DYNASTEE DYNamic Analysis, Simulation and Testing applied to the Energy and Environmental performance of buildings

Free On-Line Training Webinars; 22 and 29 September, 6 and 13 October 2021

Dynamic Calculation Methods for Building Energy Performance Assessment

Technical University of Denmark DTU · GCU Glasgow Caledonian University · Universidad del País Vasco / Euskal Herriko Unibertsitatea · Gobierno de España · Ministerio de Economía y Competitividad · Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas · University of Salford Manchester

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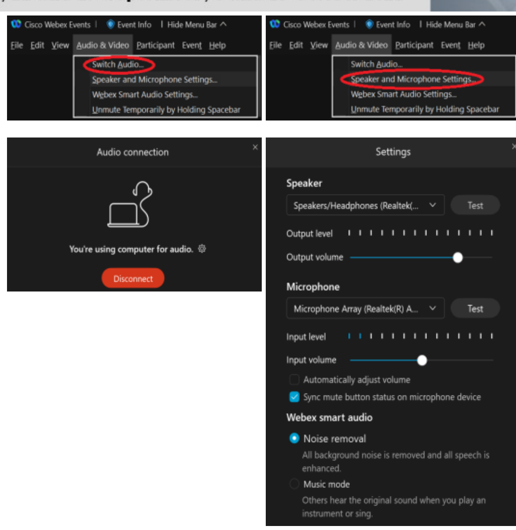

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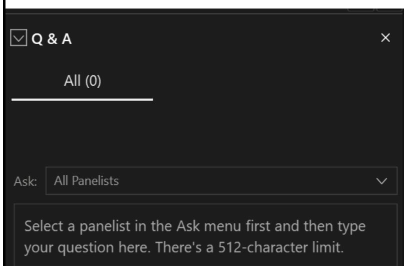
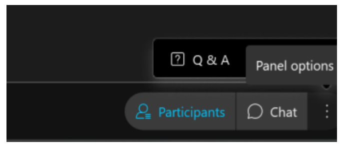
How to ask questions during the webinar

Note: Please DO NOT use the chat box to ask your questions!

Locate the **Q&A box**

Select **All Panelists** | Type your question | Click on Send





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NOTES:

1. The questions addressed to the speakers during this webinar- via the Q&A box- will be gathered and answered **during the last webinar of the series on October 13th**
2. After the end of the webinar you can also send further questions you might have, via email to Hans Bloem at: hans.bloem@inive.org
3. The webinar will be recorded and published at https://dynastee.info/ within a couple of weeks, along with the presentation slides.

Organized by https://dynastee.info/ Facilitated by INIVE

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Introduction

Richard Fitton

University of Salford MANCHESTER

Hans Bloem

DYNASTEE

Webinar management

Maria Kapsalaki (INIVE, BE)

Valérie Leprince (INIVE, BE)

Luk Vandaele

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DYNASTEE

DYNASTEE

Network for

- DYNamic
- Analysis
- Simulation and
- Testing of
- Energy and
- Environmental performance of buildings

HISTORY

DYNASTEE

- 1985 PASSYS I — *B, DK, F, D, I, NL, UK, JRC*
- 1990 PASSYS II — *+ GR, P, E*
- 1992 COMPASS PASLINK
- 1994 PASLINK EEIG European Economic Interest Grouping of Outdoor Test Centres — *+ FI*
- 1996 PV-HYBRID-PAS
- 2000 IQ-TEST — *+ CH*
- 2002 DAME-BC — *+ New member states New sites in Spain, France, ...*
- 2005 DYNASTEE — PASLINK ⇨ INIVE
- 2011 IEA Annex 58
- 2016 IEA Annex 71
- 2021

Summer schools and Training Webinars

INTERNATIONAL NETWORK

DYNASTEE

INIVE members: CETIAT, bbri.be, SINTEF, National and Kapodistrian University of Athens, TNO innovation for life, Fraunhofer IBP, CSTB le futur en construction, e ERG end-use Efficiency Research Group

INIVE projects: AIVC, TightVent Europe, Venticool, DYNASTEE, BUILDUP, EPBD feasibility study 19a, QUALICHeCK, SAVE ASIEPI

DYNASTEE

- operates under the umbrella of INIVE
  as an open platform for exchange of knowledge and experience
- Presently it facilitates ST5 Network of Excellence of IEA ECB Annex 71

DYNASTEE - OBJECTIVE

- Global leading network on dynamic testing and evaluation of Energy Performance in Buildings
- Consolidation of existing knowledge
- Bringing together academic, industry and governmental experts
  - on the **test environment and experimental setup** as well as on the **data analysis** and **performance prediction**.
- DYNASTEE - NoE: ST5 of IEA EBC Annex 71

FUNCTIONING

- DYNASTEE is the follow-up platform of PASLINK EEIG for information exchange
- Bringing together anyone with an interest in the dynamic calculation/measurement of the performance of buildings
- DYNASTEE Fund
  - PASLINK EEIG heritage after dissolution 2005
  - Governed by INIVE EEIG
  - Sponsoring by Industry
  - Voluntary work

ACTIVITIES

- DYNASTEE SubTask 5 leader of Annex 71
- Facilitates interaction with target groups: CEN, Industry, IEA Annexes, EU projects, etc.
  - Organises Workshops
  - E.g. 10-11 April 2019 Bilbao "*The building as the Cornerstone of our Future Energy Infrastructure*"
- Organises training:
  - 8 Summer School and several Webinars (2020)
- Communication
  - Publishes Newsletters; # 18
  - https://DYNASTEE.INFO website
  - Disseminates tools, data, reports, papers, ...

Background to Course

The course has two main objectives:

- Train a dynamic methodology to assess the thermal performance of a building such as a wall, and a whole buildings' performance.
- Examine and understand the performance of nZEB and renewable energy technologies in built environment

The approach to these will be a combination of **building physics, applied mathematics** and **statistical methods**

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What approaches will be used in the sessions?

We will use data that has been collected by experts that is high quality:

- Data from realistic and full scale buildings and envelope systems, **not generated by models.**
- Realistic and reliable data taken by experts **in-situ**

Using this type of data we can begin to validate and examine performance of said elements with reduced uncertainty.

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The Measurement Gap

It may be that the way that we measure things is incorrect, and not comparable other peoples studies/or the values that are used in models (which are often the results of experiments).

One of the simplest and most common value is the U value (the thermal efficiency of an element, the higher the value the quicker heat will pass thorough it)

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Summer School (Pre- COVID-19)

One week session, held in different locations throughout the EU. However this time it will be sat from the comfort of your armchair/office!

- DYNASTEE have taken a view that for the safe of health and safety this year also the Summer School will not take place and the sessions have been edited down to several webinars.

- These sessions will all be delivered online over the course of September-October 2021. In **four - two hour sessions**

  22nd of September to 16th of October 2021

- Every Wednesday, 10AM to Noon. GMT Summer Time

DYNASTEE

Overall Topic of Sessions

- Building physics to support the development of mathematical models for energy performance assessment.
- Knowledge of thermodynamic processes, heat transfer and the impact of solar radiation.
- Thermal conduction, convection, radiation and thermal mass.
- Using benchmark data for analysis
- Complexity of the physical process and how to translate the available information in mathematical models,
- Importance of model simplification of building physics represented by measured signals.
- Variability of the environments and the uncertainty of data
- Measured data and not-measured phenomena and how to build a mathematical model based on the available input.

The Experts

Presentations by

- María José Jiménez (CIEMAT, Spain),
- Irati Uriarte (UPV-EHU, Bilbao, Spain),
- Hans Bloem (INIVE-DYNASTEE, Brussels),
- Paul Baker (GCU, Glasgow, UK),
- Aitor Erkoreka (UPV-EHU, Bilbao, Spain),
- Peder Bacher (DTU, Lyngby, Denmark),
- Richard Fitton (University of Salford, UK),
- Luk Vandaele (INIVE-DYNASTEE, Brussels)

Programme

Webinar 1 - 22th September 10:00-12:00

10:00 DYNASTEE and training

10:15 Hans Bloem; General approach

- Introduction to general approach of different analysis techniques used to perform the thermal characterisation for elements (walls, roofs etc) through to the whole building.
- We will introduce 2 software tools that will be used during series of webinars; LORD, and CTSM-R
- An easy exercise will be presented with the correct result given this will help you to build confidence in your analytics skills

11:15 Aitor Erkoreka; building physics, sensors and instruments

- Introduction to measured data, specific sensors for buildings physics and energy performance and what is important to know

Programme

Webinar 2 - 29th September 10:00-12:00

10:00 Maria-Jose Jimenez; Experimental set up and data

- This session will present the experimental set up and measurement of the Plataforma Solar de Almeria (PSA), an explanation and demonstration of the data available will be given.
- An exercise that will allow of a study to be analysed with and without solar radiation .
- *Data series 16-17 will be presented here which will be used in further sessions. Data has been made available at the website dynastee.info;* zipped folder PSA_RRbox_DataSeries20

11:00 Paul Baker; Dynamic Calculations & LORD

- This session will provide an introduction to dynamic analysis methods
- A practical demonstration will be given of the software tool LORD on the PSA data series 16 and 17

Programme

Webinar 3 - 6th October 10:00-12:00

10:00 Peder Bacher Combining two disciplines building physics and mathematical techniques

- Introduction to discrete time and continuous time methods
- Using CTSM-R with statistical tools

11:00 Irati Uriarte; application of CTSM-R to real world data

- Demonstration of the CTSM-R software will take place on data series 16, 17 from PSA

Programme

Webinar 4 - 13th October 10:00-12:00

10:00 Richard Fitton;

An introduction to the analysis of metering data, the specification and limitations of the data and analysis techniques.

11:00 Questions and Answers

After the 3th Webinar we invite all attendees to submit questions/queries via email on all of the sessions. These will be collated and presented to the panel to provide answers at Webinar 4

Future; 2022

Last year is atypical; the decision was made to postpone the complete Summer School for good reasons.

However we are already planning the next summer school to take place in Almeria in Spain in 2022, this will be a full Summer School with classroom-based learning sessions and interactive sessions.

Future; 2022 and beyond

We will be using the forthcoming year to work on new topics for the summer school as follows:

- **Use of online data platforms such as weather API, renewable energy data**
- **Use of on-board systems such as connected thermostats**
- **Use of smart metering data for energy input**

Most countries now have access to at least most of this data, and some, all of it.

- The work and findings of IEA Annex 71 which focus on the data mentioned above to deem the energy performance of a dwelling. https://dynastee.info/new-iea-ebc-annex-71-building-energy-performance-assessment-based-on-in-situ-measurements/
- We will provide learning on not only the acquisition of this data using live API access to smart meter and controls, but the analytical tools to deem the energy performance.

DYNASTEE

Introduction to Dynamic Analysis Techniques for Building Energy Performance Assessment

Hans BLOEM

1

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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

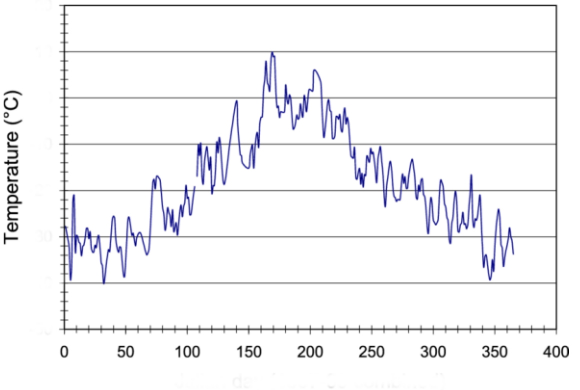
Appropriate testing should provide the requested information

Building Physics using Mathematical solutions

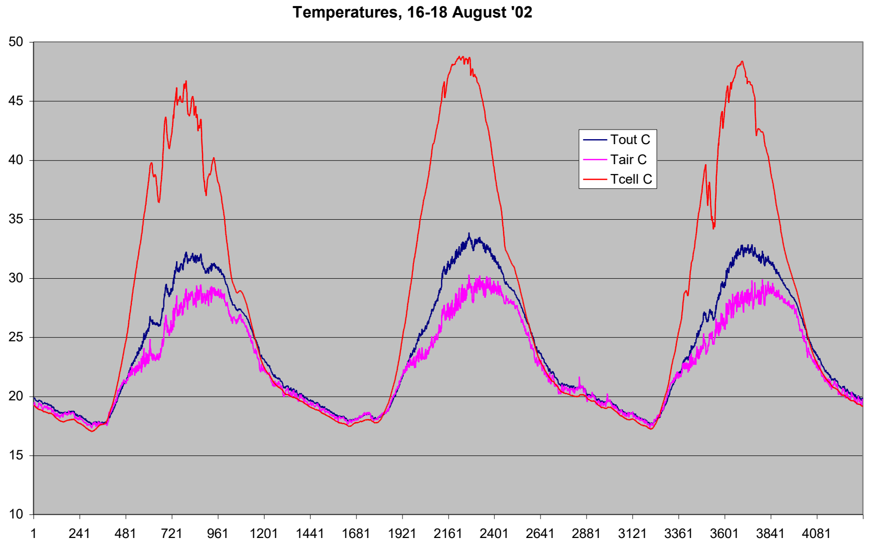
CLIMATE VARIABLES

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

- Yearly variation



OUTDOOR TESTING



Energy Performance of Buildings

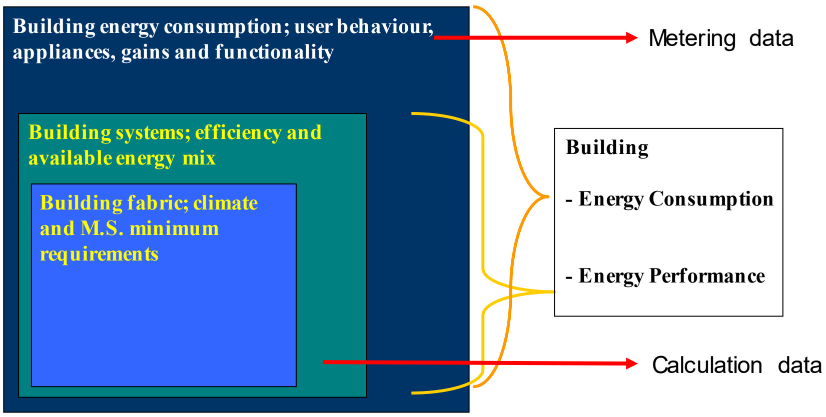
EPB Directive 2010/31/EU article 2:

*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



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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, ...)*

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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 ?

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

AVERAGE METHOD

To obtain an idea about the thermal resistance

Apply different length for period

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

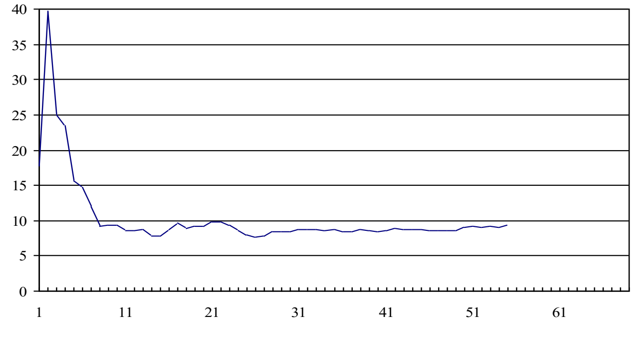
Apply increasing length.

Standard deviation

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

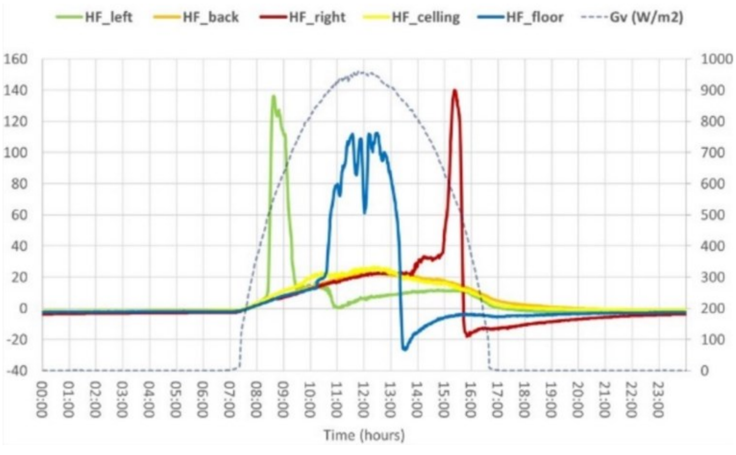
Static (average) Method

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.

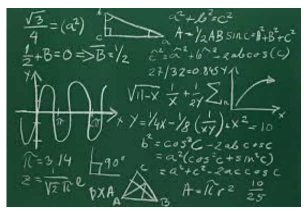
UNCERTAINTY - SIMULATION

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)

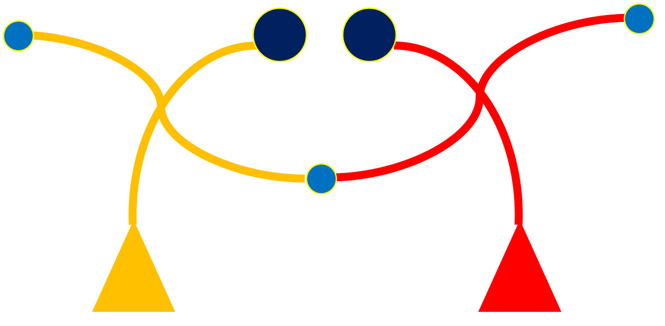
Building Physicist and **Statistician**

Notable characteristics:

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

WORKING TOGETHER

Building Physicist meets Statistician



That works well …… but

System Identification

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

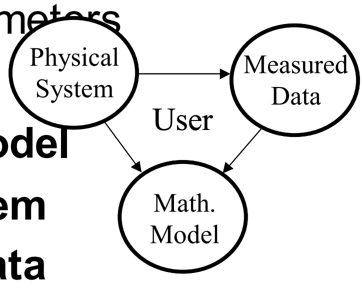
To assess Thermal Parameters

It is the application of

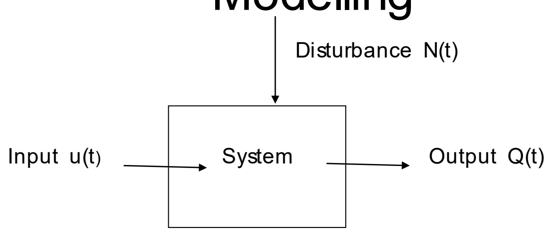
a **Mathematical Model**

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

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

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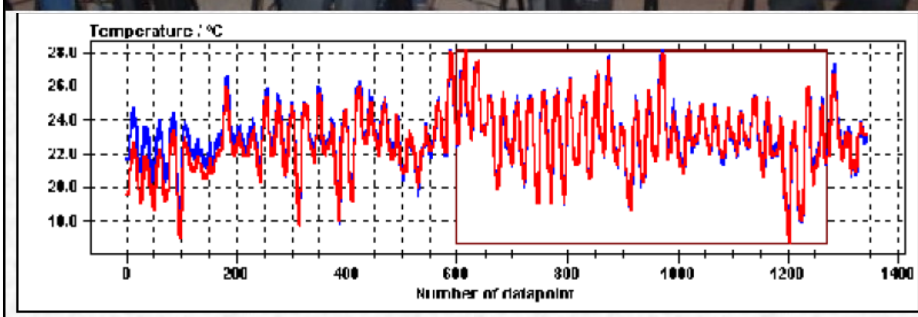

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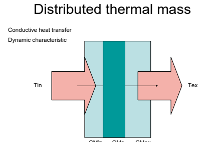
MODEL SIMPLIFICATION

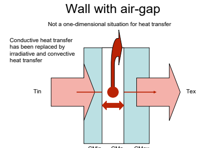
Envelope - Volume

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

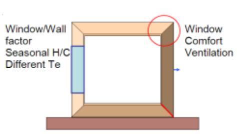
INCREASED COMPLEXITY



- Conduction only heat transfer
  - Distributed thermal mass



- Conduction, radiation and convection



- Not measured phenomena

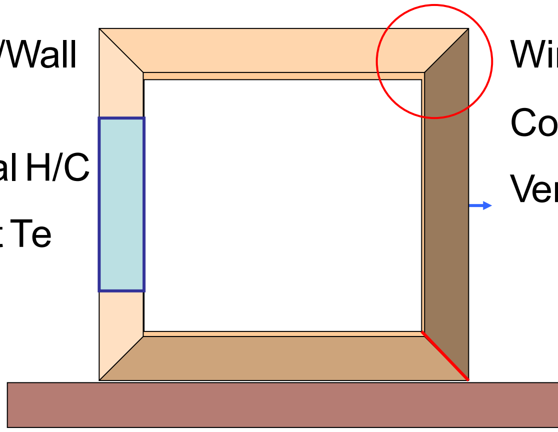
MODEL DESCRIPTION

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

Window/Wall factor

Seasonal H/C

Different Te



Window

Comfort

Ventilation

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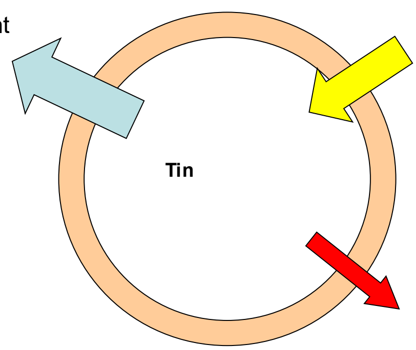
MATHEMATICAL MODEL

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



Building:

Volume

Envelop

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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

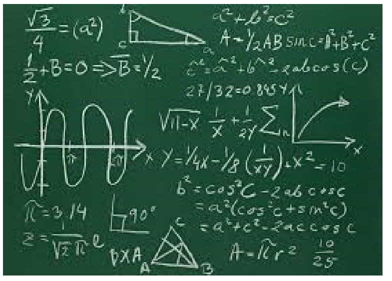
BENCHMARK DATA

- 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, …..



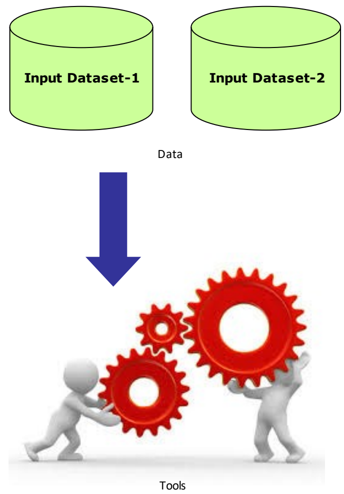
Methodologies/models/algorithms/maths

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



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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

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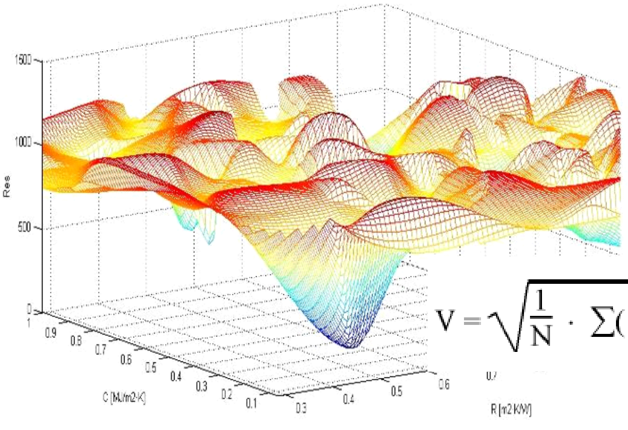
POST - PROCESSING

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

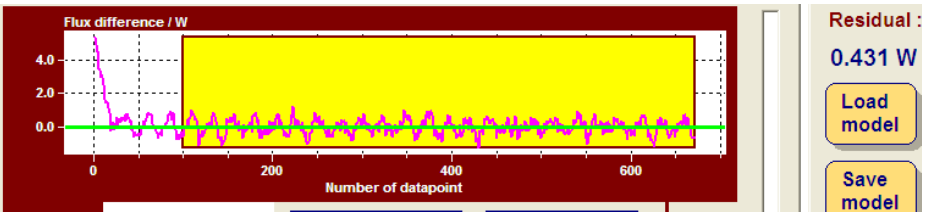
Residual patterns for the model in function of the wall parameter variations.
Does the model gets to the real lowest minimum ?



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

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

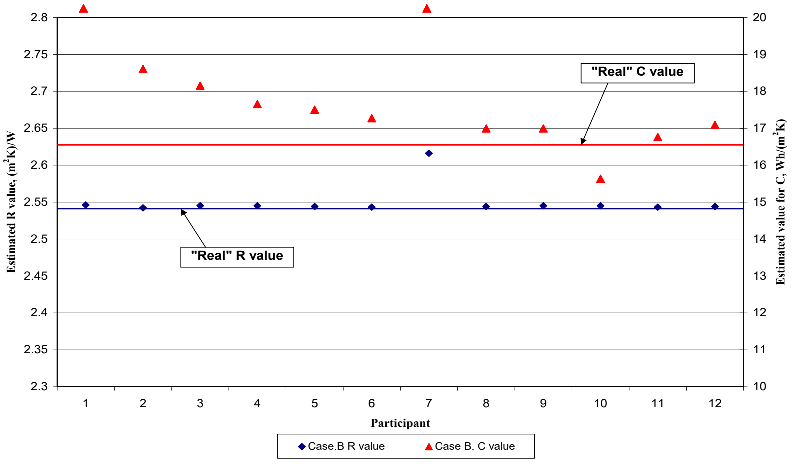
Data has been made available on:

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

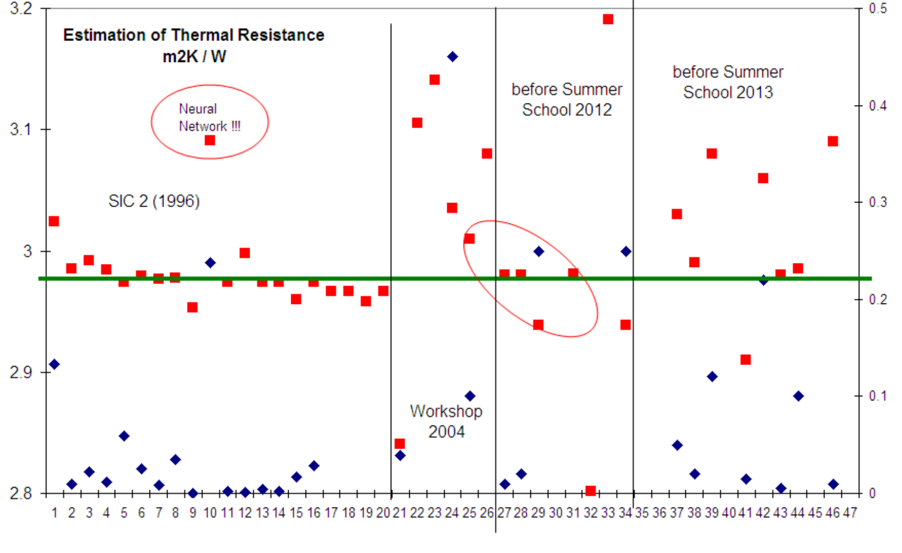
You can find it here BenchmarkTestDynMethods20.

Comparison of events results

Best and worse case identification results on simulated data



RESULTS for R (m^2K/W)



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

WWW.DYNASTEE.INFO

Introduction to measured data, instrumentation and sensors in relation to building physics and energy performance. What is important to know?

Aitor Erkoreka
University of the Basque Country (UPV/EHU)

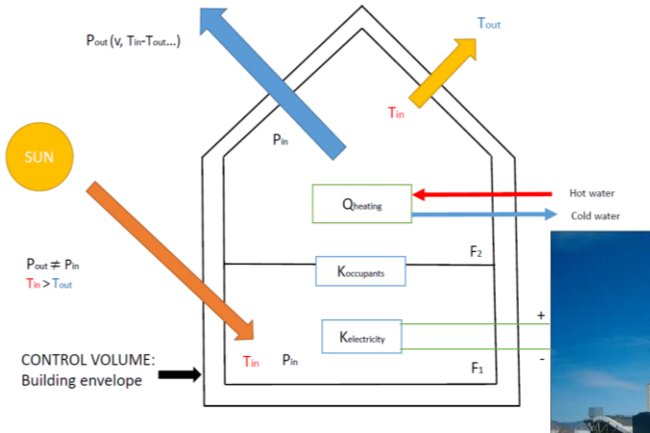
1 - INTRODUCTION

$Q_{ventilation} = C_{v\,(vent)}\,(T_{in}-T_{out}) = \dot{V}_{air(vent)}\,\rho_{air}\,Cp_{air}\,(T_{in}-T_{out})(1-\eta)$ [kW]

$Q_{infiltration} = C_{v\,(inf)}\,(T_{in}-T_{out}) = \dot{V}_{air(inf)}\,\rho_{air}\,Cp_{air}\,(T_{in}-T_{out})$ [kW]

$Q_{inf+vent} = \dot{V}_{air(inf)}\,\rho_{air}\,Cp_{air}\,(T_{in}-T_{out}) + \dot{V}_{air(vent)}\,\rho_{air}\,Cp_{air}\,(T_{in}-T_{out})(1-\eta)$ [kW]

$Q_{transmission} = UA\,(T_{in}-T_{out})$ [kW]



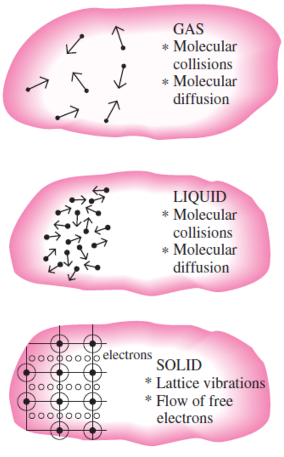
1 – INTRODUCTION: CONDUCTION

DYNASTEE

Conduction is the transfer of energy from the more energetic particles of a substance to the adjacent less energetic ones as a result of interactions between the particles. Conduction can take place in solids, liquids, or gases.

FOURIER'S LAW OF HEAT CONDUCTION:

$$\dot{Q}_{cond} = -kA\frac{dT}{dx} \qquad (W)$$



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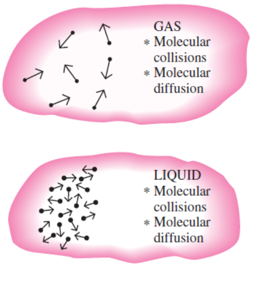
1 – INTRODUCTION: CONVECTION

DYNASTEE

Convection is the mode of energy transfer between a solid surface and the adjacent liquid or gas that is in motion, and it involves the combined effects of conduction and fluid motion. The faster the fluid motion, the greater the convection heat transfer.

NEWTON'S LAW OF COOLING:

$$\dot{Q}_{conv} = hA_s\,(T_s - T_\infty) \qquad (W)$$



In the absence of any bulk fluid motion, heat transfer between a solid surface and the adjacent fluid is by pure conduction.

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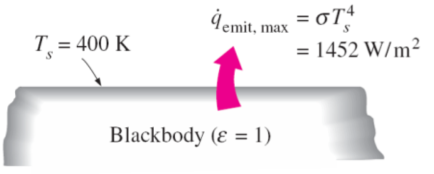
1 – INTRODUCTION: RADIATION

Radiation is the energy emitted by matter in the form of electromagnetic waves (or photons) as a result of the changes in the electronic configurations of the atoms or molecules.

STEFAN–BOLTZMANN LAW:

$$\dot{Q}_{emit,\,\max} = \sigma A_s T_s^4 \qquad \text{(W)}$$



Unlike conduction and convection, the transfer of energy by radiation does not require the presence of an intervening medium. In fact, energy transfer by radiation is fastest (at the speed of light) and it suffers no attenuation in a vacuum.

1 – INTRODUCTION: RADIATION

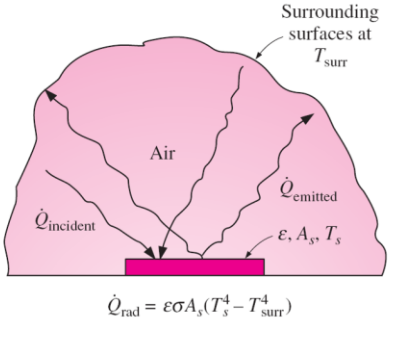
RADIATION HEAT TRANSFER:
Difference between emitted and absorbed

$$\dot{Q}_{\text{emit}} = \varepsilon\sigma A_s T_s^4 \qquad \text{(W)}$$

$$\dot{Q}_{absorbed} = \alpha \dot{Q}_{incident} \qquad \text{(W)}$$

KIRCHOFF'S LAW

$$\dot{Q}_{\text{rad}} = \varepsilon\sigma A_s (T_s^4 - T_{surr}^4) \qquad \text{(W)}$$



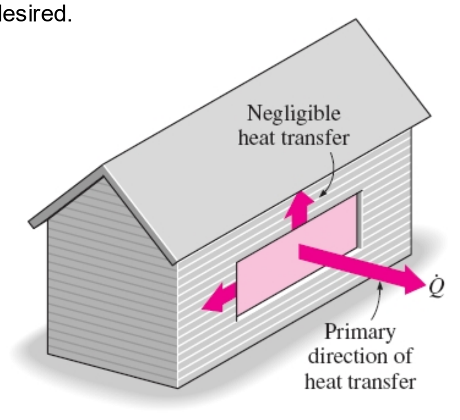
1 – INTRODUCTION: MULTIDIMENSIONAL HEAT TRANSFER

DYNASTEE

MULTIDIMENSIONAL HEAT TRANSFER

• Heat transfer problems are classified as being one-dimensional, two-dimensional, or three-dimensional.

• Depending on the relative magnitudes of heat transfer rates in different directions and the level of accuracy desired.



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1 – INTRODUCTION: SOLVING A CONDUCTION PROBLEM

DYNASTEE

Heat transfer problem

⇩

Mathematical formulation (differential equation and boundary and initial conditions)

⇩

General solution of the differential equation

⇩

Application of boundary and initial conditions

⇩

Problem solution

$$\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}+\frac{\dot{e}_{gen}}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$$

$$T = \mathrm{T(x, y, z, t)} \qquad [^{o}\mathrm{C}]$$

$$\dot{Q}_n = -k \cdot A \cdot \left|\overrightarrow{grad}(T)\right| \qquad [\mathrm{W}]$$

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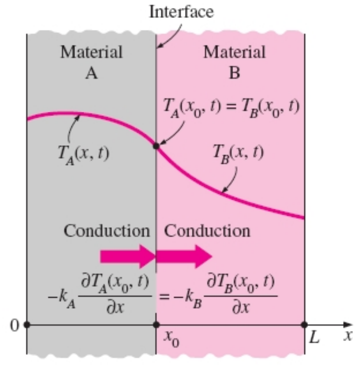
1 – INTRODUCTION: SOLVING A CONDUCTION PROBLEM

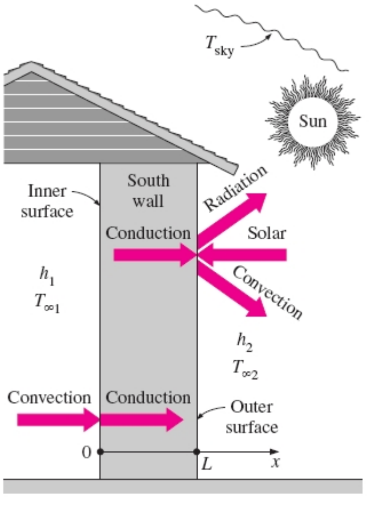
DYNASTEE

INTERFACE BOUNDARY CONDITIONS

$$T_A(x_0,t) = T_B(x_0,t)$$

$$-k_A \frac{\partial T_A(x_0,t)}{\partial x} = -k_B \frac{\partial T_B(x_0,t)}{\partial x}$$





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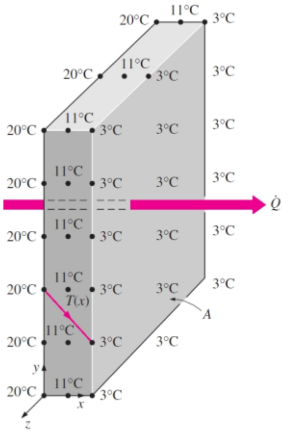
2 - STEADY HEAT CONDUCTION IN PLANE WALLS

DYNASTEE

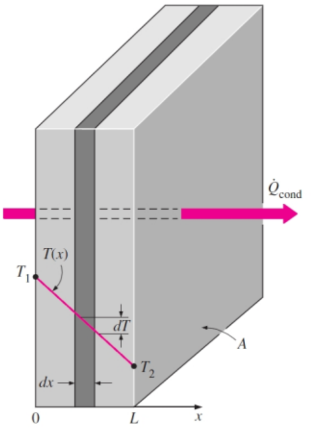
- The wall of a house during winter time



$$\dot{Q}_{cond,wall} = -kA\frac{dT}{dx}$$

⇩

$$\dot{Q}_{cond,wall} = kA\frac{T_1 - T_2}{L}$$



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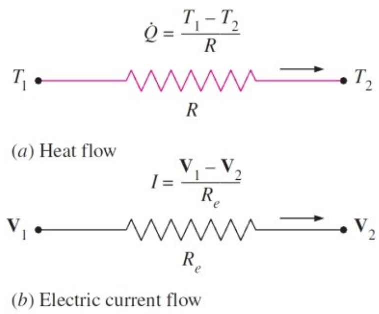
2 - STEADY HEAT CONDUCTION IN PLANE WALLS

DYNASTEE

THE THERMAL RESISTANCE CONCEPT

Thermal-Electrical analogy →



Conditions:

- Steady-state
- NO heat generation

- Conduction:

$$\dot{Q}_{cond,wall} = kA\frac{T_1 - T_2}{L} = \frac{T_1 - T_2}{R_{wall}} \Rightarrow \boxed{R_{wall} = \frac{L}{kA}}$$

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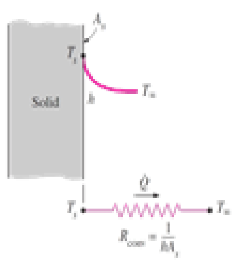
2 - STEADY HEAT CONDUCTION IN PLANE WALLS

DYNASTEE

THE THERMAL RESISTANCE CONCEPT

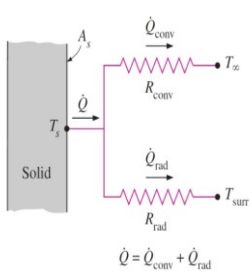
- Convection:



$$\dot{Q}_{conv} = hA(T_s - T_\infty) \Rightarrow$$

$$\Rightarrow \dot{Q}_{conv} = \frac{T_s - T_\infty}{R_{conv}} \Rightarrow \boxed{R_{conv} = \frac{1}{hA_s}}$$

- Radiation:



$$\dot{Q}_{rad} = \varepsilon \cdot \sigma \cdot A_s (T_s^4 - T_{surr}^4) = h_{rad} \cdot A_s (T_s - T_{surr}) =$$

$$= \frac{T_s - T_{surr}}{R_{rad}} \Rightarrow \boxed{R_{rad} = \frac{1}{h_{rad} A_s}}$$

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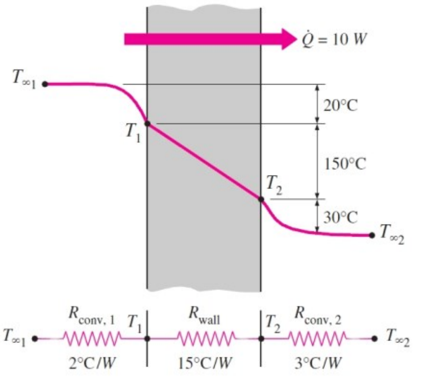
2 - STEADY HEAT CONDUCTION IN PLANE WALLS

DYNASTEE

THERMAL RESISTANCE NETWORK



$$\dot{Q} = \frac{\Delta T}{R} = UA\Delta T$$

$$UA = \frac{1}{R_{total}}$$

$$\dot{Q} = \frac{T_{\infty 1} - T_1}{R_{conv,1}} = \frac{T_1 - T_2}{R_{cond}} = \frac{T_2 - T_{\infty 2}}{R_{conv,2}} = \frac{T_{\infty 1} - T_{\infty 2}}{R_{total}}$$

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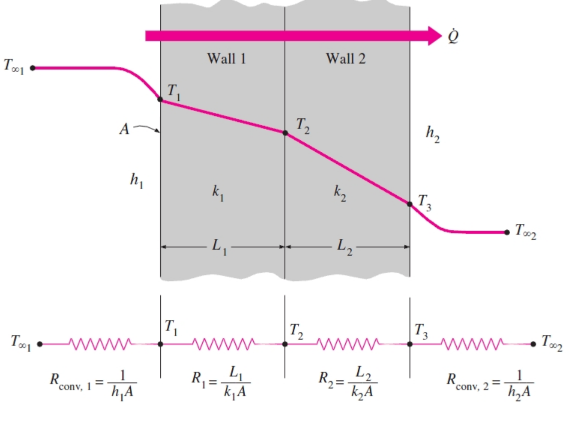
2 - STEADY HEAT CONDUCTION IN PLANE WALLS

DYNASTEE

MULTILAYER PLANE WALLS



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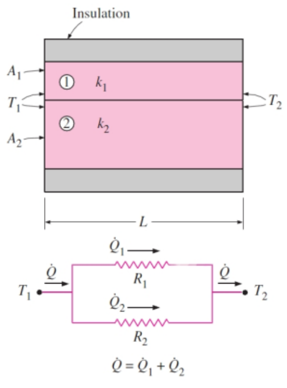
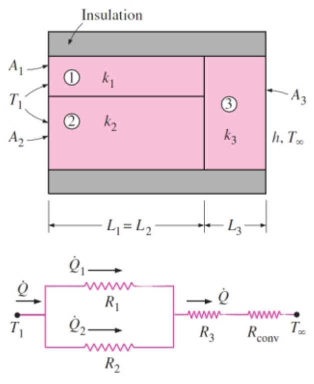
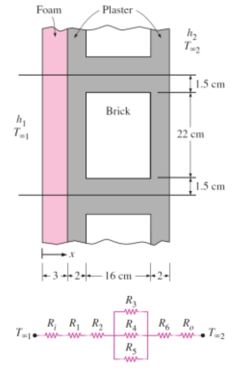
2 - STEADY HEAT CONDUCTION IN PLANE WALLS







DETAILED INFO IN REFERENCE [1]

3 – MASS TRANSFER: VENTILATION AND/OR INFILTRATION

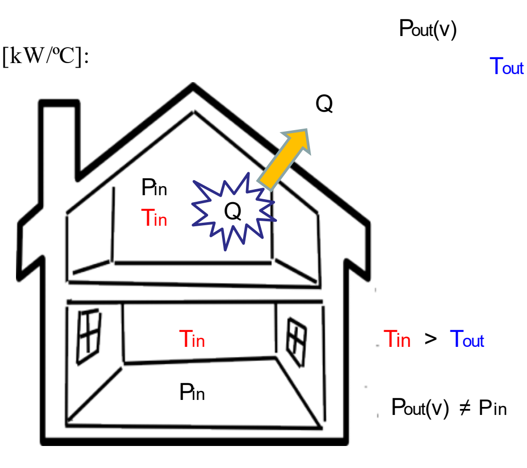
SIMPLEST CASE: ONLY INFILTRATION

The heat that the infiltrations will require for the building's heating system [kW]

$$Q_{infiltration} = \dot{V}_{air(\text{inf})}\rho_{air}cp_{air}(T_{in} - T_{out})$$

The infiltration heat loss coefficient is [kW/ºC]:

$$C_v = \dot{V}_{air(\text{inf})}\rho_{air}cp_{air}$$



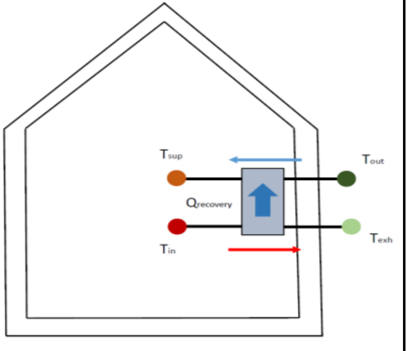
3 – MASS TRANSFER: VENTILATION AND/OR INFILTRATION

DYNASTEE

GENERAL CASE: VENTILATION WITH HEAT RECOVERY PLUS INFILTRATION

The percentage of heat recovered [-]

$$\eta = \frac{T_{sup} - T_{out}}{T_{in} - T_{out}}$$



The heat exchanged inside the heat exchanger [kW]:

$$Q_{recovery} = \dot{V}_{air}\rho_{air}cp_{air} \cdot (T_{in} - T_{exh})$$

$$Q_{recovery} = \dot{V}_{air}\rho_{air}cp_{air} \cdot (T_{sup} - T_{out})$$

The heat that the ventilation system will require for the building's heating system [kW]

$$Q_{ventilation} = \dot{V}_{air(vent)}\rho_{air}cp_{air} \cdot (T_{in} - T_{sup})$$

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3 – MASS TRANSFER: VENTILATION AND/OR INFILTRATION

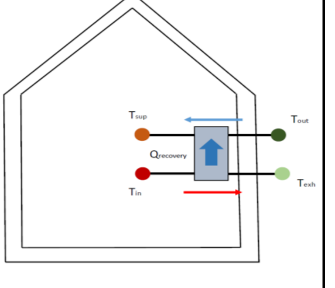
DYNASTEE

GENERAL CASE: VENTILATION WITH HEAT RECOVERY PLUS INFILTRATION

A relation between T_{sup}, T_{in}, T_{out} and η can be obtained [kW]:

$$Q_{ventilation} = \dot{V}_{air(vent)}\rho_{air}cp_{air}(1-\eta)(T_{in} - T_{out})$$

$$Q_{infiltration} = \dot{V}_{air(\inf)}\rho_{air}cp_{air}(T_{in} - T_{out})$$



Therefore, if the heat recovery system is added to the building, the ventilation plus infiltration heat loss coefficient is [kW/ºC]:

$$C_v = \dot{V}_{air(vent)}\rho_{air}cp_{air} \cdot (1-\eta) + \dot{V}_{air(\inf)}\rho_{air}cp_{air}$$

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4 – BUILDING ENVELOPE HEAT LOSS COEFFICIENT (HLC)

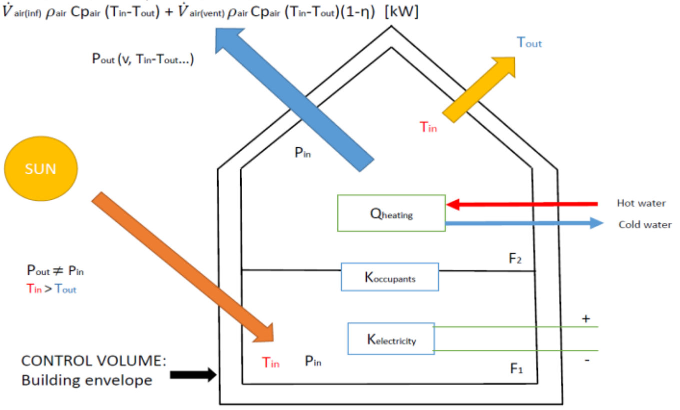
DYNASTEE

$Q_{ventilation} = C_{v\,(vent)}\,(T_{in}-T_{out}) = \dot{V}_{air(vent)}\,\rho_{air}\,Cp_{air}\,(T_{in}-T_{out})(1-\eta)$ [kW]

$Q_{infiltration} = C_{v\,(inf)}\,(T_{in}-T_{out}) = \dot{V}_{air(inf)}\,\rho_{air}\,Cp_{air}\,(T_{in}-T_{out})$ [kW]

$Q_{inf+vent} = \dot{V}_{air(inf)}\,\rho_{air}\,Cp_{air}\,(T_{in}-T_{out}) + \dot{V}_{air(vent)}\,\rho_{air}\,Cp_{air}\,(T_{in}-T_{out})(1-\eta)$ [kW]

$Q_{transmission} = UA\,(T_{in}-T_{out})$ [kW]



$$\frac{dE_{cv}}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \sum_i \dot{m}_i\left(h_i + \frac{V_i^2}{2} + gz_i\right) - \sum_e \dot{m}_e\left(h_e + \frac{V_e^2}{2} + gz_e\right) \ \text{[kW]}$$

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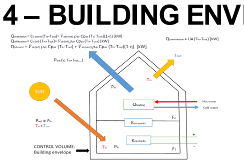
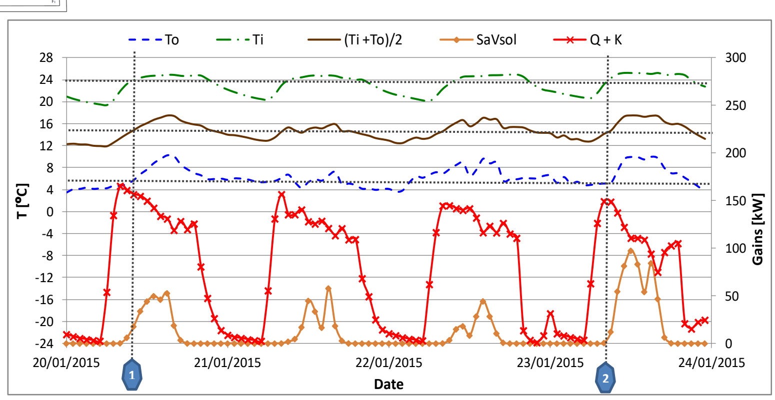
4 – BUILDING ENVELOPE HEAT LOSS COEFFICIENT (HLC)

DYNASTEE





$$\frac{dE_{cv}}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \sum_i \dot{m}_i\left(h_i + \frac{V_i^2}{2} + gz_i\right) - \sum_e \dot{m}_e\left(h_e + \frac{V_e^2}{2} + gz_e\right) \ \text{[kW]}$$

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4 – BUILDING ENVELOPE HEAT LOSS COEFFICIENT (HLC)

DYNASTEE

$$\sum_{i=1}^{z} m_i c_i(T_i(t_2) - T_i(t_1)) + \sum_{k=1}^{N} Q_k \Delta t + \sum_{k=1}^{N} K_k \Delta t = HLC \sum_{k=1}^{N} (T_{in,k} - T_{out,k})\Delta t - \sum_{k=1}^{N} (S_a V_{sol})_k) \Delta t$$

$$HLC = (UA + C_v) \text{ [kW/ºC]}$$

Thus, if the thermal level is not equal at the start and end of the analysis period [kW/ºC]

$$HLC = \frac{\sum_{i=1}^{z} m_i c_i (T_i(t_2) - T_i(t_1)) + \sum_{k=1}^{N} (Q_k + K_k + (S_a V_{sol})_k) \Delta t}{\sum_{k=1}^{N} (T_{in,k} - T_{out,k}) \Delta t}$$

Thus, if the thermal level is equal at the start and end of the analysis period [kW/ºC]

$$\text{HLC} = \frac{\sum_{k=1}^{N} (Q_k + K_k + (S_a V_{sol})_k)}{\sum_{k=1}^{N} (T_{in,k} - T_{out,k})}$$

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DETAILED INFO IN REFERENCE [2]

5 – INTRODUCTION TO MEASUREMENTS FOR BUILDING ENERGY PERFORMANCE ASSESSMENT

DYNASTEE

- Dynamic testing of building components requires a very well controlled and positioned **set of sensors** with a correct measuring and control system that will provide high quality data sets.

- The **quality requirements** developed during the different **PASSYS and PASLINK projects** have been found to perform an optimal **full scale testing of a building component**.

- These results are **also valid for any building component or building in its whole** that wants to be monitored since the focus is done in optimising the measuring and monitoring systems

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6 – BUILDING COMPONENT: PASLINK METHOD

DYNASTEE

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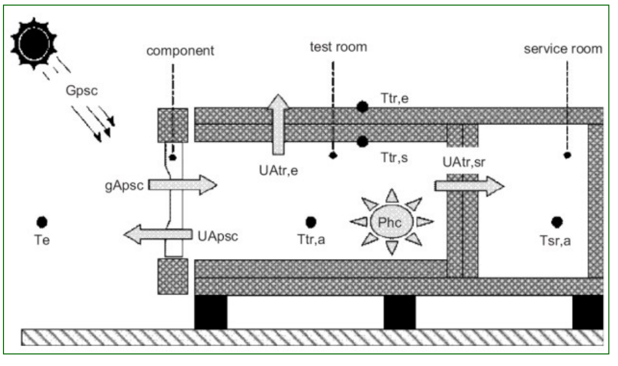
6 – BUILDING COMPONENT: PASLINK METHOD

DYNASTEE



To obtain reliable data sets for **dynamic data analysis** :

• Average temperature difference of about 20ºC. 0.5ºC accumulated error → 2.5%.

• Heating or cooling signals generated inside the test room must not be correlated to the exterior temperature → PRBS (Pseudo Random Binary Sequence) or ROLBS (Randomly Ordered Logarithmically Binary Sequence).

• Inner surface heat flux with accuracy must be better than a 5%: direct heat flux measurement vs. indirect measurement for semitransparent elements (HFS Tile method).

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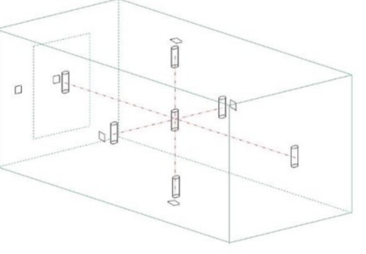
6 – BUILDING COMPONENT: PASLINK STANDARD SENSORS

DYNASTEE

Internal air temperature measurements

- Seven air temperature sensors (PT100) protected against radiation positioned as in figure with an accuracy of ± 0.1 °C.
- The PASLINK network test requires the maximum differences of indoor air temperatures must be under 0.5 °C.
- Average of those seven sensors is used as the internal air temperature.



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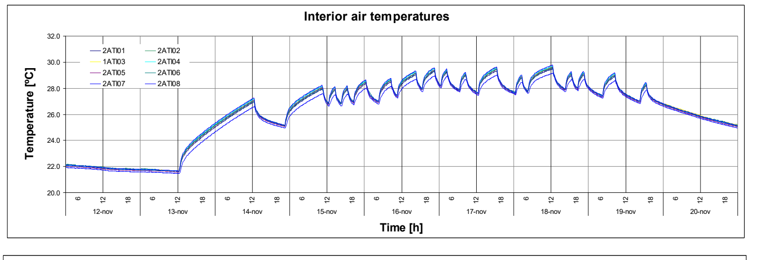
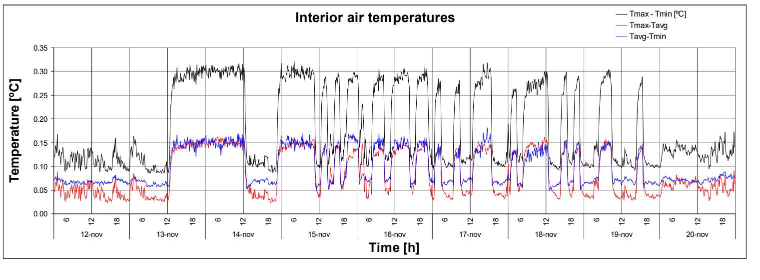
6 – BUILDING COMPONENT: PASLINK METHOD

DYNASTEE

Internal air temperature measurements





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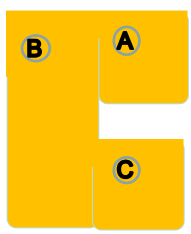
Considerations on temperature measurements: thermal equilibrium

- It is a matter of experience that when two objects are in thermal equilibrium with a third object, they are in thermal equilibrium with one another.
- This statement is called the **Zeroth law of thermodynamics** and is tacitly assumed in every measurement of temperature.



A thermal equilibrium **B**
B thermal equilibrium **C**

→ **A** thermal equilibrium **C**

Considerations on temperature measurements: THERMOCOUPLES

The main advantages of the thermocouples are:

- Low cost
- No moving parts (less likely to break)
- Wide range of temperatures
- Reasonably short response time
- Repeatability and acceptable accuracies
- Fairly linear response

The main disadvantages of the thermocouples are:

- The sensitivity is quite low, generally 50μV/°C or less
- Generally the accuracy is not greater than 0.5 ° C.
- Requires a reference temperature.

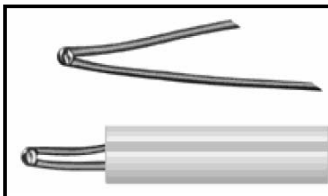


Figura 1 – Terminal soldada de un termopar

The theoretical answer for a K type of thermocouples is given by the following expression:

$$E = \sum_{i=0}^{9} c_i \cdot t^i + a_0 \cdot e^{a_1 \cdot (t-a_2)^2}$$

6 – BUILDING COMPONENT: PASLINK METHOD

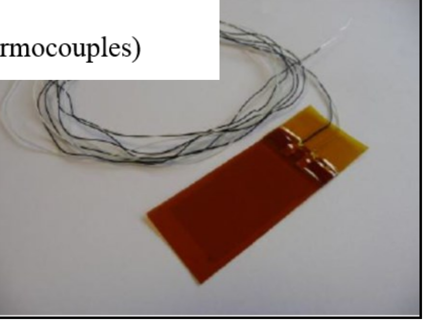
Considerations on temperature measurements: THERMORESISTANCE

The main advantages of the thermoresistances are:

- Accuracy
- Sensitivity

The main disadvantages of the thermoresistances are:

- Fragility
- Price (more expensive than thermocouples)

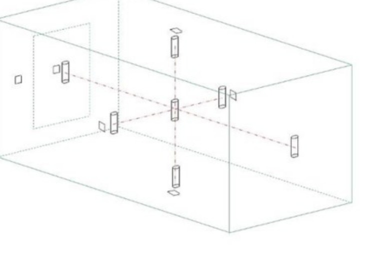


29

6 – BUILDING COMPONENT: PASLINK METHOD

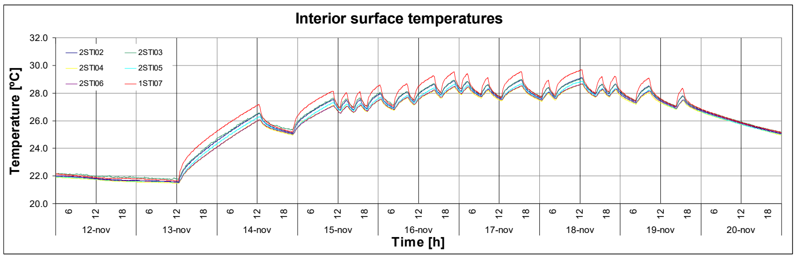
Internal surface temperature measurements

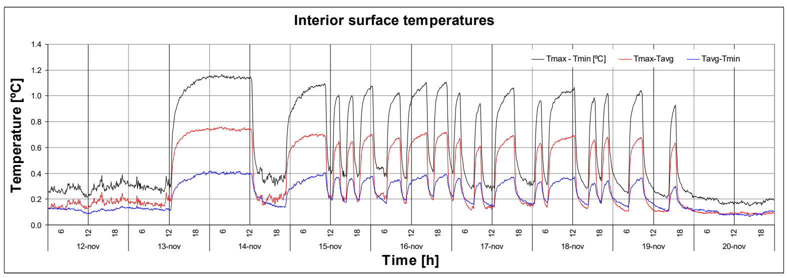
• Seven surface temperature sensors (PT100) with an accuracy of ± 0.1 °C.
• The maximum deviation between sensors is reduced to around 0.5ºC.
• This permits to work with a single value of surface temperature inside the test room, obtained by averaging.



6 – BUILDING COMPONENT: PASLINK METHOD

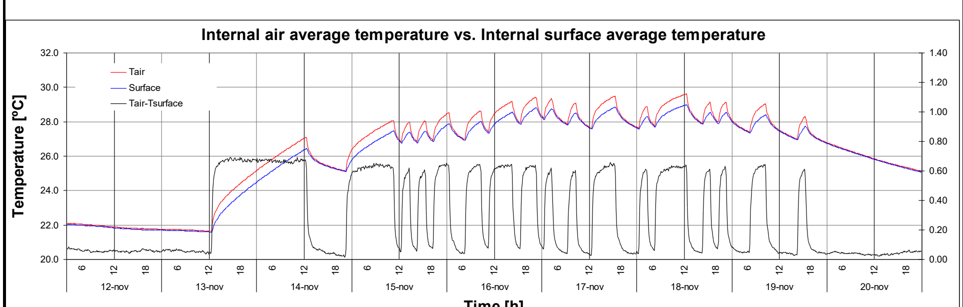
Internal surface temperature measurements





6 – BUILDING COMPONENT: PASLINK METHOD

Internal air and surface temperature measurements



6 – BUILDING COMPONENT: PASLINK METHOD

DYNASTEE

Outdoors temperature measurements

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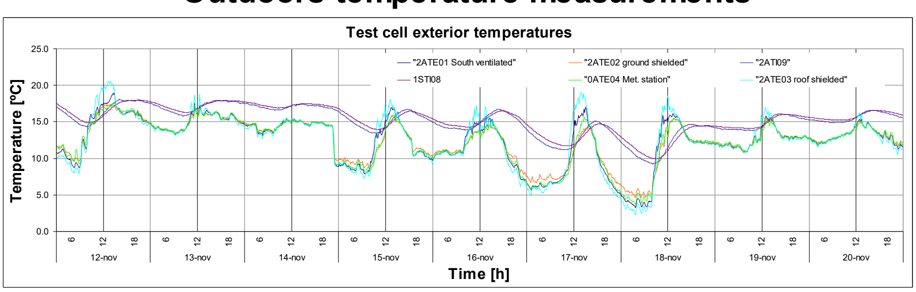
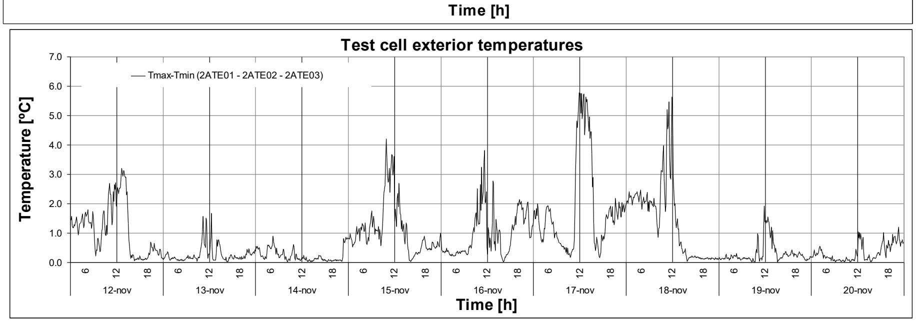
6 – BUILDING COMPONENT: PASLINK METHOD

DYNASTEE

Outdoors temperature measurements





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6 – BUILDING COMPONENT: PASLINK METHOD

Solar radiation measurements - concepts

PLANCK'S LAW: The spectral blackbody emissive power:

$$E_{b\lambda}(\lambda,T)=\frac{C_1}{\lambda^5\,[\,\exp\,(C_2/\lambda T)-1]}\quad[W/m^2\mu m]$$

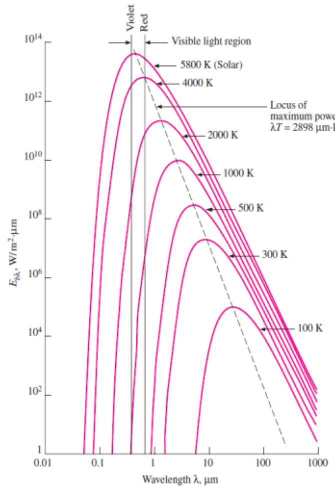
$$C_1=2\,\pi h\,c_0^2=3.74177\;x\,10^8[W\mu m^4/m^2]$$

$$C_2=h\,c_0/k=1.43878\;\;x\;\;10^4\;\;[\mu m\,K]$$

$$k=1.38065x10^{-23}[J/K]$$

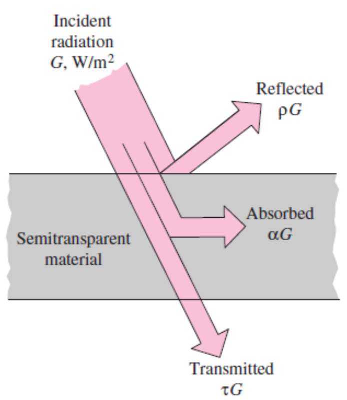
For other medium: $C_1=\frac{C_1}{n^2}$

n: Index of refraction



6 – BUILDING COMPONENT: PASLINK METHOD

Solar radiation measurements - concepts



Absorptivity: $\alpha=\frac{\text{Absorbed radiation}}{\text{Incident radiation}}=\frac{G_{abs}}{G},\quad 0\le\alpha\le1$

Reflectivity: $\rho=\frac{\text{Reflected radiation}}{\text{Incident radiation}}=\frac{G_{ref}}{G},\quad 0\le\rho\le1$

Transmissivity: $\tau=\frac{\text{Transmitted radiation}}{\text{Incident radiation}}=\frac{G_{tr}}{G},\quad 0\le\tau\le1$

$$G_{abs}+G_{ref}+G_{tra}=G$$

$$\alpha+\rho+\tau=1$$

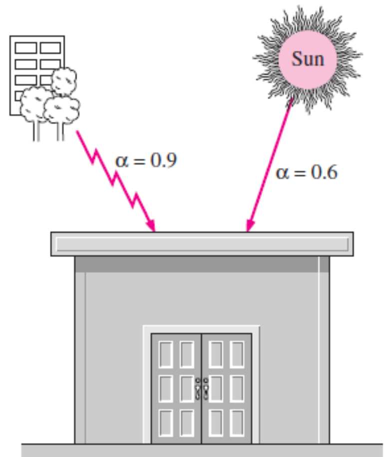
Blackbody	Specular surface	Transparent surface	Opaque surface	Matt surface
• α =1 • ρ=τ=0	• ρ =1 • α=τ=0	• τ =1 • α=ρ=0	• τ =0 • α+ρ=1	• ρ =0 • α+τ=1

DYNASTEE

Solar radiation measurements - concepts

Comparison of the solar absorptivity α_s of some surfaces with their emissivity ε at room temperature

Surface	α_s	ε
Aluminum		
Polished	0.09	0.03
Anodized	0.14	0.84
Foil	0.15	0.05
Copper		
Polished	0.18	0.03
Tarnished	0.65	0.75
Stainless steel		
Polished	0.37	0.60
Dull	0.50	0.21
Plated metals		
Black nickel oxide	0.92	0.08
Black chrome	0.87	0.09
Concrete	0.60	0.88
White marble	0.46	0.95
Red brick	0.63	0.93
Asphalt	0.90	0.90
Black paint	0.97	0.97
White paint	0.14	0.93
Snow	0.28	0.97
Human skin (caucasian)	0.62	0.97



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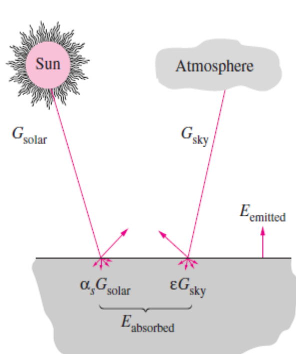
Solar radiation measurements - concepts

ATMOSPHERIC EMISSION

H_2O and CO_2: emission at λ= 5-8 μm

Effective sky temperature (T_{sky}) : depending on atmospheric conditions 230-285 K



$$G_{sky} = \sigma T_{sky}^4 \ [W/m^2]$$

Kirchhoff's law: $\varepsilon = \alpha$

$$E_{sky,abs} = \alpha \, G_{sky} = \alpha \, \sigma \, T_{sky}^4 = \varepsilon \, \sigma \, T_{sky}^4 \ [W/m^2]$$

$$q_{net,rad} = \sum E_{abs} - \sum E_{emitted}$$

$$q_{net,rad} = E_{solar,abs} + E_{sky,abs} - E_{emit}$$

$$q_{net,rad} = \alpha_s G_{solar} + \varepsilon \, \sigma \, T_{sky}^4 - \varepsilon \, \sigma \, T_s^4$$

$$q_{net,rad} = \alpha_s G_{solar} + \varepsilon \sigma (T_{sky}^4 - T_s^4) \ [W/m^2]$$

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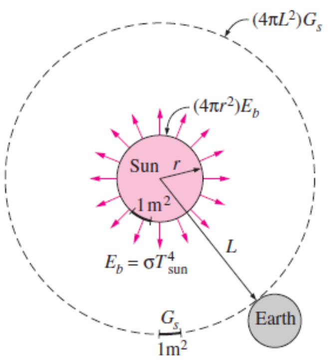
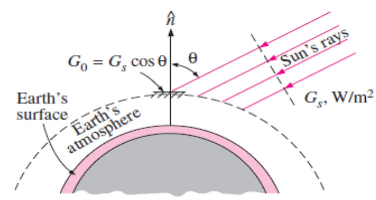
6 – BUILDING COMPONENT: PASLINK METHOD

Solar radiation measurements - concepts

CHARACTERISTICS OF THE SUN



$D = 1.39 \times 10^9$ m
$L = 1.50 \times 10^{11}$ m from the Earth
$E_{sun} = 3.8 \times 10^{26}$ W
$E_{reaching\ the\ earth} = 1.7 \times 10^{17}$ W
$T_{core} = 40\ 000\ 000$ K
$T_{exterior} = 5\ 800$ K



Total solar irradiance: solar energy reaching to the atmosphere **G_s = 1373 W/m²**

6 – BUILDING COMPONENT: PASLINK METHOD

Solar radiation measurements - concepts

ATMOSPHERE ABSORPTION

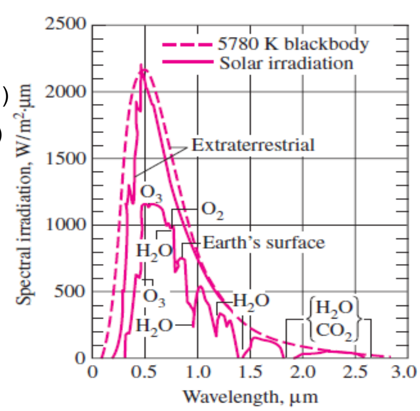
Solar radiation is attenuated when crossing the atmosphere

99% of the atmosphere is inside a distance of 30 km

O_2: absorption λ= 0.76 µm

O_3 (ozone): absorption λ= 0.30 µm (ultraviolet region)

H_2O and CO_2: absorption λ= 1.5 µm (infrared region)



Solar radiation incident over the **Earth surface**:

Solar radiation flux: 950 W/m²

Wavelength: 0.3-2.5 µm

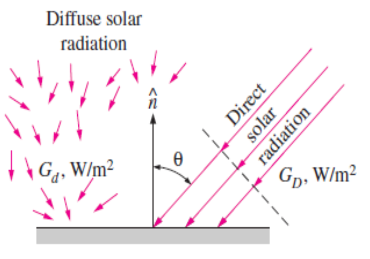
6 – BUILDING COMPONENT: PASLINK METHOD

DYNASTEE

Solar radiation measurements - concepts

Direct solar radiation G_D: The part of solar radiation that reaches the earth's surface without being scattered or absorbed by the atmosphere.

Diffuse solar radiation G_d: The scattered radiation is assumed to reach the earth's surface uniformly from all directions.



$$G_{solar} = G_D \cos\theta + G_d \;\; [W/m^2]$$

θ: angle of incidence

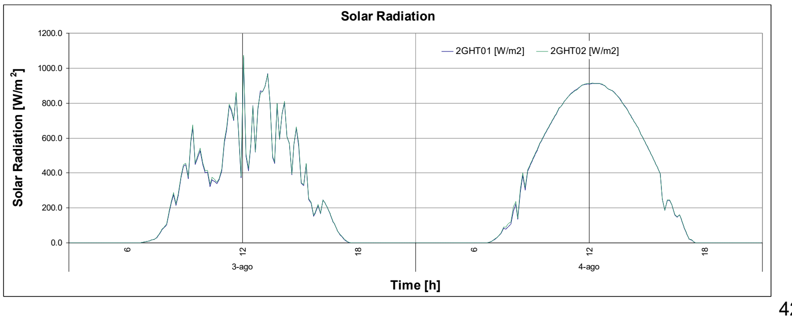
6 – BUILDING COMPONENT: PASLINK METHOD

DYNASTEE

Solar radiation measurements

• Global solar radiation on the building component plane (**pyranometers** with a 3% accuracy) and the outdoors temperature are the most important environmental variables.

• Diffuse horizontal solar radiation (**pyranometers** 3% accuracy) and longwave radiation (**pyrgeometer** 5% accuracy) are also recommended although not used in some modelling approaches.

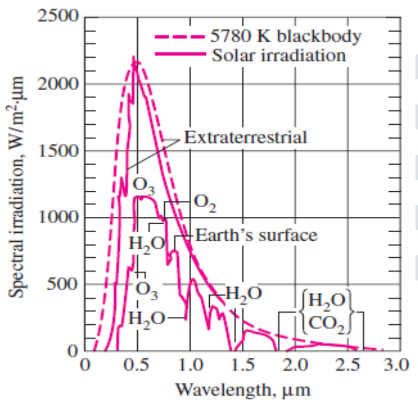


Solar radiation measurements

• Global solar radiation on the building component plane (**pyranometers** with a 3% accuracy) and the outdoors temperature are the most important environmental variables.

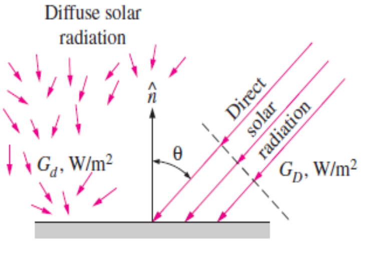
Specifications

Spectral range (50% points)	285 to 2800 nm
Sensitivity	7 to 14 µV/W/m²
Response time	< 5 s
Zero offset A	< 7 W/m²
Zero offset B	< 2 W/m²
Directional response (up to 80° with 1	< 10 W/m²
Temperature dependence of sensitivity	< 1 %
Operational temperature range	-40 °C to +80 °C
Maximum solar irradiance	4000 W/m²
Field of view	180 °



Solar radiation measurements

•Diffuse horizontal solar radiation (3% accuracy).



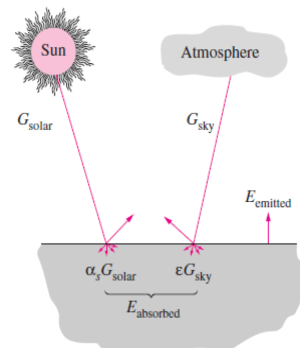
$$G_{solar} = G_D \cos\theta + G_d \quad [W/m^2]$$

θ: angle of incidence

6 – BUILDING COMPONENT: PASLINK METHOD

Solar radiation measurements

• longwave radiation (**pyrgeometer** 5% accuracy) are also recommended although not used in some modelling approaches .



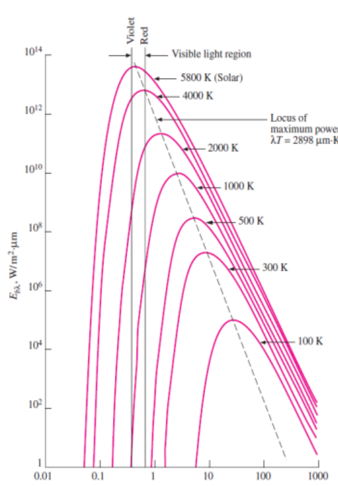
$$q_{net,rad} = \alpha_s G_{solar} + \varepsilon\sigma(T_{sky}^4 - T_s^4)\ [W/m^2]$$

6 – BUILDING COMPONENT: PASLINK METHOD

Solar radiation measurements

• longwave radiation (**pyrgeometer** 5% accuracy) are also recommended although not used in some modelling approaches .

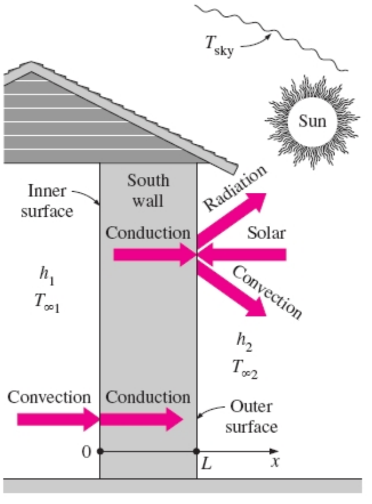
Product | Specificatio | elevant News Items | Application Examples

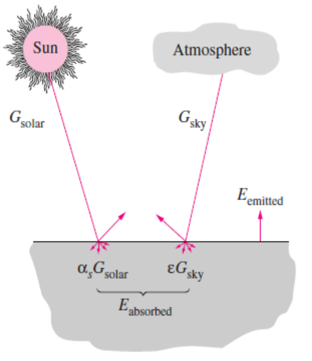


Specifications

Spectral range (50% points)	4.5 to 42 µm = 4500 to 42000 nm
Sensitivity	5 to 15 µV/W/m²
Response time	18 s
Window heating offset	< 4 W/m²
Zero offset B	< 2 W/m²
Temperature dependence of s	< 1 %
Operational temperature rang	-40 to +80 °C
Net irradiance range	-250 to + 250 W/m²
Field of view	180 °
Non-linearity	< 1 %

Solar radiation measurements

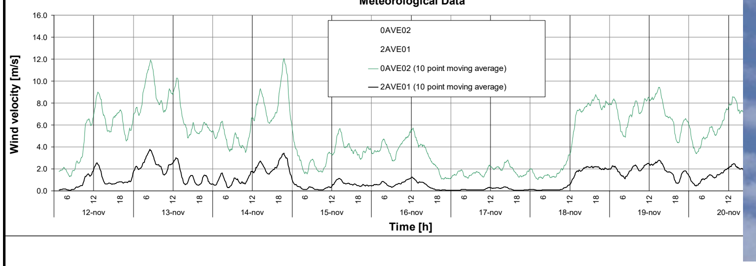




$$q_{net,rad} = \alpha_s G_{solar} + \varepsilon\sigma(T_{sky}^4 - T_s^4)\ [W/m^2]$$

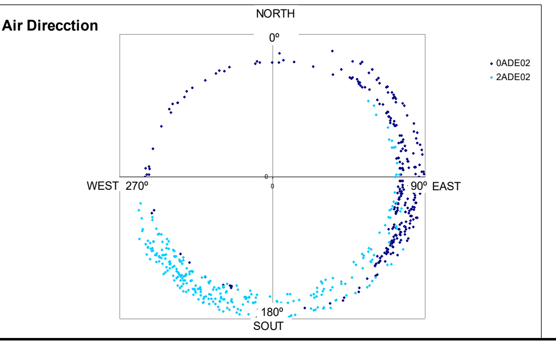
Other meteorological variables measurements

Name	Description	Accuracy
2AVE01	Anemometer. Wind velocity measurement in the same height of the sample.	± 1%
0AVE02	Anemometer. Measured in the VAISALA meteorological station 10 [m] height.	± 1%
2ADE01	Wind direction. Wind direction measurement in the same height of the sample.	± 10º
0ADE02	Wind direction. Measured in the VAISALA meteorological station 10 [m] height.	± 10º
0RHE01	Relative humidity of outdoors air. Measured in the VAISALA meteorological station 10 [m] height.	± 3%
0APE01	Atmospheric pressure. Measured in the VAISALA meteorological station 10 [m] height.	± 10 Pa
0RPE01	Rain precipitation. Measured in the VAISALA meteorological station 10 [m] height.	-



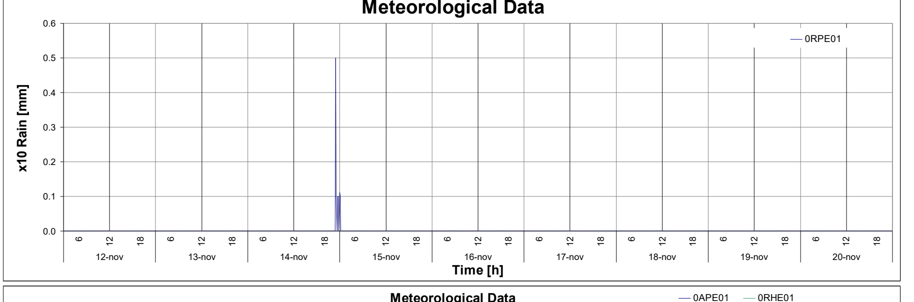
6 – BUILDING COMPONENT: PASLINK METHOD

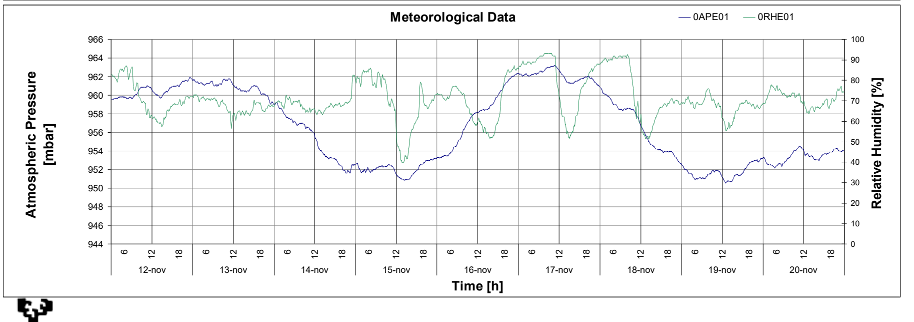
Other meteorological variables measurements



6 – BUILDING COMPONENT: PASLINK METHOD

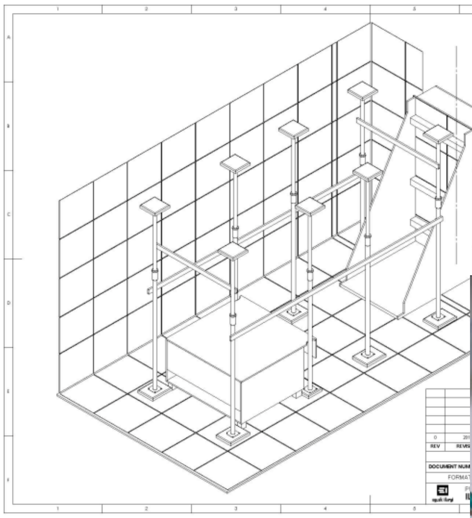
Other meteorological variables measurements

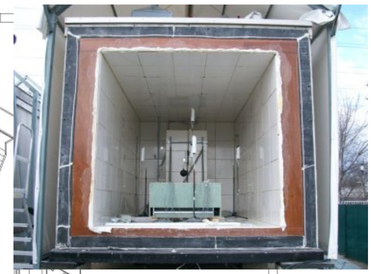




6 – BUILDING COMPONENT: PASLINK METHOD

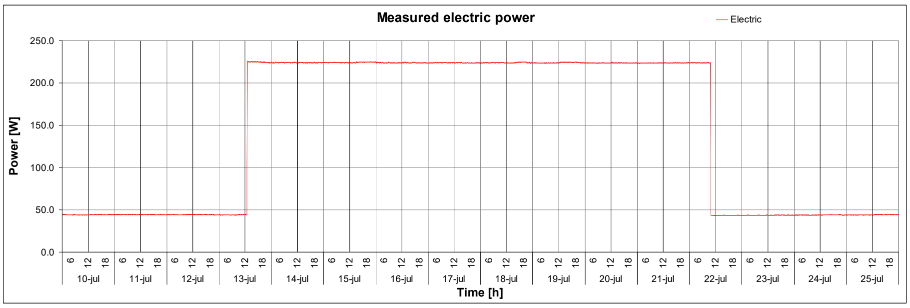
HEAT FLUX SENSITIVE TILES (HFS TILES) AND POWER TRANSDUCER FOR HEAT BALANCE ON THE TEST ROOM - **Power transducer: SINEAX model M562**





6 – BUILDING COMPONENT: PASLINK METHOD

HEAT FLUX SENSITIVE TILES (HFS TILES) AND POWER TRANSDUCER FOR HEAT BALANCE ON THE TEST ROOM - **Power transducer: SINEAX model M562**



Calibration: the maximum error is found to be 0.3 [W] (0.04%) when measuring 690 [W] while the maximum relative error is found when measuring 69 [W] with a 0.17 [W] absolute error making a 0.25%.

6 – BUILDING COMPONENT: PASLINK METHOD

HEAT FLUX SENSITIVE TILES (HFS TILES) AND POWER TRANSDUCER FOR HEAT BALANCE ON THE TEST ROOM - **Design of the HFS Tiles arrangement**

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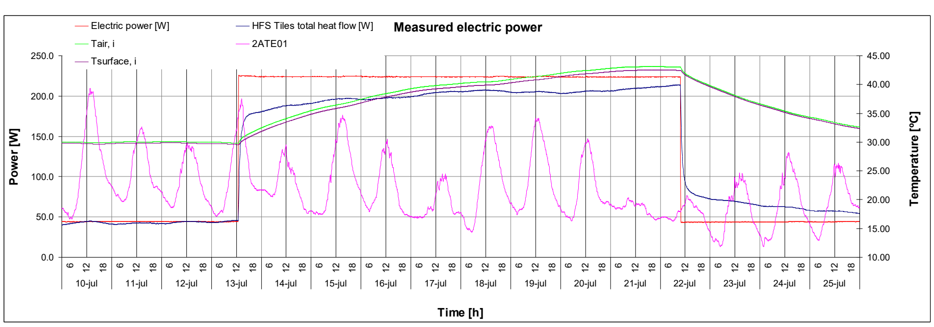
6 – BUILDING COMPONENT: PASLINK METHOD

TYPICAL SIGNALS USED FOR MODELLING PURPOUSES



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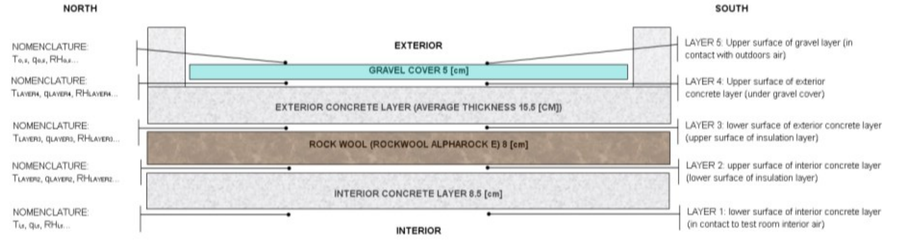
6 – BUILDING COMPONENT: PASLINK METHOD

INSTRUMENTATION ON THE ROOF TEST SAMPLE COVERED BY GRAVEL



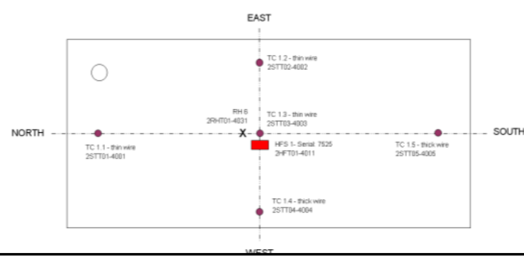
● Temperature sensor: TC (T type thermocouple) or PT100 (Platinum thermoresistance)

■ Heat flux sensor

X Relative humidity sensor

Π Pyranometer

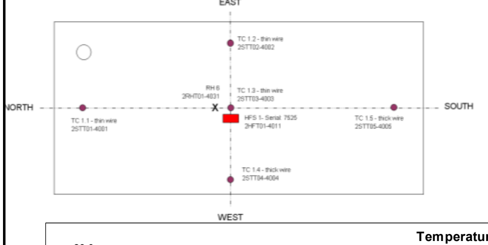
LAYER 1

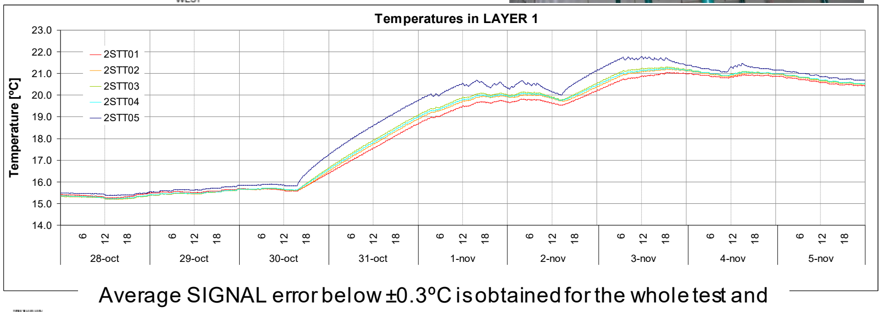


6 – BUILDING COMPONENT: PASLINK METHOD

INSTRUMENTATION ON THE ROOF TEST SAMPLE COVERED BY GRAVEL

LAYER 1



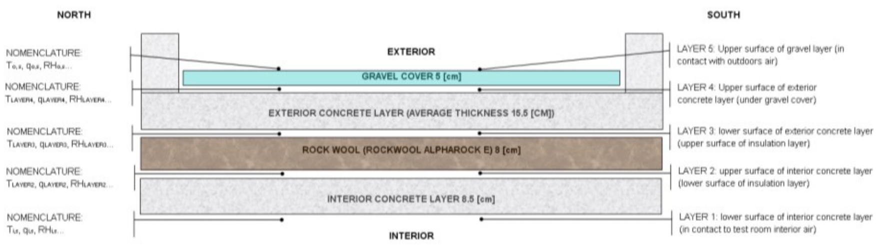


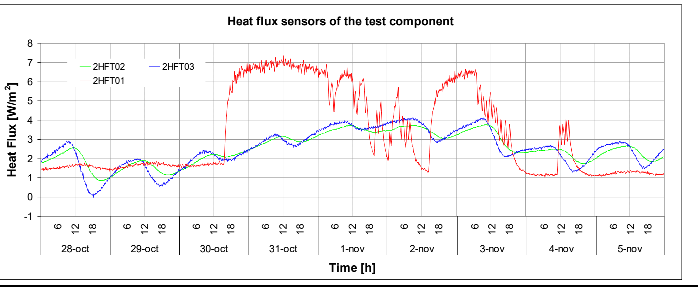
Average SIGNAL error below ±0.3°C is obtained for the whole test and using the average of the four sensors without 2STT05 an average error below ±0.1°C for the whole test

6 – BUILDING COMPONENT: PASLINK METHOD

DYNASTEE

HEAT FLUX MEASUREMENTS IN DIFFERENT LAYERS





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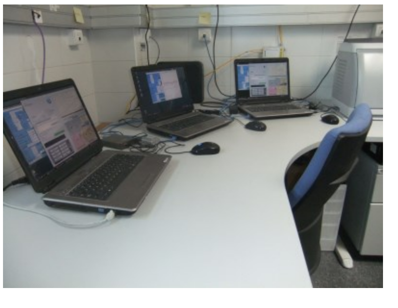
6 – BUILDING COMPONENT: PASLINK METHOD

DYNASTEE



- HP Agilent 34980A
- 5 multiplexer 34921A
- 1 control 34951A module
- "dayflies" where each sensor signal is recorded every minute

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7 – MONITORING WHOLE BUILDINGS

DYNASTEE

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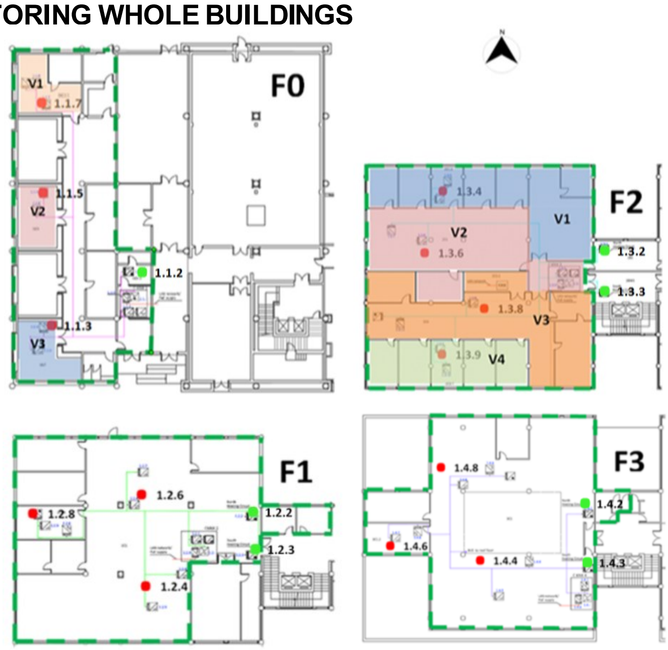
7 – MONITORING WHOLE BUILDINGS

DYNASTEE



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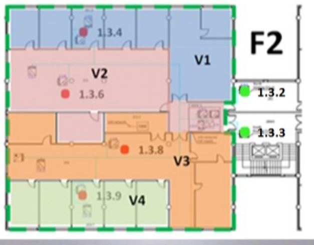
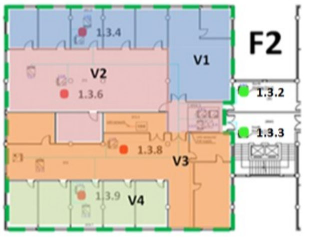
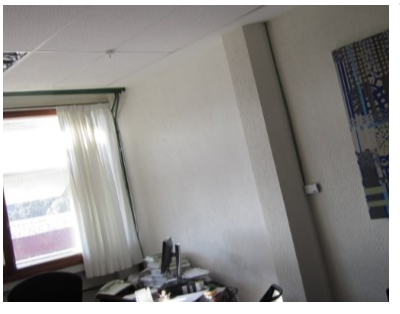
7 – MONITORING WHOLE BUILDINGS



7 – MONITORING WHOLE BUILDINGS

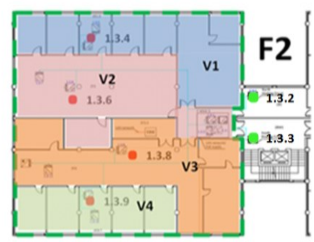




	SK04 -S8-CO2-TF	Plastic housing: 121 x 70 x 24 mm Measured temperature range: -10 .. +55 °C Measured humidity range: 10 .. 90% r.H. CO2 measuring range: 0 .. 5000 ppm On-wall mounting in dry indoor applications IP20

7 – MONITORING WHOLE BUILDINGS

DYNASTEE



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7 – MONITORING WHOLE BUILDINGS

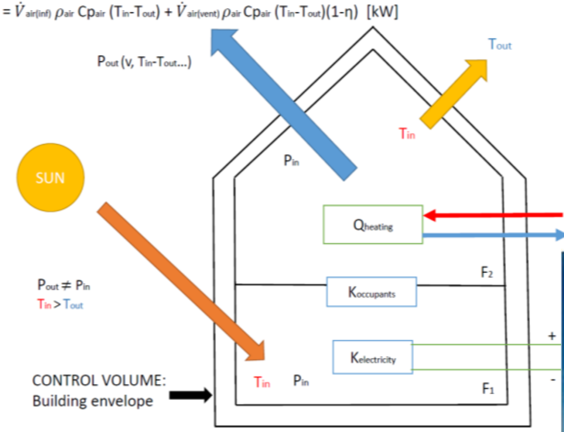
DYNASTEE

$Q_{ventilation} = C_{v\,(vent)}\,(T_{in}-T_{out}) = \dot{V}_{air(vent)}\,\rho_{air}\,Cp_{air}\,(T_{in}-T_{out})(1-\eta)$ [kW]

$Q_{infiltration} = C_{v\,(inf)}\,(T_{in}-T_{out}) = \dot{V}_{air(inf)}\,\rho_{air}\,Cp_{air}\,(T_{in}-T_{out})$ [kW]

$Q_{inf+vent} = \dot{V}_{air(inf)}\,\rho_{air}\,Cp_{air}\,(T_{in}-T_{out}) + \dot{V}_{air(vent)}\,\rho_{air}\,Cp_{air}\,(T_{in}-T_{out})(1-\eta)$ [kW]

$Q_{transmission} = UA\,(T_{in}-T_{out})$ [kW]



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7 – MONITORING WHOLE BUILDINGS

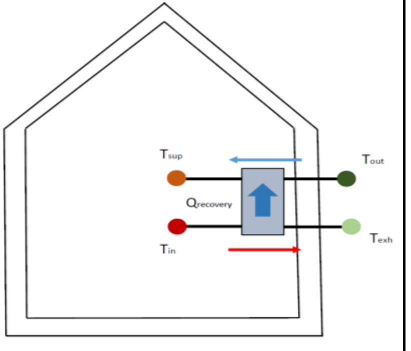
DYNASTEE

GENERAL CASE: VENTILATION WITH HEAT RECOVERY PLUS INFILTRATION

The percentage of heat recovered [-]

$$\eta = \frac{T_{sup} - T_{out}}{T_{in} - T_{out}}$$

The heat exchanged inside the heat exchanger [kW]:



$$Q_{recovery} = \dot{V}_{air}\rho_{air}cp_{air} \cdot (T_{in} - T_{exh})$$

$$Q_{recovery} = \dot{V}_{air}\rho_{air}cp_{air} \cdot (T_{sup} - T_{out})$$

The heat that the ventilation system will require for the building's heating system [kW]

$$Q_{ventilation} = \dot{V}_{air(vent)}\rho_{air}cp_{air} \cdot (T_{in} - T_{sup})$$

DETAILED INFO IN REFERENCE [3]

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8 – REFERENCES

DYNASTEE

[1] ÇENGEL, Y. A., HEAT AND MASS TRANSFER, A Practical Approach. McGraw-Hill. 3rd Edition 2007

[2] Irati Uriarte, Aitor Erkoreka. Catalina Giraldo-Soto, Koldo Martin, Amaia Uriarte, Pablo Eguia, **Mathematical development of an average method for estimating the reduction of the Heat Loss Coefficient of an energetically retrofitted occupied office building, Energy and Building, 2019, DOI:** https://doi.org/10.1016/j.enbuild.2019.03.006

[3] Giraldo-Soto, C.; Erkoreka, A.; Mora, L.; Uriarte, I.; Del Portillo, L.A. **Monitoring System Analysis for Evaluating a Building's Envelope Energy Performance through Estimation of Its Heat Loss Coefficient.** Sensors 2018, 18, 2360, **DOI:** https://doi.org/10.3390/s18072360

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