Building Serv. Eng. Res. Technol. 11(2) 49–56 (1990) Printed in Great Britain

#4550

Summary In most European countries transmission heat losses through external building elements have been calculated for many years on the basis of an ill-defined internal temperature, but with constant heat exchange coefficients at the inner side of the building elements. The paper concludes that constant heat exchange coefficients are satisfactory if dry resultant temperature is taken as the internal temperature. The advantage of this usage is that in most cases the dry resultant temperature is known *a priori* because it corresponds for practical purposes with the derived confort temperature in the rooms.

Building heat loss calculations: Choice of internal temperature and of heat exchange coefficient h_i

J Uyttenbroeck Ir
Centre Scientifique et Technique de la Construction, rue d'Arlon 53 (boite 10), B-1040 Bruxelles, Belgium

Received 17 July 1989†

1 Introduction

The German Standard *DIN 4701*[2] of 1959 indicated that the appropriate internal temperature for calculating transmission heat losses is the internal air temperature. The standard also fixed the heat exchange coefficient h_i at the constant value of 8.12 W m^{-2} K^{-1} for vertical building elements.

In 1966 the Association of the French heating and ventilating engineers (AICVF) published a new method for the calculation of the heat losses[3]. In this text it was clearly stated that the transmission heat losses should be calculated on the basis of the comfort temperature, which is nearly equal to the dry resultant temperature (the mean of the air temperature and of the mean radiant temperature of all the surfaces surrounding the room). It was also stated that a constant heat exchange coefficient $h_i = 8.9$ W m^{-2} K^{-1} should be used.

This problem has been studied in detail in a paper published by the CSTC (Belgium)[4] in 1971. This study was based on a large number of computer calculations taking into account radiative heat transfer between all the surfaces of the room and the convective heat exchange between these surfaces and the air in the room. The aim of this study was to verify the new proposed French method; the results proved clearly that transmission losses could be calculated on the basis of the dry resultant temperature with practically constant heat exchange coefficients h_i.

This study also showed that if transmission losses are calculated on the basis of the room air temperature (this is possible of course), then variable heat exchange coefficients have to be used.

The facts that the room air temperature depends largely on the general insulation level of the room (for a given comfort level) and that this air temperature is never known *a priori* constituted another disadvantage for its use. The comfort temperature, on the other hand, is always known *a priori*. These conclusions have been taken into account in several standards[5–7].

† The paper was first published in Dutch as Reference 1.

For practical purposes, however, it seems that this new idea was not generally accepted and that many engineers and contractors were continuing to consider the room air temperature as the internal temperature. The aim of this text is to clarify this new approach not only on the basis of many computer calculations but from first principles. Several simplifying hypotheses are also explained.

2 Hypothesis and definitions

2.1 Comfort temperature

We accept that the comfort temperature in a room is given by the dry resultant temperature which is defined by

$$\theta_{rs} = \frac{\theta_a + \theta_{rm}}{2} \text{ (°C)} \quad (1)$$

where θ_a is the room air temperature (°C) and θ_{rm} is the mean radiant temperature of all the surrounding elements of the room (°C).

2.2 Room air temperature θ_a

We accept that the room air temperature is practically constant in the whole occupied zone of the room. This hypothesis is acceptable for warm air heating systems or for mechanical ventilation systems with relatively high air speeds in the inlets.

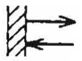
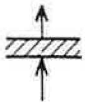
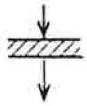
2.3 Mean radiant temperature θ_{rm}

We take as the mean radiant temperature of all the surrounding surfaces of a room the mean weighted value of the surface temperature:

$$\theta_{rm} = \frac{A_1\theta_1 + A_2\theta_2 + \ldots + A_n\theta_n}{A_1 + A_2 + \ldots + A_n} \text{ (°C)} \quad (2)$$

In this expression the values A_j represent the areas (in m^2) of all the surfaces enveloping the room and the values θ_j represent the surface temperatures of these elements. The definition of θ_{rm} following equation 2 is only valid for a central zone in a room which is approximately cubic, and which is delimited by surfaces with the same emissivity factor for longwave infrared radiation.

Table 1 h_c (W m^{-2} K^{-1}) for free or natural convection

References	Building element and heat flow configuration		
			
Kollmar and Liese[8]	$2.0\ (\theta_a - \theta_1)^{0.25}$	$2.6\ (\theta_a - \theta_1)^{0.25}$	$0.6\ (\theta_a - \theta_1)^{0.25}$
ASHRAE†[9]	$1.31\ (\theta_a - \theta_1)^{0.33}$	$1.52\ (\theta_a - \theta_1)^{0.33}$	—
Davis and Griffith[10]	$1.97\ (\theta_a - \theta_1)^{0.25}$	$2.63\ (\theta_a - \theta_1)^{0.25}$	$1.31\ (\theta_a - \theta_1)^{0.25}$

† Mean $\theta = 21°C$

3 Convective heat transfer between room air and the internal face of an enveloping room element

3.1 *Convective heat exchange coefficient h_c*

Consider an enveloping building element of a room. The temperature of the internal face of this element is θ_1. If the air temperature in the room is θ_a, the convective heat transfer between the room air and the inner surface is given by

$$q_c = h_c(\theta_a - \theta_1) \qquad (\mathrm{W\,m^{-2}}) \tag{3}$$

where q_c is the heat flow density by convection (W m^{-2}), θ_a is the room air temperature (°C), θ_1 is the surface temperature of the element under consideration (°C), h_c is the convective heat exchange coefficient (W m^{-2} K^{-1}).

3.2 *h_c for free or natural convection*

Table 1 gives expressions for h_c proposed by several sources.

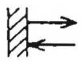
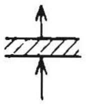
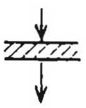
3.3 *Values of h_c for free or natural convection*

For heat loss calculations it seems acceptable to choose h_c values which probably overestimate the real values slightly.

For this reason we have chosen the expressions proposed by Davis and Griffith[10] (Table 1).

The Griffith–Davis formulae correspond very well with the Kolmar–Liese formulae, at least in two cases. On the basis of the Griffith–Davis formulae we have calculated the numerical values of h_c for several values of the temperature difference $\Delta\theta = \theta_a - \theta_1$ (see Table 2). Note that these formulae are generally valid for a mean temperature of 20°C and for a temperature difference $\Delta\theta \leq 10 \ldots 15$ K.

Table 2 h_c (W m^{-2} K^{-1}) for free convection[10]

Building element and heat flow configuration	Formula	$\Delta\theta$ (K) 2	4	8	10
	$h_c = 1.97\ (\Delta\theta)^{0.25}$	2.34	2.78	3.31	3.50
	$h_c = 2.63\ (\Delta\theta)^{0.25}$	3.13	3.72	4.42	4.68
	$h_c = 1.31\ (\Delta\theta)^{0.25}$	1.56	1.85	2.20	2.33

4 Radiant heat transfer between two bodies or surfaces

4.1 *Simplifications*

To permit manual calculations only two bodies or surfaces are considered. One body or surface is warmer and has an area of A_i (m^2), a surface temperature θ_i (°C) and an emissivity ε_i. The other body or surface is colder and has an area A_e (m^2), a surface temperature θ_e (°C) and an emissivity ε_e.

We further only consider cases where either the warmer body or surface of area A_i is completely surrounded by the colder body or surface of area A_e (Figure 1), or both surfaces of areas A_i and A_e surround the room completely (Figure 2).

Among all the possible cases the following extremes have received special attention. Case 1 is a room with one external wall and five internal walls or partitions (Figure 2(a)). Case 2 is a room with one internal wall and five external walls or partitions (Figure 2(b)).

4.2 *Radiant heat exchange coefficient h_r between surface areas A_i and A_e, calculated on A_e*

On the hypothesis that the room is completely delimited by the two surface areas A_i and A_e[10] the radiant heat flux $\phi_{i\to e}$ (W) between the warm area A_i and the colder area A_e can be calculated by the formulae of Table 3.

Once $\phi_{i\to e}$ is known, the radiant heat flux density in the colder area A_e is found from

$$q_{re} = \frac{\phi_{i\to e}}{A_e}\ (\mathrm{W\,m^{-2}})$$

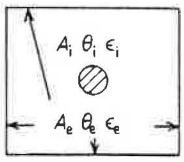


Figure 1 Warmer body (surface area A_i) completely surrounded by colder body (surface area A_e)

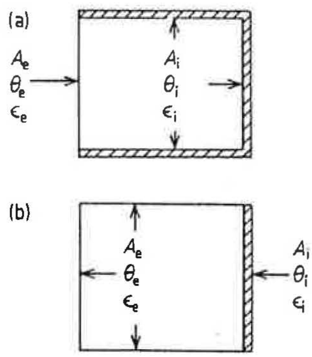


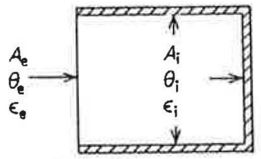
Figure 2 (*a*) Case 1: Room with one external wall and five internal walls or partitions; (*b*) Case 2: Room with one internal wall and five external walls or partitions

Table 3 Radiant heat exchange between surface areas A_i and A_e

Description	Formulae

Case 1
One external element (A_e, θ_e, ε_e) and five internal elements (A_i, θ_i, ε_i)

$$\phi_{i\to e} = \frac{CF_t(\theta_i - \theta_e)}{(1-\varepsilon_i)/A_i\varepsilon_i + (1-\varepsilon_e)/A_e\varepsilon_e + A_e^{-1}} \quad \text{(W)} \qquad (6)$$

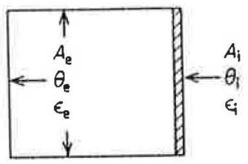


$$q_{re} = \frac{\phi_{i\to e}}{A_e} = \frac{CF_t(\theta_i - \theta_e)}{\varepsilon_e^{-1} + (A_e/A_i)(\varepsilon_i^{-1} - 1)} \quad \text{(W)} \qquad (7)$$

$$(h_r)_e = \frac{CF_t}{\varepsilon_e^{-1} + (A_e/A_i)(\varepsilon_i^{-1} - 1)} \quad (\text{W m}^{-2}) \qquad (8)$$

Case 2
One internal element (A_i, θ_i, ε_i) and five external elements (A_e, θ_e, ε_e)

$$\phi_{i\to e} = \frac{CF_t(\theta_i - \theta_e)}{(1-\varepsilon_i)/A_i\varepsilon_i + (1-\varepsilon_e)/A_e\varepsilon_e + A_i^{-1}} \quad \text{(W)} \qquad (9)$$



$$q_{re} = \frac{\phi_{i\to e}}{A_e} = \frac{CF_t(\theta_i - \theta_e)}{\varepsilon_e^{-1} + (A_e/A_i)\varepsilon_i^{-1} - 1} \quad (\text{W m}^{-2}) \qquad (10)$$

$$(h_r)_e = \frac{CF_t}{\varepsilon_e^{-1} + (A_e/A_i)\varepsilon_i^{-1} - 1} \quad (\text{W m}^{-2}) \qquad (11)$$

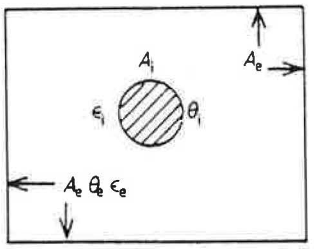
Case 3
Six external elements — No radiant exchange because $\theta_i = \theta_e$

Table 4 Radiant heat exchange in special cases

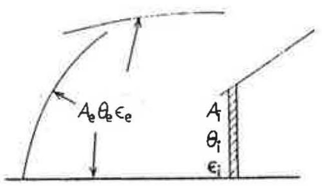
Description	Formulae

Case 4
Warm body of area A_i surrounded by colder body of area A_e

$$\phi_{i\to e} = \frac{CF_t(\theta_i - \theta_e)}{(1-\varepsilon_i)/A_i\varepsilon_i + (1-\varepsilon_e)/A_e\varepsilon_e + A_i^{-1}} \quad \text{(W)} \qquad (12)$$

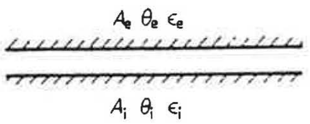


$$q_{ri} = \frac{\phi_{i\to e}}{A_i} = \frac{CF_t(\theta_i - \theta_e)}{\varepsilon_i^{-1} + (A_i/A_e)(\varepsilon_e^{-1} - 1)} \quad (\text{W m}^{-2}) \qquad (13)$$



$$(h_r)_i = \frac{CF_t}{\varepsilon_i^{-1} + (A_i/A_e)(\varepsilon_e^{-1} - 1)} \quad (\text{W m}^{-2}\ \text{K}^{-1}) \qquad (14)$$

Case 5
Two parallel planes; $A_i = A_e = A$



$$\phi_{i\to e} = \frac{ACF_t(\theta_i - \theta_e)}{\varepsilon_i^{-1} + \varepsilon_e^{-1} - 1} \quad \text{(W)} \qquad (15)$$

$$q_{ri} = q_{re} = \frac{CF_t(\theta_i - \theta_e)}{\varepsilon_i^{-1} + \varepsilon_e^{-1} - 1} \quad (\text{W m}^{-2}) \qquad (16)$$

$$(h_r)_i = (h_r)_e = \frac{CF_t}{\varepsilon_i^{-1} + \varepsilon_e^{-1} - 1} \quad (\text{W m}^{-2}\ \text{K}^{-1}) \qquad (17)$$

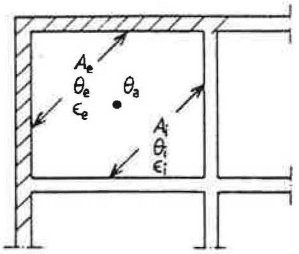


Figure 3

Table 3 also gives expressions for the heat flux density q_{re} and for the radiant heat exchange coefficient $(h_r)_e$ for the colder area A_e. C in these expressions is the Stefan–Boltzman constant

$$C = 5.67\ \text{W m}^2\ \text{K}^{-4} \tag{4}$$

and the parameter F_t is the temperature factor

$$F_t = \frac{(T_i/100)^4 - (T_e/100)^4}{\theta_i - \theta_e} \tag{5}$$

In equation 5 T_i and T_e are the absolute temperatures in K of the areas A_i and A_e.

4.3 Special cases of radiant heat exchange

In Table 4 some important practical situations are given for the case where two bodies or surfaces exchange heat by radiation, and for which one body is completely surrounded by the other, or for which the two surfaces both surround the same room or environment.

If in case 4 of Table 4 the surface of the warmer body A_i is very small compared with the surrounding area A_e, the ratio A_i/A_e can be neglected. This leads to formulae (13′) and (14′) (based on the warm surface side A_i):

$$q_{ri} = \varepsilon_i C F_t(\theta_i - \theta_e) \quad (\text{W m}^{-2}) \tag{13′}$$

and

$$(h_r)_i = \varepsilon_i C F_t \quad (\text{W m}^{-2}\ \text{K}^{-1}) \tag{14′}$$

It can thus be concluded that in such cases it makes no sense to decrease the emissivity of the larger surrounding area A_e in order to decrease the radiant heat losses of the warm body A_i.

5 Global heat exchange coefficient h_i based on the dry resultant temperature θ_{rs}

5.1 Heat flow density at the inner surface of an external building element

Consider a room with external building elements of area $A_e(\text{m}^2)$ all at the same surface temperature θ_e and internal building elements of area A_i (m^2) all at the same surface temperature θ_i (Figure 3).

The internal faces of the external elements have an emissivity ε_e and the internal faces of the internal elements have an emissivity ε_i.

The heat flux density arriving at the external elements both by radiation and convection is given by

$$q_e = q_{re} + q_{ce}\ (\text{W m}^{-2}) \tag{18}$$

where q_{re} is the radiant heat flux density and q_{ce} the convective heat flux density. Taking into account formulae 3, 7 and 8, expression 18 can be written as

$$q_e = h_{re}(\theta_i - \theta_e) + h_{ce}(\theta_a - \theta_e) \quad (\text{W m}^{-2}) \tag{19}$$

In order to calculate q_e it thus is necessary to know the values of h_{re} and h_{ce} and of θ_i, θ_e and θ_a.

5.2 Expressions for h_i

It seems reasonable to ask whether the heat flux density q_e (given by equation 19) cannot be obtained following a much simpler formula such as 20:

$$q_e = h_i(\theta_{rs} - \theta_e)\,(\text{W m}^{-2}) \tag{20}$$

where h_i should be a global heat exchange coefficient, taking into account both convective and radiative heat exchanges and where θ_{rs} is simply the dry resultant temperature.

To fix the value of the unknown global heat exchange coefficient h_i equations 19 and 20 are set equal:

$$h_{re}(\theta_i - \theta_e) + h_{ce}(\theta_a - \theta_e) = h_i(\theta_{rs} - \theta_e)$$

This leads to

$$h_i = h_{re}\frac{\theta_i - \theta_e}{\theta_{rs} - \theta_e} + h_{ce}\frac{\theta_a - \theta_e}{\theta_{rs} - \theta_e}\,(\text{W m}^{-2}\ \text{K}^{-1}) \tag{21}$$

Equation 21 can also be written as

$$h_i = h_{ri} + h_{ci}\,(\text{W m}^{-2}\ \text{K}^{-1}) \tag{22}$$

5.3 Calculation of h_i from equation 21

To follow the evolution of h_i, one can apply equation 21 to several simple but rather extreme cases. For each case all the relevant parameters are fixed: h_{re}, h_{ce}, θ_i, θ_e, θ_a and θ_{rs}. Using these values the corresponding h_i value can be calculated from equation 21. For example let us take for the comfort temperature $\theta_{rs} = 20°\text{C}$; θ_e and θ_i can then be chosen freely. As long as the U-values of the building elements (of areas A_e and A_i) remain undefined, and as long as the outdoor temperature or the indoor temperature of the adjacent rooms are not fixed, θ_e and θ_i may take any values. Once θ_e and θ_i are fixed the room air temperature θ_a can be calculated from formulae 1 and 2. With θ_a and θ_e known, the convective heat exchange coefficient on the cold area (A_e, h_{ce}) can be calculated from the formulae of Table 2. If the dimensions of the room and the areas A_i and A_e are known, the value of $(h_e)_r$ can be calculated by the formulae of Table 3.

Suppose we wish to calculate the global heat exchange coefficient h_i for an external vertical wall of a room with dimensions $6 \times 4 \times 3\ \text{m}^3$.

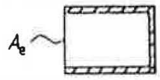
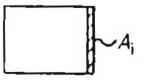
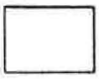
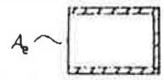
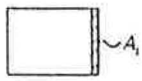
(*a*) Consider a room with only one external vertical wall: $A_e = 4 \times 3\ \text{m}^2 = 12\ \text{m}^2$. All the other delimiting elements of the room are internal elements; $A_i = 96\ \text{m}^2$.

(*b*) Suppose that a room with the same dimensions only has one internal wall with $A_i = 3 \times 4\ \text{m}^2 = 12\ \text{m}^2$. In that case all the other elements are external elements with $A_e = 96\ \text{m}^2$. In this case we have also calculated the h_i value for the vertical external wall of $3 \times 4\ \text{m}^2$.

(*c*) Suppose that all the building elements delimiting the room of $6 \times 4 \times 3\ \text{m}^3$ are external. In this case $A_e = 108\ \text{m}^2$ and $A_i = 0\ \text{m}^2$. In this case we also calculate the h_i value for the external wall of $4 \times 3\ \text{m}^2$.

(*d*) In cases (*a*) and (*b*) we can also consider two extreme heating systems. The first is a warm-air system for which we know that the surface temperature of the internal

Table 5 Calculation of h_i by formula 21 for a vertical element

Heating system	Room characteristics	Chosen θ: θ_e (°C)	Chosen θ: θ_i (°C)	θ_r† (°C)	h_r‡ (W m^{-2} K^{-1})	h_c§ (W m^{-2} K^{-1})	Calculated from formula 21: h_{ri} (W m^{-2} K^{-1})	h_{ci} (W m^{-2} K^{-1})	h_i (W m^{-2} K^{-1})
Warm air	$6 \times 4 \times 3$ m^3, one external	10	17	23.8	4.8	3.80	3.36	5.25	8.60
	element ($A_e = 12$ m^2), five	15	18	22.3	4.8	3.24	2.88	4.73	7.61
	internal elements ($A_i = 96$ m^2)	17	19	21.2	4.8	2.82	3.20	3.95	7.15
									
Warm air	$6 \times 4 \times 3$ m^3, one internal	15	18	24.67	0.6	3.47	0.36	6.71	7.07
	element ($A_i = 12$ m^2), five	17	19	22.80	0.6	3.06	0.40	5.91	6.31
	external elements	18	19	21.89	0.6	2.77	0.30	5.39	5.69
	($A_e = 96$ m^2)								
									
Warm air	$6 \times 4 \times 3$ m^3, six external	15	—	25	0	3.50	—	7.00	7.00
	elements ($A_e = 108$ m^2,	18	—	22	0	2.79	—	5.58	5.58
	$A_i = 0$ m^2)								
									
Radiant	$6 \times 4 \times 3$ m^3, one external	10	23	18.45	4.8	3.36	6.24	2.84	9.08
	element ($A_e = 12$ m^2), five	15	22	18.78	4.8	2.75	6.72	2.08	8.80
	internal elements ($A_i = 96$ m^2)	17	21	19.45	4.8	2.46	6.40	2.01	8.41
									
Radiant	$6 \times 4 \times 3$ m^3, one internal	15	28	23.56	0.6	3.37	1.56	5.77	7.33
	element ($A_i = 12$ m^2), five	17	28	21.78	0.6	2.91	2.20	4.64	6.84
	external elements	18	28	20.89	0.6	2.57	3.00	3.71	6.71
	($A_e = 96$ m^2)								
									

† From formulae 1 and 2 ‡ From Table 3 § From Table 2.

walls θ_i will always be lower than the comfort temperature $\theta_{rs} = 20$°C. The second is a radiant heating system, but notionally operating on all the internal building elements (area of the heating system = A_i). In this case we know that θ_i will always be higher than $\theta_{rs} = 20$°C.

(*e*) The following parameters have been taken as constant values for all cases: $\theta_{rs} = 20$°C, $F_t = 0.95$, $\varepsilon_i = \varepsilon_e = 0.9$. Table 5 summarises the results obtained for cases (*a*)–(*d*) (for a vertical wall).

Table 2 indicates that the h_c formulae for horizontal elements are different from those for vertical elements; they also depend on the direction of the heat flow. For horizontal external building elements we have made the same calculations and hypotheses as for the vertical building elements. The results obtained are given in Table 6 for horizontal external roofs and in Table 7 for horizontal external floors. To be able to utilise the same values of h_r as for the vertical walls, we have always taken as the horizontal external roof or floor a building element of 4×3 m^2; thus in Tables 6 and 7 the room height was always 6 m.

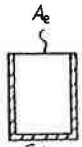
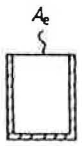
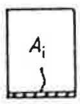
6 Discussion and conclusions

Many of the cases studied were extreme in terms of the number of external walls or elements (1 to 5) and the heating system (warm air or radiant system).

Also, in terms of the insulation value of the external building elements, we can claim to have studied all possible cases. A surface temperature $\theta_e = 10$°C corresponds practically to a double glazed area A_e with an external temperature of $\theta_{eb} \approx -8$°C. A surface temperature of $\theta_e = 17$–18°C corresponds to a well insulated opaque building element for the same external temperature of $\theta_{eb} = -8$°C. We can thus conclude that for other cases which are situated between these extremes, the real h_i values will also be situated between the obtained h_i values.

There is of course no sense in calculating a mean h_i value for each of the three tables (5, 6 and 7); the cases studied are too extreme and one would be obliged to consider very different weighting factors. In Table 5, for example, cases 1 and 4 are rather common in practice. But the other cases will be met in practice only in a few exceptional circumstances. The motivation for the extreme cases is that they are a good indicator to predict the evolution of h_i if we are going from a room with 1 external element to rooms with 2, 3, 4 or 5 external elements. We can thus conclude from Table 5 that the h_i values obtained for cases 1 and 4 will decrease a little if rooms with more than one external element are considered.

Table 6 Calculation of h_i by formula 27 for an external ceiling element

Heating system	Room characteristics	Chosen θ		θ_a† (°C)	h_r‡ (W m^{-2} K^{-1})	h_c§ (W m^{-2} K^{-1})	Calculated from formula 21		
		θ_e (°C)	θ_i (°C)				h_{ri} (W m^{-2} K^{-1})	h_{ci} (W m^{-2} K^{-1})	h_i (W m^{-2} K^{-1})
Warm air	6 × 4 × 3 m^3, one external element (A_e = 12 m^2), five internal elements (A_i = 96 m^2) 	10 15 17	17 18 19	23.8 22.3 21.2	4.8 4.8 4.8	5.07 4.32 3.76	3.36 2.88 3.20	6.99 6.31 5.26	10.35 9.19 8.46
Warm air	6 × 4 × 3 m^3, one internal element (A_i = 12 m^2), five external elements (A_e = 96 m^2) 	15 17 18	18 19 19	24.67 22.80 21.89	0.6 0.6 0.6	4.64 4.08 3.69	0.36 0.40 0.30	8.97 7.89 7.18	9.33 8.29 7.48
Warm air	6 × 4 × 3 m^3, six external elements (A_e = 108 m^2, A_i = 0 m^2) 	15 18	— —	25 22	0 0	4.68 3.72	— —	9.36 7.44	9.36 7.44
Radiant	6 × 4 × 3 m^3, one external element (A_e = 12 m^2), five internal elements (A_i = 96 m^2) 	10 15 17	23 22 21	18.45 18.78 19.45	4.8 4.8 4.8	4.48 3.67 3.29	6.24 6.72 6.40	3.78 2.77 2.69	10.02 9.49 9.09
Radiant	6 × 4 × 3 m^3, one internal element (A_i = 12 m^2); five external elements (A_e = 96 m^2) 	15 17 18	28 28 28	23.56 21.78 20.89	0.6 0.6 0.6	4.50 3.89 3.43	1.56 2.20 3.00	7.70 6.20 4.95	9.26 8.40 7.95

† From formulae 1 and 2 ‡ From Table 3 § From Table 2.

The value of $h_i = 8$ W m^{-2} K^{-1} which is generally proposed in most standards (for vertical walls) seems a very acceptable value (see last column of Table 5). For radiant heating the values of h_i obtained (last column of Table 5) are slightly higher than for warm air heating. But the differences are so small that it does not seem defensible to propose another h_i value for radiant heating systems.

The same conclusion can be deducted from Table 6. An h_i value of 9 W m^{-2} K^{-1} could be suggested for ceilings and roofs. But in this case only small errors will result from using the same value $h_i = 8$ W m^{-2} K^{-1}.

The heat exchange coefficient for external floors (Table 7) is lower than $h_i = 8$ W m^{-2} K^{-1}. In most countries this is accepted in standards, which propose for downward heat exchange coefficients $h_i \approx 5$ or 6 W m^{-2} K^{-1}.

6.1 General conclusions

(*a*) It seems that practically constant h_i values can be accepted if the dry resultant temperature is used as the indoor calculation temperature.

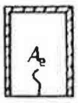
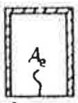
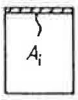
(*b*) It does not seem necessary to propose different h_i values as a function of the heating system.

(*c*) The h_i-values given in Table 8 can be proposed.

Appendix: Calculation of h_i on the basis of air temperature θ_a

It will be recalled that transmission losses can also be calculated on the basis of the room air temperature θ_a. In that

Table 7 Calculation of h_i by formula 21 for an external floor element

Heating system	Room characteristics	Chosen θ		θ_a† (°C)	h_r‡ (W m^{-2} K^{-1})	h_c§ (W m^{-2} K^{-1})	Calculated from formula 21		
		θ_e (°C)	θ_i (°C)				h_{ri} (W m^{-2} K^{-1})	h_{ci} (W m^{-2} K^{-1})	h_i (W m^{-2} K^{-1})
Warm air	6 × 4 × 3 m^3, one external element (A_e = 12 m^2), five external elements (A_i = 96 m^2)	10 15 17	17 18 19	23.8 22.3 21.2	4.8 4.8 4.8	2.52 2.15 1.87	3.36 2.88 3.20	3.48 3.14 2.62	6.84 6.02 5.82
									
Warm air	6 × 4 × 3 m^3, one internal element (A_i = 12 m^2), five external elements (A_e = 96 m^2)	15 17 18	18 19 19	24.67 22.80 21.89	0.6 0.6 0.6	2.31 2.03 1.84	0.36 0.40 0.30	4.47 3.92 3.58	4.83 4.32 3.88
									
Warm air	6 × 4 × 3 m^3, six external elements (A_e = 108 m^2, A_i = 0 m^2)	15 18	— —	25 22	0 0	2.33 1.85	— —	4.66 3.70	4.66 3.70
									
Radiant	6 × 4 × 3 m^3, one external element (A_e = 12 m^2), five internal elements (A_i = 96 m^2)	10 15 17	23 22 21	18.45 18.78 19.45	4.8 4.8 4.8	2.23 1.83 1.64	6.24 6.72 6.40	1.88 1.38 1.34	8.12 8.10 7.74
									
Radiant	6 × 4 × 3 m^3, one internal element (A_i = 12 m^2), five external elements (A_e = 96 m^2)	15 17 18	28 28 28	23.56 21.78 20.89	0.6 0.6 0.6	2.24 1.94 1.71	1.56 2.20 3.00	3.83 3.09 2.47	5.39 5.29 5.47
									

† From formulae 1 and 2 ‡ From Table 3 § From Table 2.

Table 8

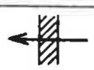
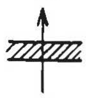
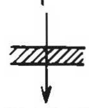
Configuration	h_i (W m^{-2} K^{-1})
	8
	8
	6

Table 9 Calculation of h_{ia} based on θ_a for vertical walls

Data from Table 5				$q = h_i(\theta_{rs} - \theta_e)$ (W m^{-2})	$\theta_a - \theta_e$ (K)	h_{ia} (Base: θ_a) (W m^{-2} K^{-1})
Case	θ_e (°C)	θ_a (°C)	h_i (Base: θ_{rs}) (W m^{-2} K^{-1})			
1	10 15 17	23.80 22.30 21.20	8.60 7.61 7.15	86.00 38.05 21.45	13.80 7.30 4.20	6.23 5.21 5.05
2	15 17 18	24.67 22.80 21.89	7.07 6.31 5.69	35.35 18.93 11.38	9.67 5.80 3.89	3.65 3.26 2.92
3	15 18	25.00 22.00	7.00 5.58	35.00 11.16	10.00 4.00	3.50 2.79
4	10 15 17	18.45 18.78 19.45	9.08 8.80 8.41	90.80 44.00 25.23	8.45 3.78 2.45	10.74 11.64 10.30
5	15 17 18	23.56 21.78 20.89	7.33 6.84 6.71	36.65 20.52 13.42	8.56 4.78 2.89	4.28 4.29 4.64

case a heat exchange coefficient indicated by h_{ia} must be considered. Thus

$$q = h_{ia}(\theta_a - \theta_e) \quad (\mathrm{W\,m^{-2}})$$

The results obtained in Tables 5–7 enable h_{ia} to be calculated for each case under consideration. The calculations of this Appendix apply only to vertical walls, i.e. they are based on the data of Table 5. The results are given in Table 9. It is easily seen that in this case the differences between the h_{ia} values obtained are much bigger. Another important disadvantage of this method is that the value of the room air temperature is never known *a priori*.

References

1 Uyttenbroeck J Keuze van de binnentemperatur voor de berekening van de warmteverliezen en van de warmteovergangskoëfficiënt h_i *WTCB Tijdschrift* 44 2–13 (Oct–Dec 1985)

2 *DIN 4701: Regeln für die Berechnung des Wärmebedarfs von Gebauden* (Berlin/Köln: Deutsches Institut für Normung/Becth)

3 *Guide de chauffage, ventilation, conditionnement d'air Fascicule I: Déperditions thermiques des locaux en régime continu. Méthode d'application des Règles de calcul données par le DTU de 1963* revised 1966 (Paris: Société d'Edition pour l'Information Technique des Ingénieurs de Chauffage) (1966)

4 Marcq H and Uyttenbroeck J *Choix de la température intérieure et du coefficient d'échange superficiel intérieur pour le calcul des déperditions calorifiques par transmission. Détermination de la température de l'air.* Revue 3 (Bruxelles: Centre Scientifique et Technique de la Construction) (1971)

5 *NBN B62-204 Détermination du coefficient de transmission thermique des éléments de construction* (Bruxelles: Institut belge de Normalisation) (1979)

6 *NBN B 62-002 Calcul des coefficients de transmission thermique des parois* (Bruxelles: Institut belge de Normalisation) (1987)

7 *NBN B 62-003 Calcul des déperditions calorifiques* (Bruxelles: Institut belge de Normalisation) (1986)

8 Kollmar A and Liese W *Die Strahlungsheizung* 4th Edition (München: Oldenburg)

9 *ASHRAE Handbook: Fundamentals* (American Society of Heating, Refrigeration and Air-conditioning Engineers) (1981)

10 Johannesson G *Active heat capacity: Models and parameters for the thermal performance of buildings* Report **TVBH 1003** (Lund, Sweden: Lund Institute of Technology, Division of Building Technology) (1981)

11 Tavernier E *De teoretische grondslagen van het warmtetransport* Kursus Koninklÿke Vlaamse Ingenieursvereniging *Termische isolatie en vochtproblemen in gebouwen* (1982–1983)

12 Tavernier E *De teoretische grondslagen van het warmtetransport* Kursus Koninklÿke Vlaamse Ingenieursvereniging *Termische isolatie en vochtproblemen in gebouwen* (1985)

13 Uyttenbroeck J *Warmtetransmissie* Kursus Rÿksdienst voor Arbeidsvoorziening Part 1 (June 1985)