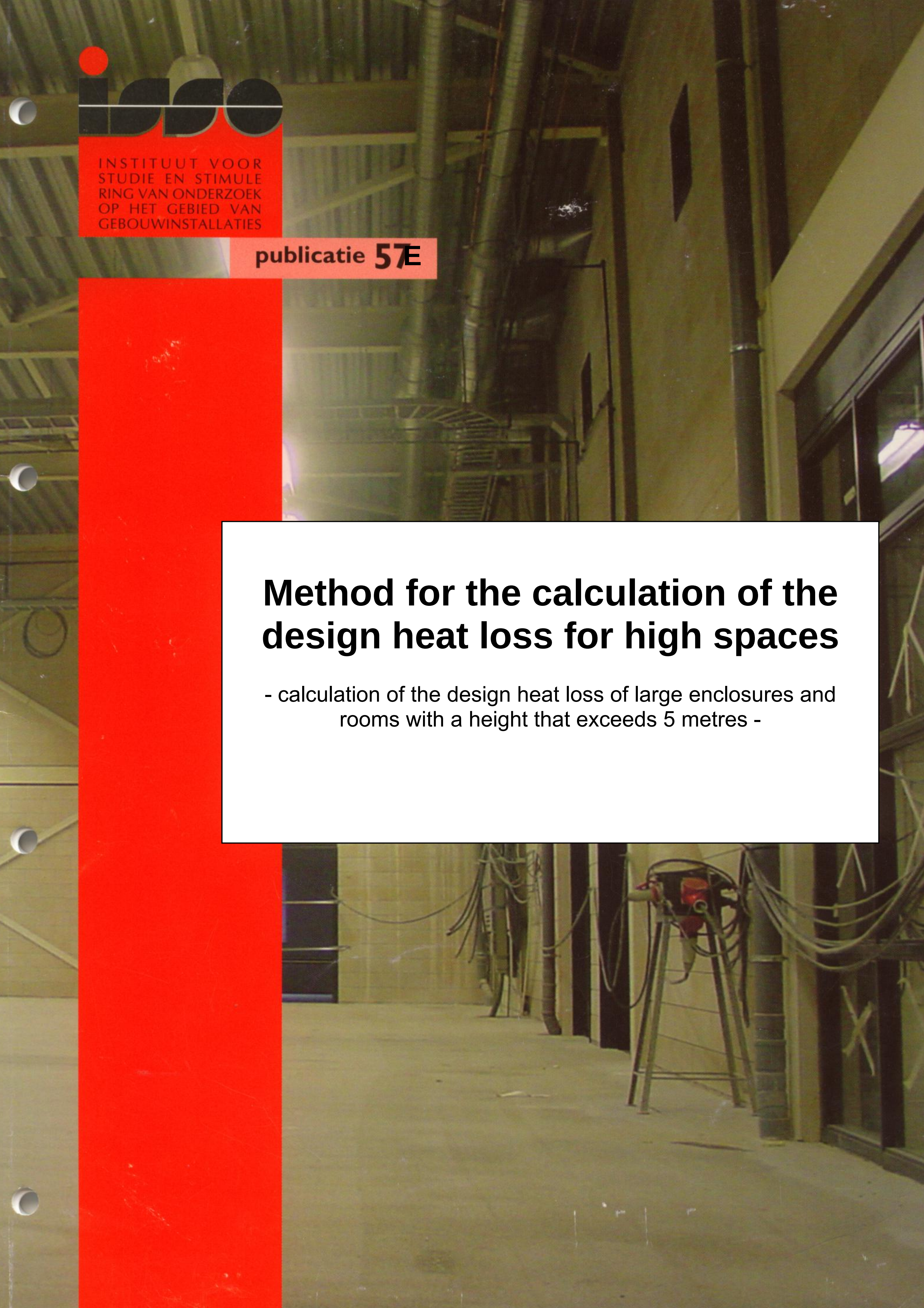

INSTITUUT VOOR STUDIE EN STIMULERING VAN ONDERZOEK OP HET GEBIED VAN GEBOUWINSTALLATIES

publicatie 57E

Method for the calculation of the design heat loss for high spaces

- calculation of the design heat loss of large enclosures and rooms with a height that exceeds 5 metres -

ISSO, institution for the study and promotion of research in the field of building services

ISSO: Instituut voor Studie en Stimulering van Onderzoek op het gebied van gebouwinstallaties (Institution for the study and promotion of research in the field of building services)

ISSO is a non-profit organization that not only coordinates research but the transfer of knowledge for the benefit of the installation sector within the building environment as well.

The following organizations participate in ISSO:

ONRI: Organisatie van onafhankelijke advies- en ingenieursbureaus (The Association of consulting engineers of the Netherlands);

TWL: Ned. Technische Vereniging voor Installaties in Gebouwen (Dutch equivalent of CIBSE);

Uneto-VNI: Ondernemersorganisatie voor de installatiebranche en de technische detailhandel (Association of Dutch Installers);

Vabi: Vereniging voor Automatisering in de Bouw en in de installatietechniek (Dutch Association for computer calculation on buildings and building installations).

The objective

The research of questions and problems existing within the field of building installations and publication of the results thereof. Thus to carry out research while employing the existing infrastructure, during which the need for knowledge transfer is of major importance.

This means that when choosing a specific subject it is especially important to be aware of the kind of information requested by the target group.
As a result, ISSO is both a co-ordinating and programming institute that endeavours to provide the entire installation field with the knowledge and rules needed as such.

The target group consists of
- the designing and executive disciplines such as, amongst others, consulting engineers, installers (contractors) and other designers.
- the supplying industry such as suppliers, manufacturers and importers
- the principles and building managers

This target group relates to mechanical, sanitary as well as electrotechnical installations inside and around buildings.

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Methode for the calculation of the design heat loss for high spaces

- calculation of the design heat loss of large enclosures and rooms with a height that exceeds 5 metres. -

ISBN 90-5044-xxx-x

SUMMERY

This publication gives the method for calculation of the design heat loss in large enclosures and rooms with a height that exceeds 5 metres. The capacity to be installed consists of three contributions:

- the transmission heat loss;
- the ventilation heat loss;
- the heating up allowance to be taken into account after a possible night setback or stoppage and/or the power needed for equalising the temperature of materials coming in with a deferring temperature.

The method is valid for both directly fired systems and centrally heated systems as used in industrial or high spaces.

(Industrial) Spaces with a maximum height of 5 m and heated with radiators are covered by EN 12831.

The method follows the European standard NEN-EN 12831.

SAMENVATTING

Deze publicatie bevat de berekeningsmethode voor het bepalen van het te installeren vermogen in industriële ruimten en ruimten met een hoogte van meer dan 5 meter.

Het in een ruimte op te stellen vermogen bestaat uit de volgende bijdragen;

- het transmissiewarmteverlies;
- het ventilatiewarmteverlies;
- eventuele toeslagen voor discontinu bedrijf en/of doorvoer of invoer van materialen met een afwijkende temperatuur.

De methode is geldig voor zowel de direct gestook-te verwarmingssystemen als de indirect gestookte verwarmingssystemen die in industriële ruimten zoal worden toegepast.

Voor (industriële) ruimten lager dan 5 meter die verwarmd worden met radiatoren wordt verwezen naar EN 12831.

De methode sluit aan bij de Europese norm NEN-EN 12831.

CONTENTS

SYMBOLS

Symbol	description	Unit
$\delta\theta_1$	vertical temperature gradient	[K/m]
$\delta\theta_2$	vertical temperature gradient	[K/m]
$\Delta\theta_1$	temperature rcorrection caused by temperature gradients	[K]
$\Delta\theta_2$	temperature rcorrection caused by temperature gradients	[K]
$\Delta\theta_v$	temperature reduction of ventilation air	[K]
Φ_{add}.	additional capacity for heating up	[W]
Φ_{pr}	heat gain or heat loss from incoming/outgoing products and/or development of heat by processes	[W]
Φ_t	design transmission heat loss for heated space	[W]
Φ_v	design ventilation heat loss for heated space	[W]
θ_a	temperature of an adjacent heated space within the building entity	[°C]
θ_e	external design temperature	[°C]
θ_i	indoor design temperature	[°C]
θ_{me}	annual mean external temperature	[°C]
θ_o	operative temperature	[°C]
θ_l	airtemperature	[°C]
θ_s	radiant temperature	[°C]
ψ_n	linear thermal transmittance of the linear thermal bridge (I)	[W/(m·K)]
a	factor dependent from the air velocity	[-]
A_k	area of building element (k)	[m^2]
f_{g2}	temperature reduction factor taking into account the difference between annual mean external temperature and external design temperature	[-]
f_{iak}	correction factor for the temperature difference between the neighbouring heated space and the external design temperature also taking into account temperature gradients	[-]
f_k	correction factor for temperature gradient	[-]
f_n	correction factor for temperature gradient	[-]
f_s	correction factor for radiant heating systems	[-]
G_w	correction factor taking into account the influence from ground water	[-]
h	height of the room or height of top of the specific surface	[m]
$H_{t,ia}$	transmission heat loss coefficient from heated space (i) to a neighbouring heated space heated at a significantly different temperature, i.e. an adjacent heated space within the building entity,	[W/K]
$H_{t,ib}$	transmission heat loss coefficient from heated space (i) to a neighbouring building	[W/K]
$H_{t,ie}$	transmission heat loss coefficient from heated space (i) to the exterior (e) through the building envelope	[W/K]
$H_{t,ig}$	steady state ground transmission heat loss coefficient from heated space (i) to the ground (g)	[W/K]
$H_{t,io}$	transmission heat loss coefficient from heated space (i) to an unheated space (u)	[W/K]
l_n	length of the linear thermal bridge (I) between the interior and the exterior	[m]
r	eduction factor for flow rates	[-]
$U_{e,k}$	equivalent thermal transmittance of building element (k)	[W/(m^2·K)]
U_{frame}	Thermal transmittance of window frame	[W/(m^2·K)]
U_{glass}	Thermal transmittance of glass	[W/(m^2·K)]
U_k	thermal transmittance of building element (k)	[W/(m^2·K)]
U_{window}	Thermal transmittance of a window (frame and glass)	[W/(m^2·K)]

TERMS AND DEFINITIONS

For the purposes of this European Standard, the following terms and definitions apply

Basement
A room is considered as a basement if more than 70% of its external wall area is in contact with the ground

Building element
Building component such as a wall, a floor

Building entity
Total volume of heated spaces served by one common heating system where the heat supplied to each single dwelling can be centrally controlled by the occupant

Design temperature difference
Difference between the internal design temperature and the external design temperature

design heat loss
quantity of heat per unit time leaving the building to the external environment under specified design conditions

Design heat loss coefficient
Design heat loss per unit of temperature difference

Design heat transfer
Heat transferred inside a building entity or a building

Design heat load
Required heat flow necessary to achieve the specified design conditions

Design transmission heat loss of the considered space
Heat loss to the exterior as a result of thermal conduction through the surrounding surfaces, as well as heat transfer between heated spaces inside a building

Design ventilation heat loss of the considered space
Heat loss to the exterior by ventilation and infiltration through the building envelope and the heat transferred by ventilation from one heated space to another heated space

External air temperature
Temperature of the air outside the building

External design temperature
External air temperature which is used for calculation of the design heat losses

Heated space
Space which is to be heated to the specified internal design temperature

Internal air temperature
Temperature of the air inside the building

Internal design temperature
Operative temperature at the centre of the heated space (between 0,6 and 1,6 m height) used for calculation of the design heat losses

Annual mean external temperature
Mean value of the external temperature during the year

Operative temperature
Arithmetic average of the internal air temperature and the mean radiant temperature

Thermal zone
Part of the heated space with a given set-point temperature and with negligible spatial variations of the internal temperature

Unheated space
Space which is not part of the heated space

Ventilation system
System to provide specified air flow rates

Zone
Group of spaces having similar thermal characteristics

LITERATURE

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1. INTRODUCTION

Until 2003 there were no methods or standards for the calculation of the design heat loss for space with large enclosures and/or a room height that exceeds 5 metres. In the informative annex B of EN 12831 an inaccurate correction factor has been given. This publication provides a more detailed calculation method that looks like the EN 12831 but has some necessairy extensions. The method is suited for both continous operation and use with night setback or stoppage and/or the power needed for equalising the temperature of materials entering the building entity with a deferring temperature.

1.1 Scope

This publication specifies methods for calculating the design heat loss and the design heat load for high ceiling buildings (> 5m) and industrial buildings with large enclosures.

1.2 calculation procedure for a heated space

The steps of the calculation procedure for a heated space are as follows (see Figure 1):

a) determine the value of the external design temperature and the annual mean external temperature;

b) specify the status of each space (heated or unheated) and the values of the internal design temperature of each heated space;

c) determine the dimensional and thermal characteristics of all building elements for each heated and unheated space;

d) calculate the design transmission heat loss coefficient and multiply by the design temperature difference to obtain the design transmission heat loss of the heated space;

e) calculate the design ventilation heat loss coefficient and multiply by the design temperature difference to obtain the design ventilation heat loss of the heated space;

f) obtain the total design heat loss of the heated space by adding the design transmission heat loss and the design ventilation heat loss;

g) calculate the heating-up capacity of the heated space, i.e. additional power required to compensate for the effects of intermittent heating and materials of different temperatures entring the heated space;

h) obtain the total design heat load of the heated space by adding the total design heat loss and the heating-up capacity.

2 BASIC PRINCIPLES

2.1 internal design temperatures

Thermal comfort is not only influenced by the air temperature but also by the radiant tempearture.
In design heat loss calculations it is necessary to give a clear definition. In general the internal design temperature is an operative temperature.
The definition of the operative temperature:

$$\theta_o = a \cdot \theta_l + (1\text{-}a) \cdot \theta_s \qquad [°C] \qquad (2.1)$$

where: θ_o = operative temperature [°C]
θ_l = air temperature [°C]
θ_s = radiant temperature [°C]
a = factor dependent from the air velocity [-]

Specification of factor a:
a = 0,5 if the air velocity around the person is less than 0,2 m/s.
a = 0,75 if the air velocity around the person is between 0,2 m/s and 1 m/s.
In this publication the operatieve temperature is used as internal design temperature.
The internal design temperature has to be based on activity and insulation of the clothing according to the method as provided in annex A or to the guidelines of table 2.1.

Tabel 2.1 Guidelines for the internal design temperature θ_i [°C] and light working clothes (0,7 clo).

activity	internal design temperature θ_i (PMV = 0) [°C]	internal design temperature PMV = -0,5 [°C]*)
low activity; in general sedentary work eg, offices, laboratory (1,7 MET)	20	17
low activity; in general sedentary work with occasianally standing or walking (< 3,5 km/h) (2,2 MET)	18	15
moderate activity; light industry; mainly manual work (2,8 MET) or walking 3,5 - 5,5, km/h	15	12
high activity; heavy industry manual work or the carry of heavy loads (3,5 MET)	12	9
very high activity; heavy manual work or the carry of heavy loads (4 MET)	10	6

*) only for heating after a setback period; the internal design temperature is the temperature at PMV = 0.

Temperature stratification and correction of (comfort) temperature for calculation of ventilation losses.

The different priciples of heat transfer and the way there is dealt with in th heat loss calculation is shown in annex B. Table 2.2, based on annex B, gives the values for the temperature gradient and the temperature correction for heat loss caused by cold air entering the building entity.

The calculation of the heat loss caused by cold air entering the building entity is based on the mean tempearture in the building entity.

The heat loss of vertical walls and/or inclined walls has to be based on the mean temperature of that wall. In case of surfaces of differing materials (eg glass in a wall) the mean temperature at the height of that specific surface has to be calculated.

Tabel 2.2 Values of $\delta\theta_1$, $\delta\theta_2$ en $\Delta\theta_v$ at design conditions for heated space wtih height h[4].

heating systems for high spaces	$\delta\theta_1$ [K/m]	$\delta\theta_2$ [K/m]	$\Delta\theta_v$[5] [K]
radiator [6]	0,60	-1	0
heating panels; black tubes [3]	0,5	0	-2
IR open heater [3]	0,9	0	-2
water fed panels [3]	0,5	0	-1,5
floor heating	0,20	0	-1,5
warm air HT[1] air change [2]	1,3	-1	0
LT[1] air change [2]	1,1	-1	0

1) HT = θ_{in} - $\theta_{space} \geq 30$ K
   LT = θ_{in} - $\theta_{space} < 30$ K
2) Number of air changes as given in table 2.3. Reduction factor r gives the influence influence of the air exchange rates on the temprature gradient (see figure 2.2)
3) This is an averidge value; above the radiating panels the temperature gradient is much higher than below it; bij de IR open heaters 1,5 K/m above open heaters and 1 K/m above the panels
4) This is the height till the roof surface; additional height for skylights and sawtooth roofs has not to be taken into account.
5) $\Delta\theta$v depends on the air flow rates. Pre heating of the ventilation air is assumed when large amounts of air are needed.
6) Not to be used in spaces higher than 5 m.

Table 2.3 Relation between the number of air exchanges and the content of the room

Volume [m3]	1000	2000	3000	5000	7000	9.000	12.000
number of air changes [-]	6	5	4	3	2,5	2	1,5

remark: each 300 m^2 requires a destratification fan.

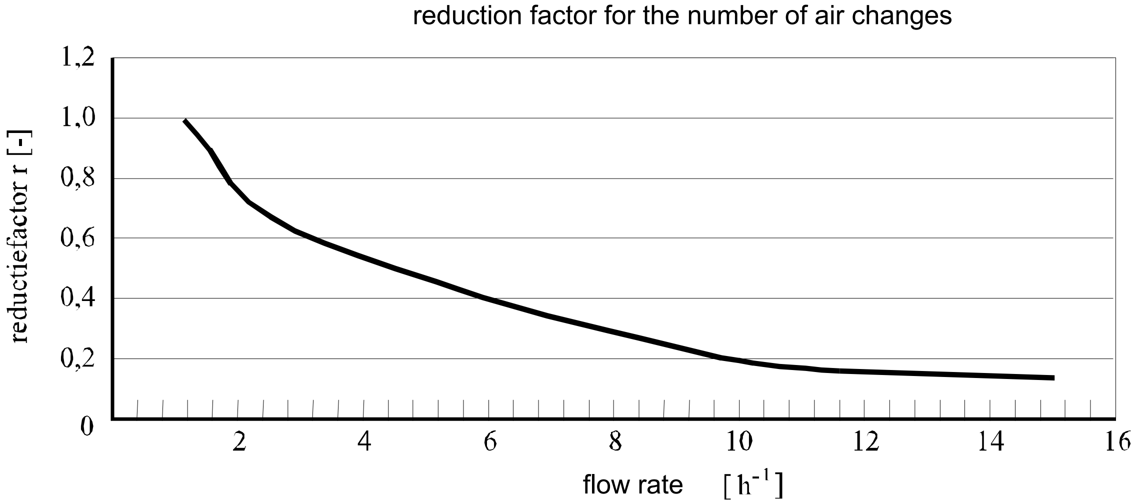


Fig. 2.2 Reduction factor r for the influence influence of the air flow rates on the temprature gradient.

Calculation of $\Delta\theta_1$ and $\Delta\theta_{a1}$

Specially in case of air heating the temperature gradient depends strongly on the air flow rates. Also in radiant heating systems the temperature gradient can be reduced by increasing the air flow rate. Table 2.2. gives the values for heating systems without destratification fans and warm air heating with a flow rate equally to 1. For higher flow rates the reduction factor *r* is given in figure 2.2

The values $\Delta\theta_1$ resp. $\Delta\theta_{a1}$ are calculated as follows:

$$\Delta\theta_1 = \Delta\theta_{a1} = r \cdot \delta\theta_1 \cdot (h - 1) \quad \text{[K]} \qquad (2.2)$$

where: *r* = reduction factor for flow rates as given in figure 2.2 [-]
$\delta\theta_1$ = vertical temperature gradient according to table 2.2 [K/m]
h = height of the room or height of top of the specific surface [m]

In case of a high induction air heating the air flow rate is set equally to 15.

Calculation of $\Delta\theta_2$ and $\Delta\theta_{a2}$

The temperature correction of $\Delta\theta_2$ and. $\Delta\theta_{a2}$ is calculated as follows:

$$\Delta\theta_2 = \delta\theta_2 \cdot (1 - h) \quad \text{in case the bottom of the area is less than 1 m above the floor} \qquad (2.3a)$$

or

$$\Delta\theta_2 = r \cdot \delta\theta_1 \cdot (h - 1) \quad \text{in all other cases} \qquad (2.3b)$$

where: r = reduction factor for flow rates as given in figure 2.2 [-]
$\delta\theta_1$ = vertical temperature gradient according to table 2.2 [K/m]
$\delta\theta_2$ = temperature correction according to table 2.2 [K/m]
h = height of the room or height of top of the specific surface [m]

2.2 Design outdoor temperature

The design outdoor temperature has to be calculated according to EN-ISO 15927-5 [3].

2.3 Surfaces and contents

Dimensions can be used according to EN-ISO 13789 [10]. In the design heat loss calculation as presented in the publication the internal dimensions are used.

2.4 Thermal resistance an d thermal transmittance

The thermal resistance R of internal and external surfaces is calculated according to EN-ISO 6946.
The thermal transmittance should be calculated according to:
- EN ISO 6946 [11] for opaque elements;
- EN ISO 10077-1 [12] for doors and windows;
- table 2.4 for windows;

Tabel 2.4 U-values for windows (frame and glass) for window surfaces of less than 5 m^2.
Interpolation of values is allowed.

U_{window} [W/($m^2 \cdot$K)]	Frame, met U_{frame} [W/($m^2 \cdot$K)]												
	1,0	1,4	1,8	2,0	2,4 1)	2,6	2,8	3,0	3,2	3,4	3,6	3,8 2)	7,0 3)
with glazing:													
single glazed, U_{glass} = 5,8 W/($m^2 \cdot$K)	4,8	4,9	5,0	5,0	5,1	5,2	5,2	5,2	5,3	5,3	5,4	5,4	6,2
multiple layer glazed, U_{glass} [W/($m^2 \cdot$K)]:													
3,3	2,9	3,0	3,1	3,1	3,2	3,3	3,4	3,4	3,4	3,5	3,5	3,6	4,6
3,2	2,9	2,9	3,0	3,1	3,1	3,2	3,3	3,3	3,4	3,4	3,5	3,5	4,5
3,0	2,7	2,8	2,9	2,9	3,0	3,1	3,1	3,2	3,2	3,3	3,3	3,4	4,4
2,8	2,5	2,6	2,7	2,7	2,8	2,9	3,0	3,0	3,1	3,1	3,2	3,3	4,2
2,6	2,4	2,5	2,5	2,6	2,7	2,8	2,8	2,9	2,9	3,0	3,1	3,1	4,1
2,4	2,3	2,4	2,4	2,5	2,6	2,7	2,7	2,8	2,8	2,9	3,0	3,0	4,0
2,2	2,1	2,2	2,3	2,3	2,4	2,5	2,6	2,6	2,7	2,8	2,8	2,9	3,8
2,0	2,0	2,0	2,1	2,2	2,3	2,4	2,4	2,5	2,6	2,6	2,7	2,7	3,7
1,8	1,8	1,9	2,0	2,0	2,1	2,2	2,3	2,4	2,4	2,5	2,5	2,6	3,6
1,6	1,6	1,7	1,8	1,9	2,0	2,1	2,2	2,2	2,3	2,3	2,4	2,5	3,4
1,4	1,5	1,6	1,7	1,7	1,9	2,0	2,0	2,1	2,1	2,2	2,3	2,3	3,3
1,2	1,3	1,4	1,5	1,6	1,7	1,8	1,9	1,9	2,0	2,1	2,1	2,2	3,1
1,0	1,2	1,3	1,4	1,5	1,6	1,7	1,7	1,8	1,9	1,9	2,0	2,0	3,0
0,9	1,1	1,2	1,3	1,4	1,5	1,6	1,7	1,7	1,8	1,9	1,9	2,0	2,9
0,7	0,9	1,1	1,2	1,2	1,4	1,5	1,5	1,6	1,7	1,7	1,8	1,8	2,8
0,5	0,8	0,9	1,0	1,1	1,2	1,3	1,4	1,5	1,5	1,6	1,6	1,7	2,7

where: U_{glass} = the thermal transmittance of the glass in W/($m^2 \cdot$K);
U_{frame} = the thermal transmittance of the frame in W/($m^2 \cdot$K).
U_{window} = the thermal transmittance of the frame with the specified glass; given in gray color in the table.

1) frame of wood or synthetic building materials: U_{frame} = 2,4 W/($m^2 \cdot$K).
2) metal frame without thermal bridges U_{frame} = 3,8 W/($m^2 \cdot$K).
3) metal frame with thermal bridges U_{frame} = 7,0 W/($m^2 \cdot$K)

3. TOTAL DESIGN HEAT LOSS FOR A HEATED SPACE

3.1 General

The total design heat loss for a heated space consists of:

- design transmission heat loss for heated space Φ_t ;
- design ventilation heat loss for heated space Φ_V;
- additional capacity for heating up Φ_{add}.

Remark:
The ventilation heat loss is the capacity needed for heating up air with a temperature that differs from the room temperature.

The ventilation heat loss is defined by infiltration (through cracks) and ventilation

The capacity needed in a room consists of:

$$\Phi_{tot} = \Phi_t + \Phi_V + \Phi_{add} + \Phi_{pr} \qquad \text{[W]} \qquad (3.1)$$

where: Φ_{pr} = heat gain or loss from incoming/outgoing products and development of heat by processes according to 3.5 [W]

3.2 Design transmission heat loss

3.2.1 General

The design transmission heat loss for a heated space (i) Φ_t, is calculated as follows

$$\Phi_t = (H_{t,ie} + H_{t,ia} + H_{t,io} + H_{t,ib} + H_{t,ig}) \cdot (\theta_i - \theta_e) \qquad \text{[W]} \qquad (3.2)$$

where: $H_{t,ie}$ = transmission heat loss coefficient from heated space (i) to the exterior (e) through the building envelope, according to 3.2.2 [W/K]

$H_{t,ia}$ = transmission heat loss coefficient from heated space (i) to a neighbouring heated space heated at a significantly different temperature, i.e. an adjacent heated space within the building entity, according to 3.2.3 [W/K]

$H_{t,io}$ = transmission heat loss coefficient from heated space (i) to an unheated space (u) according to 3.2.4 [W/K]

$H_{t,ib}$ = transmission heat loss coefficient from heated space (i) to a neighbouring building, according to 3.2.5 [W/K]

$H_{t,ig}$ = steady state ground transmission heat loss coefficient from heated space (i) to the ground (g), according to 3.2.6 [W/K]

θ_i = internal design temperature according to 2.1 [°C]

θ_e = external design temperature according to 2.2[°C]

Figure 3.1 shows the different heat losses.

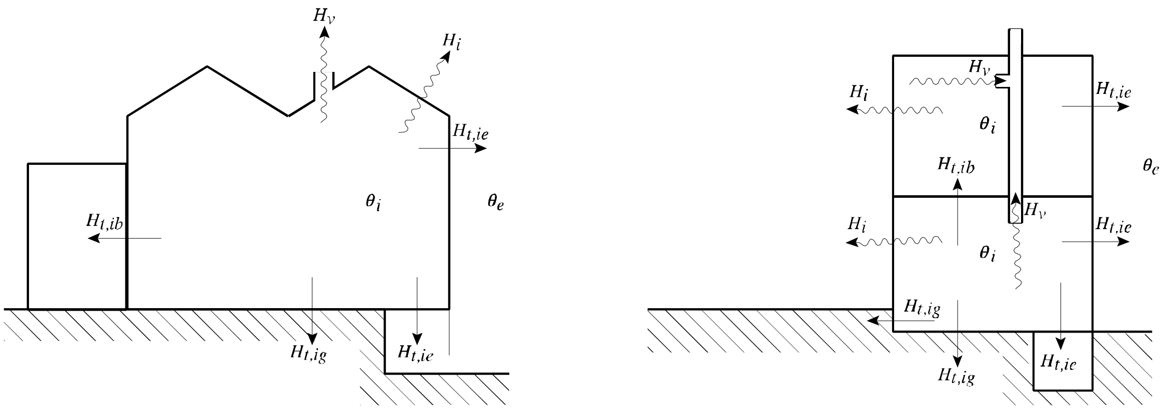


Figure 3.1 Illustration of the different heat losses.

3.2.2 Heat losses directly to the exterior - heat loss coefficient $H_{t,ie}$

The design transmission heat loss coefficient from a heated space (i) to the exterior (e), $H_{t,ie}$ is for all building elements and linear thermal bridges separating the heated space from the external environment, such as walls, floor, ceiling, doors, windows. $H_{t,ie}$ is calculated as follows:

- simplified method: $H_{t,ie} = \Sigma_k(A_k \cdot f_k \cdot (U_k + 0{,}1))$ [W/K] (3.3a)
- the exact method: $H_{t,ie} = \Sigma_k(A_k \cdot f_k \cdot U_k) + \Sigma_n(l_n \cdot \psi_n \cdot f_n)$ [W/K] (3.3b)

where:
- A_k = area of building element (k), according to 2.3 [m^2]
- U_k = thermal transmittance of building element (k), according to 2.4 [$W/(m^2 \cdot K)$]
- f_k, f_n = correction factor for temperature gradients [-]
- l_n = length of the linear thermal bridge (I) between the interior and the exterior [m]
- ψ_n = linear thermal transmittance of the linear thermal bridge (I) shall be determined in one of the following two ways: for a rough assessment, use of tabulated values provided in EN ISO 14683 [1] or calculated according to EN ISO 10211-2 [13]. [$W/(m \cdot K)$]

Correction factor f_k, is calculated as follows:

$f_k = 0$ area of the floor heated by floor heating [-]

$$f_k = \frac{(\theta_i + 0{,}5(\Delta\theta_1 + \Delta\theta_2)) - \theta_e}{\theta_i - \theta_e} \quad \text{in case of exteriour walls} \quad [-] \qquad (3.4)$$

$$f_k = \frac{(\theta_i + \Delta\theta_2) - \theta_e}{\theta_i - \theta_e} \quad \text{in case of floor above the open air} \quad [-] \qquad (3.5)$$

$$f_k = \frac{(\theta_i + \Delta\theta_1) - \theta_e}{\theta_i - \theta_e} \quad \text{in case of flat roofs} \qquad (3.6)$$

where:
- θ_i = indoor designtemperature according to 2.1 [°C]
- θ_e = outdoor design temperature according to 2.2 [°C]
- $\Delta\theta_1$ = temperature correction caused by temperature gradients according to formula 2.2 [K]
- $\Delta\theta_2$ = temperature correction caused by temperature gradients according to formula 2.3 [K]

3.2.3 Heat losses to an adjacent heated space - heat loss coefficient $H_{t,ia}$

The design transmission heat loss coefficient from a heated space (i) to an adjacent heated space within the building entity $H_{t,ia}$ is calculated as follows:

$H_{t,ia} = \Sigma_k (A_k \cdot U_k \cdot f_{iak})$ [W/K] (3.7)

where:
- A_k = area of building element (k), according to 2.3 [m^2]
- U_k = thermal transmittance of building element (k), according to 2.4 [$W/(m^2 \cdot K)$]
- f_{iak} = correction factor for the temperature difference between the neighbouring heated space and the external design temperature also taking into account temperature gradients [-]

where:

$f_{iak} = 0$ area of the room heated by floor heating [-]

$$f_{iak} = \frac{(\theta_i + 0{,}5(\Delta\theta_1 + \Delta\theta_2)) - \theta_a}{\theta_i - \theta_e} \quad \text{for walls} \quad [-] \qquad (3.8)$$

$$f_{iak} = \frac{(\theta_i + \Delta\theta_2) - (\theta_a + \Delta\theta_{a1})}{\theta_i - \theta_e} \quad \text{for floors} \quad [-] \qquad (3.9)$$

$$f_{iak} = \frac{(\theta_i + \Delta\theta_1) - (\theta_a + \Delta\theta_{a2})}{\theta_i - \theta_e} \text{ for ceilings} \quad [-] \quad (3.10)$$

where:
θ_i = indoor designtemperature according to 2.1 [°C]
θ_e = outdoor design temperature according to 2.2 [°C]
θ_a = temperature of an adjacent heated space within the building entity [°C]
$\Delta\theta_1$ = temperature correction due to temperature gradients following formula 2.2 [K]
$\Delta\theta_{a1}$ = temperature correction of adjacent heated space due to temperature gradients following formula 2.2 [K]
$\Delta\theta_2$ = temperature correction due to temperature gradients following formula 2.3 [K]
$\Delta\theta_{a2}$ = temperature correction of adjacent heated space due to temperature gradients following formula 2.3a [K]

3.2.4 Heat losses through unheated space - heat loss coefficient $H_{t,io}$

The design transmission heat loss coefficient through an unheated space (i) $H_{t,io}$ is calculated as follows:

$$H_{t,io} = \Sigma_k (A_k \cdot U_k \cdot f_k) \quad [W/K] \quad (3.11)$$

where:
A_k = area of building element (k), according to 2.3 [m²]
U_k = thermal transmittance of building element (k), according to 2.4 [W/(m²·K)]
f_k = correction factor for the temperature difference between the neighbouring unheated space and the external design temperature [-]

Correction factor f_k is calculated following one of the two methods:
- according to table 3.1;
- formula 3.12, 3.13 of 3.14 after calculating the temperature θ_a with a heat balance (Annex F).

f_k = 0 area of the floor heated by floor heating [-]

$$f_k = \frac{(\theta_i + 0{,}5(\Delta\theta_1 + \Delta\theta_2)) - \theta_a}{\theta_i - \theta_e} \text{ for walls} \quad [-] \quad (3.12)$$

$$f_k = \frac{(\theta_i + \Delta\theta_2) - \theta_a}{\theta_i - \theta_e} \text{ for floors} \quad [-] \quad (3.13)$$

$$f_k = \frac{(\theta_i + \Delta\theta_1) - \theta_a}{\theta_i - \theta_e} \text{ for ceilings} \quad [-] \quad (3.14)$$

where:
θ_i = indoor designtemperature according to 2.1 [°C]
θ_e = outdoor design temperature according to 2.2 [°C]
θ_a = temperature of an adjacent heated space within the building entity [°C]
$\Delta\theta_1$ = temperature correction due to temperature gradients following formula 2.2 [K]
$\Delta\theta_2$ = temperature correction due to temperature gradients following formula 2.3 [K]

Table 3.1 Correction factor f_k for the heat loss of unheated spaces with an unknown temperature

	f_k
A built-in area with a low air exchange rate (n < 0,5) and no exteriour walls	0
Unheated space ventilated with outdoor air (n > 0,5)	1,0
Crawling space with a low air exchange rate (n < 0,5) Crawling space with a high air exchange rate. ($n \geq$ 0,5)	0,5 1,0
Space under the roof with a not insulated floor: well insulated roof ($R_c \geq$ 2,5) non isoluted or poorly insulated roof (R_c < 2,5)	 0,2 0,5

where: R_c = thermal transmittance of the roof [$m^2 \cdot K/W$]
n = air exchange rate [-]

3.2.5 Heat losses through an neighbouring space - heat loss coefficient $H_{t,ib}$

The design transmission heat loss coefficient from a heated space (i) to a neighbouring building entity $H_{t,ib}$ is calculated as follows:

$$H_{t,ib} = \Sigma_k (A_k \cdot U_k \cdot f_b) \quad [W/K] \qquad (3.15)$$

where: A_k = area of building element (k), according to 2.3 [m^2]
U_k = thermal transmittance of building element (k), according to 2.4 [$W/(m^2 \cdot K)$]
f_b = correction factor for the temperature difference between the neighbouring space and the external design temperature [-]

Correction factor f_b is calculated as follows:
f_b = 0 area of the floor heated by floor heating [-]

$$f_b = \frac{(\theta_i + 0{,}5(\Delta\theta_1 + \Delta\theta_2)) - \theta_b}{\theta_i - \theta_e} \text{ for walls} \quad [-] \qquad (3.16)$$

$$f_b = \frac{(\theta_i + \Delta\theta_2) - \theta_b}{\theta_i - \theta_e} \text{ for floors} \quad [-] \qquad (3.17)$$

$$f_b = \frac{(\theta_i + \Delta\theta_1) - \theta_b}{\theta_i - \theta_e} \text{ for ceilings} \quad [-] \qquad (3.18)$$

where: θ_i = indoor design temperature according to 2.1 [°C]
θ_e = outdoor design temperature according to 2.2 [°C]
θ_b = temperature of the neighbouring building entity [°C]
$\Delta\theta_1$ = temperature correction due to temperature gradients following formula 2.2 [K]
$\Delta\theta_2$ = temperature correction due to temperature gradients following formula 2.3 [K]

Temperature θ_b of the neighbouring building entity is calculated following two methods:
- θ_b is calculated with a heat balance calculation (see annex F.2);
- default value: θ_b = 5 °C.

3.2.6 Heat losses through the ground - heat loss coefficient $H_{t,ig}$

The rate of heat loss through floors and basement walls, directly or indirectly in contact with the ground, depends on several factors. These include the area and exposed perimeter of the floor slab, the depth of a basement floor beneath ground level, and the thermal properties of the ground.

The design steady state ground transmission heat loss coefficient, $H_{t,ig}$ from heated space (i) to the ground (g) is calculated as follows:

$$H_{t,ig} = 1{,}45 \cdot f_s \cdot G_w \cdot \Sigma_k (f_{g2} \cdot A_k \cdot U_{e,k}) \quad [W/K] \qquad (3.19)$$

where: A_k = area of building element (k) in contact with the ground according to 2.3 [m^2]

$U_{e,k}$ = equivalent thermal transmittance of building element (k) determined according to the wall or floor-typology (see Figures 3.3 or 3.4) [W/(m²·K)]
G_w = correction factor taking into account the influence from ground water [-]
f_{g2} = temperature reduction factor taking into account the difference between annual mean external temperature and external design temperature [-]
f_s = correction factor for radiant heating systems [-]

Correction factor f_s is given by:
f_s = 1,30 in case of IR open heaters or black tube systems [-]
f_s = 1,15 in case indirectly heated systems (e.g. water fed panels) [-]
f_s = 1 all other heating systems [-]

The correction factor taking into account the influence from ground water G_w:
G_w = 1 If the distance between the assumed water table and the basement floor level (floor slab) is more than 1 m [-]
G_w = 3 If the distance between the assumed water table and the basement floor level (floor slab) is (nearly) zero [-]
G_w = 1,15 all other cases. [-]

Correction factor f_{g2} is given by:
f_{g2} = 0 area of the floor heated by floor heating [-]

$$f_{g2} = \frac{(\theta_i + \Delta\theta_2) - \theta_{me}}{\theta_i - \theta_e} \text{ for unheated floors} \quad [-] \quad (3.20)$$

$$f_{g2} = \frac{(\theta_i + 0{,}5(\Delta\theta_1 + \Delta\theta_2)) - \theta_{me}}{\theta_i - \theta_e} \text{ for walls} \quad [-] \quad (3.21)$$

where: θ_i = indoor design temperature according to 2.1 [°C]
θ_e = outdoor design temperature according to 2.2 [°C]
θ_b = temperature of the neighbouring building entity [°C]
$\Delta\theta_1$ = temperature correction due to temperature gradients following formula 2.2 [K]
$\Delta\theta_2$ = temperature correction due to temperature gradients following formula 2.3 [K]
θ_{me} = annual mean external temperature [°C]

Floors

The equivalent thermal transmittance of building element $U_{e,k}$ of floors directly in contact with the ground shall be determined for each room in one of the following three ways:

- $U_{e,k}$ = 0,30 if the thermal resistance of the floor R_c = 2,5 m²·K/W;
- $U_{e,k}$ = 0,18 if the thermal resistance of the floor R_c = 3,5 m²·K/W.
- In all other cases the following procedure has to be followed:
  - calculate the area of the considered floor slab. For a whole building, A_q is the total ground floor area.
  - For part of a building, e.g. a building entity in a row of houses, A_g is the ground floor area under consideration;
  - perimeter of the considered floor slab in metres (m). For a whole building, P is the total perimeter of the building. For part of a building, e.g. a building entity in a row of houses, P includes only the length of external walls separating the heated space under consideration from the external environment.;
  - The characteristic parameter, *B'* ; is given by $B' = 2A_g/P$ (see figure 3.3);
  - use the applicable part of figure 3.4.

Interpolation of values is allowed.

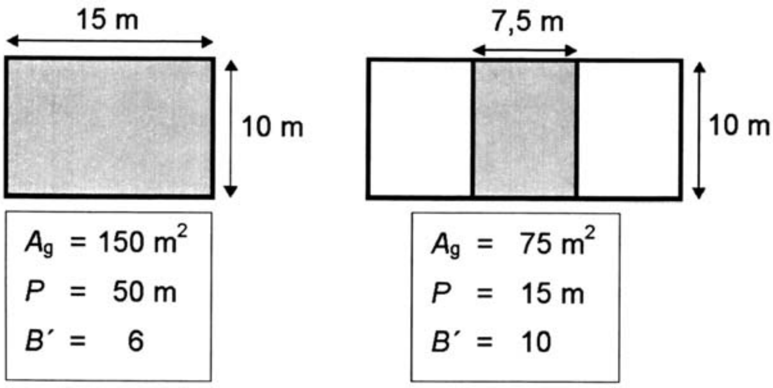
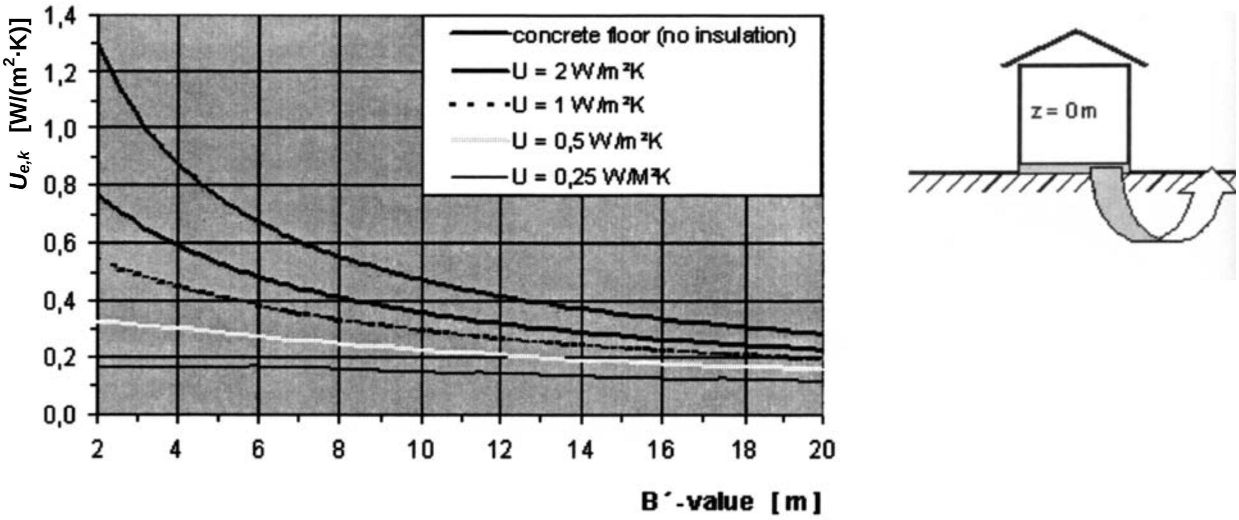
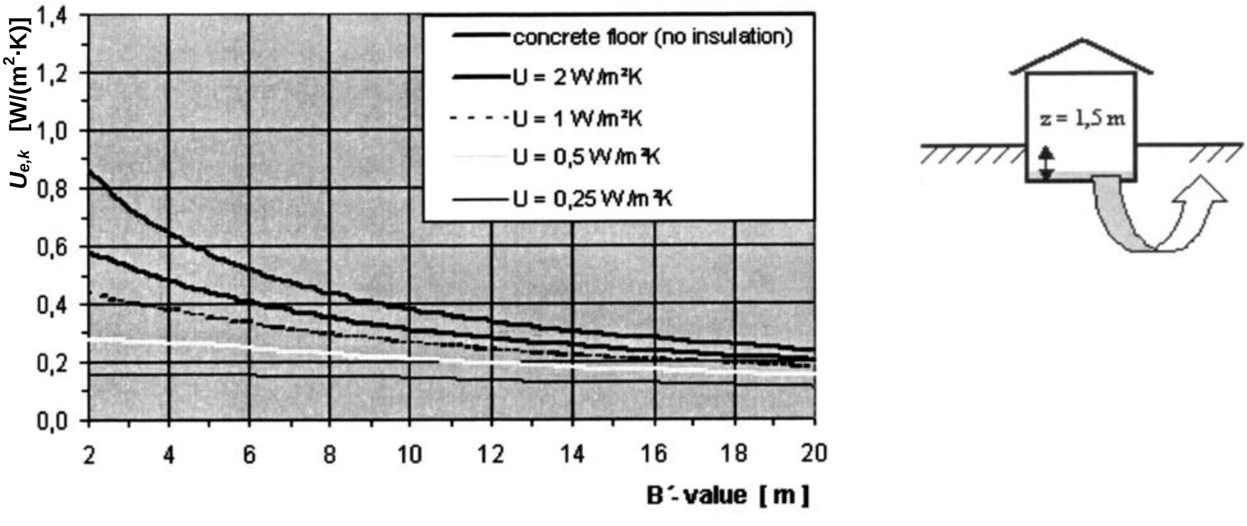


Fig. 3.3 Characteristic parameter, *B'.*

The equivalent thermal transmittance $U_{e,k}$ of walls directly in contact with the ground depends on the U-value and the level of the floor slab and is given in figure 3.5.





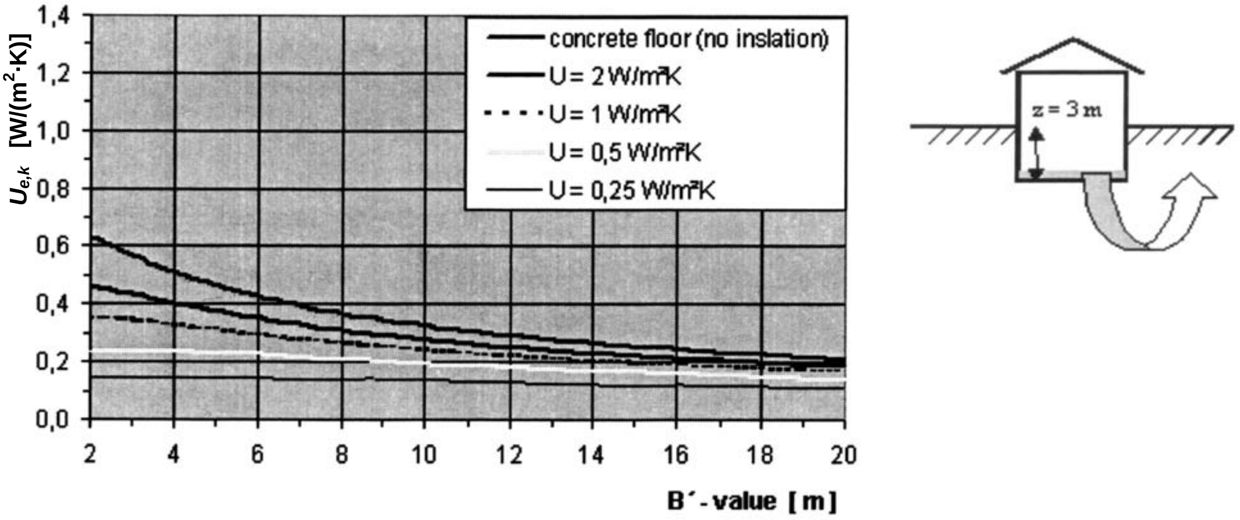


Figure 3.4 $U_{e,k}$ for floor element of a heated basement, as function of the thermal transmittance of the floor, the depth z beneath ground level and B'-value

Walls

The equivalent thermal transmittance $U_{e,k}$ of wall directly in contact with the ground depends on the U-value and the depth *z* beneath ground level and is given in figure 3.5.

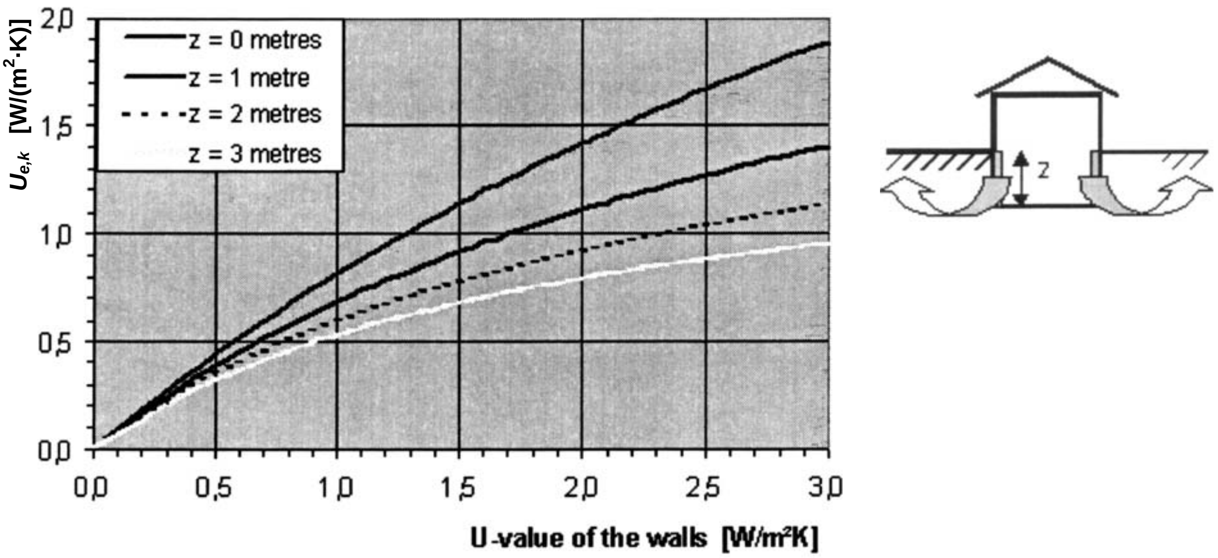


Figure 3.5 $U_{e,k}$ for wall element of a heated basement, as function of the thermal transmittance of the walls and the depth z beneath ground level

3.3 Design ventilation heat loss

The heat loss of outdoor air entering the building entity consists of:

- infiltration;
- ventilation.

The ventilation heat loss depends on:

- ventilation demands;
- type of ventilation system.

3.3.1 Infiltration heat loss Φ_i

Infiltration is outdoor air entering the building in other ways than by ventilation facilities (mechanical supply or grids).

The infiltration heat loss Φ_i is calculated as follows:

$$\Phi_i = H_i \cdot (\theta_i - \theta_e) \qquad [W] \qquad (3.22)$$

where: H_i = infiltration heat loss coefficient [W/K]
θ_i = indoor design temperature according to 2.1 [°C]
θ_e = outdoor design temperature according to 2.2 [°C]

The infiltration heat loss coefficient H_i is calculated as follows:

$$H_i = q_i \cdot \rho \cdot c_p \cdot f_v \qquad [W/K] \qquad (3.23)$$

where: q_i = air flow rate caused by infiltration (see table 3.2) [m^3/s]
ρ = density of air at θ_i [kg/m^3]
c_p = specific heat capacity of air [J/(kg·K)]
f_v = correction factor for the influence of radiant heating and/or temperature gradients [-]

Correction factor f_v is calculated as follows:

$$f_v = \frac{\theta_i + \Delta\theta_v + 0{,}5(\Delta\theta_1 + \Delta\theta_2) - \theta_e}{\theta_i - \theta_e} \qquad (3.24)$$

where: θ_i = indoor design temperature according to 2.1 [°C]
θ_e = outdoor design temperature according to 2.2 [°C]
θ_b = temperature of the neighbouring building entity [°C]
$\Delta\theta_1$ = temperature correction due to temperature gradients following formula 2.2 [K]
$\Delta\theta_2$ = temperature correction due to temperature gradients following formula 2.3a [K]
$\Delta\theta_v$ = temperature correction for influences of radiant heating systems as given in table 2.2 [K]

The infiltration air flow rate q_i is determined following one of the two ways:
- guidelines as given in table 3.2;
- calculation by the method as given in annex C (surface of cracks and openings has to be known).

Table 3.2 Guidelines for infiltration.

Specification	Air exchange rate n_i [h^{-1}]*)
Old, non insulated not air tight buildings	0,5
Modern insulated building	
boxshaped with contents ≥ 10.000 m^3 without skylight and/or fire/smoke protecting devices	0,1
boxshaped with contents < 10.000 m^3 without skylight and/or fire/smoke protecting devices	0,2
boxshaped with contents ≥ 10.000 m^3 with skylight and/or fire/smoke protecting devices	0,2
boxshaped with contents < 10.000 m^3 with skylight and/or fire/smoke protecting devices	0,3
other building shapes	0,4

*) *In case of (closed) doors positioned in opposite walls, add 0,2 to the air exchange rate.*

remark: If doors are opened for a longer period (eg cargo docks) wihout devices to reduce infiltration losses there has to be calculated with much higher exchange rates.

The infiltration air flow rate q_i is determined as follows:

$$q_i = n_i \; V / 3600 \qquad [m^3/s] \qquad (3.25)$$

where: q_i = air flow rate caused by infiltration [m^3/s]
n_i = air exchange rate [h^{-1}]
V = volume of the building entity [m^3]

3.3.2 Ventilation heat loss Φ_{vent}

Ventilation is the air supplied by mechanical supply or grids other than used in local extraction systems.

The ventilation heat loss Φ_{vent} is calculated as follows:

$$\Phi_{vent} = H_v \cdot (\theta_i - \theta_e) \quad [W] \qquad (3.26)$$

where:

H_v	= ventiltation heat loss coefficient	[W/K]
θ_i	= indoor design temperature according to 2.1	[°C]
θ_e	= outdoor design temperature according to 2.2	[°C]

The ventiltation heat loss coefficient H_v is calculated as follows:

$$H_v = q_v \cdot \rho \cdot c_p \cdot f_v \quad [W/K] \qquad (3.27)$$

where:

q_v	= air flow rate caused by ventilation	[m^3/s]
ρ	= density of air at θ_i	[kg/m^3]
c_p	= specific heat capacity of air	[J/(kg·K)]
f_v	= correction factor for the influence of radiant heating and temperature gradients	[-]

The ventilation air flow rate q_v is determined following one of the three ways:
- demand following the number of persons (at least 35 m^3/h per person);
- demands to prevent health damage;
- the amount of air needed for the processes;

Temperature correction factor f_v is given below:

f_v = 0 if the supply temperature is higher than the indoor design tempearture

$$f_v = \frac{\theta_i + \Delta\theta_v + 0{,}5(\Delta\theta_1 + \Delta\theta_2) - \theta_e}{\theta_i - \theta_e}$$ Systems without heat recovery or pre-heating of ventilation air (3.28)

$$f_v = \frac{\theta_i + \Delta\theta_v + 0{,}5(\Delta\theta_1 + \Delta\theta_2) - \theta_t}{\theta_i - \theta_e}$$ Systems with heat recovery or pre-heating of ventilation air (3.29)

where:

θ_i	= indoor design temperature according to 2.1	[°C]
θ_e	= outdoor design temperature according to 2.2	[°C]
θ_t	= temperature supplied to the room (see annex D)	[°C]
$\Delta\theta_1$	= temperature correction due to temperature gradients following formula 2.2	[K]
$\Delta\theta_2$	= temperature correction due to temperature gradients following formula 2.3a	[K]
$\Delta\theta_v$	= temperature correction for influences of radiant heating systems as given in table 2.2	[K]

3.3.3 Heat loss caused by outdoor air entering the building

The heat loss caused by outdoor air entering the building that has to be taken into account depends on the ventilation system: mechanical or non mechanical suppply.

Non mechanical air supply:

The ventialtion heat loss Φ_v to be taken into account is the maximum value of:
- the infiltration heat loss according to 3.3.1;
- the ventilation heat loss according to 3.3.2.

$$\Phi_v = \Phi_i \text{ if } \Phi_i > \Phi_{vent} \qquad (3.30)$$
$$\Phi_v = \Phi_{vent} \text{ if } \Phi_{vent} \geq \Phi_i \qquad (3.31)$$

Mechanical air supply:
The ventialtion heat loss Φ_V to be taken into account is the total of:
- the infiltration heat loss according to 3.3.1;
- the ventilation heat loss according to 3.3.2.

$$\Phi_V = \Phi_i + \Phi_{vent} \tag{3.32}$$

3.4 Additional capacity Φ_{add}

In addition to the stationary heat losses it can be necessary to install more capacity to compensate additional heat losses. Examples are:
– (quickly) heating-up after a period of setback or weekend closure (see 3.4.1);
– additional capacity needed for (not continuously) entered materials (eg semifinished products or raw materials with outdoor temperatures) (see 3.4.2).

3.4.1 Heating-up

Night setback is not always possible or advisable. In general a period of setback is not advisible when:
- the daily operating time is at least 18 hours;
- processes have a high dimensional accuracy;
- there is storage with a high mass in the building entity;
- condensation on products is not allowed.

In case there is no setback: $\Phi_{op} = 0$.
If there is setback Φ_{op} depends on:
– used control: - self learning control (see 3.4.1.1)
  - other controls (see 3.4.1.2)
– temperature drop during setback;
– alowed heating-up time;
– internal mass (products en machinery).

3.4.1.1 Self learing contol

The control starts the heating-up and calculates the needed time based on the outdoor temperature and the temerature caracteristic of the byuilding.
In this case heating-up capacity is not needed: $\Phi_{op} = 0$.

remark:
Self learning conrols need some days to adapt to new circumstances (eg. suddenly extreme temperatures or lack of internal loads). Beacuase of this it is possible that in some days the system will react not correctly.

3.4.1.2 Other controls

The capacity needed for heating-up can be reduced by allowing the heating-up a few degrees during the working hours. This means that during the working hours the PMV-value has to rize from -0,5 to 0. Before the wordking hours start there must be heated-up until at least PMV = -0,5. In practice this means that the temperature at the beginning of the working hour can be 3 degrees lower than the optimal temperature.
In large enclosures most of the thermal mass is situated in the floor (there is only a small influeence of the walls). Beacaus of this the specific heating-up capacity has been calculated for each square metre floor surface.
The heating-up capacity is calculated as follows:

$$\Phi_{op} = P \cdot (A_{fl} + A_{mass}) \quad \text{[W]} \tag{3.33}$$

where: P = specific heating-up capacity according to annex E [W/m^2]
A_{fl} = floor area coording to 2.3 [m^2]
A_{mass} = equivalent floor area for internal mass [m^2]

The equivalent floor area for internal mass i calculated as follows:

$$A_{massa} = \frac{\sum_i (m_i \cdot c_i)}{1{,}2 \cdot 10^5} \quad \text{[m}^2\text{]} \tag{3.34}$$

where: m_i = mass of machines, products, etc. [kg]
c_i = specific heat capacity of machines, products, etc. [J/(kg·K)]

3.4.1.3 Heating-up capacity Φ_o

It is assumed that during a period of setback the ventilation system has been switched off or has been operated on a lower capcity. Because of this a part of the capacity for heating the ventilation air is available for heating-up.
Because of this the heating up capacity Φ_o is calculated as follows:

– $\Phi_o = \Phi_{op}$ for all systems with a natural supply of ventilation

– $\Phi_o = \Phi_{op} - a \cdot H_v \cdot (\theta_i - \theta_e)$ for all systems with a mechanical supply of ventilation (3.35)
with $\Phi_o = 0$ if the calculated value $\Phi_o < 0$

where:
- H_v = ventiltation heat loss coefficient [W/K]
- θ_i = indoor design temperature according to 2.1 [°C]
- θ_e = outdoor design temperature according to 2.2 [°C]
- a = 1 in case of heating-up without mechanical ventilation [-]
- a = 0 in case of heating-up with mechanical ventilation [-]

3.4.2 Supplementary capacity for non continuous incoming cold materials

For heasting-up materials with a temperature less than the heated space that enters the heated space needs supplementary capacity. The time t needed for heating-up strongly depends on the compactness of the object. For sheet materials the time is several hours and for massive blocks (steel/concrete) the total time for heating-up is several days. The supplementary capacity is calculated as follows:

$$\Phi_{extra} = \frac{m \cdot c \cdot (\theta_i - \theta_m)}{t} \quad [W] \tag{3.36}$$

where:
- m = mass of the incoming material [kg]
- c = specific heat capacity [J/(kg·K)]
- θ_i = indoor design temperature according to 2.1 [ºC]
- θ_m = temperature of the incoming material (often the outdoor design temperature) [ºC]
- t = heating-up time [s]

In general a time of 4 - 8 hours is sufficiently (14.400 - 28.800 seconds) for heating-up the supplied materials.

3.4.3 Accountable capacity Φ_{add}

The aAccountable capacity Φ_{toe} is calculated as follows:

$$\Phi_{add} = \Phi_o \text{ if } \Phi_o > \Phi_{extra} \tag{3.37}$$
$$\Phi_{add} = \Phi_{extra} \text{ if } \Phi_{extra} \geq \Phi_o \tag{3.38}$$

3.5 Heat loss/gain Φ_{pr} by transferring products and/or heat from continiuous processes

When calculating the heat gains or heat losses caused by transit of products with a different temperature and/or heat gains/losses from processes it is important to know whether the gains or losses are continuous or not.

Heat gains

If the heat gains are not continuous (also during the heating-up period) they are neglected:

$\boldsymbol{\Phi_{pr} = 0}$

Remark: These gains have no influence on the maximum heat loss. They only have influence on the energy use.

If the gains are continuous, they may be substracted from the design heat loss (Φ_{pr} is negative). In general it is difficult to determine these heat gains. The following cases are considered:
a) heat gains by warm/hot products transferring through the building entity;
b) heat development by processes;
c) heat gains from illumination.

Explanations

a) The developed heat depends on the surface temperature θ_{surf} and the surface A_w. In fact it acts as heating source (e.g. radiator). The heat gains can be estimated as follows:

$$\Phi_{pr} = -8 \cdot A_w \cdot (\theta_{surf} - \theta_i) \quad \text{[W]} \qquad (3.39)$$

b) The heat development in a building entity is, in general, caused by (electric) power for the production apparatus. A part of the power is added to the product and the other part is delevered to the space. Globally seen 75 % of the power is added to the space.

c) Heat gains from illumination are in general only smal contributions. It's recommended to neglect the gains Explanation**:** Replacing the illumination system by a more energy efficient system may not be the reason for a shortage of heating capacity.

Heat loss

Two different cases are considered: heat loss caused by the extraction of air and heat transfer to cold surfaces.

Heat loss caused by local extraction of air

Heat loss Φ_{pr} caused by local extraction of air:

$$\Phi_{pr} = 1200 \cdot q_{af} \cdot (\theta_i - \Delta\theta_v - \theta_t) \quad \text{[W]} \qquad (3.40)$$

where: q_{af} = amount of extracted air [m³/s]

θ_i = indoor design temperature according to 2.1 [°C]

$\Delta\theta_v$ = correction factor for lower air temperature when using radiant heating [°C]

θ_t = temperature of the suppied air (outdoor temperature or temperature after the heat recovery unit) [°C]

Heat loss to cold surfaces

If there is heat loss caused by the production of cold products or the transport of cold products through the building entity or cooled surfaces this has to be taken into account. In general the following formula can be used:

$$\Phi_{pr} = 8\, A_k \cdot (\theta_i - \theta_{opk}) \quad \text{[W]} \qquad (3.41)$$

where: A_k = cooled or cold surface [m^2]

θ_i = indoor design temperature according to 2.1 [°C]

θ_{opk} = mean temperature of the cooled/cold surface [°C]

4 Total capacity

In chapter 3 the capacity needed for a single space has been calculated. The total capacity of a number of rooms or a building entity not always equals the sum of the calculated values for each space. The total capacity wil be calculated for the following situations:

- total capacity of a building entity (see 4.1);
- contribution to a cooperative powerplant (see 4.1.2).

4.1 Total capacity of a building entity

Different cases that are considered:

- design value for a large decentrally heated enclosure (see 4.1.1);
- several adjacent spaces heated by a cooperative powerplant (see 4.1.2).

4.1.1 Design value for a large decentrally heated enclosure

The following cases are considered:

- systems without additional capacity for heating-up (see 4.1.1.1);
- systems with additional capacity for heating-up (see 4.1.1.2).

4.1.1.1 systems without additional capacity for heating-up

The total capacity Φ_{tot} to be supplied to the space is calculated as follows:

$$\Phi_{tot} = \Sigma\Phi_t + \Phi_v + \Phi_{add} + \Phi_{pr} + \Phi_{loss} \quad [W] \qquad (4.1)$$

where:

$\Sigma\Phi_t$	= totalized transmission heat loss	[W]
Φ_v	= totalized heat loss caused by cold air entering the space	[W]
Φ_{add}	= additional capacity according to chapter 3.4	[W]
Φ_{pr}	= heat gain or heat loss from continuous processes in the building entity according to chapter 3.5	[W]
Φ_{loss}	= heat loss of tubes to heating systems and/or the downward capacity of floor heating[1)]	[W]

4.1.1.2 systems with additional capacity for heating-up

The total capacity for the building entity Φ_{tot} is the maximum value of:

$$\Phi_{tot} = \Sigma\Phi_t + \Phi_{pr} + \Phi_o + \Phi_{loss} + \Phi_v^* \quad [W] \qquad (4.2)$$

or

$$\Phi_{tot} = \Sigma\Phi_t + \Phi_v + \Phi_{extra} + \Phi_{pr} + \Phi_{loss} \quad [W] \qquad (4.3)$$

where:

$\Sigma\Phi_t$	= totalized transmission heat loss	[W]
Φ_v	= totalized heat loss caused by cold air entering the space	[W]
Φ_v^*	= infiltration heat loss + ventilation that can't be shut off	[W]
Φ_o	= heating-up capacity	[W]
Φ_{extra}	= Supplementary capacity for non continuous incoming cold materials according to chapter 3.4.2	[W]
Φ_{pr}	= heat gain or heat loss from continuous processes in the building entity according to chapter 3.5	[W]
Φ_{loss}	= heat loss of tubes between boiler and heating systems (see annex I) and/or the downward capacity of floor heating[1)]	[W]

1) EN 1264 [9] gives as a default value 10% of the capacity delivered to the room.

4.1.2 Several adjacent spaces heated by a cooperative powerplant

When the spaces are heated by the same powerplant the contribution to the needed capacity of the powerplant Φ_{wb} is calculated as follows:

$$\Phi_{wb} = \Sigma\Phi_t + \Sigma\Phi_{pr} + \Sigma\Phi_o + \Sigma\Phi_{loss} - \Sigma H_{t,ib}\cdot(\theta_i - \theta_e) \quad [W] \qquad (4.4)$$

or

$$\Phi_{wb} = \Sigma\Phi_t + \Sigma\Phi_V + \Sigma\Phi_{extra} + \Sigma\Phi_{pr} + \Sigma\Phi_{loss} - \Sigma H_{t,ib}\cdot(\theta_i - \theta_e) \quad [W] \qquad (4.5)$$

where:

$\Sigma\Phi_t$	= totalized transmission heat loss	[W]
$\Sigma\Phi_V$	= totalized heat loss caused by cold air entering the space	[W]
$\Sigma\Phi_o$	= totalize heating-up capacity	[W]
$\Sigma\Phi_{extra}$	= totalize supplementary capacity for non continuous incoming cold materials according to chapter 3.4.2	[W]
$\Sigma\Phi_{pr}$	= totalized heat gain or heat loss from continuous processes in the building entity according to chapter 3.5	[W]
θ_i	= indoor design temperature according to 2.1	[°C]
θ_e	= outdoor design temperature according to 2.2	[°C]
$\Sigma H_{t,ib}$	= specific heat loss to adjacent buildings	[W/K]
Φ_{loss}	= heat loss of tubes between boilers and the heating systems (see annex I) and/or the downward capacity of floor heating[1)]	[W]

1) EN 1264 [17] gives as a default value 10% of the capacity delivered to the room.

ANNEX A DETERMINATION OF THE INDOOR DESIGN TEMPERATURE

A1 General

Method for the determination of the indoor design temperature.

Step 1: Determine the thermal insulation for the combination of garments using one of the following ways:
- table A-1for combinations of garments;
- formula (A.1) and table A-2.

Step 2: Determine the activity level (metabolical rate) of the activiteis in the following way:
- classification as given in table A-3.

Step 3: Select the allowed percentage of dissatisfied according to A.4.

Step 4: Select the optimal indoor designtemperature and the temperature spread with figure A-1 if PPD <10% or figure A-2 if PPD <15%.

A.2 Thermal insulation of clothing

The thermal insulation for typical combinations of garments can be found in table A-1. The thermal insulation of a single garment can be found in table A-2. With formula A.1 the thermal insulation of the combination of garments can be calculated as follows

$$Clo = 0{,}08 + 0{,}74 \cdot \Sigma Is \qquad \text{[clo]} \qquad \text{A.1}$$

where: Clo = thermal insulation of combination of garments [clo]
Is = thermal insulation of a garment [clo]

Table A.1 — Thermal insulation for typical combinations of garments

Work clothing	Icl		Daily wear clothing	Icl	
	clo	$m^2 \cdot K/W$		clo	$m^2 \cdot K/W$
Underpants, boiler suit, socks, shoes	0,70	0,110	Panties, T-shirt, shorts, light socks, sandals	0,30	0,050
Underpants, shirt, boiler suit, socks, shoes	0,80	0,125	Underpants, shirt with short sleeves, light trousers, light socks, shoes	0,50	0,080
Underpants, shirt, trousers, smock, socks, shoes	0,90	0,140	Panties, petticoat, stockings, dress, shoes	0,70	0,105
Underwear with short sleeves and legs, shirt, trousers, jacket, socks, shoes	1,00	0,155	Underwear, shirt, trousers, socks, shoes	0,70	0,110
Underwear with long legs and sleeves, thermo-jacket, socks, shoes	1,20	0,185	Panties, shirt, trousers, jacket, socks, shoes	1,00	0,155
Underwear with short sleeves and legs, shirt, trousers, jacket, heavy quilted outer jacket and overalls, socks, shoes, cap, gloves	1,40	0,220	Panties, stockings, blouse, long skirt, jacket, shoes	1,10	0,170
Underwear with short sleeves and legs, shirt, trousers, jacket, heavy quilted outer jacket and overalls, socks, shoes	2,00	0,310	Underwear with long sleeves and legs, shirt, trousers, V-neck sweater, jacket, socks, shoes	1,30	0,200
Underwear with long sleeves and legs, thermo-jacket and trousers, Parka with heavy quitting, overalls with heave quilting, socks, shoes, cap, gloves	2,55	0,395	Underwear with short sleeves and legs, shirt, trousers, vest, jacket, coat, socks, shoes	1,50	0,230

Table A-2 Thermal insulation for garments.

Garment	clo
Underwear	
Panties	0,03
Underpants with long legs	0,10
Singlet	0,04
T-shirt	0,09
Shirt with long sleeves	0,12
Panties and bra	0,03
Shirts/Blouses	
Short sleeves	0,15
Light-weight, long sleeves	0,20
Normal, long sleeves	0,25
Flannel shirt, long sleeves	0,30
Light-weight blouse, long sleeves	0,15
Trousers	
Shorts	0,06
Light-weight	0,20
Normal	0,25
Flannel	0,28
Dresses/Skirts	
Light skirts (summer)	0,15
Heavy skirt (winter)	0,25
Light dress, short sleeves	0,20
Winter dress, long sleeves	0,40
Boiler suit	0,55
Sweaters	
Sleeveless vest	0,12
Thin sweater	0,20
Sweater	0,28
Thick sweater	0,35
Jackets	
Light, summer jacket	0,25
Jacket	0,35
Smock	0,30
High-insulative, fibre-pelt	
Boiler suit	0,90
Trousers	0,35
Jacket	0,40
Vest	0,20
Outdoor clothing	
Coat	0,60
Down jacket	0,55
Parka	0,70
Fibre-pelt overalls	0,55
Sundries	
Socks	0,02
Thick, ankle socks	0,05
Thick, long socks	0,10
Nylon stockings	0,03
Shoes (thin soled)	0,02
Shoes (thick soled)	0,04
Boots	0,10
Gloves	0,05

A.3 Metabolic rates

Table A-3 shows a classification van metabolic rates.

Further information on metabolic rates is given in ISO 8996. That elderly people often have a lower average activity than younger people also needs to be taken into account.

Table A.3 — Metabolic rates

Metabolic rate		Activity	
Class	Type of activity	W/m²	met
0	Reclining	46	0,8
1	Seated, relaxed	58	1,0
1	Sedentary activity (office, dwelling, school, laboratory)	70	1,2
1	Standing, light activity (shopping, laboratory, light industry)	93	1,6
2	Standing, medium activity (shop assistant, domestic work, machine work)	116	2,0
2	Walking on level ground: 2 km/h	110	1,9
2	3 km/h	140	2,4
2	4 km/h	165	2,8
3	5 km/h	200	3,4

A.4 Allowed percentage of dissatisfied PPD

For the classes 0, 1 and 2 (see table A-3) a maximum percentage of dissatisied PPD (Predicted Percentage Dissatisfied) of 10% is applicable. This means - 0,5 < PMV < + 0,5 [14].
In al other cases a PPD of 15% is allowed. This means: -0,7 < PMV < + 0,7 [14].

A.5 determination of the optimal operative temperature

For a PPD of maximal 10% the optimale operative temperature has to be derived from figure A-1.

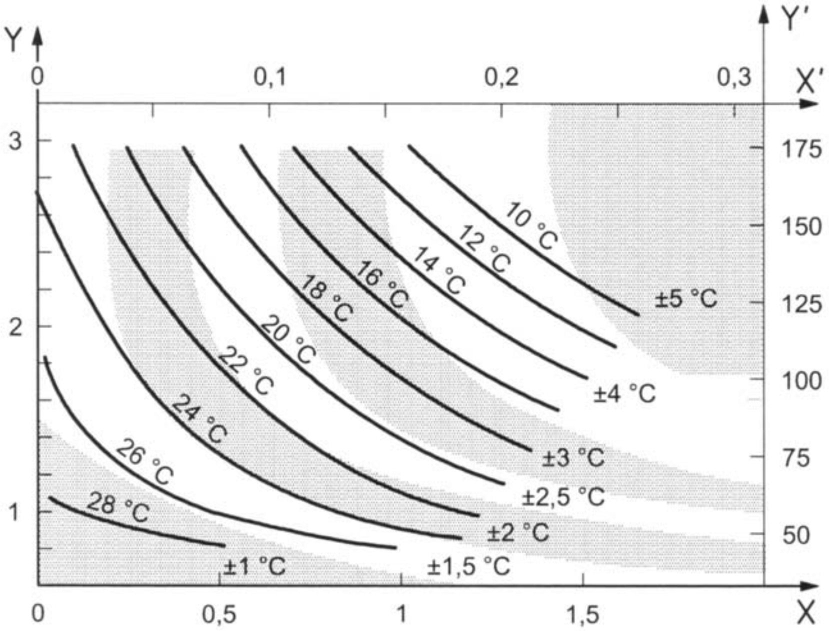


Fig. A-1 Determination of the optimal operative temperature(PPD < 10%).

Key

X basic clothing insulation, in clothing units, (clo);
X′ basic clothing insulation, in clothing units, $m^2 \cdot °C/W$;
Y metabolic rate, in metabolic units, (met);
Y′ metabolic rate, in metabolic units, W/m^2;

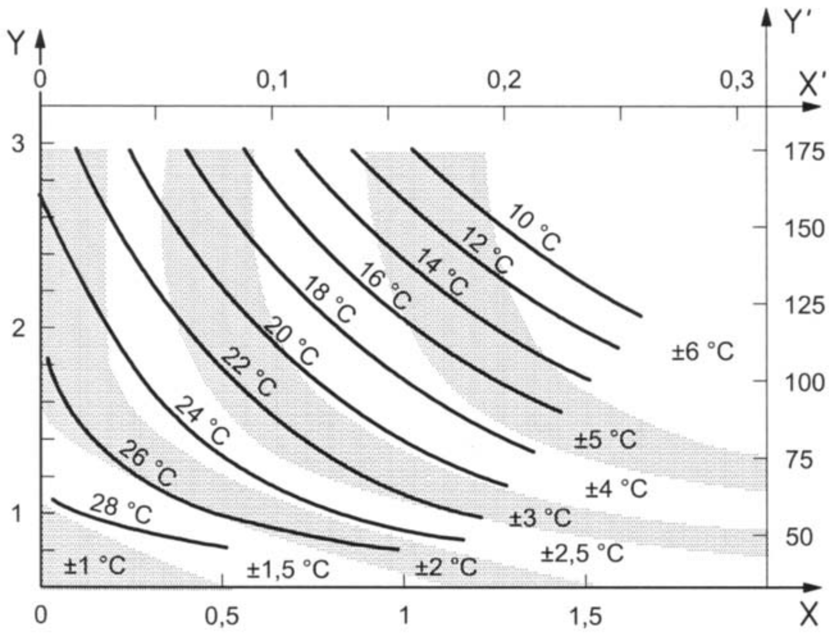


Fig. A-2 Determination of the optimal operative temperature(PPD < 150%).

Annex B PRINCIPlES OF HEAT EXCHANGE OF THE DIFFRENT HEATING SYSTEMS

What is the aim of a heat loss calculation?
The aim of a heat loss calculation is to calculate the capacity needed to maintain the tempearture of the room or to restore the temperature in a reasonable amount of time after a period of setback or stoppage.

It concerns the capacity added to the room to maintain the temperature (seen from within the room where the losses occur). Figure B.1a shows the heat loss through the building envelope, illustrated with arrows (seen from within the room) in case of radiant heating or air heating and figure B.1b in case of floor heating.

air heating
radiant heating

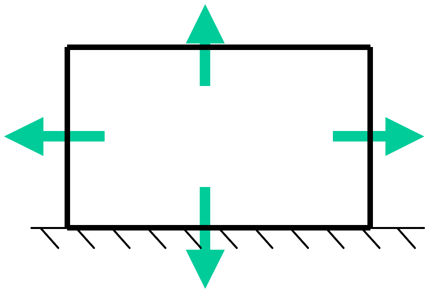


Fig. B.1a. Transmission heat loss with radiant heating and air heating.

floor heating

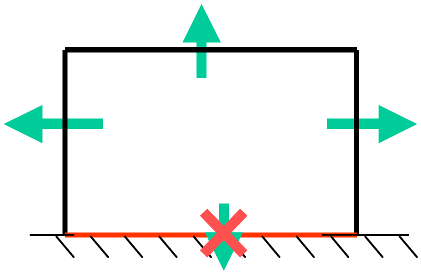
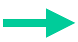
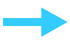


Fig. B.1b. Transmission heat loss with floor heating.

In this annex three main principles of heating an high and/or large building entity are considered:
- floor heating;
- radiant heating;
- air heating.

For every main heating system the principles of heat exchange are leading and influences of heating surfaces by radiation and/or warm air have to be taken into account in a design heat loss calculation. Showed is how this has been dealt with in this publication.

Tabel B.1: Symbols used in the heat exchange principles.

symbool	beschrijving
	radiant heat exchange from warm parts of the installation.
	radiant heat exchange from parts heated up by radiation or warm air along surfaces
	convective flow along heated parts/surfaces.
	additional heat loss to the ground of warm areas caused by conduction
	heat loss by conduction in surfaces
	transmission heat loss of a surface (seen from the inside of the room).
	ventilation heat loss.
	infiltration heat loss

The values given in this publication are values in design conditions. During partial loads the values of the temperature gradient are smaller and differences between the air temperature and the radiant temperature are also smaller.

B.1 Floor heating

With this system the floor is heated. As shown in figure B.1b, seen from within the room, there is no heat loss through the floor. The heat loss calculation has to calculate the capacity of the floor heating system delivered to the room (not including the capacity that flows downward).
The capacity that flows downward has to be taken into account for when calculating the boiler capacity and the dimensioning of the floor heating system. According to EN 1264 [15] the default downward heat loss is 10% of the capacity delivered to the room.

The principles of heat exchange in a room with floor heating are shown in figure B.2.

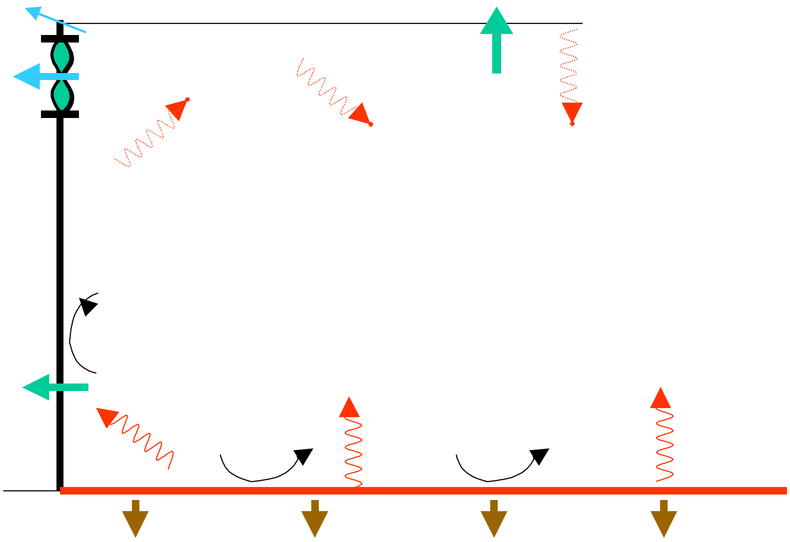


Fig. B.2 Principles of heat exchange with floor heating

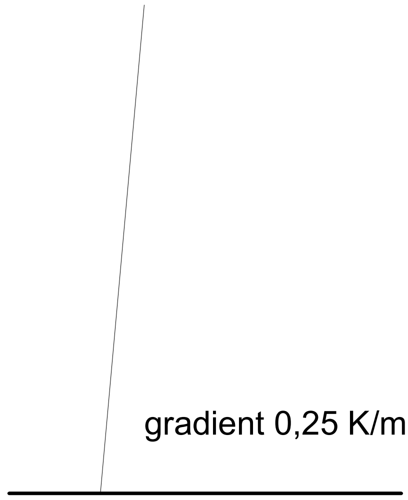


Fig.B.3 vertical temperature gradient

The warm floor (temperature 18 - 25 °C) exchanges heat with the room partially by means of convection and patially by radiation. Because of radiant influences the walls have a slightly increased temperature. This increased temperature causes convective and radiant heat exchange with the room. The ceiling is only slightly influenced. Because the walls get an increased temperature the outside walls have a slightly increased heat loss. This is taken into account by using a smal temperature gradient ($\delta\theta_1$ = 0,25 K/m). Figure B.3 shows the gradient. Because the temperature gradient is small and the main source of heat exchange is radiation there is no correction at floor level. ($\Delta\theta_2$ = 0 K).

Because the main source of heat exchange is radiation the air temperature is lower than the comfort temperature. Because of this the ventilation/infiltration heat losses are lower than calculated on basis of the comfort temperature. Because the floor temperatures differ only slightly from the comfort temperature in the room the difference between the air temperature and the comfort temperature is about 1,5 K. This is taken into account by $\Delta\theta_v$ = 1,5 K when calculating the heat loss caused by ventilation and infiltration.

B.2 Radiant heating

The principles of heat exchange with radiant heating are shown in figure B.4.
The radiant heating systems have a mainly downward radiation. Because of this a percentage of the floor and a part of the wall receive heat by means of radiation and they get an increased temperature. This increased temperature causes increased heat losses on one hand and on the other hand they support the radiant heat exchange.
In general the extra heat losses of the floor can not be neglected. In chapters 3.6 this is taken into account by the factor f_s. factor f_s strongly depends on the temperature of the radiant heating system:

f_s	= 1,30 in case of IR open heaters or black tube systems	[-]
f_s	= 1,15 in case indirectly heated systems (e.g. water fed panels)	[-]
f_s	= 1 all other heating systems	[-]

In general the radiant heating systems has a significantly higher temperature than the surrounding. Because of this, in spite of insulation on top of the radiant panels/heaters, there is a rather strong

convective heat flow around the heating system and this is the reason of an increased temperature above the radiant panels. This is taken into account with $\delta\theta_1$:
in case of black tube systems and indirectly heated systems $\delta\theta_1$ = 0,5 K/m
IR open heaters: $\delta\theta_1$ = 0,9 K/m .

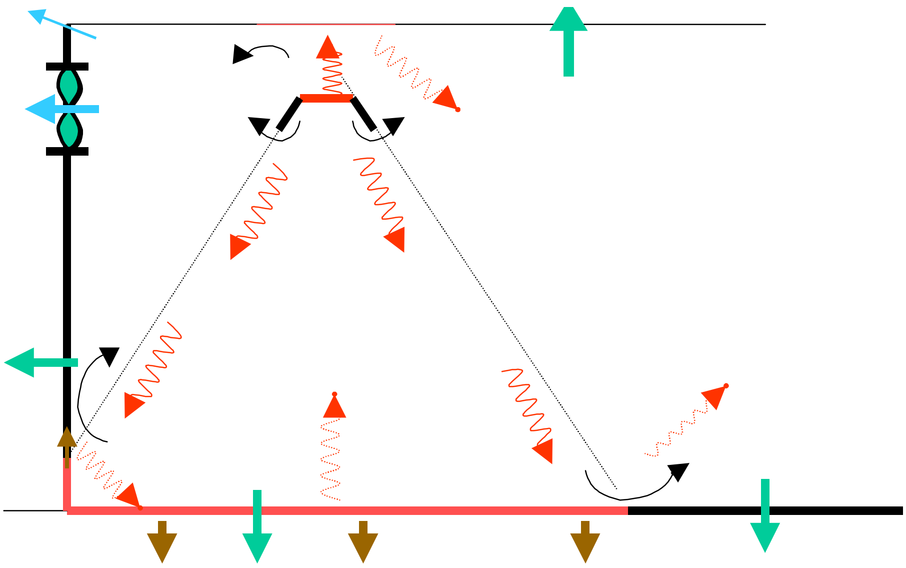


Fig. B.4 Principles of heat exchange with radiant heating systems.

The high value of the vertical temperature gradient of IR open heaters is caused by the hot combustion gasses entering the building entity. A correction at floor level is not necessary ($\Delta\theta_2$ = 0 K).

The top site of the panels have a higher temperature and because of this there is an extra radiant heat exchange with the ceiling/roof. This causes extra heat losses. Because it only concerns a small percentage of the ceiling/roof (maximum 5%) and a vertical temperature gradient has already been taken into account there is no additional correction necessary. By using insulation on the top site of the panels radiant heat exchange with the ceiling/roof can be reduced.

To keep it simple there is calculated with one vertical temperature gradient. To perform a more accurate calculation there should be calculated with two different gradients: a small value below the panels/heaters and a bigger one above the radiant heaters/panels (see figure B.5)

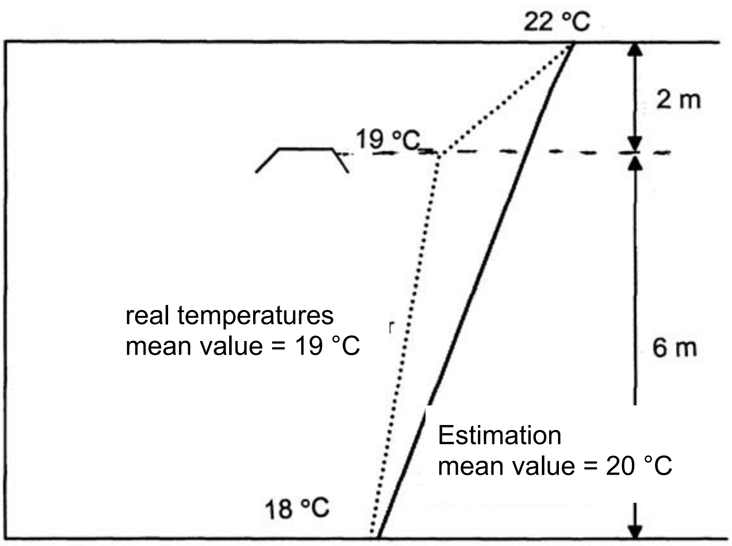


Fig. B.5 Temperatue as function of the height for a system with radiant panels/heaters.

By using only one vertical teamperature gradient the calculated transmission heat loss is 3% to high but because of the radiant influence on walls (causing higher wall temperatures) should be corrected the use of only one temperature gradient is allowed. In case of a increased surface temperature of 2 degrees caused by radiation on 50% of the height of the wall a correction of about 3% should be taken into account so the use of one temperature gradient is allowed.

Because the main source of heat exchange is radiation the air temperature is lower than the comfort temperature (see also annex HI). Because of this the ventilation/infiltration heat losses are lower than calculated on basis of the comfort temperature. The directly fired systems (infrared (IR) heaters and black tube systems) have a high temperature and because of this the difference between the air temperature and the comfort temperature is about 2,0 K. This is taken into account by $\Delta\theta_v$ = 2,0K when calculating the heat loss caused by ventilation and infiltration.

Because the directly fired systems (eg water fed panels) have a much lower temperature, the difference between the air temperature and the comfort temperature is about 1,5 K. This is taken into account by $\Delta\theta_v$ = 1,5 K when calculating the heat loss caused by ventilation and infiltration.

B.3. Air heating

The principles of heat exchange with air heating are shown in figure B.64.

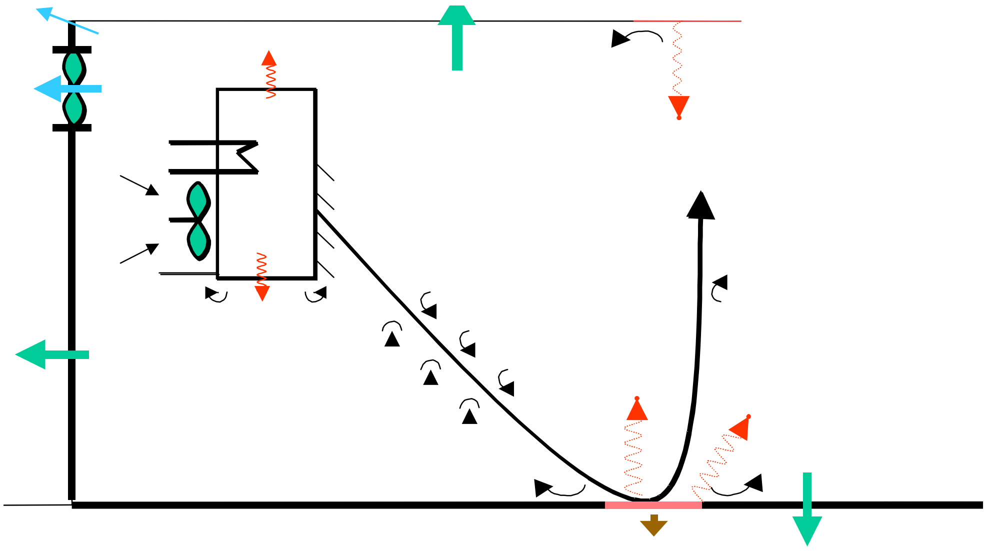


Fig. B.6 The principles of heat exchange with air heating

The main heat exchange with air heating is convective. The warm air is pushud downward by a ventilator and vanes. The warm airflow induces air in it's surrounding and losses speed and will rise because the warm air is lighter than the air in the colder surrounding (after reaching the floor or not). This causes a rather high vertical temperature gradient. This gradient increases when the temperaure of the rising air is higher (increasing of the supply temperature).
In the calculation method this is dealt with by using the following values for the vertical temperature gradient (air change rate equally to 3)

– air heating HT (θ_{supply} - $\theta_{room} \geq$ 30 K): $\delta\theta_1$ = 0,75 K/m;
– air heating LT (θ_{supply} - θ_{room} < 30 K): $\delta\theta_1$ = 0,65 K/m. .

The heat exchange is mainly convective so the vertical temperature gradient is rather big so a correction for a lower temperature near the floor has to be introduced ($\Delta\theta_2$ = -1 K). Because of this their is a slight reduction of the heat loss through the floor

Reducing the number of air change rates means increasing the vertical temperature gradient. For high temperature (HT) systems the gradient can increase to 1,3 K/m.
By using destratification fans the vertical temperature gradient can be reduced significantly. This is applied in formula 2.2 and figure B.7.

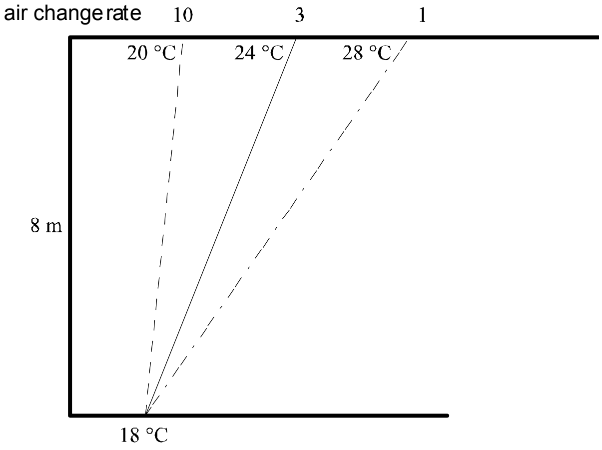


Fig. B.7 Vertical temperature as function of the air change rate.

The location where the warm air flow reaches the floor the temperature is locally increased and also the heat loss is increased. Only a small percentage of the floor area has an increased temperature so the additional heat loss through the floor can be neglected.
The area where the warm air reaches the roof/ceiling ther is also an increased temperature and additional heat loss. This also concerns only a limited area so this influence can be neglected (The vertical temperature gradient can not be neglected!). A correct location of destratification fans limits te effect of spots with increased temperatures on ceiling/roof.
Radiant influences of the warm cover of the air heater can be neglected.
In a good design there is no airflow touching the walls so this has no influence on the design heat loss calculation.

Because the heat exchange is mainly convective the air temperature is slightly higher than the comfort temperature but the difference is so small that the the calculations are carried out with the comfort temperature: $\Delta\theta_v$ = 0K.

Annex C CALCULATION OF THE INFILTRATION AIRFLOW

Method for calculating the airflow if the surface of the ventilation gaps/opemimgs is known.

The presented method has a limited accuracy. For the calculatuion of the ventilation heat loss of industrial spaces this method seems to be most appropriate because other methods are too complicated. There are simulation models for the design fase. These models are accurate but they need a lot of detailed information that is not available when designing. The measuring in large building envelops, for example with tracer gas, is not practical of not possible. In case of measuring the ventilation flow in practice the results are influenced by weather conditions. The measured value has only a limited value. The estimation of the ventilatie of infiltration air flow takes the surface of openings in walls and the air velocities in these opening for granted. The surface of not meant openings in wall vary from 0,5 to 4 cm^2 per square metre. In steel constuctions with moulded sheets the value can be much higher. Some guidelines:

building from bricks with a high level insulation:	0,5 cm^2/m^2
steel construction with well fitting brickwork:	4,0 cm^2/m^2
steel construction with moulded sheets:	till 20 cm^2/m^2.

Additional gaps for tubes passing the outside walls also have to be taken into account. The air tightness of the building envelop is also dependent on maintenance on and the finish of the building envelop. If there is no information about the air tighness of the building envelop, 2 cm^2/m^2 seems to be a reasonable value. With the help of the information given above it should be possible to calculate the surface of the not meant openings A_{inf}. For the intentionally made and visible openings the calculation is as follows: calculate the surface of all openings. Diveide them into the surface of openings in outside walls and roofs. The total suface of the openings in outside walls is A_{vent}
Add the surfaces of A_{inf} and A_{vent}

$$A_{tot} = A_{inf} + A_{vent}$$

Through these openings air enters the building due to pressure differences caused by wind and thermal draw. The amount of ventilation is calculated as follows:

$$q_v = \frac{A_{tot} \cdot V}{Y} \quad \text{[m/s]} \qquad \text{(C.1)}$$

where:
- q_v = the air flow caused by pressure differences [m^3/s]
- A_{tot} = total surface of the openings in the outside walls [m^2]
- v = the air velocity/wind speed (mean value for the height of the building) [m/s]
- Y = constant dependent of the protection from wind and the location of ventilation gaps (see table C-1) [-]

Table C-1. Values of Y.

Y	Circumstances
2	open field, gaps/openings equally divide on ouside walls and roof
3	as 2, but openings in outside walls not regularly divided
4	normal exposure, gaps/openings equally divide on ouside walls and roof
6	as 4, but openings in outside walls not regularly divided
8	all other cases; sheltered position and not regularly divided gaps/openings

Ventilation caused by thermal draw:

$$q_{v,tot} = \frac{A_{tot}\sqrt{\delta T \cdot (H)}}{Y_t} \qquad [m^3/s] \qquad (C.2)$$

waarin: $q_{v,t}$ = airflow caused by thermal draw [m^3/s]
A_{tot} = total surface of the openings in the outside walls [m^2]
H = difference in height between supply and extract [m]
δT = temperature difference between indoor temperature and outdoor temperature [K]
Y_t = constant value for thermal draw dependent from location of ventilation gaps (see table C-2) [$s{\cdot}K/m^{0,5}$]

Tabel C-2. Values of Y_t.

Y_t	Circumstances
6	same amount of low supply openings and high extract openings
9	not equally distibuted supply and extract opening (more supply openings of more extract openings)
12	all other cases and high temperature gradients

The total effect of pressure difference caused by wind and thermal draw can be calculated as follows:

$$q_{v,tot} = ((q_v)^2 + (q_{v,t})^2)^{0,5} \qquad [m^3/s] \qquad (C.3)$$

The number of air changes n is calulated as follows:

$$n = q_{v,tot} / (3600 \cdot \text{building contents}) \qquad [h^{-1}]$$

Annex D CALCULATION OF THE PROFITS OF HEAT RECOVERY

The temperature after the heat recovery unit is calulated as follows:

$$\theta_t = \eta_\theta \cdot (\theta_r - \theta_e) + \theta_e \qquad [°C]$$

where: θ_t = temperature supplied to the room (after the heat exchanger) [°C]
η_θ = temperature efficiency of the heat exchanger (heat recovery unit) [-]
θ_r = mean temperature of extract air; if this value is not known, the temperature of the main part of the building should to be used [°C]
θ_e = outdoor design temperature [°C]

Table D.1 provides the heat gains [W] of the recovery unit per m³/h ventilation air. These profits depend on the efficiency of the heat recovery unit and the temperature of the extract air.

Tabel D.1 Heat gains [W] per m³/h dependent of the efficiency and the mean temperature of the extract air.

θ_r \ η_θ	0,5	0,55	0,60	0,65	0,70	0,75	0,80	0,85	0,90	0,95
17,00	4,50	4,95	5,40	5,85	6,30	6,75	7,20	7,65	8,10	8,55
17,25	4,54	5,00	5,45	5,90	6,36	6,81	7,27	7,72	8,18	8,63
17,50	4,58	5,04	5,50	5,96	6,42	6,88	7,33	7,79	8,25	8,71
17,75	4,63	5,09	5,55	6,01	6,48	6,94	7,40	7,86	8,33	8,79
18,00	4,67	5,13	5,60	6,07	6,53	7,00	7,47	7,93	8,40	8,87
18,25	4,71	5,18	5,65	6,12	6,59	7,06	7,53	8,00	8,48	8,95
18,50	4,75	5,23	5,70	6,18	6,65	7,13	7,60	8,08	8,55	9,03
18,75	4,79	5,27	5,75	6,23	6,71	7,19	7,67	8,15	8,63	9,10
19,00	4,83	5,32	5,80	6,28	6,77	7,25	7,73	8,22	8,70	9,18
19,25	4,88	5,36	5,85	6,34	6,83	7,31	7,80	8,29	8,78	9,26
19,50	4,92	5,41	5,90	6,39	6,88	7,38	7,87	8,36	8,85	9,34
19,75	4,96	5,45	5,95	6,45	6,94	7,44	7,93	8,43	8,93	9,42
20,00	5,00	5,50	6,00	6,50	7,00	7,50	8,00	8,50	9,00	9,50
20,25	5,04	5,55	6,05	6,55	7,06	7,56	8,07	8,57	9,08	9,58
20,50	5,08	5,59	6,10	6,61	7,12	7,63	8,13	8,64	9,15	9,66
20,75	5,13	5,64	6,15	6,66	7,18	7,69	8,20	8,71	9,23	9,74
21,00	5,17	5,68	6,20	6,72	7,23	7,75	8,27	8,78	9,30	9,82
21,25	5,21	5,73	6,25	6,77	7,29	7,81	8,33	8,85	9,38	9,90
21,50	5,25	5,78	6,30	6,83	7,35	7,88	8,40	8,93	9,45	9,98
21,75	5,29	5,82	6,35	6,88	7,41	7,94	8,47	9,00	9,53	10,05
22,00	5,33	5,87	6,40	6,93	7,47	8,00	8,53	9,07	9,60	10,13
22,25	5,38	5,91	6,45	6,99	7,53	8,06	8,60	9,14	9,68	10,21
22,50	5,42	5,96	6,50	7,04	7,58	8,13	8,67	9,21	9,75	10,29
22,75	5,46	6,00	6,55	7,10	7,64	8,19	8,73	9,28	9,83	10,37

Example:
The heat gain Φ_{gain} of a heat recovery system with 2000 m³/h and an extract temperature of 20,5 °C and an efficiency of 0,7 is calculated as follows:

Φ_{gain} = 2000 x 7,12 = 14240 Watt.

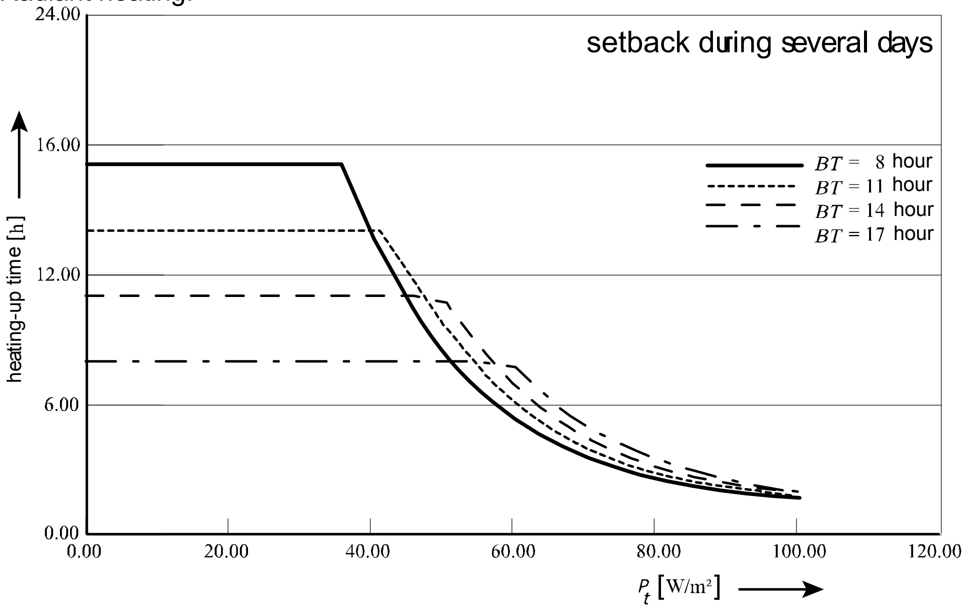
Annex E: CALCULATION OF THE SPECIFIC HEATING-UP CAPACITY

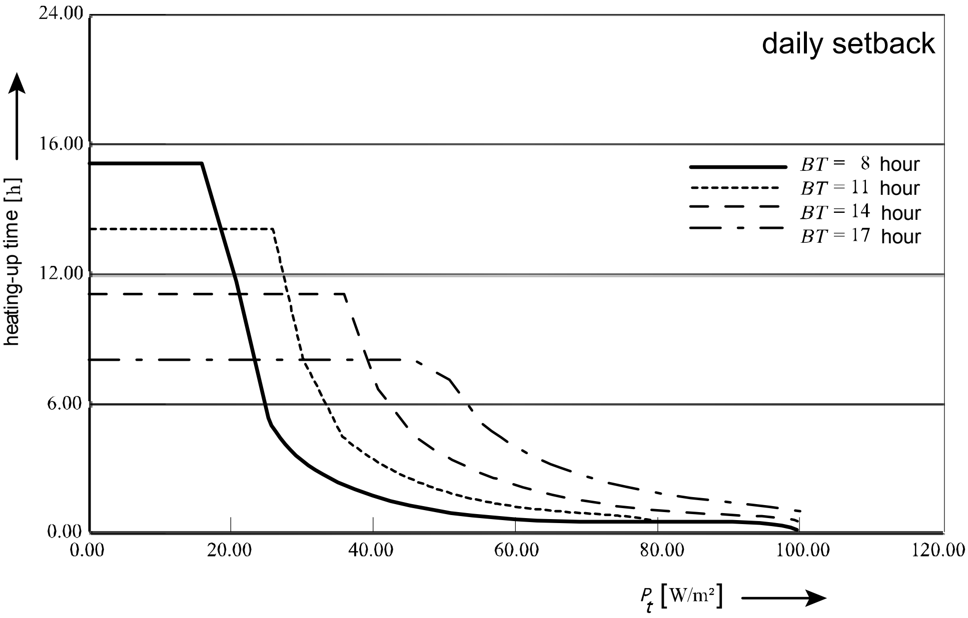
Usage with a constant temperature during 24 hours / 7 days a week or the use of a self-learning control device: P = 0.
At large enclosures the specific heating-up capacity P is calculated per square metre floor surface and depends on the amount of setback, the allowed heating-up time and the number of working hours.
The running time of the installation BT is defined as the total of the working hours and the heating-up time.
De specific heating-up capacity P is calculated as follows:

$$P = c_o \cdot P_t \qquad [\mathrm{W/m^2}] \qquad (E.1)$$

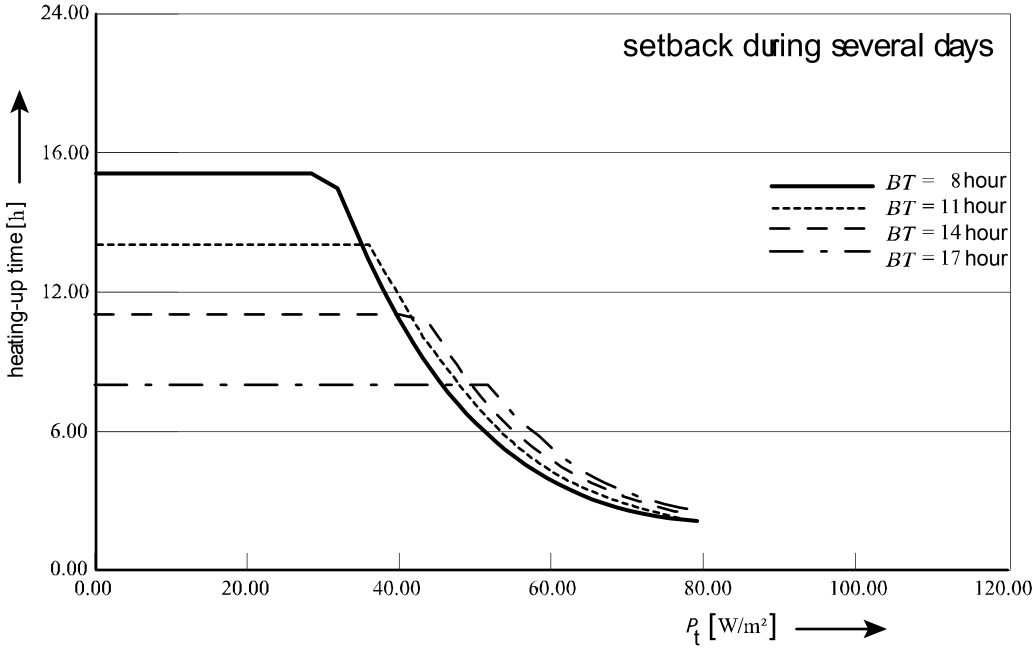
where: c_o = correction for design indoor temperatures less than 20,5 °C and heating-up until PMV = -0,5 [-]
P_t = specific capacity according to figure E.1 [W/m²]

Radiant heating:

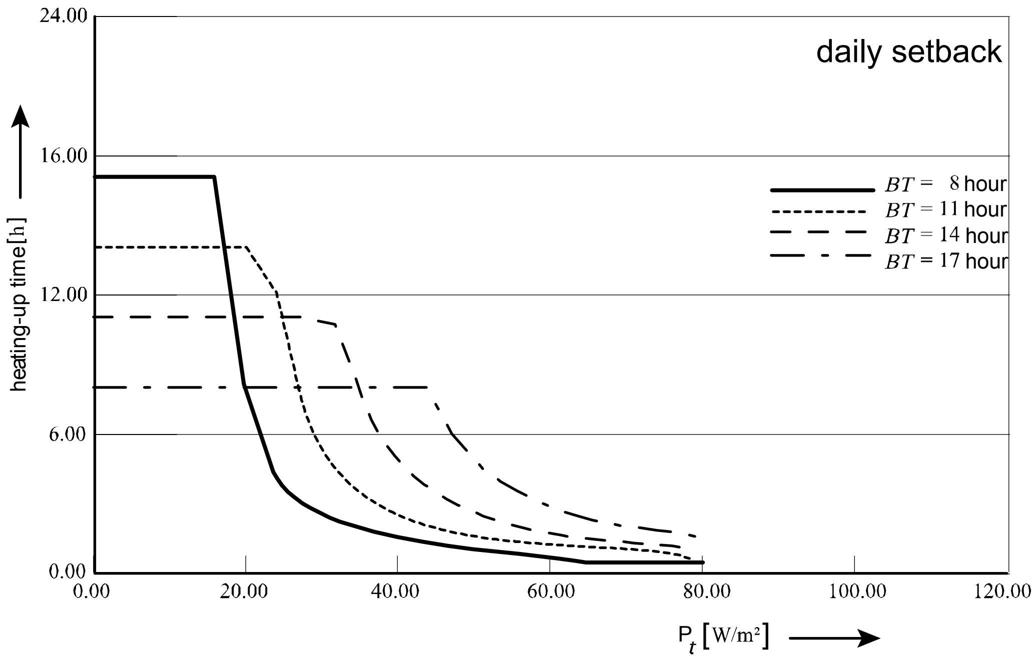




air heating:

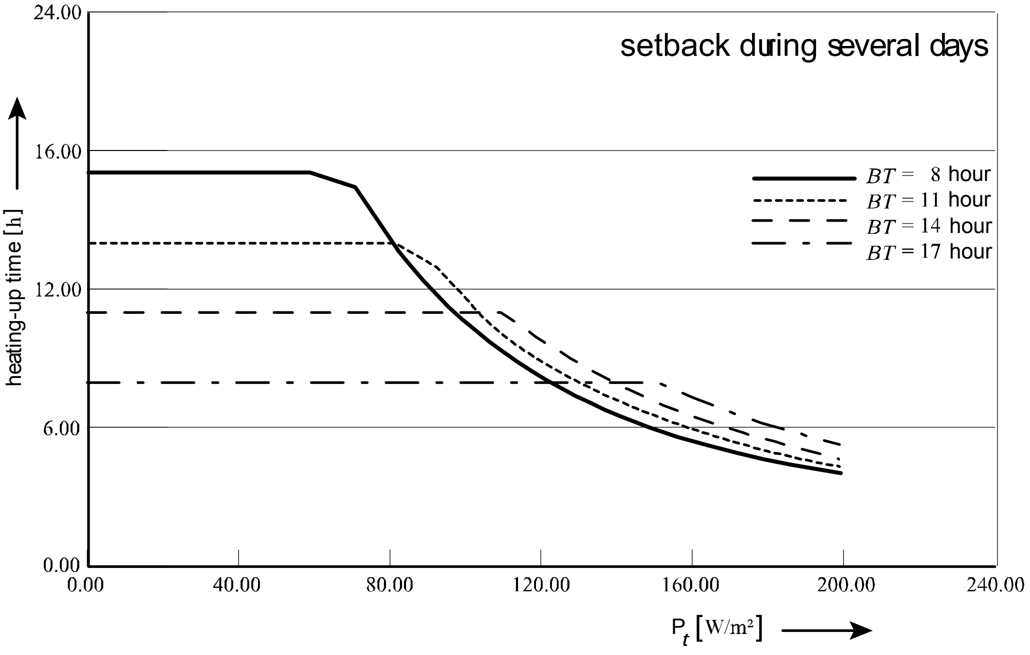


setback during several days
heating-up time [h]
24.00
16.00
12.00
6.00
0.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
BT = 8 hour
BT = 11 hour
BT = 14 hour
BT = 17 hour
P_t [W/m²]



daily setback
heating-up time [h]
24.00
16.00
12.00
6.00
0.00
0.00
20.00
40.00
60.00
80.00
100.00
120.00
BT = 8 hour
BT = 11 hour
BT = 14 hour
BT = 17 hour
P_t [W/m²]

floor heating



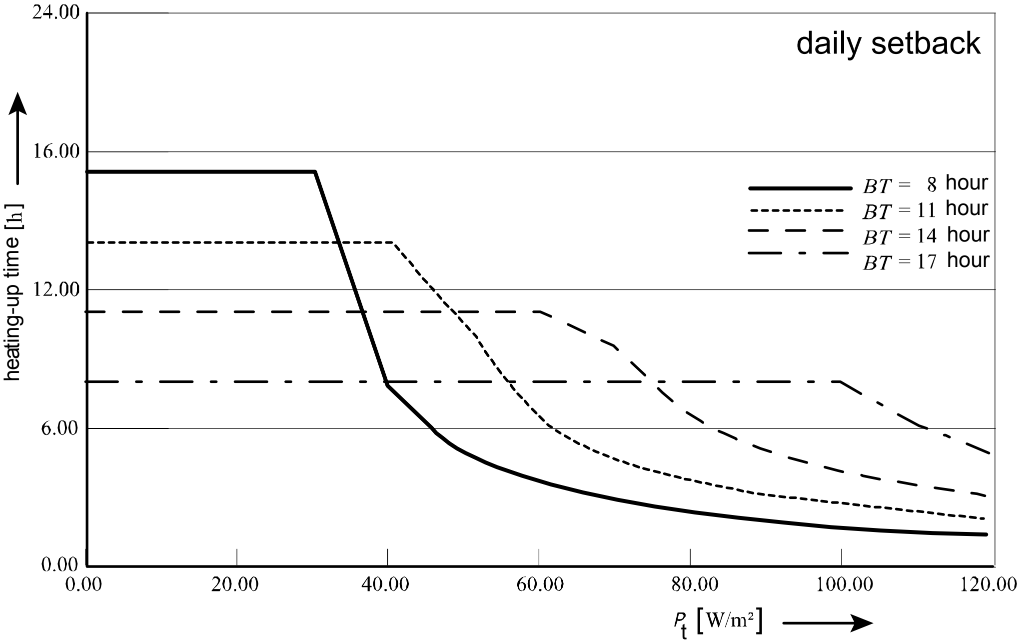


Fig. E.1 Specific capacity P_t *for the three main heating systems on monday (setback for several days) and working days (daily setback).*

Tabel E.1 Correction factor c_o

Indoor design temperature [°C]	reduction factor c_o	
	setback temperature 5 °C	setback temperature 10 °C
12	0,08	0
14	0,23	0
16	0,39	0,08
18	0,55	0,23
20,5	0,74	0,43

Annex F HEAT BALANCE TO CALCULATE THE TEMPERATURE IN ADJACENT ROOMS

Different cases are considered:
- adjacent room in the same building (see F.1);
- adjacent room in neighbouring building (see F.2);
- crawling spaces (see F.3).

F.1 adjacent room in the same building

The indoor temperature θ_i is calculated with the heat balance of the room:

$$(H_{t,ie} + H_{t,ia} + H_{t,io} + H_{t,ib} + H_{t,ig}) \cdot (\theta_i - \theta_e) + \Phi_V + \Phi_{pr} = 0 \qquad \text{(F.1)}$$

where:
- $H_{t,ie}$ = transmission heat loss coefficient from heated space (i) to the exterior (e) through the building envelope, according to 3.2.2 [W/K]
- $H_{t,ia}$ = transmission heat loss coefficient from heated space (i) to a neighbouring heated space heated at a significantly different temperature, i.e. an adjacent heated space within the building entity, according to 3.2.3 [W/K]
- $H_{t,io}$ = transmission heat loss coefficient from heated space (i) to an unheated space (u) according to 3.2.4 [W/K]
- $H_{t,ib}$ = transmission heat loss coefficient from heated space (i) to a neighbouring building, according to 3.2.5 [W/K]
- $H_{t,ig}$ = steady state ground transmission heat loss coefficient from heated space (i) to the ground (g), according to 3.2.6 [W/K]
- θ_i = internal design temperature according to 2.1 [°C]
- θ_e = external design temperature according to 2.2 [°C]
- Φ_V = design ventilation heat loss according to F.1.1 [W]
- Φ_{pr} = heat gain or loss from incoming/outgoing products and development of heat by processes according to F1.2 [W]

F.1.1 Design ventilation heat loss
The method for calculating the design ventilation heat loss has to be calculated according to 3.3.

F.1.2 heat gain or loss from incoming/outgoing products
If the flow of materials through the room is continuously and the temperatures are constant:

$\Phi_{pr} = 0$

In all other cases Φ_{pr} has to be calculated according to 3.5.

F.2 Adjacent room in neighbouring building
In the calculation of adjacent temperature θ_b the neighebouring building is treated as one room. That room is considered to be unheated.
Temperature θ_b of the neighbouring building is calculated with a heat balance:

$$(H_{t,ie} + H_{t,ib} + H_{t,ig} + H_i + H_v) \cdot (\theta_b - \theta_e) = 0 \qquad \text{(F.2)}$$

where:
- $H_{t,ie}$ = transmission heat loss coefficient from heated space (i) to the exterior (e) through the building envelope, according to F.2.1 [W/K]
- $H_{t,ib}$ = transmission heat loss coefficient from heated space (i) to a neighbouring building, according to F.2.2 [W/K]
- $H_{t,ig}$ = steady state ground transmission heat loss coefficient from heated space (i) to the ground (g), according to F.2.3 [W/K]
- H_i = infiltration heat loss coefficient, according to F.2.5 [W/K]
- H_v = ventilation heat loss coefficient, according to F.2.6 [W/K]
- θ_b = temperature of adjacent room (to be calculated) [°C]
- θ_e = external design temperature according to 2.2 [°C]

F.2.1 Transmission heat loss coefficient from heated space to the exterior $H_{t,ie}$
The design transmission heat loss coefficient from a heated space (i) to the exterior (e), $H_{t,ie}$ is for all building elements such as walls, floor, ceilings, doors, windows calculated as follows:

$$H_{t,ie} = \Sigma_k(A_k \cdot f_k \cdot (U_k + 0{,}1)) \qquad \text{[W/K]} \qquad (F.3)$$

where: A_k = area of building element (k), according to 2.3 [m²]
U_k = thermal transmittance of building element (k), according to 2.4 [W/(m²·K)]
f_k = correction factor for temperature gradients [-]

Because the room is not heated the value of f_k is as follows: $f_k = 1$

F.2.2 Transmission heat loss coefficient to a neighbouring building $H_{t,ib}$

The transmission heat loss coefficient to a neighbouring building (situated next to as well as above/below) is calculated as follows:

$$H_{t,ib} = \Sigma(A_s \cdot U_s \cdot f_{ib}) \qquad \text{[W/K]} \qquad (F.4)$$

where: A_s = area of building element (k), according to 2.3 [m²]
Us_k = thermal transmittance of building element (k), according to 2.4 [W/(m²·K)]
f_{ib} = correction factor for the temperature difference between the neighbouring space and the external design temperature [-]

Correction factor f_{ib} is calculated as follows:

$$f_{ib} = \frac{\theta_a - \theta_b}{\theta_a - \theta_e} \qquad \text{[-]} \qquad (F.5)$$

where: θ_a = indoor temperature (to be calculated) [°C]
θ_e = outdoor design temperature according to 2.2 [°C]
θ_b = temperature in space of neighbouring building:
- 10 °C for crawling spaces
- 15 °C for multi layer buildings, offices, shops
- 5 °C for shelters or stablings [°C]

F.2.3 Transmission heat loss coefficient to the ground $H_{t,ig}$

The design steady state ground transmission heat loss coefficient, $H_{t,ig}$ to the ground is calculated as follows:

$$H_{t,ig} = 1{,}45 \cdot G_w \cdot \Sigma_k(f_{g2} \cdot A_k \cdot U_{e,k}) \qquad \text{[W/K]} \qquad (F.6)$$

where: A_k = area of building element (k) in contact with the ground according to 2.1.3 [m²]
$U_{e,k}$ = equivalent thermal transmittance of building element (k) determined according to the wall or floor-typology (see Figures F.2 or F.3) [W/(m²·K)]
G_w = correction factor taking into account the influence from ground water [-]
f_{g2} = temperature reduction factor taking into account the difference between annual mean external temperature and external design temperature [-]

The correction factor taking into account the influence from ground water G_w:
G_w = 1 If the distance between the assumed water table and the basement floor level (floor slab) is more than 1 m [-]
G_w = 3 If the distance between the assumed water table and the basement floor level (floor slab) is (nearly) zero [-]
G_w = 1,15 all other cases. [-]

Correction factor f_{g2} is given by:

$$f_{g2} = \frac{\theta_i - \theta_{me}}{\theta_i - \theta_e} \qquad \text{[-]} \qquad (F.7)$$

where: θ_i = indoor design temperature according to 2.1 [°C]
θ_e = outdoor design temperature according to 2.2 [°C]
θ_{me} = annual mean external temperature [°C]

Floors

The equivalent thermal transmittance of building element $U_{e,k}$ of floors directly in contact with the ground shall be determined in the following way:

- calculate the area of the considered floor slab. For a whole building, A_q is the total ground floor area.
- For part of a building, e.g. a building entity in a row of houses, A_g is the ground floor area under consideration;
- perimeter of the considered floor slab in metres (m). For a whole building, P is the total perimeter of the building. For a part of a building, e.g. a building entity in a row of houses, P includes only the length of external walls separating the heated space under consideration from the external environment.;
- The characteristic parameter, B' ; is given by $B' = 2A_g/P$ (see figure F.1);
- use the applicable part of figure F.2.

Interpolation of values is allowed.

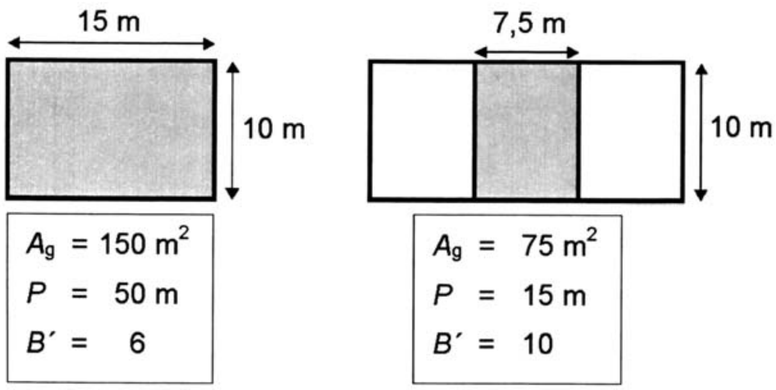
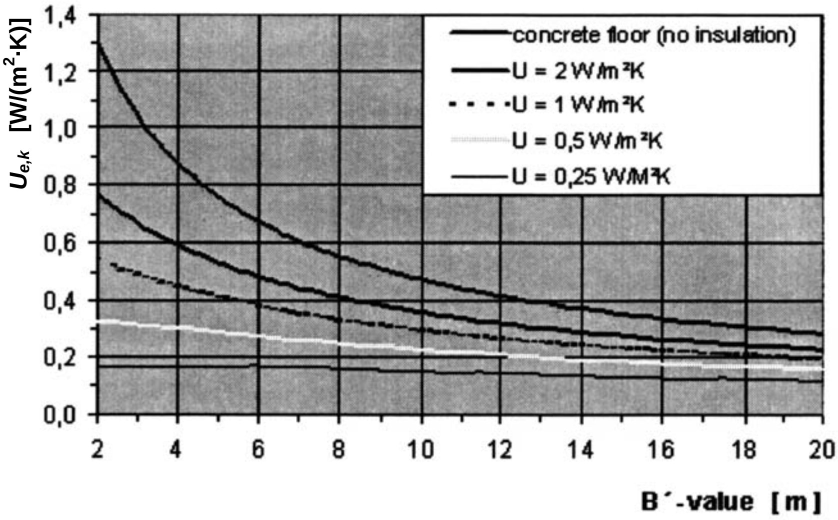
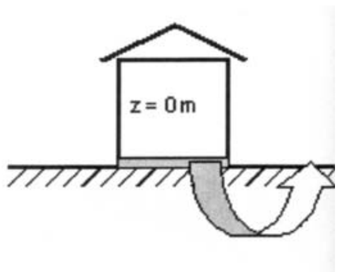


Figure F.1 Characteristic parameter, *B'*.

The equivalent thermal transmittance $U_{e,k}$ of walls directly in contact with the ground depends on the U-value and the level of the floor slab and is given in figure F.3





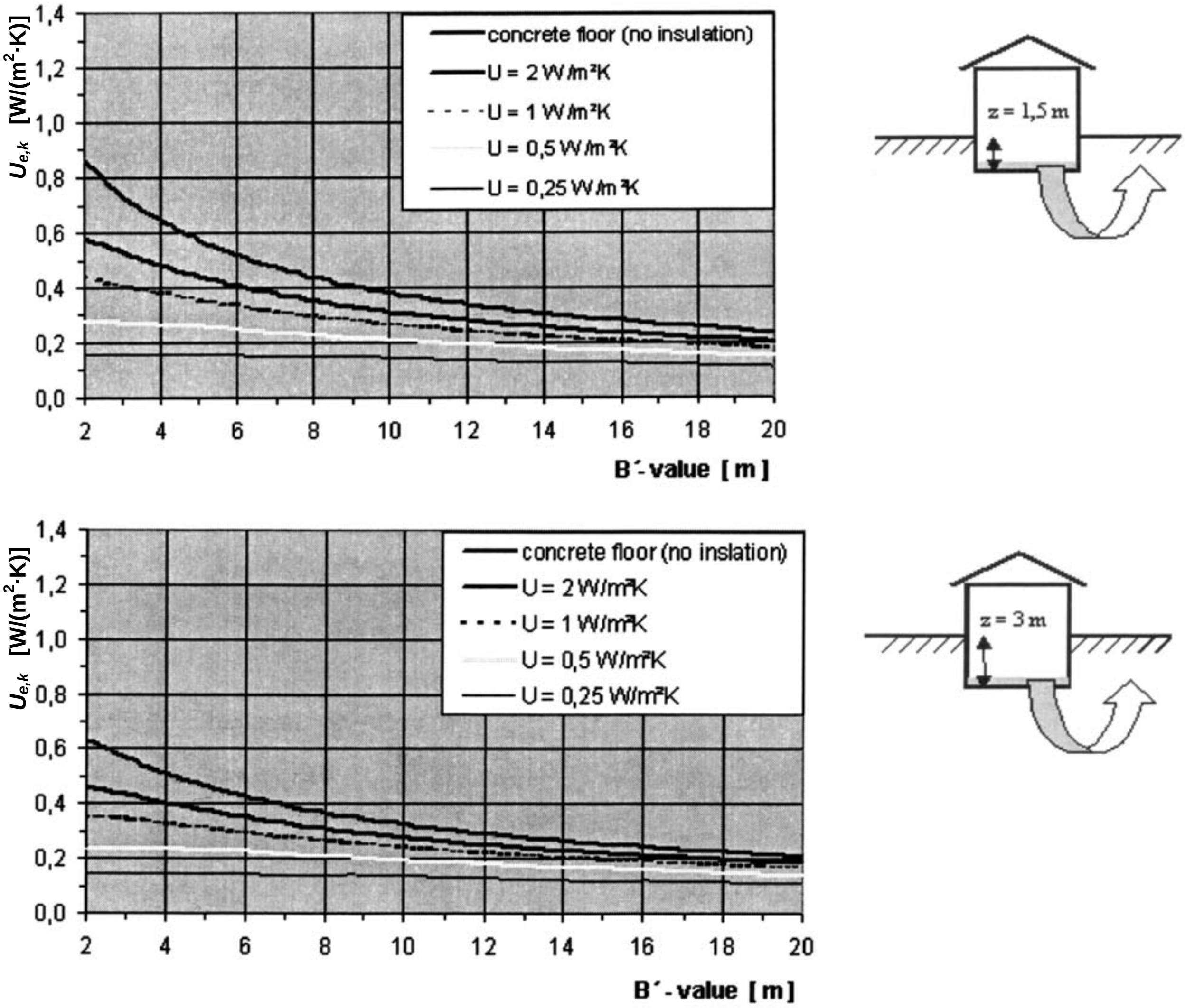
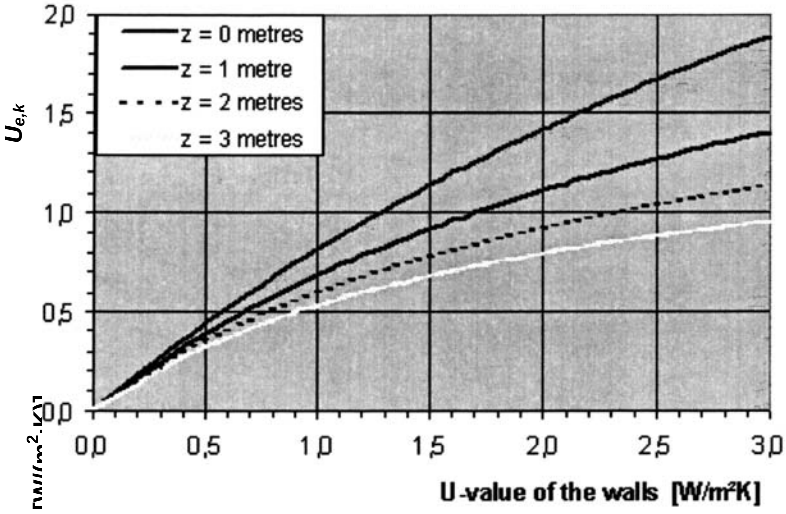


Figure F.2 $U_{e,k}$ for floor element of a heated basement, as function of the thermal transmittance of the floor, the depth z beneath ground level and B'-value

The design heat loss of storage rooms is calculated according to F.2.2.
The design heat loss of floors above crawling spaces is calculated according to F.2.4.
The design heat loss of floors above open air is calculated according to F.2.1.

Walls

The equivalent thermal transmittance $U_{e,k}$ of walls directly in contact with the ground depends on the U-value and the depth *z* beneath ground level and is given in figure F.3.



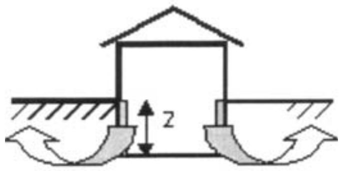


Figure F.3 $U_{e,k}$ for wall element of a heated basement, as function of the thermal transmittance of the walls and the depth z beneath ground level

F 2.4 Specific heat loss to a crawling space

Thwe specific heat loss $H_{t,io}$ to a crawling space is calculated as follows:

$$H_{t,io} = \Sigma_k (A_k \cdot U_k \cdot f_k) \qquad \text{[W/K]} \qquad \text{(F.8)}$$

where: A_k = area of building element (k) according to 2.1.3 [m²]
U_k = thermal transmittance of building element (k) determined according to 2.1.5 [W/(m²·K)]
f_k = correction factor according to tabel F.1 [-]

Table F.1 Correction factor f_k for heat loss in crawling spaces.

	f_k
Well ventilated with outside air (n > 0,5)	1,0
other cases ($n \leq$ 0,5)	0,5

where: n = numer of air changes [1/h]

F.2.5 Infiltration heat loss coefficient H_i

The infiltration heat loss coefficient H_i is calculated as follows:

$$H_i = 1200 \cdot q_i \cdot f_v \qquad \text{[W/K]} \qquad \text{(F.9)}$$

Correction factor f_v is calculated as follows:

$$f_v = \frac{\theta_i + \Delta\theta_v + 0{,}5\Delta\theta_1 - \theta_e}{\theta_i - \theta_e} \qquad \text{(F.10)}$$

where: θ_i = indoor design temperature according to 2.1 [°C]
θ_e = outdoor design temperature according to 2.2 [°C]
θ_t = temperature supplied to the room (see annex D) [°C]
$\Delta\theta_1$ = temperature correction due to temperature gradients following formula 2.2 [K]
$\Delta\theta_v$ = temperature correction for influences of radiant heating systems as given in table 2.2 [K]

The infiltration air flow rate q_i is determined following one of the two ways:
- guidelines as given in table F.2;
- calculation by the method as given in annex C (surface of cracks and openings has to be known).

Table F.2 Guidelines for infiltration.

Specification	Air exchange rate n_i [h^{-1}]*)
Old, non insulated not air tight buildings	0,5
Modern insulated building	
boxshaped with contents ≥ 10.000 m^3 without skylight and/or fire/smoke protecting devices	0,1
boxshaped with contents < 10.000 m^3 without skylight and/or fire/smoke protecting devices	0,2
boxshaped with contents ≥ 10.000 m^3 with skylight and/or fire/smoke protecting devices	0,2
boxshaped with contents < 10.000 m^3 with skylight and/or fire/smoke protecting devices	0,3
other building shapes	0,4

*) *In case of (closed) doors positioned in opposite walls, add 0,2 to the air exchange rate..*

The infiltration air flow rate q_i is determined as follows:

$$q_i = n_i \; V / 3600 \qquad [m^3/s] \qquad (F.11)$$

waarin: q_i = air flow rate caused by infiltration [m^3/s]
n_i = air exchange rate [h^{-1}]
V = volume of the building entity [m^3]

F.2.6 Ventilation heat loss coefficient H_v

The Ventilation heat loss coefficient H_v is calculated as follows:

$$H_v = 1200 \cdot q_v \cdot f_v \qquad [W/K] \qquad (F.12)$$

where: q_v = air flow rate caused by ventilation [m^3/s]
f_v = correction factor for the influence of radiant heating and temperature gradients [-]

with: $q_v = 0{,}001 \cdot A_{fl}$ [m^3/s] (F.13)

where: A_{fl} = employed surface [m^2]

Temperature correction factor f_v is given below:

f_v = 0 if the supply temperature is higher than the indoor design tempearture

fv = 1 for all systems without heat recory or preheating of ventilation air

$$f_v = \frac{\theta_a - \theta_t}{\theta_a - \theta_e} \quad \text{Systems with heat recovery or pre-heating of ventilation air} \qquad (F.14)$$

where: θ_a = temperature to be calculated [°C]
θ_e = outdoor design temperature according to 2.2 [°C]
θ_t = temperature supplied to the room (in case of heat recovery see annex C) [°C]

F.3 Calculation of the temperature in the crawling space

The indoor temperature θ_i is calculated with a heat baleance in the following way:

$$(H_{t,ie} + H_{t,ia} + H_{t,ig} + H_i) \cdot (\theta_i - \theta_e) = 0 \qquad (F.15)$$

where: $H_{t,ie}$ = transmission heat loss coefficient from space (i) to the exterior (e) through the building envelope, according to 3.2.2 [W/K]
$H_{t,ib}$ = transmission heat loss coefficient from space (i) to a adjacent space, according to 3.2.3 [W/K]
$H_{t,ig}$ = steady state ground transmission heat loss coefficient from heated space (i) to the ground (g), according to F.2.2 [W/K]
H_i = infiltration heat loss coefficient, according to F.3.15 [W/K]
θ_i = temperature of adjacent space (to be calculated) [°C]

θ_e = external design temperature according to 2.2 [°C]

F.3.1 Infiltration heat loss coefficient H_i

The infiltration heat loss coefficient H_i is calculated as follows:

$$H_i = 1200 \cdot q_{i,k} \cdot V / 3600 \quad [W/K] \qquad (F.16)$$

where: $q_{i,k}$ = number of air changes by infiltration (see table F.3) [1/h]
V = contents of crawling space [m^3]

Table F.3 Guideline for the number of air changes by infiltration $q_{i,k}$

Decription	$q_{i,k}$
little ventilation of crawling space	0,1
moderate ventilation of crawling space	0,2
strong ventilation of crawling space	0,5
unknown ventilation of crawling space	0,5

Annex G INPUT FORM

INPUT FORM DESIGN HEAT LOSS CALCULATION			
1. Project: .... 2. Place: .... 3. Contact:		Dossier no: .... Date:..	
Building			
4. main sizes	☐ length …….. m	☐ depth …….. m	☐ height ……… m
5a. Windows Frame type	☐ aluminium with thermal interruption ☐ aluminium without thermal interruption	☐ synthetic with thermal interruption ☐ synthetic with thermal interruption	☐ wood ☐ steell ☐ other ....
5b. Doors	☐ width …….. m ☐ height ……… m	☐ *U*-value = W/(m^2·K)	☐ next to each other ☐ opposite each other ☐ other
Transmission heat loss (Φ_t)			
6. Outdoor design conditions	☐ outdoor design temperature .... °C		
7. Heating system	☐ air heating HT*) ☐ air heating LT*) ☐ radiant heating; black tubes	☐ radiant heating; IR open stralers ☐ indirectly gestookte stralingspanelen ☐ floor heating ☐ radiators	
7a Number of air changes	☐ No destratification devices ☐ Destratification devices	n = …………. n = ………….	
8a internal design temperature	☐ ….. ºC ; continue at 9	☐ unknown, continue at 8b	
8b Activity and clothing	activity level ☐ low activity (1,7 MET) ☐ low activity (2,2 MET) ☐ moderate activityt (2,8 MET) ☐ high activityt (3,5 MET) ☐ very high activity (4 MET)	thermal resistance of the clothing ☐ 0,5 clo ☐ 0,7 clo ☐ 0,8 clo ☐ 0,9 clo ☐ 1,0 clo	
9. Temperature in adjacent space (θ_b)	☐ 10 °C (dwellings) ☐ 15 °C (shops , office building) ☐ 20 °C (health care buildings)	☐ …… °C	
10. ground floor	☐ floor above crawling space	☐ directly on the ground	☐ above outside air .
11. groundwater level	☐ more than 1 m below the floor	☐ against the floor	☐ between 0 and 1 m below the floor
HEAT LOSS CAUSED BY OUTDOOR AIR (Φ_v)			
12.air tightness	☐ air tight building	☐ leaky building	
13. Ventilation system	☐ - natural supply and natural extract ☐ - natural supply, mechanical extract	☐ mechanical supply, natural extract ☐ mechanical supply, mechanical extract	
14.temperature of the mechanically supplied air	θ_t = ... °C	☐ heat recovery with efficiency ……….%;	
ADDITIONAL CAPACITY FOR HEATING UP (Φ_o)			
15. Usage	☐ setback	☐ continuous use (go to 19.)	
16. Control	☐ self learning control (go to 19.)	☐ centrally controlled	☐ control idevice in each room
17a. Heating up time (Monday)	☐ 6 hour ☐ 4 hour	☐ 3 hour ☐ 2 hour	☐ 1 hour ☐ …… hour
17b. Heating up time (other days)	☐ 6 hour ☐ 4 hour	☐ 3 hour ☐ 2 hour	☐ 1 hour ☐ …… hour
18. Maximum setback	☐ …….. K	☐ free running	
CALCULATION OF SUPPLEMENTARY CAPACITY			
19. Material transit or input	Is there input or transit of materials/products? ☐ No, go to 22	☐yes, continuously	☐ yes, not continuously; go to 21
20. Gegevens materiaal	☐.... °C surface temperature	☐ m^2 surface of material	
21. Not continuous input of materials/products	☐ ………kg material/products ☐ …….. J/(kg·K) specific heat capacity	☐ …..…. °C temperature of the materials/products	☐ ..…….. h time to reach the room tenmperature
22.Heat from processes	Is there heat exchange from processes (hot or cold surfaces / products) ☐ No, go to 23	☐ yes	☐ ……. W electric consumption
23 Cold surfaces	Are there cold surfaces in the room ☐ No, continue at 24 ☐ yes	☐ ...…. °C surface temperature	☐ ……. m^2 cooled surface
24. Heat supply	☐ centrally ☐ decentrally		

Annex H BEDFORD FACTOR

Due to radiant influences the comfort temperature is in general X degree lower than the air temperature. For the estimation of value X there are several methods available. One of these methods is developed by Bedfort. This method is often used by manufacturers of radiant heating systems.

The contribution of radiation to the comfort temperature is calculated as follows:

$$\theta_c = \theta_l + f \cdot I_s \quad [°C] \qquad (H.1)$$

waarin: f = Bedford factor [K·m²/W]
I_s = radiation intensity in relation to the acual air temperature [W/m²]

In formula (J.1) the radiation intensity is expressed in relation to the acual air temperature. So the radiation intensity is relative not absolute. That why ΔI_s instead of I_s has been used in this annex.
$f \cdot \Delta I_s$ is the contribution of radiation to the comfort temperature. Formula (H.1) changes to

$$\theta_c = \theta_l + f \cdot \Delta I_s \quad [°C] \qquad (H.2)$$

The Bedford factor has (in principle) a constant value. Because there are two different ways of measuring the radiation intensity there are two Bedfort factors.

Measuring method A
The radiation intensity is mkeasured in 1 direction; from above, from the radiation source in the downward direction. In this case the Bedford factor f = 0,022 K·m²/W. Applied to formula (J.2):

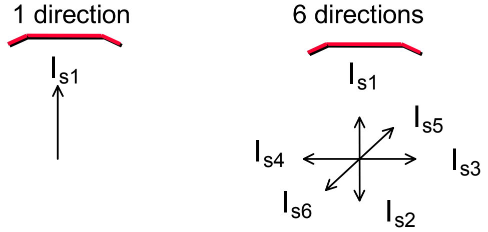
$$\theta_c = \theta_l + 0{,}022 \Delta I_s \quad [°C] \qquad (H.3)$$

There are also measuring instuments that measure the radiation intensity in two opposite directions. In this case the Bedford factor f = 0,026 K·m²/W.

Measuring method B
The radiation intensity wil be devided in 6 directions (3 dimensional). n this case the Bedfort factor is 0,072 K·m²/W. Applied to formule (H.2):

$$\theta_c = \theta_l + 0{,}072 \Delta I_s \quad [\qquad (H.4)$$

The different measuring methods are allustrated in figure H.1.



$f_{Bedfort}$ = 0,022 K·m²/W $f_{Bedfort}$ = 0,072 K·m²/W

Fig. H.1 Measuring method A (1 direction) and B (6 directions).

remark: The German DVWG Arbeitsblatt 638/I and II show other values. The values used in this annex have been measured at Gasunie and are also found in some articles in literature.

Annex I CALCULATION OF THE HEAT LOSS OF TUBES IN UNHEATED SPACES

The heat loss of tubes in unheated spaces strongly depends on the mean temperature of the fluid in the tubes and the insulation of the tubes.

The heat loss per metre tube is as follows:

$$\varphi = q_c + q_s \qquad \text{[W/m]}$$

where:

$$q_s = 5{,}67 \cdot 10^{-8} \cdot \varepsilon_s \cdot (T_{is}^4 - T_a^4) \cdot \pi \cdot (d_b + 2s) \qquad \text{[W/m]}$$

$$q_c = 1{,}35 \cdot \frac{(\theta_a - \theta_{is})^{1,25}}{(d_b + 2s)^{0,25}} \cdot \pi \cdot (d_b + 2s) \qquad \text{[W/m]}$$

where:

$$\theta_{is} = \theta_{bs} - \frac{q_s + q_c}{2\pi \cdot \lambda} \cdot ln(1 + \frac{2s}{d_b})$$

where:

φ	= heat loss per metre tube	[W/m]
T_a	= temperature of the surrounding	[K]
T_i	= surface temperature of the insulation	[K]
λ	= thermal conductivity of the insulation	[W/(m·K)]
d	= external diameter of the tube	[m]
q_c	= convective heat loss per metre tube	[W/m]
q_s	= radiant heat loss per metre tube	[W/m]
s	= thickness of the insulation	[m]
ε_s	= emission factor of the insulation	[-]
θ_{bs}	= mean temperature of the fluid in the tube	[°C]
θ_a	= temperature of the surrounding of the tube	[°C]
θ_{is}	= surface temperature of the insulation	[°C]

For thick skin tubes, different values of the thermal conductivity and thichness of the insulation, tables have been derived. The mean temperature of the fluid in the tubes is 80 °C.
For ε_s a default value of 0,5 has been used.

The total heat loss of a tube: $\Phi_{loss} = \varphi \cdot l$

waarin:

φ	= heat loss per metre with mean fluid temperature of 80 °C	[W/m]
l	= total length (in unheated space)	[m]

Indicative tables:
Het loss φ per metre tube with mean fluid temperature of 80 °C.
λ\thichness : both λ and the thickness are related to the insulation material.

Thick skin welded tubes
Tube diameter 26,9 mm
Temperature of the surrounding 5 °C
Heat loss per metre non insulated tube: 107,4 W

λ\thickness	10	20	30	40	50	60	70	80	90	100
0,030	20,9	14,0	11,3	9,7	8,8	8,0	7,5	7,1	6,8	6,5
0,035	23,7	16,1	13,0	11,3	10,1	9,4	8,7	8,3	7,9	7,6
0,040	26,5	18,2	14,7	12,8	11,5	10,6	10,0	9,4	9,0	8,6
0,045	29,1	20,2	16,4	14,3	12,9	11,9	11,2	10,6	10,1	9,7
0,050	31,6	22,1	18,1	15,8	14,3	13,2	12,3	11,7	11,2	10,7
0,055	34,0	24,0	19,7	17,3	15,6	14,4	13,6	12,8	12,3	11,8
0,060	36,4	25,9	21,3	18,7	16,9	15,7	14,7	13,9	13,3	12,8
0,065	38,6	27,7	22,9	20,1	18,3	16,9	15,9	15,1	14,4	13,8

Temperature of the surrounding 10 °C
Heat loss per metre non insulated tube: 100,2 W

λ\thickness	10	20	30	40	50	60	70	80	90	100
0,030	19,5	13,1	10,5	9,1	8,2	7,5	7,0	6,7	6,3	6,1
0,035	22,2	15,1	12,1	10,6	9,5	8,7	8,2	7,8	7,4	7,1
0,040	24,8	17,0	13,8	12,0	10,8	9,9	9,3	8,8	8,4	8,1
0,045	27,2	18,8	15,3	13,4	12,1	11,1	10,4	9,8	9,4	9,0
0,050	29,6	20,7	16,9	14,8	13,3	12,3	11,5	10,9	10,4	10,0
0,055	31,8	22,5	18,4	16,1	14,6	13,5	12,6	12,0	11,5	11,0
0,060	34,0	24,2	20,0	17,5	15,8	14,7	13,7	13,0	12,4	12,0
0,065	36,1	25,9	21,4	18,8	17,1	15,8	14,8	14,1	13,4	13,0

Tube diameter 33,7 mm
Temperature of the surrounding 5 °C
Heat loss per metre non insulated tube: 130,3 W

λ\thickness	10	20	30	40	50	60	70	80	90	100
0,030	24,7	16,2	12,9	11,0	9,8	9,0	8,4	7,9	7,5	7,2
0,035	28,0	18,6	14,8	12,7	11,4	10,5	9,7	9,2	8,7	8,3
0,040	31,2	21,0	16,8	14,5	13,0	11,9	11,1	10,4	9,9	9,5
0,045	34,3	23,3	18,7	16,2	14,5	13,3	12,4	11,7	11,1	10,6
0,050	37,2	25,5	20,6	17,8	16,0	14,7	13,7	13,0	12,3	11,8
0,055	40,0	27,7	22,5	19,5	17,5	16,1	15,0	14,2	13,5	13,0
0,060	42,7	29,9	24,3	21,1	19,0	17,5	16,3	15,4	14,7	14,1
0,065	45,3	32,0	26,1	22,7	20,4	18,9	17,6	16,7	15,9	15,2

Temperature of the surrounding 10 °C
Heat loss per metre non insulated tube: 121,6 W

λ\thickness	10	20	30	40	50	60	70	80	90	100
0,030	23,1	15,2	12,0	10,3	9,2	8,4	7,8	7,4	7,0	6,7
0,035	26,2	17,4	13,9	11,9	10,7	9,8	9,1	8,6	8,1	7,8
0,040	29,2	19,6	15,7	13,5	12,1	11,1	10,3	9,7	9,3	8,9
0,045	32,1	21,8	17,5	15,1	13,5	12,4	11,6	10,9	10,4	9,9
0,050	34,8	23,9	19,3	16,7	14,9	13,7	12,8	12,1	11,5	11,0
0,055	37,5	25,9	21,0	18,2	16,3	15,0	14,1	13,3	12,6	12,1
0,060	40,0	27,9	22,7	19,7	17,7	16,3	15,3	14,4	13,7	13,1
0,065	42,4	29,9	24,4	21,2	19,1	17,6	16,4	15,5	14,8	14,2

Tube diameter 42,4 mm
Temperature of the surrounding 5 °C
Heat loss per metre non insulated tube: 158,8 W

λ\thickness	10	20	30	40	50	60	70	80	90	100
0,030	29,5	19,0	14,8	12,6	11,1	10,1	9,4	8,8	8,3	7,9
0,035	33,5	21,8	17,1	14,6	12,9	11,8	10,9	10,2	9,7	9,2
0,040	37,2	24,5	19,4	16,5	14,7	13,4	12,4	11,7	11,0	10,5
0,045	40,8	27,2	21,6	18,4	16,4	15,0	13,9	13,0	12,4	11,8
0,050	44,3	29,8	23,8	20,3	18,1	16,6	15,4	14,4	13,7	13,1
0,055	47,6	32,3	25,9	22,2	19,8	18,1	16,8	15,8	15,0	14,3
0,060	50,8	34,8	28,0	24,1	21,5	19,7	18,3	17,2	16,3	15,6
0,065	53,8	37,2	30,0	25,9	23,2	21,2	19,7	18,6	17,6	16,8

Temperature of the surrounding 10 °C
Heat loss per metre non insulated tube: 148,3 W

λ\thickness	10	20	30	40	50	60	70	80	90	100
0,030	27,6	17,7	13,9	11,7	10,4	9,5	8,8	8,2	7,8	7,4
0,035	31,3	20,4	16,0	13,6	12,1	11,0	10,2	9,5	9,1	8,7
0,040	34,8	23,0	18,1	15,5	13,7	12,5	11,6	10,9	10,3	9,8
0,045	38,2	25,5	20,2	17,2	15,3	14,0	13,0	12,2	11,6	11,0
0,050	41,5	27,9	22,2	19,0	16,9	15,5	14,4	13,5	12,8	12,2
0,055	44,6	30,3	24,2	20,8	18,5	16,9	15,7	14,8	14,0	13,4
0,060	47,5	32,6	26,2	22,5	20,1	18,4	17,1	16,1	15,2	14,6
0,065	50,3	34,8	28,1	24,2	21,6	19,8	18,4	17,3	16,5	15,7

Tube diameter 48,3 mm
Temperature of the surrounding 5 °C
Heat loss per metre non insulated tube: 177,7 W

λ\thickness	10	20	30	40	50	60	70	80	90	100
0,030	32,7	20,8	16,2	13,6	12,0	10,9	10,0	9,4	8,9	8,5
0,035	37,1	23,9	18,7	15,8	13,9	12,7	11,7	10,9	10,3	9,8
0,040	41,3	26,9	21,1	17,9	15,8	14,4	13,3	12,5	11,8	11,2
0,045	45,2	29,8	23,5	20,0	17,7	16,1	14,9	13,9	13,2	12,5
0,050	49,0	32,7	25,8	22,0	19,5	17,8	16,4	15,4	14,6	13,9
0,055	52,6	35,4	28,1	24,0	21,4	19,5	18,0	16,9	16,0	15,3
0,060	56,1	38,1	30,4	26,0	23,1	21,1	19,6	18,4	17,4	16,6
0,065	59,4	40,8	32,6	28,0	24,9	22,8	21,1	19,8	18,7	17,9

Temperature of the surrounding 10 °C
Heat loss per metre non insulated tube: 166 W

λ\thickness	10	20	30	40	50	60	70	80	90	100
0,030	30,6	19,5	15,1	12,7	11,2	10,2	9,4	8,8	8,3	7,9
0,035	34,7	22,3	17,4	14,7	13,0	11,8	10,9	10,2	9,6	9,2
0,040	38,6	25,2	19,7	16,7	14,8	13,4	12,4	11,6	11,0	10,5
0,045	42,3	27,9	22,0	18,6	16,5	15,0	13,9	13,0	12,3	11,7
0,050	45,9	30,5	24,2	20,6	18,2	16,6	15,3	14,4	13,6	13,0
0,055	49,3	33,2	26,3	22,4	20,0	18,2	16,9	15,8	14,9	14,3
0,060	52,6	35,7	28,4	24,3	21,7	19,7	18,3	17,2	16,2	15,5
0,065	55,7	38,1	30,5	26,1	23,3	21,3	19,7	18,5	17,6	16,7

Tube diameter 60,3 mm

Temperature of the surrounding 5 °C
Heat loss per metre non insulated tube: 215,4 W

λ\thickness	10	20	30	40	50	60	70	80	90	100
0,030	39,2	24,6	18,8	15,7	13,8	12,4	11,4	10,6	10,0	9,5
0,035	44,5	28,2	21,7	18,2	15,9	14,3	13,2	12,3	11,6	11,0
0,040	49,4	31,7	24,5	20,6	18,1	16,3	15,0	14,0	13,2	12,5
0,045	54,1	35,1	27,3	23,0	20,2	18,3	16,8	15,7	14,7	14,0
0,050	58,6	38,4	30,0	25,3	22,3	20,2	18,6	17,3	16,3	15,5
0,055	62,9	41,6	32,7	27,6	24,4	22,1	20,4	19,0	17,9	17,0
0,060	67,0	44,8	35,3	29,9	26,4	24,0	22,1	20,7	19,5	18,5
0,065	70,9	47,8	37,8	32,2	28,4	25,8	23,8	22,3	21,0	20,0

Temperature of the surrounding 10 °C
Heat loss per metre non insulated tube: 201,3 W

λ\thickness	10	20	30	40	50	60	70	80	90	100
0,030	36,7	23,0	17,6	14,7	12,8	11,5	10,6	9,9	9,3	8,8
0,035	41,6	26,4	20,3	17,0	14,9	13,4	12,3	11,5	10,8	10,3
0,040	46,3	29,6	22,9	19,2	16,9	15,2	14,0	13,1	12,3	11,7
0,045	50,7	32,8	25,5	21,5	18,9	17,1	15,7	14,6	13,8	13,1
0,050	54,9	35,9	28,1	23,7	20,9	18,8	17,4	16,2	15,3	14,5
0,055	58,9	39,0	30,6	25,9	22,8	20,6	19,0	17,8	16,7	15,9
0,060	62,7	41,9	33,0	28,0	24,7	22,4	20,6	19,3	18,2	17,3
0,065	66,4	44,7	35,4	30,1	26,6	24,1	22,3	20,8	19,6	18,6

Tube diameter 76,1 mm
Temperature of the surrounding 5 °C
Heat loss per metre non insulated tube: 263,8 W

λ\thickness	10	20	30	40	50	60	70	80	90	100
0,030	47,8	29,4	22,2	18,4	16,0	14,3	13,0	12,1	11,3	10,7
0,035	54,0	33,7	25,7	21,3	18,5	16,6	15,2	14,0	13,1	12,5
0,040	60,0	37,9	29,0	24,1	21,0	18,8	17,2	16,0	15,0	14,1
0,045	65,7	41,9	32,2	26,9	23,5	21,1	19,3	17,9	16,8	15,9
0,050	71,1	45,9	35,4	29,6	25,9	23,2	21,3	19,8	18,6	17,6
0,055	76,2	49,7	38,5	32,3	28,3	25,4	23,3	21,7	20,4	19,3
0,060	81,1	53,4	41,6	34,9	30,6	27,6	25,3	23,5	22,1	21,0
0,065	85,8	57,0	44,6	37,5	33,0	29,7	27,3	25,4	23,8	22,6

Temperature of the surrounding 10 °C
Heat loss per metre non insulated tube: 246,6 W

λ\thickness	10	20	30	40	50	60	70	80	90	100
0,030	44,7	27,5	20,8	17,2	14,9	13,4	12,2	11,3	10,6	10,0
0,035	50,6	31,5	24,0	19,9	17,3	15,5	14,2	13,1	12,3	11,6
0,040	56,2	35,4	27,1	22,5	19,6	17,6	16,1	14,9	14,0	13,2
0,045	61,5	39,2	30,1	25,1	21,9	19,7	18,0	16,7	15,7	14,8
0,050	66,6	42,9	33,1	27,7	24,2	21,7	19,9	18,5	17,4	16,4
0,055	71,4	46,5	36,1	30,2	26,4	23,8	21,8	20,3	19,0	18,0
0,060	76,0	50,0	38,9	32,7	28,7	25,8	23,7	22,0	20,7	19,5
0,065	80,3	53,3	41,7	35,1	30,8	27,8	25,5	23,7	22,3	21,1

Tube diameter 88,9 mm

Temperature of the surrounding 5 °C
Heat loss per metre non insulated tube: 302,1 W

λ\thickness	10	20	30	40	50	60	70	80	90	100
0,030	54,6	33,3	25,0	20,6	17,8	15,8	14,4	13,3	12,4	11,7
0,035	61,8	38,1	28,8	23,8	20,6	18,3	16,7	15,4	14,4	13,6
0,040	68,5	42,9	32,5	26,9	23,3	20,8	19,0	17,5	16,4	15,5
0,045	75,0	47,4	36,2	30,0	26,0	23,3	21,2	19,6	18,4	17,3
0,050	81,1	51,9	39,7	33,0	28,7	25,7	23,4	21,7	20,3	19,2
0,055	86,9	56,2	43,2	36,0	31,4	28,1	25,7	23,8	22,3	21,0
0,060	92,4	60,3	46,6	39,0	34,0	30,5	27,9	25,8	24,2	22,9
0,065	97,7	64,4	50,0	41,8	36,5	32,8	30,0	27,8	26,1	24,7

Temperature of the surrounding 10 °C
Heat loss per metre non insulated tube: 282,6 W

λ\thickness	10	20	30	40	50	60	70	80	90	100
0,030	51,1	31,2	23,4	19,2	16,6	14,8	13,4	12,4	11,6	10,9
0,035	57,8	35,7	27,0	22,2	19,2	17,1	15,6	14,4	13,4	12,7
0,040	64,2	40,1	30,4	25,2	21,8	19,5	17,7	16,4	15,3	14,4
0,045	70,2	44,4	33,8	28,0	24,3	21,7	19,8	18,4	17,2	16,2
0,050	75,9	48,5	37,2	30,9	26,8	24,0	21,9	20,3	19,0	17,9
0,055	81,4	52,6	40,4	33,7	29,3	26,3	24,0	22,2	20,8	19,6
0,060	86,6	56,5	43,6	36,4	31,8	28,5	26,0	24,1	22,6	21,3
0,065	91,6	60,3	46,7	39,1	34,2	30,7	28,0	26,0	24,4	23,0

Tube diameter 114,3 mm
Temperature of the surrounding 5 °C
Heat loss per metre non insulated tube: 376,6 W

λ\thickness	10	20	30	40	50	60	70	80	90	100
0,030	68,1	41,0	30,5	24,8	21,2	18,8	17,0	15,6	14,5	13,6
0,035	77,0	46,9	35,0	28,6	24,5	21,7	19,7	18,1	16,8	15,8
0,040	85,4	52,7	39,5	32,4	27,9	24,7	22,4	20,6	19,2	17,9
0,045	93,3	58,2	44,0	36,1	31,0	27,6	25,0	23,0	21,4	20,1
0,050	100,8	63,6	48,2	39,7	34,3	30,5	27,6	25,5	23,7	22,3
0,055	107,9	68,9	52,4	43,3	37,4	33,3	30,2	27,9	26,0	24,4
0,060	114,8	73,9	56,5	46,8	40,5	36,1	32,8	30,3	28,2	26,6
0,065	121,2	78,8	60,6	50,3	43,5	38,8	35,3	32,6	30,4	28,7

Temperature of the surrounding 10 °C
Heat loss per metre non insulated tube: 352,4 W

λ\thickness	10	20	30	40	50	60	70	80	90	100
0,030	63,8	38,3	28,4	23,2	19,9	17,5	15,8	14,6	13,6	12,7
0,035	72,1	43,9	32,8	26,7	23,0	20,3	18,4	16,9	15,7	14,7
0,040	79,9	49,3	37,0	30,3	26,0	23,1	20,9	19,2	17,9	16,8
0,045	87,4	54,5	41,1	33,8	29,0	25,7	23,4	21,5	20,0	18,8
0,050	94,4	59,6	45,1	37,2	32,0	28,4	25,8	23,8	22,2	20,8
0,055	101,1	64,5	49,1	40,5	35,0	31,1	28,2	26,0	24,3	22,8
0,060	107,5	69,2	52,9	43,8	37,8	33,7	30,7	28,2	26,4	24,8
0,065	113,6	73,9	56,7	47,0	40,7	36,3	33,0	30,5	28,4	26,8

Tube diameter 139,7 mm
Temperature of the surrounding 5 °C
Heat loss per metre non insulated tube: 449,3 W

λ\thickness	10	20	30	40	50	60	70	80	90	100
0,030	63,8	38,3	28,4	23,2	19,9	17,5	15,8	14,6	13,6	12,7
0,035	72,1	43,9	32,8	26,7	23,0	20,3	18,4	16,9	15,7	14,7
0,040	79,9	49,3	37,0	30,3	26,0	23,1	20,9	19,2	17,9	16,8
0,045	87,4	54,5	41,1	33,8	29,0	25,7	23,4	21,5	20,0	18,8
0,050	94,4	59,6	45,1	37,2	32,0	28,4	25,8	23,8	22,2	20,8
0,055	101,1	64,5	49,1	40,5	35,0	31,1	28,2	26,0	24,3	22,8
0,060	107,5	69,2	52,9	43,8	37,8	33,7	30,7	28,2	26,4	24,8
0,065	113,6	73,9	56,7	47,0	40,7	36,3	33,0	30,5	28,4	26,8

Temperature of the surrounding 10 °C
Heat loss per metre non insulated tube s: 420,7 W

λ\thickness	10	20	30	40	50	60	70	80	90	100
0,030	76,4	45,5	33,5	27,1	23,0	20,3	18,2	16,7	15,4	14,4
0,035	86,3	52,1	38,6	31,2	26,6	23,5	21,1	19,4	17,9	16,8
0,040	95,6	58,4	43,5	35,3	30,2	26,6	24,0	22,0	20,4	19,1
0,045	104,4	64,6	48,3	39,4	33,7	29,7	26,8	24,6	22,9	21,4
0,050	112,8	70,5	53,0	43,3	37,1	32,8	29,7	27,2	25,3	23,6
0,055	120,7	76,3	57,6	47,2	40,6	35,9	32,4	29,7	27,6	25,9
0,060	128,3	81,9	62,1	51,0	43,9	38,9	35,2	32,3	30,0	28,1
0,065	135,5	87,3	66,5	54,8	47,2	41,9	37,9	34,9	32,4	30,4

Tube diameter 168,3 mm
Temperature of the surrounding 5 °C
Heat loss per metre non insulated tube: 529,7 W

λ\thickness	10	20	30	40	50	60	70	80	90	100
0,030	96,6	57,2	41,8	33,6	28,4	24,9	22,3	20,4	18,8	17,5
0,035	109,1	65,4	48,1	38,8	32,9	28,8	25,9	23,6	21,8	20,3
0,040	120,7	73,4	54,2	43,8	37,3	32,7	29,4	26,8	24,8	23,1
0,045	131,7	81,0	60,3	48,8	41,6	36,5	32,9	30,0	27,8	25,9
0,050	142,2	88,4	66,1	53,7	45,8	40,3	36,3	33,2	30,7	28,7
0,055	152,1	95,6	71,8	58,5	50,0	44,1	39,7	36,3	33,6	31,4
0,060	161,6	102,5	77,3	63,2	54,1	47,8	43,0	39,4	36,5	34,1
0,065	170,5	109,3	82,8	67,8	58,2	51,4	46,3	42,5	39,4	36,8

Temperature of the surrounding 10 °C
Heat loss per metre non insulated tube: 496,1 W

λ\thickness	10	20	30	40	50	60	70	80	90	100
0,030	90,5	53,5	39,1	31,4	26,6	23,3	20,8	19,0	17,6	16,3
0,035	102,2	61,2	45,0	36,3	30,8	27,0	24,2	22,1	20,4	19,0
0,040	113,1	68,7	50,7	41,0	34,8	30,6	27,5	25,0	23,1	21,6
0,045	123,5	75,9	56,4	45,7	38,9	34,1	30,7	28,1	25,9	24,2
0,050	133,3	82,8	61,8	50,3	42,8	37,7	33,9	31,0	28,7	26,8
0,055	142,7	89,5	67,2	54,7	46,7	41,2	37,1	33,9	31,4	29,4
0,060	151,5	96,1	72,4	59,1	50,6	44,7	40,2	36,8	34,0	31,9
0,065	159,9	102,4	77,5	63,5	54,4	48,1	43,3	39,7	36,7	34,4

Tube diameter 219,1 mm
Temperature of the surrounding 5 °C
Heat loss per metre non insulated tube: 669,2 W

λ\thickness	10	20	30	40	50	60	70	80	90	100
0,030	123,2	72,3	52,5	41,9	35,2	30,7	27,3	24,8	22,8	21,1
0,035	138,9	82,7	60,3	48,3	40,7	35,4	31,6	28,7	26,3	24,5
0,040	153,7	92,7	68,0	54,6	46,0	40,2	35,9	32,6	30,0	27,9
0,045	167,7	102,2	75,5	60,7	51,4	44,9	40,1	36,5	33,6	31,2
0,050	180,8	111,6	82,7	66,8	56,5	49,5	44,3	40,3	37,1	34,5
0,055	193,3	120,5	89,8	72,6	61,7	54,0	48,4	44,0	40,6	37,8
0,060	205,1	129,2	96,7	78,5	66,8	58,5	52,4	47,8	44,1	41,1
0,065	216,3	137,7	103,5	84,2	71,7	63,0	56,5	51,5	47,5	44,3

Temperature of the surrounding 10 °C
Heat loss per metre non insulated tube: 627,4 W

λ\thickness	10	20	30	40	50	60	70	80	90	100
0,030	115,4	67,7	49,1	39,1	32,9	28,6	25,5	23,1	21,2	19,8
0,035	130,2	77,4	56,5	45,1	38,0	33,1	29,5	26,8	24,6	22,8
0,040	144,1	86,7	63,6	51,0	43,1	37,6	33,5	30,5	28,1	26,0
0,045	157,1	95,8	70,6	56,8	48,0	41,9	37,5	34,1	31,3	29,1
0,050	169,6	104,4	77,4	62,4	52,9	46,3	41,4	37,6	34,6	32,2
0,055	181,3	112,9	84,0	68,0	57,7	50,6	45,3	41,1	38,0	35,2
0,060	192,4	121,1	90,5	73,4	62,5	54,8	49,1	44,7	41,2	38,3
0,065	203,0	128,9	96,9	78,8	67,0	58,9	52,8	48,2	44,4	41,4