

Heating Loads

HVAC System design

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Category of Buildings

E.1 Residential buildings

E.1 (1) Residential buildings continuative;

E.1 (2) Dwellings with occasional occupation;

E.1 (3) Buildings used as hotels, guesthouses and similar activities;

E.2 Buildings used as offices and simila

E.3 Buildings used as hospitals, clinics, or nursing homes and similar

E.4 Buildings used for recreational, associative or religious activities and similar:

Buildings used for recreational, associative, religious and similar activities:

E.4 (1) cinemas and theatres, meeting rooms for conferences;

E.4 (2) exhibitions, museums and libraries, places of worship;

E.4 (3) bars, restaurants, dance halls;

Category of Buildings

E.5 Buildings used for commercial activities and similar: such as shops, retail warehouses, supermarkets, exhibitions;

E.6 Buildings used for sports activities:

E.6 (1) swimming pools, saunas and similar;

E.6 (2) gyms and similar;

E.6 (3) support services for sports activities;

E.7 Buildings used for school activities at all levels and similar;

E.8 Buildings used for industrial activities and similar.

the design heat loss is computed using UNI EN 12831:

$$\Phi_I = \Phi_{T,i} + \Phi_{V,1}$$

$\Phi_{T,i}$ = transmission heat loss;

$\Phi_{V,1}$ = ventilation heat loss.

the losses are computed separately.

Transmission heat transfer is computed as

$$\Phi_{T,i} = (H_{T,ie} + H_{T,iue} + H_{T,ig} + H_{Tij}) \cdot (\theta_{int,i} - \theta_e)$$

$H_{T,ie}$ transmission coefficient from inside to outside

$H_{T,iue}$ transmission coefficient through unheated spaces

$H_{T,ig}$ transmission coefficient through the ground

$H_{T,ij}$ transmission coefficient with spaces at different temperatures
(eg: cold storage room)

$\theta_{int,i}$ internal temperature

θ_e external temperature

External temperature

The value of the external design temperature θ_e is set by the UNI 5364 standard and by the NA.1 table of UNI EN 12831

the following changes are considered:

- effect of altitude: gradient $-\frac{1}{100}$ K/m, the temperature decreases for every 100 m increase in altitude
- exposure to wind
 - $-0.5 \div -1$ K for buildings in small clusters
 - $-1 \div -2$ K for isolated buildings
 - $-1 \div -2$ K further correction for taller buildings of adjacent ones (only for protruding planes).

design internal temperature

is obtained from table NA.2 of UNI EN 12831 according to the type of room

Type of room	Internal temperature °C
Single office	20
Open space offices	20
Conference room	20
Auditorium	20
Bar - Restaurant	20
Classrooms	20
Kindergarten	20
Nursery school	22
Supermarket	16
Living spaces	20
Bathrooms	24
Churches	15
Museums - Galleries	16

heat loss through walls

$$H_{T,ie} = \sum_{k=1} A_k \cdot U_k \cdot e_k + \sum_{j=1} \Psi_j \cdot l_j \cdot e_j$$

A_k area of the k -th wall

U_k transmittance of the k -th wall

e_k, e_j exposure coefficients

Ψ_j dispersion coefficient of the j -th thermal bridge (linear transmittance);

l_j length of the j -th thermal bridge

Thermal resistance and transmittance of a wall

Thermal resistance and thermal transmittance can be obtained using UNI EN ISO 6946, for homogeneous layers we have:

$$R_T = R_{si} + R_1 + R_2 + \dots R_n + R_{se}$$

R_{si}, R_{se} internal and external surface resistances

R_j resistances of each layer

dove

$$R_i = \frac{d}{\lambda_i}$$

λ_i = **thermal conductivity** of the layer [W/(m K)] , takes values between 3 and 0.02 W/(m K) for stone and for insulation material, respectively.

d layer thickness

problem

$$R_j = \frac{s_j}{\lambda_j}$$

s_j layer thickness

λ_j layer conductivity

problem

$$R_j = \frac{s_j}{\lambda_j}$$

s_j layer thickness

λ_j layer conductivity

What value do I use?

Opaque components

- properties retrieved from CE marking documents
- the values must be corrected depending for operative conditions
- using UNI EN 10456
- alternatively UNI 19456, UNI 10351, UNI 1745
- walls or floors from UNI 1745 or UNI 10355

properties changes

$$\lambda_2 = \lambda_1 \cdot F_T \cdot F_m \cdot F_a$$

F_T temperature variation term

F_m humidity variation term

F_a age factor

conversion factors

temperature variation

$$F_T = e^{f_T \cdot (\theta_2 - \theta_1)}$$

humidity factor massa/massa

$$F_m = e^{f_u \cdot (u_2 - u_1)}$$

conversion factor volume/volume

$$F_m = e^{f_\psi \cdot (\psi_2 - \psi_1)}$$

f_T temperature conversion coefficient (from table)

f_u humidity conversion coefficient mass/mass

f_ψ humidity conversion coefficient volume/volume

u moisture content mass to mass

ψ moisture content volume to volume

Thermal conductivity

valori di f_T

- conductivity changes with temperature
- standard UNI-EN 10456 reports how to compute it

esempi di valori F_T

Product	Conductivity λ W/(m K)	Conversion factor f_T 1/K
Extruded Polystyrene	0,025	0,0046
	0,030	0,0045
	0,040	0,0045
Expanded Polystyrene	0,025	0,0046
	0,030	0,0045
	0,040	0,0045
Mineral wool	0,032	0,0030
	0,035	0,0033
	0,040	0,0038

thermal conductivity

values of f_{ψ}

- thermal conductivity changes with humidity
- humidity can be expressed in terms of mass/mass or volume/volume
UNI-EN 10456

typical values F_{ψ}

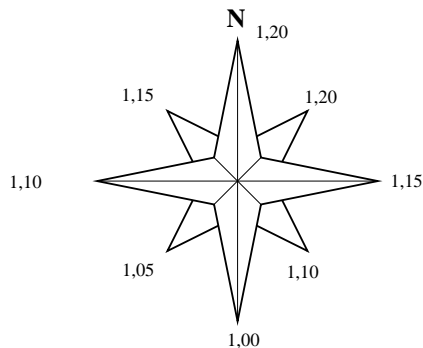
Product	humidity ψ m^3/m^3	conversion factor f_{ψ} -
expanded polystyrene boards	< 0,10	4
extruded polystyrene foam	< 0,10	2,5
Polyurethane foam, rigid	< 0,15	6
Mineral wool	< 0,15	4
Loose-fill mineral wool	< 0,15	4
wood wool board	< 0,10	1,8
Expanded cork	< 0,10	6
wood fibreboard	< 0,05	1,4

Standard UNI EN ISO 6946 surface thermal resistance

	Heat flow direction		
	ascending	horizontal	descending
R_{si}	0,10	0,13	0,17
R_{se}	0,04	0,04	0,04

Exposure Coefficient

the Exposure Coefficient $e_k = e_l$ appears in UNI EN 12831 consider the effect of sun exposition, wall humidity, and wind direction and intensity

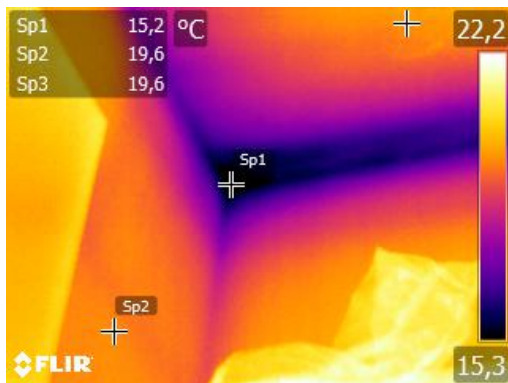


Thermal bridges

- The heat flow through the walls is considered one-dimensional;
- there may be inhomogeneities that lead to preferential paths for the heat flow;
- thermal bridges consider this effect;
- the thermal bridge is characterized by the coefficient ψ_L also called **linear transmittance**;

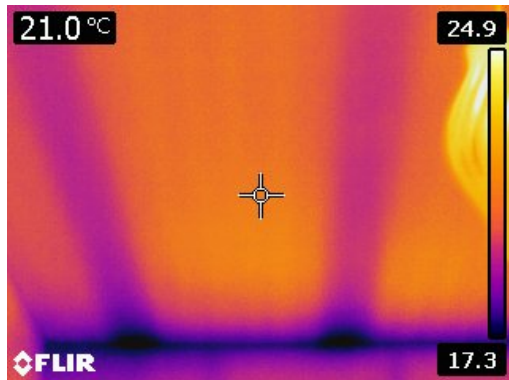
thermal bridges, examples

thermography



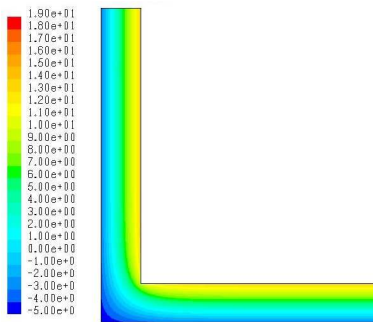
thermal bridges, examples

termografia

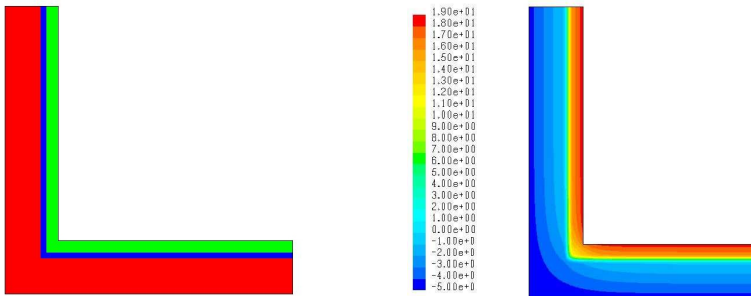


thermal bridges, corner

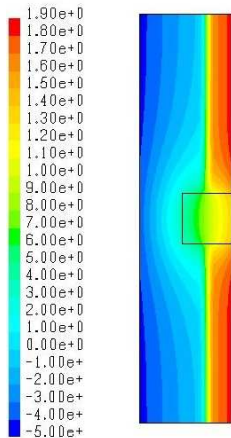
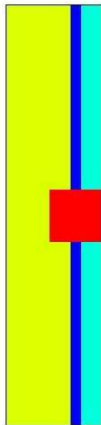
Le disuniformità geometriche modificano il campo termico



thermal bridges, insulated corner



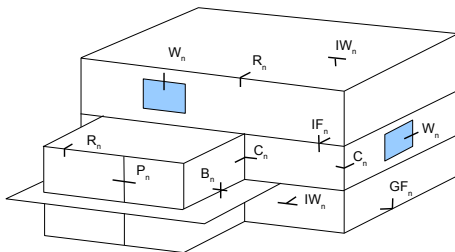
thermal bridges, concrete pillar



thermal bridges

Calculus following UNI 14683

the standard report typical values



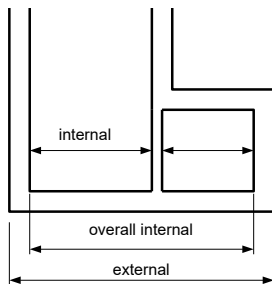
- for design calculation through numerical calculation according to UNI EN ISO 14683
- use of atlas compliant with UNI EN ISO 14683:2008
- for existing buildings use of manual calculations compliant with UNI EN ISO 14683:2008 is permitted
- use of Annex A of UNI EN ISO 14683:2008 is excluded
- percentage calculation is no longer possible for existing buildings

reference measures

the building dimensions can be selected as

- internal
- overall internal
- external

the choice must be coherent with the thermal bridge value



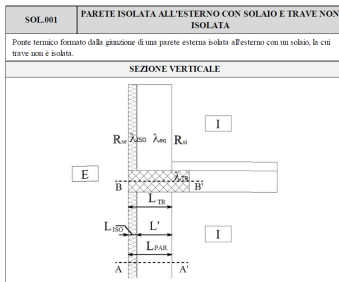
Abachi

- CENED - Thermal Bridges Abaco - developed by Politecnico di Milano, Cestec S.p.A. and ANCE Lombardia (free)
- Swiss Thermal Bridges Abaco, in French (free)
- National atlas of thermal bridges compliant with UNI EN ISO 14683 and UNI EN ISO 10211 (EDILCLIMA)
- the abacus are also implemented in thermotechnical design software

Calcolo numerico

- thermal bridges can be calculated with numerical methods
- the calculation must be performed according to UNI EN ISO 10211
- there are free programs (2d) for the calculation e.g., THERM

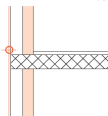
CENED



TRASMITTANZA TERMICA LINEARE	
Riferita alle dimensioni esterne	$\psi_e = 1.761 - 0.038 \cdot U' - 1.295 \cdot \lambda_{eq} \left(\frac{W}{m \cdot K} \right)$
Riferita alle dimensioni interne	$\psi_i = 2.068 - 0.056 \cdot U' - 1.329 \cdot \lambda_{eq} \left(\frac{W}{m \cdot K} \right)$
Coef. di trasmissione adimensionale	$U' = \frac{U_{TR}}{U_{PAR}}$
Trasmittanza della trave (per lo spessore pari alla parete)	$U_{TR} = \frac{1}{R_{int} + \frac{L_{TR}}{\lambda_{TR}} + R_{ext}} \left(\frac{W}{m^2 \cdot K} \right)$
Trasmittanza della parete	$U_{PAR} = \frac{1}{R_{int} + \frac{L'}{\lambda_{eq}} + \frac{L'_{ISO}}{\lambda_{ISO}} + R_{ext}} \left(\frac{W}{m^2 \cdot K} \right)$
Campo di validità	$5.75 \leq U' \leq 14.49 \quad 0.23 \leq \lambda_{eq} \leq 0.81 \left(\frac{W}{m \cdot K} \right)$
Intervallo di confidenza	$IC_E^{95\%} = \pm 0.21 \left(\frac{W}{m \cdot K} \right) \quad IC_I^{95\%} = \pm 0.19 \left(\frac{W}{m \cdot K} \right)$

Suisse Energie

Dalle continue sur appui



Conditions standard

Chauffage par le sol	Non
Isolation sous bord de dalle	Non
Isolation tête de dalle	Non

2.1-11

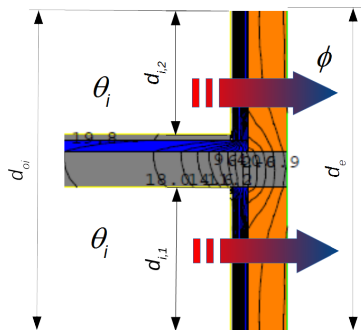
Valeur U façade en W/(m ² · K)	Mur		Valeur ψ' en W/(m · K)
	Brique t.c.	Béton armé	
0.15	0.63	0.71	
0.20	0.68	0.78	
0.25	0.71	0.83	
0.30	0.73	0.86	
0.35	0.74	0.88	
0.40	0.74	0.89	

Majorations

Chauffage par le sol	+ 0.07 W/(m · K)
Isolation sous bord de dalle (2 x 50 cm) sans isolation tête de dalle	- 0.13 W/(m · K)
Isolation tête de dalle 4 cm sans isolation sous bord de dalle	- 0.20 W/(m · K)
Isolation sous bord de dalle (2 x 50 cm) avec isolation tête de dalle 4 cm	- 0.28 W/(m · K)

thermal bridge

calculation with UNI EN 10211



θ_e

$$L_{2D} = \frac{\Phi}{\theta_i - \theta_e}$$

$$\psi_e = L_{2D} - \sum_k U_k \times d_{e,k}$$

$$\psi_i = L_{2D} - \sum_k U_k \times d_{i,k}$$

$$\psi_{oi} = L_{2D} - \sum_k U_k \times d_{oi,k}$$

heat loss from windows and doors

The reference standard is UNI EN 10077-1, the transmittance is a weighted mean transmittance of the glass, the frame and the thermal bridge between them:

$$U_w = \frac{A_g U_g + A_f U_f + \Psi_g L_g}{A_g + A_f}$$

$$\Phi_w = U_w A_w \Delta\theta$$

U_g glass transmittance

U_f frame transmittance

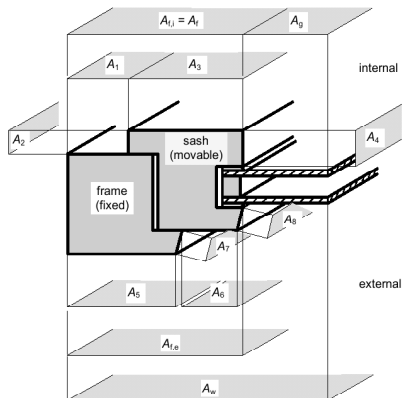
ψ_l spacer transmittance

L_g glass perimeter

A_g glass area

A_f frame area

window glossary



NOTE $A_t = \max(A_{t,i}, A_{t,e})$

$A_w = A_f + A_s$

$A_{s,i} = A_1 + A_2 + A_3 + A_4$

$A_{s,e} = A_5 + A_6 + A_7 + A_8$

glass transmittance

for single and multiple glass systems the transmittance is computed as

$$U_g = \left(R_e + \sum_{i=1}^n r_i \cdot d_i + \sum_{j=1}^{n-1} R_{sj} + R_i \right)^{-1}$$

R_e external thermal resistance $R_e = 1/h_e$;

r glass resistivity $r = 1 \text{ (m K)}/W$;

d glass thickness;

R_i internal thermal resistance $R_i = 1/h_i$;

R_s gap thermal resistance;



n number of layers.

coefficients h_i e h_e can be computed as:

$$h_e = 25 \quad h_i = 3,6 + 4,4 \frac{\varepsilon}{0,837} \text{ W}/(\text{m}^2 \text{ K})$$

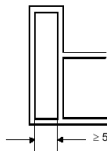
transmittance of plastic frames

Table D.1 - Thermal transmittances for plastic frames with metal reinforcements

Frame material	Frame type	U_f W/(m ² ·K)
Polyurethane	with metal core thickness of PUR ≥ 5 mm	2,8
PVC-hollow profiles ¹⁾	external  internal two hollow chambers	2,2
	external  internal three hollow chambers	2,0

¹⁾ With a distance between wall surfaces of hollow chambers of at least 5 mm (refer to Figure D.1).

Dimensions in millimetres



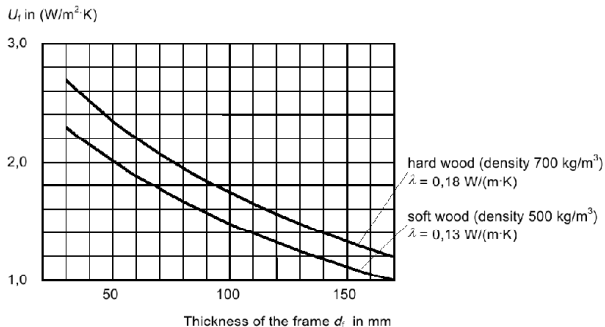


Figure D.2 - Thermal transmittances for wooden frames and metal-wood frames (see Figure D.3) depending on the frame thickness d_f

transmittance of wooden frames

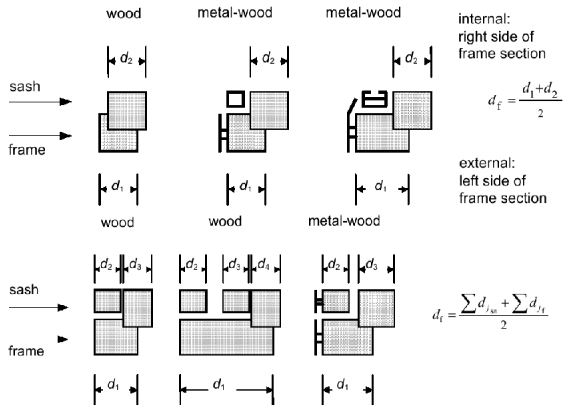


Table C.1 - Thermal resistance R_s of unventilated air spaces, in $m^2 \cdot K/W$, for coupled and double windows

Thickness of air space mm	One side coated with a normal emissivity of:				Both sides uncoated
	0,1	0,2	0,4	0,8	
6	0,211	0,190	0,163	0,132	0,127
9	0,298	0,259	0,211	0,162	0,154
12	0,376	0,316	0,247	0,182	0,173
15	0,446	0,363	0,276	0,197	0,186
50	0,406	0,335	0,260	0,189	0,179
100	0,376	0,315	0,247	0,182	0,173
300	0,333	0,284	0,228	0,171	0,163

Heat transfer via the ground UNI EN ISO 13370

Standard EN 13370 provides a methods of calculation of heat transfer coefficients and heat flow rates for buildings in contact with the ground

$$\phi_G = H_{T,g} \cdot \Delta\theta$$

ϕ_G heat flow rate exchanged with ground;

H_G ground heat transfer coefficient ;

The ground heat transfer coefficient is obtained with the thermal transmittance

$$H_{T,g} = U_{eq} \cdot A$$

Type of floors

Thermal transmittance U_{eq} is computed for

- slab-on-ground floor;
- suspended floor;
- Heated basement;
- Unheated basement
- Partly heated basement

total equivalent thickness

an equivalent thickness for slab-on ground d_t is introduced

$$d_t = w + \lambda(R_{si} + R_f + R_{se})$$

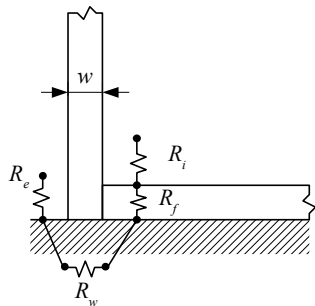
w vertical wall thickness,

λ ground thermal conductivity,

$R_{si} = \frac{1}{h_i}$ internal surface resistance,

R_f Thermal resistance of the floor slab;

$R_{se} = \frac{1}{h_e}$ external surface thermal resistance;



Characteristic dimension of floor

floor slab can be uninsulated, moderately insulated or insulated

$d_t < B'$ uninsulated or moderately insulated floors

$d_t \geq B'$ pavimenti bene isolati

$B' = 2A/P$ characteristic dimension

P perimeter

A floor area

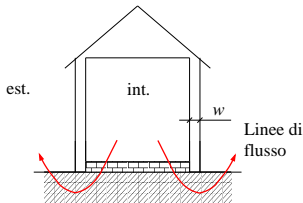
Slab on ground

- uninsulated or moderately insulated floor ($d_t < B'$)

$$U_{eq} = U_0 = \frac{2\lambda}{\pi B' + d_t} \ln \left(\frac{\pi B'}{d_t} + 1 \right) \quad \text{est.}$$

- well insulated floors ($d_t \geq B'$)

$$U_{eq} = U_0 = \frac{\lambda}{0,457 B' + d_t}$$



slab on ground can have edge insulation

- Vertical edge insulation
- horizontal edge insulation

For steady state calculations the additional insulation is incorporated into the thermal transmittance

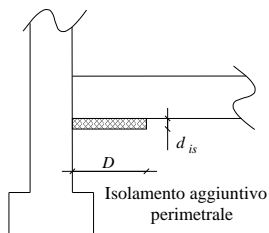
$$U_{eq} = U_0 + \frac{\Delta\Psi P}{A} = U_0 + 2\frac{\Delta\Psi}{B'}$$

with $\Delta\Psi < 0$

horizontal edge insulation

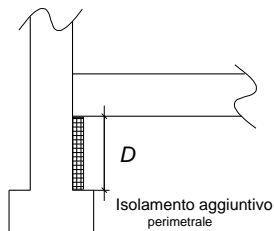
$$\Delta\Psi = -\frac{\lambda}{\pi} \left[\ln\left(\frac{D}{d_t} + 1\right) - \ln\left(\frac{D}{d_t + R'\lambda} + 1\right) \right]$$

$$R' = \frac{d_{is}}{\lambda_{is}} - \frac{d_{is}}{\lambda}$$



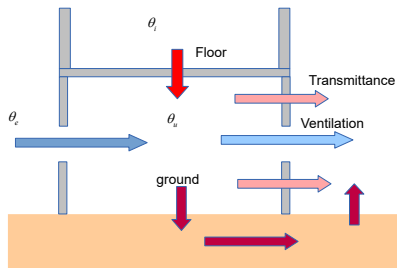
vertical edge insulation

$$\Delta\Psi = -\frac{\lambda}{\pi} \left[\ln \left(\frac{2D}{d_t} + 1 \right) - \ln \left(\frac{2D}{d_t + R'\lambda} + 1 \right) \right]$$

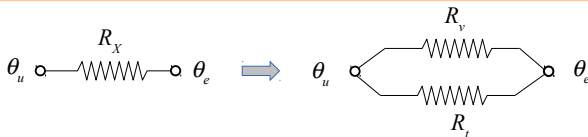
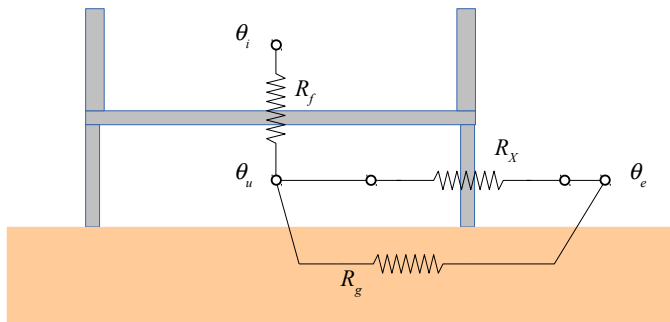


Suspended floor

The floor is held off the ground, Thermal transmittance takes into account the floor and the underneath air space



Suspended floor resistance net



Resistance and Transmittance

$$R_{Tot} = R_f + \left(\frac{1}{R_g} + \frac{1}{R_x} \right)^{-1}$$

$$R_f = \frac{1}{U_f \cdot A}$$

$$R_g = \frac{1}{U_g \cdot A}$$

$$R_x = \frac{1}{U_x \cdot A}$$

Thermal transmittance of suspended floor

The equivalent transmittance takes into account both conductive and convective heat exchanges.

$$\frac{1}{U_{eq}} = \frac{1}{U_f} + \frac{1}{U_g + U_x}$$

U_f transmittance of suspended floor;

U_g transmittance of the ground at the bottom of the air gap (treated as a slab on ground U_0);

U_x Takes into account the heat exchanges for transmission and ventilation of the gap below the floor.

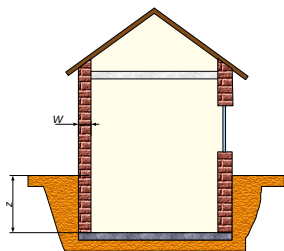
Heated basement

Heat transfer can be computed taking into account:

- depth of basement floor below ground level z ;
- different insulation layers on the floor and on vertical walls

$$U' = \frac{A \cdot U_{bf} + z \cdot P \cdot U_{bw}}{A + z \cdot P}$$

$$H_g = A \cdot U_{bf} + z \cdot P \cdot U_{bw} + P \cdot \psi_g$$



basement floors

floor part

Uninsulated or moderately insulated basement floors ($d_t + \frac{z}{2} < B'$):

$$U_{bf} = \frac{2\lambda}{\pi B' + d_t + \frac{z}{2}} \ln \left(\frac{\pi B'}{d_t + \frac{z}{2}} + 1 \right)$$

insulated basement floors ($d_t + \frac{z}{2} \geq B'$):

$$U_{bf} = \frac{\lambda}{0,457 B' + d_t + \frac{z}{2}}$$

heated basement

Basement walls contribution

The second term accounts for the basement walls

$$U_{bw} = \frac{2\lambda}{\pi z} \left(1 + \frac{d_t/2}{d_t + z} \right) \ln \left(\frac{z}{d_w} + 1 \right)$$

$d_w = \lambda(R_{si} + R_w + R_{se})$ total equivalent thickness for basement walls

$d_w < d_t$ in this case d_t should be replaced by d_w .

Heat transfer through an unheated space

The heat transfer coefficient is computed as:

$$H_{T,iue} = \sum_k A_k \cdot U_k \cdot b_u + \sum_l \Psi_l \cdot l_l \cdot b_u$$

b_u is a temperature adjustment factor that can be computed as:

a) if the temperature is known θ_u

$$b_u = \frac{\theta_{int,i} - \theta_u}{\theta_{int,i} - \theta_e}$$

b) if the temperature is unknown θ_u

$$b_u = \frac{H_{ue}}{H_{iu} + H_{ue}}$$

c) using tabular values b_u

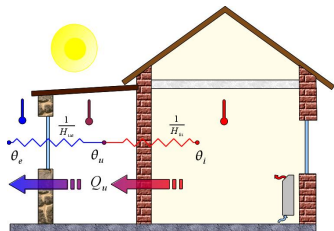
Tabulated values for b_u

Table D.4 - Temperature reduction factor, b_u

Unheated space	b_u
Room	
with only 1 external wall	0,4
with at least 2 external walls without outer doors	0,5
with at least 2 external walls with outer doors (e.g. halls, garages)	0,6
with 3 external walls (e.g. external staircase)	0,8
Basement	
without windows/external doors	0,5
with windows/external doors	0,8
Roof space	
high ventilation rate of the roof space (e.g. roofs clad in tiles or other materials giving a discontinuous cover) without sarking felts or sarking boards	1,0
other non-insulated roof	0,9
insulated roof	0,7
Internal circulation areas (without external walls, air exchange rate less than 0.5 h^{-1})	0
Freely ventilated circulation areas (area of openings/volume of space $> 0.005 \text{ m}^2/\text{m}^3$)	1,0
Suspended floor (floor above crawl space)	0,8

Unheated spaces

electrical analogy



$$R_{ie} = R_{iu} + R_{ue}$$

- iu* quantities related to the heat exchange between heated space and unheated space ;
- ue* quantities related to the heat exchanged between unheated space and external environment;
- ie* quantities related to heat transfer between heated space and external environment;

Unheated spaces, UNI EN 13789

Heat transfer coefficient

- Thermal resistance

$$R_{ie} = R_{iu} + R_{ue}$$

- Heat transfer coefficient is the reverse of thermal resistance:

$$H_{ie} = \frac{1}{R_{ie}} \quad H_{iu} = \frac{1}{R_{iu}} \quad H_{ue} = \frac{1}{R_{ue}}$$

- Heat transfer coefficient

$$H_{ie} = \frac{H_{iu}H_{ue}}{H_{iu} + H_{ue}}$$

Transmission and ventilation

The transfer heat coefficient depends on transmission and ventilation

- transmission

$$H_{T,iu} \quad H_{T,ue}$$

- ventilation

$$H_{V,iu} \quad H_{V,ue}$$

- Heat transfer coefficients

$$H_{iu} = H_{T,iu} + H_{V,iu}$$

$$H_{ue} = H_{T,ue} + H_{V,ue}$$

Temperature of the unheated space

If the unheated space is in contact with multiple heated spaces it is worth computing its temperature

$$\theta_u = \theta_i - \frac{H_{ie}}{H_{iu}}(\theta_i - \theta_e)$$

Therefore it is possible to compute the heat transfer for each heated space

$$\phi_{u,j} = (U_j A_j + \dot{m}_{u,j} c_{pa})(\theta_i - \theta_u) = H_{iu,j}(\theta_i - \theta_u)$$

dove

j subscript related to the j -th heated space;

$\phi_{u,j}$ heat flow from the j -th space;

$\dot{m}_{u,j}$ mass flow between heated and unheated space ;

c_p specific heat capacity of air.

Ventilation heat loss

Heat exchange occurs also with the ventilation of the environments

$$\Phi_v = \dot{m} c_p (\theta_i - \theta_e)$$

$$\Phi_v = \rho \dot{V} c_p (\theta_i - \theta_e)$$

$$\Phi_v = \frac{\rho V_L n c_p}{3600} (\theta_i - \theta_e)$$

$$\Phi_v = 0.34 n V_L (\theta_i - \theta_e)$$

\dot{V} volumetric flow rate;

V_L net volume;

n air change rate per hour.

using the value $c_p = 1,006 \text{ kJ/kgK}$ e $\rho = 1,2 \text{ kg/m}^3$ the following value is obtained 0.34

Ventilation heat transfer coefficient

- systems with forced ventilation systems
- systems without ventilation systems

$$\Phi_{v,i} = H_{v,i} \times (\theta_i - \theta_e)$$

$$\Phi_{v,i} = \dot{m}_i \times c_p \times (\theta_i - \theta_e)$$

$$\Phi_{v,i} = \frac{\rho \times \dot{V}_i \times c_p}{3600} \times (\theta_i - \theta_e)$$

$$H_{v,i} = 0,34 \times \dot{V}_i$$

\dot{V}_i volumetric flow rate [m³/h];

$$c_p = 1,006 \text{ kJ/kgK e } \rho = 1,2 \text{ kg/m}^3$$

volumetric flow rate

without forced ventilation systems

$$\dot{V}_i = \max(\dot{V}_{inf}, \dot{V}_{min})$$

\dot{V}_{inf} infiltration

\dot{V}_{min} minimum volumetric flow rate

with forced ventilation systems

$$\dot{V}_i = \dot{V}_{inf} + \dot{V}_{su,i} \times f_{v,i} + \dot{V}_{mech,inf,i}$$

$\dot{V}_{su,i}$ fresh air

$f_{v,i}$ temperature reduction factor $f_{v,i} = \frac{\theta_{int,i} - \theta_{su,i}}{\theta_{int,i} - \theta_e}$

$\dot{V}_{mech,inf,i}$ infiltration from plant system

Air change rate per hour (ach)

Ventilation can be

- natural, from windows doors or craks;
- forced, with a ventilation system;
- minimum values are required by regulation for hygenic problems;
- without forced ventilation nominal values can be used;

hygienic volumetric flow rated

minimum volumetric flow rate:

$$\dot{V} = n_{min} \times V_i$$

n_{min} minimum ach;

V_i internal volume (net)[m³]

environment	n_{min} (h ⁻¹)
dwelling	0,5
kitchen, bathroom with windows	1,5
Offices	1,0
meeting rooms, classrooms	2,0

infiltration

infiltration volumetric flow rate can be computed as:

$$\dot{V}_{inf} = 2 \times V_i \times n_{50} \times e_i \times \epsilon_i$$

n_{50} number of change rate with a different pressure difference of 50 Pa;

e_i screening coefficient

ϵ_i height correction factors

Ventilation rate for building n_{50}

construction	tightness of building fabric		
	high	medium	low
	high sealing quality	double glass window	single glass window
Single-family apartments	< 4	4-10	> 10
other apartments or buildings	< 2	2-5	> 5

screening coefficient e_i

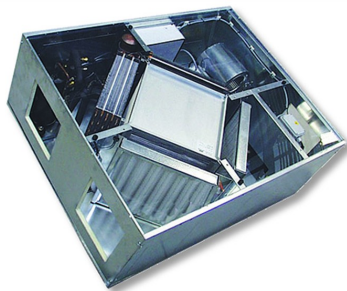
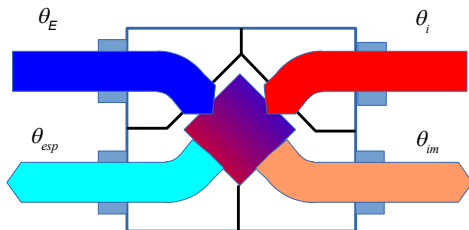
screening class	with one opening	with multiple openings
no screen	0,03	0,05
moderate screening	0,02	0,03
heavy screening	0,01	0,02

height correction ϵ

Height of heated space (center of room) above ground level	ϵ
0-10 m	1,0
10 > 30 m	1,2
> 30 m	1,5

Heat recovery units

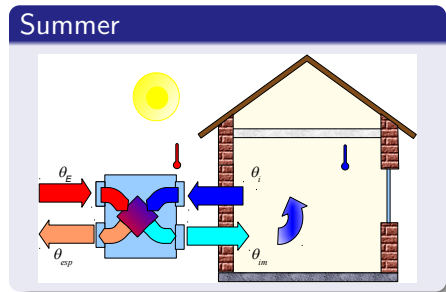
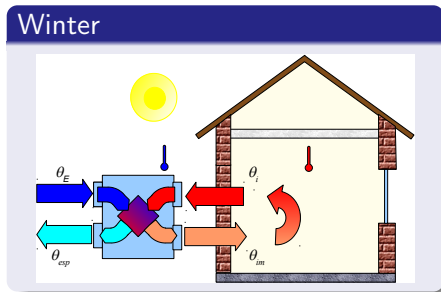
Energy recovery of the ventilation system



Forced ventilation

Heat recovery systems

- recuperators can be used in forced systems
- allow the recovery of part of energy otherwise wasted



Heat recovery systems

efficiency

- Heat recovery systems are characterized by efficiency
- efficiency is the fraction between heat recovered and maximum heat that can be recovered
- For ventilation equal mass flow are considered $c_{pf} \times \dot{m}_f = c_{pc} \times \dot{m}_c$

$$\eta_V = \frac{\Phi_r}{\Phi_{r,max}} = \frac{\theta_{su} - \theta_e}{\theta_{int} - \theta_e}$$

$$f_v = \frac{\theta_{int} - \theta_{su}}{\theta_{int} - \theta_e} = 1 - \eta_V$$

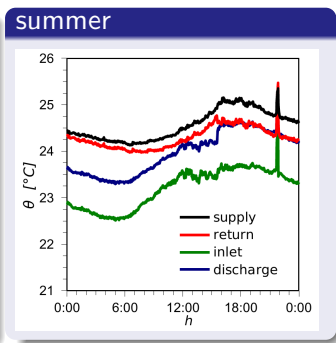
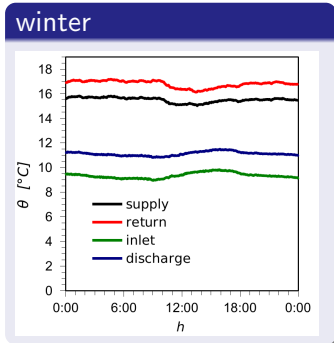
$$\Phi_V = \dot{m} \times c_{pa} \times (\theta_{int} - \theta_{su}) = \dot{m} \times c_{pa} \times (1 - \eta_V)(\theta_{int} - \theta_e) \quad [\text{W}]$$

$$\Phi_V = \dot{m} \times c_{pa} \times f_v \times (\theta_{int} - \theta_e) = \rho \times c_p \times \frac{\dot{V}_{su}}{3600} \times f_v \times (\theta_{int} - \theta_e)$$

$$H_V = 0,34 \times \dot{V}_{su} \times f_v = 0,34 \times \dot{V}$$

$\dot{V}_{su}, \dot{V} \text{ [m}^3/\text{h]}$

Experimental measures



Heat recover unit

recover unit



distribution



- Boiler must provide heat required for heating and ventilation;

$$\Phi = \Phi_d + \Phi_v$$

- plant efficiency must be added:

η_e terminal efficiency takes into account the addition of power required by the emission system;

η_c efficiency of control system;

η_d heat distribution efficiency.

Correction for ceiling height

Heating system	$f_{h,i}$	
	da 5 a 10 m	da 10 a 15 m
MOSTLY RADIANT		
heating floor	1	1
hot ceiling (temperature < 40 °C)	1,15	not used
hot ceiling (medium high temperature)	1	1,15
MOSTLY CONVECTIVE		
Natural convection	1,15	not used
FORCED CONVECTION		
crossed low level	1,30	1,60
from top	1,21	1,45
medium or high temperature at low level	1,15	1,30

Additional power required to reach steady state condition

$$\Phi_{RH,i} = A_i \cdot f_{RH}$$

A_i floor area

f_{RH} reheat factor

Table D 10b - Reheat factor, f_{RH} , for residential buildings, nightsetback maximum 8 h

Reheat time hours	f_{RH} W/m ²		
	Assumed internal temperature drop during setback ¹⁾		
	1 K	2 K	3 K
	building mass high	building mass high	building mass high
1	11	22	45
2	6	11	22
3	4	9	16
4	2	7	13

1) In well insulated and airtight buildings, an assumed internal temperature drop during set back of more than 2 to 3 K is not very likely. It will depend on the climate conditions and the thermal mass of the building.

heat output can be computed as:

$$\Phi_{HL} = \sum \Phi_{T,i} + \sum \Phi_{V,i} + \sum \Phi_{RH,i}$$

Nominal boiler heat output

$$\Phi_n \geq \left(\frac{\Phi_{HL}}{\eta_e \eta_c \eta_d} \right) C_s$$

Φ_n Nominal heat output of boiler;

C_s Additional correction factor

η_e terminal efficiency

η_c control efficiency

η_d distribution efficiency