DYNASTEE

Introduction to Dynamic Analysis Techniques for Building Energy Performance Assessment

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WEBINARS 2021

22 September 10:15 – 11:15

Dynamic Calculation Methods for Building Energy Performance Assessment

Technical University of Denmark

presented by DYNASTEE-INIVE, CIEMAT, DTU, University of Bilbao, GCU, University of Salford

DYNASTEE

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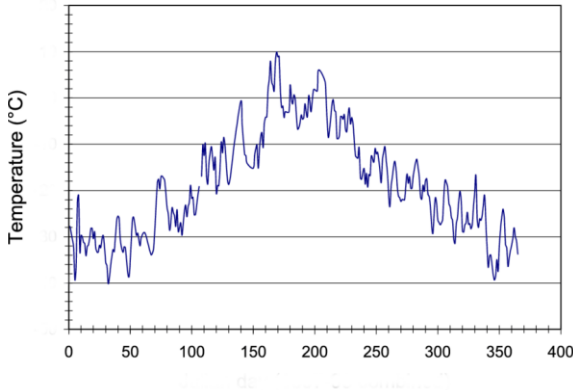
WHAT IS DYNAMIC

Dynamic processes involve the aspect of TIME

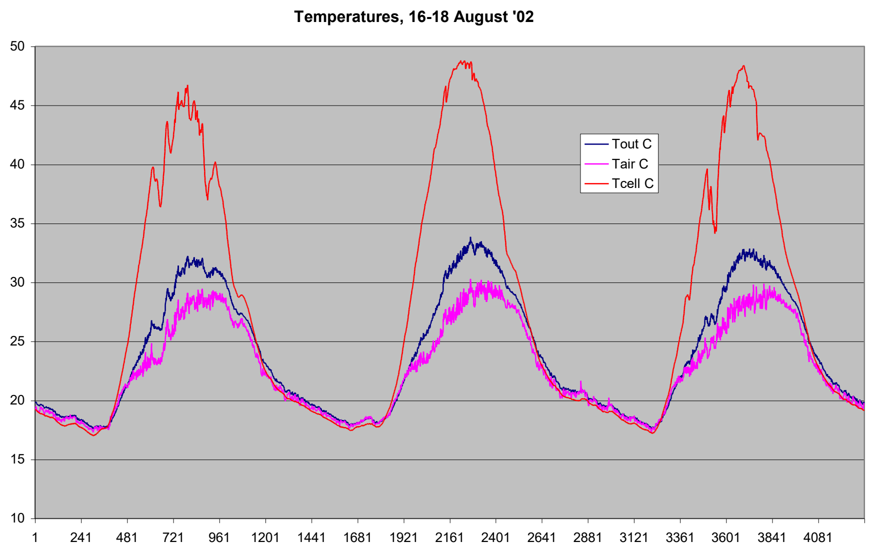
- To analyse dynamic processes,
  - dynamic mathematical techniques are required
  - to extract dynamic information from experimental observations
- Dynamic behaviour due to thermal mass
- Dynamic behaviour; up to 4 time constants
- Appropriate testing should provide the requested information
- Building Physics using Mathematical solutions

CLIMATE VARIABLES

- Daily, monthly and seasonal variations of air temperature, insolation, wind speed and direction, humidity
- Yearly variation



OUTDOOR TESTING



Energy Performance of Buildings

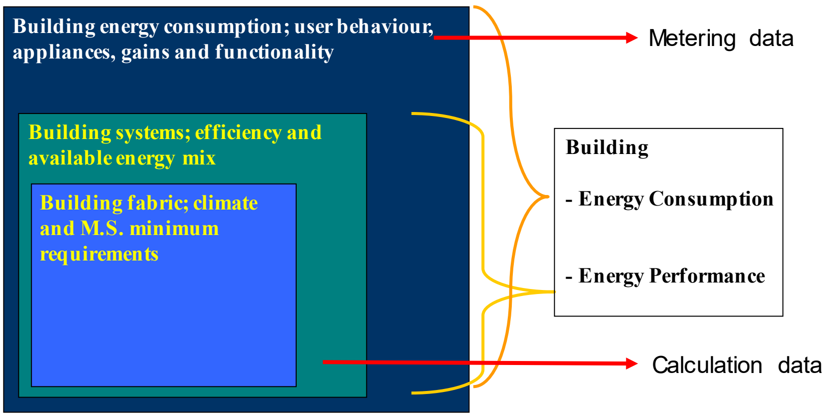
EPB Directive 2010/31/EU article 2:

*The 'energy performance of a building' means the **calculated** or **measured** amount of energy needed to meet the energy demand associated with a typical use of the building, which includes, inter alia, energy used for heating, cooling, ventilation, hot water and lighting;*

INSPIRE *offers a third, **holistic** approach using administrative databases*

ENERGY AND BUILDINGS

Relation of energy consumption and energy performance of a building



BRIDGING the GAP

EPBD related energy standards

The GAP; which GAP

Calculation (design of buildings)
Measurement (measurement of energy performance and /of consumption)

Standardization (CEN, ISO)

- TC371 *Energy Performance of Buildings*
- TC89 *Thermal Performance of Buildings and Building Components*
- *TC's related to EPBD (ventilation, light, ...)*

Performance Assessment

- Reduce building energy consumption (**Savings**)
- Improve Energy **Efficiency** (appliances and systems)
- Overall Energy **Performance** Assessment (including Renewable Energy)
- **Dynamic** characteristics more prominent (time constants; gains, occupancy)
- Net Zero-Energy Building (**EPBD** – annual/monthly calculation);
- **Renewable Energy:** Solar passive design and energy storage, e.g. thermal mass or batteries
- Energy balancing at infra structure level. **Building** as key element. Where to balance?

OVERVIEW

- Variability
  - Indoor environment (Occupants)
  - Outdoor environment (Weather conditions)
- Uncertainty
  - Measured and not-measured phenomena
  - Dynamic information; correlation
- Accuracy
  - Space and time filtering
- Errors
  - Measurement, Instrument, Sensor positioning

TWO ROADS

Testing, **Analysis** and Modelling

- Train a method for analysis; it is NOT an instrument
- Analysis of data from time-series
  - Data signals have a common time-step
- Data is supposed to contain all relevant information to describe a physical process
- Physical process is defined by physical parameters

Common methods

- Steady state:
  - Average Method (only Thermal resistance)
    - rough indicator; thermal capacitance can not be estimated
- Dynamic methods:
  - Thermal network models: white/grey box
    - Allows input of knowledge into model (e.g. LORD)
  - Mathematical models: grey/black box
    - limited input of knowledge possible (e.g. CTSM)

ANALYSIS

INPUT	METHODOLOGY	OUTPUT
Many observations from time and space ; raw data Physical processes Literature General knowledge	Description of physical processes into mathematical equations. Method should fulfil the aim taking into account the searched output	Limited value(s) Period; annual, daily, hourly Performance Efficiency; reference value Data for simulation
	Pre-processing, Model choice Iteration process, Post-processing Statistical tests, Model validation External tests	

How to derive valuable results from many observations ?

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PRE-PROCESSING

check for irregularities:

- plot important input signals
  - (sensor hit by radiation, opening of door, broken sensor)
- apply the average method
  - get feeling with the data by increasing data length
  - check for consistency
- examine statistical information
  - minimum, maximum, average, standard deviation
- Example: reduction from 7 indoor temperature sensor minutely observations to one -10 minute data series

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AVERAGE METHOD

To obtain an idea about the thermal resistance

Apply different length for period

$$\hat{R}_{avg} = \frac{\sum_{k=1}^{600}\left[\theta_i(k) - \theta_e(k)\right]}{\sum_{k=1}^{600} q_i(k)}$$

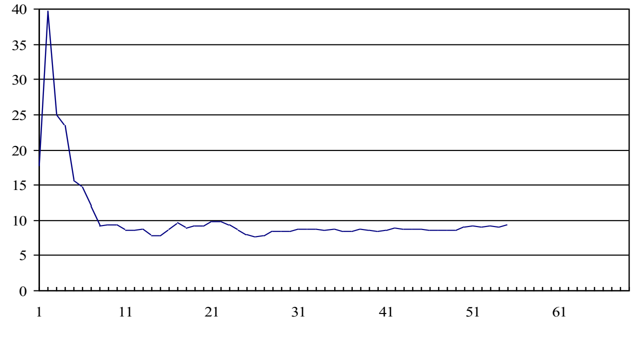
Apply increasing length.

Standard deviation

$$\sigma^2 = \frac{\sum_{k=1}^{600}(R_k - \hat{R}_{avg})^2}{599}$$

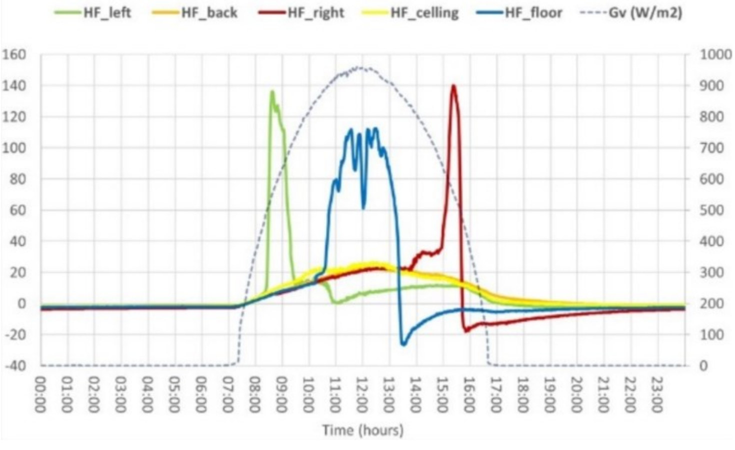
Static (average) Method

simple method to check order of magnitude of the estimate



MEASUREMENT

Sensor hit by solar radiation



Definitions

- A ***model*** is a mathematical description of a physical system or process. By definition it is a simplification of the reality
- A ***method***, here a system identification technique, consists of two major parts:
  - Define:
    - 1. the mathematical model
    - 2. estimate the parameters (such as; least squares method)
  - Process of optimization and minimization
- A ***tool*** is a sophisticated software program which allows the user to apply a method in a user friendly way.

UNCERTAINTY - SIMULATION

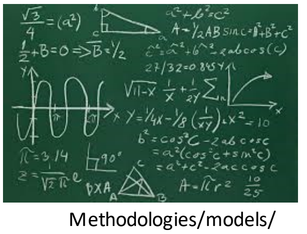
The world is managed through models
Model is a simplification of reality
made by **you**!
based on **your** interpretation of reality.

APPROACHES

Input Dataset-1

Input Dataset-2

Data



Methodologies/models/
algorithms/maths

Tools

Result

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Physicists versus Statisticians

- Building physicists solve a physical problem using mathematics
- Statisticians solve mathematical problems

- Physicists lower frequency
- Statisticians higher frequencies

7.1 versus 7.085

Together they perform successful Dynamic Analysis

TWO PERSPECTIVES (1)

Building Physicist and Statistician

Notable characteristics:

- Model should describe the process
- Seeks physical parameters
- Can cope with non-measurable phenomena
- Focus on Low frequency
- Static, steady state
- 7.1 °C

TWO PERSPECTIVES (2)

Building Physicist and **Statistician**

Notable characteristics:

- Model should fit the data
- Seeks mathematical parameters
- Residual should be white noise
- Focus on High frequency
- Dynamic
- 7.085 °C

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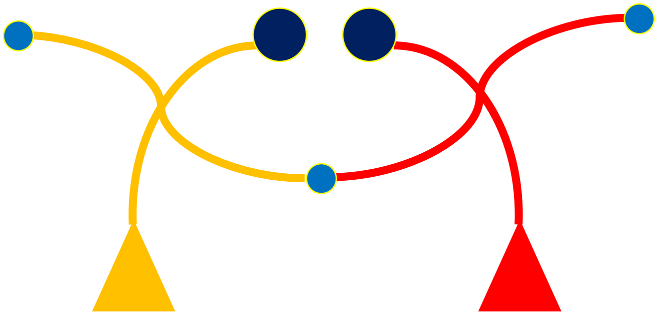
WORKING TOGETHER

Building Physicist meets Statistician



That works well …… but

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System Identification

What is System Identification in the context of Energy Performance Assessment in Buildings?

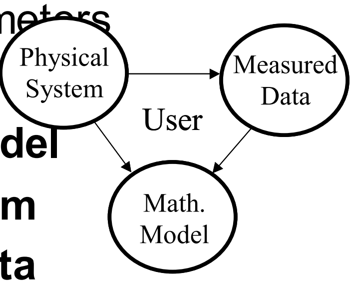
To assess Thermal Parameters

It is the application of

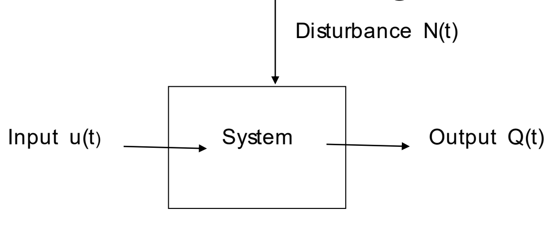
a **Mathematical Model**

of a **Physical System**

using **Measured Data**



Dynamic Analysis Methods and Modelling



PEM Prediction Error Model

$$Q(t) = G(q)u(t) + H(q)e(t)$$

OEM Output Error Model when H(q) = 1

$$Q(t) = G(q)u(t) + e(t)$$

Electrical system

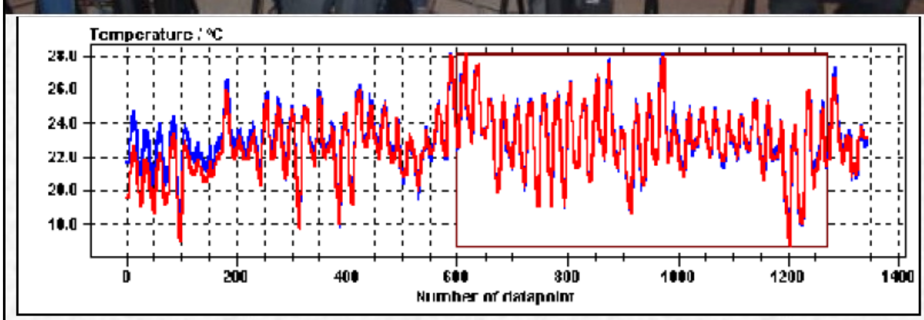
Water flow system

Heat flow transfer

What is System Identification

- Physical system with unknown parameters
- Mathematical process
  - Set of differential equations
  - Application of statistical rules
- Mathematical model
- Solving mathematical parameters
- Time series of observations are needed

$$V = \sqrt{\frac{1}{N} \cdot \sum (T_{meas} - T_{calc})^2}$$

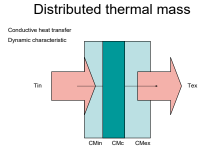


MODEL SIMPLIFICATION

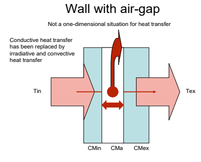
Envelope - Volume

- Thermal Losses — 3 zones
  - Heat transfer
  - Ventilation
- Variable Gains
  - Solar
  - Occupants
  - Others

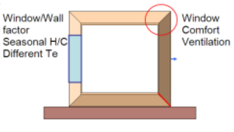
INCREASED COMPLEXITY



- Conduction only heat transfer
  - Distributed thermal mass



- Conduction, radiation and convection



- Not measured phenomena

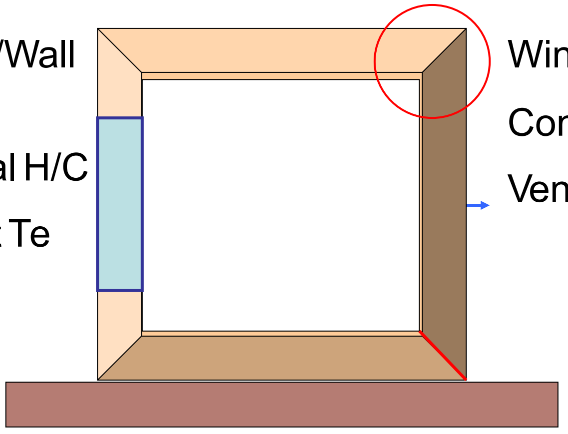
MODEL DESCRIPTION

$$UA^*(\theta i-\theta o)+Qvent-gA^*I-Q=0$$

Window/Wall factor

Seasonal H/C

Different Te



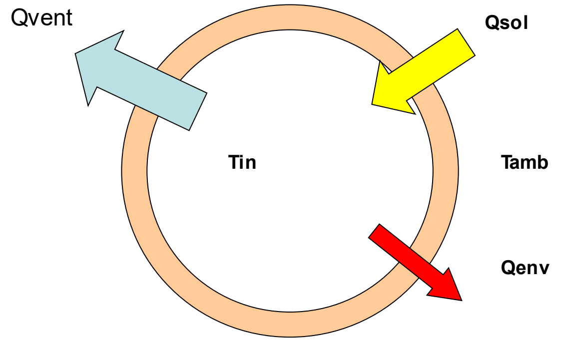
Window

Comfort

Ventilation

MATHEMATICAL MODEL

$$UA^*(\theta i-\theta o)+Qvent-gA^*I-Q=0$$



Building:

Volume

Envelop

TWO TOOLS

Two perspectives will be discussed and applied using two tools on benchmark data

- LORD; lumped parameter model
- CTSM-R; continuous time model
- See extended description; document Softw are techniques applied to thermal performance characteristics

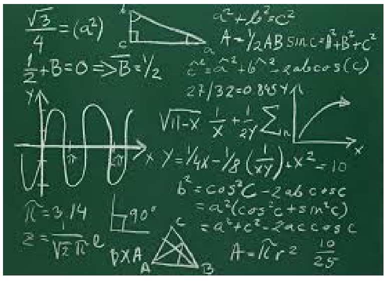
BENCHMARK DATA

- Simulated data homogenous wall
- In-Situ data from homogenous wall
- In-Situ data from composition wall
- Data from Round Robin box (research)
- In-Situ data from an air gap envelop
- Data from a whole building
- Data from a co-heating site experiment

HOW TO DO (1)

ANALYSIS SOFTWARE

- Environments
  - MatLab, Excel, R, …..
- Tools
  - LORD, CTSM-R …..
- Methods
  - OEM and PEM, LSM and MLH, …..
- Models
  - Many, …..



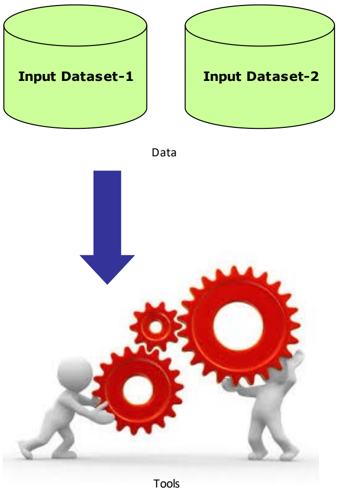
Methodologies/models/algorithms/maths

HOW TO DO (2)

- Start with understanding the available data
- How to go from measured data to model input data
- From many sensors (temperatures, …) to ONE input temperature for your model
  - Understand data reduction (time and spatial)
  - Understand model reduction (simplification)
- Develop a SKILL – perform exercises
- Decision making – WHY report this result

GENERAL APPROACH

- Plot the data
- Average method
  - steady state
- Regression
  - Introduce dynamics
- ARX
- Grey Box
  - Apply physical knowledge



ACCURACY

The resulting accuracy of the estimate depends on three types of errors:

- Experimental **boundary conditions**.
  - Choice and position of sensors, homogeneity
  - Reduction of input signals
- **Measurement error**.
  - Sensors and instruments
  - Calibration of sensors
  - Spikes and missing observations
- Error introduced by the **analysis method**.
  - Mathematical to Physical parameters
  - correlation between input signals

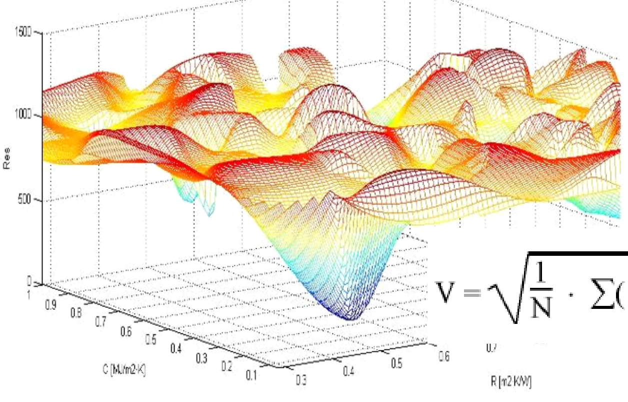
POST - PROCESSING

1. Fit to the data. Residuals are 'small' and 'white noise'
2. Reliability. Same results with different data
3. Internal validity. Cross-validation; the model agrees with other data than those used for estimation
4. External validity. Results are in general not in conflict with previous experience
5. Dynamic stability. From a steady state, the response from a temporary change in an input variable fades out
6. Identifiability. Model's parameters are uniquely determined by the data
7. Simplicity. The number of parameters is small

Conversion from mathematical parameters into physical ones.

Residual Evaluation

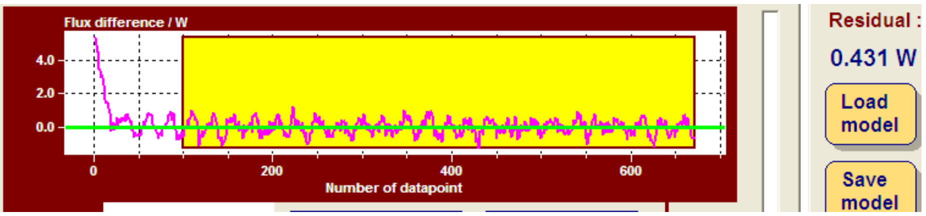
Residual patterns for the model in function of the wall parameter variations.
Does the model gets to the real lowest minimum ?



$$V = \sqrt{\frac{1}{N} \cdot \sum(T_{meas} - T_{calc})^2}$$

Residual Evaluation (2)

- Correlation and residual analysis
- Feedback to model selection
  - (daily frequency may indicate impact from solar radiation)



SIMULATED DATA

- BESIM20.pdf
  - Description of two benchmark cases
  - Based on simulated data, including noise
- Defstatest.pdf
  - Description of physical definitions and statistical tests

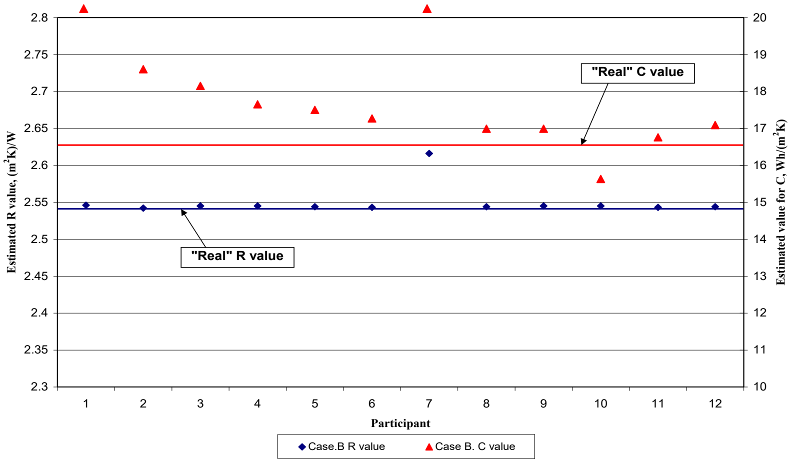
Data has been made available on:

dynastee.info/data-analysis/on-line-training

You can find it here BenchmarkTestDynMethods20.

Comparison of events results

Best and worse case identification results on simulated data



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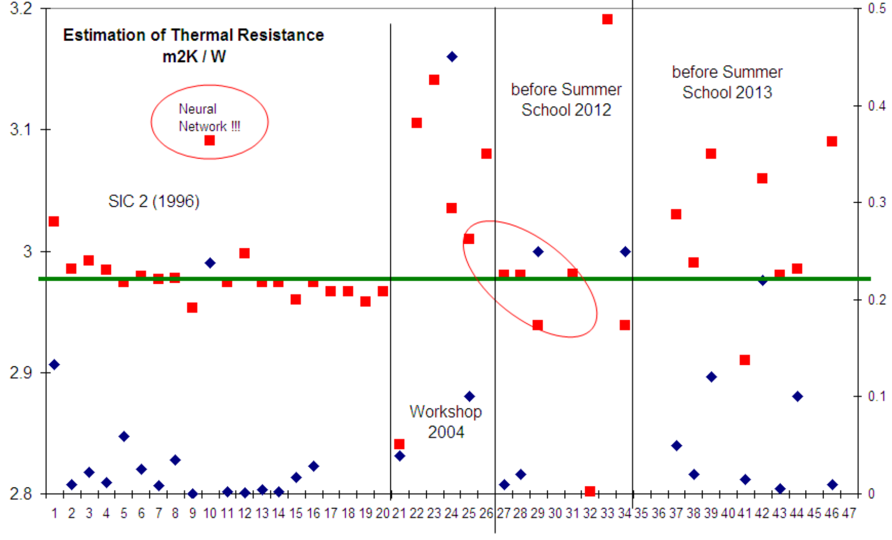
RESULTS for R (m^2K/W)



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CONCLUSION

"One needs a certain level of skill to perform well"

- Improve knowledge through a Training and Competition
- After >25 years DYNASTEE states:

Training make sense

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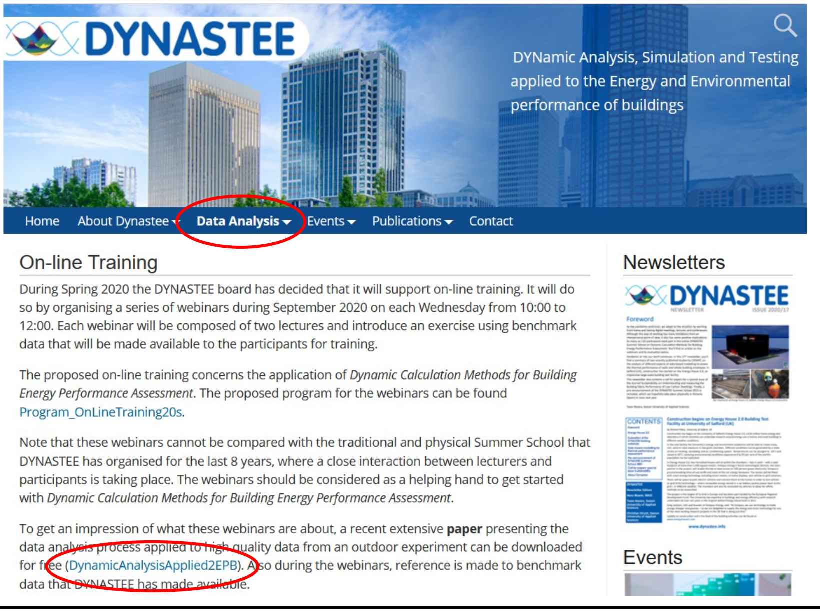
WWW.DYNASTEE.INFO



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