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Summary With the advent of 1992 European building services engineers will be looking at the possibilities of 'spreading their wings' and working in other countries. Calculation methods will come under close scrutiny. This paper shows how the heat losses for a reference room are calculated in four European countries. The basis of these calculations was the German *DIN 4701* from 1959. This has been improved slowly over the years by Germany, the Netherlands and Belgium. The CIBSE method was the fourth method to be compared. The results do not differ greatly but the approach is different for each method. The first conclusion is that it wil take a great deal of discussion before a uniform European code can be produced.

Heat loss: A comparison of four European calculation methods

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List of symbols

Q_T	Heat loss by transmittance (W)
U	Thermal transmittance (W m^{-2} K^{-1})
A	Surface area (m^2)
T_{ai}	Inside air temperature of the room (°C)
T_e	Outside air temperature (°C)
T_m	Mean surface temperature (°C)
T_{ei}	Inside environmental temperature (°C)
T_r	Dry resultant temperature (°C)
R_{si}	Inside air surface resistance (m^2 K W^{-1})
R_{se}	Outside surface resistance (m^2 K W^{-1})
C_w	Wind pressure coefficient
d	Thickness of layers (m)
ρ	Density (kg m^{-3})
C	Specific heat capacity (J kg^{-1} K^{-1})
R	Thermal resistance (m^2 K W^{-1})
R_c	Thermal resistance of the construction (m^2 K W^{-1})

1 Introduction

Germany, Holland, Belgium and the UK form a substantial part of the European Community. For British-based engineers who use the *CIBSE Guide*[1] as a basis for calculations it is worthwhile knowing how 'continentals' tackle the problem of calculating the required capacity of a heating system.

The German method is also used in Austria and Switzerland. The minimum continental winter temperatures range from −70°C to −18°C. Assuming an inside air temperature of 20°C then gives a 27 K or 38 K difference across the building envelope. This is considerably higher than in the UK (even Cambridgeshire and parts of Scotland).

It should be noted that these are purely steady-state calculations. Building dynamics are used only in the Dutch and British methods. The methods are very different but they produce nearly identical answers.

2 Heat transmittance

Since transmission is regarded as a steady-state process, it is most convenient to use air temperatures for the calculation. This results in a simple formula for the heat loss (assuming the heating is by convection):

$$Q_T = \sum UA(T_{ai} - T_e) \qquad (1)$$

All heat loss calculation standards give recommendations for the appropriate temperature level, expressed as a design temperature. For comfort both the air temperature and the surface temperatures of all room partitions (the radiant temperatures) should be taken into consideration, not just air temperature. We speak of comfort if the heat production of a person is in balance with heat losses due to convection (air temperature) and radiation (surface temperatures of the surroundings). It is assumed that air velocity and relative humidity comply with the relevant standards.

2.1 Design indoor temperatures

The influence of radiation varies with position in the room and with emissivity; the calculation is complicated. For most practical situations it is permissible to use the average of mean radiant temperature and air temperature as an acceptable index temperature for comfort. This is called the dry resultant temperature T_r and also referred to as comfort temperature. For an office the Belgian, German and Dutch standards and the *CIBSE Guide*[4] all recommend 20°C as the resultant temperature (design temperature). The heat loss by transmittance is then calculated as

$$Q_T = \sum UA(T_r - T_e) \qquad (2)$$

Since T_r is lower than T_{ai}—except in cases of radiant heating—the transmittance calculated according to equation 2 is less than the actual values. The difference increases with decreasing insulation; in that case the surface temperatures become lower, so that the air temperature must be raised for the same degree of comfort. The same occurs with air heating compared to a system with more radiant components. The influence on Q_T can easily amount to 5%. Most standards have a correction method for this. The *CIBSE Guide*[1] bases the calculations on the inside environmental temperature T_{ei} and uses $(T_{ei} - T_{ao})$ as the temperature difference in equation 1. Approximately it can be written as:

$$T_{ei} = \tfrac{1}{3}T_{ai} + \tfrac{2}{3}T_m$$

Equation 1 can be written as:

$$Q_T = F_1 \sum AU(T_r - T_e) \qquad (3)$$

Comparison of equation 3 with equation 2 shows that the factor F_1 accounts for the difference between environmental temperature and resultant temperature; it is called the temperate ratio:

$$F_1 = \frac{T_{ei} - T_e}{T_r - T_e}.$$

This compensates automatically for the relationship between inside air and mean surface temperatures. F_1 is given in tables for various types of heating system. In each table the room is defined by an insulation and ventilation heat factor.

2.2 Design outdoor temperature

The criteria for selecting the design outdoor temperatures mentioned in the standards will be dealt with in the ventilation heat loss section. With regard to transmittance losses it should be noted that *DIN 4701-1983*[(2)] uses a correcting factor for the standard outside temperature.

Since the design outside conditions will only obtain for a short period, a room temperature decrease of 1 K is judged acceptable. This makes the calculation value of the outside temperature dependent on the accumulation rate of the building. The outside temperature can be raised by 4 K for a heavyweight structure, 2 K for a medium-weight structure and 0 K for a lightweight structure.

2.3 Thermal transmittance U

The *U*-value is used to apply corrections necessary because of the simplification of heat transfer represented by equation 2. In the Dutch standard (NEN 5066)[(3)] a correction is applied for the exchange of radiation from an outside wall and the influence of the wind. For this purpose the outside surface resistance R_{se} is reduced to $0.02\ m^2\ K\ W^{-1}$ instead of the usual $0.04\ m^2\ K\ W^{-1}$. The latter value refers to a wind-velocity of $4\ m\ s^{-1}$, whereas in the new Dutch standard the value at design conditions is $6\ m\ s^{-1}$.

In the Dutch standard the heat resistance of the partition is adapted by reducing the inside surface resistance R_{si}, using $0.11\ m^2\ K\ W^{-1}$ instead of the usual value of $0.13\ m^2\ K\ W^{-1}$. It results in a marked difference when the heat resistance of the wall itself (i.e. surface resistances excluded) is lower than $0.5\ m^2\ K\ W^{-1}$. The heating system influences R_{si} as well; from the many calculations made for this purpose, it can be concluded that for the purposes of accuracy one value for R_{si} is sufficient.

Both the German standard (DIN 4701-1983) and the Belgian standard (NBN-B62-003)[(4)] have a correction for cold walls. In the German standard the *U*-value of the wall is raised by 0.1 to $0.3\ W\ m^{-2}\ K^{-1}$, depending on its true value (1.6–3.5 $W\ m^{-2}\ K^{-1}$). The Belgian standard applies a correction for walls larger than $1\ m^2$ with a *U*-value over $1\ W\ m^{-2}\ K^{-1}$, provided the cold wall effect is not compensated (e.g. by a radiator). The sum of transmittance and ventilation losses is multiplied by the correction factor. In both cases the heating capacity is increased by the correction factor, resulting in a higher air temperature, which compensates for the cold wall effect.

The German standard increases the *U*-value to compensate for cold surfaces, i.e. to bridge the gap between air temperature and resultant temperature. The correction increases for increasing *U*-values; e.g. for *U*-values between 2.6 and $3.1\ W\ m^{-2}\ K^{-1}$ the increment is $0.2\ W\ m^{-2}\ K^{-1}$. This is in agreement with the Dutch standard, where the inside surface resistance is reduced from 0.13 to $0.11\ m^2\ K^{-1}\ W^{-1}$. Applying this to *U*-values of 2.6 and $3.1\ W\ m^{-2}\ K^{-1}$ gives corrected values of 2.8 and $3.3\ W\ m^{-2}\ K^{-1}$. However for windows the German standard also has a correction for the heat gain by diffuse solar radiation. For clear glass it is $-0.3\ W\ m^{-2}\ K^{-1}$.

2.4 Surfaces

Differences occur in the way the standards describe how to measure the surface of the heat transferring partitions. For the same room it leads to different heat loss results.

Dimensions to be considered are horizontal, vertical, and those of openings (doors and windows). For doors and windows the standards prescribe the use of the dimensions of the opening in the wall. Vertical dimensions have to be measured from the topside of one floor to the topside of the next, although the *CIBSE Guide* takes the inside dimension. The main differences between standards relate to the way of determining the horizontal dimensions:

(*a*) NEN 5066 uses the inside dimension plus half the width of the adjoining walls.

(*b*) DIN 4701-1983 uses the inside dimensions.

(*c*) NBN-B62-003 uses the outside dimensions for external walls, and the inside dimensions for internal surfaces.

(*d*) *CIBSE Guide* uses the inside dimensions.

3 Application of standards to a reference room

The heat losses by transmittance have been calculated for a reference room; details of the room are given in Appendix 4. The assumptions are that the room is an office of medium-weight structure, that there is no heat loss to adjoining rooms; only through the facade, and that the thermal resistances of the structural components are as given in Table 1.

Table 1 Thermal resistance of structural components ($m^2\ K\ W^{-1}$)

Insulation	Element	
	Wall	Window
Normal	1.48	0.14
Heavy	2.57	0.60

The design indoor temperature is 20°C, the design outdoor temperature is −7°C, heating is by radiators and orientation is eastward.

3.1 Dutch standard NEN 5066[(3)]

For $R_{si} = 0.11\ m^2\ K\ W^{-1}$ and $R_{se} = 0.02\ m^2\ K\ W^{-1}$ the *U*-values are as given in Table 2.

Table 2 *U*-values ($W\ m^{-2}\ K^{-1}$) for Dutch standard NEN 5066[(3)]

Component	Insulation	
	Normal	Heavy
Outer wall	0.62	0.37
Window	3.70	1.37

The window area is $1.2 \times 3 = 3.6\,m^2$; the outer wall area is $3.6 \times 3 - 3.6 = 7.2\,m^2$. The temperature difference is 27 K. The heat loss for normal insulation is $(0.62 \times 7.2 + 3.70 \times 3.6) \times 27 = 480\,W$, and for heavy insulation $(0.37 \times 7.2 \times 1.37 \times 3.6) \times 27 = 205\,W$.

3.2 German standard DIN 4701-1983[2]

For $R_{si} = 0.13\,m^2\,K\,W^{-1}$ and $R_{se} = 0.04\,m^2\,K\,W$ the U-values are as given in Table 3.

Table 3 U-values ($W\,m^{-2}\,K^{-1}$) for German standard DIN 4701-1983[2]

Component	Insulation	
	Normal	Heavy
Outer wall	0.61	0.365
Window	3.2	1.3

The U-values should be corrected for:

- cold walls; for the outer wall the correction is 0, for the window the correction is $0.3\,W\,m^{-2}\,K^{-1}$.
- diffuse solar radiation (only for transparent surfaces); for the window the correction is $-0.3\,W\,m^{-2}\,K^{-1}$.

The window area is $1.2 \times 3 = 3.6\,m^2$; the outer wall area is $(3.6 - 0.07) \times 3.0 - 3.6 = 7.0\,m^2$.

3.3 Design outdoor temperature

The German standard DIN 4701-1983 suggests that for a medium-weight structure the design outdoor temperature may be raised by 2 K. This accounts for a 1 K fall of the inside temperature, which is judged acceptable since the period to which the design outdoor temperature applies is only short. So the design temperature difference is 25 K. The heat loss for normal insulation is $(0.62 \times 7.0 + 3.2 \times 3.6) \times 25 = 395\,W$, and for heavy insulation $(0.365 \times 7.0 \times 1.3 \times 3.6) \times 25 = 181\,W$.

3.4 Belgian standard NBN-B62-003

For $R_{si} = 0.125\,m^2\,K\,W^{-1}$ and $R_{se} = 0.043\,m^2\,K\,W^{-1}$ U-values are as given in Table 4.

Table 4 U-values ($W\,m^{-2}\,K^{-1}$) for Belgian standard NBN-B62-003

Component	Insulation	
	Normal	Heavy
Outer wall	0.61	0.365
Window	3.2	1.3

The window area is $1.2 \times 3.0 = 3.6\,m^2$; the outer wall area is $3.6 \times 3.0 - 3.6 = 7.2\,m^2$. There is no addition for cold walls (i.e. windows) since a radiator is placed underneath the window. 2½% is added for eastward orientation. A temperature difference of 27 K results in the following heat losses: For normal insulation $(0.61 \times 7.2 + 3.2 \times 3.6) \times 27 \times 1.025 = 440\,W$ and the heavy insulation $(0.365 \times 7.2 \times 1.3 \times 3.6) \times 27 \times 1.025 = 202\,W$.

3.5 CIBSE Guide (1986)[1]

For $R_{si} = 0.12\,m^2\,K\,W^{-1}$ and $R_{se} = 0.06\,m^2\,K\,W^{-1}$ U-values are as given in Table 5.

Table 5 U-values ($W\,m^{-2}\,K^{-1}$) for *CIBSE Guide* 1986[1]

Component	Insulation	
	Normal	Heavy
Outer wall	0.60	0.364
Window	3.1	1.28

The window area is $1.2 \times 3.0 = 3.6\,m^2$; the outer wall area is $(3.6 - 0.07) \times (3.0 - 0.226) - 3.6 = 6.19\,m^2$.

3.6 Correction factor for indoor temperature

This correction factor F_1 depends on the ratio $\Sigma AU/\Sigma A$ where ΣA is the total area of all surfaces bounding the enclosure and ΣAU refers to the external walls. For the reference room this ratio takes the value 0.2 for normal insulation and 0.1 for heavy insulation. For normal radiators (about 70% convective and 30% radiant heat) the correction factor F_1 is 1.00 for both cases.

3.7 Influence of structural mass on the selection of outdoor temperature

In selecting the external design temperature the building inertia is taken into account. For structures with high thermal inertia the design temperature is 1 or 2 K higher than for buildings with low thermal inertia. Buildings classified as of low thermal inertia are typically single-storey. Those of high thermal inertia are typically multi-storey buildings with solid intermediate floors and partitions. For this reason the design outdoor temperature is raised here by 1 K. The temperature difference is 26 K, which results in the following heat losses: For normal insulation $(0.60 \times 6.05 + 3.1 \times 3.6) \times 26 = 384\,W$ and for heavy insulation $(0.364 \times 6.05 + 1.28 \times 3.6) \times 26 = 177\,W$.

3.8 Evaluation of the differences

The heat losses expressed as a percentage of the lowest values are presented in Table 6. This table shows that a calculation according to the *CIBSE Guide* method results in the lowest values. Since in all cases the heat loss is calculated by the formula

$$Q_T = \Sigma\, UA(T_r - T_e)$$

the differences can be caused by each of the factors U,

Table 6 Relative heat losses (%) for reference room

Standard	Insulation	
	Normal	Heavy
NEN 5066[3]	125	116
DIN 4701[2]	103	102
NBN-B62-003[4]	115	114
CIBSE Guide[1]	100	100

Table 7 U-values ($Wm^{-2} K^{-1}$)

Standard	Insulation			
	Normal		Heavy	
	Wall	Window	Wall	Window
NEN 5066[3]	0.62	3.7	0.37	1.37
DIN 4701[2]	0.61	3.2	0.365	1.3
NBN-B62-003[4]	0.61	3.2	0.365	1.3
CIBSE Guide[1]	0.60	3.1	0.364	1.3

A and $(T_r - T_e)$. The separate influence of each factor is evaluated in sections 3.9–3.11.

3.9 U-values

The Dutch standard uses lower surface resistance factors, partly in order to compensate for the difference between resultant temperature and air temperature. This correction only plays a role for components with relatively high U-values. In our example this is the window in the normally insulated room; see Table 7. If we take the same values for the areas, there is no difference between the results of the Belgian, German and British standards. The Dutch standard however shows 11% greater heat loss for the normally insulated room. For heavy insulation there are no differences; see Table 8.

Table 8 Global deviations (%) from heat loss values according to *CIBSE Guide*[1] for normal (N) and heavy (H) insulation

Standard	Insul.	U-value	Area (m^2)	$T_i - T_e$	Addition
NEN 5066[3]	N	10	4	4	—
	H	—	6	4	—
DIN 4701[2]	N	—	3	−4	—
	H	—	5	−4	—
NBN-B62-003[4]	N	—	4	4	2.5
	H	—	6	4	2.5

3.10 Areas

Here the results for the window are the same for all standards. Differences occur with the opaque wall part (Table 9). Compared with the results obtained by the *CIBSE Guide* method, the other standards (using the same U-value) give higher values. For 'normal insulation' the difference is 4% for the Belgian and Dutch standards and 3% for the German standard; for 'heavy insulation' it is 6 and 5% respectively (see Table 8).

3.11 Temperature difference indoor–outdoor

Both the German and British methods include an outdoor temperature correction depending on the weight of the structure. This results in a heat loss difference from the British value of −4% for the German standard and +4% for the Belgian and Dutch standards. (See Table 8.)

3.12 Additions

For the reference room only the Belgian standard gives an addition for orientation.

Table 9 Areas (m^2)

Standard	Wall	Window
NEN 5066[3]	7.2	3.6
DIN 4701[2]	7.0	3.6
NBN-B62-003[4]	7.2	3.6
CIBSE Guide[1]	6.05	3.6

3.13 Conclusion

The global results are summarised in Table 8. Apart from the correction of the U-value in the Dutch standard the main differences regard the determination of the areas and the corrections for the outdoor temperature. This last point is arbitrary; it has to do with the willingness of the occupants to accept a slight decrease in indoor temperature during the (short) period that the outdoor climate accords with the outdoor design conditions. We can leave this point—the correction for the outdoor design temperature—out of consideration; the results are given in Table 10. One might say that this approximates to the physical model somewhat better. The other point, the determination of the areas, is more complicated. It has to do with the heat flow at the boundaries of the areas. Thermal bridging also plays a role.

Table 10 Relative heat losses for reference room if $T_r - T_e = 27$ K for all cases

Standard	Insulation	
	Normal	Heavy
NEN 5066[3]	120	111
DIN 4701[2]	107	106
NBN-B62-003[4]	110	110
CIBSE Guide[1]	100	100

3.14 Design outdoor air temperature T_e

The design outdoor temperature in the various standards is given in Table 11.

Table 11 Design outdoor temperature in standards

Standard	Value (°C)	Correction
NEN 5066[3]	−7	Comfort calculations
DIN 4701[2]	−10–−24†	Lowest 48 hours average in a period of 20 years (1951–1970)
NBN-B62-003[4]	−7–−12†	Lowest 24 hours average only occurring one day in a year
CIBSE Guide[1]	0–−7.5†‡	24 or 48 hours period mean temperature not to be exceeded more than one occasion in 10 years

† Depends on geographic location.
‡ Depends on building inertia.

Comfort calculations were carried out for poorly and medium insulated buildings. Results of dynamic calculations proved that even temporarily very low temperatures (−10–17°C) cause only 25% PPD (predicted percentage dissatisfied) at 0700. The choice of −7°C was based on:

- the occurrence (in combination with windspeed)
- comfort criteria
- choices of Germany and Belgium near the Dutch respectively; −8°C according to DIN 4701 (*schwere bauart*) and −7°C to −9°C according to NBN-B62.

4 Calculation method for infiltration

4.1 Infiltration through cracks and other small openings

Some empirical values are given in different standards. These values may differ significantly because of different building techniques and products[5]. Table 12 gives crack flow coefficient values for movable windows. The flow coefficient for porous brick wall construction is given by NEN[3] as $C_1 = 0.04 \times 10^{-3}\ \mathrm{m^3\ m^{-1}\ s^{-1}\ Pa^{-2/3}}$.

Table 12 Crack flow coefficient values for movable windows ($10^{-3}\ \mathrm{m^3\ m^{-1}\ s^{-1}\ Pa^{-2/3}}$)

Weather stripping?	Standard		
	NEN[3]	DIN[2]	CIBSE[1]
No	0.45	0.6	0.25
Yes	0.20	0.3	0.05

4.2 Comparison of mass flow rate in different standards

The calculation of mass flow through natural exhaust systems is as follows. NEN 5066[3] recommends the calculation method given above when calculation of infiltration is needed. The other three standards offer no guidelines for mass flow calculation through natural exhaust systems.

4.3 Comparison of wind pressure coefficient C_w in different standards

NEN 5066[3] gives values for different

- building shapes
- shielding factors
- wind direction angles
- building heights.

DIN 4701 adopts a different approach, so the factors are difficult to compare. Influences such as the following are taken into account:

- height
- shielding
- wind speed and location
- internal air transmittance.

NBN-B62-003[4] offers no values.

CIBSE Guide[1] has only limited information on C_w. A minimum value of 0.2 is recommended.

5 Wind speed and direction

5.1 Comparison of design wind speed in different standards

NEN 5066[3] uses three geographical locations and two orientation areas. The given wind speed ranges from 5 to 13 m s^{-1}.

DIN 4701[2] considers three wind speeds, 2, 4 and 6 m s^{-1} depending on location and shielding. There are no orientation differences.

NBN-B62-003[4] offers no values.

CIBSE Guide gives design wind speeds for various locations (3.5–6.5 m s^{-1}). Hourly values are taken to be exceeded for 50% of the time. There are no orientation differences.

5.2 Influence of shielding

The values in Table 7 need to be corrected for the influence of shielding. NEN, DIN and CIBSE use comparable corrections.

NEN 5066[3] distinguishes three shielding categories: Free, moderate local shielding with some obstacles (villages), and heavy shielding with many obstacles (city centres).

DIN 4701[2] uses two shielding categories, *CIBSE Guide*[1] uses three shielding categories, and NBN[4] does not mention shielding influence.

6 Comparison of different standards and recommendations

6.1 CIBSE Guide (1986) section A4

The *Guide*[1] gives an extensive method to calculate infiltration based on generally accepted principles. The calculation method is recommended but a table is given with empirical values for air infiltration and ventilation allowance for buildings on normal sites in winter. The given air infiltration rates range in general between 0.5 and 1.5 ach^{-1}.

For rectangular buildings a simplified method is given to estimate infiltration from the knowledge of:

- wind speed
- building height (10–100 m)
- location
- window characteristics (from a table).

The chart has been constructed on the basis of assuming:

- a difference in pressure coefficient across the building of 1.1
- average wind speed, average crackform coefficient, identical leakage on both sides and average location.

A correction for geographical location and for internal resistance is also possible. The basic infiltration rate can later be used to calculate the infiltration rate of rooms by using the crack length of the windows and doors in the room. A simple method is given to calculate the total maximum infiltration of the building.

It is stated that the sum of the infiltrations of all the rooms might normally be two to three times higher than the real maximum. A representative area of the facade is used for this calculation to avoid overdimensioning of the boilerplant.

CIBSE gives extensive and less extensive methods to calculate the infiltration. Apart from that, CIBSE gives a table with empirical values but does not recommend their use.

No relation with an airtightness requirement standard is indicated.

6.2 German standard DIN 4701[2]

This standard gives an extensive calculation method based on the general principles of airflow through cracks and small openings. The method is simplified in use by the following simplifications:

- No stack effect if the building is lower than 10 m
- Two types of buildings: with and without inner partitioning in the vertical sense
- Several tables are given with coefficients to take into account such influences as: geographical location (wind speed and shielding), height of the building etc.

A simplified method considering only ventilation rates is not given. It is necessary to know the infiltration coefficients of windows, doors etc. The standard provides some calculation values.

This standard gives information for a simplified hand calculation method, and does not relate to any airtightness requirements or standards.

6.3 Belgian standard NBN-B62-003[4]

The Belgian standard gives no infiltration calculation methods because of the lack of reliable data to be used for these calculation methods. This standard does not refer to ventilation standards or airtightness standards but simply gives the values for the ventilation/infiltration to be taken into account as follows.

(a) Rooms without mechanical ventilation

- if poorly occupied (e.g. dwellings) $n = 1$
- if highly occupied (e.g. meeting rooms) $n = 1$, or if higher: $10\,m^3\,h^{-1}$ per person (non smoking); $20\,m^3\,h^{-1}$ per person (smoking allowed)
- for rooms with a high expected ventilation and infiltration rate because of the circumstances (shops etc.) the higher expected ventilation rate ($n > 1$).

(b) Rooms with mechanical air supply

n_{mech} taking into account the design air supply temperature and $n_{infil} = 0.3$ to be added (except in cases where overpressure will always be maintained).

(c) Special cases

The ventilation heat loss will be based on fixed accepted values.

7 Intermittent heating in other standards

The German and Belgian standards assume continuous heating of the building at design conditions, so additional heat is not needed. In Britain the *CIBSE Guide* gives some information about preheat time and plant oversizing when the building is heated intermittently. The *ASHRAE Guide*[6] mentions the relation between preheat time and furnace output capacity after night setback in a limited way.

8 Heat loss calculations applied to a reference room

The heat loss calculations prescribed in the various standards, are applied to an office room. Details are shown in Appendix 1. To obtain comparable results the same design outdoor conditions must be taken in all cases. The following assumptions are made:

- room with medium-weight structure (see Table 13)
- no heat loss to any adjoining rooms
- design outdoor temperature -7°C
- design wind speed at 10 m height in open country $6\,m\,s^{-1}$
- design indoor resultant temperature 20°C
- thermal resistance of outer wall $1.482\,m^2\,K^{-1}\,W^{-1}$
- thermal resistance of double glazed window $0.143\,m^2\,K\,W^{-1}$
- the room is furnished
- balanced ventilation
- temperature of supply air equals indoor temperature
- radiator heating.

Table 13 Relative heat requirements (%) for one week at design conditions with normal insulation

Night temperature (°C)	Weight of structure		
	Heavy (910 Kg)	Medium (770 Kg)	Light (310 Kg)
20	100	100	100
17	93	93	93
14	92	90	87
11	92	89	83

8.1 Dutch standard NEN 5066 (1988)[3]

For $R_{si} = 0.11\,m^2\,K\,W^{-1}$ and $R_{se} = 0.02\,m^2\,K\,W^{-1}$ the thermal transmittance of the outer wall is $U = 0.62\,W\,m^{-2}\,K^{-1}$ and of the window $U = 3.66\,W\,m^{-2}\,K^{-1}$. The area of the outer wall is $3.6 \times 3 - 1.2 \times 3 = 7.2\,m^2$. The area of the window is $1.2 \times 3 = 3.6\,m^2$.

(a) Heat loss by transmittance

Outer wall:	$0.62 \times 7.2 \times 27 = 121$ W
Window:	$3.66 \times 3.6 \times 27 = 356$ W
Total	477 W

(b) Infiltration heat loss

In accordance with both the standard concerning air leakage of the building envelope (in preparation) and the standard NEN 5066[3] the air infiltration quantity per m^2 facade area is $0.0005\,m^3\,m^{-2}\,s^{-1}$. The facade area is $10.8\,m^2$. The infiltration heat loss will be $0.0005 \times 10.8 \times 1330 \times 27 = 194$ W.

(c) Additional heat capacity

The weekend thermostat setback is 3 K. The preheat time is 5 h. With these values it follows from Figures 1–3 that the additional heat capacity is 5.4 W per m^2 storing area.

The storing surface areas are as follows:

Floor with covering:

$0.7 \times 3.6 \times 5.5 = 13.9\,m^2$

(a factor 0.7 takes account of the covering)

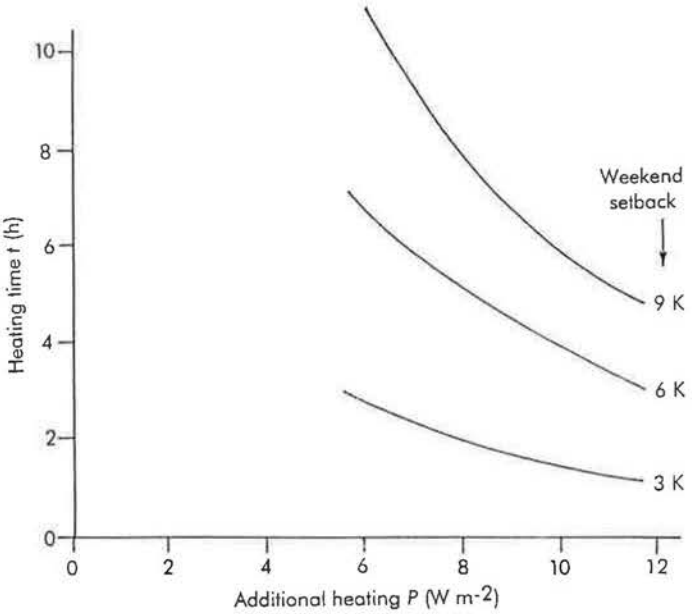

Figure 1 Lightweight building

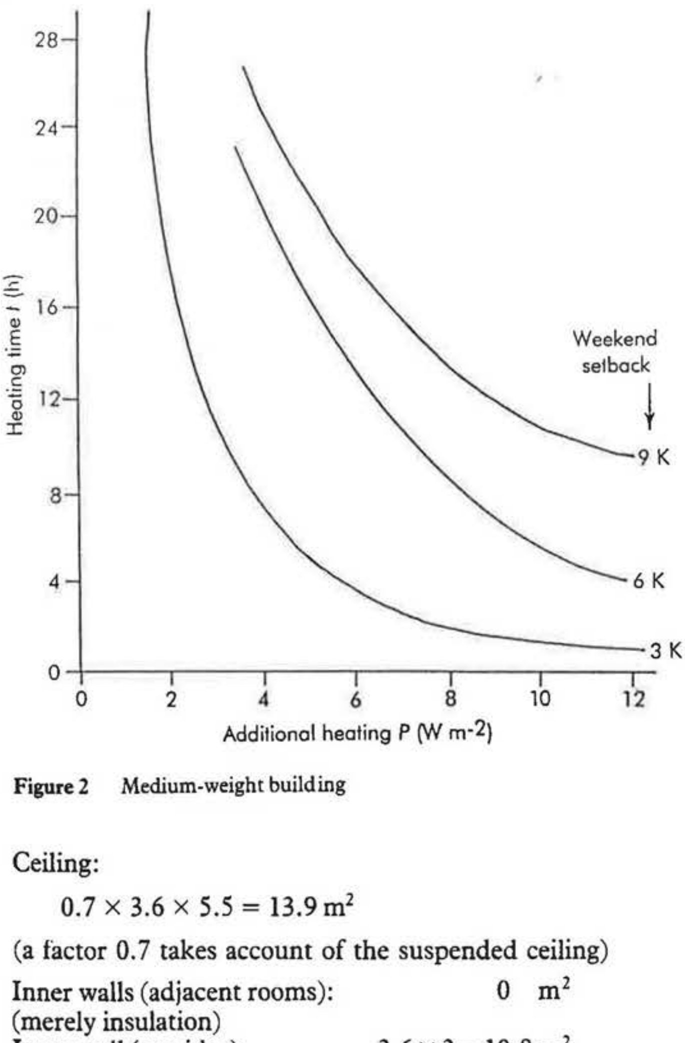

Figure 2 Medium-weight building

Ceiling:

$0.7 \times 3.6 \times 5.5 = 13.9\ m^2$

(a factor 0.7 takes account of the suspended ceiling)

Inner walls (adjacent rooms): (merely insulation)	0 m^2
Inner wall (corridor):	$3.6 \times 3 = 10.8\ m^2$
Outer wall:	7.2 m^2
Furniture:	40 m^2
Total area	85.8 m^2

With these values it has been calculated that the required additional heat capacity is 5.4 W per m^2 encasing area of the room.

Additional heat capacity:

$85.8 \times 5.4 = 463$ W

Total required heat capacity:

$477 + 194 + 463 = 1134$ W.

8.2 German standard DIN 4701 (1983)[2]

For $R_{si} = 0.13\ m^2\,K\,W^{-1}$ and $R_{se} = 0.04\ m^2\,K\,W^{-1}$ the thermal transmittance of the outer wall is $U = 0.61\ W\,m^{-2}\,K^{-1}$ and the thermal transmittance of the window is $U = 3.2\ W\,m^{-2}\,K^{-1}$.

The standard thermal resistance U_n is

$$U_n = U + \Delta U_a + \Delta U_s$$

where ΔU_a is the correction for cold walls and ΔU_s is the correction for diffuse solar radiation. In this case $\Delta U_a = 0$ and $\Delta U_s = 0$ for the outer wall, and $\Delta U_a = 0.3\ W\,m^{-2}\,K^{-1}$ and $\Delta U_s = -0.3\ W\,m^{-2}\,K^{-1}$ for the window, so for the outer wall $U_n = 0.61\ W\,m^{-2}\,K^{-1}$ and for the window $U_n = 3.2\ W\,m^{-2}\,K^{-1}$. The area of the outer wall is $(3.6 - 0.07) \times 3 - 1.2 \times 3 = 7.0\ m^2$. The area of the window is $1.2 \times 3 = 3.6\ m^2$.

(a) Heat loss by transmittance

Outer wall:	$0.61 \times 7.0 \times 27 = 115$ W
Window:	$3.2 \times 3.6 \times 27 = 311$ W
Total	426 W

(b) Infiltration heat loss

For a shaft type of building the infiltration heat loss will be

$$Q_w = (\Sigma s_a C_{ta} + \Sigma s_n C_{tn}) Hr (T_i - T_e)$$

where C_{ta} is the air leakage through the facade at 1 Pa, C_{tn}

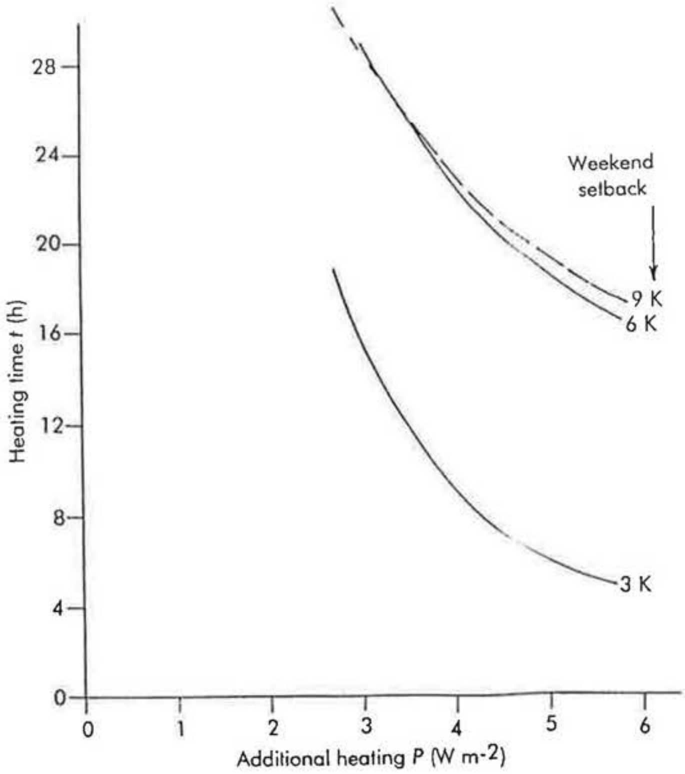

Figure 3 Heavy-weight-building

is the air leakage through the inner walls at 1 Pa, H is the building factor, r is the room factor.

Supposing a strong wind, normal exposure, a building height of 20 m and the room at 5 m height above ground it appears that $s_a = 1.3$ and $s_n = 0$, $H = 2.2\ \mathrm{W\,h\,Pa^{2/3}\,m^{-3}\,K^{-1}}$, $r = 0.9$.

The air leakage of the facade per m^2 surface area is taken as $0.064 \times 10^{-3}\ \mathrm{m^3\,m^{-2}\,s^{-1}\,Pa^{-2/3}}$, so $C_{ta} = 10.18 \times 0.064 \times 10^{-3} = 0.7 \times 10^{-3}\ \mathrm{m^3\,s^{-1}\,Pa^{-2/3}}$. Then the infiltration heat loss is $1.3 \times 0.7 \times 10^{-3} \times 3600 \times 2.2 \times 0.9 \times 27 = 175$ W. The total required heat capacity is $426 + 175 = 601$ W.

8.3 Belgian standard NBN-B62-003 (1986)[4]

For $R_{si} = 0.125\ \mathrm{m^2\,K\,W^{-1}}$ and $R_{se} = 0.043\ \mathrm{m^2\,K\,W^{-1}}$, the thermal transmittance of the outer wall is $U = 0.61\ \mathrm{W\,m^{-2}\,K^{-1}}$ and the thermal transmittance of the window is $U = 3.2\ \mathrm{W\,m^{-2}\,K^{-1}}$. The area of the outer wall is $3.6 \times 3 - 1.2 \times 3 = 7.2\ \mathrm{m^2}$. The area of the window is $1.2 \times 3 = 3.6\ \mathrm{m^2}$.

(a) Heat loss by transmittance

Outer wall: $0.61 \times 7.2 \times 27 = 119$ W
Window: $3.2 \times 3.6 \times 27 = 311$ W

Total 430 W

(b) Infiltration heat loss

Infiltration rate $n = 0.3\ \mathrm{h^{-1}}$. The inside volume of the room is $V = (3.6 - 0.07) \times (5.5 - 0.16 - 0.07) \times (3 - 0.27) = 50.8\ \mathrm{m^3}$. The infiltration heat loss is $0.34 \times 0.3 \times 50.8 \times 27 = 140$ W.

(c) Additions

Supposing a north orientation, the additional allowance is $N_0 = 0.05$. No addition for cold walls is needed since a radiator is placed underneath the window. The total required heat capacity is $(430 + 140) \times (1 + 0.05) = 599$ W.

8.4 CIBSE Guide (1986)[1]

For $R_{si} = 0.12\ \mathrm{m^2\,K/W^{-1}}$ and $R_{se} = 0.06\ \mathrm{m^2\,K\,W^{-1}}$ the thermal transmittance of the outer wall $U = 0.61\ \mathrm{W\,m^{-2}\,K^{-1}}$. The thermal transmittance of the window $U = 0.31\ \mathrm{W\,m^{-2}\,K^{-1}}$. The area of the outer wall is $(3.6 - 0.07) \times 2.73 - 1.2 \times 3 = 6.0\ \mathrm{m^2}$. The area of the window is $1.2 \times 3 = 3.6\ \mathrm{m^2}$.

The total required heat capacity is

$$(F_1\,\Sigma AU + \tfrac{1}{3}F_2 nV)(T_i - T_e)$$

F_1 and F_2 are temperature ratio factors and depend on the ratios $\Sigma AU/\Sigma A$ and $nV/3\Sigma A$. ΣA is the total area of the inside surfaces:

Outer wall: $AU = 6.0 \times 0.61 = 3.7$
Window: $AU = 3.6 \times 3.1 = 11.2$

$\Sigma AU = 14.9$

According to Table A4.12[1], for an unoccupied room $n = 0.5$; $V = (3.6 - 0.07) \times (5.5 - 0.16 - 0.07) \times (3 - 0.27) = 50.8\ \mathrm{m^3}$; $\Sigma A = 85.6\ \mathrm{m^2}$; $\Sigma AU/\Sigma A = 0.2$ and $nV/3\Sigma A = 0.1$. From Table A9.5[1] (single radiator, 50% convection, 50% radiation) it can be seen that $F_1 = 1.00$ and $F_2 = 1.00$.

The total required heat capacity is $(1.00 \times 14.9 + \tfrac{1}{3} \times 1.00 \times 0.5 \times 50.8) \times 27 = 631$ W.

Table 14 Results of heat loss calculations

Heat loss mode	Dutch	Belgium	German	British
Transmission	477	452	426	402
Infiltration	194	147	175	229
Additional	463	—	—	448†
Totals	1134	599	601	1079

† See Appendix 4.

8.5 Summary of results

The results of the heat loss calculations are summarised in Table 14.

It appears that the sum of the heat losses by transmittance and infiltration is almost the same in the four cases.

Appendix 1: Derivation of environmental temperature

The equation for heat transfer between a single surface of area A and its enclosing space is

$$Q = A_s[\alpha h_r(t_i + t_s) + h_c(t_s - t_s)]$$

Also

$$t_m\Sigma(A) = A_s t_s + (\Sigma A - A_s)t_i$$

$$Q = A_s\left(\frac{\alpha h_r(t_m - t_s)\Sigma A}{(A - A_s)} + h_c(t_{ai} - t_s)\right)$$

as

$$\frac{\Sigma A}{\Sigma A - A_s} = \tfrac{6}{5}$$

for most cases. When

$$\alpha = 0.9$$
$$h_r = 5.7$$
$$h_c = 3.0 \text{ on average,}$$
$$Q = 0.9 \times 5.7 \times \tfrac{6}{5}(t_m - t_s) + 3.0(t_{ai} - t_s)$$
$$A_s = 6.0(t_m - t_s) + 3.0(t_{ai} - t_s)$$

The standard calculation method includes a calculation temperature such that

$$Q = (h_r + h_c)(t_x - t_s)$$
$$= 9(t_x - t_s)$$
$$6(t_m - t_s) + 3(t_{ai} - t_s) = 9(t_x - t_s)$$

As

$$t_{ri} = t_{ml}$$
$$t_x = \tfrac{1}{3}t_{ai} + \tfrac{2}{3}t_{ri}$$

Appendix 2: Relationship between traditional and environmental temperature methods of calculation

$$Q = \Sigma AU(t_{ei} - t_{ao}) \quad \text{(A1)}$$

$$Q = \Sigma Ah_c(t_{ai} - t_r) \quad \text{(A2)}$$

and

$$t_{ei} = \tfrac{1}{3}t_{ai} + \tfrac{2}{3}t_r \quad \text{(A3)}$$

Transposing equation A2:

$$t_r = t_{ai} - \frac{Q_f}{h_c\Sigma A} \quad \text{(A4)}$$

Substituting equation A4 into equation A3:

$$t_{ei} = t_{ai} - (Q_f/1.5h_c\Sigma A) \quad \text{(A5)}$$

Substituting equation A5 into equation A1:

$$Q_f = AU\left(t_{ai} - t_{as} - \frac{Q_f}{1.5h_c\Sigma A}\right)$$

$$Q_f = \left(\frac{1.5h_c\Sigma(A)}{\Sigma AU + 1.5h_c\Sigma(A)}\right)\Sigma AU(t_{ai} - t_{ao})$$

Appendix 3: System oversize with intermittent heating

$$Q_d = (\Sigma AU + C_v)(t_d - t_o)$$

$$Q_i = \overline{Q}_i + Q_i$$

$$Q_i = (AU + C_v)(t_i - t_o)$$

$$Q_i = (AY + C_v)(t_d - t_i)$$

By definition, areas

$$B + D = A + D + C$$

Therefore

$$nQ_i = 24Q_i$$

or

$$Q_i = \frac{24}{n}(\Sigma(AU) + C_v)(t_i - t_o)$$

The oversize ratio is $F_3 = Q_i/Q_d$, therefore

$$F_3Q_d = Q_i + Q_i$$

$$= (\Sigma AU + C_v)(t_i - t_o) + (\Sigma AY + C_v) + (t_d - t_i)$$

From equation A5,

$$t_1 = \frac{nQ_i}{24(AU + C_v)} + t_0 = \frac{F_3Q_d}{24(AU + C_v)}$$

and, from equation A1,

$$t_d = \frac{Q_d}{(AU + C_v)} + t_0$$

By substitution,

$$F_3Q_d = \frac{(\Sigma AU + C_v)nF_3Q_d}{24(\Sigma AU + C_v)} + \frac{Q_d(\Sigma AY + C_v)}{\Sigma AU + C_v} - \frac{nF_3Q_d(\Sigma AY + C_v)}{24(\Sigma AU + C_v)}$$

$$F_3 = \frac{nF_3}{24} + f_r + \frac{nF_3f_r}{24}$$

$$F_3 = \frac{24f_r}{24 - n + nf_r}$$

$$F_3 = \frac{(24 - n)(f_r - 1)}{24 + n(f_r - 1)}$$

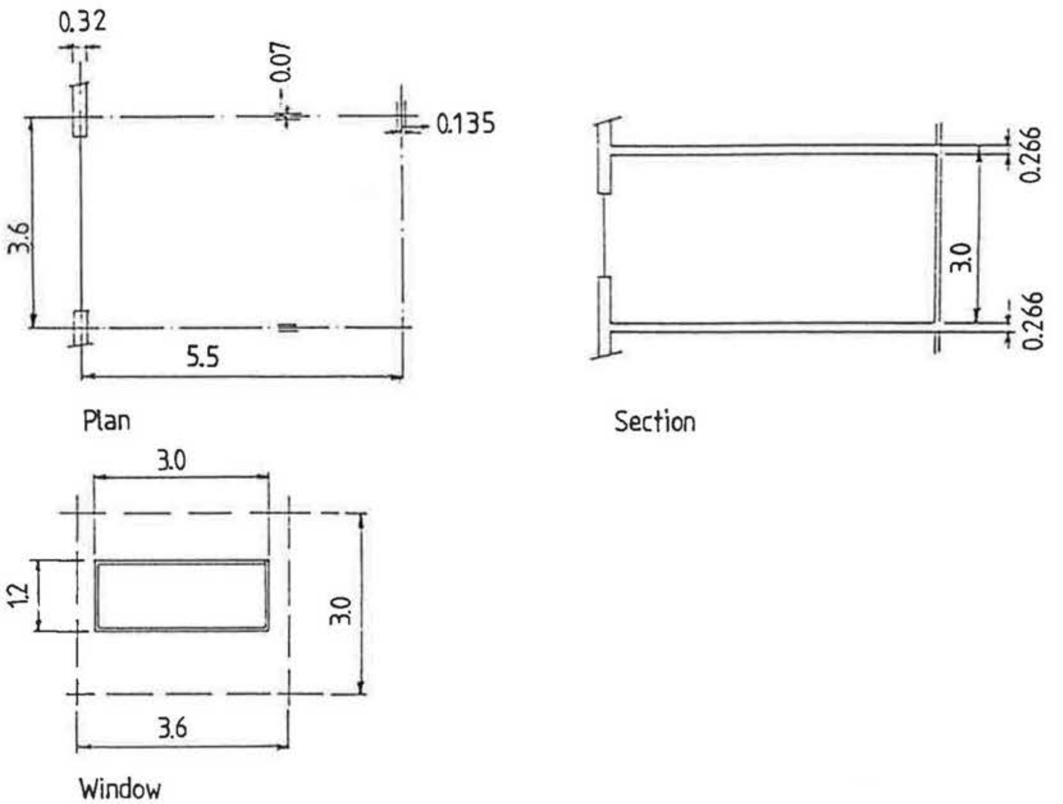

Figure 4 Reference room with medium-weight structure (dimensions in m)

Appendix 5: Thermal properties of structure of reference room

Table 15

Element	Material	Thickness (m)	$W\,m^{-2}\,K^{-1}$	$kg\,m^{-3}$	$J\,kg^{-1}\,K^{-1}$	$m^2\,K\,W^{-1}$
Floor/ceiling	Screed	0.006	0.093			0.065
	Concrete	0.03	1.6	2000	840	0.019
	Concrete	0.20	1.9	2500	840	0.105
	Cavity	0.02				0.170
	Ceiling tiles	0.01	0.08	300	2100	0.125
		0.266				$R_c = 0.484$
Inner wall (adjacent room)	Concrete	0.02	1.9	2500	840	0.011
	Mineral wool	0.03	0.041	40	840	0.732
	Concrete	0.02	1.9	2500	840	0.011
		0.07				$R_c = 0.754$
Inner wall (corridor)	Plasterboard	0.0125	0.7	1600	840	0.018
	Brickwork	0.11	0.41	1150	840	0.268
	Plasterboard	0.0125	0.7	1600	840	0.018
		(0.07)?				$R_c = 0.304$
Outer wall	Concrete	0.08	2.1	2500	840	0.038
	Cavity	0.05				0.12
	Insulation	0.05	0.04	200	1760	1.25
	Concrete	0.14	1.9	2500	840	0.074
		0.32				$R_c = 1.482$

Note that f_r is a room response factor, but that the value calculated using the admittance method is numerically different from that obtained using the ASHRAE method.

$$f_r = \frac{\Sigma AY + C_v}{\Sigma AU + C_v}$$

Appendix 4: Description of the reference room

The heat loss calculations, prescribed in the various standards, are applied to a reference office room of medium-weight structure (about 790 kg m^{-2} floor area). The plan, section and facade view of the room are shown in Figure 4, in which the dimensions are given.

References

1 *CIBSE Guide* (London: Chartered Institution of Building Services Engineers) (1986)
2 DIN 4701-1983 (1983)
3 NEN 5066 (1988)
4 NBN-B62-003 (1986)
5 *AIVC Guide* (Air Infiltration and Ventilation Centre) (1986)
6 *ASHRAE Handbook* (Atlanta, GA: American Society of Heating, Refrigeration and Airconditioning Engineers) (1985)