BUILDING RESEARCH NOTE

NET ANNUAL HEAT LOSS FACTOR METHOD

FOR ESTIMATING HEAT REQUIREMENTS OF BUILDINGS

by

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The development of energy budget standards for buildings makes it necessary for designers to produce accurate estimates of the amount of energy required to heat a building. The most widely used method of calculating annual heating requirement is the ASHRAE degree-day procedure (Ref. 1, see p. 43.8):

$$E = 24 \times D \times \frac{H_L}{\Delta t} \times C_D \times C_F / (\eta \times V) \qquad (1)$$

where

- E = annual heating requirement
- D = number of degree-days for heating season, calculated by summing the daily values of the difference between 65°F and the mean of the maximum and minimum temperatures for the days for which the mean is lower than 65°F
- H_L = design heat loss (including infiltration)
- Δt = design temperature difference
- C_D = correction factor, which depends on the outdoor design temperature
- C_F = part-load correction factor for fueled systems only; equals 1.0 for electric resistance heating
- η = rated full load efficiency, equals 1.0 for electric resistance heating
- V = heating value of fuel, consistent with H_L and E; equals 1.0 for electric resistance heating.

Equation (1) ignores the following building design features: orientation of windows and colour of exterior surfaces of the building envelope, variations of infiltration rate with wind and stack effect. This Note presents a modification of the degree-day method to allow designers to take more accurate account of:

- solar radiation incident on a building surface,
- variation of solar energy gained through windows (with orientation and type of window),
- variation of air infiltration rate with wind speed and difference between inside and outside air temperature,
- heat generated by inside activity such as lights, people, etc., and its effect on building energy needs.

This modified degree-day method is called the "Net Annual Heat Loss Factor" method of estimating heat requirements of buildings. It is based on the fact that the total annual building heat loss can be separated into the following four components:

1. window heat loss,
2. opaque wall and ceiling heat loss,
3. air infiltration-ventilation heat loss,
4. basement (below ground) heat loss.

Expressed in equation form it is:

$$
\begin{aligned}
Q_{total} = {} & Q_{window} \\
& + Q_{wall\ and\ ceiling} \\
& + Q_{air\ infiltration} \\
& + Q_{basement} \qquad (2)
\end{aligned}
$$

Each of these heat loss components can be calculated separately using Net Annual Heat Loss Factors (NAHLF). The following sections describe how these factors have been evaluated and how they can be used to estimate net annual heating requirements for simple buildings.

EVALUATING NAHLF FOR HOUSES

The values of the NAHLF given in this Note were determined by using a computer program (2) to evaluate the annual heating requirements of a "standard" and a modified bungalow exposed to "test" year weather cycles for several locations across Canada. The various factors were obtained by making the annual heating requirement calculation first for the standard house and then for a similar, modified house (for example, increased area of wall or window facing a particular direction). The NAHLF value was obtained by taking the difference between the standard case and the modified case and dividing the difference by the numerical value of modification (for example, extra area for wall or window).

The standard house is assumed to be well insulated and relatively tight - representative of the type of construction that will probably be needed to meet future energy standards. It is a bungalow with the following features:

- length, 11.3 m
- width, 8.5 m
- gross floor area, 90 m^2
- volume, 415 m^3
- opaque exterior wall area, 71 m^2
- glazed area, 21 m^2
- basement wall above grade level, 19 m^2
- opaque wall thermal resistance, 4.2 $m^2 \cdot K/W$
- ceiling thermal resistance, 6.2 $m^2 \cdot K/W$
- exposed basement wall thermal resistance 1.5 $m^2 \cdot K/W$
- occupancy, family of four persons
- appliances (television, stove, lights, refrigerator, etc.) approx. average, 1.4 kW
- air leakage characteristics - infiltration rate of 125 m^3/h at 30 K temperature difference and 4 m/s wind speed. Note that this low leakage characteristic is possible with a "tight" house without a chimney.

NAHLF were calculated for a range of degree-day values by using test year (3) weather cycles for Vancouver, Lethbridge, Saskatoon, Winnipeg, Toronto, Montreal, Fredericton, Halifax, and St. John's. They are plotted against the degree-day value so that factors for any other locations in Canada can be estimated simply by taking the heating degree-day value for the location in question (4) and reading the values of the NAHLF from the graphs. It should be noted that the heating degree-days given in Supplement No. 4 to the National Building Code of Canada (4) are for temperature in F deg. They can be converted to metric equivalents and a base of 18°C by a procedure given by Boyd (5).

Window Heat Loss

Heat is transferred through windows by two different mechanisms:

- solar radiation through the window,
- heat transfer by the combined mechanisms of convection, conduction and long-wave radiation.

Heat loss by air leakage through cracks around the window frame is taken into account along with the rest of the air leakage. It should be noted that net annual heat loss through a window depends on window orientation because of the solar radiation admitted through it.

The value of the conduction/convection/long-wave radiation component, on the other hand, is independent of direction: it is the product of window "U" value (where U is over-all window conductance) and inside-outside temperature difference. The annual net heat loss through unit area of windows, called Window Heat Loss Factors, has been plotted against number of degree-days for each of eight orientations (Figures 1 to 3). The values used are for single, double and triple glazing, respectively. The window factors correlate quite well with the number of degree-days for the various localities, although the localities have different latitudes and different types of climate. It is possible, therefore, to use these graphs to obtain window factors for any locality where the number of heating degree-days is known.

The Window Heat Loss Factor for an orientation that does not correspond exactly to one of the eight that are plotted can be obtained by interpolation of the given values. Once the Window Heat Loss Factors, HLF_{window}, for all orientations and all windows in question have been determined, the annual heat loss through all the windows in a building can be calculated by:

$$Q_{window} = \text{sum of all "}A_{window} \times HLF_{window}\text{" products for all windows in the building}$$

where

HLF_{window} = window Heat Loss Factor obtained from Figures 1, 2 or 3

A_{window} = glazed area of the window.

Opaque Wall Heat Loss

Heat is lost through opaque segments of a building envelope by conduction and air leakage. In this section only conduction heat loss will be considered. (Heat loss by air leakage through all parts of the building enclosure is the subject of the next section.)

Heat transfer by conduction through a wall is proportional to the average temperature difference between the two surfaces of the wall. Surface temperatures, in turn, are functions of the air temperatures adjacent to the surfaces and the long- and short-wave radiation incident on the surfaces. The heat flux through an opaque building envelope segment is, therefore, related to the following basic parameters:

- inside and outside air temperatures,
- wall conductance, i.e., U value of the wall,
- solar radiation incident on the outer surface,
- exterior surface solar absorptivity, i.e., colour of the surface,
- emissivity and absorptivity, e, of the surfaces for long-wave radiation (e = 0.95 is typical for all types of building envelope surface except metal).

To facilitate the selection of Wall Heat Loss Factors for a given set of parameters the factors are plotted against degree-day values (see Figures 4 to 7) and normalized with respect to wall over-all conductance; this, in turn, is the reciprocal of over-all thermal resistance.

The factors for specific wall exterior surface colour are given for only light, medium and dark shades because the factors are not particularly sensitive to this parameter. In the ceiling-roof system the colour of the roof has very little effect if the ceiling is reasonably well insulated. The effect of roof colour on ceiling heat loss factor can therefore be neglected. It should also be noted that ceiling factors plotted in Figure 7 are normalized using the conductance value of the ceiling because ceiling conductance is the principal factor governing heat loss through ceiling-roof systems when the ceiling is well insulated. Factors for orientation other than one of the cardinal directions can be obtained by interpolating the plotted values.

The annual heat loss through all the opaque segments of a building can be calculated by:

$$Q_{opaque} = \text{sum of all the products "}HLF_{wall} \times A_{wall}/R_{wall}\text{" for all opaque segments of the building envelope} \quad (4)$$

where

HLF_{wall} = wall heat loss factor that is derived from Figures 4, 5, 6 or 7,

R_{wall} = resistance of the element in question which includes inside and outside surface resistances,

A_{wall} = area of the element in question.

Sensible Heat Loss by Air Infiltration

One of the major components of the annual heating requirement for most buildings is the energy needed to heat infiltration and ventilation air. The crucial data for calculating this energy are the appropriate average rates of infiltration for a whole heating season. Reliable infiltration values are scarce, but some have been given by Tamura and Wilson (6). Once this infiltration has been established it is very simple to calculate the annual heat loss by infiltration:

$$Q_{infilt.} = HLF_{infilt.} \times IR \quad (5)$$

where

$HLF_{infilt.}$ = infiltration heat loss factor given in Figure 8

IR = building average infiltration rate over heating season.

Basement Heat Loss

The prediction of the annual heat loss from a basement depends on the thermal characteristics of the surrounding ground, weather, and the thermal characteristics of the building. These calculations are the subject of a companion report (7).

SAMPLE CALCULATION

Calculate annual heat loss of a house located in Pine Falls, Manitoba. The pertinent house construction data are given in Table I.

The heating degree-days given in Supplement No. 1 to the National Building Code (4) for Pine Falls, Manitoba, is 11,000 Fahrenheit degree-days. Thus, in metric units and based on 18°C, the number is 6011 (5).

Determination of Heat Loss Factors for House in Question

Heat loss factors for 6011 K·d value are:

Windows (Figures 2 and 3):

Orientation	Triple Glazed		Double Glazed	
180°	-145	$kW\cdot h/(m^2\cdot yr)$	-55	$kW\cdot h/(m^2\cdot yr)$
135°, 225°	-73	"	40	"
90°, 270°	80	"	218	"
45°, 315°	160	"	335	"
0°	170	"	355	"

Walls (Figures 5 and 6):

Orientation	Colour	
	Medium	Dark
0	130 kh·K	128 kh·K
90, 270	118 "	113 "
180	98 "	92 "

Ceiling (Figure 7): 94.5 kh·K

Infiltration heat loss factor (Figure 8) = 49 $kW\cdot h^2/m^3$

The factors for the specified orientations are obtained by interpolation. Thus, the heat loss factor for a double-glazed window oriented 15 degrees W of S (i.e., wall azimuth angle of 195°) is:

$$HLF_{195} = \frac{225 - 195}{225 - 180} HLF_{180} + \frac{195 - 180}{225 - 180} HLF_{225}$$

$$= \frac{30 \times (-55) + 15 \times (40)}{45}$$

$$= -23.3 \text{ kW}\cdot\text{h/m}^2$$

The factors for other specified window and wall orientations obtained in a similar way are given in Table II.

Calculation of House Heat Loss

Window, wall, ceiling and infiltration heat losses are calculated by Equations (3), (4) and (5), respectively. The summary of data and results are given in Table III.

DISCUSSION

Total house heat loss (except for basement below grade) calculated by the ASHRAE degree-day method (i.e., Equation (1)) is 14,880 kW·h/yr

$$E = 24 \times (11000/1.8) \times 178 \times 0.57 \times 1.0/(1.0 \times 1.0)$$

$$= 14.88 \text{ MW}\cdot\text{h/yr}$$

where

D = 11000/1.8 K·d

$HL/\Delta t$ = 178 W/K (based on infiltration rate of 170 m^3/h at design temperature of -33°C and 4 m/s wind speed*, i.e., 0.33 air changes per hour)

C_D = 0.57 (see Reference 1: Table II, p. 43.8)

C_F, n and V = 1.0 (since fuel fired equipment is not considered in this sample problem).

* This 170 m^3/h infiltration rate at design conditions of -33°C and 4 m/s wind speed is consistent with the average infiltration rate of 150 m^3/h over the heating season.

This compares well with the total heat loss calculated by the Heat Loss Factor method. The agreement of house heat loss components calculated by the two methods, however, is not so good as the comparison of the total losses (Table IV) where the highest difference is in window and infiltration components. Thus, the good agreement of the total house heat loss values calculated by the two methods is due to compensating error in window and infiltration heat loss components calculated by the ASHRAE degree-day method.

REFERENCES

1. ASHRAE Handbook; 1976 Systems Volume. American Society of Heating, Refrigerating and Air-Conditioning Engineers.

2. Larsen, B.T. Digital Simulation of Energy Consumption in Residential Buildings. Presented at International CIB Symposium on Energy Conservation in the Built Environment. Building Research Station, Garston, 6-8 April 1976.

3. Boyd, D. Procedure for Selecting a Test Year of Weather Data. Private communication.

4. Climatic Information for Building Design in Canada, 1975. Supplement No. 1 to the National Building Code of Canada.

5. Boyd, D. Converting Heating Degree-Days from Below 65°F to Below 18°C. National Research Council of Canada, Division of Building Research, Building Research Note 98, 1975.

6. Tamura, G.T. and A.G. Wilson. Air Leakage and Pressure Measurements on Two Occupied Houses. ASHRAE Journal, Vol. 5, No. 12, Dec. 1963.

7. Shirtliffe, C.J. and W.C. Brown. Basement Heat Loss. To be published.

TABLE I

EXAMPLE PROBLEM: HOUSE CONSTRUCTION DATA

Orientation, Wall Azimuth Angle Measured Clockwise from North, degree		15	105	195	285
Windows	Glazed Area, m^2	3	3	10	4
	Type	Triple Glazed	Double Glazed	Double Glazed	Triple Glazed
Opaque Exterior Walls	Area, m^2	30	17	23	16
	Thermal Resistance $m^2 \cdot K/W$	3.5	3.5	3.5	3.5
	Colour*	M	M	M	D
Basement Walls Above Ground	Area, m^2	7	4	7	4
	Thermal Resistance $m^2 \cdot K/W$	1.8	1.8	1.8	1.8
	Colour*	M	M	M	D
Exterior Doors	Area, m^2	2		2	
	Thermal Resistance $m^2 \cdot K/W$	0.7		0.7	
	Colour*	M		M	
Ceiling	Area, m^2	112			
	Resistance $m^2 \cdot K/W$	5.6			
Infiltration	Average Infiltration Rate = 150 m^3/h				

* M = Medium
D = Dark

TABLE II

HEAT LOSS FACTORS FOR THE HOUSE OF EXAMPLE PROBLEM

Orientation, Wall Azimuth Angle Measured Clockwise from North, degree		15	105	195	285
Window Heat Loss Factor, $kW \cdot h/m^2$	Double Glazed		159	-23.3	
	Triple Glazed	167			107
Wall Heat Loss Factor, $kh \cdot K$	Medium Colour	128	115	101	
	Dark Colour				116
Ceiling, $kh \cdot K$	94.5				
Infiltration, $kW \cdot h^2/m^3$	49				

TABLE III

SUMMARY OF HOUSE CONSTRUCTION DATA AND CALCULATED HOUSE HEAT LOSS COMPONENTS

Orientation, Wall Azimuth Angle Measured from North, degree		15	105	195	285	Total for All Orientations
Windows	Area, m^2	3	3	10	4	20
	Heat Loss Factor, $kW \cdot h/m^2$	167	159	-23.3	107	
	Heat Loss kW·h/yr	501	477	-233	428	1,173
Walls	Area, m^2	30	17	23	16	86
	Resistance, $m^2 \cdot K/W$	3.5	3.5	3.5	3.5	
	Heat Loss Factor, kh·K	128	115	101	116	
	Heat Loss, kW·h/yr	1097	559	664	530	2,850
Basement Walls Above Ground	Area, m^2	7	4	7	4	22
	Resistance, $m^2 \cdot K/W$	1.8	1.8	1.8	1.8	
	Heat Loss Factor, kh·K	128	115	101	116	
	Heat Loss, kW·h/yr	498	256	393	258	1,405
Exterior Doors	Area, m^2	2		2		4
	Resistance, $m^2 \cdot K/W$	0.7		0.7		
	Heat Loss Factor, kh·K	128		101		
	Heat Loss kW·h/yr	366		289		655

(Cont'd)

TABLE III (Cont'd)

Ceiling	Area, m^2	112	
	Resistance, $m^2 \cdot K/W$	5.6	
	Heat Loss Factor, kh·K	94.5	
	Heat Loss, kW·h/yr	1890	1,890
Infiltration	Average Infiltration Rate, m^3/h	150	
	Heat Loss Factor, $kW \cdot h^2/m^3$	49	
	Heat Loss, kW·h/yr	7350	7,350
		Total House Heat Loss*	= 15,324 kW·h/yr

* excluding losses through walls and floor below outside grade level

TABLE IV

HOUSE HEAT LOSS COMPONENTS CALCULATED BY

HEAT LOSS FACTOR AND DEGREE-DAY METHODS

House Heat Loss Component	Heat Loss Factor Method MW·h/yr	Degree-Day Method MW·h/yr	Difference MW·h/yr
Windows	1.17	4.92	+3.75
Exterior Walls	2.85	2.06	-0.79
Basement Walls Above Ground	1.41	1.02	-0.39
Exterior Doors	0.65	0.48	-0.17
Ceiling	1.89	1.67	-0.22
Infiltration	7.35	4.73	-2.62
Total	15.32	14.88	-0.44

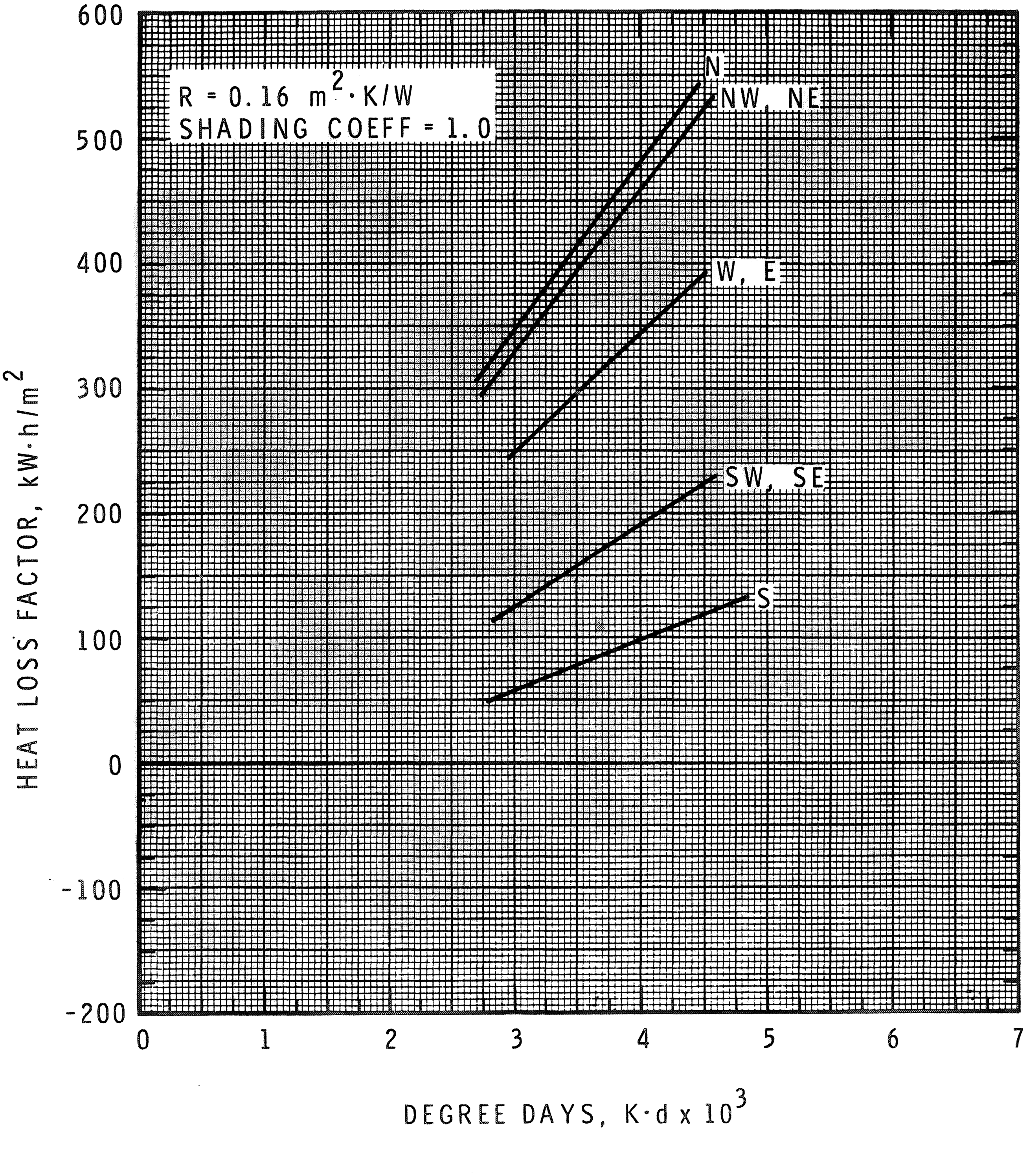

FIGURE 1

WINDOW HEAT LOSS FACTORS
FOR SINGLE GLAZING

BR 5522 – 1

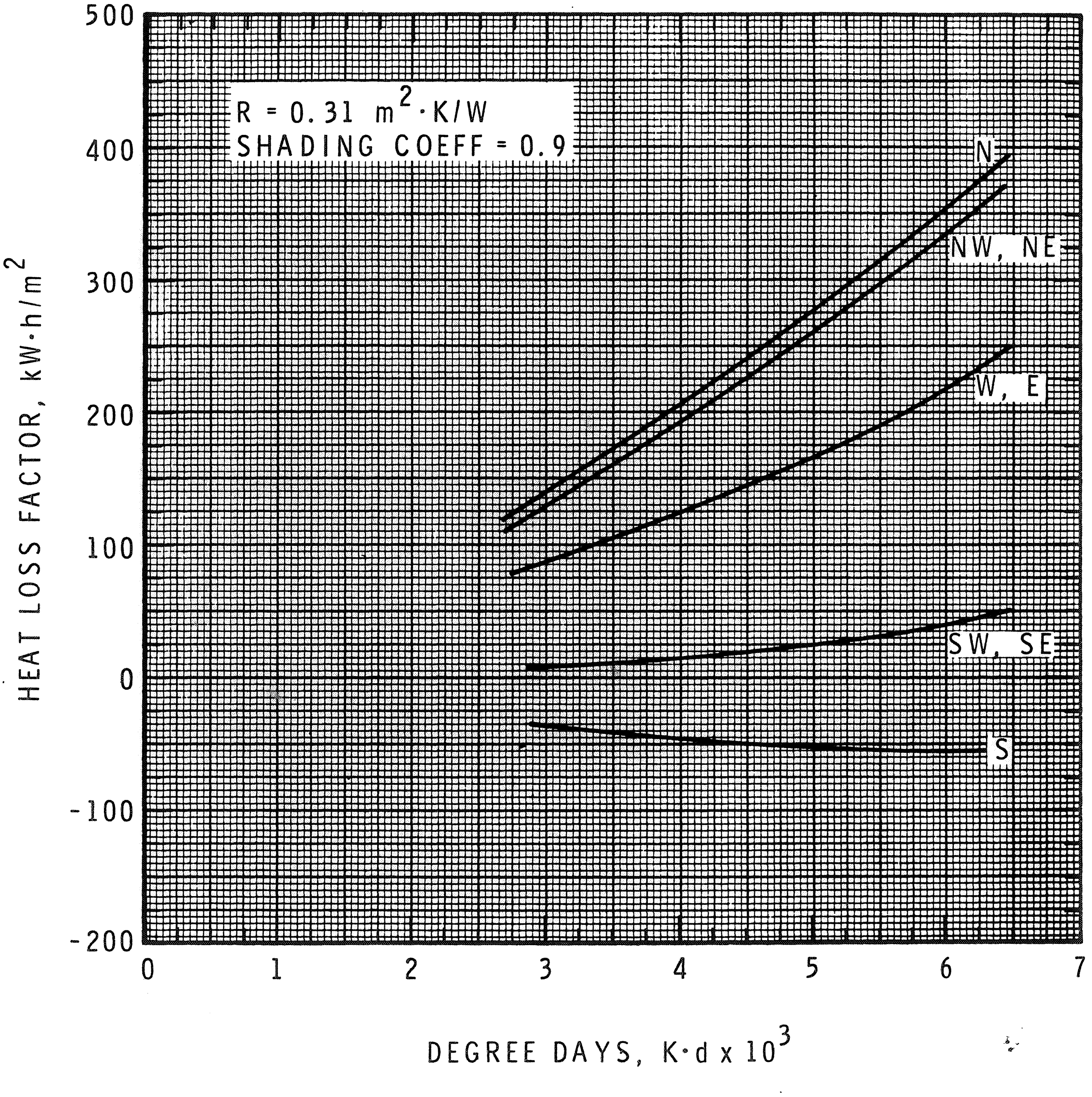

FIGURE 2

WINDOW HEAT LOSS FACTORS
FOR DOUBLE GLAZING

BR 5522 - 2

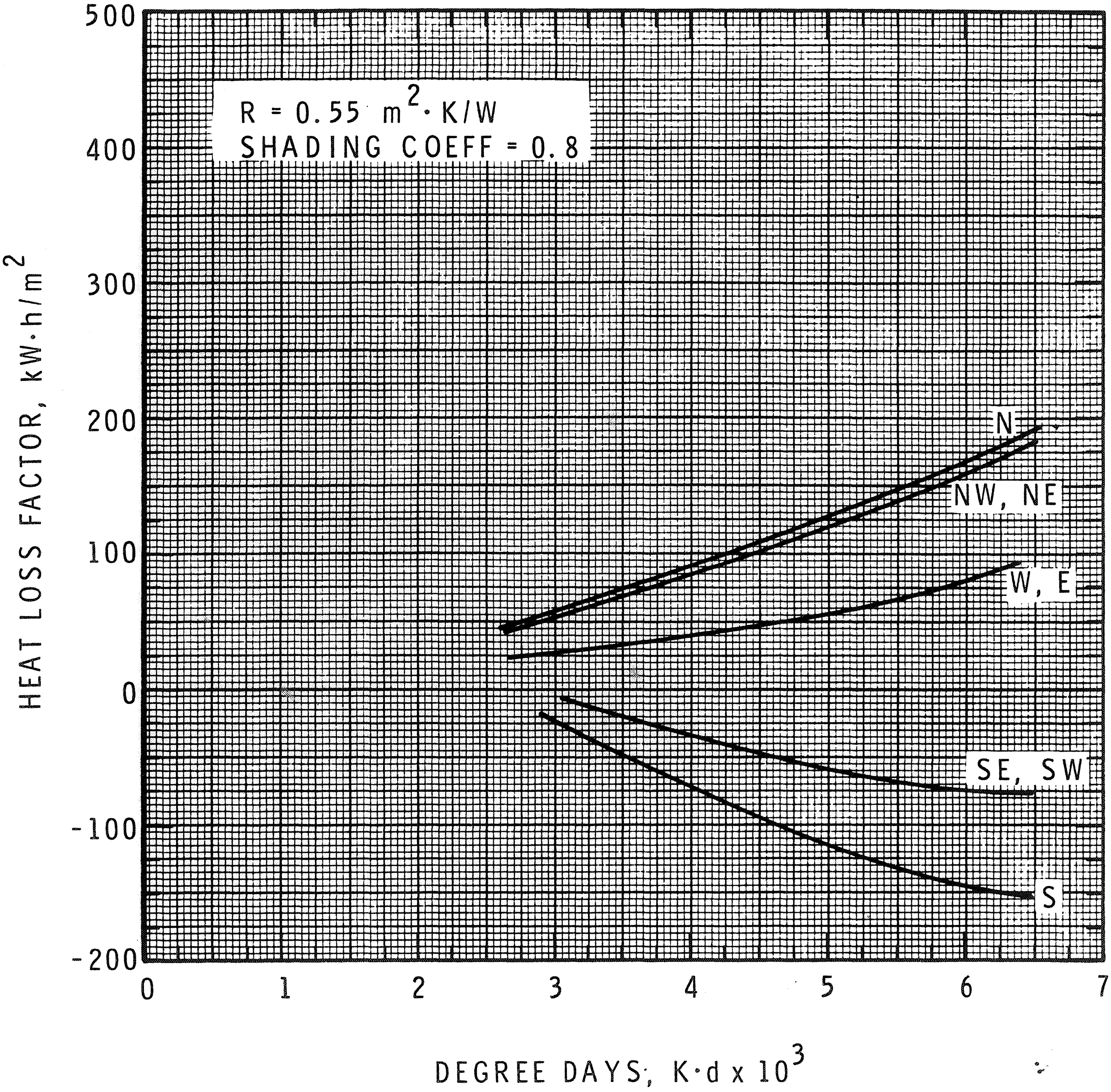

FIGURE 3

WINDOW HEAT LOSS FACTORS
FOR TRIPLE GLAZING

BR 5522 - 3

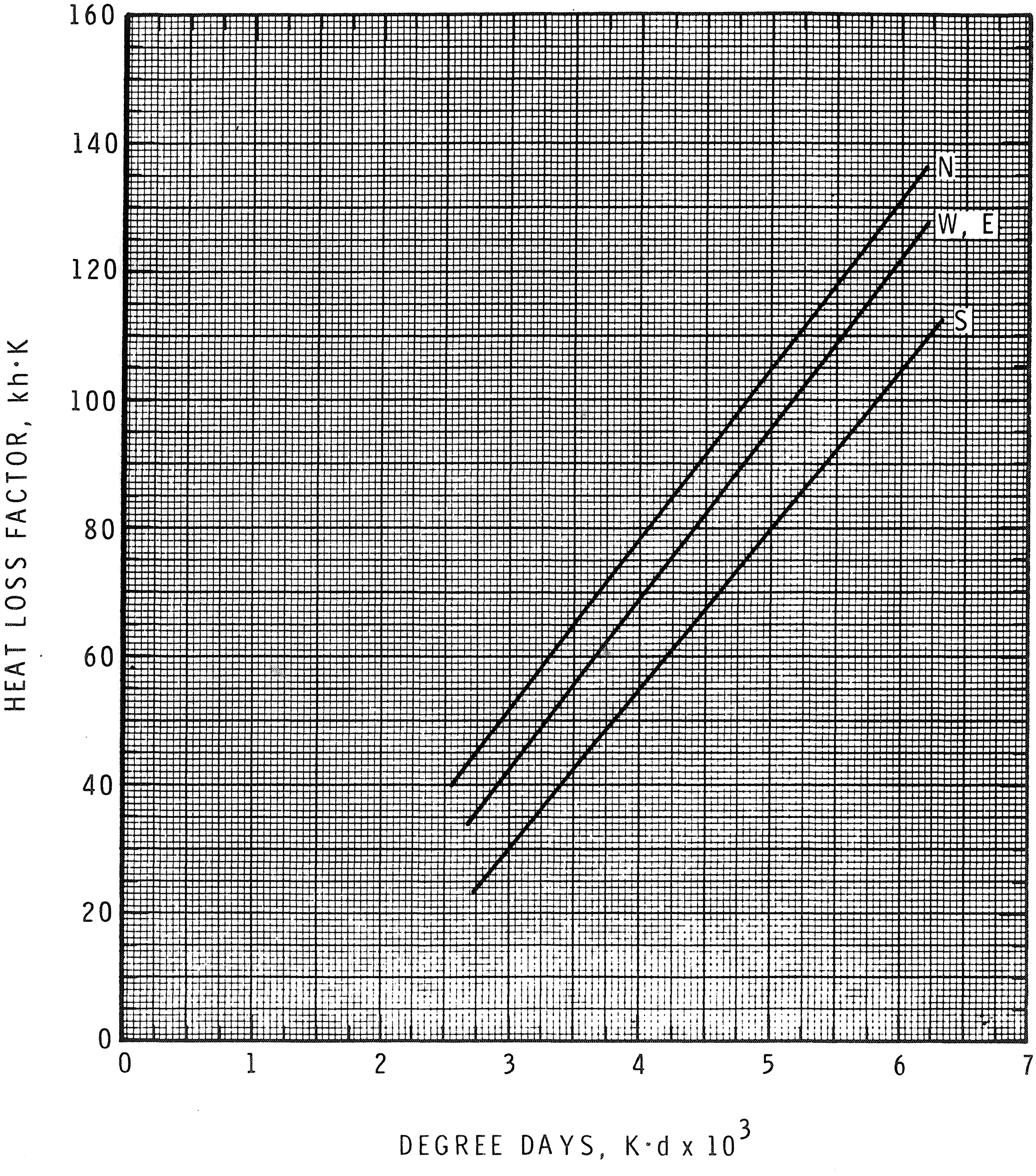

FIGURE 4

WALL HEAT LOSS FACTORS
(EXTERIOR SURFACE COLOUR - LIGHT)

BR 5522 - 4

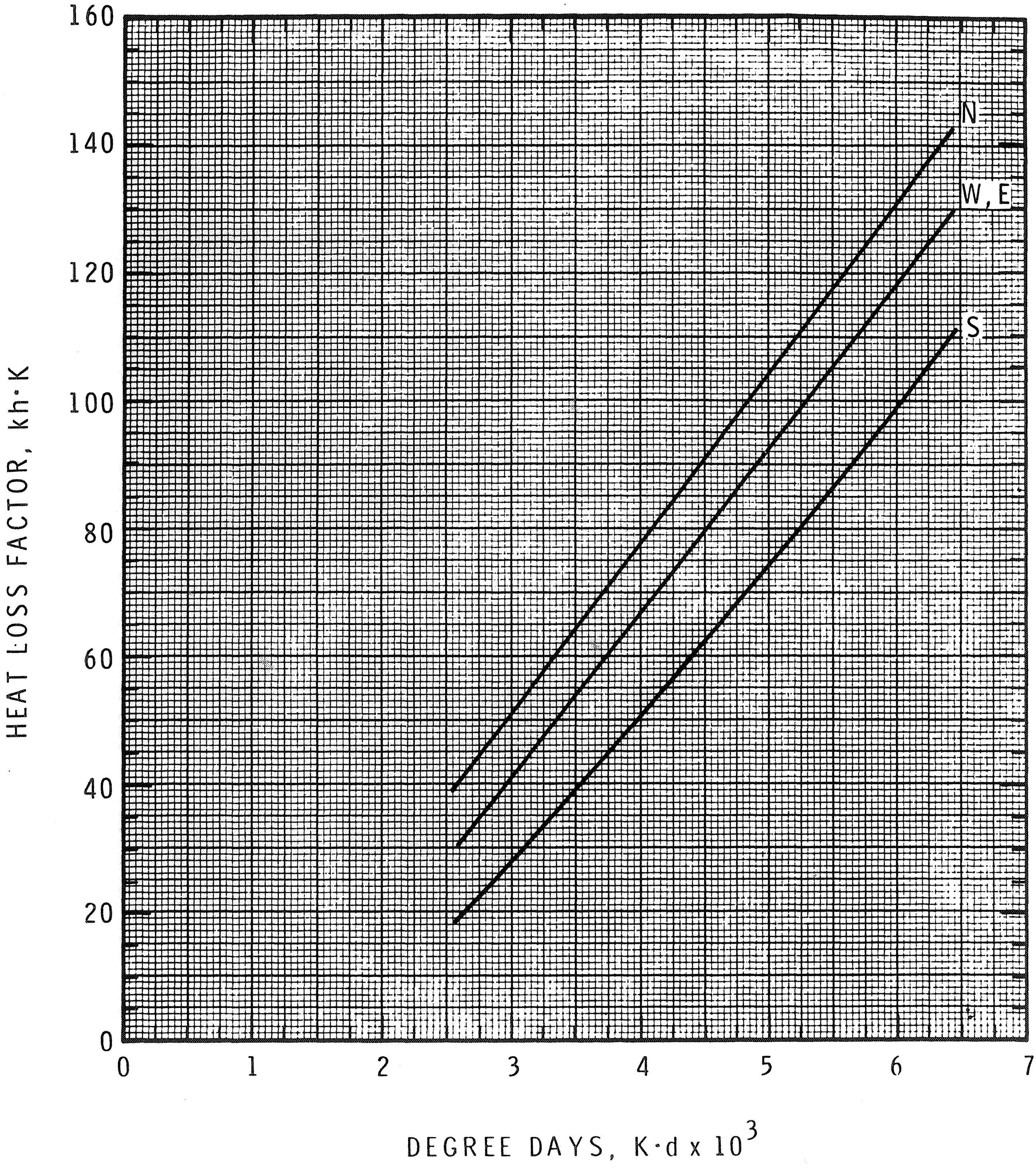

FIGURE 5

WALL HEAT LOSS FACTORS
(EXTERIOR SURFACE COLOUR - MEDIUM)

BR 5522 - 5

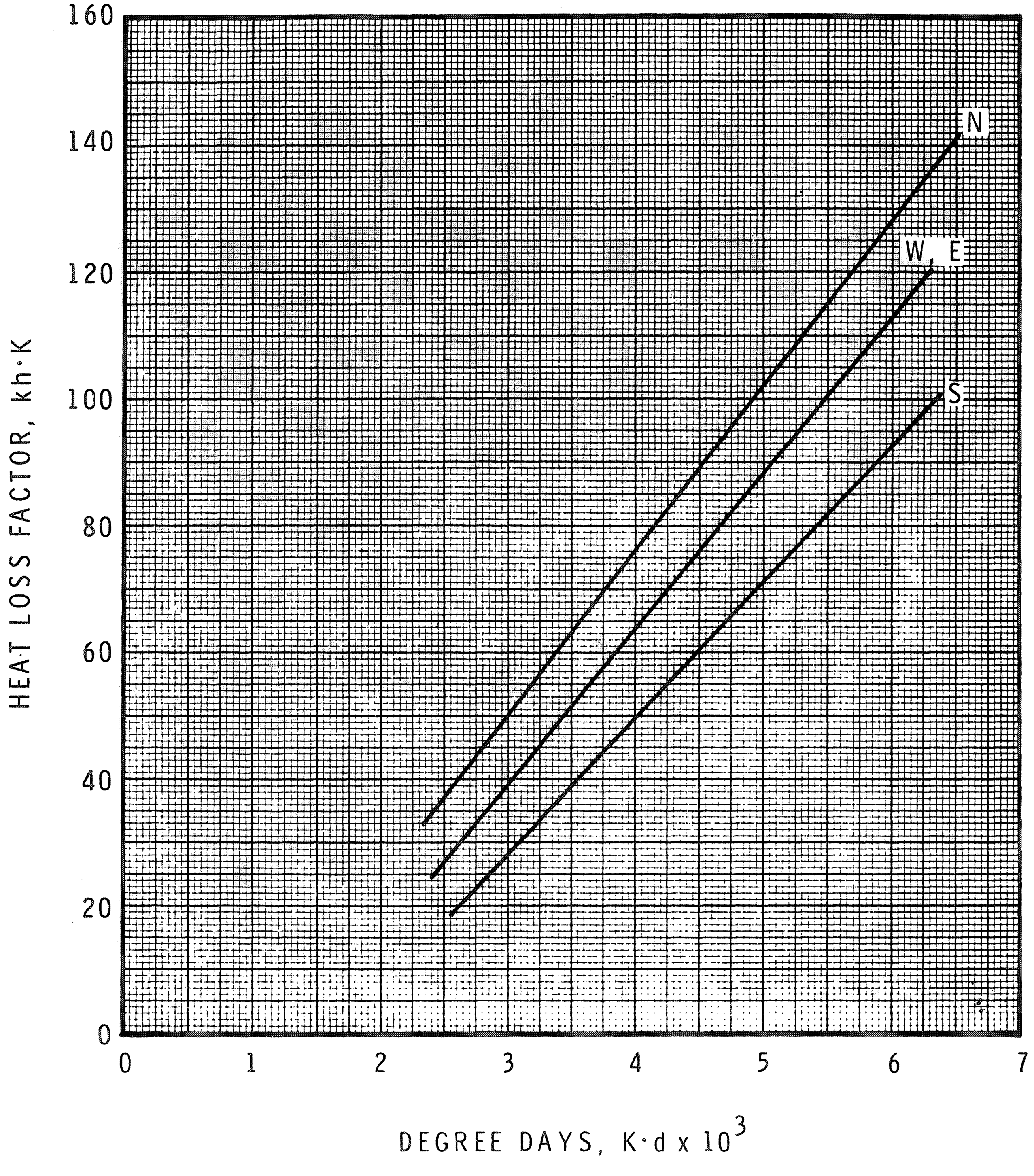

FIGURE 6

WALL HEAT LOSS FACTORS
(EXTERIOR SURFACE COLOUR - DARK)

BR 5522 - 6

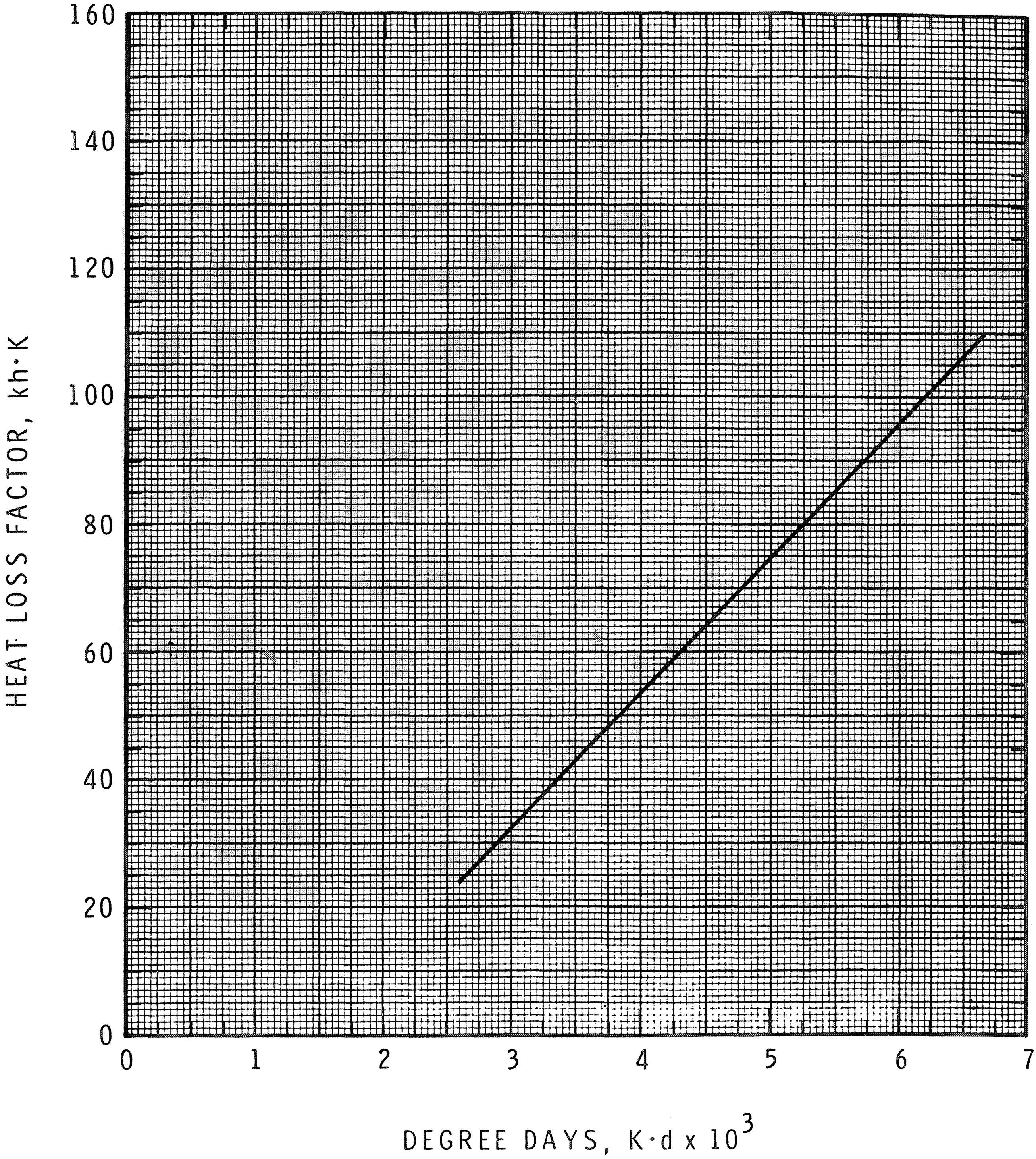

FIGURE 7

CEILING - ROOF HEAT LOSS FACTORS

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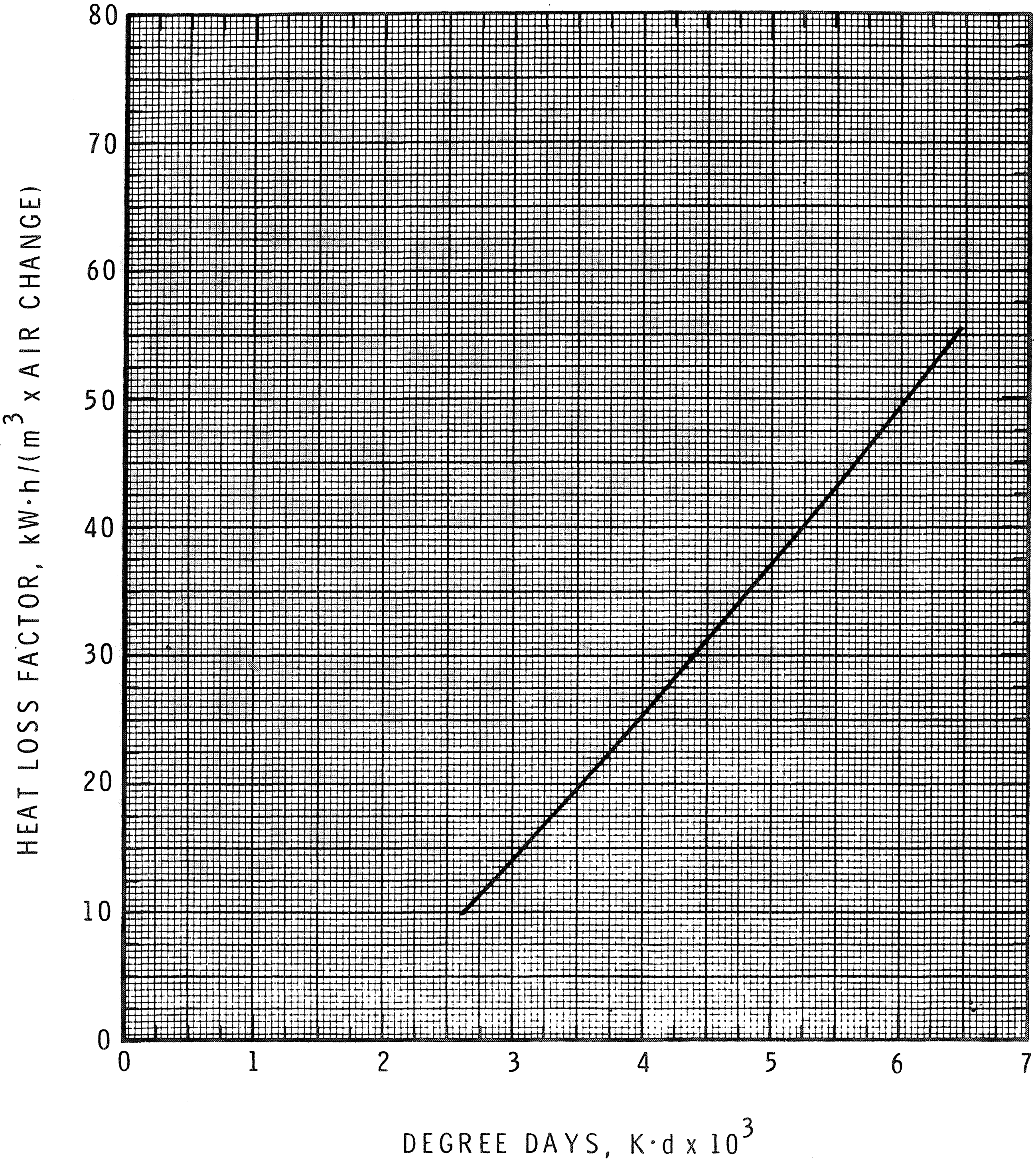

FIGURE 8

INFILTRATION HEAT LOSS FACTOR

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