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

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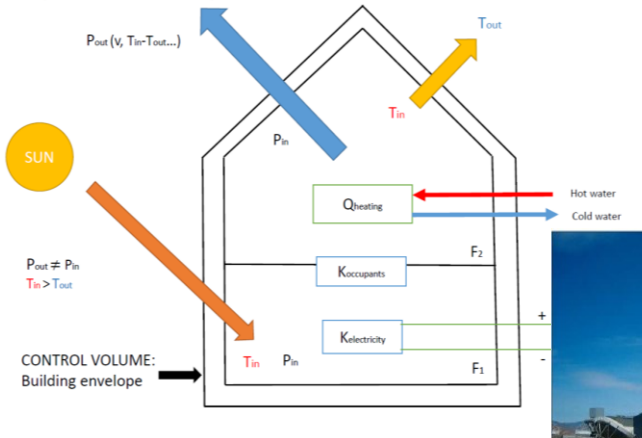
1 - INTRODUCTION

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

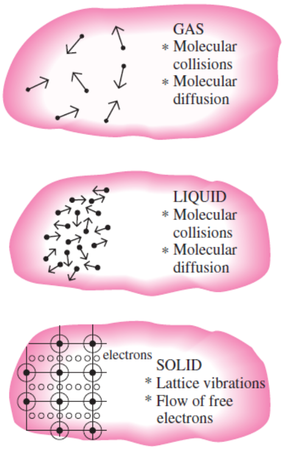


1 – INTRODUCTION: CONDUCTION

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:

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

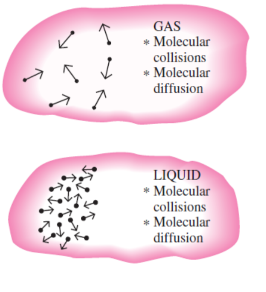


1 – INTRODUCTION: CONVECTION

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:

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



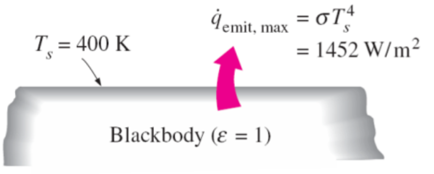
In the absence of any bulk fluid motion, heat transfer between a solid surface and the adjacent fluid is by pure conduction.

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

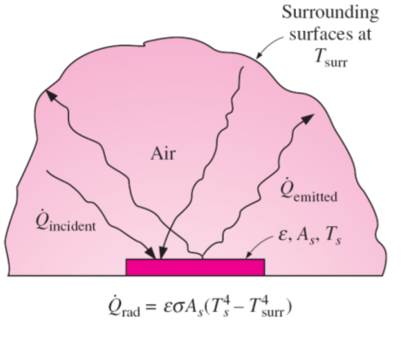
RADIATION HEAT TRANSFER:
Difference between emitted and absorbed

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

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

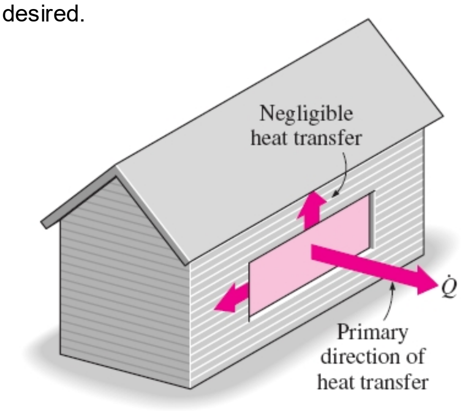
KIRCHOFF'S LAW

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



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.



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

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

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

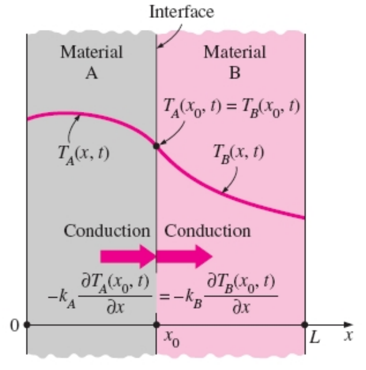
$$\dot{Q}_n=-k\cdot A\cdot\left|\overrightarrow{grad}(T)\right| \qquad [\mathrm{W}]$$

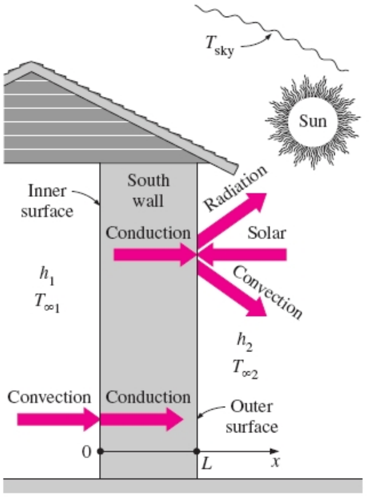
1 – INTRODUCTION: SOLVING A CONDUCTION PROBLEM

INTERFACE BOUNDARY CONDITIONS

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

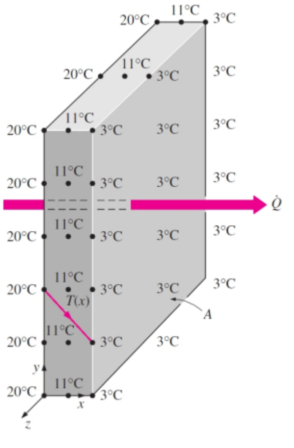
$$-k_A \frac{\partial T_A(x_0,t)}{\partial x} = -k_B \frac{\partial T_B(x_0,t)}{\partial x}$$





2 - STEADY HEAT CONDUCTION IN PLANE WALLS

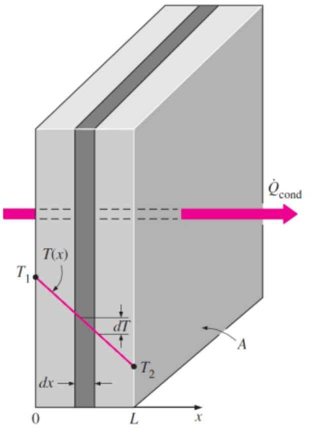
- The wall of a house during winter time



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

$$\Downarrow$$

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



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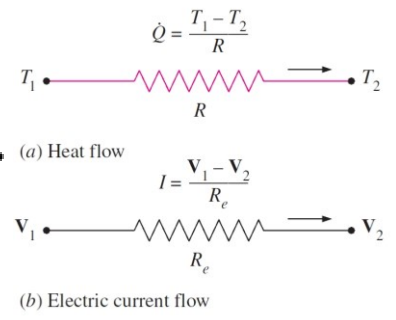
THE THERMAL RESISTANCE CONCEPT

Thermal-Electrical analogy



Conditions:

- Steady-state
- NO heat generation

- Conduction:

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

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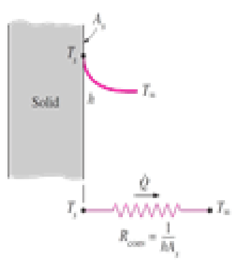
THE THERMAL RESISTANCE CONCEPT

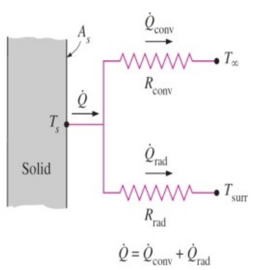
- Convection:



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

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

- Radiation:

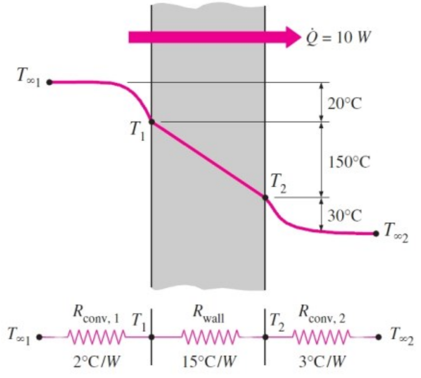


$$\dot{Q}_{rad} = \varepsilon \cdot \sigma \cdot A_s\left(T_s^4 - T_{surr}^4\right) = h_{rad} \cdot A_s\left(T_s - T_{surr}\right) =$$

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

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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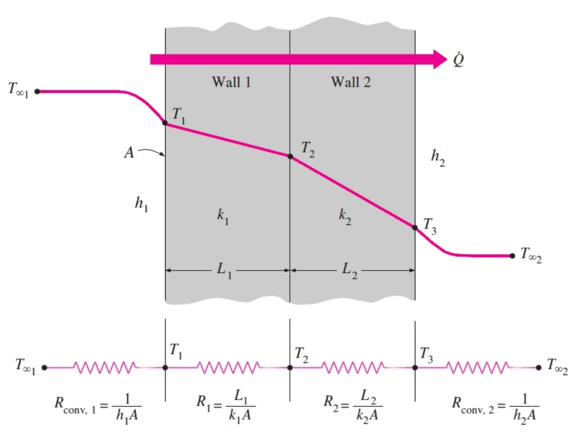
MULTILAYER PLANE WALLS



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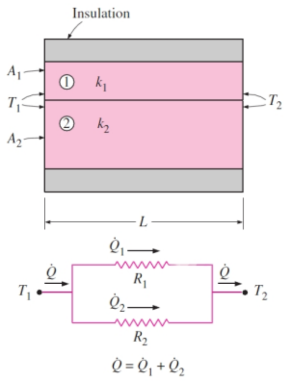
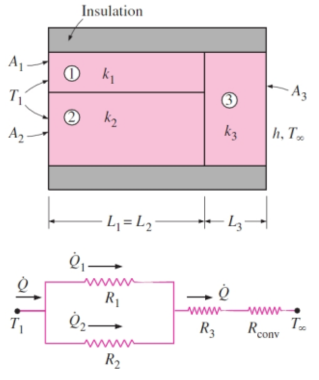
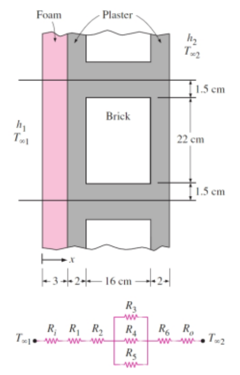
2 - STEADY HEAT CONDUCTION IN PLANE WALLS

DYNASTEE







DETAILED INFO IN REFERENCE [1]

3 – MASS TRANSFER: VENTILATION AND/OR INFILTRATION

DYNASTEE

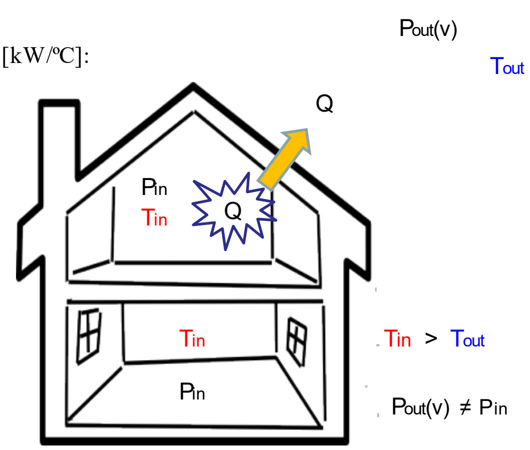
SIMPLEST CASE: ONLY INFILTRATION

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

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

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

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



3 – MASS TRANSFER: VENTILATION AND/OR INFILTRATION

GENERAL CASE: VENTILATION WITH HEAT RECOVERY PLUS INFILTRATION

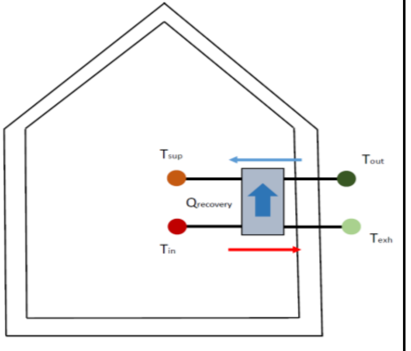
The percentage of heat recovered [-]

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

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]

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

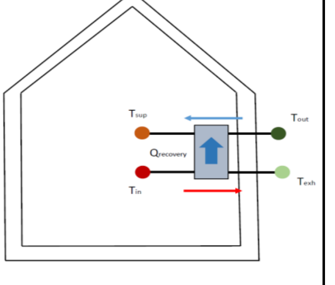
3 – MASS TRANSFER: VENTILATION AND/OR INFILTRATION

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]:

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

4 – BUILDING ENVELOPE HEAT LOSS COEFFICIENT (HLC)

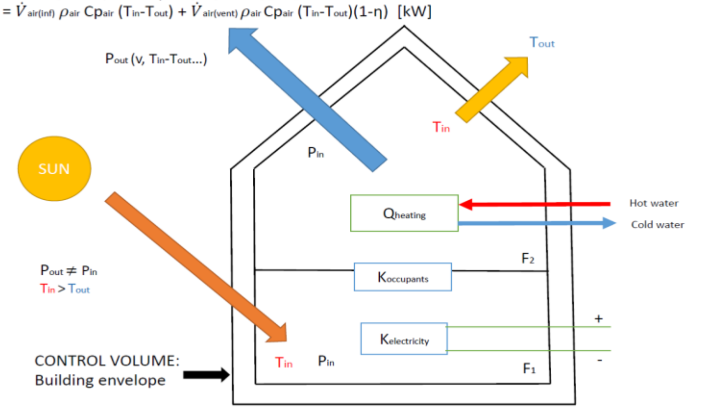
DYNASTEE

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

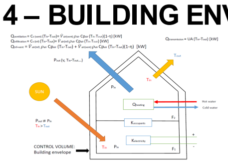
$Q_{transmission} = UA\,(T_{in}-T_{out})$ [kW]

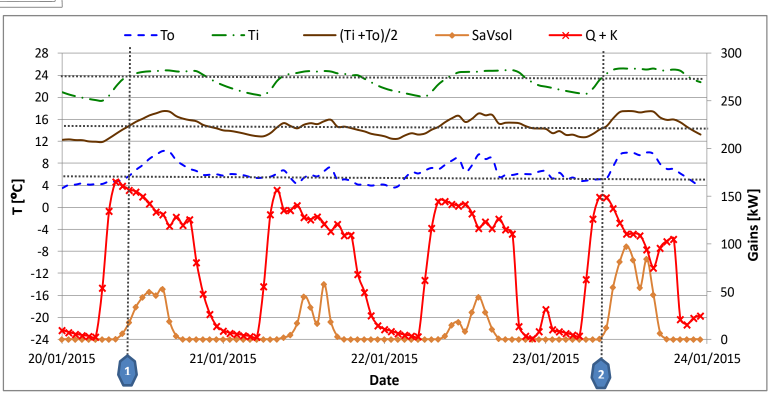


$$\frac{dE_{cv}}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \sum_i \dot{m}_i\left(h_i + \frac{V_i^2}{2} + gz_i\right) - \sum_e \dot{m}_e\left(h_e + \frac{V_e^2}{2} + gz_e\right)\ \ [\mathrm{kW}]$$

4 – BUILDING ENVELOPE HEAT LOSS COEFFICIENT (HLC)

DYNASTEE





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

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

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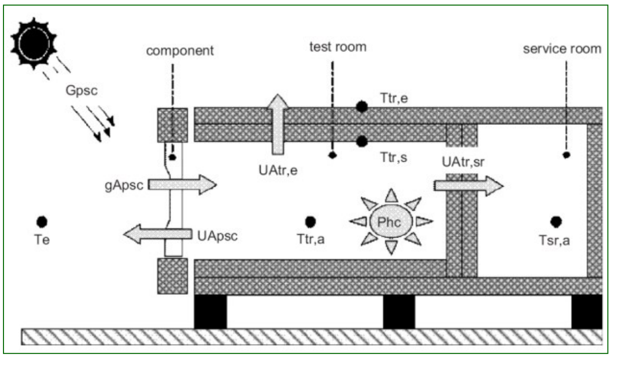


To obtain reliable data sets for **dynamic data analysis** :

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

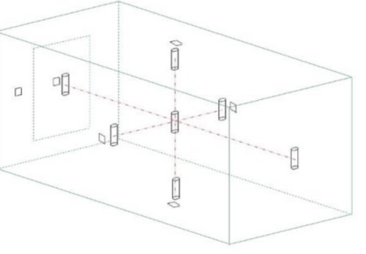
• Heating or cooling signals generated inside the test room must not be correlated to the exterior temperature → PRBS (Pseudo Random Binary Sequence) or ROLBS (Randomly Ordered Logarithmically Binary Sequence).

• 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).

6 – BUILDING COMPONENT: PASLINK STANDARD SENSORS

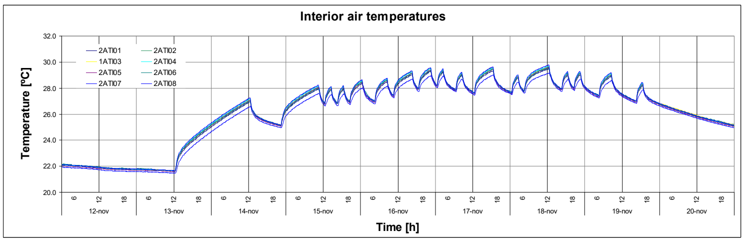
Internal air temperature measurements

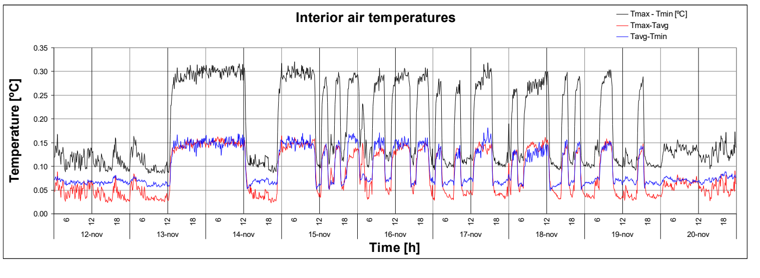
- Seven air temperature sensors (PT100) protected against radiation positioned as in figure with an accuracy of ± 0.1 °C.
- The PASLINK network test requires the maximum differences of indoor air temperatures must be under 0.5 °C.
- Average of those seven sensors is used as the internal air temperature.



6 – BUILDING COMPONENT: PASLINK METHOD

Internal air temperature measurements

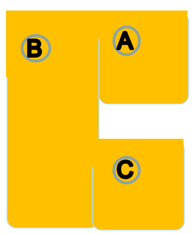




Considerations on temperature measurements: thermal equilibrium

• 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.

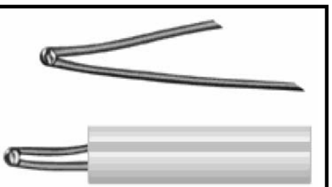


Figura 1 – Terminal soldada de un termopar

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

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

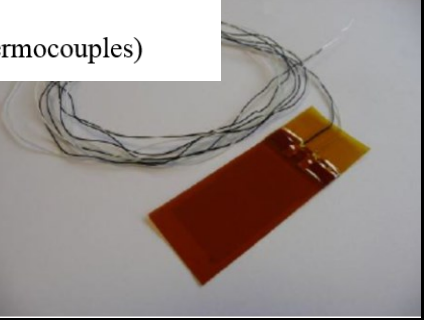
Considerations on temperature measurements: THERMORESISTANCE

The main advantages of the thermoresistances are:

- Accuracy
- Sensitivity

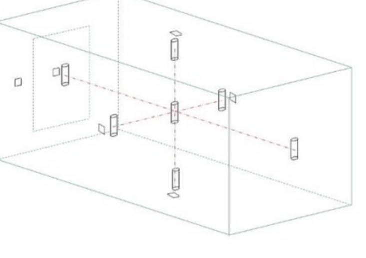
The main disadvantages of the thermoresistances are:

- Fragility
- Price (more expensive than thermocouples)



Internal surface temperature measurements

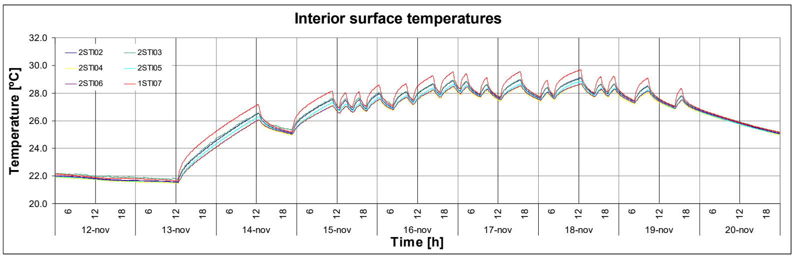
- Seven surface temperature sensors (PT100) with an accuracy of ± 0.1 °C.
- The maximum deviation between sensors is reduced to around 0.5ºC.
- This permits to work with a single value of surface temperature inside the test room, obtained by averaging.

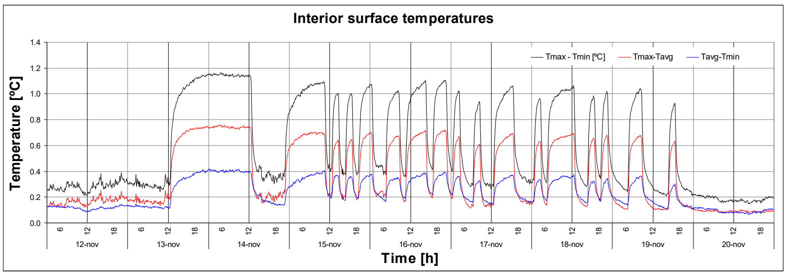


6 – BUILDING COMPONENT: PASLINK METHOD

DYNASTEE

Internal surface temperature measurements





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6 – BUILDING COMPONENT: PASLINK METHOD

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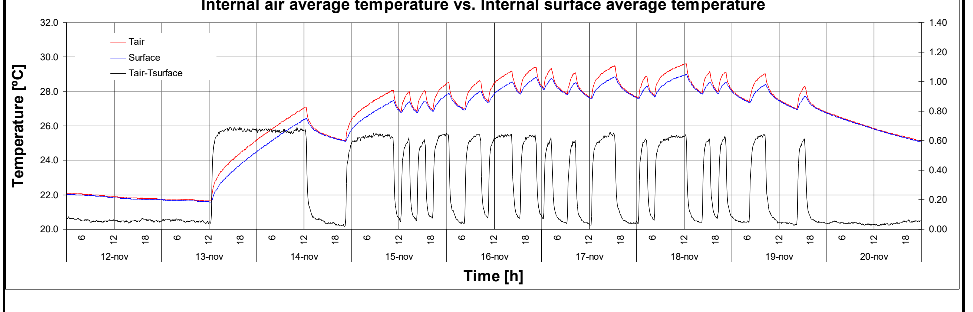
Internal air and surface temperature measurements



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6 – BUILDING COMPONENT: PASLINK METHOD

Outdoors temperature measurements

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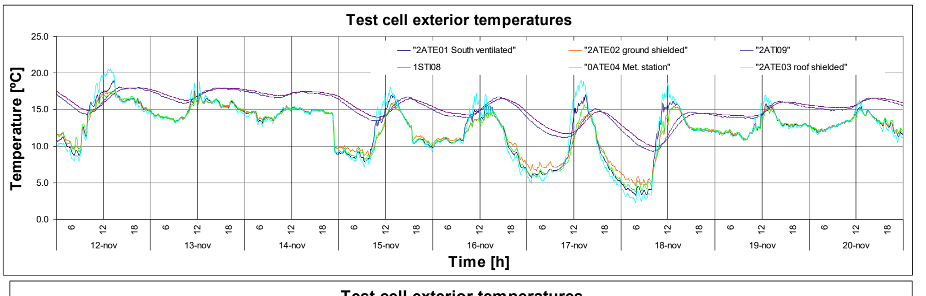
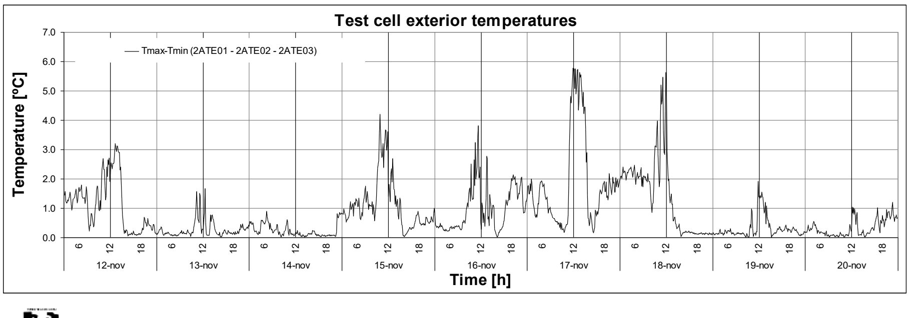
6 – BUILDING COMPONENT: PASLINK METHOD

Outdoors temperature measurements





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6 – BUILDING COMPONENT: PASLINK METHOD

DYNASTEE

Solar radiation measurements - concepts

PLANCK'S LAW: The spectral blackbody emissive power:

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

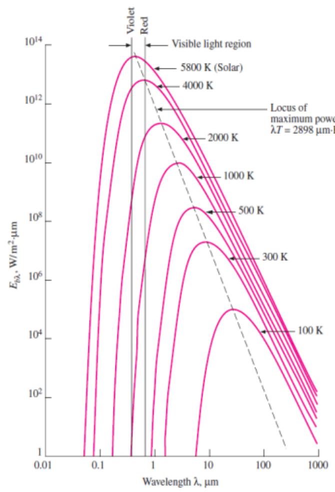
$$C_1=2\,\pi h\,c_0^2=3.74177\ x\,10^8[W\mu m^4/m^2]$$

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

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

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

n: Index of refraction



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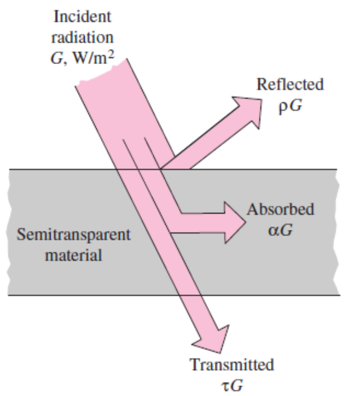
6 – BUILDING COMPONENT: PASLINK METHOD

DYNASTEE

Solar radiation measurements - concepts



Absorptivity: $\alpha=\frac{\text{Absorbed radiation}}{\text{Incident radiation}}=\frac{G_{abs}}{G},\quad 0\le\alpha\le 1$

Reflectivity: $\rho=\frac{\text{Reflected radiation}}{\text{Incident radiation}}=\frac{G_{ref}}{G},\quad 0\le\rho\le 1$

Transmissivity: $\tau=\frac{\text{Transmitted radiation}}{\text{Incident radiation}}=\frac{G_{tr}}{G},\quad 0\le\tau\le 1$

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

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

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

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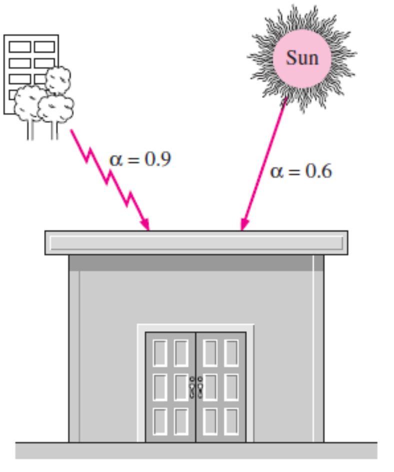
DYNASTEE

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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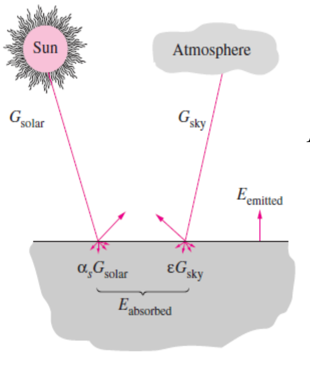
Solar radiation measurements - concepts

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



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

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

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

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

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

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

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

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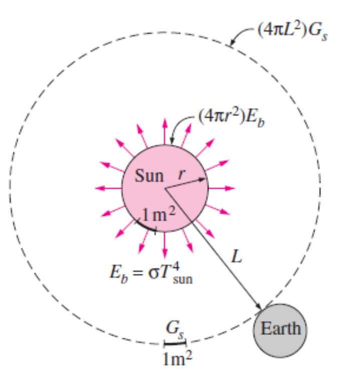
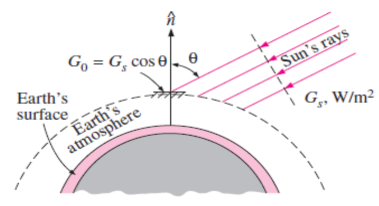
Solar radiation measurements - concepts

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**

Solar radiation measurements - concepts

ATMOSPHERE ABSORPTION

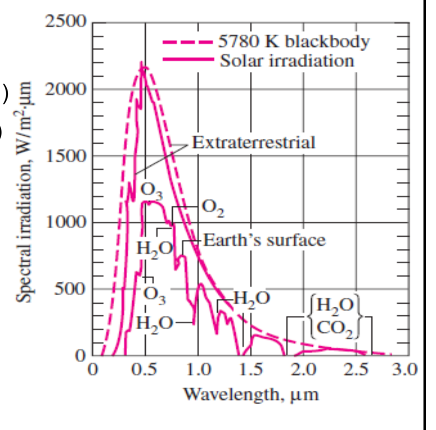
Solar radiation is attenuated when crossing the atmosphere

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

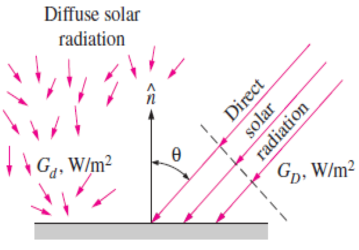
Wavelength: 0.3-2.5 µm

6 – BUILDING COMPONENT: PASLINK METHOD

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.



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

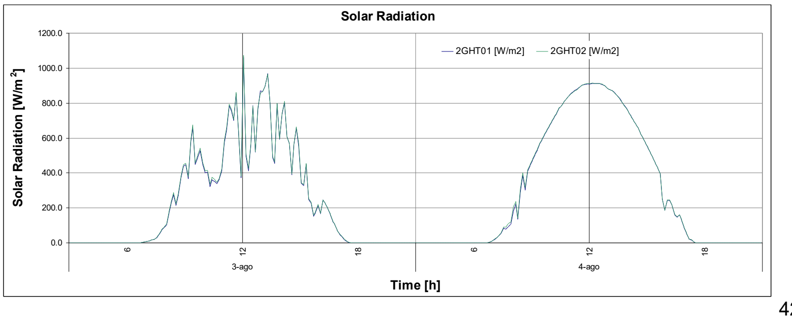
θ: angle of incidence

6 – BUILDING COMPONENT: PASLINK METHOD

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.



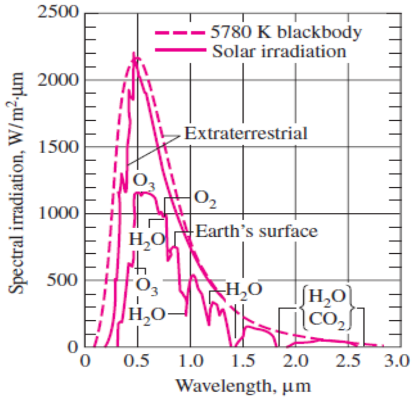
DYNASTEE

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.

Specifications

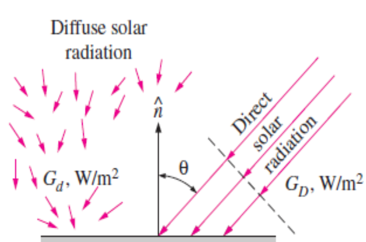
Spectral range (50% points)	285 to 2800 nm
Sensitivity	7 to 14 μV/W/m²
Response time	< 5 s
Zero offset A	< 7 W/m²
Zero offset B	< 2 W/m²
Directional response (up to 80° with 10	< 10 W/m²
Temperature dependence of sensitivity	< 1 %
Operational temperature range	-40 °C to +80 °C
Maximum solar irradiance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



DYNASTEE

Solar radiation measurements

•Diffuse horizontal solar radiation (3% accuracy).



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

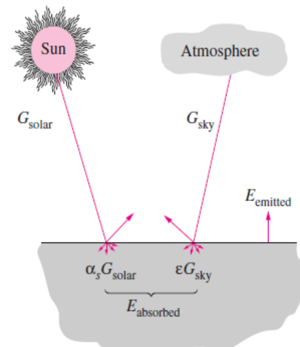
θ: angle of incidence

6 – BUILDING COMPONENT: PASLINK METHOD

DYNASTEE

Solar radiation measurements

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



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

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6 – BUILDING COMPONENT: PASLINK METHOD

DYNASTEE

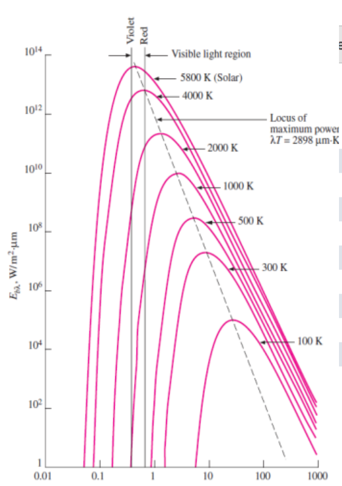
Solar radiation measurements

• 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 %



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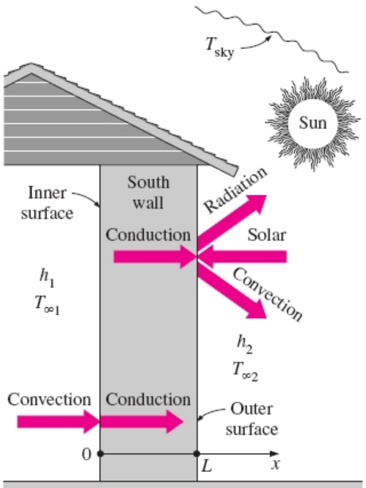
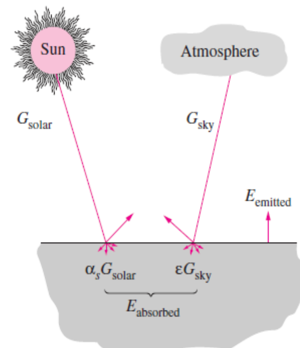
Solar radiation measurements



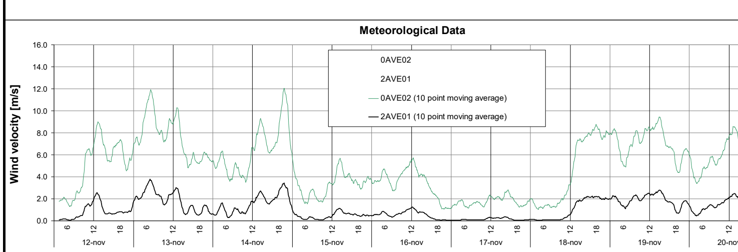


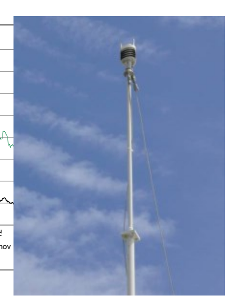
$$q_{net,rad} = \alpha_s G_{solar} + \varepsilon\sigma(T_{sky}^4 - T_s^4)\ [W/m^2]$$

DYNASTEE

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.	-





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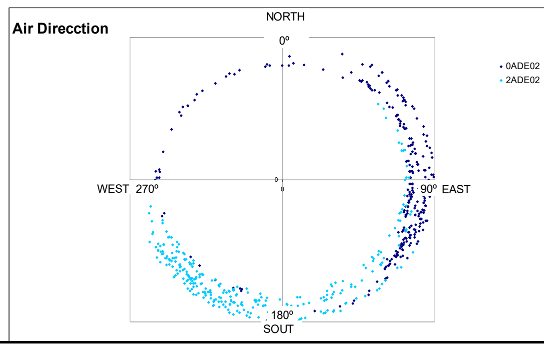
Other meteorological variables measurements



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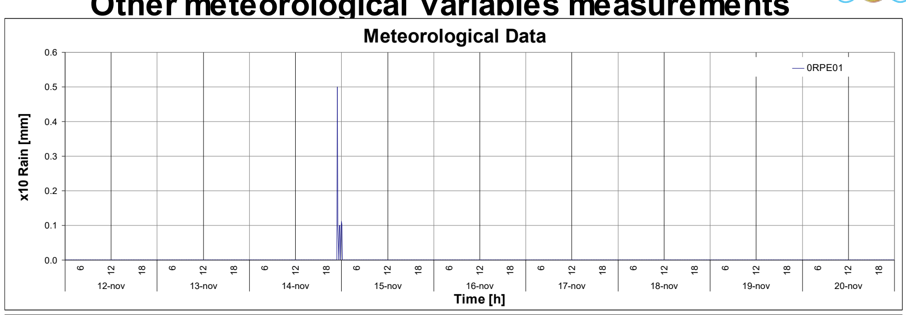

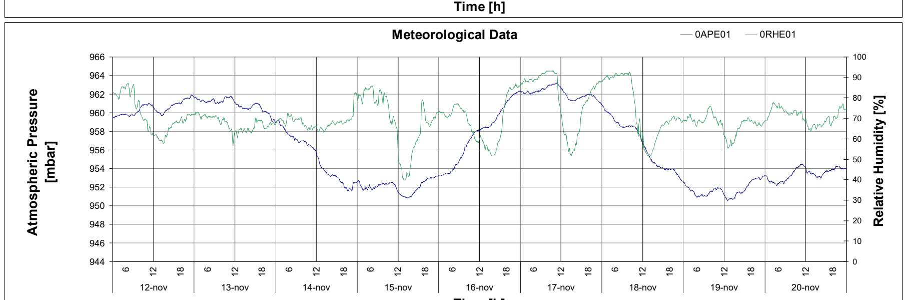

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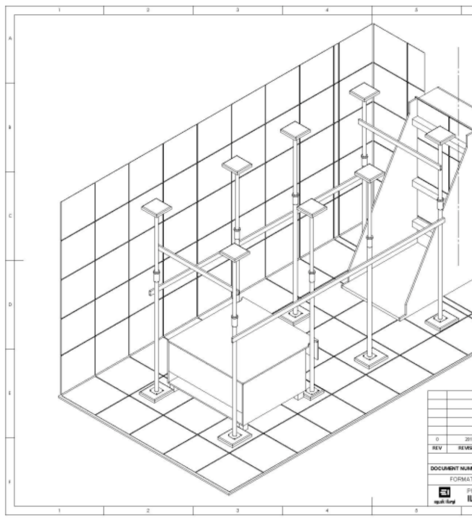
6 – BUILDING COMPONENT: PASLINK METHOD

DYNASTEE

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



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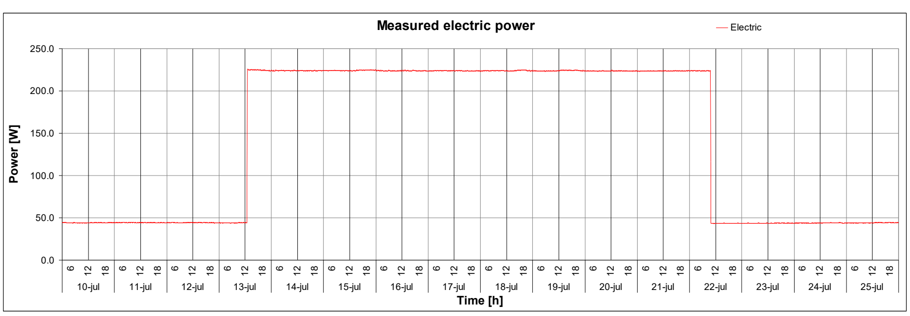
6 – BUILDING COMPONENT: PASLINK METHOD

DYNASTEE

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%.

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6 – BUILDING COMPONENT: PASLINK METHOD

DYNASTEE

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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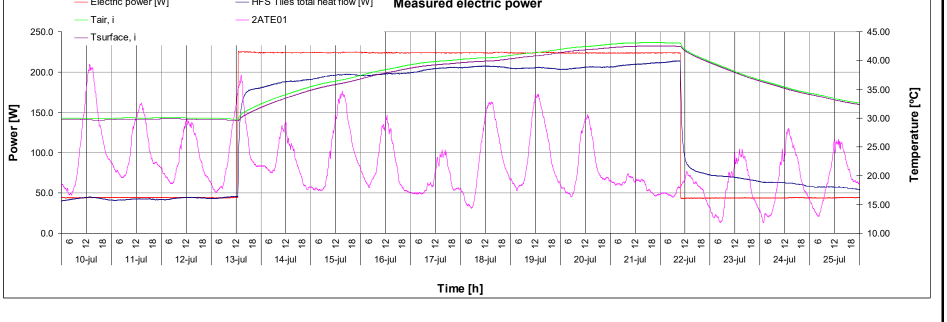
6 – BUILDING COMPONENT: PASLINK METHOD

DYNASTEE

TYPICAL SIGNALS USED FOR MODELLING PURPOUSES



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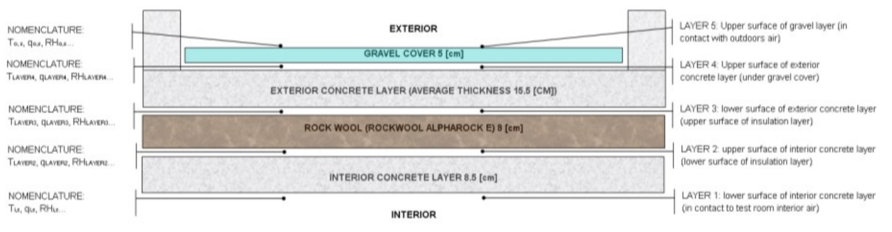
6 – BUILDING COMPONENT: PASLINK METHOD

DYNASTEE

INSTRUMENTATION ON THE ROOF TEST SAMPLE COVERED BY GRAVEL

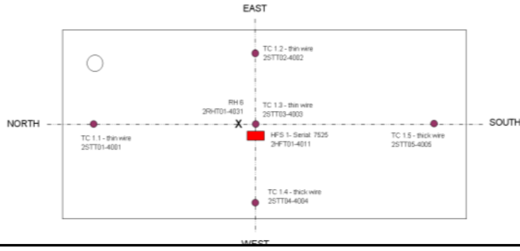


● Temperature sensor: TC (T type thermocouple) or PT100 (Platinum thermoresistance)

■ Heat flux sensor

X Relative humidity sensor

Π Pyranometer



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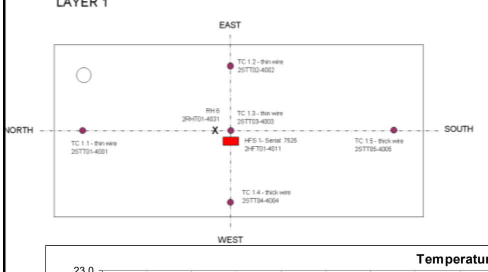
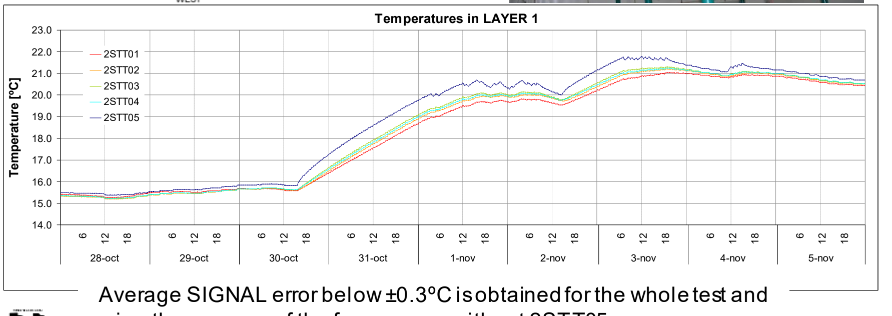
6 – BUILDING COMPONENT: PASLINK METHOD

DYNASTEE

INSTRUMENTATION ON THE ROOF TEST SAMPLE COVERED BY GRAVEL





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

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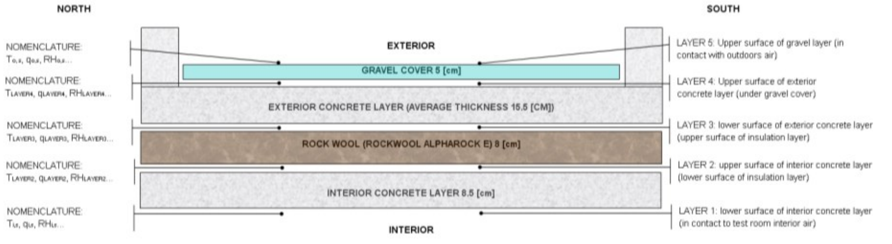
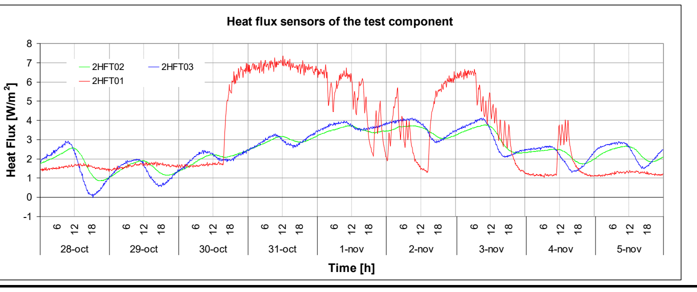
6 – BUILDING COMPONENT: PASLINK METHOD

DYNASTEE

HEAT FLUX MEASUREMENTS IN DIFFERENT LAYERS





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6 – BUILDING COMPONENT: PASLINK METHOD

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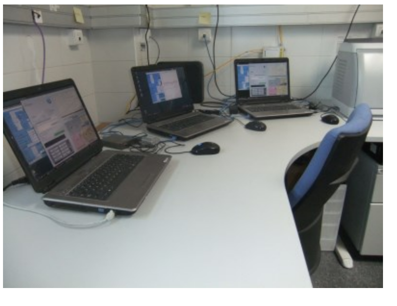

- HP Agilent 34980A
- 5 multiplexer 34921A
- 1 control 34951A module
- "dayflies" where each sensor signal is recorded every minute

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7 – MONITORING WHOLE BUILDINGS

DYNASTEE

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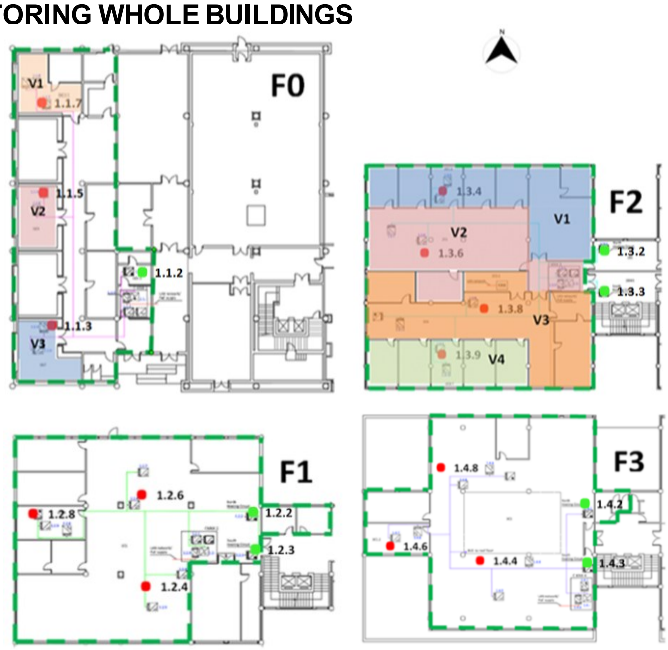
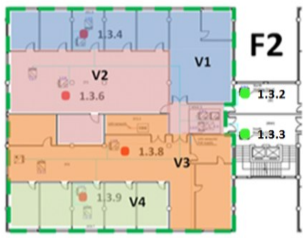


7 – MONITORING WHOLE BUILDINGS



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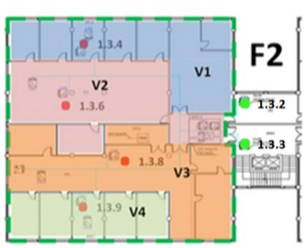
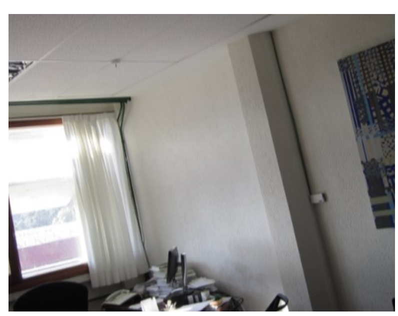
7 – MONITORING WHOLE BUILDINGS





	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. CO_2 measuring range: 0 .. 5000 ppm On-wall mounting in dry indoor applications IP20

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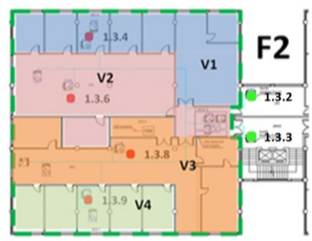
7 – MONITORING WHOLE BUILDINGS

DYNASTEE



7 – MONITORING WHOLE BUILDINGS

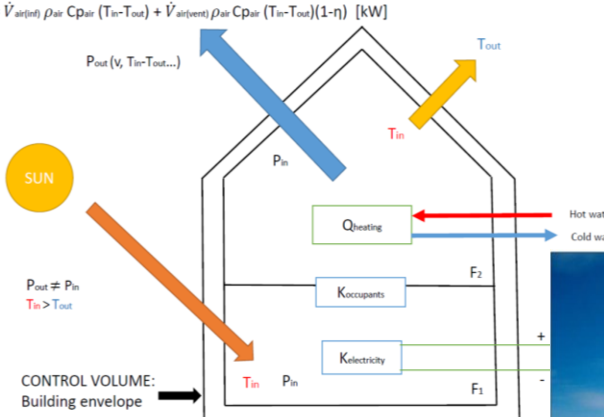
DYNASTEE

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



7 – MONITORING WHOLE BUILDINGS

DYNASTEE

GENERAL CASE: VENTILATION WITH HEAT RECOVERY PLUS INFILTRATION

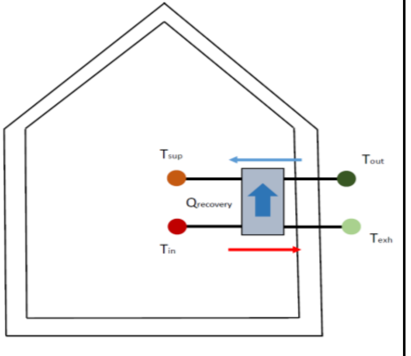
The percentage of heat recovered [-]

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

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]

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