WALL MODEL DEFINITION

The wall resistances and capacities are adjusted through a *frequency characteristic analysis* for a 24h time period sinusoidal solicitation, instead of a step solicitation. Sinusoidal 24h time period solicitation is more realistic than step solicitation because it is closer to the daily variations the model will be submitted to: solar radiation, night indoor temperature setback and occupancy schedules are all 24h time period solicitations (not always sinusoidal but periodical).

3.1. Wall frequency analysis

3.1.1. Wall admittance matrix

A wall including *n* layers of material is submitted to sinusoidal temperature or heat flow variations as function of the time, on both sides (fig. 3.1) (ref.[25],[26]).

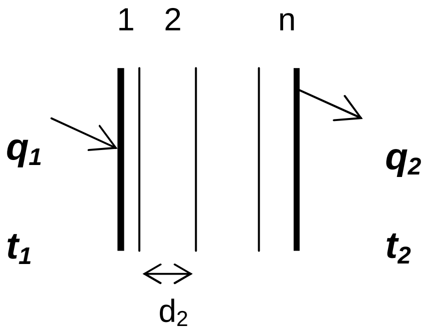

Fig.3.1. Temperature and heat flow variations as function of the time, on the two sides of a wall including n layers

The temperature and heat flow variations are correlated by:

$$\begin{pmatrix} \tilde{t}_1 \\ \tilde{q}_1 \end{pmatrix} = \begin{pmatrix} A_1 & B_1 \\ C_1 & D_1 \end{pmatrix} \begin{pmatrix} A_2 & B_2 \\ C_2 & D_2 \end{pmatrix} \cdots \begin{pmatrix} A_n & B_n \\ C_n & D_n \end{pmatrix} \begin{pmatrix} \tilde{t}_2 \\ \tilde{q}_2 \end{pmatrix} \qquad (3.1)$$

$\tilde{t}_1, \tilde{t}_2$: Temperature variations expressed as complex quantities *°C*
$\tilde{q}_1, \tilde{q}_2$: Heat flow variations expressed as complex quantities W/m^2

The matrixes appearing in the product of (3.1) are composed of complex quantities defined as follows for each wall layer *i*:

$$A_i = \cosh\sqrt{\tau_i.\omega.j} \qquad B_i = \frac{R_i}{\sqrt{\tau_i.\omega.j}}\sinh\sqrt{\tau_i.\omega.j}$$

$$C_i = \frac{\sqrt{\tau_i.\omega.j}}{R_i}\sinh\sqrt{\tau_i.\omega.j} \qquad D_i = \cosh\sqrt{\tau_i.\omega.j} \qquad (3.2)$$

$$R_i = \frac{d_i}{\lambda_i} \qquad \tau_i = \frac{d_i^2}{\alpha_i} \qquad \alpha_i = \frac{\lambda_i}{\rho_i c_i}$$

ω:	Pulsation *rad/s*	d_i:	Layer thickness *m*
α_i:	Layer thermal diffusivity *m²/s*	λ_i:	Layer thermal conductivity *W/m.K*
ρ_i:	Layer mass density *kg/m³*	c_i:	Layer specific heat *J/kg.K*

The matrix product of equation (3.1) yields the *reverse transfer matrix*:

$$\begin{pmatrix} \tilde{t}_1 \\ \tilde{q}_1 \end{pmatrix} = \begin{pmatrix} A & B \\ C & D \end{pmatrix} \begin{pmatrix} \tilde{t}_2 \\ \tilde{q}_2 \end{pmatrix} \tag{3.3}$$

The reverse transfer matrix is also noted **Q**:

$$\begin{pmatrix} \tilde{t}_1 \\ \tilde{q}_1 \end{pmatrix} = \begin{pmatrix} Q_{11} & Q_{12} \\ Q_{21} & Q_{22} \end{pmatrix} \begin{pmatrix} \tilde{t}_2 \\ \tilde{q}_2 \end{pmatrix} \tag{3.4}$$

The determinant of **Q** equals 1.

Equation (3.4) can be transformed in order to express heat flows as function of temperatures, through an *admittance matrix* **Y**:

$$\begin{pmatrix} \tilde{q}_1 \\ \tilde{q}_2 \end{pmatrix} = \begin{pmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{pmatrix} \begin{pmatrix} \tilde{t}_1 \\ \tilde{t}_2 \end{pmatrix} \tag{3.5}$$

Where:

$$\begin{pmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{pmatrix} = \begin{pmatrix} \frac{Q_{22}}{Q_{12}} & -\frac{1}{Q_{12}} \\ \frac{1}{Q_{12}} & -\frac{Q_{11}}{Q_{12}} \end{pmatrix} \tag{3.6}$$

Equation (3.4) can be also transformed in order to express temperatures as function of heat flows, through an *impedance matrix* **Z**:

$$\begin{pmatrix} \tilde{t}_1 \\ \tilde{t}_2 \end{pmatrix} = \begin{pmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{pmatrix} \begin{pmatrix} \tilde{q}_1 \\ \tilde{q}_2 \end{pmatrix} \tag{3.7}$$

Where:

$$\begin{pmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{pmatrix} = \begin{pmatrix} \frac{Q_{11}}{Q_{21}} & -\frac{1}{Q_{21}} \\ \frac{1}{Q_{21}} & -\frac{Q_{22}}{Q_{21}} \end{pmatrix} \tag{3.8}$$

3.1.2 Wall boundary conditions

3.1.2.1 Imposed temperature

The external walls or the walls in contact with a neighbor 'cold' zone are submitted to an outdoor imposed temperature on side 1. The heat flow on the indoor side 2 can be computed from (3.6):

$$\tilde{q}_2 = \frac{1}{Q_{12}} \tilde{t}_1 - \frac{Q_{11}}{Q_{12}} \tilde{t}_2 \qquad (3.9)$$

The external wall *isothermal transmittance* is defined as the ratio of the indoor side heat flow variation to the outdoor side temperature variation, for a constant indoor temperature and for a given frequency ν :

$$\tilde{K}_\nu = \left(\frac{\tilde{q}_2}{\tilde{t}_1} \right)_{\tilde{t}_2 = 0} \qquad (3.10)$$

The external wall *isothermal admittance* is defined as the ratio of the indoor side heat flow variation to the indoor side temperature variation, for a constant outdoor temperature and for a given frequency ν :

$$\tilde{A}_\nu = \left(\frac{\tilde{q}_2}{\tilde{t}_2} \right)_{\tilde{t}_1 = 0} \qquad (3.11)$$

From (3.9):

$$\tilde{K}_\nu = \frac{1}{Q_{12}} \qquad \tilde{A}_\nu = -\frac{Q_{11}}{Q_{12}} \qquad (3.12)$$

3.1.2.2 Imposed heat flow

The internal walls entirely included in a zone are crossed by a null heat flow plane. The wall is then subdivided into two parts, each of them being analyzed as a wall with an imposed null heat flow on the "outdoor" side 1. The temperature variation on the indoor side 2 can be computed from (3.8):

$$\tilde{t}_2 = \frac{1}{Q_{21}} \tilde{q}_1 - \frac{Q_{22}}{Q_{21}} \tilde{q}_2 \qquad (3.13)$$

The internal wall *adiabatic admittance* is defined as the ratio of the indoor side heat flow variation to the indoor side temperature variation, for a constant outdoor heat flow and for a given frequency ν :

$$\tilde{A}_\nu = \left(\frac{\tilde{q}_2}{\tilde{t}_2} \right)_{\tilde{q}_1 = 0} \tag{3.14}$$

From (3.13):

$$\tilde{A}_\nu = -\frac{Q_{21}}{Q_{22}} \tag{3.15}$$

In case of a homogenous or symmetric internal wall, the null heat flow plane is the plane of symmetry, while if the wall isn't symmetric, the null heat flow plane position is defined by equalizing the dampening factors of two sinusoidal temperature solicitations acting separately on each wall side. The dampening factor of a signal crossing *n* wall layers is equal to:

$$f_d = \prod_{i=1}^{n} \exp\left(-d_i \cdot \sqrt{\frac{\omega}{2\alpha_i}} \right) \tag{3.16}$$

ω: Pulsation *rad/s*
d_i: Layer thickness *m*
α_i: Layer thermal diffusivity *m²/s*

3.2. Wall network model

The building walls can be modeled through *2R1C networks* i.e. including two resistances and one capacity, or through *3R2C networks*. The wall resistances and capacities can be adjusted through its Heavyside *step responses* or through a *frequency characteristic analysis* such as that performed in §3.1 (ref. [13],[18],[25],[26]).

The following choices are made:

- The wall resistances and capacities are adjusted through a *frequency characteristic analysis* for a 24h time period sinusoidal solicitation, instead of a step solicitation. Anyway a traditional external wall, whose 2R1C network is modeled through sinusoidal solicitation, will be further submitted to an indoor heat flow step solicitation (see chapter 5, §10, fig. 5.29), and the one zone model, adjusted through sinusoidal solicitation, will be validated through experimental results for an indoor heat flow step solicitation (see chapter 5, §11).

- *Internal walls* are modeled through *3R2C networks*, those being reliable enough to reproduce the wall behavior over the whole range of frequencies [18], [13] (see also Bode diagrams in §4.2 fig. 3.8 and §4.3 fig. 3.10, and conclusions related to model validation in chapter 5, §5.1). As internal walls are modeled with adiabatic boundary conditions, they must be shared in two parts by a null heat flow plane, each part being associated to its related indoor zone. As each wall part is then modeled through a 2R1C network, and both 2R1C networks are equivalent to one 3R2C network. All the 2R1C networks related to a zone will be gathered in one indoor branch.

- *External walls* can be modeled through *2R1C networks*: those networks are quicker to compute than 3R2C networks, but less reliable at high frequencies (see Bode diagrams in §4.1 fig. 3.7 and chapter 5, §10, fig. 5.30). 2R1C networks are chosen anyway because they can be generated through two parameters θ and φ (§ 2.1) instead of four. As there is a wider variety of external walls, compared to internal ones, the definition of parameters default values is easier with two parameters instead of four (§5). Moreover, if the zone model must be further improved, it is preferred to add more branches instead of one more capacity on each branch, i.e. it is preferred to share the whole 2R1C networks, related to different external walls surrounding a zone, in more categories before gathering them in separate branches (one branch for each category). That process will be used to improve the model behavior when submitted to opaque wall absorbed solar gains and infrared losses (see chapter 5, § 7.2)

The resistances and the capacity of the 2R1C model are chosen in order to reproduce the wall admittance and transmittance for a 24 hour period.

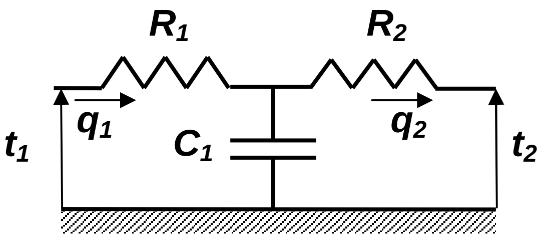

Fig.3.2. 2R1C network

The reverse transfer matrix **Q** of the 2R1C network is:

$$\begin{pmatrix} \tilde{t}_1 \\ \tilde{q}_1 \end{pmatrix} = \begin{pmatrix} Q_{11} & Q_{12} \\ Q_{21} & Q_{22} \end{pmatrix} \begin{pmatrix} \tilde{t}_2 \\ \tilde{q}_2 \end{pmatrix} = \begin{pmatrix} R_1 C_1 \omega . j + 1 & R_1 R_2 C_1 \omega . j + R_1 + R_2 \\ C_1 \omega . j & R_2 C_1 \omega . j + 1 \end{pmatrix} \begin{pmatrix} \tilde{t}_2 \\ \tilde{q}_2 \end{pmatrix} \qquad (3.17)$$

3.2.1. Imposed temperature

The network *isothermal transmittance* of the 2R1C network is given by:

$$\tilde{K}_v = \left(\frac{\tilde{q}_2}{\tilde{t}_1} \right)_{\tilde{t}_2 = 0} = \frac{1}{R_1 + R_2 + R_1 . R_2 . C_1 \omega . j} \qquad (3.18)$$

The network *isothermal admittance* of the 2R1C network is equal to:

$$\tilde{A}_v = \left(\frac{\tilde{q}_2}{\tilde{t}_2}\right)_{\tilde{t}_1 = 0} = -\frac{1 + R_1.C_1\omega.j}{R_1 + R_2 + R_1.R_2.C_1\omega.j} \tag{3.19}$$

3.2.2. Imposed heat flow

The network *adiabatic admittance* of the 2R1C network is computed from:

$$\tilde{A}_v = \left(\frac{\tilde{q}_2}{\tilde{t}_2}\right)_{\tilde{q}_1 = 0} = -\frac{C_1\omega.j}{1 + R_2.C_1\omega.j} \tag{3.20}$$

3.3. Wall network adjustment process

We already distinguished two types of boundary conditions for walls: either *isothermal*, when walls are submitted to *imposed temperature* boundary conditions, or *adiabatic* when walls are submitted to *imposed heat flow* boundary conditions. An adjustment process is defined for each type of wall.

We will latter define criteria to classify the different building walls into *isothermal* and *adiabatic* categories.

Let's first describe the adjustment process as function of boundary conditions. Isothermal boundary conditions walls are modelled through a 2R1C cell (fig. 3.2), while adiabatic boundary conditions walls are first shared in two parts (eq. 3.16) both being modelled through a 2R1C cell, thus providing a 3R2C model for the whole wall.

The wall resistance *R* and capacity *C* are calculated from a complete description of its layers. The total resistance of the model equals the invert of the wall U-value. Other model parameters are deduced from the frequency analysis wall behaviour. The adjustment is performed for a 24h time period solicitation, for imposed boundary conditions related either to temperature (then called isothermal) or to heat flow (then called adiabatic).

3.3.1. Modelling isothermal boundary conditions walls

For *isothermal boundary conditions*, the adjustment process consists in equalizing the magnitudes of the wall isothermal admittance $\left|\tilde{A}_v\right|$ and transmittance $\left|\tilde{K}_v\right|$, computed for a 24 hours time period (equations 3.12), with the corresponding 2R1C network values (equations 3.18 and 3.19).

The adjustment provides two resistances and one capacity (R_1, R_2, C_1) which can be expressed as fractions of the wall total resistance and capacity, through not dimensional factors θ and ϕ (fig. 3.3):

$$\left|\tilde{A}_\nu\right| = -\left|\frac{Q_{11}}{Q_{12}}\right| = -\left|\frac{1+\phi(1-\theta)RC\omega j}{R+\phi\theta(1-\theta)R^2C\omega j}\right| \qquad \left|\tilde{K}_\nu\right| = \left|\frac{1}{Q_{12}}\right| = \left|\frac{1}{R+\phi\theta(1-\theta)R^2C\omega j}\right| \qquad (3.21)$$

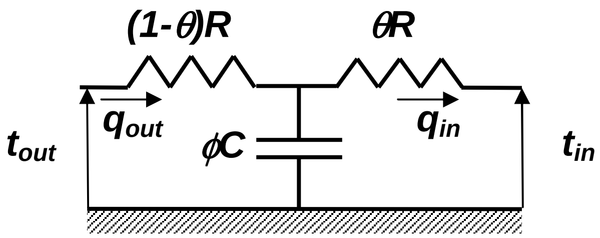

Fig.3.3. Adjusted 2R1C network for an isothermal boundary conditions wall

Equation (3.21) yields the parameters θ and ϕ:

$$\theta = \sqrt{\frac{U^2 - \left|\tilde{K}_\nu\right|^2}{\left|\tilde{A}_\nu\right|^2 - \left|\tilde{K}_\nu\right|^2}} \qquad \phi = \frac{1}{(1-\theta).\omega.R.C}\sqrt{\frac{\left|\tilde{A}_\nu\right|^2}{\left|\tilde{K}_\nu\right|^2} - 1} \qquad U = \frac{1}{R} \qquad (3.22)$$

Factor ϕ defines the proportion of the whole wall capacity accessed by a 24 h time period, while factor θ gives the position of that capacity on the whole wall resistance *R*. Factor θ is commonly called *accessibility*, though its value decreases as the wall capacity becomes more accessible from the model internal node.

3.3.2. Modelling massive isothermal boundary conditions walls when highly insulated from the outside

Ground contact walls are considered as reinforced by a fictitious outdoor resistive layer modeling the ground insulation effect. For those walls with a high mass and highly insulated from the outdoor, the adjustment process can provide too high capacity values i.e. $\phi > 1$. The capacity is then limited to the total wall capacity $\phi = 1$, and the adjustment process consists only in equalizing the 24 h wall admittance magnitude. Thus, the adjustment doesn't reproduce the exact value of the 24 h wall transmittance magnitude, which is quite low, as the wall is submitted to almost adiabatic boundary conditions.

The adjustment process requires solving a 4th degree equation in order to get θ parameter. The equation is provided by the admittance magnitude expressed from (3.21) with $\phi = 1$:

$$\theta^2(1-\theta)^2\left|\tilde{A}_\nu\right|^2 R^4C^2\omega^2 - (1-\theta)^2R^2C^2\omega^2 + \left|\tilde{A}_\nu\right|^2 R^2 - 1 = 0 \qquad (3.23)$$

Or $\quad \theta^2 = \dfrac{\beta^2(1-\theta)^2 + 1 - \gamma^2}{\beta^2\gamma^2(1-\theta)^2} \quad$ with $\quad \beta = R.C.\omega \quad$ and $\quad \gamma = R.\left|\tilde{A}_\nu\right| \qquad (3.24)$

As $\left|\tilde{A}_\nu\right| > U$ with $U = \dfrac{1}{R}$, $\gamma > 1$ (3.25)

Considering the following function *y(x)*, with *x=1-*θ and $x \in [0;1[$, which is the right hand side of expression (3.24):

$$y(x) = \frac{\beta^2 x^2 + 1 - \gamma^2}{\beta^2 \gamma^2 x^2} \qquad y'(x) = \frac{1}{\gamma^2} \tag{3.26}$$

Function *y(x)* is an increasing function with:

$$\lim_{x \to 0} y(x) = -\infty \qquad \lim_{x \to 1} y(x) = \frac{(RC\omega)^2 + 1 - \left(R.\left|\tilde{A}_\nu\right|\right)^2}{\left(\left|\tilde{A}_\nu\right| RC\omega\right)^2} \tag{3.27}$$

$$\lim_{x \to 1} y(x) > 0 \qquad \text{if} \qquad C^2\omega^2 + U^2 - \left|\tilde{A}_\nu\right|^2 > 0 \tag{3.28}$$

As $\phi = 1$:

$$\left|\tilde{A}_\nu\right|^2 - \left|\tilde{K}_\nu\right|^2 = (1-\theta)^2.(\omega.R.C)^2.\left|\tilde{K}_\nu\right|^2$$

And as:

$$\left|\tilde{A}_\nu\right|^2 - \left|\tilde{K}_\nu\right|^2 = \frac{\left|\tilde{A}_\nu\right|^2 - U^2}{\left(1-\theta^2\right)} \qquad \left|\tilde{K}_\nu\right| < U \text{ with } U = \frac{1}{R}$$

$$\left|\tilde{A}_\nu\right|^2 - U^2 = \left(1-\theta^2\right)(1-\theta)^2.(\omega.R.C)^2.\left|\tilde{K}_\nu\right|^2 < C^2\omega^2$$

So $\lim_{x \to 1} y(x) > 0$ (3.29)

On the other side, considering the function *z(x)*, with *x=1-*θ and $x \in [0;1]$, which is the left member of expression (3.24):

$$z(x) = (1-x)^2$$

Function *z(x)* is decreasing from $z(x) = 1$ for *x=0*, to $z(x) = 0$ for *x=1*.

Thus, a value of *x* exists, $x \in [0;1[$, for which *y(x)= z(x)*. This means that a value of θ exists, $\theta \in [0;1[$, which is a solution of expression (3.24). The θ value, solution of expression (3.24), is found by approximation.

An interpolation is first performed through three points in order to get an approximation of the right hand side of equation (3.24):

$$y(\theta)=\frac{\beta^2(1-\theta)^2+1-\gamma^2}{\beta^2\gamma^2(1-\theta)^2} \tag{3.30}$$

The points are named $(\theta_1, y_1), (\theta_2, y_2)$ and (θ_3, y_3). Function $y(\theta)$ is approximated by interpolation through Lagrange polynomials:

$$y(\theta)=\frac{(\theta-\theta_2)(\theta-\theta_3)}{(\theta_1-\theta_2)(\theta_1-\theta_3)}.y_1+\frac{(\theta-\theta_1)(\theta-\theta_3)}{(\theta_2-\theta_1)(\theta_2-\theta_3)}.y_2+\frac{(\theta-\theta_1)(\theta-\theta_2)}{(\theta_3-\theta_1)(\theta_3-\theta_2)}.y_3 \tag{3.31}$$

Function $y(\theta)$ can be reduced to:

$$y(\theta)=a.\theta^2+b.\theta+c \tag{3.32}$$

Where *a* coefficient is equal to:

$$a=\frac{y_1}{(\theta_1-\theta_2)(\theta_1-\theta_3)}+\frac{y_2}{(\theta_2-\theta_1)(\theta_2-\theta_3)}+\frac{y_3}{(\theta_3-\theta_1)(\theta_3-\theta_2)}$$

And solving equation (3.24) comes to solving a 2nd degree equation:

$$y(\theta)-\theta^2=(a-1).\theta^2+b.\theta+c=0 \tag{3.33}$$

For the three chosen points $\theta_1=0.1$, $\theta_2=0.3$ and $\theta_3=0.5$:

$$a=\frac{53.125(1-\gamma^2)}{\beta^2\gamma^2}<1 \qquad \text{as} \qquad \gamma>1 \quad \text{from (3.25)}$$

The solution of (3.33) to be considered is:

$$\theta=\frac{-b-\sqrt{b^2-4(a-1)c}}{2(a-1)} \tag{3.34}$$

3.3.3. Modelling adiabatic boundary conditions walls

For *adiabatic boundary conditions*, the adjustment process concerns both parts of the wall shared by a null heat flow plane whose position is defined by equalizing the dampening factors of two sinusoidal temperature solicitations acting separately on each wall side (3.16).

The adjustment consists in equalizing the magnitude and angle of the wall adiabatic admittance $\tilde{A}_V$, computed for a 24 hours time period (equation 3.13), with the corresponding two-port network values (equation 3.20).

The adjustment provides two resistances and one capacity (R_1, R_2, C_1) which can also be expressed as fractions of the wall total resistance and capacity, through factors θ and ϕ (fig. 3.3):

$$\tilde{A}_v = -\frac{Q_{21}}{Q_{22}} = -\frac{\phi.C\omega j}{1+\phi.\theta.R.C\omega j} \tag{3.35}$$

The resistance $(1-\theta)R$, located on the null heat flow plane side, can be erased from the model, as there is no heat flow passing through this network connection (fig. 3.4).

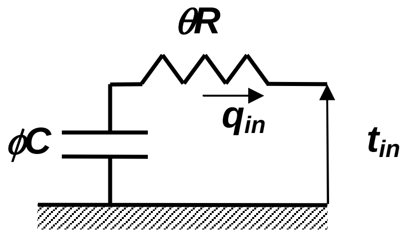

Fig.3.4. Adjusted 2R1C network for an adiabatic boundary conditions wall

Equation (3.35) yields the parameters θ and ϕ:

$$\theta = \frac{\left|\Re\left(\tilde{A}_v\right)\right|}{R.\left|\tilde{A}_v\right|^2} \qquad \phi = \frac{\left|\tilde{A}_v\right|^2}{\omega.C.\left|\Im\left(\tilde{A}_v\right)\right|} \tag{3.36}$$

3.4. Building walls classification

Building walls surrounding a zone or included into it, need to be shared in both *isothermal* and *adiabatic* categories. Three types of wall are related to a building zone under study:

- *External walls*, surrounding the zone and in contact with the outdoor
- *Internal walls*, i.e. internal walls entirely involved in the zone under study
- *Partition walls*, i.e. internal walls dividing the building into different zones.

External walls are modeled with *isothermal boundary conditions* walls. They include external walls surrounding the zone, including walls in contact with ‘cold’ neighbor zones, such as outdoor car parks, whose temperature is strongly influenced by the outdoor temperature. Isothermal boundary conditions are also associated to walls in direct or un-direct contact with ground (through cellars and crawl spaces). In those cases, the wall U-value is reduced through a weighting factor ranging from 1/3 to 2/3, depending on the type of ground contact: this is equivalent to adding an outdoor pure resistive layer.

Internal walls are modeled with *adiabatic* boundary conditions. They include walls and floors entirely included in the zone under study, or partition walls when in contact with neighbor zones heated or cooled following a schedule similar to the zone under study. As those walls are submitted to similar temperature profiles on both faces, they include a *null heat flow plane*. The ζ parameter, comprised between 0 and 1, defines the position of the null heat flow plane in the internal wall. This plane shares the wall in two parts, both being modeled with adiabatic boundary conditions through a 2R1C network, so that the model of the whole wall is a 3R2C network (fig. 3.5).

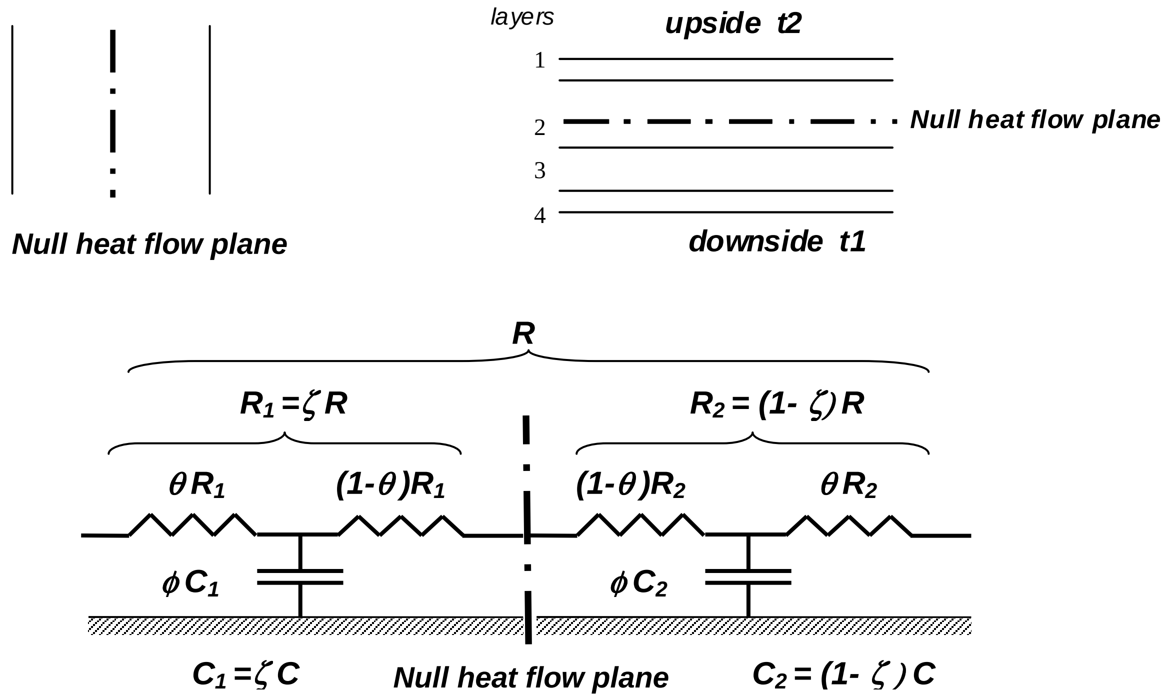

Fig.3.5. Null heat flow plane for an homogenous internal wall (upside left), for a multilayer internal floor (upside right) and scheme of the internal wall model (below)

Partition walls can be shared by a *null heat flow plane* defined as for internal walls, but they are modeled through a 2R1C network, the network capacity being equal to the whole wall capacity and located at the level of the wall null heat flow plane.

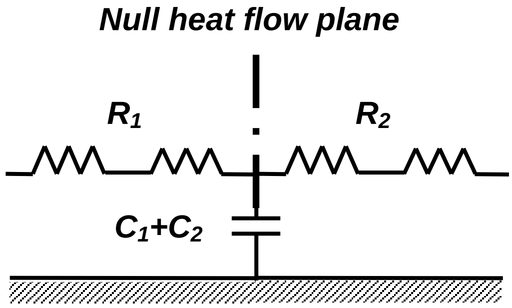

Fig.3.6: Model 2R1C of a partition wall.

3.5. Examples of adjusted wall network models

3.5.1. External walls

Table 3.1 displays the parameters resulting from an adjustment performed for different external walls, modeled with isothermal boundary conditions.

Table 3.1. Adjusted parameters for a set of external walls

External walls	a	1/R	C	ϕ	θ
		W/m²K	*J/m²K*		
Concrete bloc, insulation, brick	1	0.39	290190	0.64	0.07
Wooden wall, insulation, brick	1	0.30	235327	0.53	0.11
Wooden structure insulated roof	1	0.28	21552	0.75	0.09
Concrete flat roof, external insulation	1	0.37	455924	1	0.08
Floor in contact with outdoor	1	0.64	364882	0.65	0.14
Floor on crawl space	1	0.59	364882	1	0.13
Floor on cellar	2/3	0.40	364882	1	0.09
Ground contact floor	1/3	0.22	391762	1	0.05
Ground contact wall	2/3	0.38	320652	1	0.08
Internal wall in contact with unheated room	2/3	0.93	304661	0.90	0.18
Internal wall in contact with heated room	1/3	0.62	304661	1	0.13

Fig. 3.7 compares the exact values of the transmittances and admittances magnitudes computed for different walls, with the corresponding values yield by adjusted networks. Transmittances and admittances magnitudes are presented as function of frequency, on Bode diagrams. The full line displays the exact value computed from the wall layer description, while the dotted line represents the response of the 2R1C network adjusted for a 24 h time period. The horizontal line represents the stationary behavior of the wall.

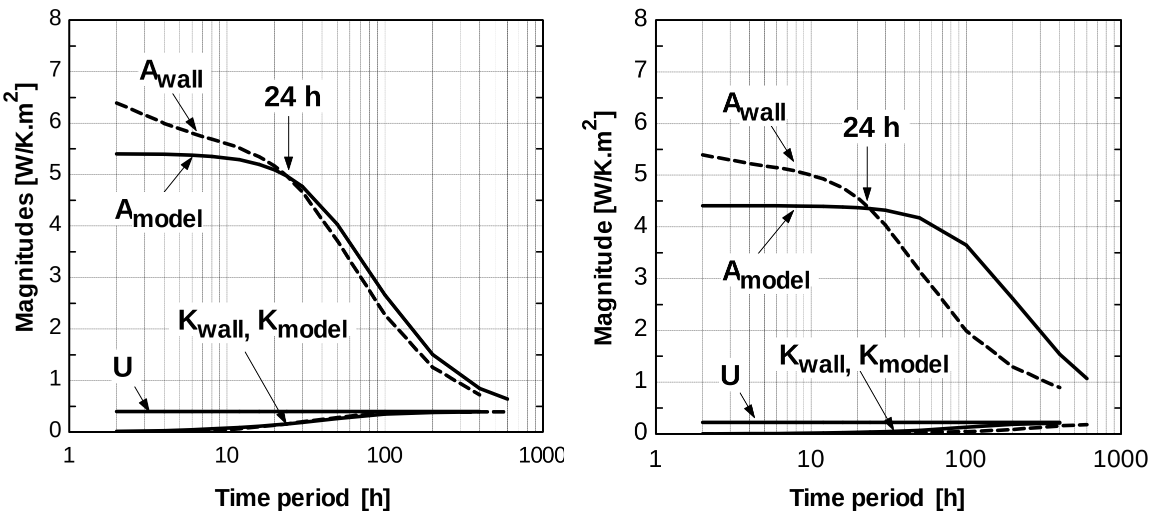

Fig.3.7. Transmittance and admittance Bode diagrams for a traditional external wall modeled with isothermal boundary conditions (left) and for a ground contact floor (right).

Fig.3.7. displays comparisons for an external wall, modeled with isothermal boundary conditions, and for a ground contact floor. Ground contact walls are considered as reinforced by a fictitious outdoor resistive layer modeling the ground insulation effect. The boundary conditions associated to those walls are nearly adiabatic, though there still exists a small heat flow crossing them.

For a 24 h time period, the curves provide the same values of admittance and transmittance as the adjustment is performed to do so. The external wall network adjustment is reliable for low frequencies, but discrepancies are observed for high frequencies. The adjustment is less reliable for the ground contact floor but this wall is crossed by a much smaller heat flow compared to other building external walls.

3.5.2. Internal walls

Table 3.2 displays the parameters resulting from an adjustment performed for different internal walls, modeled with adiabatic boundary conditions.

Table 3.2. Adjusted parameters for a set of internal walls

Internal walls	**1/R**	**C**	**ϕ**	**θ**
	W/m²K	*J/m²K*		
Internal concrete bloc	5.02	81480	1	0.80
Massive wooden wall	2.07	48504	1	0.50
Concrete partition wall	1.85	152331	0.96	0.30
Internal concrete floor (upside part)	3.79	180600	1	0.75
Internal concrete floor (downside part)	4	178920	1	0.75
Internal wooden floor with screed (upside part)	4.67	71904	1	0.75
Internal wooden floor with screed (downside part)	3.47	38528	1	0.75

Fig.3.8. displays comparisons of admittances for an internal wall, modeled with adiabatic boundary conditions. The quality of the adjustment is better for the internal wall than for an external wall (fig. 3.7) because both parts of the internal wall are modeled by a 2R1C model, which means that the whole internal wall is modeled by a 3R2C network (§2.2.3). That conclusion was already observed by M. Kummert in his thesis work: a 3R2C model is reliable enough to reproduce the wall behavior over the whole range of frequencies [18],[13].

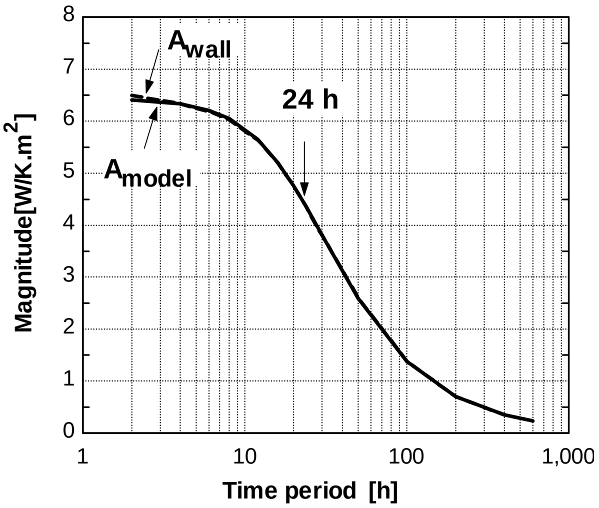

Fig.3.8: Admittance Bode diagrams for half an internal hollow concrete wall modeled with adiabatic boundary conditions.

3.5.3. Partition walls

Partition walls, as already mentioned, are modeled through a 2R1C network, the network capacity being equal to the whole wall capacity and located at the level of the wall null heat flow plane (fig. 3.6 and fig. 3.9, left).

A 3R2C network of the partition wall could also be obtained by connecting the 2R1C models associated to both parts of the wall when it is shared with a null heat flow plane and modeled with adiabatic boundary conditions, (see fig. 3.9, right). Fig. 3.10 displays the Bode diagrams corresponding to both models of fig. 3.9.

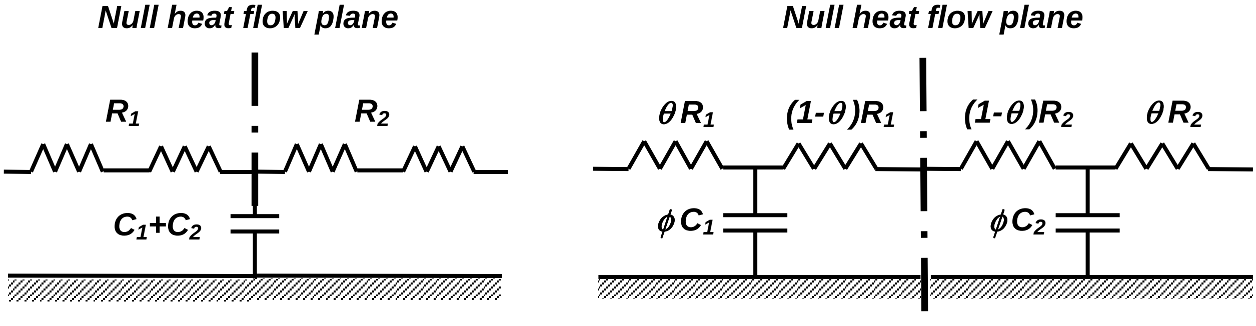

Fig.3.9: 2R1C network (left) and 3R2C network (right) of a partition wall.

The 3R2C model resulting from the connection of two 2R1C models is more reliable than the 2R1C model of the whole wall. Anyway, the 2R1C model provides a sufficient approximation for partition walls when they are integrated in a model representing the whole building behavior.

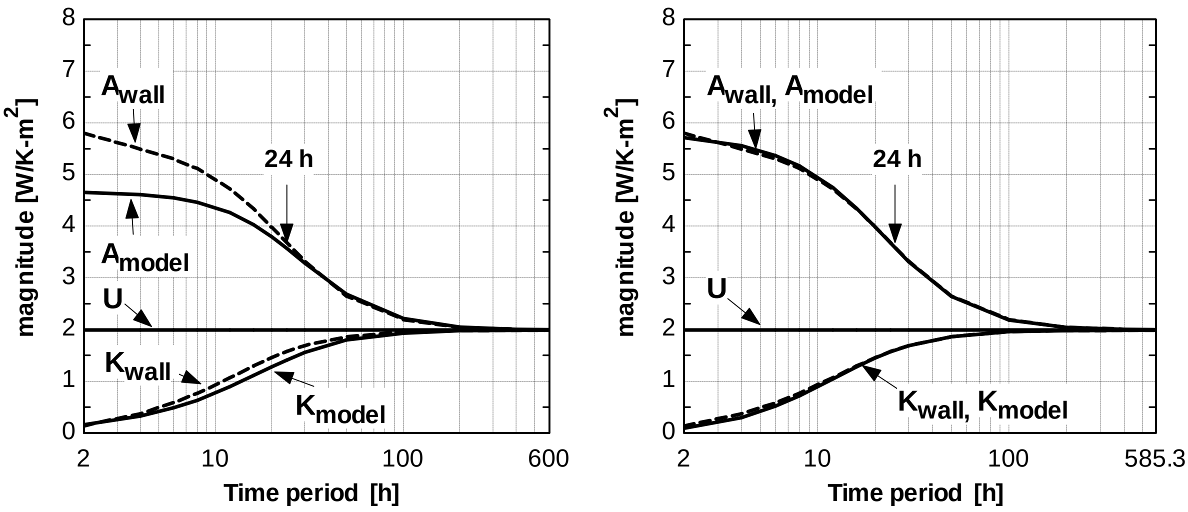

Fig.3.10: Admittances and transmittances Bode diagrams for the partition wall (exact value in dotted line) for a 2R1C model (full line left) and for a 3R2C model (full line right).

3.6. Wall parameters default values

A wall catalog was established and listed in annex 1. The adjustment process described in § 3.2.2 was performed for each wall of the catalog in order to provide their non dimensional parameters θ and ϕ. Those parameters were represented on a graph in order to make appear different wall categories and to assign them default values. Two examples of results are presented here: those related to external walls and roofs. The complete list of wall default parameters and associated graphs is included in annex 1.

3.6.1 External walls default parameters

Figure 3.11 shows the graph related to external walls. Three wall categories can be distinguished:

Category A includes:

- concrete or clay blocs, insulation and strongly ventilated air layer
- massive wooden structure, insulation and strongly ventilated air layer
- cellular concrete with outdoor insulation

Default values: θ = 0.10 ϕ = 1

Category B includes:

- concrete or clay blocs, insulation and outside brick
- not insulated cellular concrete
- triple panel with two insulation layers

Default values: θ = 0.10 ϕ = 0.70

Category C includes:

- massive wooden structure
- wooden structure
- sandwich panel

Default values: θ = 0.10 ϕ = 0.50

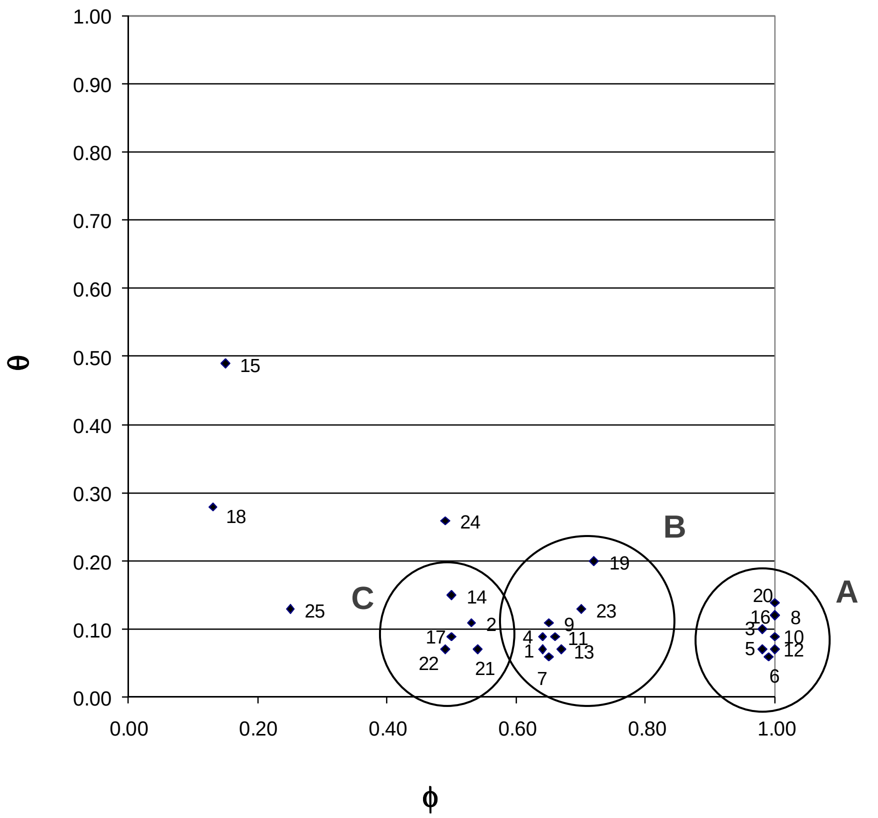

Fig.3.11: External walls ϕ and θ parameters

3.6.2 Roofs default parameters

Figure 3.12 shows the graph related to roofs. Three roof categories can be distinguished:

Category A: includes precast concrete roofs with outdoor insulation

Default values: $\theta = 0.10$ $\phi = 1$

Category B: includes wooden structure insulated roofs

Default values: $\theta = 0.10$ $\phi = 0.85$

Category C : includes precast concrete roofs with indoor insulation

Default values: $\theta = 0.40$ $\phi = 0.20$

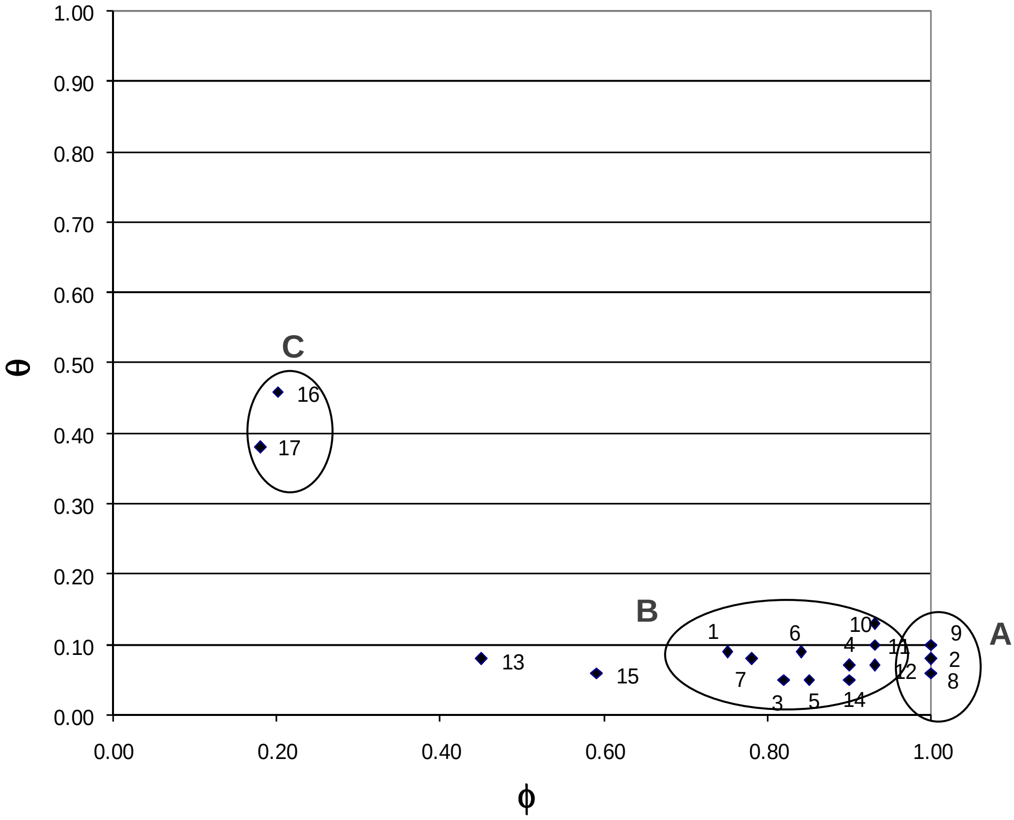

Fig. 3.12: Roofs ϕ and θ parameters