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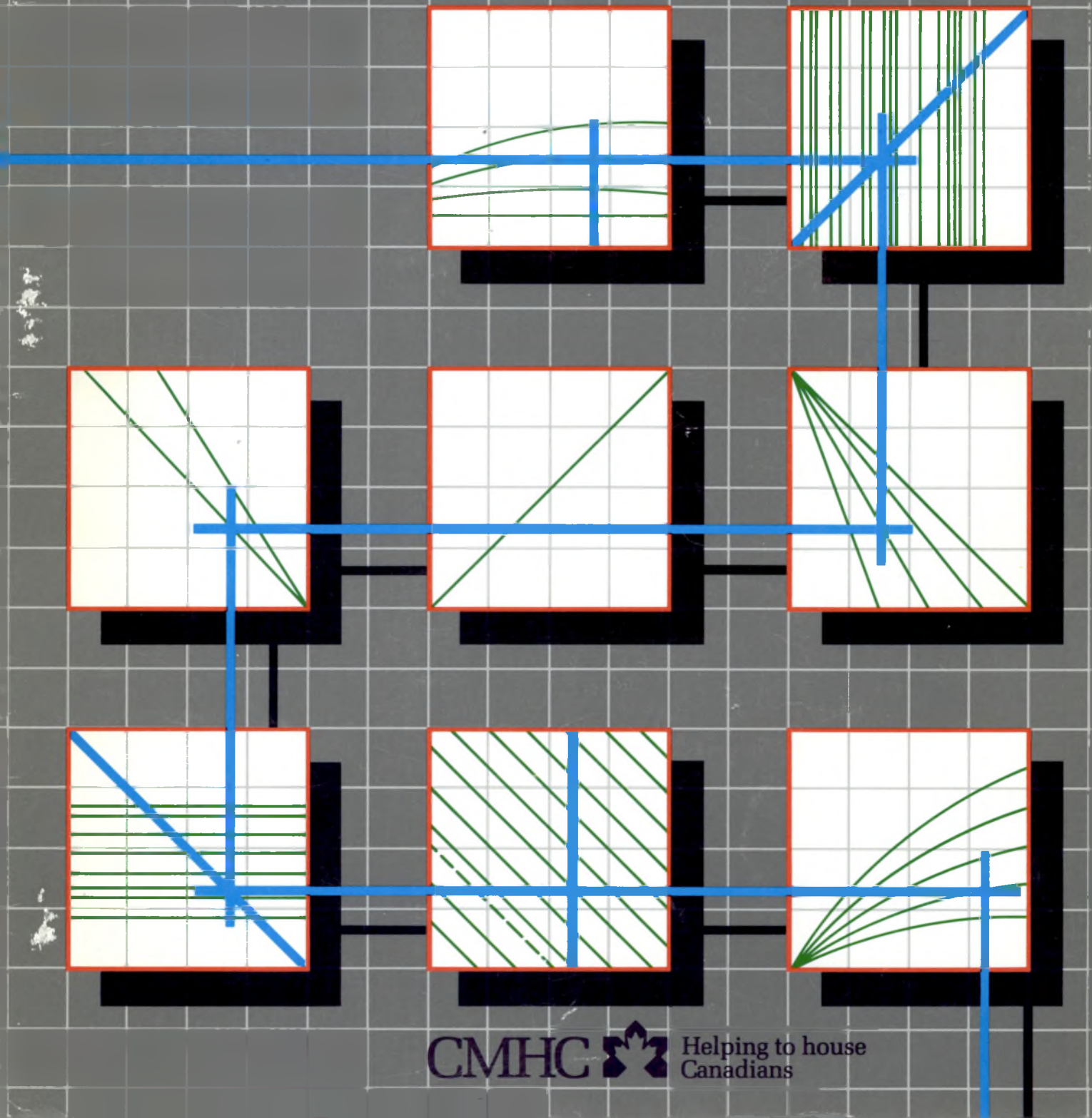
Canada Mortgage and Housing Corporation

Société canadienne d'hypothèques et de logement

GRAPHEAT

An Energy Analysis Technique for Houses



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GRAPHEAT:

An Energy Analysis Technique for Houses

Prepared by the Building Engineering Group, Waterloo, Ontario, for Canada Mortgage and Housing Corporation, Ottawa, Ontario.

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Abstract

This manual presents a simple graphical method for estimating quickly the annual space-heating energy consumption and assessing the thermal comfort in low-energy, passive-solar houses. It is intended primarily for use at the conceptual stage of design. The method comprises four steps:

1. the calculation of the above-grade heat loss coefficient,
2. the calculation of the maximum indoor temperature swing resulting from solar heat gain,
3. the calculation of the below-grade heat loss, and
4. the calculation of the annual space-heating energy consumption.

A worksheet and nomogram are used in each step. A worked example is presented. Climatic data for 23 Canadian cities are provided.

Preface

The procedure for graphical energy analysis presented in this manual is based on work prepared for Canada Mortgage and Housing Corporation by Okins, Leipciger, Cuplinskas, Kaminker and Associates, Consulting Engineers. The original graphical method, which was largely developed by Eugene Cuplinskas, has been extended, and the procedure has been significantly revamped by the Building Engineering Group at the University of Waterloo. Initially, the method was restricted to house designs that met certain criteria: due-south orientation, full basements, flat grade, and relatively simple house plans. GRAPHEAT, the graphical method presented herein, is an extension and redraft of the original work. This "extended" method is more general in that it can, to some extent, accommodate the following factors:

- "non-south" orientation
- partial basements or sloping grade
- various amounts of thermal mass in the south zone
- effect of an air movement system for the purposes of controlling temperature swing
- various sizes of a rock bin thermal storage unit
- wide variety of house plans.

Worksheets have been developed to accompany each nomogram. A procedure for calculating the annual cost of space heating has been added.

The temperature swing, below-grade heat loss, and annual energy calculations are based on the methodology developed and described in the publications *Residential Passive Solar Heating*[1] and *A Manual Method for Optimizing Low-Energy/Passive Solar Home Designs*.[2] The above-grade heat loss graphs were developed using long-term average degree-day totals. The solar gains graphs in Appendix B are based on solar radiation averages published by the Atmospheric Environment Service.

The project team consisted of Lorne Wheeler, Mark Chamberlain, and Eric Burnett of the Building Engineering Group, and Stephen Carpenter, of Enermodal Engineering. Fanis Grammenos was the project manager for Canada Mortgage and Housing Corporation.

[1]Cuplinskas, E.L. et al. *Residential Passive Solar Heating*, 1980. Ontario Ministry of Energy.

[2]Ontario Ministry of Energy, *A Manual Method for Optimizing Low-Energy/Passive Solar Home Designs*, 1984.

Introduction

The graphical method presented in this manual is a tool for use in the design of energy-efficient housing. It enables designers of low-energy, passive-solar housing to do the following:

- estimate annual space-heating energy consumption
- assess thermal comfort.

Architects, builders, and even non-professionals can use the method to quantify the thermal performance of detached, semi-detached, or row houses.

The method presumes that the designer is well intentioned and the house is to be energy conserving, that is, the enclosure is to be well insulated and relatively air-tight, and southerly glazing is to be used to advantage. The use of GRAPHEAT enables the building designer to assess readily the effect of many design changes on energy consumption and thermal comfort. The method entails the calculation of the above-grade heat-loss coefficient, the maximum swing of indoor air temperature, the below-grade heat loss, and the annual energy consumption.

The method cannot model directly earth-bermed buildings, a slab-on-grade floor, sloped glazings, or any sunspace that is both unheated and an integral part of the internal space.

The method is unique in that it enables the designer to estimate the solar-induced air temperature swing without tedious engineering calculations. The temperature swing is one of the indicators of thermal comfort, which is of fundamental importance in the design of low-energy, passive-solar buildings. The method also provides a quick and graphic means of estimating annual space-heating energy costs.

To use the method, appropriate weather data are required. Weather data for 23 locations representative of most Canadian climatic regions are provided in Appendix B.

This manual has been written for two types of users: the first-time user and the experienced user. The first-time user should read through the entire manual, which explains the procedure using data for a typical house to demonstrate the method. The experienced user will find blank nomograms and worksheets provided in Appendix A.

Method

A flowchart depicting the overall approach is presented in Figure 1. There are four sequential parts to GRAPHEAT, in which the following are evaluated:

- above-grade heat loss coefficient
- maximum indoor temperature swing
- below-grade heat loss
- annual energy consumption.

As shown in Figure 1, for a comprehensive analysis, all four parts of the method must be completed. For subsequent design variations it may be possible to skip Parts 1, 2, or 3 depending on what changes are made to the building. Eleven sheets are involved — on some, data is recorded (data-sheets), on some, calculations are carried out (worksheets) and on the others, nomograms or graphs are provided. These sheets are numbered 1 to 11.

Only simple, readily available information about the building is required. The necessary data items are identified and listed on Sheets 1 and 2. It is recommended that these worksheets be completed for each building design. Most of the terms of Sheets 1 and 2 are self-explanatory. Four terms that are unique to this method are defined below.

Above-Grade Floor Area: This area (expressed in square metres) is the sum of the areas of each above-grade floor based on internal dimensions. Stairwells or other open areas of floor should be included in the calculation of the area of each floor. For complex house plans (for example, vaulted ceilings), the equivalent floor area may be calculated by dividing the above-grade house volume (m^3) by 2.5 m.

South-Zone Floor Area: This area (expressed in square metres) is the total floor area of all those rooms that receive significant solar gains (any room with a south-glass-to-floor area ratio of more than 5%), plus the floor area of any adjacent rooms where more than 50% of the partition wall is open. This south-zone floor area is sometimes referred to as the passive zone. The remainder of the house is categorized as either the north zone or the basement. The method assumes that the rooms are of regular shape and that each floor is 2.5 m high. Note that the temperature swing calculation is very sensitive to the south floor area calculation, and, therefore, care should be taken in evaluating the south-zone floor area.

Heavy Mass Surface Area: This area (expressed in square metres) is the area of all surfaces of concrete, block, brick, or other thick or thermally heavy materials within the south zone. The area of any opening into the non-south zones is also included in the calculation of the heavy surface area. If the floor area is heavy but carpeted, include only the non-carpeted area as heavy surface area.

Total South-Zone Surface Area: This area (expressed in square metres) includes all interior surface areas surrounding the south floor area such as floors, ceilings, walls, doors, windows, and archways.

Sheets 3 and 4 are used to determine the above-grade heat loss coefficient. Sheets 5, 6, 7 and 8 are used to determine the maximum indoor air temperature swing. Sheet 9 is used to determine the below-grade heat loss. Sheets 10 and 11 are used to record and modify this information and to complete the annual space-heat energy consumption. Data from Sheets 1 and 2 are used to calculate input data for each nomogram. A detailed step-by-step procedure and key diagrams lead the user through each step in GRAPHEAT. Worksheets and nomograms that have been filled in and completed for an example house are included in the text following the explanation of each calculation step. The floor plan and evaluations for this house are presented in Figure 2. "Blank" worksheets and nomograms are contained in Appendix A, ready for copying.

FIGURE 1. FLOWCHART FOR GRAPHEAT

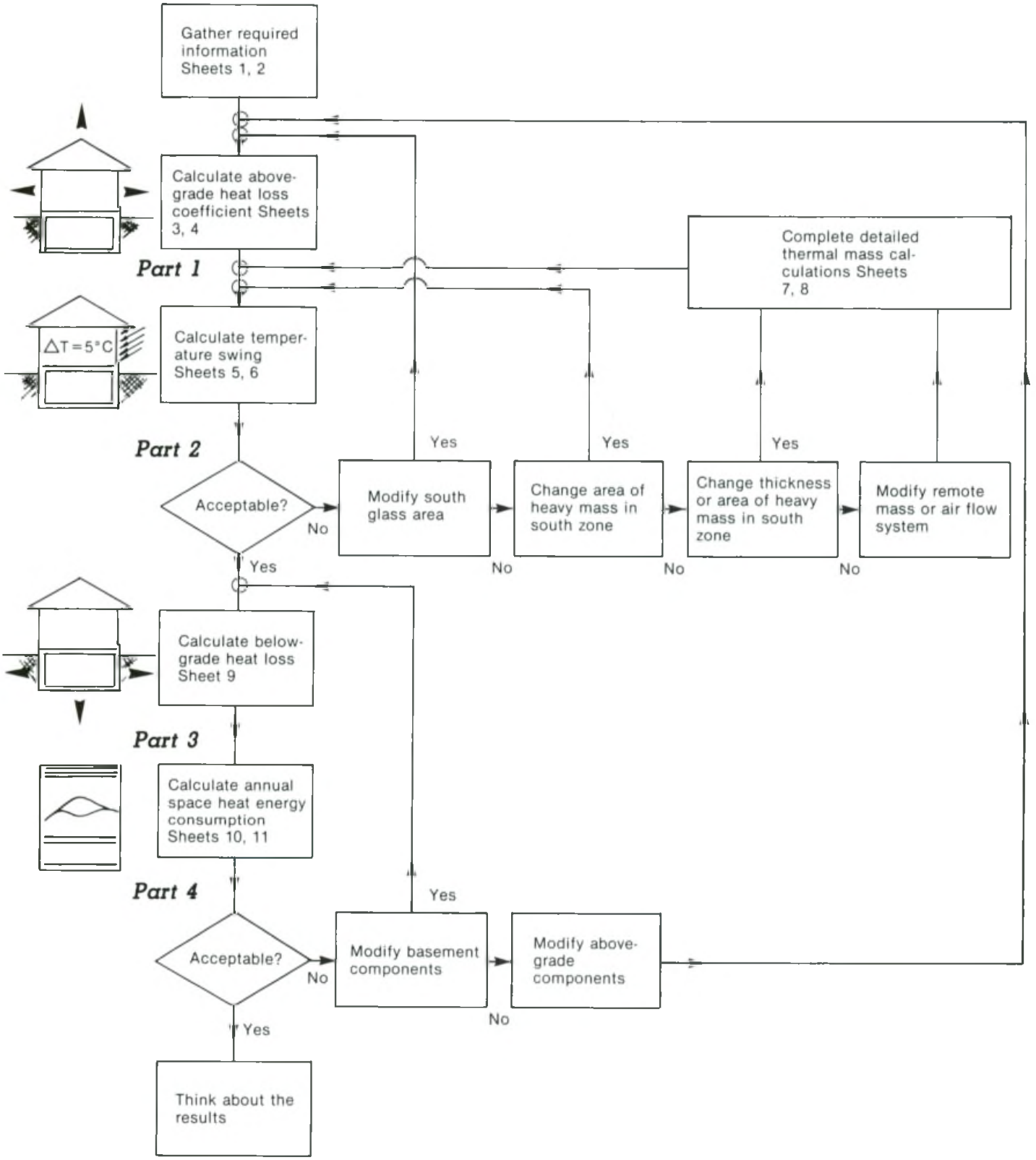
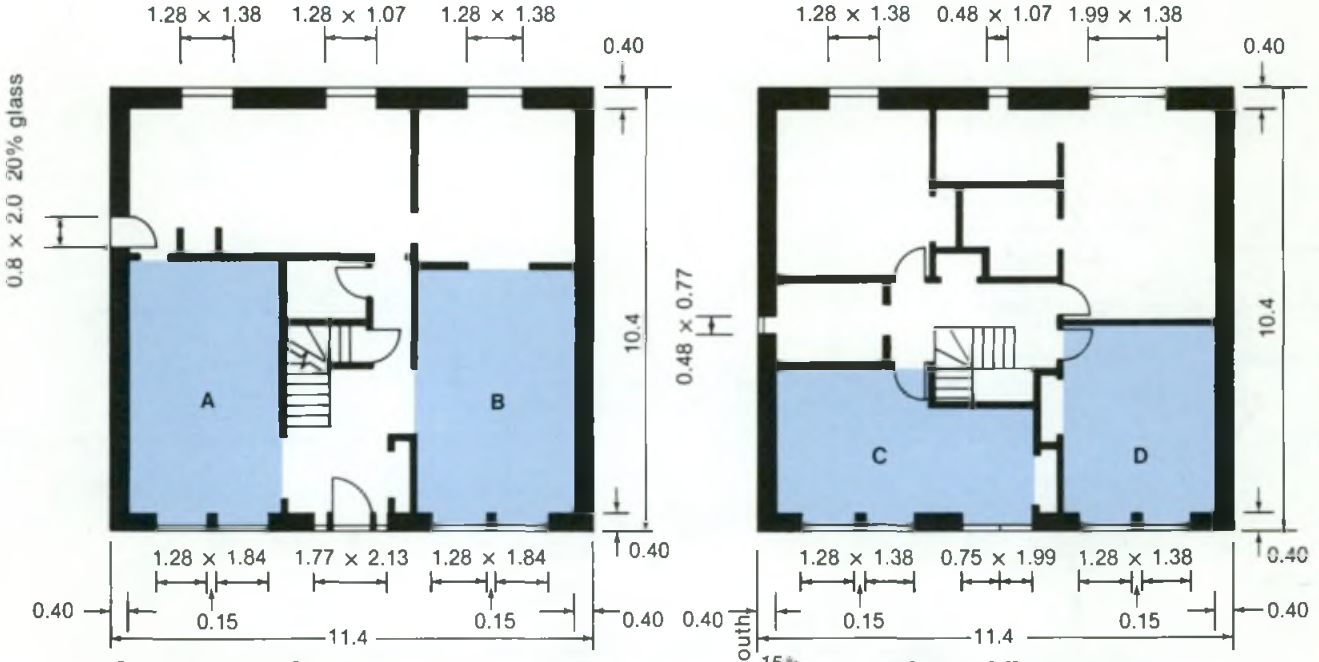
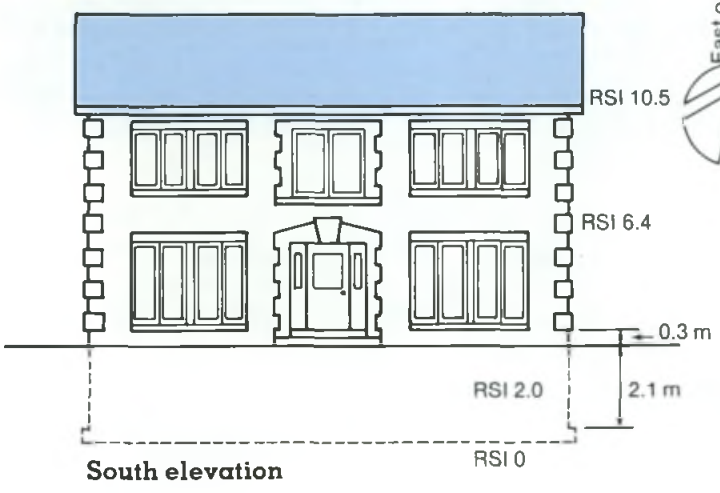


FIGURE 2.
OTTAWA HOUSE USED IN THE WORKED EXAMPLE.

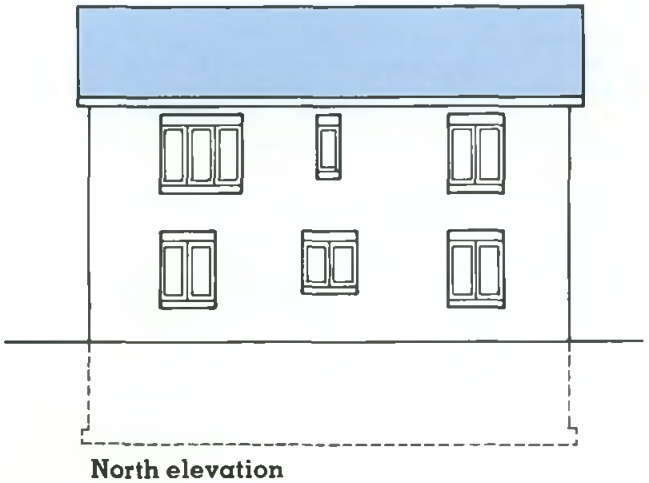


Ground floor plan (south wall 30% glass)

Second floor plan



South elevation



North elevation

Area calculations

Above-grade floor area: $10.6 \times 9.6 \times 2 = 204\ m^2$
South zone floor area: A (3.64×5.96) + B (3.75×5.74) + C (3.71×3.4) + D (2.5×2.5) + $(3.71 \times 4.5) = 79\ m^2$
Basement floor area: $10.6 \times 9.6 = 102\ m^2$
Above-ground wall area: $2 \times (10.6 + 9.6) \times 2.5 \times 2 = 202\ m^2$
Basement wall height below grade = 2.1 m
Basement wall height above grade = 0.3 m
Basement wall perimeter: $2 \times (10.6 + 9.6) = 40$ m
Surface area of south zone:

Floor	—	= 79
Wall	— $(34.8 \times 2.44) + (38.2 \times 2.44)$	= 178
Ceiling	—	= 79
		336 m^2

Clear glass areas (20% frame, 80% glass)
South windows: $[(1.28 \times 1.84 \times 4) + (1.77 \times 2.13 \times 0.3) + (1.28 \times 1.38 \times 4) + (0.75 \times 1.99 \times 2)] \times 0.8 = 16.5\ m^2$
East windows: Nil
West windows: $[(0.8 \times 2.0 \times 0.2) + (0.48 \times 0.77) \times 0.8 = 0.6\ m^2$
North windows: $[(1.28 \times 1.38 \times 3) + (1.28 \times 1.07) + (0.48 \times 1.07) + (1.99 \times 1.38)] \times 0.8 = 7.9\ m^2$
Total clear glass area: $16.5 + 0.6 + 7.9 = 25\ m^2$

BUILDING DATA SHEET

Project Name: EXAMPLE HOUSE FROM FIG. 2

City: OTTAWA, ONTARIO

Temperatures

			Ref. No.
• mean annual outdoor — Choose the city and refer to its Climate Data Graph (App. B)	5.8	C°	1
• mean January outdoor at noon	-6.4	C°	2

Floors

• Number of above-grade floors	2		3
• **Above-grade floor area**: include the floor area of stairwells and other two-storey high spaces as a part of each floor area. For buildings with an irregular form, use the above-grade internal volume (exclude basement volume) divided by 2.5 m.	204	m^2	4
• **South zone floor area**: include all rooms with significant solar gain and north rooms where over 50% of the connecting wall is open to the south room.	79	m^2	5
• **Basement floor area**, internal dimensions: include any vertical wall area at change in floor level.	102	m^2	6
• **Basement floor insulation value**: for the insulation only, do not include the ground or the slab.	0	RSI	7

Walls

• **Above-grade wall area**: include windows and doors and any floor area over an unheated space; do not include any portion of the above-grade basement.	202	m^2	8
• **Above-grade wall insulation**: if there are several wall types with different RSI values, use the average value based on relative areas (ignore the doors and windows).	6.4	RSI	9
• Average basement wall height below grade.	2.1	m	10
• Average basement wall height above grade.	0.3	m	11
• Perimeter of exterior basement wall: do not include party walls in townhouses or semi-detached houses.	40	m	12
• Basement wall insulation (of the thermal insulation only; not the wall or ground).	2.0	RSI	13

Interior Surfaces

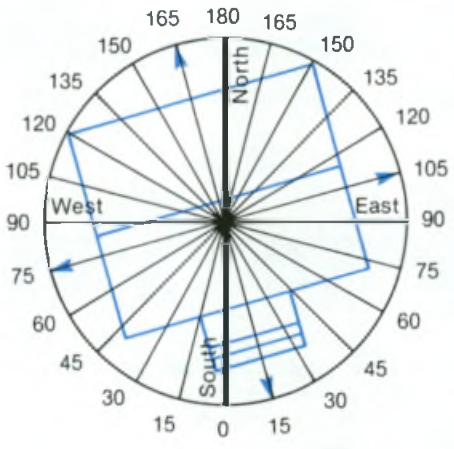
• Surface area of all surfaces within the south zone (i.e., ceiling, walls, floors — typically four times the floor area).	336	m^2	14
• Surface area of all south zone heavy surfaces plus the area of all door openings into the north zone.	18	m^2	15

Roof

• Roof insulation.	10.5	RSI	16

Windows

- Orientation: sketch the building on compass shown, and determine deviation from south for each set of windows.



BUILDING IS 15° EAST OF SOUTH

			Ref. No.
• Ratio of clear glass area to rough window opening		0.8	17
• Clear glass for each orientation:	South Zone 18	Total Building	19
NOTE: the south zone consists of all those rooms that are subjected to significant amounts of sunlight in January.	southerly 15.6 m²	15.6 m²	
	easterly — m²	— m²	
	westerly — m²	0.6 m²	
	northerly ____ m²	7.9 m²	
Total clear glass area:		25.0 m²	20
• Glass type: SG, DG, TG, QG, or RSI value (Single, double, triple, quadruple glazed)		0.9 RSI	21
• Thermal shutter RSI value (0 if none)		0 RSI	22

Infiltration

• Desired average ventilation rate (Natural and Mechanical)	0.5	ACPH	a
• Natural ventilation rate (infiltration)	0.16	ACPH	b
• Heat exchanger efficiency (0 if no heat exchanger)	.80		c

a b c b

Effective cold air infiltration rate: = (0.5 − 0.16) × (1 + .80) + 0.16 = 0.23 ACPH — 23

Annual Energy Consumption

• Furnace seasonal efficiency Gas furnace: normal 0.65, spark ign.: 0.70; condensing: 0.95 Oil furnace: normal 0.65 Electric baseboard or furnace: 1.00	1.0	24
• Fuel energy content Electricity — 278 kwh/GJ Natural Gas — 27 m³/GJ Fuel Oil — 26 litre/GJ	278	25
• Fuel cost: $ per appropriate unit (kwh, m³, or litres) of fuel from local utility	0.040	26

Part 1: Above-Grade Heat Loss Coefficient

The above-grade heat loss coefficient must be calculated in order to determine both the annual space-heating energy consumption and the temperature swing. This coefficient indicates the rate of heat loss (i.e., Watts per degree Celsius per unit area) from the above-grade portion of the building for each degree of temperature difference between the indoors and outdoors. As such, it is a useful thermal index of the likely performance of the above-grade portion of any house.

Sheets 3 and 4 are used to evaluate the above-grade heat loss coefficient. The procedure is described in the following section, and Sheets 3 and 4 have been completed for the example house shown in Figure 2.

3 ABOVE-GRADE HEAT LOSS WORKSHEET 3

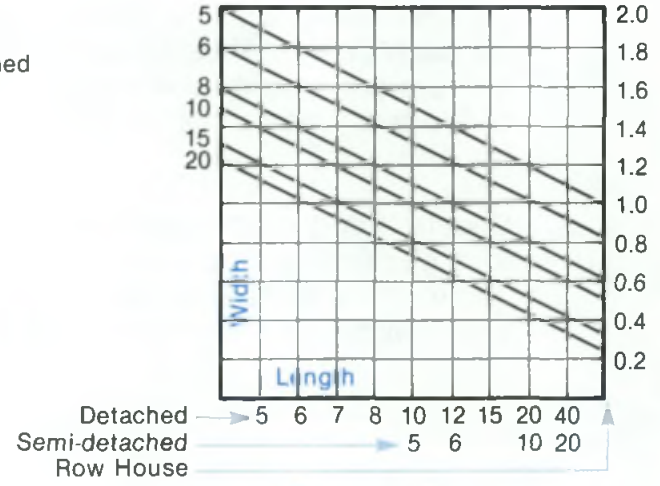
Nomogram Input Data

- Ratio of the above-grade exterior wall area to the total floor area.
- If the building is a simple rectangle with no unheated spaces (e.g., garage) projecting into the house volume, the ratio 27 may be obtained using the graph at the right.

Ref. No.

(8) (4)

202 ÷ 204 = 0.99 — 27



27

- Ratio of the exposed basement wall RSI to the main wall RSI. This value includes 1-, 2-, 3-storey buildings and wall heights other than 0.5 m.

(13) (3) (9) (11)

$$\frac{2.0 \times 2}{4 \times 6.4 \times 0.3} = 0.52$$ — 28

- Roof thermal resistance adjusted for 1-, 2-, or 3-storey buildings.

(16) (3)

0.5 × 10.5 × 2 = 10.5 RSI — 29

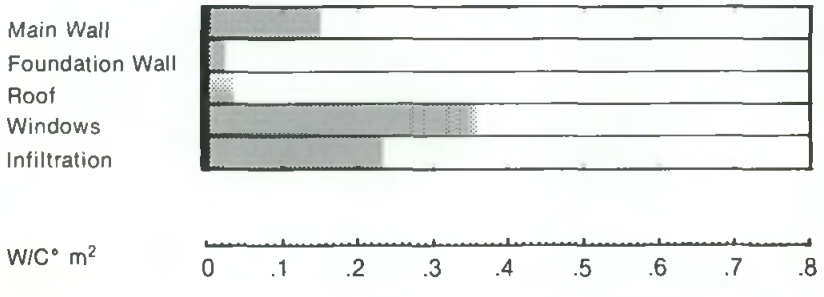
- Ratio of gross window area to total floor area.

(20) (17) (4)

25.0 ÷ 0.8 ÷ 204 = 0.15 — 30

Result: Above-Grade Heat Loss Coefficient: W/C° m² 0.82 (31)

Graphical Summary of Above-Grade Heat Loss Component Parts

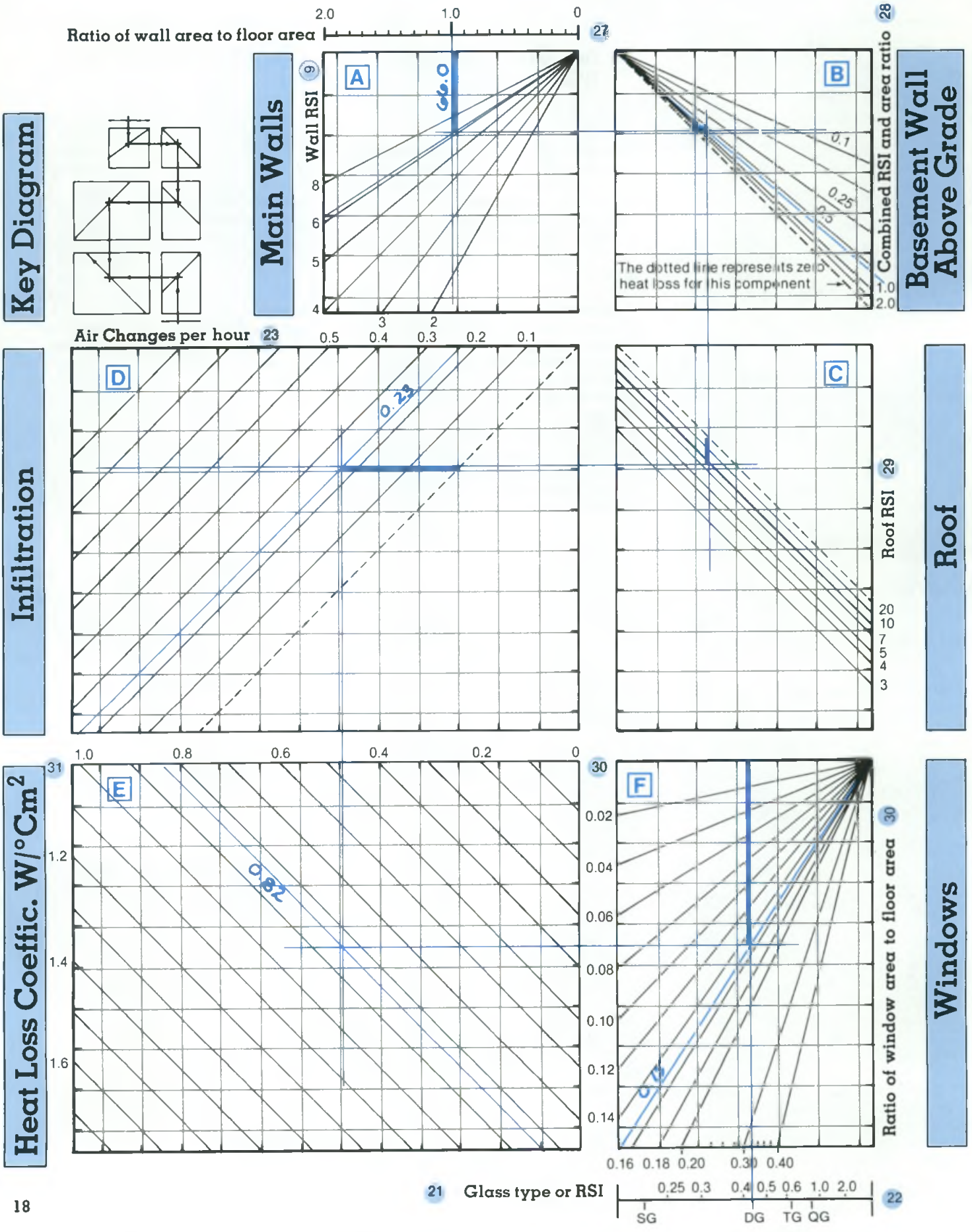


Procedure

1-a Determine the Main Wall Heat Loss

Using Sheet 3 (opp.), determine the ratio of the gross above-grade exterior wall area to the total above-grade floor area **27**. Include in the wall area doors, windows, any overhanging floor area, and any area of the garage walls or ceiling that project into the building. Do not include that area of the foundation wall that is above grade.

If neither the wall area nor the floor area is known, for example, in a preliminary design, the other approach shown on Sheet 3 may be used to determine the above ratio **27**. This graph relates length and width, and house type. Note that this somewhat simpler approach assumes that the building is rectangular and that there are no floor overhangs or unheated spaces projecting into the house volume. To use the graph, determine the house type: detached, semi-detached, or row house, and select the appropriate scale below the graph. Mark on the scale the value of the house length or depth, and draw a vertical line up into the graph. Where this line intersects with the line that represents the house width, draw a horizontal line to the right, and read the value of the ratio of the above-grade exterior wall area to the total floor area **27** in the scale at the right side of the graph. This ratio may then be used as the first step on Sheet 4. The completed Sheet 4 and each of the steps in its completion are described and shown overleaf.


Key Diagram
Main Walls
Basement Wall Above Grade
Infiltration
Roof
Windows
Ratio of wall area to floor area
2.0
1.0
0
27
28
A
B
Wall RSI
9
8
6
5
4
3
2
0.0
0.1
0.25
0.5
1.0
2.0
Combined RSI and area ratio
The dotted line represents zero heat loss for this component
Air Changes per hour
23
0.5
0.4
0.3
0.2
0.1
D
0.23
C
Roof RSI
29
20
10
7
5
4
3
Heat Loss Coeffic. W/°Cm²
31
1.0
0.8
0.6
0.4
0.2
0
E
0.82
1.2
1.4
1.6
30
F
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.30
0.40
0.24
Ratio of window area to floor area
30
21
Glass type or RSI
0.25
0.3
0.4
0.5
0.6
1.0
2.0
22
SG
DG
TG
QG

On Sheet 4, mark on the scale above Graph A, the ratio of wall area to floor area 27.

Draw a vertical line down to intersect with the wall RSI value 9. If there are many above-grade wall types, find an average value for their thermal resistance as follows:

$$RSI_{AVE} = AREA_{TOTAL} \div \left[\frac{(AREA_1}{RSI_1} + \frac{AREA_2}{RSI_2} + \frac{AREA_3}{RSI_3} + \ldots\right]$$

Doors and windows may be excluded from this calculation. The vertical distance represents the wall heat loss.

1-b Determine the Above-Grade Basement Wall Heat Loss

From the intersection point on Graph A, draw a line to the right through Graph B to intersect the diagonal line that represents the ratio of thermal resistances of the above-grade basement wall to the upper walls 28. The horizontal distance from the intersection point to the diagonal dashed line represents the above-grade basement wall heat loss (in W/°C m^2 of total above-grade floor area).

1-c Determine Roof Heat Loss

From the intersection point on Graph B, draw a vertical line down to Graph C to intersect the line that represents the thermal resistance of the roof 29. The vertical distance from the dashed line represents the roof heat loss.

1-d Determine Infiltration Heat Loss

Natural ventilation (infiltration) and mechanical ventilation combined should add up to a ventilation rate adequate to ensure the occupants' comfort and safety. An air change rate of 0.5 air changes per hour (ACPH) is commonly used in the design of residential buildings.

Using Sheet 2 (pg. 14), calculate the effective infiltration rate of cold air in terms of air changes per hour. Typical new housing exhibits the following natural ventilation rates:

Calibre of construction	Natural ventilation rate (ACPH)
Very tight	0.05-0.15
Tight (R2000, SEEH)	0.15
Better quality, regular	0.4-0.6

Seasonal efficiencies for heat exchangers should be used if they are available from the manufacturer. If they are unavailable, the steady-state efficiency is commonly used. Efficiencies typical of heat exchangers vary from 0.70 to 0.75 in warmer regions in Canada, and 0.50 to 0.60 in colder regions.

From the intersection point in Graph C, draw a horizontal line to the left through Graph D to intersect the line that represents the cold air infiltration rate caused by the combined effects of natural and mechanical ventilation. The horizontal distance from the dashed line represents the infiltration heat loss.

From this intersection point, draw a vertical line down through Graph E.

1-e Determine Glazing Heat Loss

Mark the glazing type 21 on the scale below Graph F. If the actual thermal resistance is known, use the upper scale. If the building has more than one window type, find the average RSI by area as in 1-a. Make a linear provision for the effect of thermal shutters. For example, if thermal shutters are used on all windows for half of the day, make a mark on the scale halfway between the glass type 21 and the combined window-thermal shutter RSI 22. From this mark, draw a vertical line up through Graph F to intersect the line that represents the ratio of window area to floor area 30. The vertical distance from the top of Graph F represents the window heat loss.

The ratio of clear glass area to rough window opening 27 varies with window size and type. This information is best derived from the manufacturer's specifications, but some representative values are listed as follows.

Window type	Window size	Ratio of glass area to rough opening 17
Awning, casement, or single hung	Small	0.65
	Large	0.75
Picture	Large	0.84

1-f Determine the Above-Grade Heat Loss Coefficient

From the intersection point on Graph F, draw a horizontal line to the left through Graph E.

Where the horizontal line from Graph F and the vertical line from Graph D intersect, draw a diagonal line upwards to the left (parallel to the graph lines).

Where the diagonal line meets the top of Graph E, read the value of the above-grade heat loss coefficient (W/°C m^2) 31. Record this value in the space provided on Sheet 3.

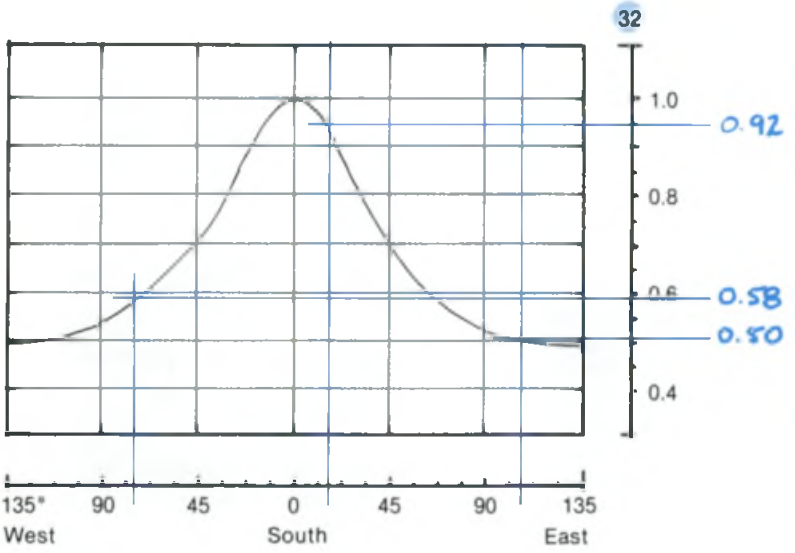
The above-grade heat loss coefficient 31 is used twice in GRAPHEAT, first in Part 2, the temperature swing calculation, and secondly, in Part 4, the annual energy consumption calculation.

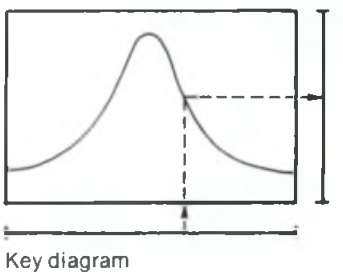
1-g Summary of the Calculations

The contribution to heat loss from walls, roof, infiltration, and windows may be summarized graphically on Sheet 3. Simply scale off the appropriate distance on Sheet 4, and complete the table on Sheet 3. These distances are indicated by the heavy lines on Sheet 4 in the example.

If the glazing area is to be changed, then it is sufficient to draw a new horizontal line from Graph F to Graph E. If the wall RSI value is to be changed, then re-do the calculation beginning with Graph A. Note that in these calculations, average infiltration rates are used, and below-grade heat loss has not been included; therefore, these values should not be used to size the heating system.

5 TEMPERATURE SWING WORKSHEET 5




Key diagram

Orientation Factor for Non-South Glass

- Equivalent south glass area:

	32 orientation factor		18 glazing area			
Southerly	0.92	×	15.6 m²	=	14.4 m²	
Easterly	0.50	×	0 m²	=	m²	
Westerly	0.58	×	0 m²	=	m²	
Total equivalent south glass area				=	14.4 m²	33

- Ratio of equivalent south glass area to south zone floor area: 33 14.4 ÷ 5 79 = 0.18 — 34
- January noon temperature difference: 23°C − ② −6.4 = 29.4°C — 35
- Ratio of heavy mass area to total surface area in the south zone: 15 18 ÷ 14 336 = 0.05 — 36

Result Temperature Swing = 12°C

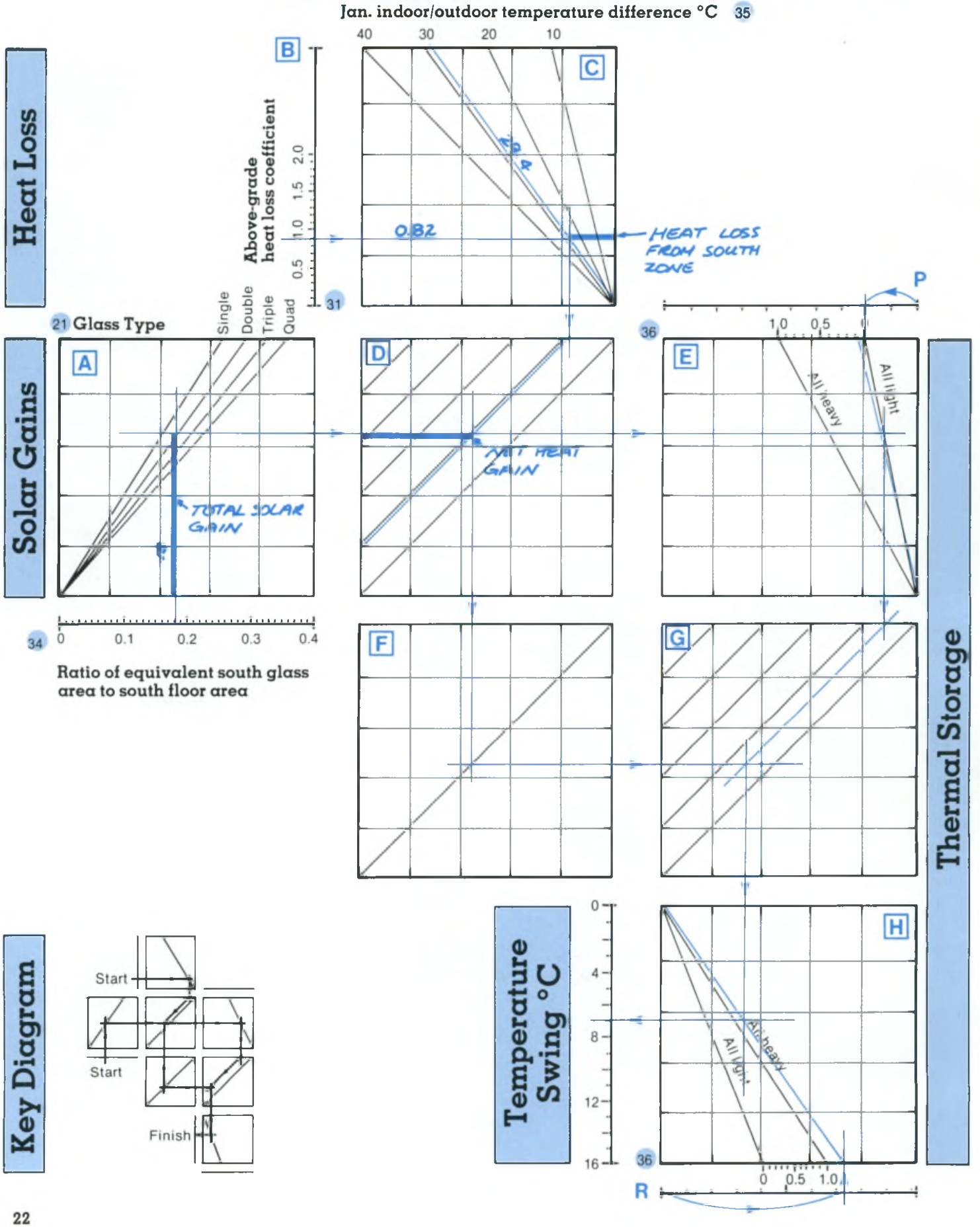
Note: If the design includes remote thermal mass or special air recirculation systems, complete Sheets 7 and 8.

Part 2:
Indoor Temperature Swing

One measure of the level of thermal comfort in a building is the daily variation or swing in the indoor temperature as a result of solar heat gain. Energy-conserving homes can overheat on cold, sunny days unless measures are taken to control or store solar energy. A temperature swing of between 5°C and 7°C is an appropriate design target. A large temperature swing (above 7°C) will cause discomfort and unnecessary heat loss. GRAPHEAT enables the user to estimate the likely temperature swing, and to assess the effect of varying the area of south-facing glass and other design variables.

The indoor temperature swing is determined by using Sheets 5 and 6. This procedure is based on a typical, clear, sunny day in January. Solar gain minus heat loss constitutes the amount of solar heat to be stored (that is, the net gain). For most locations in Canada, during the heating season, a doubled-glazed south window will gain more energy during the day by solar radiation than it will lose by transmission and re-radiation during the night and day. If a room overheats on a cold, clear, sunny day, thus requiring drawn drapes or open windows, the net gain will be reduced and possibly become a net loss. A January clear-day temperature swing, therefore, provides a means of sizing the area of south windows and building thermal mass for acceptable comfort and best use of the available solar radiation. If the temperature swing is acceptable, the user should then proceed with Part 3. If, however, this calculation indicates that the temperature swing is too large, the temperature swing can be reduced by decreasing the net solar gain (less south glazing), increasing the south-zone mass, or changing the airflow system to better use any existing mass. The user should turn to Sheets 7 and 8, which contain a detailed procedure for accounting for thermal mass, or sizing either a forced-air system or a rock bin unit to control the temperature swing. Refer to the Bibliography for references that describe how to use window shading, ventilation, and other passive cooling techniques.

A step-by-step procedure for using the temperature-swing nomograms is described in the text that follows. Sheets 5, 6, 7, and 8 have been completed for the example house described in Figure 2.


Jan. indoor/outdoor temperature difference °C 35
40 30 20 10
Heat Loss
B
C
Above-grade heat loss coefficient
0.5 1.0 1.5 2.0
31
0.82
HEAT LOSS FROM SOUTH ZONE
21 Glass Type
Single
Double
Triple
Quad
Solar Gains
A
D
E
P
36
1.0 0.5 0
All heavy
All light
NET HEAT GAIN
TOTAL SOLAR GAIN
34
0 0.1 0.2 0.3 0.4
Ratio of equivalent south glass area to south floor area
F
G
Thermal Storage
Temperature Swing °C
0 4 8 12 16
H
All heavy
All light
36
0 0.5 1.0
R
Key Diagram
Start
Start
Finish

Procedure

2-a Determine Solar Gain

Establish the orientation factor for all the relevant glazing — refer to the compass sketch on Sheet 2, and use the figure on Sheet 5 (pg. 20). Work through the four simple calculations on Sheet 5. Note that the equivalent south glass area 33 is the sum of all the contributing glass areas converted to due-south by means of an orientation factor 32.

Using Sheet 5, calculate the ratio of the equivalent south glass area 33 to the south floor area 5. Note that the temperature swing calculation is very sensitive to this ratio.

Knowing the ratio of equivalent south glass area to the south floor area 34, enter the nomogram (Sheet 6) at Graph A by drawing a vertical line from the scale below Graph A up into Graph A. In Graph A, the vertical distance represents the total solar gain through the windows. From the intersection point for the appropriate glazing type 21 in Graph A, draw a horizontal line across through both Graphs D and E.

2-b Determine Net Solar Gain

Knowing the above-grade heat loss coefficient 31, enter the nomogram at Graph C on Sheet 6. Draw a horizontal line to the right through Graph C. At the top of Graph C, mark in the temperature difference between indoors and outdoors 35. Draw in the sloping line to represent the appropriate indoor-outdoor temperature difference.

From the intersection point, draw a vertical line down to the top of Graph D. The horizontal distance represents the passive-zone heat loss.

From this point at the top of Graph D, draw a diagonal (parallel to the graph lines) to intersect the horizontal line drawn previously through Graph D. In Graph D, the horizontal distance to the left-hand axis represents the net gain. If there is no net gain, there are no problems with the temperature swing. However, zero net solar gain also means that little advantage is taken of any passive solar energy and design change might be contemplated.

From the intersection point on Graph D, draw a vertical line down to the diagonal line on Graph F.

From this intersection point, draw a horizontal line to the right through Graph G.

2-c Determine the Thermal Storage Effects

The extent of thermal storage in the passive zone is reflected in the ratio of heavy mass area to total surface area 36. Mark this value on the scales on the top and bottom axis of Graphs E and H, respectively.

On Graph E, draw a diagonal line from the origin to this point. This line represents the thermal storage capabilities of the passive zone. From the intersection of this line and the horizontal line from Graph A, draw a vertical line down to the *top* of Graph G.

From this point at the top of Graph G, draw a diagonal (parallel to graph lines) down to intersect the horizontal line from Graph F.

From this intersection, draw a vertical line down through Graph H.

2-d Determine the Temperature Swing

In Graph H, draw a diagonal line from the origin to the point 36 previously marked on the bottom axis.

Where this line intersects the vertical line from Graph G, draw a horizontal line to the temperature swing scale.

Read and record the temperature swing. If the value is acceptable, proceed with Part 3. If it is not acceptable, i.e., too high, either the south glass area may be reduced, or the heavy mass in the south zone may be increased. If the building already includes double gypsum board or forced air systems and remote mass, a more-detailed thermal storage calculation, using Sheets 7 and 8, may be used as follows to determine the temperature swing.

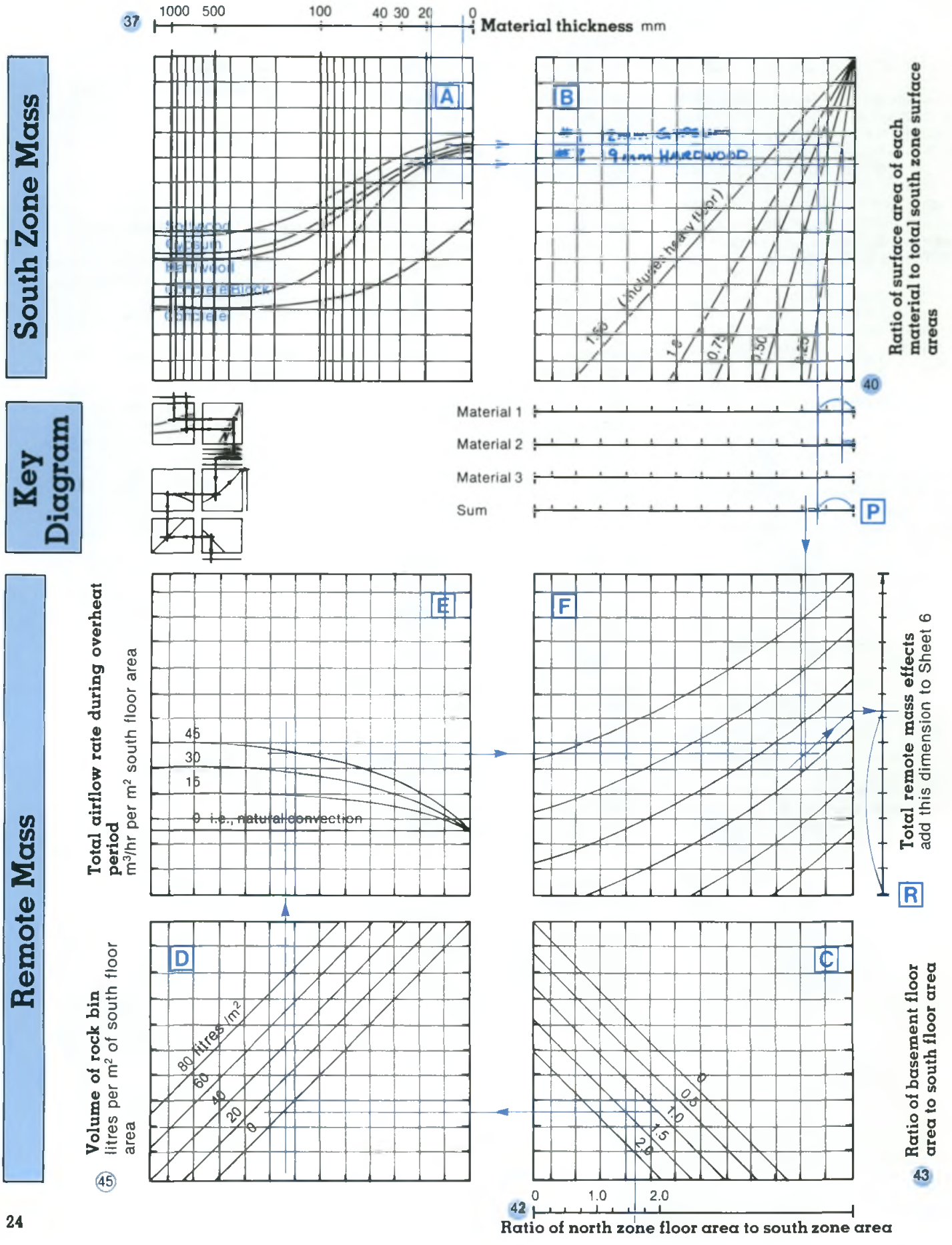
THERMAL STORAGE NOMOGRAM

7

South Zone Mass

Key Diagram

Remote Mass



2-e Detailed Provision for Thermal Mass in the South Zone or Air-Moving Systems and Remote Thermal Mass

Sheets 7 and 8 can be used to determine the effect on the temperature swing of making adjustments in the thickness of the thermal mass, or by making better use of the thermal storage capacity of the north zone, basement, or a rock bin.

2-f Determine the South Zone Mass Effects

First, compiete Step One of Sheet 8 (pg. 26). if the floor is heavy and not carpeted, muitiply the area of exposed concrete by a factor of 3 to account for the extra storage capability.

On Graph A of Sheet 7, enter the average thickness of each building material in the south zone 37. For each material (there are not likely to be more than three), drop a vertical line down to intersect with the curved line representing one of five different materials. Only five common construction materials are shown. If other materials are to be used, their effect may be approximated by choosing the most similar material; for example, brick-concrete block, plywood-softwood.

From the intersection point for each material type in Graph A, draw a horizontal line to the right through Graph B.

From the intersection point for the ratio of the material's surface area to the total surface area in the south zone 40, draw a vertical line down to the scales below Graph B. The distance to the right-hand side of the scale represents the thermal storage of that material.

Repeat the latter process for each material in the south zone using a separately numbered scale below Graph B for each. Those ordinates are then added together on Scale P. From the point that represents the total on Scale P, draw a vertical line down through Graph F.

2-g Determine the Remote Mass Effects

Complete Step 2 on Sheet 8.

On Sheet 7, mark the ratio of the north-zone floor area to the south-zone floor area 42 on the scale below Graph C. From this point, draw a vertical line up to intersect with the line that represents the ratio of the basement floor area to the south floor area 43. Note that any air flow must be operating during the period of overheating. If the air flow system does not or cannot distribute air either to the north zone or to the basement, the floor area must be considered to be zero.

From this intersection point, draw a horizontal line to the left through Graph D. Where this line intersects the line that represents the volume of the rock bin 45, draw a vertical line up through Graph E.

Where this vertical line intersects with the appropriate air flow curve 47, draw a horizontal line to the right through Graph F. The air flow through the house is a function of the forced air system blower capacity. Graph E is based on a system with one return air grill, located at the highest point in the south zone. Typical capacities of forced warm air furnace blowers range from 900 to 3400 m^3/hour (530 to 2000 cfm). The blower capacity can be estimated by assuming an air flow requirement of between 9.0 and 18.0 m^3/hour per square metre of total above-grade floor area.

Where the vertical line from Scale P intersects with the horizontal line from Graph E, draw a parallel curving line upwards to the right following the curves in Graph F. Where this curved line intersects the right-hand side of Graph F, draw a horizontal line to the right to intersect Scale R.

2-h Determine Temperature Swing

Transfer the dimension from Scale P on Sheet 7 to Scale P above Graph E on Sheet 6 and drop a vertical line down to intersect the top of Graph E. Connect this intersection point to the bottom right-hand corner on Graph E.

Transfer the dimension from Scale R on Sheet 7 to the Scale R below Graph H on Sheet 6 and draw a vertical line up to intersect the bottom of Graph H. Draw a diagonal line connecting this point with the upper left-hand corner of Graph H. Finally, repeat the temperature swing calculation from Graph E of Sheet 6 onwards. If the temperature swing is acceptable, proceed to Part 3.

8 THERMAL STORAGE WORKSHEET 8

To complete the thermal storage calculation, additional information is required

Step 1: South Zone Mass

For each material in the south zone, list the following information:

	37 thickness mm	38 material surface area m^2		39 storage factor		14 south zone surface area m^2		40 surface area ratio
Material 1	12	257	×	1.0	÷	336	=	0.77
Material 2	19	79	×	1.0	÷	336	=	0.23
Material 3			×		÷		=	

If the south zone floor is "heavy" and not carpeted, the storage factor is 3.0, otherwise the factor is 1.0. 39

Complete upper section of the nomogram.

Add results on Scale P on Sheet 7 to the Scale P on Sheet 6.

If there are no remote mass or forced air flow modifications, complete the temperature swing calculation.

Step 2: Remote Mass and Air Flow

List the following information:

North zone floor area: 4 [204] − 5 [79] = [125 m^2] 41

Ratio of north zone area to south zone floor area: 41 [125] ÷ 5 [79] = [1.58] 42

Ratio of basement area to south zone floor area: 6 [102] ÷ 5 [79] = [1.29] 43

Volume of rock including voids in rock bin: [ ] [ ] = [0 m^3] 44

Ratio of rock volume to south zone floor area: 1000x [0] ÷ 5 [79] = [0] L/m^2 45

Air moving system blower capacity: 44 [3400] m^3/hr 46

either [2000] cfm × 1.7 = [3400] m^3/hour *or* [ ] L/sec × 3.6 = [ ] m^3/hour

Blower capacity per unit of south zone floor area: 46 [3400] ÷ 5 [79] = [43] 47

Complete the lower section of the nomogram.
Add the result on scale R on Sheet 7 to the scale R on Sheet 4.
Complete the temperature swing calculation.

RESULT: By including the effects of the air-moving system, the temperature swing is reduced from 12°C to 7°C. A swing of 7°C is at the high end of the acceptable range

Part 3:
Below-Grade Heat Loss

The nature of heat transfer through below-grade basement walls and floor is very different from that of those above grade. Because of the large thermal mass of the ground, the ground temperature will lag behind the ambient above-ground temperature by several months. Subgrade heat loss is greatest in late winter and in early spring.

GRAPHEAT estimates the average monthly below-grade heat loss over a seven-month heating season (i.e., the period over which heating is required). In Part 4, the actual length of the heating season is evaluated. If the actual heating season is greater than or less than seven months, the correction factor provided in Part 4 should be used to modify the average subgrade heat loss. Note that with very well-insulated passive-solar houses, the heating season can be relatively short.

The below-grade heat loss is calculated in two stages, that is, the floor is considered before the below-grade foundation walls. All of the information required to complete Sheet 9 is available from Sheets 1 and 2.

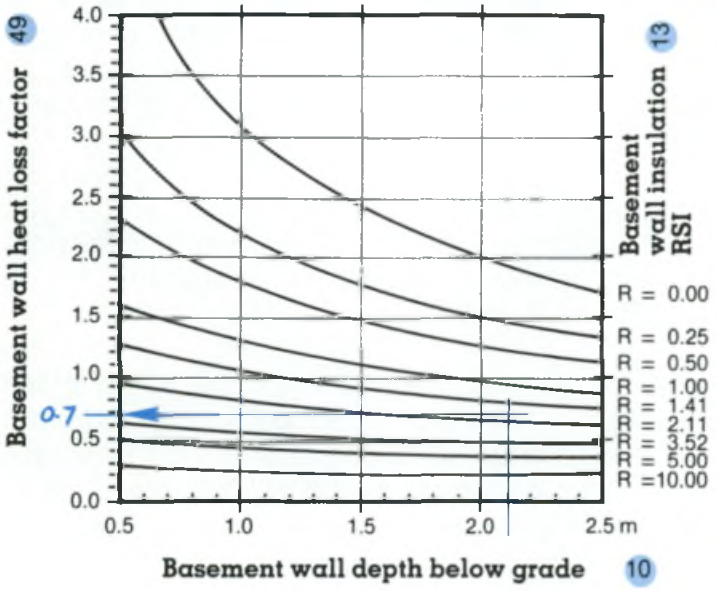
Note that if the calculations indicate that the below-grade heat loss is a major contributor to annual energy consumption, a more accurate analysis procedure is recommended. Relevant references for calculating basement heat loss are provided in the Bibliography.

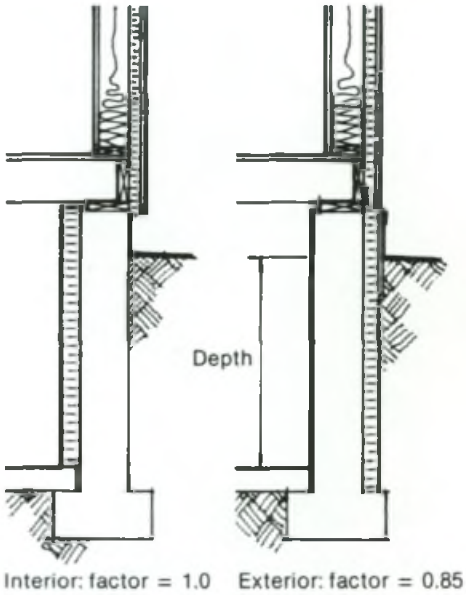
9 BELOW-GRADE HEAT LOSS CALCULATION 9

Floor Basement floor loss per unit of house floor area

$$\frac{\boxed{102}\ (6) \times (20° - \boxed{5.8}\ (1)) \times 2.62}{(\boxed{0}\ (7) + 3.6) \times \boxed{204}\ (4)} = \boxed{5.2}\ \text{MJ/month m}^2\ (48)$$

Wall Basement wall below-grade loss per unit of house floor area





Basement Wall Heat Loss Factor (49)

Insulation Location Factor (50)

$$\frac{\boxed{0.7}\ (49) \times \boxed{0.85}\ (50) \times \boxed{2.1}\ (10) \times \boxed{40}\ (12) \times [5.5 + (20° - \boxed{5.8}\ (1))]}{\boxed{204}\ (4)} = \boxed{4.8}\ \text{MJ/month m}^2\ (51)$$

Result Total below-grade heat loss per unit of house floor area

$$\boxed{5.2}\ (48) + \boxed{4.8}\ (51) = \boxed{10.0}\ \text{MJ/month m}^2\ (52)$$

Procedure

3-a Calculate the Basement Floor Heat Loss per Unit Area of Above-Grade Floor

The calculation will produce an average monthly energy loss value per unit of above-grade floor area. Complete the one-line calculation on Sheet 9 to evaluate this heat loss rate 48.

3-b Determine the Basement Wall Below-Grade Heat Loss per Unit Area of Above-Grade Floor

The calculation involved in this step will produce a monthly energy loss value per unit of above-grade floor area.

On the graph given in Sheet 9, mark the average depth of the basement wall below grade 10. Draw a vertical line upwards to intersect the curve that indicates the amount of insulation in the basement wall 13.

From this intersection point, draw a horizontal line to the left side of the graph and record the basement wall heat loss factor 49.

Using this value and data from Sheet 1, complete the one-line calculation to establish the wall heat loss 51.

3-c Calculate the Total Below-Grade Heat Loss per Unit Area of Above-Grade Floor

Add the values for the monthly heat losses for the floor 48 and the walls 51. The result is the averaged monthly below-grade heat loss in MJ/month m^2 52.

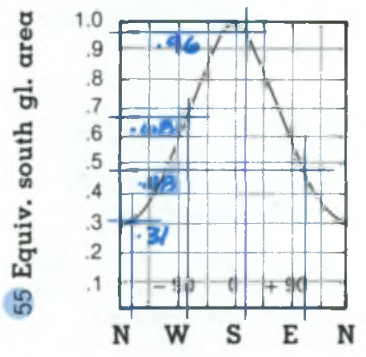
10 ANNUAL SPACE HEAT ENERGY WORKSHEET 10

4-a Trace the appropriate above-grade heat loss curve 31 *onto Sheet 11* 0.82

4-b Add basement heat loss 52 10.0

4-c Add internal gains: see text 53 13.0

4-d Calculate equivalent south glass area 56



Glazing type factor: SG = 1.1 DG = 1.0 TG = 0.91 QG = 0.83 54

	Area 19		type 54		direction 55		
Southerly	16.5	×	1.0	×	0.96	=	15.8
Easterly	—	×	1.0	×	0.48	=	0
Westerly	0.6	×	1.0	×	0.68	=	0.4
Northerly	7.9	×		×	0.31	=	2.4
Total equivalent south glass area							18.6 56

Ratio of equivalent south glass area to total floor area: 18.6 (56) ÷ 204 (4) = 0.09 57

4-e Complete sheet 11 and measure the total heating load and the total solar gains

Total heat losses minus internal gains = 310 MJ/m²yr 58

Total available solar gains = 129 MJ/m²yr 59

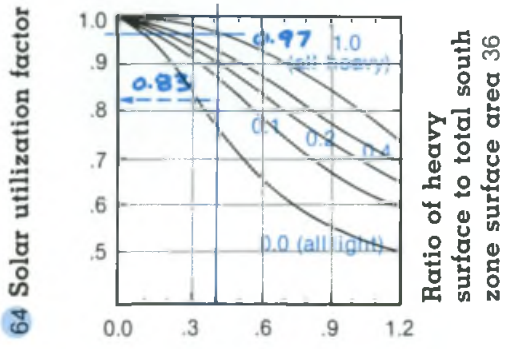
4-f Below-grade heat loss modification if heating season is not seven months

Heating Season	Factor 60
5 month	7.8
6 month	6.65
7 month ✓	5.5 ✓
8 month	4.33
9 month	3.15

[(60: 5.5 ÷ 5.5) − 1] × 7 × (51: 4.8) = 0 MJ/m²yr 61

58: 310 + 61: 0 = 310 MJ/m²yr 62

4-g Solar gains modification to account for solar utilization of less than 1.0



59: 129 ÷ 62: 310 = 0.42 63

NOTE: The ratio 36 is increased in this case from 0.05 to 1.0 (maximum) to account for the thermal storage effects of the air moving system, as shown on Sheet 6.

Seasonal solar utilization factor = 0.97 64

4-h Calculate the total annual space heat energy consumption and cost

Annual space heat energy consumption: [62: 310 − (64: 0.97 × 59: 129)] ÷ 1000 × 4: 204 = 37.7 GJ/yr 65

Annual space heat energy cost: 25: 278 × 26: 0.04 × 65: 37.7 ÷ 24: 1.0 = 419 $/yr 66

Part 4:
Annual Energy Consumption

This graphical method for calculating annual energy consumption is an adaptation of the degree-day method. In this section, the previously calculated above-grade heat loss coefficients and the below-grade heat loss are used to evaluate transmission and infiltration heat loss, after which solar and internal heat gains are evaluated. The annual energy consumption and cost are then determined.

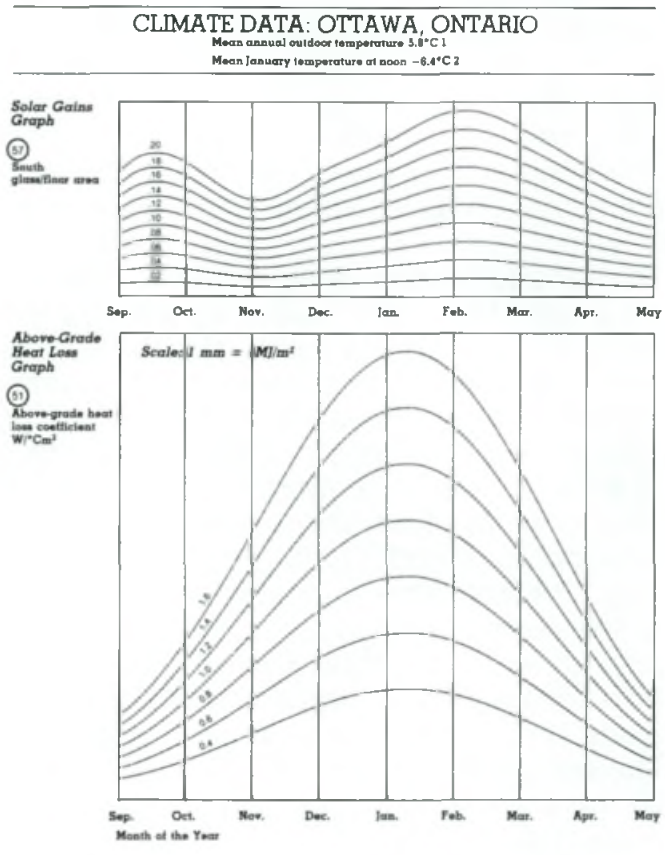
The various heating energy graphs provided in Appendix B are plots of monthly degree-days for 23 representative locations, multiplied by a series of above-grade heat loss coefficients compatible with low-energy housing. The graphs are plotted to a vertical scale of one millimetre to one MJ per square metre per month, that is, each millimetre along each vertical "month" line represents one MJ of heat loss per square metre of above-grade floor area. Each graph covers a nine-month period, starting with September and ending with May. The above-grade heat loss coefficient 31 identifies which curve on the Heating Energy Graph is to be used. The area under the Heating Energy Graph curve is indicative of the nine-month heat requirement before any allowance is made for basement losses, internal gains, and solar gains. The basement heat loss 52 (Sheet 9) and internal heat gains 53 are accounted for by graphical addition and subtraction, respectively.

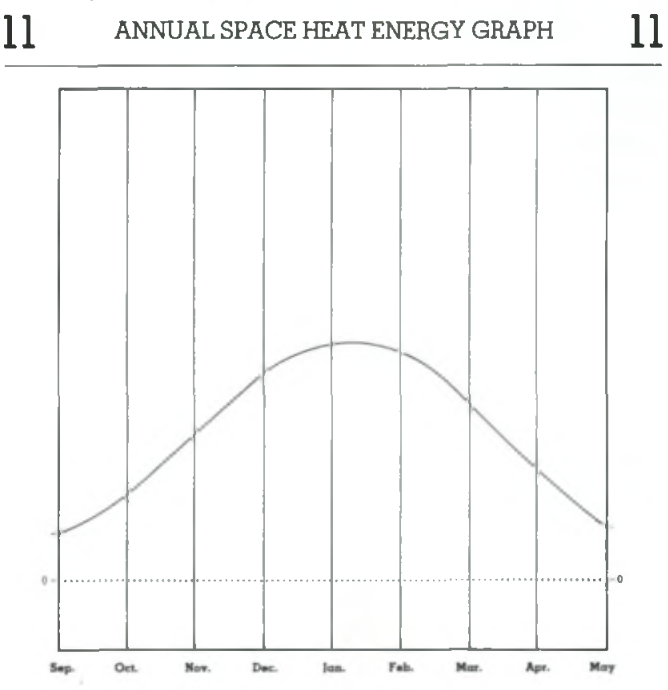
To account for solar gains, a graph has been prepared for each of the 23 locations. The relevant graphs for these representative locations are provided in Appendix B. Each solar gains graph represents the solar gains through south-oriented double-glazing, multiplied by a range of likely ratios of glass area to above-grade floor area.

By using Sheet 10, the total annual space-heating energy consumption, illustrated in Sheet 11, can be evaluated. Sheet 10 also describes how to convert this energy value to a dollar value.

The monthly contributions of the above- and below-grade heat losses, and the internal and solar heat gains, are drawn on Sheet 11. This graphical representation of the monthly contribution of both gains and losses is a valuable aid in understanding the nature of space-heating energy demand over the duration of the heating season.

Procedure





4-a Select the Above-Grade Heat Loss Curve

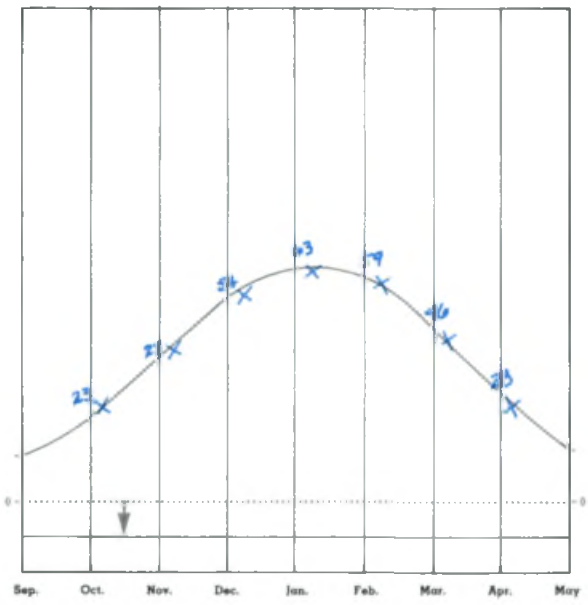
From Appendix B, select the above-grade heat loss graph and the solar gains graph for the appropriate location (in this example, Ottawa). Place Sheet 11 (shown, completed, on pg. 36) over the appropriate heating energy graph, matching up the two sidelines and the dotted baseline of Sheet 11 with the solid baseline of the graph. Each of the procedures needed to complete Sheet 11 is described and illustrated here, step by step.

Refer to Sheet 4 for the above-grade heat loss coefficient 31. On the underlying above-grade heat loss graph on the Climate Data Sheet, identify the curve corresponding to this heat-loss coefficient. On the overlay sheet (Sheet 11), draw small crosses on the intersection of each vertical month line and the appropriate above-grade heat loss curve. If the above-grade heat loss coefficient falls between two curves, then interpolate (estimate) the location of the intersection point by eye.

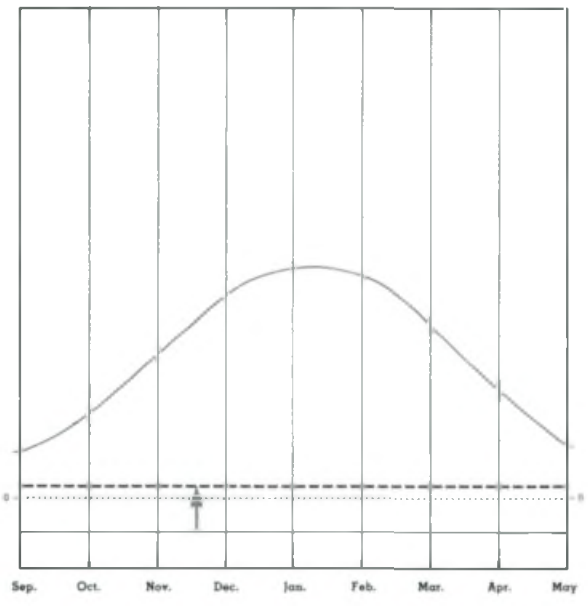
Sketch a curve connecting all the crosses. The accuracy of this curve is not critical because all measurements will be to the monthly cross marks.

Remove the underlay. The first step of Sheet 11 is now completed.

11 ANNUAL SPACE HEAT ENERGY GRAPH 11



11 ANNUAL SPACE HEAT ENERGY GRAPH 11



4-b Add Basement Heat Loss

Using the millimetre scale (1 mm for each MJ/month m^2), mark *down* from the dotted baseline on Sheet 11 the average monthly value of heat loss from below-grade, that is, from the below-grade basement walls and floor slab 52 from Sheet 9.

Draw a horizontal line at this point. This line represents the added contribution to heat loss from the sub-grade portion of the building.

4-c Subtract Internal Heat Gains

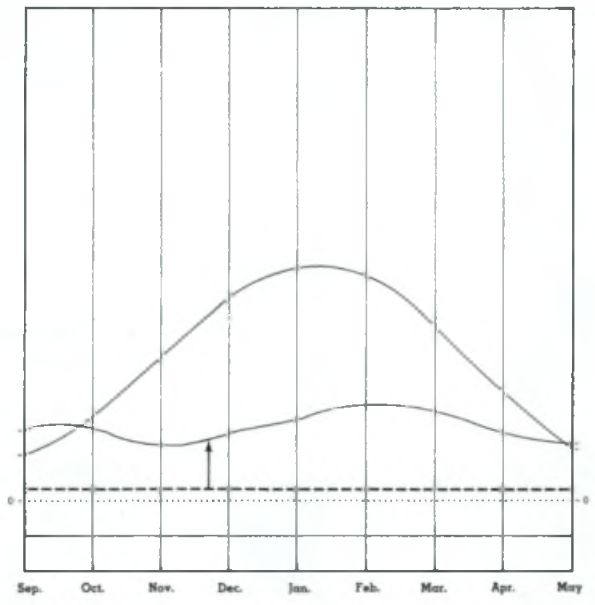
The beneficial effect of the internal heat gains from people, lights, and appliances is accounted for by moving up from the lowest line (the basement heat loss line 52, Sheet 9). The internal gains 53 may be calculated as follows, or a value from the table that follows may be used. Note that the floor area to be used is the *total above-grade floor area* 4.

$$\frac{130}{\sqrt{\text{FLOOR AREA}}} + \frac{200 \times \text{no. of persons}}{\text{FLOOR AREA}} = \frac{\text{MJ}}{m^2\ \text{month}} \quad 53$$

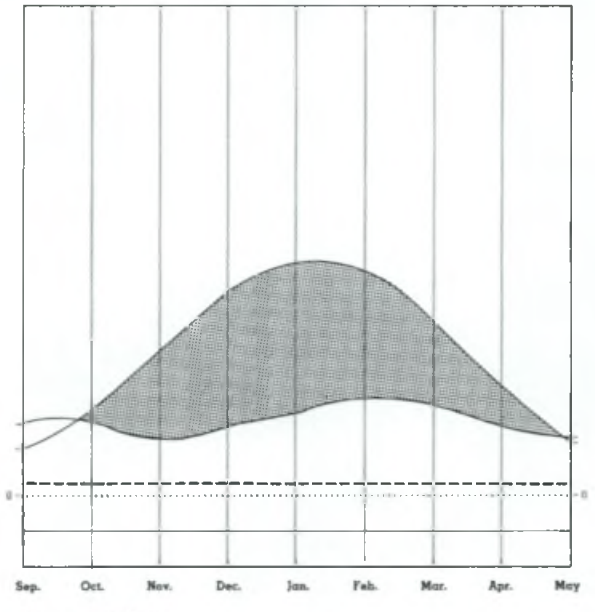
Floor area m^2	No. of persons	53 Internal gains MJ/m^2 month
100	2	17
100	4	21
150	2	13
150	4	16
200	2	11
200	4	13
200	6	15
250	4	10
250	6	13
250	8	15
300	6	12
300	8	13

Locate the internal gains mark on one of the month lines (Sheet 11), and draw a *dashed* line horizontally through this mark. The area between the basement line 52 and the internal gains line 53 represents the beneficial contribution of internal gains.

11 ANNUAL SPACE HEAT ENERGY GRAPH 11



11 ANNUAL SPACE HEAT ENERGY GRAPH 11



Scale: 1 mm = 1 MJ/m² month

Summary			
Total heat losses minus internal gains	(62)		MJ/m²
Useful solar gain	(59) × (64)		MJ/m²
Annual energy consumption	(65)		GJ/yr
Annual energy cost	(66)		$

4-d Subtract Solar Gains

A glazing factor and a graph are provided on Sheet 10 to convert all glazing on the house into the equivalent area of south-facing double glazing.

Using Sheet 10, calculate the equivalent south glass area **56**. The graph at the top of Sheet 10 gives the ratio of the amount of solar energy transmitted through a window at any orientation to the amount of solar energy that would have been admitted into the building had the window been oriented due south. If, during the winter, a window is shaded by adjacent buildings or trees, exclude it from the calculation.

On Sheet 10 multiply the clear glass area on each face **19** by the orientation factor **55** and the glazing type factor **54** . Divide the total equivalent south glass area **56** by the total above-grade floor area **4** to obtain the equivalent south glass area to floor area ratio **57**.

As before, place Sheet 11 (with the partially completed graph) over the Solar Grains Graph at the top of the Climate Data Sheet for your location. Line up the dashed baseline (obtained in Step 4-c when internal gains were subtracted) with the baseline of the Solar Gains Graph. Select the curve corresponding to the calculated ratio of equivalent south glass area to floor area **57** (Sheet 10). Using a procedure similar to that used in Step 4-a, mark in crosses at every month line, and then draw the solar gains curve through these crosses. This line represents the beneficial contribution of solar gains. Remove the Solar Gains Graph.

4-e Determine the Total Heating Load and the Total Solar Gains

The Annual Space Heat Energy graph is now complete. The length of the heating season and the nature of the space-heating energy demand is clearly evident.

Measure (in millimetres), the distance between the dashed line and the above-grade heat loss points on the curve for each month where the total losses exceed the total gains. The sum of those distances is the total heating load before solar gains are subtracted (MJ/m^2 of floor area). Transcribe this value onto Sheet 10 **58**. Next, measure the distance between the dashed line and the points on the solar gains curve for each month where the total losses exceed the total gains. The sum is the total solar gains (MJ/m^2 of floor area). Transcribe this value onto Sheet 10 **59**.

4-f Below-Grade Heat Loss Modification

Should Sheet 11 indicate that the heating season is not seven months long, the below-grade heat loss **51** on Sheet 9 must be modified. Note that if the losses exceed the gains at any month line, that entire month is part of the heating season. Values for the modifying factor **60** are provided in the table on the left-hand side of Sheet 10. Complete the one-line calculation **61** and add the result (positive or negative) to the total heating load excluding solar gains **58** to obtain the seasonal total heating load excluding solar gains **62**.

4-g Solar Gains Modification

Not all the transmitted solar energy will be useful in reducing the annual space heating load. The graph on Sheet 10 relates the solar gain to heating load ratio **63** and the ratio of heavy surfaces in the south zone to total south zone surface areas **36** on Sheet 5 to produce a seasonal solar utilization factor **64**. If the design includes the detailed design of mass thickness or special air flow considerations, the ratio **36** may be increased, as shown on Scale R on Sheet 6.

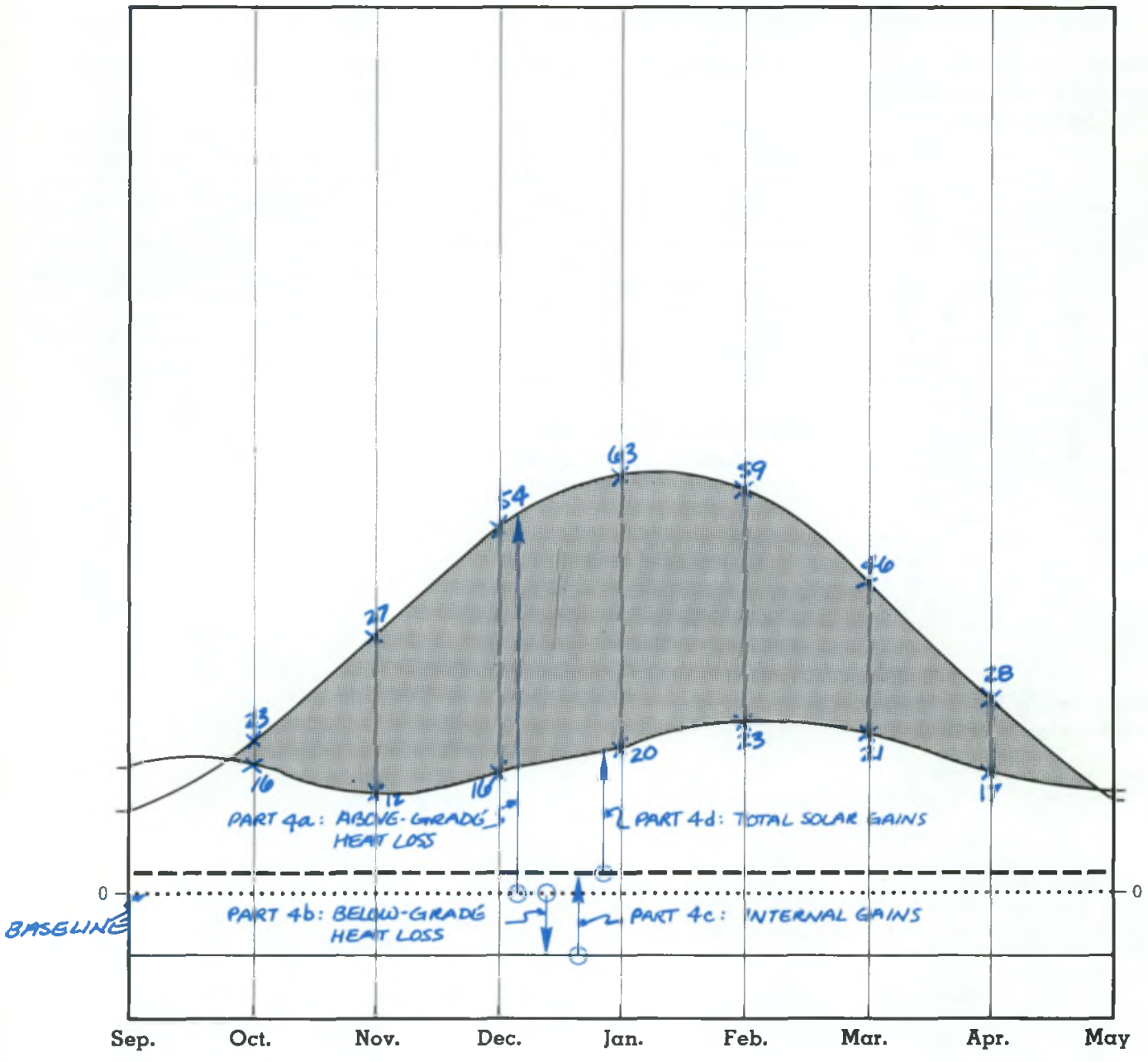
4-h Calculation of the Annual Space Heat Energy Consumption and Cost

For the final step in the sequence, Sheet 10 has one line for the calculation of the annual space heat energy consumption **65**, and another for the annual space heat energy cost **66**.

Note Concerning Internal Temperatures:

GRAPHEAT assumes that the *average* indoor temperature during the heating season is 20°C. This temperature is typical of the thermostat setpoint in most energy-efficient houses. On average, raising the setpoint temperature one Celsius degree will increase energy consumption by 6%. For every Celsius degree that the temperature is set back at night, energy consumption will typically decrease by about 2% to a maximum of 10%.

11 ANNUAL SPACE HEAT ENERGY GRAPH 11



Scale: 1 mm = 1 MJ/m² month

Summary			
Total heat losses minus internal gains	62	310	MJ/m²
Useful solar gain	59 × 64	125	MJ/m²
Annual energy consumption	65	37.7	GJ/yr
Annual energy cost	66	419	$

Commentary

GRAPHEAT, a graphical method for assessing the thermal performance of low-energy/passive housing, offers some decided advantages. It is quick and relatively simple to use. It permits a visual and a quantitative understanding of the issues involved. It can become a constructive design tool in that a "feel" for the influence of different variables or effects can readily be developed.

Dealing with the Results

The final graph (Sheet 11) and the summary of the above-grade heat loss component parts on Sheet 3 are the main guides for the designer. The annual space heat energy graph (Sheet 11) clearly shows the relative significance of the above-grade and below-grade heat loss, and the internal and solar gains over the heating season. If energy consumption is considered to be too high, the losses can either be reduced or the solar gain can be increased.

The heat loss may be reduced by changing the below-grade components or the above-grade heat loss coefficient. If the above-grade components are altered, especially the south glass area, the tempertaure swing should be recalculated. A change in the effective south glass area 56 will also change the solar gains. The flow chart (see Figure 1) indicates which parts of the method need to be repeated for various design modifications. Because testing various alternatives can be done relatively quickly, it is recommended that several design alternatives be checked. These results should be compared to ensure that the design does yield the target annual energy consumption, and that the temperature swing is not excessive.

Accuracy of Results

As with any predictive technique, the results obtained using GRAPHEAT are estimates. The precision with which the energy-related performance of any building can be estimated, even with the most sophisticated computer program, is a fairly contentious issue. With a graphical procedure, in addition to the numerous assumptions and approximations, both visual judgement and drafting skill influence the accuracy of any numerical result. In general, relative differences will be more accurate than absolute values; that is, the difference in performance between designs is likely to be more accurate than the specific value for either design. The primary value of GRAPHEAT is, therefore, as a design aid — to assess design changes.

In reality, the actual maximum temperature swing and the annual energy consumption may differ from the predicted values as a result of the manner of building operation, weather conditions, quality of construction, and other variables that have been excluded to make the procedure easier to use. Solar gains may differ from those predicted if there is considerable shading of the windows or if there is considerable non-south glazing. The graphical method provides a useful and — when properly used — powerful tool. Common sense and some caution are required to use GRAPHEAT properly. Designers interested in accounting for secondary effects, or in need of a more-detailed analysis of residential energy consumption, should resort to a suitable computer program. The Bibliography contains a list of useful publications on energy-efficient house design.

Appendix A: Worksheets and Nomograms

Warning:
Be very careful when photocopying the Nomograms (specifically Sheets 4, 5, 6, 7, 9 and 11) to ensure that the scale is *not* affected in any way.

1 BUILDING DATA SHEET 1

Project Name: _____

City: _____

Temperatures

		Ref. No.
• mean annual outdoor — Choose the city and refer to its Climate Data Graph (App. B)	____ C°	(1)
• mean January outdoor at noon	____ C°	(2)

Floors

• Number of above-grade floors	____	(3)
• **Above-grade floor area**: include the floor area of stairwells and other two-storey high spaces as a part of each floor area. For buildings with an irregular form, use the above-grade internal volume (exclude basement volume) divided by 2.5 m.	____ m^2	(4)
• **South zone floor area**: include all rooms with significant solar gain and north rooms where over 50% of the connecting wall is open to the south room.	____ m^2	(5)
• **Basement floor area**, internal dimensions: include any vertical wall area at change in floor level.	____ m^2	(6)
• **Basement floor insulation value**: for the insulation only, do not include the ground or the slab.	____ RSI	(7)

Walls

• **Above-grade wall area**: include windows and doors and any floor area over an unheated space; do not include any portion of the above-grade basement.	____ m^2	(8)
• **Above-grade wall insulation**: if there are several wall types with different RSI values, use the average value based on relative areas (ignore the doors and windows).	____ RSI	(9)
• Average basement wall height below grade.	____ m	(10)
• Average basement wall height above grade.	____ m	(11)
• Perimeter of exterior basement wall: do not include party walls in townhouses or semi-detached houses.	____ m	(12)
• Basement wall insulation (of the thermal insulation only; not the wall or ground).	____ RSI	(13)

Interior Surfaces

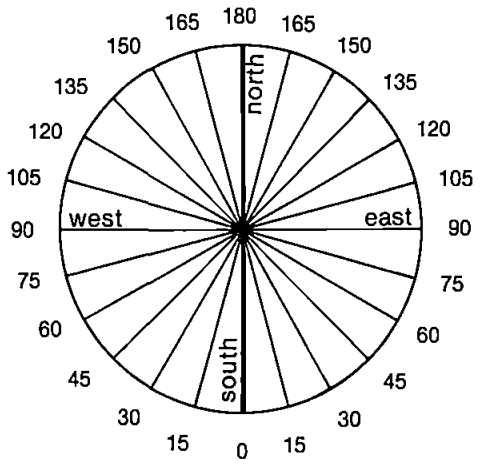
• Surface area of all surfaces within the south zone (i.e., ceiling, walls, floors — typically four times the floor area).	____ m^2	(14)
• Surface area of all south zone heavy surfaces plus the area of all door openings into the north zone.	____ m^2	(15)

Roof

• Roof insulation.	____ RSI	(16)

Windows

- Orientation: sketch the building on compass shown, and determine deviation from south for each set of windows.



Ref. No.

- Ratio of clear glass area to rough window opening _____ (17)
- Clear glass for each orientation: South Zone (18) Total Building (19)

NOTE: the south zone consists of all those rooms that are subjected to significant amounts of sunlight in January.

southerly	_____ m^2	_____ m^2
easterly	_____ m^2	_____ m^2
westerly	_____ m^2	_____ m^2
northerly	_____ m^2	_____ m^2

Total clear glass area: _____ m^2 (20)

- Glass type: SG, DG, TG, QG, or RSI value (Single, double, triple, quadruple glazed) _____ RSI (21)
- Thermal shutter RSI value (0 if none) _____ RSI (22)

Infiltration

- Desired average ventilation rate (Natural and Mechanical) _____ ACPH a
- Natural ventilation rate (infiltration) _____ ACPH b
- Heat exchanger efficiency (0 If no heat exchanger) _____ c

Effective cold air infiltration rate: $= (\square - \square) \times (1 + \square) + \square =$ (a, b, c, b) _____ ACPH (23)

Annual Energy Consumption

- Furnace seasonal efficiency _____ (24)
  Gas furnace: normal 0.65, spark ign.: 0.70; condensing: 0.95
  Oil furnace: normal 0.65
  Electric baseboard or furnace: 1.00
- Fuel energy content _____ (25)
  Electricity — 278 kwh/GJ
  Natural Gas — 27 m^3/GJ
  Fuel Oil — 26 litre/GJ
- Fuel cost: $ per appropriate unit (kwh, m^3, or litres) of fuel from local utility _____ (26)

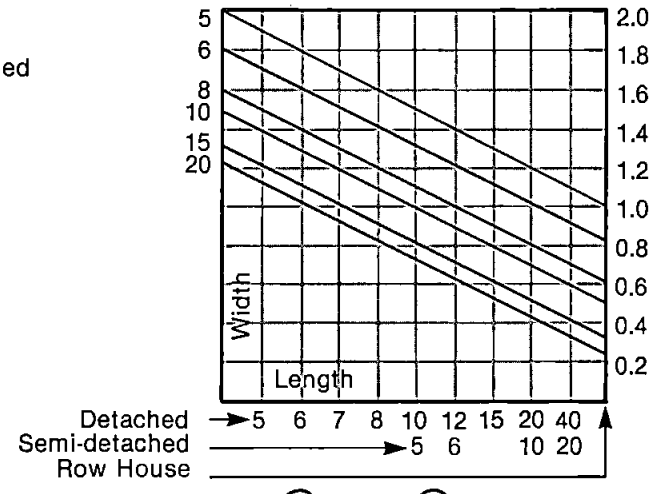
3 ABOVE-GRADE HEAT LOSS WORKSHEET 3

Nomogram Input Data

- Ratio of the above-grade exterior wall area to the total floor area.
- If the building is a simple rectangle with no unheated spaces (e.g., garage) projecting into the house volume, the ratio (27) may be obtained using the graph at the right.

Ref. No.

(8) ÷ (4) = (27)



(27)

- Ratio of the exposed basement wall RSI to the main wall RSI. This value includes 1-, 2-, 3-storey buildings and wall heights other than 0.5 m.

$$\frac{(13) \times (3)}{4 \times (9) \times (11)} = \quad (28)$$

- Roof thermal resistance adjusted for 1-, 2-, or 3-storey buildings.

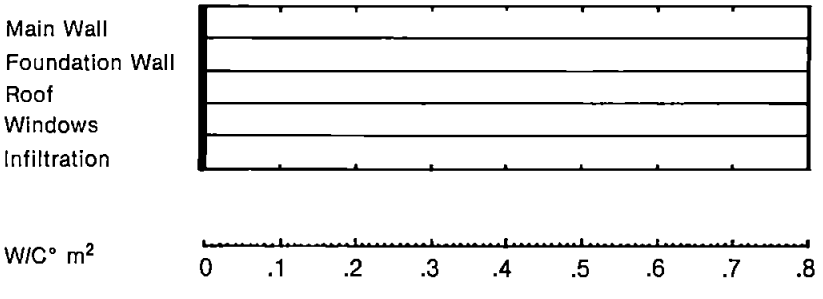
$$0.5 \times (16) \times (3) = \text{RSI} \quad (29)$$

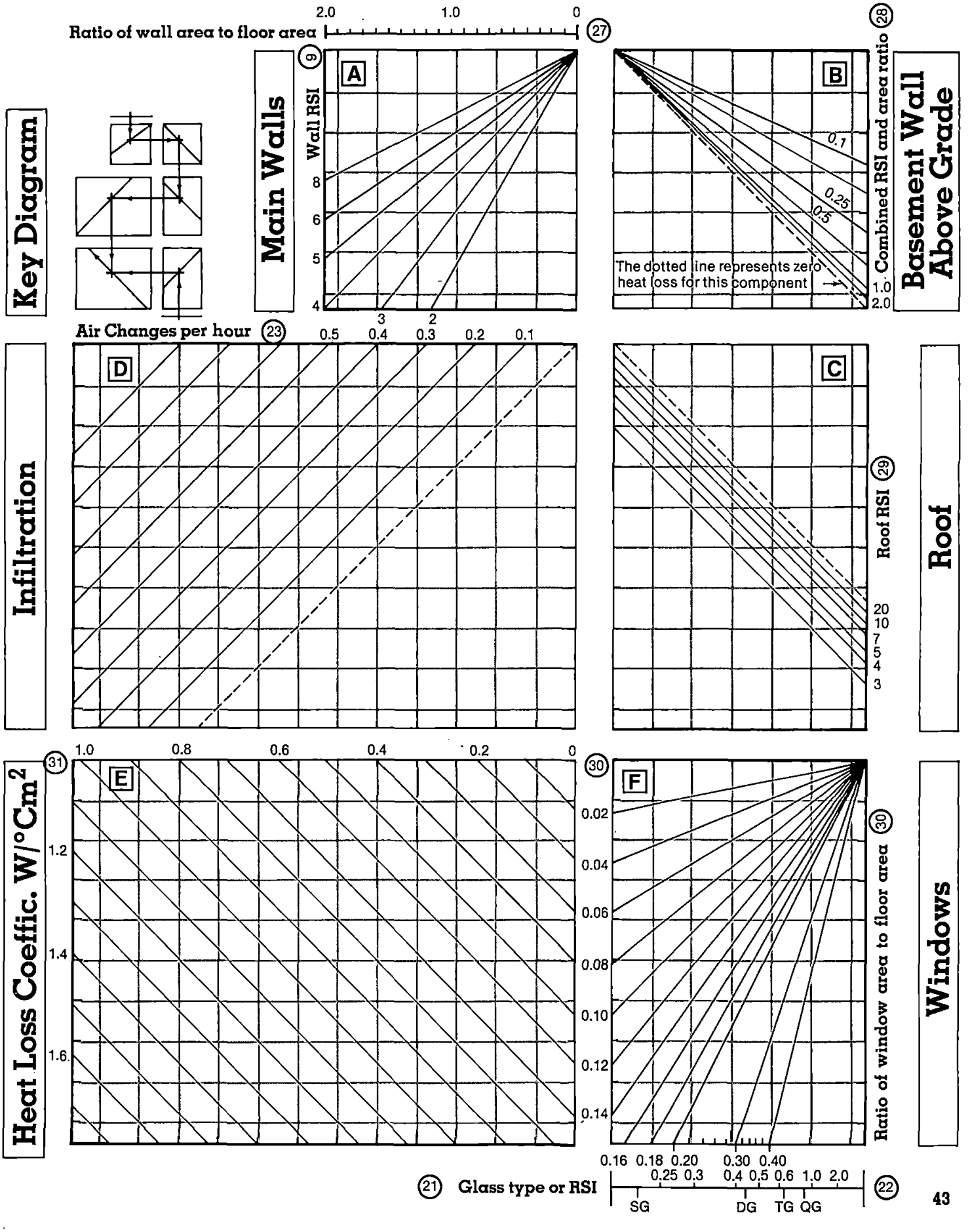
- Ratio of gross window area to total floor area.

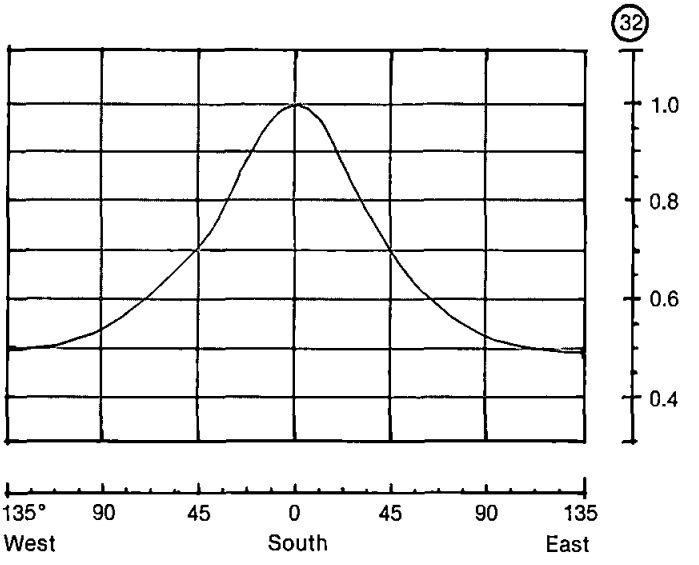
$$(20) \div (17) \div (4) = \quad (30)$$

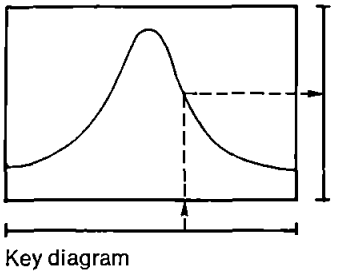
Result: Above-Grade Heat Loss Coefficient:	W/C° m²	(31)

Graphical Summary of Above-Grade Heat Loss Component Parts




Key Diagram
Main Walls
Ratio of wall area to floor area
2.0
1.0
0
27
9
A
Wall RSI
8
6
5
4
3
2
B
28
Combined RSI and area ratio
0.1
0.25
0.5
The dotted line represents zero heat loss for this component
1.0
2.0
Basement Wall Above Grade
Air Changes per hour
23
0.5
0.4
0.3
0.2
0.1
D
C
Roof RSI
29
20
10
7
5
4
3
Infiltration
Roof
Heat Loss Coeffic. W/°Cm²
31
1.0
0.8
0.6
0.4
0.2
0
E
1.2
1.4
1.6
30
F
0.02
0.04
0.06
0.08
0.10
0.12
0.14
Ratio of window area to floor area
30
0.16 0.18 0.20 0.25 0.3 0.30 0.4 0.40 0.5 0.6 1.0 2.0
21
Glass type or RSI
22
SG
DG
TG QG
Windows




Key diagram

Orientation Factor for Non-South Glass

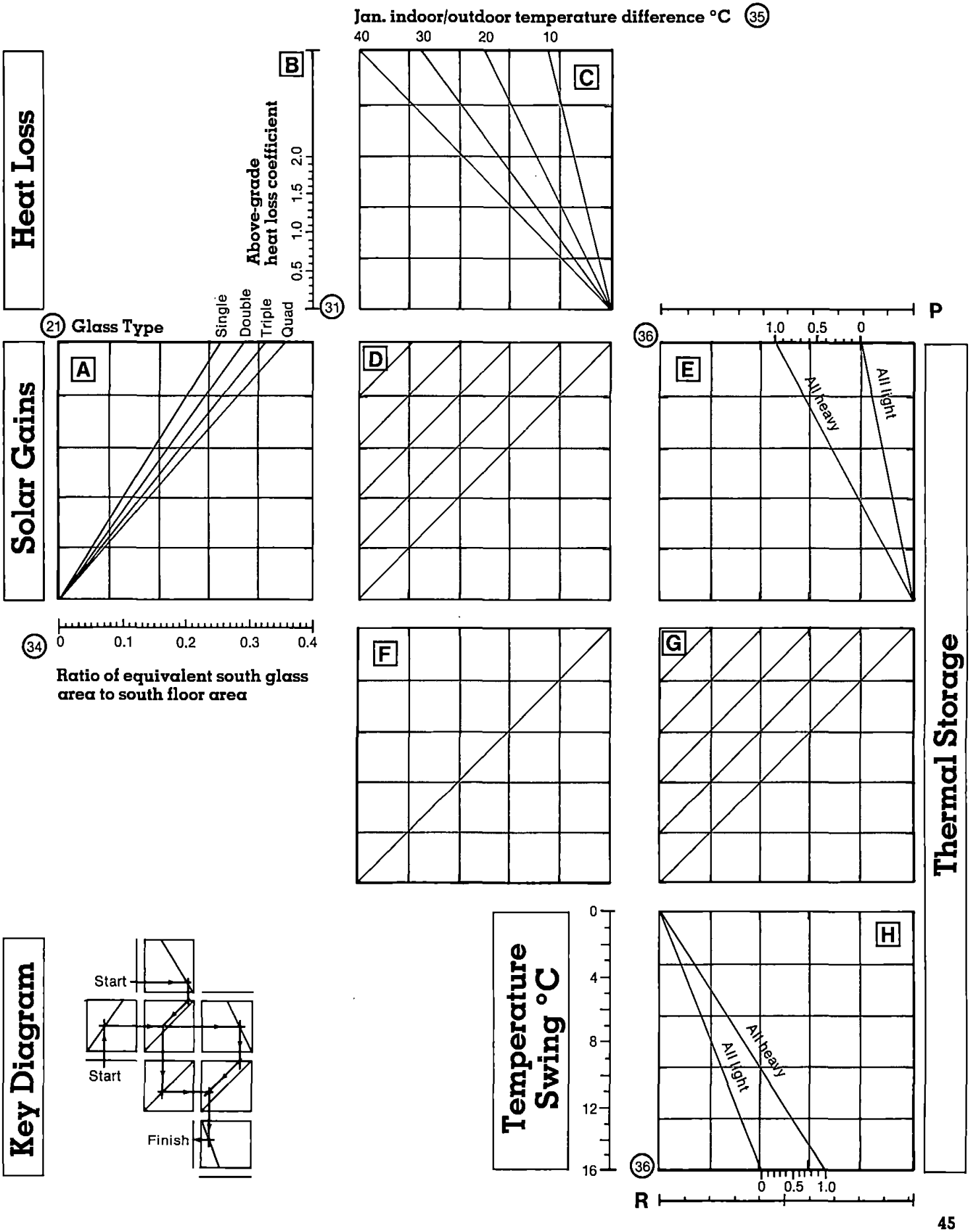
- Equivalent south glass area:

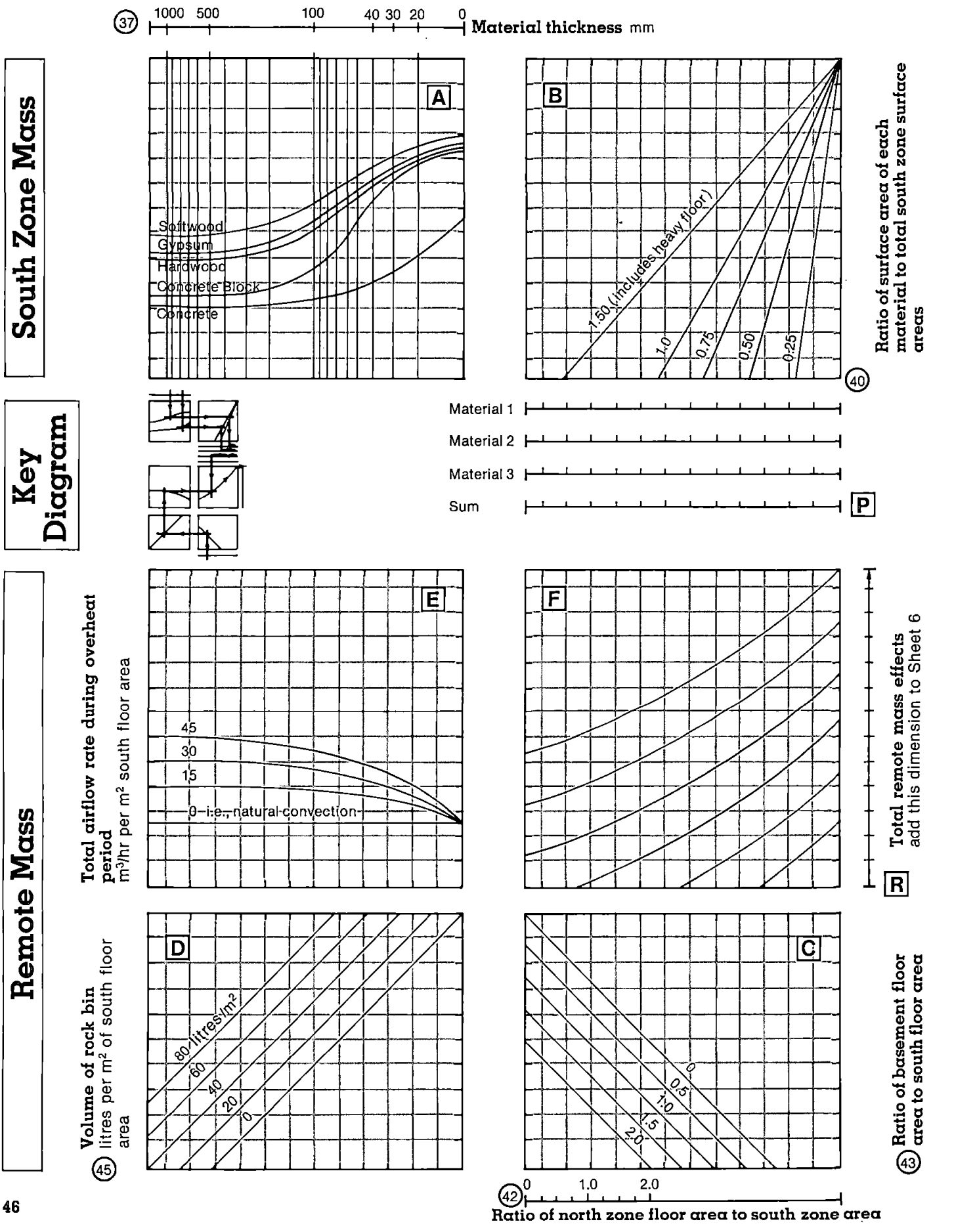
	(32) orientation factor		(18) glazing area		
Southerly		×		m² =	m²
Easterly		×		m² =	m²
Westerly		×		m² =	m²
Total equivalent south glass area				=	m² (33)

- Ratio of equivalent south glass area to south zone floor area: (33) ÷ (5) = (34)
- January noon temperature difference: 23°C − (2) = °C (35)
- Ratio of heavy mass area to total surface area in the south zone: (15) ÷ (14) = (36)

Result Temperature Swing = °C

Note: If the design includes remote thermal mass or special air recirculation systems, complete Sheets 7 and 8.


Heat Loss
Solar Gains
Thermal Storage
Key Diagram
Temperature Swing °C
Jan. indoor/outdoor temperature difference °C (35)
40 30 20 10
B
C
Above-grade heat loss coefficient
0.5 1.0 1.5 2.0
(31)
(21) Glass Type
Single
Double
Triple
Quad
A
D
E
F
G
H
P
1.0 0.5 0
(36)
All heavy
All light
(34)
0 0.1 0.2 0.3 0.4
Ratio of equivalent south glass area to south floor area
Start
Start
Finish
0 4 8 12 16
0 0.5 1.0
R


South Zone Mass
37
1000 500 100 40 30 20 0
Material thickness mm
A
Softwood
Gypsum
Hardwood
Concrete Block
Concrete
B
1.50 (includes heavy floor)
1.0
0.75
0.50
0.25
40
Ratio of surface area of each material to total south zone surface areas
Key Diagram
Material 1
Material 2
Material 3
Sum
P
Remote Mass
E
45
30
15
0 – i.e., natural convection
Total airflow rate during overheat period
m³/hr per m² south floor area
F
R
Total remote mass effects
add this dimension to Sheet 6
D
80 litres/m²
60
40
20
0
Volume of rock bin
litres per m² of south floor area
45
C
0
0.5
1.0
1.5
2.0
Ratio of basement floor area to south floor area
43
42
0 1.0 2.0
Ratio of north zone floor area to south zone area

8 THERMAL STORAGE WORKSHEET 8

To complete the thermal storage calculation, additional information is required

Step 1: South Zone Mass

For each material in the south zone, list the following information:

	(37) thickness mm	(38) material surface area m^2		(39) storage factor		(14) south zone surface area m^2		(40) surface area ratio
Material 1			×		÷		=	
Material 2			×		÷		=	
Material 3			×		÷		=	

If the south zone floor is "heavy" and not carpeted, the storage factor is 3.0, otherwise the factor is 1.0. (39)

Complete upper section of the nomogram.

Add results on Scale P on Sheet 7 to the Scale P on Sheet 6.

If there are no remote mass or forced air flow modifications, complete the temperature swing calculation.

Step 2: Remote Mass and Air Flow

List the following information:

North zone floor area (4) [ ] − (5) [ ] = [ ] m^2

Ratio of north zone area to south zone floor area (41) [ ] ÷ (5) [ ] = [ ] (42)

Ratio of basement area to south zone floor area (6) [ ] ÷ (5) [ ] = [ ] (43)

Volume of rock including voids in rock bin = [ ] m^3 (44)

Ratio of rock volume to south zone floor area 1000x (44) [ ] ÷ (5) [ ] = [ ] L/m^2 (45)

Air moving system blower capacity [ ] m^3/hr (46)

either [ ] cfm × 1.7 = [ ] m^3/hour *or* [ ] L/sec × 3.6 = [ ] m^3/hour

Blower capacity per unit of south zone floor area (46) [ ] ÷ (5) [ ] = [ ] (47)

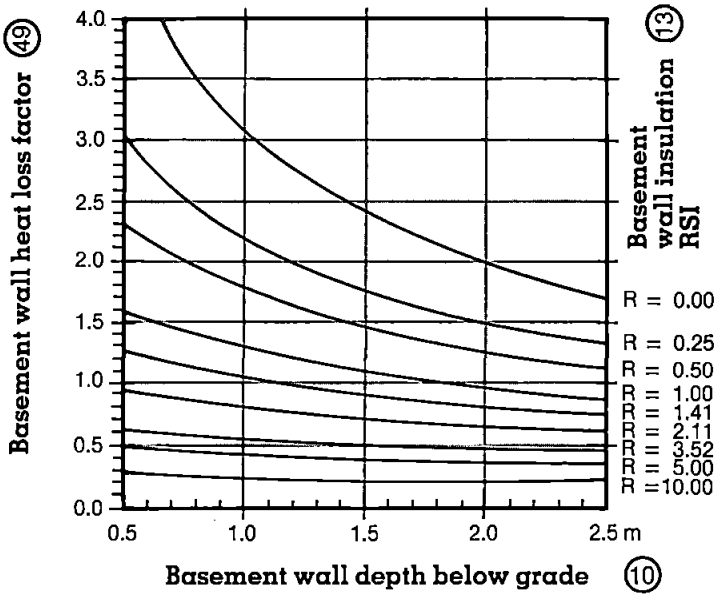
Complete the lower section of the nomogram.
Add the result on scale R on Sheet 7 to the scale R on Sheet 4.
Complete the temperature swing calculation.

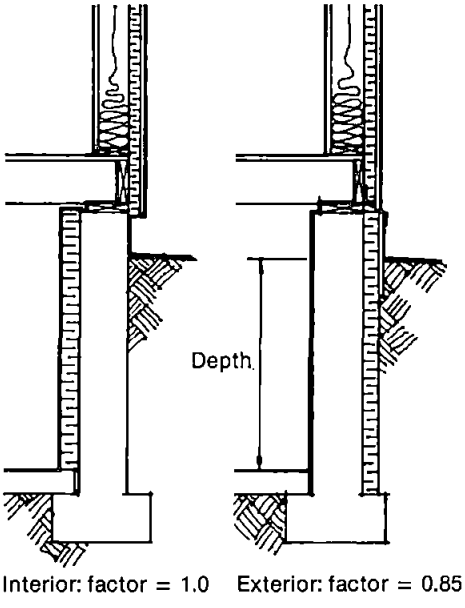
9 BELOW-GRADE HEAT LOSS CALCULATION 9

Floor Basement floor loss per unit of house floor area

$$\frac{\overset{⑥}{\boxed{}} \times (20° - \overset{①}{\boxed{}}) \times 2.62}{(\underset{⑦}{\boxed{}} + 3.6) \times \underset{④}{\boxed{}}} = \boxed{} \text{ MJ/month m}^2 \ ㊽$$

Wall Basement wall below-grade loss per unit of house floor area





Interior: factor = 1.0 Exterior: factor = 0.85

Basement Wall Heat Loss Factor ㊾

Insulation Location Factor ㊿

$$\frac{\overset{㊾}{\boxed{}} \times \overset{㊿}{\boxed{}} \times \overset{⑩}{\boxed{}} \times \overset{⑫}{\boxed{}} \left[\times 5.5 + (20° - \overset{①}{\boxed{}})\right]}{\underset{④}{\boxed{}}} = \boxed{} \text{ MJ/month m}^2 \ (51)$$

Result Total below-grade heat loss per unit of house floor area

$$\underset{㊽}{\boxed{}} + \underset{(51)}{\boxed{}} = \boxed{} \text{ MJ/month m}^2 \ (52)$$

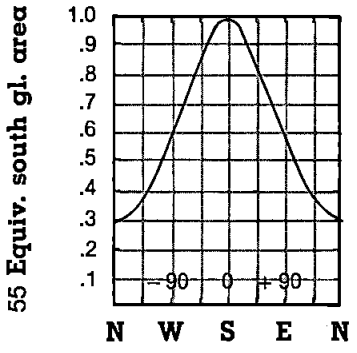
10 ANNUAL SPACE HEAT ENERGY WORKSHEET 10

4-a Trace the appropriate above-grade heat loss curve (31) onto Sheet 11

4-b Add basement heat loss (52)

4-c Add internal gains: see text (53)

4-d Calculate equivalent south glass area (56)



Glazing type factor: SG = 1.1 DG = 1.0 TG = 0.91 QG = 0.83 (54)

	Area (19)		type (54)		direction (55)		
Southerly		×		×		=	
Easterly		×		×		=	
Westerly		×		×		=	
Northerly		×		×		=	

Total equivalent south glass area (56)

Ratio of equivalent south glass area to total floor area: (56) ÷ (4) = (57)

4-e Complete sheet 11 and measure the total heating load and the total solar gains

Total heating losses minus internal gains = MJ/m²yr (58)

Total available solar gains = MJ/m²yr (59)

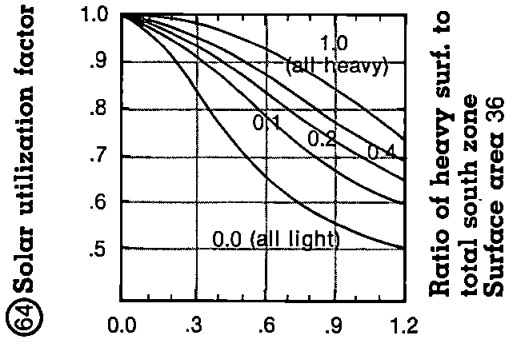
4-f Below-grade heat loss modification if heating season is not seven months

Heating Season	Factor (60)
5 month	7.8
6 month	6.65
7 month	5.5
8 month	4.33
9 month	3.15

$$[((60) \div 5.5) - 1] \times 7 \times (51) = \text{MJ/m}^2\text{yr} \quad (61)$$

$$(58) + (61) = \text{MJ/m}^2\text{yr} \quad (62)$$

4-g Solar gains modification to account for solar utilization of less than 1.0



(59) ÷ (62) = (63)

NOTE: The ratio (36) is increased in this case from 0.05 to 1.0 (maximum) to account for the thermal storage effects of the air moving system, as shown on Sheet 6.

Seasonal solar utilization factor = (64)

4-h Calculate the total annual space heat energy consumption and cost

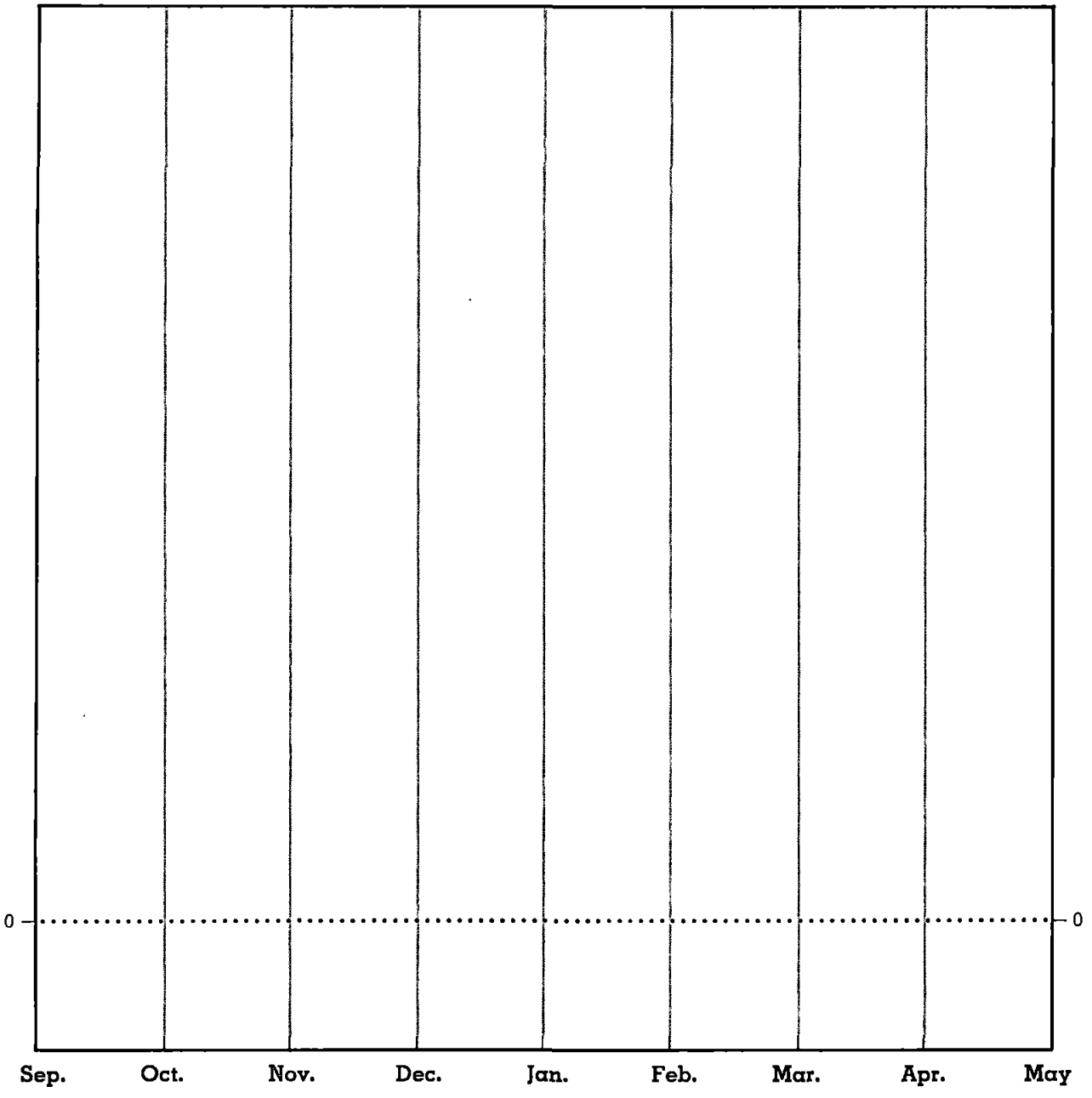
Annual space heat energy consumption:

$$[(62) - ((64) \times (59))] \div 1000 \times (4) = \text{GJ/yr} \quad (65)$$

Annual space heat energy cost:

$$(25) \times (26) \times (65) \div (24) = \$/\text{yr} \quad (66)$$

11 ANNUAL SPACE HEAT ENERGY GRAPH 11

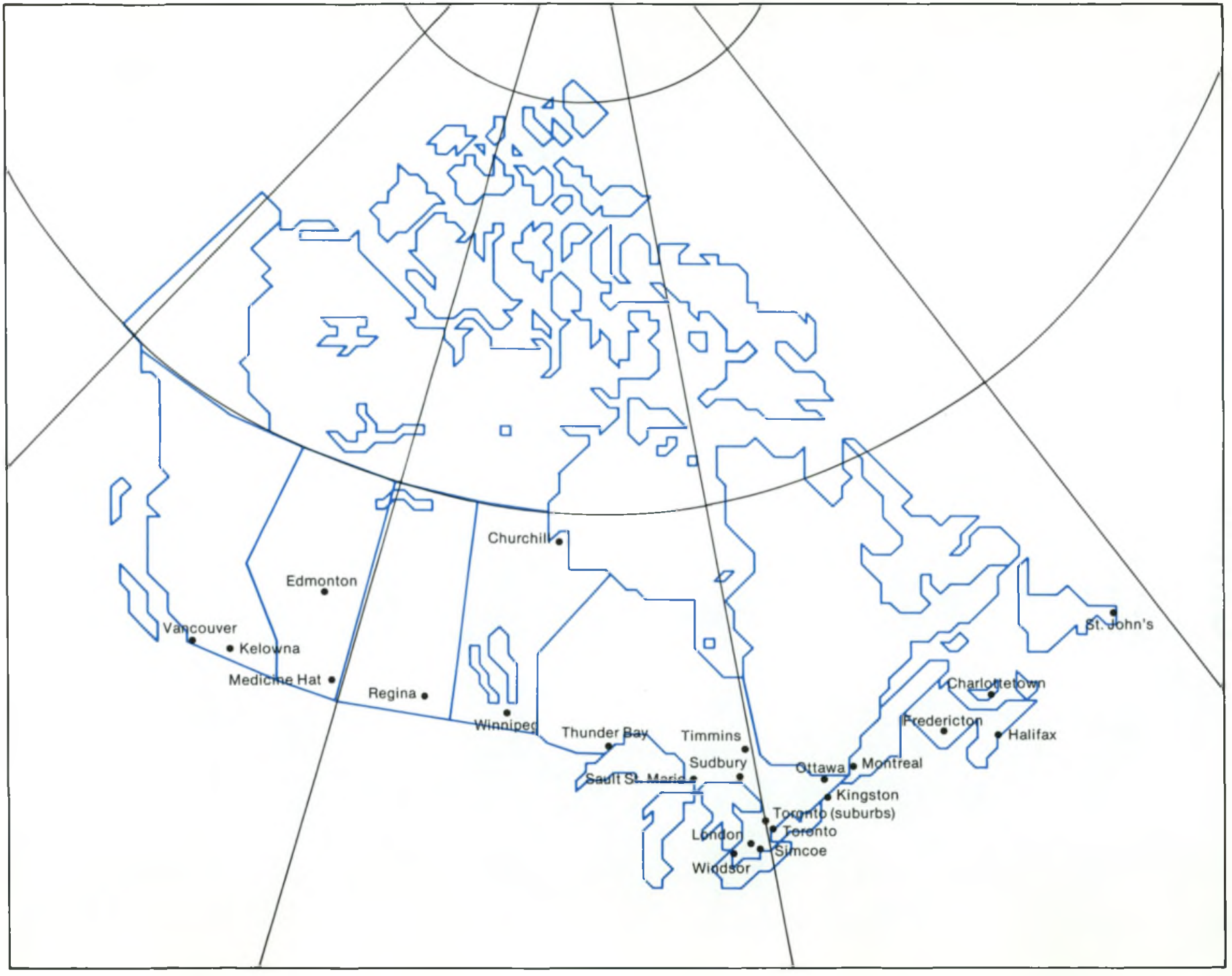


Scale: 1 mm = 1 MJ/m^2 month

Summary			
Total heat losses minus internal gains	(62)		MJ/m^2
Useful solar gain	(59) × (64)		MJ/m^2
Annual energy consumption	(65)		GJ/yr
Annual energy cost	(66)		$

Appendix B: Climate Data Graphs

Warning: When photocopying, ensure that the scale is not altered.


Churchill
Edmonton
Vancouver
Kelowna
Medicine Hat
Regina
Winnipeg
Thunder Bay
Timmins
Sudbury
Sault St. Marie
Ottawa
Montreal
Kingston
Toronto (suburbs)
Toronto
London
Simcoe
Windsor
Fredericton
Charlottetown
Halifax
St. John's

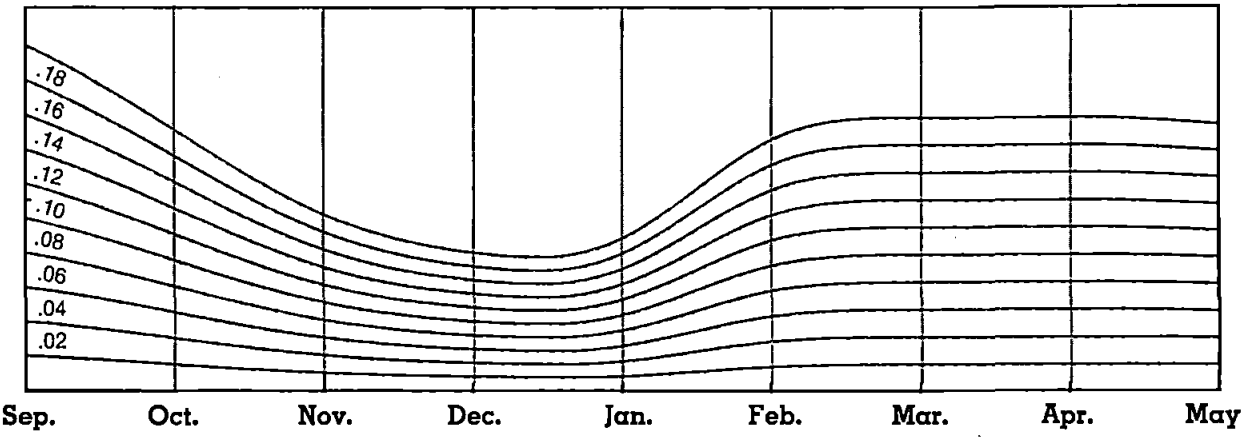
CLIMATE DATA: VANCOUVER, B.C.

Mean annual outdoor temperature 9.8°C (1)

Mean January temperature at noon 5.2°C (2)

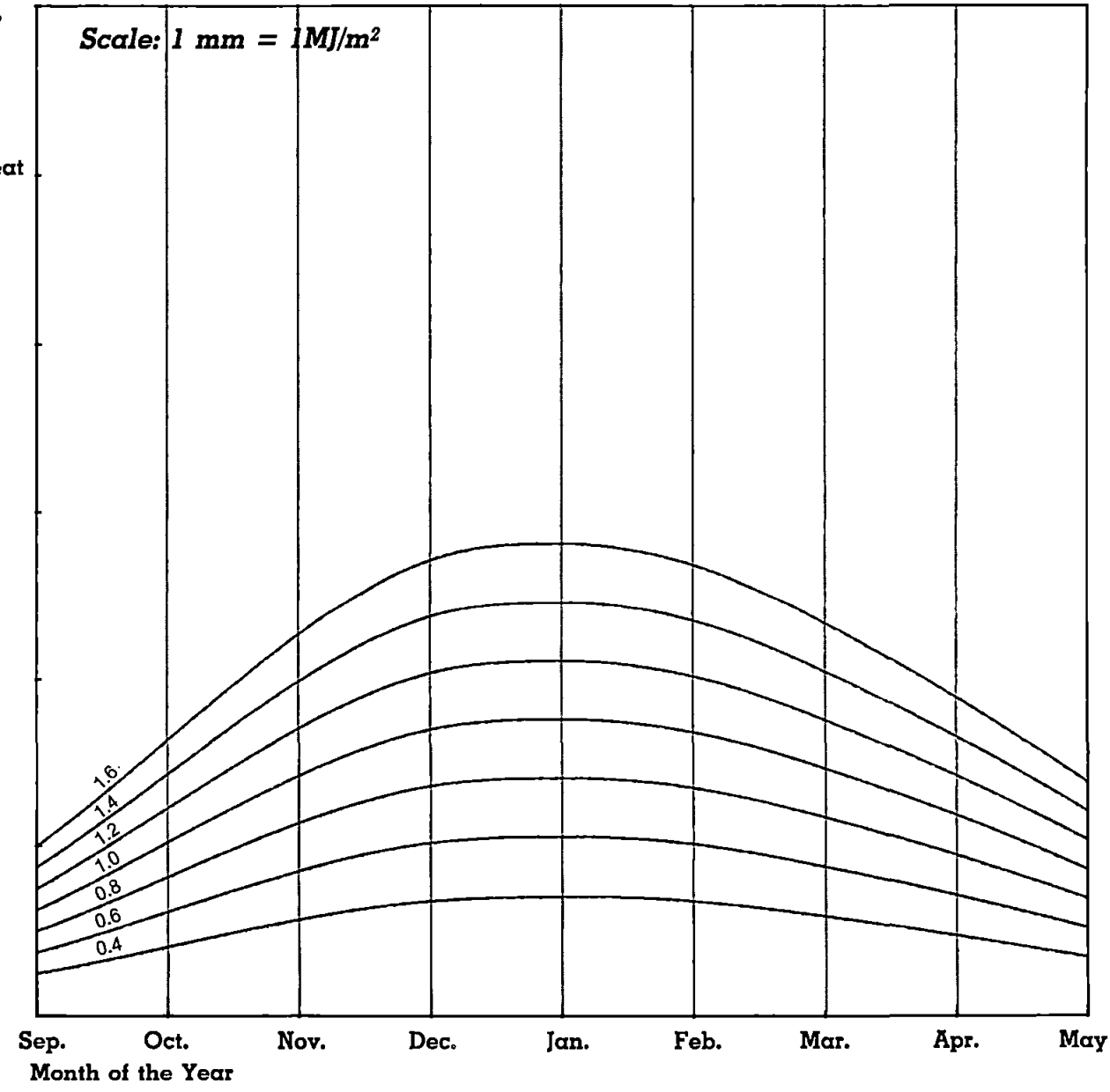
Solar Gains Graph

(57)
South glass/floor area



Above-Grade Heat Loss Graph

(31)
Above-grade heat loss coefficient W/°Cm²



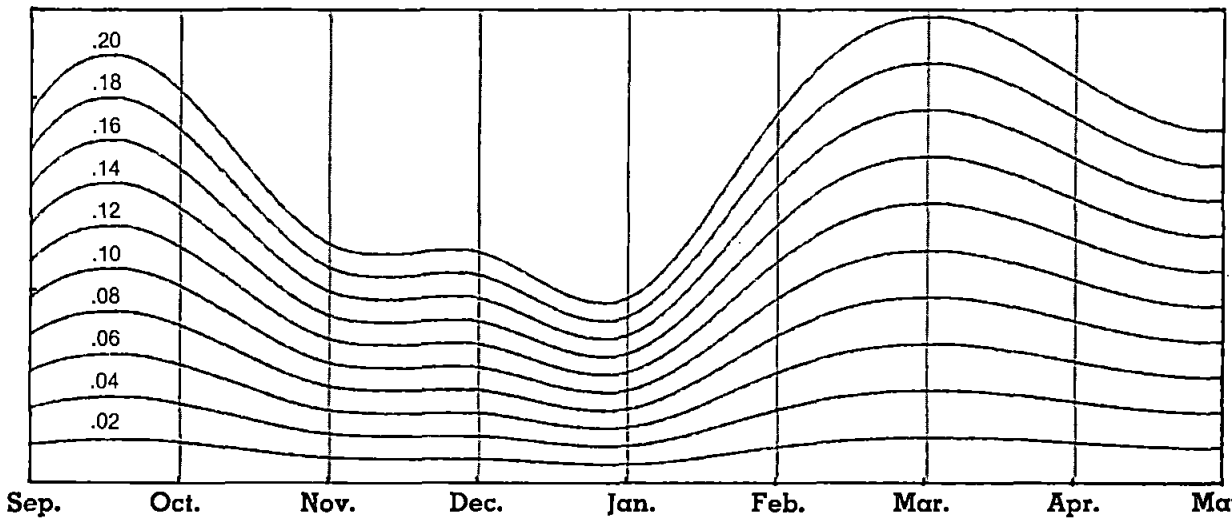
CLIMATE DATA: KELOWNA, B.C.

Mean annual outdoor temperature 7.0°C (1)

Mean January temperature at noon −1.5°C (2)

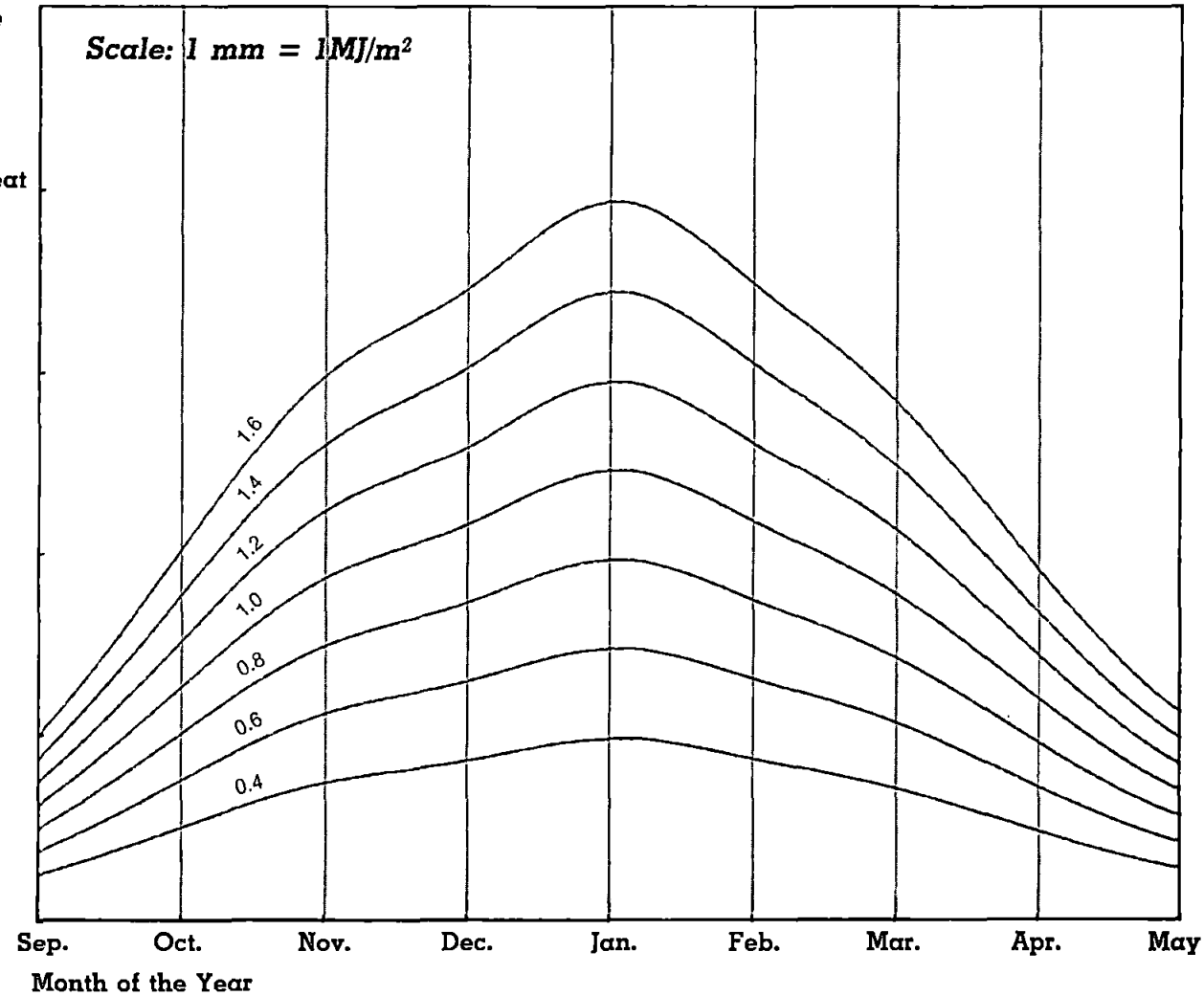
Solar Gains Graph

(57)
South glass/floor area



Above-Grade Heat Loss Graph

(31)
Above-grade heat loss coefficient W/°Cm²



CLIMATE DATA: EDMONTON, ALBERTA

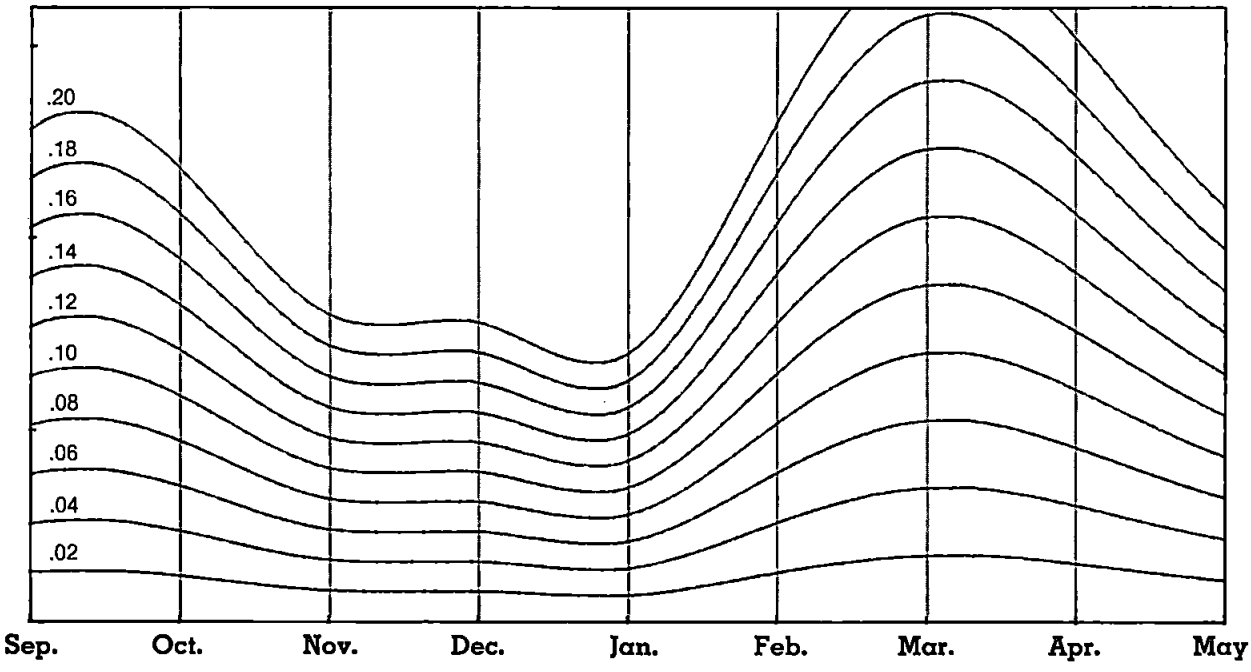
Mean annual outdoor temperature 1.4°C 1

Mean January temperature at noon −10.6°C 2

Solar Gains Graph

57

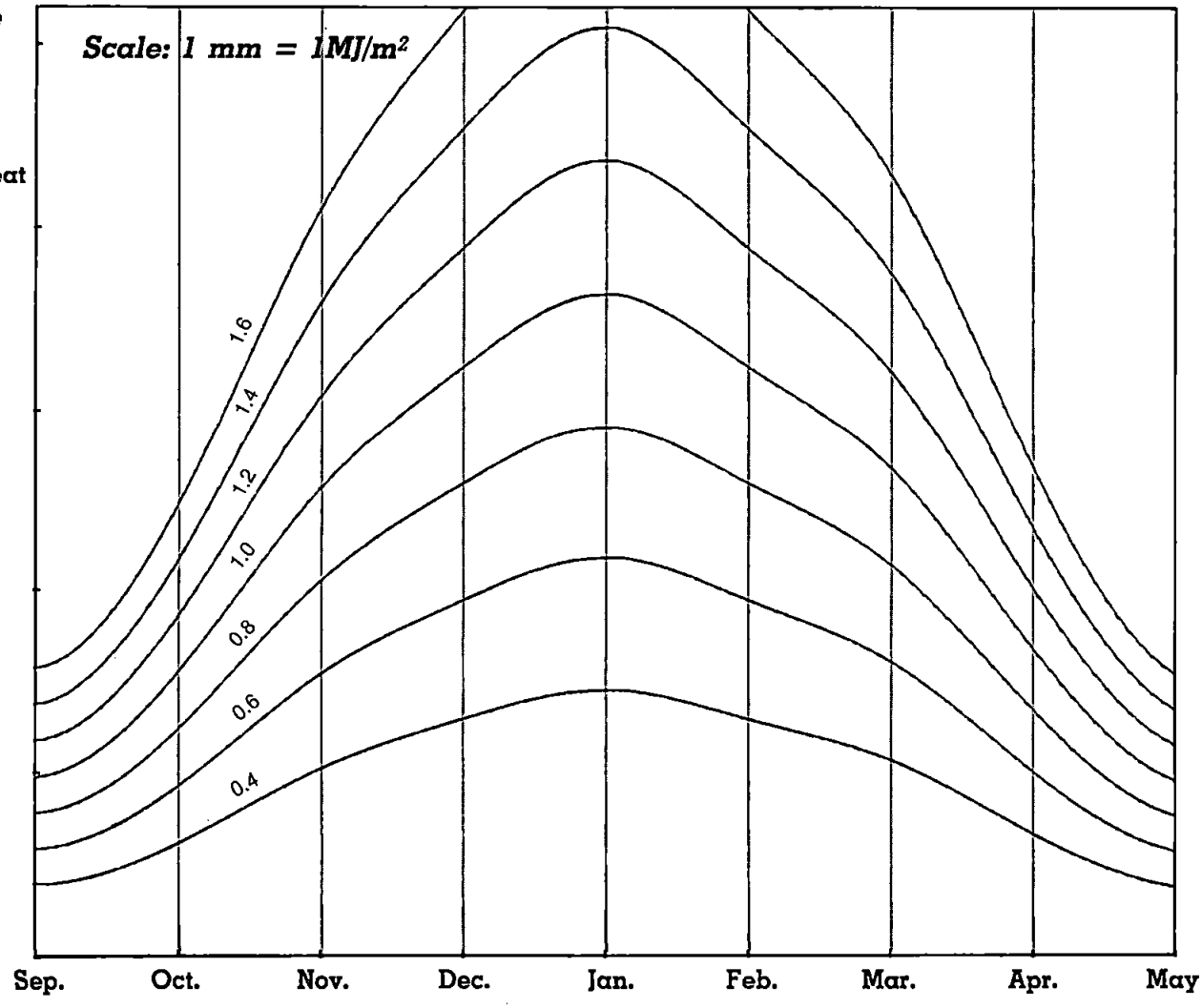
South glass/floor area



31

Above-Grade Heat Loss Graph

Above-grade heat loss coefficient W/°Cm²



Month of the Year

CLIMATE DATA: MEDICINE HAT, ALBERTA

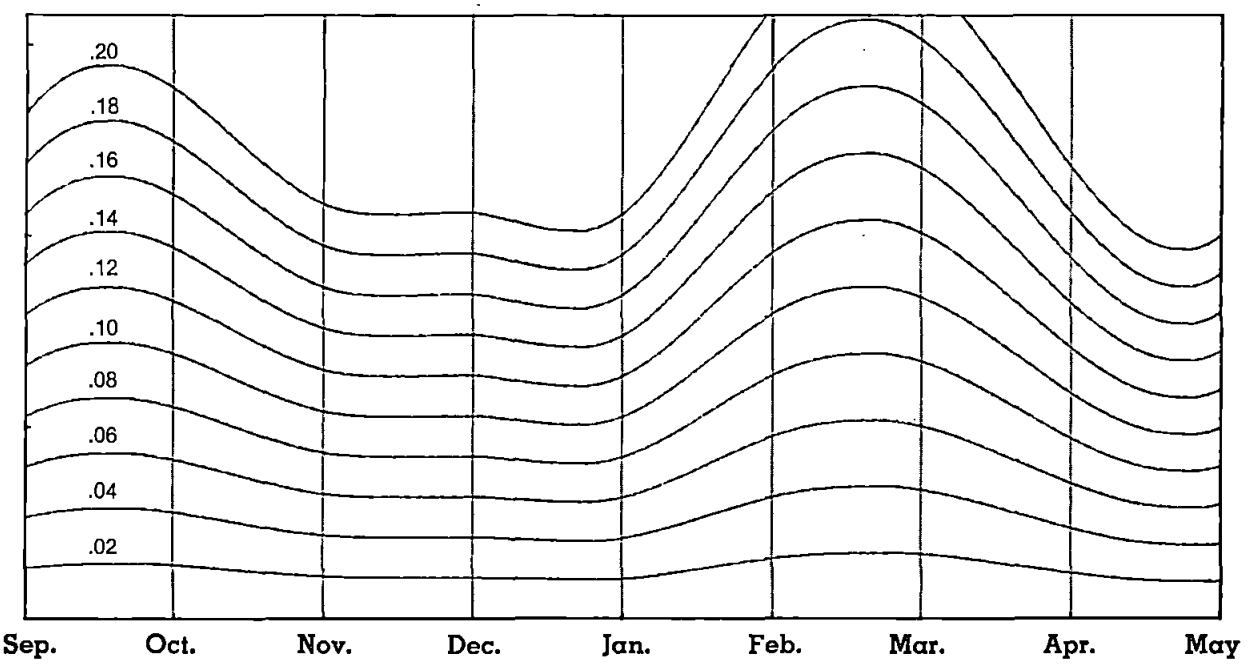
Mean annual outdoor temperature 5.1°C (1)

Mean January temperature at noon −6.4°C (2)

Solar Gains Graph

(57)

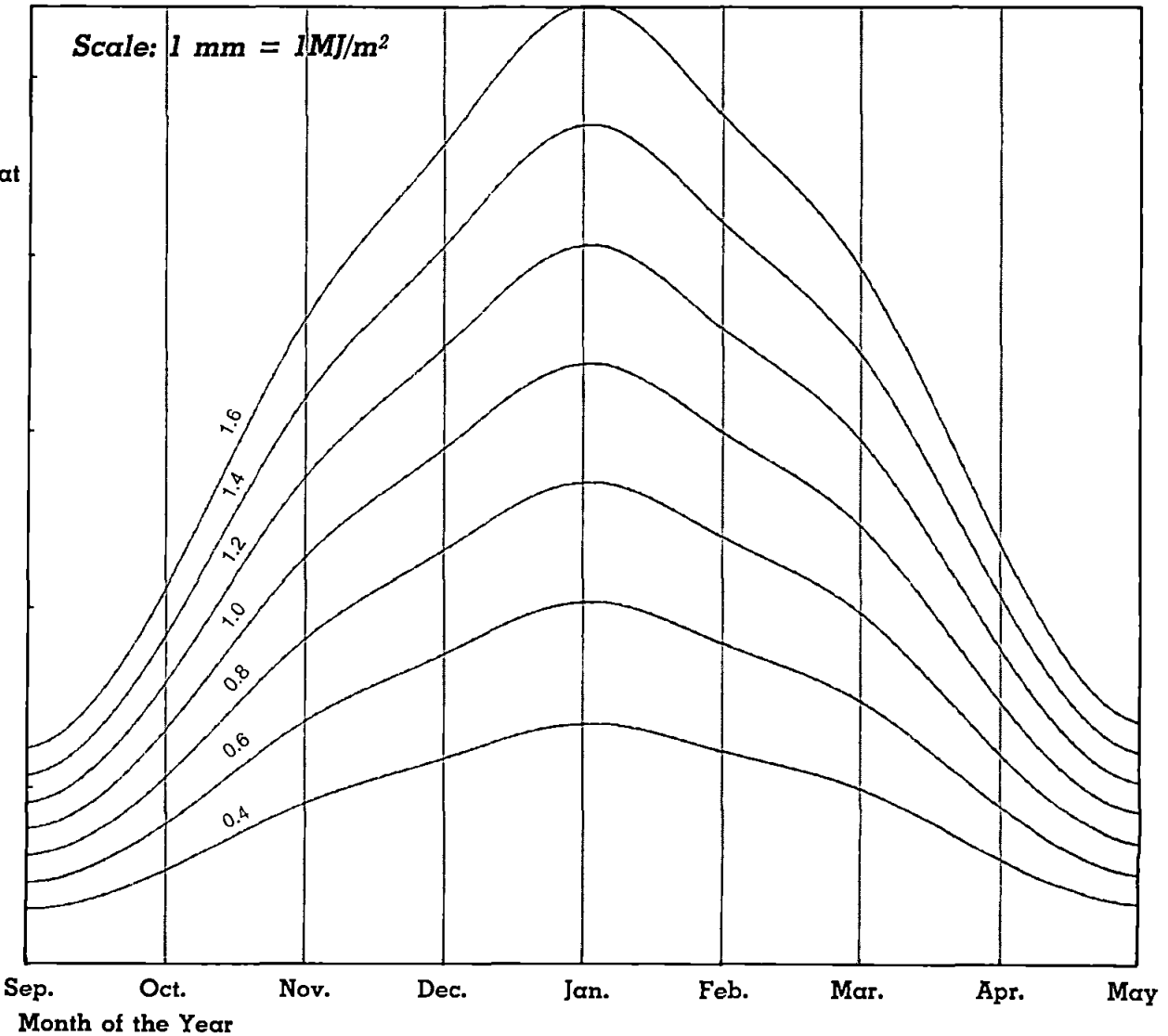
South glass/floor area



Above-Grade Heat Loss Graph

(31)

Above-grade heat loss coefficient W/°Cm²



CLIMATE DATA: REGINA, SASKATCHEWAN

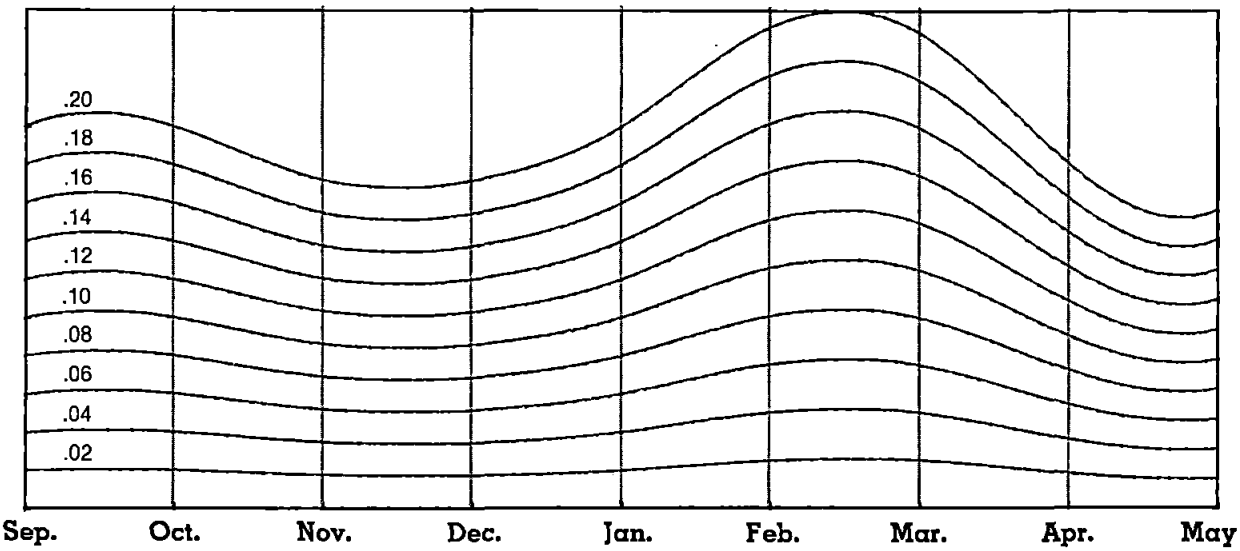
Mean annual outdoor temperature 2.1°C (1)

Mean January temperature at noon −12.0°C (2)

Solar Gains Graph

(57)

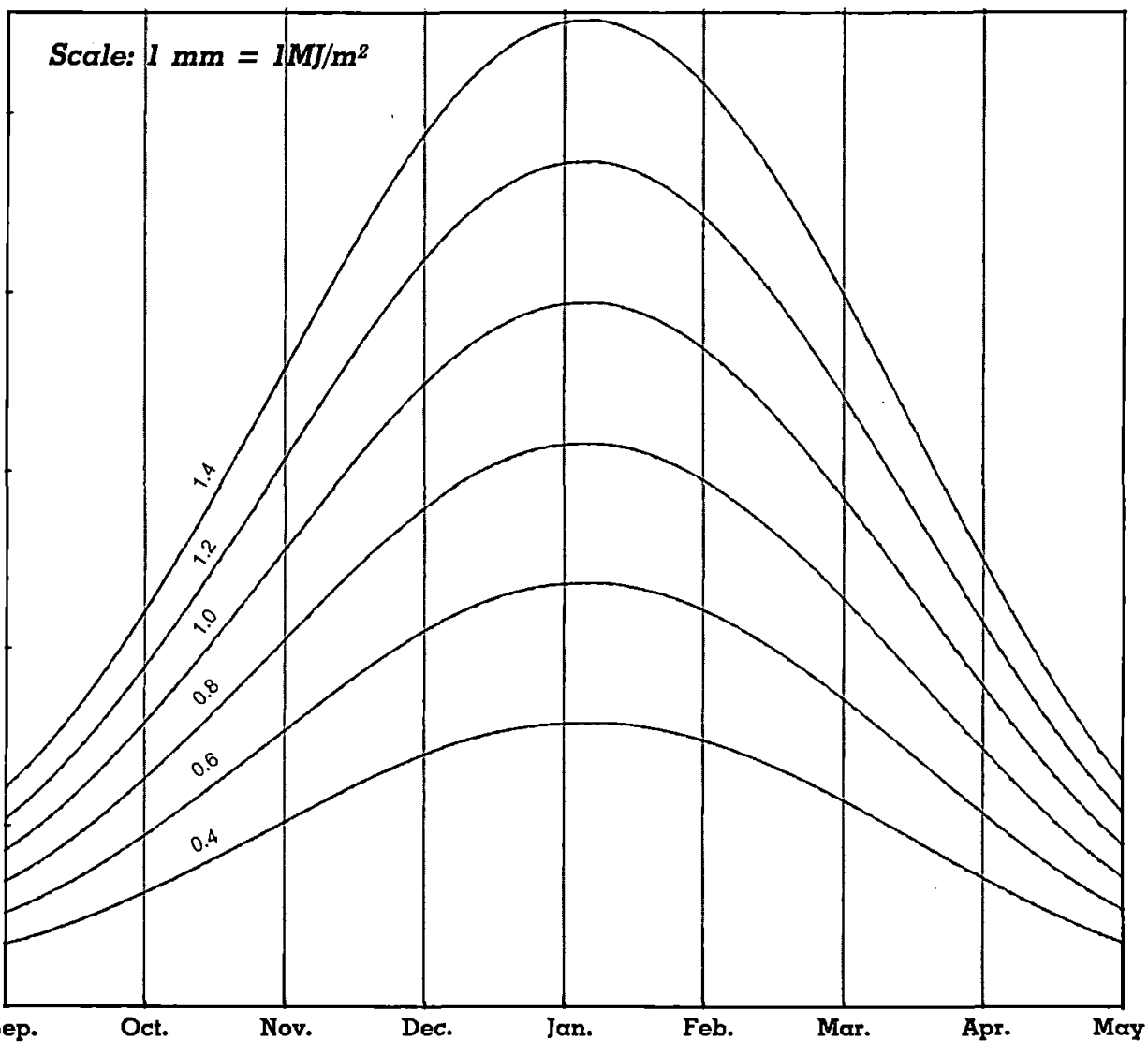
South glass/floor area



Above-Grade Heat Loss Graph

(31)

Above-grade heat loss coefficient W/°Cm²



Month of the Year

CLIMATE DATA: WINNIPEG, MANITOBA

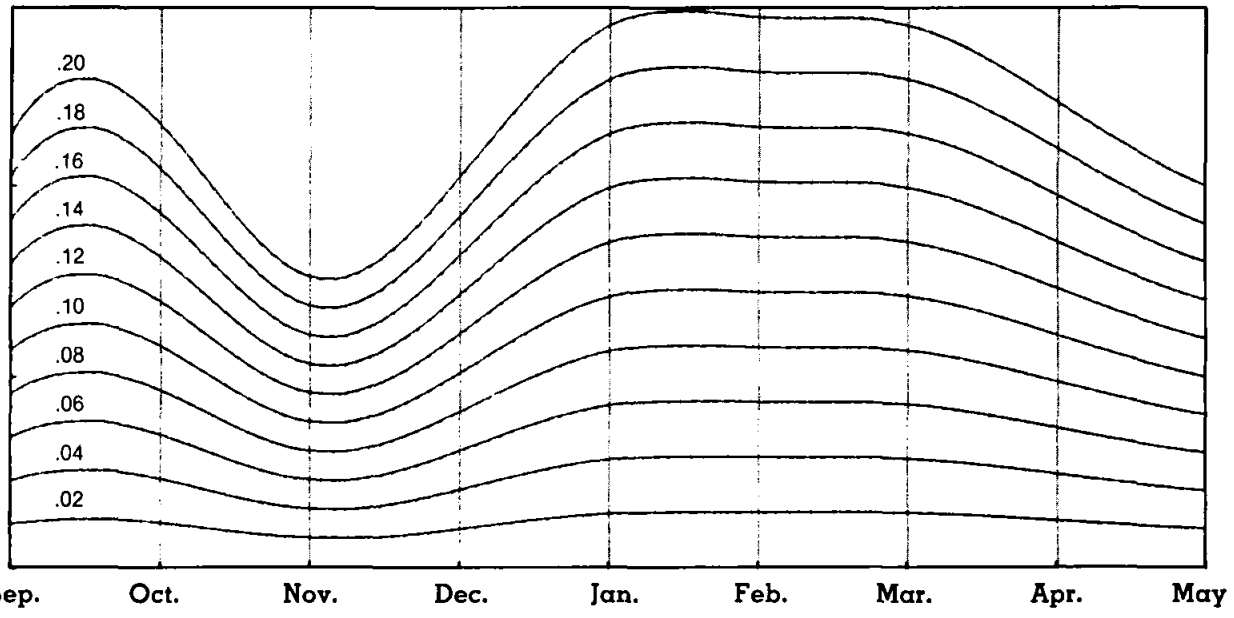
Mean annual outdoor temperature 2.3°C (1)

Mean January temperature at noon −13.4°C (2)

Solar Gains Graph

(57)

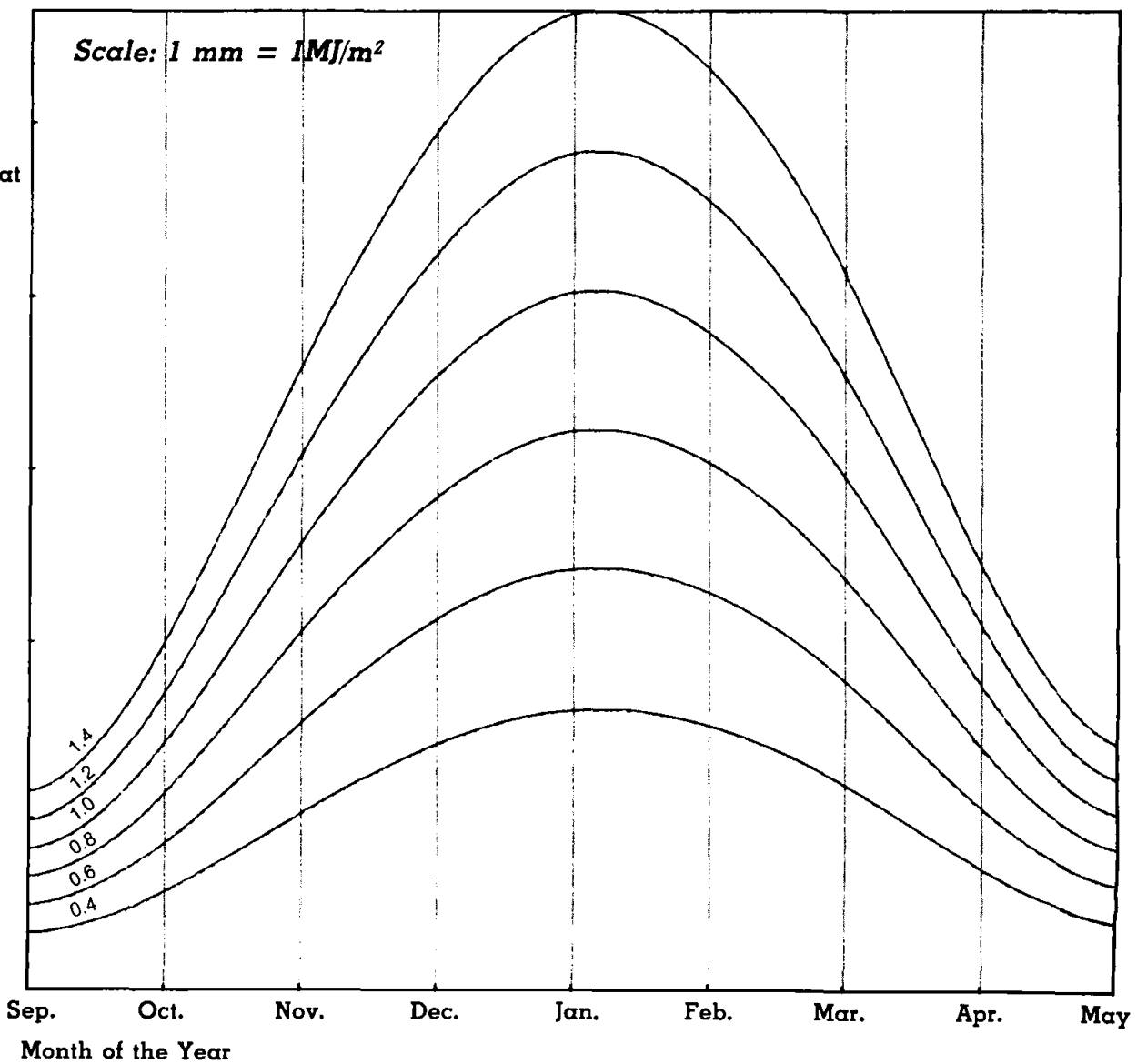
South glass/floor area



Above-Grade Heat Loss Graph

(31)

Above-grade heat loss coefficient W/°Cm²



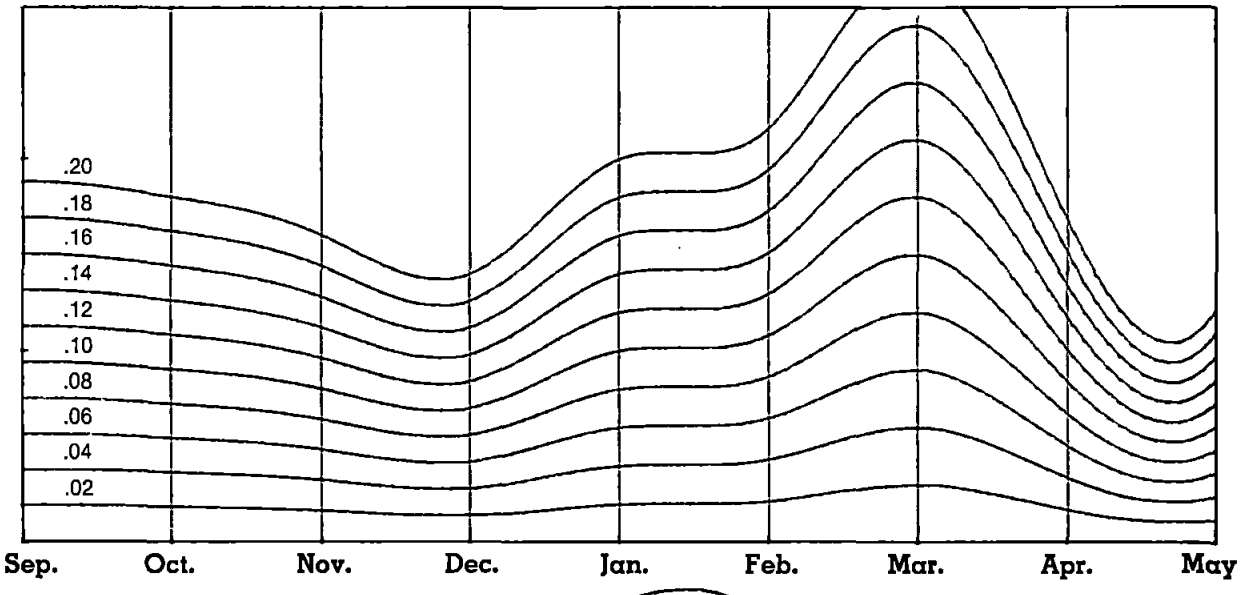
CLIMATE DATA: CHURCHILL, MANITOBA

Mean annual outdoor temperature −7.3°C (1)

Mean January temperature at noon −23.7°C (2)

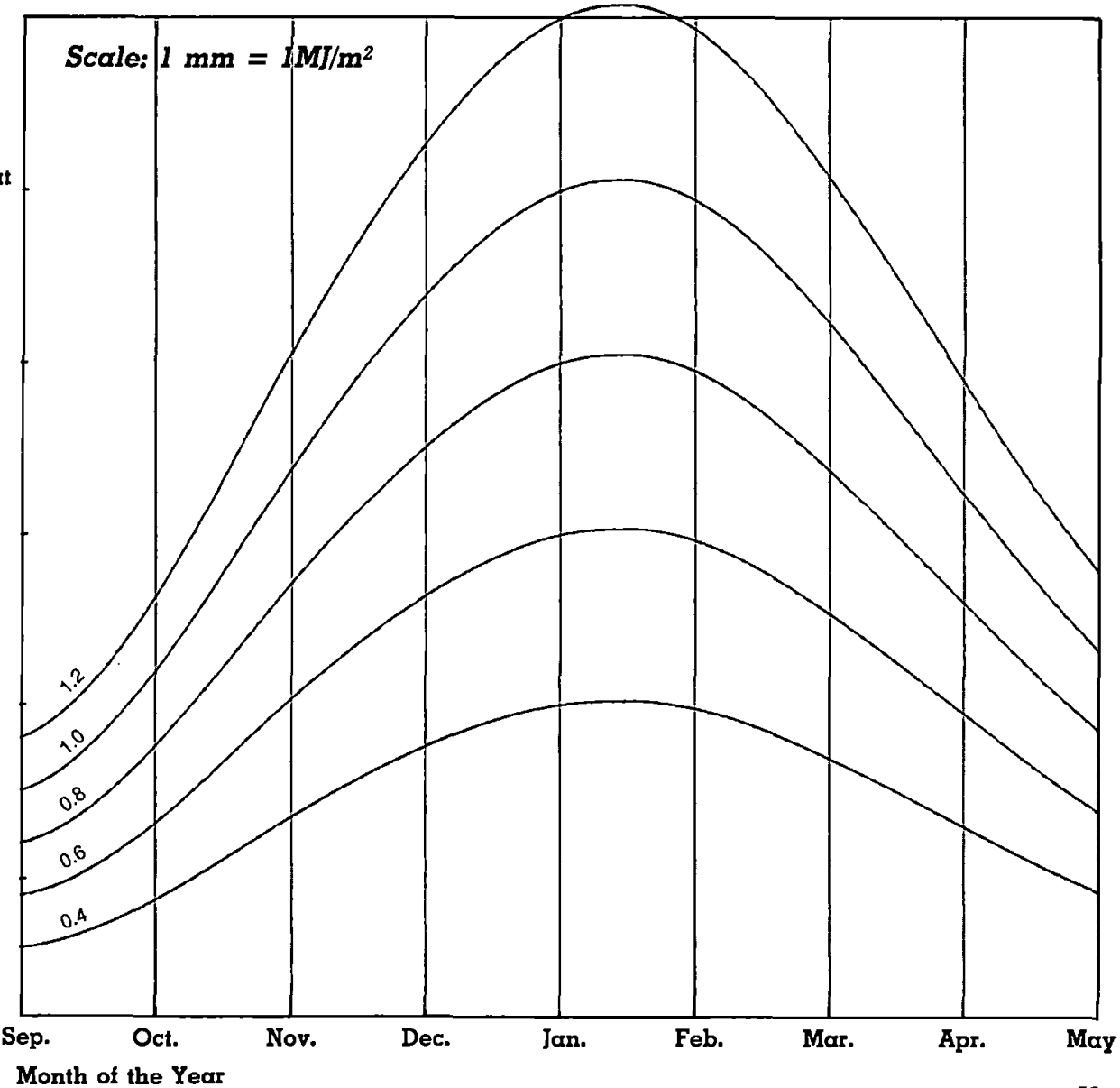
Solar Gains Graph

(57)
South glass/floor area



Above-Grade Heat Loss Graph

(31)
Above-grade heat loss coefficient W/°Cm²



Month of the Year

CLIMATE DATA: THUNDER BAY, ONTARIO

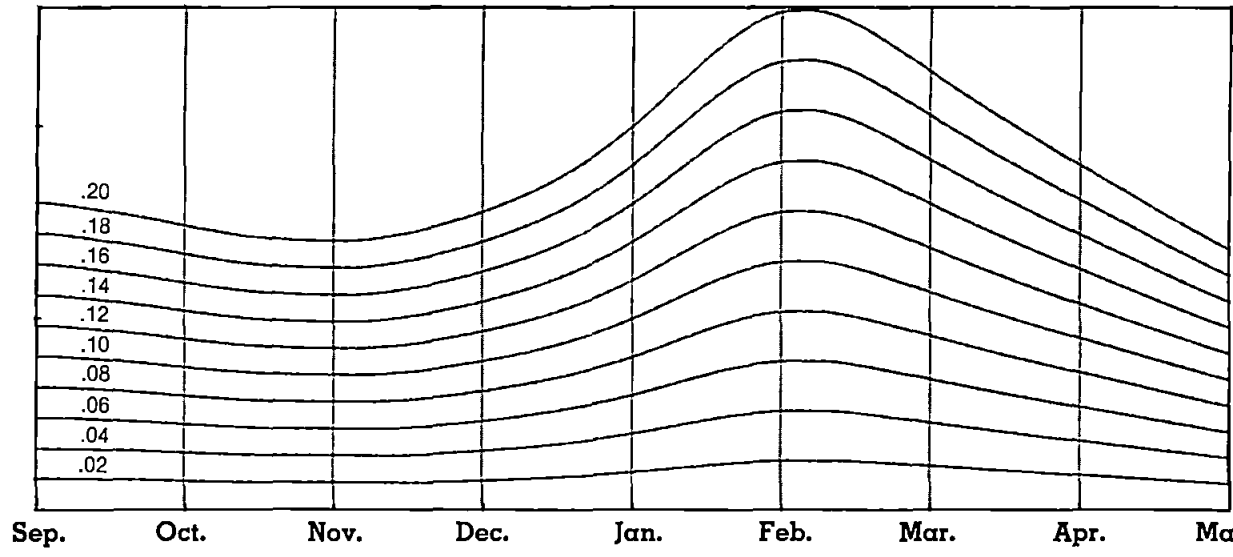
Mean annual outdoor temperature 2.4°C (1)

Mean January temperature at noon −8.9°C (2)

Solar Gains Graph

(57)

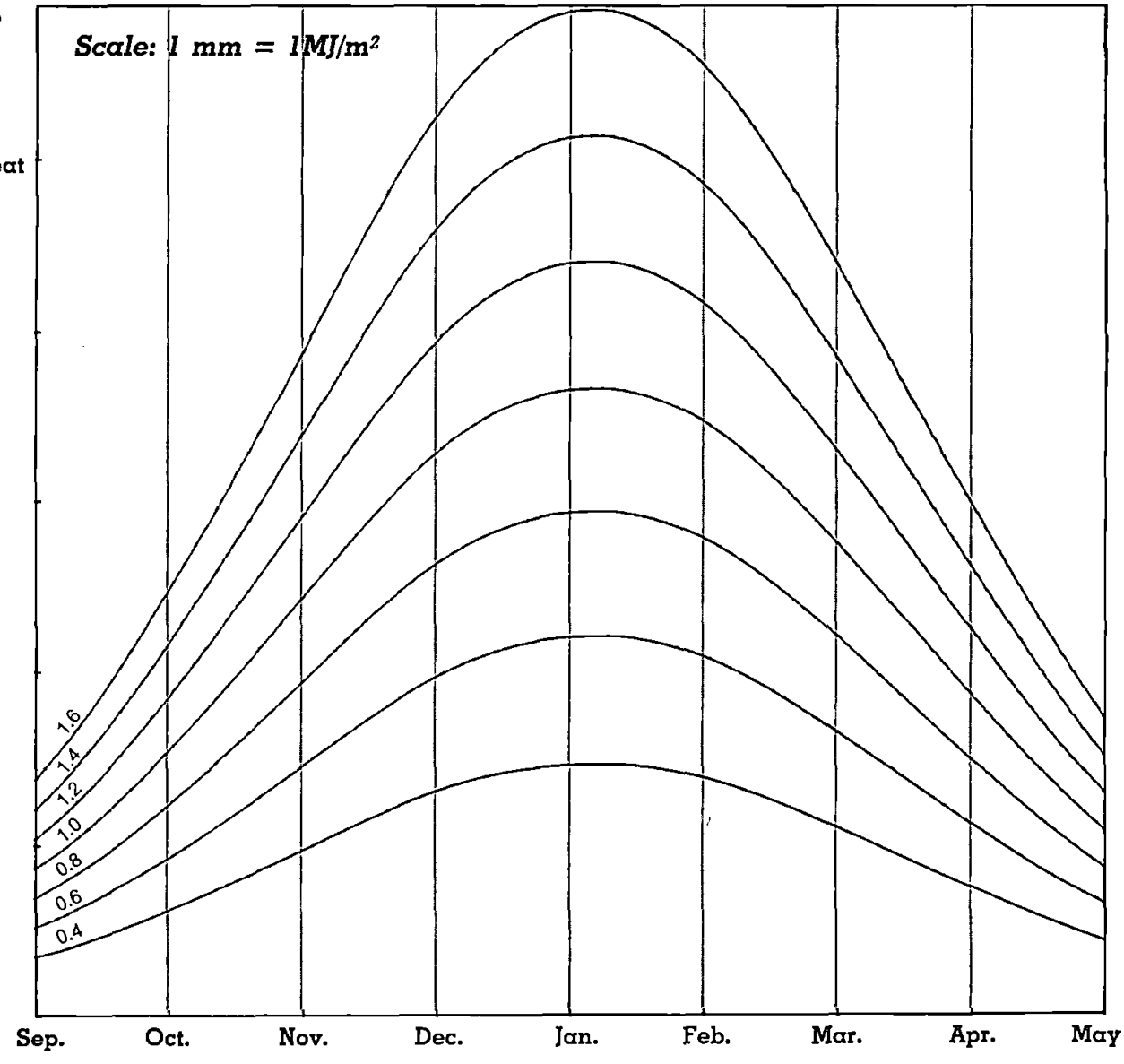
South glass/floor area



Above-Grade Heat Loss Graph

(31)

Above-grade heat loss coefficient W/°Cm²



CLIMATE DATA: SAULT ST. MARIE, ONTARIO

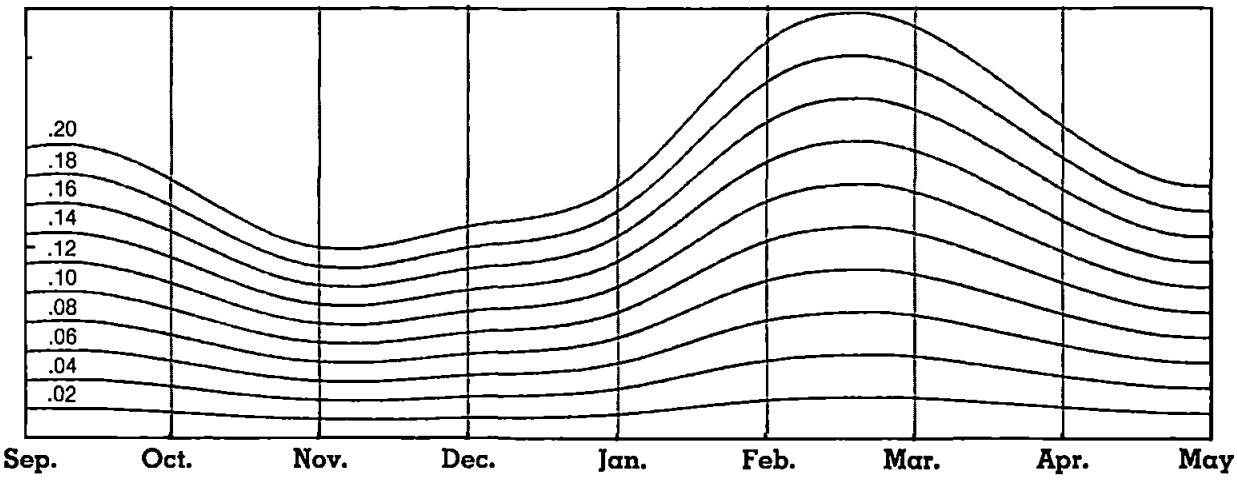
Mean annual outdoor temperature 4.1°C (1)

Mean January temperature at noon −5.9°C (2)

Solar Gains Graph

(57)

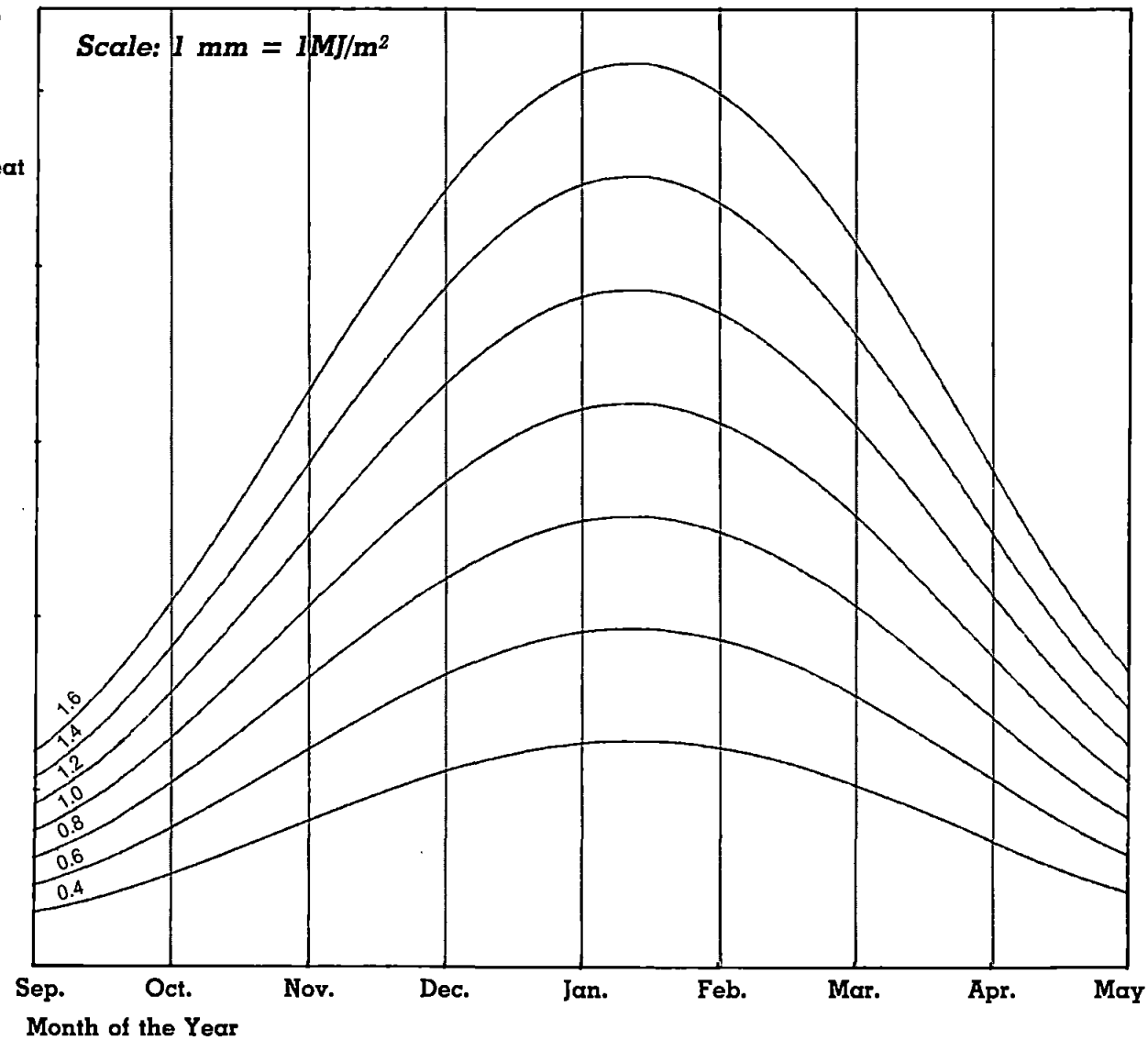
South glass/floor area



Above-Grade Heat Loss Graph

(31)

Above-grade heat loss coefficient W/°Cm²



Month of the Year

CLIMATE DATA: TIMMINS, ONTARIO

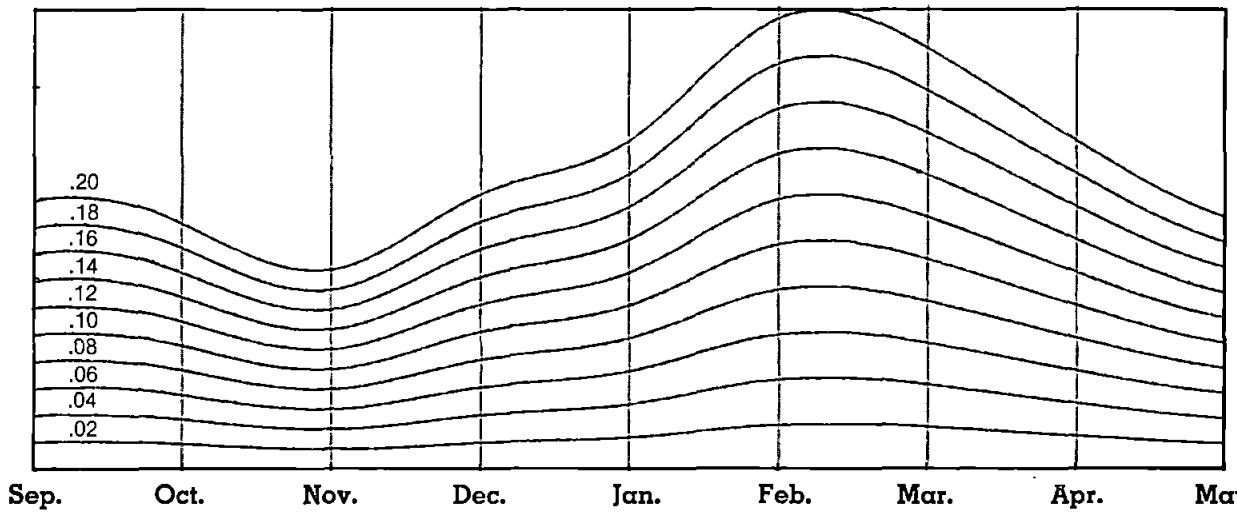
Mean annual outdoor temperature 1.4°C (1)

Mean January temperature at noon −10.8°C (2)

Solar Gains Graph

(57)

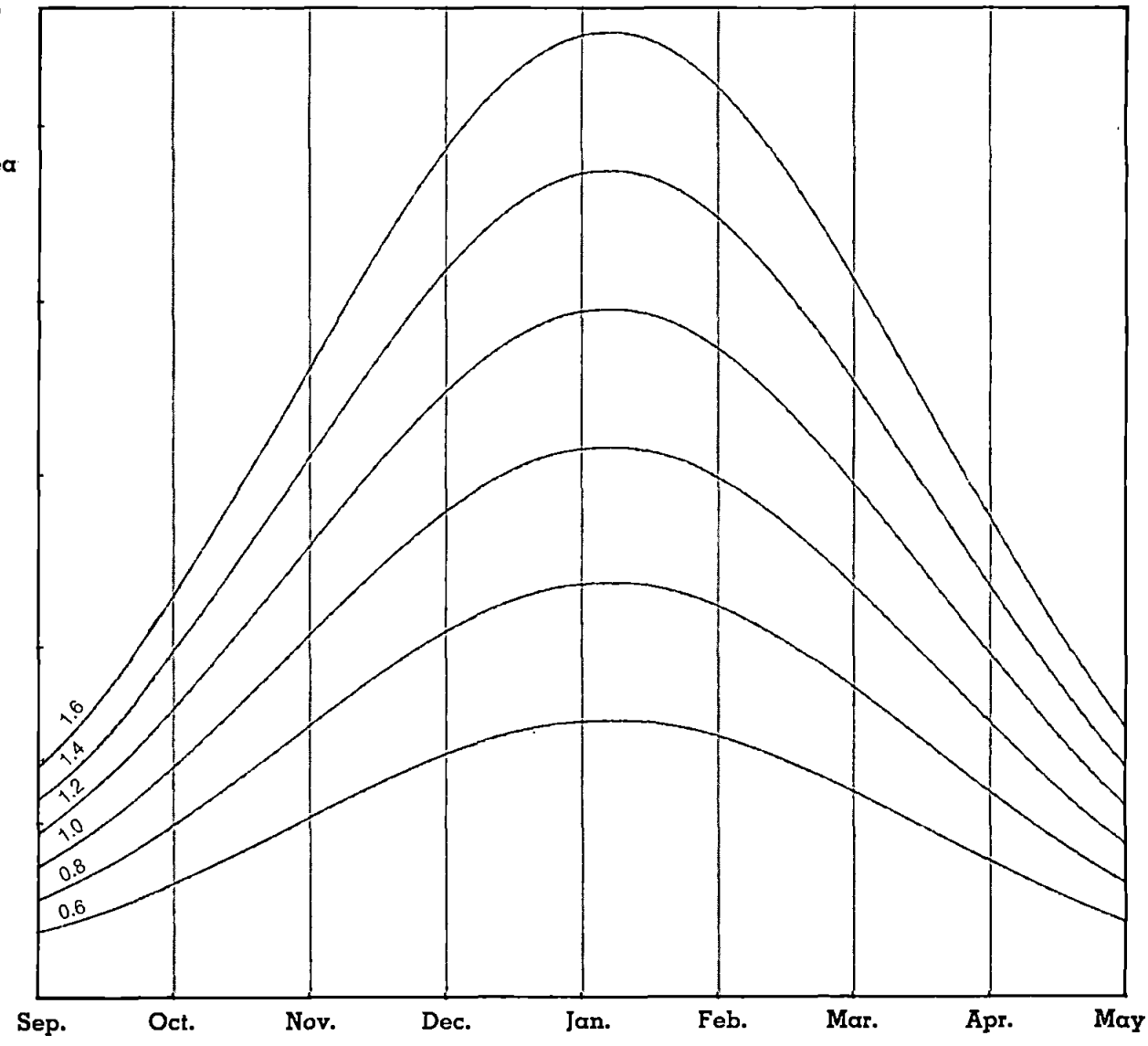
South glass/floor area



Above-Grade Heat Loss Graph

(31)

Above-grade hea loss coefficient W/°Cm²



CLIMATE DATA: SUDBURY, ONTARIO

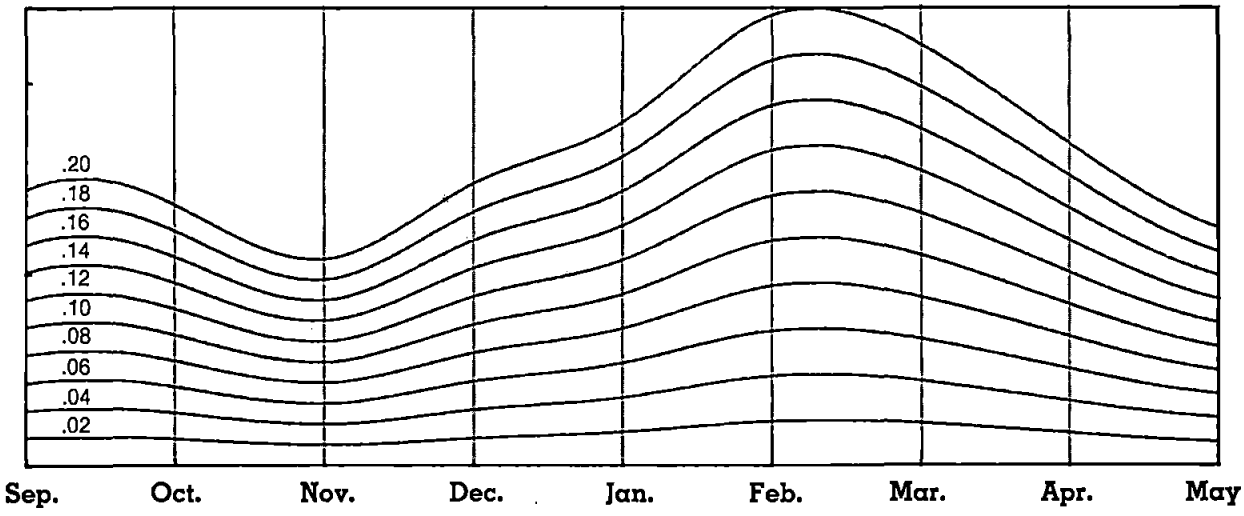
Mean annual outdoor temperature 3.6°C (1)

Mean January temperature at noon −8.4°C (2)

Solar Gains Graph

(57)

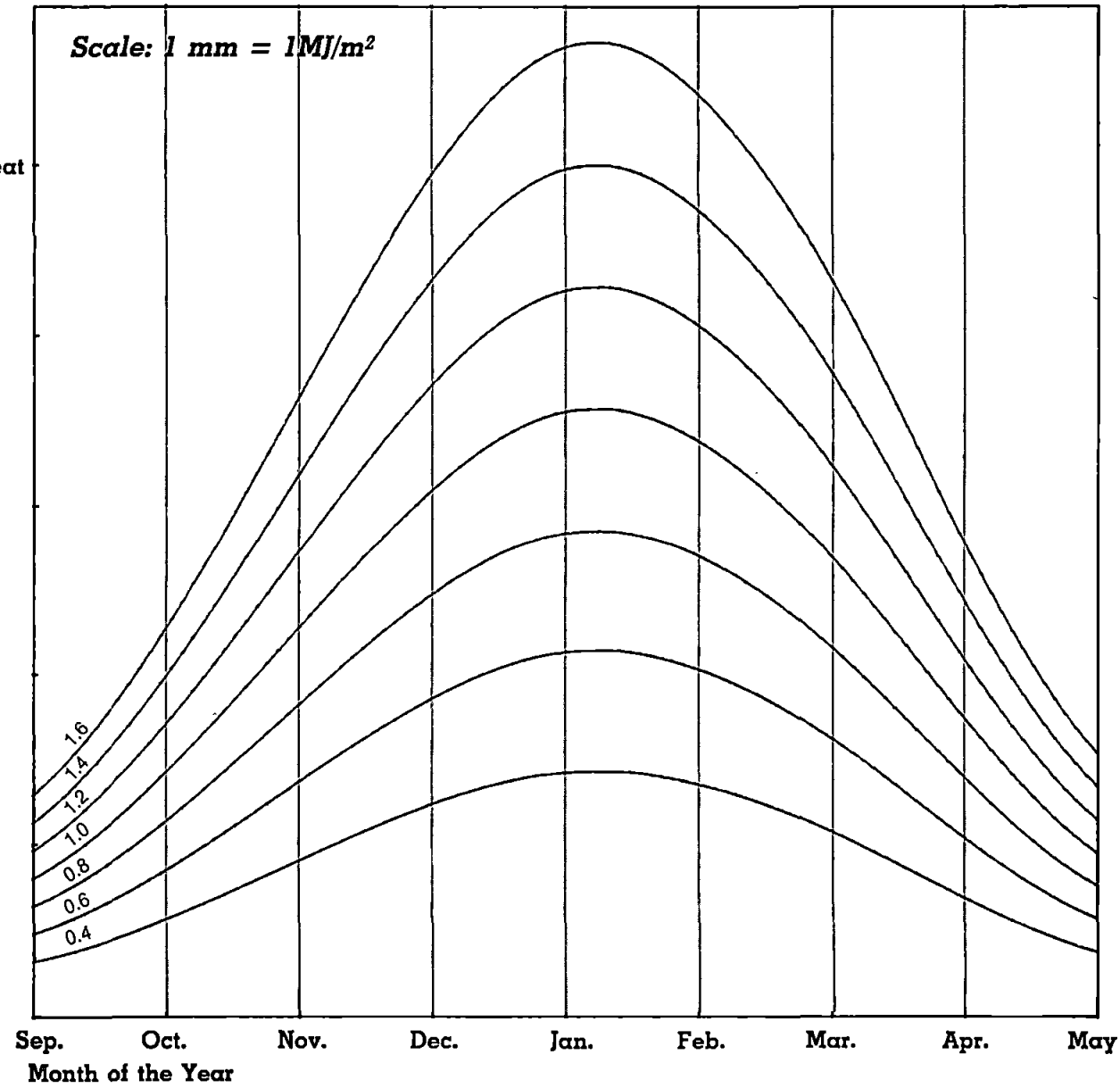
South glass/floor area



Above-Grade Heat Loss Graph

(31)

Above-grade heat loss coefficient W/°Cm²



Month of the Year

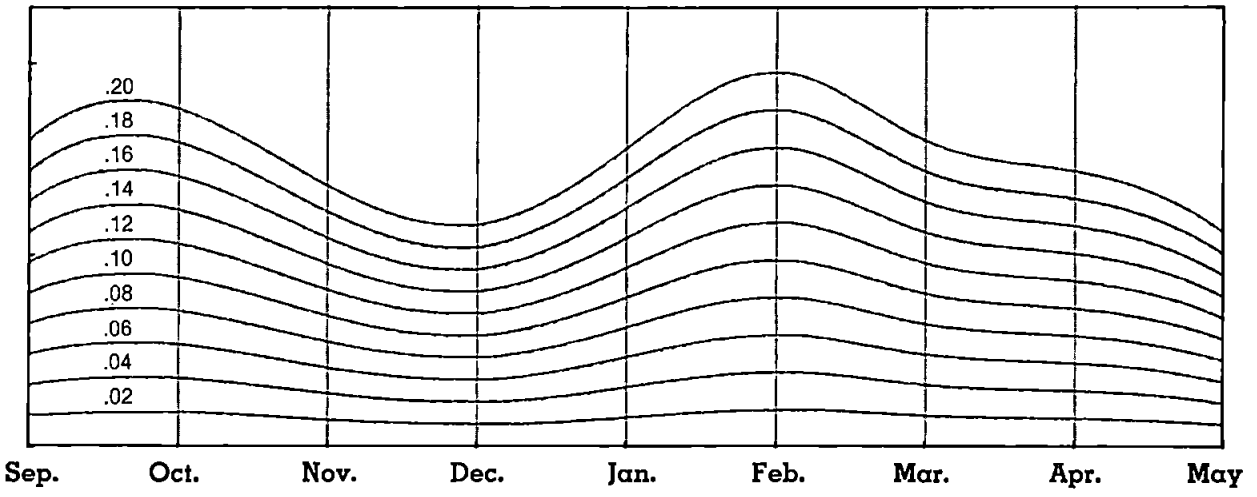
CLIMATE DATA: WINDSOR, ONTARIO

Mean annual outdoor temperature 9.2°C (1)

Mean January temperature at noon −0.7°C (2)

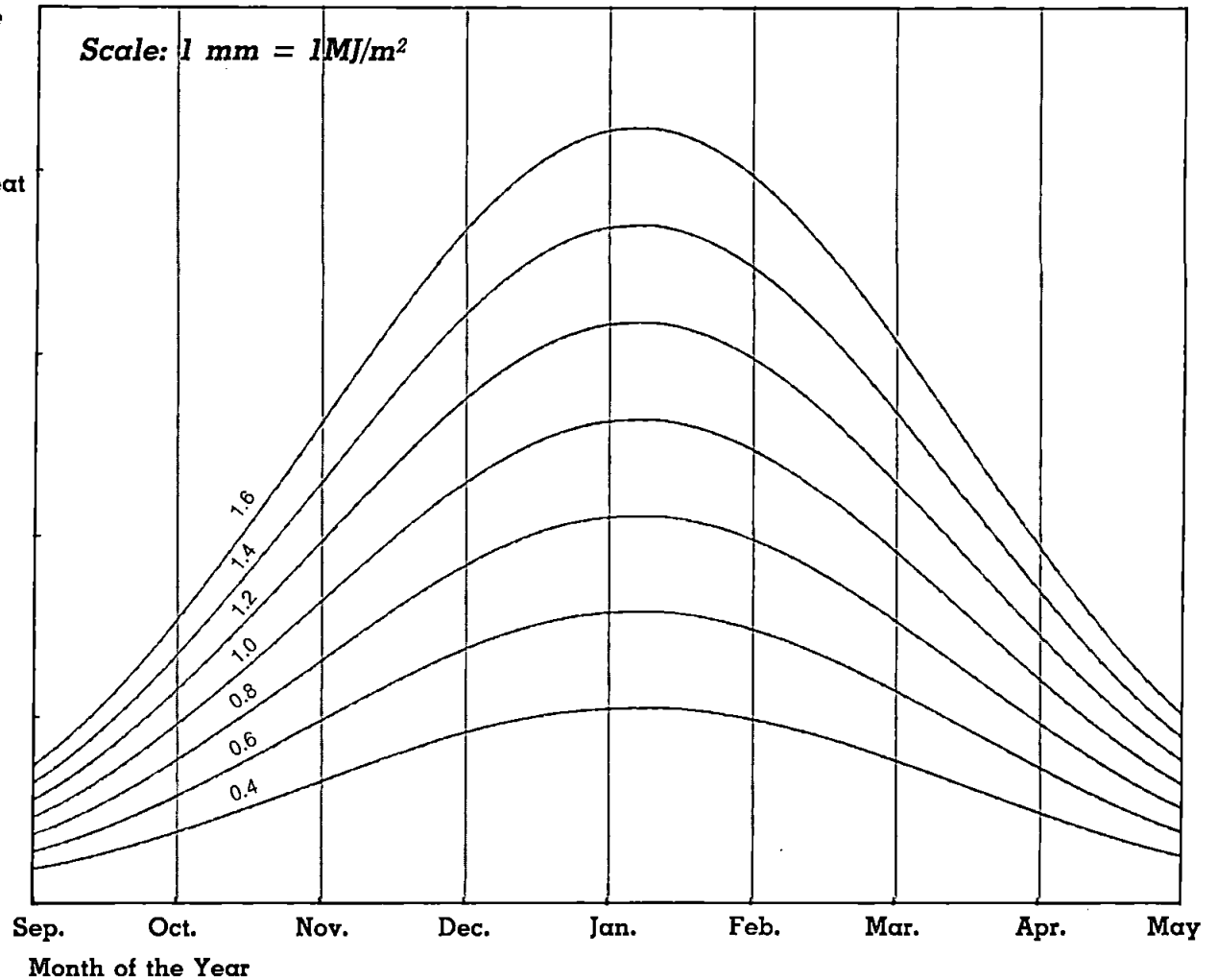
Solar Gains Graph

(57)
South glass/floor area



Above-Grade Heat Loss Graph

(31)
Above-grade heat loss coefficient W/°Cm²



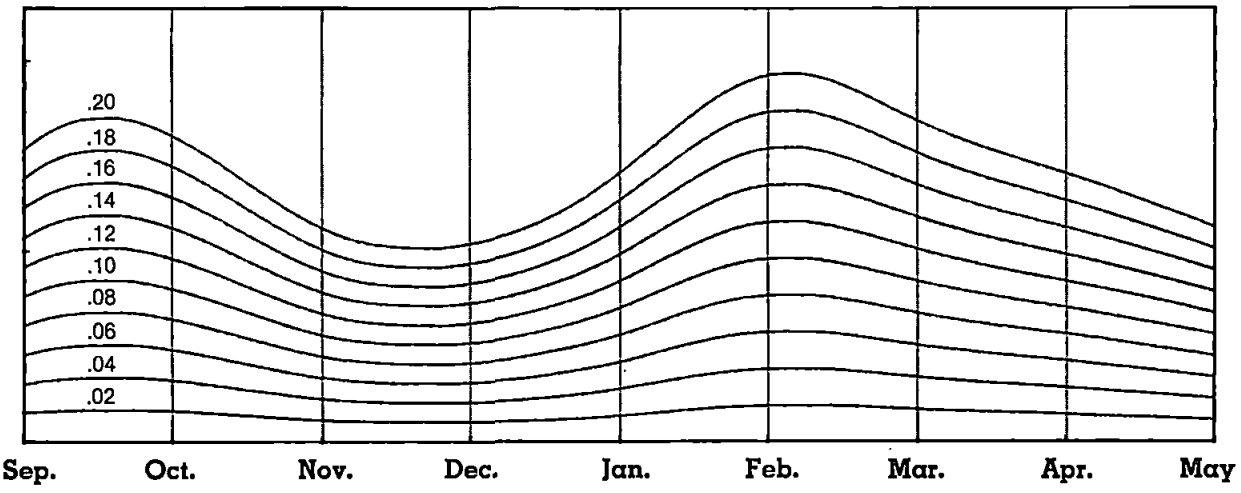
CLIMATE DATA: LONDON, ONTARIO

Mean annual outdoor temperature 7.5°C (1)

Mean January temperature at noon −2.2°C (2)

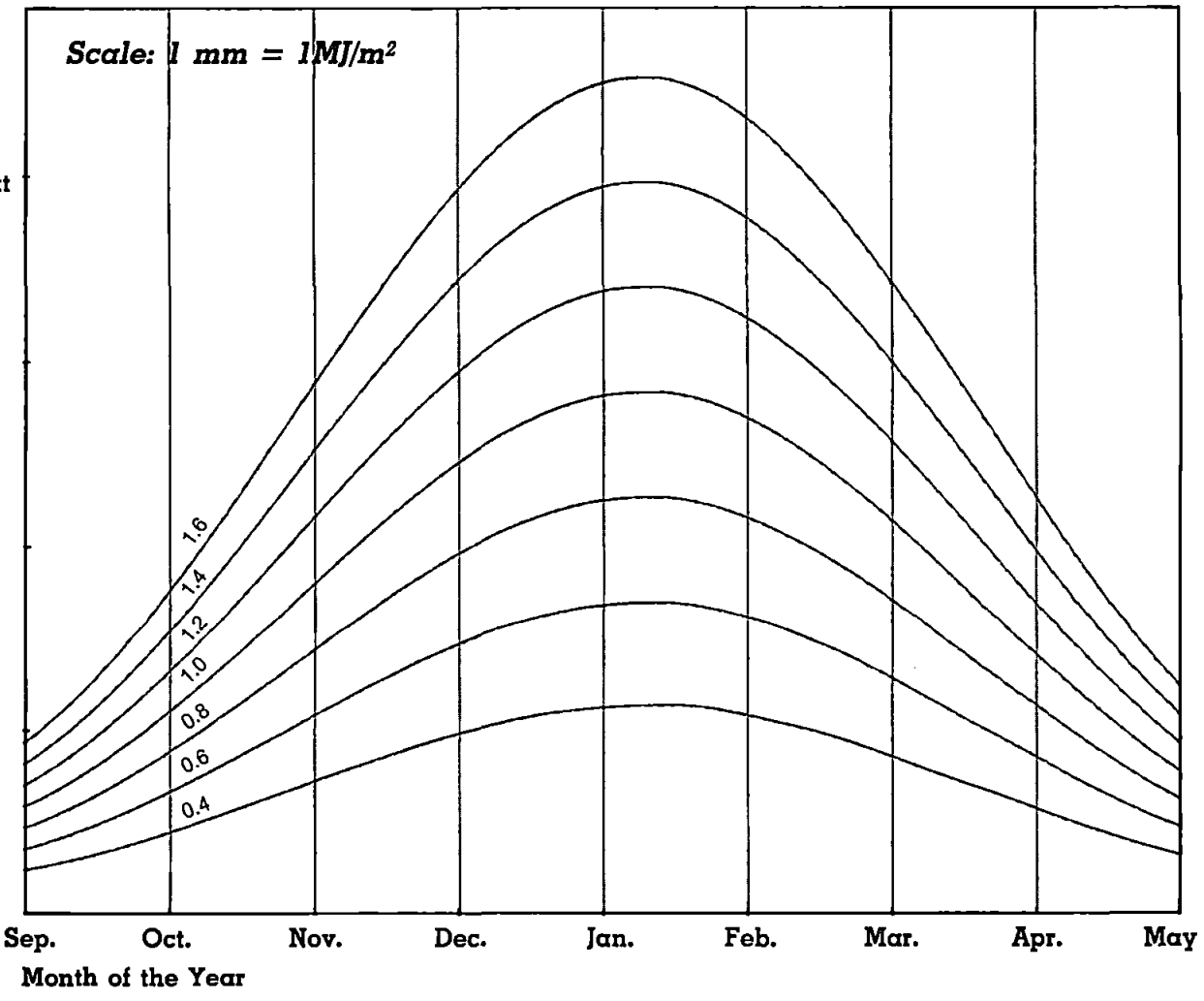
Solar Gains Graph

(57)
South glass/floor area



Above-Grade Heat Loss Graph

(31)
Above-grade heat loss coefficient W/°Cm²



Month of the Year

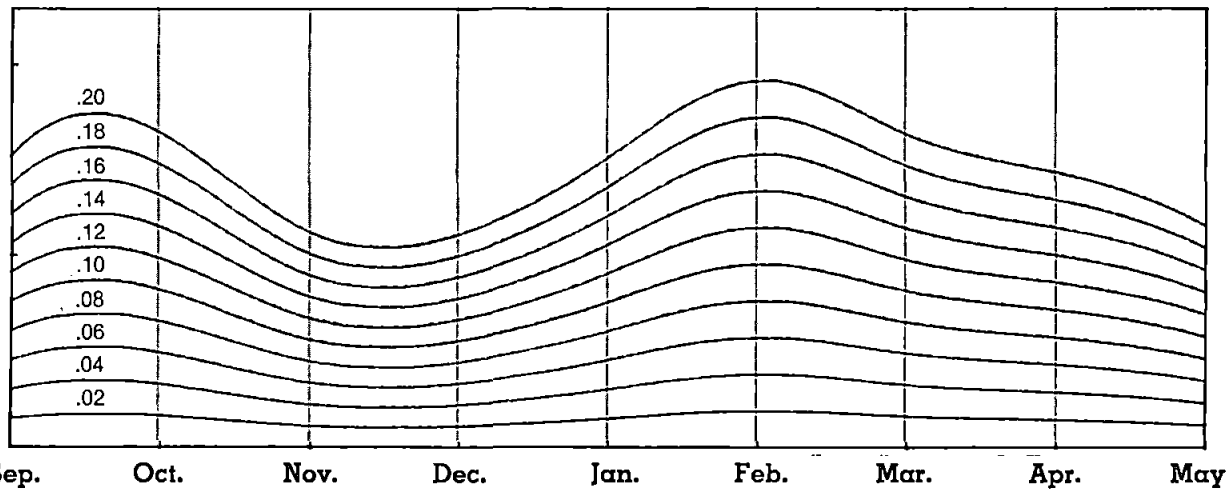
CLIMATE DATA: SIMCOE, ONTARIO

Mean annual outdoor temperature 7.6°C (1)

Mean January temperature at noon −2.2°C (2)

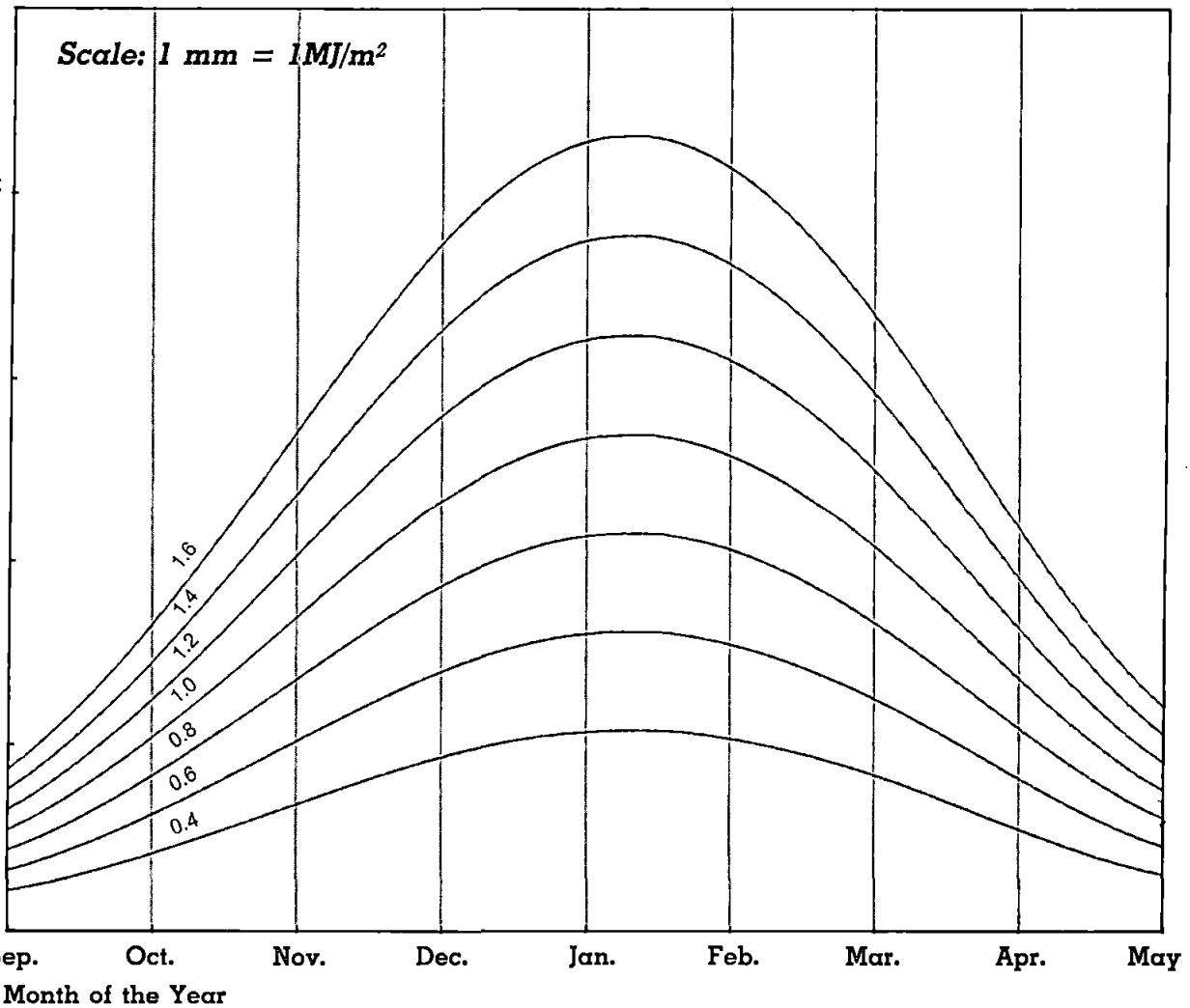
Solar Gains Graph

(57)
South glass/floor area



Above-Grade Heat Loss Graph

(31)
Above-grade heat loss coefficient W/°Cm²



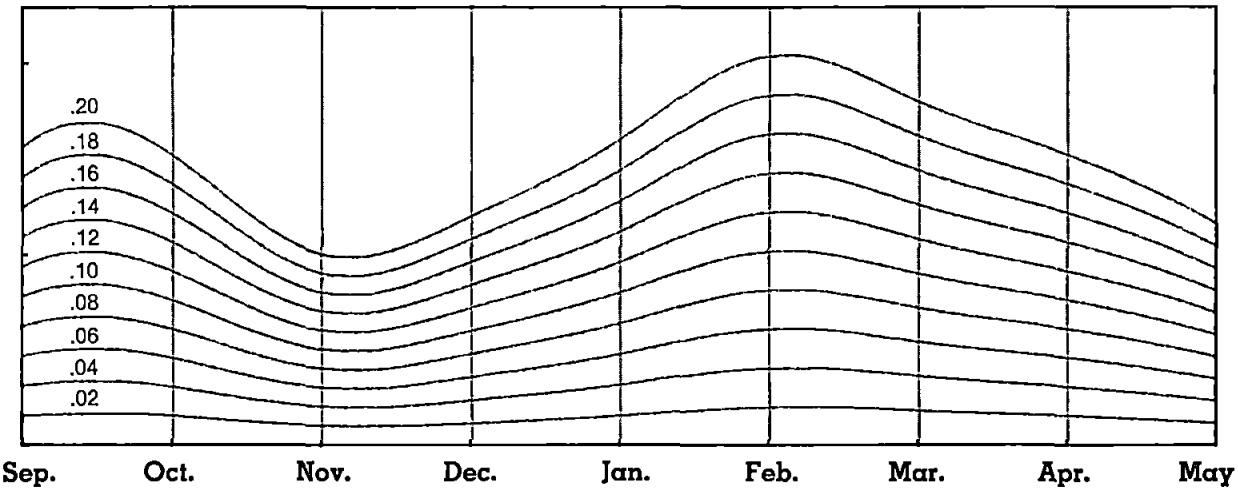
CLIMATE DATA: TORONTO (SUBURBS), ONTARIO

Mean annual outdoor temperature 7.5°C (1)

Mean January temperature at noon −2.2°C (2)

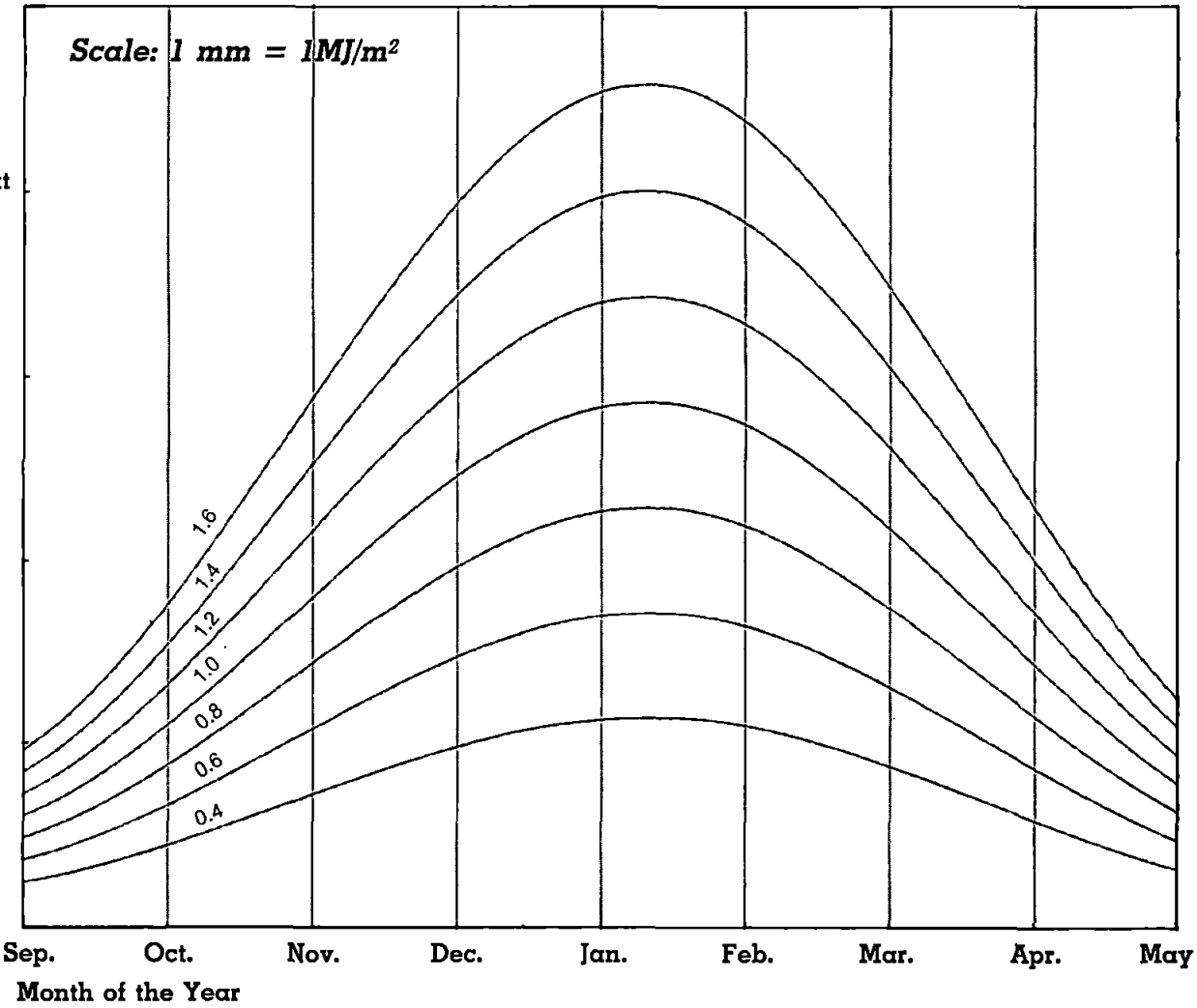
Solar Gains Graph

(57)
South glass/floor area



Above-Grade Heat Loss Graph

(31)
Above-grade heat loss coefficient W/°Cm²



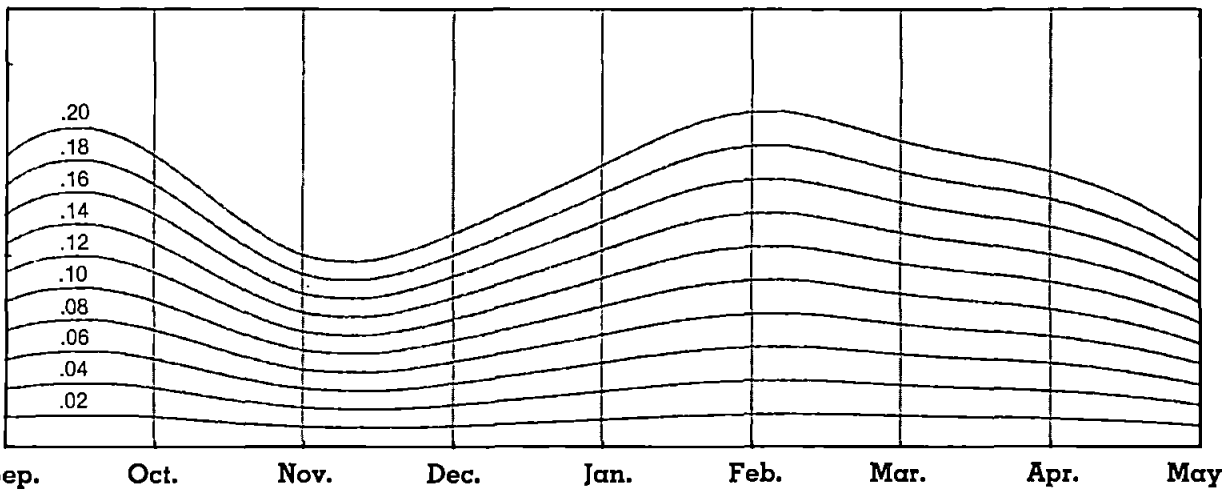
CLIMATE DATA: TORONTO (URBAN), ONTARIO

Mean annual outdoor temperature 8.9°C (1)

Mean January temperature at noon −1.1°C (2)

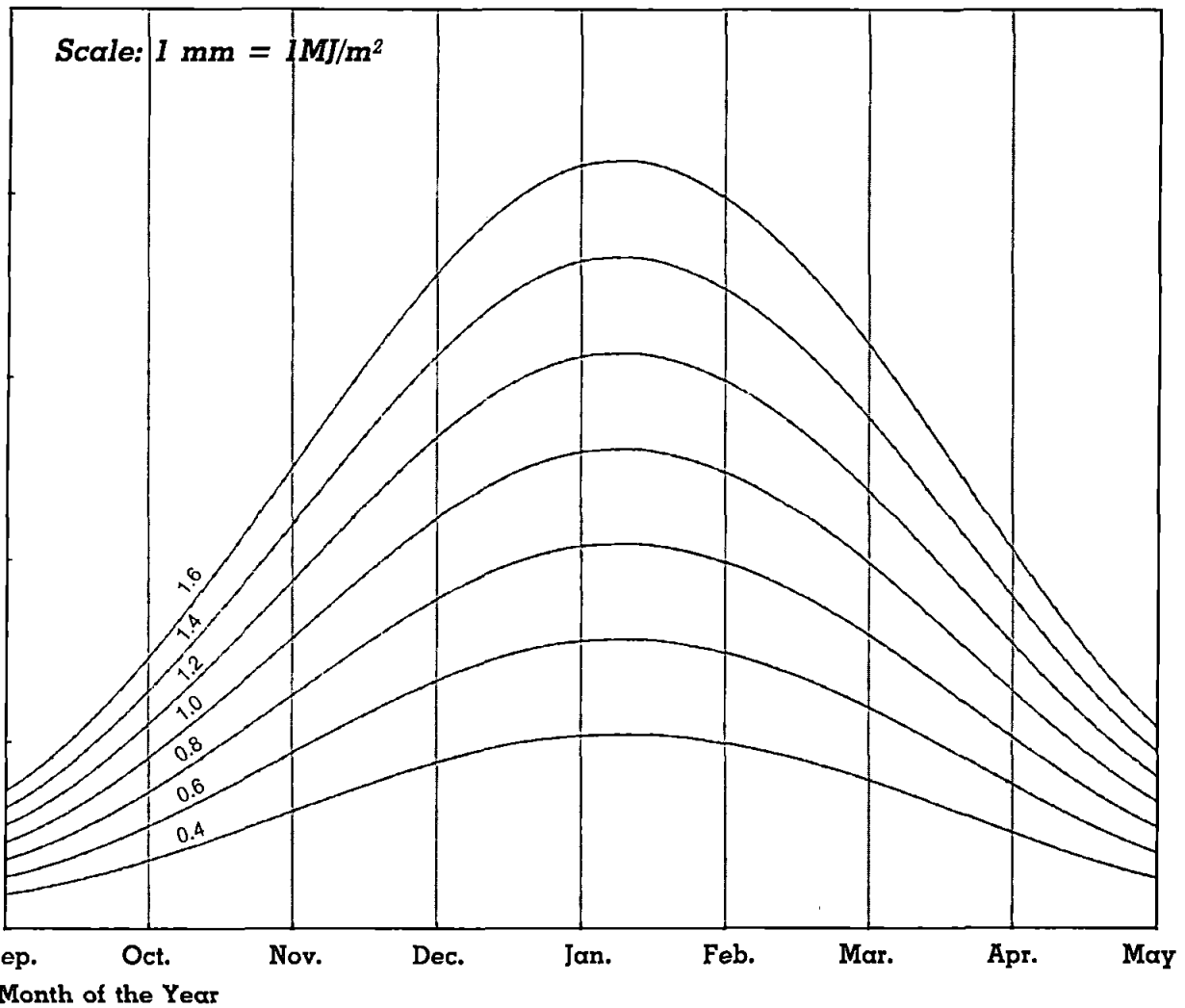
Solar Gains Graph

(57)
South glass/floor area



Above-Grade Heat Loss Graph

(31)
Above-grade heat loss coefficient W/°Cm²



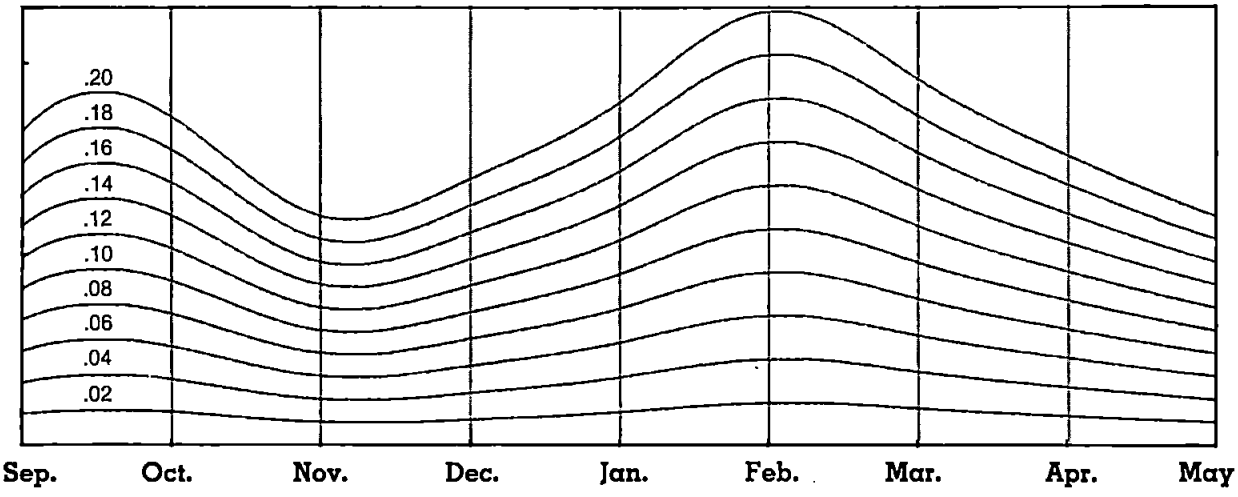
CLIMATE DATA: KINGSTON, ONTARIO

Mean annual outdoor temperature 7.2°C (1)

Mean January temperature at noon −3.4°C (2)

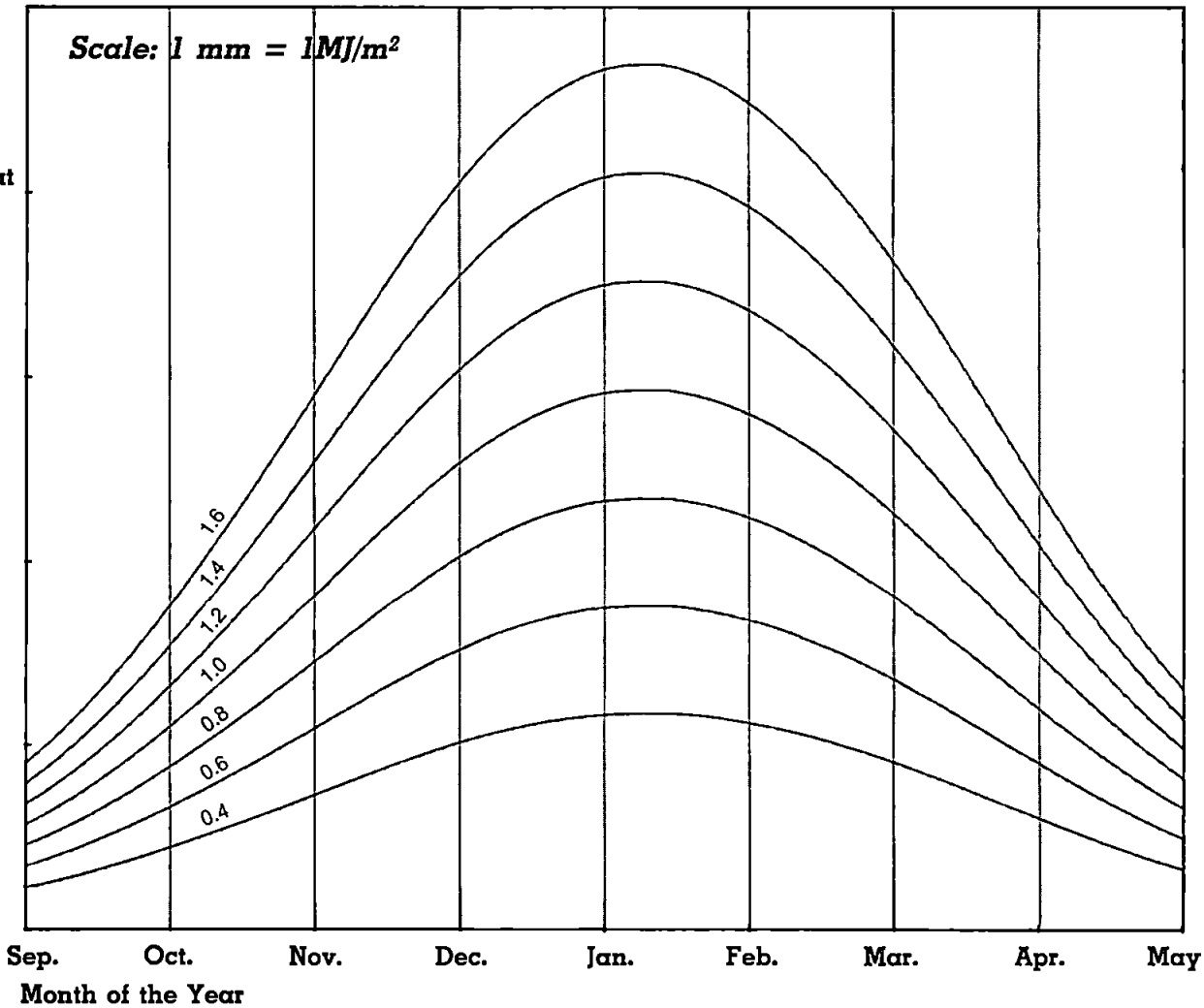
Solar Gains Graph

(57)
South glass/floor area



Above-Grade Heat Loss Graph

(31)
Above-grade heat loss coefficient W/°Cm²



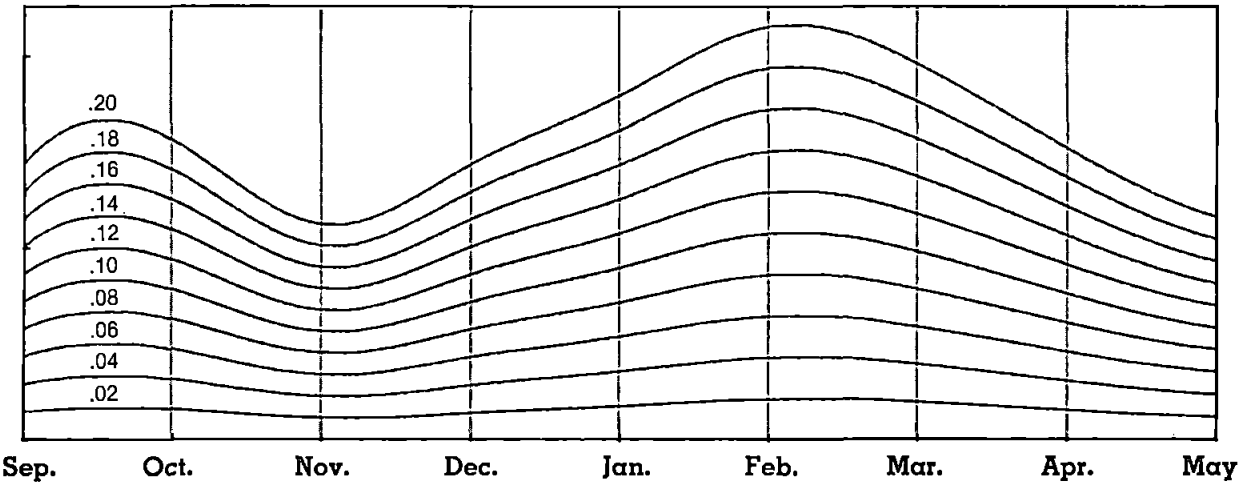
CLIMATE DATA: OTTAWA, ONTARIO

Mean annual outdoor temperature 5.8°C (1)

Mean January temperature at noon −6.4°C (2)

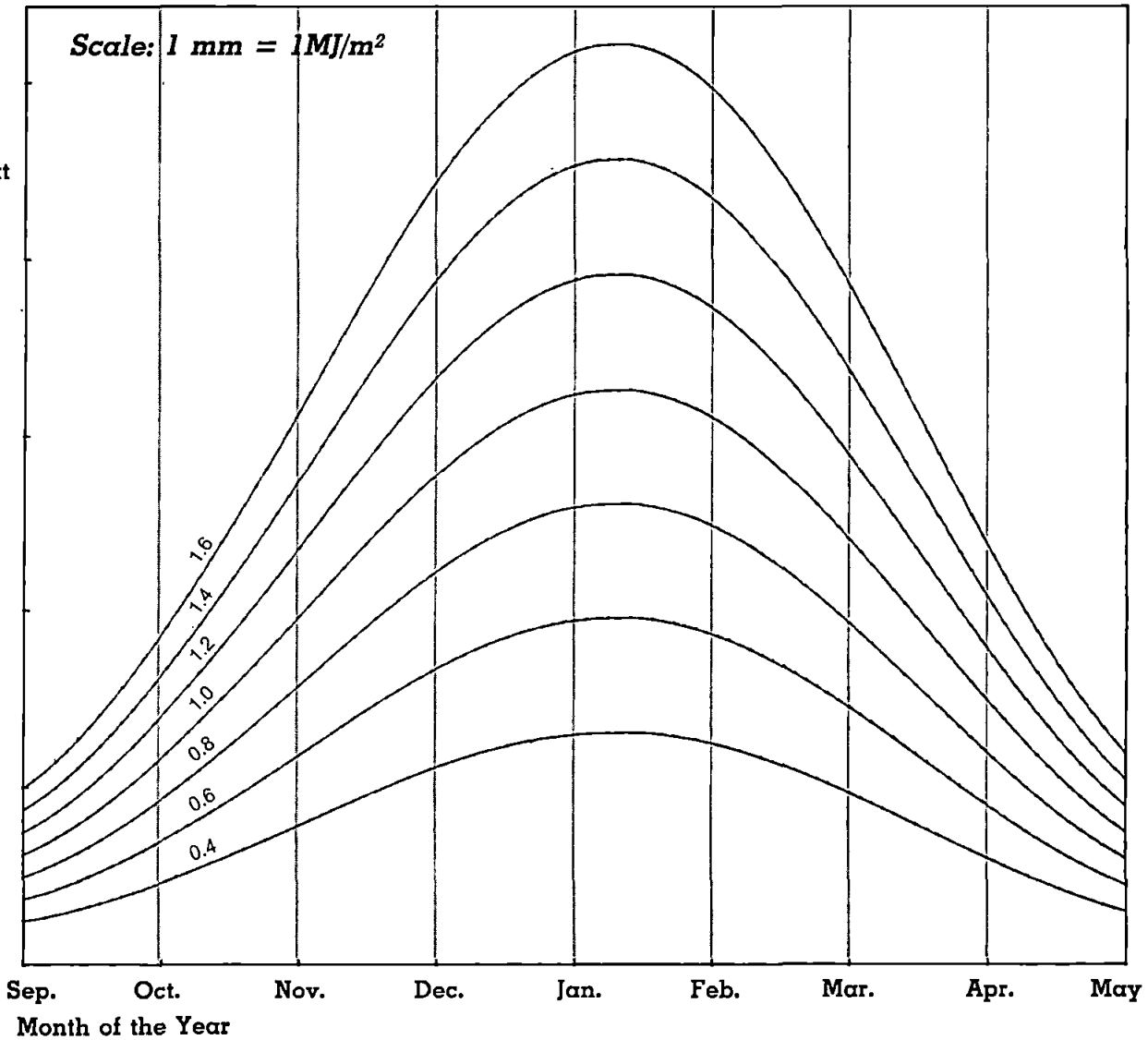
Solar Gains Graph

(57)
South glass/floor area



Above-Grade Heat Loss Graph

(31)
Above-grade heat loss coefficient W/°Cm²



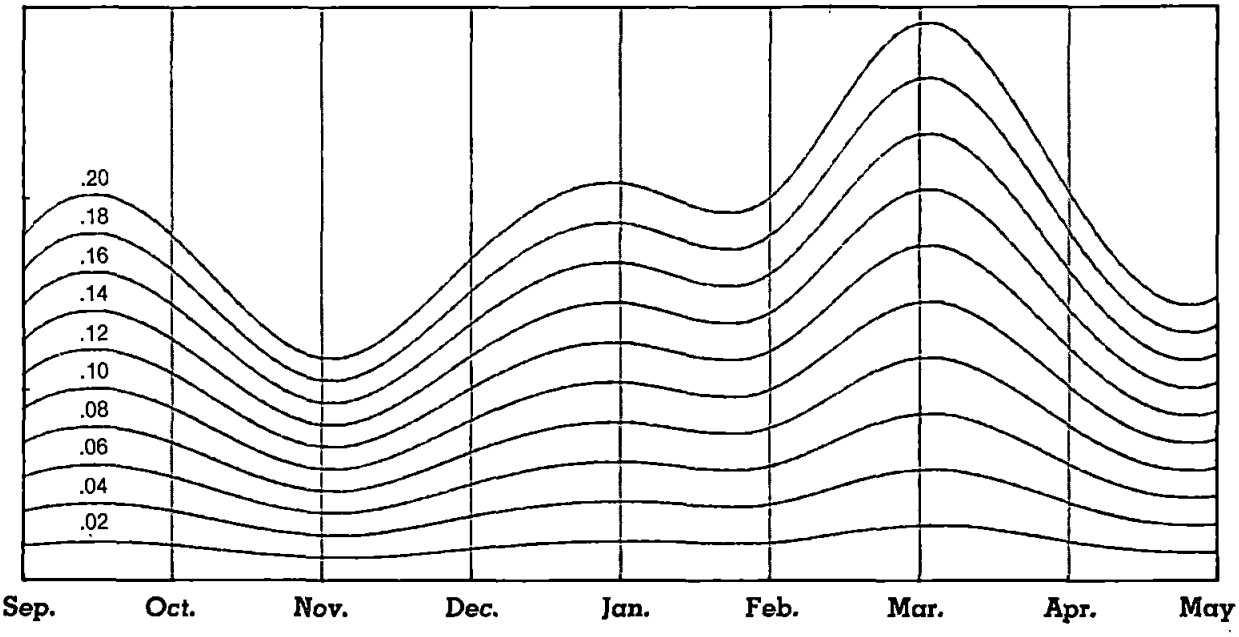
CLIMATE DATA: MONTRÉAL, P.Q.

Mean annual outdoor temperature 6.5°C (1)

Mean January temperature at noon −5.4°C (2)

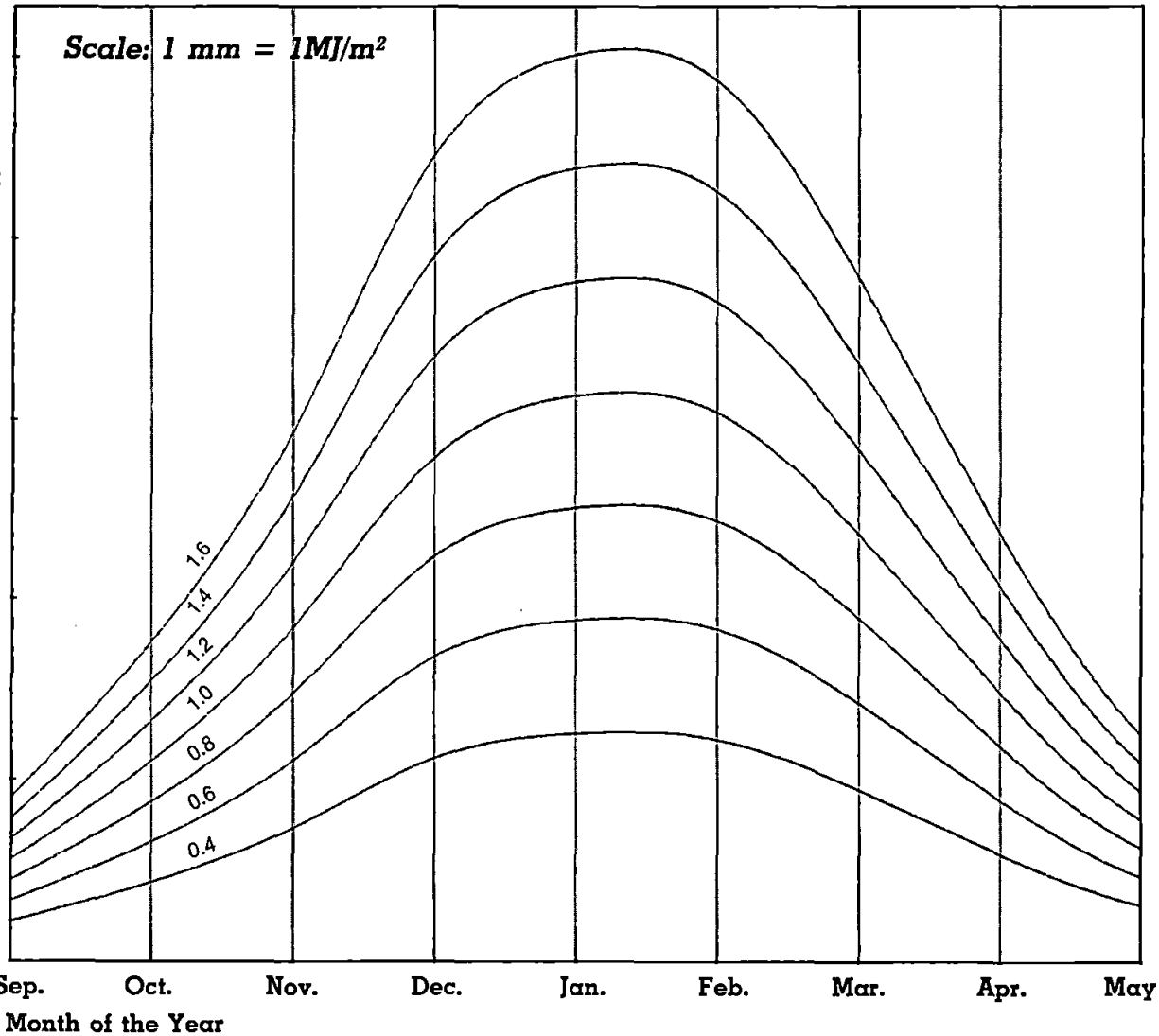
Solar Gains Graph

(57)
South glass/floor area



Above-Grade Heat Loss Graph

(31)
Above-grade heat loss coefficient W/°Cm²



Month of the Year

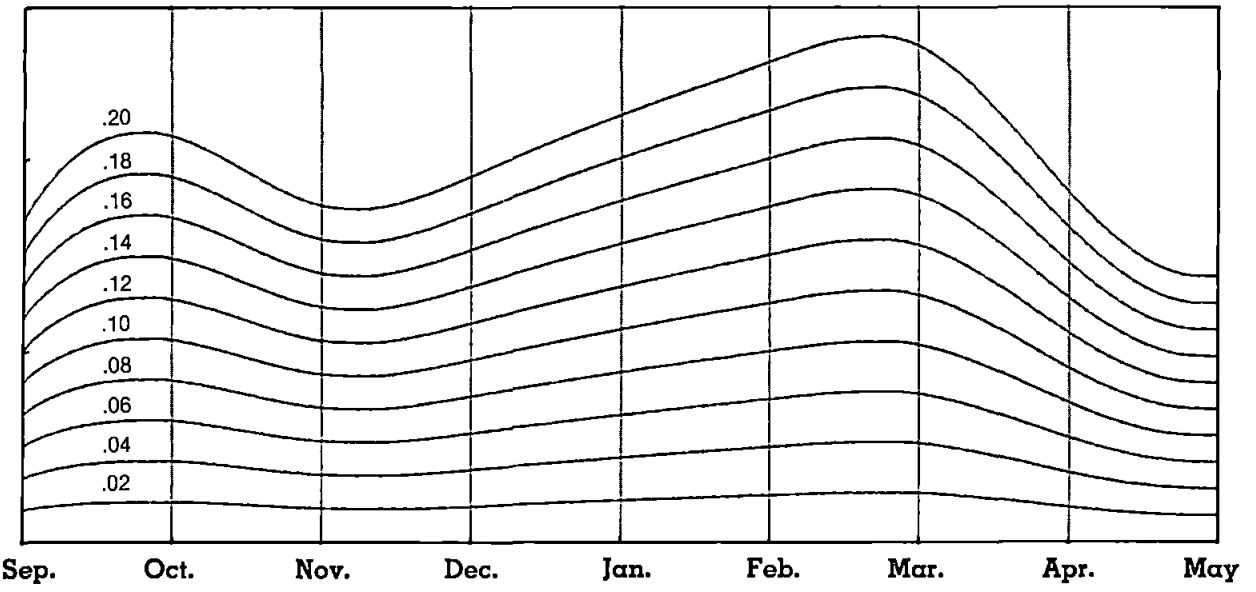
CLIMATE DATA: FREDERICTON, N.B.

Mean annual outdoor temperature 5.5°C (1)

Mean January temperature at noon −3.7°C (2)

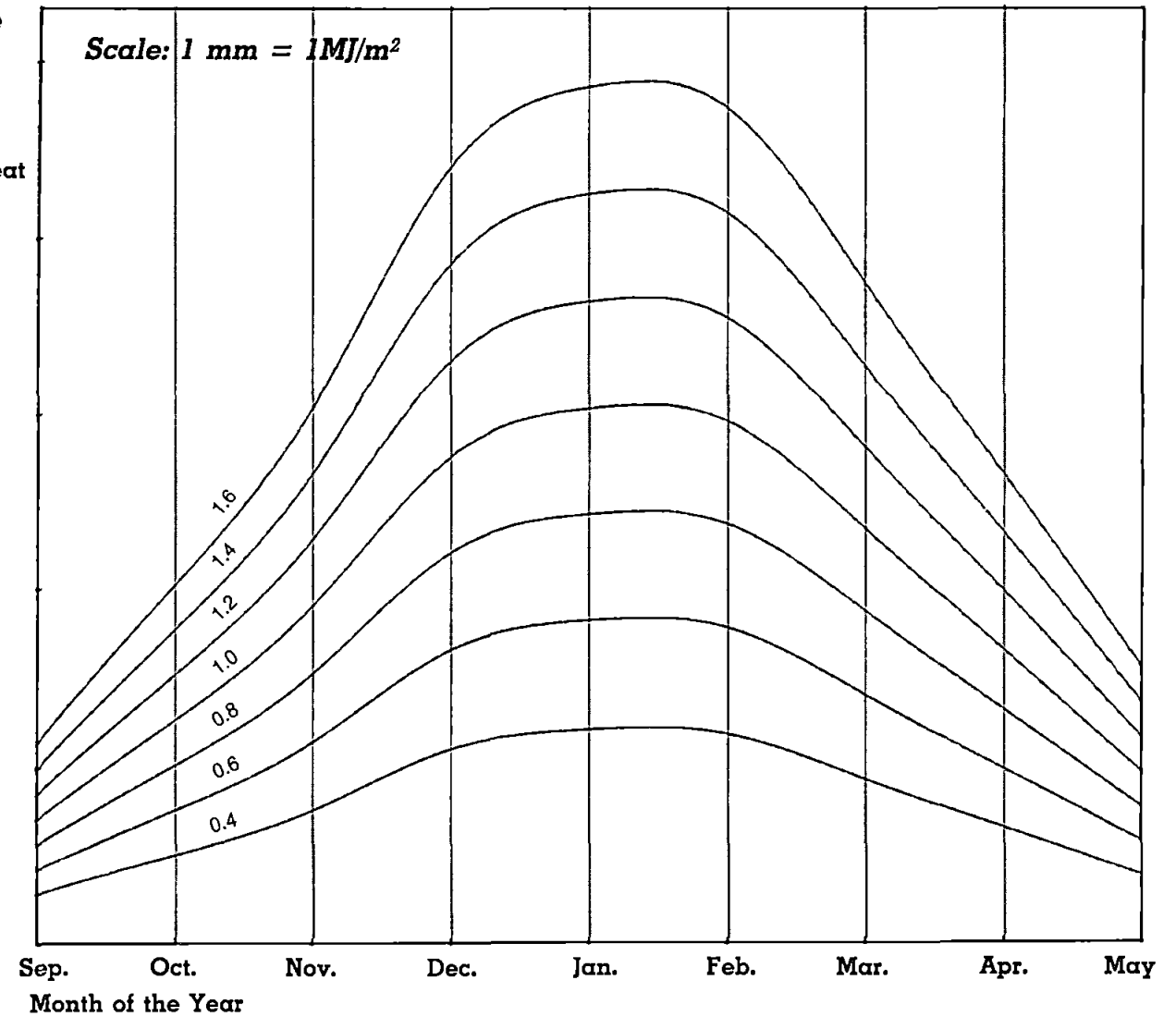
Solar Gains Graph

(57)
South glass/floor area



Above-Grade Heat Loss Graph

(31)
Above-grade heat loss coefficient W/°Cm²



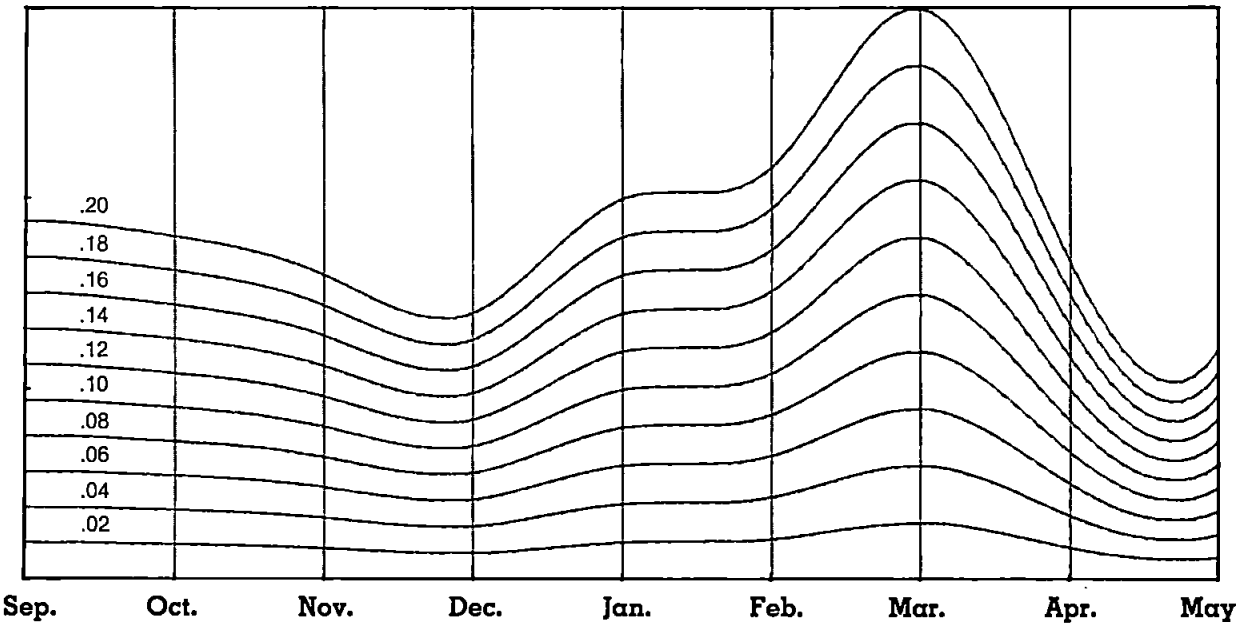
CLIMATE DATA: CHARLOTTETOWN, P.E.I.

Mean annual outdoor temperature 5.6°C (1)

Mean January temperature at noon −2.8°C (2)

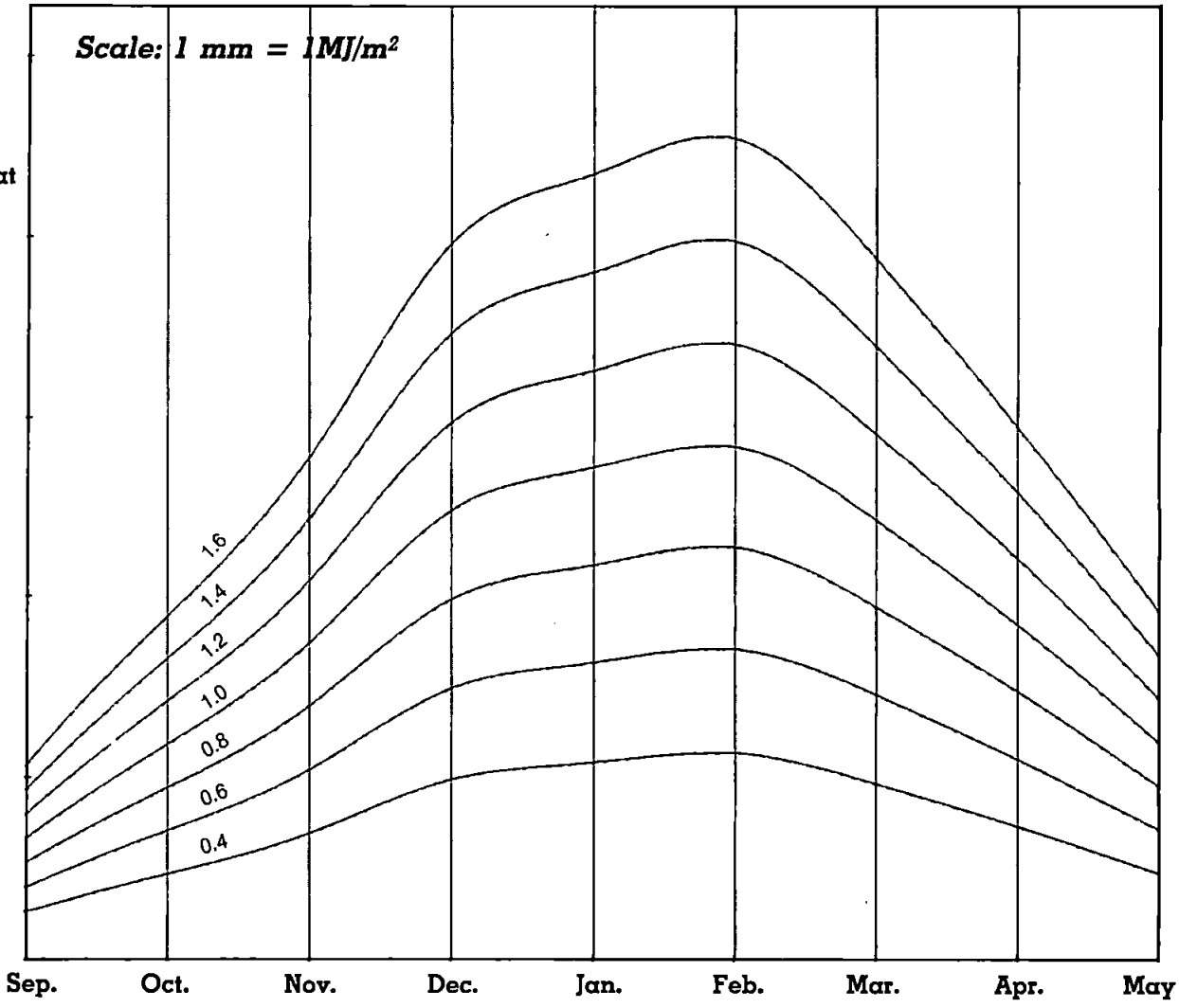
Solar Gains Graph

(57)
South glass/floor area



Above-Grade Heat Loss Graph

(31)
Above-grade heat loss coefficient W/°Cm²



Month of the Year

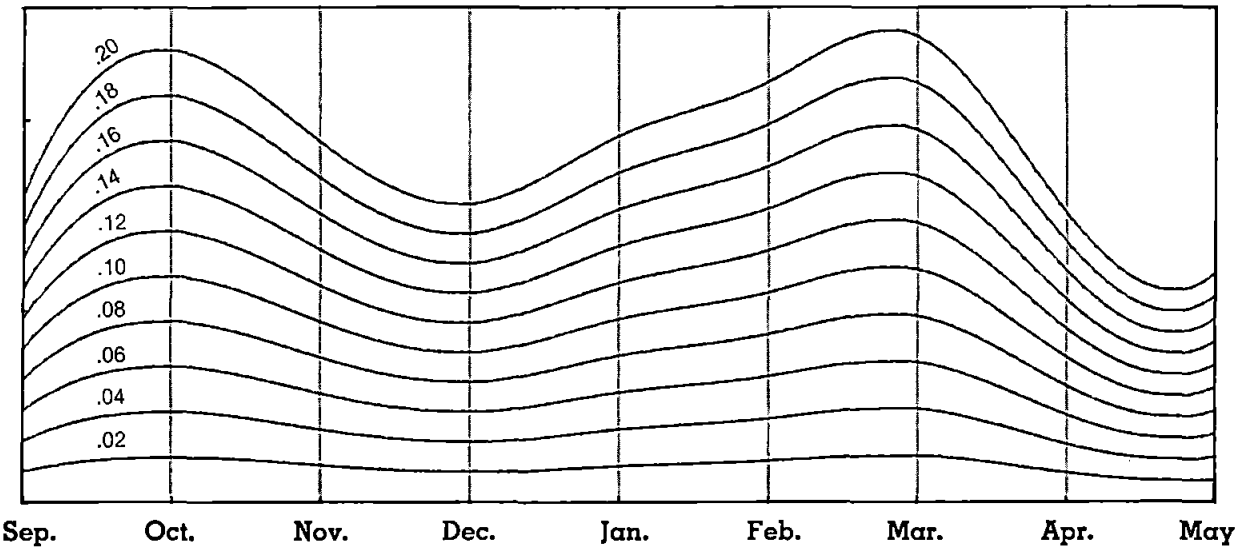
CLIMATE DATA: HALIFAX, N.S.

Mean annual outdoor temperature 6.0°C (1)

Mean January temperature at noon −1.8°C (2)

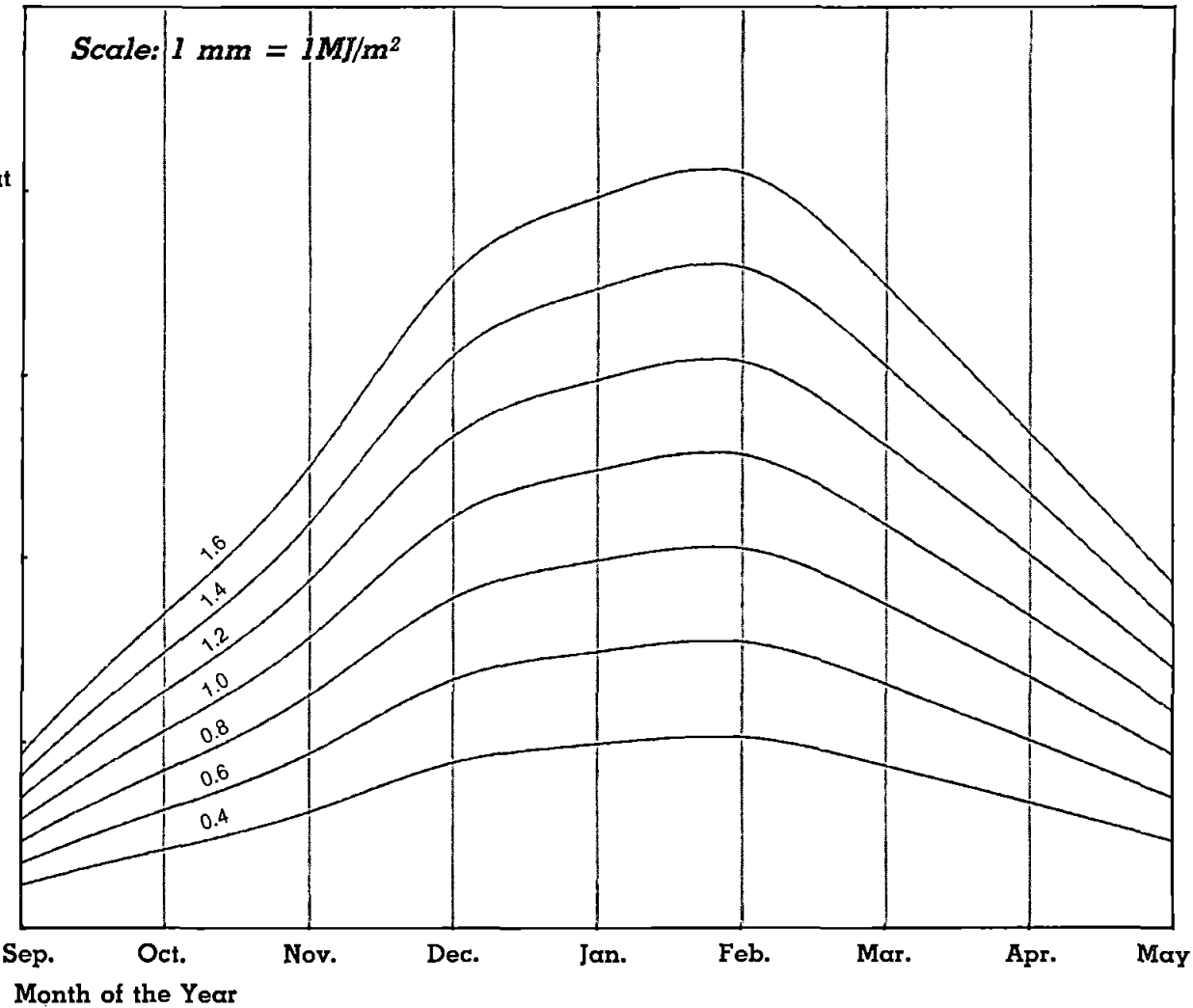
Solar Gains Graph

(57)
South glass/floor area



Above-Grade Heat Loss Graph

(31)
Above-grade heat loss coefficient W/°Cm²



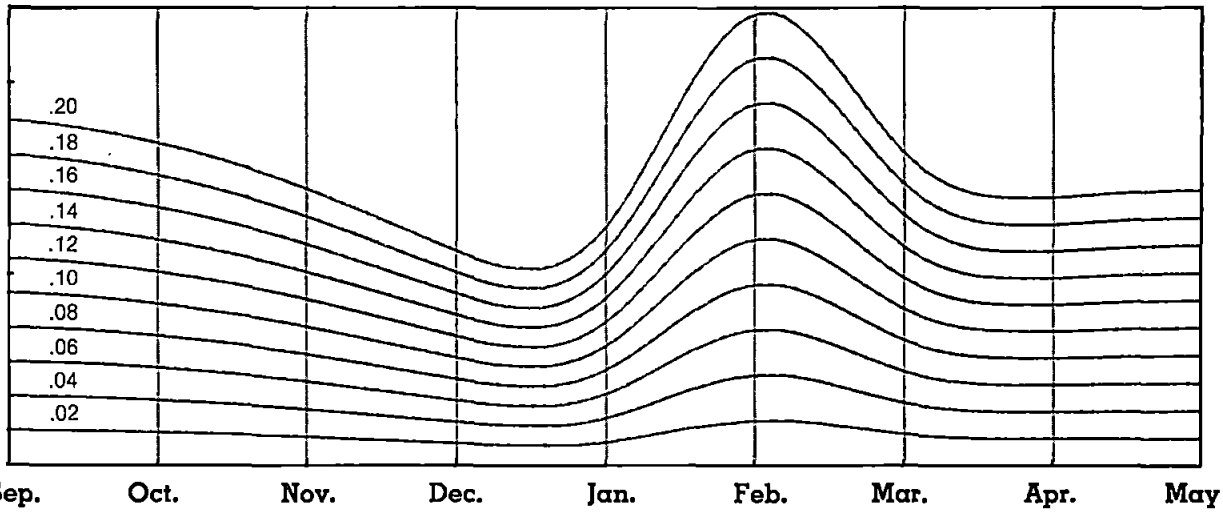
CLIMATE DATA: ST. JOHN'S, NEWFOUNDLAND

Mean annual outdoor temperature 4.9°C (1)

Mean January temperature at noon −0.6°C (2)

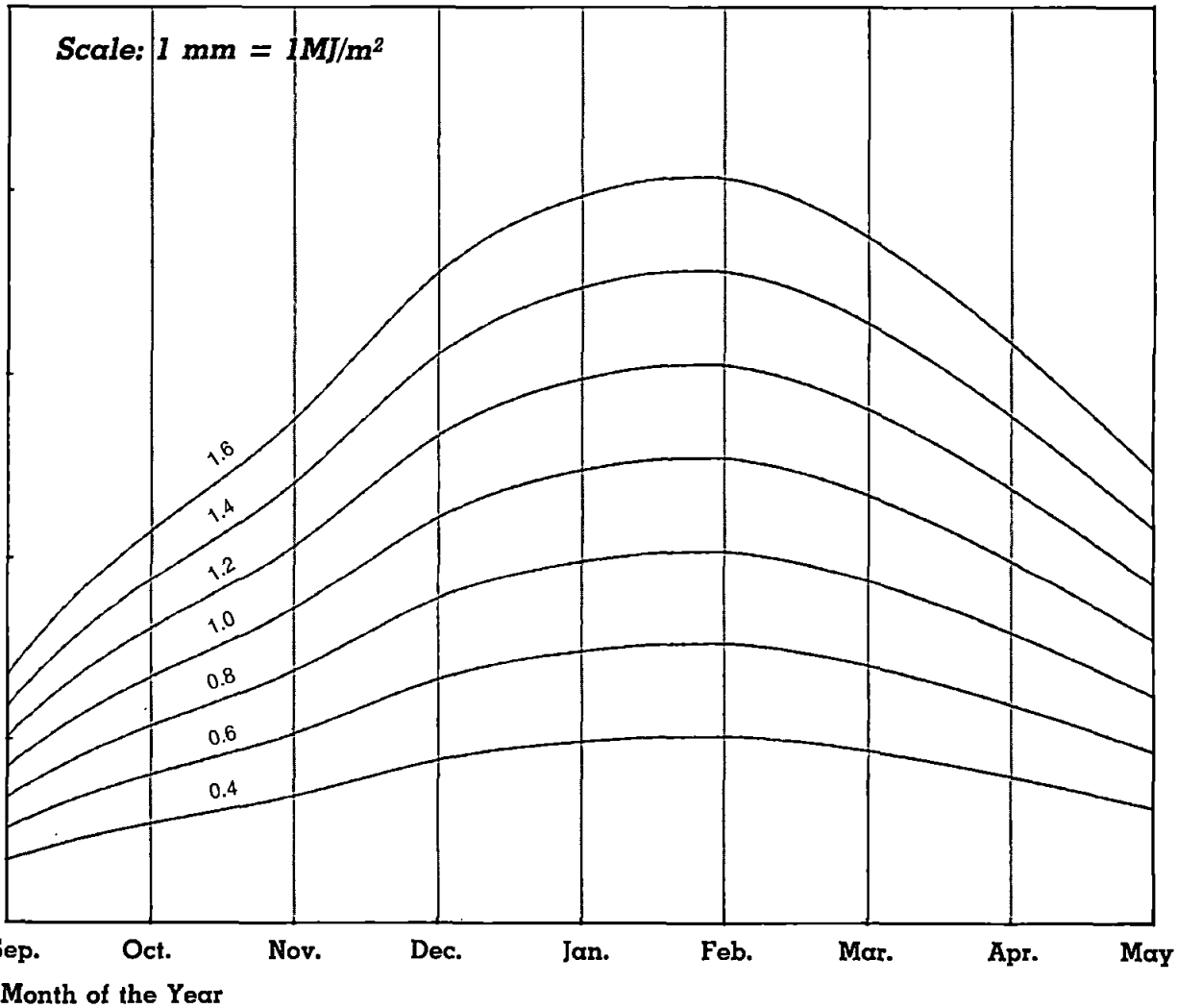
Solar Gains Graph

(57)
South glass/floor area



Above-Grade Heat Loss Graph

(31)
Above-grade heat loss coefficient W/°Cm²



Month of the Year

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