildings or apartments.It can be destinguished between two types of meters:

- Meter, which show only the amount in any period of time and
- meters that collect the amount per unit of time (such as flow /hour)

Older hot water meters are usually only manually readable, should a new installation being considered and an appropriate communication in the rooms under examination may be available, a meter with pulse output should be installed so that the hot water consumption will be recorded in appropriate intervals.

Electricity meters (1)
Universal and individual meters

The electric meter is a measuring instrument integrating over a time course to record the amount of a delivered or consumed electrical size.

The associated physical unit is the kilowatt hour (kWh).

It is possible to provide the universal electric meter with a reading device.

These devices record the status of the mechanical consumption display using an optical institution. Using text recognition (OCR), the captured image will be transformed into electronic information.

This information can then, as in the electronic energy meters using various data interfaces, be transmitted. Therefore, an automatic reading of the meter is possible.

Electricity meters (2)
Universal and individual meters

If a new universal electric meter will be installed, make sure that it is an electronic energy meter according to IEC 62053-21 to -23.

The relative error limits as a measure of the accuracy of the counters are in the household sector at 2%.
At high electrical work to be counted also meters for class 1, 0.5 and 0.2 are used.

Electricity meters for measurement of individual consumers

Reed contact / windows and doors

Because of the significant influence of the user behavior on the energy efficiency of the building, the knowledge of door and windows position is important.

Reed contact

For windows not only the status open /closed, but also with appropriately installed reed contacts the tilted position can be detected.

For the evaluation of user behavior and the influence of door and window position on the indoor climate and any existing technical systems, it makes sense not only count, but also to analyze their status over time.

Air change / Infiltration air change

Air currents can occur in buildings by natural origin or forced. As a natural form of ventilation the infiltration air change can be found (joints of windows and doors).

The infiltration air change rate has a significant influence on the heat and moisture balance of the building and often leads to noticeable drafts.

For high moisture loads the infiltration air exchange is mostly not sufficient to ensure a suitable environment. This is especially true if existing joint were sealed to reduce drafts and energy losses.

Air change

Prerequisite for forced ventilation are technical systems, which transport air in addition to infiltration air-change.

In the context of the energy efficiency of a building is a small, controlled air exchange of advantage, in which may also be the possibility of heat recovery.

In terms of the thermal-hygric load of historic surfaces an uncontrolled ventilation may have a negative influence on their preservation.

Air velocity

Sensors for laminar flow and for installing in ducts with an analog output signal

The flow rate of air in ventilation systems, in the area of windows or at historic surfaces are to be recorded in m/s

CO_2-level

CO_2- Sensor for rooms

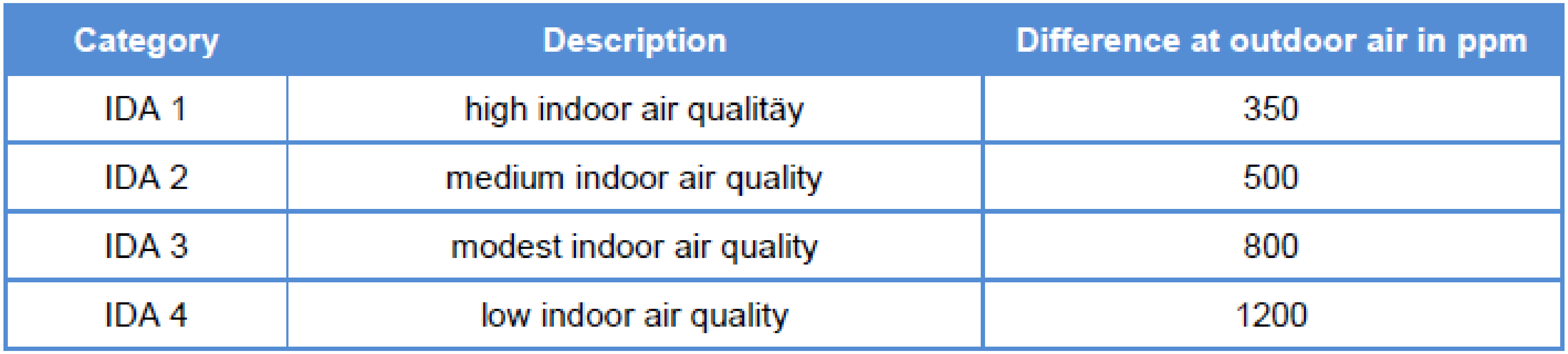
CO_2- Sensor for air ducts

- Indoor air quality refers all non-thermal aspects of the ambient air, which will affect the comfort and health of users.
- The concentration of CO_2 in an indoor environment is used primarily as a general indicator of the total quantity of organic emissions and odors given off by humans.
- Because of the human respiration, the CO_2 content of the indoor air directly reflects the intensity of the use of a room.
- The CO_2 concentration is measured in ppm (parts per million).

Classification of the indoor air quality to DIN EN 13779

The illustrated classification of indoor air quality according to DIN EN 13779 indicates that there is not an absolute value used for the classification of room air.

The indoor air quality is defined as the concentration difference between room air and outside air. This has the need of an sensor for the outside CO_2 concentration additional to the installed sensors in the measured rooms as a consequence.



Category	Description	Difference at outdoor air in ppm
IDA 1	high indoor air qualitäy	350
IDA 2	medium indoor air quality	500
IDA 3	modest indoor air quality	800
IDA 4	low indoor air quality	1200

Light conditions

- Increasing the energy efficiency of a building can also be achieved by optimizing the day-light illumination. So far it is an assumption that the buildings lighting accounts approximately 10% of total electricity consumption.

- To evaluate the incident daylight in a room, sensors can measure the light intensity. The illuminance lux (lm/m²) is the photometric equivalent of irradiance.

- For the selection of a suitable sensor for the measurement task, commercial sensors with various measuring ranges are available.

Light sensor for rooms

Location	Illumination [lx]
Surgical field illumination	20000…120000
Sunny summer day	60000…100000
cloudy summer day	20000
cloudy winter day	3000
well-lit workplace	500…750
Pedestrian zone	5…100
Full Moon night	0,25
New moon night	0,01

Temperature and relative humidity

In several respects the recording of temperature and relative humidity in a building has an extremel~~y~~ importance.

- On one hand these values are used for the evaluation of user comfort (room climate) and the energy demand, on the other hand for the monitoring and evaluation of the historical surfaces and critical construction details adjusting near field climates and surface temperatures.

T/RH sensor

HVAC systems are another area of application of these sensors.

Temperature sensor

For the measurement of the temperature generally resistance sensors with different accuracy are used. Higher accuracies are achieved with so-called Pt 100 sensors, but they cause considerable costs.

The temperature values are measured in degrees Celsius (C).

Temperature and relative humidity

T/RH sensor

relative humidity sensor

The measurement of the relative humidity is typically capacitive.

Increase of the relative humidity increases also the capacitance of the capacitor.

The measuring signal is independent of the ambient pressure and directly proportional to the relative humidity.

The capacitive humidity sensor is largely maintenance-free and can be used also below freezing, however, his long term stability is limited and the sensor signal can be disturbed by condensation or rain.

Dew point temperature
Dew point sensor

The dew point temperature is referred to as the temperature at which the condensate is formed on a surface. This effect is the greater, the lower the temperature of the surfaces and the higher relative humidity is.

As part of energy rehabilitation of historic buildings often the application of an internal insulation is the choice. At low ambient temperatures this installation causes a reduction of temperature between the exterior wall and interior insulation.

As a result of this the temperature behind the insulation may drop under the dew point of the ambient air. Water vapor diffusion or convection of air from the living room leads to an increase in humidity in this area.

Dew point temperature Dew point sensor

For this reason, the monitoring of critical structural details such as thermal bridges etc. recommends using dew point sensors.

An energetic retrofitting is often combined with the installation of HVAC ventilation systems whose control patterns often are not adapted to the historic building materials. Because the operation of these systems can lead to temperatures falling below the dew-point at historic surfaces what implies the formation of condensate, a dew point sensor is useful here too.

Alternativ method:

Measuring microclimate (T/RH) → calculate dew point temperature

Measuring surface temperature → compare with dew point temperature

Dew point sensor

Heat flux sensor (1)

Heat flux or thermal flux is the rate of heat energy transfer through a given surface and is measured in W/m².

When the heat flux sensor has to be mounted on top of the wall, one has to take care that the added thermal resistance is not too large.

Heat flux sensor

Also the spectral properties should be matching those of the wall as closely as possible. If the sensor is exposed to solar radiation, this is especially important.

In this case one should consider painting the sensor in the same color as the wall.

Also in walls the use of self-calibrating heat flux sensors should be considered.

Heat flux sensor (2)

Transparent
heat flux sensor

Because heat conduction processes in walls are irregular, it makes sense to measure, the heat flow for a sufficient period.

Important here is that the recording time is long and the sampling rate small compared to the thermal time constants of the wall.

Heat flux sensors should always be positioned so that close contact between the sensor surface and the corresponding surface is ensured.

Global solar radiation

Because the exact knowledge of the solar gains is of great importance for the energy balance or the energy requirements of a building, it is useful to capture the global radiation in depending on the time.

Global solar radiation sensor

The collection of global radiation can be used not only for realistic simulation calculations but also to evaluate user behavior and improving any existing technical equipment.

To measure the present value of global radiation pyranometers are used. This current value has the unit Watts per square meter (W/m²). By summation of radiated energy of determined periods of time, is apparent in kilowatt hour per square meter an energy input (kWh/m²) is specified.

A separate measurement of global radiation may be omitted if there is a weather station in close to the building.

Wind speed sensor

The wind speed is the distance, air covers in space per unit of time. It is a directed quantity, defined as a vector with a horizontal and a vertical component.

The wind speed is measured typically with a small rotating wind meter, the anemometer. The wind speed is measured in m / s.

Beaufort number	Description	Wind speed [m/s]
0	calm	0 - 0,2
1	light air	0,3 - 1,5
2	light breeze	1,6 - 3,3
3	gentle breeze	3,4 - 5,4
4	moderate breeze	5,5 - 7,9
5	fresh breeze	8,0 - 10,7
6	strong breeze	10,8 -13,8
7	high wind, moderatre gale, near glae	13,9 - 17,1
8	gale, fresh gale	17,2 - 20,7
9	storm gale	20,8 - 24,4
10	storm, whole gale	24,5 - 28,4
11	violent storm	28,5 -32,6
12	hurricane	ab 32,7

Wind speeds are classified after the Beaufort scale.

Wind direction sensor

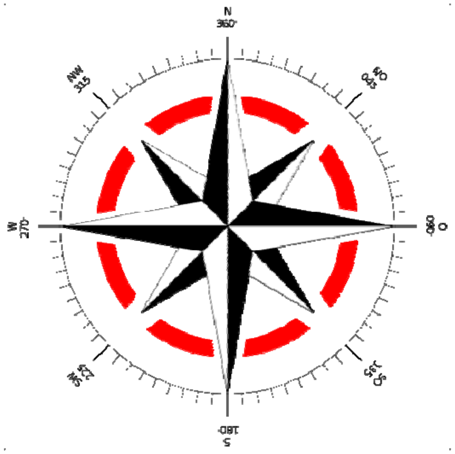
Together with a wind speed sensor and a recording device, are permanently installed wind direction sensors a part of weather stations.

A wind direction sensor is a meter to determine the wind direction.

It is based on a mobile measuring element that aligns to the dynamic pressure of the wind.

The wind direction is one of eight main wind directions, or as a degree (1 - 360 C) indicated the compass rose.

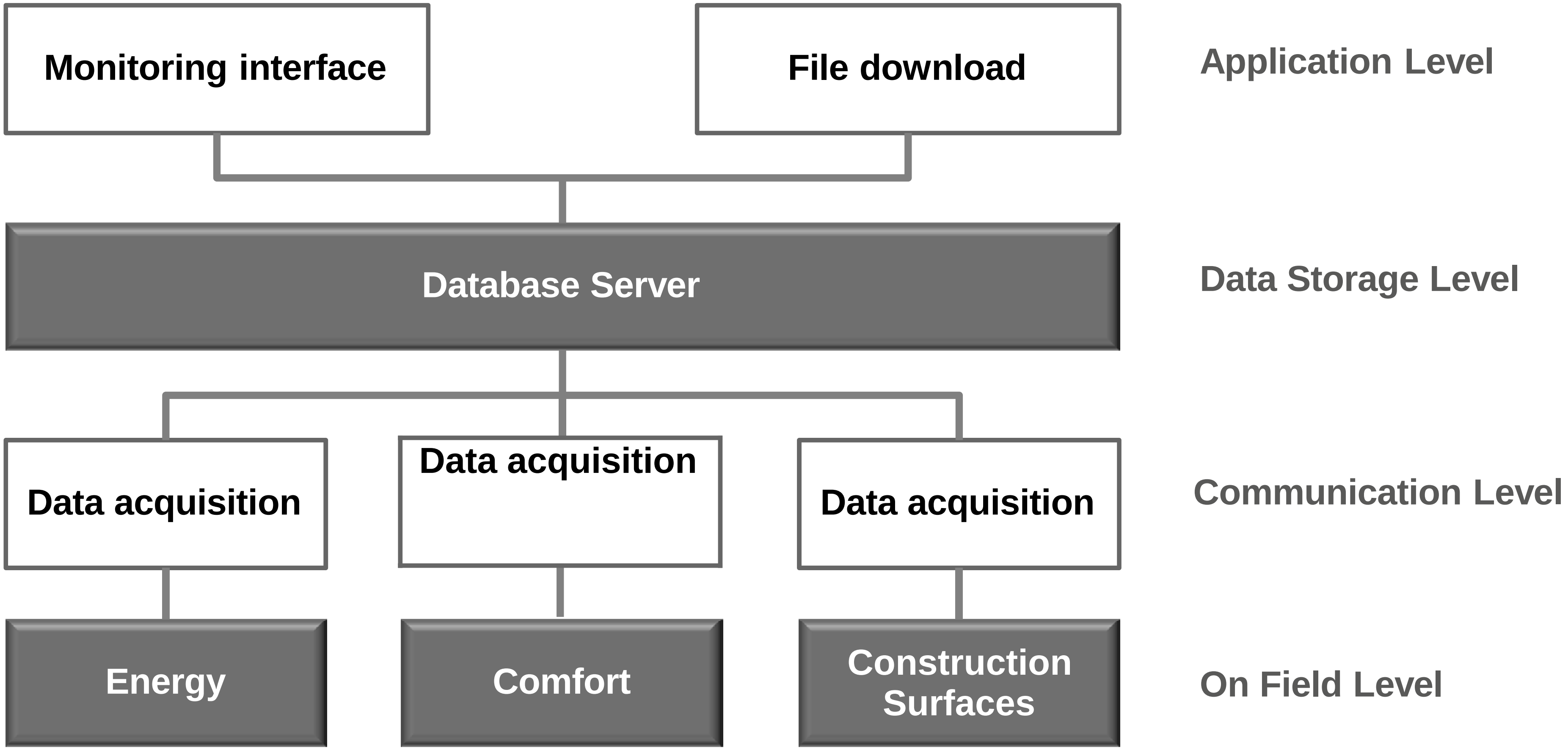
By using the degree of specification is one of degrees from north clock-wise direction.



Wind rose

AUTOMATION
DATA AQUISITION

First automation system


Monitoring interface

File download

Application Level

Database Server

Data Storage Level

Data acquisition

Data acquisition

Data acquisition

Communication Level

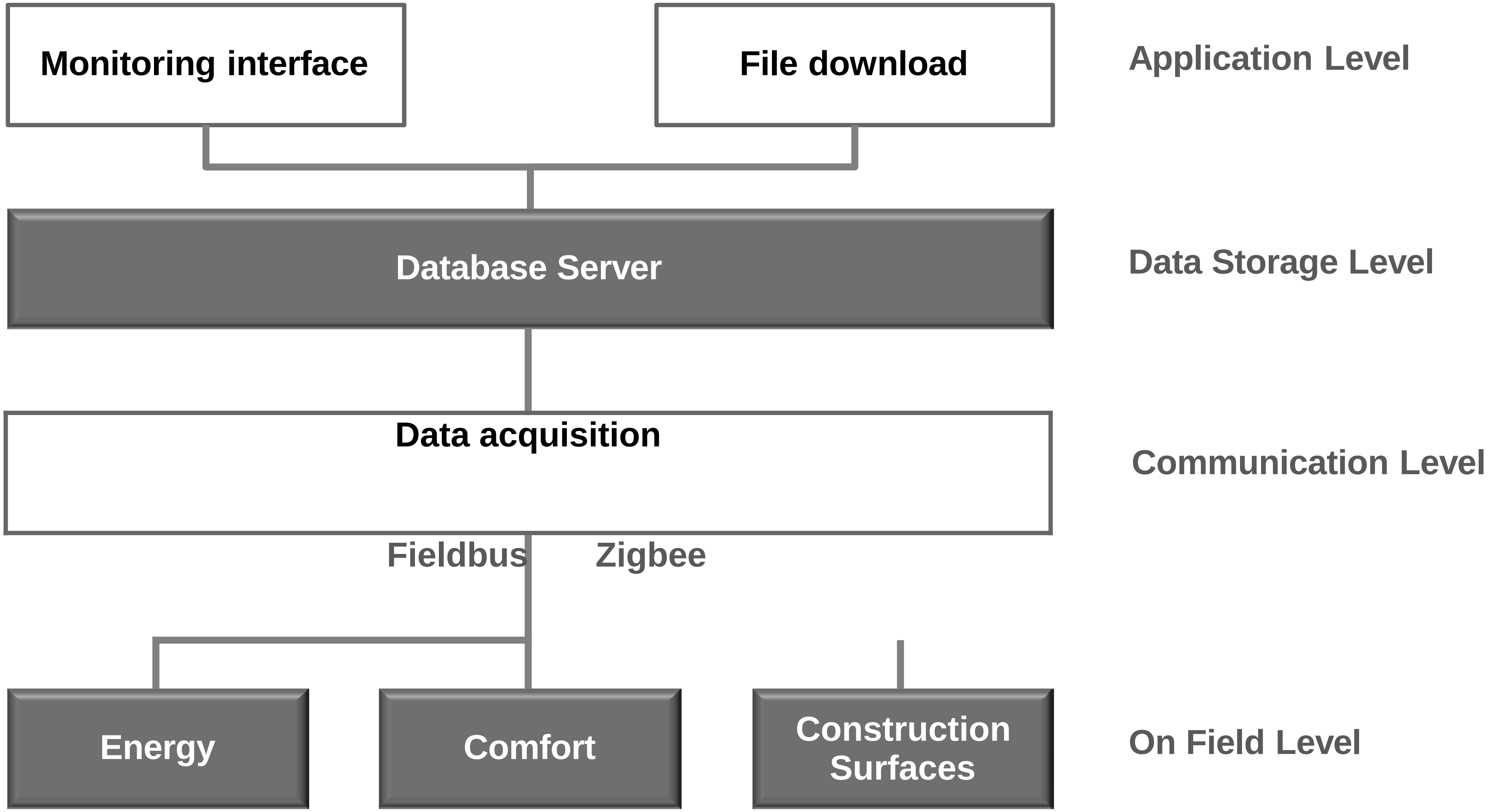
Energy

Comfort

Construction Surfaces

On Field Level

Final automation system



Monitoring interface

File download

Application Level

Database Server

Data Storage Level

Data acquisition

Communication Level

Fieldbus

Zigbee

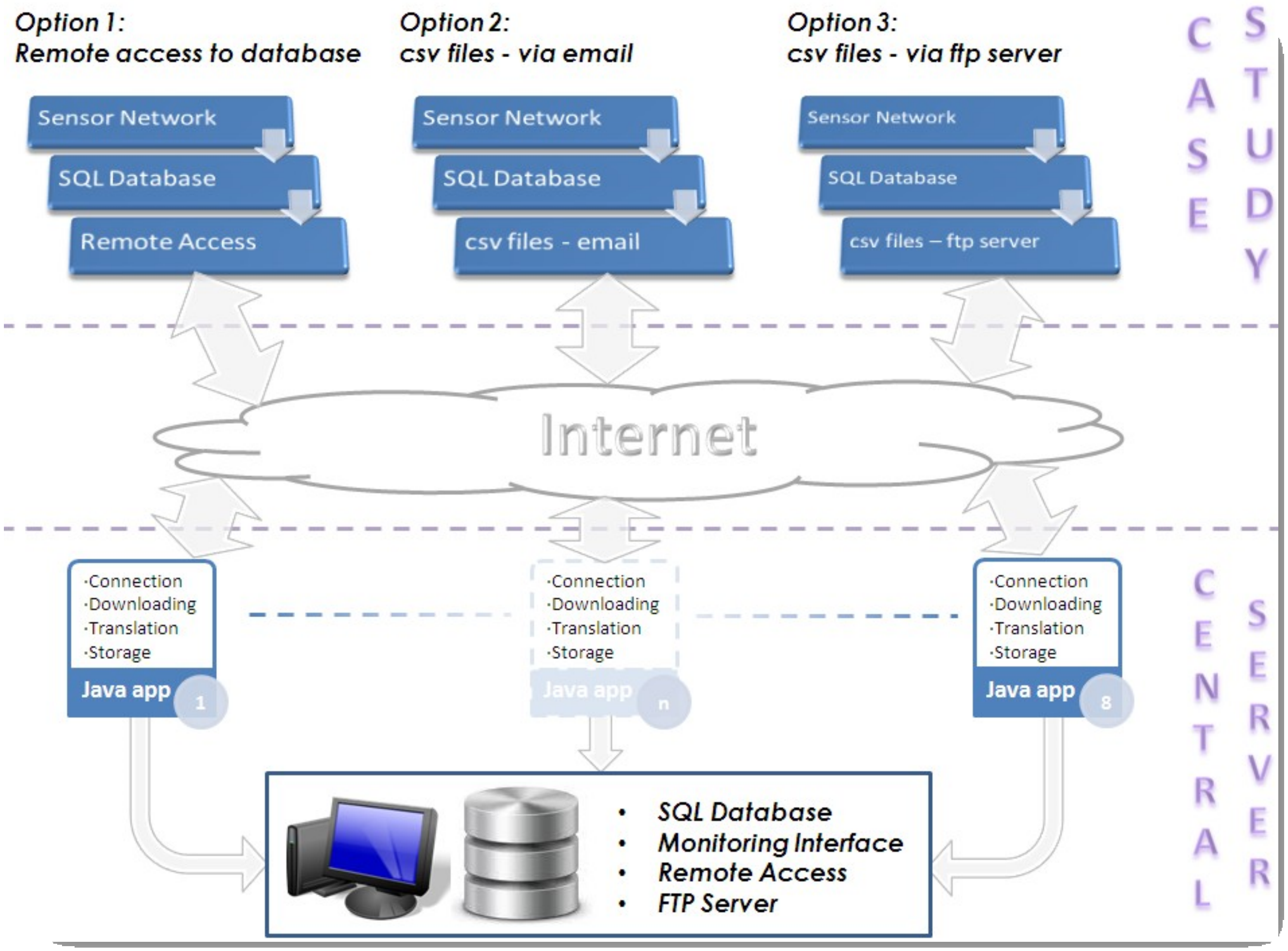
Energy

Comfort

Construction Surfaces

On Field Level

Data acquisition



Methods & tools for complete diagnosis

IR, flux meters, T & RH monitoring
Enrico Esposito, Artemis

Diagnostics and monitoring for the energy efficiency of CH

Diagnostics and monitoring are instruments to raise the knowledge level of a building, and to verify its performance. Considering the high historical, artistical and cultural value of the buildings that 3ENCULT will deal with, it is highly recommendable to utilize non invasive, non-destructive techniques.

- **IR TERMOGRAPHY**
- **THERMAL FLUX METERS**
- **WIRELESS SENSOR NETWORKS (WSN)**

Diagnostics and monitoring for the energy efficiency of CH

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EFFICIENT ENERGY FOR EU CULTURAL HERITAGE

- Thermal bridges
- Hidden structures
- Humidity
- Leakeages
- …..

Measurement of transmittance (U) and/or conductance (C) of walls, roofs, floors…

- IR TERMOGRAPHY

- THERMAL FLUX METERS

- WIRELESS SENSOR NETWORKS (WSN)

Environmental monitoring (outside/inside)

Artemis
DIAGNOSTICA EDILIZIA

IR Termography

Infrared thermography (IRT) is a two-dimensional, noncontact technique for the measurement of radiant heat flow; due to the physical link between this flow and surface temperature, IRT is commonly referred as a technique for the non-contact mapping of the temperature distribution on a surface. Basically, an *infrared camera* (IR camera) detects the electromagnetic energy radiated in one infrared spectral band by an object (whose surface temperature is to be measured and which should be fully opaque to the detected band) and converts it into an electronic signal, that, by digital/analog encoding, is usually presented as a video image and stored in a non volatile memory support.

Radiant heat flow depends on many characteristics of the materials and of environment surrounding the examined structural component. Generally speaking, differences in recorded thermograms may depend on:

1. Surface characteristics (e.g. smoothness/roughness, presence of humidity)
2. Surface materials
3. Substrate materials
4. Presence of discontinuities in the substrate (including structural defects, e.g. voids)

IR Termography

These characteristics may be present simultaneously, so IRT investigation is not simple, especially in the data analysis phase. Different sequences of images of the same sample should be acquired in different thermal situations, e.g. with cold surface, irradiated surface and cooling surface, so to be able to separate all mentioned contributions. For example, when looking at an apparently uniform plaster, an intervention with different plaster will show up even at ambient temperature, while a defect will generally appear only after thermal excitation of the surface: so, taking measurements with and without thermal excitation may help to understand which type of inhomogeneity we are observing.

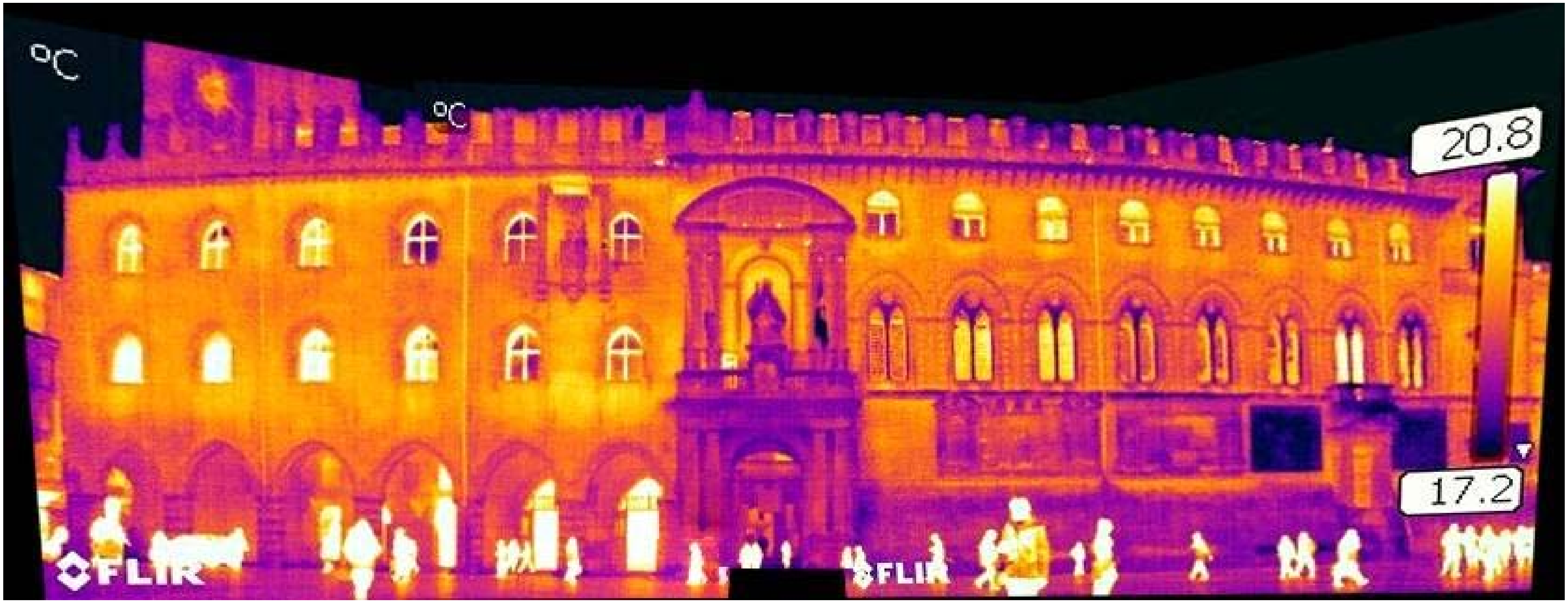
IR Termography

FLIR ThermaCAM™ B400: caratteristiche tecniche

Immagine Termica	Campo Visivo 25° x 18.75°
Risoluzione spaziale (IFOV)	1.36 mrad
Sensibilità termica (a 30 °C)	70 mK o migliore
Distanza minima di messa a fuoco	0,4 m
Frequenza acquisizione immagine	9 o 30 Hz
Zoom Elettronico	8 x
Messa a fuoco	Automatica/Multifocus
Immagine nel visibile:	Video camera da 1.3Mp a colori con illuminatore incorporato
Detector	Focal Plane Array (FPA), microbolometro non raffreddato 320x240 pixels, campo spettrale da 7,5 a 13 µm
Rappresentazione Immagine	LCD incorporato, Touch-screen 3,5" ad alta risoluzione
Capacità di misura	Campo di misura della temperatura da -20°C a +120°C (disponibile come opzione estensione a +350°C)
Precisione (della lettura)	± 2°C o ± 2%
Configurazione Software	▪ Area di misura, Max/Min/Media, 5 punti ▪ Indicatore di posizione temperatura Max e Min ▪ Isoterma ▪ Funzione Isoterma ad intervalli ▪ Funzione differenza di temperatura ▪ Temperature di riferimento ▪ Allarmi di temperatura, 3 ▪ Allarmi umidità (incluso punto di rugiada) ▪ Allarmi isolamento ▪ Formato file IR radiometrico ▪ Thermal Fusion ▪ Marcatori su IR/visibile, 4 ▪ Annotazioni commenti vocali e di testo ▪ Bozze/Schizzi ▪ Colori Palette B/N, B/N inv, Ferro, Arcobaleno, Arcobaleno AltoContrasto, B/R ▪ Tabella di Emissività
Puntatore Laser	Attivazione Laser attraverso tasto dedicato
Salvataggio Immagini	SD-Card estraibile
Interfaccia	▪ USB, trasferimento files da/a PC ▪ Connessione Audio con auricolare ▪ Uscita video output RS170 EIA/NTSC or CCIR/PAL comp. video ▪ Alimentazione
Specifiche Ambientali	▪ Temperatura di esercizio da -15°C a +50°C ▪ Temperatura di conservazione in stato di non utilizzo da -40°C a +70°C ▪ Umidità IEC 68-2-30/24 h 95% ▪ Urel da +25°C a +40°C ▪ Grado di protezione, valigia di trasporto IP 54 (IEC 60529) ▪ Grado di protezione, involucro termocamera e lente IP 54 (IEC 60529)

IR Termography

Case Study #2 (CS2) - D’Accursio Palace, Bologna

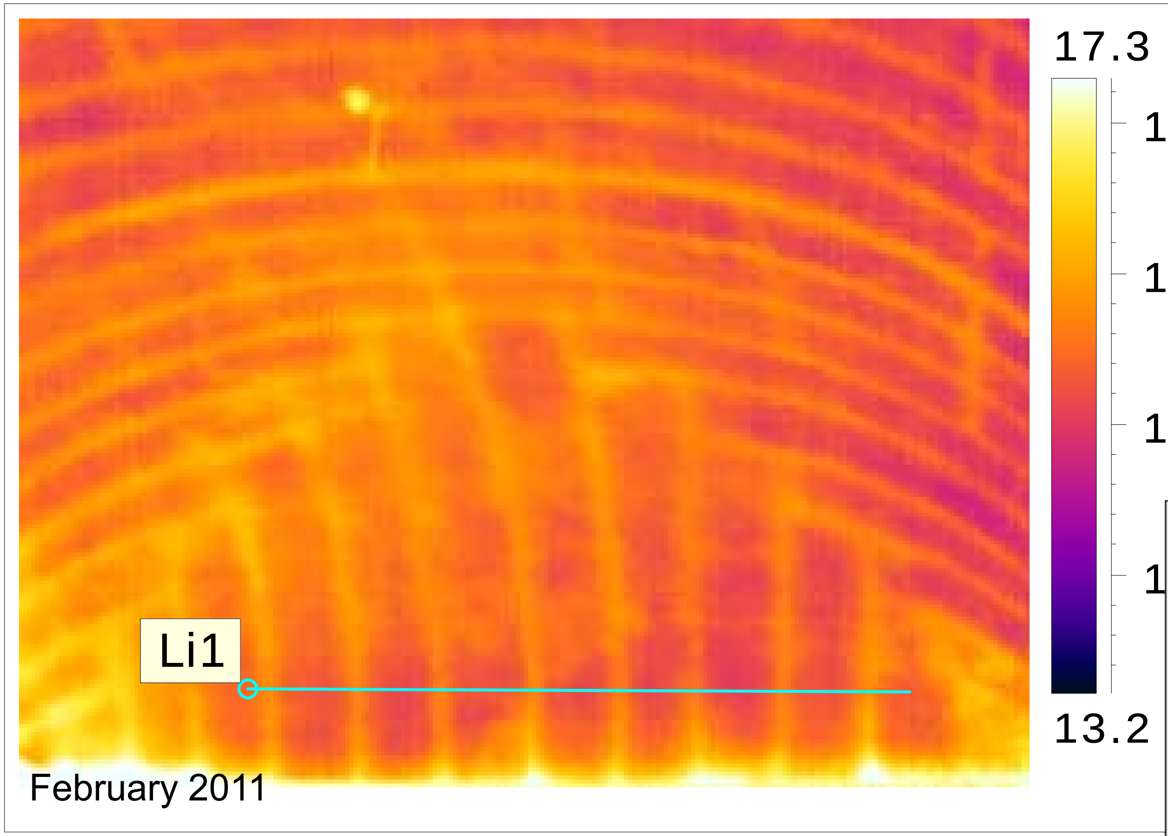


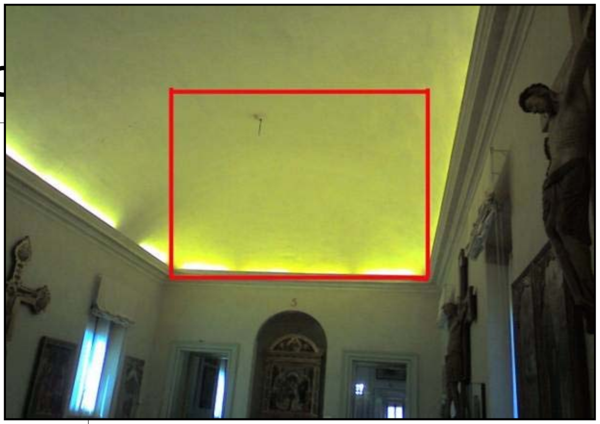
IR Termography

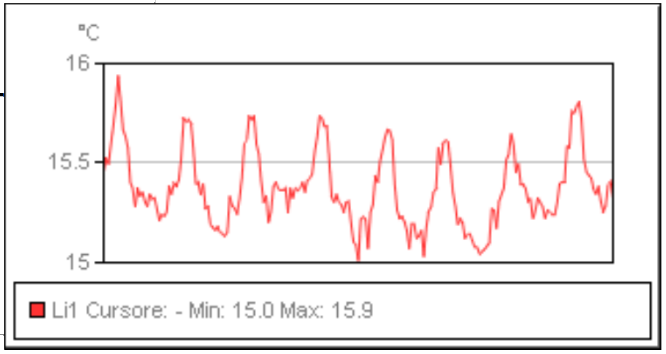
CS2 - Municipal Collections – “Dei Primitivi” Room

IR Termography

CS2 - Municipal Collections – “Dei Primitivi” Roo



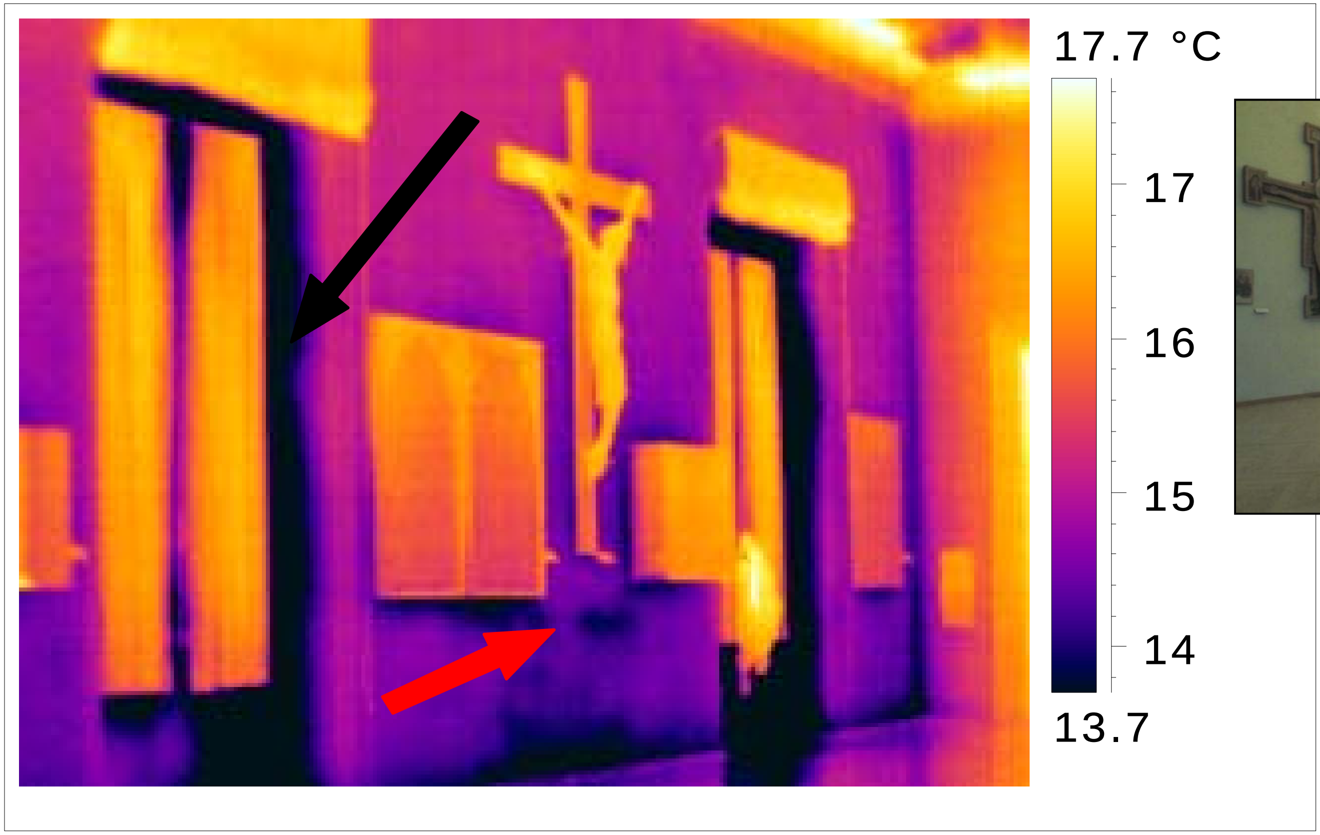




Characterization of the structure of the thin wood/plaster vault

IR Termography

CS2 - Municipal Collections – “Dei Primitivi” Room



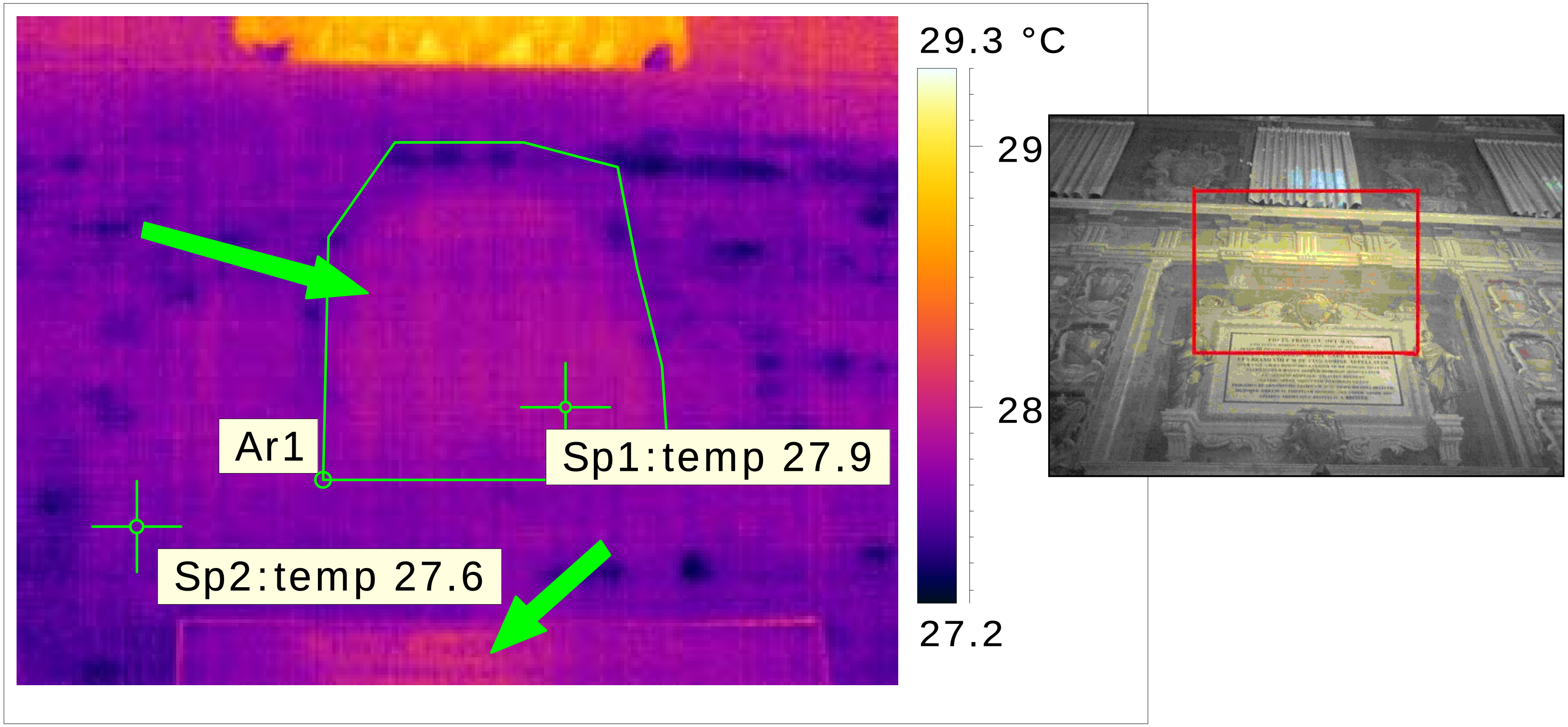
Thermal bridges and cool air infiltrations

IR Termography

CS2 - Municipal Collections – “Coats of Arms” Room

IR Termography

CS2 - Municipal Collections – “Coats of Arms” Room

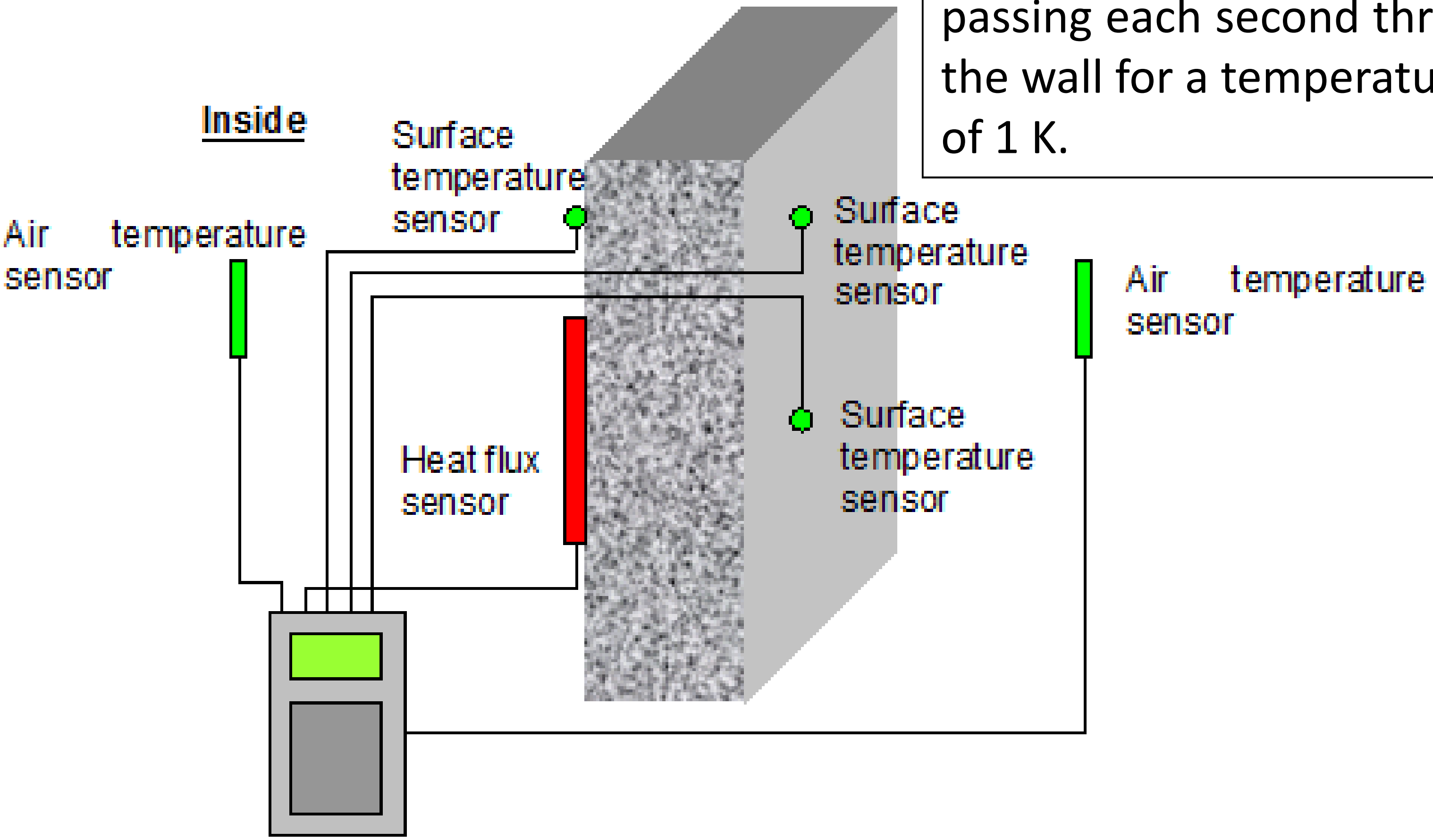


North wall: closed arch

Thermal flux measurements

Scheme of instrumentation

We measure Conductance (C) and/or Transmittance (U), i.e. the heat flux passing each second through 1 m^2 of the wall for a temperature difference of 1 K.

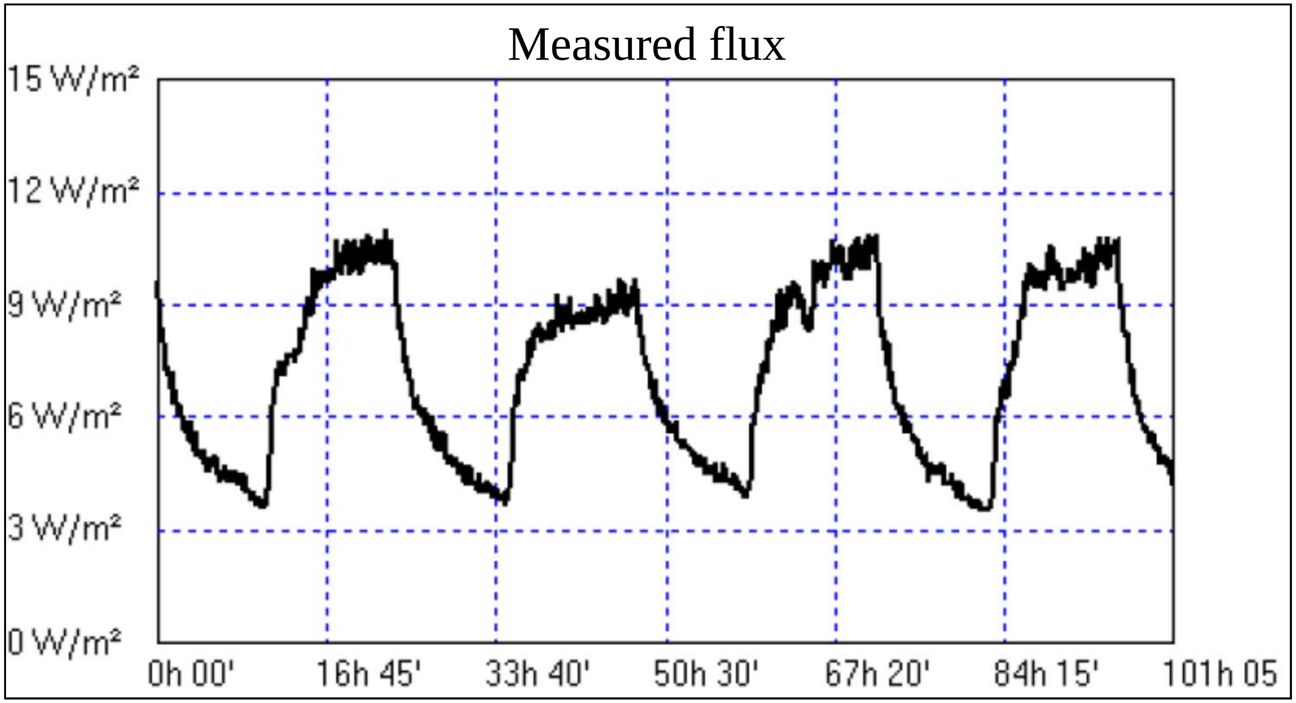


Thermal flux measurements

Solutions for sensors installation – “Vidoniana Gallery”

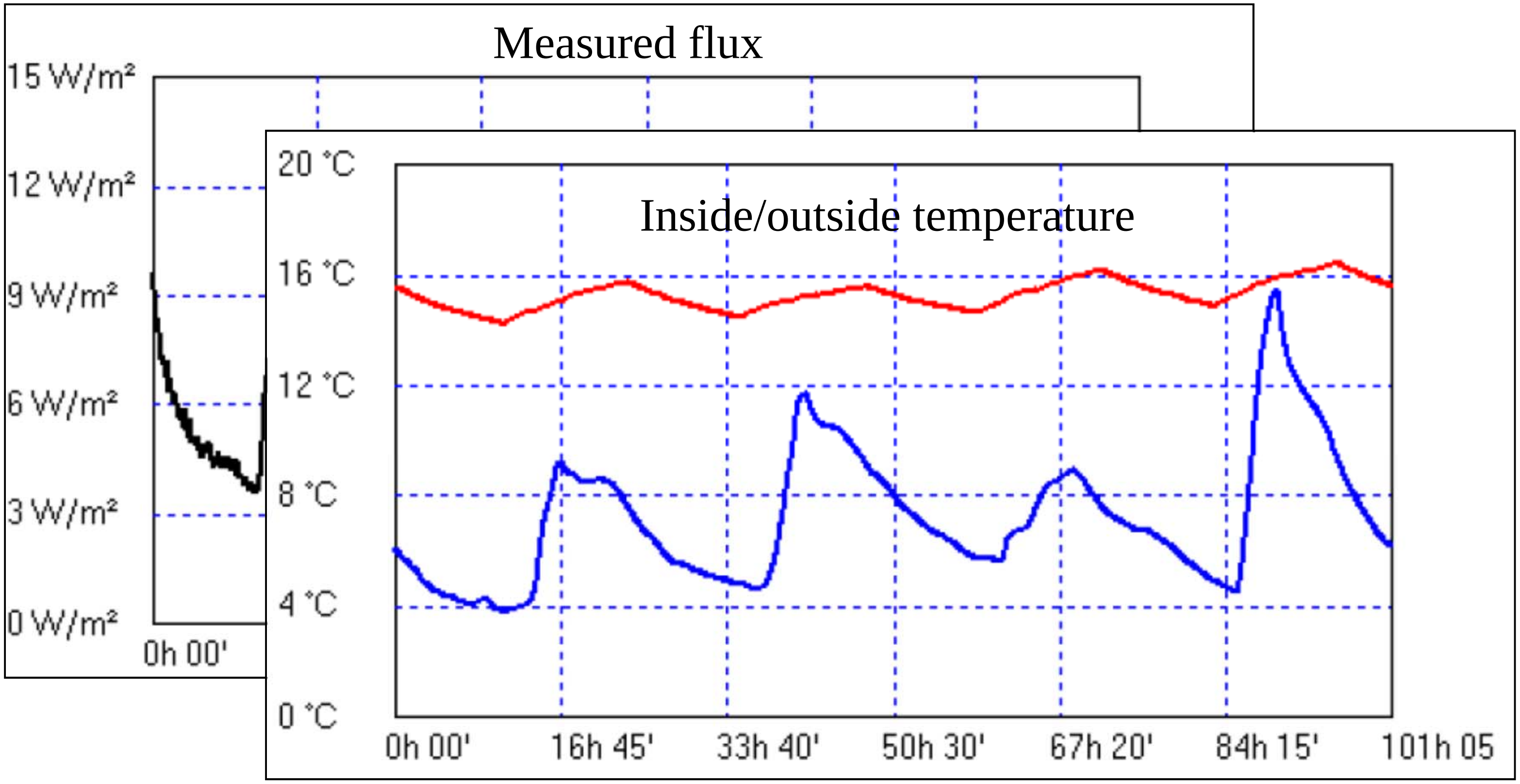
Thermal flux measurements

Example – “dei Cavalleggeri” room (21-25/01/2012)



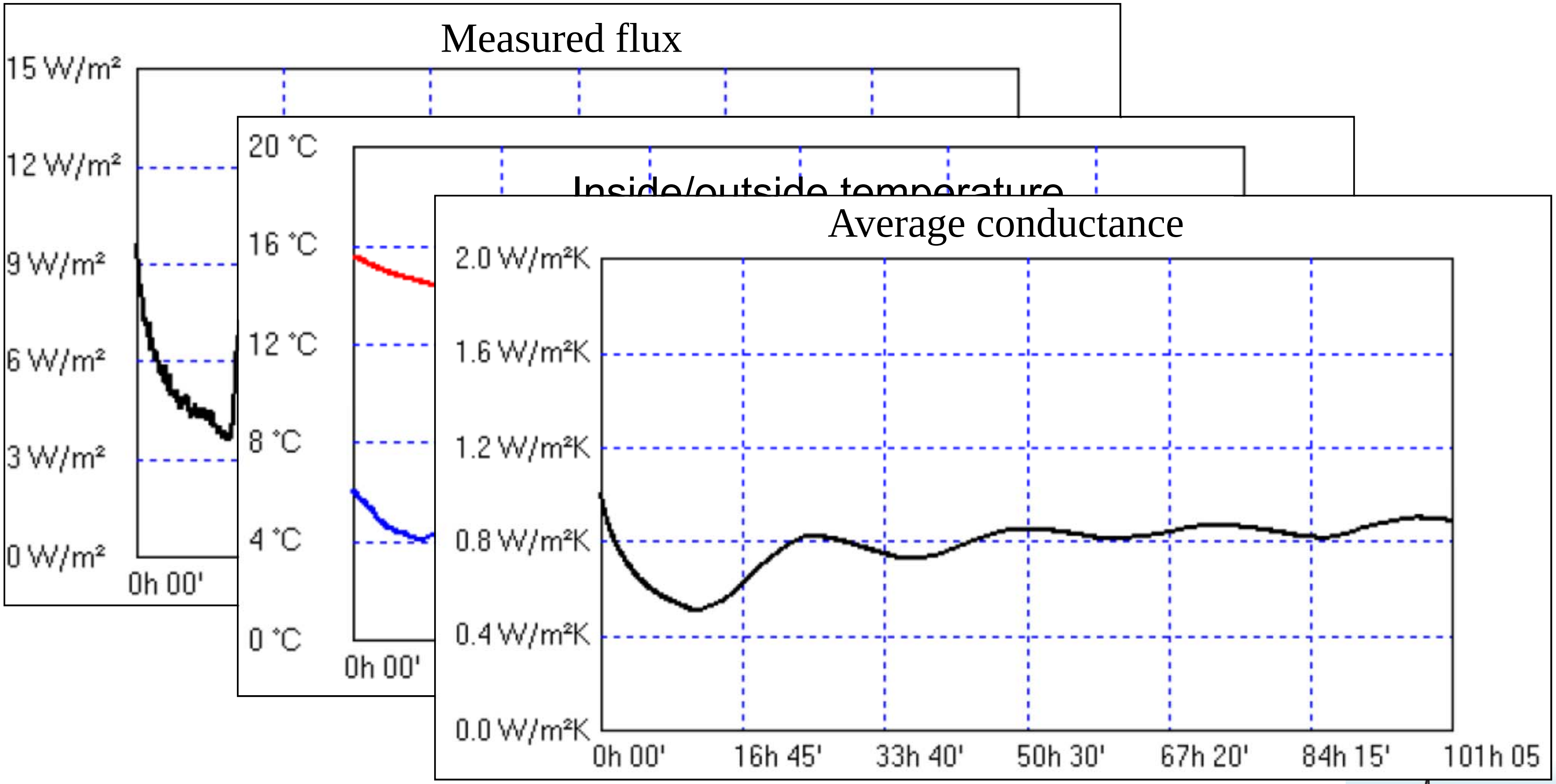
Thermal flux measurements

Example – "dei Cavalleggeri" room (21-25/01/2012)



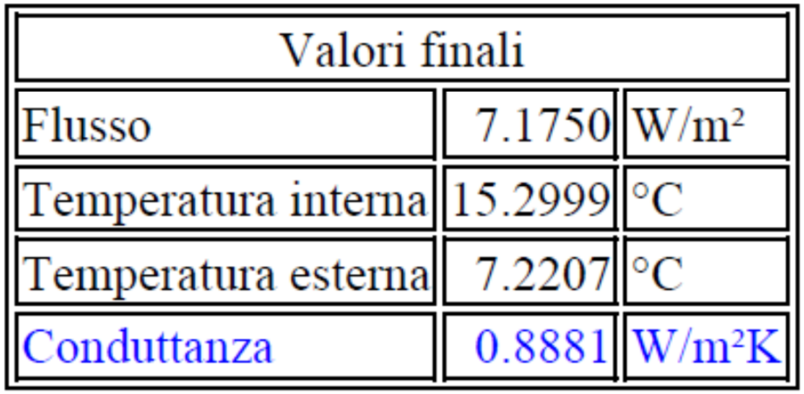
Thermal flux measurements

Example – “dei Cavalleggeri” room (21-25/01/2012)



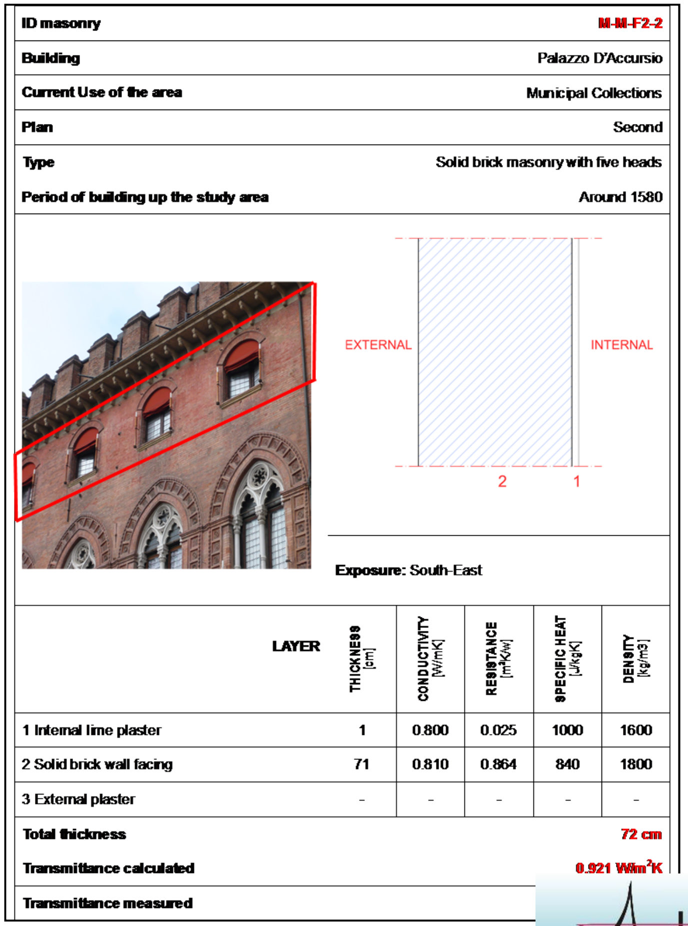
Thermal flux measurements

Example – “dei Cavalleggeri” room (21-25/01/2012)



Valori finali		
Flusso	7.1750	W/m²
Temperatura interna	15.2999	°C
Temperatura esterna	7.2207	°C
Conduttanza	0.8881	W/m²K

Masonry handbook



ID masonry	M-M-F2-2
Building	Palazzo D'Accursio
Current Use of the area	Municipal Collections
Plan	Second
Type	Solid brick masonry with five heads
Period of building up the study area	Around 1580

Exposure: South-East

LAYER	THICKNESS [cm]	CONDUCTIVITY [W/mK]	RESISTANCE [m²K/w]	SPECIFIC HEAT [J/kgK]	DENSITY [Kg/m3]
1 Internal lime plaster	1	0.800	0.025	1000	1600
2 Solid brick wall facing	71	0.810	0.864	840	1800
3 External plaster	-	-	-	-	-

Total thickness	72 cm
Transmittance calculated	0.921 W/m²K
Transmittance measured	

Wireless Sensors Networks

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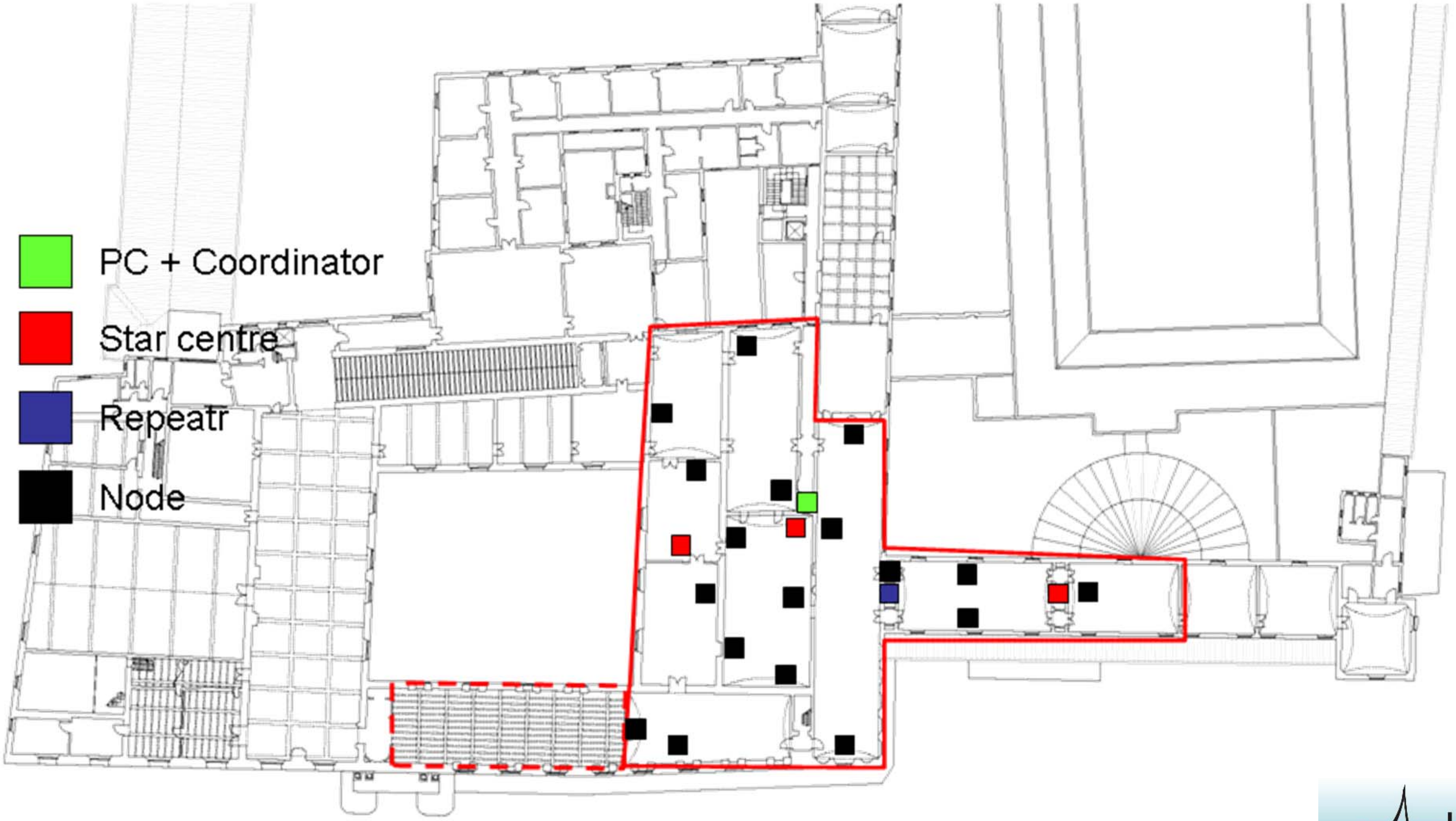
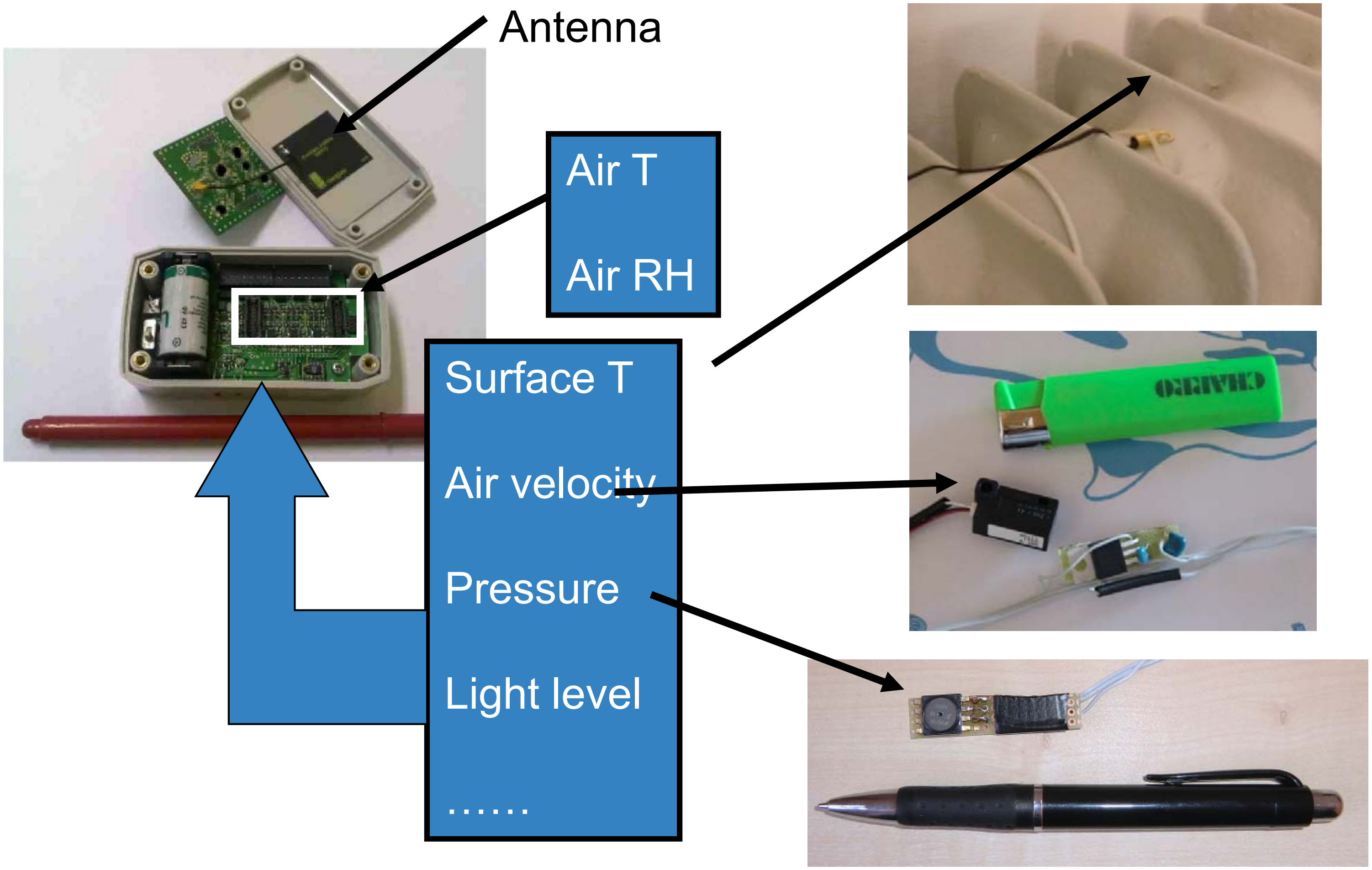
Network topology



Artemis
DIAGNOSTICA EDILIZIA

Wireless Sensors Networks

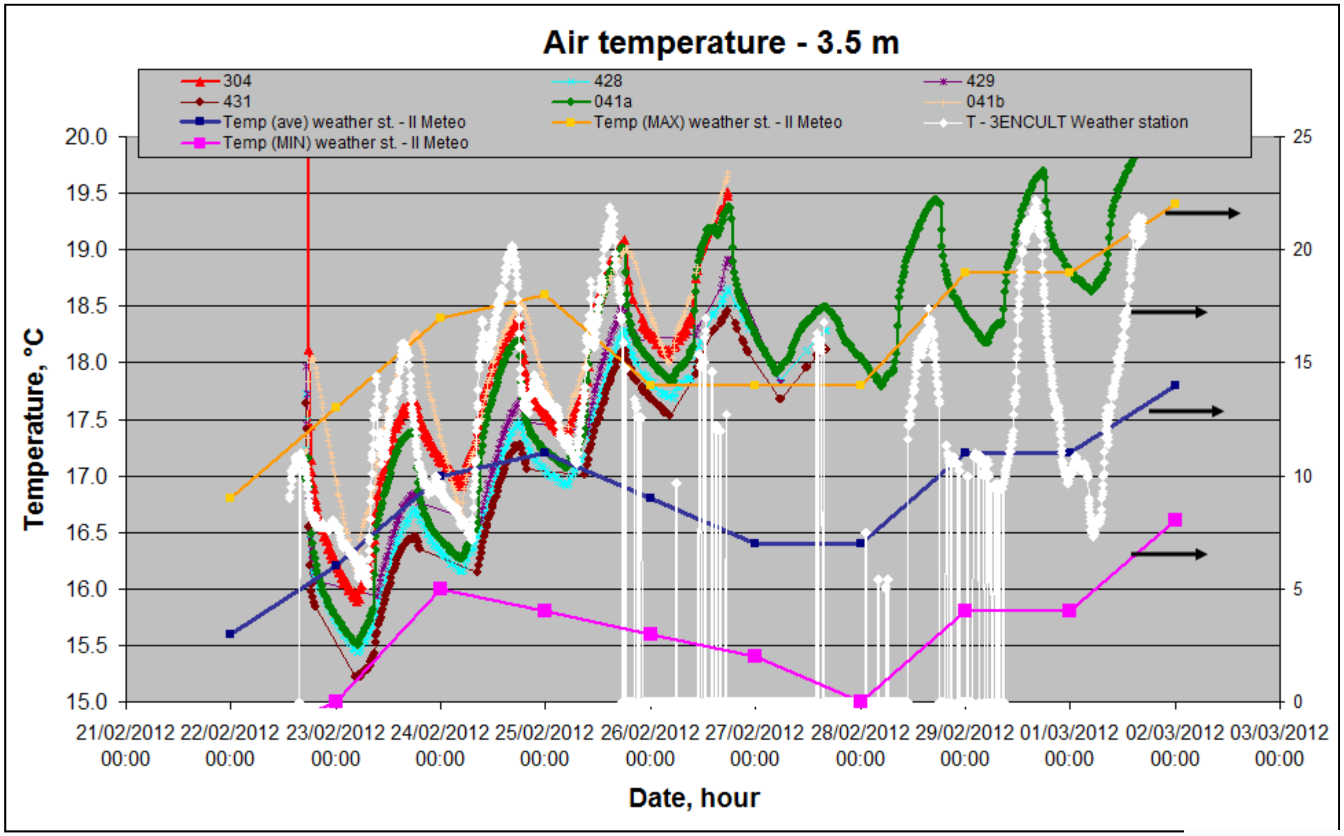
Network node **WITH INTERNAL AND ATTACHED EXTERNAL SENSORS**



Wireless Sensors Networks

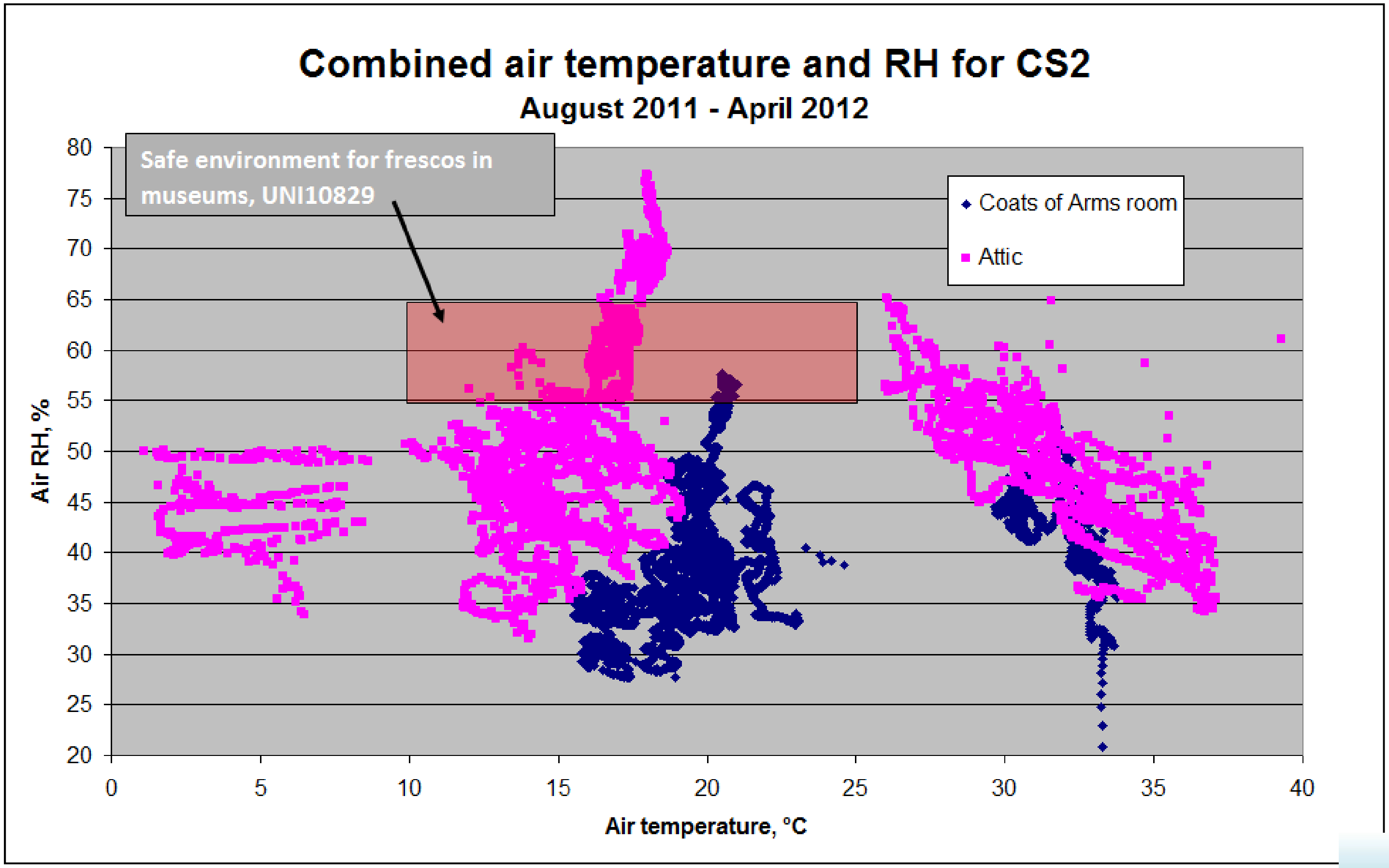
Example – “Coats of Arms” room

February 2012



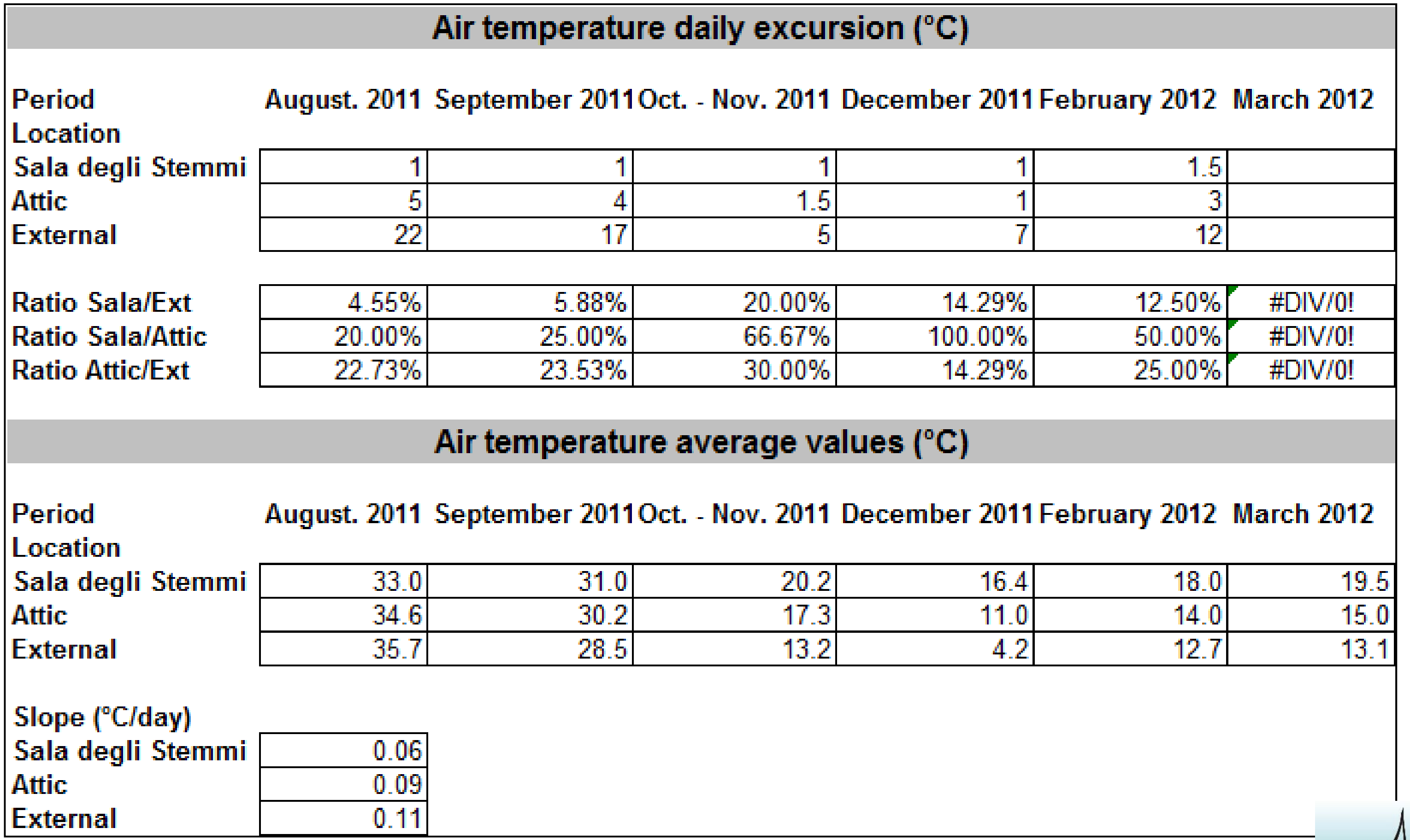
Wireless Sensors Networks

Example – "Coats of Arms" room



Wireless Sensors Networks

Example – “Coats of Arms” room



Air temperature daily excursion (°C)

Period Location	August. 2011	September 2011	Oct. - Nov. 2011	December 2011	February 2012	March 2012
Sala degli Stemmi	1	1	1	1	1.5	
Attic	5	4	1.5	1	3	
External	22	17	5	7	12	
Ratio Sala/Ext	4.55%	5.88%	20.00%	14.29%	12.50%	#DIV/0!
Ratio Sala/Attic	20.00%	25.00%	66.67%	100.00%	50.00%	#DIV/0!
Ratio Attic/Ext	22.73%	23.53%	30.00%	14.29%	25.00%	#DIV/0!

Air temperature average values (°C)

Period Location	August. 2011	September 2011	Oct. - Nov. 2011	December 2011	February 2012	March 2012
Sala degli Stemmi	33.0	31.0	20.2	16.4	18.0	19.5
Attic	34.6	30.2	17.3	11.0	14.0	15.0
External	35.7	28.5	13.2	4.2	12.7	13.1

Slope (°C/day)	
Sala degli Stemmi	0.06
Attic	0.09
External	0.11

Methods & tools for complete diagnosis

IR, GPR, T & RH monitoring, light

Camilla Colla, University of Bologna

Diagnostic procedure

Structural diagnosis

- Visual inspection
- Search for historical information
- Geometry, materials, decay and crack pattern surveys
- Monitoring of crack opening
- On-site test
  - non-destructive (IR thermography and GPR)
  - loading test

Energetic diagnosis

- Visual inspections
- Search for historical information and uses of the building
- heating system survey
- daylight measurements and thermo-hygrometric survey

- On-site test:
  - Blower Door Test (BDT)
  - non-destructive test (IR thermography and GPR)
  - U-value measurements
  - Air flow dynamics
- Wireless monitoring


Wooden beam: load test


Load test on a masonry vault


IR thermography


GPR investigations


Window frames survey


Blower door test

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Palazzina della Viola (BO)

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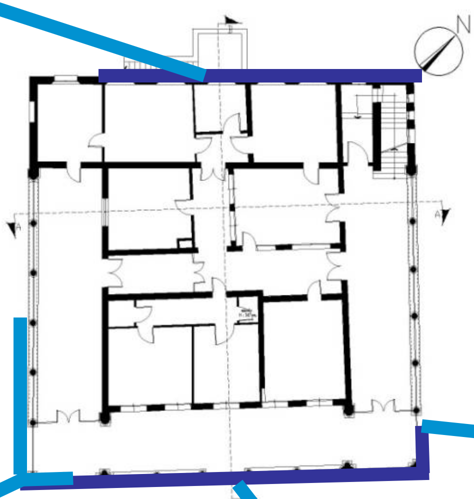
View from N-W



Isolated building, role of trees shading

Porch

View from the South corner

Façade

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Pal. Viola: IR Thermography investigation

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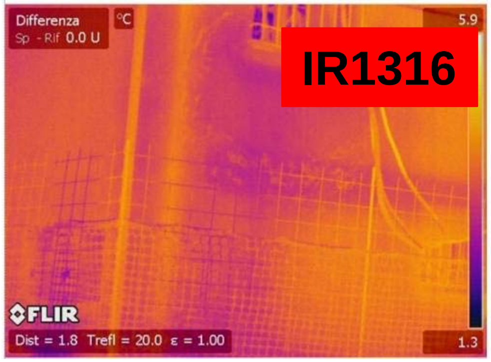

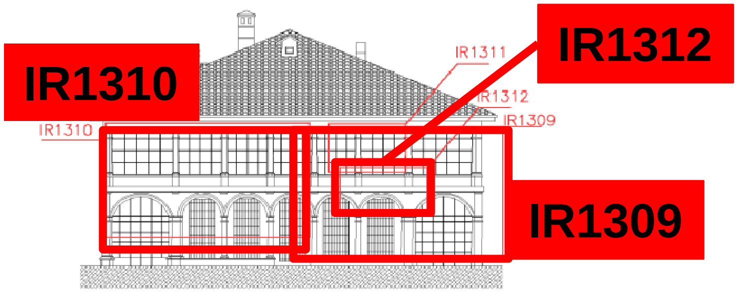

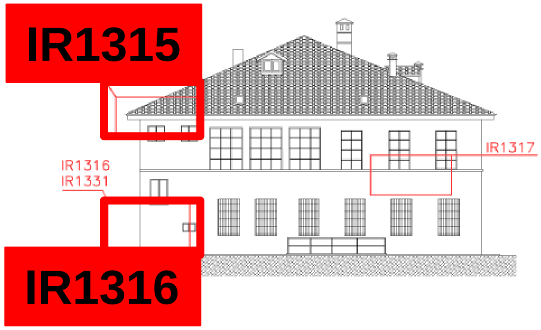

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GPR technique

The aim of the GPR (Ground Penetrating Radar) technology is to investigate in depth, by electromagnetic waves, walls or structural elements. In the construction industry, GPR is particularly suitable for the structural diagnosis of existing historical buildings on which it is required to not perform interventions with invasive inspection techniques or coring. Often, for these buildings technical drawings or detailed information on structural scheme and materials are missing. By GPR it’s possible to investigate ceiling structures, the arrangement of beams, piers, the presence of metal reinforcement within the walls and to evaluate the thickness of the construction elements and layers as well as the presence of cavities and defects or inhomogeneities.

For the purposes of energy efficiency radar allows to obtain information on thickness and layering of walls and ceilings and thus to estimate the values of air tightness and thermal-acoustic insulation. By this technique it is possible to detect the presence of cracks and voids that are both sources of heat losses and a source of danger for the architectural heritage. GPR is a very efficient way to identify moisture in walls providing much more detailed and in depth information than visual analysis; it highlights not only the saturated areas in the walls but also distinguishes between the visible level of capillary rise and dry areas.

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Pal. Viola: GPR investigation of masonry

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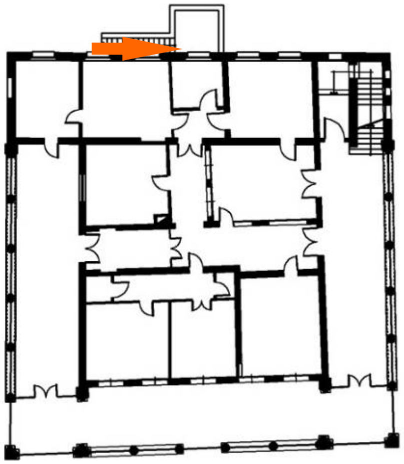
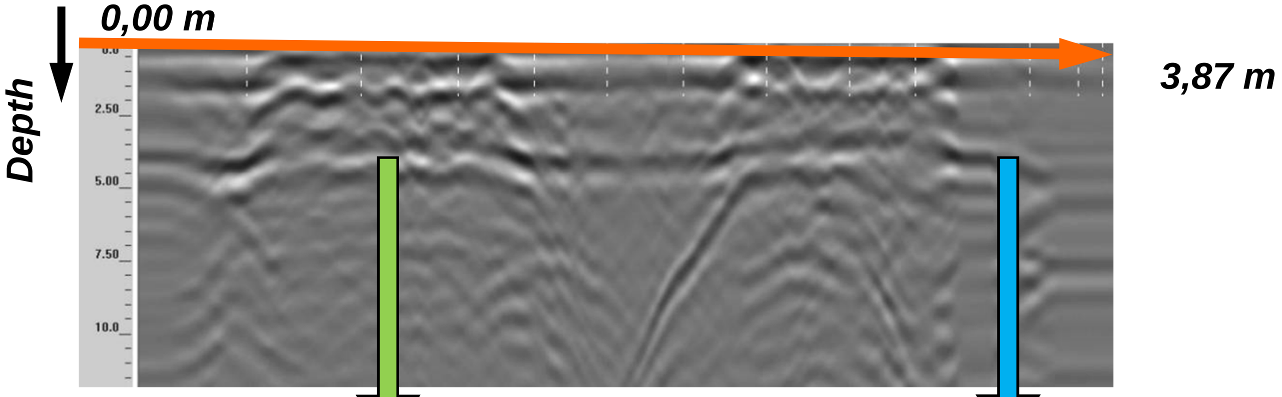


Ground floor

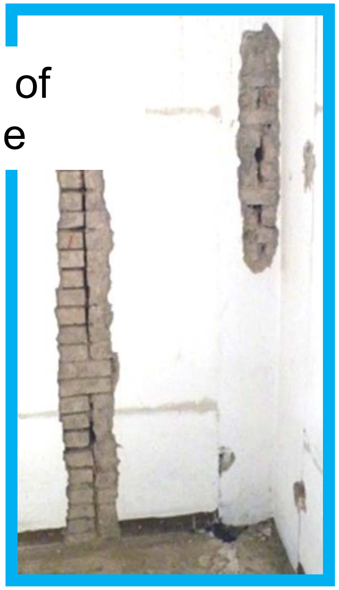


Radargram on a wall.

Investigated wall

Opposite wall

Identification of chimney flue



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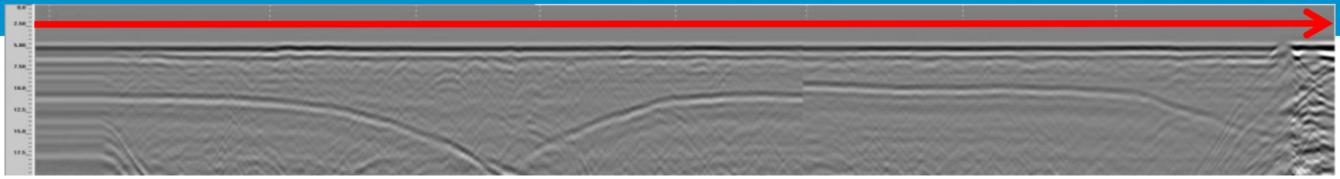
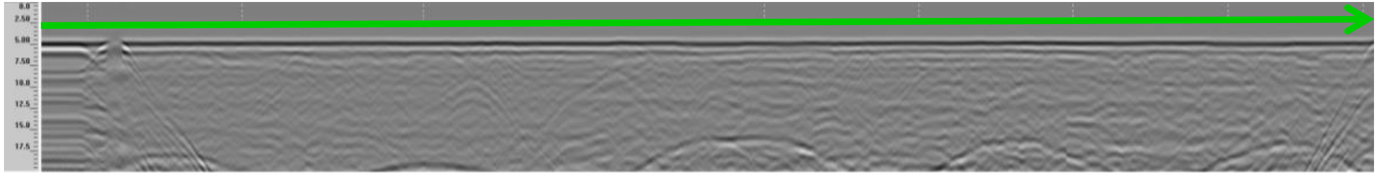
Palazzo D’Accursio (Bo)



File 109-110-111: line lenght=16,73 m, at 4,53 m from South wall.

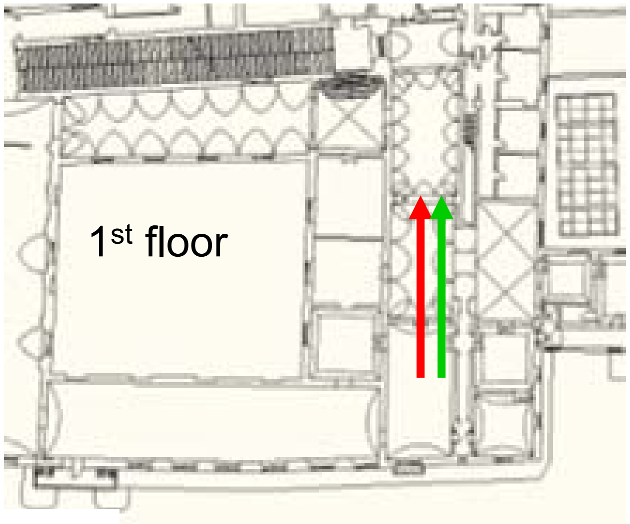


File 112-113-114-115: line lenght=16,73 m, at 6,53 m from South wall.

GPR investigation of masonry stratigraphy

Setup of the GPR system

Sala degli Stemmi



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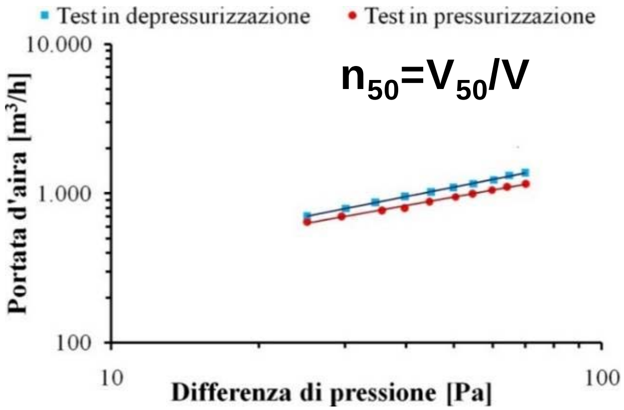
Blower Door Test in historical buildings

1) Sealing of the volume
2) Installation of the fan frame
3) Progressive decrease of pressure
4) Positive and negative pressure
5) Extimation of air exchanges (at 50 Pa)

Sealings

Equipment

Test setup



$n_{50}=V_{50}/V$

Results

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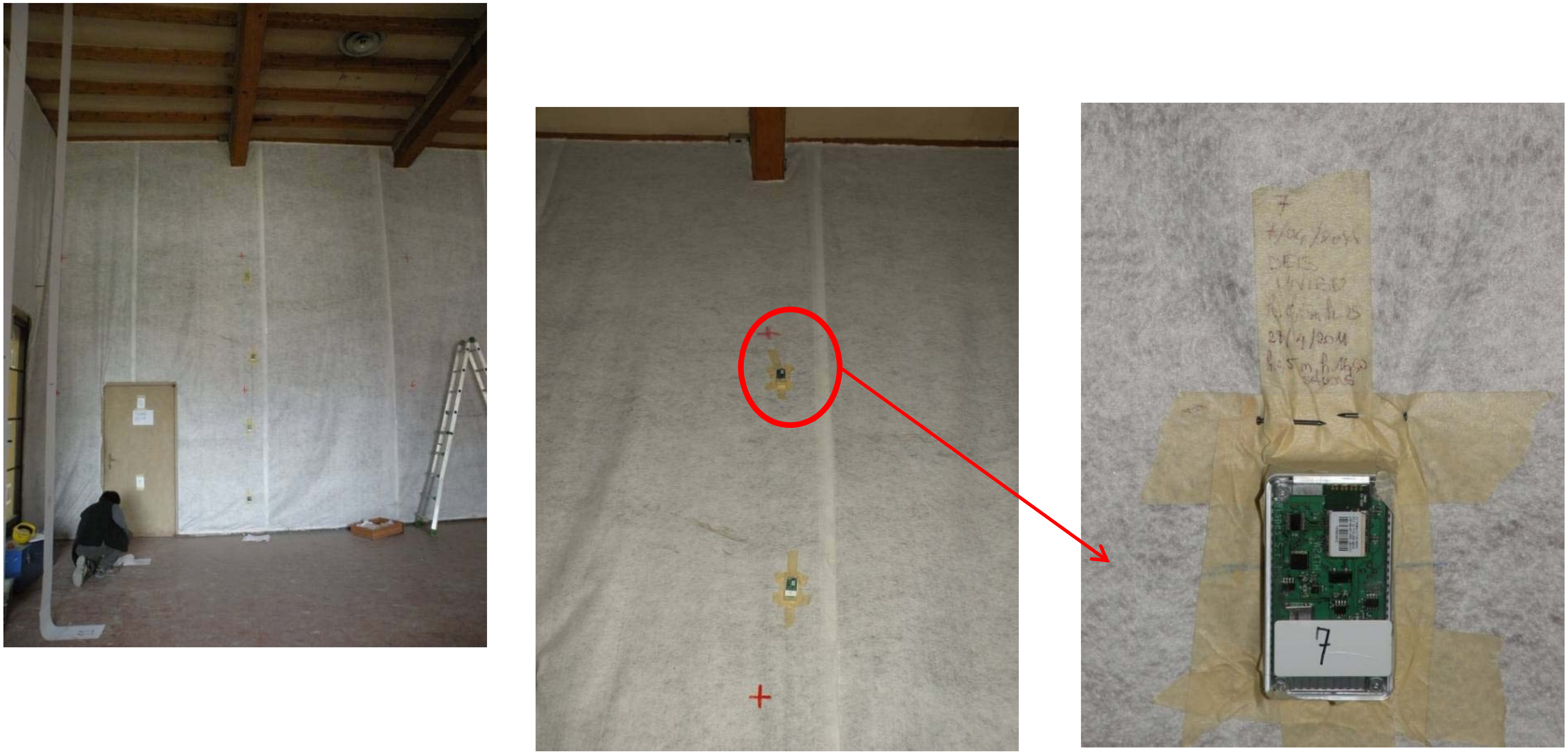
Pal. Viola: wireless monitoring system



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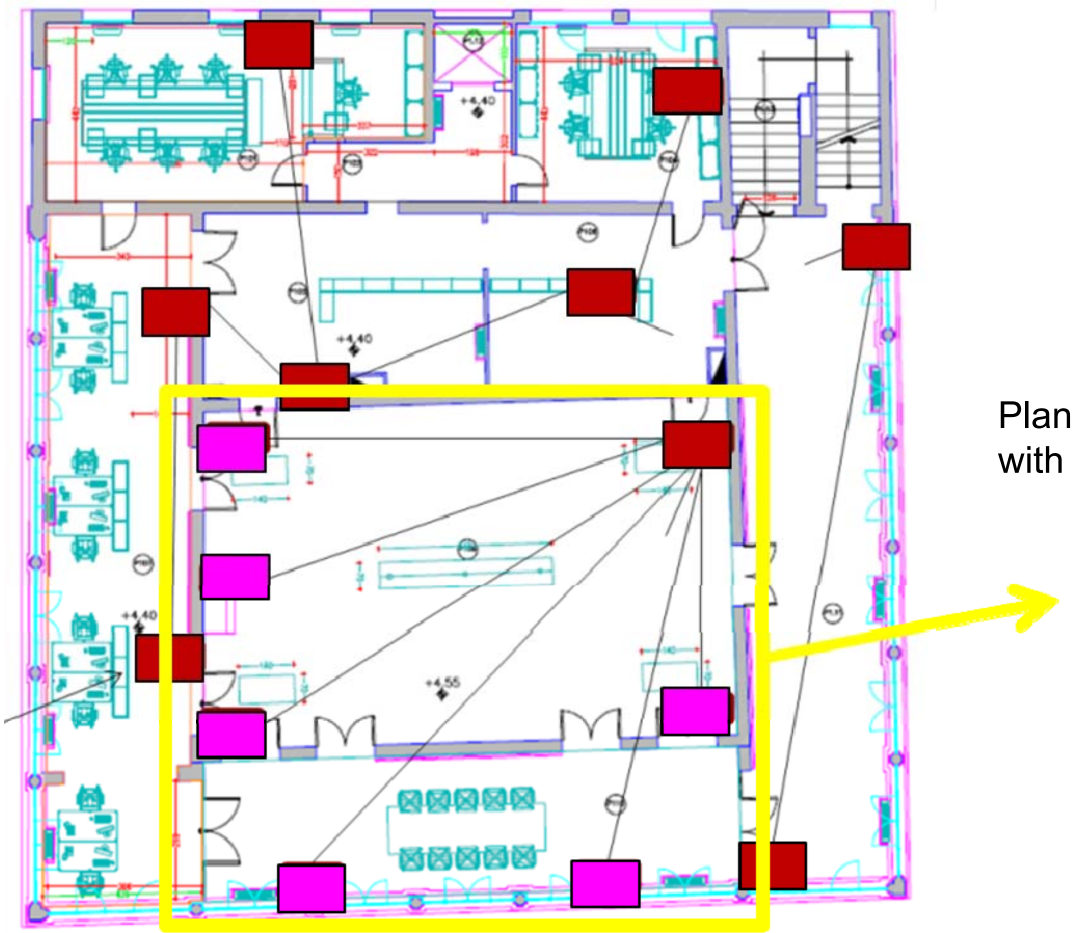
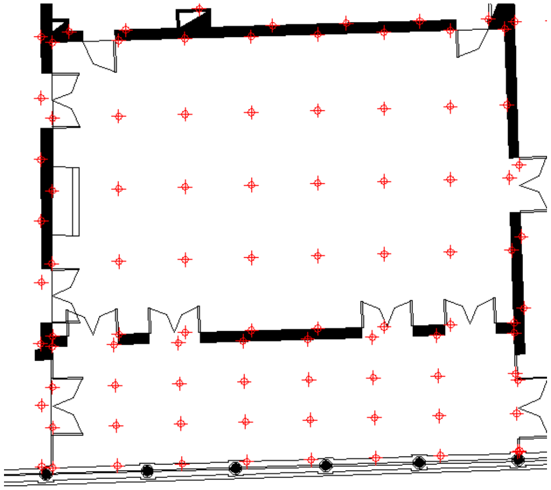
Pal. Viola, post intervention: WSN dynamic climate



🟪 Movable nodes

Plan view, 1st floor

Plan view of the large hall and front loggia, 1st floor, with distribution of the measurement points



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Daylight measurements
Testing conditions

Important to evaluate the risk of decay on surfaces, particularly if decorated and of high-value, and of dis-comfort in the work environment such as due to glaring or bad-lighting

Front loggia,
1st floor.

Different testing conditions
(opened and closed curtains)

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Monitoring of light distribution

Artificial light & natural daylight

Front loggia, 1st floor.
WSN measurements at different heights
(0, 1.20, 1.75 and 3.80m height)

Large hall, 1st floor.
WSN measurements at different heights
(0, 1.20, 1.75, 3.80 & 5.10m height)

Vertical section B-B'

Post intervention

Glaring problems from glass table

Data acquisition,
front loggia

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Maps of air temperature & relative humidity distribution

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Front loggia & large hall, 1st floor

Post intervention

WSN measurements in a hot July day

- at different heights
- different time instants
- various testing conditions → *doors & windows closed/opened*; → *with/without air conditioning*

without air conditioning

with air conditioning

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Pal. D'Accursio, museum area: daylight measures

In Museum environments, it is particularly meaningful to keep under control the natural and artificial light levels that works of art are exposed to.

Phases of data acquisition, Sala Cavalleggeri

Investigated areas with measurement grid

Data acquisition by
ARUP, BLL with UNIBO's help

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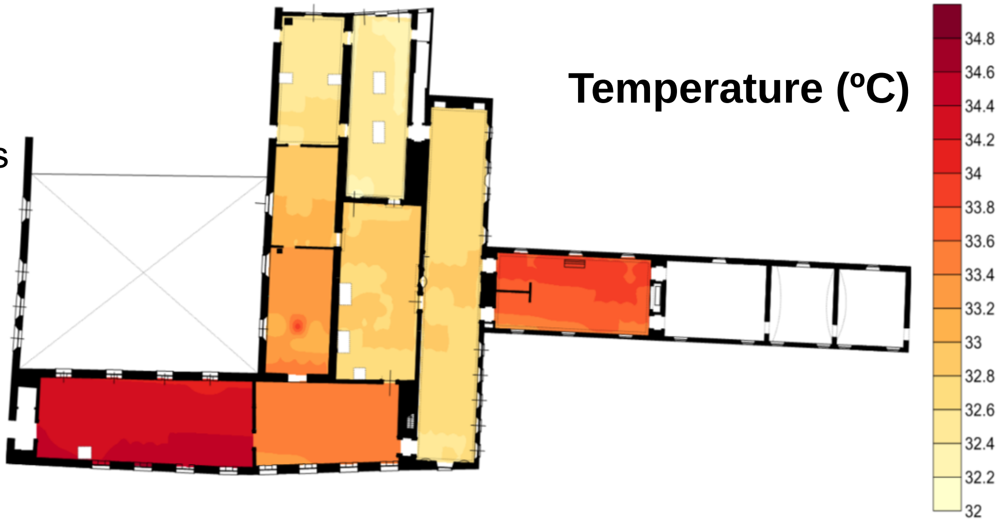
Pal. d’Accursio, museum area: psycrometric maps, closed windows

Even a detailed map of temperature and air humidity representative of a day in a critical season (hot August) can give valuable hints on unsuitable micro-climate for art collections and comfort of museum visitors



Results in a hot August day *(closed windows)*

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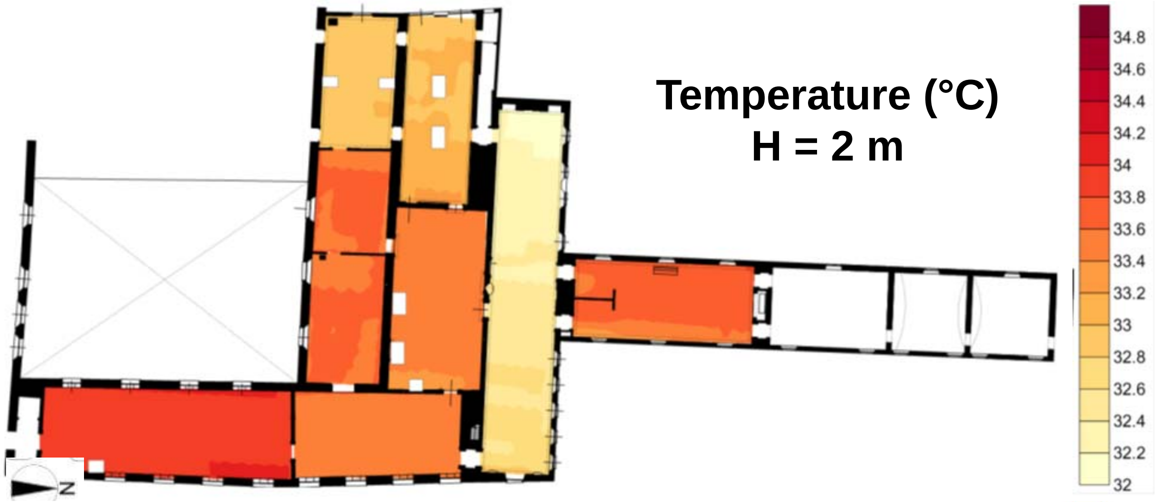
Pal. d'Accursio, museum area: psycrometric maps, open windows



Temperature (°C)
H = 2 m

Relative humidity (%)

Results in a hot August day
(open windows)

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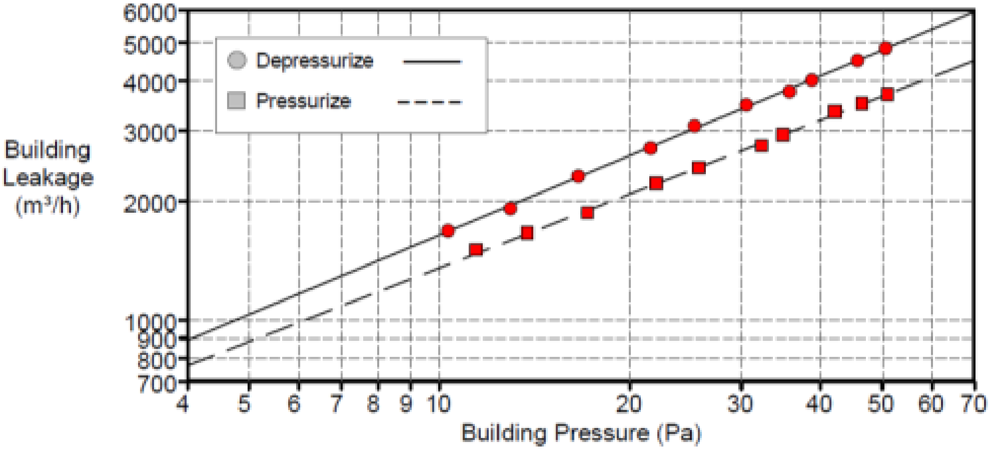
Pal. D’Accursio: BDT

- Sealing of the volume
- Positive and negative pressure
- Identification of un-tight points
- Building leakeage curve

Building
Leakage
Curve

Sealings



Anemometer

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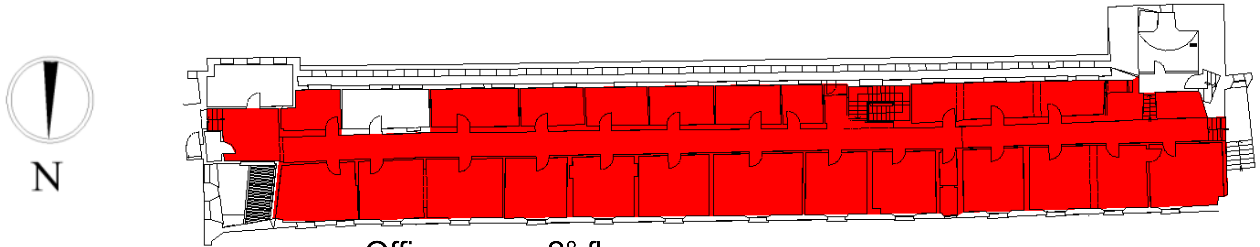
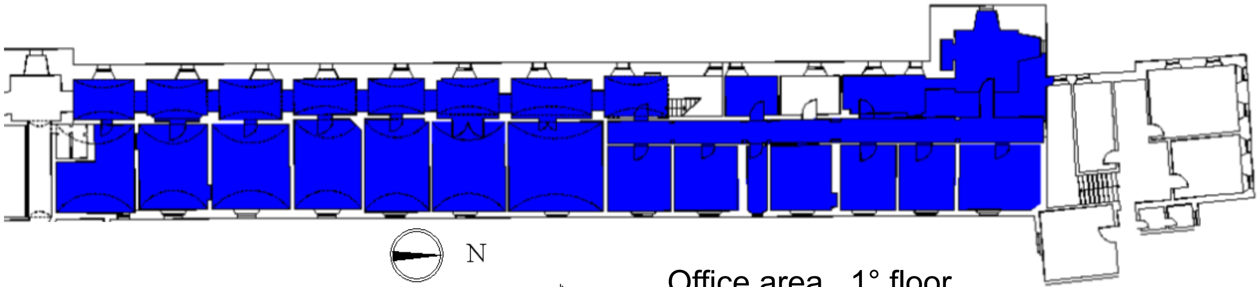
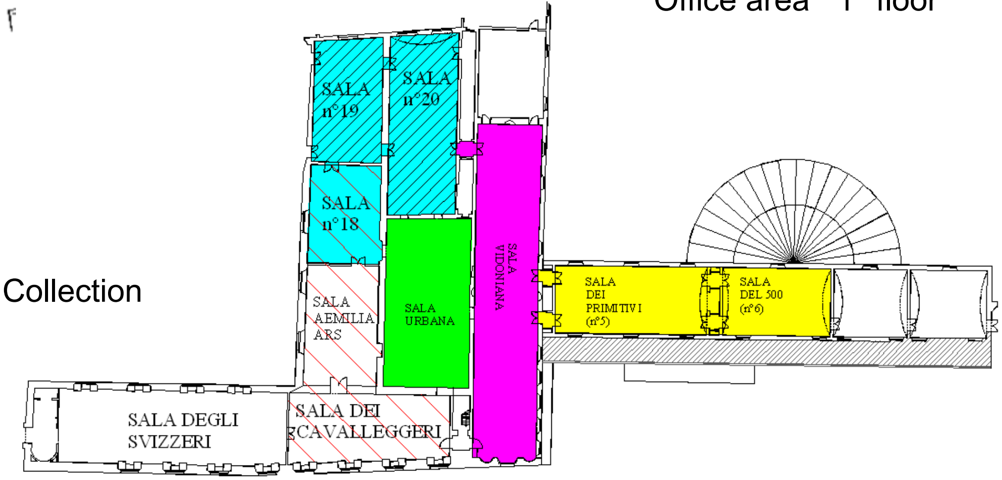
Pal. D'Accursio: BDT results



Office area 2° floor



Office area 1° floor



Municipal Collection

Vol	$n_{50}=V_{50}/V$ (1/h)
🟥	6.29
🟦	4.68

Vol	$n_{50}=V_{50}/V$ (1/h)
🟩	2.51
🟪	4.52
🟨	6.85
🟪🟨	4.4
🟦	6.27
▨	2.38
▧	14.69

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