Calculating energy budgets for new schools

Jones, L.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/20338279
Internal Report (National Research Council of Canada. Division of Building Research), 1978-12-01

CALCULATING ENERGY BUDGETS FOR NEW SCHOOLS

by L. Jones

Private copy for: Library

DBR Internal Report 448

TABLE OF CONTENTS

Page

SECTION B

NATIONAL RESEARCH COUNCIL OF CANADA

DIVISION OF BUILDING RESEARCH

DBR INTERNAL REPORT NO. 448

CALCULATING ENERGY BUDGETS FOR NEW SCHOOLS

by L. Jones

Checked by: D.G.S. **Approved by:** L.W.G. **Date:** December 1978

Prepared for: limited distribution

This report is concerned with the development of a rational method of calculation and application of 'Energy Budgets' for new buildings. Specifically it reports on energy budgets for new school construction in Canada.

The document is in three main sections:

(1) An introduction and brief description of energy budgets and performance standards.

(2) The definition of a computer model which could be used to calculate energy budgets for schools.

(3) Reports of analyses carried out, based on the computer model, to determine suitable energy budgets and determine what parameters should be considered in setting such budgets.

SUMMARY AND RECOMMENDATIONS

1. The purpose of study - To develop a method of calculating *Energy Budgets for use with Performance Code. (*Annual unit energy allowance for which the building should be designed and/or operated). Deals specifically with schools.

2. Method adopted - To calculate energy use of a series of hypothetical school buildings and check consistency/trends with available fuel consumption records.

3. A set of rules/prescriptions were developed to define school models. Physical layout of schools was based on consideration of existing facilities (Ottawa); thermal performance to ASHRAE 90-75 - Section A.

4. Extensive use made of Meriwether ESA series (ERE only) to calculate energy consumption figures for various sizes of schools in 11 locations throughout Canada.

5. The results of the calculations/analyses are presented in Section B of the report (p. 70), the salient points are detailed below.

6. The setting of Energy Budgets based on a computer model appears satisfactory although the model could be refined. See "Possible Changes to School Model" at end of summary (p. 5).

   A data base is useful to compare/verify the results of the model but is not considered suitable on its own to define budgets because:

   a. records (data base) reflect pre-energy conscious design,

   b. large variations in fuel consumptions make trends difficult to perceive and it is almost impossible to quantify the major influences on energy consumption.

7. Analyses show that school type, size, location and hours of use all have significant but varying effects on energy consumption and that all of these factors must be considered when setting energy budgets for schools.

8. School type - Two groups have been identified for the analysis, primary and secondary. The two groups can be considered as having differing occupancy density, activities and physical requirements.

9. Size - Because of scaling effects (less exposed area per unit of floor area in larger buildings) energy use, particularly heating, is strongly related to the building size. It is suggested that energy budgets for schools can be specified as a function of gross floor area, i.e., kW•h/annum/sq ft floor area. (This may not be a suitable base for other classes of buildings, e.g., for tall office buildings where site restrictions prevent the construction of a compact building, some allowance may be deemed desirable based on the number of levels/floors.)

An additional study suggests that it is not practicable to normalize the effects of size by forcing smaller buildings to have a higher standard of construction.

10. Location - The location/climate affects building energy consumption in various degrees depending on the building size and hours of use. The energy using systems in a building are, in turn, affected in varying amounts by different aspects of the climate. It is assumed that some energy using systems, e.g., lighting, are not influenced by climate.

An energy budget for a building can be arrived at with consideration of those specific aspects of the local climate that affect the individual component systems' energy consumption. This is best achieved by using meteorological data for the actual city in which the building is to be constructed, and not by using climatic zones (see Sections B4 (p. 90), B5 (p. 95) and B8 (p. 114).

Analyses so far indicate that the following factors can be used to define components of the total building energy budget:

(i) Heating - normal heating degree days.

(ii) Cooling - "cooling degree days" (specifically degree hours > 55°F/24).

(iii) Fans (Heating) - winter design temperature.

Further analyses could provide relationships for the remaining components, i.e., fan (A/C), heating and cooling peripherals and domestic hot water (DHW). It may, however, where the effect on the total consumption is minimal, be desirable to make the following simplifications:

(a) to combine components, e.g., heating and heating peripherals, and

(b) to assume some components independent of climate, e.g., DHW.

11. Hours/Pattern of Use - This presents one of the larger unresolved problems in the application of Energy Budgets - it is particularly troublesome if post construction monitoring is the means by which compliance with the energy code is determined.

Two major problems are apparent:

(i) The calculation of energy consumption is dependent on the assumed usage profiles; e.g., for lighting, occupancy, DHW and miscellaneous equipment. It is felt that the current knowledge of such aspects is not adequate to present a realistic modelling of actual use.

(ii) No two schools are likely to operate on identical schedules particularly when schools are used extensively for "community activities". A direct correlation of energy consumption with hours of use is unlikely. Further monitoring of usage to determine compliance with the energy code would be a problem, not only would hours of use be required but also when it was used (winter/summer, day/night) and to what extent it was occupied (e.g., 1 classroom/all classrooms).

12. Because the hours of use significantly affect the energy use, particularly that required for lighting and heating, ventilating and air-conditioning (HVAC) fans, it is not considered appropriate to set budgets such that extensive community activity is possible within the budget since this would result in unreasonably high allowances for those schools with minimal community use.

These problems can be avoided in part (i) and total (ii) if a pre-construction energy analysis check is used to determine compliance with the energy code.

13. Fundamental to the adoption of a performance code is the ability to calculate energy consumption with some degree of accuracy and consistency. Recent studies show that this is not always achievable (AEC Symposium 1971, Spielvogel - ASHRAE Semi-annual Conference Halifax 1977, Ayres - HPAC Feb 1977. International Energy Agency - Comparison of Load and Energy Analysis Computer Programs in Progress. NRC comparison of 22 analyses carried out on a test building using the Meriwether ESA series).

14. Until energy analysis techniques can be relied on to produce consistent results that model actual energy consumptions (this as yet has no wide scale verification), it seems inappropriate to adopt post control monitoring as the means of satisfying compliance with the energy code.

15. Due to problems described above and in 11, it is suggested that:

(i) initially compliance with the energy code be set by pre-construction analysis. (A methodology to limit variations in input - resulting from "engineering judgement" should be developed);

(ii) energy monitoring and reporting be made compulsory and would be used to check consistency of actual and calculated consumption but would have no mandatory significance; and

(iii) the energy consumption records to be used to aid the development and change to code compliance by means of post-construction monitoring.

16. It is accepted that post construction monitoring is the desirable end goal to minimize energy use. (Poor building management and faulty design cannot be controlled by pre-construction checks.) In the meantime, however, it is hoped that (ii) above will encourage good energy management.

Possible Changes to School Model

(1) Below 10,000 sq ft, go to simple plan building.

(2) Below 40,000 sq ft, go to mechanical ventilation with perimeter radiation.

(3) Decrease U values to Canadian Code.

(4) Decrease U values as building size reduces.

(5) Improve estimates of miscellaneous electrical use.

(6) Adjust fresh air minimum to reflect practical minimum mixing percentages.

(7) Improve daily usage profiles to reflect more typical operation.

(8) Improve DHW estimate.

(9) Re-appraise environmental criteria used, particularly lighting and minimum air movement.

(10) Re-appraise infiltration rates and modeling.

(11) Add summer maintenance schedules to standard school use pattern.

(12) Consider calculating and presenting budgets by defined areas, e.g., classrooms, laboratories, cafeterias, gymnasium, etc.

(13) Confirm or otherwise, acceptable life cycle cost of school built to meet budget derived from model.

INTRODUCTION

While there is a growing agreement that some form of positive influence, beyond normal market forces, is required to reduce significantly the amounts of energy consumed in buildings, there is much dispute on the form this "influence" should take.

At present, attention is being focused on the formulation of, or modification to, building codes in order to include some form of mechanism for reducing energy consumption. Two approaches to the problem are generally considered, either to have a "prescriptive" standard, where constraints are placed on individual building components and systems, or a "performance" standard where the only constraint is that the building in use must not exceed a specified consumption.

The most widely known energy standard to date is that published by ASHRAE, Standard 90-75 "Energy Conservation in New Building Design." This Standard has been adopted, or used as a basis for mandatory controls, in several American States, and is essentially a "prescripitive standard."

Despite the Standard's widespread general acceptance there are two groups who have taken exception to it (1); of particular importance is the American Institute of Architecture who claim the Standard is restrictive to design and who have stated their preference for a "performance oriented" code.

A recent critique of the Standard (2) does not recommend its adoption for use in Canada but instead suggests the alternative route of performance oriented legislation. To this end the National Research Council of Canada was assigned the task of co-ordinating the preparation of a "model standard" for energy conservation in buildings.

A performance type standard was envisaged for new buildings that would give maximum freedom of choice to the designers and operators of buildings, the required performance to be specified in the form of an "energy budget" that must not be exceeded when the building is in use. In the case of housing and other small buildings with simple heating systems it was suggested that designers be allowed to choose between a set of prescriptive standards or meet the energy budget. All other buildings should be governed by an energy budget, the intention being that the building designer should carry out an analysis to show that a proposed building could be operated without exceeding the allowable energy budget. Further it was suggested that after the building is in use an annual energy consumption report be submitted by the building operator to show that the building is operating in an efficient manner. This check on the building's operation is considered most desirable since there is considerable evidence to suggest that poor operation and maintenance can significantly increase a building's energy consumption.

This report is concerned with the calculation of energy budgets for new schools, for use with the model standard and is based on the following proposals:

(i) Energy budgets should be produced for differing types of occupancy; and in the first instance budgets should be prepared for offices and schools only.

(ii) These energy budgets should be set both by examination of existing building consumption records and by analysis of a hypothetical building.

(iii) The energy budgets should be moderated by climate. It was proposed that a particular budget should apply over a limited specified zone or "Climatic Area". An alternative climatic modifier is suggested in this report.

(iv) The Standard should be cognizant of the differing rate of consumption of primary fuel resources. This requires that different forms of energy be reported separately and their impact on available fuel and energy resources considered.

Initial consideration of available information suggested that the budgets be related to the size and type of school (i.e., primary or secondary) and that some account be made for differing hours of use.

REFERENCES

(1) Status Report: Standard 90-75. A Presidential Statement on the Occasion of ASHRAE Standard 90-75's First Birthday. Heating/Piping, Air-Conditioning, Vol. 48, No. 9, September 1976, p. 51.

(2) Stephenson, D.G. Proposed guidelines for the design of building enclosures and lighting systems for use in Canada in place of Sections 4 and 9 of ASHRAE Standard 90-75 on Energy Conservation in New Building Design. 11 p., January 1977. (Internal Report No. 433).

SECTION A

DEFINITION OF SCHOOL MODEL

The following section defines in detail the building model proposed to calculate energy budgets for new school buildings.

The parameters used are considered to be reasonably energy conservative, typical of school construction, and practicable; it should, however, be readily possible to design buildings with better consumption figures.

1. BUILDING DESCRIPTION

1.1 Size and Shape

1.1.1 General

Because the shape of a building has a considerable impact on fuel consumption and since internal planning requirements restrict the shape, it was felt necessary to have an appreciation of school planning to avoid choosing a model which is neither representative of school buildings, nor capable of accommodating school facilities effectively.

With this in mind, a brief study of school layout planning was carried out based on schools operated by the Carleton School Board. From the results obtained the following model is suggested.

1.1.2 Definition

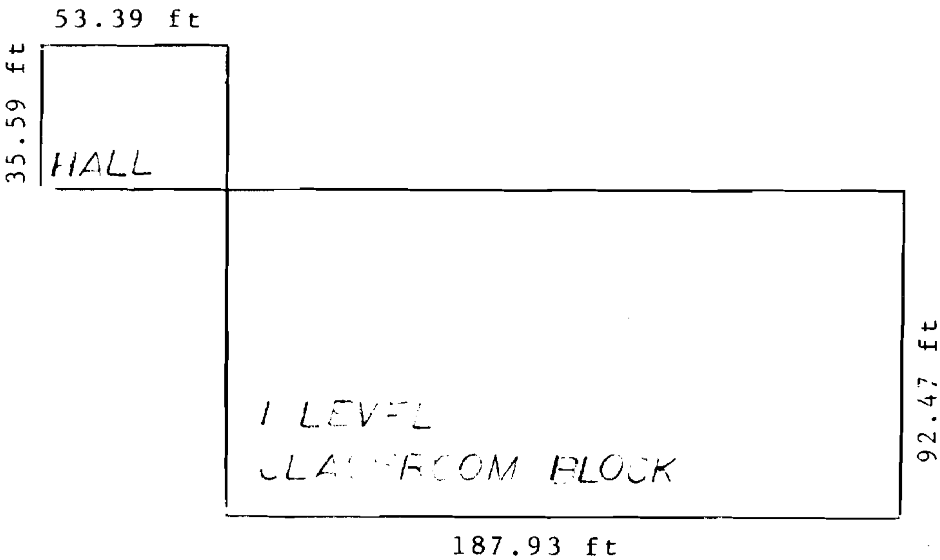
The model is assumed to comprise of:

(i) Gynmasia/auditoria/hall, occupying 10 per cent of the total floor area in Primary Schools and 14 per cent in Secondary. The longer plan dimension being 1.5 times that of the shorter.

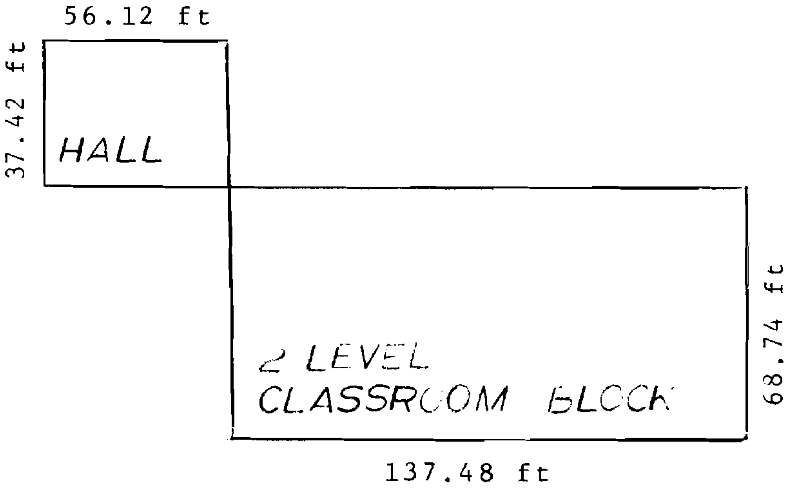
(ii) Single or two level teaching block. Based on practical planning arrangements, assuming a typical classroom area of 780 sq ft with a minimum plan dimension of 23 ft all schools over 20,000 sq ft are assumed to be two level. The larger plan dimension is assumed to be twice that of the shorter. The classroom block has no common walls with the Gym/Hall block.

1.1.3 Examples

For a 19,000 sq ft Primary School the arrangement is assumed to be:



and for a 21,000 sq ft, school it is assumed to be:



1.2 Internal Planning

1.2.1 General

To make allowance for differing environmental criteria and varying usage the model has been developed from a consideration of the separately identifiable areas within the over-all school plan. Table 1.2.1(1) lists the average values for area usage as percentages of total floor area. The values were arrived at by looking at some 25 arbitrarily selected schools (Carleton School Board).

TABLE 1.2.1(1)

	Classroom	Special Teaching	Total Teaching	Auditoria/ Cafeteria	Gymnasia	Combined Usage	Toilet and Changing	Administration	Teachers	Plant Rooms	Storage
Primary	38%	12%	50%	-	-†	10%	4%	1.5%	1.5%	1.5%	2%
Secondary	14%	22%	36%	5%	8%		3%	2%	2%	5%	2%

† nominal number have a gymnasium

where:

Special Teaching includes

Primary - library and kindergarten

Secondary - art rooms, science labs, library, workshops, music rooms and library, drafting offices, seminar and lecture theatre, secretarial/business machines.

Remaining areas consist of cloakrooms, circulation, kitchen, etc.

For the purpose of the model the values given in Table 1.2.1(2) are used.

TABLE 1.2.1(2)

	Classroom	Special Teaching	Auditoria/Cafeteria	Gymnasium	Common Usage Hall	Toilet and Changing	Administration	Teachers	Circulation, Cloaks	Plant Rooms and Storage (Non-Serviced)
Primary	40%	15%	-	-	10%	4%	2%	2%	21%	6%
Secondary	18%	27%	6%	8%	-	4%	2%	2%	26%	6%

1.3 Building Height

For the purposes of the model the following heights are assumed:

Gymnasia, Auditoria and Halls: 26 ft over-all height with 21 ft floor to ceiling in Auditoria and Hall (Gymnasia clear height)

Classroom Block: 12 ft 6 in. over-all height per floor with 9 ft 0 in. floor to ceiling.

1.4 Building Orientation

The "major axis" of the building is SW to NE.

2. CONSTRUCTION

2.1 General

The construction meets the requirements of ASHRAE 90-75 with the following restraints.

2.2 Fenestration

Gymnasia and auditoria are unglazed. All other areas are double glazed with sealed double pane and have internal medium coloured venetian blinds. (For the purposes of calculation the blinds are assumed down continuously and shading coefficient = 0.57).

The glazing is distributed equally around the perimeter with 25 per cent of the wall area glazed (as viewed from inside).

2.3 Fabric

The wall transmittances are selected from ASHRAE 90-75 based on the locality of the building and the glazing details as just described.

2.4 Building Weight

The building is assumed to be of "Medium Weight" construction - 70 lb of material/sq ft of floor area.

3. OCCUPANCY

For the purpose of the model definition the design occupancy densities in Table 3 have been assumed.

TABLE 3

Area	Square feet/occupant (1)		ASHRAE
	Primary	Secondary	Standard 62-73
Classrooms	25	40	20
Special Teaching	40	70	33
Auditoria	-	20	7
Gymnasia	-	100	14
Combined Usage Auditoria	20	-	14
Toilet and Changing (2)	10	10	10
Administration	200	200	100
Teachers	20	20	14
Circulation and Cloakrooms (2)	30	40	20
Teaching Block Composite Figure (3)	60	115	-
Over-all Figure	70	130	-

(1) Includes staff at staff/student ratio of 1.20
Over-all figures compare with schools at
CBOE - Primary 71.5 sq ft/occupant, Secondary 128 sq ft/occupant
Waterloo - Combined 98 sq ft/occupant (~50% area primary, 50% secondary)

(2) Not simultaneous occupancy areas, i.e., occupants from other specified zones.

(3) Teaching block composite figure is based on occupancy of classrooms, special teaching and administration (i.e., simultaneously occupied areas) and assumes that only 80% of this area is used at any one time.

4. BUILDING USAGE

4.1 General

Because of varied community use of schools no two school buildings operate on identical schedules and between any two schools the occupancy pattern may vary considerably.

In order to consider the variation of energy consumption with hours of use the following three occupancy periods are defined for use with the building model:

(a) Basic school use;

(b) School used during the evenings on "school days"; and

(c) School used through year, i.e., evenings, weekends and for summer school.

4.2 Period of Operation

For ease of computation the energy budget figures are calculated for a calendar year and not for an academic year (September to September). Computations are based on 200 days of operation between the following dates:

2 January to 25 March
1 April to 30 June, with a holiday 19 May
2 September to 19 December, with holidays 11 October and 11 November
(Based on 1975 calendar, 1 January was a Wednesday)

For those cities whose Test Reference Year weather data is a leap year the following dates are used:

2 January to 14 April inclusive
22 April to 30 June inclusive, with a holiday 24 May
2 September to 21 December inclusive, with holidays 6 September, 11 October and 11 November
(Based on 1976 calendar 1 January was a Thursday)

4.3 Table of Basic Schedules

The following schedules define the school's operation:

Schedule Number	
1.	Lighting - School Day Classrooms
2.	Lighting - School Day Gymnasium and Auditorium
3.	Lighting - Weekend and Holidays - All Areas
4.	Occupancy - School Day Classrooms, Gymnasium
5.	Occupancy - School Day Auditorium
6.	Occupancy - Weekend and Holidays - All Areas

7. Domestic Hot Water - School Day Classroom
8. Domestic Hot Water - School Day Gymnasium
9. Domestic Hot Water - Weekend and Holiday

The schedules can be found in Appendix A.

4.4 Supplementary Schedules (for community use)

4.4.1 Weekend and vacation use

For weekend and vacation use the same schedules as for standard schooldays are used.

Lighting	-	Classrooms - Schedule #1
Lighting	-	Gymnasium and Aduitorium - Schedule #2
Occupancy	-	Classrooms, Gymnasium - Schedule #4
Occupancy	-	Auditorium - Schedule #5
*DHW	-	Classrooms - Schedule #7
DHW	-	Gymnasium - Schedule #8

4.4.2 Evening use

Six new schedules are proposed.

4.4.3 Table of supplementary schedules

Schedule Number		
9.	Lighting	- Classroom
10.	Lighting	- Gymnasium, Auditorium
11.	Occupancy	- Classrooms and Gymnasium
12.	Occupancy	- Auditorium
13.	DHW	- Classrooms
14.	DHW	- Gymnasium

5. ENVIRONMENTAL CRITERIA

5.1 General

Based on ASHRAE 90-75, the conditions for each of the areas defined in Section 1 are tabulated in Tables 5.1(1) and 5.1(2). Where the classification covers areas with differing criteria average values or ranges are given. The values given in these tables are those used in the model and are not necessarily recommended values.

*DHW = Domestic Hot Water

TABLE 5.1(1)

ENVIRONMENTAL CRITERIA - PRIMARY SCHOOLS

	Temperature		Humidity		Ventilation			
	Winter	Summer	Min^{m} Winter	Max^{m} Summer	OA per (1) person	OA per (2) sq ft	*Lighting Level ft candles	Air Movement (min^{m}) cfm/sq ft
Classrooms	72	78 (8)	30	60	5	0.2	70 (3)	0.5
Special Teaching	72	78 (8)	30	60	5	0.125	15-70 (3)	
Combined Use Auditorium	68	78 (8)	30	60	5	0.25	50 (3)	
Toilet and Changing	72	78 (8)	(6)	60	6.7 (4)	0.67 (Extract Rate)	20-30 (3)	
Administration	72		30	60	5	0.025	70 (3)	
Teachers	72		30	(5)	5	0.25	70 (3)	
Plant Rooms	(7)	78 (8)	(6)		-	0	10	-
Storage	(7)	78 (8)	(6)	-	-	0	25	-
Circulation and Cloakrooms		78 (8)			5 (4)	0.17 (Extract Rate)	25	

NOTE: Numbers in parentheses refer to the Notes on p. 16.

*Alternative lighting levels are suggested in Section B2

TABLE 5.1(2)

ENVIRONMENTAL CRITERIA - SECONDARY SCHOOL

	Temperature		Humidity		Ventilation			
	Winter	Summer	Min^{m} Winter	Max^{m} Summer	OA per(1) person (cfm)	OA per(2) sq ft (cfm)	*Lighting Level ft candles	Air Movement (min^{m}) cfm/sq ft
Classrooms	72	72(9)	30	60	5	0.125	70(3)	0.5
Special Teaching	72	72(9)	30	60	5	0.071	15-70(3)	
Auditoria	72	72(9)	30	60	5	0.25	15-70(3)	
Gymnasia	65	(5)	30	(5)	6.7	0.067	30	
Toilet and Changing	72	(5)	(6)	(5)	6.7(4)	0.67 (Extract Rate)	20-30(3)	
Administration	72		30	60	5	0.025	70(3)	
Teachers	72		30	(5)	5	0.25	70(3)	
Plant Rooms	(7)	(5)	(6)		-	-	10	-
Storage	(7)	(5)	(6)	-	-	-	25	-
Circulation and Cloakrooms		(5)			5(4)	0.13 (Extract Rate)	25	

NOTE: Numbers in parentheses refer to the Notes on p. 16.

*Alternative lighting levels are suggested in Section B2

Notes

(1) Assumes recirculating HVAC systems

(2) Based on occupancy density as per Table 3

(3) Equivalent sphere illumination

(4) These areas not simultaneously occupied zones, i.e., occupants removed from other areas therefore extract only from these areas, ventilation by virtue of make-up air

(5) These areas are non air-conditioned and consequently no humidity control in summer

(6) No winter humidification provided

(7) These areas are not conditioned

(8) It is assumed that primary schools are not air-conditioned - increased ventilation which may be required to maintain suitable conditions in warmer weather assumed to be provided by opening windows

(9) A constant year round temperature of 71°F is used.

Over-all Outside Air Supply Rate: Teaching Block

Based on the occupancy rates, air volume and mix of areas in the teaching block, the over-all outside air supply rates have been calculated as:

Primary - cfm/sq ft 0.085

Secondary - cfm/sq ft 0.045

6. DIVISION OF BUILDING INTO THERMAL BLOCKS

6.1 General

For the purpose of mathematical modelling the building is divided into "Thermal Blocks" as described in the following sections.

6.2 Major Divisions

The major divisions are, based on usage and comprising:

(i) Gymnasium

(ii) Auditorium

(iii) General Purpose Hall

(iv) Teaching Block

6.2.1 Gymnasia

A single space (Secondary Schools)

6.2.2 Auditoria

A single space (Secondary Schools)

6.2.3 General purpose

A single space (Elementary Schools)

6.2.4 Teaching block

Comprising one or more thermal blocks.

Assuming non-open plan teaching spaces the internal division can be considered an acceptable division into thermal blocks.

For purposes of the model a standard method of division into thermal blocks, depending on the over-all building size, is used viz.

Single Level

Up to 10,000 sq ft floor area - 2 thermal blocks (Fig. 6.2.4(1))

10,000 to 20,000 sq ft floor area - 3 thermal blocks (Fig. 6.2.4(2))

Two Level

20,000 to 40,000 sq ft floor area - 4 thermal blocks (Fig. 6.2.4(3))

40,000 ⟶ sq ft floor area - 6 thermal blocks (Fig. 6.2.4(4)).

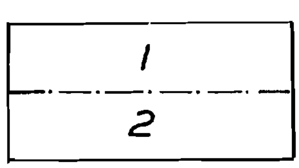


Figure 6.2.4(1)
5-10,000 sq ft (Single Level)

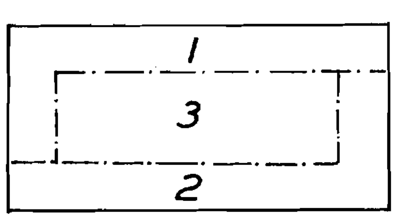


Figure 6.2.4(2)
10-20,000 sq ft (Single Level)

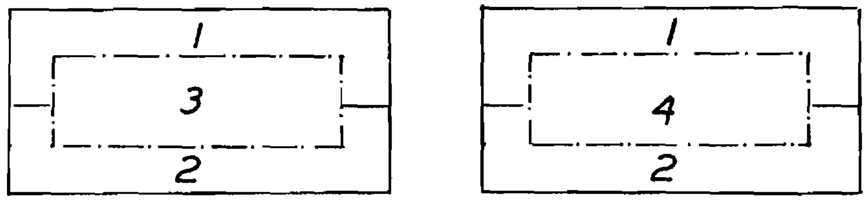


Figure 6.2.4(3) 20-40,000 sq ft (Two Level)

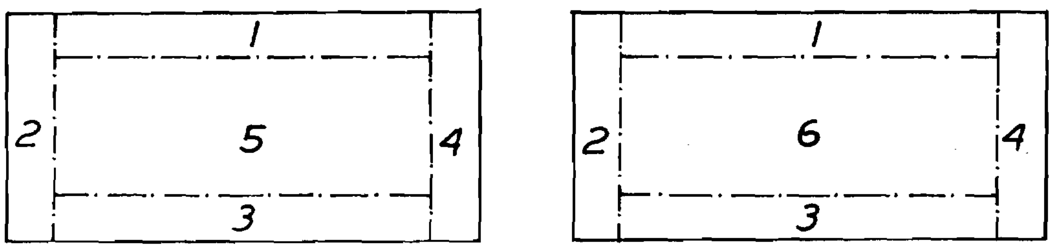


Figure 6.2.4(4) 40,000 ⟶ (Two Level)

NOTE: Width of Perimeter Zones = 28 feet

7. SPACE INTERNAL LOADS

7.1 General

Space internal loads are considered to result from occupancy and lighting only.

7.2 Occupancy

Based on the occupancy densities given in Table 3, the resultant peak sensible occupancy gains are detailed in Table 7.2

TABLE 7.2

Area	Density (sq ft per occupant)	Gain (Btu/hr per occupant)	Per Cent latent	Gain (Btu/hr sq ft)
Gymnasium	100	1100	50	11
Auditorium (Secondary)	20	430	40	22
Hall (Primary)	20	360	40	18
Class (Primary)	60	360	40	6.0
Class (Secondary)	115	430	40	3.8

7.2.1 Weighted occupancy profiles

The use of a "weighted profile" for the radiant heat gain from occupancy is used calculated in the following manner: Latent and convective gains are assumed to follow the occupancy profile. Thirty-four per cent of the sensible gain is assumed to be convective. The radiant component is lagged in the following manner:

$$q_{(n)} = a_o W_{(n)} + a_1 W_{(n-1)} - biq_{(n-1)}$$

where

$q_{(n)}$ = radiant component of sensible cooling load for occupants at time n, and

$W_{(n)}$ = occupancy radiant heat gain at time n.

a_o, a_1 and b_1 the weighting factors, are taken to be 0.43, -0.3 and -0.87 respectively. These values are typical for a "medium weight" construction. Weighted schedules are given in Appendix B.

The instantaneous and lagged "peak loads" to which the schedules will apply have been calculated from Table 7.2 and are given in Table 7.2.1

TABLE 7.2.1

Area	Instantaneous Btu/hr sq ft (convective and latent)	Per Cent latent	Lagged Btu/hr sq ft (radiant)
Gymnasium	7.36	75	3.63
Auditorium (Secondary)	13.29	66	8.71
Hall (Primary)	10.87	66	7.13
Class (Primary)	3.62	66	2.38
Class (Secondary)	2.28	66	1.52

7.3 Lighting

Based on the lighting levels given in Tables 5.1(1) and 5.1(2) and the area mix of spaces in the Teaching Block, and using the ASHRAE 90-75 procedure for the calculation of a "Lighting Budget" the resultant peak lighting loads were estimated. The resultant loads are shown in Table 7.3. (An alternative model with lower installed lighting load is considered in Section B2, p. 80.)

TABLE 7.3

Area	Installed Lighting Level (watts/ft^2)	Space Load (Btu/hr ft^2)
Gymnasium	1.1	3.75
Auditorium General Purpose	2.9	9.89
Classroom Block	2.3	7.85

7.3.1 Weighted lighting profiles

Weighted lighting profiles are used to simulate the heat storage effects of the building. ASHRAE coefficients of Room Transfer Functions are used to weight the lighting profiles.

$$q_{(n)} = a_1 W_{(n-1)} + a_2 W_{(n-2)} + b q_{(n-1)}$$

$q_{(n)}$ = cooling load for lights at t = n

$W_{(n)}$ = power input to lights at t = n

a_1, a_2 and b_1, the weighting factors, are taken to be 0.53, -0.4 and 0.87 respectively. These values are for fluorescent fixtures recessed into a suspended ceiling, ceiling plenum not ventilated and "Medium Weight Structure". The weighted profiles are shown in Appendix B.

7.4 Miscellaneous

With the exception of domestic hot water the building model does not include non HVAC/lighting equipment such as audio/visual aids, catering equipment, etc.

7.4.1 Domestic hot water

Hot water energy consumption peaks: 150 Btu h/student for school classroom areas and 160 Btu h/student for gymnasia.

Based on square footage this becomes

Primary Schools	- Classroom Block	- 2.5 Btu h/sq ft
Secondary Schools	- Gymnasium	- 1.6 Btu h/sq ft
	Classroom Block	- 1.3 Btu h/sq ft

8. EXTERNAL LOADS

8.1 Weather Data

The operation of the building as defined so far, is modelled through a year's operation using weather data, based on "Test Reference Years", for the following locations:

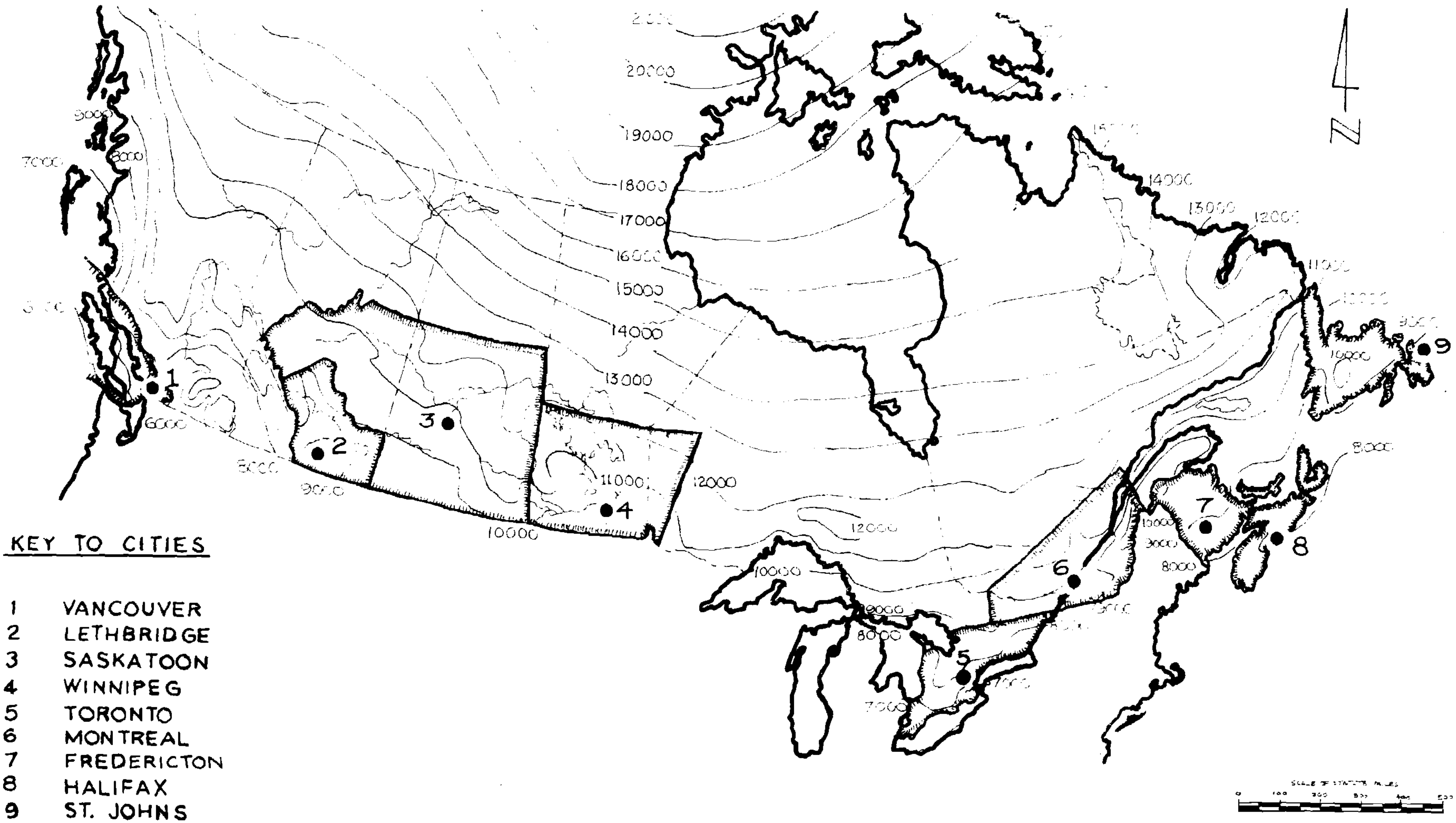
Weather Station	Year
1. Vancouver Intl. Airport	1959
2. Lethbridge Airport	1956
3. Saskatoon Airport	1956
4. Winnipeg Intl. Airport	1970
5. Toronto Intl. Airport	1968
6. Montreal Intl. Airport	1966
7. Fredericton Airport	1966
8. Shearwater Airport	1971
9. St. John's. Newfoundland	1963

The Test Reference Years were selected on the basis of recommended ASHRAE procedure (Don Boyd method).

Associated with each set of weather data is an area over which the data can be considered representative. These areas are defined on Figure 8.1

FIG. 8.1
REFERENCE CITY LOCATIONS AND CLIMATIC AREAS

ISO DEGREE-DAY LINES SHOWN



KEY TO CITIES

1 VANCOUVER
2 LETHBRIDGE
3 SASKATOON
4 WINNIPEG
5 TORONTO
6 MONTREAL
7 FREDERICTON
8 HALIFAX
9 ST. JOHNS

8.2 Heat Losses and Gains

Heat losses and gains are handled in the way prescribed in the reference document accompanying the Meriwether ESA package with the following restrictions.

8.2.1 Solar data

"Weighted Solar" data is used to give some account of building storage effects. This involves the use of the Solar Heat Gain Factor generating program SL2 with the following specific details. Solar Heat Gains (See Appendix 5) are assumed to appear as cooling load in the following manner.

Vertical (Windows)	71 per cent in first hour with a 9-hr "sum of digits" spread for remainder.
Horizontal (Roof)	0 per cent in first hour with a 9-hr equal percentage spread for the remainder.

8.2.2 Solar transmission through opaque fabric

This was considered for the roof only, by using the "Equivalent glass area" concept.

8.2.3 Infiltration

The limitation of available software to predict infiltration rates with any degree of certainty leads to the oversimplification of the approach presented here.

Infiltration is assumed to be constant throughout the year, resulting from a steady wind acting on the NW facing wall.

The actual wall leakage rate is given in Figure 8.2.3 as a function of the average of the mean fall/winter/spring wind speed. These average wind speeds for the defined climatic areas are given in Table 8.2.3.

In order to calculate min/max load on individual zones, infiltration is considered to occur across all walls at the same rate as that found for the NW wall.

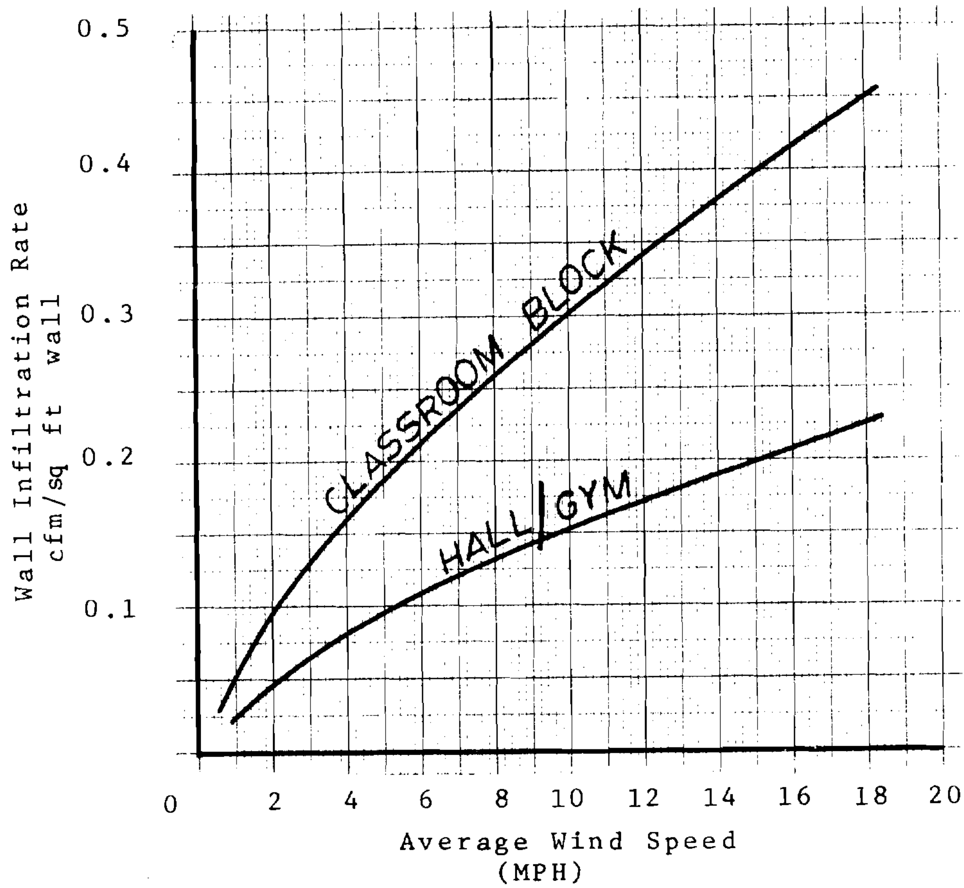


Figure 8.2.3

TABLE 8.2.3

Climatic Area	Weather Station	Wind Speed (mph)
1.	Vancouver	10
2.	Lethbridge	10
3.	Saskatoon	10
4.	Winnipeg	10
5.	Toronto	10
6.	Montreal	10
7.	Fredericton	11
8.	Shearwater	13
9.	St. John's, Nfld.	15

9. HVAC SYSTEMS

9.1 General

For purposes of the model definition the following HVAC systems are used.

The systems have been selected as being suitable and practical for schools; the operation of the system is such that they are reasonably energy conservative. All systems are assumed to have "economiser" mixed air control and spray air washer or sprayed coils, for humidification.

9.1.1 Gymnasia, auditoria and general purpose hall

Single duct, constant volume variable temperature system. (As Meriwether Type "O" system, Fig. 9.1.1).

9.1.2 Classroom block - primary schools

Terminal re-heat system with supply air temperature scheduled with outside air. The terminal reheat in practice is most likely to be perimeter radiation but for the purposes of the model the two are thermodynamically similar. (Fig. 9.1.2).

9.1.3 Classroom block - secondary schools

Variable air volume system, with scheduled supply air temperature and terminal reheat controlled by roomstat. As above terminal re-heat is most likely to be perimeter radiation in external zones; Minimum air flow no less than 50 per cent the full volume (Fig. 9.1.3)

9.2 System Shut Off/Set Back

System operation is matched to follow occupancy schedules, the following shut-off and set-back procedures are used:

9.2.1 Heating season set-back

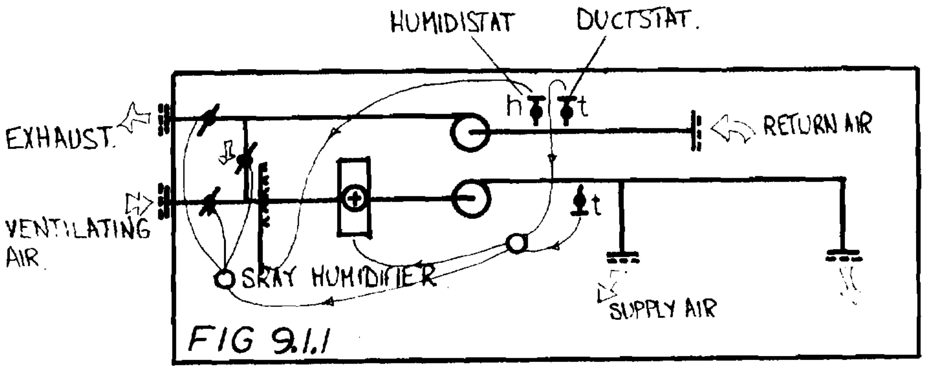
All areas are set-back 10°F during "scheduled periods" as defined in Section 9.2.5.

9.2.2 Cooling season set-up

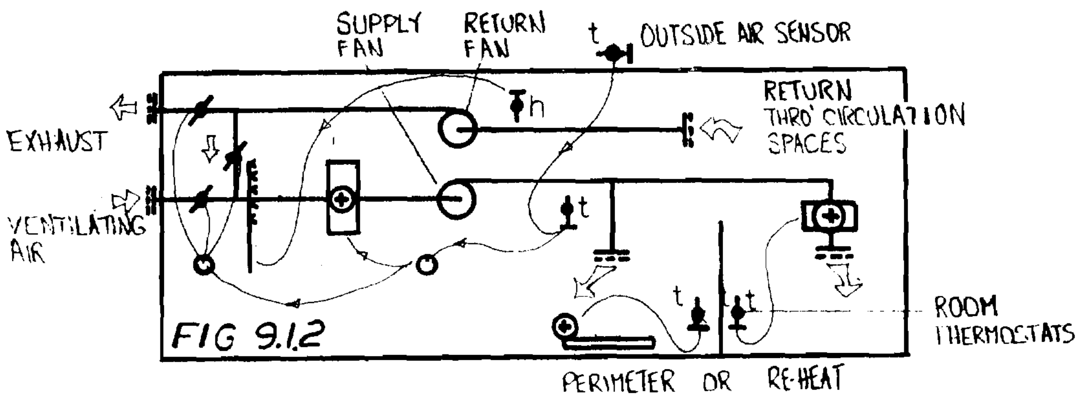
No set-up temperature.

9.2.3 Ventilation air

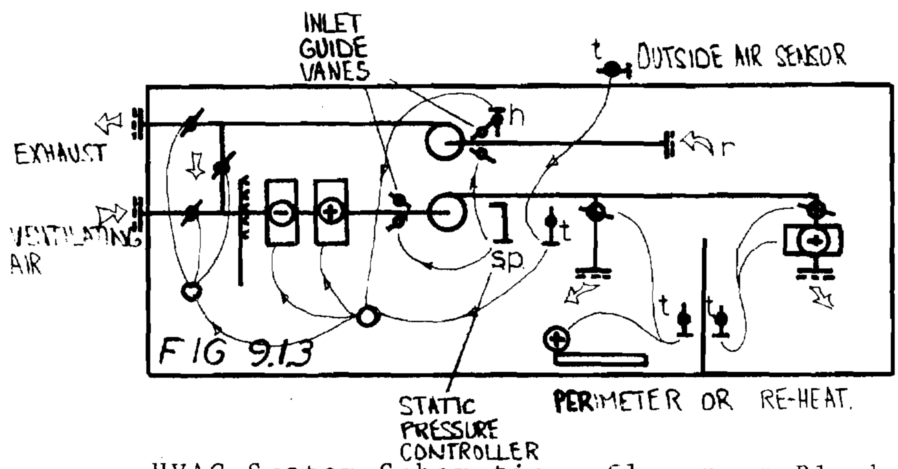
Ventilation (i.e., outside air) reduced to zero and all extract fans off during the scheduled periods as defined in Section 9.2.5.



H.V. System Schematic - Hall, Auditorium & Gymnasium



H.V. System Schematic - Classroom Block Primary Schools



HVAC System Schematic - Classroom Block Secondary Schools

9.2.4 Air handling plant

In the classroom block only, the air handling plant is shut off during scheduled periods as defined in Section 9.2.5, room temperature being maintained by perimeter heating.

9.2.5 Shut off/set back schedules

Normal operation, scheduled "off period" 6 pm to 6 am schooldays and off all day weekends and holidays. Community use operation, scheduled off period 10 pm to 6 am schooldays, and 6 pm to 6 am weekend holidays.

9.3 Room Air Supply Rates

For heated and cooled areas the room air change rates are based on the sensible heat loss or gain, whichever is the greater, with a maximum room-supply temperature differential of 15°F during cooling and 30°F during heating. A minimum air supply rate of 0.5 cfm/sq ft is assumed.

For areas with no mechanical cooling, room air change rates are based upon the heat loss and a room/supply temperature differential of 30°F. Any increased ventilation required during warmer months to minimize internal temperatures is deemed to be by virtue of open windows and not by oversizing ventilation plant.

9.4 Fan Power Required for HVAC Systems

The calculations for fan motor absorbed power and fan Δt (motors assumed not in air stream) are based on the following assumptions.

9.4.1 Fan pressure

VAV systems supply 4 in. return 1½ in. All other systems supply 2 in. and return 1 in.

9.4.2 Fan efficiency

(η_F) 70 per cent.

9.4.3 Drive transmission efficiency

(η_T) 95 per cent.

9.4.4 Motor efficiency

(η_M) From Table 9.4.4

TABLE 9.4.4

Motor Size (HP)	Efficiency
Less than 1	65%
1-5	74% + 2.75X (HP-1)
5-20	85% + .333x (HP-5)
20+	90%

9.4.5 Air stream (fan) Δt

Based on fan efficiency of 70 per cent with 2/3 of fan losses into air stream, the fan Δt is given by 0.44X Fan Total Pressure using ΔP as detailed in 9.4.1 the fan Δt's are as shown in Table 9.4.5.

TABLE 9.4.5

Fan/System	ΔP (in.)	†ΔT (°F)
Supply VAV	4	2
Return VAV	1½	0.66
Supply all others	2	1°
Return all others	1	0.44

† Supply air Δt's are limited to nearest integer by computer model.

9.4.6 Fan motor sizes

The fan motor size is given by the relationship

$$\text{Fan Motor} = \frac{\text{air power}}{\eta_F \times \eta_t \times \eta_m}$$

where air power = Fan Pressure x Air Volume

= 5.2 x P x Q ft lb f/min

or 0.1175 x P x Q watts

where

P = Fan Pressure in in. water

Q = Air Flow rate in cfm

9.4.7 VAV fans

These have an inlet guide vane static pressure control on both the supply and exhaust fans. The fan power - air flow relationships are as shown in Figure 9.4.7 Meriwether Fan Key 5 is used.

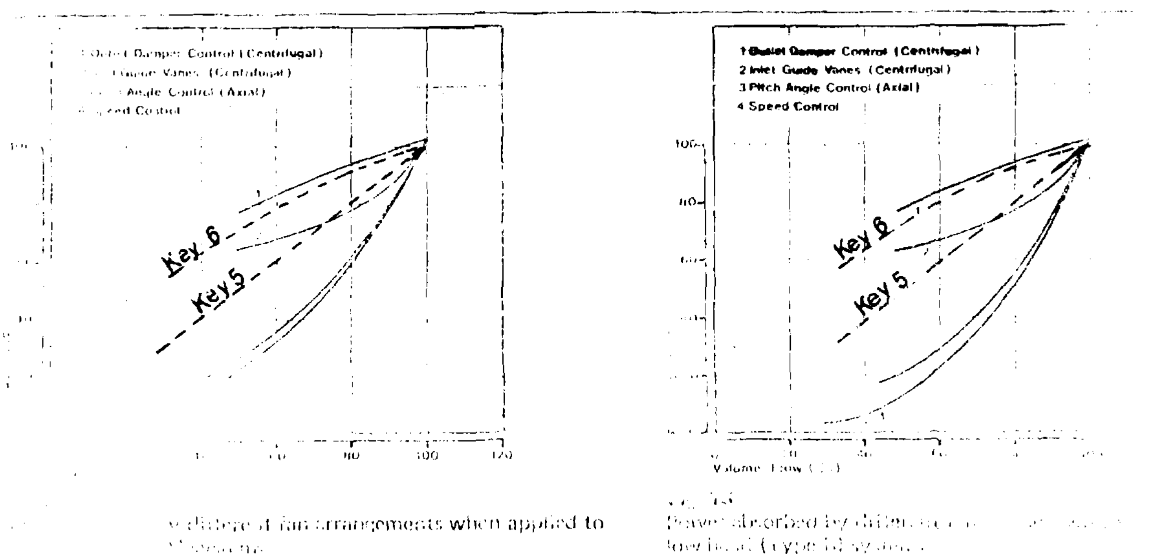


Figure 9.4.7 Fan Power vs Air Volume

(Source: M.E.D. Notes #13 Ove Arup & Partners U.K. October 1974)

Type A System	Discharge Pressure 5 in. w.g.	
	Suction Pressure 2 in. w.g.	
Type B System	Discharge Pressure 0.5 in. w.g.	
	Suction Pressure 2 in. w.g.	

SUPPLEMENTARY LITERATURE

1. ASHRAE Standard 90-75. Energy Conservation in New Building Design.

2. ASHRAE Standard 62-73. Standards for Natural & Mechanical Ventilation.

3. ASHRAE Standard 55-74. Thermal Environmental Conditions for Human Occupancy.

4. Meriwether, Ross F., Reference Manual for Energy Systems Analysis Series. Department of Public Works, Canada.

5. Axcess - Engineering Costs.

6. ASHRAE Handbook of Fundamentals, 1972.

7. Mitalas, G.P., and J.G. Arseneault. Fortran IV Program to Calculate Z-transfer Functions for the Calculation of Transient Heat Transfer Through Walls and Roofs. National Research Council of Canada, Division of Building Research, Computer Program 33. June 1972.

8. IES Lighting Handbook, 5th Edition. Illuminating Engineering Society, New York.

9. Climatological Atlas of Canada. National Research Council of Canada, Division of Building Research, 1953. (NRC 3151).

10. Guidelines to Environmental Designs in Educational Buildings. Department of Education & Science, U.K. August 1972.

11. Jones, W.P., Air Conditioning Engineering. Edward Arnold (Publishers) Ltd., Glasgow, 1969.

12. Design Data. IHVE London U.K. Guide Book A, 1970.

13. Installation & Equipment Data. IHVE London U.K. Guide Book B.

14. Règles de calcul des caractéristiques thermiques utiles des parois de construction, des perditions de base des bâtiments et du coefficient G des logements et autres locaux d'habitation. Le Centre scientifique et technique du bâtiment, Paris, fevrier 1975.

15. Fan Selection for Variable Volume Air Conditioning Systems. M.E.D. Notes #13, October 1974. OVE ARUP & Partners, U.K.

16. Climatic Information for Building Design in Canada 1975. Supplement No. 1 to the National Building Code of Canada. (NRCC 15556).

17. The Carleton Board of Education, Energy Management Program, Report No. 2, March 1976.

18. The Carleton Board of Education, School Floor Plans.

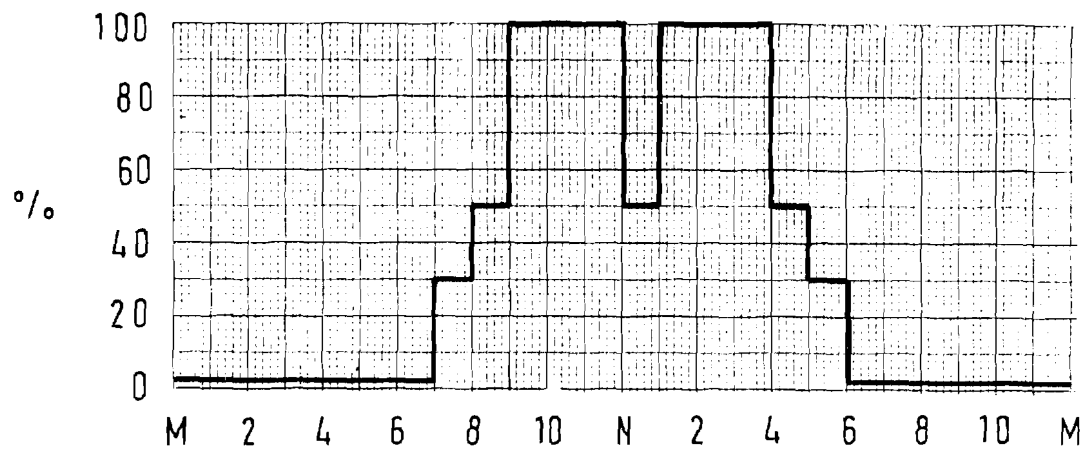
19. The Carleton School Board of Education, Miscellaneous Data by Correspondence.

APPENDIX A

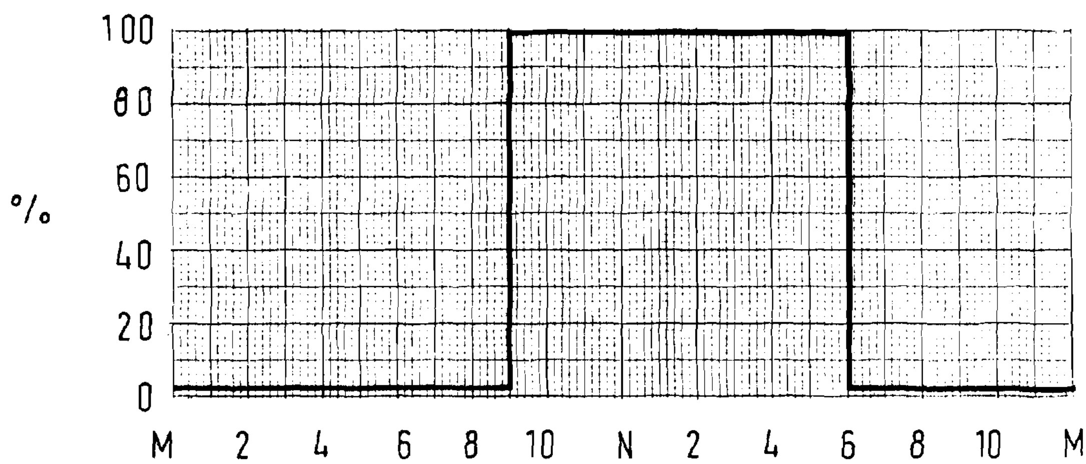
OCCUPANCY, LIGHTING AND DOMESTIC HOT WATER SCHEDULES

BASIC LIGHTING SCHEDULES

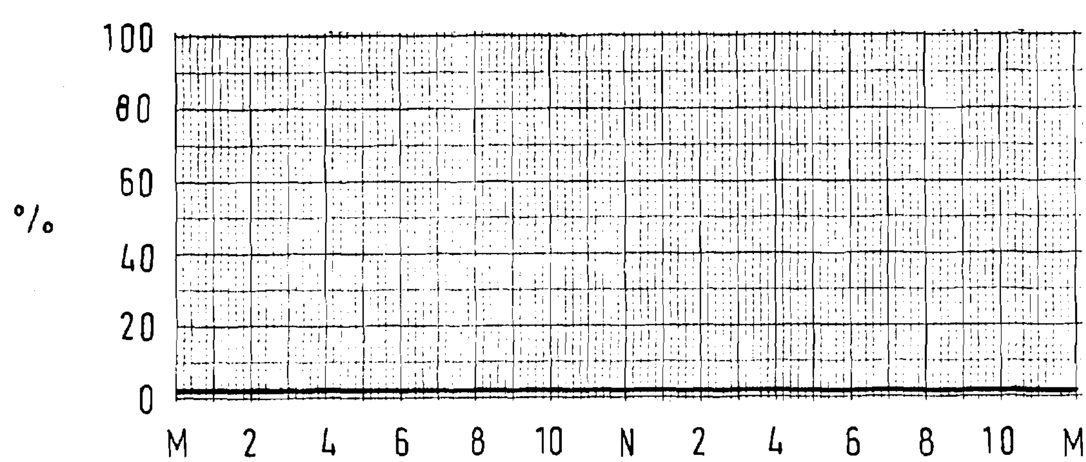
SCHEDULE #1 SCHOOL DAY - CLASSROOMS



SCHEDULE #2 SCHOOL DAY - GYM & AUDITORIUM

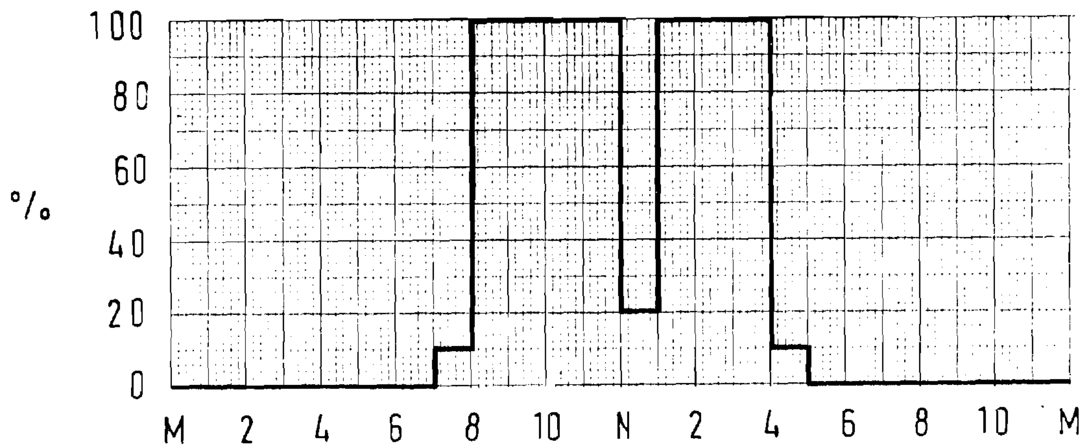


SCHEDULE #3 WEEKEND & HOLIDAYS - ALL AREAS

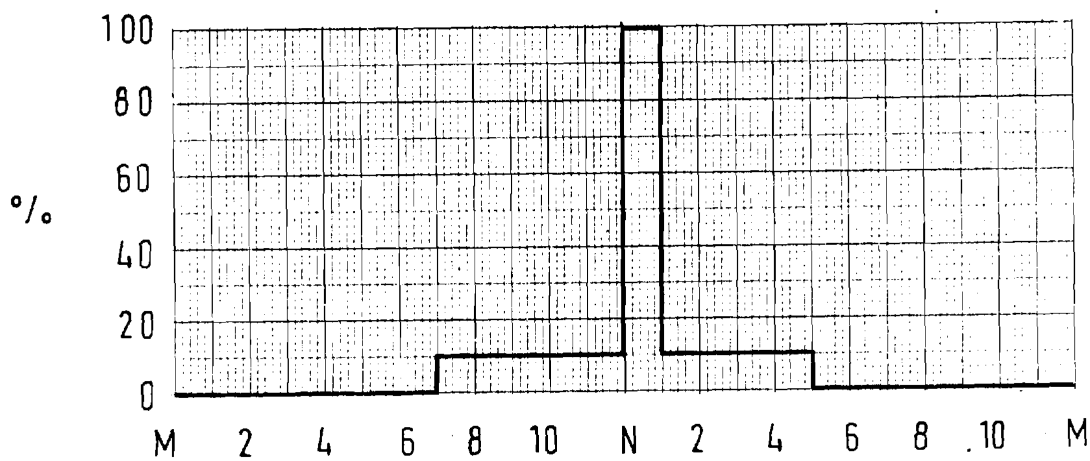


BASIC OCCUPANCY SCHEDULES

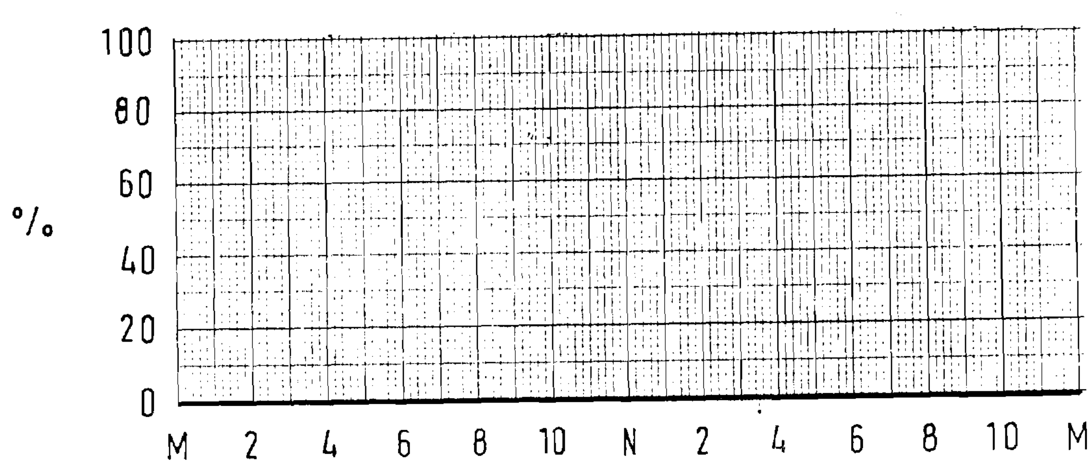
SCHEDULE #4 - SCHOOL DAY - CLASSROOMS & GYMNASIUM



SCHEDULE #5 - SCHOOL DAY - AUDITORIUM

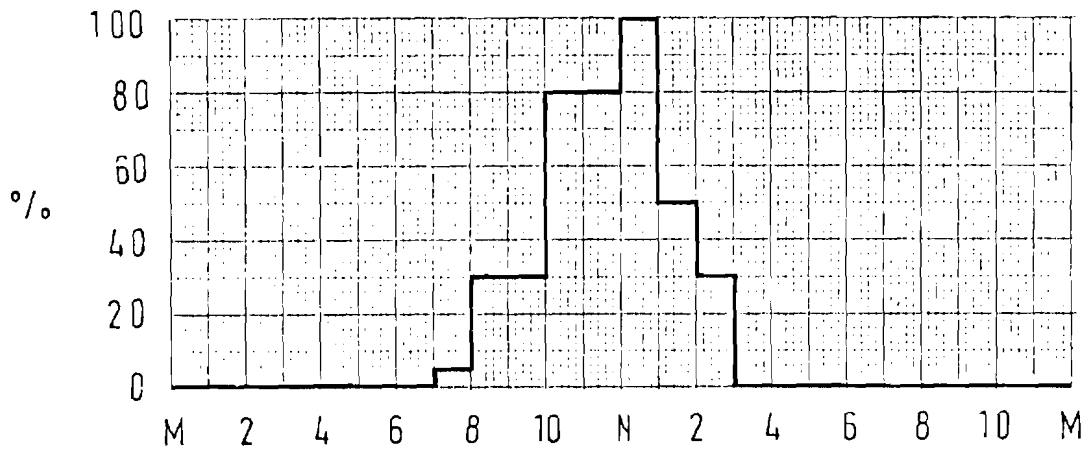


SCHEDULE #6 - WEEKENDS & HOLIDAYS

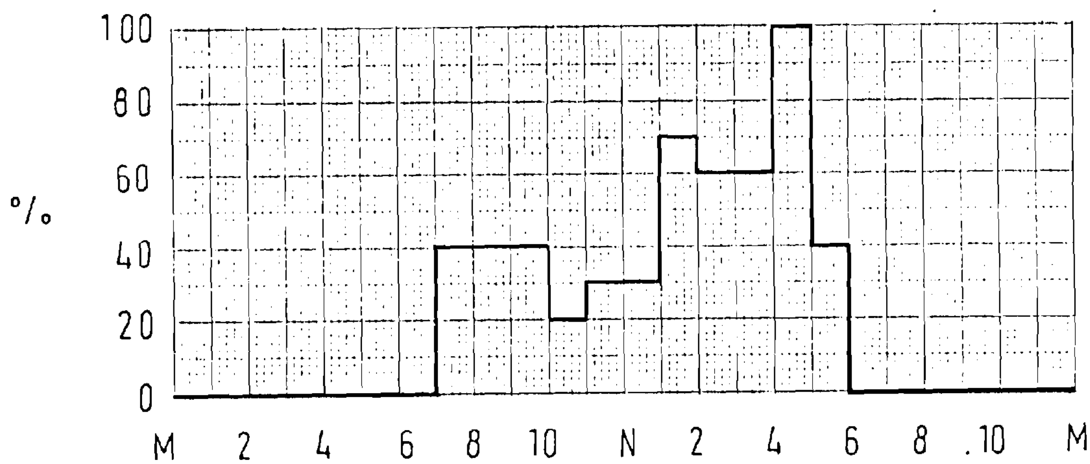


BASIC DOMESTIC HOT WATER SCHEDULES

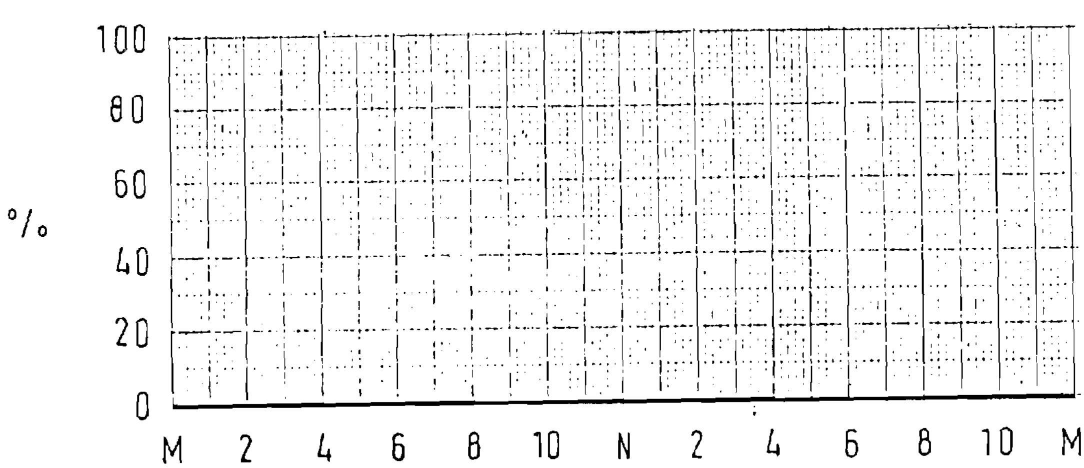
SCHEDULE #7 SCHOOL DAY CLASSROOMS



SCHEDULE #8 SCHOOL DAY GYM

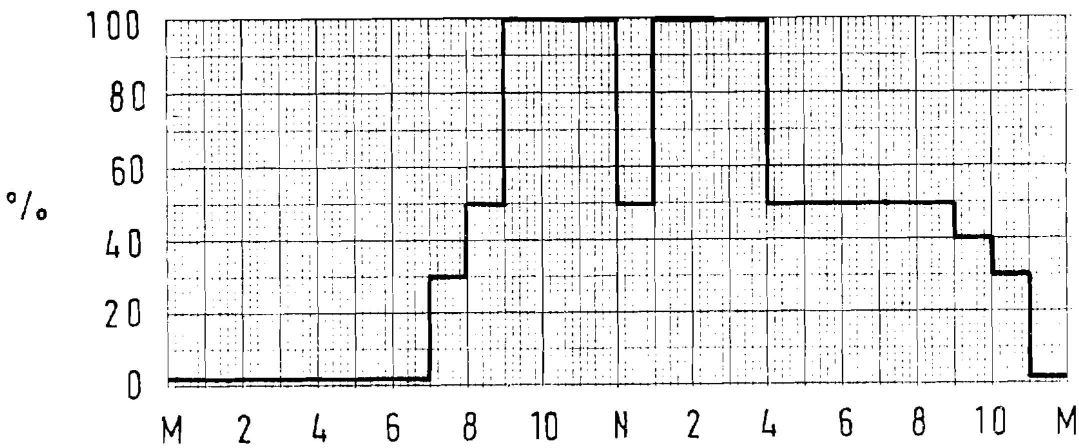


AS SCHEDULE #6 WEEKEND & HOLIDAY

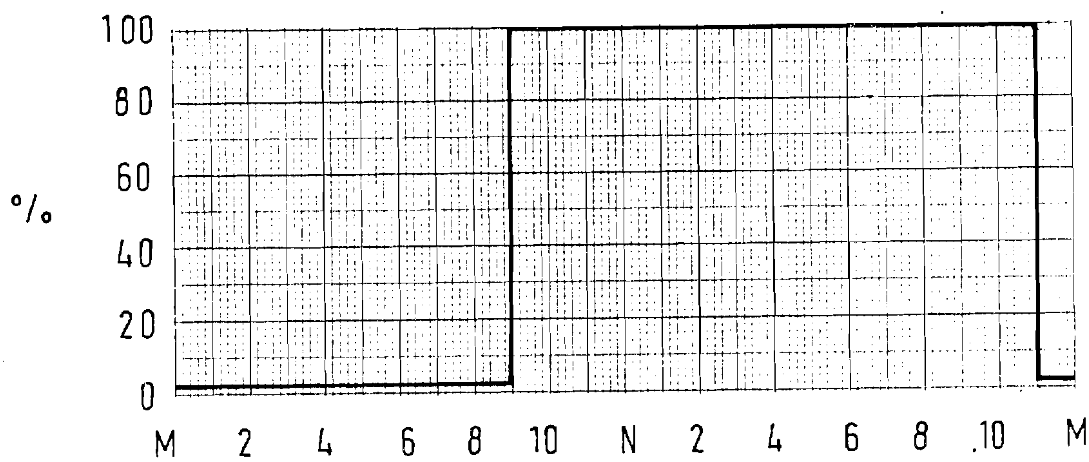


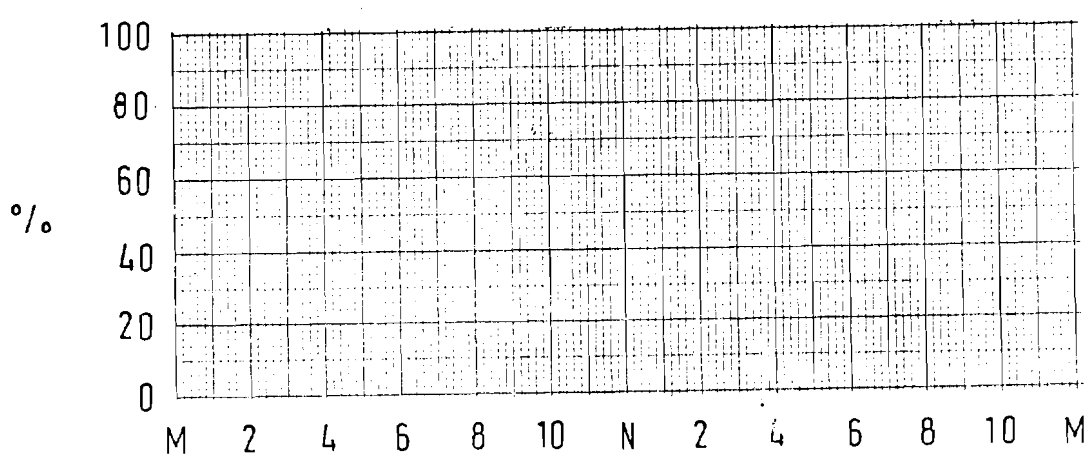
SUPPLEMENTARY SCHEDULES - LIGHTING

SCHEDULE #9 SCHOOL DAY & EVENINGS - CLASSROOMS



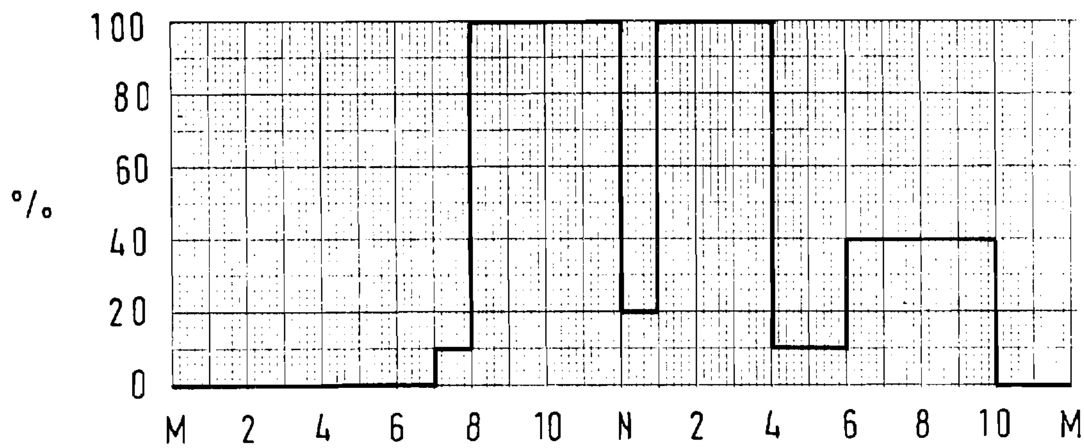
SCHEDULE #10 - SCHOOL DAY & EVENINGS GYM & AUDITORIUM



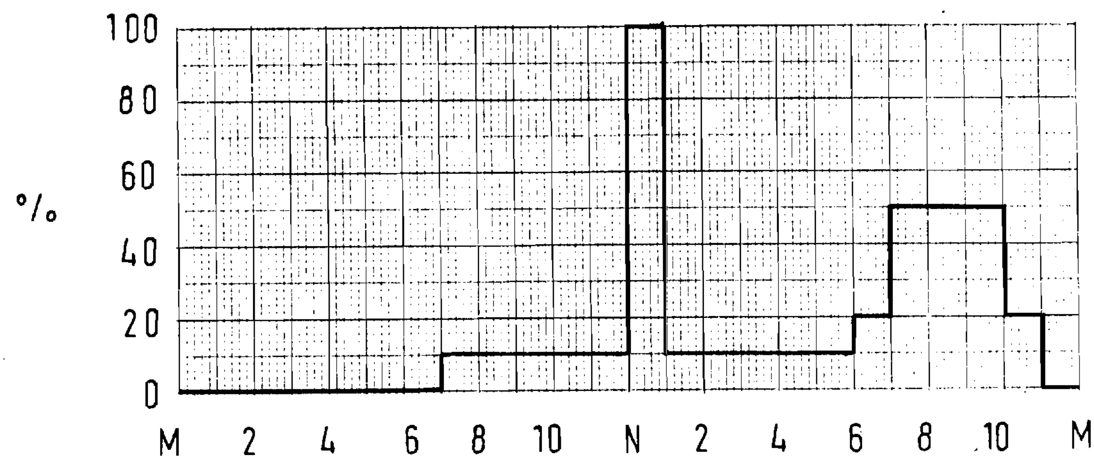


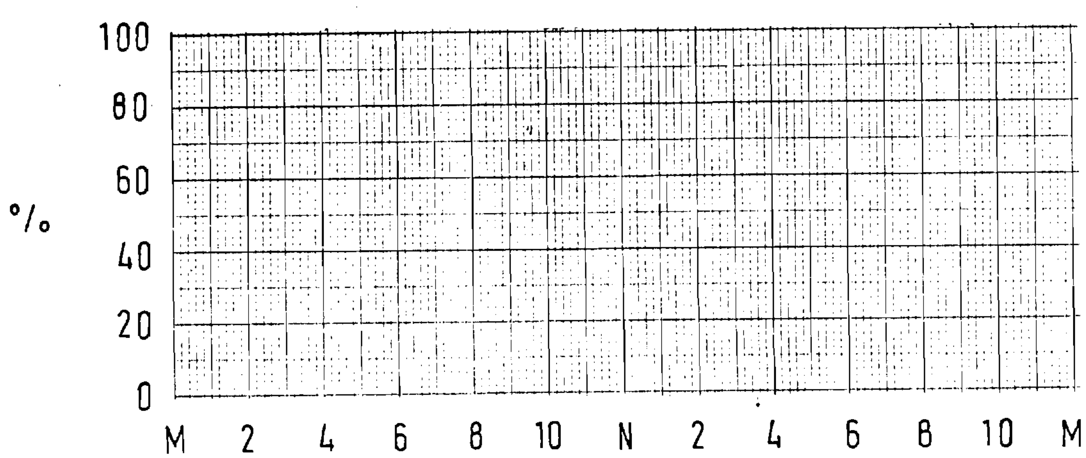
SUPPLEMENTARY SCHEDULES OCCUPANCY

SCHEDULE #11 SCHOOL DAY & EVENINGS - CLASSROOMS, GYM



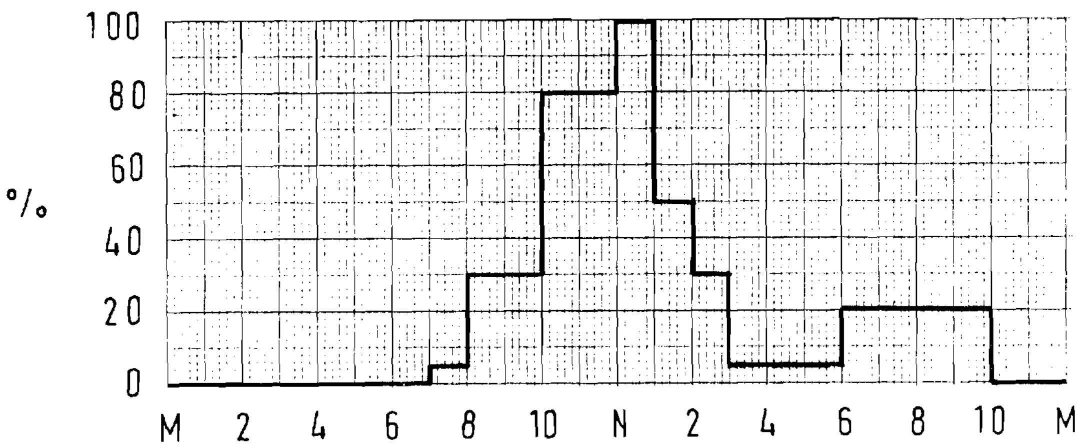
SCHEDULE #12 - SCHOOL DAY & EVENINGS - AUDITORIUM



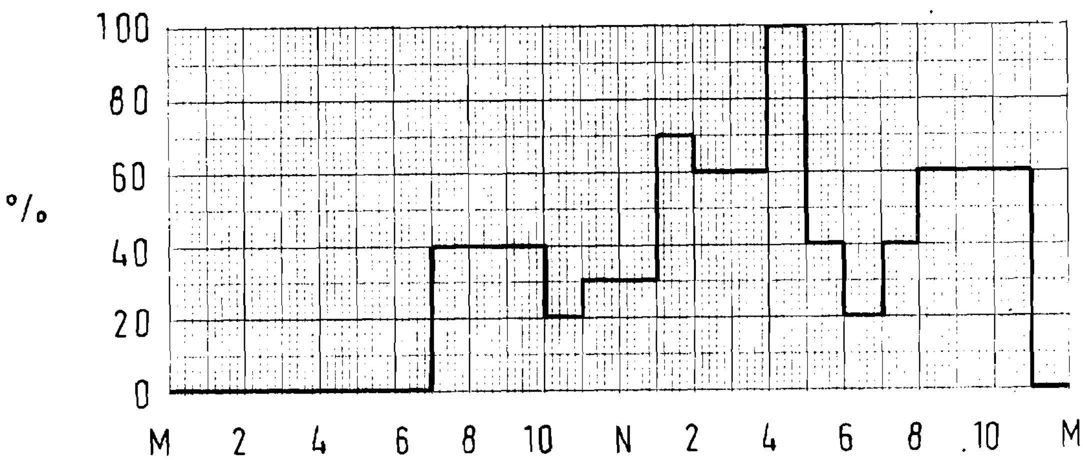


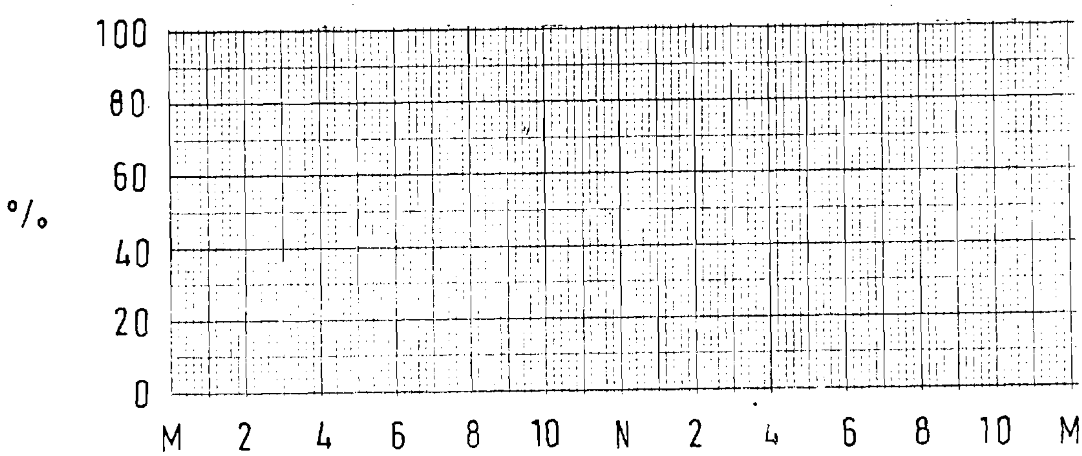
SUPPLEMENTARY SCHEDULES DOMESTIC HOT WATER

SCHEDULE #13 SCHOOL DAY & EVENINGS - CLASSROOMS



SCHEDULE #14 SCHOOL DAY & EVENINGS GYMNASIUM





APPENDIX B

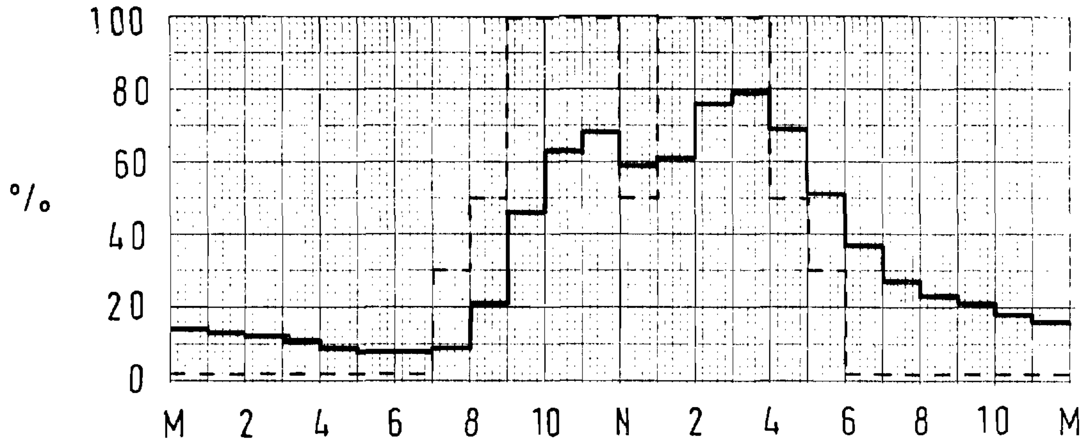
WEIGHTED OCCUPANCY AND LIGHTING SCHEDULES

The following profiles were compiled for use in the Meriwether ESA series to simulate the effects of building heat storage.

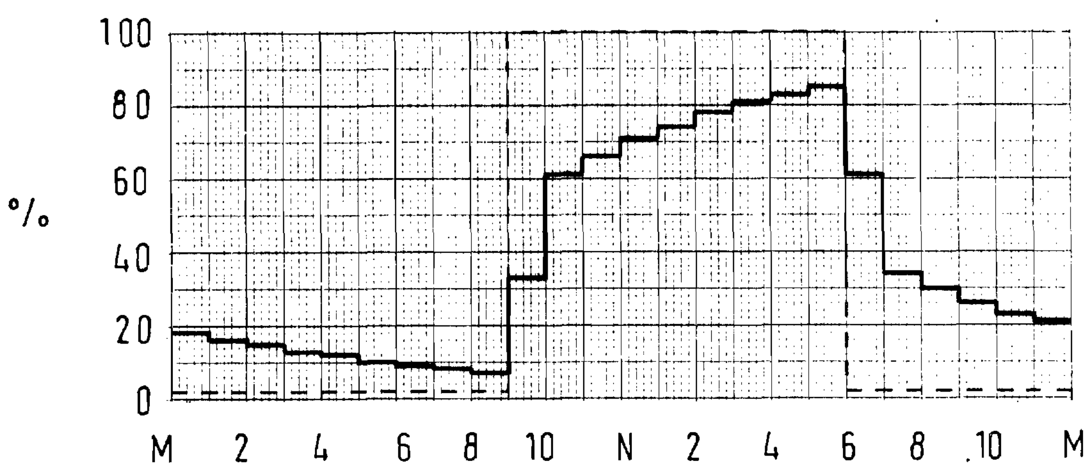
The profiles were derived using ASHRAE 'coefficients of room transfer functions'.

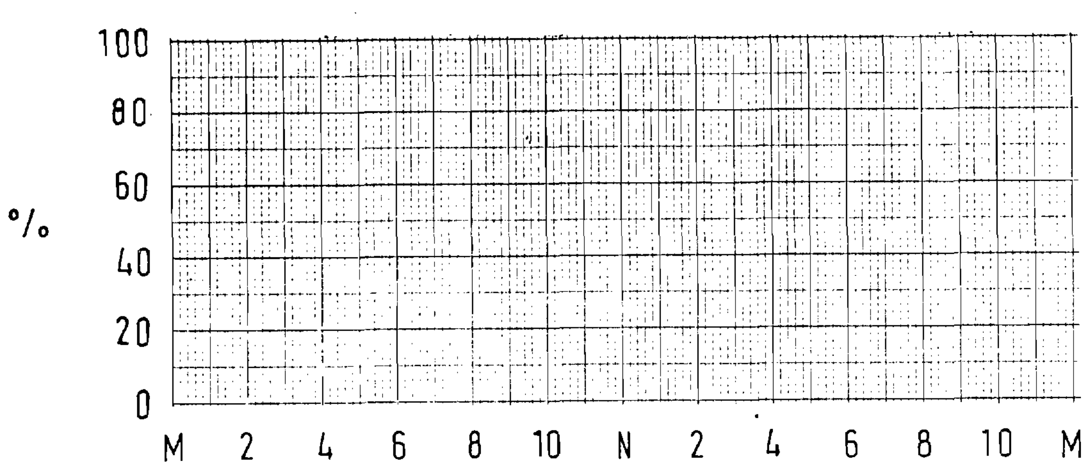
WEIGHTED LIGHTING SCHEDULES

SCHEDULE #15 SCHOOL DAY - CLASSROOMS



SCHEDULE #16 SCHOOL DAY - GYM & AUDITORIUM

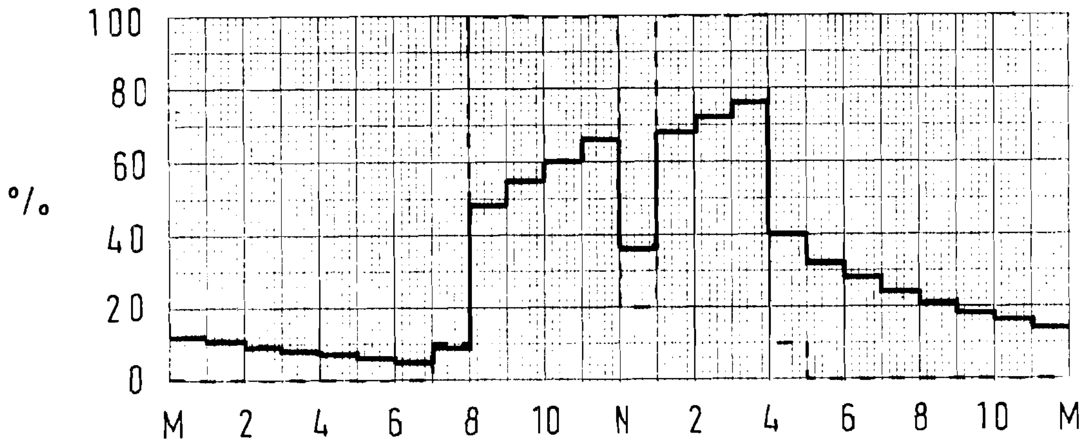




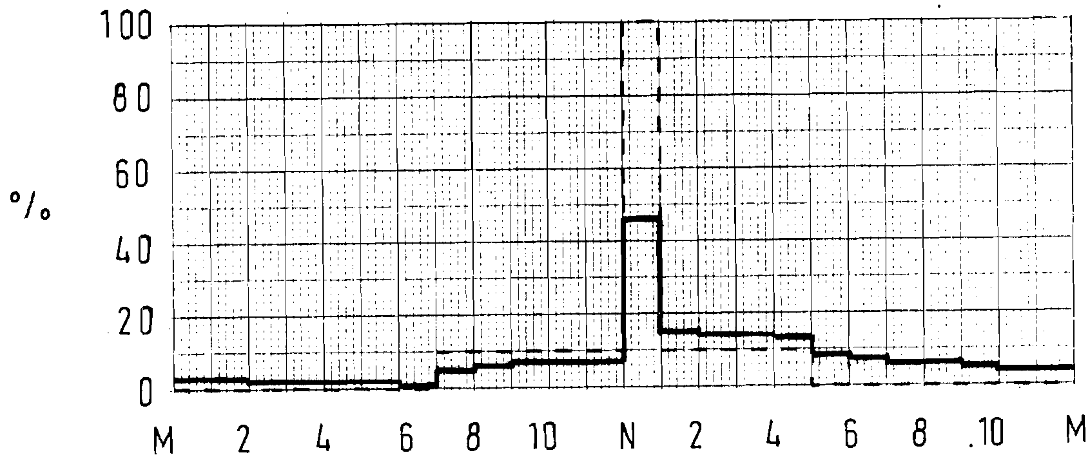
WEIGHTED OCCUPANCY SCHEDULES

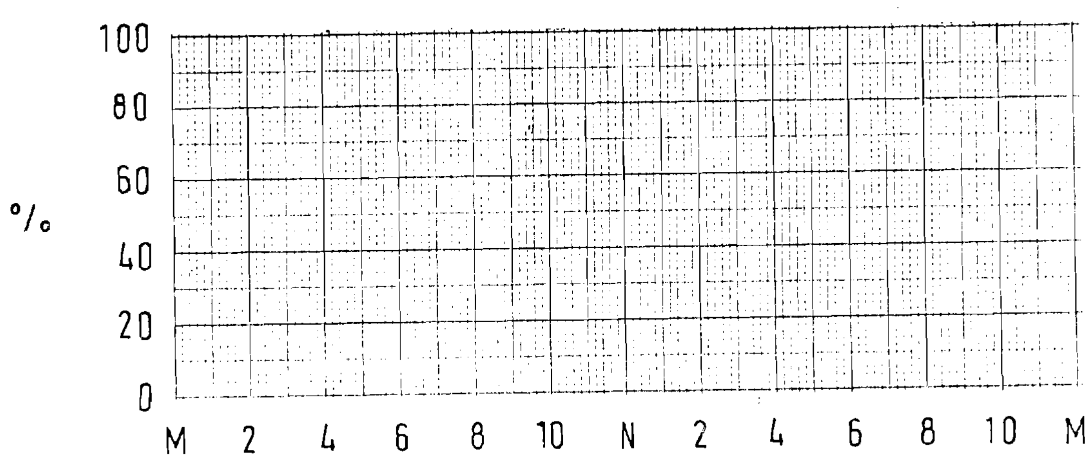
(RADIANT COMPONENT)

SCHEDULE #17 - SCHOOL DAY - CLASSROOMS & GYMNASIUM



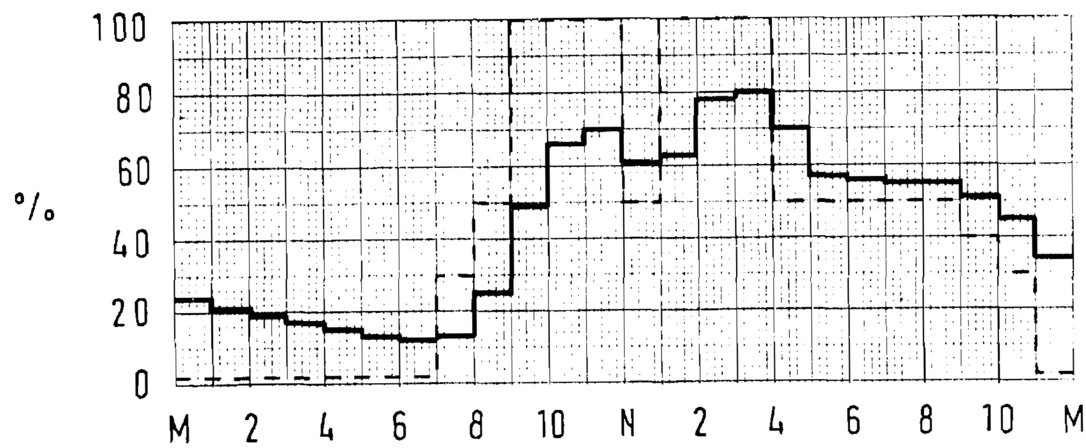
SCHEDULE #18 - SCHOOL DAY - AUDITORIUM



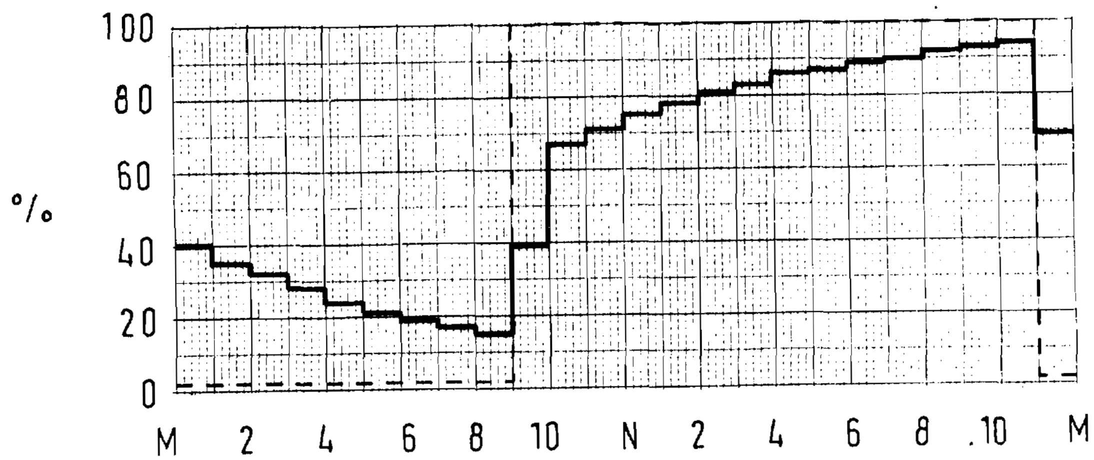


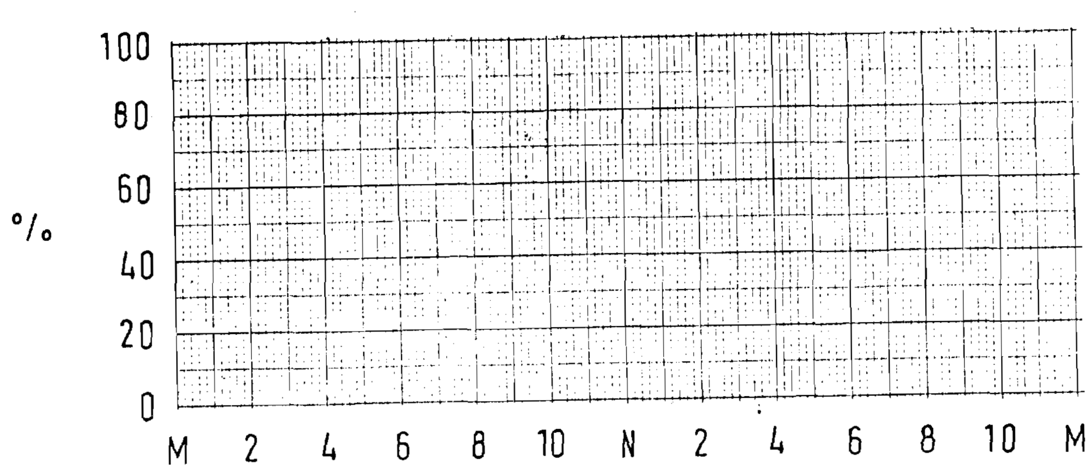
SUPPLEMENTARY SCHEDULES - LIGHTING WEIGHTED

SCHEDULE #19 SCHOOL DAY & EVENINGS - CLASSROOMS



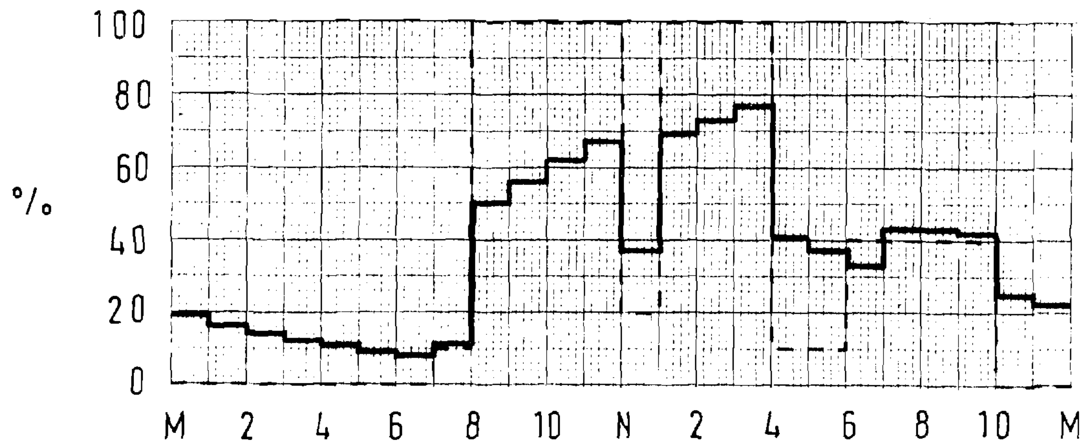
SCHEDULE #20 - SCHOOL DAY & EVENINGS GYM AUDITORIUM



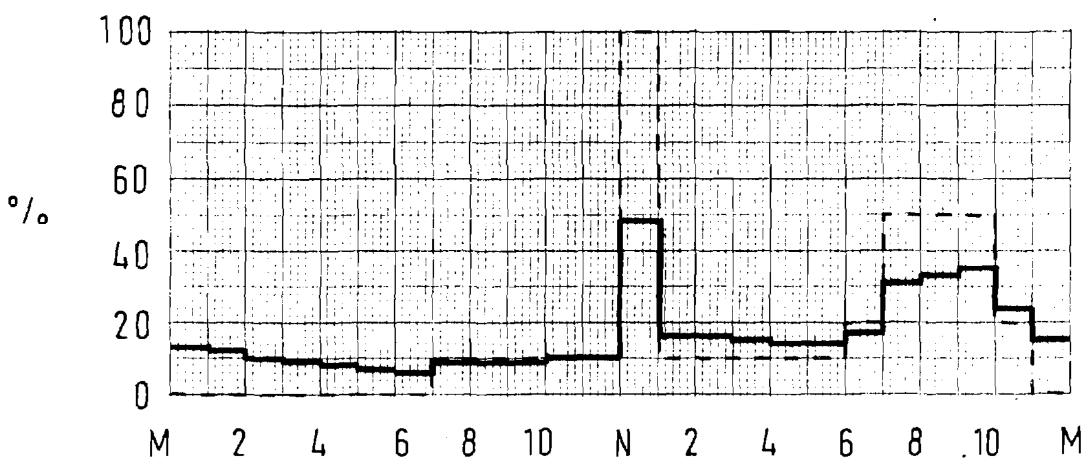


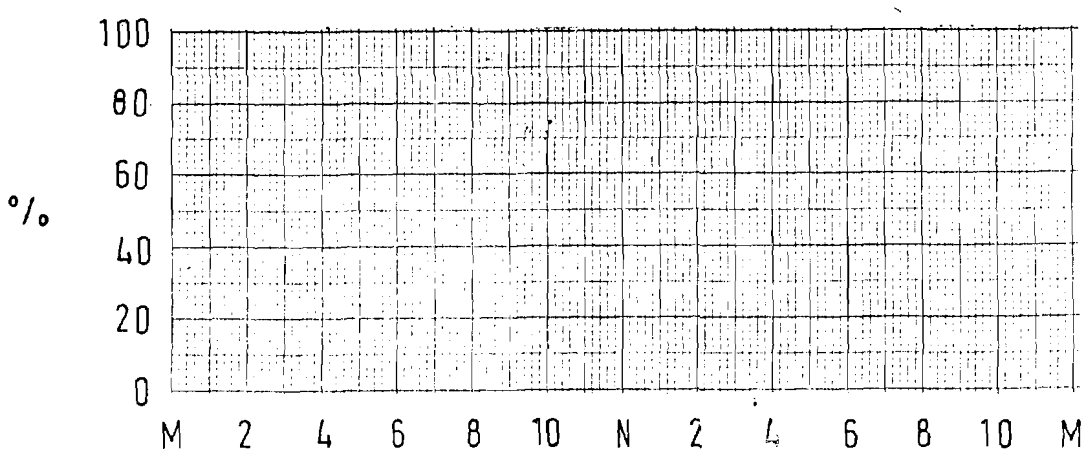
SUPPLEMENTARY SCHEDULES OCCUPANCY WEIGHTED (RADIANT COMPONENT)

SCHEDULE #21 SCHOOL DAY & EVENINGS - CLASSROOMS, GYM



SCHEDULE #22 - SCHOOL DAY & EVENINGS - AUDITORIUM





APPENDIX C

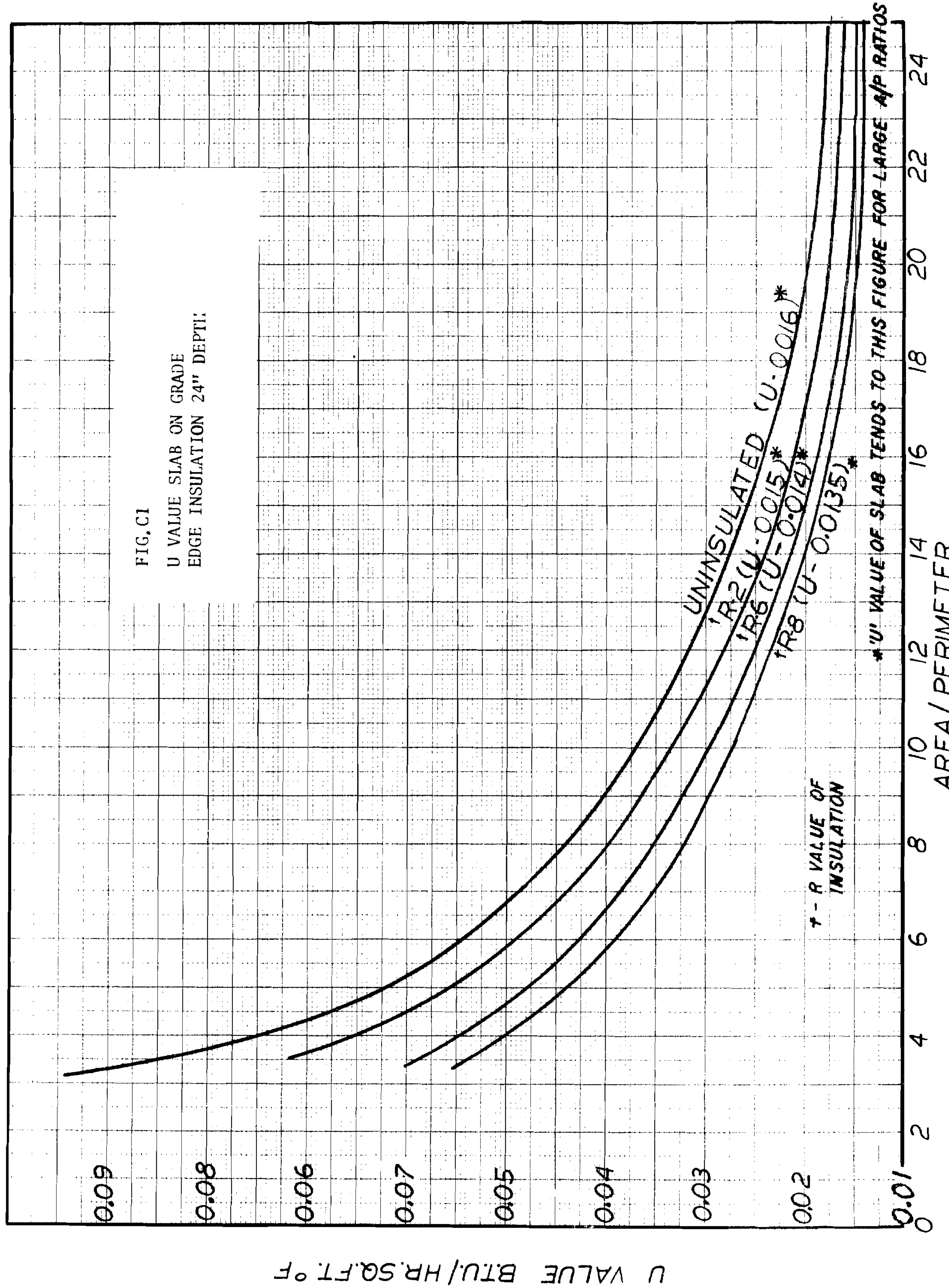
HEAT LOSSES FROM SLAB ON GRADE

For the computer model the heat loss from slab on grade is assumed to be directly proportional to the ambient temperature with U values as shown in Figure C1, which is derived from data from

(1) IHVE London U.K. Guide Book A, 1970 and

(2) Règles de calcul des caractéristiques thermiques utiles des parois de construction, des perditions de base des bâtiments et du coefficient G des logements et autres locaux d'habitation, le Centre scientific et technique du bâtiment. Paris, février 1975.

(Because the foregoing information is not comprehensive it is suggested that the values found from the graph should not be used other than for the purposes of the school model).



FIG, C1
U VALUE SLAB ON GRADE
EDGE INSULATION 24" DEPTH

APPENDIX D

PROCEDURE FOR THE CALCULATION OF AIR SUPPLY RATES AND SUPPLY AIR TEMPERATURE SCHEDULES

AIR SUPPLY RATES

To reflect the practice of selecting air supply rates to satisfy space loads, the air quantity for each zone in each school is calculated separately, based on the design peak heating or cooling loads.

For heated only buildings the air supply rate is determined by the design maximum heating requirement. This is deemed to result from:

(1) Fabric loss at winter design Δt

(2) Infiltration loss at winter design Δt

(3) Min^{m} internal load (taken at 0900 hr)

(4) Zero solar gains.

A room supply air temperature differential of 30°F is assumed.

For heated and cooled buildings the air supply rate is determined by the design maximum cooling requirement.

This is deemed to result from:

(1) Fabric gain at summer design Δt

(2) Infiltration gain at summer design Δt

(3) Coincident maximum of internal and solar loads (taken at 1500 hr - June solar data is assumed).

A room supply air temperature differential of 15°F is assumed.

PRIMARY SUPPLY AIR TEMPERATURE SCHEDULES

For terminal re-heat and V.A.V. systems only.

Winter heating

For winter heating, the primary supply air temperature is selected on the basis of satisfying the minimum heating demand within the zone when the outdoor temperature is at winter design point.

This is deemed to result from:

(1) Fabric loss at winter design Δt

(2) Zero infiltration (zone assumed on leeward side of building).

(3) Coincident maximum of internal and solar loads (taken at 1500 hr - January solar data is assumed).

Summer cooling

By earlier definition the primary supply air temperature for mechanically cooled schools are

(t - 15°F) - perimeter zones

(t - 10°F) - internal zones   t = room temperature

For non-mechanically cooled schools (e.g., primary schools), the primary supply air temperature schedule is calculated as though cooling were available.

The minimum supply air temperature is taken to be that temperature necessary to remove the design maximum heat gain from the space. This is deemed to result from:

(1) Fabric gain at summer Δt

(2) Infiltration gain at summer Δt

(3) Coincident maximum of the internal and solar loads (taken at 1500 hr - June solar data assumed).

APPENDIX E

TREATMENT OF SOLAR LOADS IN ESA ANALYSIS

SOLAR GAINS THROUGH WINDOWS

As previously stated, double glazed windows with medium colour internal venetian blinds are assumed. Blinds are assumed to be down all year.

To use the best approximation for cooling load that is available in the Meriwether SL2 package, the variation of cooling load with respect to time for a unit pulse of solar gain was calculated using the Transfer Function method, and the results compared with the SL2 options.

From Table 7 of Chapter 22[1] the coefficients of room transfer functions for windows with internal shading are as follows:

$$Vo = 0.7108,\ V1 = -1.4456,\ V2 = 0.9639,\ V = 0.2108$$

and

$$W1 = -2.1082,\ W3 = 1.4606,\ W3 = 0.3331$$

("Medium Weight Construction")

Assuming all the solar gain eventually appears as cooling load:

$$Q_t = Vo\ (G\tau) + V1(G\tau-1) + V2(G\tau-2) + V3(G\tau-3)$$
$$-W1(Q\tau-1) - W2(Q\tau-2) - W3(Q\tau-3)$$

where

$Q\tau$ = cooling load at time τ
G = gain at time τ
τ-1, τ-2 etc. = time less 1, 2 hours etc.
and V and W, coefficients as above.

The value of Q for a unit pulse (G0 = 1, G1 = 0) calculated using the foregoing formula is as shown in Figure E1.

S.L.2 Options

The percentage solar gain to cooling load can be specified for the first hour. The logical choice in this instance is to use the first hour value as calculated previously, i.e., 71 per cent. The remaining gain can be spread over a maximum of 9 hours by either:

a. "Uniform Spread" assuming 9-hr spread, this results in (100-71 per cent)/9 i.e., 3.22 per cent for the next 9 hr.

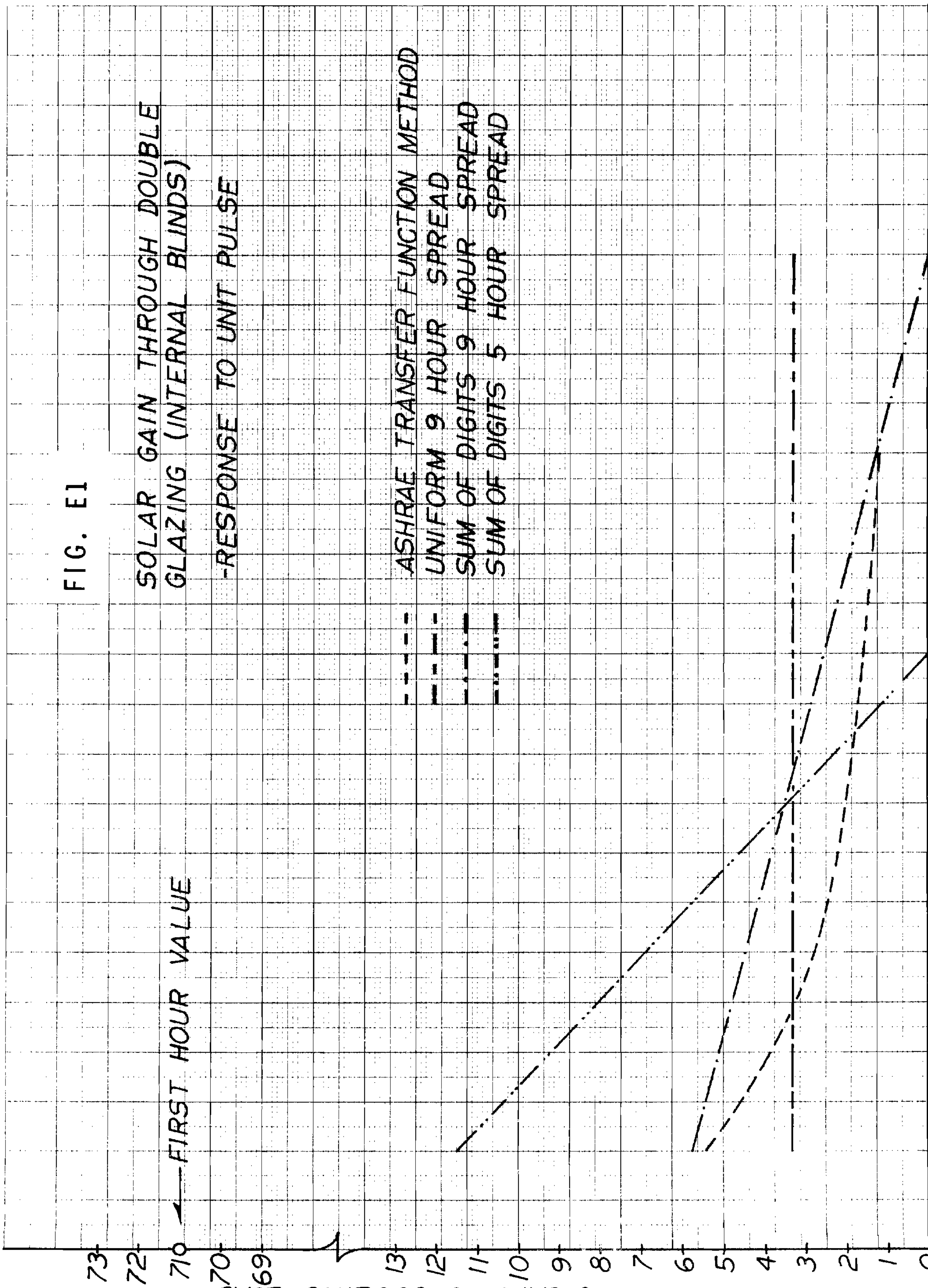

SOLAR GAIN THROUGH DOUBLE GLAZING (INTERNAL BLINDS)
-RESPONSE TO UNIT PULSE
ASHRAE TRANSFER FUNCTION METHOD
UNIFORM 9 HOUR SPREAD
SUM OF DIGITS 9 HOUR SPREAD
SUM OF DIGITS 5 HOUR SPREAD
FIRST HOUR VALUE
% GAIN TO COOLING LOAD
TIME HOURS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
69
70
71
72
73

FIG. E1

b. "Sum of Digits Spread" assuming 9-hr spread, this results in

$$9/\sum_{n=1}^{n=9} in. \times (100\text{-}71 \text{ per cent}) \quad \text{i.e., } 5.8 \text{ per cent in the 2nd hr}$$

$$/\sum_{n=1}^{n=9} in. \times (100\text{-}71 \text{ per cent}) \quad \text{i.e., } 5.16 \text{ per cent in the 3rd hr, etc.}$$

(for an 8 hr spread the 2nd low value would be 6.4 per cent, for 7 hr, 7.25 per cent, for 6 hr - 8.29 per cent, and for 5 hr 11.6 per cent).

The foregoing results are plotted on Figure E1 consideration of which suggest that the sum of digits (9 hr spread) is the best approximation.

TRANSMISSION OF RADIANT HEAT (SOLAR) ABSORBED BY THE ROOF

In order to calculate the cooling load by the transfer function method, a roof construction - as shown in Figure E2 is assumed, and the transfer function coefficients[2] and heat gain calculated.

The calculations are based on a roof (U value of 0.06) subjected to a unit pulse of solar radiation. The results are shown on Figure E3

The cooling load, resulting from the gain through the roof, is calculated in a similar manner to that described for the windows. The results are plotted on Figure E3.

S.L.2 Options

By consideration of Figure E3 the percentage in the first hour is taken as 0 per cent. The alternatives for the distribution of the "remaining" gain being either

a. Uniform Spread. Assuming 9-hr spread this results in 100 per cent/9 = 11.11 per cent per hr.

b. Sum of Digits Spread. Assuming 9-hr spread this results in

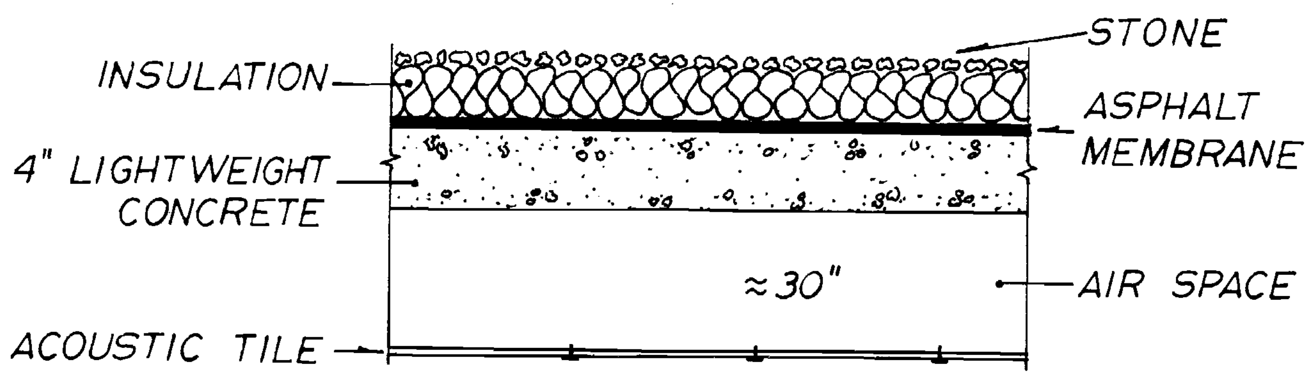
$$9/\sum_{i=1}^{i=9} in. \times 100 \text{ per cent i.e.} \quad 20 \text{ per cent in the 2nd hr}$$

$$8/\sum_{i=1}^{i=9} in. \times 100 \text{ per cent i.e.} \quad 18 \text{ per cent in the 3rd hr}$$

$$7/\sum_{i=1}^{i=9} in. \times 100 \text{ per cent i.e.} \quad 16 \text{ per cent in the 4th hr, etc.}$$

Consideration of the alternatives plotted on Figure E3 suggested the choice of the uniform spread as the nearest approximation.

FIG. E2 ROOF CONSTUCTION USED IN EXAMPLE



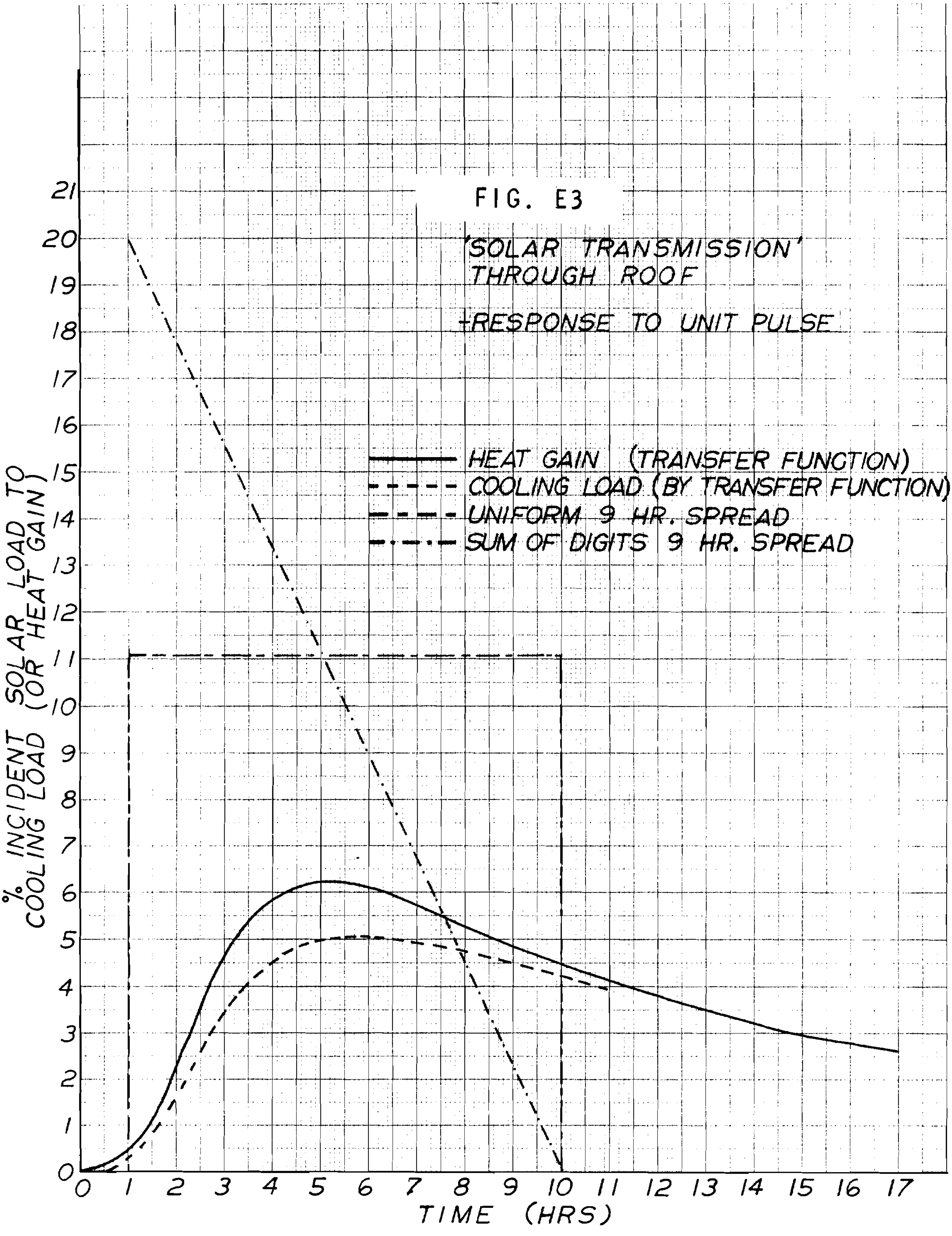


FIG. E3
'SOLAR TRANSMISSION'
THROUGH ROOF
-RESPONSE TO UNIT PULSE
HEAT GAIN (TRANSFER FUNCTION)
COOLING LOAD (BY TRANSFER FUNCTION)
UNIFORM 9 HR. SPREAD
SUM OF DIGITS 9 HR. SPREAD
% INCIDENT SOLAR LOAD TO
COOLING LOAD (OR HEAT GAIN)
TIME (HRS)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21

REFERENCES

1. ASHRAE Handbook of Fundamentals, 1972

2. Mitalas, G.P. and J.G. Arseneault, Fortran IV Program to Calculate Z-Transfer Functions for the Calculation of Transient Heat Transfer Through Walls and Roofs, National Research Council of Canada, Division of Building Research, Computer Program 33, June 1972.

APPENDIX F

SAMPLE PREPARATION OF MERIWETHER ERE INPUT

(FOR A 20,000-SQ FT SINGLE LEVEL PRIMARY SCHOOL)

This appendix illustrates how the school Model Definition is used to generate the necessary data input for the running of the Meriwether ERE energy analysis.

SAMPLE CALCULATION - OTTAWA 20,000-SQ FT PRIMARY SCHOOL

From model definition 20,000 sq ft is the limit of single-story construction. Thus it would be appropriate to produce a single- or a two-level model.

In this example the single-level case is considered.

(The numbers in brackets after the sub-headings refer to the relevant chapter in the model definition.)

1. SHAPE/SIZE (1.1.2)

Classroom block; by definition = 90 per cent total area with longer side twice that of shorter.

i.e., $2w \times w = 18{,}000$ where w = short side

$w = 94.87$ ft.

Hall: by definition = 10 per cent total area, i.e., 2000 sq ft with longer side 1.5 times that of the shorter

i.e., $1.5w \times w = 2000$ where w = short side

$w = 36.51$ ft

2. ZONES (FIGS. 6.2.4(1,2,3 and 4)) ORIENTATION (1.4) HEIGHTS (1.3)

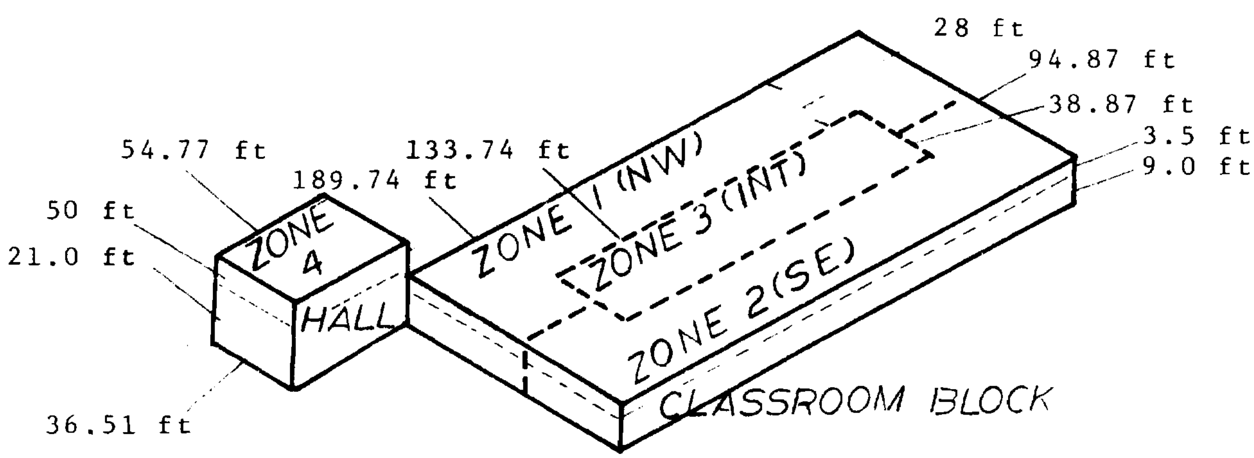


Figure F 2

3. CONSTRUCTION (2) (WINDOWS (2.2) FABRIC (2.3))

Section 2 references ASHRAE 90-75 from which for Ottawa, degree days = 8693, required U_o walls (90-75 Figure 3) = 0.225 and U_o roof = 0.06.

4. FABRIC TRANSMISSION

Convention: U value of external wall forming side of plenum is assumed to be the same as roof, i.e., 0.06.

TABLE F4(1)

	Fabric Area			U.A. Fabric			
Zone	Wall	Plenum	Roof	Wall	Plenum	Roof	ΣUA
1.	2562	996	6401	576.5	60	384	1020
2.	2562	996	6401	576.5	60	384	1020
3.	0	0	5198	0	0	312	312
4.	3834	913	2000	863	55	120	1038

Slab: From graph for heat loss for slab on grade - Appendix C, Figure Cl.

$$\left[\frac{\text{Area}}{\text{Perimeter}}\right] \text{classroom block} = \frac{18,000}{569} = 31.62$$

and U value = 0.014 Btu/hr $ft^2{}^\circ F$

Qslab = 0.014 × 18000 × 89

= 22.428 M.Btu/hr

Assumption: Qslab lost at external zones only

therefore Qslab 1 = Qslab 2 = 22.428/2 = 11.214 M.Btu/hr

Similarly for Hall

Qslab = 0.026 × 2000 × 85 = 4.42 M.Btu/hr

TABLE F4(2)

	Losses (M.Btu/hr to - 17°F)			Gains (M.Btu/hr to 87°F)
Zone	Walls and Roof	Slab	Total	Walls and Roof
1.	90.780	11.214	101.99	15.300
2.	90.780	11.214	101.99	15.300
3.	27.768	0	27.768	4.680
4.	88.230	4.42	92.65	19.722

5. SOLAR TRANSMISSION (8.2)

TABLE F5(1)

Exposure	*Reference Solar
NE	52
NW	34
SE	101
SW	69
Horizontal	108

*For definition see Ross F. Meriwether Reference Manual solar data: output from SL2 run for June at Noon

<u>Transmission of Radiant Heat (Solar) Absorbed by Roof</u>

$Q = U.A\Delta teo$

Δteo = Sol air increment

$= \frac{\alpha It}{ho} - \frac{\varepsilon \Delta R}{ho}$

α = absorptance of surface to solar radiation - value $\alpha = 0.5$ assumed

ε = hemispherical emittance of surface value $\varepsilon = 1.0$ assumed

ho = coefficient of heat transfer at surface value ho = 4.5 assumed based on average winter/spring/fall wind speed of 10 mph

ΔR = re-radiation from surface value ΔR = 20 Btu/hr sq ft assumed

It = total solar radiation incident on surface

= Reference Solar × 1.15

= 108 × 1.15

= 124 Btu/hr sq ft

Hence

$$\Delta_{teo} = \frac{0.5 \times 124}{4.5} - \frac{1 \times 20}{4.5}$$

$$= 9.3°F$$

$$Q_s = U.A\Delta t_{eo}$$

U = transmittance = 0.06

A = Area ft^2

i.e. $Q_s = 0.558\ A$

TABLE F5(2)

SOLAR LOAD

Zone 1

Exposure	Window Area	Heat Gain M. Btu/hr	Equivalent Glass Area	Percentage Equivalent Glass Areas
NE	106.7	3.16	60.82	15.3%
SW	106.7	4.20	60.82	15.3%
NW	427	8.27	243.4	61.1%
Horiz.	6401	3.57	33.1	8.3%
TOTALS		19.20	398.14	

where

"Equivalent Glass Area" = Area of Window x S.C. for glazing

or for transmission through roof = $\frac{\text{Heat Gain}}{\text{Horizontal Reference Solar}}$ and

Percentage Equivalent Glass Area = $\frac{\text{Equivalent Glass Area on Exposure}}{\text{Total Equivalent Glass Area}}$

TABLE F5(3)

	Exposure	Window Area	Solar Heat Gain M. Btu/hr	Equivalent Glass Area	Percentage Equivalent Glass Area
Zone 2					
	NE	106.7	3.16	60.82	15.3%
	SE	427	24.58	243.4	61.1%
	SW	106.7	4.2	60.82	15.3%
	Horiz.	6401	3.57	33.1	8.3%
	TOTALS		35.51	398.14	
Zone 3					
	Horiz.	5198	2.9	26.86	100%
Zone 4					
	Horiz.	2000	1.12	10.3	100%

6. INFILTRATION (8.2.3)

Classroom Block 0.3 cfm/sq ft

Hall 0.15 cfm/sq ft

Infiltration based on wind on the longest wall:

Classroom = 189.74 × 12.5 × 0.3 = 711 cfm

Hall = 54.77 × 26 × 015 = 213 cfm

For Classroom Infiltration into Zone 1

TABLE F6

ZONE	INFILTRATION
1	711
2	0
3	0
4	213

7. INTERNAL LOADS (7)

Classroom Block - convective and latent load (instantaneous)

= 3.62 Btu/hr sq ft with 66 per cent latent radiant load (lagged)

= 2.38

Hall - convective and latent load

= 10.87 with 66 per cent latent radiant

= 7.12

TABLE F7(1)

Zone	Convective and Latent Load (Instantaneous)		Radiant Load (Lagged) M. Btu/hr
	M. Btu/hr	% Latent	
1	23.17	66%	15.23
2	23.17	66%	15.23
3	18.82	66%	12.37
4	21.74	66%	14.26

Lights (Tables 7.2 (1) and (2))

Classroom Block 7.85 Btu/hr sq ft

Hall 9.89 Btu/hr sq ft

TABLE F7(2)

Zone	Space Load M. Btu/hr
1	50.25
2	50.25
3	40.80
4	19.78

8. HOT WATER (7.4.1)

Classroom Block 2.5 Btu/hr sq ft

Hall 0

TABLE F8

Zone	Domestic Hot Water M.Btu/hr
1	16
2	16
3	13
4	0

9. VENTILATION AND AIR CHANGE RATES (5)

Ventilation outside air

Classroom Block - 0.085 cfm/sq ft
Hall - 0.25 cfm/sq ft

Air supply (9.4)

Supply air volume

$V = Q/\Delta t_s \times 1.08$ subject to minimum of 0.5 cfm/sq ft

Δt_s = room air supply temperature differential (temperature supply air - temperature room)

= 30°F

Q_R = maximum zone heating load during occupied period

Zone 1

Losses

Fabric Loss	@ outside design -17°F	101.99 M. Btu/hr
Infiltration	771 cfm × 89°F × 1.08	74.108 M. Btu/hr

Gains

Lights	46% @ 09:00 PM × 50.25	23.12 M. Btu/hr
Occ (Radiant)	55% @ 09:00 PM × 15.23	8.38 M. Btu/hr
Occ (Convec.)	100% @ 09:00 × 34% × 23.17	7.88 M. Btu/hr

Q = 136.72

$$V = \frac{136,720}{30 \times 1.08} = 4219.75 \text{ cfm or } 0.66 \text{ cfm/sq ft}$$

Zone 2 As Zone 1

Zone 3

Losses			
Fabric		27.768	M. Btu/hr
Infiltration		0.00	M. Btu/hr
Gains			
Lights	46% × 40.8	18.77	M. Btu/hr
Occ (Radiant)	55% × 12.37	6.80	M. Btu/hr
Occ (Convec.)	100% × 34% × 18.82	6.40	M. Btu/hr
	Q =	- 4.20	("Cooling" Required)

V subject to minimum of 0.5 cfm/sq ft
= 2589 cfm

Zone 4

Losses			
Fabric		92.14	M. Btu/hr
Infiltration	213 cfm × 85°F × 1.08	19.55	M. Btu/hr
Gains			
Lights	33% × 19.78	6.53	M. Btu/hr
Occ (Radiant)	7% × 14.26	1.00	M. Btu/hr
Occ (Convec.)	10% 34% × 21.74	0.74	M. Btu/hr
	Q =	103.42	

$$V = \frac{103,420}{30 \times 1.08} = 3191.98 \text{ or } 1.6 \text{ cfm/sq ft}$$

TABLE F9

Zone	Minimum Outside Air (Ventilation) cfm	Supply Air Volume cfm
1	544	4220
2	544	4220
3	442	2599
4	500	3192

10. ELECTRICAL CONNECTED LOADS

Lighting (Table 7.2)

Classroom Block - 2.3 watts/sq ft

Hall - 2.9 watts/sq ft

TABLE F10(1)

Zone	Connected Lighting Load (kW)
1	14.722
2	14.722
3	11.955
4	5.80

Fans (9.4)

Assumption: A separate fan/HVAC system is provided for each of the zones defined in the model.

Fan Size: Air Power = 0.1175 × P × Q watts

where P = Fan Pressure in in. water

Q = Air Flow cfm

E. Zone 1 Supply P = 2 in.

Q = 4041 cfm

Air Power = 0.1175 × 2 × 4041 = 949 watts or 1.33 hp

$$\text{Motor shaft output} = \frac{\text{Air Power}}{\eta_F \times \eta_T}$$

η_F = Fan efficiency assumed to be 70 per cent

η_T = Drive Transmission efficiency assumed to be 95 per cent

$$\text{Motor Shaft out} = \frac{949}{70\% \times 95\%} = 1428 \text{ watts } (1.915 \text{ hp})$$

$$\text{Motor input} = \frac{\text{output}}{\eta_m}$$

η_m = motor efficiency

= 74 + 2.75 (1.915 - 1) = 76.52 (see Table 9.4.4)

$$\text{Motor input} = \frac{1428}{76.52} = 1941 \text{ watts}$$

Summary: i.e., Supply Fan Zone 1 = 1.886 kW connected load.

TABLE F10(2)

Zone	Air Power Supply (W) (Return = 50% supply)	Motor Output Supply (W)	Motor Efficiency (%)		Electrical Load kW		
			Supply	Return	Supply	Return	Total
1	949	1428 (1.9 HP)	76.52	74	1.886	0.964	2.85
2	949	1428 (1.9 HP)	76.52	74	1.886	0.964	2.85
3	611	918 (1.2 HP)	74.6	65	1.231	0.706	1.937
4	750	1190 (1.6 HP)	75.65	65	1.573	.915	2.488

11. SPACE HEATING CAPACITY

Convention

Installed capacity to be 1.5 × (Maximum load)†

† Assumed to be load during morning pre-heat when, for simplicity, space gains are assumed to be zero.

TABLE F11

Zone	Fabric Loss	Infiltration M. Btu/hr	Ventilation M. Btu/hr	Total Load	Installed Capacity
1	101.99	68.341	52.289	222.62	334
2	101.99	0	52.289	154.279	231
3	27.768	0	42.485	70.253	105
4	92.14	19.55	45.900	157.590	236

12. SUPPLY AIR TEMPERATURE SCHEDULE (9.1.2, AND APPENDIX D)

From method outlined in Appendix D:

Supply air temperature at Winter Design Point (^{t}outside -17°F)

Zone 1

Losses: (min likely at t = -17°F)

		M.Btu/hr
Fabric		101.99
Infiltration (Zone on leeward side of building)		0
Gains: (max gains - taken at 3:00 pm)		
Lights	79% × 50.25	39.698
Occupants (Radiant)	76% × 15.23	11.575
Occupants (Convec.)	100% × 34% × 23.17	7.868
Solar NE	= †60.82 × 10*	0.608
SW	= 60.82 × 179	10.886
NW	= 293.4 × 11	2.677
HOR	= 33.1 × 51	1.688
		Q = 26.99 LOSS

$$\Delta t = \frac{Q}{1.08\ V} = \frac{26{,}990}{1.08 \times 4042} = 6.182$$

$$ts = 72 + 6 = 78°F$$

† Equivalent glass area see section on solar ad.
* Jan 3:00 pm solar data

Zone 2

As Zone 1 with solar on SE face replacing solar on NW

$$ISE = 243.4\ ft^2 \times 48 = 11.683$$

$$INW\ (Zone\ 1) = 2.677$$

$$\Delta = 9.006$$

$$t\ \Sigma = 26.99 - 9.006$$

$$= 17.984$$

$$\Delta t = \frac{17,984}{1.08 \times 4042} = 4.119$$

v $\quad ts = 72 + 4 = \underline{\underline{76°F}}$

Zone 3

Losses

Fabric		-27.768
Gains		
Lights	79% × 40.80	32.232
Occupants (Radiant)	76% × 12.37	9.401
Occupants (Convec.)	100% × 34% 18.82	6.399
Solar (Roof)	26.86 sq ft × 51	1.369
	EQ =	21.633 GAIN

$$V = \frac{21,633}{1.08 \times 2599} = 7.707 \rightarrow 8$$

$$ts = 72 - 8 = 64°F$$

Supply Air Temperature at Summer Design Point (t outside = 87°F)

Zone 1

Fabric				15.30
Infiltration				12.490
Lights (max @ 3:00 pm)				39.698
Occupants (Radiant)				11.575
Occupants (Convec.)				7.868
Solar	NE	60.02 × 40*		2.400
	SW	60.82 × 148		9.001
	NW	293.4 × 78		22.885
	HOR	33.1 × 190		6.289
			Q =	127.510

* June 3:00 pm Solar Data

$$\Delta t = \frac{127.510}{1.08 \times 4220} = 27.98 \simeq 28$$

$$ts = 72 - 28 = 44°F$$

Zone 2

$I_{se} = 243.4 \times 52 = 12.656$ replaces I_{nw} @ 22.885

$$ts = \frac{117.281}{1.08 \times 4220} = 25.33 \simeq 26$$

and ts 46°F

Zone 3

Fabric		4.680
Lights		32.232
Occupants (Radiant)		9.401
Occupants (Convec.)		6.395
Solar - 26.86 sq ft × 190		-5.103
	Q =	57.811

$$\Delta ts = \frac{57,811}{1.08 \times 2599} = 20.596 \simeq 21°F$$

$$ts = 72 - 21 = 21°F$$

SUMMARY

Zone	Primary Supply Air Winter @ -17°F	Temperature (°F) Summer @ 87°F
1	78	44
2	76	46
3	64	51

SECTION B

ENERGY ANALYSIS

THE CALCULATION OF ENERGY BUDGETS FOR NEW SCHOOLS

The following sections detail the results of analyses carried out using the school model as defined in Section A. Where possible the results have been compared with recorded data.

1. COMPARISON OF CALCULATED ENERGY CONSUMPTION AND ACTUAL RECORDED VALUES FOR SAMPLE OTTAWA AREA SCHOOLS (1974)

Based on the model defined in Section A, calculations of annual energy consumptions for 9 schools of various sizes were made using the Meriwether ESA/ERE program.

Actual 1974 Ottawa weather data was used for comparison with existing records of fuel consumption of some 64 schools in the Ottawa area.

The results for the 9 schools are shown in Table B1(1).

The net consumption figures shown in Table B1(1) have been adjusted to produce gross consumption figures in the manner indicated below. (Figures given in Table B1(2)).

These 'gross consumption' figures are compared with measured data in Figures B1.1, B1.2 and B1.3.

<u>Heating and DHW</u>	Seasonal boiler efficiency of 70 per cent is assumed.
<u>Cooling</u>	Over-all Refrigeration C.O.P. (includes consumption by pumps cooling tower, etc.) of 2.7 i.e., 1.3 kW•h of electricity will provide 1 ton•hr of cooling.
<u>Electricity</u>	To provide for miscellaneous electrical use (including heating pumps) 20 per cent of the basic light and fan consumption has been added to calculated figures.

TABLE B1(1)

RESULTS FROM ERE RUNS

School Type and Area (sq ft)	Type of Usage †	Net Heating and D.H.W. (kW·h/sq ft ann)	% D.H.W.	Net Cooling (ton hr/sq ft ann)	Electricity (Lights and fans) (kW·h/sq ft ann)
ELEMENTARY:					
5,000	(1)	21.03	2.5	0	7.51
	(2)	22.22	3.0	0	9.33
	(3)	24.91	4.4	0	13.72
10,000	(1)	15.27	3.5	0	6.39
	(2)	15.85	4.9	0	8.02
	(3)	17.72	6.2	0	12.06
20,000	(1)	12.19	4.3	0	5.97
	(2)	12.88	5.0	0	7.49
	(3)	14.65	7.5	0	11.36
40,000	(1)	9.21	5.7	0	5.49
	(2)	9.62	6.8	0	6.95
	(3)	10.87	10.0	0	10.79
60,000	(1)	8.49	6.2	0	5.49
	(2)	9.26	7.0	0	6.95
	(3)	9.94	11.0	0	10.90
SECONDARY:					
62,790	(1)	7.17	4.3	0.34	6.05
	(2)	7.25	5.2	0.39	7.74
	(3)	8.06	7.9	1.21	12.11
100,000	(1)	5.92	5.2	0.34	5.92
	(2)	5.96	6.4	0.39	7.57
	(3)	6.72	9.5	1.21	11.89
150,000	(1)	5.12	6.1	0.346	5.83
	(2)	5.16	7.4	0.395	7.47
	(3)	5.86	10.9	1.193	11.78
220,000	(1)	4.62	6.7	0.35	5.8
	(2)	4.66	8.2	0.40	7.43
	(3)	5.33	12.0	1.20	11.74

† (1) Basic use (2) Used evenings on school days (3) Used evening on school days, plus daytime use weekends and holidays

TABLE B1(2)

ESTIMATED GROSS CONSUMPTION FIGURES

School Type and Area (sq ft)	Type of Usage †	Heating (kW•hr/sq ft)	Electricity (kW•hr/sq ft)	% † Lights	% † Fans	% † Cooling
ELEMENTARY						
	(1)	30.0	9.0	46	37	0
5,000	(2)	31.7	10.8	50	36	0
	(3)	35.6	15.3	56	33	0
	(1)	21.8	7.7	55	29	0
10,000	(2)	22.7	8.3	58	28	0
	(3)	25.3	13.3	64	26	0
	(1)	17.4	7.1	59	24	0
20,000	(2)	18.4	8.7	62	24	0
	(3)	20.9	12.5	68	22	
	(1)	13.2	6.6	64	19	0
40,000	(2)	13.7	8.0	67	19	0
	(3)	15.5	11.9	72	18	0
	(1)	12.1	6.6	64	19	0
60,000	(2)	13.2	8.0	67	19	0
	(3)	15.6	12.0	72	18	0
SECONDARY						
	(1)	10.2	7.7	54	24	6
62,790	(2)	10.3	9.5	54	28	5
	(3)	11.5	14.9	55	26	11
	(1)	8.4	7.5	55	23	6
100,000	(2)	8.5	9.3	55	27	6
	(3)	9.6	14.6	57	25	11
	(1)	7.3	7.4	56	22	6
150,000	(2)	7.4	9.1	56	26	6
	(3)	8.4	14.5	57	24	11
	(1)	6.6	7.4	56	22	6
220,000	(2)	6.7	9.1	56	25	6
	(3)	7.6	14.5	57	24	11

† % of Electricity Consumption

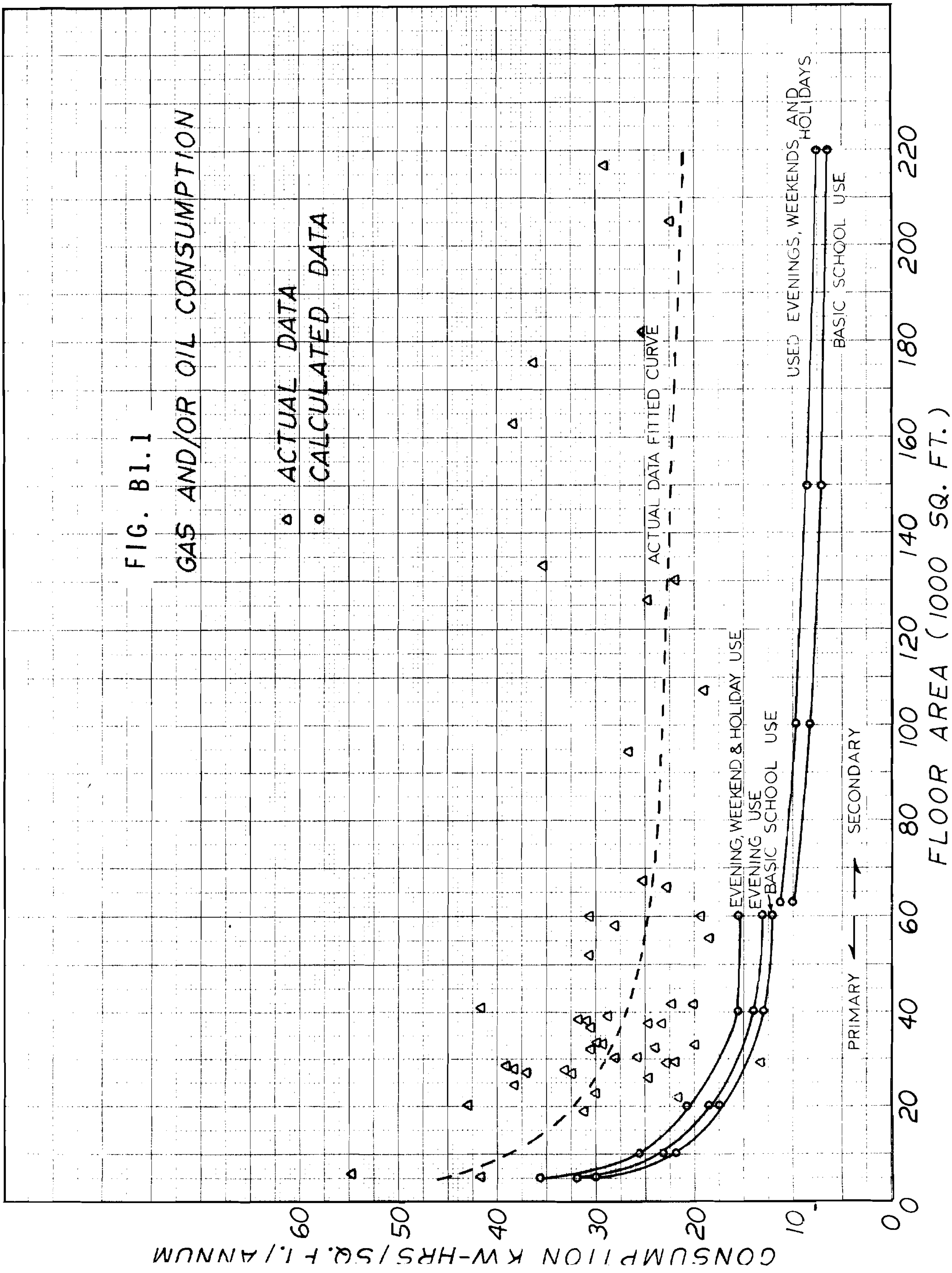


FIG. B1.1
GAS AND/OR OIL CONSUMPTION

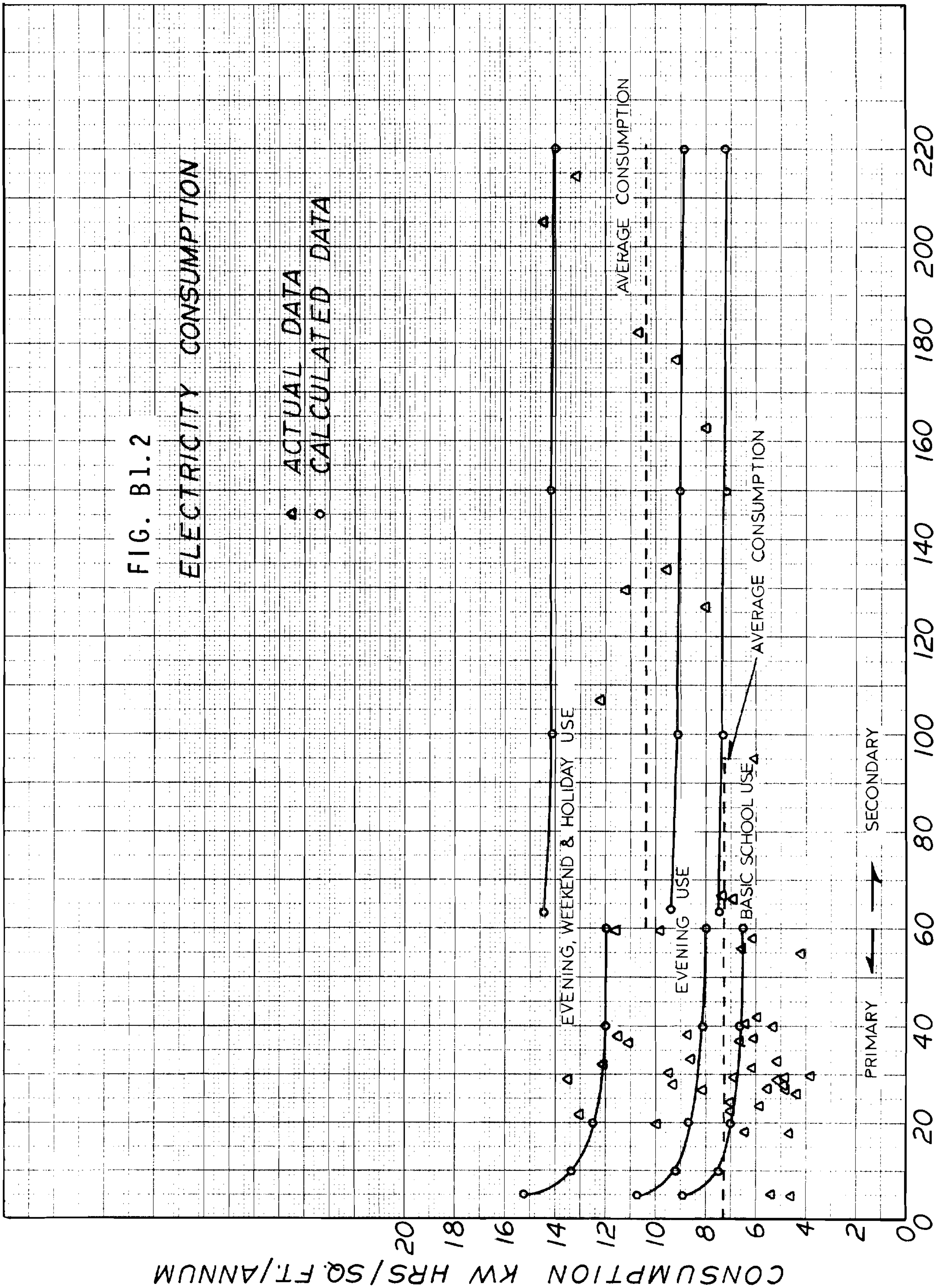


FIG. B1.2
ELECTRICITY CONSUMPTION
ACTUAL DATA
CALCULATED DATA
EVENING, WEEKEND & HOLIDAY USE
EVENING USE
BASIC SCHOOL USE
AVERAGE CONSUMPTION
AVERAGE CONSUMPTION
PRIMARY
SECONDARY
0 20 40 60 80 100 120 140 160 180 200 220
FLOOR AREA (1000 SQ.FT.)
0 2 4 6 8 10 12 14 16 18 20
CONSUMPTION KW HRS/SQ.FT./ANNUM

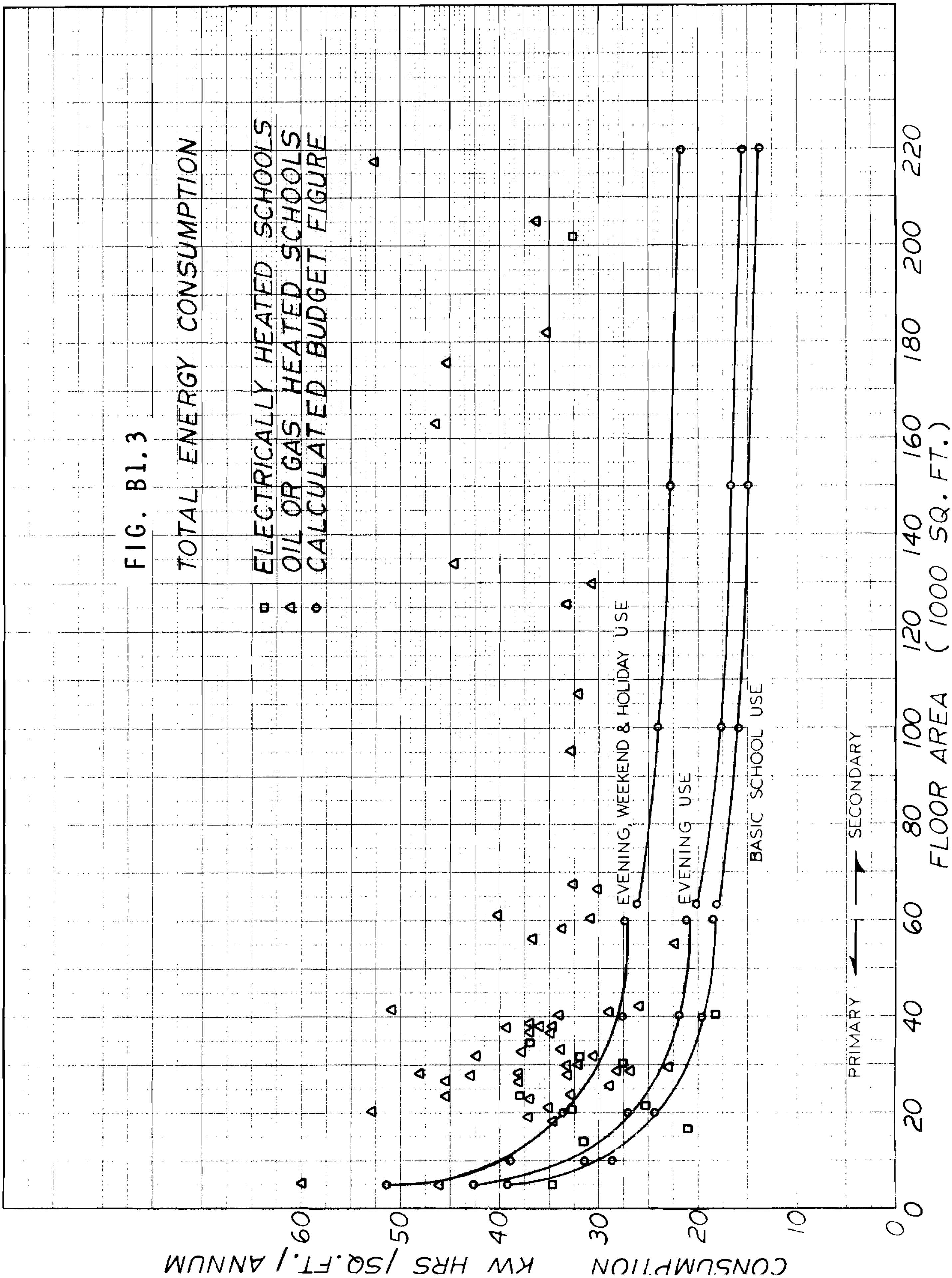


FIG. B1.3
TOTAL ENERGY CONSUMPTION
ELECTRICALLY HEATED SCHOOLS
OIL OR GAS HEATED SCHOOLS
CALCULATED BUDGET FIGURE
EVENING, WEEKEND & HOLIDAY USE
EVENING USE
BASIC SCHOOL USE
PRIMARY
SECONDARY
FLOOR AREA (1000 SQ. FT.)
CONSUMPTION KW HRS / SQ. FT. / ANNUM
0
10
20
30
40
50
60
80
100
120
140
160
180
200
220

Comparison of actual and calculated figures generally reinforce the choice of parameters for the school model, in particular they illustrate the need for an energy budget related to school size. There is, however, sufficient divergence between calculated and actual consumptions for secondard schools to warrant further comment.

This discrepancy could be the result of any one or combination of the following factors, which were not specifically considered in the analysis.

(i) Longer hours of use of secondary schools where after school activity is more frequent than in primary schools.

(ii) Differing environmental standards; secondary schools traditionally enjoy better facilities than primary schools. This is reflected typically in higher ventilation and air change rates, controlled humidity, higher lighting levels, etc.

(iii) The potential for energy waste in non air-conditioned buildings is less than that in air-conditioned buildings where simultaneous heating and cooling is an acknowledged problem.

(iv) Secondary schools have many special teaching aids that use energy. Equipment such as ovens and ranges in domestic science classrooms, metalworking and welding equipment in instructional workshops, and exhaust fans for special purpose exhaust such as fume hoods and cupboards in laboratories, are common in secondary schools but not in primary. Such equipment has the potential to consume large amounts of energy, both in the form of direct or primary energy to drive the machine and the secondary energy required to maintain acceptable environmental standards around the machine.

Miscellaneous Electrical Use

Miscellaneous electrical use is considered to include consumption by any electrical equipment not directly related to the environmental system and would include such items as teaching aids, cleaning and cooking equipment, etc.

Analyses carried out so far include calculations of electricity consumption solely for lighting and fans. An estimate of consumption was made for all other electrical equipment in order to compare actual and calculated data.

While a better estimate of consumption by plant peripherals such as pumps, burners, cooling tower fans, etc., could be made, lack of information at the present time prevents realistic estimates being made of miscellaneous electrical useage. To fill this apparent gap in knowledge the National Research Council's Division of Building Research intends to monitor electrical useage in schools.

Lighting

Analysis shows lighting to be the largest single user of electricity. For large secondary schools with extended hours of use consumption can exceed that required for heating and ventilation.

If considered in terms of primary energy, assuming the electricity used is produced by fossil fuel burning generating stations, then for all but the very smallest schools with limited hours of use, lighting can be the single highest consumer of primary fuel resources.

As it appears that lighting is such a significant user of energy it would seem sensible to ensure that the assumptions made for lighting in the school model are realistic and consistent with energy conservation.

Calculations of lighting electricity consumptions are based on illumination levels recommended by the Illuminating Engineering Society (I.E.S.) (American) and on assumed profiles of lighting useage. Before adopting the results as suitable components of an energy budget consideration should be given to the following points.

(1) Although there is strong evidence to support the illumination levels recommended by the I.E.S., (and in many cases to support even higher levels), it must be asked whether we can 'afford' levels of illumination that demand so much energy. How much we can afford is a matter of conjecture. By way of illustrating the possible savings in energy that could be achieved by an acceptable illumination level, Section B 2 presents results of an energy analysis using commonly used European lighting levels.

(2) Lighting useage, reflected in the profiles used, assumes 100 per cent lighting (i.e., all lights on) during occupied periods, and a considerable amount of useage in immediate pre and post occupancy periods. Further the pattern of lighting use in internal zones is assumed to be similar to that in perimeter zones.

While this could be typical in instances where energy costs are neither important nor directly passed onto the user, this usage pattern could be considered inappropriate as the basis of a lighting budget. To what extent occupants can be reasonably expected to, or do, in fact, switch off lights when not required is questionable and would require further study if such 'economics of use' were to be considered in the calculation of energy budgets. Such a study is now being undertaken by the National Research Council of Canada.

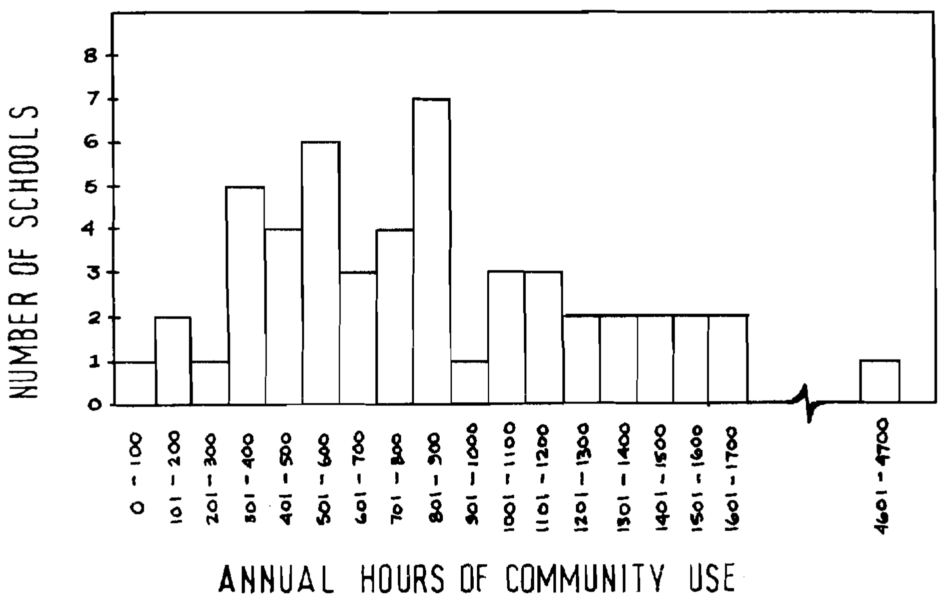
The Effect of Occupancy on Energy Consumption

The results of the analysis suggest that the hours of occupancy have a significant impact on the energy consumption of the school. By way of illustration:

School	Percentage Increase in Consumption			
	Used Evenings*		Used Weekend, Evenings, Holidays*	
	Gas/Oil	Electricity	Gas/Oil	Electricity
20,000 sq ft Primary School	+6%	+21%	+20%	+75%
150,000 sq ft Secondary School	+1%	+14%	+23%	+95%

The percentages will vary with the size of school
"*Evening Use" involves operation of the school for an additional 800 hours. (Basic use 1600 hours)
"*Evening, Weekend and Holiday use" involves operation of the school for additional 2120 hours.

Records obtained from the Carleton Board of Education show the following pattern of useage with average hours of community use of 879 hours for primary schools and 2307 for secondary schools. (Based on records of one year's community use.)



It should be noted that the hours of community use reported may include simultaneous useage of school facilities by a number of separate community groups and are not necessarily additional hours of use of the school facilities.

Because of the diversity and extent of community use there is some justification for increasing energy budgets to allow for extra curricula activity. The method and extent of such allowances require further consideration. For instance the calculated consumptions (given in Tables B1(1) and B1(2)) are based on extended hours of use of the whole building, involving full plant operation and 50 per cent lighting. While there is little justification for operating all school services to accommodate nominal community use, there is a practical limit to the way in which buildings can be designed and operated to achieve minimum energy useage during partial occupation.

To illustrate the significance of the hours of use on energy consumption it is useful to compare the variation of consumption with community use and the variation of consumption with location. (This example makes use of the results reported in Section B5).

Additional consumption for a 20,000-sq ft primary school is as follows:

Ottawa	(i) Evening Use	Oil/gas + 6% electricity +21%
	(ii) Evening, Weekend and Holidays	oil/gas +20% electricity +75%
Regional Variation across Canada	Evening Use	oil/gas 10.36 to 18.34 kW•hr/sq ft annum or ±28% of mean. or excluding extreme zones (1, 3 and 4) ±5% of mean. electricity 4.46 to 5.25 kW•hr/sq ft annum or ±8% of mean.

2. ENERGY CONSUMPTION FIGURES FOR OTTAWA AREA SCHOOL MODEL WITH REDUCED LIGHTING LEVEL

As lighting consumes a great deal of electricity and in view of increasing criticism of current levels of illuminance, there is some justification for energy budgets to be based on lower over-all levels of illumination than has currently been the fashion.

To investigate the energy consequences of reduced illumination the lighting specification of the school model, as defined in Part A, was changed to reflect typical European lighting practice.

The following Table compares the values of illuminance used in this investigation, (based on U.K. current recommended practice) with those used in the original model.

TABLE B2(1)

Space	Original Model (Based on I.E.S., U.S.A.) ft cd*	Reduced Illuminance (Based on I.E.S., U.K.) lux*
Classrooms	70	Primary 300 Secondary 500
Special Teaching	15-70	300-500
Assembly Halls	15-70	300
Circulation	25-30	100-150
Gymnasia	30	300

* 1 ft cd = 10.76 lux (lux = 1 lumen/sq metre)

These lighting levels translate to the following electrical loads, using ASHRAE 90-75 "Lighting Budget" method.

TABLE B2(2)

Space	Original Model (W/ft^2)	Reduced Illuminance (W/ft^2)
Classroom Block	2.3	Primary - 1.12 Secondary - 1.59
Hall	2.9	1.77
Gymnasium	Approximately similar loads	

Because a reduction in illuminance will be accompanied by a lower thermal input to the space, a change in energy usage affecting heating, cooling, fan and pump consumption will occur as well as the obvious change in lighting consumption.

For a heated only building, the following effects might be observed.

(1) Increased heating energy consumption,

(2) Increased "balance temperature" of building with probable lengthening of the "heating season" and possible increased energy consumption by heating plant peripherals.

(3) Larger pumps and fan sizes to handle increased loads resulting in higher electricity consumption.

For heated and cooled building the following additional effects might be observed:

(1) Reduced cooling consumption,

(2) Shortened cooling season with possible reduced energy consumption by cooling plant components/peripherals,

(3) Smaller pump and fan* sizes because of reduced loads.

Figures B2.1, .2 and .3 illustrate various energy consumptions. Table B2(3) compares energy consumptions of low illuminance and original models.

* (For heated/cooled building the air supply rate is most usually determined by the cooling required and therefore reduced lighting should permit a reduced fan size).

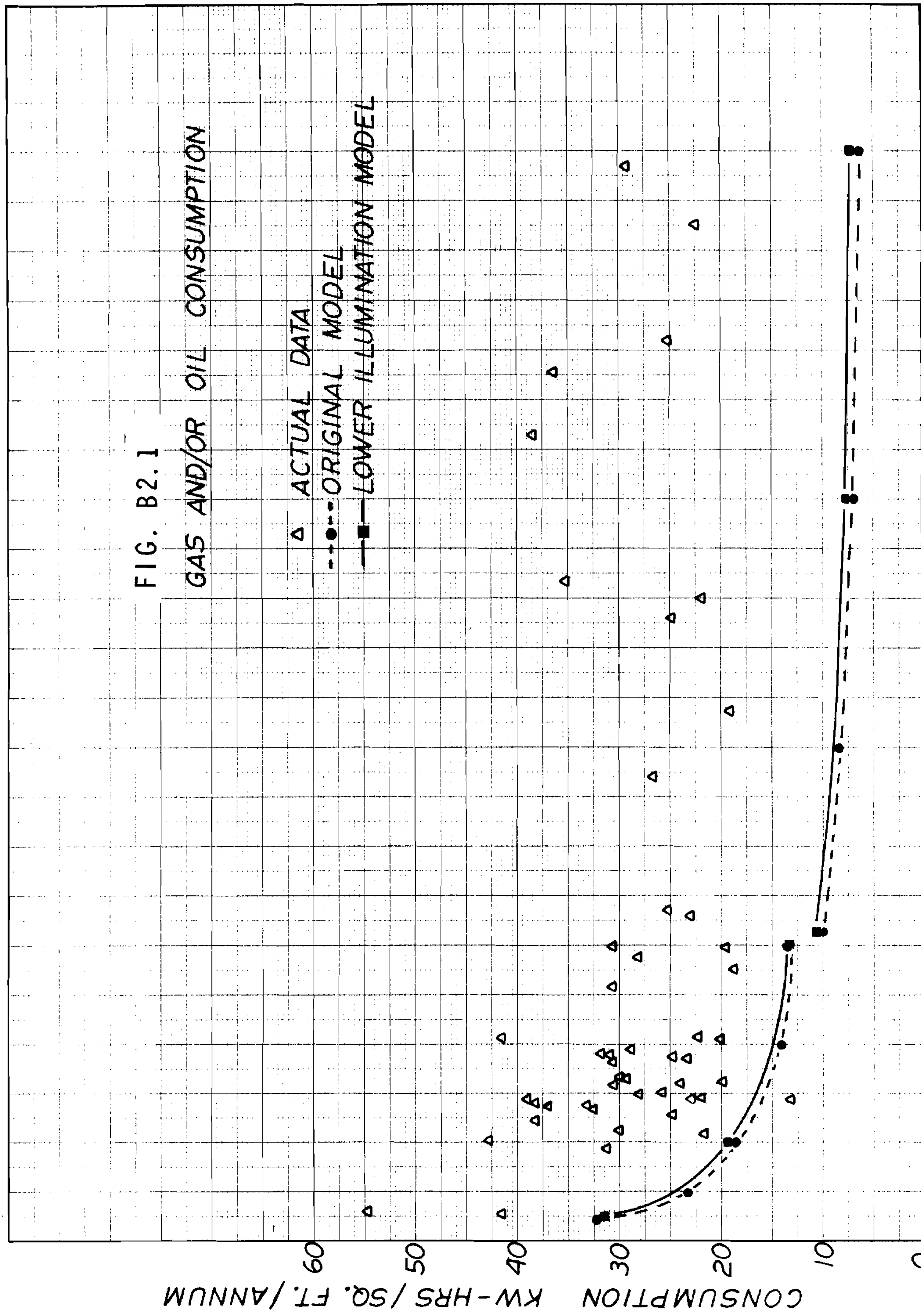


FIG. B2.1
GAS AND/OR OIL CONSUMPTION

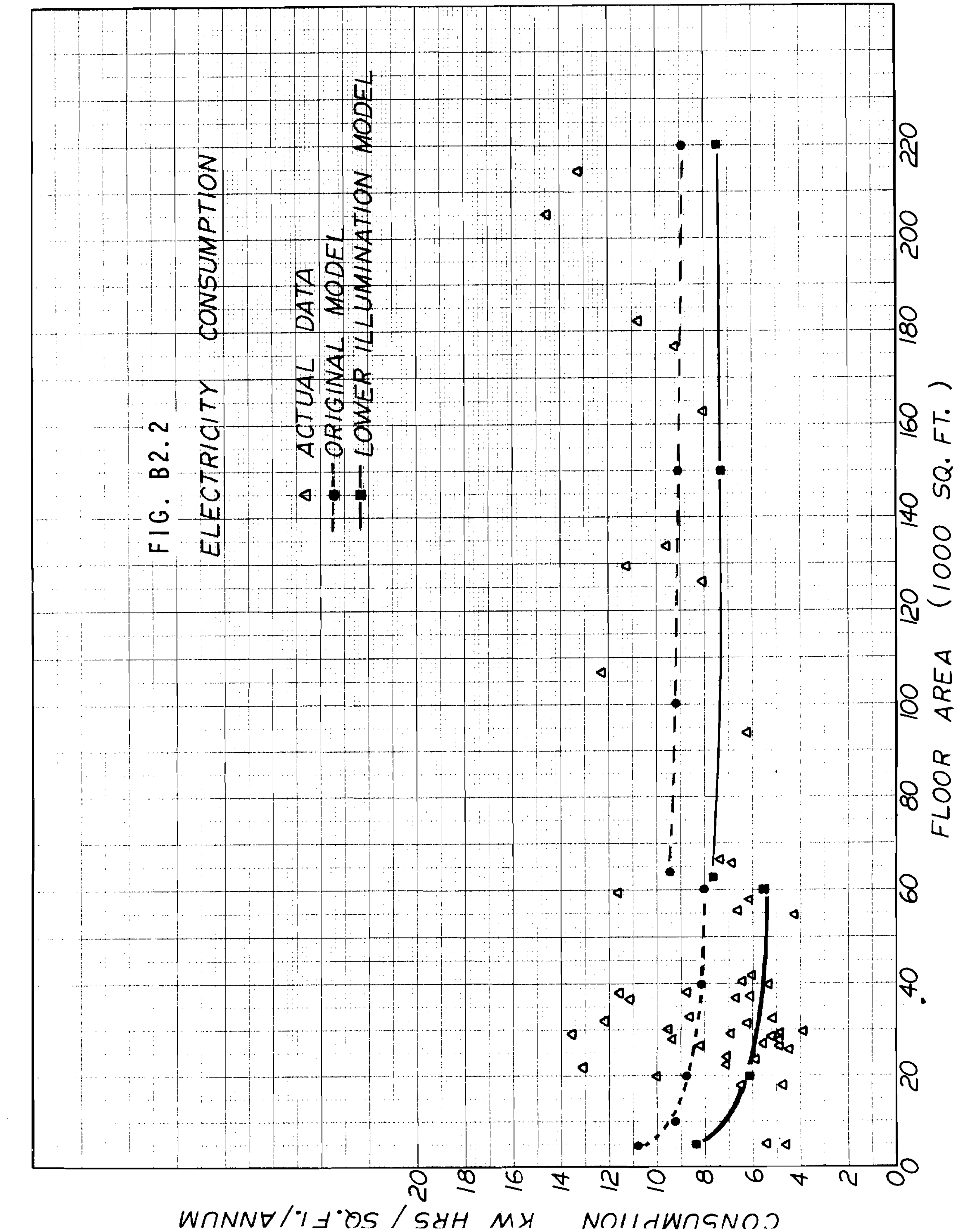


FIG. B2.2
ELECTRICITY CONSUMPTION

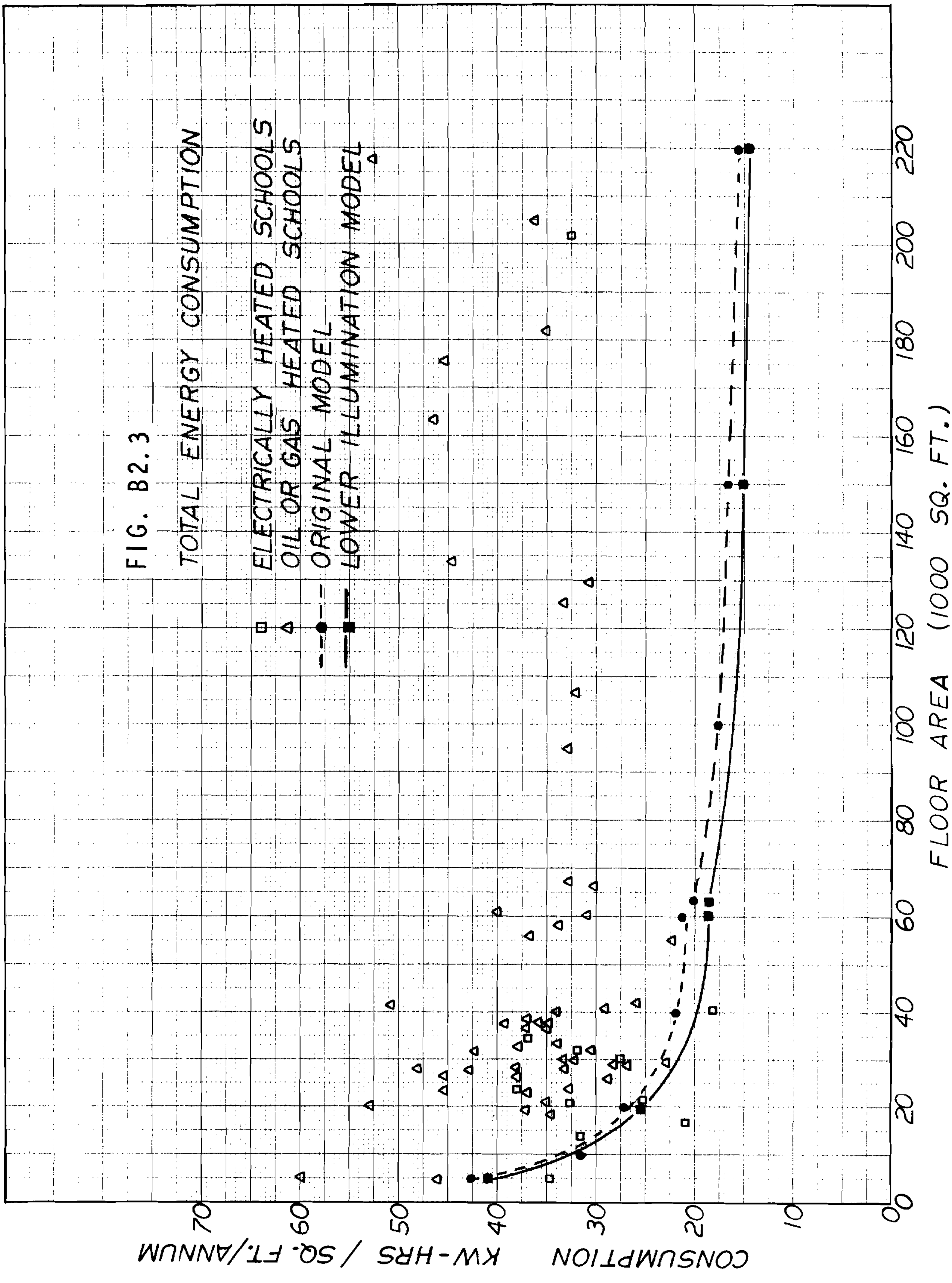


FIG. B2.3

TOTAL ENERGY CONSUMPTION

TABLE B2(3)

COMPARISON OF ENERGY CONSUMPTIONS FOR "LOW ILLUMINANCE" AND "ORIGINAL" MODELS. VALUES CALCULATED FOR SCHOOL DAY AND EVENING USAGE. ("ORIGINAL" MODEL VALUES SHOWN IN BRACKETS)

School	Net Consumptions (kW•hr/sq ft)			Gross Consumptions (kW•hr.sq ft)	
	Heating and DHW	Electricity (Fans and Lights)	Cooling	Heating and DWH	Electricity
5,000 sq ft Primary	22.92(22.22)	6.86(9.33)	-	32.74(31.7)	8.36(10.83)
20,000 sq ft Primary	13.59(12.88)	4.95(7.45)	-	19.4 (18.4)	6.16(8.68)
60,000 sq ft Primary	9.33(9.26)	4.41(6.95)	-	13.33(13.2)	5.51(8.05)
62,790 sq ft Secondary	7.69(7.25)	6.04(7.74)	0.3174(0.39)	10.99(10.3)	7.66(9.46)
150,000 sq ft Secondary	5.52(5.16)	5.81(7.47)	0.3047(0.395)	7.89(7.37)	7.38(9.15)
220,000 sq ft Secondary	4.94(4.66)	5.84(7.43)	0.3026(0.40)	7.06(6.66)	7.39(9.11)

In the results reported here the effects of increased pump size, and change in seasonal efficiency are not considered. Further to limit computation, one pattern of use, basic school use and evenings, is considered.

Computations are made using Ottawa 1974 weather data to enable comparison with the original model results. (Section B1).

The results of the analysis are self-evident and indicate a useful saving in electrical energy.

What is significant, however, is that it would appear that high lighting levels cannot be condoned in general on the basis that heat from the lamp will significantly offset heating demand. It may, however, do so in specific instances e.g., where heat recovery techniques are utilized; every case should be assessed on merit. In this respect, it should be remembered that based on the amount of primary energy needed to produce a unit of electricity, a kW•hr of electricity is worth more than an equivalent kW•hr of heating.

On the basis of this useful saving all other analyses are based on the low illuminance model.

3. INVESTIGATION INTO THE IMPLICATIONS OF AN ENERGY BUDGET FIGURE INDEPENDENT OF FLOOR AREA

This section explores the possibility of adopting an energy budget independent of floor area. This type of standard, if it be realistic to adopt such, could be considered administratively desirable because similar budgets could be used for all building sizes; complications such as might be encountered in phased construction for example, could be avoided.

Further, because greater restraints would be required to make smaller buildings meet the standard, the inherent high energy consumption of small buildings could be reduced. How much it is practical to reduce consumption is considered.

This type of reasoning could be extended to argue the case for a single budget figure for all locations (climatic areas) throughout Canada. (The effect of climate on energy consumption is discussed later).

Rather than seeking a solution to what is essentially an open ended problem, two examples are considered to illustrate the implications of an area independent budget.

Previous ESA runs for Ottawa (Based on Primary School Low Illuminance Model 1974 Weather - Section B2) gave "schoolday and evening use" net heating consumptions of 8.67 kW•hr/sq ft (floor) annum for a 60,000-sq ft school and 22.26 kW•hr/sq ft (floor) annum for a 5,000-sq ft school.

The first possibility is for an energy budget based on the average of the consumptions of the two schools at extreme ends of the primary area scale (i.e., 5,000 and 60,000 sq ft as above). In this case the allowable net heating consumption would be 15.47 kW•hr/sq ft annum equivalent to 23.04 gross consumption.

As can be seen from Figure B3 a significant number of existing schools, particularly the larger ones, already satisfy this requirement and therefore to adopt such a level could be considered a retrograde step.

The second possibility is for a budget based on the consumption of the larger school, i.e., 8.67 kW•hr/sq ft annum. Consider the problem:

The heat loss at design Δt for the 60,000-sq ft school is:

Fabric	10.48 Btu/sq ft floor area (Equivalent to 0.1178 Btu/sq ft °F)
Infiltration	3.39 Btu/sq ft floor area (Equivalent to 35.22 cfm/1000 sq ft floor area)

A similar "per floor area" heat loss of:

Fabric	10.51 Btu/sq ft, and
Infiltration	3.39 Btu/sq ft

could be achieved in the 5,000-sq ft school by implementing <u>all</u> the following changes:

(1) reducing the U values of the walls and roof by one half, to 0.05 and 0.03 respectively

(2) providing triple glazed windows or reducing the glazing percentage to 14.5 per cent of internal wall area and using double glazing

(3) adopting a single square shape floor plan with the "hall" as an internal zone, of similar height to the classrooms

(4) reducing the previously used wall infiltration rate of 0.3 cfm/sq ft to 0.1992 cfm/sq ft, and

(5) replacing perimeter slab insulation R6 with R8.

Based on the results of the analyses (see Table B3) and the restrictions that would be necessary to achieve such uniform consumption figures, it is felt that to adopt an area-independent budget based on the 60,000 sq ft figure would be impracticable.

FIG. B3 ESTIMATED GROSS HEATING AND DOMESTIC HOT WATER CONSUMPTION FOR PRIMARY SCHOOLS:

Comparison of Possible Area Independent Budget with Fuel Consumption Records

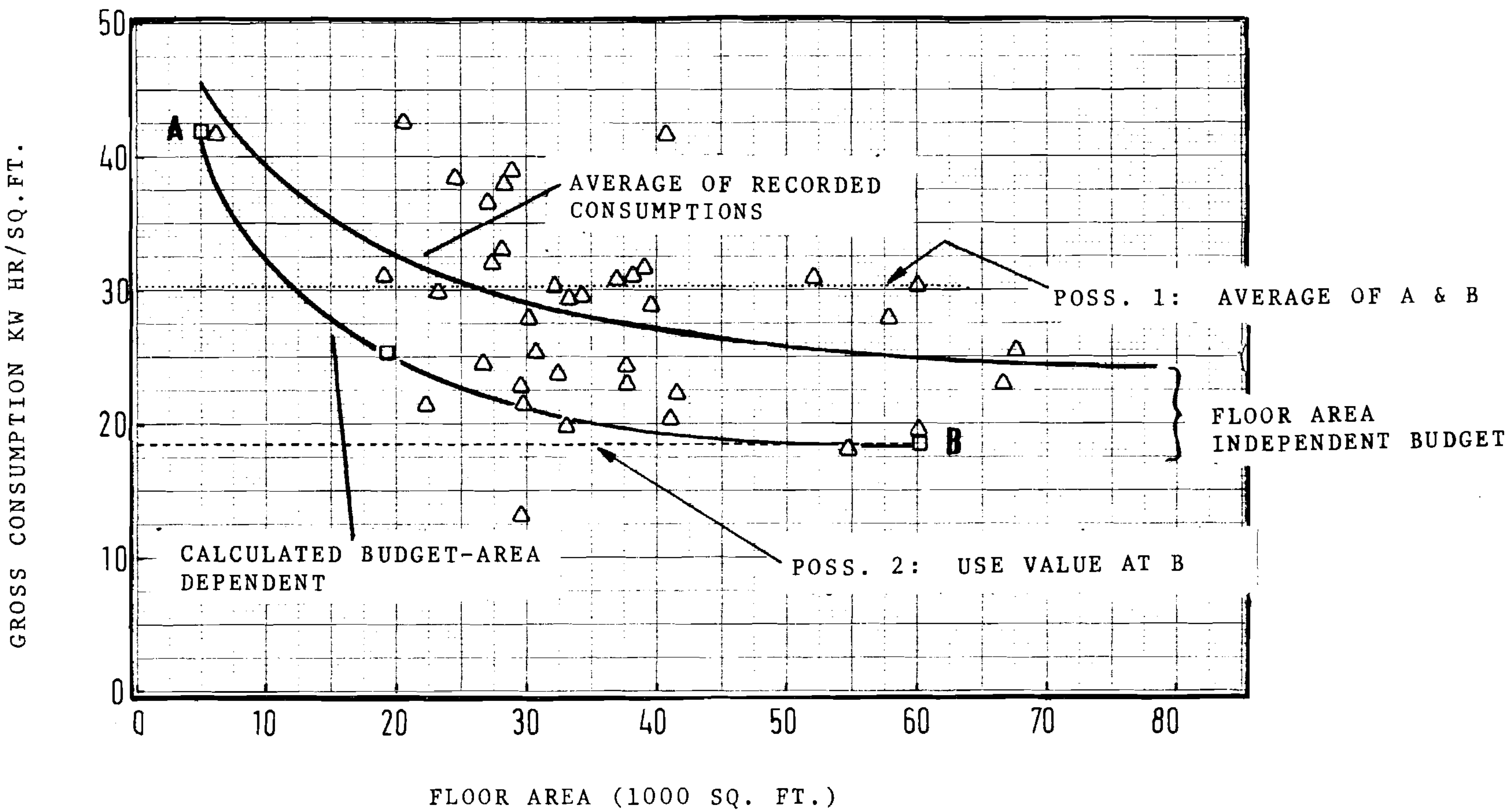


TABLE B3

NET ANNUAL CONSUMPTIONS

	Annual Heating Consumption	Electricity Consumption (Fans and Lights only)
5000 sq ft primary School (original low illuminance model)	22.26	6.86
5000-sq ft "per floor area" heat loss as 60,000-sq ft school		
~25% triple glazed	9.42	4.19
~14.5% double glazed	9.54	4.19
5000-sq ft "per floor area" fabric loss as 60,000 sq ft but wall infiltration as original model		
~25% triple glazed	10.61	4.42
~14.5% double glazed	10.61	4.42
60,000-sq ft Primary School (original low illuminance model)	8.67	4.41

Further to choose any higher budget figure would negate the advantages to be gained from having a practicable lower budget for larger buildings.

In conclusion a budget figure based on floor area, or a floor area related parameter such as occupancy, is recommended.

There is, however, some justification for reducing the apparently higher consumption of smaller buildings. Energy budgets could be calculated using models in which the thermal performance is related to the size of building.

4. VARIATION IN CALCULATED ENERGY CONSUMPTION FOR VARIOUS LOCATIONS IN CLIMATIC AREA 6 (MONTREAL AREA)

This section investigates the effect of differing location and weather on the calculated energy consumption of a 20,000 sq ft primary school, in various locations in climatic zone 6. (Figure B4.1).

ESA runs were made to calculate the energy consumption of a 20,000 sq ft primary school being used in the evening. Input for the runs was based on a model with parameters as defined in the main section of this document. In particular for the "Lower Illuminance Model" (see Section B2).

Three specific models were used:

1. Montreal Design with U values selected on the basis of Montreal average degree days† (see Section 2 of Model Definition) i.e., based on a 8208 Degree Days below 65°F.

U walls/windows	0.235	Btu/hr ft^2 °F
U roof	0.06	Btu/hr ft^2 °F
R slab	6.3	Btu/hr ft^2 °F

2. Ottawa Design with U values selected on the basis of Ottawa average degree days † i.e., based on 8693 Degree Days below 65°F.

U walls/windows	0.225	Btu/hr ft^2 °F
U roof	0.06	Btu/hr ft^2 °F
R slab	6.6	°F hr ft^2/Btu

3. Quebec Design with U values selected on the basis of Quebec average degree days† i.e., based on 8937 Degree Days below 65°F

U walls/windows	0.219	Btu/hr ft^2 °F
U roof	0.06	Btu/hr ft^2 °F
R slab	6.8	°F hr ft^2/Btu

† Average degree days are taken from "Climatic Information for Building Design in Canada 1975 - Supplement No. 1 to the National Building Code of Canada."

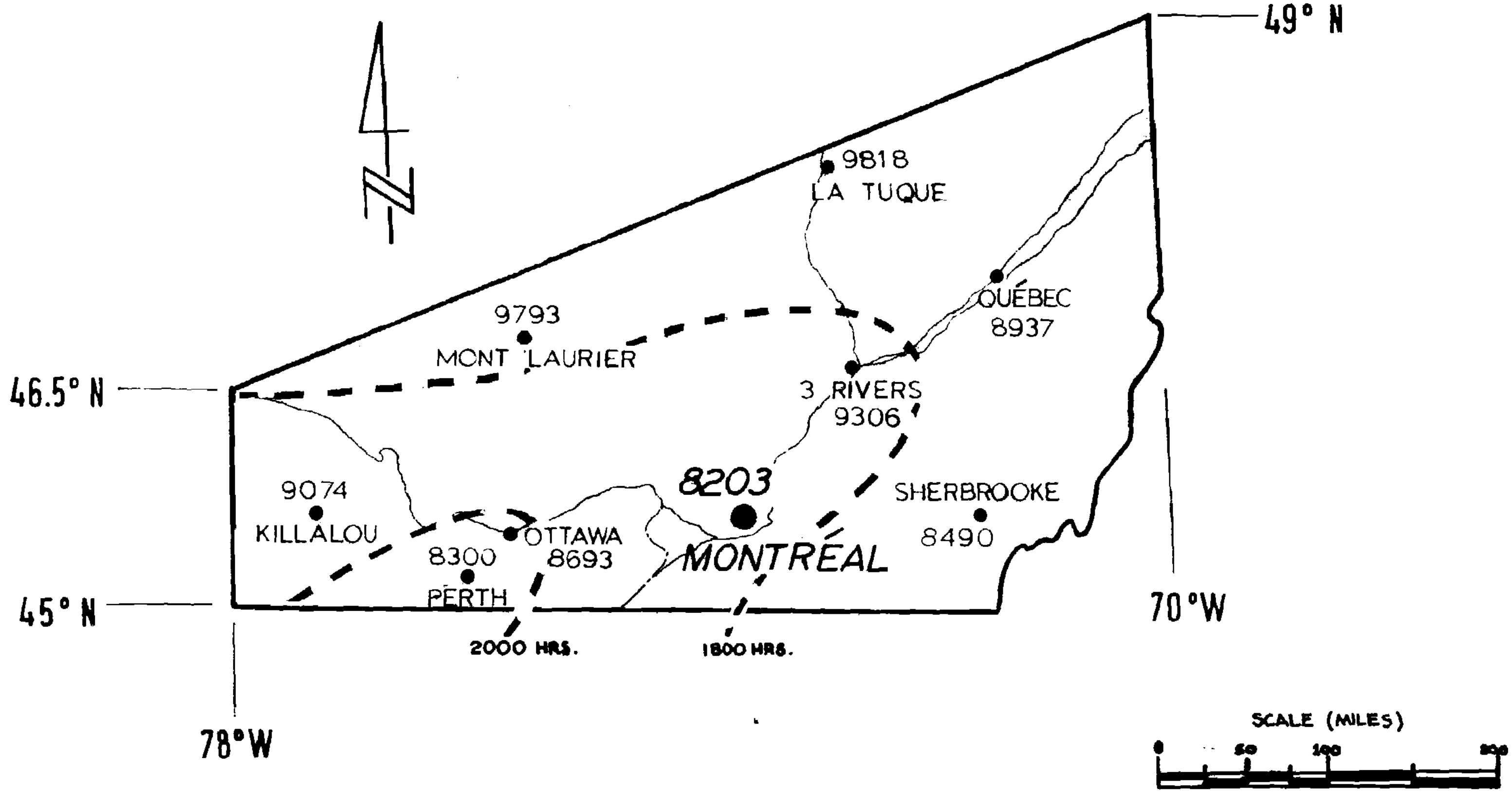


FIG. B4.1 CLIMATIC ZONE 6: SHOWING SELECTED CITIES AND ASSOCIATED AVERAGE DEGREE DAYS, AND CONTOURS OF HOURS OF BRIGHT SUNSHINE

The results of Meriwether ESA runs using these three models and various weather data are shown in Table B4 and graphically in Figure B4.2.

If the Montreal model with 'Reference Year' weather data is to be used as the basis for the energy budget in the climatic zone 6 (see Fig. B4.1), then the budget figures would be:

net heating 13.6 kW•h/sq ft annum

electricity (fans and lights) 4.95 kW•h/sq ft annum

If a school were designed to meet this budget based on an analysis using the zone reference weather data (i.e., Montreal RY), and should this school be built at any location other than Montreal, then the actual consumption of the school would be significantly higher over most of the zone.

As can be seen from Figure B4•2, the highest heating consumption of the zone would be of the order of 17.1 kW•h/sq ft annum for an average winter. This is a range of 3.6 over the zone or + 26.5 per cent of the calculated budget figure.

This range is wide enough to force us to formalize our thinking on possible allowances for location or, alternatively, to consider the implications of adopting a single budget figure that must be met throughout the zone. Should it be decided to adopt a standard incorporating allowances for location, then these allowances, or a method of obtaining such, would need to be specified in the code/standard document.

Alternatively, if a single budget is to apply throughout the zone then we must be confident that it is practicable for buildings at the weather extremes of the zone to meet this budget. Further it is desirable that budgets for adjacent zones not be significantly different. The problem is considered on a broader base in Section B5 where calculated consumptions for the nine climatic zones are reported.

Annual Variation in Consumption at any given Location

Any year that weather conditions are significantly different from the test reference year, one can expect different consumptions. For example, calculations based on the Ottawa School Model using weather data from 1972 to 1975 show heating consumptions varying from 12.83 kW•h/sq ft in 1973 (Dd = 9128) to 14.98 in 1972 (Dd = 8064), a variation of 15.3 per cent based on the consumption of an average year (Dd = 8693).

Clearly some method of correcting budget figures to allow for annual weather conditions will need to be formulated; - this question is pursued later in Sections B5 and 8.

TABLE B4

CALCULATED NET HEATING AND ELECTRICAL (FANS AND LIGHTS) ANNUAL CONSUMPTIONS FOR A 20,000 SQ FT PRIMARY SCHOOL

Building Model	Weather			Calculated Consumption	
	City	Year	Degree Days	Heating (kW•h/sq ft annum)	Electricity
Montreal Design	Montreal	RY	8058	13.6	4.95
	Montreal	66	8036	13.55	4.95
	Ottawa	72	9128	15.50	4.97
	Ottawa	73	8064	13.01	4.97
	Ottawa	74	8615	13.83	4.97
	Ottawa	75	8181	13.48	4.97
	Quebec	65	9768	16.19	5.07
	Quebec	70	9586	15.67	5.07
	Quebec	66	8969	14.93	5.07
Ottawa Design	Ottawa	72	9128	14.98	4.93
	Ottawa	73	8064	12.83	4.93
	Ottawa	74	8615	13.63	4.93
	Ottawa	75	8181	13.03	4.93
Quebec Design	Quebec	65	9768	15.55	4.95
	Quebec	70	9586	15.05	4.95
	Quebec	66	8969	14.37	4.95

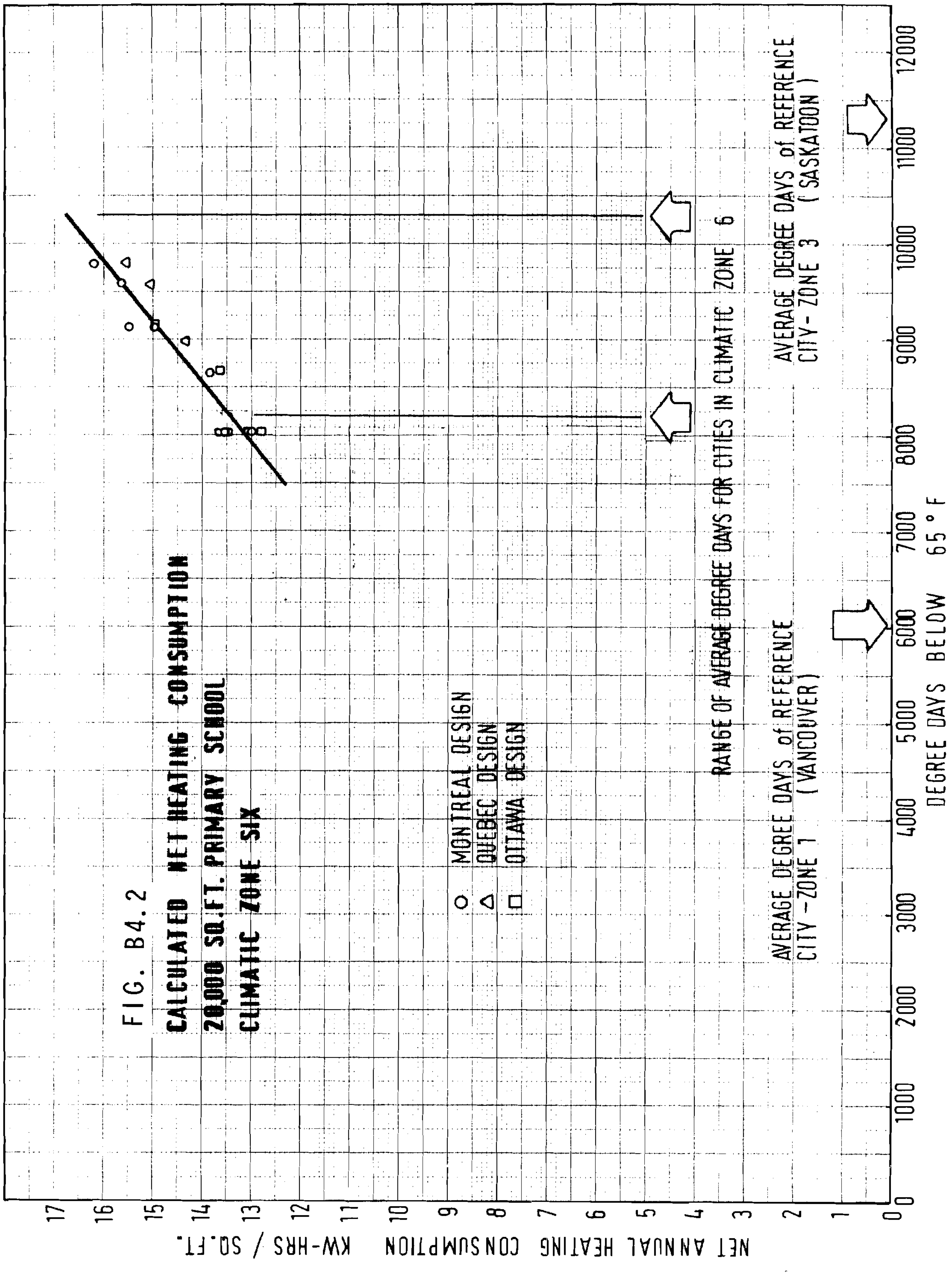


FIG. B4.2
CALCULATED NET HEATING CONSUMPTION
20,000 SQ.FT. PRIMARY SCHOOL
CLIMATIC ZONE SIX
○ MONTREAL DESIGN
△ QUEBEC DESIGN
□ OTTAWA DESIGN
RANGE OF AVERAGE DEGREE DAYS FOR CITIES IN CLIMATIC ZONE 6
AVERAGE DEGREE DAYS of REFERENCE
CITY - ZONE 1 (VANCOUVER)
AVERAGE DEGREE DAYS of REFERENCE
CITY - ZONE 3 (SASKATOON)
NET ANNUAL HEATING CONSUMPTION KW-HRS / SQ.FT.
DEGREE DAYS BELOW 65 ° F
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

5. VARIATION IN CALCULATED ENERGY CONSUMPTION FOR VARIOUS CLIMATIC AREAS ACROSS CANADA

Calculated energy consumptions for schools in various locations throughout Canada are reported in this Section.

For each of the nine reference cities, school models were defined as in the method outlined in Model Definitions (Section A), specifically a 20,000 sq ft primary school, "Lower Illuminance Model" with evening use. U values for the enclosure were selected in accordance with ASHRAE 90-75 and based on the Design Degree Days for the cities. Reference year weather data were used. The results are shown in Table B5 and graphically as a function of Degree Days in Figure B5.1.

TABLE B5

CALCULATED NET ANNUAL CONSUMPTIONS

Area	City	*Design Degree Days	Test Re Reference Year (RY)	†Degree Day (RY)	Heating kW•h/sq ft	Electrictiy (Fans and Lights) kW•h/sq ft
1	Vancouver	5,515	1959	5,609	10.36	4.46
2	Lethbridge	8,644	1956	8,809	14.52	5.25
3	Saskatoon	10,856	1956	11,385	18.28	5.22
4	Winnipeg	10,679	1970	11,391	18.34	4.97
5	Toronto	6,827	1968	7,782	13.80	4.83
6	Montreal	8,203	1966	8,058	13.60	4.95
7	Fredericton	8,671	1966	8,035	13.29	4.95
8	Shearwater	7,361	1971	7,805	13.75	4.80
9	St. Johns	8,991	1963	9,051	14.91	4.70

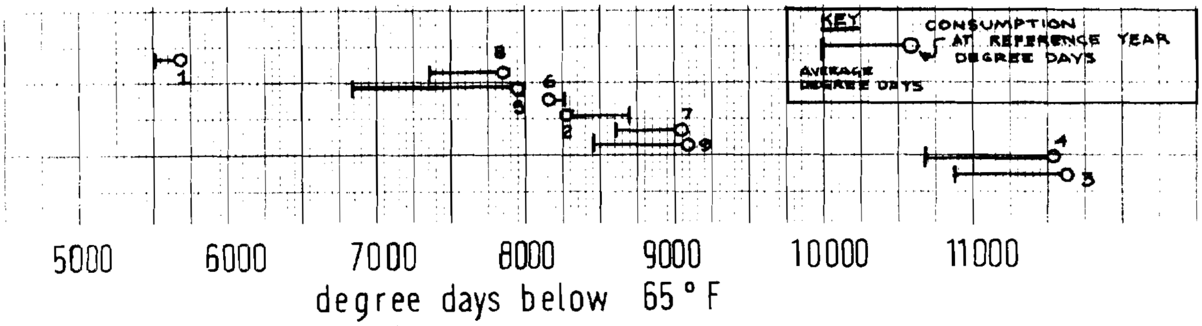
* Obtained from Climatic Information for Building Design in Canada 1975 (NRC 13986)

† Degree Days for actual RY weather computed using the formula

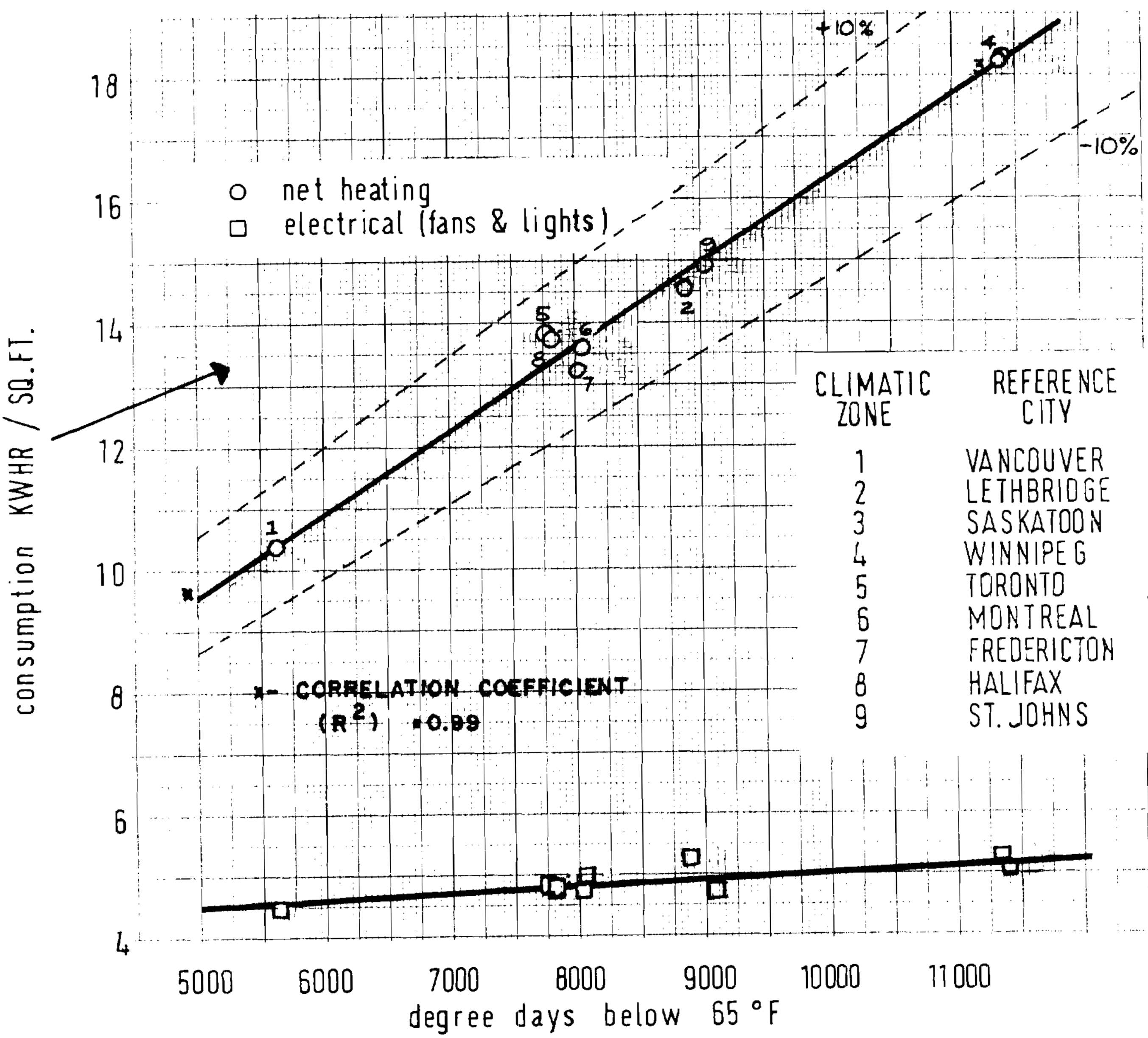
$$D_{65} = \sum_{d=1}^{d=365} 65 - t_d' \quad \text{for} \quad t' < 65°F$$

where

t_d' = average daily temperature



DIFFERENCE BETWEEN AVERAGE AND REFERENCE YEAR DEGREE DAYS FOR REFERENCE CITIES



CALCULATED NET HEATING AND ELECTRICAL CONSUMPTION

FIG. B5.1

Variation in Heating Consumption

As can be seen from Figure B5.1, the heating consumption bears a reasonably consistant relationship with annual degree days. Figures B5.2 and B5.3 show the variation between the reference city average degree days and the reference year (RY) degree days. Because reference city designs are based on average degree days, calculations based on RY weather data significantly different from average can be expected to show proportionately differing consumptions.

For example, Toronto design is based on average degree days of 6827 with U values of wall and roof of 0.26 and 0.069 respectively. RY weather has 7782 degree days, which would demand U values of 0.24 and 0.06. If these values were used it can be appreciated that the Toronto point would be closer to the average line, i.e., lower consumption. Consequently, it can be anticipated that if weather data nearer to average degree days were used, then the slope and possibly fit of the line could vary, albeit a marginal amount.

If the RY data is to be used to produce energy budgets without any further correction, then to be consistent it should be close to the average for the reference city or average for the climatic area. Unless this is observed anomolies can occur such as between Lethbridge and Fredericton where Fredericton with lower average degree days than Lethbridge has a higher calculated heating consumption. It is possible that this anomoly could be allowed for by some form of correction factor as discussed briefly in Section 4.

If, as it has been suggested, all buildings be monitored after construction and those with higher than budget consumption figures be investigated, then buildings in areas with budgets based on higher than average degree day weather will have a bonus allowance to those whose RY is close to or lower than the average.

Because it seems logical to have all budgets based on a similar consistent criteria, it is worth while to reconsider the concept on climatic zones and reference city calculations based on selected reference years.

Figure B5.4 shows the range of average degree days for each of the climatic zones and the position in the range of the reference city. Figure B5.5 shows net heating for actual degree days of reference year. It is obvious from this graph that the variation in degree days in some zones is considerably more than the variation between zones. Indeed zone 7 degree days are completely enclosed by zone 6, likewise 2 by 9 and 4 by 3.

At this point it is worth reconsidering the question raised in Section B4 concerning allowance to location within climatic zones.

Figure B5.6 shows the location of the climatic zones and the calculated budget figures for a 20,000 sq ft school based on the recommended reference year weather data.

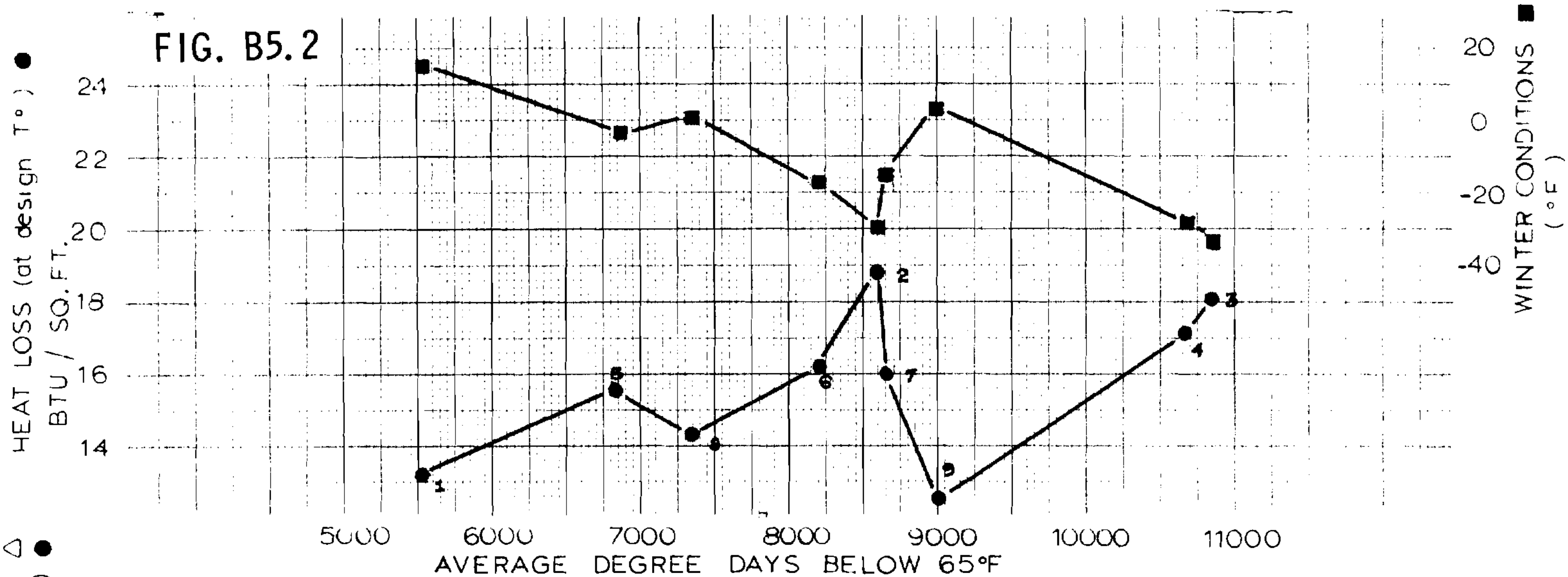


FIG. B5.2
HEAT LOSS (at design T°) ●
BTU / SQ.FT.
WINTER CONDITIONS ■
(°F)
AVERAGE DEGREE DAYS BELOW 65°F

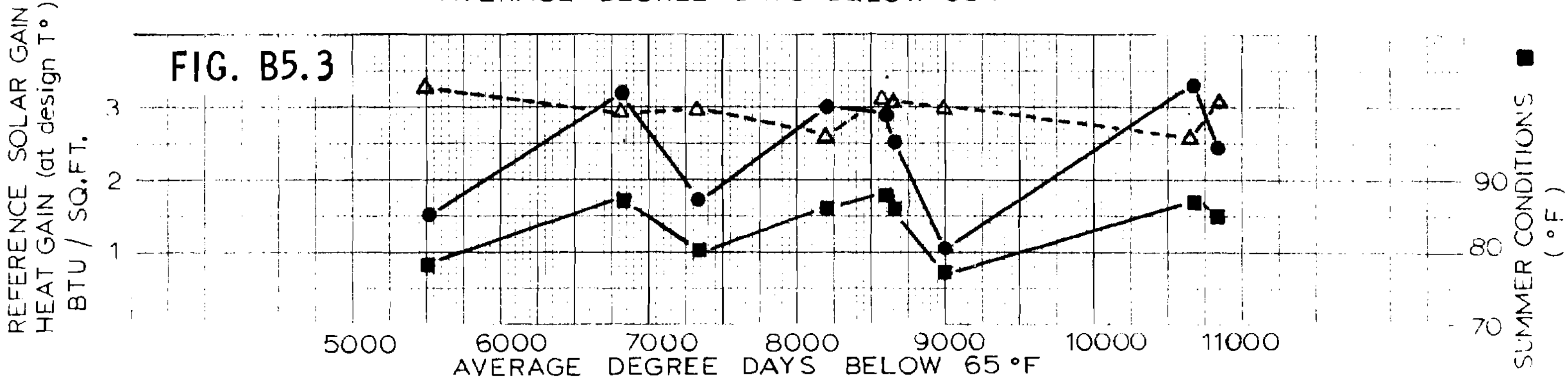
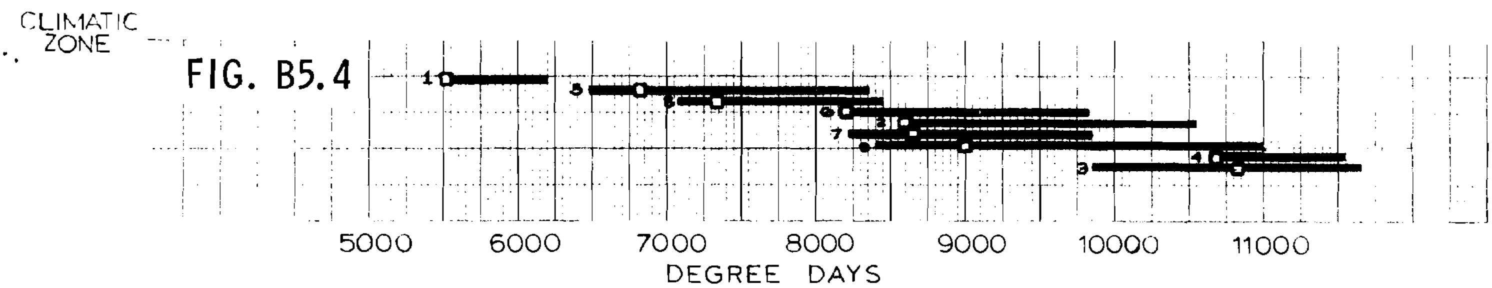


FIG. B5.3
REFERENCE SOLAR GAIN △
HEAT GAIN (at design T°) ●
BTU / SQ.FT.
SUMMER CONDITIONS ■
(°F)
AVERAGE DEGREE DAYS BELOW 65 °F


CLIMATIC ZONE
FIG. B5.4
DEGREE DAYS

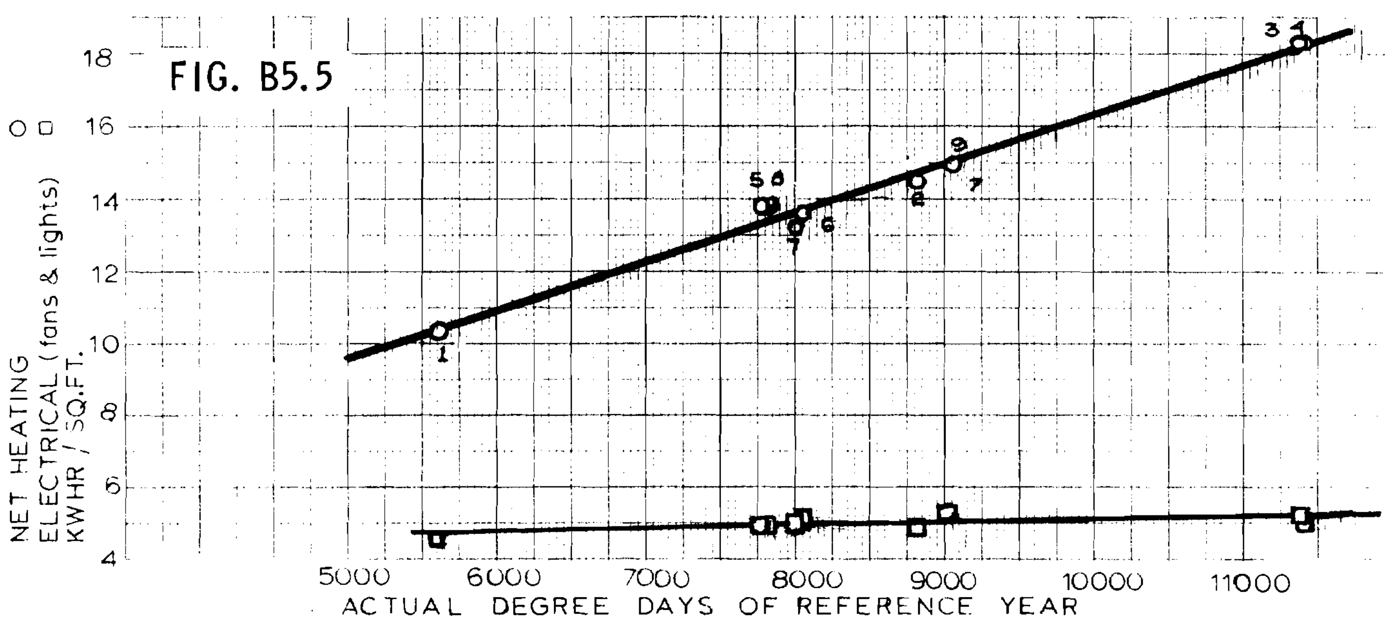
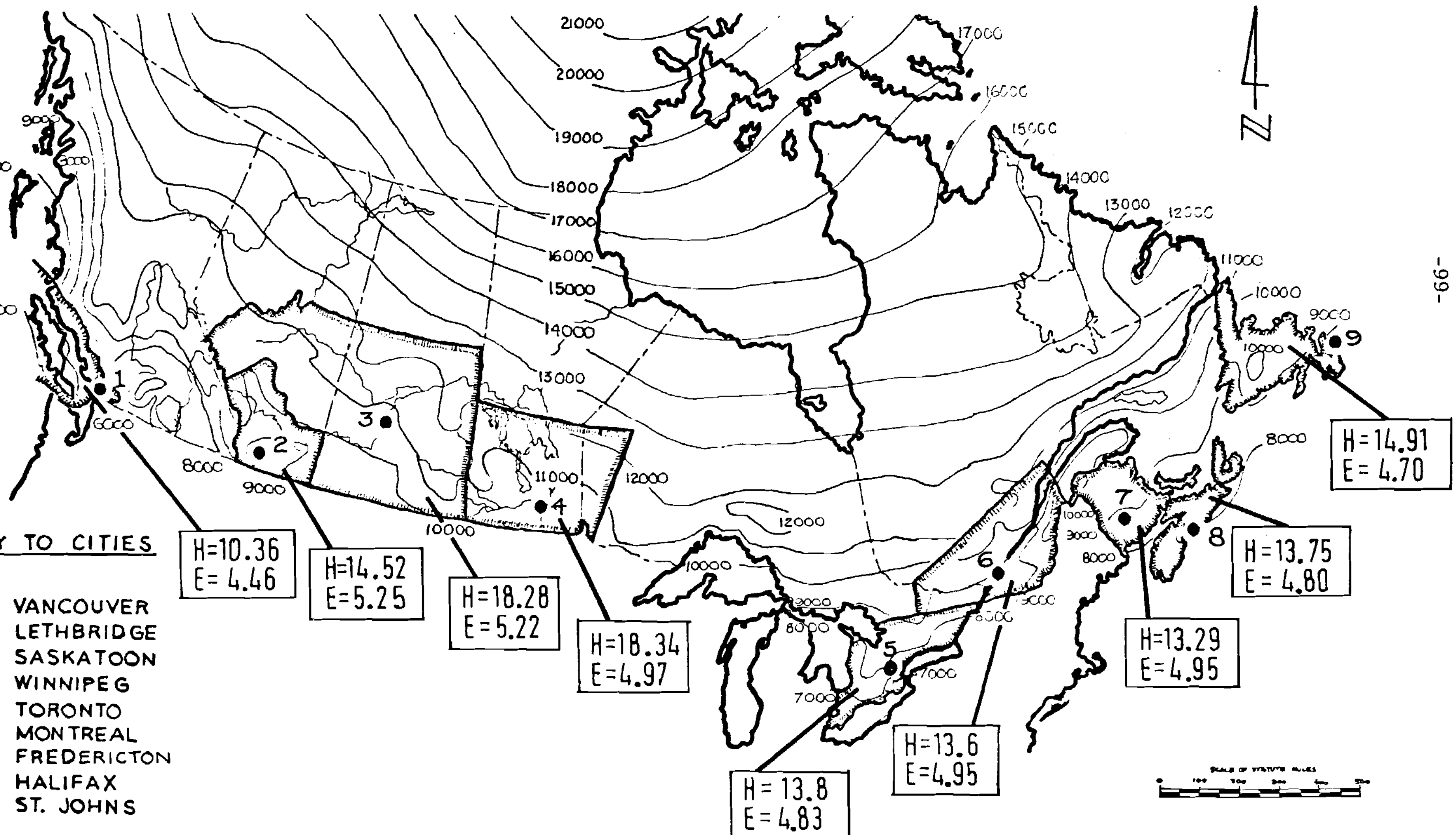


FIG. B5.5
NET HEATING ○
ELECTRICAL (fans & lights) □
KWHR / SQ.FT.
ACTUAL DEGREE DAYS OF REFERENCE YEAR

FIG. B5.6

REFERENCE CITY LOCATIONS AND CLIMATIC AREAS

SHOWING CALCULATED ENERGY CONSUMPTION FOR 20 000 SQ FT PRIMARY SCHOOL AT REFERENCE CITIES AND BASED ON REFERENCE YEAR WEATHER DATA



KEY TO CITIES

1 VANCOUVER
2 LETHBRIDGE
3 SASKATOON
4 WINNIPEG
5 TORONTO
6 MONTREAL
7 FREDERICTON
8 HALIFAX
9 ST. JOHNS

H: HEATING CONSUMPTION - KWHR / SQ.FT.
E: ELECTRICAL CONSUMPTION (FANS & LIGHTS)-KWHR / SQ.FT.

If we consider the second alternative proposed in Section B4 i.e., for a calculated budget to apply over the whole zone, then it becomes obvious that the calculated consumptions at the selected reference cities are not suitable since they are not representative of the average consumption expected in the area.

As an alternative, budget figures based on the consumption on an average or near average degree day location in the zone could be used. The results would be similar to those detailed on Figure B5.7.

While this might be representative of the average heating in the zone, a problem may arise for air conditioned buildings if this location is not in an average cooling area.

Additional problems are inherent with the 'budget for zone approach' such as:

(1) The large variation in building insulation standard across the zone necessary for the extreme areas to maintain 'budget figure consumption'. This could be minimized by choosing smaller zones;

(2) Discontinuity at zone boundaries, if greater than a nominal amount, create an inconsistent set of rules; and

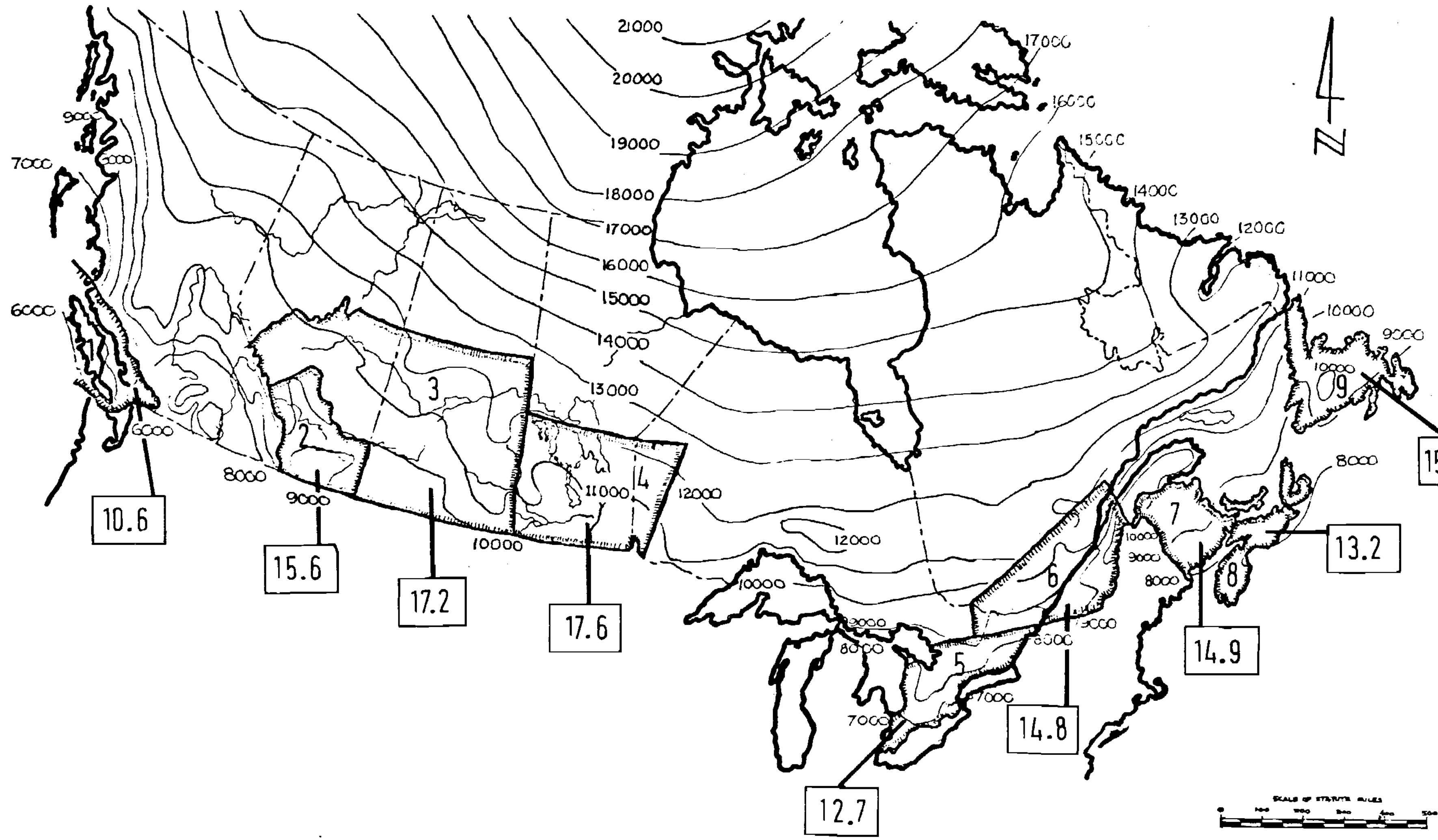
(3) Energy analysis at design stage to check compliance cannot be achieved solely by computations based on a single RY weather data unless the proposed building is actually at or near the reference city.

The alternative solution suggested in Section B4, i.e., to make allowances for location avoids the problems raised previously. It becomes necessary, however, to devise a method of correcting for location within a climatic zone. Because the variation in consumption across a zone, at least for heating, is greater than that between some zones, it seems inconsistent to make complex computer analysis for several reference city locations with similar consumptions then make a correction factor in the zone for those locations with different weather. Either the zones should be re-defined to smaller areas with less variation or an alternative solution sought.

Further, the desirability of the design analysis based on weather data significantly different from the actual operating conditions must be questioned. For instance whether to analyse a building to be built in Quebec city using Montreal weather is satisfactory or not is open to question. If it is not the analysis may have to be made twice, once for design purposes, the other to comply with the code/standard.

A third alternative would be to avoid climatic zones and base energy budgets on local climatic factors. Based on the results in this Section and Section B4 it appears that a heating budget, based on degree days is quite feasible.

FIG. B5.7 ESTIMATED HEATING CONSUMPTION FOR AVERAGE DEGREE DAY LOCATION IN EACH OF THE NINE CLIMATIC ZONES



Variation in Electrical Consumption

Electrical equipment can be considered as falling into one of the following two categories:

A - Equipment selected with consideration of, and influenced by, climate; and

B - All other equipment

Category A can be considered as the heating and air-conditioning (HAC) system and is generally under the control of the Heating, Ventilating and Air Conditioning (HVAC) engineer.

Category B can be split into three subsections:

(i) Lighting (interior);

(ii) Mechanical equipment other than that included in A, e.g., non HAC equipment; and

(iii) All other miscellaneous equipment.

The groups, as defined above, might typically include the following equipment:

Category A — Heating peripherals, including burner, oil heating, oil circulating pumps, heating circulating pumps. Cooling equipment, including refrigeration compressor, chilled and condenser cooling water pumps, cooling tower fans HVAC (supply and return air) fans.

Category B

(i) Interior lighting equipment

(ii) Other mechanical equipment (non HAC) including sump pumps, toilet exhaust fans, special exhaust fans (e.g., fume hoods), domestic hot water circulating pumps and compressors.

(iii) Teaching equipment that might be found, for example, in art rooms, laboratories, workshops or domestic science rooms. Such equipment might include pottery kilns, metal working machines, stoves and dishwashers. School services equipment such as cafeteria equipment, janitorial equipment and car plug-ins. There may also be special facilities provided such as swimming pools.

Up till now the analysis has included considerations of electricity consumption by lights, fans and refrigeration compressor; only calculated consumptions by lights and fans are considered in this Section. A separate study of the variation of cooling with location (climate) is presented in Section B8.

The following conclusions can be drawn from the results calculated in this analysis.

Lighting

Considering the assumptions made, lighting consumption can be considered independent of climate and school size, but is very dependent upon use.

Fans (see also Figure B5.8)

In the case of heating only, assuming constant volume, fan size and consequently fan consumption can be considered as a function of the design heating requirement and hours of use. For schools of similar type, size, construction and servicing, operating for the same number of hours, fan consumption can be considered to be a function of the outside winter design temperature. See Figure B5.6.

Heating Peripherals (pumps, burners, oil heating)

Estimates of consumption and the variation of consumption with climate could be made using an equipment simulation program such as Meriwether (EEC). No attempt to make these calculations has been made at this date.

Consumption by the peripherals can be considered as a function of both the design heating load, seasonal climatic variation, and hours of use. As such it is probable that, for a given period of use, consumption would vary somewhat linearly with heating degree days.

Meriwether EEC runs could be used to derive the consumption figures necessary to determine variation with climate.

Miscellaneous and Non HAC Mechanical Equipment Consumption

With the possible exception of toilet and washroom extract systems, the extent and type of such equipment may vary enormously between schools. As explained in Section 1 there appears to be little information available with which to make a realistic estimate on such items, or even if consumption by such equipment is significant to the over-all energy consumption of the school. Greater knowledge is required on this aspect before energy budgets can be set with confidence; this is particularly important if compliance with the energy budgets standard is to be maintained by post construction monitoring of consumption.

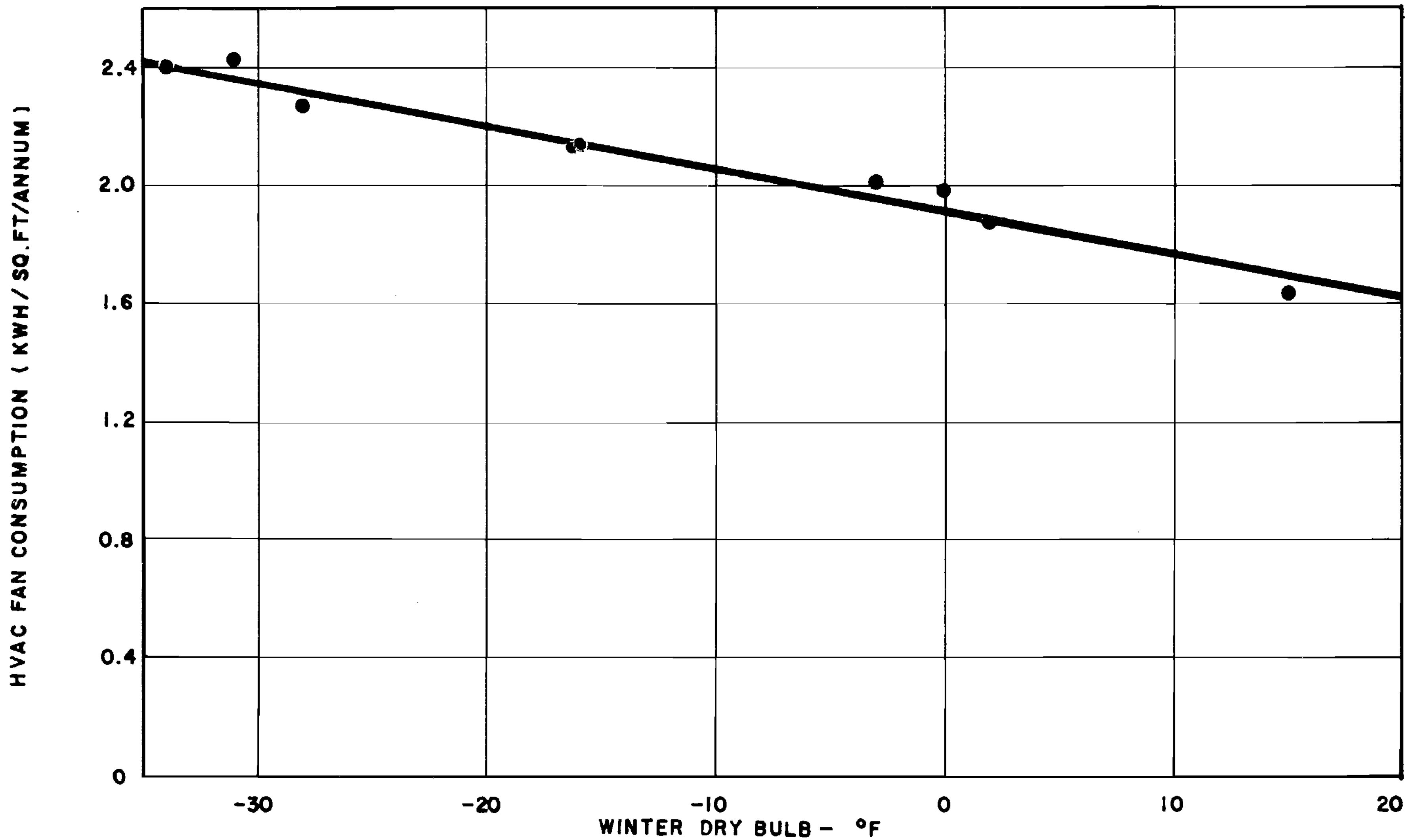


FIG. B5.8 VARIATION OF FAN CONSUMPTION WITH WINTER DESIGN DRY BULB TEMPERATURE

(FOR 20,000 SQ.FT. PRIMARY SCHOOL–DEFINED USE 2)

6. A COMPARISON OF SCHOOL MODEL AND ENERGY CALCULATIONS WITH DATA FROM "AN IMPACT ASSESSMENT OF ASHRAE 90-75" (1)

Comparison of Building Model Parameters

	Prototypical School	ASHRAE 90-75 Modified School	Energy Budget Model
Size	40,000 sq ft	40,000 sq ft	Variable
Shape			
Dimensions	400 x 100 ft	400 x 100 ft	Variable
Height	14 ft	14 ft	26 ft Hall and Gym 12.5 ft classroom
No. Levels	1	1	Variable Two levels above 20,000 sq ft floor area
Occupancy	80/100 sq ft per student	80/100 sq ft per student	133 sq ft/student primary 70 sq ft/student secondary
Lighting	4 W/sq ft	3.5 W/sq ft	2.36 W/sq ft primary 2.24 W/sq ft secondary (Low Illuminance Model)
Glazing	20% single glazed	16% single glazed	25% inside wall area (18% total wall area) in classroom block and 0% in Hall and Gym
Ventilation	0.5 cfm/sq ft	0.25 cfm/sq ft	0.1 cfm/sq ft primary 0.06 cfm/sq ft secondary over-all
Infiltration	0.5 Ac/hr	0.3 Ac/hr	Variable: Function of wall area equivalent to 0.187 Ac/hr primary and 0.18 Ac/hr secondary. For 40,000 sq ft school at wind speed of 10 mph
Hot Water Demand	720 gallons/hr or 18 Btu/hr sq ft	720 gallons/hr 12.6 Btu/hr sq ft	2.5 Btu/hr sq ft primary 1.25 Btu/hr sq ft secondary

Comparison of Building Model Parameters (cont'd)

	Prototypical School	ASHRAE 90-75 Modified School	Energy Budget Model
U Values	0.306 wall 0.14 roof	Based on degree days and ASHRAE 90-75	Based on degree days and ASHRAE 90-75
Indoor Design Conditions Summer	75°F and 50% Max RH	78°F and 60% Max RH	65°F Gymnasium 68°F Multi-use Rooms 72°F Classrooms min humidity 30% max humidity 60% (in secondary schools only)
HVAC Systems	Unit Ventilators - 4 Pipe System (Hot and Chilled Water) No Humidification, no night set back Economiser cycle		Terminal perimeter pre-heat with scheduled supply air temperature in classrooms demand system Hall/Gym (secondary schools variable air volume) humidification and enthalpy economiser cycle. Night set back

Comparisons of Energy Consumption Figures

	As Taken From "An Impact Assessment of ASHRAE Standard 90-75"(1)	As Calculated Using ESA Anaylsis Based on School Model as Defined (See Addendum 1)
Location	Omaha	Ottawa
Degree Days	6612	8615 (1976)
School Size	40,000 sq ft	40,000 sq ft
Type	not specified	Primary
Comparison of Typical or Average consumption Based on:	Prototypical School	Average of measured consumption Carleton Board of Education
Electricity	14.01 Includes 2.28 for chiller	7.25 Generally not air-conditioned (average consumption secondary schools 10.4)
Domestic Hot Water	3.95	Not available separately (included in "Heating")
Heating	25.02 Corrected by degree days (i) 30.51(2) (ii) 32.6(3)	27

Comparison of Effects of Energy Standard Based on:	ASHRAE 90-75	Energy Budget Derived for Ottawa Based on a "Model School"
Electricity	9.99 includes 1.14 for chiller	Basic use: 6.59 Evening use: 8.05 Evening, weekend and holiday use: 11.89 no chiller
Domestic Hot Water	2.78	Basic use: 0.75 Evening use: 0.93 Evening, weekend and holiday use: 1.55
Heating	11.4 Corrected by degree days (i) 13.9(2) (ii) 14.85(3)	Basic use: 12.41 Evening use: 12.80 Evening, weekend and holiday use: 13.98

NOTES:

1. All units in kW•h/sq ft floor area•annum
2. Consumption corrected using the ratio of degree days but based on the relationship derived for 20,000 sq ft school by ESA analysis at various locations throughout Canada (See addendum 5) (This is strictly true for a 20,000 sq ft school only)
   Corrected consumption = 1.2193 x consumption @ 6612 degree days.
3. Consumption corrected using ratio of degree days 8615/6612
   Corrected Consumption = 1.3029 x consumption @ 6612 degree days.

References

(1) An Impact Assessment of ASHRAE Standard 90-75, Energy Conservation in New Building Design, Arthur D. Little Inc., Report To: Federal Energy Administration, December 1975.

7. COMPARISON OF CALCULATED ENERGY CONSUMPTION AND ACTUAL RECORDED VALUES FOR SAMPLE WINNIPEG AREA SCHOOLS

Calculations of annual energy consumptions for six schools of various sizes were made using the Meriwether ESA/ERE program. Consumptions are calculated for schoolday and evening usage only and are based on the "Low Illuminance" model.

Actual 1973 Winnipeg weather data is used for comparison with existing fuel consumption records of some 37 schools in the Winnipeg area.

Gross consumption figures are estimated as in method used in Section B1. (The results for the six schools are shown in Table B7.)

Figures B7.1, .2 and .3 illustrate certain energy consumptions.

TABLE B7

ESTIMATED NET AND GROSS CONSUMPTION FIGURES

School Type and Area	Net Consumptions (kW•h/sq ft average)			Gross Consumptions (kW•h/sq ft average)	
	Heating and DHW	Electricity (Fans and Lights)	Cooling	Heating and DHW	Electricity
Primary					
5,000	27.64	7.11	0	39.49	8.61
20,000	16.90	4.97	0	24.14	6.16
60,000	12.28	4.39	0	17.54	5.49
Secondary					
62,790	9.69	5.90	0.25	13.81	7.40
150,000	7.31	5.70	0.21	10.44	7.17
220,000	6.34	5.68	0.20	9.05	7.09

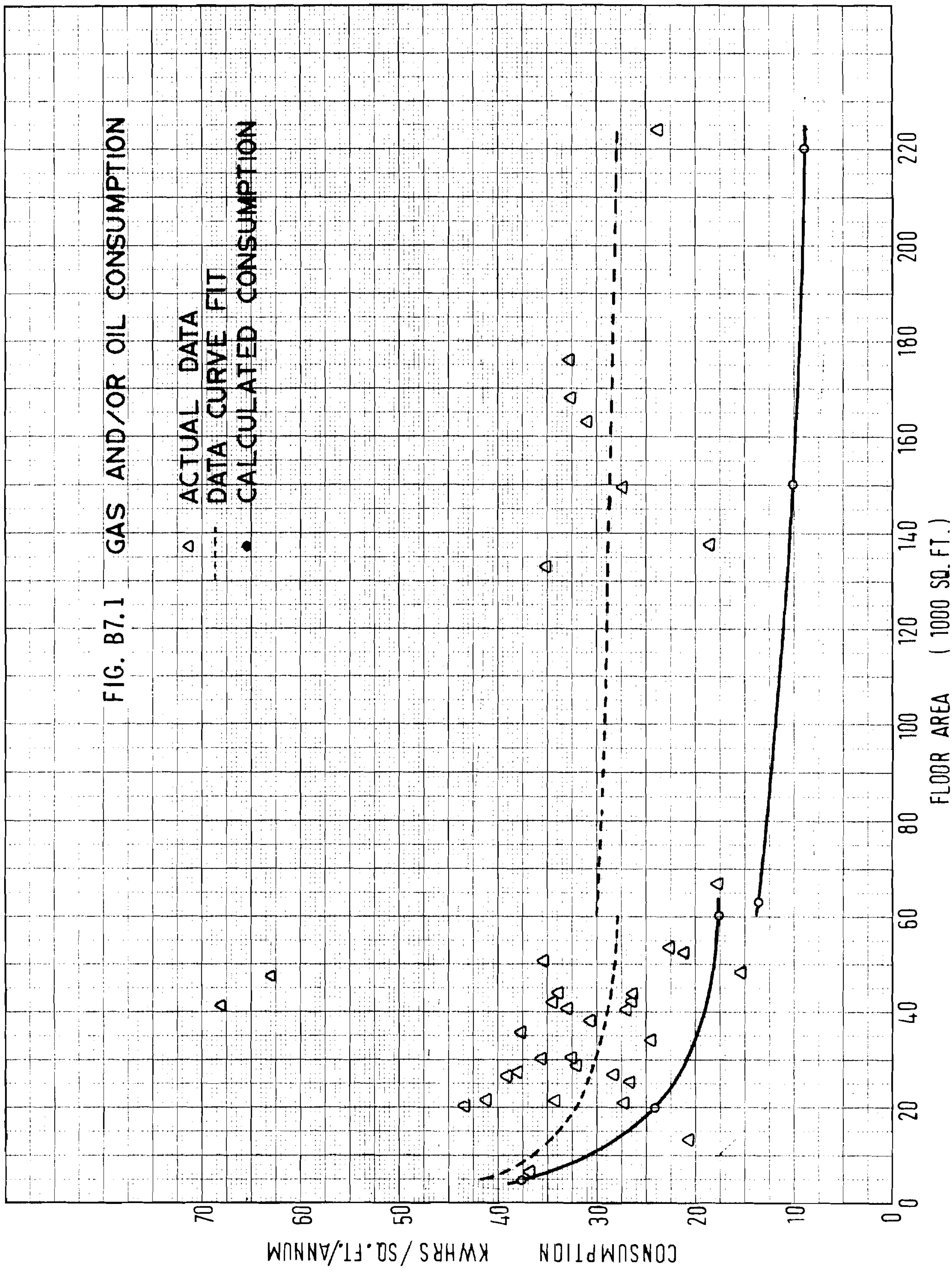


FIG. B7.1 GAS AND/OR OIL CONSUMPTION
ACTUAL DATA
DATA CURVE FIT
CALCULATED CONSUMPTION
FLOOR AREA (1000 SQ. FT.)
0 20 40 60 80 100 120 140 160 180 200 220
CONSUMPTION KWHRS/SQ.FT./ANNUM
0 10 20 30 40 50 60 70

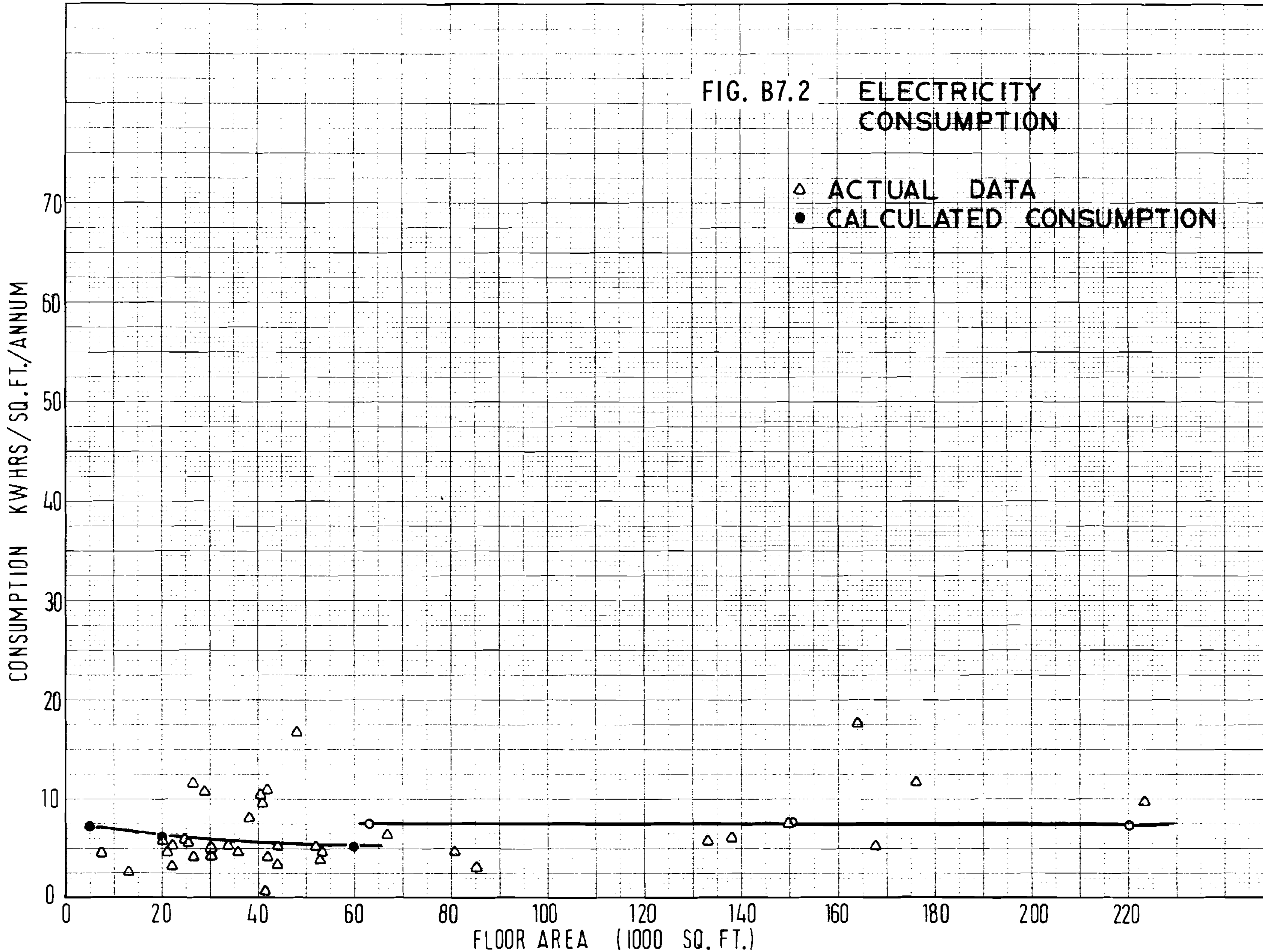


FIG. B7.2 ELECTRICITY CONSUMPTION
△ ACTUAL DATA
● CALCULATED CONSUMPTION
CONSUMPTION KWHRS/SQ.FT./ANNUM
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
140
160
180
200
220
FLOOR AREA (1000 SQ.FT.)

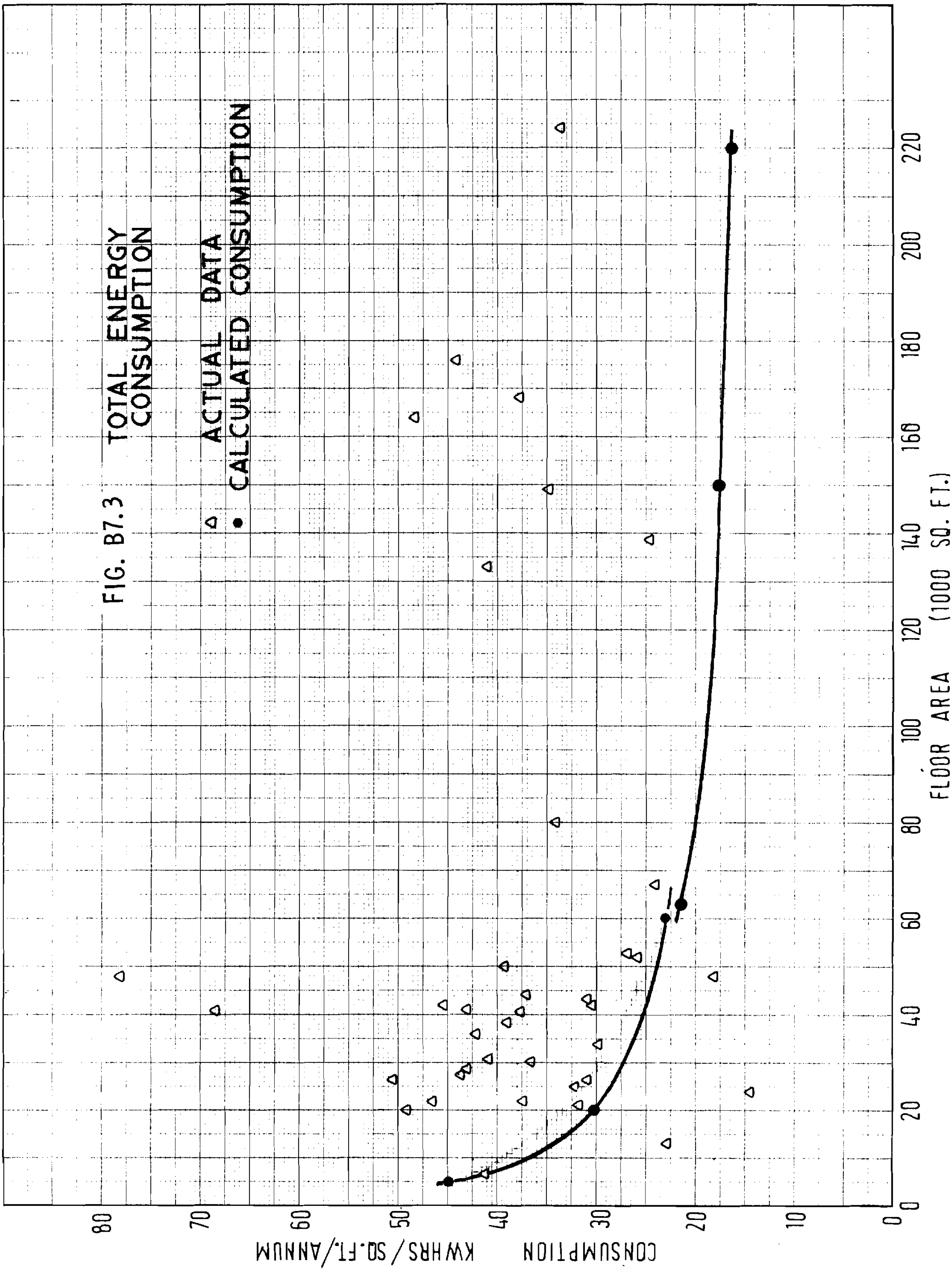


FIG. B7.3
TOTAL ENERGY CONSUMPTION
ACTUAL DATA
CALCULATED CONSUMPTION
CONSUMPTION KWHRS/SQ.FT./ANNUM
FLOOR AREA (1000 SQ. FT.)
0
10
20
30
40
50
60
70
80
0
20
40
60
80
100
120
140
160
180
200
220

8. THE DETERMINATION OF A SUITABLE CLIMATIC FACTOR ON WHICH TO BASE COOLING BUDGETS

To investigate the variation of cooling with climate and location, Meriwether ERE runs were made for 70,000 sq ft secondary schools in each of the reference locations. "Reference Year" weather data was used.

The results of the runs are tabulated in Table B8(1)

TABLE B8(1)

Reference City	† Cooling ton hr/sq ft/annum
Vancouver	0.47
Lethbridge	0.74
Saskatoon	0.72
Winnipeg	0.92
Toronto	0.95
Montreal	0.95
Fredericton	0.76
Halifax	0.62
St. Johns	0.32

† The calculations are based on summer use of the school. The "Low Illuminance" school model is used.

Figures B8.1, .2 and .3 show the relationship between these results and readily available climatic information†, i.e.,

i) Heating Degree Days;

ii) Summer Design Dry Bulb Temperature; and

iii) Summer Design Wet Bulb Temperature.

---

† Supplement #1 to the National Building Code of Canada

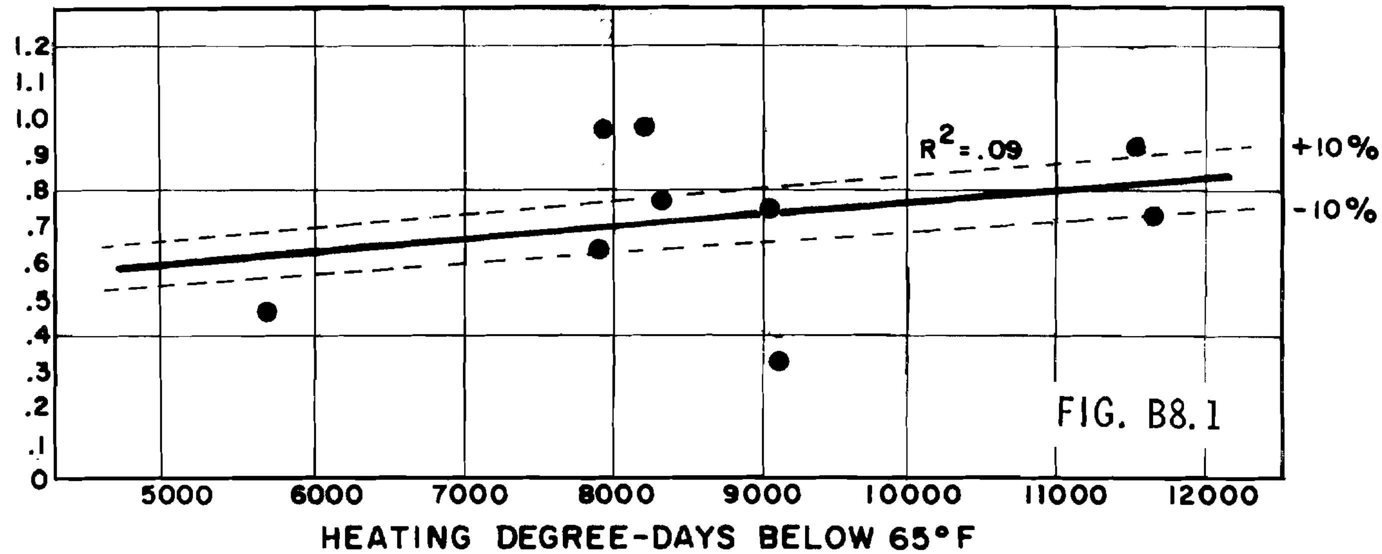


FIG. B8.1

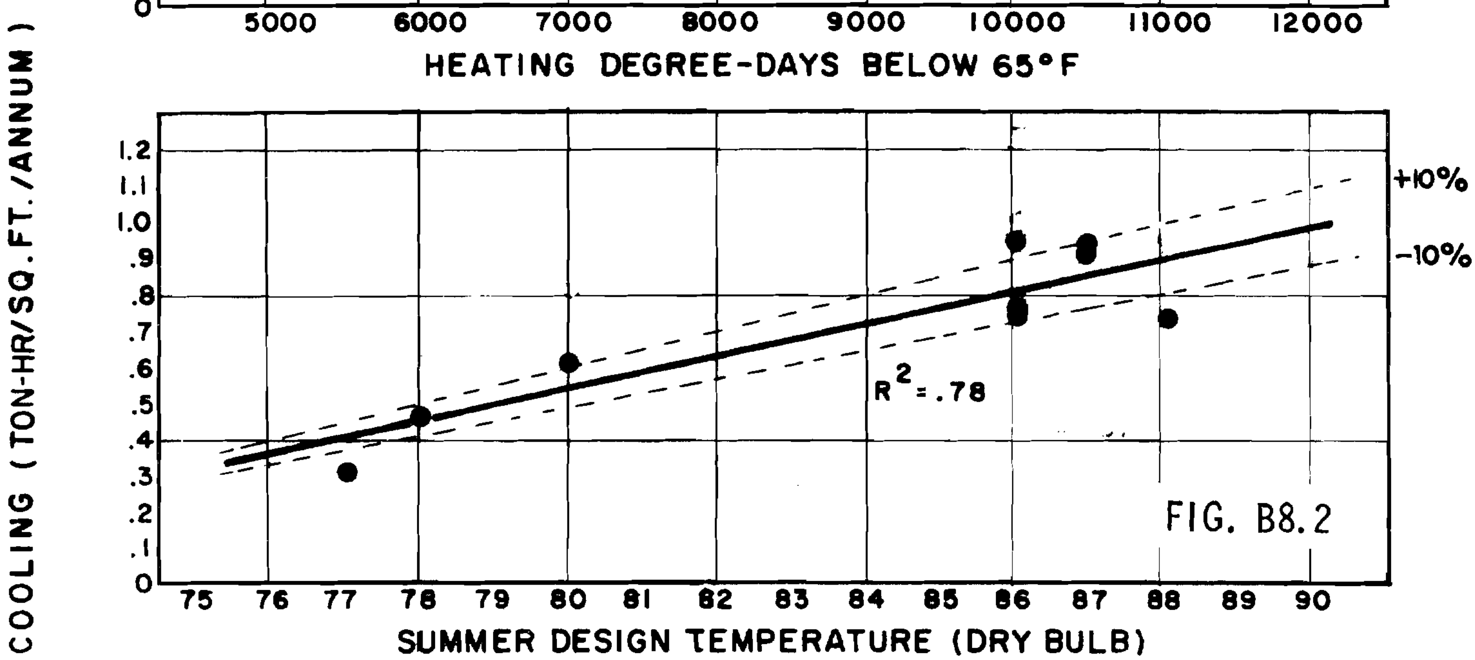


FIG. B8.2

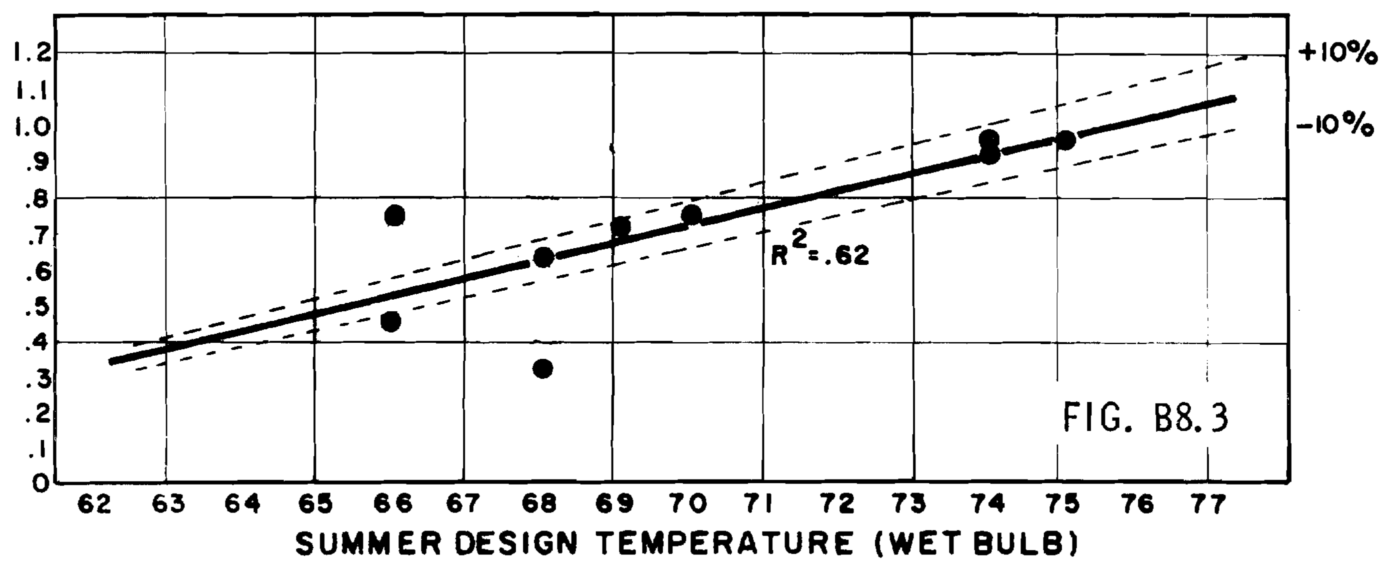


FIG. B8.3

R^2 = CORRELATION COEFFICIENT

As can be seen from these graphs it cannot be considered appropriate to specify cooling budgets based on any of the foregoing parameters.

As an alternative since the "readily available climatic factors" do not seem appropriate, cooling degree days are considered. For convenience and to be consistent with the heating case a base of 65°F is considered.

Based on the definition of heating degree days, cooling degree days, above a base of 65°F, are calculated for each of the "Reference Years", i.e.,

$$D_{tb} = 65°F \Big|_{cooling} \sum_{d=1}^{d=365} (t' - tb) \qquad (1)$$

where

t' = daily mean temperature

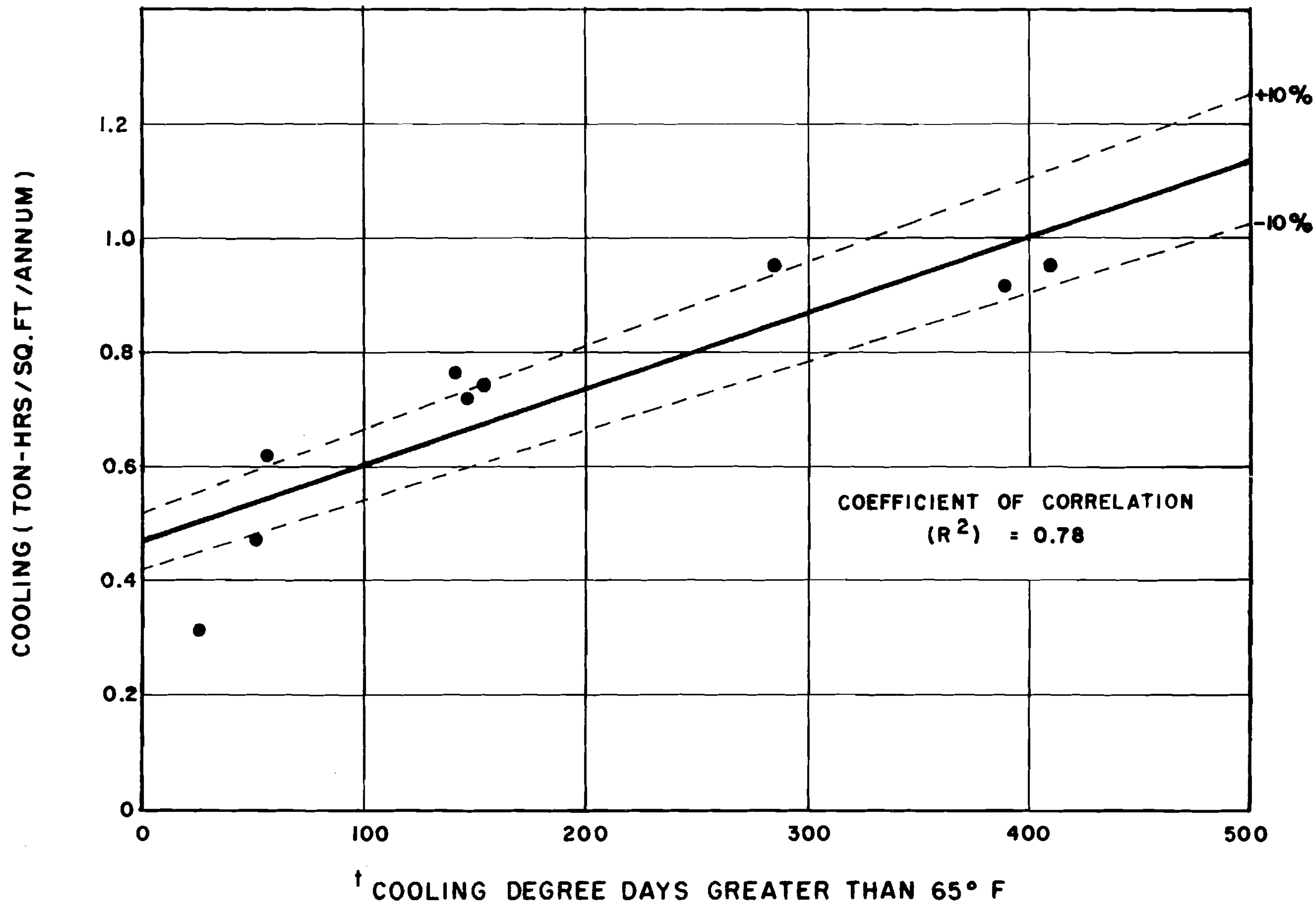
$$= \frac{1}{24} \sum_{i=1}^{i=24} ti \qquad (2)$$

tb = base temperature = 65°F

The results are tabulated in Table B8(2). Figure B8.4 shows the relationship between cooling and cooling degree days as calculated.

TABLE B8(2)

Reference Year Weather for	Cooling Degree Days > 65°F
Vancouver	51
Lethbridge	154
Saskatoon	147
Winnipeg	391
Toronto	285
Montreal	409
Fredericton	143
Halifax	57
St. Johns	26



† (calculated by mean deviation above base temperature)

FIG. B8.4

Figure B8.4 does not exhibit a good linear trend as might be expected.

If the way in which degree days are calculated is considered, four typical relationships between temperature variation, mean temperature and base temperature can be expected through the year.

These are illustrated in Figure B8.5 and are:

i) tb > tmax

ii) tmax > tb > t'

iii) tmin < tb < t'

iv) tb < tmin

where

tb = base temperature

tmax = maximum daily temperature

tmin = minimum daily temperature

t' = mean daily temperature

The shaded areas in the Figures can be considered to illustrate a heating requirement. As can be seen from cases (ii) and (iii) both heating and cooling requirements are suggested.

The calculation of heating and cooling degree days is mutually exclusive as previously calculated, i.e., to say for case (ii) tb > t' only a heating requirement is calculated and for case (iii) tb < t' only a cooling requirement is calculated. This may be considered inappropriate for estimating heating and cooling requirements for real buildings, especially those of light construction.

Errors introduced into the results can be considered to be significant only if the predominant daily temperature profiles throughout the year follow the patterns shown in Figures B8.5 (ii) and (iii). Hence for heating degree days below 65°F where many degree days are collected with tb > tmax the error can be considered negligible. For cooling however, there will be few instances where tb < tmin at tb = 65°F, hence the results should be considered questionable.

The objections just raised could be eliminated if hour by hour variations above the base temperature were considered, i.e., for each day

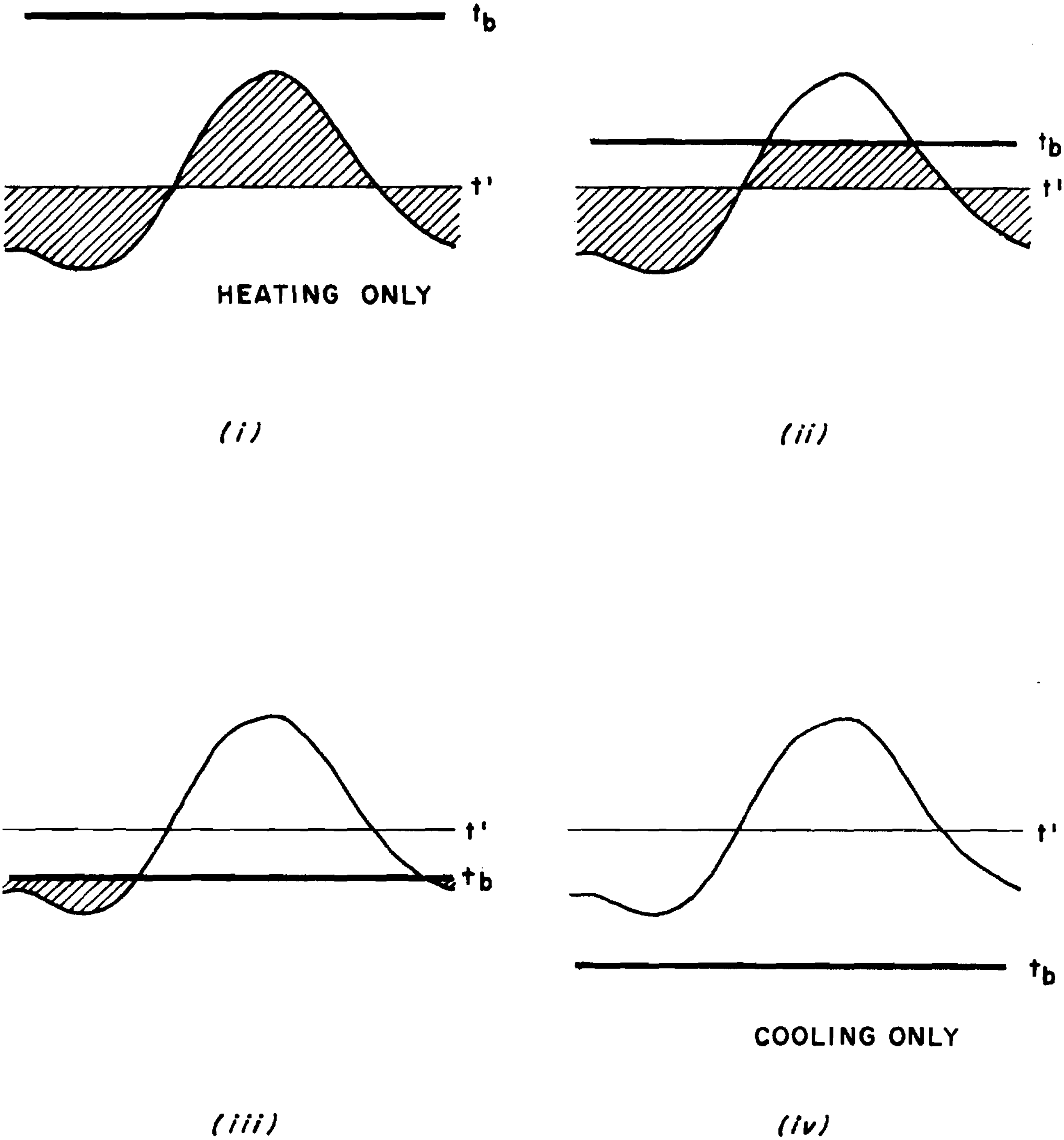


FIG. B8.5

$$Dd_{tb = 65°F} \Bigg|_{cooling} = \sum_{i=1}^{i=24} ti - tb \Bigg|_{for\ ti > tb}$$

where

ti = temperature at hour i

Table B8(3) compares degree days calculated in this manner with the previously calculated values.

TABLE B8(3)

RY Weather for	Cooling Degree Days	
	Using Daily Means	Using Hourly Hour Variations
Vancouver	51	124
Lethbridge	154	399
Saskatoon	147	371
Winnipeg	391	550
Toronto	285	452
Montreal	409	535
Fredericton	142	375
Halifax	57	145
St. Johns	26	68

Figure B8.6 shows cooling requirement as a function of these new "Degree Days". As can be seen the fit is improved. It is, however, worth considering one further aspect.

A base of 65°F for heating degree days was chosen on the assumption that the amount of fuel or energy required to keep the interior of a small building at about 70°F when the outside temperature is below 65°F is roughly proportional to the difference between 65°F and the outside temperature. It is assumed that no heat is required when the mean outside temperature for the day is 65°F or higher.

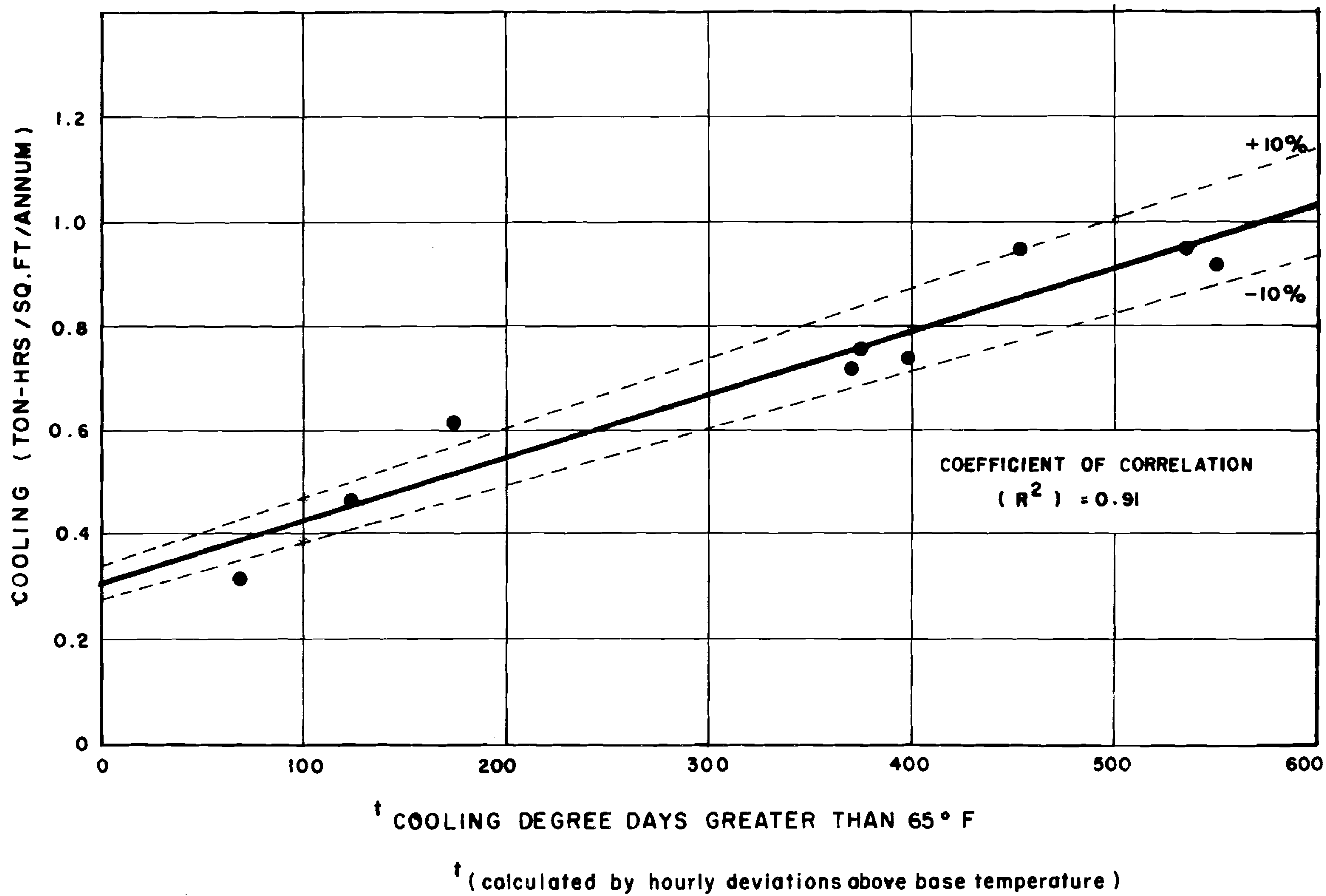

COOLING (TON-HRS / SQ.FT/ANNUM)
0
0.2
0.4
0.6
0.8
1.0
1.2
0
100
200
300
400
500
600
+10%
-10%
COEFFICIENT OF CORRELATION
(R2) = 0.91
t COOLING DEGREE DAYS GREATER THAN 65° F
t (calculated by hourly deviations above base temperature)

FIG. B8.6

The 65°F can be considered as a balance point of the building. However, buildings of different types, usage and size, may well have different internal heat gains and consequently a base temperature somewhat lower than 65°F might be appropriate for estimating consumption.

For example Table B8(4) gives some guidance in this respect.

TABLE B8(4)†

Class of Building	Building Structure	d (°C)
1	Building with large area of external glazing, much internal heat-producing equipment* and densely populated	5 to 6
2	Buildings with one or two of the above factors	4 to 5
3	'Traditional' buildings with normal glazing, equipment and occupancy	3 to 4
4	Sparsely occupied buildings with little or no heat-producing equipment and small glazed area	2 to 3
5	Dwellings	5 to 8

Notes:

*Unless separately allowed for in the design heat loss. Add 1°C for single storey buildings.

†Taken from IHVE Guide Book B, U.K. 1970.

d = the average temperature rise which can be maintained by the miscellaneous gains alone, and

tb = t - d

where

tb = base temperature

t = design temperature

d for "traditional buildings" in the U.K. is given as 38 (4°C) or 5.48 (7.2°F) (Base Temperature U.K. 15.5°C or 60°F). d is dependent on the amount of energy released and the rate of heat loss from the building.

NATIONAL RESEARCH COUNCIL OF CANADA

DIVISION OF BUILDING RESEARCH

ERRATUM

CALCULATING ENERGY BUDGETS FOR NEW SCHOOLS (I.R. 448)

by

L. Jones

NOTE: There is a typographical error on page 121. The last paragraph should read:

d for "traditional buildings" in the U.K. is given as 3 to 4°C or 5.48 to 7.2°F (Base Temperature U.K. 15.5°C or 60°F).

For large secondary schools, one would expect d to be somewhat greater than 5°F. The value of d, however, is somewhat difficult to determine since it is essentially an annual average of the daily and seasonal variation of occupancy lighting and solar gains. By way of illustration, using values taken from the school model, the daily average internal heat input from lights and occupants in the classroom block of a 70,000 sq ft school is calculated to be 2.74 Btu/h sq ft floor. The heat loss comprising fabric, infiltration and ventilation (fabric based on U values selected at Lethbridge) is calculated to be 0.17 Btu/h sq ft °F.

$$d \text{ - neglecting solar (for this typical day only)} = \frac{2.74}{0.17}$$

$$d = \underline{\underline{15.8°F}}$$

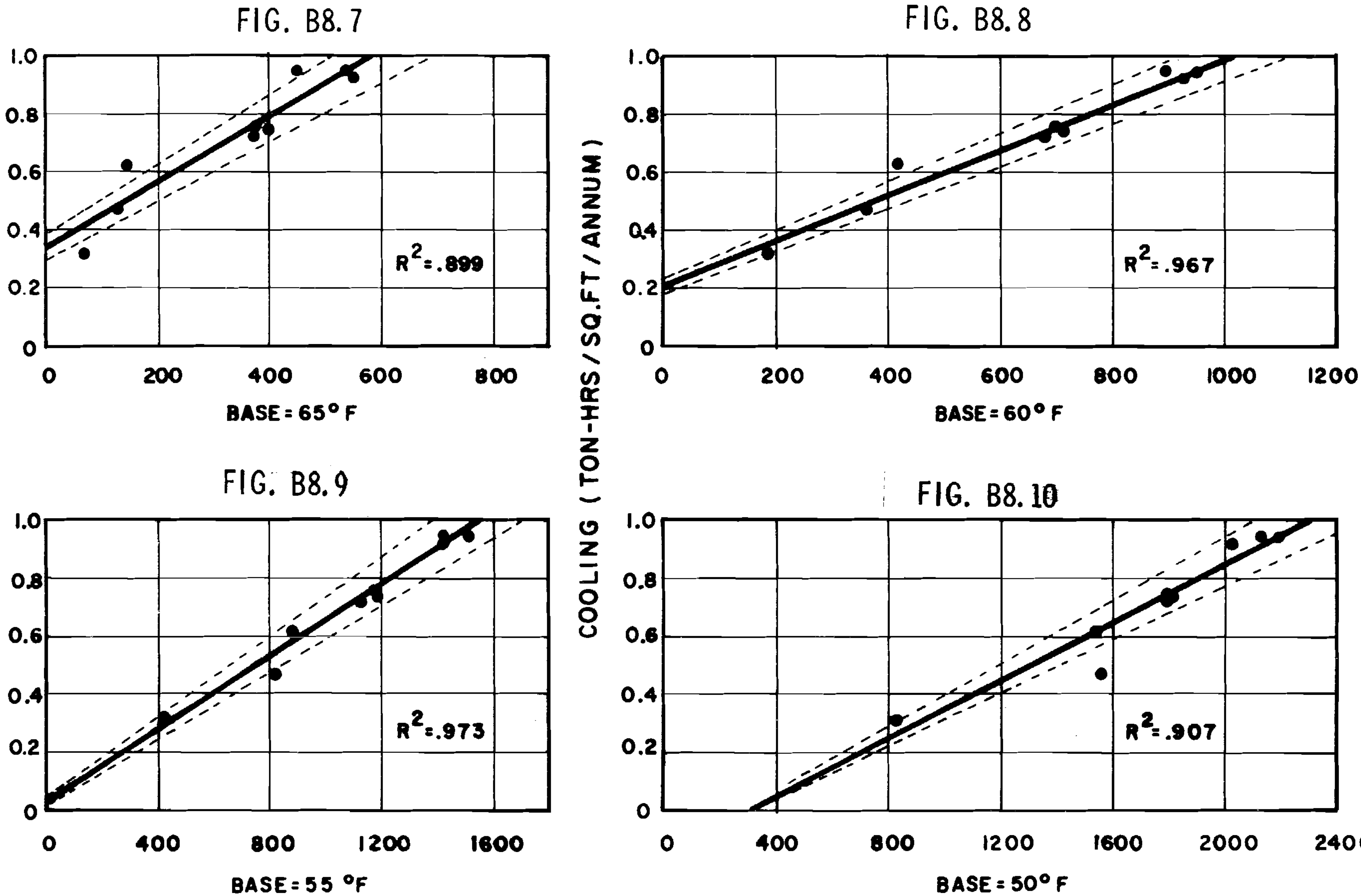
Figures B8.7 to .10 show the calculated cooling requirement against degree days at various bases (degree days calculated on the hour by hour temperature difference above the base temperature).

The results are tabulated in Table B8(5).

TABLE B8(5)

Reference Year Weather for	Degree days at various bases			
	65°F	60°F	55°F	50°F
Vancouver	124	364	825	1564
Toronto	452	899	1412	2134
Halifax	145	413	882	1535
Montreal	535	952	1514	2216
Lethbridge	399	713	1180	1819
Fredericton	375	698	1175	1803
St. Johns	68	189	422	830
Winnipeg	550	930	1421	2018
Saskatoon	371	681	1123	1691
Correlation (r^2)	0.899	0.967	0.973	0.907

The degree of correlation based on linear fits to the data is given in the foregoing table.



FIGS. 7-10 **COOLING LOAD VS COOLING DEGREE-DAYS ABOVE VARIOUS BASE TEMPERATURES**

(dotted line indicates ± 10 % about fitted line ; R^2 = correlation coefficient .)

While it appears that the best fit is around the base of 55°F it should be appreciated that this is not necessarily the best fit for other sizes of buildings or other patterns of occupancy. It may, however, prove a satisfactory basis for specifying cooling budgets for schools.

To pursue the matter further, two more series of ERE runs were made. The results are reported in Figures B8.11 and .12 and in Tables B8(6) and (7). Figure B8.11 shows the calculated cooling consumption for the three defined periods of use, and Figure B8.12 shows the calculated cooling consumptions for two different sizes of schools.

TABLE B8(6)

CALCULATED COOLING REQUIREMENTS - VARIATION WITH USE

Reference City	Cooling (70,000 sq ft secondary ton hr/sq ft annum)		
	Use 1†	Use 2	Use 3
Montreal	0.28	0.34	0.95
St. Johns	0.06	0.07	0.32
Saskatoon	0.22	0.25	0.72

† for definition of uses see Model Definition

Basically Use 1 - School use
Use 2 - Used evening or school days
Use 3 - Used evening or school days and daily through vacation

TABLE B8(7)

ESTIMATED COOLING REQUIREMENT - VARIATION WITH SCHOOL SIZE

Reference City	Cooling ton hr/sq ft annum*	
	250,000 sq ft Secondary School	70,000 sq ft Secondary School
Montreal	0.87	0.95
St. Johns	0.31	0.32
Saskatoon	0.68	0.72

*Calculations for Use 3

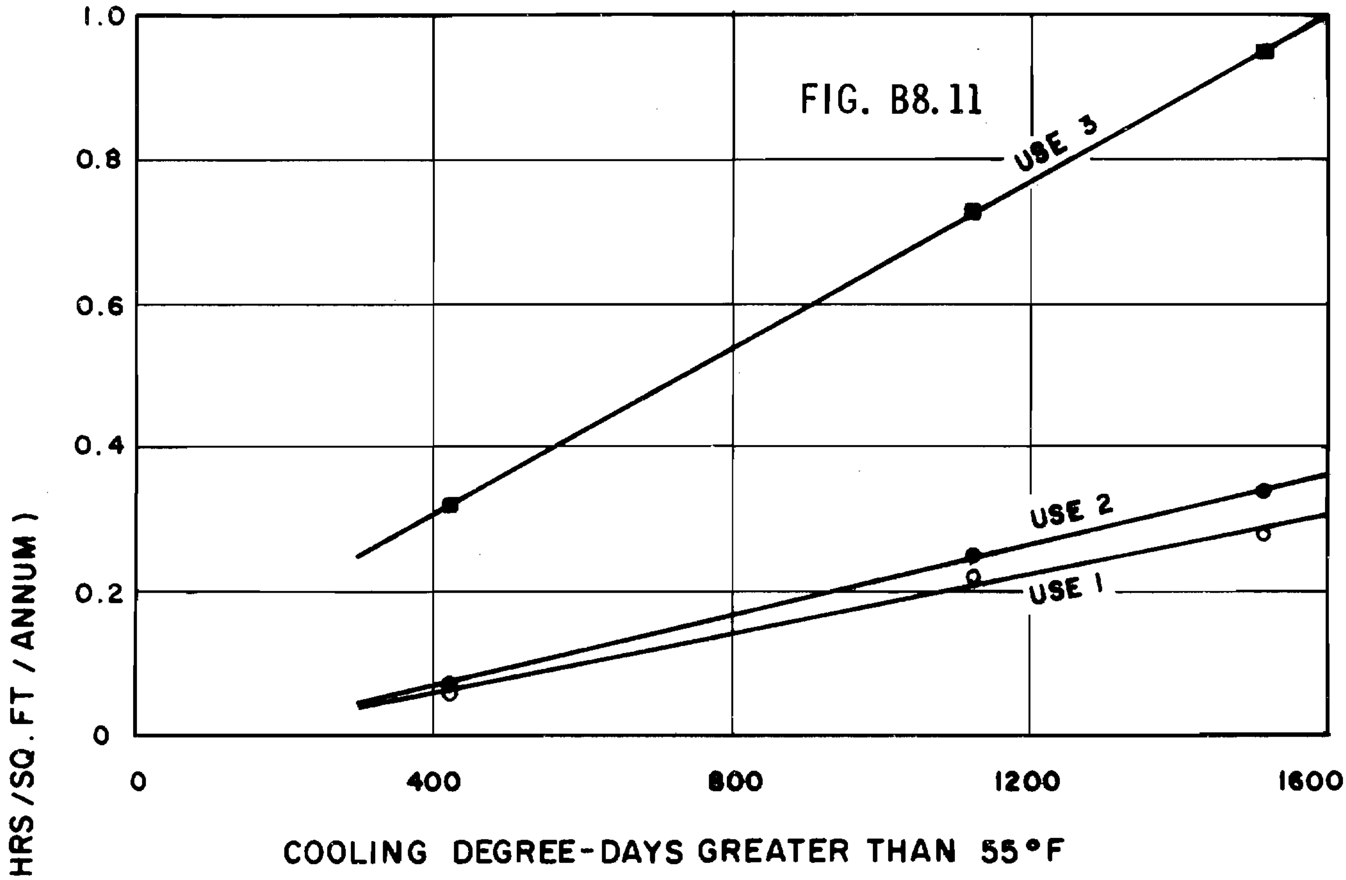


FIG. B8.11
USE 3
USE 2
USE 1
1.0
0.8
0.6
0.4
0.2
0
0
400
800
1200
1600
COOLING DEGREE-DAYS GREATER THAN 55°F
COOLING (TON-HRS/SQ.FT / ANNUM)

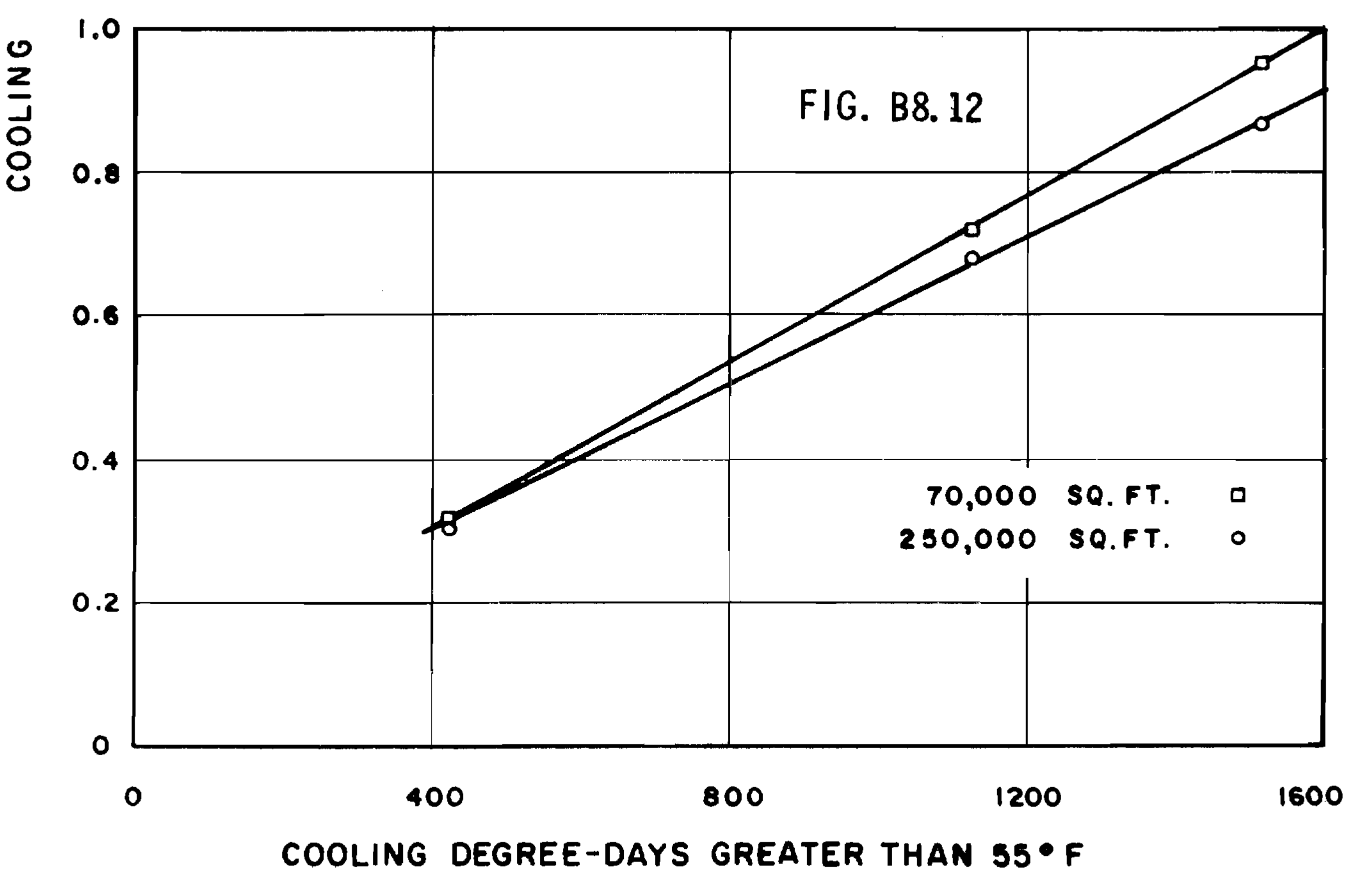


FIG. B8.12
70,000 SQ. FT.
250,000 SQ.FT.
1.0
0.8
0.6
0.4
0.2
0
0
400
800
1200
1600
COOLING DEGREE-DAYS GREATER THAN 55° F

It would appear satisfactory to set cooling budgets based on cooling degree days above 55°F. Degree days should be calculated from the hour by hour variation above the base temperature. Further cooling budgets should vary with the size of the school and its hours of use.

Fan Consumption

For heated and cooled buildings it is most probable that the fan capacity will be determined by the cooling load. Thus for constant volume systems the fan consumption can be considered as a function of the design peak cooling loads and the hours of operation of the system. For a variable air volume (V.A.V.) system, however, the annual fan consumption will be modified by the seasonal variation in climate.

For given sizes of schools of similar type, construction and servicing, operating for similar hours of use, fan consumption can be considered to bear the following relationships. For constant volume systems, consumption will be some function of summer design dry bulb, wet bulb and a solar factor.

For V.A.V. systems a further factor, to account for climatic variation, should be considered. Because the modulation of the fan should occur through the cooling season with minimum flow during the heating season, this additional factor might very well be cooling degree days.

Figures B8.13 and .14 show the fan consumption, for the classroom block only, plotted as functions of summer design dry bulb and cooling degree days. Two values of fan consumption are shown; consumption of the V.A.V. fans as obtained from the Meriwether output and a manual calculation of consumption if these fans were constant volume. (This calculation is simply the product of the number of hours of operation and the V.A.V. fan full volume consumption).

While both Figures B8.13 and .14 show fan consumption to be weak functions of climate and that a single value of fan consumption would involve little error, it is worthwhile considering the following points.

(1) The school model used to produce the results represents a 70,000 sq ft two level school that is relatively insensitive to climate. If the analysis had been carried out on a smaller building, a stronger effect might have been apparent. This is illustrated by the fan consumption for a heated 20,000 sq ft primary school (Figure B5.6).

(2) In large deep plan buildings with a predominance of internal zones the fan volume may well be limited by the minimum air movement considered appropriate. In the building model used the internal zones are such that air volumes, below the assumed minimum of 0.5 cfm/sq ft, would have been appropriate to meet the loads. Consequently, lower air volumes and smaller

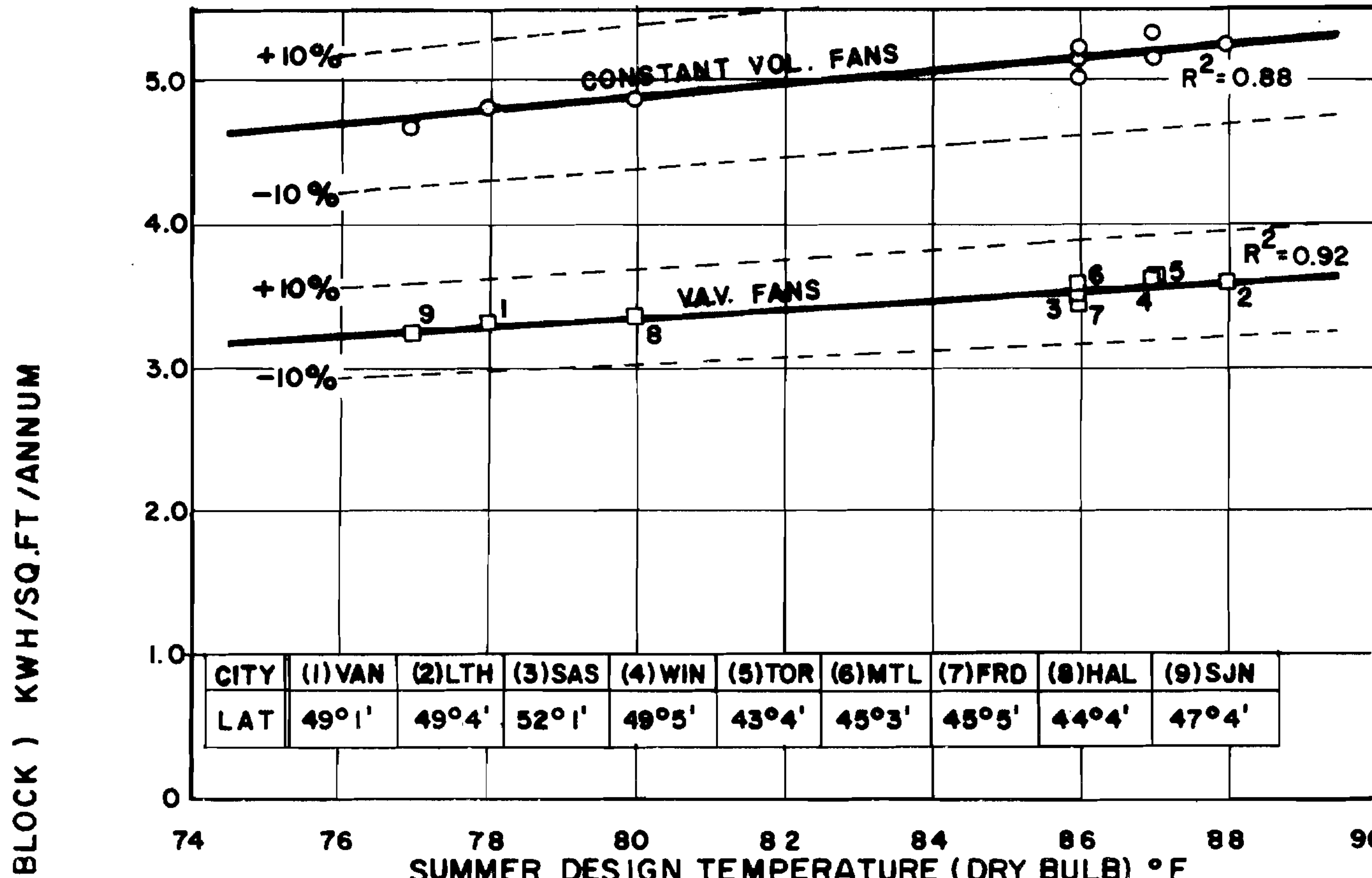


FIG. B8.13

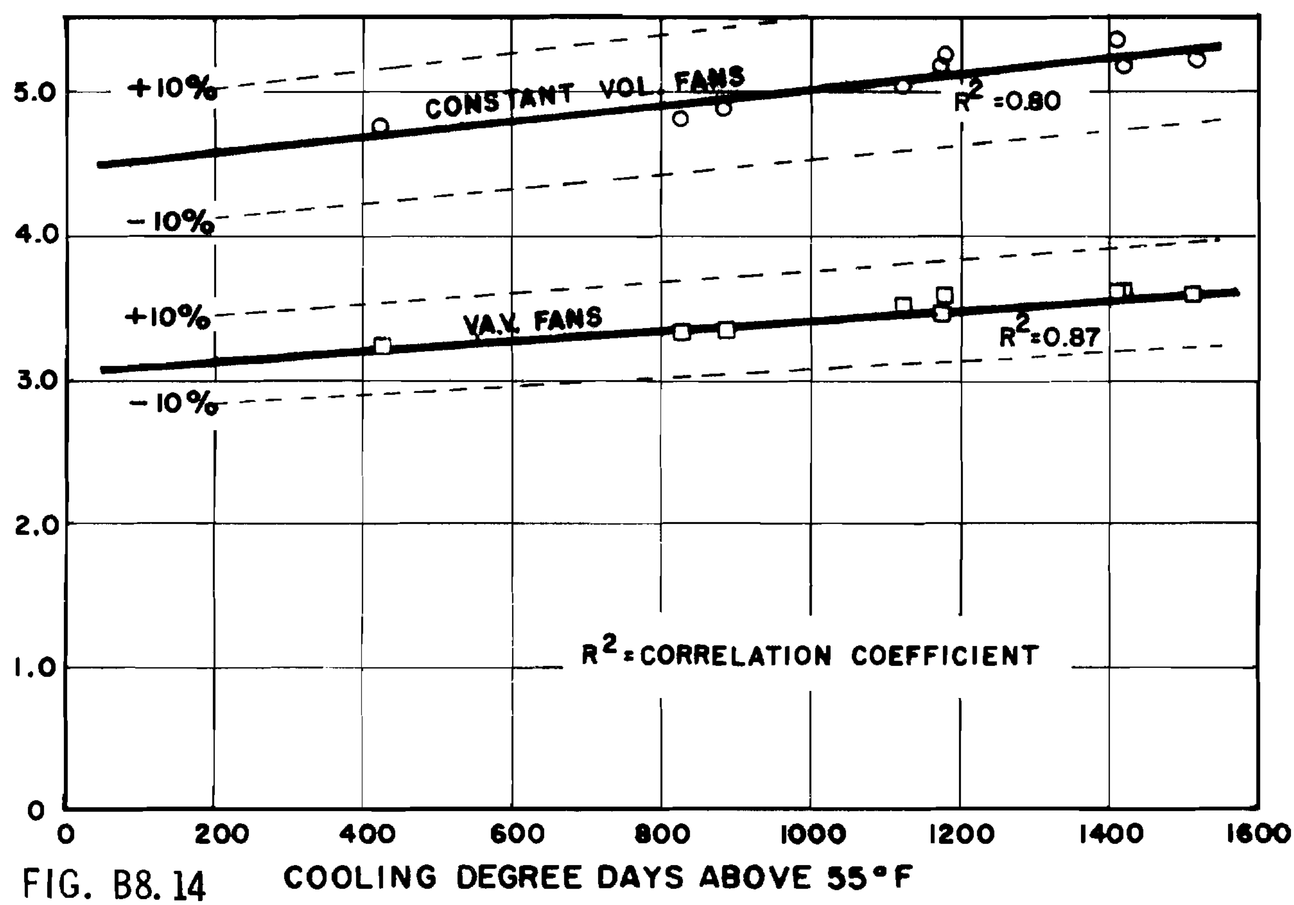


FIG. B8.14

fans could have been used in these areas. Further, for V.A.V. systems, considerable savings in consumption should be realized if the system is not restricted to supply this minimum air movement.

Because these minimum air movement figures create an artificial HVAC fan sizing (for instance the Department of Public Works minimum is 0.75 cfm/sq ft) it would seem appropriate to examine the necessity for such values.

(3) The results show a significant saving in fan consumption for the V.A.V. system. It may be, however, that setting energy budgets based on a model incorporating a V.A.V. system may put undue restrictions on fan consumption for all constant volume systems. This may, however, not be considered too significant in the over-all energy allowance of the building.

(4) Should it be considered prudent to set fan allowances by consideration of climate, a more suitable factor might be sought than those suggested in Figures B8.13 and .14. This would best be done by considering a smaller building model.

Electricity Consumption by Refrigeration Machine and Cooling Peripherals

Estimates of consumption and the variation of consumption with climate could be made using an equipment simulation program such as Meriwether (EEC), but no attempt to make these calculations has yet been made.

9. WEATHER DATA REQUIRED FOR SETTING BUDGETS, PRE-CONSTRUCTION ANALYSIS AND POST-CONSTRUCTION MONITORING

The following comments pre-suppose that heating or cooling budgets will be partly or wholly specified by heating and cooling degree days.

Weather Data for Setting Budgets

Test Reference Year (RY)* weather data has been used throughout this analysis, however, it may be more appropriate to use Typical Year (TY)* weather data.

U values for the school models have been selected on the basis of average degree days of the reference city, where RY weather has a

---

* see p. 131 for definitions

significantly different degree day value than the average an inconsistency in the results is created. This is illustrated in Figure B9 and explained in further detail in Section B5, p. 95.

(This effect could be offset by selecting U values for the model based on the actual degree days of weather used and not the average).

If TY weather data is to be used it is desirable that the weather tapes be produced in the same manner used by Crow[1] which avoids abrupt changes in weather data at month ends.

Weather Data for Pre-Construction Analysis

Weather data will be required by the building analyst to enable him to carry out his energy analysis. The weather he has to use could be either specified, or left up to him to choose. For consistent reporting of results it would be desirable to specify the weather. If this is to be adopted weather data should be made available for all major locations; it is not considered appropriate, for instance, to carry out an energy analysis for a building in Quebec City using Montreal weather (see Section B5, p. 95).

If the analyst is left to choose his own weather, then guidance should be given on the method of selection; for reasons as previously described the weather used should have near average degree days. Further the method in which the degree days' heating and cooling are to be calculated should also be specified.

Weather Data for Post-Construction Monitoring

If a check on the building's consumption is to be made by monitoring its energy use after construction, some means must be specified to allow for the annual variation in weather.

It seems reasonable to do this by checking the relevant energy budget based on the recorded heating and cooling degree days for the particular location and year; the measured consumptions should be less than this adjusted budget figure. This method would be subject to the limitations mentioned previously and illustrated in Figure B9. However, the additional complication of producing different heating/cooling vs degree day relationships, based on constant U values, is not warranted by the nominal inaccuracy of this proposed method.

Such post construction monitoring will require the annual reporting of heating and cooling degree days for all major locations. As suggested in Section 8, cooling degree days computed from the hourly variations above a base are desired. This may necessitate additional facilities at those stations that at present record only daily minimum and maximum temperatures.

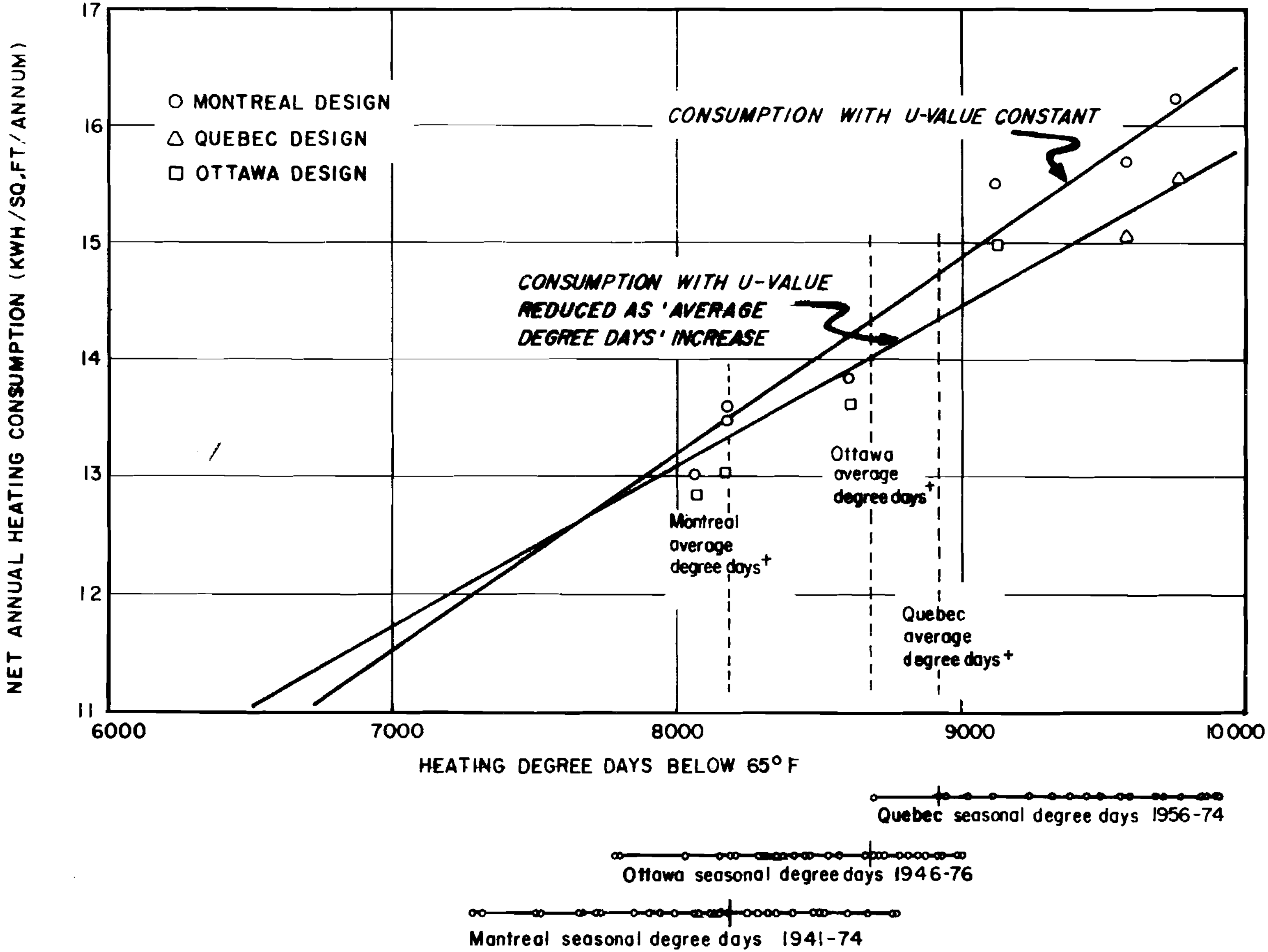


FIG. B9

+ *FROM SUPPLEMENT Nº 1 TO NATIONAL BUILDING CODE OF CANADA*

DEFINITIONS

Reference Year (RY)

A calendar year selected from 20 or more weather years based on an elimination process involving monthly mean temperatures. This is a process recommended by ASHRAE T.C. 4.2 and selects a weather year appropriate for comparing computed energy requirements of different buildings in the same municipality.

Typical Year (TY)

A typical year comprising 12 months of weather made up by selecting each month from averages over a number of years. While fairly representative of average weather conditions, error in energy calculations may occur as a result of large step changes at month ends. This however can be avoided by careful preparation of typical year weather tapes[1].

REFERENCE

1 Crow, Loren W., Summary description of typical year weather data Chicago Midway Airport. Prepared for ASHRAE., Research Project RP100, February 1970.