Preface:

This report is intended to provide Ontario users interested in obtaining meteorological information for the design of a solar energy heating system, with a single, complete information package. It was prepared by Miss Janice Hall as a student project during the summer of 1977.

The report contains information on the spatial and temporal variations of all the significant meteorological parameters which should be considered in the design of a solar energy system in Ontario. In particular, the distributions of heating degree days, sunshine hours, radiation and cloud are documented. After assuming some typical system characteristics, the feasibility of using solar heating systems is assessed for six Ontario locations.

It should be noted that this is an internal report. Although you are invited to use the information in this report, you are requested to reference official AES publications in any papers or documents that may result from your work.

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A REVIEW OF THE METEOROLOGICAL INFORMATION REQUIRED FOR THE DESIGN OF SOLAR ENERGY HEATING SYSTEMS IN ONTARIO

1. INTRODUCTION

Interest in utilizing natural energy flows has increased rapidly in the past 5 years. This interest has been sparked by a realization that we have only a limited quantity of fossil fuels left in the ground and by concerns that alternative sources such as nuclear energy may have long-term environmental impacts. One of the principal natural energy flows being considered as a viable alternative to our conventional sources, is solar energy.

When designers begin to plan a home heated by solar energy, they frequently realize that they require a substantial amount of meteorological data. The purpose of this report is to provide a comprehensive summary of meteorological information that can be used in the design of a solar energy system anywhere in Ontario.

The various applications of solar energy are discussed in Chapter 2. In addition the factors to be considered in designing a solar energy system are described.

In Chapter 3 the heating requirements for homes in Ontario are discussed. The capability of solar energy to heat a house throughout the winter depends on the amount of solar energy available for storage, after the house has been heated, and the efficiency and size of the heat storage system.

The factors that affect the availability of solar energy are meteorological factors such as cloudiness, sunshine hours and global solar radiation, as well as the latitude of the home. The temporal and spatial variations of these meteorological factors are described in Chapter 4.

In Chapter 5 the capabilities of a solar energy system are assessed for a number of Ontario locations.

2. APPLICATIONS OF SOLAR ENERGY

2.1 OVERVIEW OF A SOLAR ENERGY SYSTEM

Homes heated by solar energy require a system consisting of a solar energy collector, a method for storing the energy and a method for using this energy to heat the home. Figure 1 shows a solar heating system (Sasaki, 1975). The collectors are usually found on the roof facing south. They may be horizontal or tilted (as shown). The heat storage system is usually located in the basement.

2.2. USES OF SOLAR ENERGY

The various applications of solar energy include:

(1) Solar water heating
(2) House heating
(3) Conversion to electricity
(4) Solar houses
(5) Swimming pool heating
(6) Solar baking (solar ovens)
(7) Solar distillation
(8) Solar refrigeration and air conditioning
(9) Solar cooking
(10) Solar furnace
(11) Mechanical power
(12) Closed-cycle hot air engines
(13) Open-cycle hot air engines
(14) Solar pumps
(15) Solar turbines
(16) Solar gravity motors
(17) Solar phase-shift reciprocating engines
(18) Sewage treatment
(19) Transportation

(Farber, 1973).

Rather than provide a detailed description of each application, only solar water heating, space heating, conversion of solar energy to electricity and solar houses are summarized here. Readers wishing more detail on the applications should refer to Farber (1973).

One of the major difficulties in utilizing solar energy involves finding materials that will withstand the exposure to the sun and the wind. Materials are usually given rigorous field tests. Materials which survive these exposure tests are assessed in terms of their reflection, absorption, and transmission properties. Plastic and glass were both found to be satisfactory but no plastic was found to be as good as glass.

If the right materials are selected, the conversion of solar energy to heat energy can be highly efficient. In fact, it has been demonstrated that some collectors are capable of converting 82% of incident radiation to heat. (Fowler, 1975).

2.2.1. Space Heating

The most promising immediate use of solar energy is space heating.

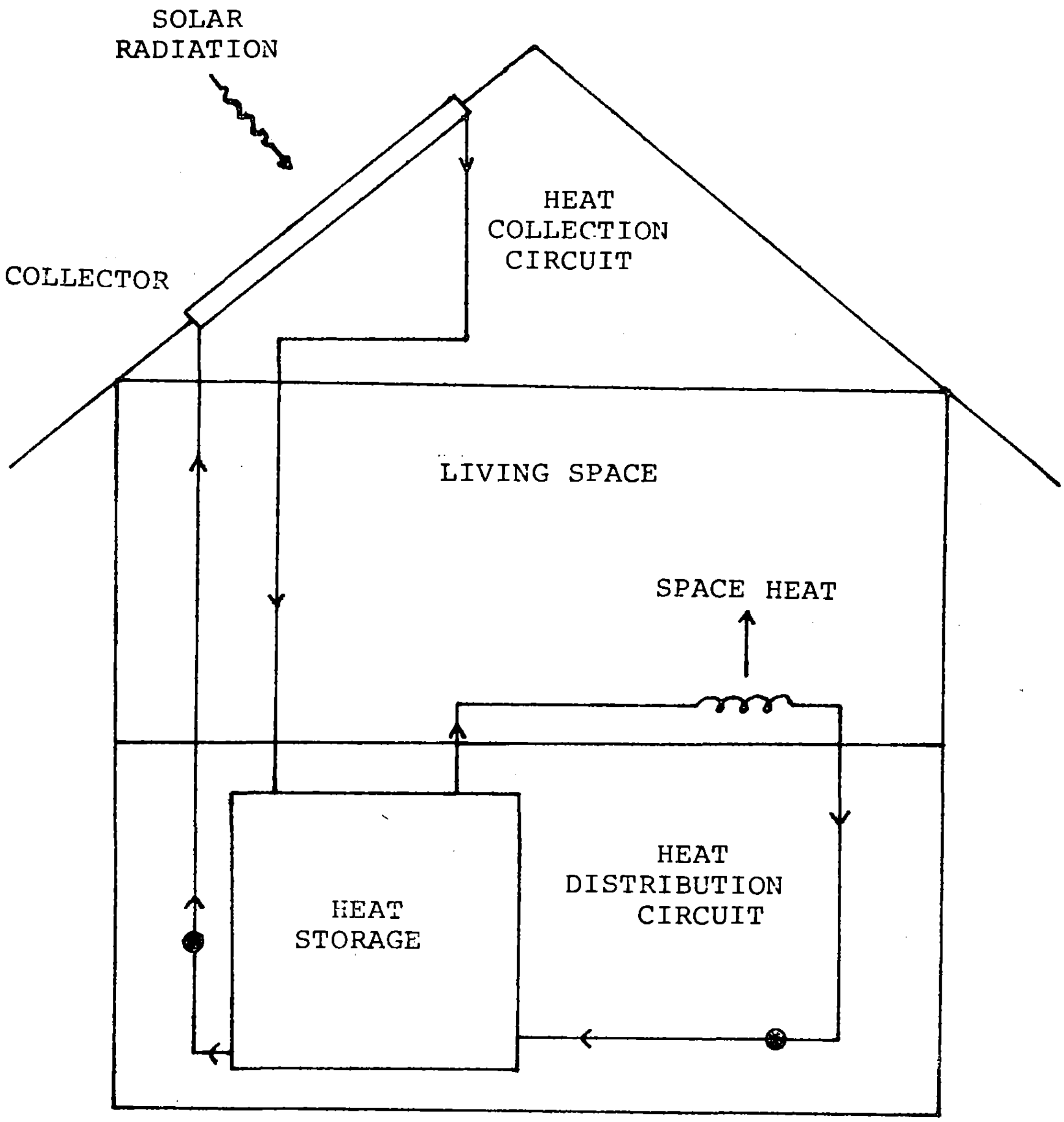


FIGURE 1. Schematic of a Solar Heated House (Sasaki, 1975).

Space heating is carried out by circulating water heated by solar energy through baseboard pipes in a conventional hot water system. In a solar home the water is heated by roof-top collectors and then pumped to a storage tank. This type of heating system is capable of carrying the heat load for one to two typical cloudy winter days.

However, it may be more convenient to heat a building by hot air than by water. An air heater usually consists of overlapping aluminum plates painted black on the portion exposed to the sun. These plates are put into a glass-covered box. The air which is heated in this box is then circulated through the heating system.

2.2.2. Water Heating

Many flat plate collectors are designed for use in water heating.

One of the most efficient collector units consists of thin flat copper sheets which absorb the solar radiation and allow the layer of water underneath to be heated. The water is then circulated to water storage tanks for future use.

2.2.3. Conversion of Solar Energy into Electricity

Solar energy can be converted into electricity by first converting the solar energy into mechanical power which in turn drives a conventional generator (this is presently the most economical method). Another method involves the use of photovoltaic (solar) cells to convert solar energy into electricity directly. The photovoltaic process involves a semiconductor which then generates an electric current when light falls on it. This current can then be collected on contacts applied to the surface of the semi-conductor.

Although the theoretical efficiency of this conversion process is 25%, it has not been achieved. The efficiency of conversion in 1971 was reported to be 11%. (Fowler, 1975).

Because of the high cost of solar cells, large photovoltaic systems for terrestrial applications have not been built.

Solar cells could have wide application in Canada because they are not affected by cold air temperatures. In fact, in the colder climates, there is less resistance in their circuitry; consequently, the cells themselves operate efficiently. On the other hand, in hot humid air photovoltaic cells degrade rapidly.

2.2.4. Meteorological Factors Affecting the Design of Solar Energy Systems

The availability of solar energy must be considered in the design of a home dependent on solar energy. The factors affecting the availability of solar energy include:

1. Latitude of the home.
2. Cloudiness
   - spatial variations
   - diurnal variations
   - seasonal variations
   - year-to-year variations.
3. Haze and pollution.

According to Farber(1973), the collectors for the heating system should all face south and be inclined with the horizontal at an angle equal to the local latitude plus ten degrees, if optimum collection efficiency is desired. This gives significantly higher collection efficiencies during the winter when the days are shorter and the heat is needed. Hay(1977) has recently carried out more detailed computations to evaluate the optimum collector angle. His results are given in Section 4.3.

The collector area required for a particular building is dependent on the floor space to be heated, the type of insulation used in the building and other such parameters that would contribute to heat loss from the building.

Sasaki(1975) has indicated that a solar heating system should be designed to ensure:

(1) that the maximum amount of heat is transferred to the working fluid,
(2) that heat losses to the environment are minimized.

The factors influencing the form of solar heating system that should be used are:

(1) The intensity of solar radiation per unit area of collector. In general this intensity is relatively low in Ontario. According to Sasaki (1975), the collector area must be approximately 1/3 to 1/2 the floor area of the living space (excluding the basement) to satisfy even half the heating requirements of a house.
(2) The intensity of solar radiation and building heating load both vary on a daily and seasonal basis. The degree of mismatching between the load and available solar energy will determine the type of heat storage that is required.

Another meteorological factor which must be considered in the design of a solar energy system, involves the persistency of cloud. Prolonged cloudy spells during periods of low intensity insolation increase the requirements for energy storage.

2.3. DESIGN OF A SOLAR ENERGY SYSTEM

2.3.1. Collectors

2.3.1.1. Flat Plate:

This type of collector is usually preferable to the collectors described below because it can collect both direct and diffuse solar radiation. Consequently, it can also perform on cloudy days. Furthermore, it can be maintained in a fixed position while exhibiting a conversion efficiency in excess of 50% (Quirouette, 1975). There are two types of flat-plate collectors including the liquid type and the air type.

The Liquid Type:

This type of flat-plate collector uses a liquid such as water, for the heat absorbing fluid. The sun heats the collector surface. As water travels through the tubes in the collector it picks up heat from the surface by conduction. The heated water is then pumped to storage or used in the heating system.

The Air Type:

This type of collector is similar to the liquid type flat-plate collector. However, air instead of water is pumped through the collector. The collector surface is heated by the sun and in turn the air in the collector is warmed.

2.3.1.2. The Focusing Collector:

Focusing collectors are capable of generating much higher operating temperatures than flat-plate collectors. However, they must follow the sun and be kept clean at all times. Due to the cost of these collectors, they are not as popular as flat-plate collectors. Furthermore, focusing collectors use only direct radiation. Therefore, on cloudy days they will not work as well as flat-plate collectors.

2.3.1.3. The Solar Pond:

The solar pond may be used for the collection of solar energy. The bottom of the pond has a black surface to absorb the heat. The heat is then transferred to the water in the pond by conduction. However, both latent and sensible heat are lost from the pond to the outside air. Consequently, solar ponds tend to be very inefficient.

2.3.2. Heat Storage Systems

The type and the capability of the heat storage system required for a particular home depends on collector size, the energy demand, and the variations in solar energy. In particular, the system design should be based on a knowledge of the variations in the intensity of solar energy which occurs from season to season and collector inclination. The different types of storage are described in Chapter 4.

2.4. EXPERIMENTAL SOLAR HOMES

A number of experimental solar homes have already been built in Ontario. Three of these homes include:

(1) A bungalow built near Gananoque, Ontario by Gregory Allen.

The house was built in 1974. It is a four bedroom, two storey house with 205 square metres of living space - excluding the garage.

In this house 20 square metres of collector surface are mounted on the south side of the roof. The heating system uses water as a heat transport medium and 1815 kilograms of paraffin wax as a heat storage unit. This solar heating system will provide about half the heating requirements of the house (Quirouette, 1975).

(2) In Mississauga a 2 storey, 3 bedroom house was designed by Blair Ferguson, (a Toronto Engineer/Economist). The house was designed to have 70% of the heating requirements supplied by solar energy. The house has 150 square metres of living space. The collector consists of 70 sqare metres of metallic panels. The accumulated heat is stored in two 75 litre water tanks. The total project cost $113,000 (Jeffery, 1975).

(3) John Hix (Architect) and Frank Hooper (Engineer at University of Toronto) are currently designing a solar heated house to be built in Mississauga. It will be a two storey, single-family residence of 220 square metres.

The house will have more than 75 square metres of collector surface and a 2070 litre water storage unit.

The house will be heated entirely by solar energy. It uses long-term (annual) storage (Quirouette, 1975).

3. HEATING REQUIREMENTS

3.1. HEATING DEGREE DAY DEFINITION

Heating degree days are used to estimate the amount of energy required to keep the temperature of a house at 18°C.

In calculating heating degree days, one degree-day is assigned for each degree that the daily mean temperature departs below 18°C. The degree-days for a "heating season" are obtained by summing the daily values for each day during the season. In accumulating degree days, days on which the mean temperature exceeds 18°C are ignored.

3.2. THE DISTRIBUTION OF HEATING DEGREE DAYS IN ONTARIO

Heating degree day values were computed for the stations shown in Figure 2 for the period from 1941 to 1970 and plotted on maps.

Figure 3 is a map of heating degree days below 18°C. As shown in Figure 3, the number of heating degree days are larger in northern Ontario than in southern Ontario. According to the available normal values, the lowest number of heating degree days occurs in Windsor(299) and the highest number can be found in Trout Lake(641).

In general, for a given location in northern Ontario, values to the east of Lake Nipigon are higher than those to the west of Lake Nipigon. The highest number of degree days found to the east of Lake Nipigon is 559 hours in Nakina and the highest number of heating degree days to the west occurs at Dryden (509 hours).

3.3. RELATIONSHIP BETWEEN HEATING DEGREE DAYS AND HEATING REQUIREMENTS

It is assumed that the domestic space heating requirements of a house are based on a building heat-loss characteristic of 113.5 KJm^{-2} degree day^{-1} (Hay, 1976). From this value the space heating requirements of a house may be found using the number of degree days.

To find the average hourly requirement for space heating the following formula was used:

$$\text{(1)} \quad \text{Hourly heating requirement } (MJh^{-1}) = \frac{H.D.D. \times 113.5 \times A_h}{24 \times DAYS \times 1000}$$

where H.D.D. - the heating degree days for the month
113.5 - building heat-loss (KJm^{-2}degree day^{-1})
A_h - floor area of living space
24 - the number of hours in the day
1/1000 - conversion from KJ to MJ
DAYS - number of days in the month.

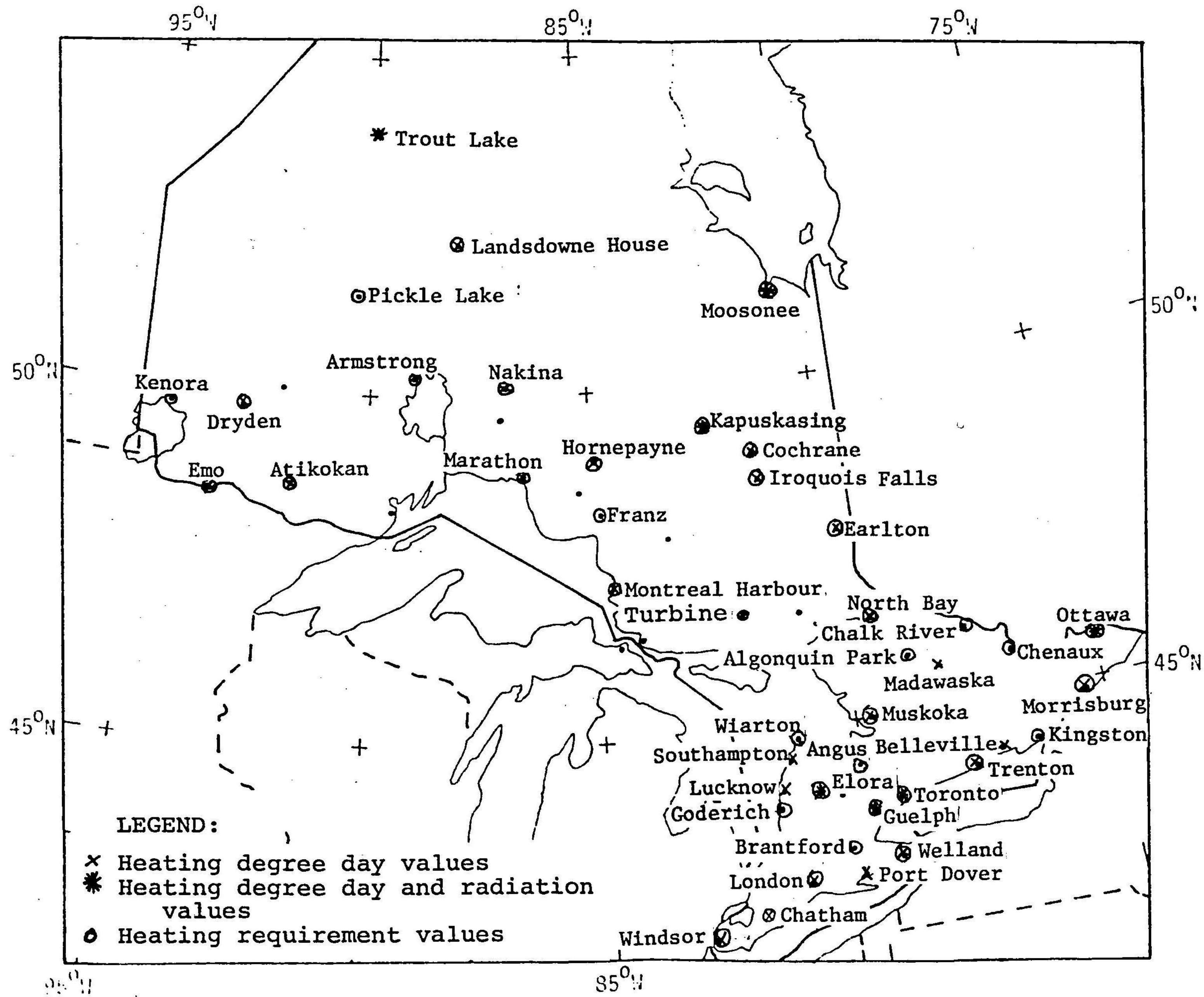


FIGURE 2. Locations where heating degree day values, radiation values and heating requirement values were calculated.

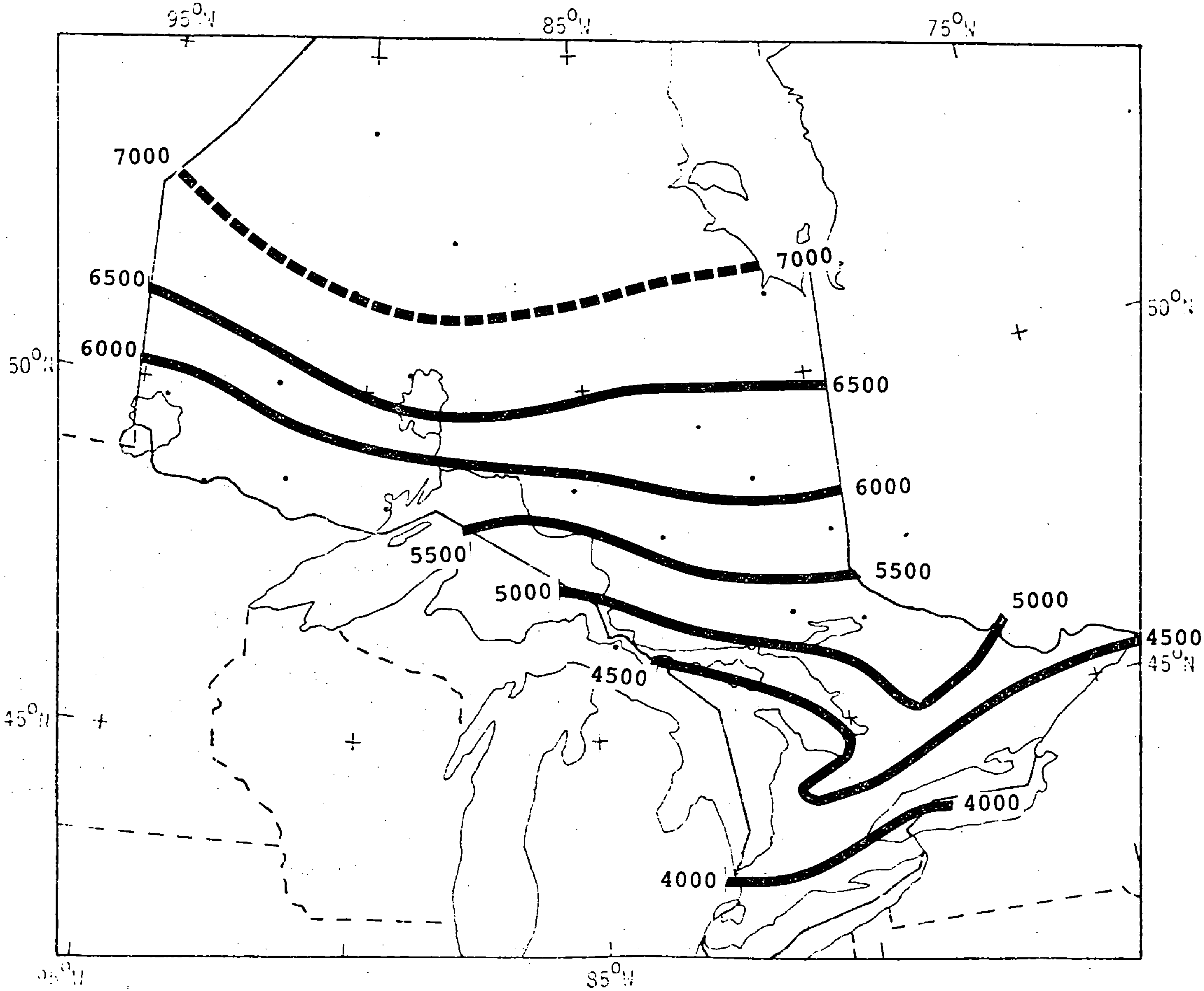


FIGURE 3. Annual Heating Degree Days using a base temperature of 18°C.

The average hot water consumption is assumed to be 2.7×10^3 MJmonth^{-1} (Hay, 1976).

To find the average hourly energy consumption for heating hot water, the following formula was used:

$$\text{(2)}\quad \text{Average Hourly Energy Consumption for Heating Hot Water. } (\text{MJh}^{-1}) = \frac{2.7 \times 10^3}{24 \times \text{DAYS}}$$

where 2.7×10^3 - average hot water consumption (MJmonth^{-1})
24 - the number of hours in the day
DAYS - number of days in the month.

To find the total heating requirements (hot water + space heating), the results of Equations (1) and (2) are added together.

In this study the heating requirements of a house were estimated from equations (1) and (2) assuming that the house had a floor area of $135 m^2$ and a $65 m^2$ collector working at 30% efficiency.

The storage used was assumed to be 80% efficient from month to month.

3.4. DESCRIPTION OF HEATING REQUIREMENTS

3.4.1. Space Heating during Specific Months

Figure 4 shows the average hourly space heating requirements for January. According to this map the amount of energy required to heat a house during January is almost twice as large in northern Ontario as in Southern Ontario. Average hourly heating requirements vary from 45.7 MJh^{-1} at Trout Lake to 24.8 MJh^{-1} at Chatham. The heating requirements for December and February are distributed in a pattern similar to that shown in Figure 4. In December, the heating requirements are 88 to 91% as large as the requirements in January. On the other hand, the heating requirements at a number of stations in southern Ontario in February are equal to, or slightly larger than, the January values.

Figure 5 shows the total heating (space plus water) requirements for Ontario for January. These requirements vary from values of less than 30 MJh^{-1} in southern Ontario to values of more than 50 MJh^{-1} in northern Ontario.

In July, the values of heating requirements are much greater in Marathon than in any other part of Ontario (map not shown). Marathon has a value of 4.8 MJh^{-1} and Trout Lake, Cochrane and Kenora have values of 2.2, 2.0 and 1.5 MJh^{-1} respectively. The high value at Marathon results from the cooling effect of Lake Superior. In southern Ontario during July the heating requirements are very small at all locations ranging from 1.3 in Algonquin Park to .1 in Welland.

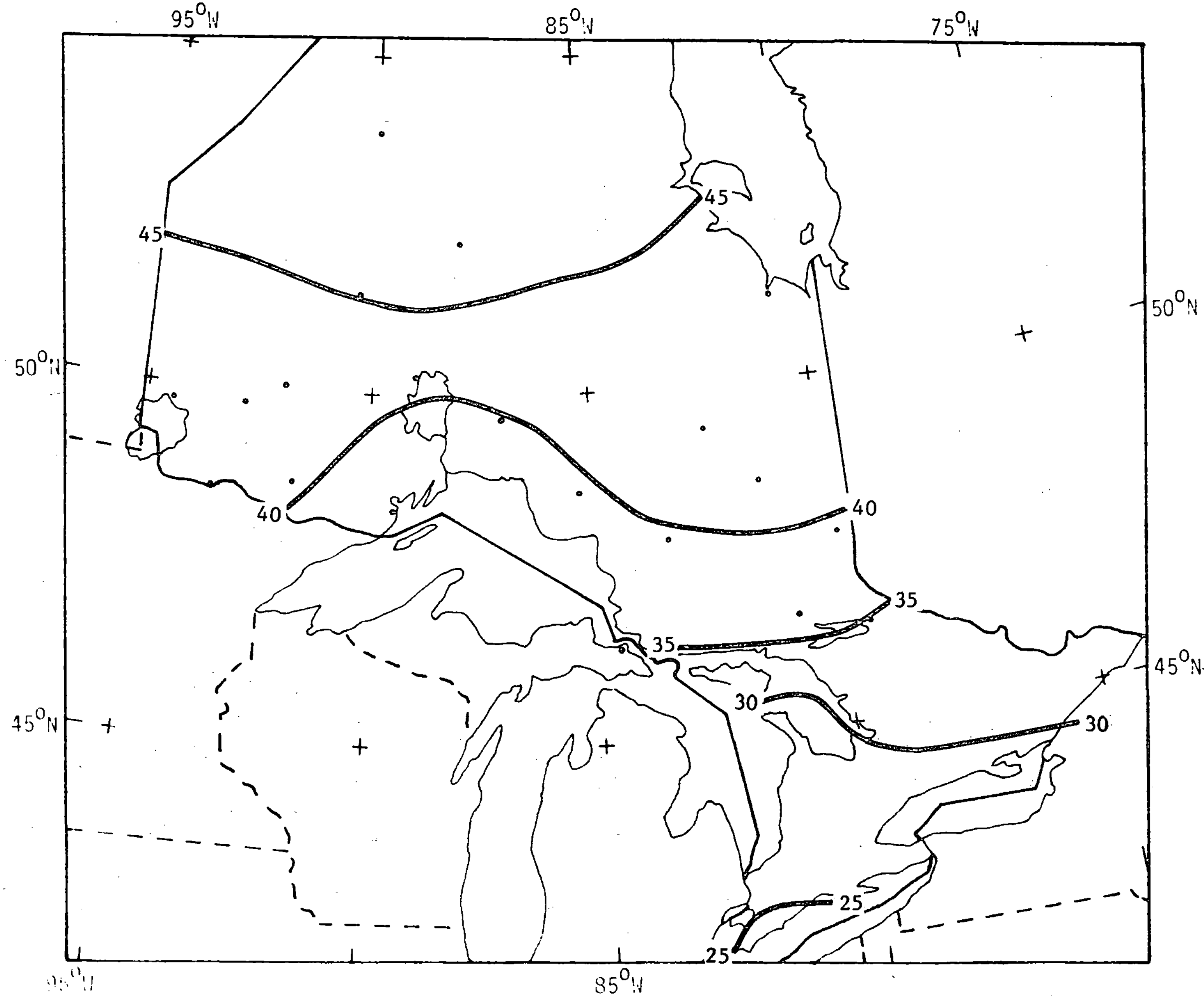


FIGURE 4. The Average Hourly Requirement (MJh^{-1}) for Space Heating during January for a 135 m^2 house.

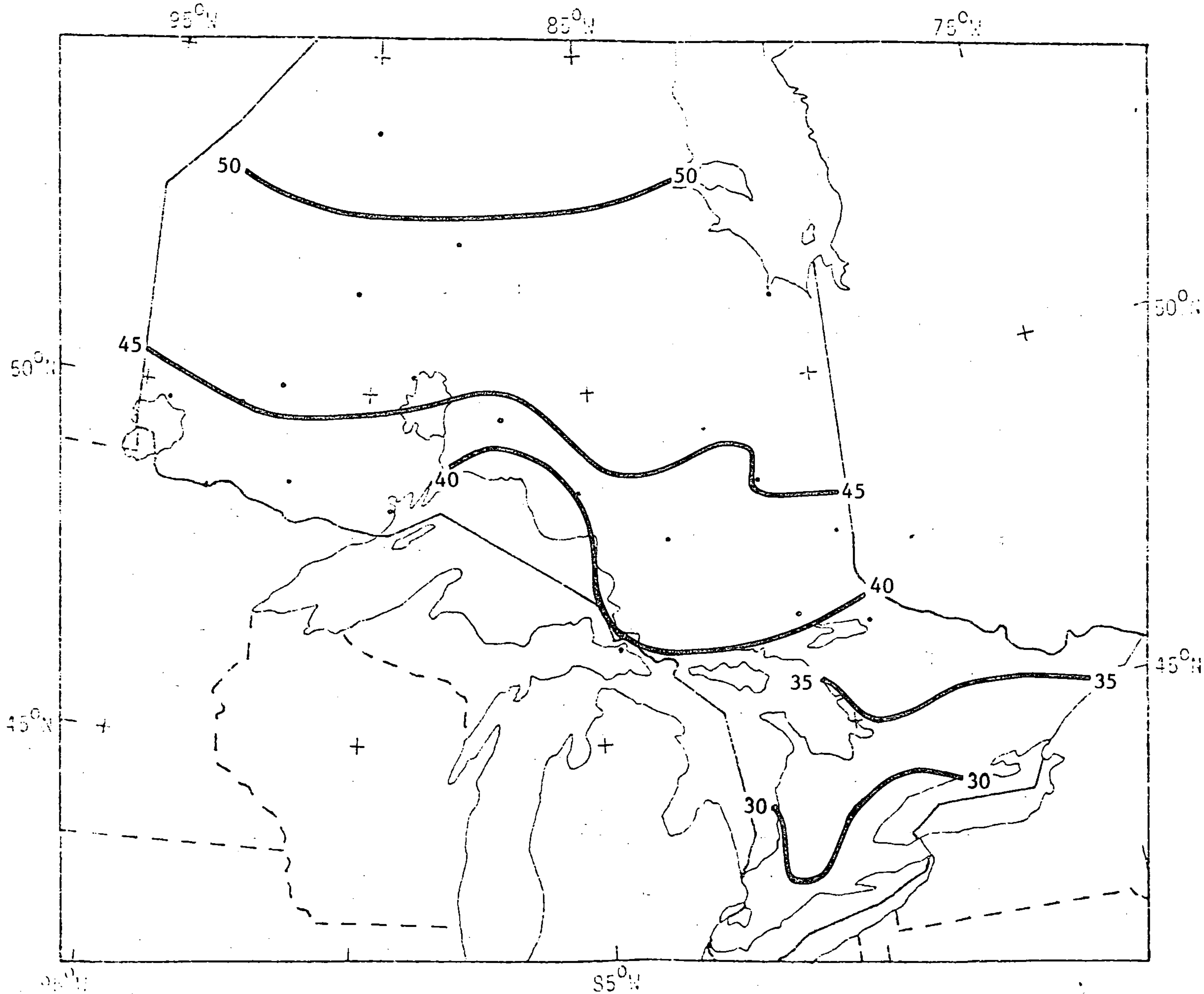


FIGURE 5. The Average Hourly Requirement (MJh^{-1}) for Total Heating for January in a 135 m^2 House.

3.4.2. Space Heating Requirements during the Heating Season (November to April)

Figure 6 shows the average hourly requirement for space heating during the period from November to April inclusive. In southern Ontario values range from 20.2 MJh^{-1} at Windsor to 27.1 MJh^{-1} at North Bay.

In northern Ontario the heating requirements (on the average) are slightly lower along Lake Superior than at other locations. For example, Marathon has a value of 28.8 MJh^{-1}, while Kapuskasing, Trout Lake and Kenora have values of 32.8, 36.6 and 31.6 MJh^{-1} respectively. In general, the heating requirements increase with increasing latitude.
Appendix 1. includes maps showing the distribution of average hourly values of total heating requirements for the heating season and space heating requirements for the complete year.

3.4.3. Other factors which influence heating requirements

The amount of insulation used in a house also influences heating requirements. The Housing and Urban Development Association of Canada (Hay, 1976) gives a value of 102 KJm^{-2} degree day^{-1} as the heat-loss characteristic for a raised basement house built to the 1975 Canadian code for residential construction. For a house not built to that standard, a value of 134 KJm^{-2} degree day^{-1} is given. Therefore, for a well insulated house, the heat-loss characteristic is much smaller.

Other factors which may influence the heat-loss characteristic of a house include the wind on a given day and the solar radiation falling on the roof of the house. The wind increases the rate at which heat is lost through cracks in the building. In addition the wind also increases the heat lost from the building by convection.

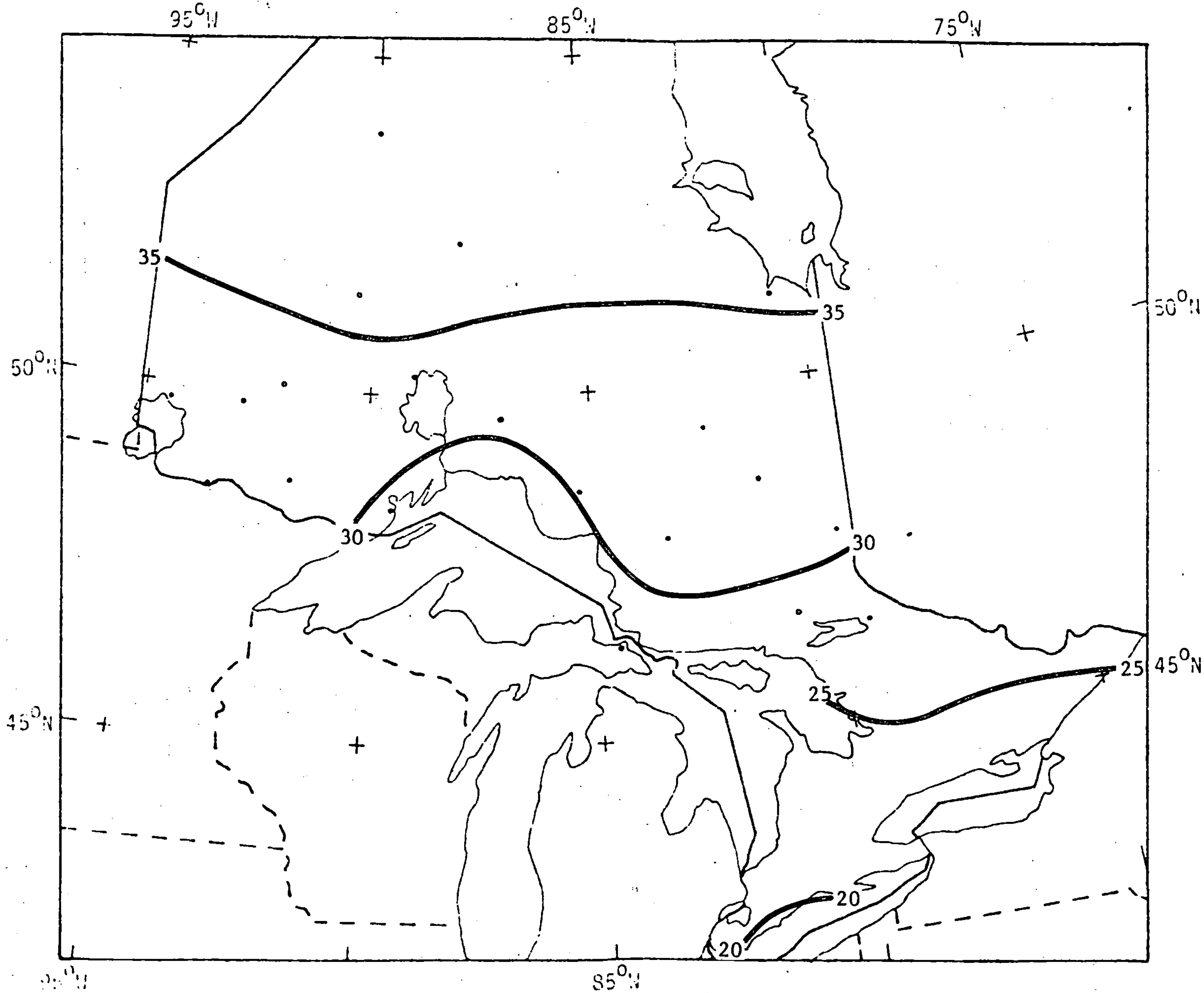


FIGURE 6. The Average Hourly Requirement (MJh^{-1}) for Space Heating during the Heating Season in a 135 m^2 House.

4. THE AVAILABILITY OF SOLAR ENERGY

4.1. THE HOURS OF BRIGHT SUNSHINE

4.1.1. The Measurements of Bright Sunshine

Bright sunshine is measured with a Campbell-Stokes sunshine recorder. This recorder consists of a glass sphere 4" in diameter, mounted concentrically in a section of a spherical bowl.such that the sun's rays are focused sharply on a sunshine card held in position by a pair of grooves in the bowl. The focused rays of the sun burn a trace on the sunshine card. As the sun "moves" across the sky, the burn moves lengthwise along the card opposite in direction to the apparent motion of the sun. (Environment Canada, 1974).

4.1.2. Hours of Bright Sunshine by Season

Figures 7A to 7E show the spatial variations of the hours of bright sunshine throughout Ontario for 5 different months based on observations for the period from 1941 to 1970.

As can be seen by Figure 7A, the number of sunshine hours during March varies between 120 hours along Lake Erie and the southern part of Lake Huron to values greater than 160 hours in northwestern Ontario. The decrease in sunshine hours in the southwestern part of Ontario is likely due to cloudiness resulting from moisture picked up by winds blowing from the northwest over Lakes Superior and Huron.

As can be seen by Figure 7B, the number of sunshine hours in the southern part of Ontario is approximately 240 during June. In northern Ontario the values range from 230 hours around Thunder Bay to 180 hours on the northwest shore of James Bay. Bright sunshine occurs more frequently in southeastern Ontario than it does in southwestern Ontario during June. As Figure 7B shows, most of southeastern Ontario receives more than 240 hours during an average June.

According to Figure 7C, sunshine hours for July in southern Ontario range from 260 around North Bay to 290 near Lakes Ontario and Erie. In northern Ontario the values range from 300 hours between Kenora and Thunder Bay to 240 hours around Moosonee. The increase in the number of sunshine hours between June and July could be due to the fact that the air masses moving into Ontario from the northwest would tend to be moister during late May and June.

As can be seen by Figure 7D, the distribution of hours of bright sunshine in September is similar to the one for July. The decrease in the number of sunshine hours is due to the decrease in the hours of daylight.

Figure 7E indicates that the number of sunshine hours in December is greater than 60 hours south of a line from North Bay to Goderich. In northern Ontario the

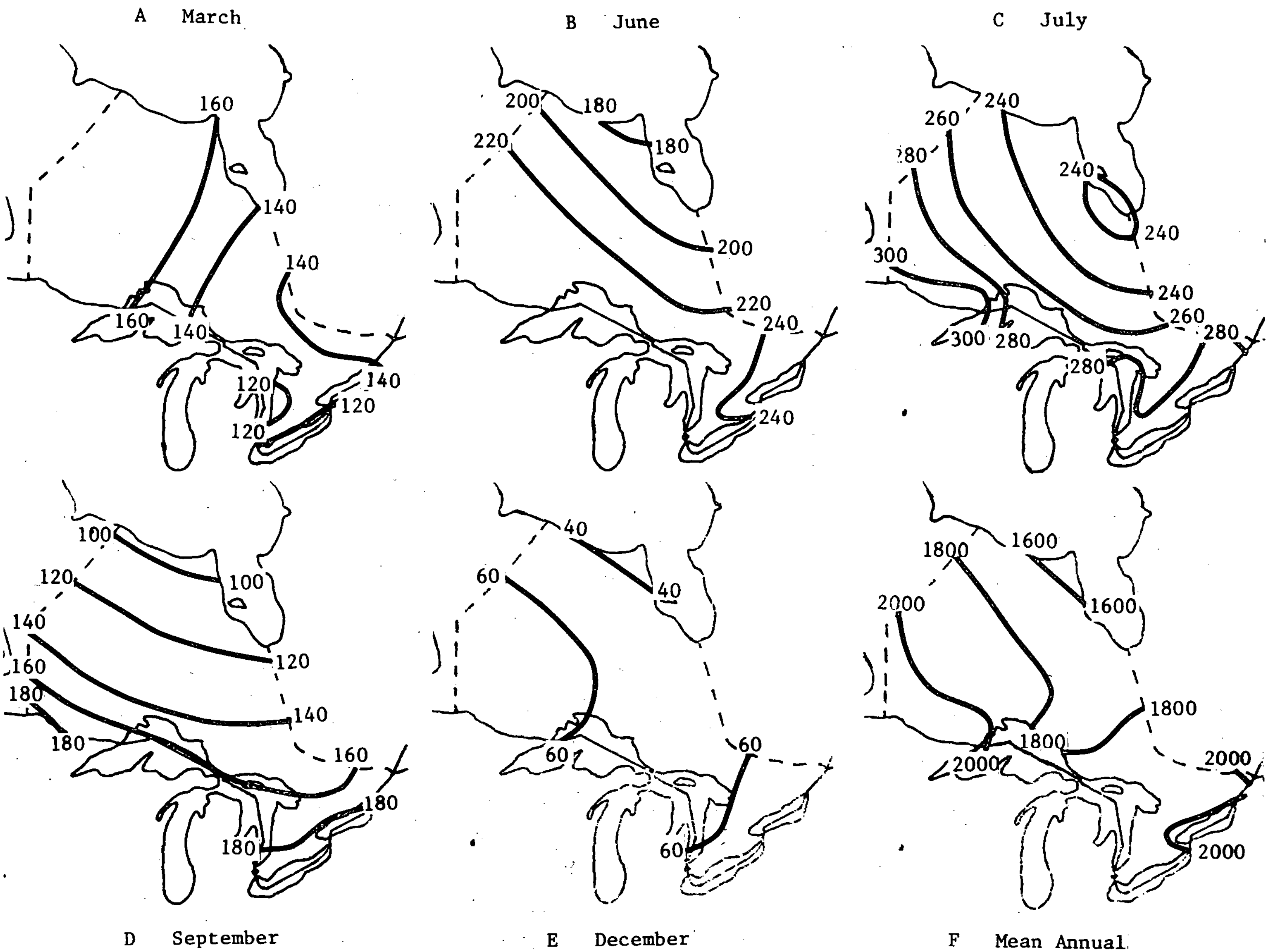


FIGURE 7. Maps showing the hours of Bright Sunshine (Based on the Period from 1941 to 1970).

number of sunshine hours ranges from approximately 70 in the western part of the province to 40 near the northwestern part of James Bay. The lower numbers of sunshine hours on the eastern shore of Lake Huron and in the vicinity of James Bay result from the increased cloudiness that occurs in the vicinity of Lake Huron and Hudson Bay in December.

4.1.3. Hours of Bright Sunshine by Year

As can be seen by Figure 7F, in southern Ontario the number of hours of bright sunshine varies from 2000 hours along Lake Ontario to 1800 hours around Earlton. In northern Ontario the number of hours of bright sunshine varies from 2000 hours in the Red Lake - Thunder Bay area to 1600 hours north of Moosonee along the northern part of James Bay. There is a significant decrease in the number of sunshine hours from July to December. In southern Ontario the value in July averages approximately 280 hours and in December the number of sunshine hours is approximately 60. In northern Ontario the maximum value in July is approximately 310 hours and the maximum number of sunshine hours in December is approximately 70. In summary, the map shows minimum values in the vicinity of James Bay and maximum values in western and eastern Ontario.

4.2. THE PERCENTAGE OF POSSIBLE HOURS OF BRIGHT SUNSHINE

The percent of possible hours of bright sunshine is the ratio of the observed hours of bright sunshine divided by the hours of bright sunshine that would be observed if there were no clouds in the sky. The percentages presented in the following section are based on statistics for the 1931-60 period.

In northern Ontario this percentage is usually lowest in November and highest in July. For example, at Armstrong the value in July is 53% and only 18% in November. A comparison between Armstrong and more eastern locations indicates that the yearly average for Armstrong (40%) is higher than the yearly average for Kapuskasing (35%) and Moosonee (33%). These results show that the Manitoba border area is sunnier than the area to the east.

According to Table 1 (Table of Mean Monthly Percentage of Possible Bright Sunshine) northern Ontario, east of Armstrong, appears to get about the same proportion of sunny weather as southern Ontario in the winter (Kapuskasing - 27% and Toronto - 27% in December). However, during the summer, the percent of possible sunshine is less in northern Ontario (Kapuskasing - 43% and Toronto - 56% in June) (Chapman and Thomas, 1968).

In southern Ontario, July is the sunniest month, having values as high as 62% in Toronto and Harrow. December is the dullest month with values as low as 20% in Turbine.

TABLE 1

MEAN MONTHLY PERCENT OF POSSIBLE BRIGHT SUNSHINE
BASED ON THE PERIOD 1931-1960

Station	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Armstrong	36	45	45	44	45	45	53	52	35	32	18	30	40
Kapuskasing	27	37	37	41	41	43	49	45	33	27	16	21	35
Moosonee	30	39	37	39	39	36	48	43	31	24	16	18	33
Turbine	24	33	37	44	48	50	58	55	41	35	20	20	39
Toronto	27	36	38	43	49	56	62	60	53	45	29	27	44
Harrow	24	32	33	40	51	53	62	61	52	47	29	24	42

(Chapman and Thomas, 1968)

An analysis of the records of sunshine hours for Toronto shows that the number of sunshine hours may be from 41-52% of the total number of sunshine hours possible for an entire year. The number of hours available in a given year may be as little as 90% or as much as 113% of the normal value (Lawford, 1977).

4.3. ANALYSIS OF RADIATION MEASUREMENTS

4.3.1. Method of Measurement

Solar irradiance measurements are taken with Epply normal-incidence pyrheliometers.

The Epply normal-incidence pyrheliometer was designed specifically for continuous measurements of solar irradiance. The pyrheliometer consists essentially of a brass tube with a set of three diaphragms to limit the aperture angle to 5.7^{o}, a thermopile detector at the base, and a window of quartz sealing the tube at the front end. The interior is blackened to eliminate unwanted reflections and the external surface is chromeplated to minimize solar heating. The pyrheliometer tube has a double wall with an air space between to achieve high detector stability during windy weather. An automatically rotatable disk is placed over the open end with two aperatures, one covered by a Schott RG2 glass filter, and the other uncovered to admit the total spectrum (Latimer, 1974).

4.3.2. Analysis of Spatial and Temporal Variations in Radiation Measurements

Some physical parameters which govern the intensity of radiation are: day of the year, latitude and elevation of a particular location.

Table 2 contains actual radiation measurements (maximum, average and minimum) for 7 locations. According to this table, the average value of radiation in northern Ontario in December is .13 $MJm^{-2}h^{-1}$. The values in northern Ontario range from .12 $MJm^{-2}h^{-1}$ in Trout Lake to .14$MJm^{-2}h^{-1}$ in Kapuskasing. In southern Ontario the average value of radiation is .17 $MJm^{-2}h^{-1}$ in December where the values range from .15 $MJm^{-2}h^{-1}$ in Toronto to .19 $MJm^{-2}h^{-1}$ in Guelph.

The minimum values of radiation in Table 2 show that, in December, in northern Ontario, the average hourly value of radiation can be as small as .11 $MJm^{-2}h^{-1}$. Individual station values range from .10 in Trout Lake to .12 $MJm^{-2}h^{-1}$ in Moosonee and Kapuskasing. In southern Ontario the minimum average hourly values range from .10 $MJm^{-2}h^{-1}$ in Toronto to .15 $MJm^{-2}h^{-1}$ in Guelph.

In July, the average value of radiation in northern Ontario is .72 $MJm^{-2}h^{-1}$. On the other hand, the average value is .77 $MJm^{-2}h^{-1}$ in southern Ontario.

TABLE 2

VALUES OF GLOBAL SOLAR RADIATION ($MJm^{-2}h^{-1}$)

Station		Month											
		Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Trout Lake (4 Yrs. Record)	max.	.17	.51	.58	.83	.87	.89	.85	.72	.44	.27	.15	.13
	avg.	.16	.33	.55	.79	.82	.76	.80	.67	.39	.24	.14	.12
	min.	.16	.32	.51	.74	.75	.64	.71	.64	.37	.19	.11	.10
Guelph (18 Yrs. Record)	max.	.3	.47	.68	.78	.97	1.05	1.07	.89	.68	.5	.25	.23
	avg.	.25	.39	.55	.66	.83	.93	.93	.79	.60	.4	.21	.19
	min.	.19	.32	.46	.51	.58	.73	.78	.73	.46	.29	.16	.15
Toronto (38 Yrs Record)	max.	.25	.43	.62	.79	.98	1.03	1.04	.87	.66	.48	.25	.21
	avg.	.19	.32	.48	.65	.79	.9	.91	.77	.59	.38	.19	.15
	min.	.13	.25	.36	.5	.62	.77	.75	.67	.49	.29	.14	.1
Elora (6 Yrs. Record)	max.	.26	.44	.61	.79	.88	.93	.98	.79	.66	.43	.21	.19
	avg.	.24	.38	.53	.72	.78	.87	.91	.77	.54	.36	.18	.17
	min.	.23	.33	.4	.64	.62	.78	.79	.72	.46	.29	.15	.14
Moosonee (13 Yrs. Record)	max.	.19	.44	.59	.85	.89	.96	.83	.72	.53	.32	.17	.15
	avg.	.18	.33	.54	.7	.76	.84	.77	.64	.45	.25	.14	.13
	min.	.15	.29	.47	.59	.64	.75	.68	.52	.42	.21	.11	.12
Kapuskasing (14 Yrs. Record)	max.	.28	.41	.67	.83	.88	1.15	.96	.8	.59	.36	.19	.18
	avg.	.19	.32	.55	.69	.76	.91	.85	.69	.49	.29	.15	.14
	min.	.14	.28	.46	.53	.64	.80	.76	.61	.29	.22	.12	.12
Ottawa (24 Yrs. Record)	max.	.32	.45	.68	.77	.95	1.05	1.01	.87	.67	.49	.28	.24
	avg.	.24	.38	.57	.69	.83	.9	.9	.77	.57	.37	.19	.18
	min.	.19	.31	.41	.59	.63	.72	.76	.65	.45	.28	.15	.14

From the maximum values of radiation in Table 2 it can be seen that, in December, the average value of radiation is .15 $MJm^{-2}h^{-1}$ in northern Ontario and .22 $MJm^{-2}h^{-1}$ in southern Ontario.

In July, the average value of radiation in northern Ontario is .88 $MJm^{-2}h^{-1}$ ranging from .83 $MJm^{-2}h^{-1}$ in Moosonee to .96 $MJm^{-2}h^{-1}$ in Kapuskasing. In southern Ontario, the average value of radiation is 1.03 $MJm^{-2}h^{-1}$ where the values range from .98 $MJm^{-2}h^{-1}$ in Elora to 1.07 $MJm^{-2}h^{-1}$ in Guelph.

In northern Ontario the variation in solar radiation (given by $\frac{\text{Range}}{\text{Average}} \times 100\%$) increases from 28.0% In July to 48.0% in December. In southern Ontario the value increases from 20.1% in July to 29.9% in December.

These results indicate that the variability of monthly totals of solar radiation is largest in the winter in northern Ontario.

4.3.3. Variations between a Rural and an Urban Location

In the previous section radiation values from downtown Toronto were used instead of the observations from a site near Woodbridge, Ontario because the downtown location had a longer period of record (38 years record for Toronto as compared to 8 years record for Woodbridge). Hay (1977) used Woodbridge values in his program for evaluating the amount of radiation falling on a collector inclined from the horizontal. The values obtained from his calculations are shown in Table 3. By taking the average values of radiation per month for the period 1968 - 1975 for Toronto and Woodbridge, the percent difference between the two locations was evaluated.

To estimate the percent difference, the following formulae were used:

$$\text{Percentage difference for each month} = \frac{\text{Woodbridge Radiation} - \text{Toronto Radiation}}{\text{Average Radiation}}$$

$$\text{Average Percentage difference} = \frac{\text{sum of percent differences for each month}}{12}$$

It was observed that, for the period from 1968 to 1975 inclusive, the Woodbridge values were (on the average) 6.5% larger than downtown Toronto values.

The values for the rural location would be expected to be higher because there is less particulate matter in the air to scatter the incoming radiation.

4.3.4. The Effect of Collector Angle

Table 3 summarizes the results obtained for calculations of the solar radiation falling on a south-facing collector with varying angles of elevation. These calculations are taken from results presented by Hay (1977) for the radiation received on a unit area. The results in Table 3 indicate that the total radiation received by a collector over an entire year is a maximum for a collector elevation angle of 30°.

TABLE 3

The Energy Available (MJh^{-1}) using a south-facing $65m^2$ collector at 30% efficiency (Hay, 1977).

	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
YEAR	129.5	130.7	140.0	140.4	137.7	131.6	122.7	111.0	96.9	81.1
JULY	18.1	18.3	17.9	17.4	16.2	14.8	13.1	11.1	9.0	6.6
DEC	3.5	4.1	4.5	4.9	5.3	5.5	5.5	5.3	5.1	4.7

In July, the best collector is shown as being 10° from the horizontal whereas the best collector angle in December is shown as being 60°.

In Toronto, as the collector angle is changed, the radiation values do not change very much. (Annual values go from 129.5 MJh^{-1} for a horizontal collector to a maximum of 140.4 MJh^{-1} for a collector at angle of 30°). For locations further north it would be expected that the change would be greater because the sun does not rise as far above the horizon.

4.4. CLOUD COVER

4.4.1. Role of Cloud Cover in Storage Requirements

Cloud cover is important because it affects the amount of solar radiation that reaches the earth. The amount and opacity of cloud affects the character and quantity of radiation received by a collector at the earth's surface. The amount of cloud is estimated by assessing the fraction of the sky covered by cloud. The opacity refers to the fraction of the sky that is concealed by opaque cloud. These two fractions are frequently different because light can be transmitted through thin cloud. Under cloud cover, the amount of available radiation is reduced. Consequently it is important to know the frequency and duration of cloudy conditions in order to design a storage system which will carry the excess solar energy from a sunny day over for use in heating on subsequent cloudy days.

4.4.2. Types of Storage Systems

Storage systems are usually classified as long-term or short-term. Short-term storage systems will retain available heat for one or two typical winter days. Long-term storage systems should be able to retain heat for a few months. Speyer (1959) suggests that at least 50% of the energy put into storage must be available three months later and that the quantity of stored energy must be sufficient to significantly reduce the collector area needed.

Long-term storage involves not only increasing the capacity but also improving the efficiency of the system. The solar heating system thus benefits every day from the reduction in energy leakage and loss. If more insulation is used the efficiency of the storage will increase.

The storage media that can be used are water, air, rocks, waxes and salts. Water is the most popular type of storage medium. It is cheap and convenient to use because it can be distributed with a conventional hot water radiator system. In Canada, anti-freeze is frequently used as the collector medium because of the cold climates. Water is then used for storing and distributing the energy.

Rocks are also used as a storage medium because they are cheap, readily available and quite effective. Rock storage systems usually consist of at least fist-sized rocks packed around a large water tank. These rocks absorb heat from the tank. The heat is then distributed to the house by blowing air through rocks. This system can be readily incorporated into homes that have forced-air distribution systems.

Eutectic salts and waxes have many problems associated with them. One problem is that many salts are incompatible with metal containers and cause corrosion of the metal. In addition, salts quickly lose their capability to release the heat which they have absorbed.

4.4.3. Analysis of the Frequency of Successively Cloudy Days

In this analysis a 'cloudy' day is defined to be a day when the opacity is equal to or greater that 6/10 for at least six hours between 05-19 LST. For the purpose of this section the winter months are taken as December, January and February and the summer months are taken as June, July and August, Unless otherwise stated, the period of record is 20 years (1953-1972). The analyses have been carried out in four representative locations.

Figurs 8A and 8B show the number of successively cloudy days during winter and summer for Timmins based on 17 years record. As indicated in Figure 8B, there can be as many as 24 successively cloudy days (two occurrences in 17 years) in the summer. There are more occurrences of three or less successively 'cloudy' days in the winter than in the summer. However, the total number of cloudy days is similar in both winter and summer. On the average, there are 70 cloudy days in the summer and 65 cloudy days in the winter.

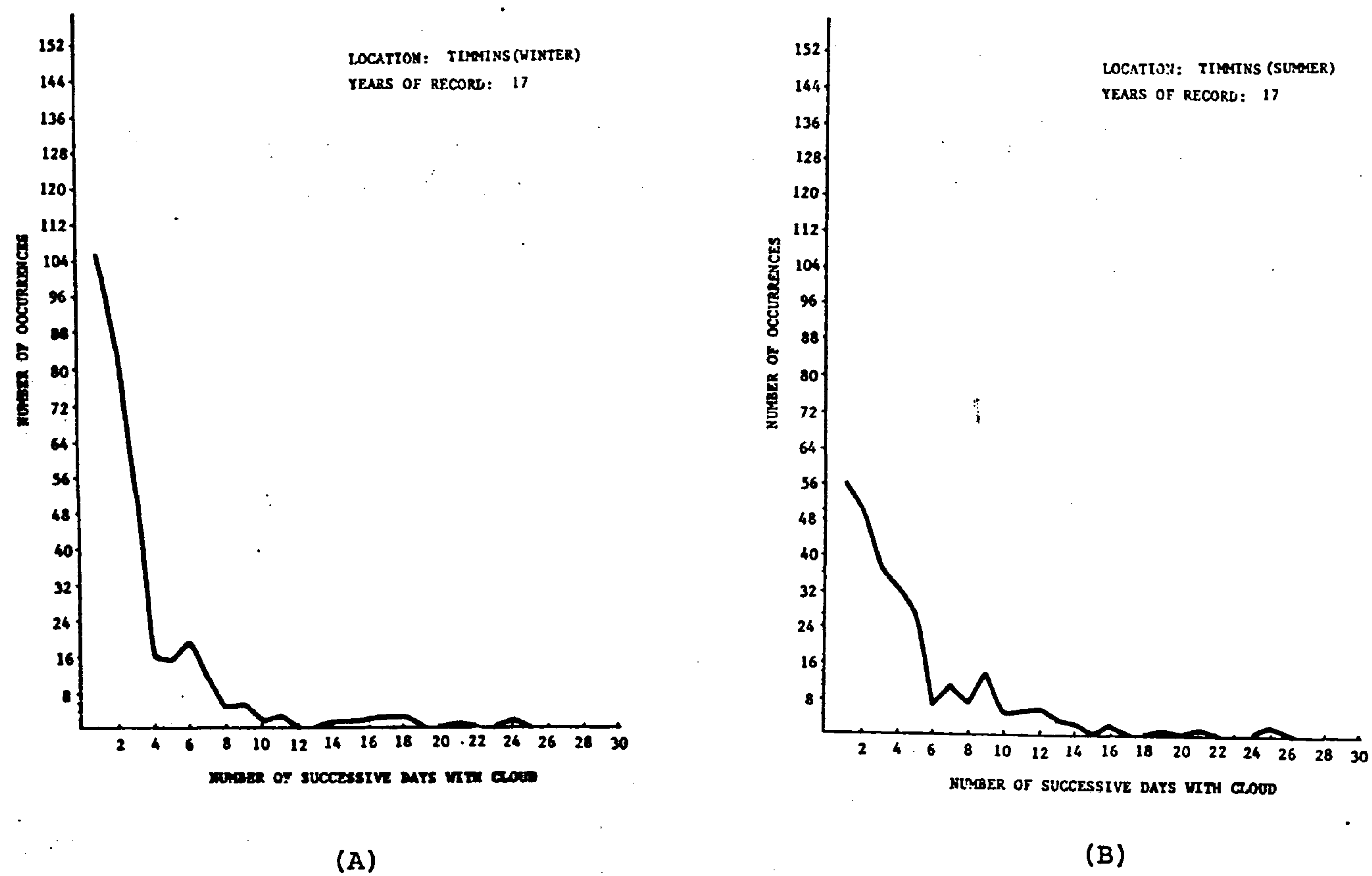


FIGURE 8. Graphs showing the frequency of successively cloudy days at Timmins during (A) winter and (B) summer.

Figures 9A and 9B show the number of successively cloudy days at Toronto. According to these curves, there can be as many as 25 successive days (1 occurrence in 20 years) of cloud in the winter in Toronto and as many as 11 days of cloud (2 occurrences in 20 years) in the summer. This comparison between Figures 9A and 9B indicates that, in Toronto, prolonged cloudy periods are much more likely to occur in the winter than in the summer. The average number of cloudy days is 50 in the summer and 68 in the winter.

In order to assess the relative frequency of prolonged intervals with cloud, an analysis of the percentage of cloudy days which were part of a prolonged interval of cloudy days was carried out. For the purposes of this analysis a period of 9 or more successively cloudy days was defined to be a prolonged cloudy interval. According to this analysis 30% of the 'cloudy' days in Toronto in the winter occur during prolonged cloudy intervals, while only 6% of the 'cloudy' days in the summer occur during prolonged cloudy intervals.

Graphs showing the frequency of successively cloudy days at Ottawa and Kenora are shown in Appendix B.

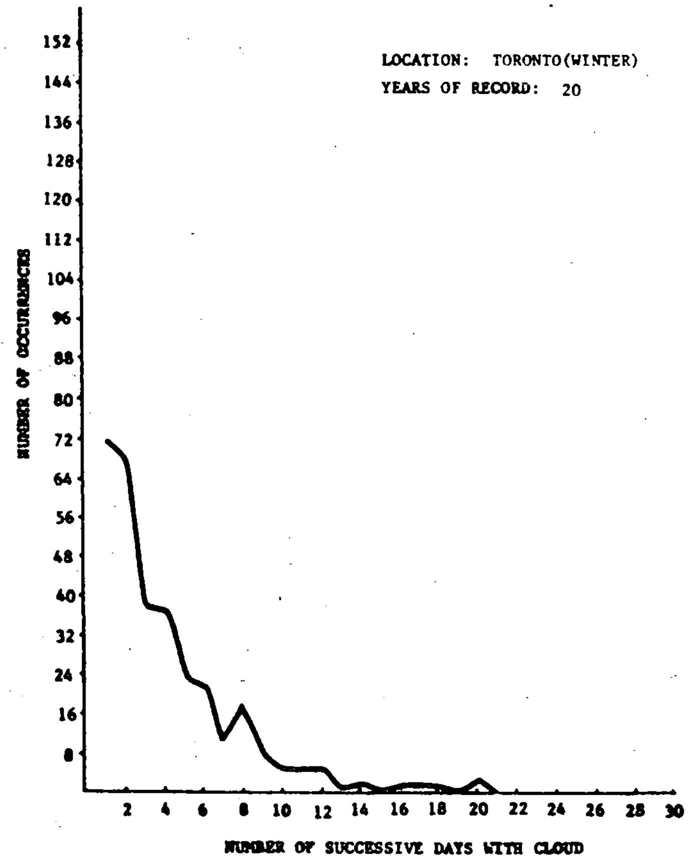
The analysis of cloudiness at these four locations has shown that cloudy periods can be longer in Timmins than at the other locations. Toronto has the fewest average number of cloudy days (50) in the summer and Kenora has the fewest average number of cloudy days (53.6) in the winter. Timmins has the greatest average number of cloudy days (70) in the summer and Toronto has the greatest average number of cloudy days (68) in the winter. Furthermore, the occurrence of single 'cloudy' days occurs most frequently during the summer. Although Toronto shows that prolonged cloudy intervals are much more likely to occur in the winter that in the summer, this trend was not evident in the graphs for the other three locations.

4.4.4. The Probability that a Cloudy Day will be Followed by Four or More Cloudy Days

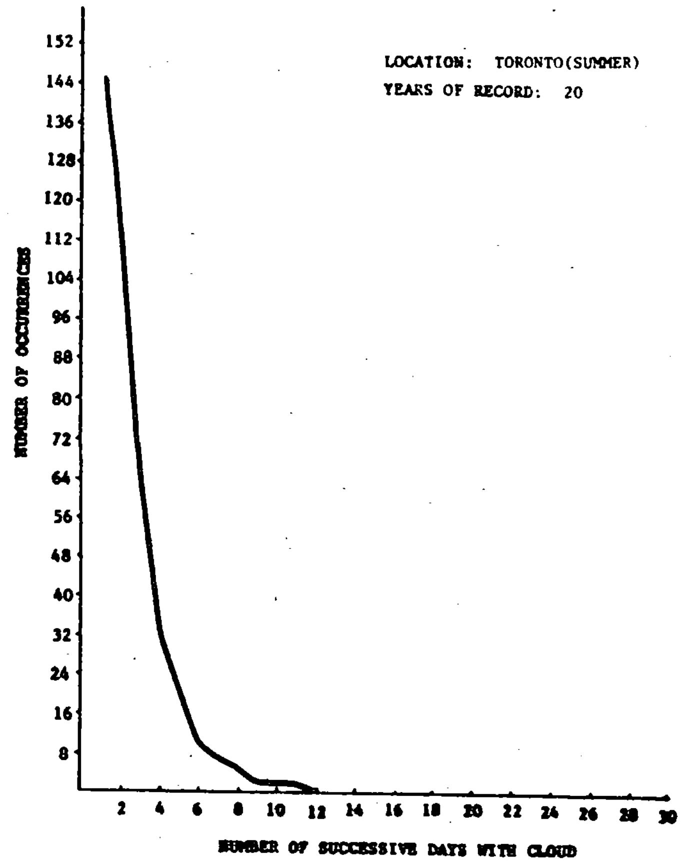
A period of 5 or more cloudy days during the winter would strain the capability of a solar heating system with only a short-term storage system. In order to assess the probability that prolonged cloudy intervals would occur, Figure 12 was prepared. The graph is based on an analysis of cloud data for 20 years of record (1953-1972) for 10 locations.

This figure shows the probability that a cloudy day will be followed by 4 or more cloudy days.

In Southern Ontario the probability that a cloudy day will be followed by 4 or more cloudy days ranges from .35 in London to .15 in Ottawa. In general the probabilities decrease east of Lake Huron. The cloud cover would be expected to be a maximum in southwestern Ontario because the Great Lakes act as a moisture source during the early and mid-winter.



(A)



(B)

FIGURE 9. Graphs showing the frequency of successively cloudy days at Toronto during (A) winter and (B) summer.

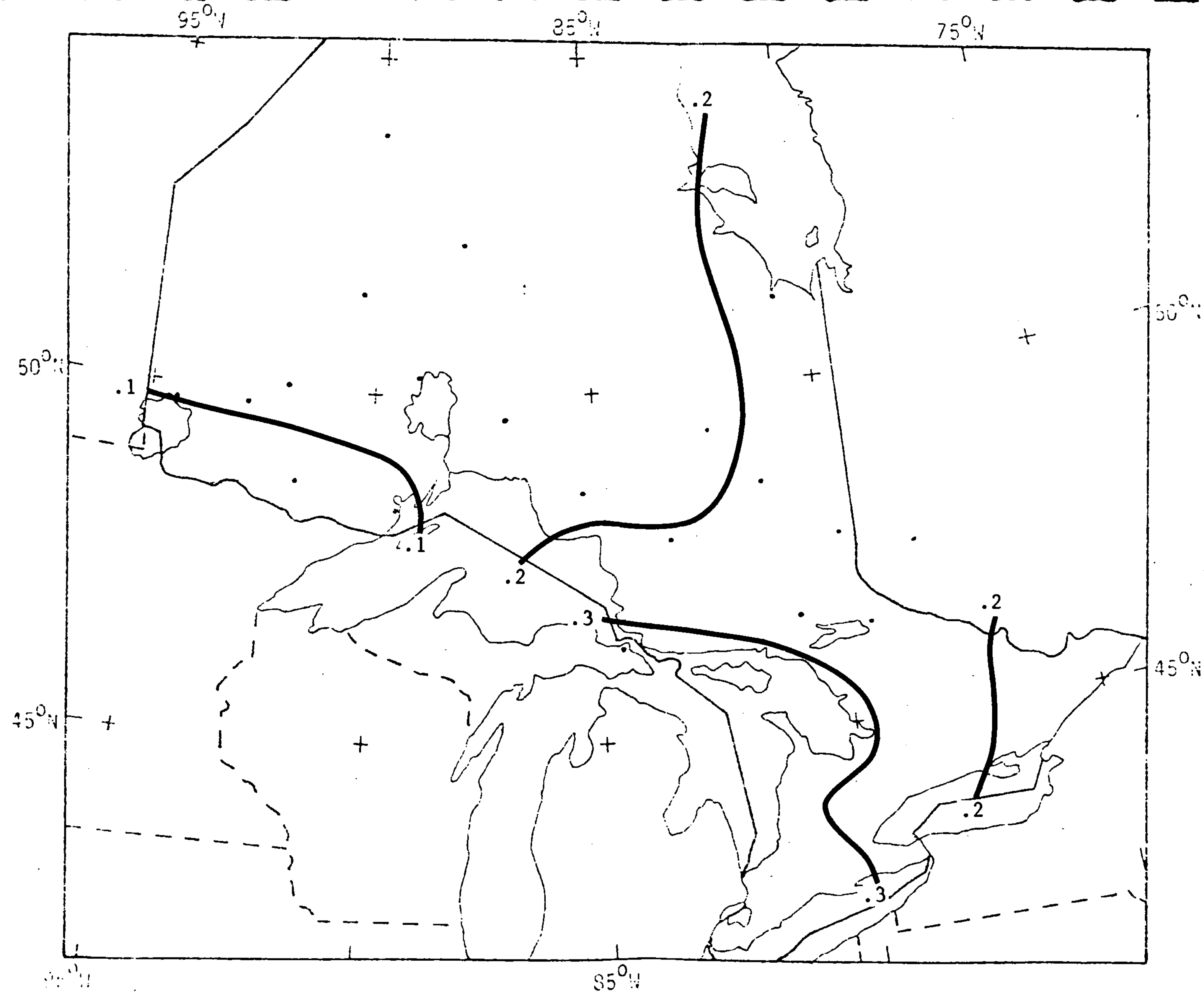


FIGURE 10. The probability that a cloudy day will be followed by 4 or more cloudy days during the winter.

In northwestern Ontario, the probabilities decrease to the west. For example, the probability of a 'cloudy' day being followed by 4 more 'cloudy' days is .3 at Sault Sainte Marie and only .1 at Thunder Bay. In southwestern Ontario, there is a greater probability that a cloudy day will be followed by 4 or more cloudy days near the Great Lakes.

From the results of this analysis of cloud alone, one may infer that there is a greater requirement in the area of the Great Lakes for storage systems that will conserve heat for periods longer than 5 days, than there is in northern and eastern Ontario. However, other factors, such as the frequency of prolonged cold spells, would have to be accounted for before this inference could be used as a basis for design of storage systems.

5. COMPARISONS BETWEEN THE AMOUNTS OF AVAILABLE SOLAR ENERGY AND HEATING REQUIREMENTS IN ONTARIO

5.1 SOLAR ENERGY AVAILABLE

In order to assess the solar energy available for heating a home at a particular location it is necessary to have some knowledge of the characteristics of the collector. The assumptions made in this particular chapter are based on information presented by Hay (1976) and Speyer (1959). According to Sasaki a house area of $135m^2$ requires a collector of $65m^2$ (1/2 the area of the house). This collector size was assumed for the calculations in this chapter. Futhermore, the efficiency of the collector was assumed to be 30%. It was also assumed that a storage system would carry over 80% of its heat storage from one month to the next.

5.2 DISCUSSION OF AVERAGE VALUES AND FLUCTUATIONS

Figures 11 to 14 are graphs showing the heat available with a $65m^2$ collector at 30% efficiency at four Ontario locations. The graphs show the month-by-month variations in the average hourly energy available (calculated from average radiation values per month), minimum monthly values of hourly energy available (using minimum radiation values each month over the total period of record) and maximum monthly values of hourly energy available (using maximum radiation values each month over the total period of record).

The percentage variations in the radiation values were found by using the following formula:

$$\% \text{ Variation} = \frac{M - m}{a} \times 100$$

where: M - maximum value of radiation
m - minimum value of radiation
a - average value of radiation

Substituting monthly values of radiation for Toronto into the above equation shows that the minimum variation in radiation in Toronto occurs in August (25%) and the maximum variation occurs in December (66%). The curves for the other three stations shown in Figures 12, 13 and 14 with the maximum percentage year-to-year variations occurring in the winter and minimum variations being observed in the summer.

The year-to-year percentage variations in the monthly amounts of solar energy are greater during the winter than during the summer for all locations where radiation data are available.

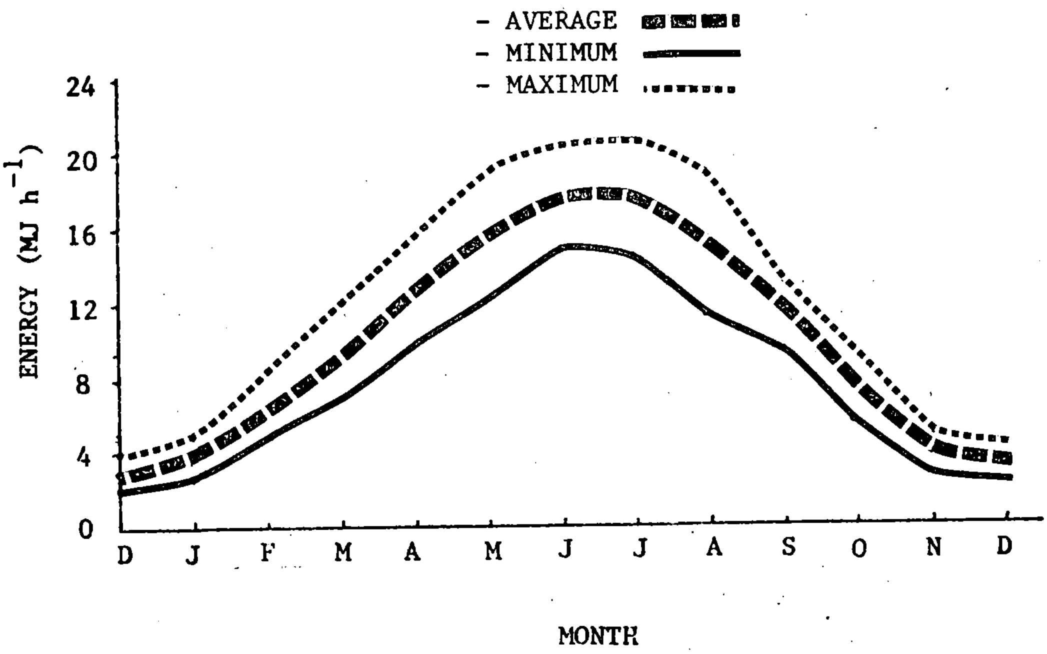


FIGURE 11: The energy available from a 65m^2 collector located in Toronto (assuming a collector efficiency of 30%).

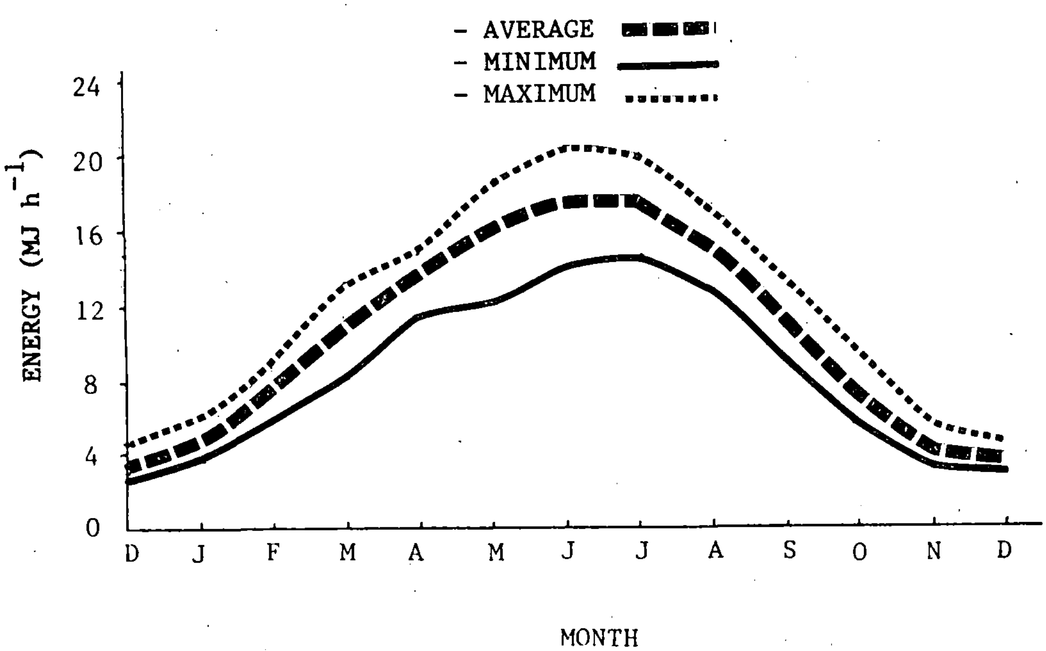


FIGURE 12. The energy available from a 65m^2 collector located in Ottawa (assuming a collector efficiency of 30%).

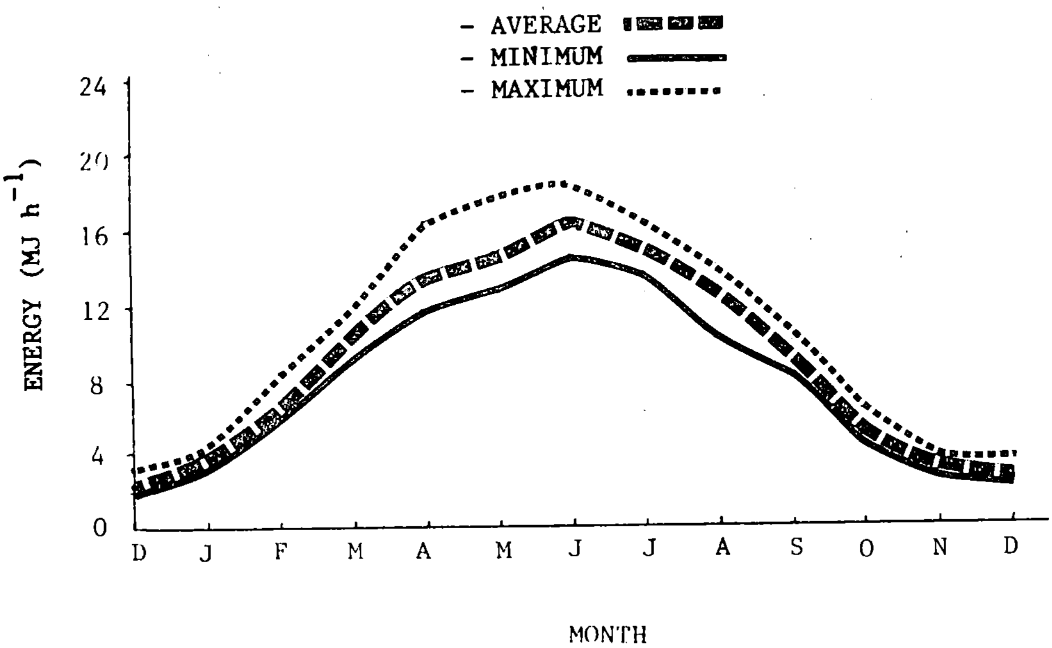


FIGURE 13: The energy available from a 65m^2 collector located in Moosonee (assuming a collector efficiency of 30%).

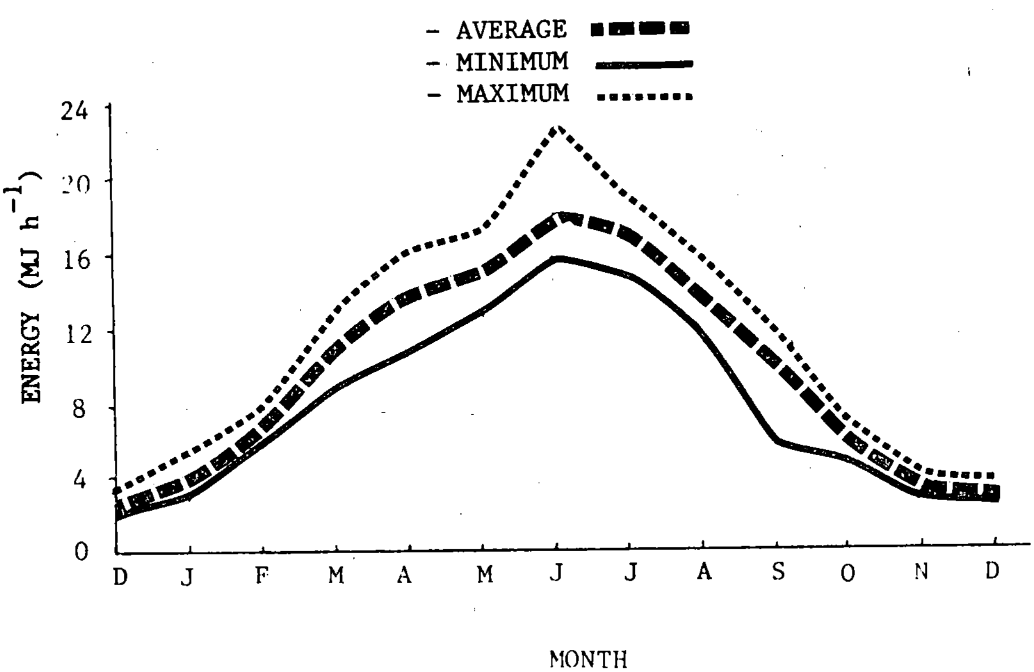


FIGURE 14. The energy available from a 65m^2 collector located in Kapuskasing (assuming a collector efficiency of 30%).

A comparison between these 4 locations indicates that during a hypothetical year with minimum observed monthly values of radiation, the peak monthly energy is largest in June at Kapuskasing (15.6 MJh^{-1}) and smallest in June at Moosonee (14.6 MJh^{-1}). Again, there is very little variation between the 4 locations in the summer values of radiation associated with the curves of minimum monthly radiation.

5.3. COMPARISONS BETWEEN SUPPLY AND DEMAND

5.3.1. Capability of the Energy Supply to cope with the Energy Demand.

In this section, the values of demand computed in Chapter 2 are compared to the values of available solar energy in order to estimate the capability of solar energy to meet heating demands. The amount of solar energy available from systems with no heat storage, with 80% heat storage and with 100% heat storage are all considered. In the case of 80% heat storage, the amount of energy in storage at the end of a given month has been calculated by the following formula:

$$E_{st}(P) = E_{st}(P-1) \times .8 + E_{su}$$

where: $E_{st}(P)$ - amount of energy in storage at the end of the present month.

$E_{st}(P-1)$ - the amount of energy in storage at the end of the last month.

E_{su} - the amount of solar energy available the present month.

For example, energy stored in a system at Guelph at the end of June = $(8.9 \times .8) + 18.1$ = 25.2 MJh^{-1}

5.3.2. Assessment of Capabilities of Solar Heating for Toronto.

Figures 15, 16 and 17 show the seasonal variations of the heating requirements (MJh^{-1}), the energy available with a 65m^2 collector operating at 30% efficiency (MJh^{-1}), the energy consumed from a system with 30% efficient collector and 80% storage from month to month (MJh^{-1}) and the total energy available from the system (MJh^{-1}). These graphs are drawn assuming space heating and total heating requirements (using average radiation available) and space heating requirements using minimum monthly radiation values.

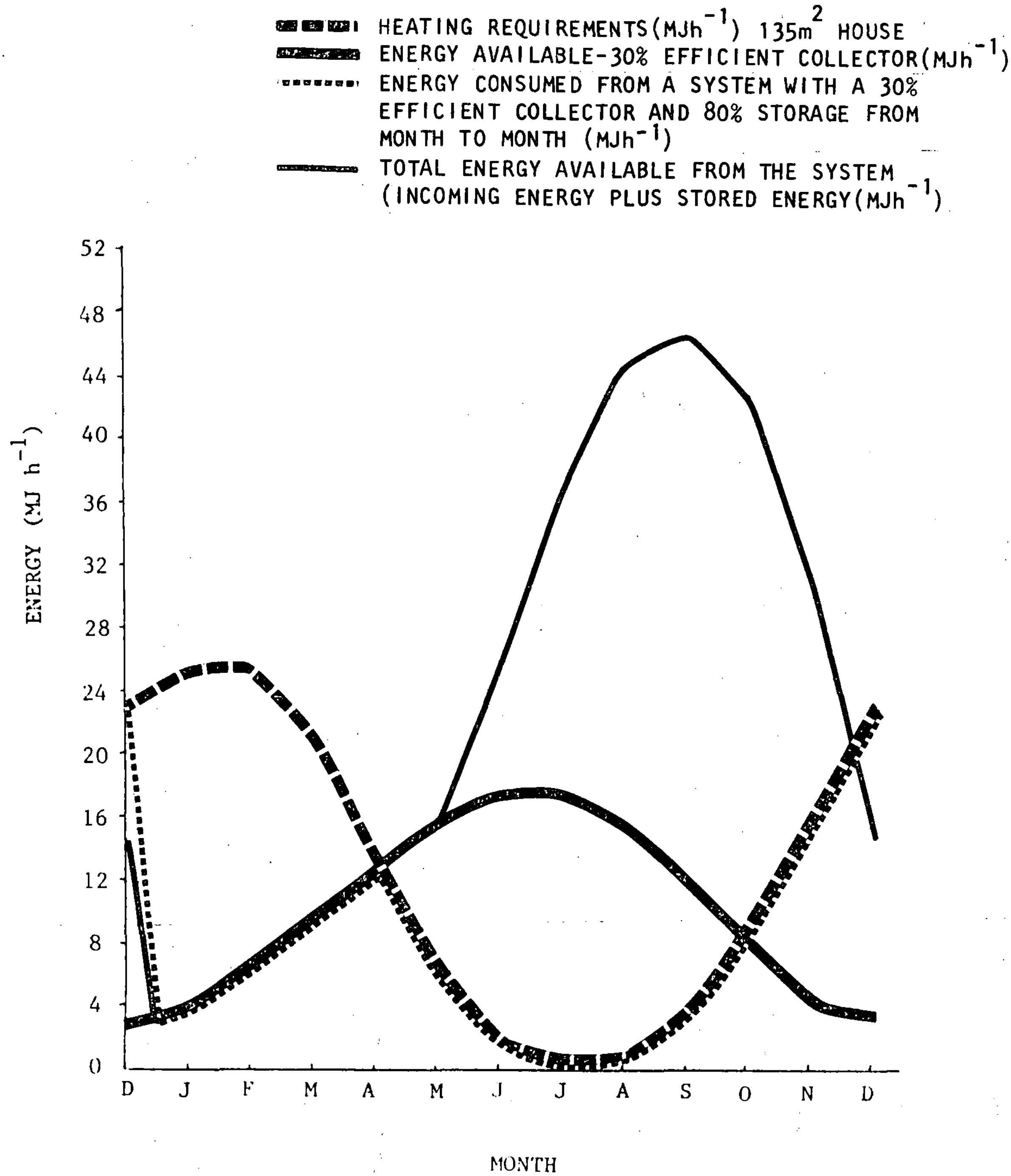


FIGURE 15. Graph showing the seasonal variations in space heating requirements and the energy available from the sun and from an 80% efficient storage system for a year of average heating requirements and average monthly values of radiation at Toronto.

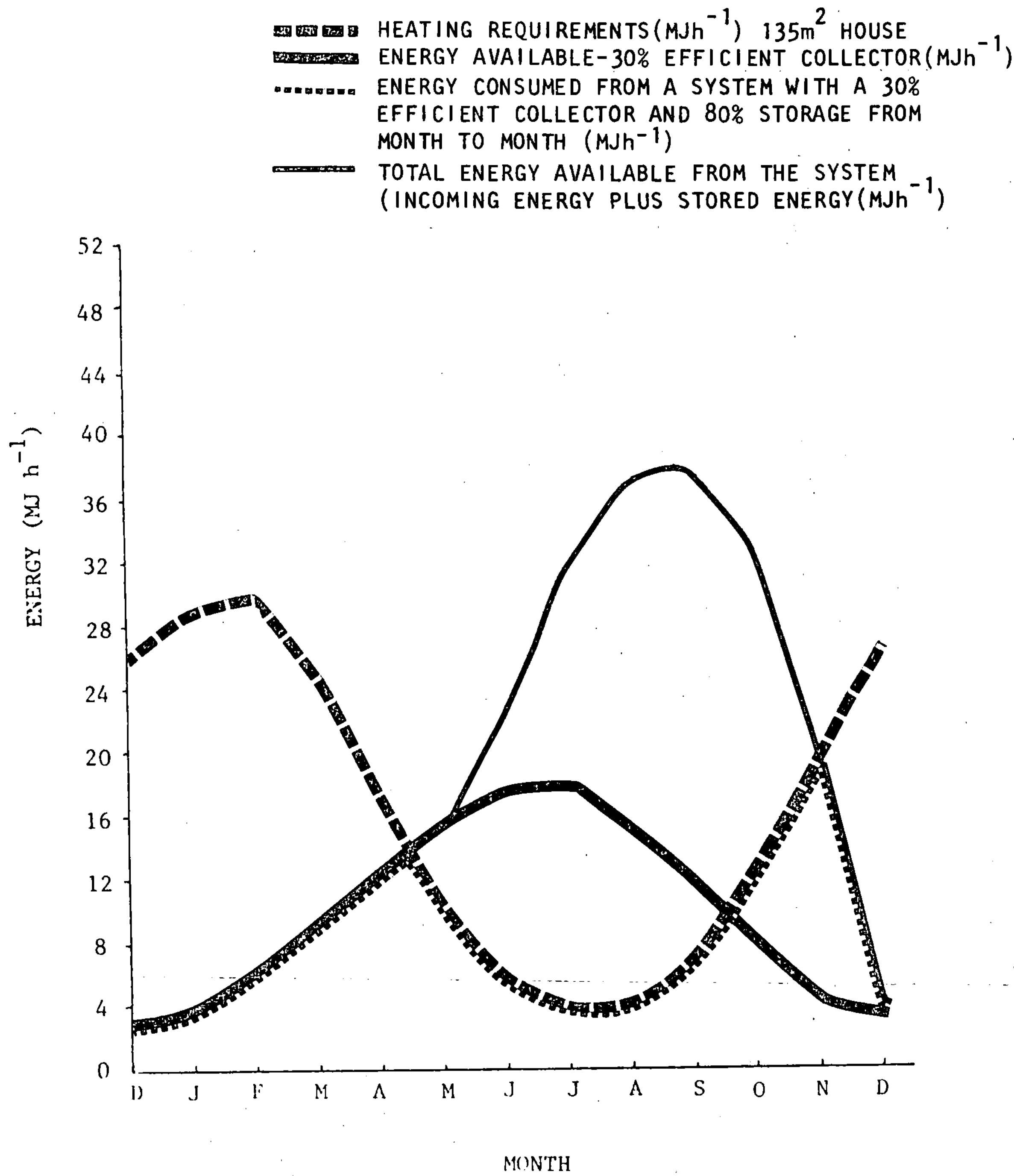


FIGURE 16. Graph showing the seasonal variations in total heating requirements and the energy available from the sun and from an 80%-efficient storage system for a year of average radiation values at Toronto.

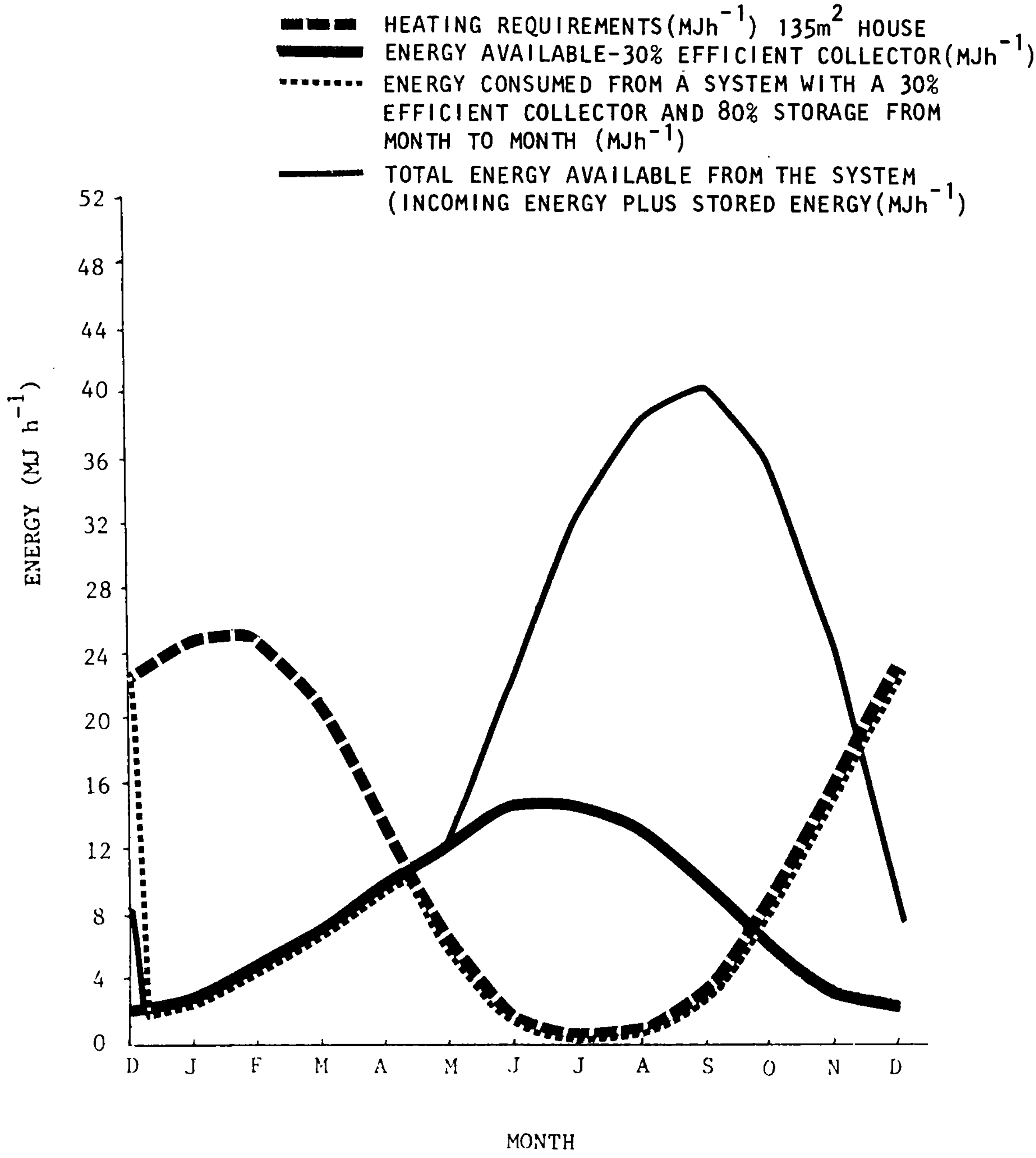


FIGURE 17. Graph showing the seasonal variations in total heating requirements and the energy available from the sun and from an 80%-efficient storage system for a year of minimum radiation in Toronto.

Figure 15 shows the month-by-month variations in heating assuming only space heating requirements and average radiation available. According to Figure 15, all the heating requirements are met by the incoming solar energy and storage with 80% efficiency from the beginning of April to the middle of December.

If one considers the entire year, 57% of the total heating requirements are met with 80% efficient storage. however with 100% efficient storage, 86% of the heating requirements are taken care of. On the other hand, if there was no storage in the system only 40% of the heating requirements would be taken care of by the available solar energy. As would be expected, conventional methods of heating would have to be relied on when the energy in storage runs out.

Figure 16 shows the total heating requirements met by the average amounts of solar energy for Toronto. From the middle of April to the end of November all the heating requirements are met by solar energy combined with the energy available from the 80% efficient storage system. With 100% storage, 66% of the annual heating requirements would be met; with 80% efficient storage, 51% of the annual heating requirements would be met, and with no storage only 40% of the requirements would be met with solar energy.

Figure 17 shows the space heating requirements met by the minimum monthly amounts of solar energy for Toronto. From the beginning of April to the beginning of December all heating requirements are met by solar energy combined with a storage system of 80% efficiency. Figure 17 also shows that the peak demand occurs in February. It is evident that the peak demand (25.5 MJh^{-1}) is greater than the peak value of incoming radiation (15.0 MJh^{-1}). The maximum amount of energy is in storage in September. At that time 40.5 MJh^{-1} can be extracted from storage. This energy is entirely depleted before the peak demand occurs in February. When 100% efficient storage is used, 69% of the heating requirements are met; with 80% efficient storage, 47% of the requirements are met, and with no storage 32% of the heating demands are met.

5.3.3. <u>Assessment of Capabilities of Solar Heating at other Ontario Locations</u>.

Analyses, similar to those in Section 5.3.2., were carried out for the space heating requirements for a year of average radiation values. Figures 18 and 19 show the results for Moosonee and Elora respectively.

According to Figure 18, heating requirements in Moosonee are completely satisfied from May to November by solar energy and a storage system with 80% efficiency. The peak heating requirement is 44.8 MJh^{-1} and occurs in January, the peak insolation period is June (16.4 MJh^{-1}) and the

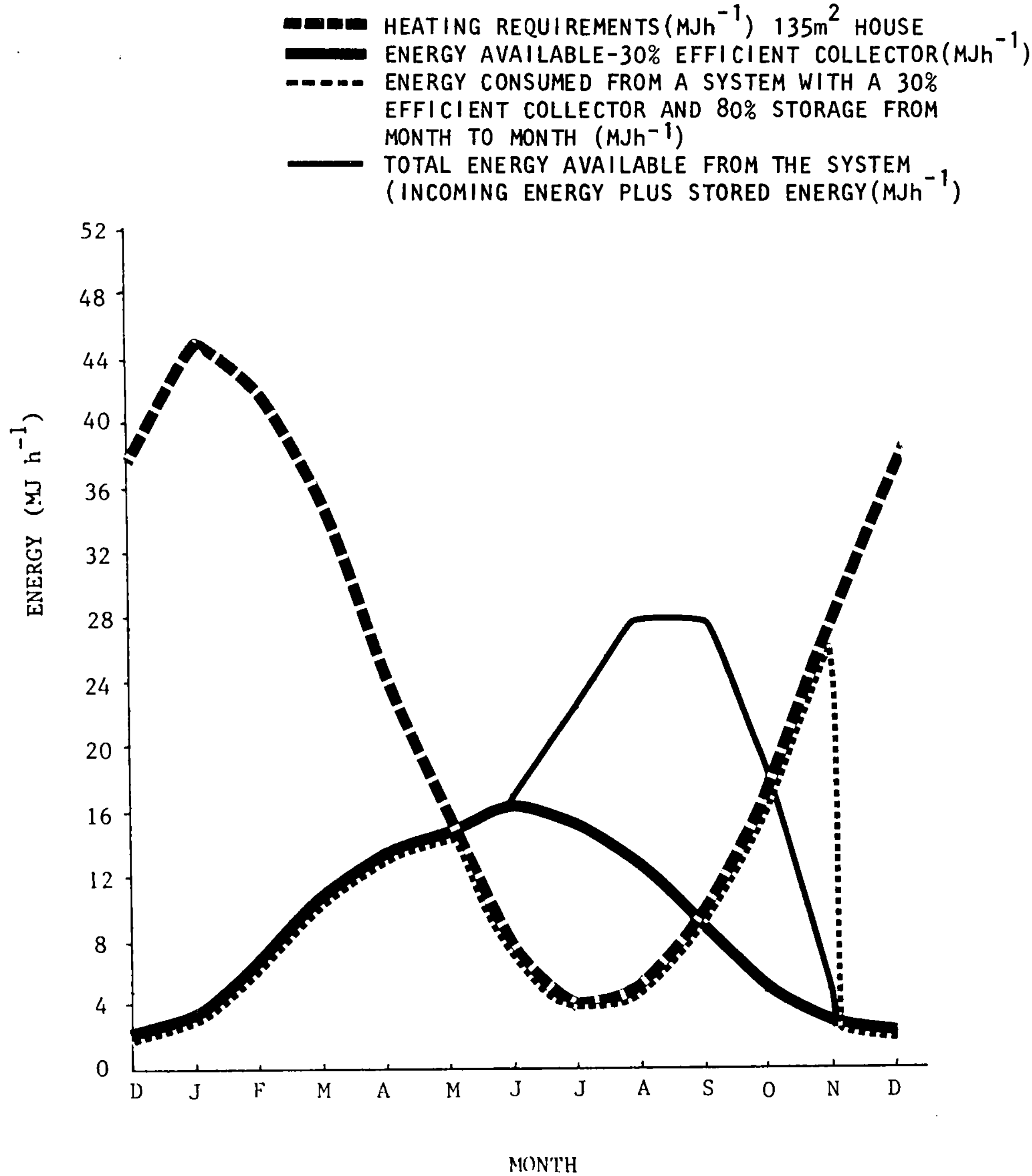


FIGURE 18. Graph showing the seasonal variations in space heating requirements and the energy available from the sun and from an 80%-efficient storage system for a year of average heating requirements and average monthly values of radiation at Moosonee.

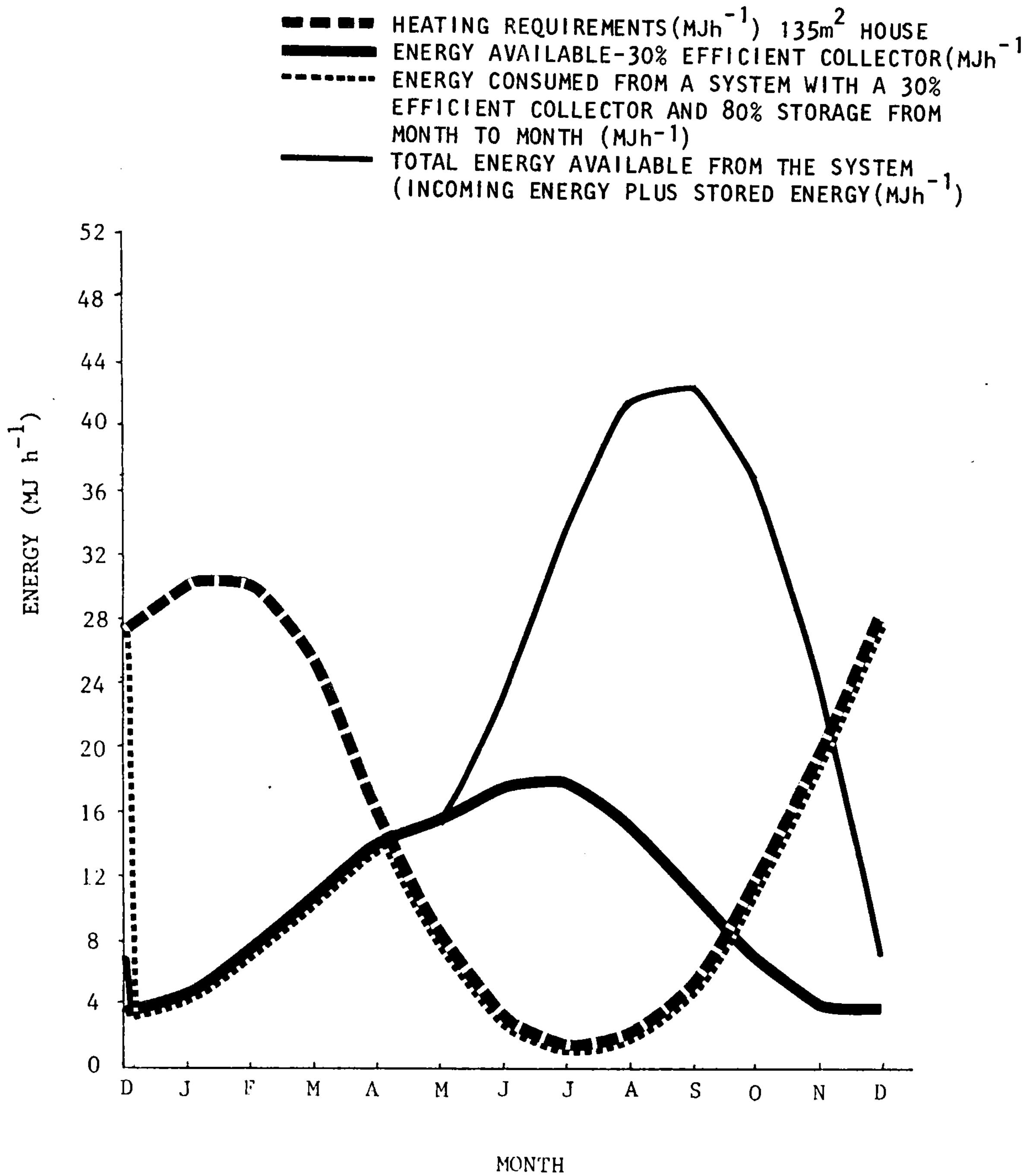


FIGURE 19. Graph showing the seasonal variations in space heating requirements and the energy available from the sun and from an 80%-efficient storage system for a year of average heating requirements and average monthly values of radiation at Elora.

maximum amount that can be extracted from storage is 42.2 MJh^{-1} in September.

Appendix C shows similar graphs for space heating requirements at Guelph, Ottawa, Trout Lake and Kapuskasing.

5.4. THE PROPORTION OF ANNUAL HEATING DEMANDS MET BY SOLAR RADIATION

5.4.1. The Percentage of Heating Demand met with no Storage During the Average Year.

Table 4 shows the percentage of heating demand met: with no storage during the average year, with no storage during the year of minimum radiation, with 100% efficient storage during the year of minimum radiation, with the year of coldest months, with 100% efficient storage during the year of minimum radiation, for both space and total heating.

The year of minimum radiation for a particular location is defined as being a year with minimum observed monthly values taken over the period of record. Similarly, the average year is defined as being a year with the average monthly values taken over the period of record for a particular location.

There is very little difference in the percentage of space and total heating demands met by a solar heating system without storage. For example, without storage 31% of the space heating requirements and 32% of the total heating requirements are met with solar radiation at Kapuskasing. Similarily, Trout Lake has values of 29% and 28% of the heating requirements met for space and total heating respectively for solar heating without storage. This small difference in heating demand met is due to the fact that the amount of solar energy used during the winter is the same for both space and total heating systems. The percentage of the demand met in Toronto is smaller for total heating (7.0%) than it is for space heating (9.1%) in the winter. On the other hand, 100% of the space and total heating demands are met by solar energy in the summer. However, the summer requirements account for 6.8% of the annual space heating requirements. Consequently, the percentage contribution of solar radiation to both space and total heating requirements are approximately the same.

When 100% efficient storage is included, there is a greater increase in the percentage of heating requirements met by solar energy in the southern part of the province than in the northern part. For example, in Kapuskasing the percentage of heating requirements met rise from 31% to 48% and from 32% to 41% for space and total heating respectively. In Toronto, the percentage of heating requirements met rise from 40% to 86% and from 40% to 66% for space and total heating respectively.

TABLE 4

THE PERCENTAGE OF HEAT DEMANDS MET BY SOLAR ENERGY

Stations	The % of Heating Demand Met With No Storage and the Average Year		The % of Heating Demand Met With 100% Efficient Storage and the Average Year		The % of Heating Demand Met With No Storage and a Year of Minimum Radiation		The % of Heating Demand Met With 100% Efficient Storage and a Year of Minimum Radiation		The % of Heating Demand Met During the Year of Coldest Months with 100% Efficient Storage and a Year of Minimum Radiation	
	Space	Total	Space	Total	Space	Total	Space	Total	Space	Total
Kapuskasing A.	31.3	31.5	48.4	40.9	26.3	26.3	39.8	33.7	32.3	28.2
Elora	38.8	39.3	70.9	56.8	34.4	35.8	60.7	48.6	45.7	38.4
Guelph	41.1	41.2	80.6	63.4	34.2	35.8	64.3	50.5	47.3	39.4
Toronto	40.0	40.4	85.9	65.7	32.1	34.2	68.9	52.8	44.3	36.9
Ottawa CDA.	36.4	37.3	70.2	56.5	30.5	32.5	56.2	45.3	42.0	32.5
Moosonee	31.1	30.2	41.8	35.8	27.6	27.2	36.1	30.9	28.8	25.5
Trout Lake	28.9	28.3	38.2	33.2	26.8	26.6	34.7	30.1	28.3	25.0

Table 4 also shows the percentages of the demand met for a year with minimum monthly radiation values. The values indicate that during a year of minimum radiation approximately 27% of the space heating demand would be met in northern Ontario and approximately 33% of the demand would be met in southwestern Ontario. The addition of a 100% efficient storage system would increase these percentages to 36% in northern Ontario and 64% in southwestern Ontario.

5.4.2. The Percentage of Demand met during a Year of Coldest Months and a Year of Minimum Radiation.

The greatest test of the capabilities of a solar energy heating system comes during a year when heating requirements are a maximum and the incoming solar radiation is a minimum. Under these conditions we find that between 28.3 and 47.3% of the space heating requirements and 25.0 and 39.4% of the total heating requirements would be met by a system with 100% efficient storage. As would be expected from earlier results, the percentage of the requirements met by solar energy are smaller in the north than in the south.

The difference between the percentage of heating demand met in the average year and the year of coldest months is larger in the southern part of the province than in the northern part of the province. For example, in Trout Lake values decrease from 38.2 to 28.3% and from 33.2 to 25.0% for space and total heating values respectively. In Toronto the percentage of heating demand met decreases from 85.9 to 68.9% and from 65.7 to 36.9% respectively for space and total heating.

6. SUMMARY

The largest potential application for solar energy involves heating houses and other buildings by means of collectors mounted on the roofs of these buildings. In designing solar heating systems of this type it is necessary to consider at least three meteorological variables. First, one must assess the heating requirements by analyzing the number of heating degree days that accumulate during the heating season. Then, one must determine the availability of solar energy at a particular site. Finally, the effects of cloud on storage requirements must be evaluated.

The temporal and spatial distributions of heating requirements, solar energy and cloud cover are documented in Chapters 3 and 4. The information in Chapter 3 indicates that the mean hourly space heating requirements are largest during January and February. During those months the requirements for a 135 m^2 home range from approximately 25 MJh^{-1} in southwestern Ontario to values in excess of 45 MJh^{-1} in northern Ontario. The mean hourly values of incoming solar radiation can exceed 1.0 MJ m^{-2} h^{-1} during the months of June and July although the values average 0.9 MJ m^{-2} h^{-1} at most Ontario locations. During December, the month of minimum radiation, the hourly average global radiation can be as small as .1 MJ $m^{-2}h^{-1}$. The frequency of successively cloudy days is largest in southwestern Ontario and smallest in western Ontario.

In Chapter 5 the potential solar energy heating system was assessed for a number of Ontario locations. It was assumed that area of the collector was one-half the area of the house. Futhermore, the collector efficiency was assumed to be 30% and the efficiency of the heat storage system was assumed to be 80%. The results in Chapter 5 show that, given a system of this type, supplementary heating will be required at all Ontario locations. However, solar energy could cover a greater percentage of the heating needs if the collector size and efficiency were increased and the efficiency of the heat storage system was improved.

7. ACKNOWLEDGEMENTS

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APPENDIX A

Maps showing the spatial distributions
of seasonal and annual heating requirements

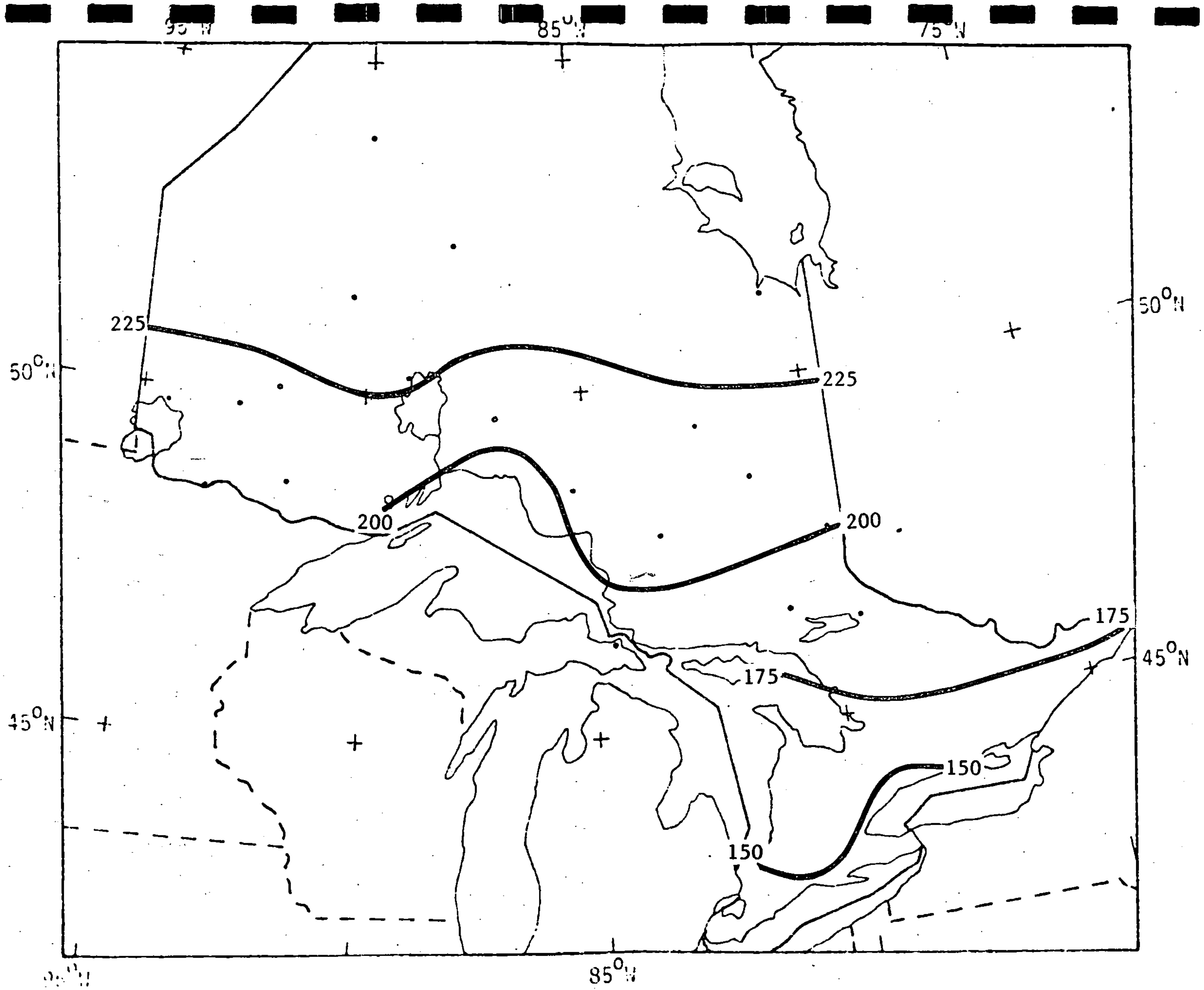


FIGURE A.1. The Hourly Requirement (MJh^{-1}) for Total Heating for the Heating Season (assuming a $135m^2$ house).

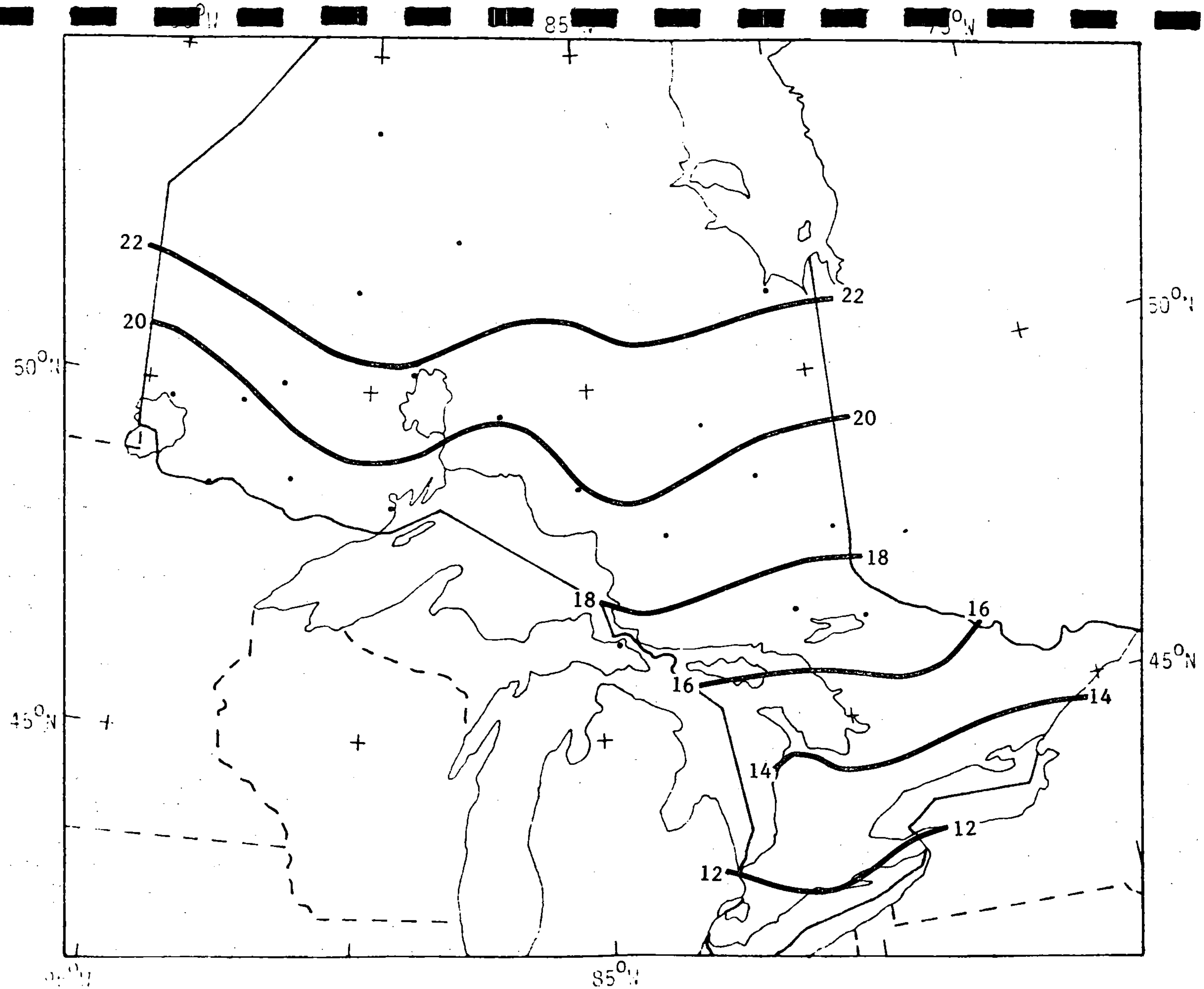
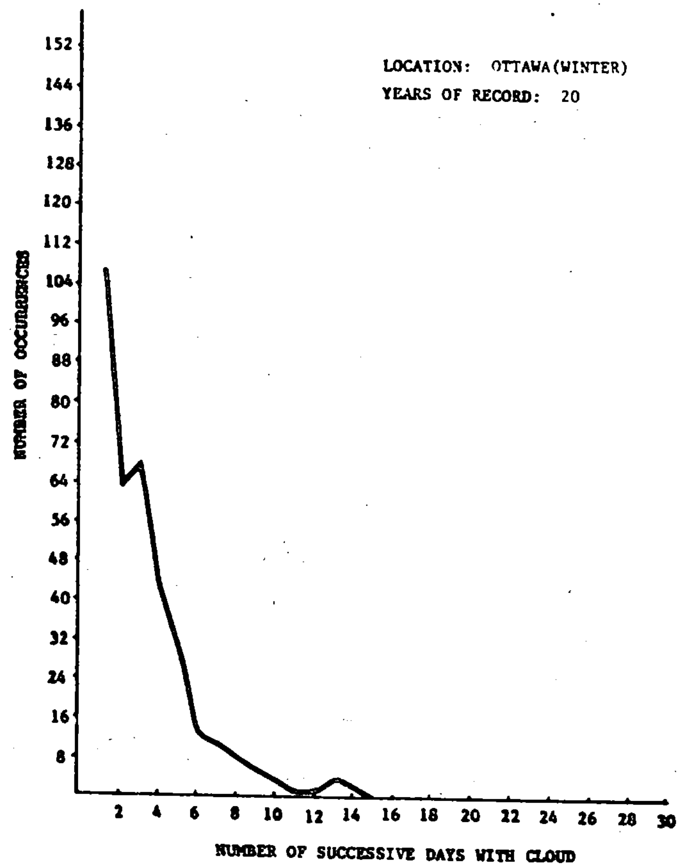


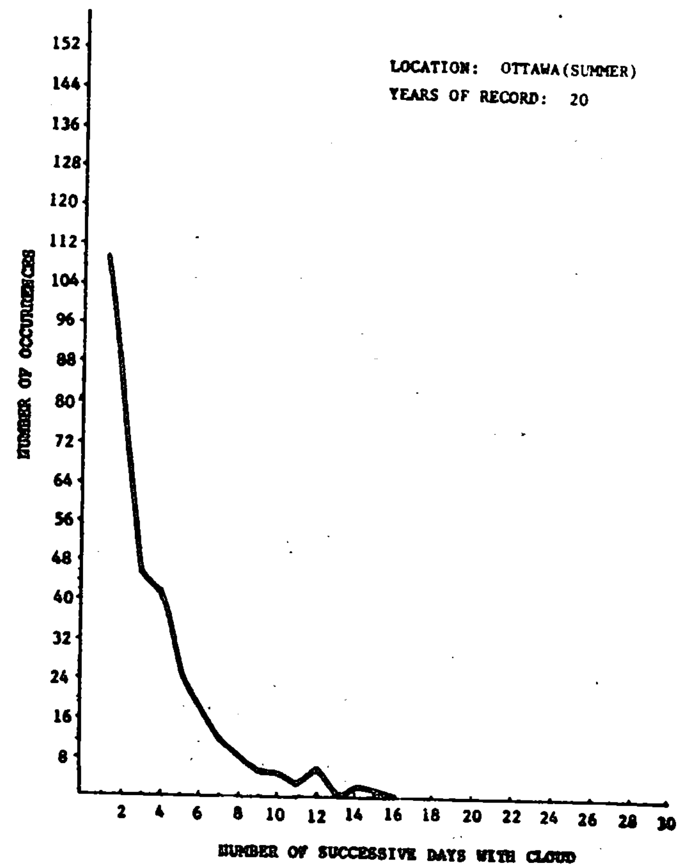
FIGURE A.2. Average Annual Hourly Requirement for Space Heating a 135m^2 House (MJh^{-1})

APPENDIX B

Graphs showing the frequency
of successively cloudy days at:
Ottawa
Kenora

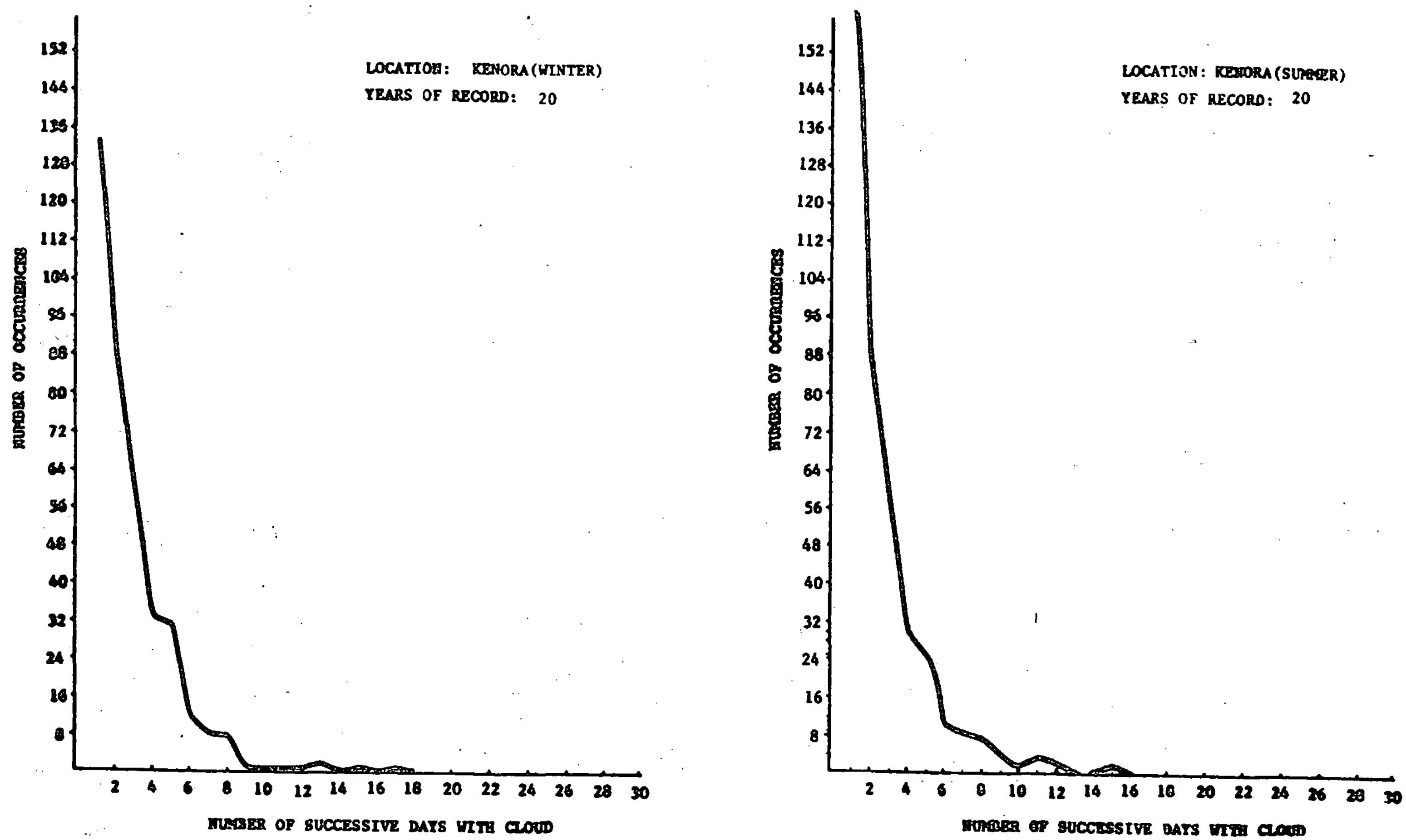


(A)



(B)

FIGURE B.1. Graphs showing the frequency of successively cloudy days at Ottawa during (A) winter and (B) summer.



(A) (B)

FIGURE B.2. Graphs showing the frequency of successively cloudy days at Kenora during (A) winter and (B) summer.

APPENDIX C

Graphs Showing Space Heating Requirements
and Energy Available for:
Kapuskasing
Ottawa
Trout Lake
Guelph

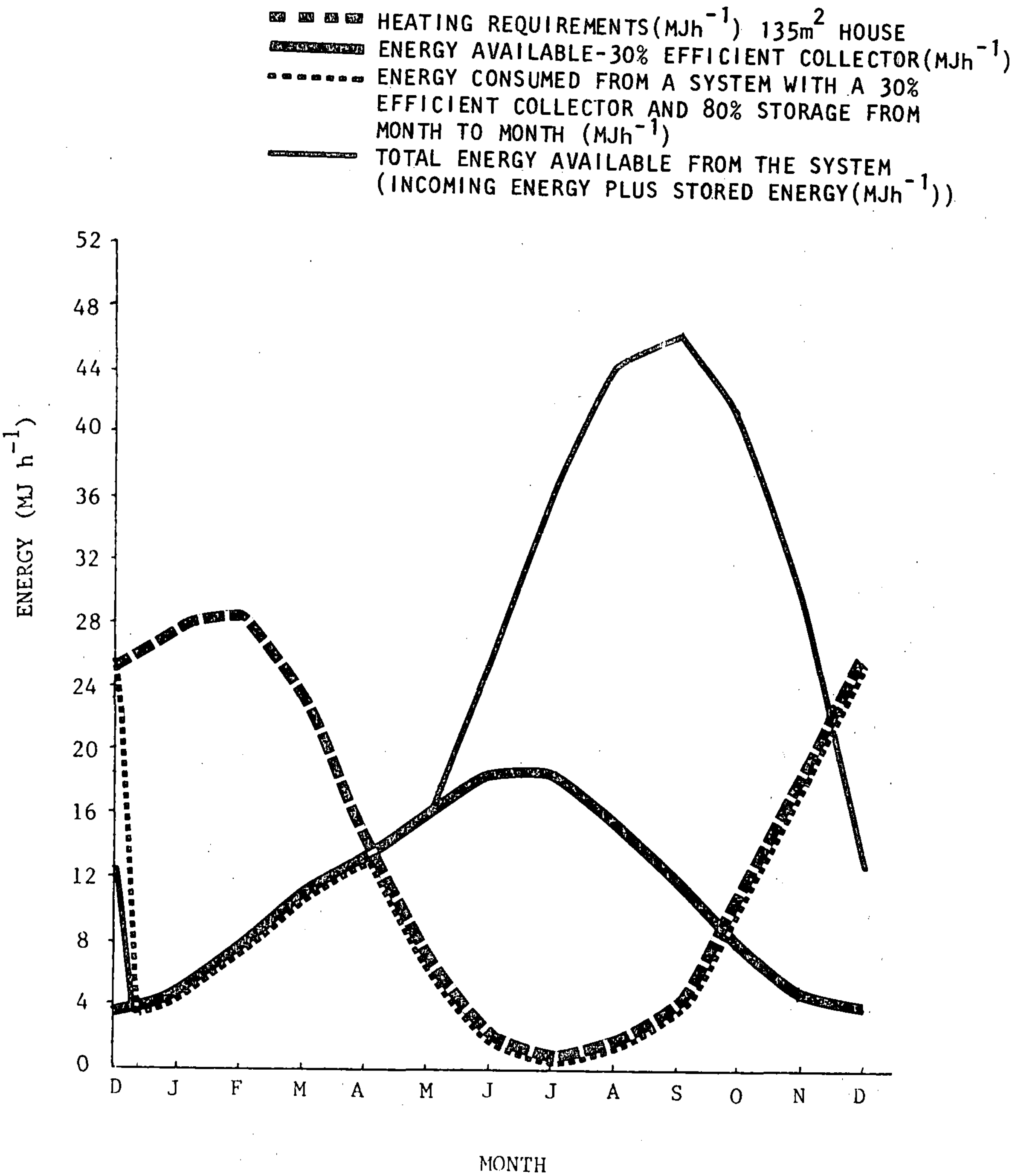


FIGURE C.1. Graph showing the seasonal variations in space heating requirements and the energy available from the sun and from an 80%-efficient storage system for a year of average heating requirements and average monthly values of radiation at Guelph.

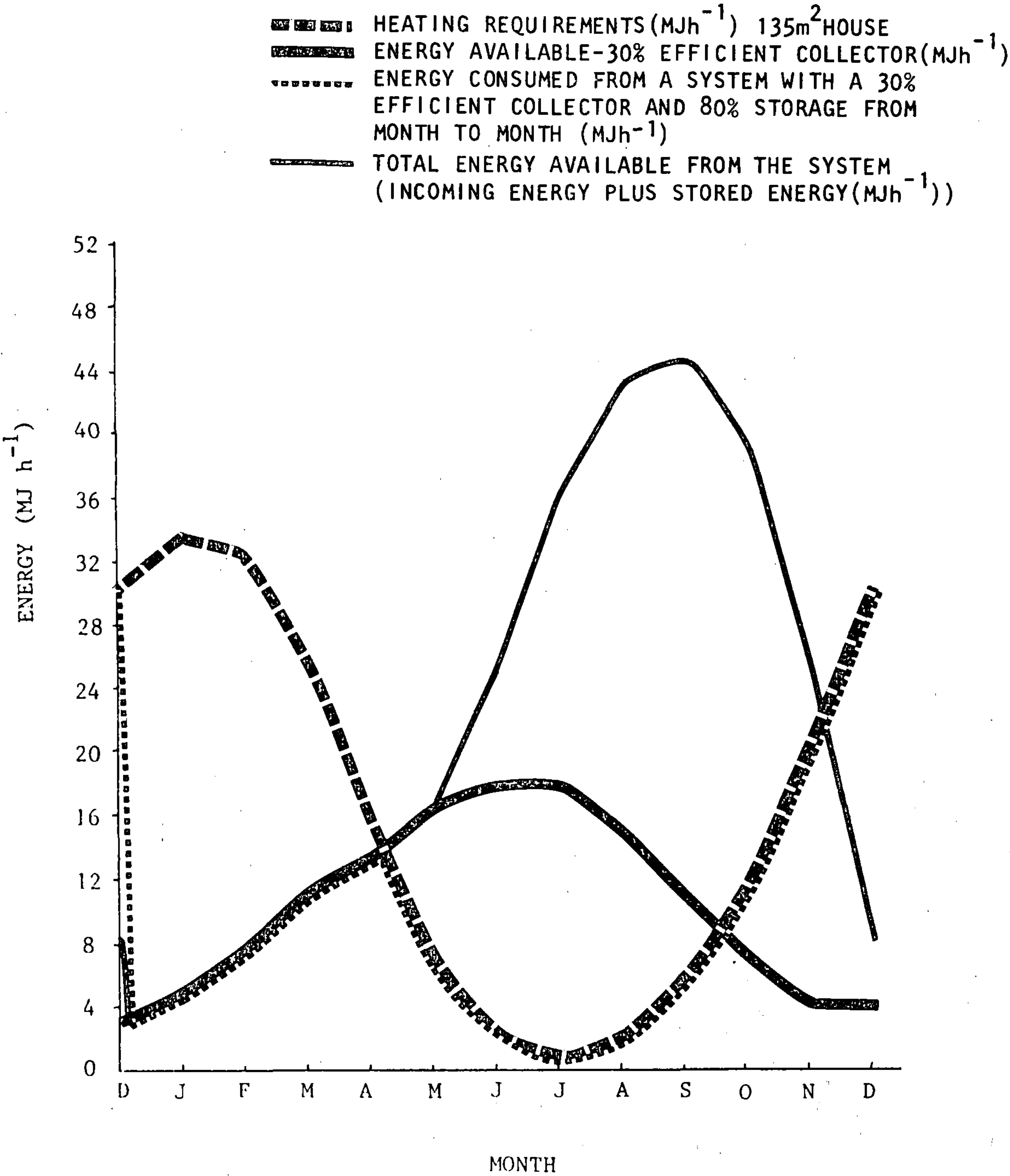


FIGURE C.2. Graph showing the seasonal variations in space heating requirements and the energy available from the sun and from an 80%-efficient storage system for a year of average heating requirements and average monthly values of radiation at Ottawa.

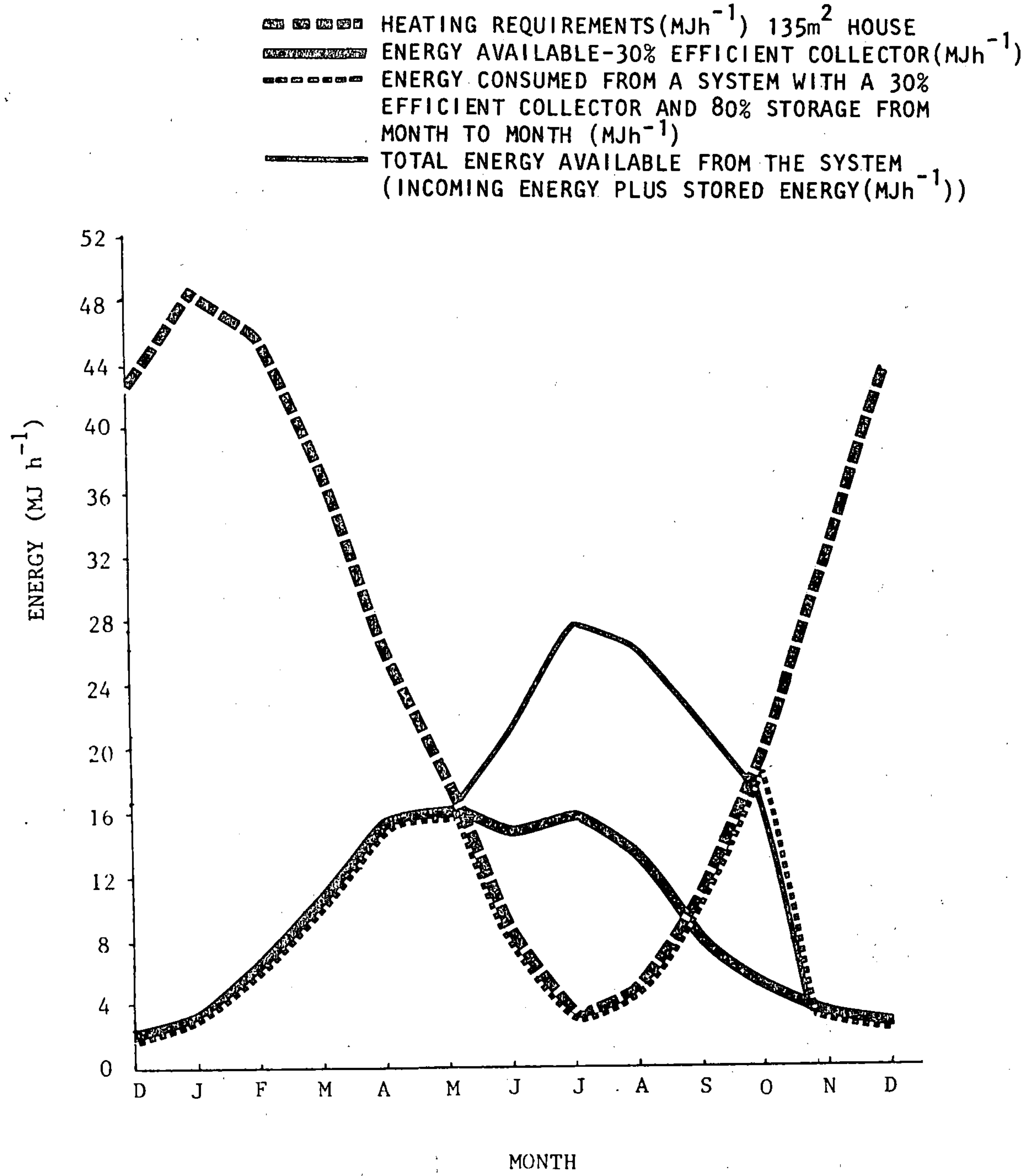


FIGURE C.3. Graph showing the seasonal variations in space heating requirements and the energy available from the sun and from an 80%-efficient storage system for a year of average heating requirements and average monthly values of radiation at Trout Lake.

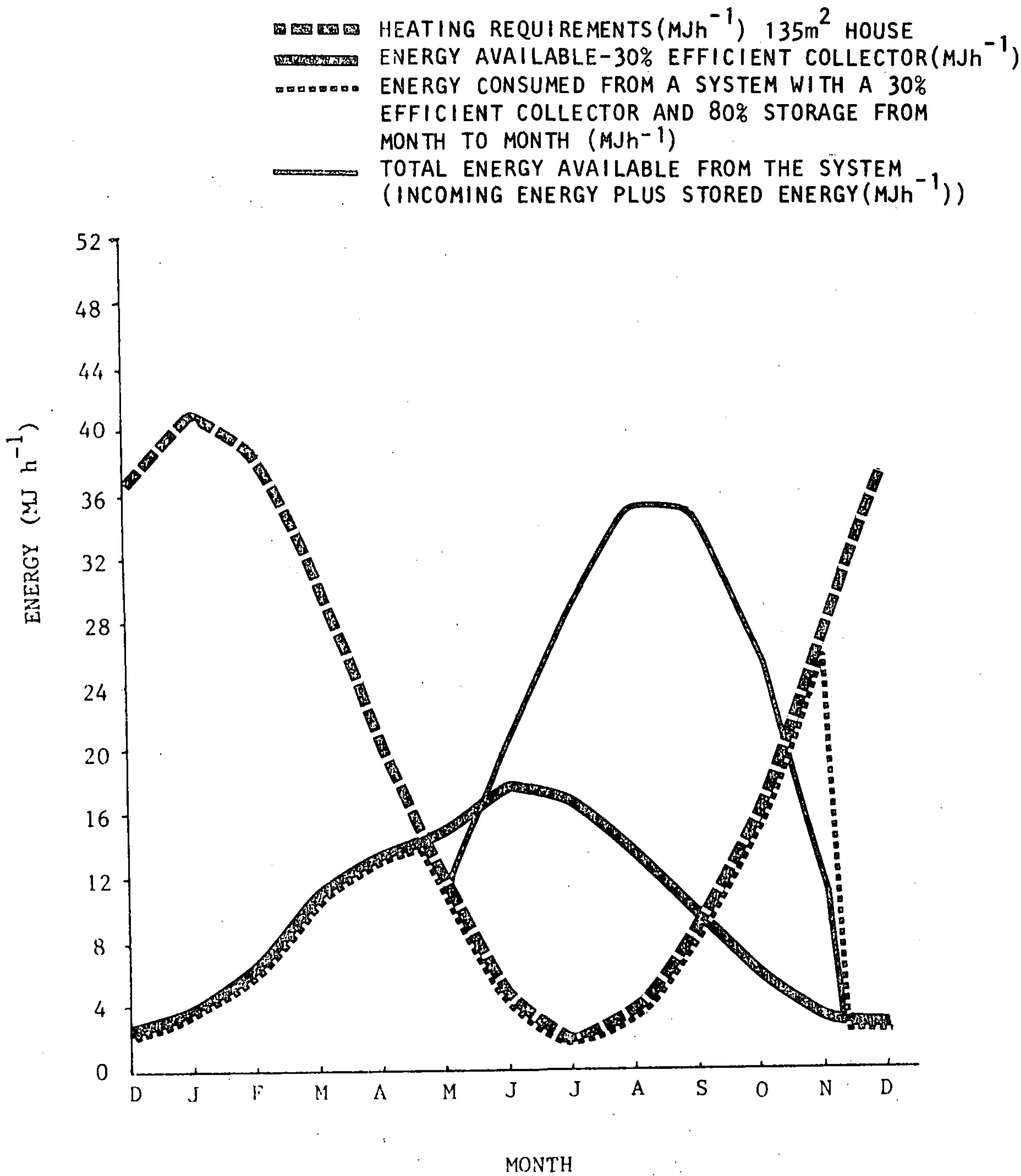


FIGURE C.4. Graph showing the seasonal variations in space heating requirements and the energy available from the sun and from an 80%-efficient storage system for a year of average heating requirements and average monthly values of radiation at Kapuskasing.