BUILDING PHYSICS

Linear heat transmission (thermal bridges) Thermal capacity

Part 2

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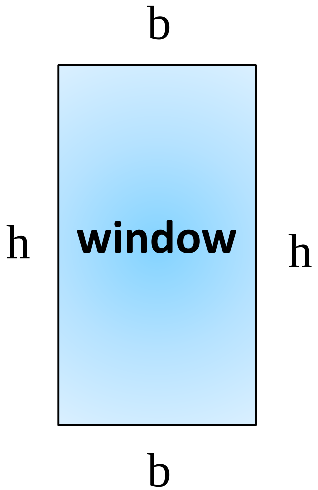
Thermal Bridges
Linear Heat Loss Coefficient

To **simplify the calculation of the extra heat losses** due to the thermal bridge effect, the concept of **linear heat loss coefficient** was implemented. This refers to the **extra heat losses along a unit length of a thermal bridge**, at a unit temperature difference and in a unit time. $\boldsymbol{\Psi}$ **[psi]** is measured in **[W/mK]**, where $\boldsymbol{L}$ is the length of the edge (corner, joint, column, window perimeter).



$$Q_\Psi = L \times \Psi (t_i - t_e)$$

$$Q_R = Q + \sum_j Q_{\Psi_j} = AU(t_i - t_e) + \sum_j L_j \Psi_j (t_i - t_e)$$

$$U_R = U + \frac{\sum_j L_j \Psi_j}{A}$$

Note that the extra heat losses due to the thermal bridge effect are in general 20~50% of the losses calculated on one dimensional basis.

Thermal Bridges
Linear Heat Loss Coefficient

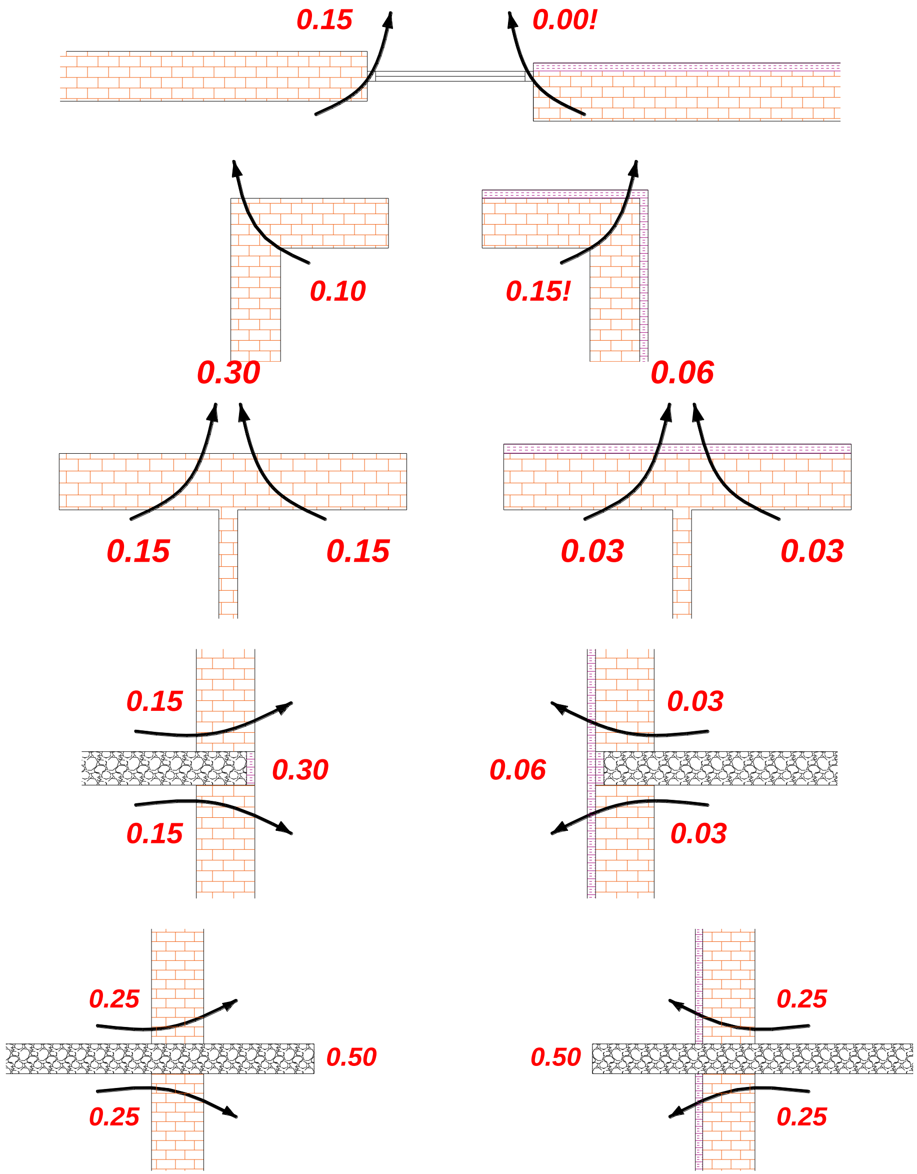
$$U_R = U + \frac{\sum_j l_j \Psi_j}{A}$$

$$U_R = U + \frac{U}{U}\frac{\sum_j l_j \Psi_j}{A} = U \cdot \left(1 + \frac{\sum_j l_j \Psi_j}{A \cdot U}\right)$$

[chi] $$\chi = \frac{\sum_j l_j \Psi_j}{A \cdot U} \quad [-]$$

$$U_R = U(1+\chi)$$

Linear Heat Loss Coefficient



Window perimeter

Outer comer of homogeneous wall

Joint of homogeneous external wall and internal wall

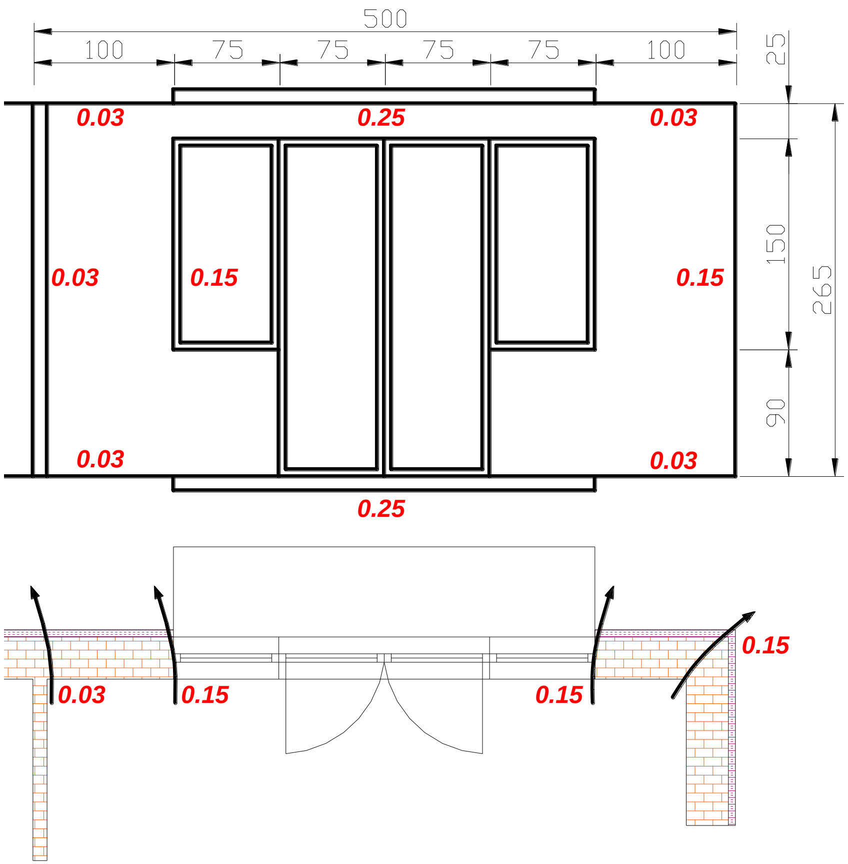
Joint of homogeneous external wall and floor slab with insulated strip

Balconies

Linear Heat Loss Coefficient
typical values

Description	***Ψ (W/mK)***
Window perimeter	0.15
Window perimeter if the frame is in the plane of the thermal insulation	0.00
Outer corner of homogeneous wall	0.10
Outer corner of wall with external insulation	0.15
External wall with internal insulation	0.00
Joint of homogeneous external wall and internal wall (both edges counted)	0.12
Joint of external wall with external insulation and internal wall (both edges counted)	0.06
Joint of homogeneous external wall and floor slab with insulated strip (booth edges counted)	0.15
Joint of external wall with external insulation and floor slab (both edges counted)	0.06
Parapet wall, cornice	0.20
Balconies	0.30

Thermal Bridges
Calculation of equivalent U-value



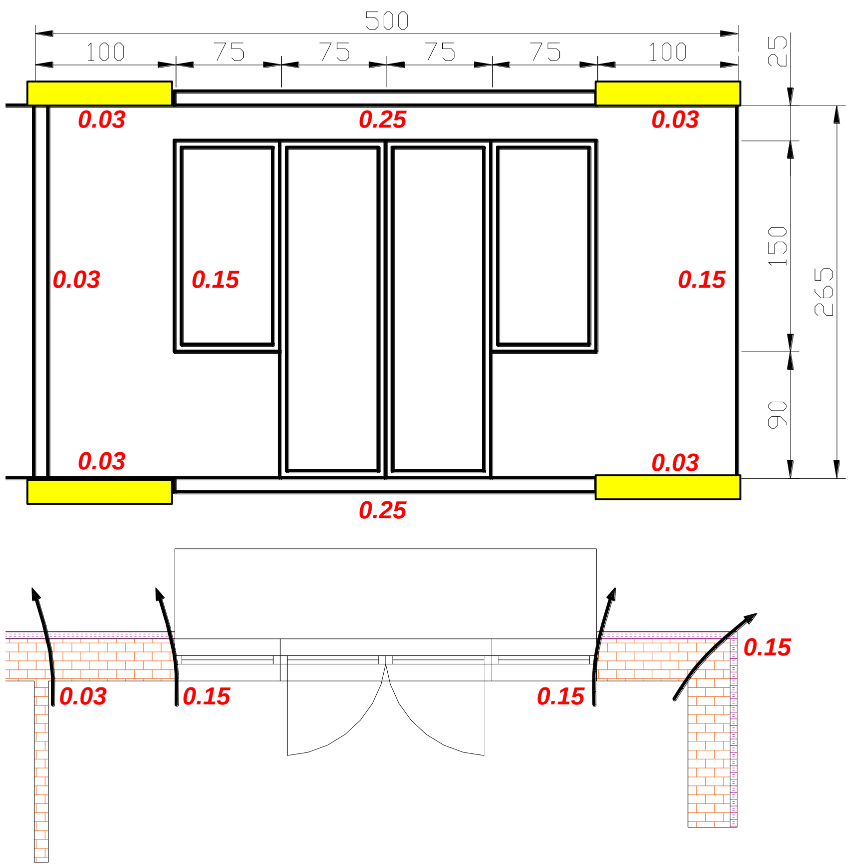
Exercise:

(A): Calculate the equivalent U-value of the enclosed wall section including additional heat loss due to thermal bridges. The wall is at one of the intermediate floors. It has a wall corner, partition wall, and balcony. The wall is insulated and its **U-value without thermal bridges is 0,65W/m^{2}K**.

Linear losses are insulated corner (Ψ=0.15W/mK), insulated „T" (Ψ=0.03W/mK) window perimeter (Ψ=0.15W/mK), joint of wall and floor slab: (Ψ=0.03W/mK), balcony (Ψ=0.25W/mK)

(B): Calculate the **total heat loss of a wall [W/K]** at 1˚C temperature difference if the U-value of the window is 3.0W/m^{2}K

Thermal Bridges
Calculation of equivalent U-value



Total surface: A=5·2.65=13.25m2

Window surface:

A_w=2·0.75 ·1.5+1.5 ·2.4m=

2.25+3.6=5.85m2

Surface of the brick wall:

A_{wa}=A-Aw=13.25-5.85=7.4m2

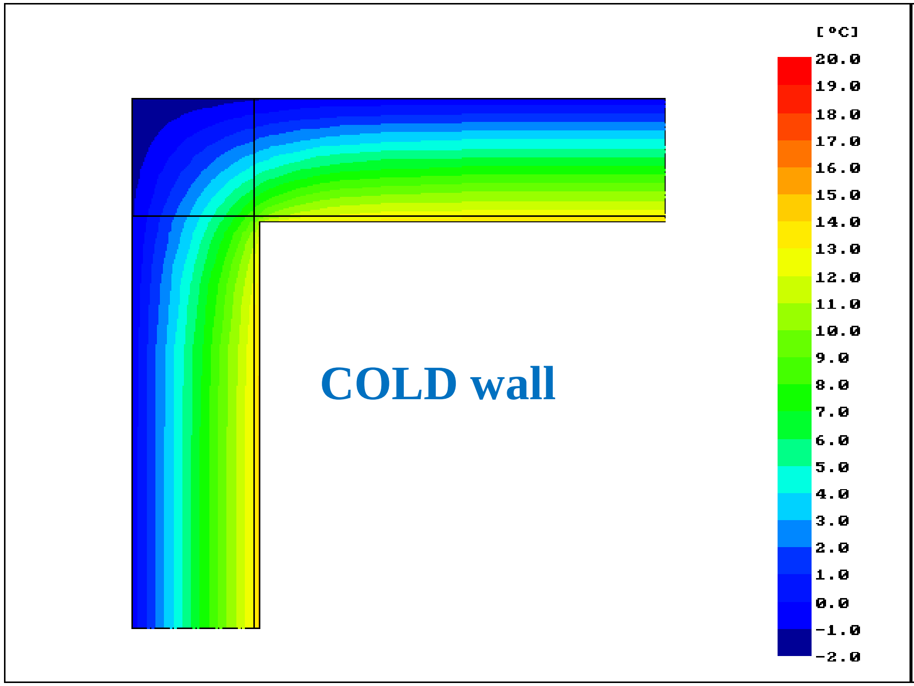
∑Ψ·l =

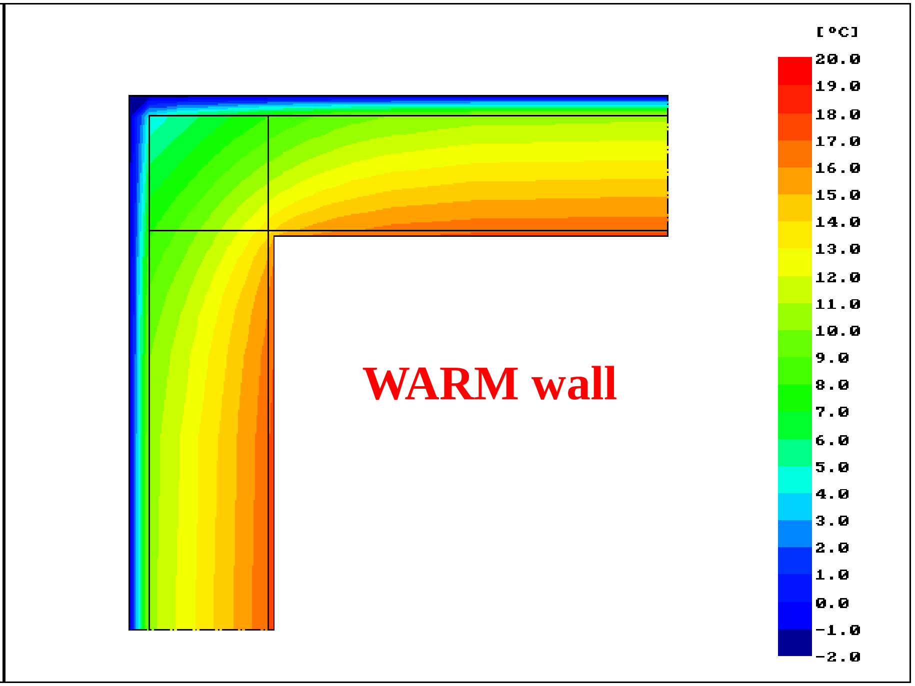
0.15 ·(3 +1.5+1.5+2 ·0.75+2 ·0.9)	=1.395W/K window
0.15 ·2.65	=0.398W/K corner
0.25 · (3+3)	=1.500W/K balcony
0.03 · (2+2)	=0.120W/K ring beam
0.03 · 2.65	=0.080W/K partition
Sum:	=3.493W/K

Ue=U_{wa}+ ∑Ψ·l /A_{wa}=0.65 + 3.493/7.4=1.122W/m^2K

Q= ∑U·A+∑Ψ·l =U_{wa}·A_{wa}+ U_w·A_w+Ψ·l = =0.65·7.4+3 ·5.85+3.493=25.853W/K

Wall corner simulation result
without and with 5cm external XPS insulation





Layer order: 30cm brick; 1,5cm gypsum plaster

k_{B30}= 0.64 W/mK

$k_{plaster}$= 0.34 W/mK

Ψ= 0.15 W/mK

t_C (t_e=-2°C)= 10.7°C

t_{iw}(t_e=-2°C)= 14.2°C

Heat loss of one meter : 62.4w/m

Layer order: 5cm XPS inst.; 30cm brick; 1,5cm gypsum plaster

k_{xps}= 0.054 W/mK

k_{B30}= 0.64 W/mK

$k_{plaster}$= 0.34 W/mK

Ψ= 0.19 W/mK

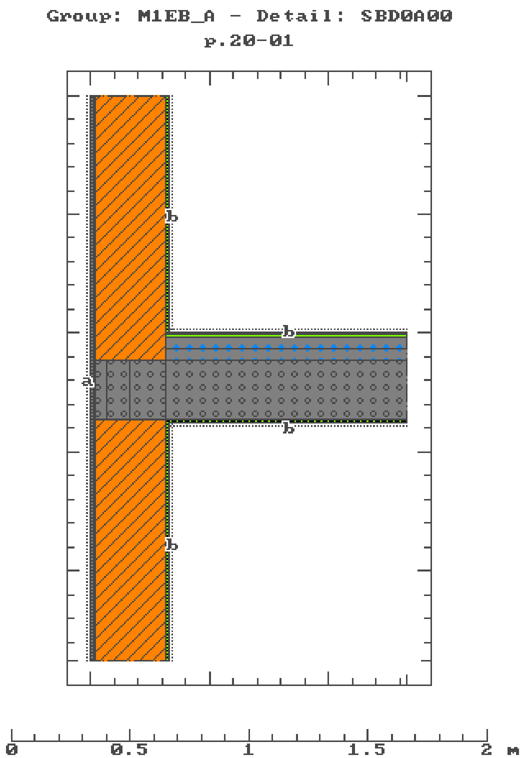
t_C (t_e=-2°C)= 14.8°C

t_{iw} (t_e=-2°C)= 17.3°C

Heat loss of one meter : 30.5w/m

Thermal Bridges

Reinforced concrete floor slab(25cm), Porotherm NF30

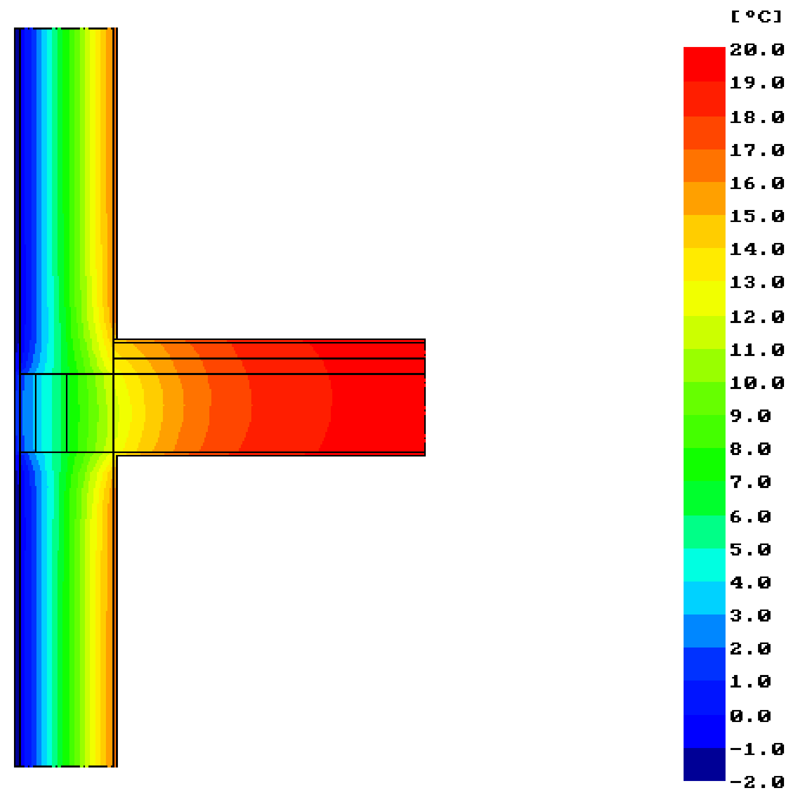


INPUT DATA

Material	W/mK
mortar 1800	0.900
brickwork 1000	0.290
brickwork 1000	0.290
gypsum 1000	0.350
gypsum 1000	0.350
floor tiles	1.000
concrete 2400	1.800
concrete 2400	1.800
reinf concrete	2.200
reinf concrete	2.200
reinf concrete	2.200
reinf concrete	2.200

Environment	°C	W/m2K	W/m2
a: outside	-2.0	25.0	0.0
b: inside	20.0	5.0	0.0

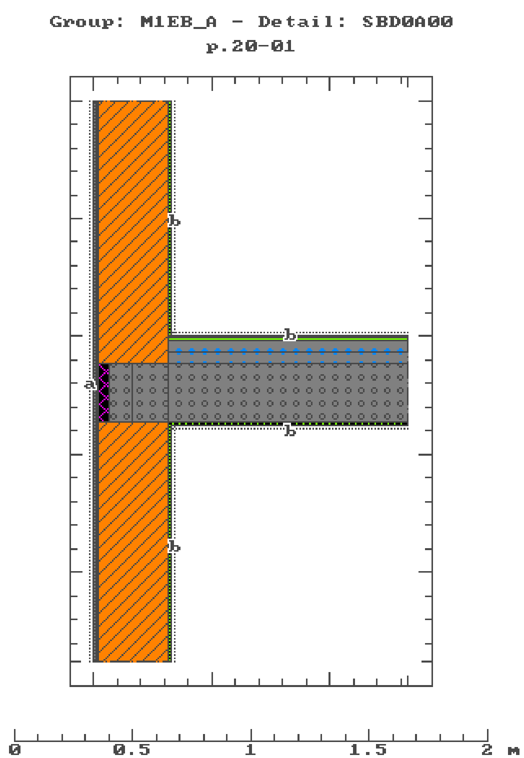
H-size = 1.33 m
V-size = 2.38 m



Ψ = 0.90 W/mK

Thermal Bridges

Reinforced concrete floor slab(25cm), Porotherm NF30

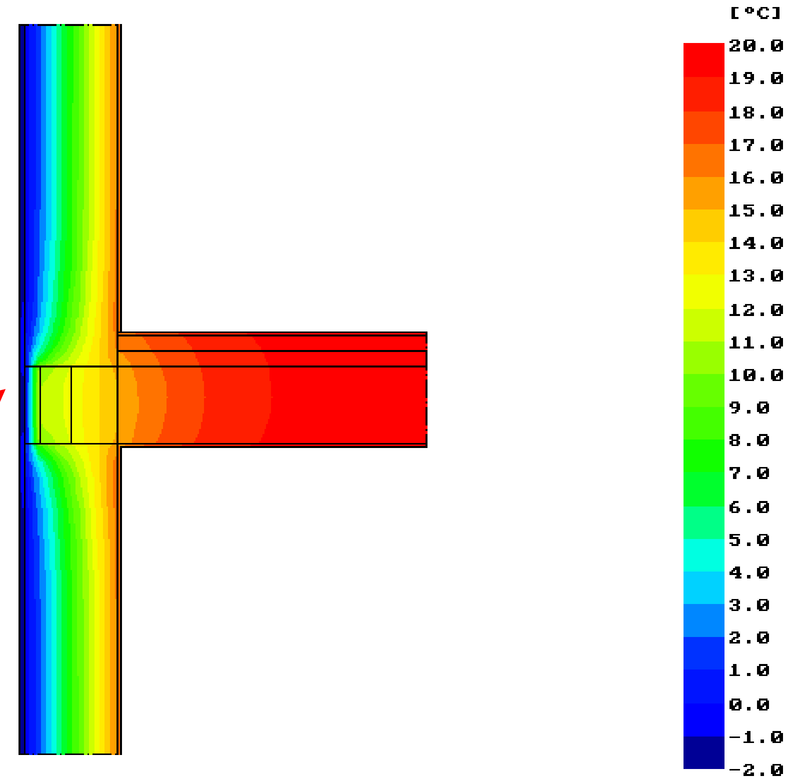


INPUT DATA

Material	W/mK
mortar 1800	0.900
brickwork 1000	0.290
brickwork 1000	0.290
gypsum 1000	0.350
gypsum 1000	0.350
floor tiles	1.000
concrete 2400	1.800
concrete 2400	1.800
expanded PS 15	0.054
reinf concrete	2.200
reinf concrete	2.200
reinf concrete	2.200

Environment	°C	W/m2K	W/m2
a: outside	-2.0	25.0	0.0
b: inside	20.0	5.0	0.0

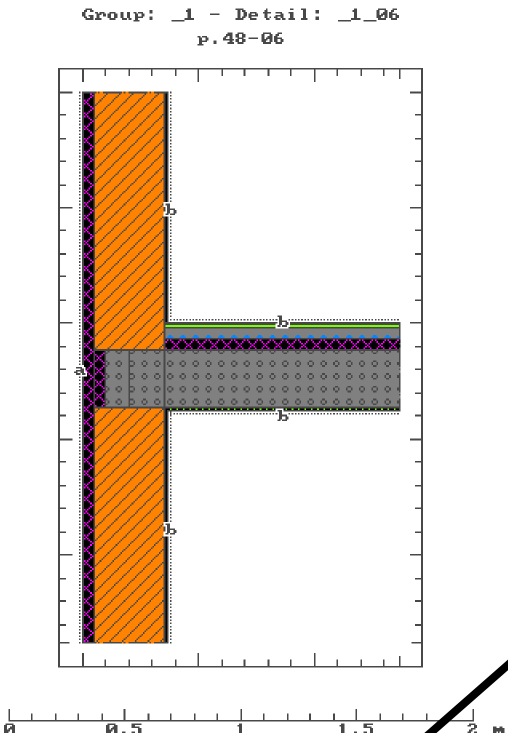
H-size = 1.32 m
V-size = 2.38 m



5cm EPS Insulation at the face of the reinforced concrete slab.

$\Psi = 0.47$ W/mK $((\Psi - \Psi_0)/\Psi 0 = 47\%)$

Thermal Bridges
Reinforced concrete floor slab(25cm), Porotherm NF30

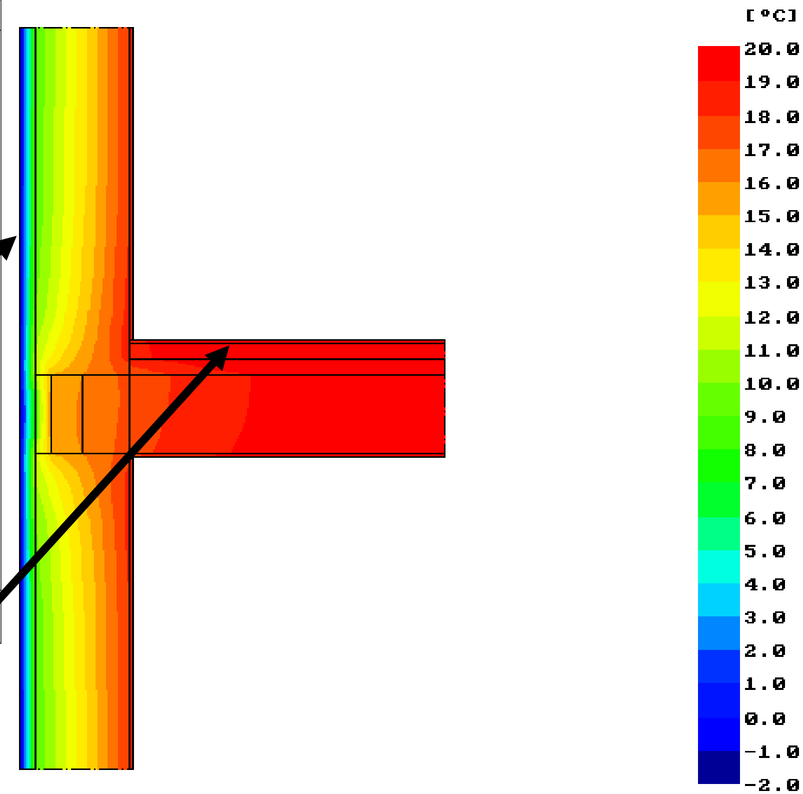


INPUT DATA

Material	W/mK
expanded PS 15	0.040
brickwork 1000	0.290
brickwork 1000	0.290
gypsum 1000	0.350
gypsum 1000	0.350
floor tiles	1.000
concrete 2400	1.800
expanded PS 15	0.040
expanded PS 15	0.054
reinf concrete	2.200
reinf concrete	2.200
reinf concrete	2.200

Environment	°C	W/m2K	W/m2
a: outside	-2.0	25.0	0.0
b: inside	20.0	5.0	0.0

H-size = 1.365 m
V-size = 2.38 m



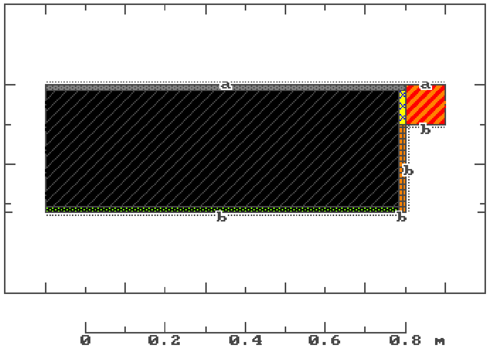
5cm exp. pol. insulation at the face of the reinforced concrete slab. Ψ=0.47 W/mK

5cm floor insulation. (Ψ=0.45)

5cm Dryvite external insulation. (Ψ=0.18)

Place of the window frame (P. NF30)

Group: M1CA_A - Detail: LBB20A1
p.05-01



INPUT DATA

Material	W/mK
lght mortar 800	0.340
gypsum 1000	0.350
cell concr 600	0.180
polyurethane	0.027
wood 600-800	0.160
wood panel 600	0.160

Environment	°C	W/m2K	W/m2
a: outside	0.0	25.0	0.0
b: inside	20.0	5.0	0.0

H-size = 1 m
V-size = 0.32 m

KOBRA RESULTS

Rsi = 0.20 m²K/W   hi = 5.0 W/m²K
θi = 20.0 °C   θe = 0.0 °C

CONDENSATION RISK EVALUATION

Belgium: use hi = 5 W/m²K

K: f(0.20) = 0.74   θ = 14.8 °C
OK : low risk (C70)

O: f(0.20) = 0.74   θ = 14.8 °C
OK : low risk (C70)

HEAT LOSS EVALUATION

use hi = 8 W/m²K for best accuracy

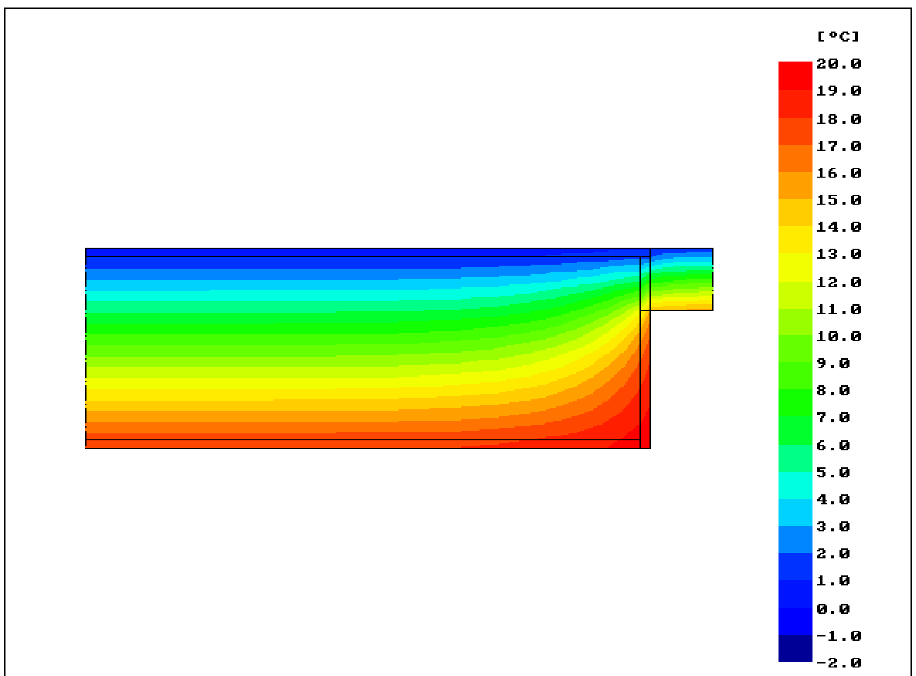
U-values [W/m²K]
A-B: 0.52   C-D: 1.16

Total heat loss   Q(B-D) =12.68 W/m

Coupling coefficient Lie= 0.6 W/mK

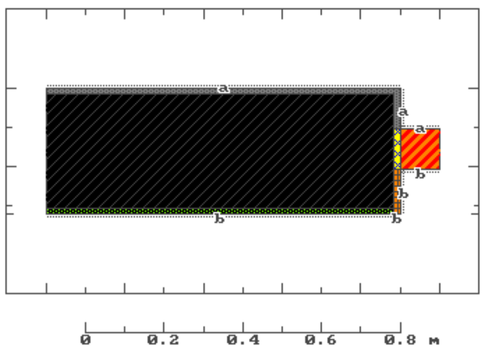
psi-e = Lie - U(AB)*BQ - U(CD)*QD
= 0.05 W/mK   negligible (C1)

psi-i = Lie - U(AB)*AR - U(CD)*KC
= 0.05 W/mK   negligible (C1)



Place of the window frame (P. NF30)

Group: M1CA_A - Detail: LBB10A1
p.05-02

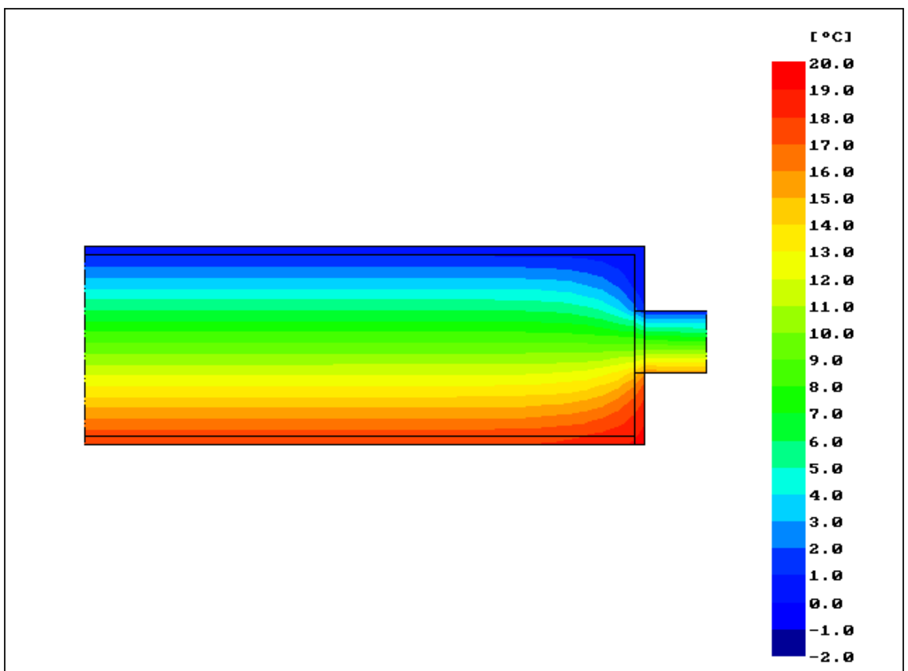


INPUT DATA

Material	W/mK
lght mortar 800	0.340
gypsum 1000	0.350
cell concr 600	0.180
polyurethane	0.027
wood 600-800	0.160
wood panel 600	0.160

Environment	°C	W/m2K	W/m2
a: outside	0.0	25.0	0.0
b: inside	20.0	5.0	0.0

H-size = 1 m
V-size = 0.32 m



KOBRA RESULTS

Rsi = 0.20 m²K/W   hi = 5.0 W/m²K
θi = 20.0 °C   θe = 0.0 °C

CONDENSATION RISK EVALUATION

Belgium: use hi = 5 W/m²K

K: f(0.20) = 0.79   θ = 15.8 °C
OK : low risk (C75)

O: f(0.20) = 0.77   θ = 15.4 °C
OK : low risk (C75)

HEAT LOSS EVALUATION

use hi = 8 W/m²K for best accuracy

U-values [W/m²K]
A-B: 0.52   C-D: 1.16

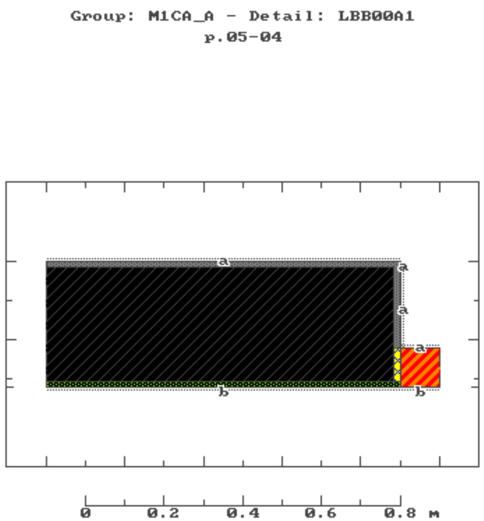
Total heat loss   Q(B-D) =12.06 W/m

Coupling coefficient Lie= 0.6 W/mK

psi-e = Lie - U(AB)*BQ - U(CD)*PD
= 0.02 W/mK   negligible (C1)

psi-i = Lie - U(AB)*AR - U(CD)*KC
= 0.02 W/mK   negligible (C1)

Place of the window frame (P. NF30)

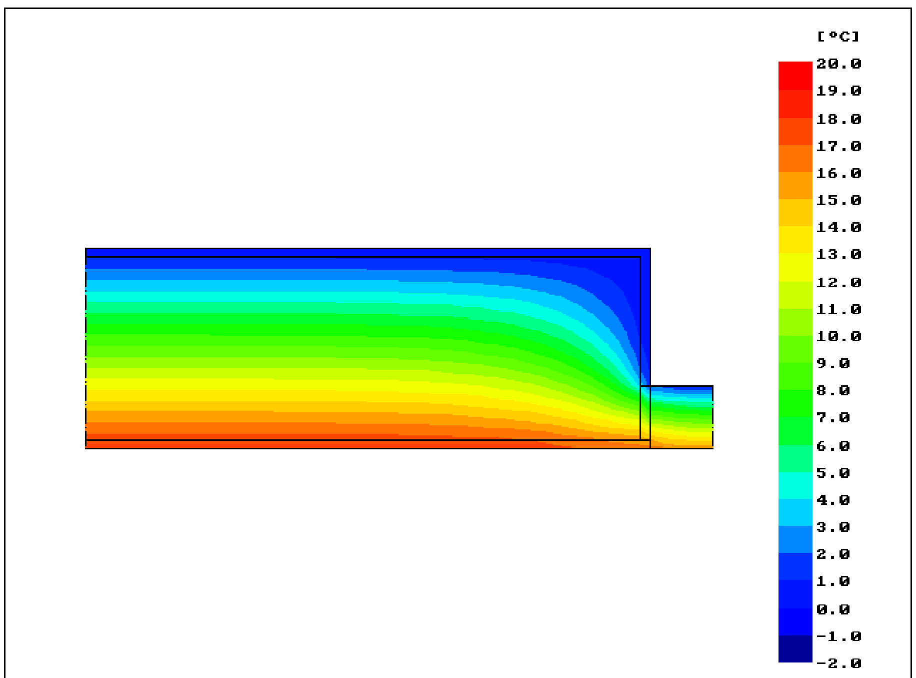


INPUT DATA

	Material	W/mK
	lght mortar 800	0.340
	cell concr 600	0.180
	gypsum 1000	0.350
	polyurethane	0.027
	wood 600-800	0.160

Environment	°C	W/m2K	W/m2
a: outside	0.0	25.0	0.0
b: inside	20.0	5.0	0.0

H-size = 1 m
V-size = 0.32 m



KOBRA RESULTS

Rsi = 0.20 m²K/W   hi = 5.0 W/m²K
θi = 20.0 °C   θe = 0.0 °C

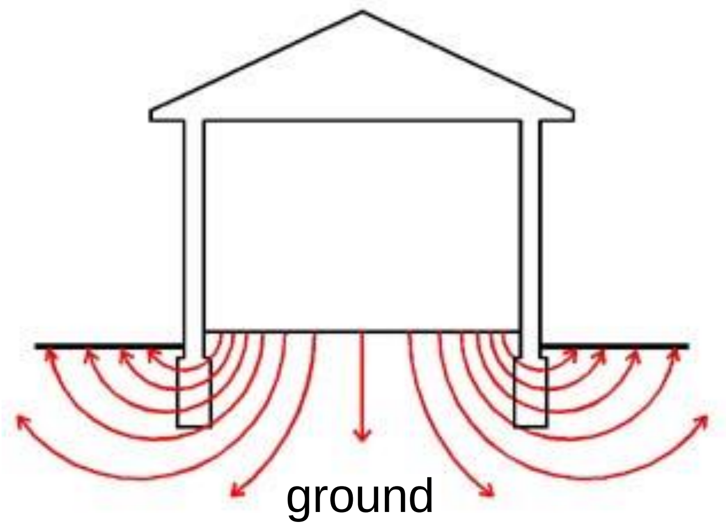
CONDENSATION RISK EVALUATION

Belgium: use hi = 5 W/m²K
K: f(0.20) = 0.81   θ = 16.2 °C
OK : minimal risk (C80)
O: f(0.20) = 0.78   θ = 15.6 °C
OK : low risk (C75)

HEAT LOSS EVALUATION

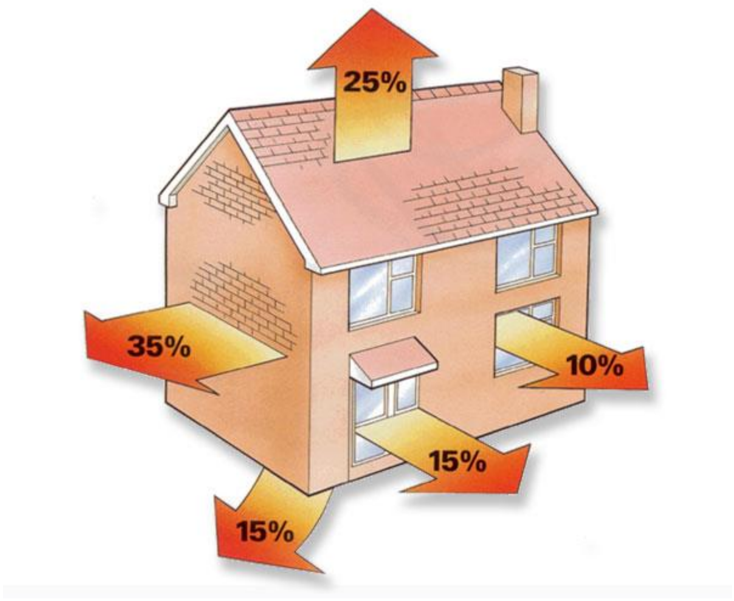
use hi = 8 W/m²K for best accuracy
U-values [W/m²K]
A-B: 0.52   C-D: 1.16
Total heat loss Q(B-D) = 12.8 W/m
Coupling coefficient Lie= 0.6 W/mK
psi-e = Lie - U(AB)*BQ - U(CD)*DP
= 0.06 W/mK negligible (C1)
psi-i = Lie - U(AB)*AK - U(CD)*CK
= 0.06 W/mK negligible (C1)

Ground losses
Heat flow paths to the ground



Ground and footing losses are calculated with **linear heat transfer coefficients** too, along the perimeter of the building.

$$Q_{\Psi} = l \times \Psi(t_i - t_e)$$

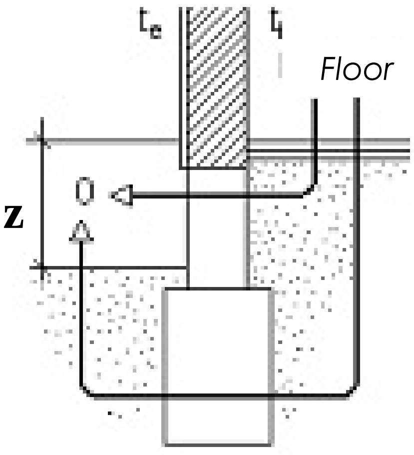


The total heat loss of a floor is:

ground and floor loss
+
thermal bridge loss

Ground losses

Heat flow paths to the ground



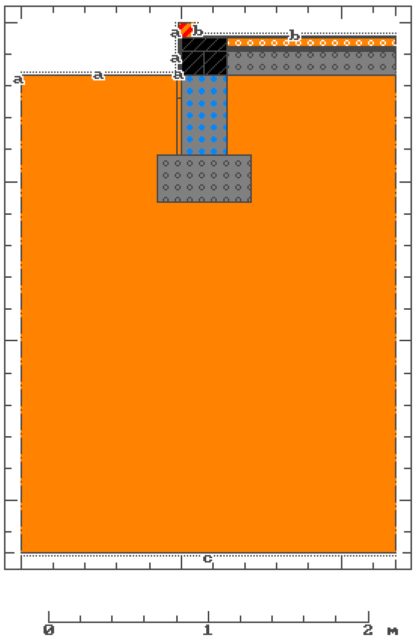
$$Q_\Psi = l \times \Psi (t_i - t_e)$$

Elevation difference relative to the external ground level	Thermal resistance of floor (considere area 1,5m from the external wall) $R = \sum \frac{d}{\lambda} \quad (m^2K/W)$						
z (m)	Non insulated	0,20--0,35	0,40--0,55	0,60--0,75	0,80--1,00	1,05--1,50	1,55--2,00
-6,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
-6,00...-4,05	0,20	0,20	0,15	0,15	0,15	0,15	0,15
-4,00...-2,55	0,40	0,40	0,35	0,35	0,35	0,35	0,30
-2,50...-1,85	0,60	0,55	0,55	0,50	0,50	0,50	0,45
-1,80...-1,25	0,80	0,70	0,70	0,65	0,60	0,60	0,55
-1,20...-0,75	1,00	0,90	0,85	0,80	0,75	0,70	0,65
-0,70...-0,45	1,20	1,05	1,00	0,95	0,90	0,80	0,75
-0,40...-0,25	1,40	1,20	1,10	1,05	1,00	0,90	0,80
-0,20...+0,20	1,75	1,45	1,35	1,25	1,15	1,05	0,95
0,25....0,40	2,10	1,70	1,55	1,45	1,30	1,20	1,05
0,45....1,00	2,35	1,90	1,70	1,55	1,45	1,30	1,15
1,05....1,50	2,55	2,05	1,85	1,70	1,55	1,40	1,25

Ground losses

Heat flow paths to the ground – example 1

Group: M1DB_A – Detail: LBA7AHA
p.13-01



INPUT DATA

Material	W/mK
sand or gravel	2.000
sand or gravel	2.000
sand or gravel	2.000
concrete 2400	1.800
reinf concrete	2.200
wood 600-800	0.160
mortar 1800	0.900
cell concr 600	0.180
cell concr 600	0.180
cell concr 600	0.180
floor tiles	1.000
light conc 1600	0.510
light conc 1200	0.410
reinf concrete	2.200

	Environment	°C	W/m2K	W/m2
a:	outside	0.0	25.0	0.0
b:	inside	20.0	5.0	0.0
c:	soil	10.0	99.0	0.0

H-size = 2.34 m
V-size = 3.33 m

KOBRA RESULTS

Rsi = 0.20 m²K/W hi = 5.0 W/m²K
θi=20°C θe= 0°C θs=10°C

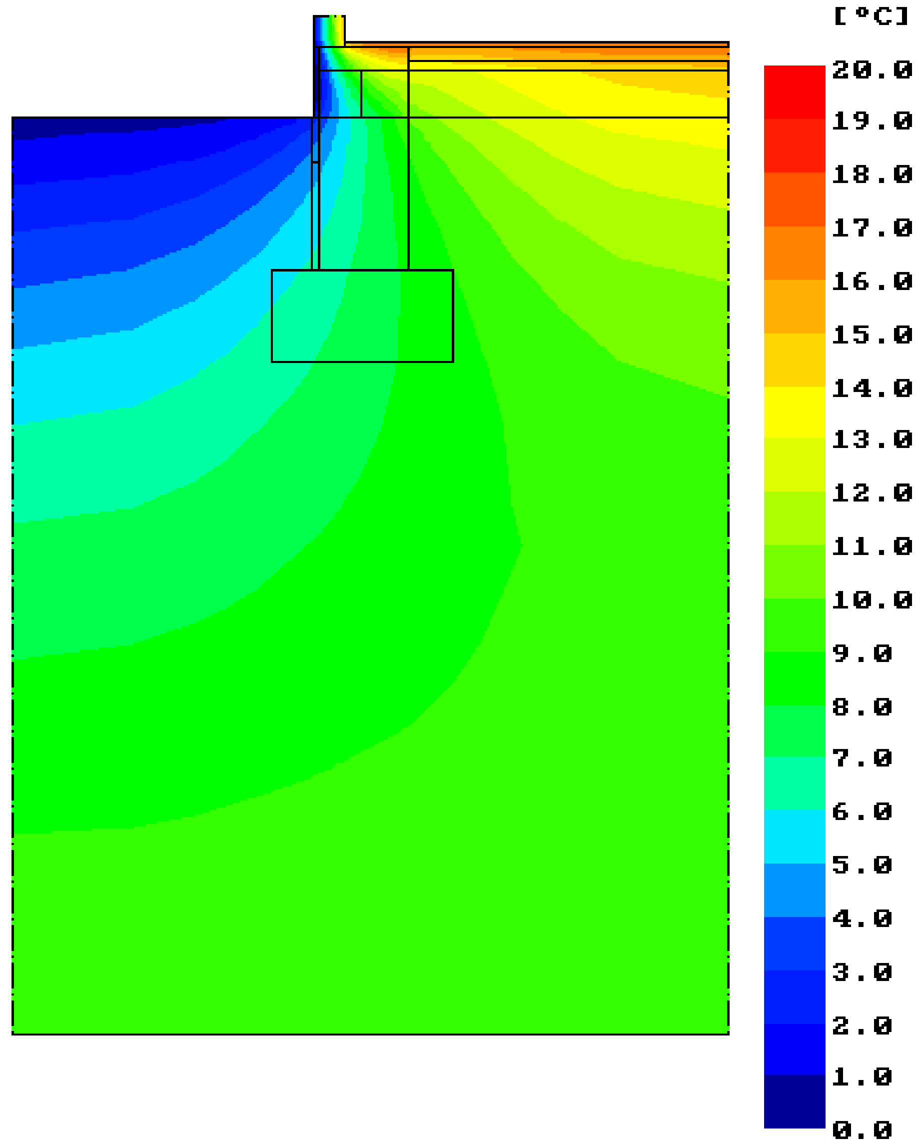
CONDENSATION RISK EVALUATION

Belgium: use hi = 5 W/m²K
K: f(0.20) = 0.71 θ = 14.1 °C
OK : low risk (C70)
O: f(0.20) = 0.71 θ = 14.1 °C
OK : low risk (C70)

HEAT LOSS EVALUATION

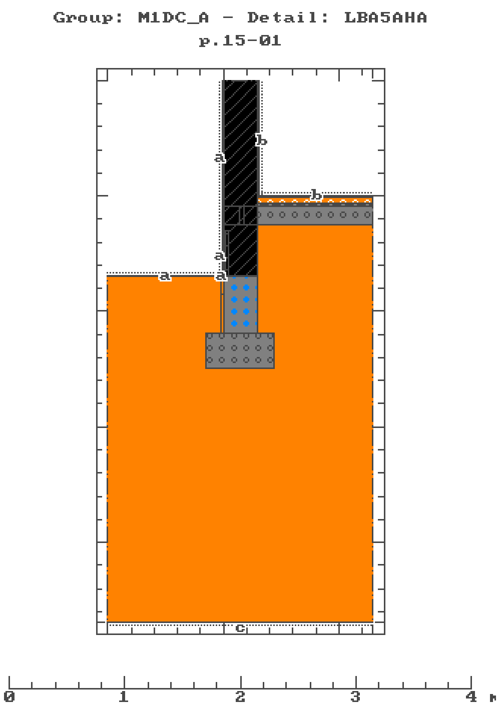
use hi = 8 W/m²K for best accuracy
U-values [W/m²K]
A-B: 1.16 C-D: 2.20
Total heat loss Q(B-D) = 22.8 W/m
Coupling coefficient Lie= 1.1 W/mK

evaluation: cf. next detail



Ground losses

Heat flow paths to the ground – example 2



INPUT DATA

	Material	W/mK
	sand or gravel	2.000
	sand or gravel	2.000
	sand or gravel	2.000
	concrete 2400	1.800
	reinf concrete	2.200
	lght mortar 800	0.340
	cell concr 600	0.180
	cell concr 600	0.180
	cell concr 600	0.180
	cell concr 600	0.180
	cell concr 600	0.180
	stone +-3000	3.500
	stone +-3000	3.500
	cell concr 600	0.180
	gypsum 1000	0.350
	floor tiles	1.000
	light conc 1600	0.510
	light conc 1200	0.410
	reinf concrete	2.200

	Environment	°C	W/m2K	W/m2
a:	outside	0.0	25.0	0.0
b:	inside	20.0	5.0	0.0
c:	soil	10.0	99.0	0.0

H-size = 2.29 m
V-size = 4.695 m

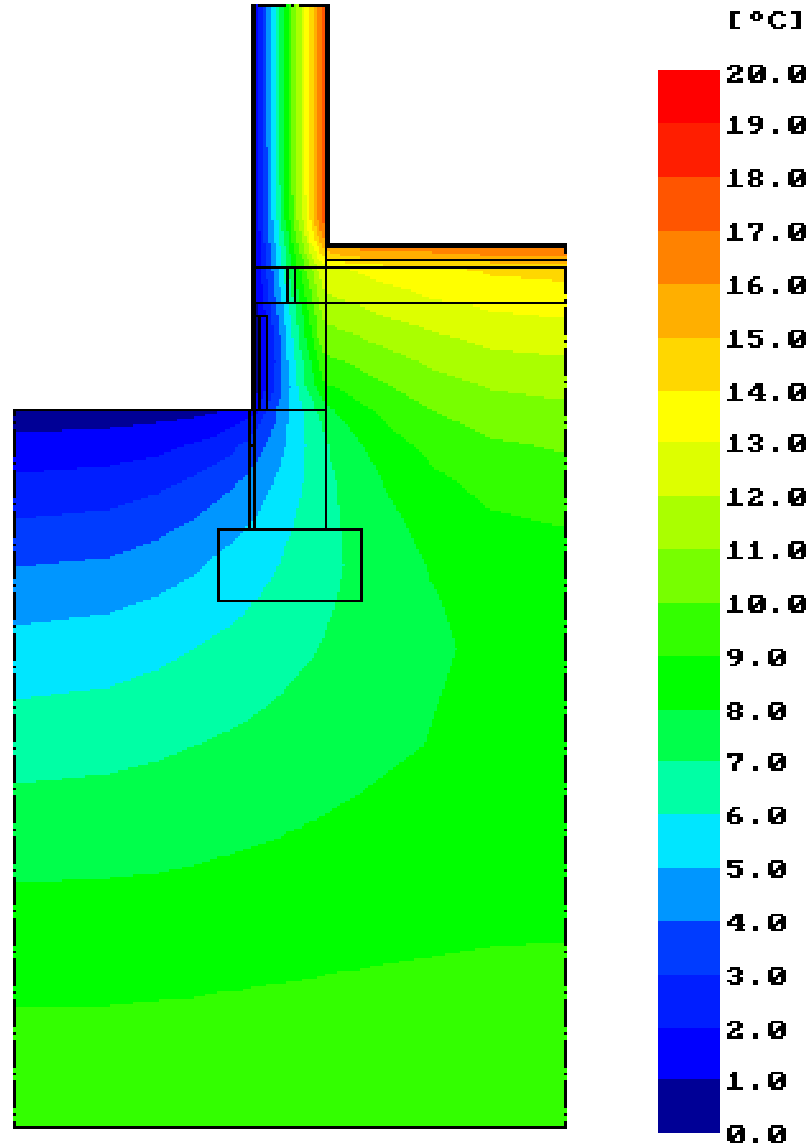
KOBRA RESULTS

Rsi = 0.20 m²K/W hi = 5.0 W/m²K
θi=20°C θe= 0°C θs=10°C

CONDENSATION RISK EVALUATION
Belgium: use hi = 5 W/m²K
K: f(0.20) = 0.79 θ = 15.8 °C
OK : low risk (C75)
O: f(0.20) = 0.79 θ = 15.8 °C
OK : low risk (C75)

HEAT LOSS EVALUATION
use hi = 8 W/m²K for best accuracy
U-values [W/m²K]
A-B: 0.52 C-D: 2.20
Total heat loss Q(B-D) = 26.9 W/m
Coupling coefficient Lie= 1.3 W/mK

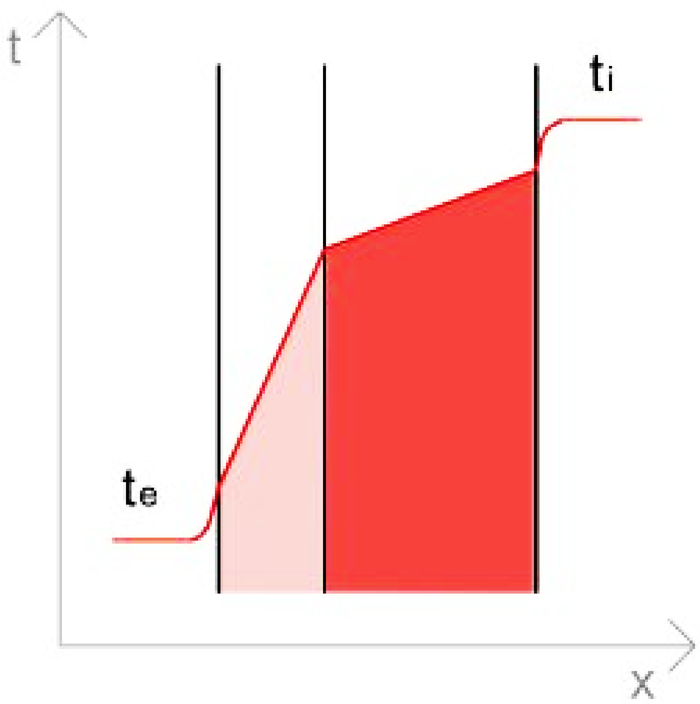
evaluation: cf. next detail



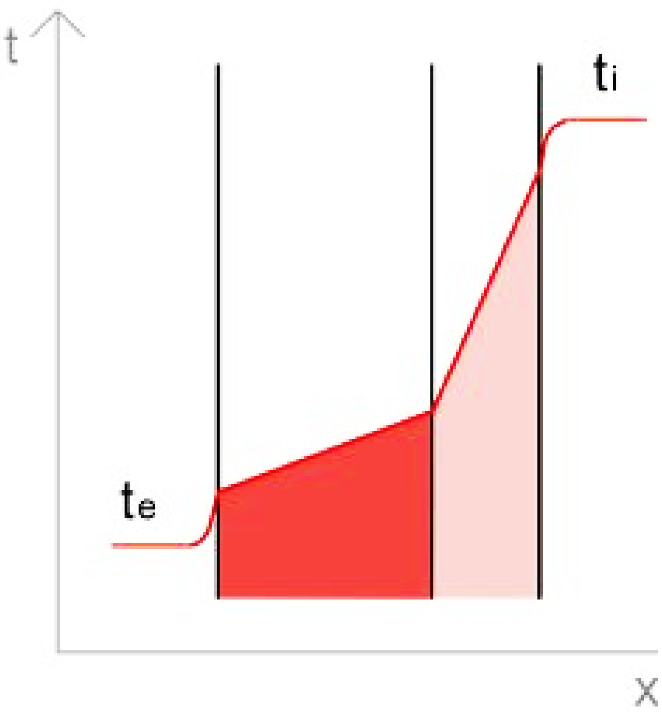
Heat Storage capacity

Temperature Distribution and place of the insulation

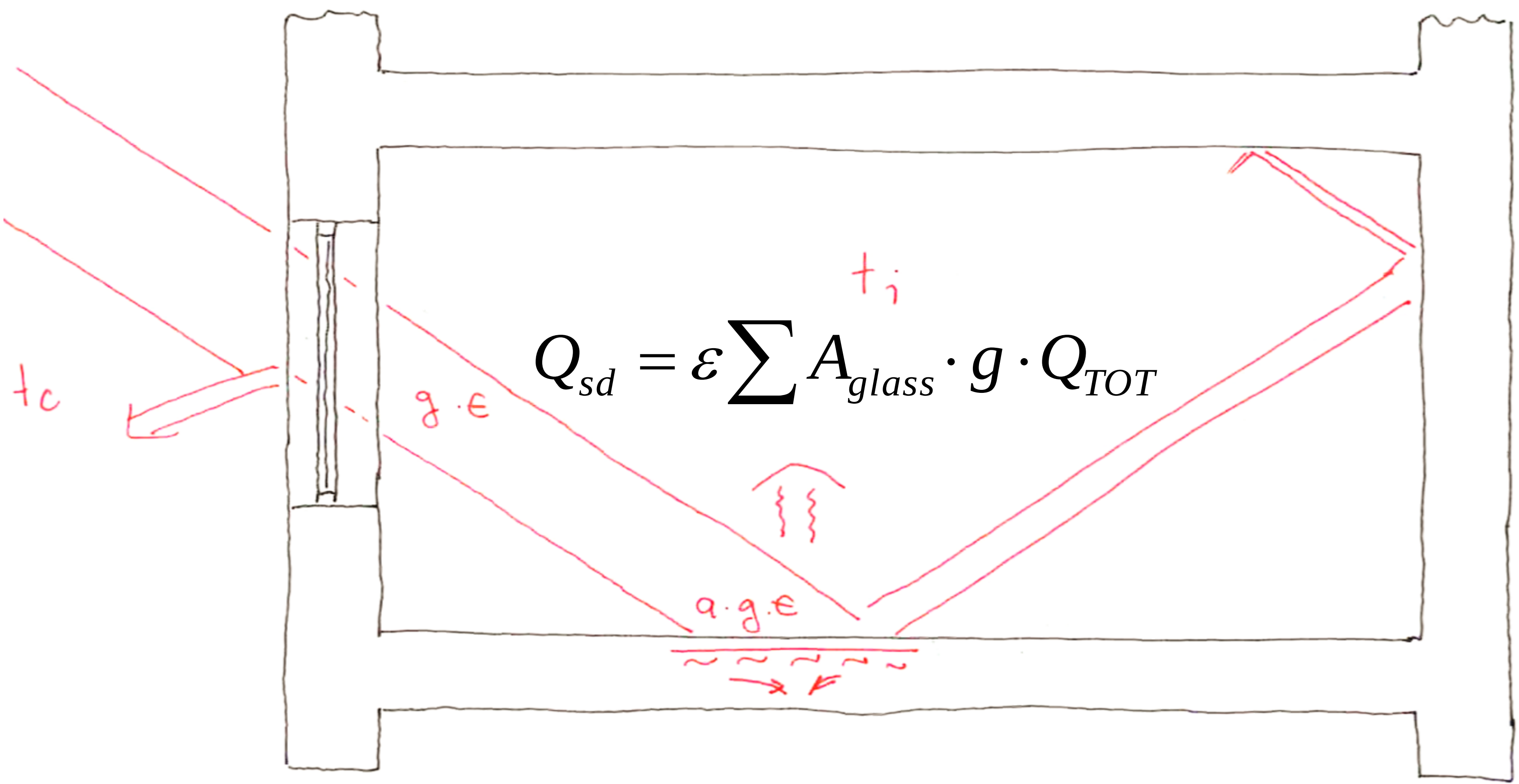
Heat storage is USED



Heat storage is NOT USED



Heat Storage capacity
passive heating – effeciency of direct solar gain



$$Q_{sd} = \varepsilon \sum A_{glass} \cdot g \cdot Q_{TOT}$$

$$\varepsilon = 0{,}1 - 0{,}9 \quad (400\, kg / m^2)$$

Heat Storage capacity
Definition of a Thermal mass

The change of the **stored heat is proportionate to the change of the temperature**, the mass and the specific heat:

$$\Delta \dot{Q} = m \cdot c \cdot \Delta t \qquad [kg] * [J/(kg*K)] * [K] = [J]$$

thus a body of bigger mass and/or **higher specific heat accumulates** or releases the given amount of energy with less temperature change:

$$\Delta t = \frac{\Delta \dot{Q}}{m \cdot c}$$

Specific heat of the majority of building materials: c = 0,85-0,95 kJ/kgK

An important exception is the **wood**, its **specific heat** is 1,7-3,0 kJ/kgK.

The mass of the building elements around a room is considerable.
In general the **partitions** have more important role, partly due to the big mass of floor slabs, partly due to the fact, that they **absorb and release energy on both surfaces** from and to the adjacent rooms.

Heat Storage capacity

Calculation of a heat storage capacity (classical way)

According to another convention the **active depth** is measured in **thermal resistance**. For a 24 h period the active depth is

$$R = 0.15\, m^2 K / W$$

The heat storage capacity of any heavy floor slab can be "cut away" from the room if carpets, suspended ceilings are applied. Insulate the thermal mass!

In many cases major part of the heat storage capacity of massive walls and floors is inactive, due to the limited depth of heat flow penetration.

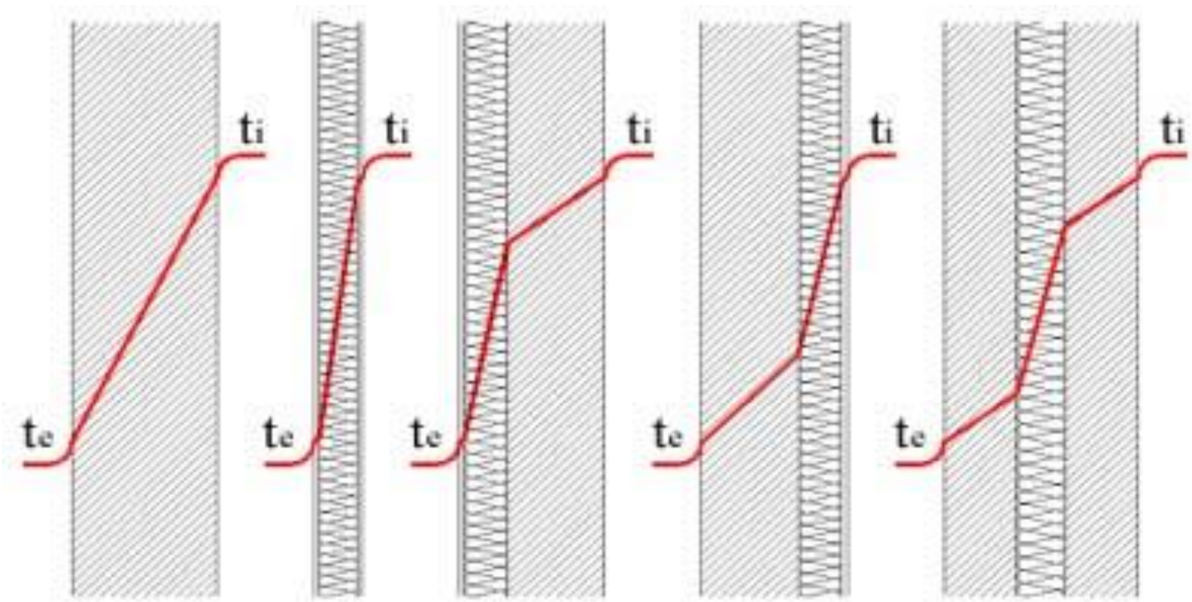
According to the previous rule the **thickness of the active zone** is

$$d_i = k_i R = k_i 0.15$$

Where k_i is the conduction coefficient of a building material. The **specific thermal mass** for 1 m^2 building element is:

$$m_i = d_i \rho_i$$

Heat Storage capacity
Effective thickness according to the EU directive



- The **concept of the "active thermal mass"** has been implemented in order to **simplify the design process**.
- When calculating the active thermal mass, the **depth of the penetration of the heat flow,** i.e. the **thickness**, where considerable temperature swings are accompanied with charging and discharging of heat, **has to be determined**.
- This **thickness depends on the period**: the longer the period is, the thicker the layer is. Usually the **24 hour period** is considered. The depth of penetration can be **calculated in an accurate way**.

Heat Storage capacity
Thermal mass of a room

Thermal mass of a room is the **sum of the specific thermal mass of the elements** around the room, each **multiplied by the area of the element**.

$$M_{room} = \sum M_i = \sum m_i A_i$$

Room section