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# Thermal insulation — Calculation of space heating requirements for residential buildings

*Isolation thermique — Calculs des besoins en chauffage pour les bâtiments résidentiels*

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# Contents



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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 9164 was prepared by Technical Committee ISO/TC 163, *Thermal insulation.*

Annex A forms an integral part of this International Standard. Annexes B to G are for information only.

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## Introduction

Estimates of the space heating requirements for residential buildings may be needed for several purposes. These include judging compliance with regulations written in terms of energy targets, assessing the effect of possible energy-conserving measures or checking the effectiveness of measures which have been carried out and, on a wider national or international scale, predicting future energy resource requirements.

There exist many detailed and complex computer programs which simulate heat interchange within buildings and with their external environment. Often the use of these is not convenient as they usually require very detailed input information. This International Standard provides a relatively simple calculation procedure which will give sufficiently reliable results for the purposes mentioned above.

The method predicts the annual heating requirements. It is based on the fundamental equations for heat transfer in which a number of simplifying assumptions are made, the principal one being to replace continuously varying quantities by appropriate averages. Where the data required cannot be obtained by simple calculation, this International Standard uses or refers to tabulated data.

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# Thermal insulation — Calculation of space heating requirements for residential buildings

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## 1 Scope

This International Standard identifies the terms in the heat balance equation, and describes a method for the calculation of the annual energy requirements for the space heating of residential buildings. The method cannot be applied to special buildings such as those incorporating passive solar design, greenhouses or sunspaces.

## 2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 6946-1 : 1986, *Thermal insulation — Calculation methods — Part 1 : Steady state thermal properties of building components and building elements.*

ISO 6946-2 : 1986, *Thermal insulation — Calculation methods — Part 2 : Thermal bridges of rectangular sections in plane structures.*

ISO 7345 : 1987, *Thermal insulation — Physical quantities and definitions.*

## 3 Definitions and symbols

The terms, symbols and units used are in accordance with ISO 7345. The following additional symbols are specific to this International Standard.

| Term and definition | | Symbol | Unit |
|---|---|---|---|
| **3.1 accumulated temperature difference (to a base temperature):** | Sum of (base temperature less mean daily external temperature, if positive) over all days in period considered. | ATD ($\theta_b$) | °C |
| **3.2 base temperature:** | Internal temperature less temperature increment produced by internal and solar gains. | $\theta_b$ | °C |
| **3.3 external temperature** | | $\theta_e$ | °C |
| **3.4 internal gains:** | Average rate of heat input to dwelling from internal sources other than space heaters. | $\Phi_i$ | W |
| **3.5 internal temperature** | | $\theta_i$ | °C |
| **3.6 space heating requirement (annual):** | Energy output from space heaters in one year. | $Q_h$ | J, MJ, GJ, (kWh, MWh) |
| **3.7 space heating requirement (monthly):** | Energy output from space heaters in one month. | $Q_{h,m}$ | J, MJ, GJ, (kWh, MWh) |
| **3.8 solar gains:** | Average rate of heat input to dwelling from solar radiation. | $\Phi_s$ | W |
| **3.9 specific heat loss:** | Total heat loss from dwelling (by fabric transmission and ventilation) divided by the difference between the internal and external temperatures. | $H$ | W/K |
| **3.10 time step:** | Period of integration of the heat balance equation. | $t$ | s |
| **3.11 utilization factor:** | Proportion of the internal and solar gains which contribute to reducing the space heating requirements. | $\eta_m$ | |

**Conversion factors:**

1 W = 0,024 kWh/day
1 kWh/day = 41,7 W
1 MJ = 0,278 kWh
1 kWh = 3,6 MJ

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## 4 General considerations

**4.1** The factors which together contribute to space heating energy requirements are

a) characteristics of the house — transmission and ventilation heat losses (allowing for any heat recovery), and thermal capacity;

b) characteristics of the heating system — particularly control systems and ability to respond to changes in heat requirements;

c) internal temperatures — the temperature level required by the user and variations in this level both in different parts of the house and at different times of the day;

d) internal heat gains other than from the heating system — from occupants, cooking and hot water, lighting and electrical appliances;

e) solar gains;

f) external weather conditions — principally temperature.

**4.2** This International Standard specifies a method which takes account of these factors, and it follows that data for each of them are required for a calculation. In many cases the necessary information may be contained in national standards or other suitable documents, and these should be used where available. Annexes to this International Standard are provided, however, giving representative values or methods for obtaining representative values for use when the required information is not otherwise available.

There is very wide variation in energy consumption in houses. This can be ascribed to variations in the factors listed above; in principle, to the extent that precise information is available, the calculation can be applied to a single specific dwelling.

However, it should be noted that large variations in consumptions have been observed over groups of nominally identical houses attributable to variations in user requirements and living patterns (e.g. internal temperatures, window opening). Where there is no detailed knowledge of user requirements and living patterns, the calculation is made for a "typical" household.

The calculation can be made either for an "average" year using weather data for the locality concerned averaged over a number of years, or for a particular year using the recorded weather data for that year, depending on the purpose of the calculation. The former would be appropriate for predictive purposes, and the latter when comparing with recorded fuel consumption.

This International Standard gives a method for the calculation of space heating requirements; the energy requirements for other purposes are not included.

The energy balance on which the calculation method is based is defined as including the following:

a) transmission and ventilation losses from the internal to the external environment;

b) the net output from the heating system (which differs from the energy input when the fan conversion efficiency is other than unity);

c) the net internal heat gains, that is the heat actually released to the house from the factors in 4.1 d), which in the case of appliances involving water heating is somewhat less than the energy input to these appliances (the difference being lost in waste water);

d) the net solar gains, not including any proportion either lost through increased ventilation during periods of high solar gain or contributing to the temperature rising above the set point.

## 5 Calculation method

### 5.1 Introduction

The calculation method is based on a steady-state energy balance for the house with an allowance for the dynamic effect of internal and solar gains. Part of the energy needed to maintain a given internal temperature $\theta_i$ comes from the internal and solar gains. The method calculates the remainder which is needed from the space heating system.

The calculation basis, described in annex A, allows for day-by-day variations in external temperature, and month-by-month variations in mean solar radiation. The heating requirement for one month is obtained from a summation of the heating requirement for each day in the month, using the average daily values of the temperatures and average monthly values of the gains, thus

$$Q_{h,m} = \Sigma\,[H(\theta_i - \theta_e) - \eta_m(\Phi_i + \Phi_s)]_{d,pos}\,t \qquad \dots (1)$$

where

$Q_{h,m}$ is the space heating requirement for month, in joules;

$H$ is the specific heat loss, in watts per kelvin;

$\theta_i$ is the daily average internal temperature, in degrees Celsius;

$\theta_e$ is the daily average external temperature, in degrees Celsius;

$\eta_m$ is the utilization factor for gains;

$\Phi_i$ are the average internal gains over month, in watts;

$\Phi_s$ are the average solar gains over month, in watts;

$t$ is the number of seconds in a day (86 400);

$_{d,pos}$ signifies that the sum is carried out for all days in the month for which the expression is positive.

NOTE — In equation (1) the daily average internal temperature, $\theta_i$, can be assumed to be the same for each day in the month, calculated from the monthly average temperatures. Thus only $\theta_e$ varies on a day-by-day basis in the equation.

Equation (1) is conveniently evaluated as

$$Q_{h,m} = H \times \mathrm{ATD}(\theta_b)$$

where $\mathrm{ATD}(\theta_b)$ represents the accumulated daily mean temperature difference to base $\theta_b$ for the locality and month concerned[1].

The annual space heating requirement is obtained from a summation of the requirements for individual months.

NOTE — The above procedure gives the energy output required from the space heaters. This differs from the energy delivered to the dwelling because

a) the space heating appliance may have a conversion efficiency other than unity;

b) the delivered energy also includes that required for water heating, lighting and electrical appliances.

### 5.2 Zones

When the house is heated to the same temperature throughout, it shall be treated as a single zone and the space heating requirement obtained in accordance with 5.3.

1) Also known as "variable-base degree-days".

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If different design temperatures apply in different parts of the house, it shall be determined on a national basis whether the calculation is made

a) with the house as a single zone, or

b) with the house divided into two zones of different temperature standards.

In the case of a single zone calculation, the internal temperature $\theta_i$ shall be a spatial average over the house.

In the case of a two-zone calculation, the procedure of 5.3 shall be followed for each zone and the space heating requirements for each zone added together. In this case the specific heat loss, the internal gains and solar gains shall be divided appropriately between the zones.

### 5.3 Calculation procedure

The annual space heating requirement shall be calculated as follows.

**5.3.1** Define the building envelope and calculate the specific thermal loss $H$ in watts per kelvin (see 6.1).

**5.3.2** Specify the design internal temperature, $\theta_{i,d}$.

**5.3.3** For each month

a) calculate the mean value over the month of the gross internal and solar gains $\Phi_i + \Phi_s$ (see 6.2);

b) determine the utilization factor $\eta_m$ for these gains (see 6.3);

c) for continuous heating, set the mean internal temperature $\theta_i$ equal to $\theta_{i,d}$ : otherwise determine the mean internal temperature (see 6.4);

d) find the base temperature $\theta_b$ from

$$\theta_b = \theta_i - \frac{\eta_m (\Phi_i + \Phi_s)}{H}$$

e) find the accumulated temperature difference to this base temperature ATD($\theta_b$), for the climate concerned (see 6.5);

f) obtain the space heating requirement for the month from

$$Q_{h,m} = H \times \text{ATD}(\theta_b)$$

NOTE — Any consistent system of units can be used in the above expression for $Q_{h,m}$. With $H$ expressed in watts per kelvin, then ATD($\theta_b$) expressed in degrees Celsius multiplied by day must be multiplied by 86 400 to obtain $Q_{h,m}$ in joules.

**5.3.4** Total the space heating requirements for each month in the heating season to obtain the annual requirement, $Q_h$ :

$$Q_h = \Sigma\, Q_{h,m}$$

NOTE — The heating season is defined to include all months for which the following apply:

a) the accumulated temperature difference to the applicable base temperature is greater than zero; and

b) the gross internal and solar gains do not exceed 2,5 times the heat loss:

$$\Phi_i + \Phi_s \leqslant 2{,}5 H (\theta_i - \theta_e)$$

## 6 Factors in equations

Where national standards exist, these should be used to obtain the data required for the calculation, having regard to the considerations given below. If an appropriate national standard does not exist, or contains insufficient information, the necessary data can be obtained from the annexes to this International Standard.

### 6.1 Transmission and ventilation heat losses

The parameter $H$ is given by

$$H = H_T + H_V$$

where

$$H_T = \Sigma\, AU + \Sigma\, lU_l$$

in which

$A$ is the area of exposed fabric, in square metres;

$U$ is the thermal transmittance of exposed fabric, in watts per square metre kelvin;

$l$ is the length of thermal bridge, in metres;

$U_l$ is the linear thermal transmittance of thermal bridge, in watts per metre kelvin;

and

$$H_V = c\varrho \dot{V}$$

in which

$c$ is the specific heat capacity of air, in joules per kilogram;

$\varrho$ is the density of air, in kilograms per cubic metre;

$\dot{V}$ is the volumetric air change rate, in cubic metres per second.

#### 6.1.1 Transmission losses

Simple $U$-values can be calculated by the methods given in ISO 6946-1. For other values a relevant national standard should be used to calculate $U$-values or to obtain suitable values from tabulated data.

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Effects of thermal bridges should be included for structures where thermal bridges are present. $U_l$ for rectangular-shaped thermal bridges can be calculated by the methods given in ISO 6946-2.

Effective $U$-values for ground floors can be used in climates where the heating season is sufficiently long (that is, several months of the year), so that it is reasonable to make an approximation of steady-state conditions. In such cases there may be large proportionate errors near either end of the heating season, but at these times the losses are small compared with the annual total.

### 6.1.2 Ventilation losses

Ventilation rates vary with wind speed and direction, and with temperature differences. An appropriate average value is required. Where there is ventilation heat recovery this should be taken account of in determining the ventilation heat loss. Further guidance is given in annex B.

During periods of high solar gain, windows may be opened to increase the ventilation. This is allowed for in the utilization factor for the solar gains and should not be allowed for in the determination of average air change rate.

## 6.2 Internal heat gains and solar gains

Internal heat gains should include

- metabolic gains (from people);
- gains to the house from hot water system;
- gains to the house from cooking;
- the power consumption of electrical appliances;
- the power consumption of artificial lighting.

All of these vary during the day, but average daily values are appropriate for the present purpose. With the exception of lighting, the average daily values will be relatively constant throughout the year.

Further guidance on internal heat gains is given in annex C.

Solar gains should take account of the normally available sunshine in the locality concerned, the orientation of the windows, shading, and the solar transmission characteristics of the glazing. Further guidance is given in annex D.

Solar radiation also affects the heat transmission through walls and roofs, but this is usually small compared with solar gains through windows, and for the purposes of this International Standard need not be included.

## 6.3 Utilization factor

It is not usually appropriate to count the gross internal and solar gains as useful (in the sense of contributing to reducing the space heating requirement). This is because during periods of high heat gain, the gains may exceed the instantaneous loss rate, or gains may be received during periods when heating is not required. For this reason the internal and solar gains must be reduced by a utilization factor, the magnitude of which depends on the relative sizes of the gains and losses and on the thermal mass of the building. Further guidance on utilization factors is given in annex E.

## 6.4 Internal temperatures

The value of internal temperature $\theta_i$ required for the calculation method is a spatial average over the house or, in the case of a two-zone calculation, over the zone (where the whole house or zone is not at a uniform temperature), and it is also a temporal average over each month (when the internal temperature is not constant, that is when the heating is not operated continuously).

For heating 24 h per day, the design internal temperature is used.

When heating is switched off at night, the design internal temperature will apply during the daytime. At night the temperature will gradually fall. The rate of fall of temperature depends on the transmission and ventilation losses, the thermal capacity, the external temperature, and the responsiveness of the heating system, and these factors must be allowed for in determining the appropriate value of $\theta_i$. Further guidance on internal temperatures is given in annex F.

During periods of high solar gain, the internal temperature may rise above the design value. This is allowed for in the utilization factor for the solar gains, and should not be allowed for in the determination of average internal temperature.

## 6.5 Accumulated temperature difference

Accumulated temperature differences, calculated from the difference between base temperature and mean daily external temperature, to the appropriate base temperature are required for each month. A different base temperature will normally apply in each month. Accumulated temperature difference data may be calculated; it will form the subject of a future International Standard.

NOTE — "Accumulated temperature difference" used in this standard is also known as "variable-base degree-days". Accumulated temperature difference to fixed base, which are tabulated for many climates (for example to base 20 °C, 18 °C or 15,5 °C), are inappropriate and should not be used.

A good approximation to the accumulated temperature difference can in many cases be obtained from monthly mean external temperatures. Further information is provided in annex G.

In some climates it is a sufficient approximation to take

$$\mathrm{ATD}(\theta_b) = N(\theta_b - \theta_e)$$

where $N$ is the number of days in the month. This method of calculation can be adopted on a national basis.

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## 7 Report

A report giving the space heating requirements obtained in accordance with this International Standard shall include

a) a description of the dwelling and its construction;

b) reference to any International Standards, national standards or other documents used to obtain climatological data and utilization factors, or reference to the appropriate annexes to this International Standard;

c) assumptions made in regard to ventilation rates, occupancy, heating patterns, internal temperatures;

d) whether the house was treated as one zone or two zones, and if two zones, the zone division (that is, the allocation of rooms to each zone) shall be stated.

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# Annex A
(normative)

## Basis of calculation method

The following analysis applies to a house which is uniformly heated throughout. It can also be applied for other houses either by using a spatial average for the internal temperature, or by dividing the house into two or more zones and applying the equations separately to each zone.

The balance describing the heat interchange between the house and its surroundings may be written as follows:

$$\Phi_h + \Phi_i + \Phi_s = H(\theta_i - \theta_e) + \Delta \quad \text{... (A.1)}$$

where

$\Phi_h$ is the output from heating system, in watts;

$\Phi_i$ is the other internal heat gains, in watts;

$\Phi_s$ is the solar gains, in watts;

$H$ is the specific heat loss, in watts per kelvin;

$\theta_i$ is the internal temperature, in degrees Celsius;

$\theta_e$ is the external temperature, in degrees Celsius;

$\Delta$ is the rate of heat storage within the structure, in watts;

which can be rewritten

$$\Phi_h = H(\theta_i - \theta_e) - (\Phi_i + \Phi_s) + \Delta \quad \text{... (A.2)}$$

Each variable in equations (A.1) and (A.2) represents an instantaneous value, as they will all vary continuously with time. The space heating requirement $Q$, in joules, over any time period is then given by

$$Q_h = \int \Phi_h \, dt \quad \text{... (A.3)}$$

NOTE — In equations (A.2) and (A.3), $\Phi_h$ cannot be negative. During periods of high heat gain either $\theta_i$, the ventilation part of $H$, or $\Delta$ (in practice, usually a combination of all three) increase so that equation (A2) is always satisfied with $\Phi_h \geqslant 0$.

The instantaneous power balance of equation (A.2) is modified by the following steps to obtain a monthly balance.

First it is assumed that equation (A.2) is linear so that the variables can be replaced by daily average values:

$$\overline{\Phi}_n = \overline{H}(\overline{\theta}_i - \theta_e) - (\overline{\Phi}_i + \Phi_s) + \overline{\Delta} \quad \text{... (A.4)}$$

where a single overlining of variable denotes its daily average.

In equation (A.4), $\overline{H}$ is the average value of $H$ including any period of time when $H$ may be increased (by opening of windows, for example) to counteract high solar gain. $\overline{\theta}_i$ is the average value of $\theta_i$ including any period when $\theta_i$ may be increased above the design value (or the value set by a thermostat), by high solar gain or because $\theta_e$ is greater than the design value of $\theta_i$. It is, however, much more convenient to evaluate both quantities without these complications. Let

$H'$ be the specific heat loss in the absence of heat gains, that is evaluated using the design value of air change rate,

$\theta_i'$ be the average internal temperature assuming that $\theta_i$ is always less than or equal to the set point.

Then

$$\overline{\Phi}_h = H'(\overline{\theta}_i' - \overline{\theta}_e) - \eta_d(\overline{\Phi}_i + \overline{\Phi}_s) + \overline{\Delta} \quad \text{... (A.5)}$$

if $\Phi_h$ is positive, otherwise $\overline{\Phi}_h = 0$.

$\eta_d$ is a utilization factor modifying the heat gains. The effect of $\eta_d$ is to include in equation (A.5) only that proportion of the gains which reduce the space heating requirement, and to exclude the proportion which causes $\theta_i$ to increase above the set point, or $H$ to increase above the design value. It is now necessary to include explicitly the condition that $\overline{\Phi}_h > 0$ since a negative value could result at high values of $\overline{\theta}_e$. It is assumed that the building has sufficient mass so that $\overline{\theta}_e$ is not modified in equation (A.5).

The total heating requirement for a month, m, is then

$$Q_{h,m} = \Sigma \, \overline{\Phi}_{h,pos} \, t'$$

where

$t'$ is the number of seconds in a day (86 400);

$\overline{\Phi}_{h,pos}$ signifies that the summation is made over all days in the month having positive values of $\Phi_h$.

Thus

$$Q_{h,m} = t' \Sigma \, [H'(\overline{\theta}_i' - \overline{\theta}_e) - \eta_d(\overline{\Phi}_i + \overline{\Phi}_s) + \overline{\Delta}]_{pos} \quad \text{... (A.6)}$$

The next step is to replace the internal temperature and gains in equation (A.6) by the monthly average values. In respect of $\theta_i'$, it will in any case be a constant for continuous heating. For intermittent heating it will vary on a daily basis with $\theta_e$ but since $\theta_i$ is maintained at a particular value for part of the day, the day-by-day variation of $\theta_i'$ will be less than that of $\overline{\theta}_e$. It is assumed that the monthly average value of internal temperature, calculated from the monthly average value of the external temperature, can be used.

In respect of gains, it is assumed that the monthly average values can be used with the heat storage term $\overline{\Delta}$ subsumed

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into monthly utilization factor $\eta_m$. With these assumptions, equation (A.6) becomes

$$Q_{h,m} = t' \Sigma [H' (\overline{\overline{\theta}}_i - \overline{\theta}_e) - \eta_m (\overline{\overline{\Phi}}_i + \overline{\overline{\Phi}}_s)]_{pos} \qquad \dots (A.7)$$

where a double overlining of variables denotes its monthly average.

(A strict definition of $\eta_m$ would be the value of $\eta_m$ in equation (A.7) such that equations (A.7) and (A.3) give identical results.)

Defining the base temperature $\theta_b$ as

$$\theta_b = \overline{\overline{\theta}}_i' - \frac{\eta_m (\overline{\overline{\Phi}}_i + \overline{\overline{\Phi}}_s)}{H'} \qquad \dots (A.8)$$

which is constant for a given month, equation (A.7) becomes

$$Q_{h,m} = t' H' \Sigma (\theta_b - \overline{\theta}_e)_{pos} \qquad \dots (A.9)$$

The base temperature can be visualized as the value of mean daily external temperature above which no space heating will be required on that day.

The summation in equation (A.9) is the accumulation of excess of base temperature over mean daily external temperature for each day in the month, that is the accumulated daily mean temperature difference[1)] ATD($\theta_b$) to base $\theta_b$ defined by

$$\text{ATD}(\theta_b) = \Sigma (\theta_b - \overline{\theta}_e)_{pos}$$

The monthly space heating requirement is then

$$Q_{h,m} = t' H' \text{ATD}(\theta_b) \qquad \dots (A.10)$$

The annual space heating requirement is obtained from summation of the monthly heating requirements, including each month having a non-zero value.

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1) Also known as "variable-base degree-days".

# Annex B
(informative)

# Air change rates

## B.1 Basic equation

In 6.1, the ventilation losses, in watts per kelvin, are given by the equation

$$H_V = c \cdot \varrho \cdot n_s \cdot V \qquad \text{... (B.1)}$$

where

$\varrho$ is the density of air, in kilograms per cubic metre;

$c$ is the specific heat capacity of air, in joules per kilogram kelvin;

$n_s$ is the air change rate, in seconds to the power minus one;

$V$ is the ventilated volume, in cubic metres.

For convenience, this can be rewritten as

$$H_V = 0{,}33\, n_h V \qquad \text{... (B.2)}$$

where $n_h$ is the air change rate, in hours to the power minus one.

The term 0,33 is the thermal capacity per unit volume of air, in kilograms per cubic metre times joules per kilogram kelvin, divided by the number of seconds per hour.

$$\frac{\varrho c}{3\,600} = \frac{1{,}184 \times 1\,006}{3\,600} = 0{,}33\ \mathrm{J \cdot h/(m^3 \cdot K \cdot s)} \qquad \text{... (B.3)}$$

$\varrho$ and $c$ vary slightly with temperature and pressure but this is neglected in the above equations. The values given correspond to a temperature of 20 °C and a pressure of 100 kPa. The increase in enthalpy between incoming and outgoing air is also neglected.

## B.2 System dependence

In this annex three types of ventilation systems are considered:

a) natural ventilation;

b) exhaust fan ventilation;

c) balanced ventilation with or without heat exchanger.

### B.2.1 Natural ventilation

For naturally ventilated buildings, infiltration rates vary considerably due to factors such as geometry and tightness of the building, wind speed and direction, and temperature difference between inside and outside [1].

Natural ventilation rates have to be determined on a national basis, taking account of climate and built form. When no national information is available a recommended value for $n$, inclusive of infiltration and occupant-controlled ventilation, is 1,0 $h^{-1}$.

### B.2.2 Exhaust fan ventilation

During the heating season the exhaust air flow will normally be set to meet the specified minimum ventilation rate. Due to the resulting pressure difference between inside and outside, additional infiltration is reduced. The ventilation rate may be expressed as

$$n = n_{set} + n_{ie} \qquad \text{... (B.4)}$$

where

$n_{set}$ is the ventilation rate through ventilation system, in hours to the power minus one;

$n_{ie}$ is the additional infiltration rate for exhaust-fan-ventilated buildings, in hours to the power minus one.

$n_{ie}$ varies with climatic conditions and built form. When no national information is available, a recommended value for $n_{ie}$ is 0,1 $h^{-1}$.

### B.2.3 Balanced ventilation

For balanced ventilation systems with heat recovery between incoming and outgoing air, the ventilation rate may be expressed as

$$n = n_{set}(1 - \xi) + n_{ib} \qquad \text{... (B.5)}$$

where

$n_{set}$ is the ventilation rate for outlet air through the ventilation system, in hours to the power minus one;

$n_{ib}$ is the additional infiltration rate for buildings with balanced ventilation, in hours to the power minus one;

$\xi$ is the efficiency factor for the air to air heat recovery system.

Since there is a smaller pressure difference between inside and outside compared to the exhaust system, the additional infiltration $n_{ib}$ is greater than $n_{ie}$. $n_{ib}$ varies with climatic conditions and built form. When no national information is available a recommended value for $n_{ib}$ is 0,2 $h^{-1}$.

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The efficiency factor $\xi$ is defined for the outlet air

$$\xi = \frac{\theta_i - \theta_{ex}}{\theta_i - \theta_e} \qquad \ldots \text{(B.6)}$$

where

$\theta_i$ is the internal air temperature, in degrees Celsius;

$\theta_e$ is the external air temperature, in degrees Celsius;

$\theta_{ex}$ is the temperature of outlet air leaving the heated space, in degrees Celsius.

In many systems this efficiency will differ considerably from the efficiency for inlet air provided by the manufacturers of heat recovery systems. The latter is suitable to calculate the demand for preheating but can be misleading when the total loss of energy through the ventilation system is being calculated.

## Bibliography

[1] AICV (Air Infiltration and Ventilation Centre) Calculation Handbook.

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# Annex C
(informative)

# Internal heat gains

The calculation procedure requires an average rate of internal heat gain which allows for intermittency of occupation and of use of appliances. There are substantial variations between households and climates, and values should normally be determined on a national basis. The following are values for use where no national document exists.

## C.1 Occupants

Rates of heat emission vary, for an adult, between 65 W (sleeping) to about 200 W (moderate activity). There is also a dependence on body size. Allowing for absence from the house for part of the day, a typical value is

65 $N_p$ in watts (1,5 $N_p$ in kilowatt hours per day)

where $N_p$ is the number of persons in the household.

## C.2 Hot water

There are heat gains to the house from the hot water system from standing losses from tanks and pipes, and from condensation of evaporated water vapour. The contribution to space heating depends on various factors including

- the type of water system;
- the length of time for which a high water temperature is maintained;
- the volume of hot water used;
- the insulation standard of the hot water cylinder and pipes;
- the length of pipe runs.

A typical value may be obtained from

25 + 15 $N_p$ in watts (0,6 $N_p$ + 0,4 $N_p$ in kilowatt hours per day)

where $N_p$ is the number of persons in the household.

There is also a heat loss to the water system : the heat gained by cold water drawn into the house at the below-ground temperature and which rises in temperature towards the house temperature whilst standing in cold water tanks and pipes. This loss can be allowed for by subtracting a suitable amount from the total internal heat gains, but it is usually sufficiently small (in relation to the internal heat gains) to be ignored.

## C.3 Cooking

The energy consumed by a gas cooker is greater than that consumed by an electric cooker, due to the need to ventilate the oven to remove combustion products and to the gas consumed by pilot lights. The useful contribution to the space heating requirements is largely offset by the additional ventilation required for gas cooking. In all cases the heat gain to the house is less than the energy consumed since part is lost in latent heat. A typical value is

110 in watts (2,6 in kilowatt hours per day).

## C.4 Electrical appliances

The heat gain from electrical appliances will depend on the number of appliances and the extent of their use. Typical values for various appliances are

| | |
|---|---|
| television: | 35 (W) 0,8 (kWh/day) |
| refrigerator: | 40 (W) 1,0 (kWh/day) |
| kettle: | 20 (W) 0,5 (kWh/day) |
| freezer: | 90 (W) 2,2 (kWh/day) |
| washing machine: | 10 (W) 0,2 (kWh/day) |
| dishwasher: | 20 (W) 0,5 (kWh/day) |
| tumble drier: | 20 (W) 0,5 (kWh/day) |
| miscellaneous items: | 20 (W) 0,5 (kWh/day) |

NOTE — These values may be reduced in future by technical developments.

## C.5 Lighting

The heat gain from lighting depends on the number of rooms in use, and at most latitudes will vary through the heating season according to hours of daylight. It will be greater at high latitudes than nearer the equator. In the absence of other information the following values can be used:

| | |
|---|---|
| small dwelling (< 50 m²), no children: | 15 (W) 0,3 (kWh/day) |
| medium dwelling (50 m² to 100 m²), no children: | 30 (W) 0,6 (kWh/day) |
| large dwelling (> 100 m²), no children: | 45 (W) 0,9 (kWh/day) |
| add, if children: | 15 (W) 0,3 (kWh/day) |

NOTE — These values may be reduced in future by technical developments.

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## C.6 Typical value for total internal gains

Where details of the household are not known, it is recommended that the following values be used (based on a three person household):

| | | |
|---|---|---|
| occupants<br>65 × 3 (1,5 × 3): | 195 (W) | 4,5 (kWh/day) |
| hot water<br>25 + 15 × 3(0,6 + 0,4 × 3): | 70 (W) | 1,8 (kWh/day) |
| cooking: | 110 (W) | 2,6 (kWh/day) |
| electrical appliances: | 180 (W) | 4,6 (kWh/day) |
| lighting, medium house + children: | 45 (W) | 0,9 (kWh/day) |
| *Total*: | 600 (W) | 14,4 (kWh/day) |

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# Annex D
(informative)

# Solar heat gains

This annex provides a method for calculating the average monthly solar input. Before inserting in the energy balance equation, this value must be multiplied by a utilization factor (see annex E). The solar heat gains of a building depend upon the following factors:

— the amount of solar radiation on surfaces of different orientations;

— the area of transparent surfaces;

— the solar transmittance of transparent surfaces;

— the shading of transparent surfaces.

The effect of solar radiation on non-transparent surfaces is neglected.

The net average solar gain $\Phi_{s,m}$ can be calculated, in watts, for each month as follows

$$\Phi_{s,m} = \Sigma (r_{i,m} g_{i,m} I_{i,m} A_i)_{\text{orientation}} \quad \text{... (D.1)}$$

where

$I_{i,m}$ is the average monthly solar radiation on vertical surface at orientation $i$ during month $m$, in watts per square metre;

$A_i$ is the area of transparent surfaces at orientation $i$, in square metres;

$g_i$ is the solar transmission factor of glazing at orientation $i$;

$r_{i,m}$ is the shading factor for the transparent surface at orientation $i$ during month $m$.

NOTE — The formulae in this annex give the solar input to the building, in watts, averaged over the days in the month and over 24 h, as required by the International Standard.

## D.1 Average monthly insolation on vertical surfaces

The following method can be used to calculate the mean monthly radiation $I_{i,m}$ on vertical surfaces, for each orientation $i$ and month $m$. The method is based on the work of Liu and Jordan and of Page [1], [2], [3]. It can be applied to sites located between 30° and 65° latitude in both hemispheres.

The calculation method depends on whether average monthly values of insolation on horizontal surfaces (global radiation) are available for the location in question. In both cases the insolation is derived from the extra-terrestrial global radiation, which is readily calculated from first principles for a given latitude and day of the year.

Absorption in the atmosphere, including the effect of clouds, must be allowed for. This is done by introducing a "clearness index" $k_h$ which is defined for the radiation, $I_h$, received on a horizontal surface by

$$K_h = \frac{I_h}{I_o} \quad \text{... (D.2)}$$

where $I_o$ is the extra-terrestrial radiation.

When the global radiation on the horizontal $I_h$ is known, this information can be used to obtain the clearness index for the locality concerned (case 1). This method should be used wherever possible.

When $I_h$ is not known, an estimate has to be used for $K_h$ (case 2).

As mean monthly values are required, $I_o$ is obtained for a particular day in each month for which the radiation closely approximates the average of the month.

Relationships are provided to convert the radiation on the horizontal to radiation on vertical surfaces orientated N, NE, S, SE, SW, W or NW.

### D.1.1 Case 1 (the global radiation is known)

**Step 1:** Calculate the extra-terrestrial global radiation $I_{o,m}$, in watts per square metre, for a representative day $n$ of the month (see table D.1).

$$I_{o,m} = \frac{S}{\pi} \left(1 + 0{,}033 \cos \frac{360\, n}{365}\right) \left(\cos \phi \cos \delta \sin \omega + \frac{\omega\, \pi}{180} \times \sin \Phi \cdot \sin \delta\right) \quad \text{... (D.3)}$$

where

$S$ is a solar constant (1 353 W/m$^2$);

$n$ is a representative day of the month (see table D.1);

$\phi$ is the latitude;

$\delta$ is the sun declination;

$\omega$ is the sunset angle (hour at sunset expressed in degrees, midday = 0°).



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$\delta$ and $\omega$ are given by:

$$\delta = 23{,}45 \sin \frac{360\,(284 + n)}{365} \qquad \text{... (D.4)}$$

$$\omega = \arccos\,(-\tan\phi \tan\delta) \qquad \text{... (D.5)}$$

NOTE — All angles are expressed in degrees.

**Table D.1 — Recommended characteristic day for each month**

| Month | Day of the year | Date |
|---|---|---|
| January | 17 | 17 January |
| February | 47 | 16 February |
| March | 75 | 16 March |
| April | 105 | 15 April |
| May | 135 | 15 May |
| June | 162 | 11 June |
| July | 198 | 17 July |
| August | 228 | 16 August |
| September | 258 | 15 September |
| October | 288 | 15 October |
| November | 318 | 14 November |
| December | 344 | 10 December |

**Step 2:** Obtain the clearness index $K_h$

$$K_h = \frac{I_{h,m}}{I_{o,m}} \qquad \text{... (D.6)}$$

The measured global radiation $I_{h,m}$ can be found in tables for the locality concerned.

**Step 3:** Calculate the average monthly radiation $I_{i,m}$ on vertical surfaces.

$$I_{i,m} = y_i K_h I_{o,m} \qquad \text{... (D.7)}$$

The orientation factor $y_i$ of a particular surface orientation $i$ is calculated using the regression equation given in table D.2. The orientation $i$ can be N, NE, E, SE, S, SW, W or NW.

Figure D.1 shows, as an example, the orientation factors as a function of the difference of latitude and solar declination, with a clearness index of 0,3 and a ground reflectance of 0,3.

### D.1.2 Case 2 (the global radiation is unknown)

If the average monthly radiation on a horizontal surface is not known for a location concerned, the clearness index has to be estimated in order to estimate the radiation on vertical surfaces. No systematic examination of this subject is available, but the higher the latitude and the lower the air pollution of the locality, the greater is the value of $K_h$.

Typical values of $K_h$ are

urban regions of low altitude: $0{,}1 < K_h < 0{,}4$ (average 0,3 to 0,45)[1)]

rural areas with high altitude (> 500 m): $0{,}4 < K_h < 0{,}7$

The radiation on vertical surfaces of different orientations can then be calculated in a manner equivalent to case 1 using formula (D.7) and the regression relations (table D.2).

**Table D.2 — Regression relations to determine orientation factors for differently oriented surfaces**

| Vertical surface orientation, $i$ | Orientation coefficients | | |
|---|---|---|---|
| | $a_0$ | $a_1$ | $a_2$ |
| S | 0,559 | $-1{,}61 \times 10^{-2}$ | $5{,}43 \times 10^{-4}$ |
| SW/SE | 0,705 | $-1{,}88 \times 10^{-2}$ | $4{,}84 \times 10^{-4}$ |
| W/E | 0,641 3 | $-0{,}783 \times 10^{-2}$ | $1{,}84 \times 10^{-4}$ |
| NW/NE | 0,527 2 | $-0{,}164 \times 10^{-2}$ | $-5{,}73 \times 10^{-6}$ |
| N | $y = (0{,}6\,R + 0{,}82)\,(0{,}635 - 0{,}55\,K_h)$ | | |

NOTE — The ground reflectance $R$ is typically 0,3 without snow, and 0,5 to 0,7 with snow.

$K_h$ clearness index

$R$ ground reflectance

$x$ difference between latitude and sun declination

$y_i = (0{,}6\,R + 0{,}82)\,(a_0 + a_1 z + a_2 z^2)$

$z = x - 17{,}5 + 35\,K_h$

## D.2 Solar transmission factors

The energy transmission through transparent surfaces depends on the type of glass. The solar transmission factor is the ratio of energy passing through the glazing to that incident upon it. Typical solar transmission factors $g$ are given below:

| | |
|---|---|
| single glazing | 0,9 |
| double glazed clear glass | 0,8 |
| double glazed insulation glass | 0,7 to 0,8 |
| triple glazed clear glass | 0,7 |
| multiple glazed special glass | 0,2 to 0,8 |

NOTE — These are values for normal incidence, assuming clean surfaces. The values are reduced at other angles of incidence.

1) Monthly values of clearness index vary throughout the year, due to changes in weather conditions and cloud cover. Typical values are given in table D.3.

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**Table D.3 — Typical clearness indices for each month**

| Month | Typical clearness indices, $K_h$ |
|---|---|
| January | 0,3 |
| February | 0,35 |
| March | 0,4 |
| April | 0,4 |
| May | 0,45 |
| June | 0,45 |
| July | 0,45 |
| August | 0,45 |
| September | 0,4 |
| October | 0,35 |
| November | 0,3 |
| December | 0,3 |

## D.3 Shading factors

The shading factor, $r$, which is in the range 0 to 1, represents any reduction in incident solar radiation due to shading of the surface concerned. It is usually less than 1,0 because of one or more of the following factors (see [4]):

- shading by other buildings;
- shading by topography (hills, trees, etc.);
- overhangs;
- shading by other walls of the same building;
- position of window relative to plane of wall exterior.

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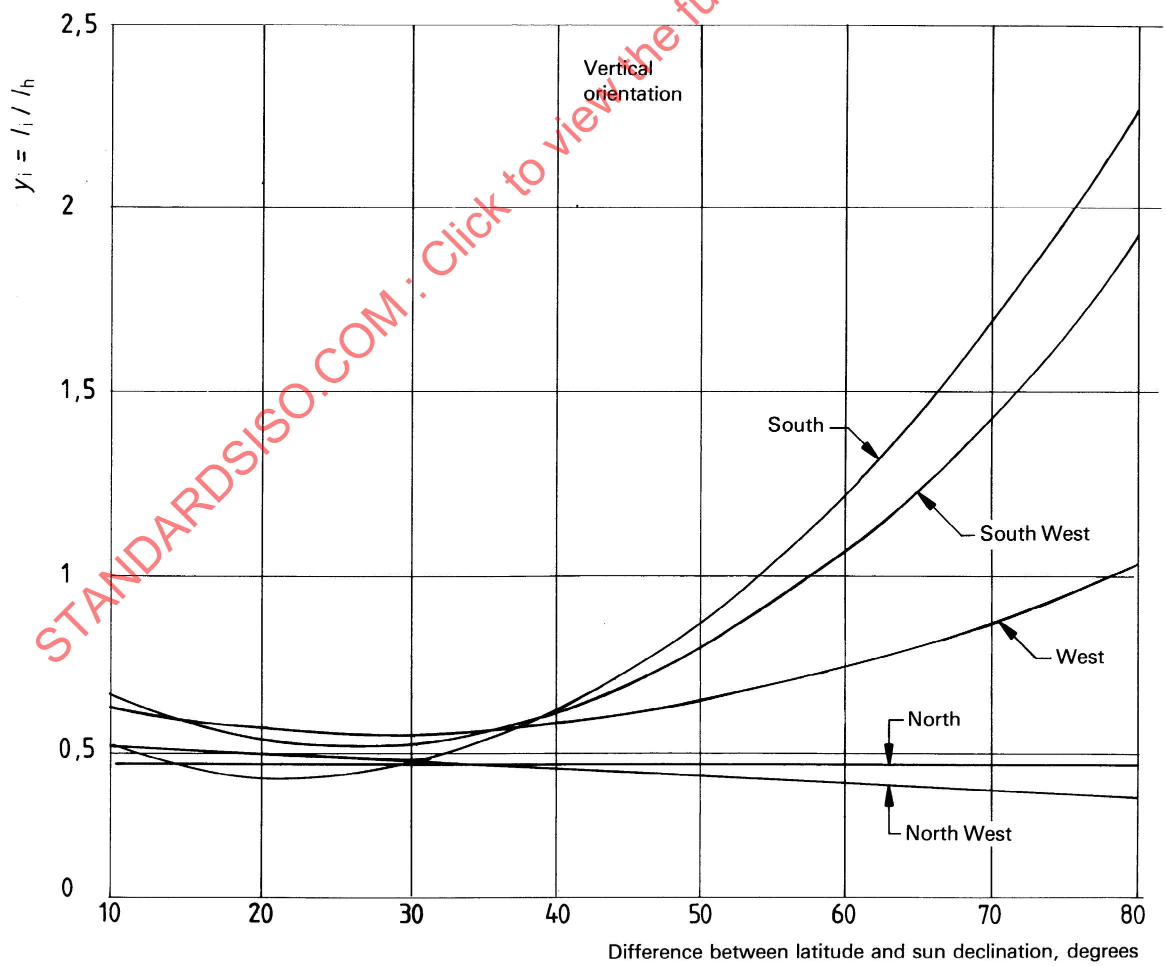


**Figure D.1 — Orientation factors depending on difference of latitude and sun declination for $K_h$ = 0,3 and $R$ = 0,3, obtained from the relations in table D.2**

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[4] Danish Building Research Institute : *SBI-Rapport 140*, chapter 9.

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# Annex E
(informative)

# Utilization factors

## E.1 Methods of deriving values of utilization factor

The utilization factor, $\eta_m$, is a weighting factor for the average monthly heat gains (internal and passive solar gains), in joules:

$$\Phi_g = \Phi_i + \Phi_s$$

in the mean monthly energy balance of a building, introduced to allow for dynamic behaviour of these gains in the steady-state model. Its value is such that the net heat requirement $Q_h$ given by the following heat balance, in joules

$$Q_h = \sum[\Phi_l - \eta_m \Phi_g]_{d,pos}\, t \qquad \text{... (E.1)}$$

where $\Phi_l$ are the heat losses in the average model (that is one month), is equal to the net heat requirement obtained by integration over the same period of the instantaneous power balance of the same building simulated in a computer, taking account of the thermal storage, temperature control and extra losses to avoid overheating.

The utilization factor can be obtained by computer simulations, with the following procedure:

a) on one hand, the instantaneous power balance is computed using a suitable simulation program with a short time step. Suitable temperature control and ventilation strategies are incorporated in the program. The power is then integrated over a longer period (month or heating season) to obtain the exact net heat demand, $Q_{he}$;

b) on the other hand, the heat losses $\Phi_l$ and gains $\Phi_g$ of the monthly (or seasonal) energy balance are calculated by a simplified method. The utilization factor, $\eta_m$, is then obtained by

$$\eta_m = \frac{\Phi_l \cdot t - \Phi_{he}}{\Phi_g \cdot t} \qquad \text{... (E.2)}$$

This procedure is used for various buildings, having various gains, losses, thermal inertia and temperature control methods to obtain the utilization factor curves.

The utilization factor obtained this way is strictly valid only for the simplified model used for computing $\Phi_l$ and $\Phi_g$ and for the buildings simulated.

## E.2 Typical values of utilization factor

The most important influence on the utilization factor is the "Gain/Loss Ratio" (GLR) which is defined as

$$\text{GLR} = \frac{\Phi_s + \Phi_i}{\Phi_l} \qquad \text{... (E.3)}$$

NOTE — $\Phi_l$ is calculated using the average internal temperature: see annex F.

The ideal $\eta$-curve, theoretically obtainable with infinite thermal inertia, perfect temperature control and no limitations of indoor temperature swing, is given by

$\eta_m = 1/\text{GLR}$ if GLR $\geqslant 1$

$\eta_m = 1$ if GLR $< 1$

In practice, the utilization factor is lower than the ideal curve for the following reasons (in order of importance):

a) the indoor temperature control system is not perfect and maintains the heating system on even when not necessary;

b) the action of inhabitants when the solar gains are large (for example allowing the temperature to rise, opening the windows, using internal or external blinds, etc.), in other words the extent to which they limit the internal temperature swing;

c) the thermal mass — or more exactly the mass in thermal contact with the indoor air — is not large enough to store all the heat gains.

Figure E.1 shows the ideal curve (A), together with the range likely to occur in practice (hatched zone), obtained from computer simulation for a realistic range of temperature control methods, internal temperature swing and thermal mass.

When no information is available, the following approximation may be used (curve B in figure E.1):

$$\eta_m = 1 - \exp(-1/\text{GLR}) \qquad \text{... (E.4)}$$

NOTE — Equations (E.3) and (E.4) give a value of $\eta_m$ based on the mean monthly gains, not allowing for day-by-day variations in the gains. This is a valid approximation load. When the gains are large, however, the approximation may have the effect of predicting a heating requirement when none exists. For this reason it is recommended that the monthly heating requirement be set equal to zero for any month for which GLR $\geqslant$ 2,5.

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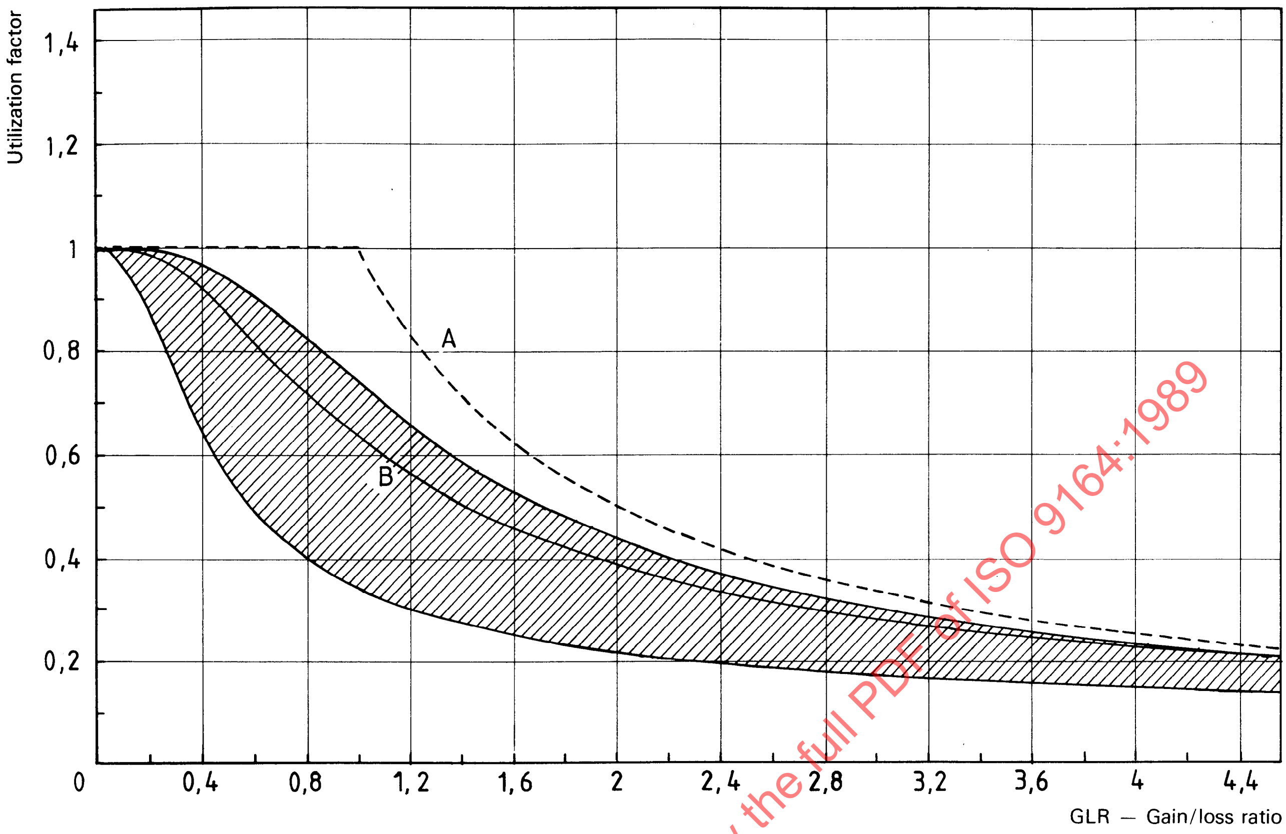


**Figure E.1 — Utilization factor**

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# Annex F
(informative)

## Daily average internal temperature

The internal air temperature $\theta_i$ to be used in the calculation method is a daily average value.

When heating is used the whole day, $\theta_i$ is equal to the design internal temperature. This annex gives a simplified procedure for obtaining the average temperature, when the heating is switched off during the night, if no national information exists.

The daily average internal temperature depends on the external temperature, the gains and losses of the building, and the thermal inertia of the building. It can be computed by

$$\theta_i = \theta_{i,d} - \left[ a \frac{t}{24} - b \frac{\eta_m \Phi_g}{H(\theta_{i,d} - \theta_e)} \right] (\theta_{i,d} - \theta_e) \quad \ldots \text{(F.1)}$$

where

$\theta_{i,d}$ is the design internal temperature during the day, when the heating is on;

$\theta_e$ is the external monthly average temperature;

$\Phi_g$ is the sum of the solar and internal gains;

$H$ is the specific heat loss;

$\eta_m$ is the utilization factor (see annex E);

$t$ is the number of hours in which the heating plant is off (this annex is valid for 6 h $< t <$ 14 h);

$a$ and $b$ are coefficients dependent on the specific heat loss and the thermal inertia of the building.

NOTE — An iterative approach can be adopted to evaluate $\theta_i$ from this equation in conjunction with equation (E.4) of annex E.

If $\theta_i$, obtained by equation (F.1) is greater than $\theta_{i,d}$, then let $\theta_i = \theta_{i,d}$.

The thermal inertia can be expressed by the active thermal capacity, $C$, that is the total thermal capacity which is active for heat storage.

For one element, $j$, of the structure

$$C_j = \varrho_j c_j d'_j A_j \quad \ldots \text{(F.2)}$$

where

$\varrho$ is the density of the material;

$c$ is its specific heat;

$d'$ is its effective thickness;

$A$ is the area of the element.

The effective thickness can be evaluated in several ways. A simple method is to take the thickness of the first layer of material from the indoor air with the following conditions:

— the thickness cannot be more than

0,1 m for masonry or concrete,
0,05 m for insulating material and wood;

— the layers behind an insulating material (including acoustic panels) are not taken into account.

For the whole building, the total active capacity, $C$, is the sum over all the elements in thermal contact with the indoor air.

The constant is taken in figure F.1, where it is represented as a function of $H/V$ ($H$ is the specific heat loss in watts per kelvin and $V$ the volume of the building in cubic metres) and $C/V$, in joules per cubic metre kelvin. These curves are approximated by

$$a = \frac{H}{V} \left[ 0{,}753\,5 - 0{,}077\,81 \frac{H}{V} + \frac{C}{V} \left( 3{,}774\,E^{-12} \frac{C}{V} - 2{,}263\,5\,E^{-6} \right) \right] \quad \ldots \text{(F.3)}$$

The constant $b$ is taken from figure F.2, an approximation being

$$b = \frac{H}{V} \left( 0{,}414 - 0{,}094 \frac{H}{V} \right) \quad \ldots \text{(F.4)}$$

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