DYNAMIC HEAT TRANSFER IN WALLS: HEAT FLUX METERS LIMITATION

Ibán NAVEROS
Christian GHIAUS

Membre de UNIVERSITÉ DE LYON

INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES LYON

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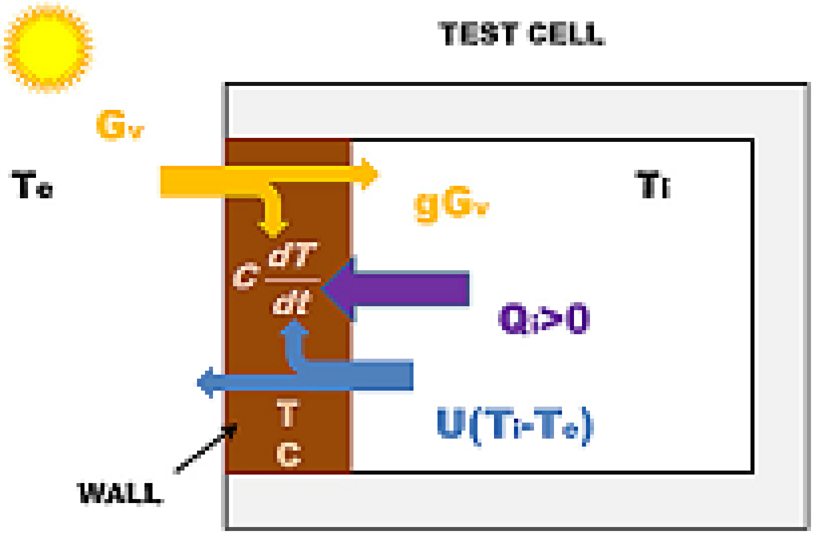
INTRODUCTION

Heat transfer through **walls** needs to be **characterized**.

Test cells are usually **used** for this purpose.

Naveros et al. 2013 [9]

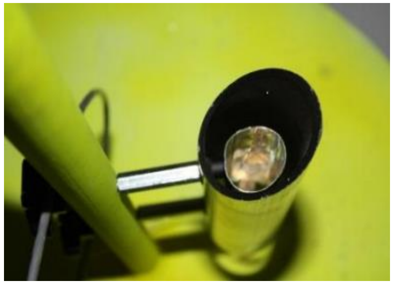


INTRODUCTION

Inputs and **outputs** are **measured** for the thermal characterization of the wall

Outdoor temperature

Indoor temperature



Solar irradiance

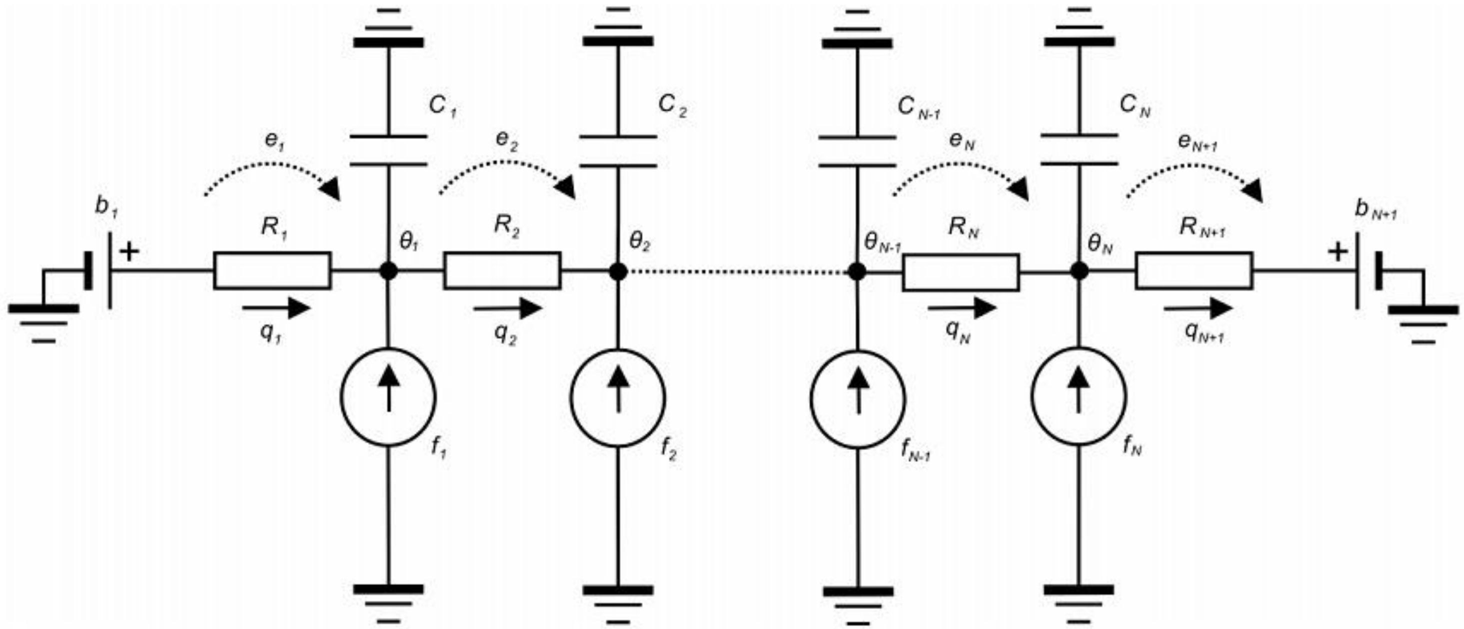
Heat flux density

Naveros et al. 2013 [9]

METHODOLOGY

- **Thermal models** for the study of heat transfer in **walls**
- From **heat equation** to **transfer function matrix**
- Each **transfer function** is given by the system characteristics for a **particular output** regarding to each **particular input**

THERMAL NETWORK



LEGEND

C_l	thermal capacity in node l, JK^{-1}
e_k	temperature difference over the thermal resistance on branch k, K
b_k	temperature source on branch k, K
R_k	thermal resistance on branch k, KW^{-1}
θ_l	temperature of node l, K
q_k	heat transfer rate on branch k, W
f_l	heat rate source in node l, W

HEAT EQUATION

$$\rho c \frac{\partial \theta}{\partial t} = -\nabla \cdot (-\kappa \nabla \theta) + p$$

DIFFERENTIAL AND ALGEBRAIC EQUATIONS

$$\mathbf{C}\dot{\boldsymbol{\theta}} = -\mathbf{A}^T\mathbf{G}\mathbf{A}\boldsymbol{\theta} + \mathbf{A}^T\mathbf{G}\mathbf{b} + \mathbf{f}$$

NOMENCLATURE

θ	is the function of temperature distribution in the medium, K,
ρ	- the medium density, kg m^{-3},
c	- the medium heat capacity, J kg^{-1} K^{-1},
∇	- the gradient operator, m^{-1},
$\nabla \cdot$	- the divergence operator, m^{-1},
κ	- the medium thermal conductivity, W m^{-1} K^{-1}, and
p	- the function of heat rate sources supplied to the solid, W m^{-3}.

$\boldsymbol{\theta}$	is the vector of temperatures in the nodes, K,
$\mathbf{C}$	- the diagonal matrix of thermal capacities, JK^{-1},
$\mathbf{A}$	- the incidence matrix of the thermal network,
$\mathbf{A}^T$	- the transpose of the incidence matrix,
$\mathbf{G}$	- the diagonal matrix of thermal conductivities, WK^{-1},
$\mathbf{b}$	- the vector of temperatures sources on the branches, K, and
$\mathbf{f}$	- the vector of heat rate sources, W.

Transfer Matrix

State-state: Inputs($\mathbf{u}$)/State variables($\mathbf{x}$)/Outputs($\mathbf{y}$) relation

$$\dot{\mathbf{x}} = \mathbf{A}_S\mathbf{x} + \mathbf{B}_S\mathbf{u}$$
$$\mathbf{y} = \mathbf{C}_S\mathbf{x} + \mathbf{D}_S\mathbf{u}$$

Transfer function **matrix**:

$$\mathbf{H}_S = \mathbf{C}_S(s\mathbf{I} - \mathbf{A}_S)^{-1}\mathbf{B}_S + \mathbf{D}_S$$

$$\mathbf{H}_S = [\mathbf{H}_1 \quad \mathbf{H}_2]^T = \begin{bmatrix} H_{11} & H_{12} & H_{13} \\ \hdashline H_{21} & H_{22} & H_{23} \end{bmatrix}$$

HEAT FLUX AS OUTPUT

If the **heat flux** density is chosen as **output**, the observation equation is:

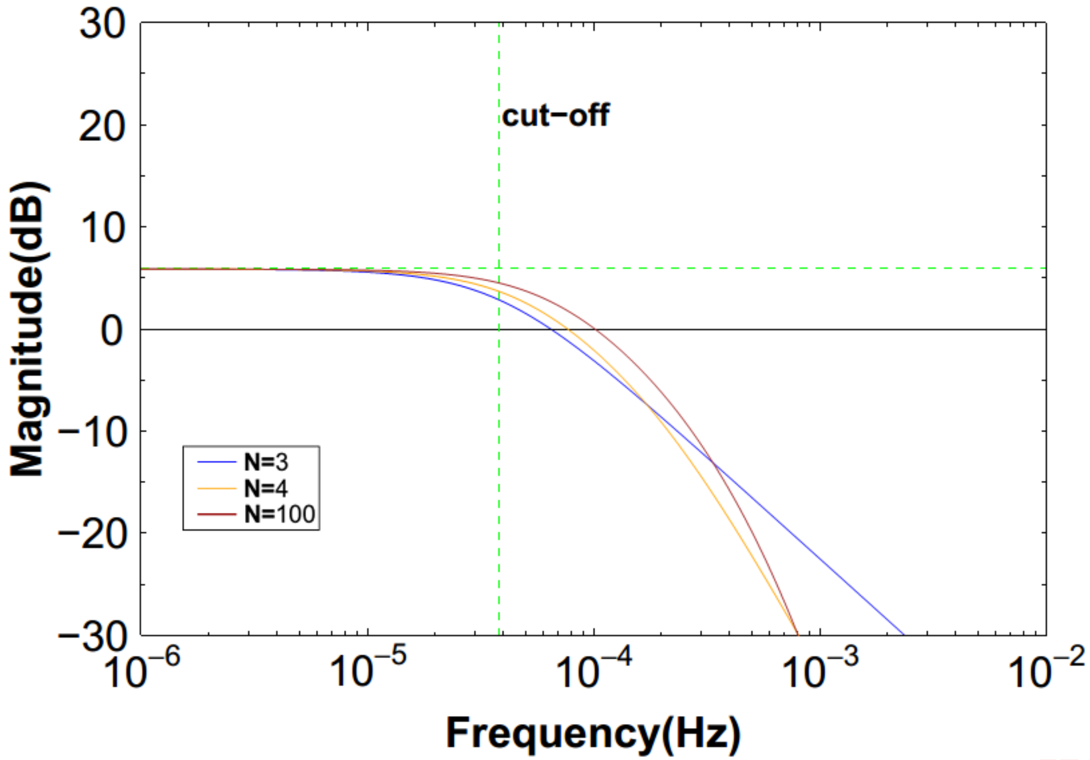
$$Q_i = \frac{1}{S}\frac{R_3^{-1}R_{si}^{-1}}{R_3^{-1}+R_{si}^{-1}}(T_i - \theta)$$

The **transfer function** will **filter** the different **inputs** as a function of the **frequency** to give the heat flux density output.

Strictly Proper Transfer Function

Input: Outdoor temperature

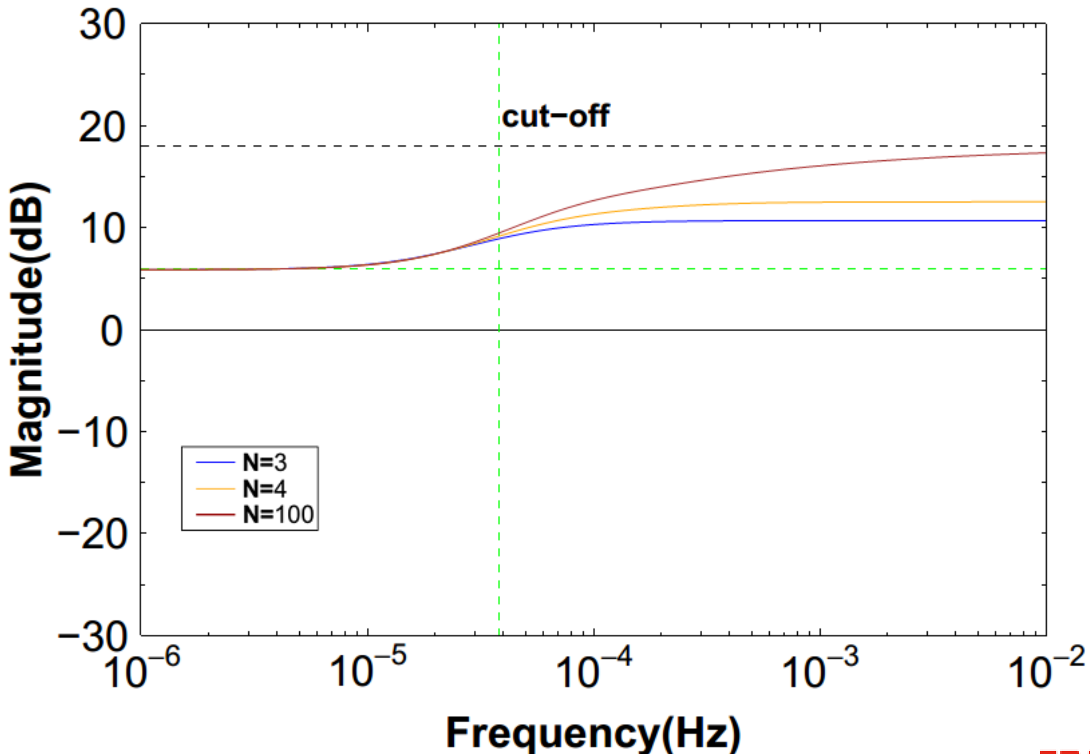
Output: Inside heat flux density



Proper Transfer Function

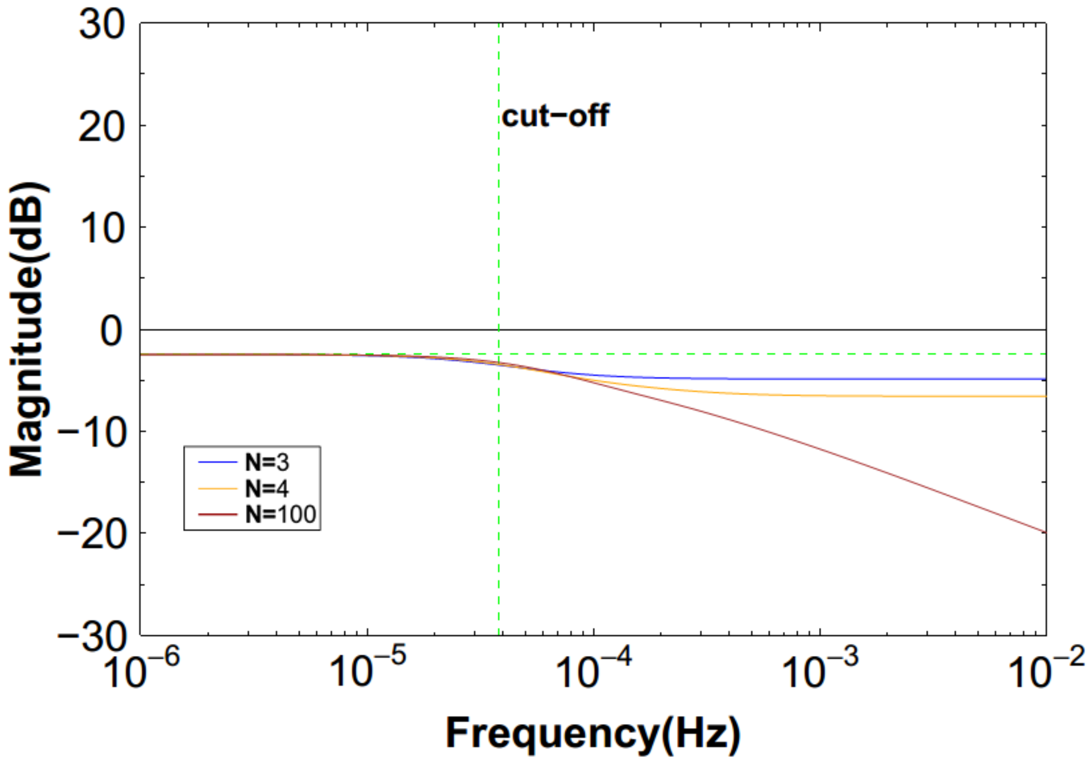
Input: Indoor temperature

Output: Inside heat flux density



Surface temperature as output

Input: Indoor temperature
Output: Inside surface temperature



CONCLUSIONS

- The **output** is **infinitely damped** for **strictly proper** transfer functions for **high frequencies**.

- The **output** can be **finitely amplified** for a **proper** transfer function for **high frequencies**.

- The use of **heat flux meters** is **limited**, **not** only for the measurement **device but** for the **heat flux** through the **wall** itself.

- The **outside heat flux density** will have a **major problem** to **high frequencies** present in **inputs** and/or **noise**.

Thanks for your attention

Ibán NAVEROS
Christian GHIAUS

iban.naveros-mesa@insa-lyon.fr
christian.ghiaus@insa-lyon.fr

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