Co-funded by the Erasmus+ Programme of the European Union

Master Degree in InnovativeTechnologies in Energy Efficient Buildings for Russian & Armenian Universities and Stakeholders

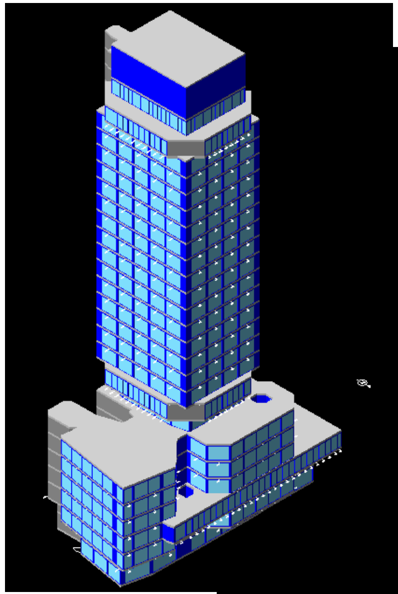
Prof. Ph.D. Federico Valsuani

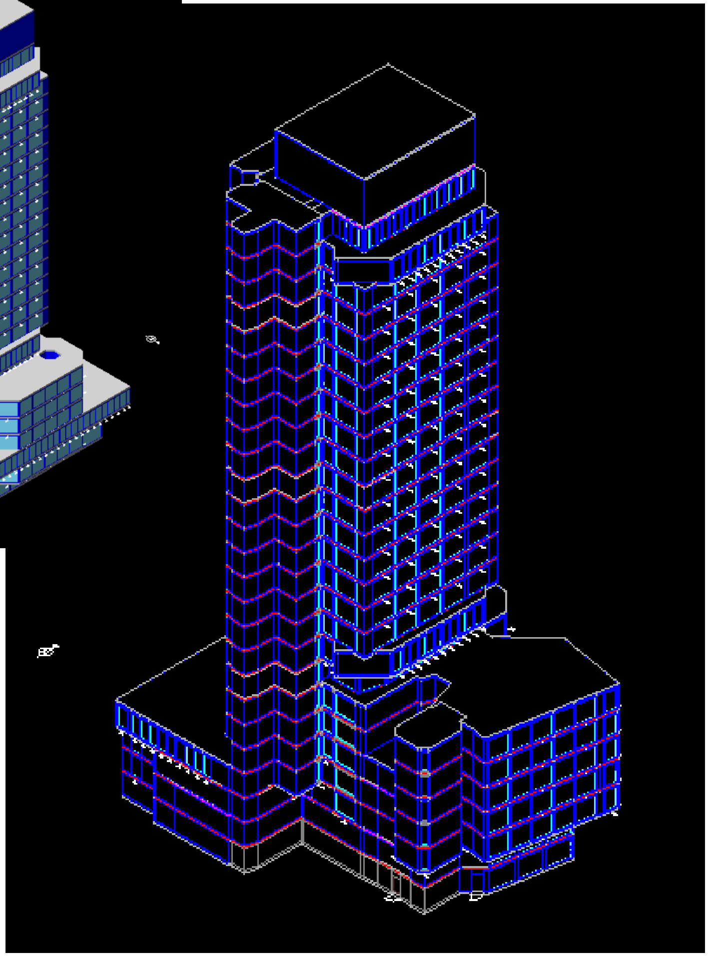
INTRODUCTION

A building is a system consisting of:
- the external building structures that delimits a defined volume;
- the internal structures that divide all the rooms;
- all systems and technological devices that are permanently inside;

- the external environment, the land, other buildings;
- the people that live/work in the building;

- Use of the building .
- Building cladding;
- Climatic conditions of the installation site;
- Type of power plants, distribution and emission;

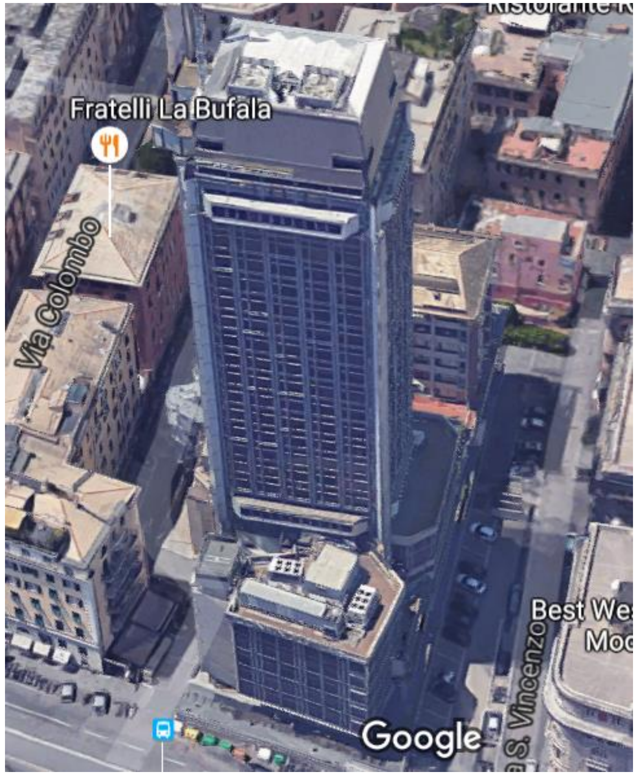


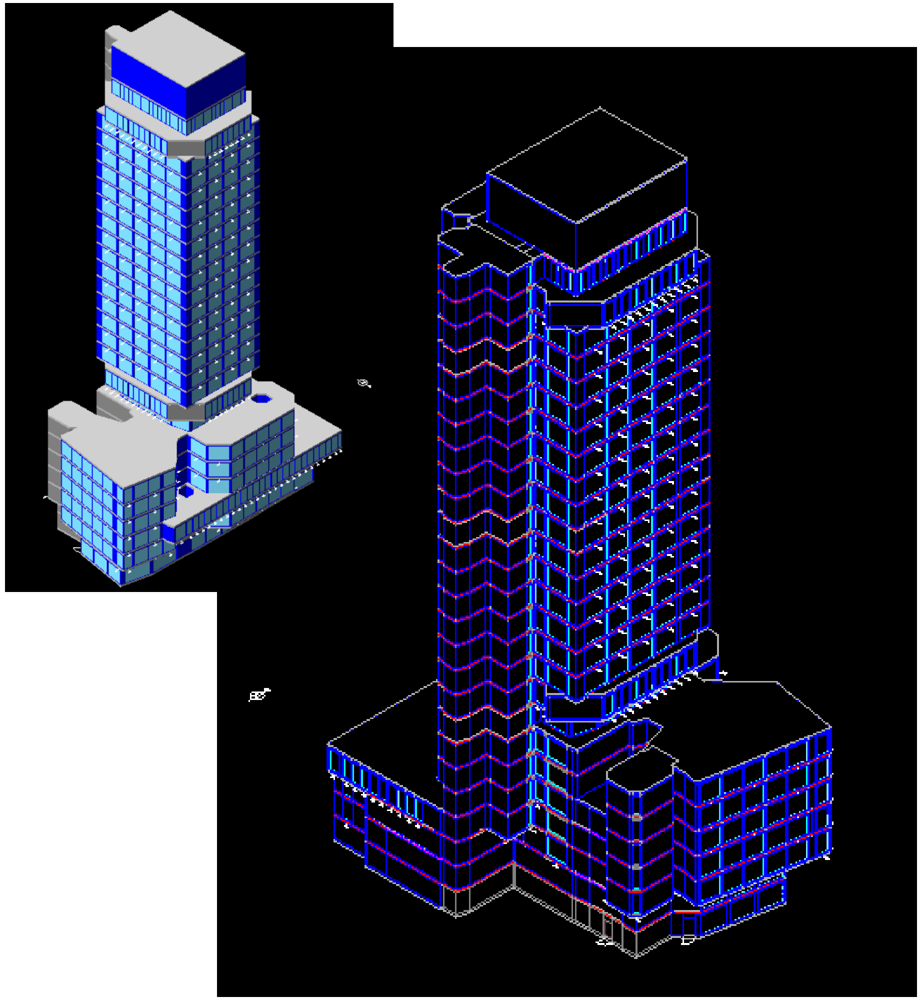


INTRODUCTION

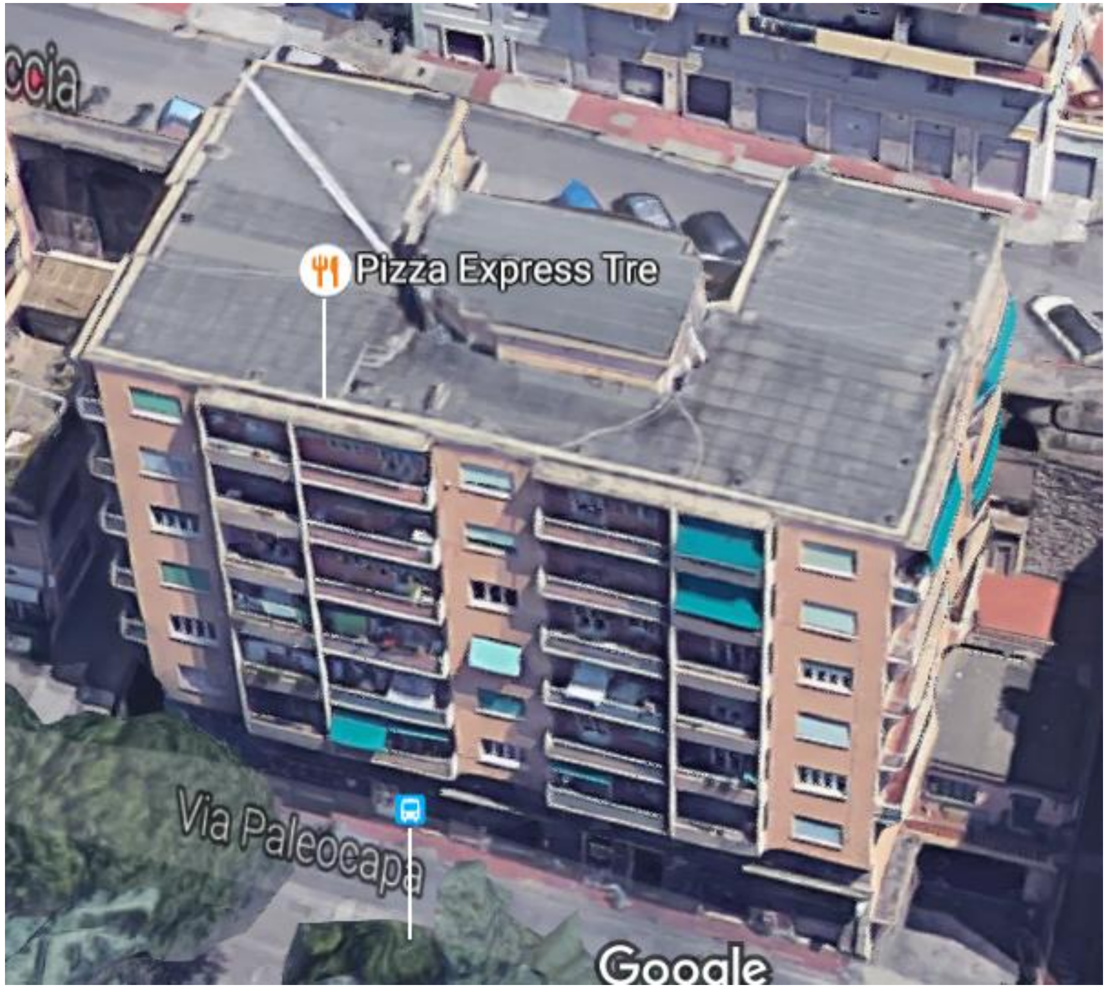
Which is the goal of the simulation ?

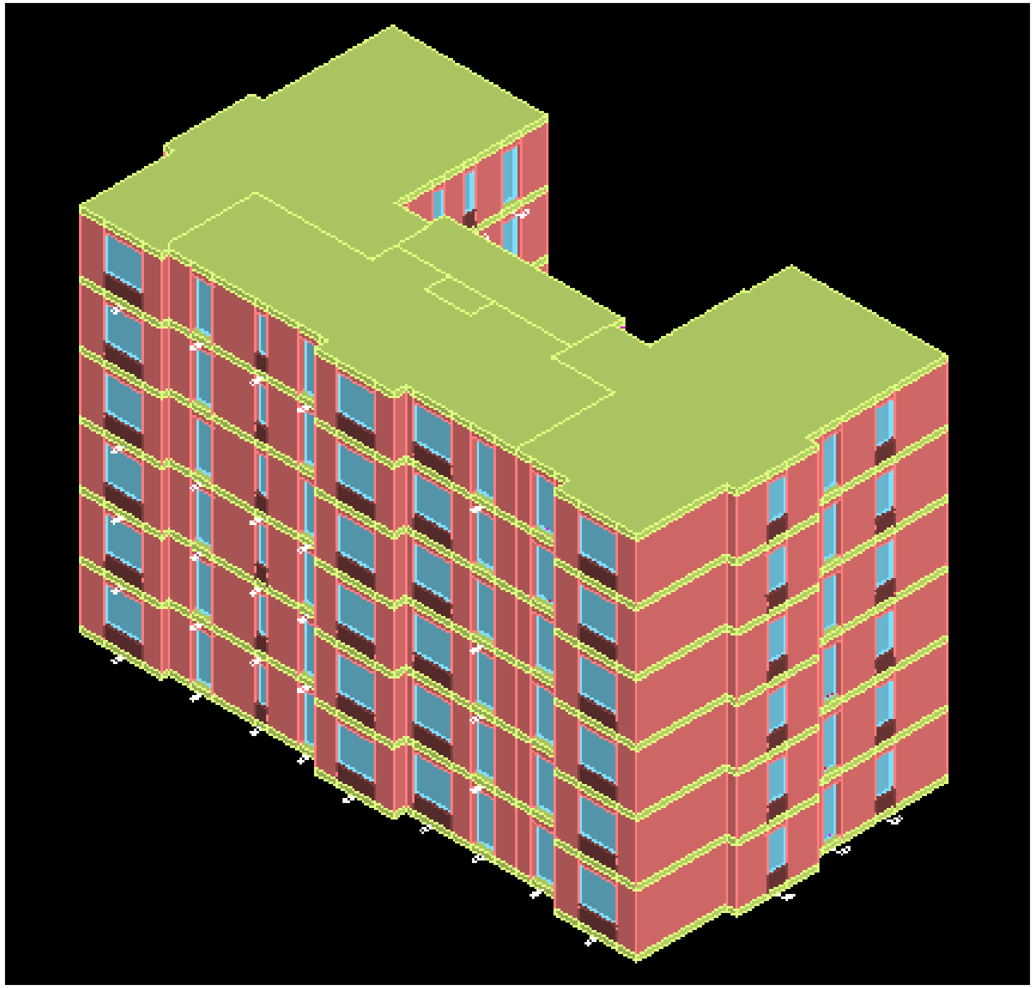
- design (cladding/plant);
- energetic analysis;
- dynamic response of materials;





INTRODUCTION





INTRODUCTION

Design (UNI 11300)

Simulation
Monthly based steady state condition

External temperature – UNI 10349

Internal design temperature – 20°C/26°C

Energy audit (UNI 11300)

Simulation
Monthly based steady state condition

External temperature – UNI 10349 or data

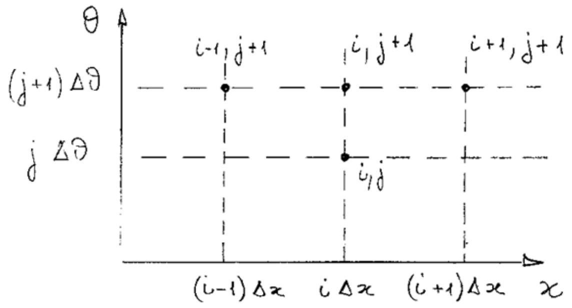
Internal design temperature – 20°C/26°C or data

Dynamic anaysis

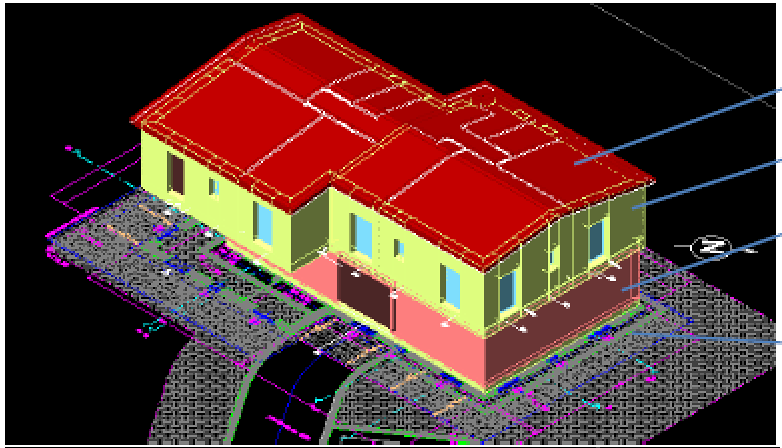
Simulation
Numerical model
<u>Finite difference method</u>

External temperature – data

Internal temperature – data



INTRODUCTION

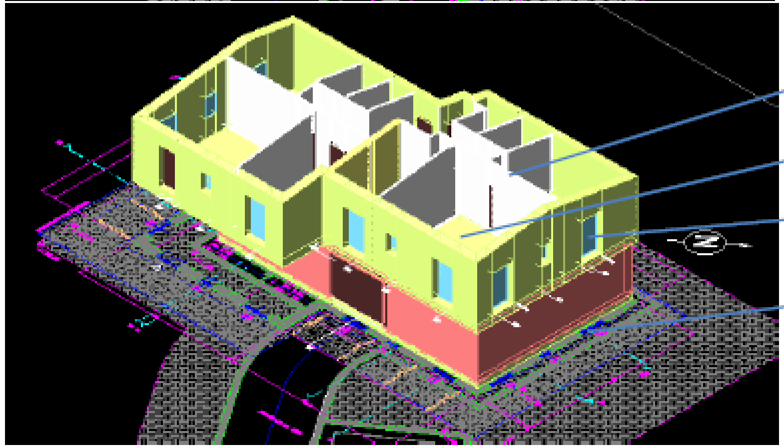


Roof

External wall

Retaining wall

Foundation



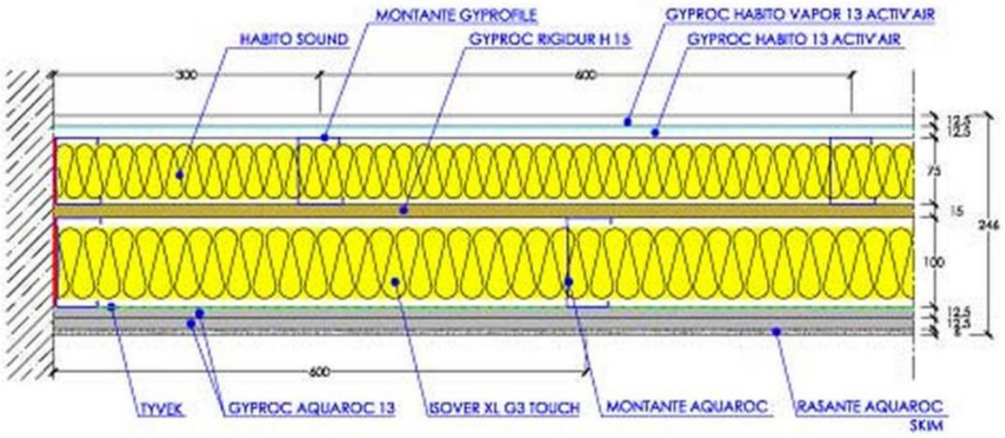
Internal division

Ceiling

Windows

Foundation

To analyze a building is important to know all of the components of the wall/windows and the different exposures of this elements



INTRODUCTION

the generalized equation integration of Fourier, for example particularized to one-dimensional conduction problems in varying arrangements, namely in the form:

$$a \cdot \frac{\delta^2 t(x, \vartheta)}{\delta x} = \frac{\delta t(x, \vartheta)}{\delta \vartheta}$$

where t is the temperature and θ is the time.

δ, c , λ , l, a: respectively the density [kg / m^3], the specific heat [J / kgK], the thermal conductivity [W / mK], the thickness [m] and the thermal diffusivity (a = λ / δ c) [m / s^2].

t^*_e : the temperature of the outer face, sum of a sinusoidal temperature t_e of period and an average temperature tem *, You, tim analogs values related to the inner face * * The angular speed = 2 * / *

$$t_i^* = t_{em} + t_e\, e^{-\Gamma l}\, \mathrm{sen}[\omega(\theta - \beta l/\omega)]$$

$$t_e^* = t_{em} + t_e\, \mathrm{sen}(\omega\theta)$$

$$\beta = \sqrt{\frac{\omega}{2\,a}}$$

INTRODUCTION

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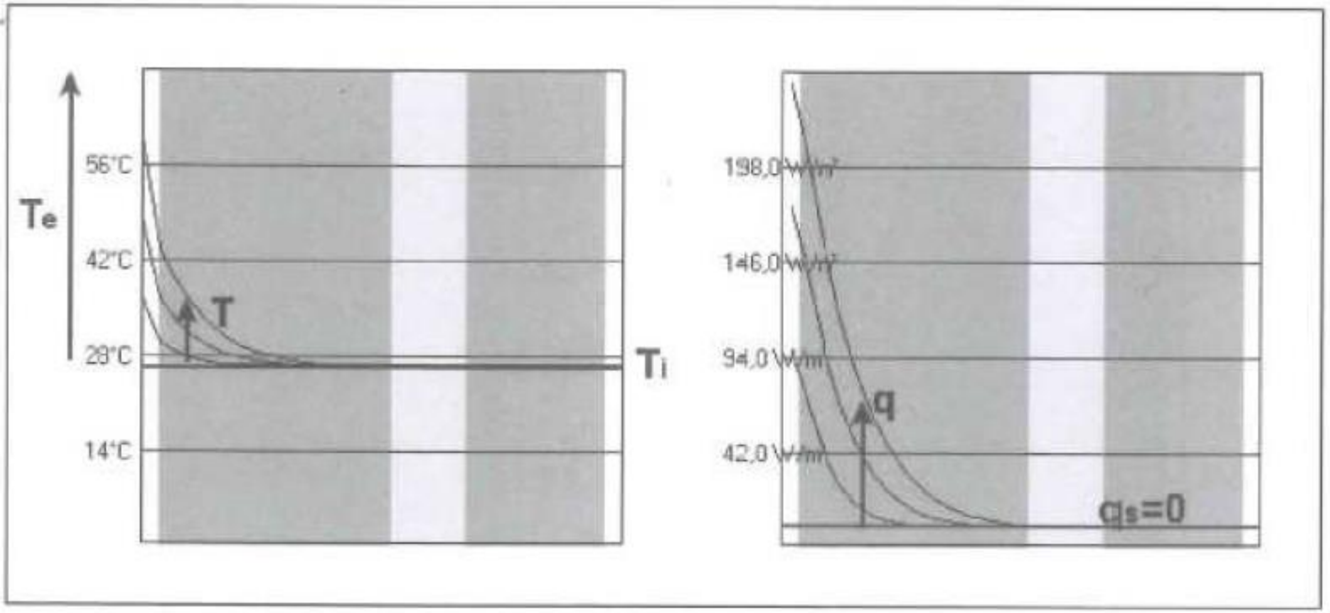

The thermal flux inside the structure has values that depend on the x coordinate:

$$q''(x) = -\lambda(\delta T/\delta x)(x)$$

INTRODUCTION

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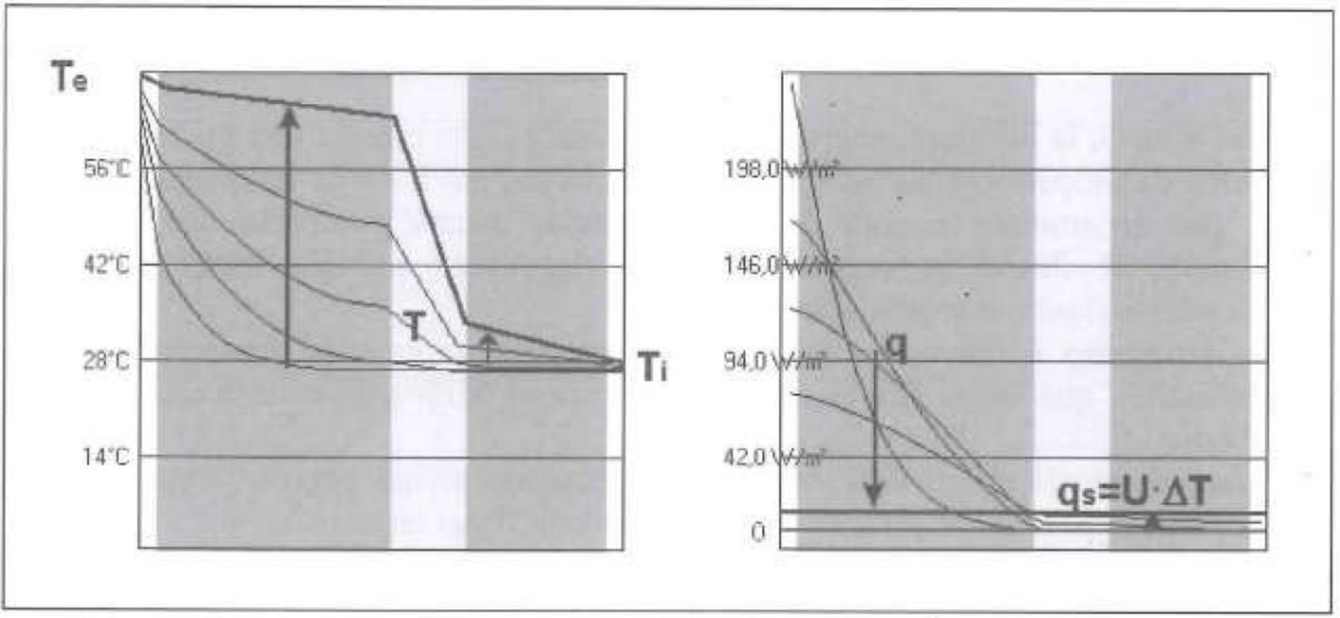


The thermal flow inside the structure has values that depend on the x coordinate

$$q''(x) = -\lambda(\delta T/\delta x)(x)$$

After some time the flux reach the steady state condition

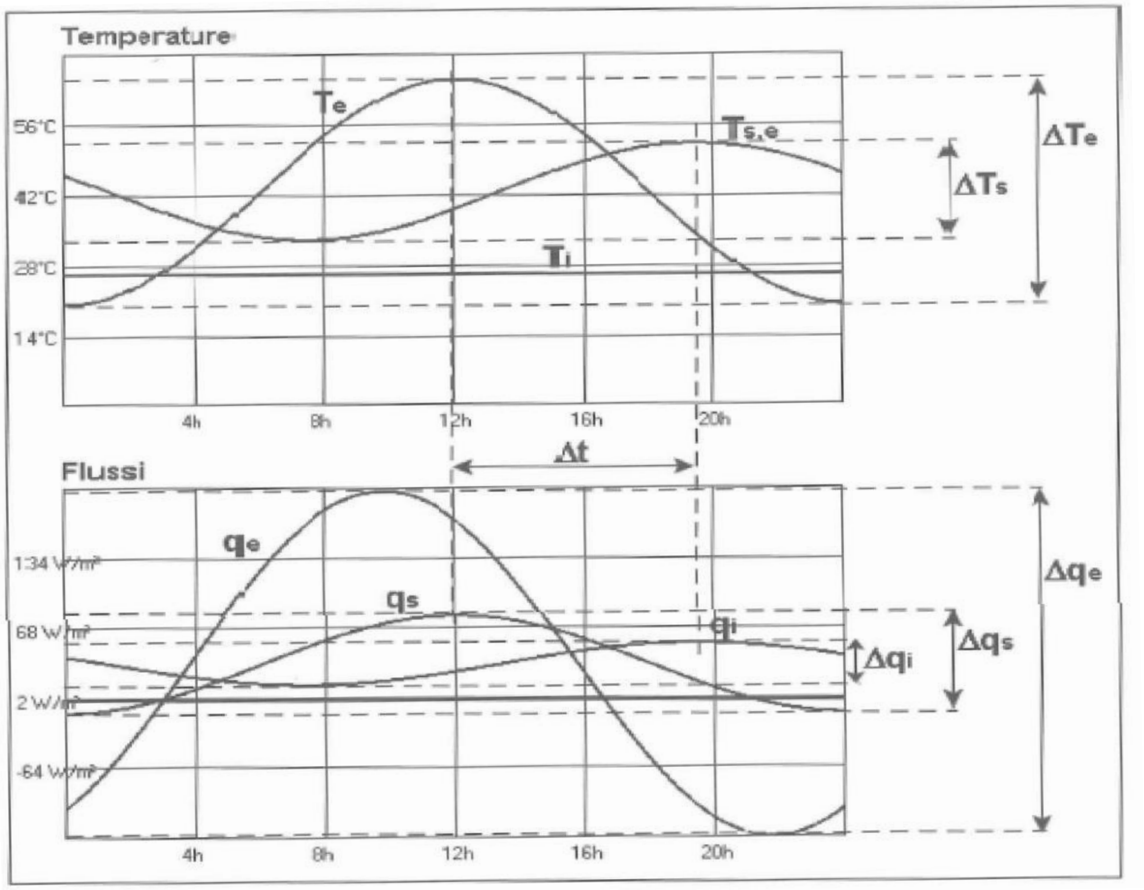
$$q''_s = U(\Delta T)$$

INTRODUCTION

The main dynamic parameter to study the thermal energy transferred throught the wall structure are:

The periodic thermal transmittance (or dynamic) **Yie**: the ratio between the heat flow per unit surface which crosses a face of the structure and the temperature change on the opposite face, calculated keeping constant the temperature on the first face.

$$Y_{ie} = \frac{\Delta q''_i}{\Delta T_e} \ [\mathrm{W/m^2K}]$$



INTRODUCTION

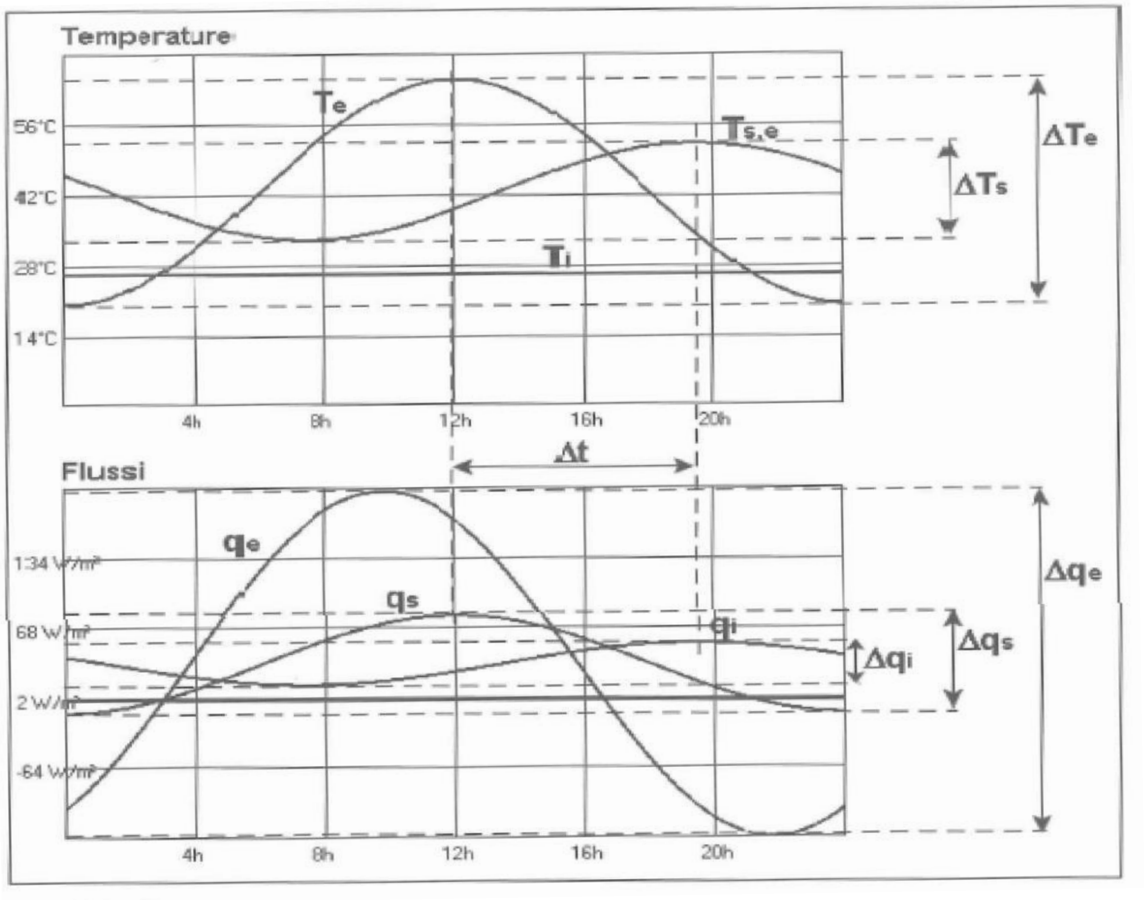
The main dynamic parameter to study the thermal energy transferred throught the wall structure are:

Lag or thermal wave time delay **φ [h]**: The time period between the maximum value of the external stress (Te) and the maximum of its effect (q”i)

Inverse of the imaginary part of the inverse of thermal periodic conductance, refers to a side of the element, divided by the angular frequency (kJ/m^2 K):

Heat capacity per unit area **χ_m**: heat capacity Cm divided by the area of the element:

$$\chi_m = \frac{C_m}{A} = \frac{1}{\omega\, \Im\left(\frac{1}{Y_{mm}}\right)} = \frac{T}{2\pi \Im\left(\frac{\hat{\theta}_m}{\hat{q}_m}\right)}$$



INTRODUCTION

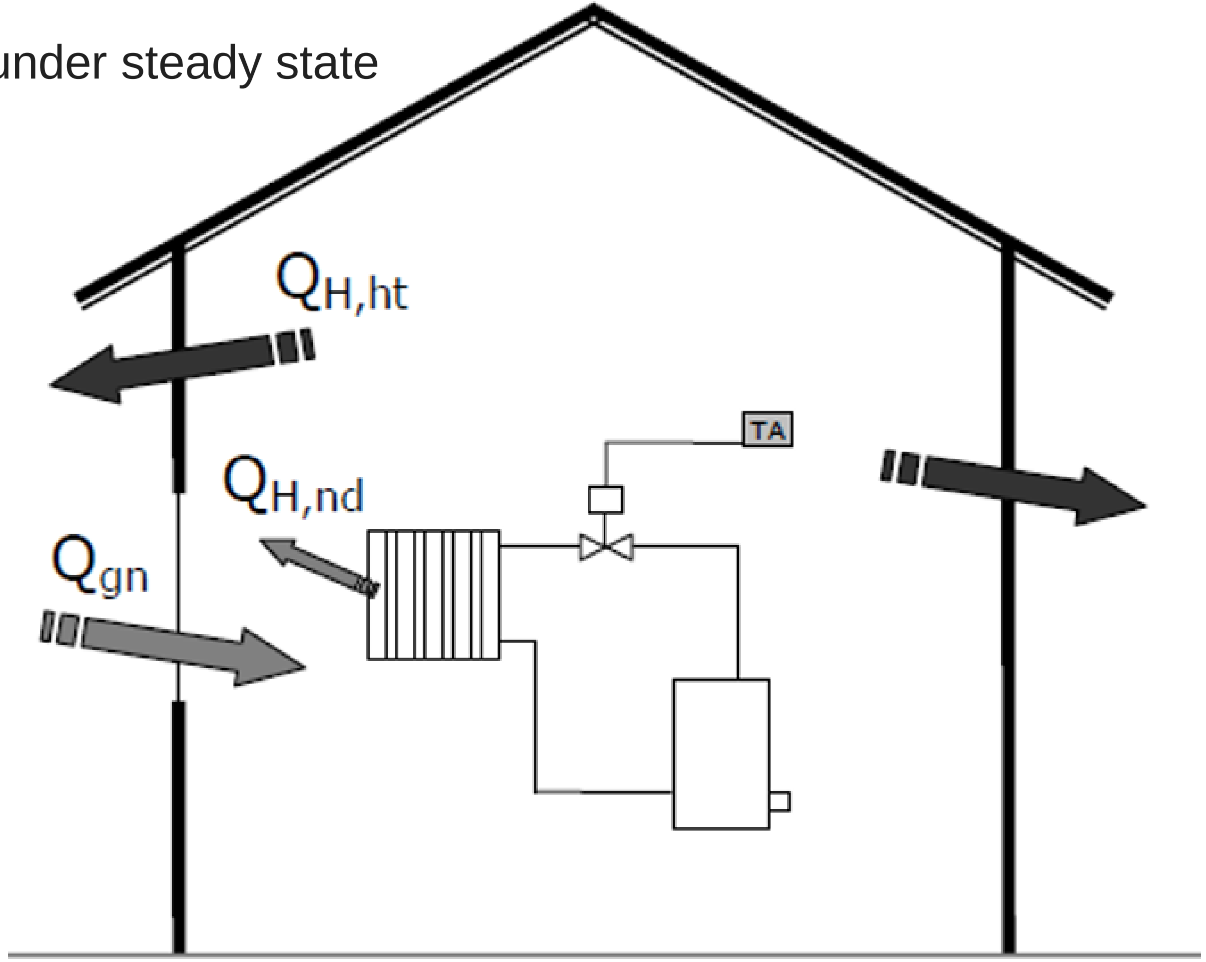
The equation that describes the behaviour of a building under steady state condition is:

Utilization factor of the free contributions (0-1)

$$Q_{H,nd} = Q_{H,ht} - \eta_{H,gn} Q_{gn}$$

Energy losses

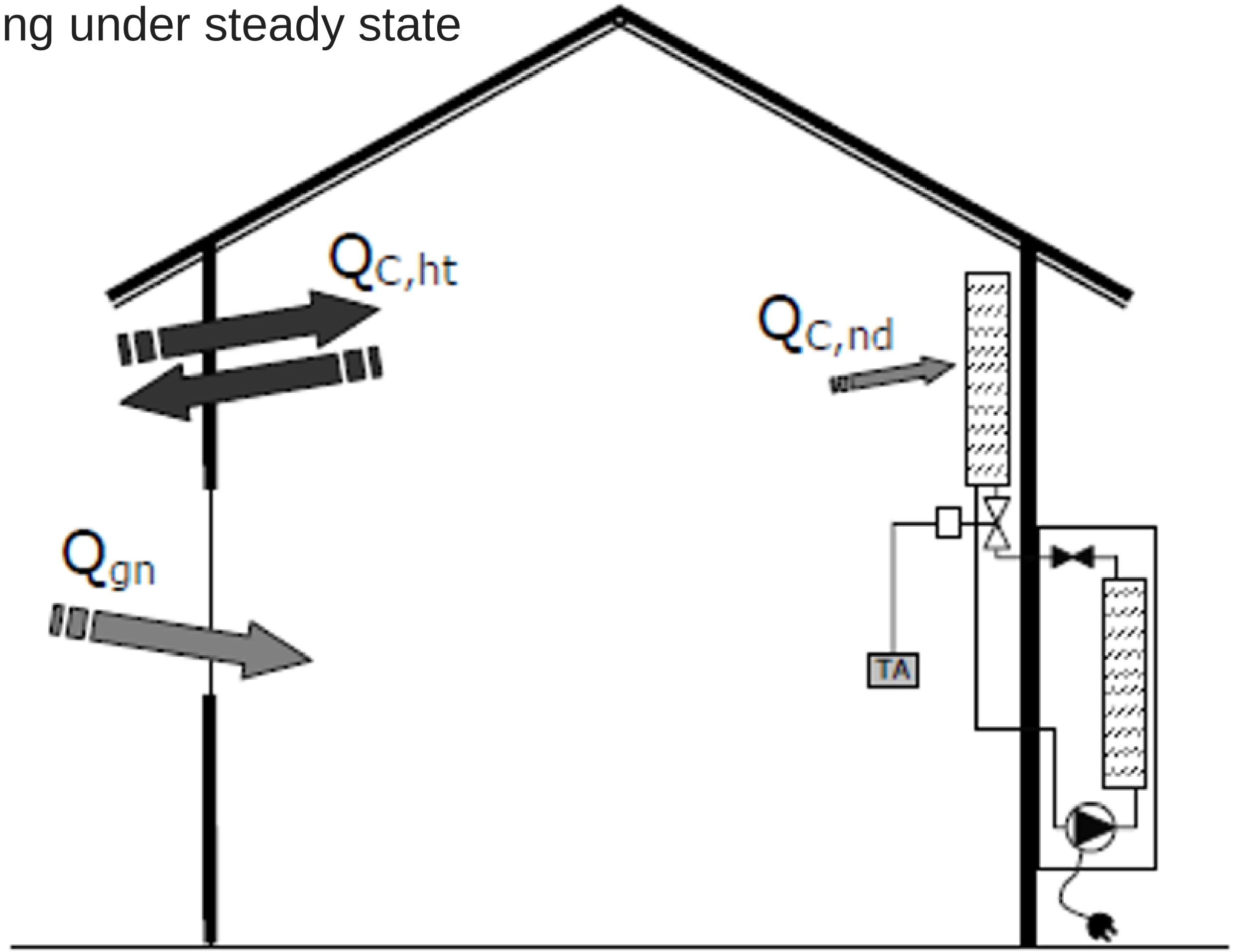
Energy gain



INTRODUCTION

The equation that describes the behaviour of a building under steady state condition is:

$$Q_{C,nd} = Q_{gn} - \eta_{C,ls} Q_{C,ht}$$



INTRODUCTION

The equation that describes the behaviour of a building under steady state condition is:

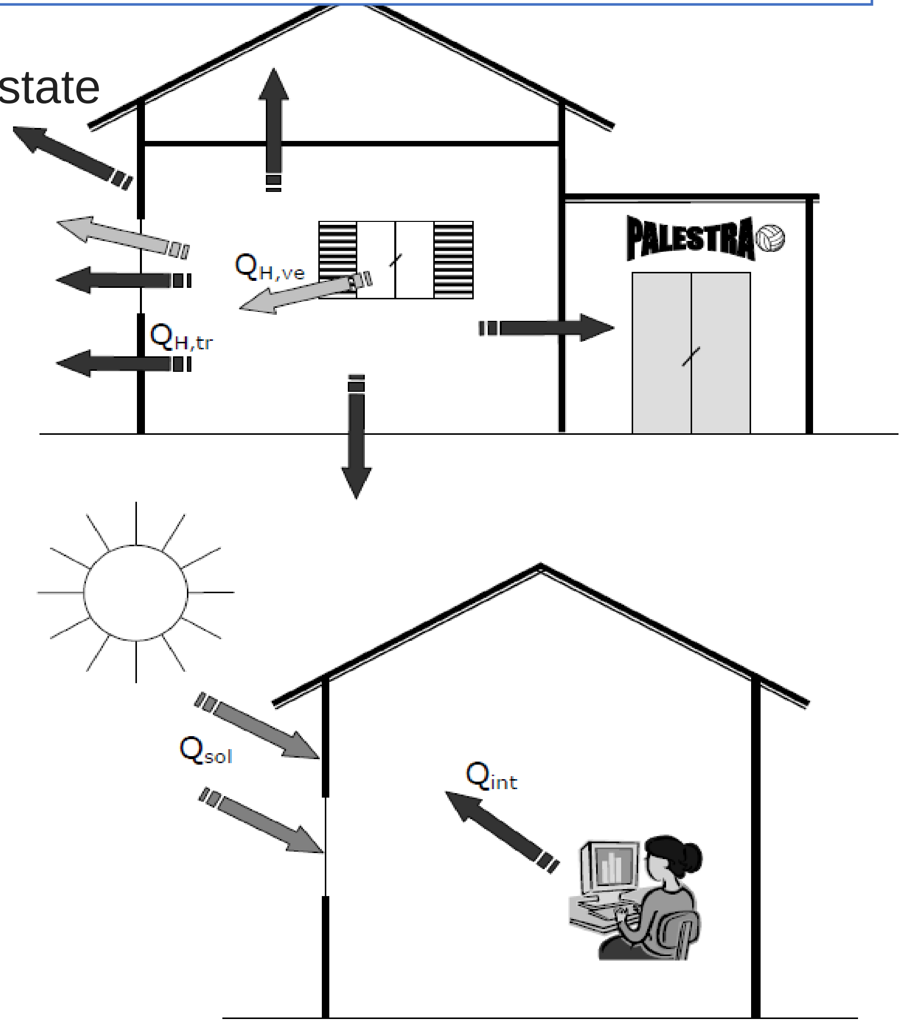
$$Q_{gn} = Q_{int} + Q_{sol}$$

Energy gain

$$Q_{H,nd} = Q_{H,ht} - \eta_{H,gn} Q_{gn}$$

Energy losses

$$Q_{H,ht} = Q_{H,ve} + Q_{H,tr}$$



STEADY STATE ANALISYS

The equation that describes the behaviour of a building under steady state condition is:

Net energy demand for heating

Energy contribution for solar gains

Energy contribution for internal gains

$$Q_{H,nd} = Q_{H,ht} - \eta_{H,gn} \cdot Q_{gn} = \left(Q_{H,tr} + Q_{H,ve}\right) - \eta_{Hgn} \cdot (Q_{int} + Q_{sol,w})$$

Energy loss for ventilation

Energy loss for transmission

Net energy demand for cooling

Energy contribution for solar gains

Energy contribution for internal gains

$$Q_{C,nd} = Q_{gn} - \eta_{H,ls} \cdot Q_{C,ht} = (Q_{int} + Q_{sol,w}) - \eta_{Hgn} \cdot \left(Q_{C,tr} + Q_{C,ve}\right)$$

Energy loss for ventilation

Energy loss for transmission

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STEADY STATE ANALISYS

The equation that describes the behaviour of a building under steady state condition is:

Net energy demand for heating

$$Q_{H,nd} = Q_{H,ht} - \eta_{H,gn} Q_{gn}$$

Energy contribution for solar gains

Energy contribution for internal gains

$$Q_{H,nd} = (Q_{H,tr} + Q_{H,ve}) - \eta_{gn}(Q_{int} + Q_{sol})$$

Energy loss for ventilation

Energy loss for transmission

$\eta_{H,gn}$: utilization factor of the free contributions (function of the ratio of $Q_{gn}/Q_{H,ht}$)

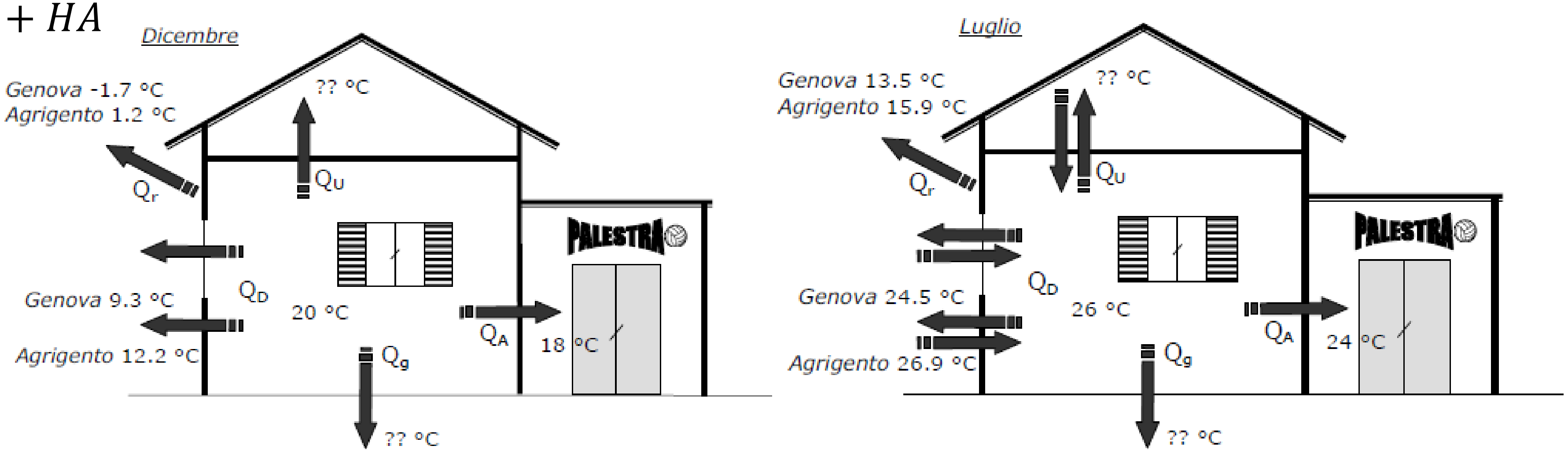
ENERGY LOSSES FOR TRANSMISSION

The transmission energy losses can be calculated as:

$$Q_{H,tr} = H_{tr,adj}\,(\theta_{int,set,H} - \theta_e)\,t + \left(\sum F_{r,k}\varphi_{r,mn,k}\right)t + \left(\sum (1-b_{tr})F_{r,l}\varphi_{r,mn,u,l}\right)t - Q_{sol,op}$$

- $H_{tr,adj}$: global heat transfer coefficient (W/K)
- $\sum F_{r,k}\varphi_{r,mn,k}$: skywards extra flux (W)
- $\sum (1-b_{tr})F_{r,l}\varphi_{r,mn,u,l}$: skywards extra flux for non-heated zones (W)

$$H_{tr,adj} = HD + Hg + HU + HA$$

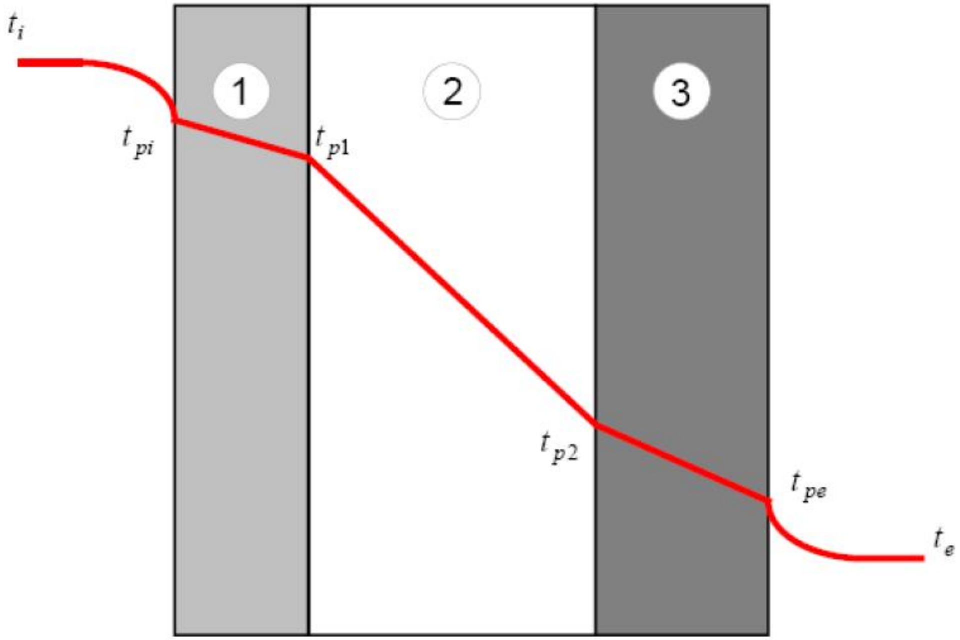


ENERGY LOSSES FOR TRANSMISSION

The transmission losses through external walls are calculated as below

$$\dot{Q}_{H,tr} = \frac{A(\theta_i - \theta_e)}{R_i + R_1 + R_2 + \cdots + R_n + R_e}$$

$$\frac{Q}{A} = h_{a,i}\left(t_i - t_{pi}\right) = \frac{t_i - t_{p1}}{\frac{1}{h_{a,i}} + \frac{s_1}{\lambda_1}} = \frac{t_i - t_{p2}}{\frac{1}{h_{a,i}} + \frac{s_1}{\lambda_1} + \frac{s_2}{\lambda_2}} = \ldots = U\left(t_i - t_e\right)$$



UNI 6946: external ed internal convective/radiative heat transfer coefficient (m² K/W)

	Ascending heat flux	Descending heat flux	Horizontal heat flux
Ri	0,1	0,17	0,13
Re	0,04	0,04	0,04

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ENERGY LOSSES FOR TRANSMISSION

Good insulation

Low environmental impact

Flammable

Very good insulation

Hight environmental impact

Good insulation

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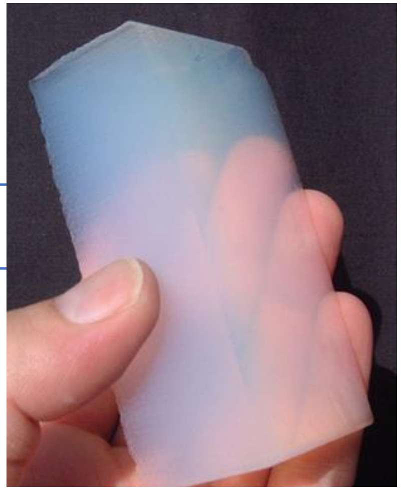
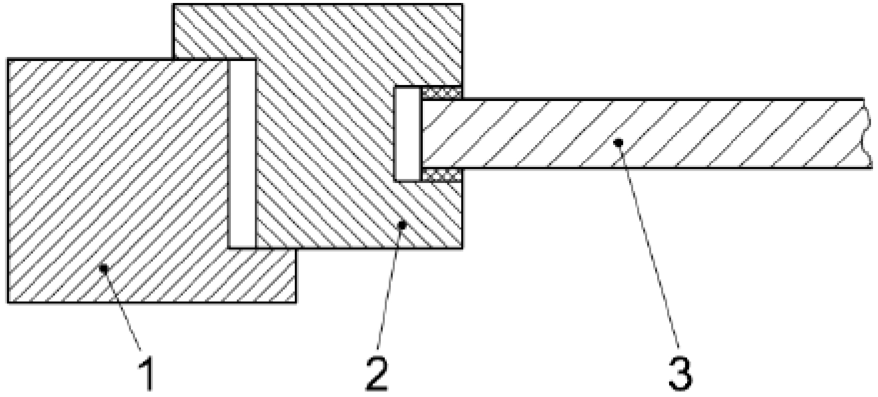
ENERGY LOSSES FOR TRANSMISSION



The airgel is a nanoporous material that is compound by 97% of air and 3% of silicon dioxide. It is really light and it has a very low thermal conductivity, equal to λ = 0.013 W / mK, making it the material with higher insulating power in the world.

DATI TECNICI*	VALORE	UNITÀ	METODO DI PROVA
Formato Pannello	1400x720	mm	-
Conduttività Termica (λ_D) a 10°C	0.0131	W/m·K	EN 12667
Permeabilità al vapore acqueo	4.51×10^{-6}	g/Pasm²	ASTM E 96
Resistenza diffusione vapore acqueo	5	μ	ASTM E 96
Temperature limite di impiego	-200 +200	°C	-
Resistenza alla Compressione (Per una deformazione del 10%)	70 0.7	KPa kg/cm²	ASTM C 165
Resistenza alla Compressione (Per una deformazione del 25%)	210 2.1	KPa kg/cm²	ASTM C 165
Calore Specifico	1.000	J/kgK	ASTM E 1269
Densità nominale	150	kg/m³	-
Classe di Reazione al Fuoco	C S_1 D_0	-	EN 13501-1
Assorbimento di acqua a lungo termine per immersione totale (28 giorni)	ca. 6	% vol.	EN 12087

ENERGY LOSSES FOR TRANSMISSION

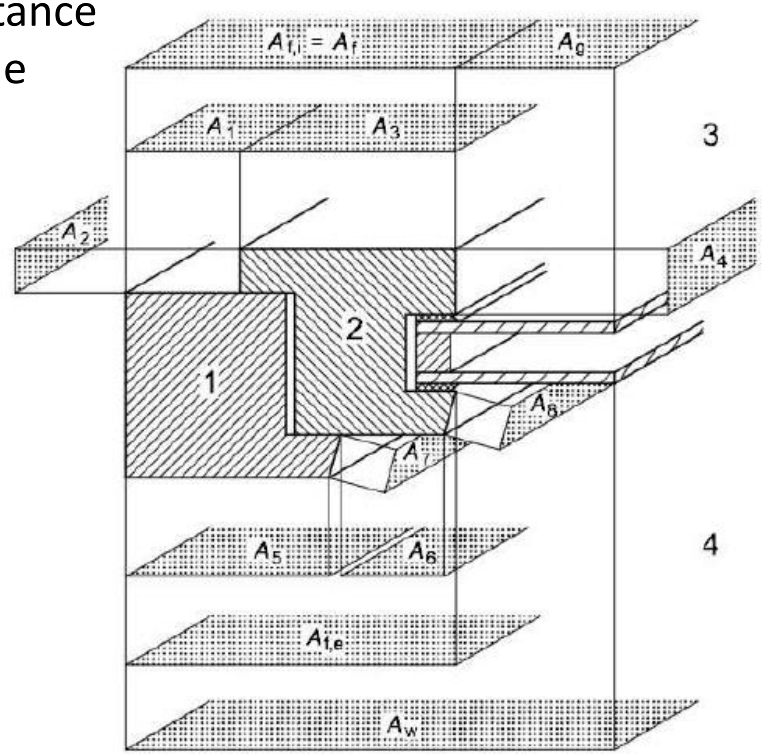


The transmission losses through windows are calculated as below

$$\dot{Q}_{H,tr} = AU_W(\theta_i - \theta_e)$$

$$U_W = \frac{A_g U_g + A_f U_f + I_g \psi_g}{A_f + A_g}$$

linear (lineaica) thermal transmittance due to the combined effects of the spacer, frame and glaze



UNI 6946: external ed internal convective/radiative heat transfer coefficient (m² K/W)

	Horizontal heat flux
Ri	0,13
Re	0,04

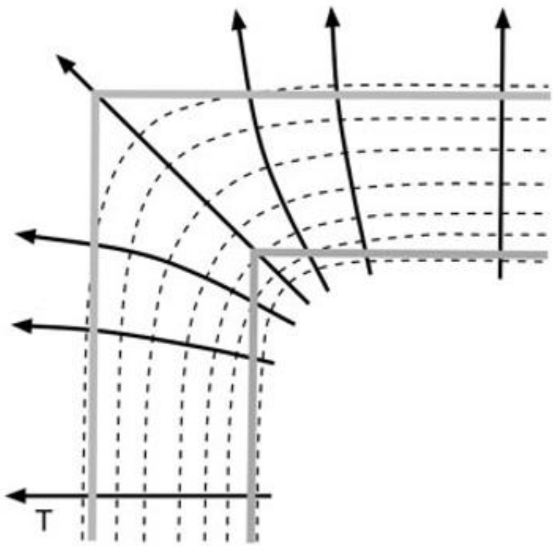
ENERGY LOSSES FOR TRANSMISSION

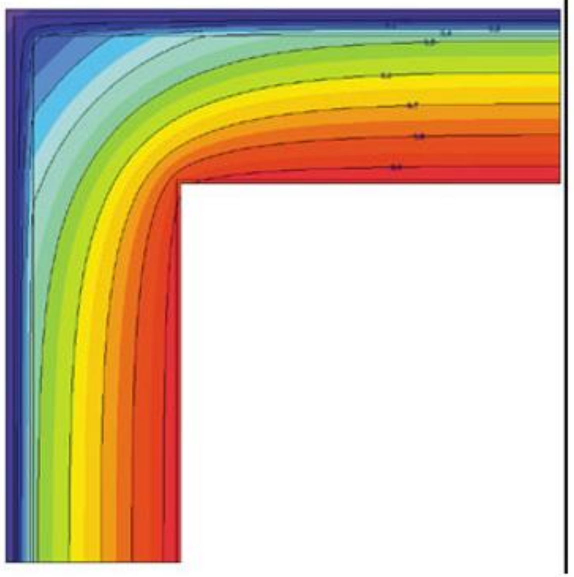
ENERGY LOSSES FOR TRANSMISSION

Extra flux for thermal bridge are calculated as below (UNI 14683, UNI 10211)

$$H_D = \sum_i A_i U_i + \sum_k l_k \psi_k + \sum_j \chi_j$$

The linear thermal transmittance (Ψ) is equal to the heat flux gap (compared to the value obtained with a one-dimensional calculation) in a bi-tri dimensional thermal field, under steady state condition, divided by a characteristic length of the thermal bridge and to the temperature difference between inlet-outlet surface:





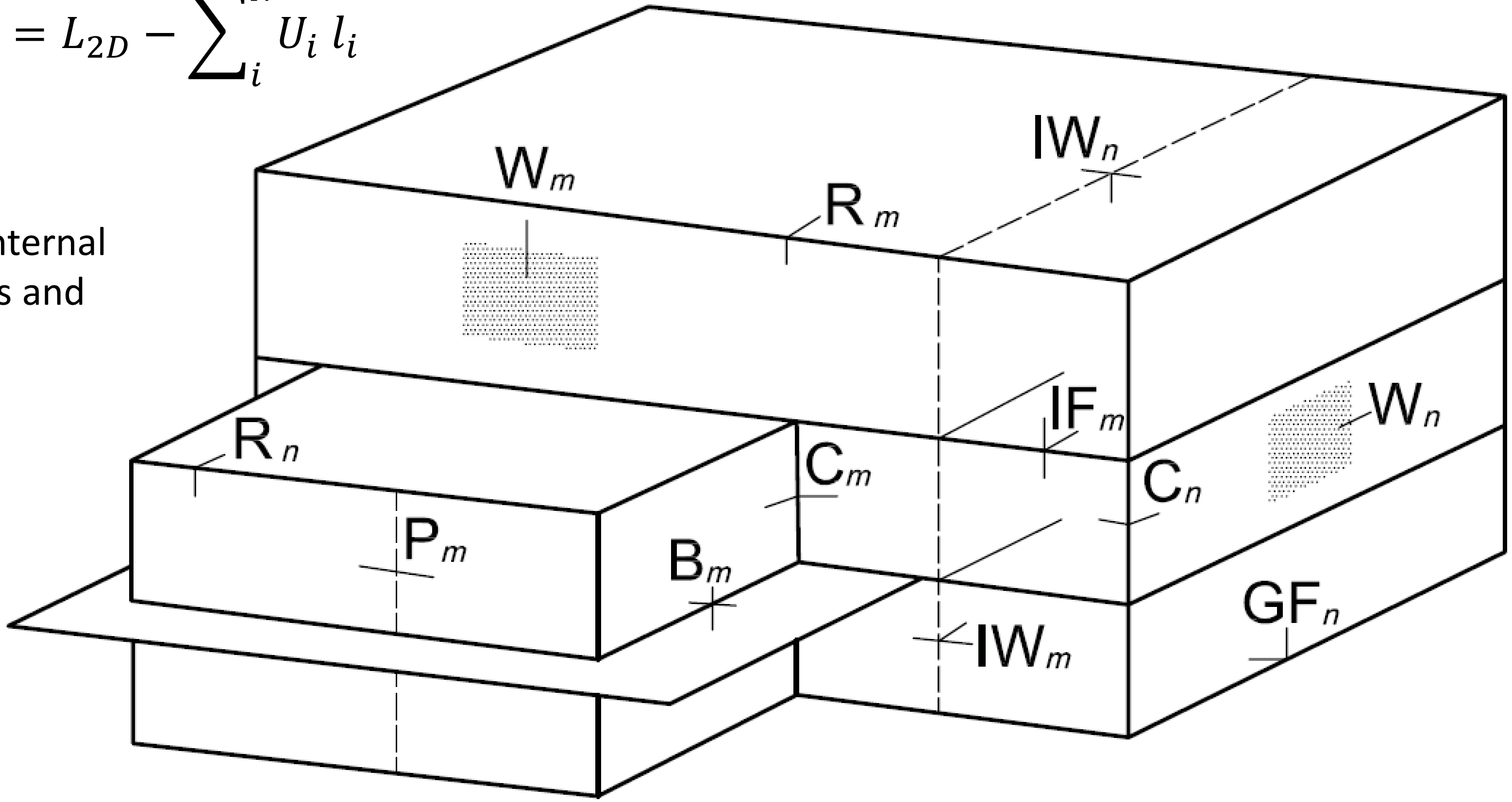
$$\psi = \frac{\phi^{2D} - \sum_i^N \phi_i^{1D}}{L_{PT}\Delta\theta} = \frac{\phi^{2D}}{L_{PT}\Delta\theta} - \sum_i^N \frac{\phi_i^{1D}}{L_{PT}\Delta\theta} = L_{2D} - \sum_i^N U_i\, l_i$$

ENERGY LOSSES FOR TRANSMISSION

Extra flux for thermal bridge are calculated as below (UNI 14683, UNI 10211)

$$\psi = \frac{\phi^{2D} - \sum_i^N \phi_i^{1D}}{L_{PT}\Delta\theta} = \frac{\phi^{2D}}{L_{PT}\Delta\theta} - \sum_i^N \frac{\phi_i^{1D}}{L_{PT}\Delta\theta} = L_{2D} - \sum_i^N U_i\, l_i$$

R – Roofs; C – Corners; IF – Internal Floors; IW – Internal Wall; GF – Ground floors; P – Pillars; W – Windows and door openings.



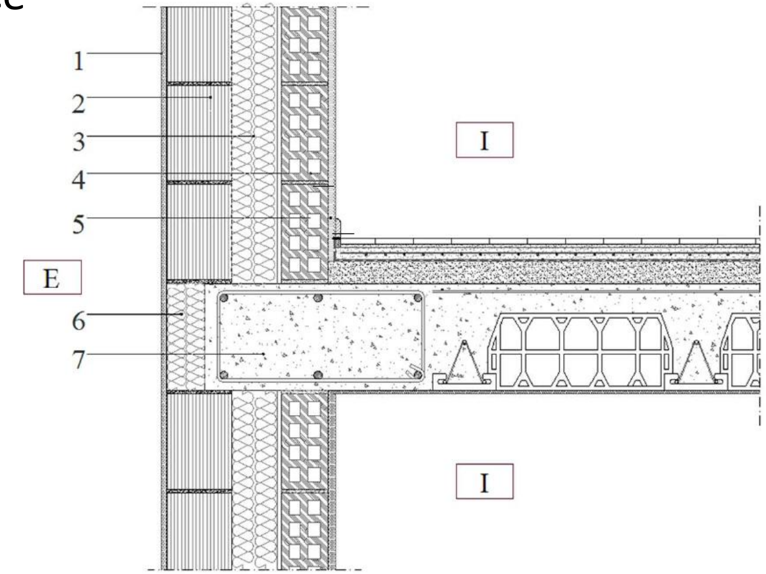
ENERGY LOSSES FOR TRANSMISSION

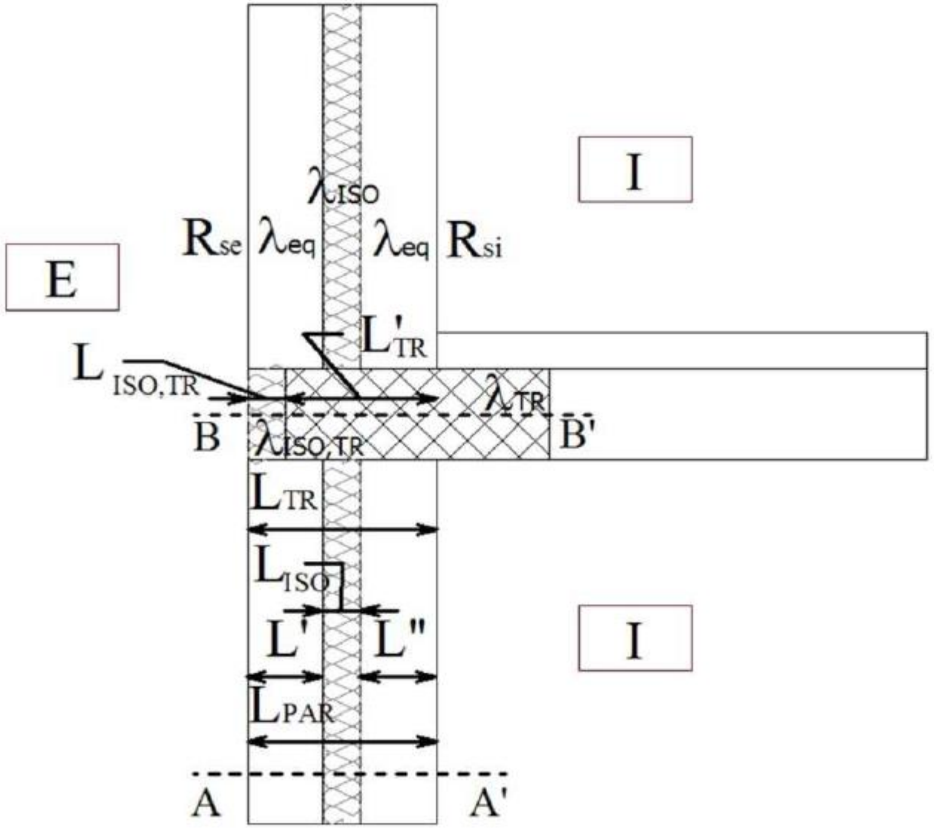
The linear thermal transmittance of thermal bridges must be calculated through numerical models or manual calculation methods (UNI 14683). Some abacus are available to simplified the calculation.

$$\psi_E = 0.112 + 0.428 \cdot U^* - \frac{0.127}{\lambda_{eq}} \quad \left(\frac{W}{m \cdot K}\right)$$

A-dimensional transmittance
U* = Uwall/Ubeam

Equivalent transmittance
λeq= transmittance without insulation





ENERGY LOSS VS INTERNAL ZONE

If we analysis the thermal loss trought a wall that divides a heated room by a un-heated zone a correction factor (b_{tr}) must be considered.

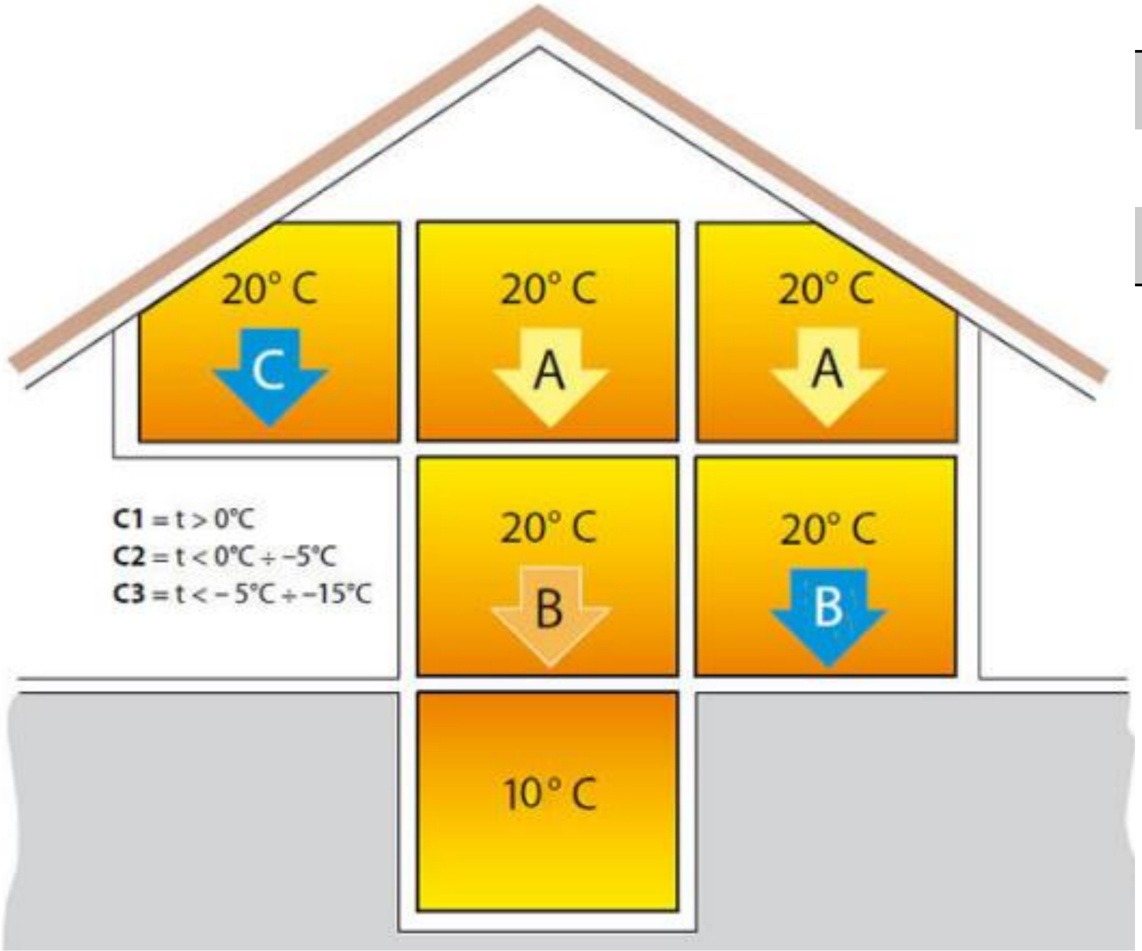
$$b_{tr,U} = \frac{H_{ue}}{H_{iu} + H_{ue}}$$

Where:

- H_{iu} is the heat exchange coefficient between the air-conditioned and non-conditioned environment, calculated according to UNI 13789 (W/K);
- H_{ue} is the heat exchange coefficient between the and non-conditioned environment and the external, calculated according to UNI 13789 (W/K);

Adjacent environment	$b_{tr,U}$
Room with windows and at least two external wall	0,6
Not insulated crawl space	0,9
Cellar	0,5

ENERGY LOSS VS INTERNAL ZONE



Adjacent environment	$b_{tr,U}$
Room with windows and at least two external wall	0,6
Not insulated crawl space	0,9
Cellar	0,5

$$b_{tr,U} = \frac{H_{ue}}{H_{iu} + H_{ue}}$$

ENERGY LOSSES FOR VENTILATION

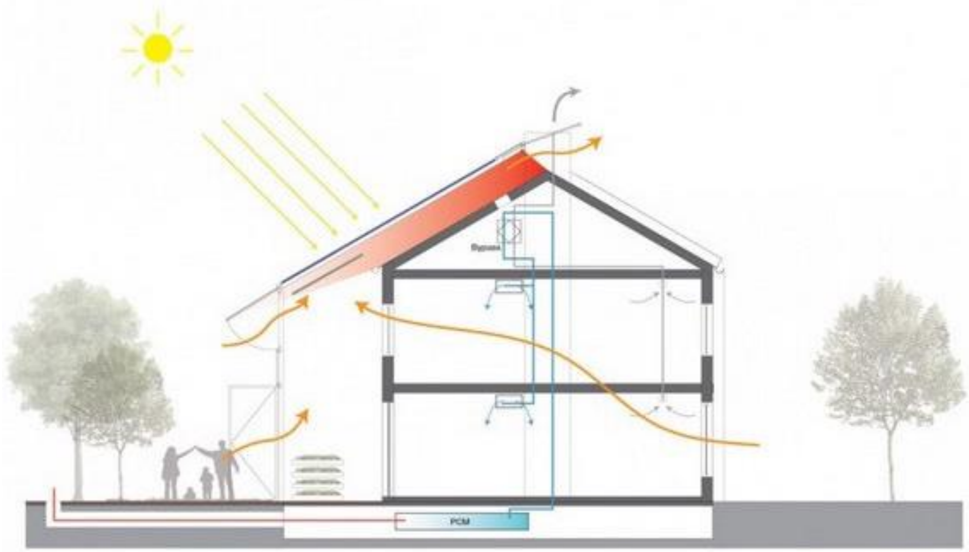
The transmission losses due to ventilation (natural or forced) can be calculated as below:

$$Q_{H,ve} = H_{ve,adj} \cdot (\theta_{int,set,H} - \theta_e) \cdot t$$

$$H_{ve,adj} = \rho_a \cdot C_a \cdot \sum_K b_{ve,k} \cdot q_{ve,k,mn}$$

Dove:

$H_{ve,adj}$	ventilation global coefficient[W/K];
$\theta_{int,set,H}$	set point internal temperature[K];
$\theta_{e,}$	the external average monthly temperature [K];
$b_{ve,k}$	temperature correction factor;
$q_{ve,x}$	is the air flow rate averaged on time [m^3/s];
C_a	is the air specific heat 1000 J/kg K



ENERGY LOSSES FOR VENTILATION

$$Q_{H,ve} = H_{ve,adj} \cdot (\theta_{int,set,H} - \theta_e) \cdot t$$

correction factor < 1 (=1 with mechanical ventilation)

$$H_{ve,adj} = \rho_a \cdot C_a \cdot \sum_K b_{ve,k} \cdot q_{ve,k,mn}$$

Ventilation heat transfer coefficiente

$$q_{ve,k,mn} = \left(\overline{q_{ve,0}} + \overline{q'_{ve,x}}\right)_k \times (1 - \beta_k) + \left(q_{ve,f} \times b_{ve} \times FC_{ve} + \overline{q_{ve,x}}\right)_k \times \beta_k$$

Dove:

$\overline{q_{ve,0}}$ is the flow air rate for natural ventilation [m^3/s];

$\overline{q'_{ve,x}}$ is the flow rate due to wind effect [m^3/s];

during the time fraction in which the mechanical ventilation system is not working $(1 - \beta_k)$

$q_{ve,f}$ is the nominal flow rate of air for mechanical ventilation [m^3/s];

$\overline{q_{ve,x}}$ is the extra air flow rate for leak [m^3/s];

b_{ve} is the temperature correction factor;

FC_{ve} is the ventilation system regulation efficiency factor (tab);

β_k is the time fraction in which the mechanical ventilation system is working

ENERGY LOSSES FOR VENTILATION

$$Q_{H,ve} = H_{ve,adj} \cdot (\theta_{int,set,H} - \theta_e) \cdot t$$

correction factor < 1 (=1 with mechanical ventilation)

$$H_{ve,adj} = \rho_a \cdot C_a \cdot \sum_K b_{ve,k} \cdot q_{ve,k,mn}$$

Ventilation heat transfer coefficiente

$$q_{ve,k,mn} = \left(\overline{q_{ve,0}} + \overline{q'_{ve,x}}\right)_k \times (1 - \beta_k) + \left(q_{ve,f} \times b_{ve} \times FC_{ve} + \overline{q_{ve,x}}\right)_k \times \beta_k$$

$$q_{ve,k,mn} = q_{ve,0,k} \times f_{ve,t,k}$$ (Design condition – UNI 10339)

$f_{ve,t,k}$= utilization factor for time correction (table)

$q_{ve,0,k}$= design flow rate. For residential buildings is equal to n V/3600 with n=0,5h^{-1}

ENERGY LOSSES FOR VENTILATION

$$q_{ve,k,mn} = q_{ve,0,k} \times f_{ve,t,k}$$ (Design condition – UNI 10339)

$f_{ve,t,k}$= utilization factor for time correction (table)

$q_{ve,0,k}$= design flow rate. For residential buildings is equal to n V/3600 with n=0,5h^{-1}

$q_{ve,0,k}$ is defined by the standard UNI 10339.

The standard provides the methodology for calculating the mechanical ventilation flow rate according to the type of building.

prospetto E.2 **Fattore di correzione per la ventilazione in condizioni di riferimento**

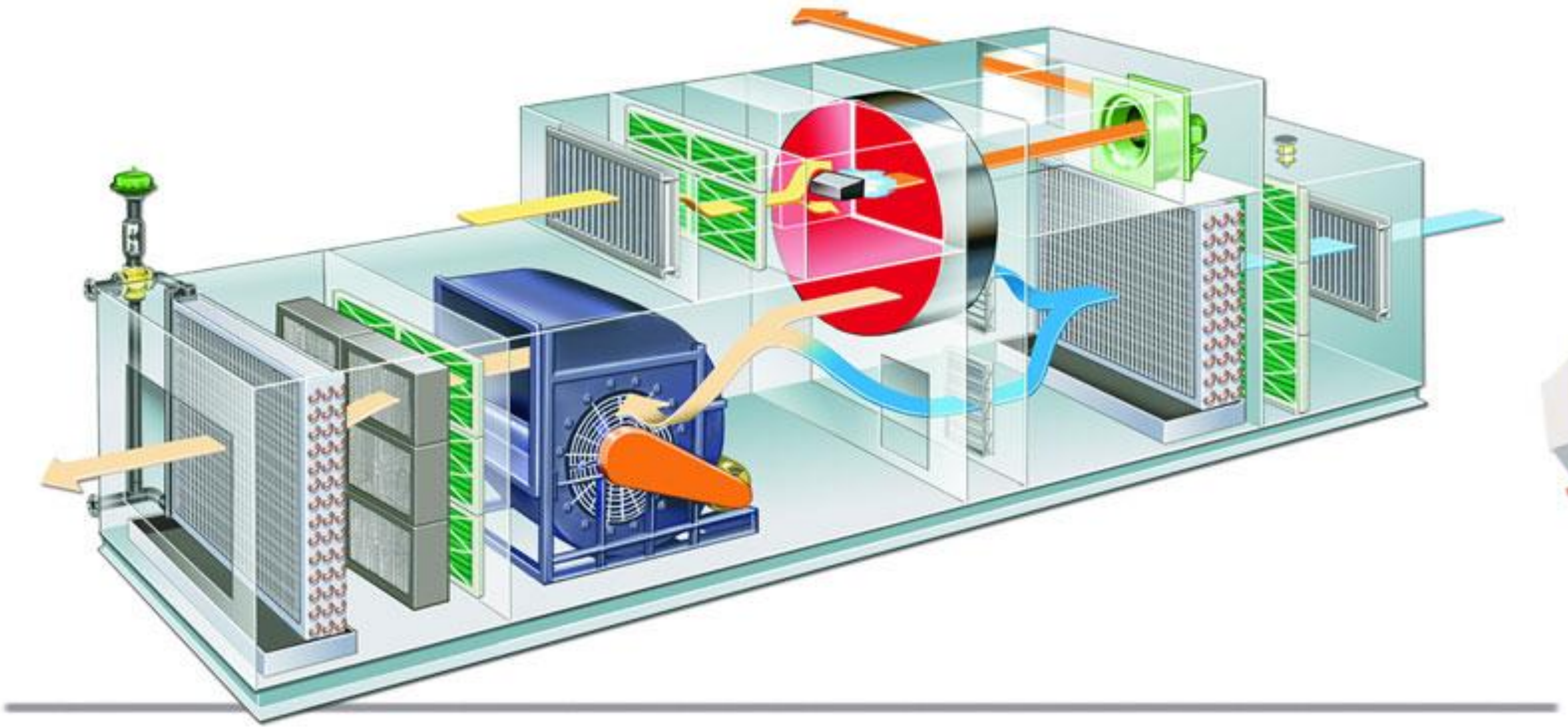
Categoria di edificio	Sottocategoria di edificio	Destinazione d'uso	$f_{ve,t}$
E.1 Edifici adibiti a residenza e assimilabili	E.1.1 Residenze a carattere continuativo	Abitazioni civili[a)]	0,60
		Collegi, luoghi di ricovero, case di pena, caserme, conventi	
		Sale riunioni	0,51
		Dormitorio/camera	1,00
		Servizi igienici con estrazione	0,08
	E.1.2 Residenze occupate saltuariamente	Vale quanto prescritto per le residenze a carattere continuativo	0,60
	E.1.3 Alberghi pensioni e attività similari	Ingresso, soggiorni	1,00
		Sale conferenze/auditori (piccoli)	0,47
		Sale da pranzo	0,34
		Camere da letto	0,26
E.2 Edifici per uffici e assimilabili		Uffici singoli	0,59
		Uffici open space	0,59
		Call-Center/centro inserimento	0,59
		Locali riunione	0,51
E.3 Ospedali cliniche, case di cura e assimilabili		Degenze (2 -3 letti)	1,00
		Corsie	1,00
		Camere per infettivi	1,00
		Camere per immunodepressi	1,00
		Sale mediche	1,00
		Soggiorni	0,68
		Terapie fisiche	0,51
		Diagnostiche	0,51

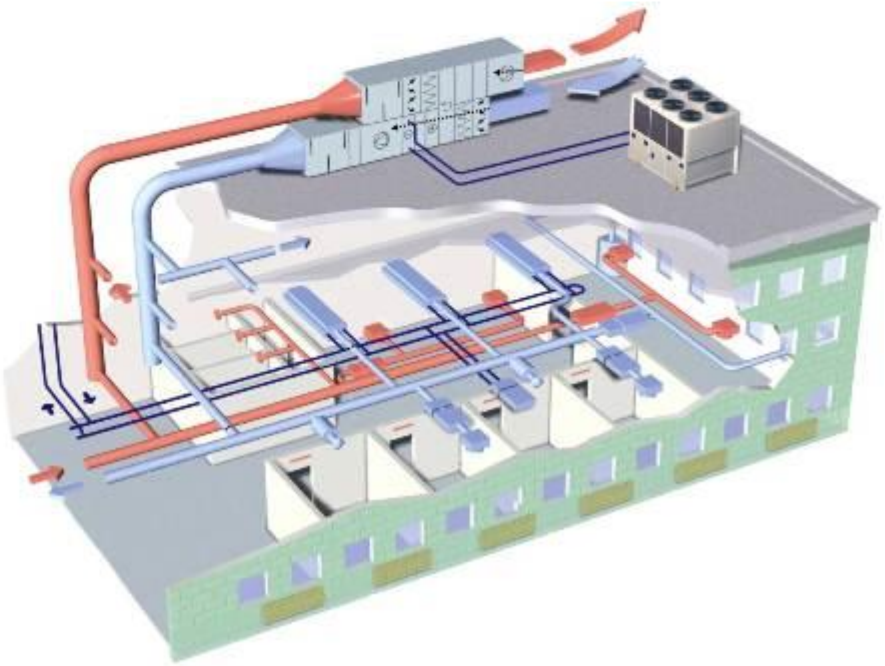
ENERGY LOSSES FOR VENTILATION

$$q_{ve,k,mn} = q_{ve,0,k} \times f_{ve,t,k}$$ (Design condition – UNI 10339)

$f_{ve,t,k}$= utilization factor for time correction (table)

$q_{ve,0,k}$= design flow rate. For residential buildings is equal to n V/3600 with n=0,5h^{-1}





ENERGY LOSSES FOR VENTILATION

$$Q_{H,ve} = H_{ve,adj} \cdot (\theta_{int,set,H} - \theta_e) \cdot t$$

correction factor < 1 (=1 with mechanical ventilation)

$$H_{ve,adj} = \rho_a \cdot C_a \cdot \sum_K b_{ve,k} \cdot q_{ve,k,mn}$$

Ventilation heat transfer coefficiente

$$q_{ve,k,mn} = \left(\overline{q_{ve,0}} + \overline{q'_{ve,x}}\right)_k \times (1 - \beta_k) + \left(q_{ve,f} \times b_{ve} \times FC_{ve} + \overline{q_{ve,x}}\right)_k \times \beta_k$$

Dove:

$\overline{q_{ve,0}}$ is the flow air rate for natural ventilation [m³/s];

$\overline{q'_{ve,x}}$ is the flow rate due to wind effect [m³/s];

during the time fraction in which the mechanical ventilation system is not working $(1-\beta_k)$

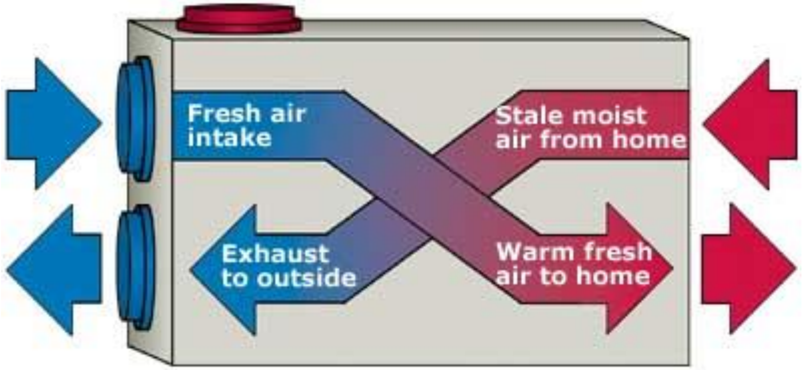
$q_{ve,f}$ is the nominal flow rate of air for mechanical ventilation [m³/s];

$\overline{q_{ve,x}}$ is the extra air flow rate for leak [m³/s];

b_{ve} is the temperature correction factor;

FC_{ve} is the ventilation system regulation efficiency factor (tab);

β_k is the time fraction in which the mechanical ventilation system is working



ENERGY LOSSES FOR VENTILATION

Presence Sensor
Movement Sensor
CO_2 Sensor

Flow rate control
Fun velocity control

prospetto 11 **Fattore di efficienza della regolazione dell'impianto di ventilazione meccanica, FC_{ve}, per destinazione d'uso in funzione della tipologia di sistema di rilevamento e di attuazione del controllo della portata d'aria di ventilazione**

Destinazione d'uso dell'edificio	Tipo di sensore							
	Presenza[a]			Movimento[a]		CO_2[b]		Umidità relativa
	Bocchetta con rilevatore di presenza integrato	Modulo di regolazione della portata	Ventilatore a velocità variabile	Modulo di regolazione della portata	Ventilatore a velocità variabile	Modulo di regolazione della portata	Ventilatore a velocità variabile	
E.1 - Residenze	0,80	0,80	0,80	0,70	0,70	0,70	0,70	0,60
E.1 (3) - Camere d'albergo	0,80	0,80	0,80	0,70	0,70	0,70	0,70	0,60
E.2 - Uffici singoli	0,68	0,64	0,64	0,67	0,70	0,57	0,61	-
E.2 - Open space	0,80	0,80	0,80	0,53	0,59	0,45	0,50	-
E.2 - Sala riunioni	0,55	0,55	0,60	0,34	0,43	0,29	0,37	-
E.3	-	-	-	-	-	-	-	-
E.4 - Ristorazione	0,8	0,8	0,8	0,58	0,63	0,49	0,53	-
E.4 - Cinema, teatri, sale per congressi	-	-	-	-	-	0,33	0,40	-
E.5	-	-	-	-	-	0,33	0,40	-
E.6	-	-	-	-	-	-	-	-
E.7 - Edificio scolastico primario	0,64	0,64	0,68	0,67	0,70	0,57	0,61	-
E7. - Edificio scolastico secondario	0,8	0,8	0,8	0,48	0,54	0,41	0,47	-
E.8	-	-	-	-	-	-	-	-

a) I tipi di sensore "Presenza" e "Movimento" corrispondono alla funzione 2 "*Presence control*" riportata al punto 4.1 del prospetto 2 della UNI EN 15232:2012.
b) Il tipo di sensore CO_2, corrisponde alla funzione 3 "*Demand control*" riportata al punto 4.1 del prospetto 2 della UNI EN 15232:2012.

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ENERGY LOSSES FOR VENTILATION

$$q_{ve,k,mn} = \left(\overline{q_{ve,0}} + \overline{q'_{ve,x}}\right)_k \times (1 - \beta_k) + \left(q_{ve,f} \times b_{ve} \times FC_{ve} + \overline{q_{ve,x}}\right)_k \times \beta_k$$

$$q_{ve,0} = \left(\sum_k n_{per,k} \times q_{ve,o,p,k} + \sum_k A_{f,k} \times q_{ve,o,s,k}\right) \times \frac{0,8}{\varepsilon_{ve,c}} \times (C_1 \times C_2)$$

Dove:

$q_{ve,o,p,k}$	specific air flow rate per person [m^3/sec person];
$q_{ve,o,p,k}$	specific air flow rate per unit surface [m^3/sec m^2];
$\varepsilon_{ve,c}$	ventilation system efficiency (0,8);
C_1	coefficient for miscellaneous systems (1);
C_2	altitude correction factor (UNI 10339);

$$q_{ve,0} = \left(\sum_k n_{per,k} \times q_{ve,o,p,k} + \sum_k A_{f,k} \times q_{ve,o,s,k}\right)$$ Tutti gli edifici tranne:

$$q_{ve,0} = \left(\frac{n\,V}{3600}\right)$$ Residential buildings with n equal to 0,5 h^{-1}

SKYWARDS EXTRA FLOW

At the end we have to consider the skywards extra flow between the external wall and the sky:

$$Q_r = \left\{ \sum_k F_{r,k} \varphi_{r,k} \right\} t$$

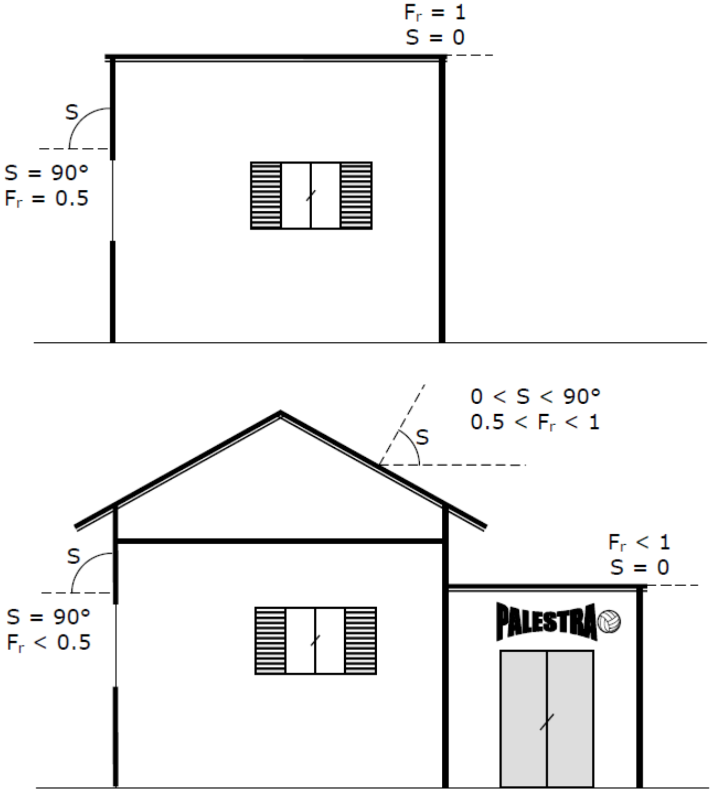
$$F_r = F_{sh}, ob, d \frac{1 + \cos\Sigma}{2}$$

$$\varphi_{r,k} = R_{se} U_c A_C h_r \Delta\theta_{er}$$

$$h_r = \frac{\varepsilon\sigma\left((\theta_e + 273)^4 - (\theta_e + 273)^4 -\right)}{\left(\theta_e + \theta_{sky}\right)}$$

$$\Delta\theta_{er} = \theta_e - \theta_{sky}$$

$$\theta_{sky} = 18 - 51{,}6\, e^{-p_v, \frac{e}{1000}}$$



Where ε is the emissivity, Θ_{sky} is the sky temperature, Σ is the angle of inclination between the horizontal and the component, F_{sh}, ob, d is the shading correction factor (1 with no shading).

SOLAR GAIN/LOAD

The solar heat gain/load can be calculate as the sum of the solar heat flux on the transparent and opaque surfaces:

$$Q_{sol,op} = \sum (\varphi_{sol,op,mn,k}) t + \sum \left((1 - b_{tr}) \varphi_{sol,mn,u,l} \right) t$$

$$Q_{sol,w} = \sum (\varphi_{sol,w,mn,k}) t$$

$$\varphi_{sol,w/op} = F_{sh,ob} \, A_{sol_{w/op}} \, \mathrm{I_{sol,k}}$$

$$A_{sol,w} = F_{sh,gl} \, g_{gl} \, (1 - \mathrm{F_F}) \mathrm{A_{w,p}}$$

$$A_{sol,op} = \alpha_{sol,c} \, R_{se} U_{c,eq} A_c$$

$F_{sh,gl}$: solar gains reduction factor for mobile screenings (rolling shutter) (0,25 – 0,6 curtain)
g_{gl}: solar energy transmittance of the glass (0,85 – 0,2 from high to low emissivity)
$\alpha_{sol,c}$: solar absorption factor of the opaque component (0,3 – 0,6 – 0,9 from light to dark colour)

SOLAR GAIN/LOAD

The solar heat gain/load can be calculate as the sum of the solar heat flux on the transparent and opaque surfaces:

$$Q_{sol,op} = \sum(\varphi_{sol,op,mn,k})t + \sum\left((1 - b_{tr})\varphi_{sol,mn,u,l}\right)t$$

$$Q_{sol,w} = \sum(\varphi_{sol,w,mn,k})t$$

$$\varphi_{sol,w/op} = F_{sh,ob}\, A_{sol_{w/op}}\ \mathrm{I_{sol,k}}$$

$$A_{sol,w} = F_{sh,gl}\, g_{gl}\, (1 - \mathrm{F_F})\mathrm{A_{w,p}}$$

$$A_{sol,op} = \alpha_{sol,c}\, R_{se} U_{c,eq} A_c$$

$F_{sh,gl}$: solar gains reduction factor for mobile screenings (rolling shutter) (0,25 – 0,6 curtain)
g_{gl}: solar energy transmittance of the glass (0,85 – 0,2 from high to low emissivity)
$\alpha_{sol,c}$: solar absorption factor of the opaque component (0,3 – 0,6 – 0,9 from light to dark colour)

INTERNAL GAIN

In generale il calcolo degli apporti termici deve essere svolto applicando la seguente formula:

$$\Phi_{int} = \left\{\sum_k \phi_{int,mn,k}\right\} t + \left\{\sum_k (1 - b_{tr,l}) \phi_{int,mn,u,l}\right\} t$$

Dove:

$b_{tr,l}$ è il fattore di riduzione per ambiente non climatizzato avente la sorgente di calore interna;

$\Phi_{int,mn,k}$ è il flusso termico prodotto dalla k-esima sorgente di calore interna mediato sul tempo;

$\Phi_{int,mn,k}$ è il flusso termico prodotto dalla k-esima sorgente di calore interna all'ambiente non climatizzato mediato sul tempo;

Nota:

L'area climatizzata netta, in assenza di informazioni specifiche, può essere calcolata secondo la seguente formula:

$f_n = 0{,}9761 - 0{,}3055\ d_m$ dove dm è lo spessore delle pareti estene.

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INTERNAL GAIN

The internal gain/load depend on the use of the building.

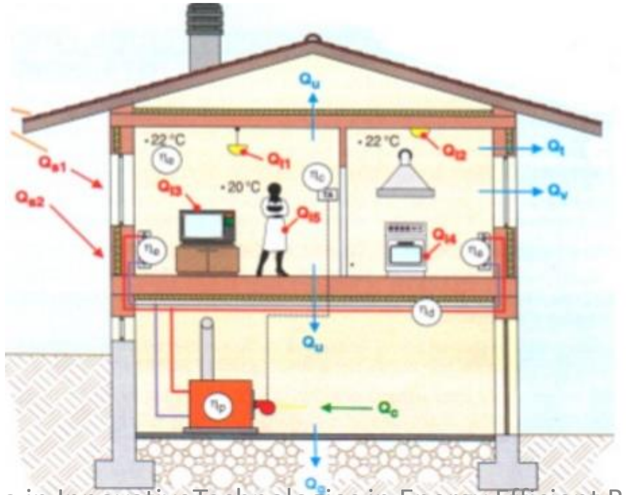
For residential buildings it's possible to use the following correlations:

$$\Phi_{int} = 7{,}987 * A_f - 0{,}0353 * A_f^2 \qquad \text{with Af <= 120 m}^2$$
$$\Phi_{int} = 450\ W \qquad \text{with Af > 120 m}^2$$

In other cases it's possible to use tabuled data

Categoria di edificio	Apporto termico delle apparecchiature durante il periodo di funzionamento $\Phi_{int,A}/A_f$ [W/m²]	Fattore di simultaneità f_A	Apporto termico medio dalle apparecchiature $\Phi_{int,A}/A_f$ [W/m²]
Uffici	15	0,20	3
Attività scolastiche	5	0,15	1
Cura della salute, attività clinica	8	0,50	4
Cura della salute, attività non clinica	15	0,20	3
Servizi di approvvigionamento	10	0,25	3
Esercizi commerciali	10	0,25	3
Luoghi di riunione	5	0,20	1
Alberghi e pensioni	4	0,50	2
Penitenziari	4	0,50	2
Attività sportive	4	0,25	1

$\Phi_{int,A}$ è il flusso termico dalle apparecchiature, in W;
A_f è la superficie utile di pavimento.



INTERNAL GAIN

$Q_{H,hum,nd} = - \min(0\ ;\ Q_{wv,int} - Q_{H,wv,ve})$

$Q_{C,dhum,nd} = \max(0\ ;\ Q_{wv,int} - Q_{C,wv,ve})$

$$Q_{HC,wv,ve} = \rho_a\, h_{wv}\, q_{ve,mn}\, (x_{int} - x)\, t/3600$$

- air flow rate m^3/s ($q_{ve,mn}$)
- internal air humidity g/kg (x_{int})
- external air humidity g/kg (x)
- enthalpy: 2544 J/g (h_{wv})
- density: 1,2 kg/m^3 (ρ_a)

Categoria di edificio	Tipo di ambiente	Attività	$G_{wv,per}$ [g/h]
E.1	Ufficio, appartamento	Seduto in attività leggera	65
E.2	Ufficio, appartamento	Seduto in attività media	80
E.4.1	Teatro	Seduto a riposo	45
E.4.3	Ristorante	Seduto al ristorante	115
	Sala da ballo	Danza moderata	230
	Discoteca	Attività atletica	450
E.5	Negozio	In piedi, lavoro leggero	80
E.5	Banca	In movimento	100
E.6.2	Palestra	Attività atletica	450
E.8	Officina	In piedi, lavoro medio	200
	Officina, cantiere	In piedi, lavoro pesante	410
Varie	Corridoi	In cammino a 1,3 m/s	265

INTERNAL GAIN

Per le abitazioni di categoria E.1 (1) e (2):
$G_{wv,Oc} + G_{wv,A} = 250$ [g/h]

$G_{wv,Oc}$ steam mass flow rete due to the equipment;
$G_{wv,A}$ steam mass flow rete due to the equipment.

$Q_{H,hum,nd} = - \min (0 ; Q_{wv,int} – Q_{H,wv,ve})$
$Q_{C,dhum,nd} = \max (0 ; Q_{wv,int} – Q_{C,wv,ve})$

$Q_{wv,int} = h_{wv}(G_{wv,Oc}+G_{wv,A})t/3600$

h_{wv} → enthalpy: 2544 J/g

Categoria di edificio	Tipo di ambiente	Attività	$G_{wv,per}$ [g/h]
E.1 E.2	Ufficio, appartamento	Seduto in attività leggera	65
	Ufficio, appartamento	Seduto in attività media	80
E.4.1	Teatro	Seduto a riposo	45
E.4.3	Ristorante	Seduto al ristorante	115
	Sala da ballo	Danza moderata	230
	Discoteca	Attività atletica	450
E.5	Negozio	In piedi, lavoro leggero	80
E.5	Banca	In movimento	100
E.6.2	Palestra	Attività atletica	450
E.8	Officina	In piedi, lavoro medio	200
	Officina, cantiere	In piedi, lavoro pesante	410
Varie	Corridoi	In cammino a 1,3 m/s	265

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$$x_{int} = 622 \times \frac{p_{wv,s,int} \times \varphi_{int}}{101325 - p_{wv,s,int} \times \varphi_{int}}$$

dove $p_{wv,s}$ è la pressione parziale del vapore di acqua, in condizioni di saturazione, ricavata come:

INTERNAL GAIN

For example:

$G_{wv,Oc} + G_{wv,A} = 250$ [g/h]

T_{in} = 20°C – 50%;

T_{ext}: 5°C – 35%;

$Q_{ve,mn}$=50 m^3/h

$Q_{H,hum,nd}$ = - min (0 ; $Q_{wv,int}$ – $Q_{H,wv,ve}$)

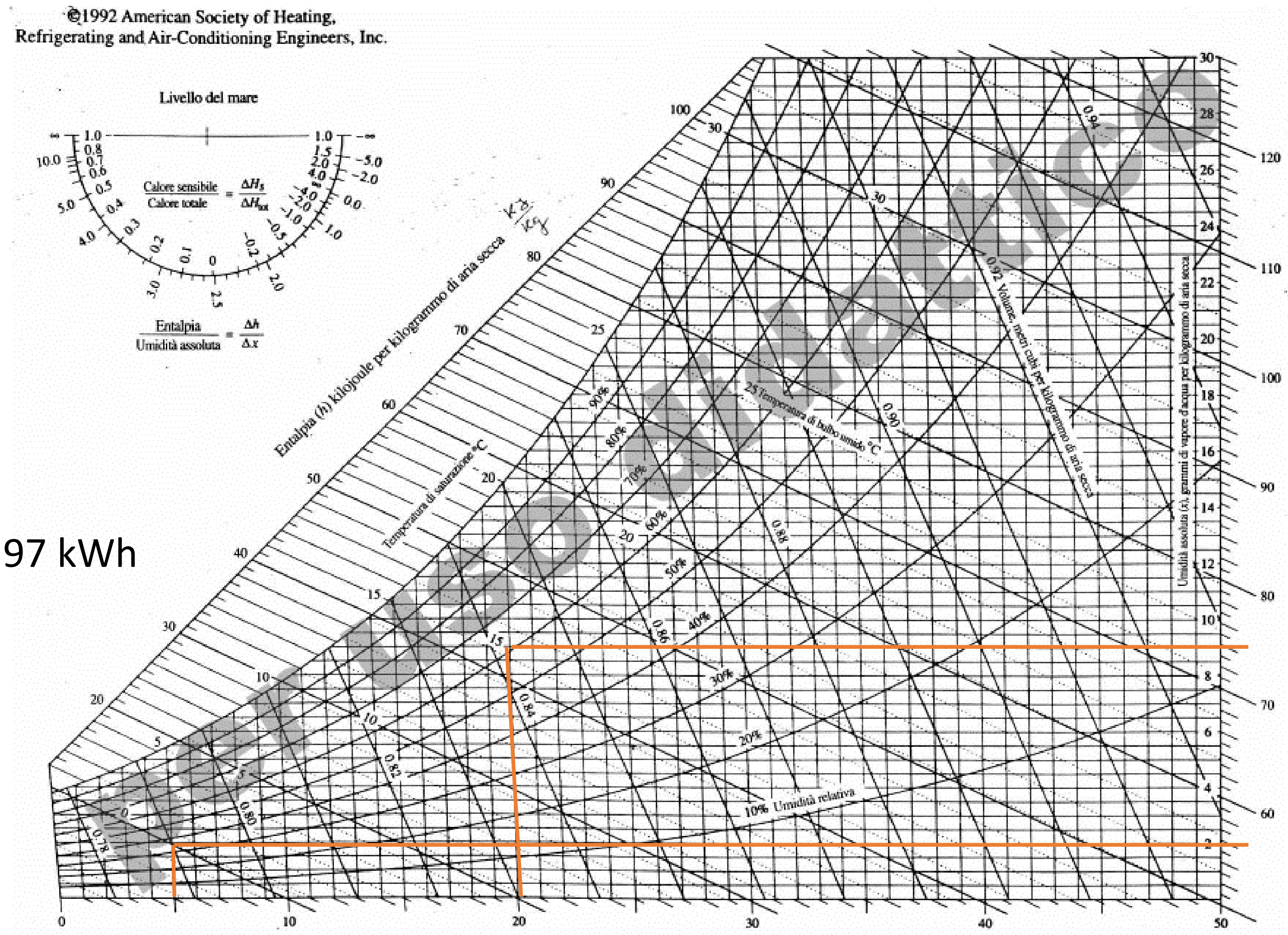
$Q_{HC,wv,ve} = \rho_a \, h_{wv} \, q_{ve,mn} \, (x_{int} - x) t$

= 1,2 x 2544 x 500 x (9–2) x 1/1000 = 10685 kJ = 2,97 kWh

$Q_{wv,int} = h_{wv}(G_{wv,Oc} + G_{wv,A}) t / 3600$

= 2544 x 250 / 1000 = 636 kJ = 0,18 kWh

-min (0; 0,18 – 2,97) = 2,79 kWh is the energy that has to be transferred to air.



FREE CONTRIBUTION - UTILIZATION FACTOR

The utilization factor is the only dynamic parameter and it can be calculated with the following wquations:

Heating

$\gamma_H > 0$ e $\gamma_H \neq 1$: $$\eta_{H,gn} = \frac{1 - \gamma_H^{a_H}}{1 - \gamma_H^{a_H + 1}}$$

$\gamma_H = 1$: $$\eta_{H,gn} = \frac{a_H}{a_H + 1}$$

$\gamma = Q_{gn}/Q_{h,ht}$

$a_H = a_{H,0} + \tau / \tau_{H,0}$

Caratteristiche costruttive dei componenti edilizi				Numero di piani		
Intonaci	Isolamento	Pareti esterne	Pavimenti	1	2	≥3
				Capacità termica areica		
Gesso	Interno [a]	qualsiasi	tessile	75	75	85
	interno [a]	qualsiasi	legno	85	95	105
	interno	qualsiasi	piastrelle	95	105	115
	assente/esterno	leggere/blocchi	tessile	95	95	95
	assente/esterno	medie/pesanti	tessile	105	95	95
	assente/esterno	leggere/blocchi	legno	115	115	115
	assente/esterno	medie/pesanti	legno	115	125	125
	assente/esterno	leggere/blocchi	piastrelle	115	125	135
	assente/esterno	medie/pesanti	piastrelle	125	135	135

Where τ is the thermal time constant of the time zone $\tau = Cm/H_{tr,adj}$ where Cm is the internal thermal capacity.

$a_{H,0}$: 1

$\tau_{H,0}$: 15 h

$$Q_{H,tr} = H_{tr,adj}\,(\theta_{int,set,H} - \theta_e)\,t + \left(\sum F_{r,k}\varphi_{r,mn,k}\right)t + \left(\sum (1 - b_{tr})F_{r,l}\varphi_{r,mn,u,l}\right)t - Q_{sol,op}$$

FREE CONTRIBUTION - UTILIZATION FACTOR

The utilization factor is the only dynamic parameter and it can be calculated with the following wquations:

Cooling

se $\gamma_C > 0$ e $\gamma_C \neq 1$: $$\eta_{C,ls} = \frac{1 - \gamma_C^{-a_C}}{1 - \gamma_C^{-(a_C+1)}}$$

se $\gamma_C = 1$: $$\eta_{C,ls} = \frac{a_C}{a_C + 1}$$

$\gamma = Q_{gn}/Q_{h,ht}$

$a_C = a_{C,0} + \tau / \tau_{C,0} - K(A_w/A_f)$

Caratteristiche costruttive dei componenti edilizi				Numero di piani		
Intonaci	Isolamento	Pareti esterne	Pavimenti	1	2	≥3
				Capacità termica areica		
Gesso	interno [a]	qualsiasi	tessile	75	75	85
	interno [a]	qualsiasi	legno	85	95	105
	interno	qualsiasi	piastrelle	95	105	115
	assente/esterno	leggere/blocchi	tessile	95	95	95
	assente/esterno	medie/pesanti	tessile	105	95	95
	assente/esterno	leggere/blocchi	legno	115	115	115
	assente/esterno	medie/pesanti	legno	115	125	125
	assente/esterno	leggere/blocchi	piastrelle	115	125	135
	assente/esterno	medie/pesanti	piastrelle	125	135	135

Where τ is the thermal time constant of the time zone $\tau = Cm/H_{tr,adj}$ where Cm is the internal thermal capacity, Aw is the windows and Af is the floor surface.

$a_{C,0}$: 8,1

$\tau_{C,0}$: 17 h

K : 13

$$Q_{H,tr} = H_{tr,adj}\,(\theta_{int,set,H} - \theta_e)\,t + \left(\sum F_{r,k}\varphi_{r,mn,k}\right)t + \left(\sum (1-b_{tr})F_{r,l}\varphi_{r,mn,u,l}\right)t - Q_{sol,op}$$

END PART 1/2