THE CALCULATION OF SPACE-HEATING REQUIREMENTS FOR RESIDENTIAL BUILDINGS

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ABSTRACT

A draft international standard for calculating the space heating requirements for residential buildings has been written by ISO Working Group TC 163-SC2-WG5. This paper presents factors contributing to the space heating requirements considered by the Working Group and an outline of the calculation method included in the draft standard.

Estimates of the 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 that have been carried out, and, on a wider national or international scale, predicting future energy resource requirements. Many detailed, complex computer programs exist that predict heating requirements for buildings. Often, the use of these is not convenient. They are usually implemented on large computers and require detailed input information. The standard method should provide a relatively simple calculation procedure, which gives sufficiently reliable results for the purposes outlined above.

The method predicts the annual space 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. The factors included are: (1) characteristics of the house, (2) characteristics of the heating system, (3) internal temperatures, (4) internal heat gains other than from the heating system, (5) solar gains, and (6) external weather conditions.

The Standard specifies a method that takes account of these factors. In some cases the necessary information to make the calculation will be available in national standards or other suitable documents, and these should be used when available. Appendices will be provided that give values or methods for obtaining representative values for use when the required information is not otherwise available. These Appendices have not been included in this paper because they are still under discussion in the Working Group. Although this paper is not the final version of the ISO Standard, it illustrates the direction the Working Group is taking.

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INTRODUCTION

Estimates of 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 effects of possible energy-conserving measures or checking the effectiveness of measures that have been carried out, and, on a wider national or international scale, predicting future energy resource requirements.

Many detailed, complex computer programs exist that predict heat requirements for buildings. Often, using these programs is not convenient, because they are implemented on large computers and require detailed input information. Recognizing these needs and limitations, ISO TC 163 SC2 commissioned a working group to develop a relatively simple calculation procedure, which will give sufficiently reliable results for the purposes mentioned above. The method developed predicts annual space heating requirements. It is based on the fundamental equations of heat transfer. A number of simplifying assumptions are made, the principal one being to replace continuously varying quantities by appropriate averages. It is felt that the method described can be implemented on a hand-held calculator and certainly on a personal computer. At this time, a draft standard has been written, and this paper outlines the general considerations, method of calculation, and factors in the heat balance equation.

GENERAL CONSIDERATIONS

The factors that contribute to the space heating requirements are:

1. Characteristics of the house, that is, transmission and ventilation heat losses (allowing for heat recovery) and thermal capacity.

2. Characteristics of the heating system, particularly the control system and the heating system's ability to respond to changes in heating requirements.

3. Internal temperature, that is, the temperature level required by the users and variations in the temperature level in different parts of the house and at different times of the day.

4. Internal heat gains other than from the heating system, that is, from occupants, cooking and hot water, lighting and electrical appliances.

5. Solar gains.

6. External weather conditions, principally temperature.

The draft standard specifies a method taking account of these factors. In many cases national standards or other suitable documents provide methods to evaluate these factors, and these should be used where available. However, appendices to the Standard are provided that give representative values or methods for obtaining values for use when the required information is not available otherwise. These Appendices have not been included in this paper because they are still under discussion in the Working Group.

It should be kept in mind that there is a very wide variation in energy consumption in houses. This can be ascribed to variations in the factors listed above, and in principle, to the extent that precise information is available to describe these factors. The calculation can be applied to a single specific dwelling. Also, it should be noted that large variations in consumption have been observed over groups of nominally identical houses attributable to variations in user requirements and living patterns (such as internal temperatures desired and window-opening patterns). Where detailed knowledge of user requirements and living patterns is not available, the calculation is done for a typical or nominal household.

The calculation can be done 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 draft Standard gives a method for the calculating space heating requirements sometimes referred to as the load. Calculation of input energy to the heating system is not included in this method. The energy balance on which the calculation method is based is defined as including the following:

1. Transmission and ventilation losses from the internal to the external environment.

2. The net output from the heating system (which differs from the energy input when the conversion efficiency is other than unity).

3. The net internal heat gains, that is, the heat actually released to the house from the factors in item 4 above, 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).

4. 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 setpoint.

CALCULATION METHOD

The model considers the house to be uniformly heated throughout, but the result can be used for other houses with small errors. The balance describing the heat interchange between the house and its surroundings may be written as follows:

$$\phi_h + \phi_i + \phi_s = (\Sigma AU + \Sigma lU_l + C\rho\dot{V})(T_i - T_o) + \Delta \qquad (1)$$

where

ϕ_h	=	output from heating system	(W)
ϕ_i	=	other internal heat gains	(W)
ϕ_s	=	solar gains	(W)
ΣAU	=	transmission heat loss per degree	(W/K)
ΣlU_l	=	transmission losses at thermal bridges	(W/K)
$C\rho\dot{V}$	=	ventilation heat loss per degree	(W/K)
T_i	=	internal temperature	(°C)
T_o	=	external temperature	(°C)
Δ	=	rate of heat storage within the structure	(W)

Although all the terms vary with time, the equation may be applied to mean values over 24 hour periods. Writing

$$H = \Sigma AU + \Sigma lU_l + C\rho\dot{V}$$

the mean daily output required from the heating system to achieve a mean internal temperature, T_i, is

$$\phi_h = H\,(T_i - (\phi_i + \phi_s)/H - T_o)$$

or

$$\phi_h = H(T_b - T_o) + \Delta \qquad (2)$$

where

$$T_b = T_i - (\phi_i + \phi_s)/H$$

is called the base temperature.

To obtain the space heating requirement, this equation is integrated over the period under consideration (e.g., one month). The heat storage term, Δ, has been dropped from Equation 2, since the net heat storage will be negligible over a heating season. In this integral, there are two cases to consider:

(a) days for which $T_b > T_o$

In this case the internal and solar gains are insufficient to attain the required internal temperature T_i and heating is required.

(b) days for which $T_b < T_o$

In this case the internal and solar gains exceed the heat losses. In practice either T_i or the ventilation part of H must increase, since Equation 1 must always be satisfied; but no output is required by the heating system.

Thus the integral may be obtained by a summation of $(T_b - T_o)$ over days for which case (a) applies, with nothing included for other days when case (b) applies. In this way both T_i and H can be treated as constants, the values of which are those which apply when heating is required.

The integral is the accumulated temperature difference, also known as "variable base degree-days" to base T_b, which will be denoted by $ATD[T_b]$.

The heating requirement is, therefore,

$$Q_h = \int \phi_h \, dt$$
$$= H \, ATD[T_b] \qquad (3)$$

Equation 3 can be used for any period over which T_b can reasonably be treated as constant. The principal factor causing variations in T_b is the solar gain term, ϕ_s. Separate values of ϕ_s, and therefore T_b, can be obtained for each month, and Equation 3 used with $ATD[T_b]$ as the accumulated temperature difference for that month. Summation of Q_h for each month then gives the annual heating requirement.

During periods of high solar gain, the gains can exceed the heat losses; this can occur in respect of daily mean values, as noted in case (b) above, and also for part of the day even though not applying the average daily values as in case (a). To allow for this, the gains are multiplied by a utilization factor (less than unity) so that only the proportion of the gains that contributed to the heating requirement are included. Therefore, the space heating requirement can be calculated on a monthly basis as follows:

1. Define the building envelope and calculate the specific thermal loss H(W/K).

2. Specify the mean internal temperature T_i.

3. Calculate the gross internal and solar gains $\phi_i + \phi_s$ (W).

4. Determine the utilization factor η for these gains.

5. Find the base temperature T_b from

$$T_b = T_i - \frac{\eta(\phi_i + \phi_s)}{H}$$

6. Find the accumulated temperature difference to this base temperature

$ATD\,[T_b]$

7. The space heating requirement is then given by

$$Q_h = H \ ATD \ [T_b]$$

This procedure is followed for each month in the heating season, and the sum of the heating requirement for each month gives the annual requirement. The solar gains, ϕ_s, and consequently η and T_b, are calculated separately for each month. The heating season is defined to include all months for which the accumulated temperature difference to the applicable base temperature is greater than zero, (Any consistent system of units can be used in the above expression for Q_h. If H is expressed in W/K and $ATD[T_b]$ in K.s, Q_h will be in J.).

DISCUSSION OF FACTORS IN THE EQUATIONS

Where national standards exist, these should be used to obtain the data required for the calculation. If an appropriate national standard does not exist or contains insufficient information, the necessary data can be obtained from the appendices to the Standard. The specific thermal loss (H) is given by

$$H = H_T + H_{TB} + H_V$$

where

H_T = ΣAU = sum of (area x thermal transmittance) over all exposed fabric

H_{TB} = $\Sigma l U_l$

U_l = lineal thermal transmittance of thermal bridge (W/mK)

l = length of thermal bridge (m)

H_V = $C\rho\dot{V}$

C = specific heat capacity of air (J/kg)

ρ = density of air (kg/m^3)

$\dot{V}$ = volumetric air change rate (m^3/s)

Simple U-values can be calculated by the methods given in ISO DP 6946/1.4 Thermal Insulation - Calculation Rules - Part 1. For other values, a relevant national standard should be used to calculate U-values or to obtain suitable values from tabulated data.

The parameter H_{TB} should be included for structures where thermal bridges are present. U_l for beam-shaped thermal bridges can be calculated by the methods given in ISO DP 6946/2.1 Thermal Insulation - Calculation Rules - Part 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.).

Ventilation rates vary with wind speed and direction and with temperature difference; an appropriate average value is required. Where there is ventilation heat recovery, this should be taken into account of in determining the ventilation heat loss, (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 ventilation rate.).

Internal heat gains should include: (1) metabolic gains (from people), (2) gains to the house from hot water system, (3) gains to the house from cooking, (4) the power consumption of electrical appliances, and (5) 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.

$$T_b = T_i - (\phi_i + \phi_s)/H$$

is called the base temperature.

To obtain the space heating requirement, this equation is integrated over the period under consideration (e.g., one month). The heat storage term, Δ, has been dropped from Equation 2, since the net heat storage will be negligible over a heating season. In this integral, there are two cases to consider:

(a) days for which $T_b > T_o$

In this case the internal and solar gains are insufficient to attain the required internal temperature T_i and heating is required.

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In this case the internal and solar gains exceed the heat losses. In practice either T_i or the ventilation part of H must increase, since Equation 1 must always be satisfied; but no output is required by the heating system.

Thus the integral may be obtained by a summation of $(T_b - T_o)$ over days for which case (a) applies, with nothing included for other days when case (b) applies. In this way both T_i and H can be treated as constants, the values of which are those which apply when heating is required.

The integral is the accumulated temperature difference, also known as "variable base degree-days" to base T_b, which will be denoted by $ATD[T_b]$.

The heating requirement is, therefore,

$$\begin{aligned} Q_h &= \int \phi_h \, dt \\ &= H \, ATD[T_b] \end{aligned} \qquad (3)$$

Equation 3 can be used for any period over which T_b can reasonably be treated as constant. The principal factor causing variations in T_b is the solar gain term, ϕ_s. Separate values of ϕ_s, and therefore T_b, can be obtained for each month, and Equation 3 used with $ATD[T_b]$ as the accumulated temperature difference for that month. Summation of Q_h for each month then gives the annual heating requirement.

During periods of high solar gain, the gains can exceed the heat losses; this can occur in respect of daily mean values, as noted in case (b) above, and also for part of the day even though not applying the average daily values as in case (a). To allow for this, the gains are multiplied by a utilization factor (less than unity) so that only the proportion of the gains that contributed to the heating requirement are included. Therefore, the space heating requirement can be calculated on a monthly basis as follows:

1. Define the building envelope and calculate the specific thermal loss H(W/K).

2. Specify the mean internal temperature T_i.

3. Calculate the gross internal and solar gains $\phi_i + \phi_s$ (W).

4. Determine the utilization factor η for these gains.

5. Find the base temperature T_b from

$$T_b = T_i - \frac{\eta(\phi_i + \phi_s)}{H}$$

6. Find the accumulated temperature difference to this base temperature

$$ATD\,[T_b]$$

7. The space heating requirement is then given by

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

As pointed out above, it is not usually appropriate, however, to count the gross internal and solar gains as useful in the sense of contributing to reducing the space heating requirement. This is because (1) during periods of high heat gain, the gains may exceed the instantaneous loss rate, or (2) 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 in thermal contact with the conditioned space.

The value of internal temperature T_i required for the calculation method is an average over the house and over the time step of the calculation. For heating 24 hours per day, the required, or design, heating temperature is used. When heating is switched off at night, the required, or design, heating 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 T_i. During periods of high solar gain, the internal temperature may rise above the required, or 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.

Accumulated temperature differences are required for each month of the heating season; a different base temperature will normally apply in each month. In some extreme climates, it may be a sufficient approximation to take $ATD[T_b] = N(T_b - T_o)$ where N is the number of days in the month.

If ATDs to various base temperatures are not available, an estimate can be obtained using the Thom method, provided that the mean outdoor temperature for the period of interest and the standard deviations of daily mean temperature are known, (see Thom, H.C.S., "The Rational Relationship Between Heating Degree Days and Temperature," Monthly Weater Review, Volume 82, Number 1, January 1954, pages 1 through 6.). Mean temperatures are usually readily available, however, the availability of the standard deviation data is less likely. A method to estimate the standard deviation for the periods of interest is included in the appendices to the Standard.

It would of course be advantageous if an annual or seasonal one-step calculation could be made. This would be especially useful for initial design estimate of heating requirements. Figure 1 shows the idealized situation in which the external temperature, T_o, is represented by a smooth curve, which is reasonable when considering monthly mean values of external temperature, the internal temperature, T_i, is constant, and the base temperature, T_b, is also constant. The heating requirement is then proportional to the shaded area, which is the accumulated temperature difference to base T_b. The heating season is defined by the two points in the year for which $T_o = T_b$; and to this base temperature, the accumulated temperature difference over the heating season and over one year will be the same, since there will be accumulation outside the heating season.

In practice T_b is not constant since the solar gains (at least) change through the heating season, being smallest near the middle of winter, as shown in Figure 2. A method is outlined in an appendix to the Standard to estimate the annual heating requirement directly using T_b in terms of average solar gains. The method requires only the annual value of accumulated temperature difference instead of the monthly values, but information about external temperature and solar gains is still required on a monthly basis in order to determine T_{bal} and the average solar gain over the heating season.

CONCLUSION

The Standard method outlined above meets the objective set out in ISO TC 163 SC2. It is relatively simple and should give reasonably reliable results evaluated on a monthly basis given the input data are accurate. Methods similar to this have been programmed on a hand calculator while others have been coded for use on personal computers.

Some work remains to be done on certain appendices to the Standard referred to as Annexes by ISO. As such they are not part of the Standard, so review of the body of the standard can proceed. The areas where more effort is needed are: (1) effects of shading elements on determination of solar gains, and (2) the magnitude of utilization factors as a function of gain/load ratio, thermal storage, and temperature control systems.

Although it is theoretically possible to extend the integration period over the heating season, the definition of its length remains somewhat in question. Therefore, annual calculation will probably not yield a reliable result unless the solar gains are relatively small or the heating season extends over the whole year.

NOMENCLATURE

The terms, symbols, and units used are in accordance with ISO DIS 7345/1 (Thermal Insulation - Vocabulary - Part 1). The following are specific to this Standard.

Quantity	Definition	Symbol	Unit
Space heating requirement	Energy output from space heaters	Q_h	J,MJ,GJ, kWh, MWh
Specific thermal loss	Total heat loss from dwelling (by fabric transmission and ventilation) per degree temperature difference between inside and outside	H	W/K
Internal temperature		T_i	°C
Base temperature	Internal temperature less temperature increment produced by internal and solar gains	T_b	°C
External temperature		T_o	°C
Accumulated temperature difference (to a base temperature)	The sum of (base temperature less mean daily external temperature, if positive) over all days in period considered	$ATD[T_b]$	°C s, °C days
Internal gains	Average rate of heat input to dwelling from internal sources other than space heaters	ϕ_i	W
Solar gains	Average rate of heat input to dwelling from solar radiation	ϕ_s	W
Utilization factor	The proportion of the internal and solar gains which contribute to reducing the space heating requirement	η	-
Time step	The period of integration of the heat balance equation	t	s

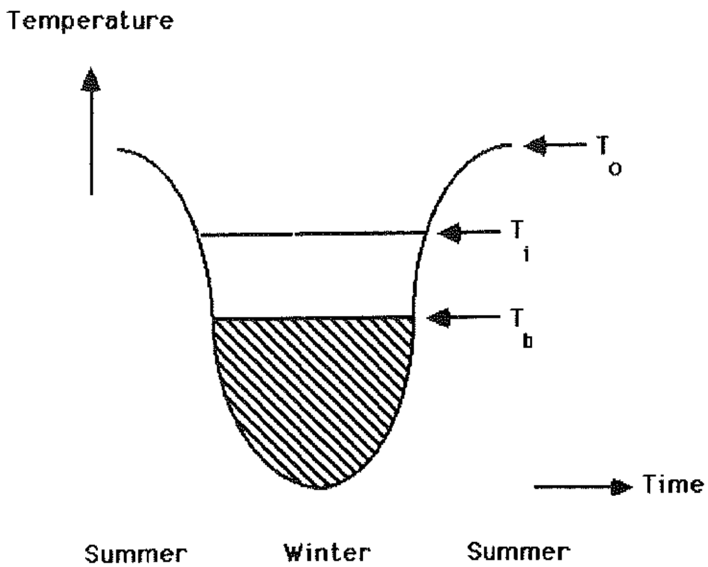

Figure 1. Heating requirements for constant gains (shaded)

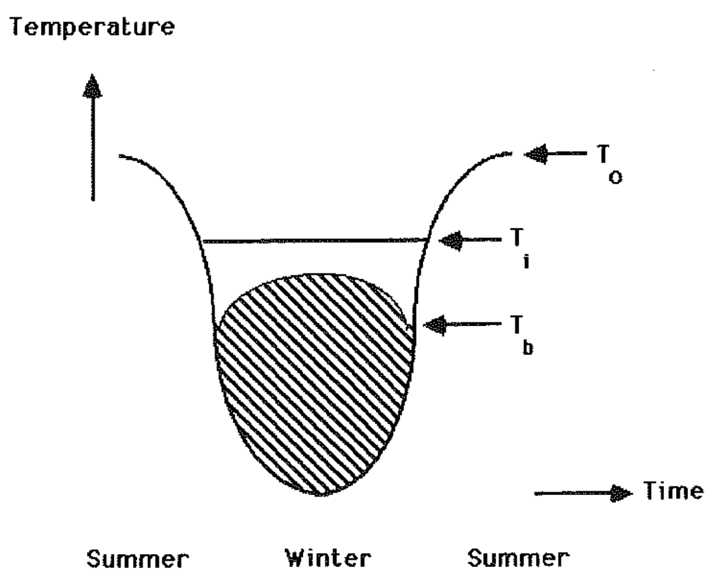

Figure 2. Heating requirements for variable gains (shaded)