# Measurement uncertainty assessment for building energy simulation

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# Summary

- Some metrology
- Uncertainty assessment  :  methods
- Sampling theory in statistics
- Exercises : indoor temperature

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# Ressources

-

| | |
|---|---|
| 00 PPT simu...nty workshop | R-3.3.0 Mac.pkg |
| data | R-3.5.1-win.exe |
| R sources | |
| ressources | |

| | |
|---|---|
| 00 PPT simu...nty workshop | mesures.Rdata |
| data | permea.txt |
| R sources | permeaData.Rdata |
| ressources | simurex18 permea.R |
| | simurex18.R |
| | temp building |
| | temp meeting room |
| | temp room 105 |

| | |
|---|---|
| 00 PPT simu...nty workshop | echantillonage_ch4.pdf |
| data | IEA april 2018 temperature definition.pdf |
| R sources | international vocabulary of metrology JCGM_200_2008.pdf |
| ressources | population and sample sampling_en.pdf |
| | SamplingTechniques.pdf |

# Some metrology

*Eléments de métrologie*

# Definitions

Measure :

The dimensions, quantity, or capacity of something as ascertained by comparison with a standard

*Mesurer*

*« action d'évaluer une grandeur d'après son rapport avec une grandeur de même espèce, prise comme unité de référence »*

Measure = Comparison

# Definitions

Measurand *(Mesurande )*
"quantity intended to be measured"

*« grandeur que l'on veut mesurer »*

Measurement *(Mesurage )*
"process of experimentally obtaining one or more quantity values that can reasonably be attributed to a quantity"

*« ensemble d'opération ayant pour but de déterminer une valeur d'une grandeur »*

Measured quantity value *(Valeur mesurée)*
"measured value of a quantity /
quantity value representing a measurement result"

*« valeur d'une grandeur issue d'un mesurage »*

# Definitions

True value *(Valeur vraie )*

"quantity value consistent with the definition of a quantity"

*« valeur d'une grandeur compatible avec la définition de la grandeur »*

value that would be obtained with a perfect measurement process (which do not exist) => the value we never know !!

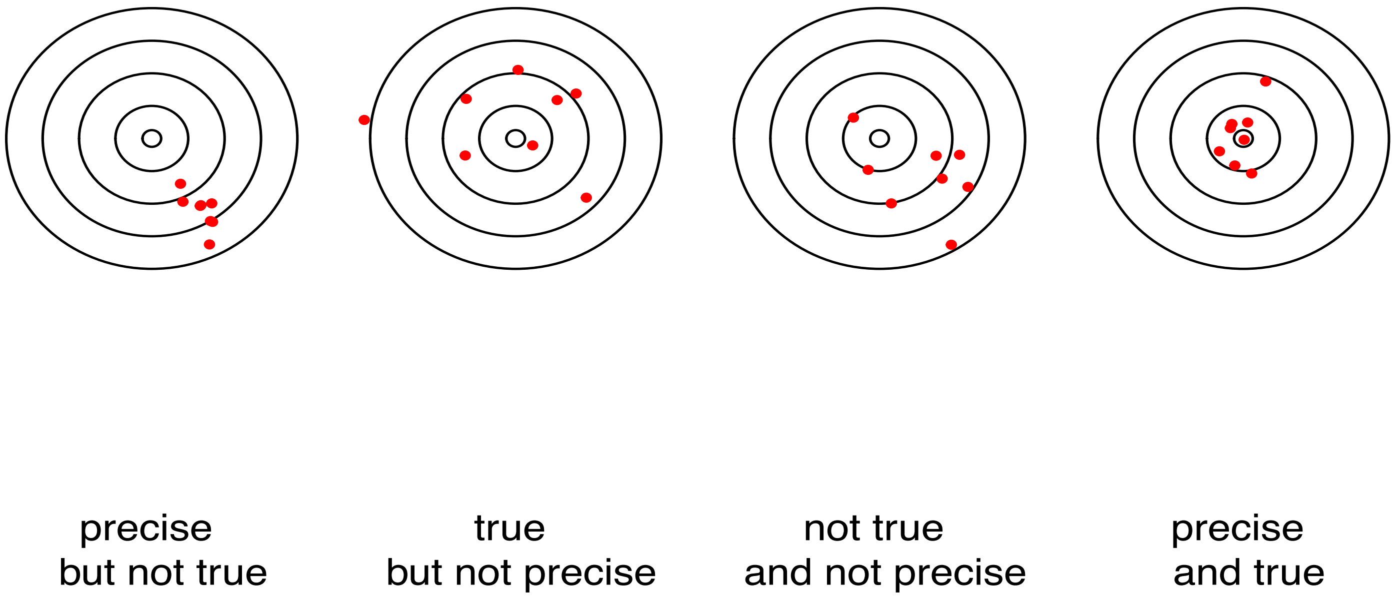
Measurement result *(résultat de mesure)*

" set of quantity values  being attributed to a measurand together with any other available relevant information"

" ensemble de valeurs  attribuées à un mesurande,  complété par toute autre nformation pertinente disponible"

# Definitions

Trueness and precision *(justesse et répétabilité)*



# Definitions : error

Measurement **error** *(Erreur de mesure)* :
difference between measured quantity value and true value

*« Différence entre la valeur mesurée  et la valeur vraie »*

2  component of measurement error :

Systematic error *(erreur systématique)* :
constant component of error of replicate measurments

*composante constante de l'erreur de mesurage répétés*

Random error *(erreur aléatoire)*:
unpredictable manner variation of replicate measurements

*variation imprévisible de mesurage répétés*

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# Definitions : uncertainty

Measurement Uncertainty *(incertitude de mesure)* :
non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand,

« paramètre non négatif qui caractérise la dispersion des valeurs attribuées à un mesurande »

measurement truness (justesse de mesure) = systematic uncertainty

measurement precision (fidélité de mesure) = random uncertainty

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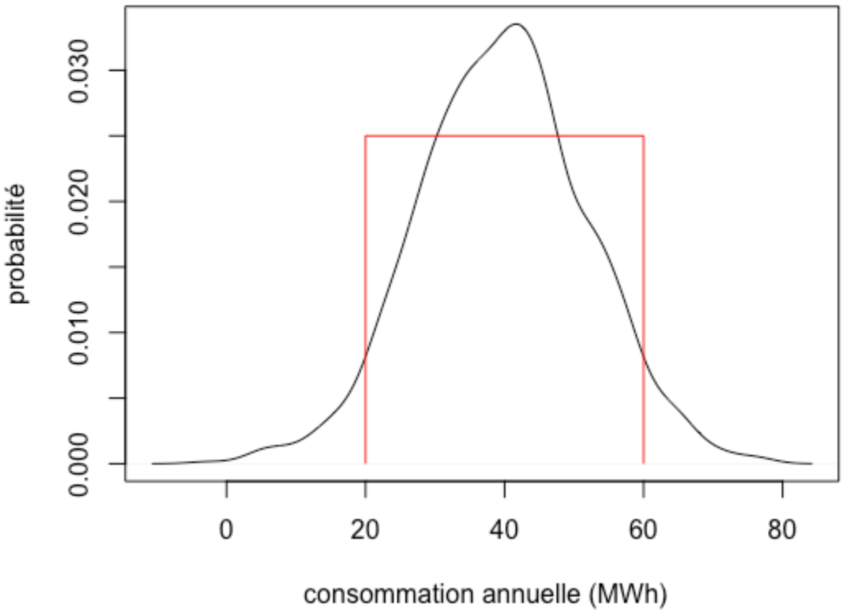
# uncertainty and probability distribution

Probability distribution (loi de probabilité)

- Décrit le comportement d'un phénomène aléatoire
- Exemple : uniform or normal distribution

Uncertainty

- « paramètre qui caractérise
  la dispersion des valeurs (…) »
- Exemple : standard deviation

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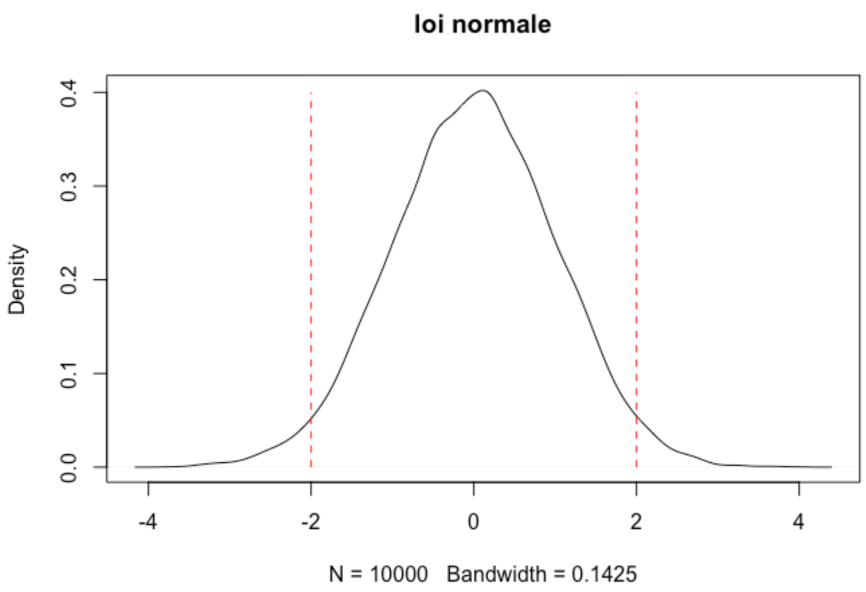
# uncertainty and probability distribution

The most common distributions :

- Uniform (range, min, max)
- Triangular
- Normal (average and standar deviatio)

Normal distribution properties :

- $P(\mu - \sigma < X < \mu + \sigma) = 67\%$
- $P(\mu - 2\sigma < X < \mu + 2\sigma) = 95\%$
- $P(\mu - 3\sigma < X < \mu + 3\sigma) = 99\%$



# Methods :

# GUM

## *(Guide to the expression of Uncertainty in Measurements)*

Method A :
based on statistical analysis of measured quantity

Method B :
Based on other means *(all available information)*

# Components of uncertainty

- Measurement process, including :
    - the sensors
    - data acquisition configuration (recording frequency, pulse value, etc.)

- Sampling / number of sensors (ex : temperature)
- Gap between measured physical quantity and needed quantity
  (occupant number vs internal gains / energy consumption vs gaz volume)

# Components of uncertainty

Adding uncertainties ($\sigma$) :

with the assumption of uncorrelated uncertainties :

Addition of variance (square of standard deviation)

$$\sigma^2 = \Sigma \sigma_i^2$$

# 1st Exemple

Airtightness in new buildings

*With R :*

*"simurex18 permea.R"*

*data in "permaData.Rdata" (or .txt)*

context :

- building energy computing in design phase

- what it is needed :
  - average
  - standard deviation
  - distribution shape

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# Sampling in statistics

*Eléments de métrologie*

# The sampling theory in statistics

Definitions :
Population : a group of experimental data, person, etc.
Unit : undecomposable elementary unit of the population

A population could be finite (dim=N) or infinite
It is made of units that have one or several properti(es)

For example :

- population = people registered on electoral list
  properties ($x_i$) = ages, socio economic category,
  quantity under study (y) = voting intention
- population = French adults
  properties ($x_i$) = age, genre,
  quantity under study (y) = height,

# The sampling theory in statistics

Definitions :
sampling = selection of a fraction of units (n) from a population (N or infinite)

aims : assess a quantity of population (sum, average, proportion) from a sample

simple random sampling : every unit of the population has the same probability to be selected

# The sampling theory in statistics

*From sample to population :*

estimate of the average :

$$\mu_{pop} \approx \mu_{sample}$$

uncertainty of the estimate :

$$\sigma(\mu_{pop}) \approx \sqrt{\left( (1-n/N) /(n-1) \right)} * \sigma_{sample}$$

with N $\sim \infty$ : $\sigma(\mu_{pop}) \approx \sigma_{sample} / \sqrt{(n-1)}$

*rigorously with n > 30,*
*whatever the probability distribution*

# The sampling theory in statistics

*From sample to population :*

estimate of the standard deviation

*(that we want to know for Uncertainty propagation in BES)*:

$$\sigma_{pop} \approx n * \sigma_{sample} / (n-1)$$

if pop follow a normal distribution, and n > 30 :

$\sigma_{sample}^2 \sim> N( \sigma_{pop}^2 , \sigma_{pop}^2 \sqrt{2/n})$

# The sampling theory in statistics

Different ways of sampling :

Among the properties of the units, some are under study (y = voting intention) others are only descriptive supplementary information (x = socio economic category)

Stratified sampling :

- the population is divided into homogeneous groups,
- random sampling are made in each group
- sample size of each group can be made proportionally to the number of unit of each group in the population

# 1st Exemple

Airtightness in new buildings

*random sampling*

- take 100, or 500 samples from the dataset
- compute average
- do this 100 times and draw the density plot (of average)

*stratified sampling*

# Indoor temperature measurement for Building Energy Simulation

# What to measure ?

What the model says ?

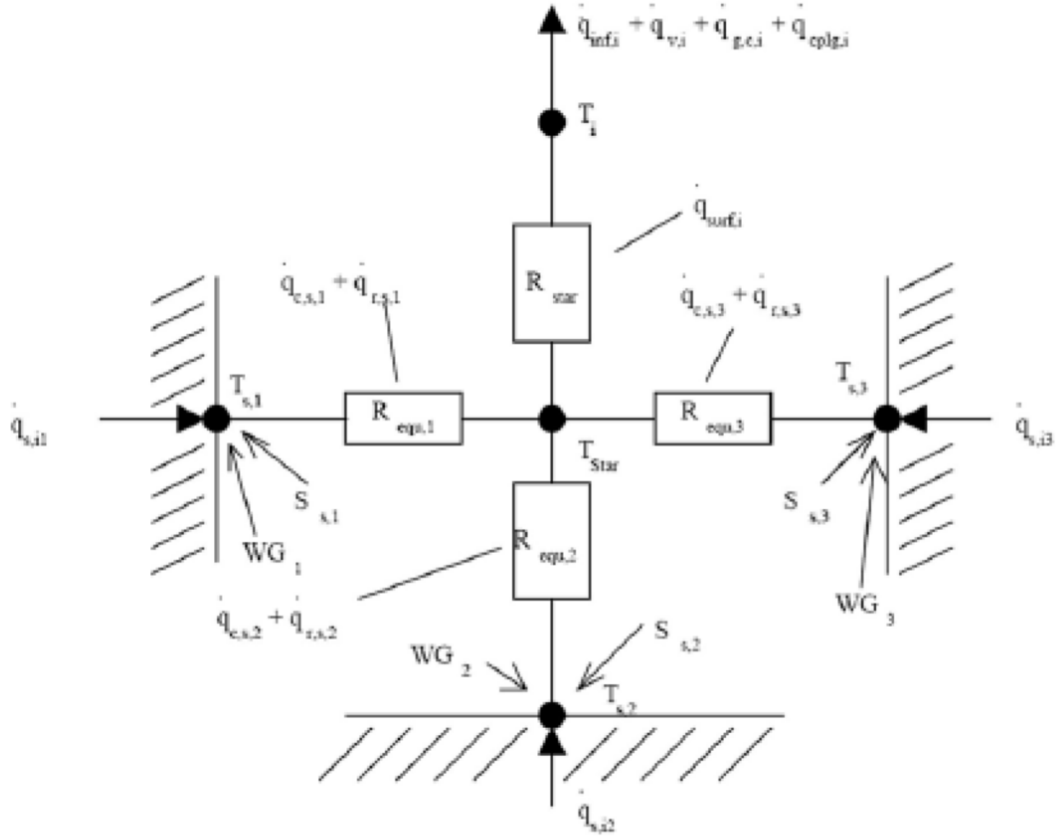



Figure 5.4.1-7: Star network for a zone with three surfaces.

# What to measure ?

Measure the temperature that corresponds the most to the model :

- the average temperature of the zone ?
- the average temperature in the building ?
- the temperature that corresponds to heat exchanges ?
    - for convection, air flows, radiation ?

# What to measure
## *Back to fundamentals*

In the transmission heat exchanges through building fabrics, many phenomenon are involved:

- Radiation,
- Convection
- Conduction

Air temperature is (only) involved in convection,

So the question is: what is the air temperature that have to be measured in a building for convection exchange assessment.

# What to measure
## *Back to fundamentals*

In heat transfer theory, the characteristic fluid temperature has to be:

“the temperature of the fluid far away from the surface, often identified as $T_{infinite}$ “

In the building, it could be

the temperature of air far away enough from the surface but still realistic for convection exchanges.

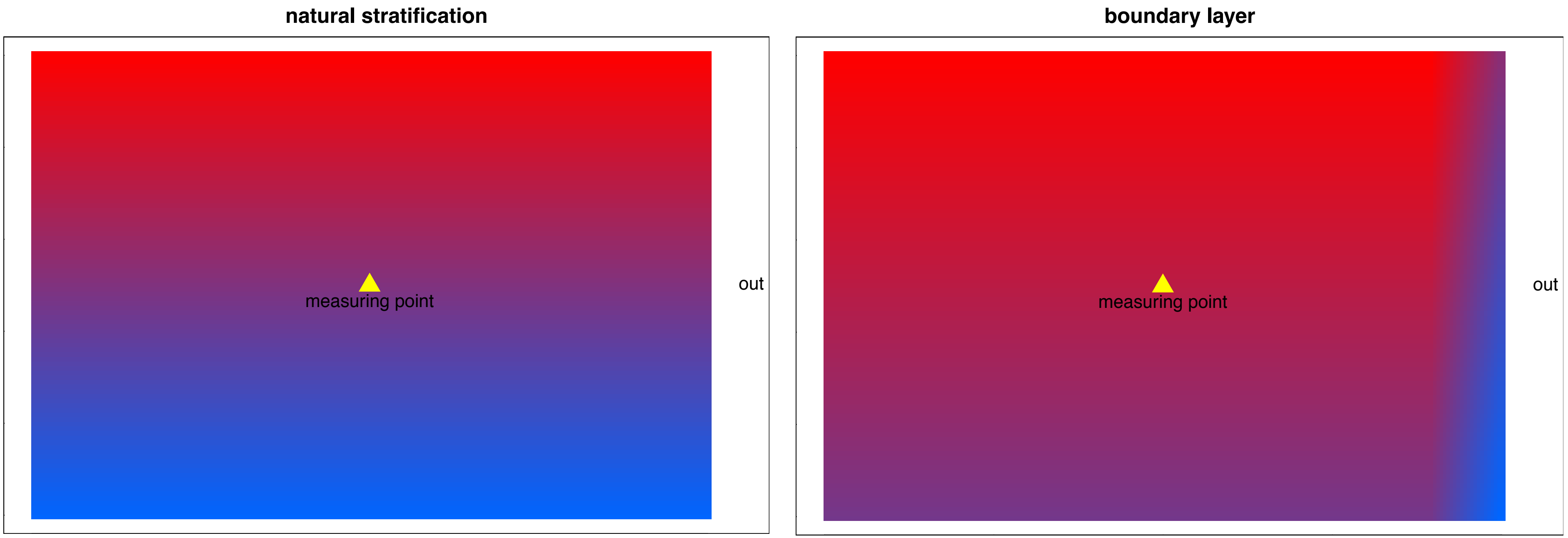
# What to measure
## *Back to fundamentals*

The temperature of air far away enough from the surface but still realistic for convection exchanges.

And 2 difficulties :
- The temperature in the building (in any room) is not really homogeneous
- The building envelope is not really homogeneous

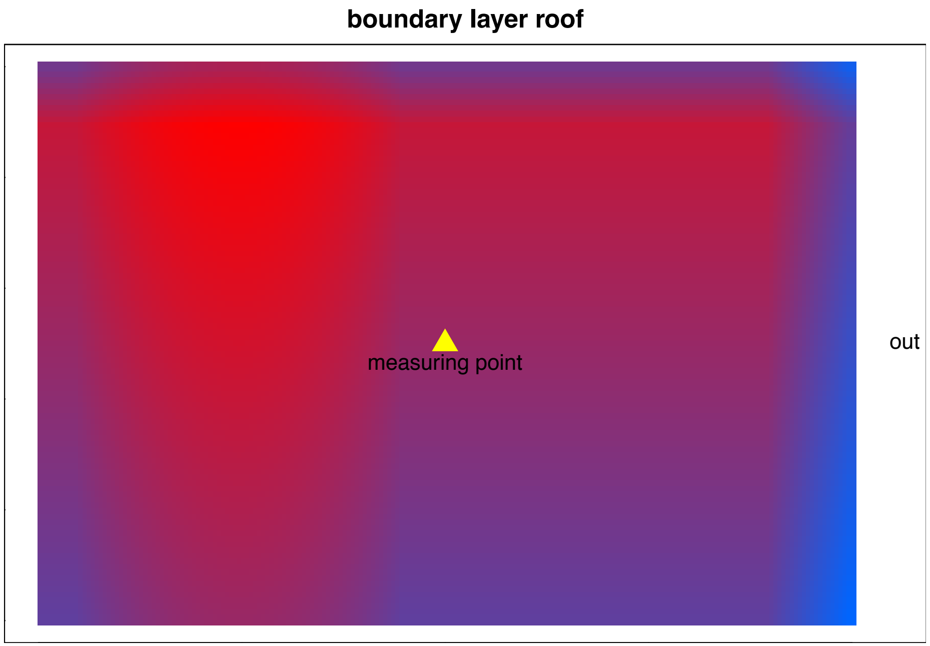
# What to measure
## *what happens in a building*

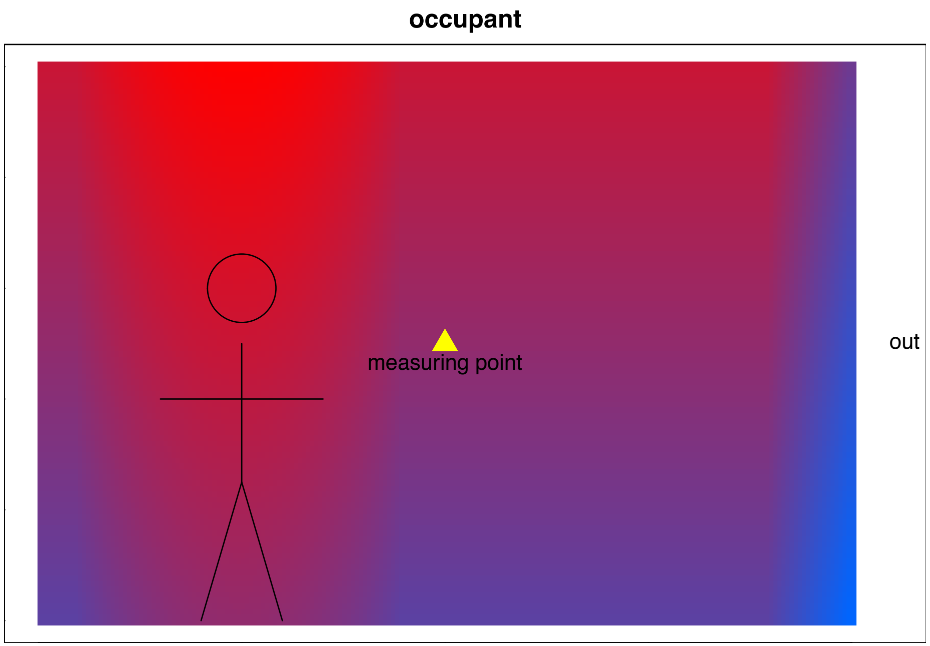
From natural heat flows…



# What to measure
## *what happens in a building*

… or more artificial heat island

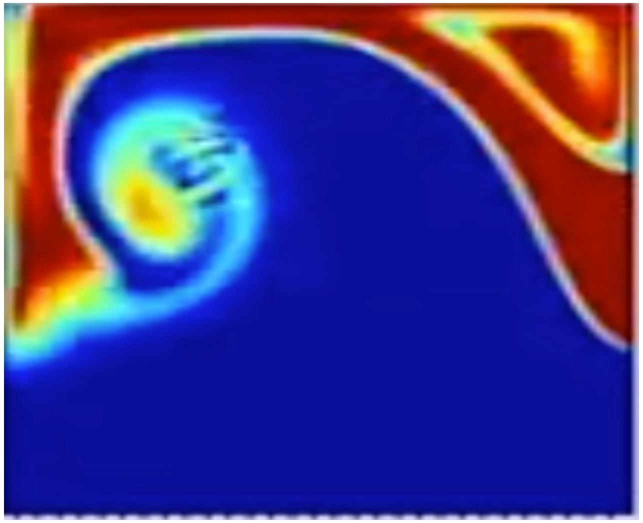


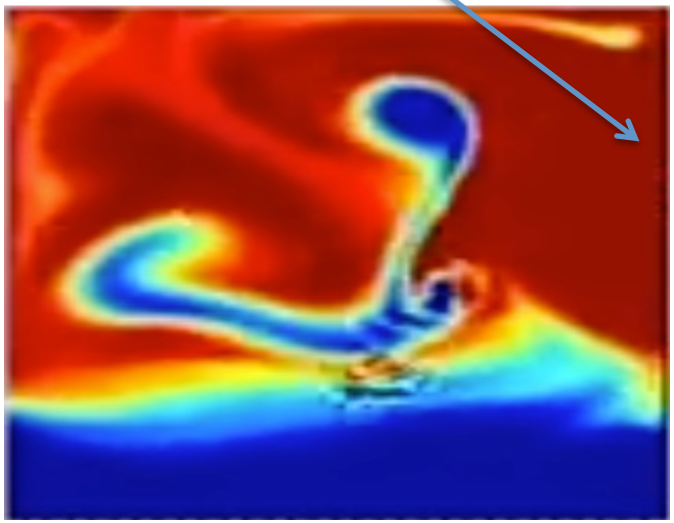



# What to measure
## *what happens in a building*

Sometimes, there’s a heater

Increase of temperature
along the wall







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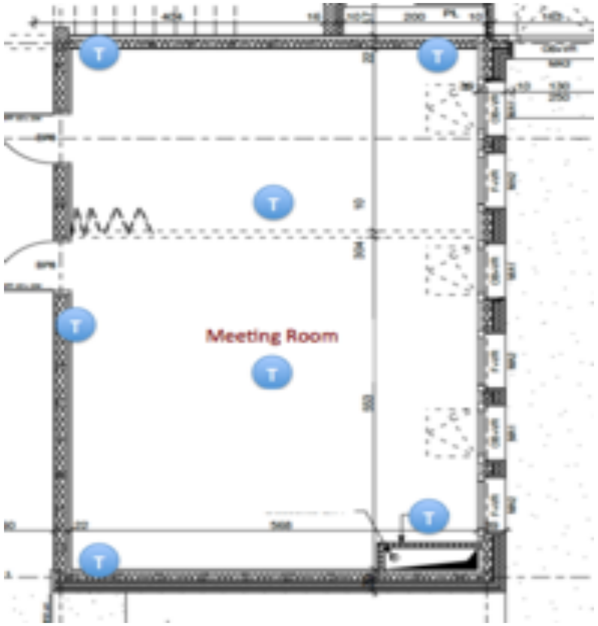
# Case study

# Case study

Recent building (2012) wood and concrete.

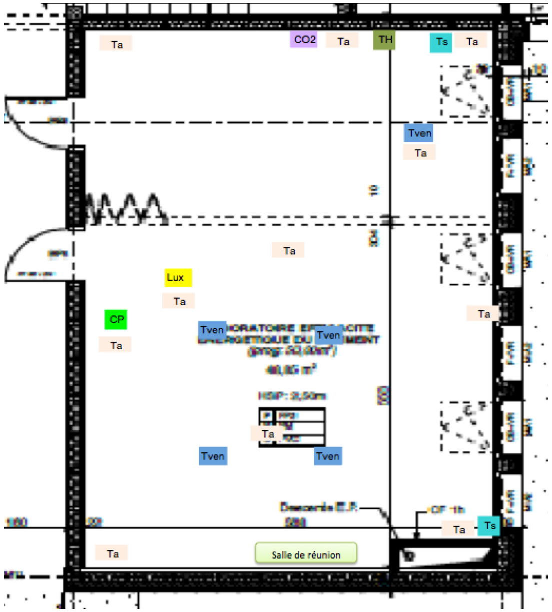
# Case study

Unoccupied office (room 105)




# Case study

Meeting room : 50 m2




- Average for each sensors for 2 month
- Then standard deviation of the averages

# 2nd Exemple : indoor temperature

Temperature in buildings / in a room

*With R :*
*"simurex18.R"*

*data in "mesures.Rdata"*
*or - temp room 105.txt*
*- temp meeting room.txt*
*- temp building.txt*

# 2nd Exemple: indoor temperature

*aims :*

What is the uncertainty of measured temperature ?
for
Building energy performance assessment
/ BES calibration

# 2nd Exemple: indoor temperature

**1st step**: define what is the problem

What is the quantity of interest ?

- average temperature of a building
- average temperature in a room

How is it measure ?

- many temperature sensors (n)
  - ≠ entire knowledge
  - = a sample of the total volume

# 2nd Exemple: indoor temperature

**1st step**: define what is the problem

What are their uncertainties ?
- for measurement in a room with 1 sensor
- for measurement in the building with n sensors

How to extract them from measured data ?
- precision / trueness ??
- distribution shape ?

How to take it into account in BES ?

# 2nd Exemple: indoor temperature

**2nd step**: Observations

*- time serie plot*
*- density plot*
*- boxplot*

*Influence of position in a room :*
*- mean = f(height)*
*- mean = f(distance from outdoor)*

# 2nd Exemple: indoor temperature

**3rd step**: compute the quantity of interest average at each time step

- *office / meeting room / building*

**4th step**: extract standard deviation of the sample

- *at each time step*
- *of the average*

Trueness (~ systematic error )
Precision (~ random error )

# 2nd Exemple: indoor temperature

**5th step**: compute uncertainty
- from standard error
- applying sampling theory

Trueness (~ systematic error )
Precision (~ random error )

**6th step**: uncertainty propagation in BES
- compute average time serie
- sample a systematic error to add to time serie

*next step with Jeanne Goffart on wednesday*

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# Statistical approach

What is the error made in the assessment of the average temperature of the building by measuring with n sensors ?

Assumption of sampling theory (And its limits…)

- Random location of sensors (in the building / in each room)
- *for some uses, the distribution of the temperature for any subvolume of the building needs to be Normal*

2 ways to solve the problem:

- Building considered as a whole,
- Statistical stratification considering rooms as subsets

*cf. "measuring building indoor temperature for energy performance assessment, definition proposal and uncertainties" IEA EBCAnnex 71, april 2018 meeting*.

# Statistical approach
## *building as a whole*

The average temperature can be approximated by the average of the sample's n measurements.

The uncertainty on the average follows a student distribution that can be approximate by a normal distribution (n>30):

$$\frac{n-1}{n-3}\frac{\sigma_{sam}}{\sqrt{(n-1)}}$$

Where $\sigma_{sam}$ is the standard deviation of the measured sample.

# Statistical approach
## *statistical stratification*

Each room is considered as a subset.
The uncertainty of the average temperature can be decomposed in:

- Differences between rooms ($\sigma_{room}$)
- Room's unhomogeneity (sensor location in a room: $\sigma_{loc}$)

# Statistical approach
## *statistical stratification*

with:

- $N_{bui}$ the number of room in the building,
- n the number of rooms where there is a measure
- n’ the number of sensors in the same room

The uncertainty in the average temperature became:

$$\sigma_{bui} = \sqrt{\left(\frac{n-1}{n-3}\right)^2 * \frac{N_{bui}-n}{n*(N_{bui}-1)} * \sigma_{sam-room}^2 \quad + \left(\frac{n'-1}{n'-3}\right)^2 \frac{\sigma_{loc}^2}{n'}}$$



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