PROJECT REPORT NO. 17

EFFECT OF URBAN EXPANSION ON FUEL CONSUMPTION FOR SPACE HEATING

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ABSTRACT

The effect of the total annual increase of dwellings on fuel consumption for space heating per unit home per degree-day is studied. A discussion of the results and a description of the relationship between the two factors, will provide useful guidelines for energy saving on the urban scale.

INTRODUCTION.

Western Countries showed great concern over the energy crisis that resulted from the political clashes between the Arab countries and the Western World. Several measures were taken to save energy. The United Kingdom went on a three day work week. The United States reacted immediately to the situation and fuel rationing was contemplated. Limited driving and speed reduction were suggested to reduce energy waste. As far as space heating is concerned, a study completed in September 1973, by a special Task Group was done to determine the extent to which the national total demand for heating fuels in 1973/74 season would depend on the weather (1973). A national map of the U.S.A. displaying the percentage reduction in heating fuel by lowering the thermostat 5^{o}F was also prepared (figure Ia). Such contingency measures, an urgent reaction to the fuel shortage, may provide relief in the immediate future, but will neither give a solid understanding of the problem, nor lay basic guidelines for long term energy saving.

In an attempt to understand the problem an analysis of the fuel consumption per dwelling per degree-day for the cities of Calgary and Edmonton was done. It would have been desirable to perform the same analysis for several cities across the country to emphasize and confirm the results, however the difficulty in obtaining accurate consumption data and yearly increase in dwellings limited the study to the two cities.

Data acquisition.

Total natural gas consumption data for Calgary was obtained from Canadian Western Natural Gas Co., and the Edmonton data (which included industrial consumption) from Northwestern Utility Limited, total number of dwellings and population growth was taken from Statistics Canada publications, mean temperatures during the heating season, the heating degree-days, from the Annual Meteorological Summary published by the Atmospheric Environment

Service.

Sources of errors.

Since gas is the fuel used for heating in 98.5% of Calgary dwellings and 99.6% of Edmonton dwellings, neglecting other heating fuels such as oil, electricity, coal, coke, wood, is a minor source of error.

Total number of dwellings for Calgary was given by Statistics Canada for Census years only, i.e. 1961, 1966 and 1971, and the annual total number of dwellings was obtained by adding the completed number of dwellings in a particular year to the total number of dwellings of the preceding, the cumulative totals calculated for 1966 and 1971 differed slightly from the ones given by Statistics Canada for these Census years. The same was observed for Edmonton. One could then anticipate the extent of the error introduced by this factor.

History and definition of the heating degree-day.

In 1927 the American Gas Association found that there exists a quantitative relashionship between the ambient air temperature and the heating load. The A.G.A. determined that the fuel consumption varied directly as the difference in ^{o}F between 65 and the mean ambient air temperature (the mean being calculated from an average of the maximum and the minimum). Each degree that the average temperature falls below $65^{o}F$ represents one degree-day. For example, for an average outside temperature of $25^{o}F$, the number of degree-day is 40. The degree-days for any given period are obtained by totalling the degree-days for each day of the period. It will be noted that for days where the average temperature is $65^{o}F$ or above, the number of degree-days will be nil.

Analysis of data.

Before proceding with the analysis of the data, the choice of the consumption per dwelling per degree-day is discussed. In order to isolate the effect of the weather, the consumption per dwelling is divided by the annual heating degree-day. To explain, let's consider a city with a fixed number of dwellings (i.e. the number of dwellings remaining constant with time), the seasonal variation in weather will give different consumption values. A cold season will result in a relatively high consumption, whereas a mild season will result in a low one. Let's now consider a city where the number of dwellings increases annually, the consumption will no longer depend on the weather only, but will also depend on the increase of dwellings. In order to investigate the effect of increasing the number of dwellings the variation in consumption due to the weather should be isolated, this is accomplished by evaluating the consumption per dwelling per degree-day. To illustrate consider the years 1967 and 1972 in table 1. The annual heating degree-days for Calgary were 9771 and 10691 respectively and the corresponding consumptions per dwelling were $2.302X10^8$ BTU and $2.416X10^8$ BTU. The ratio consumption per dwelling per degree-day is $2.302X10^8$ BTU for 1967 and $2.260X10^4$ BTU for 1972. It is clear, that even though the dwelling consumption increased from $2.302X10^8$ BTU to $2.416X10^8$ BTU because the accompanying heating degree-days went from 9771 to 10691, the consumption per dwelling per unit degree-day decreased from $2.356X10^4$ BTU to $2.260X10^4$ BTU, this decrease in consumption per dwelling per degree-day could then be attributable to the increase in number of dwellings (95,779 in 1967 to 128,865 in 1972). Another way to observe the effect of the increase in number of dwellings on consumption, is to consider two years with similar heating degree-day values, a comparison of the consumption per dwelling will reveal the effect of the increasing number of dwellings. Consider 1956 and 1970 in table 1. The heating degree-days for these two years are very close 10,061 and 10,049. The consumption per dwelling dropped from $2.678X10^8$ BTU to $2.363X10^8$ BTU as the number of dwellings increased from 56,631 in 1956 to 112,154 in 1970.

Returning to table 1 (Calgary), one could observe the decreasing trend in the consumption per dwelling per degree-day. Consumption in column 6 starts at $2.6X10^4$ BTU the beginning of the period and decreases gradually (with a few exceptions) to about $2.3X10^4$ BTU towards the last years. The average value of the consumption per dwelling per degree-day for the first 10 years (1955-1964) was $2.5X10^4$ BTU whereas for the ramaining 9 years (1965-1973) was $2.3X10^4$ BTU.

Table 2 (Edmonton), even though for only a decade, exhibits the same trend observed for Calgary. An increase in consumption per dwelling per degree-day is observed in 1967, 69, and 70, however, the arithmetic average for the first five years is $4.1X10^4$ BTU whereas for the last five it drops to $3.9X10^4$ BTU (one of the reasons consumption figures for Edmonton are higher than Calgary is because they include industrial consumption).

Figure 1b is a plot of the mean temperature during the heating season (the heating season being January to May (inclusive) and September to December (inclusive) vs time). The words run from 1956 to 1973 for Calgary and from 1964 to 1973 for Edmonton.

Figures 1c and 1d display the regular changes in population, total number of dwellings, total consumption, consumption per dwelling, consumption per dwelling per degree-day, for Calgary and Edmonton respectively.

Figure 2 (Calgary) and figure 3 (Edmonton), are graphical representation of the decreasing trend of consumption/dwelling/degree-day as the total number of dwellings increases. A linear correlation analysis was performed to obtain the trend of the data.

The rate of decrease of consumption/dwelling/degree-day for Calgary and Edmonton given by the slopes in figure 2 and figure 3 are: -0.4 (Calgary) and -0.7 (Edmonton).

It could be inferred then, that as the total number of dwellings increases, the consumption per unit dwelling per degree-day decreases. The decrease is appreciable even over a period of 10 years. Moreover, this trend is evident despite the lower temperatures of recent years (Figure 1 b), the increase in dwellings, and the increase in overall gas consumption (Figures 1 c, and 1 d).

Proposals and Conclusion.

Urban expansion and city planning will play a very important role in maximizing energy savings, the extent to which an increasing number of dwellings alters the heat-island effect should be a primary research topic. Factors, such as urban fabric, city structure, artificial heat production, urban water balance, urban air pollution, which control the urban heat-island are described by T.R. OKE (1969), special emphasis should be put on city structure since we saw its importance in energy saving. Types of construction material, size, shape, density and orientation of houses will certainly prove to be determining factors for long term energy saving. Regional effects on the shape of large buildings, and the morphology of town structure presented by V. OLGYAY (1963) provide a basic understanding of the problem, but by no means, a complete one.

This study indicates that while the fuel consumed by the cities of Calgary and Edmonton is increasing annually, the fuel consumed per heating unit is decreasing. This decrease may be attributable to the increasing influence of the heat island effect with increasing city size, but may also be the result of improved building technology.

REFERENCES

1. 1963 DESIGN WITH CLIMATE. BIOCLIMATIC APPROACH TO ARCHITECTURAL REGIONALISM. VICTOR OLGYAY. PRINCETON UNIVERSITY PRESS.

2. 1969 TOWARDS A MORE RATIONAL UNDERSTANDING OF THE URBAN HEAT-ISLAND. T.R. OKE McGILL UNIVERSITY, CLIMATOLOGICAL BULLETIN NO. 5, JAN. 1969

3. 1973 VARIABLITY OF SEASONAL TOTAL HEATING FUEL DEMAND IN THE UNITED STATES (PREPARED BY SPECIAL TASK GROUP):

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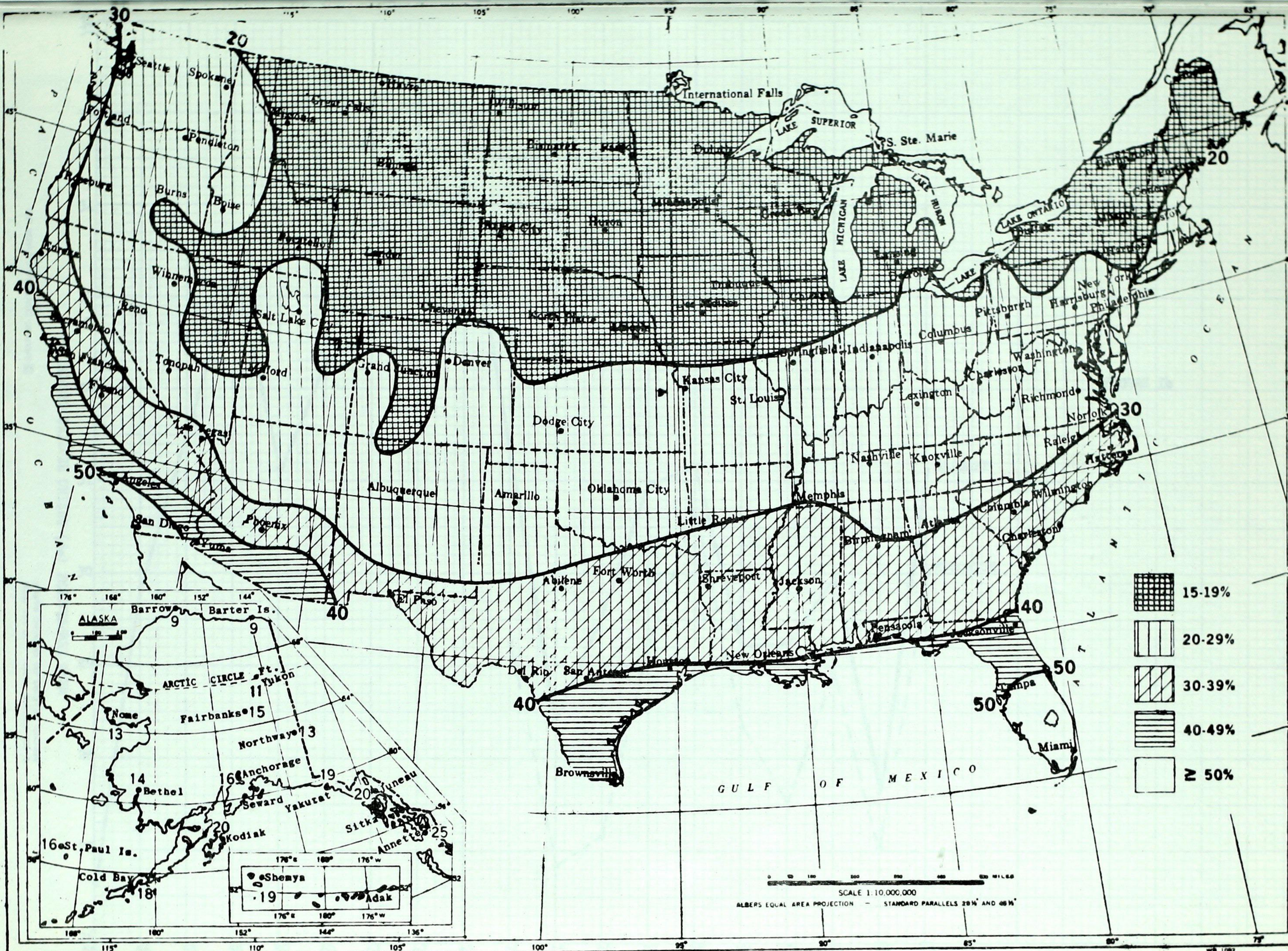
TABLE 1 CALGARY

YEAR	TOTAL CONSUMPTION $X10^{12}$ BTU	TOTAL NO. OF DWELLINGS	CONSUMPTION PER DWELLING $X10^{8}$ BTU	DEGREE-DAY	CONSUMPTION PER DWELLING PER DEGREE-DAY $X10^{4}$ BTU
1955	12.742089	47408	2.6878	11008	2.441
1956	13.563009	51631	2.6269	10061	2.619
1957	14.242085	54511	2.6127	9768	2.674
1958	14.238590	57430	2.4793	9259	2.677
1959	14.892813	62353	2.3885	9870	2.420
1960	15.035202	67745	2.2194	9569	2.319
1961	17.511451	72253	2.4236	9091	2.665
1962	18.206707	76059	2.3938	9289	2.577
1963	18.343471	80672	2.2738	8822	2.577
1964	19.839831	84455	2.3492	9723	2.416
1965	22.263148	88103	2.5269	10446	2.419
1966	22.484470	92027	2.4432	10799	2.262
1967	22.049511	95779	2.3021	9771	2.356
1968	23.483376	100078	2.3465	10004	2.345
1969	25.734585	104379	2.4465	10367	2.378
1970	26.508499	112154	2.3636	10049	2.353
1971	27.968903	121155	2.3085	9981	2.312
1972	31.145226	128865	2.4169	10691	2.260
1973	30.424322	136598	2.2273	9693	2.297

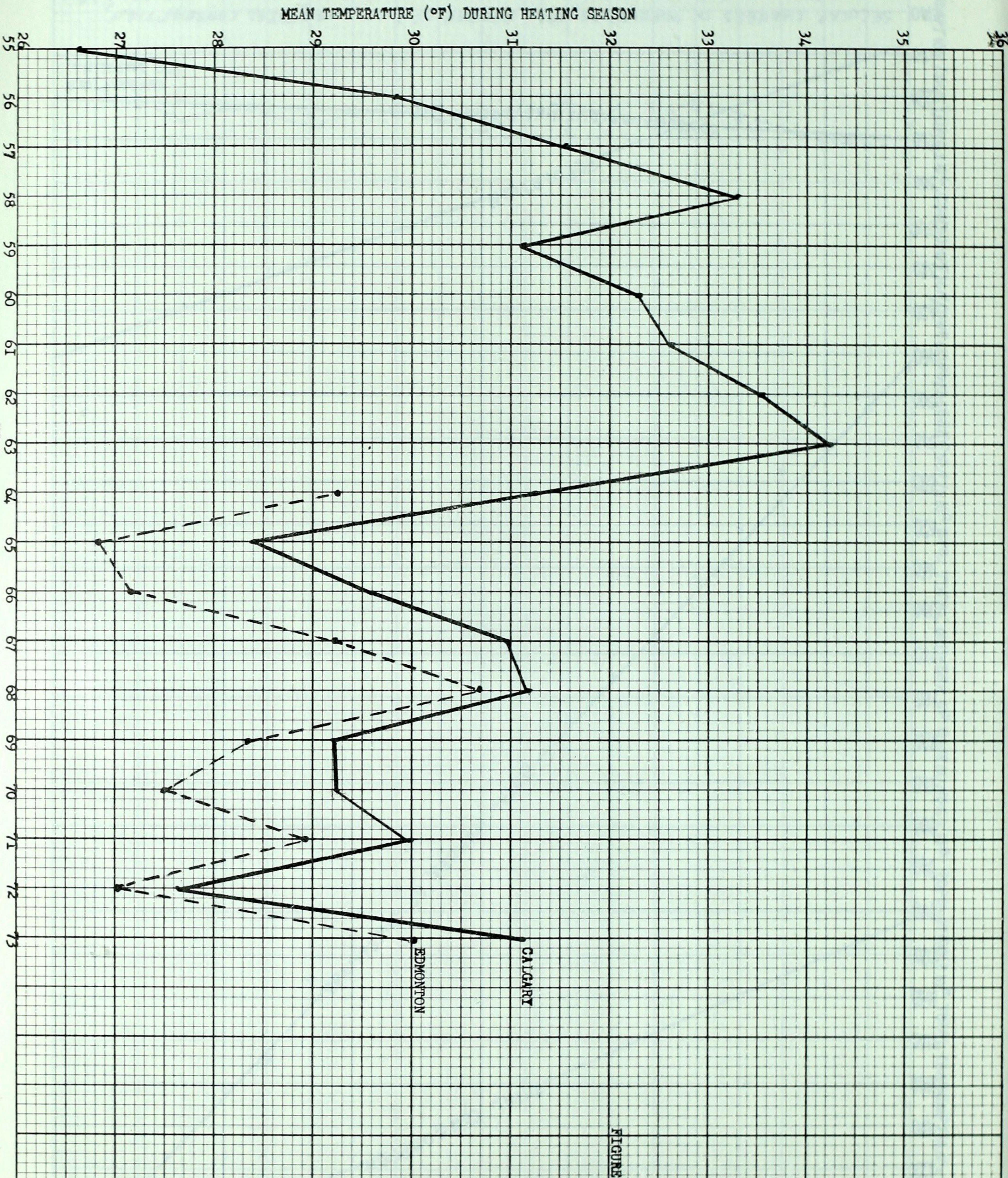
TABLE 2 EDMONTON

YEAR	TOTAL CONSUMPTION $X10^{12}$ BTU	TOTAL NO. OF DWELLINGS	CONSUMPTION PER DWELLING $X10^{8}$ BTU	DEGREE-DAY	CONSUMPTION PER DWELLING PER DEGREE-DAY $X10^{4}$ BTU
1964	41.4	101161	4.09	10172	4.02
1965	45.5	105998	4.29	10721	4.00
1966	48.4	110224	4.39	10801	4.06
1967	50.8	114701	4.42	10081	4.39
1968	53.9	122473	4.40	9882	4.45
1969	58.1	131074	4.43	10331	4.29
1970	62.3	138203	4.50	10440	4.31
1971	58.1	146455	3.96	10207	3.88
1972	61.8	156387	3.95	10748	3.67
1973	60.1	166190	3.61	9871	3.66



PERCENTAGE REDUCTION IN HEATING FUEL USE EXPECTED BY LOWERING THE THERMOSTAT 5 DEGREES

FIGURE Ia


MEAN TEMPERATURE (°F) DURING HEATING SEASON
26
27
28
29
30
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32
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34
35
36
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
YEAR
EDMONTON
CALGARY

FIGURE 1b

G-5DL SQUARE 10X10 TO THE INCH
SPECIFY TRACING OR DRAWING PAPER

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MADE IN CANADA

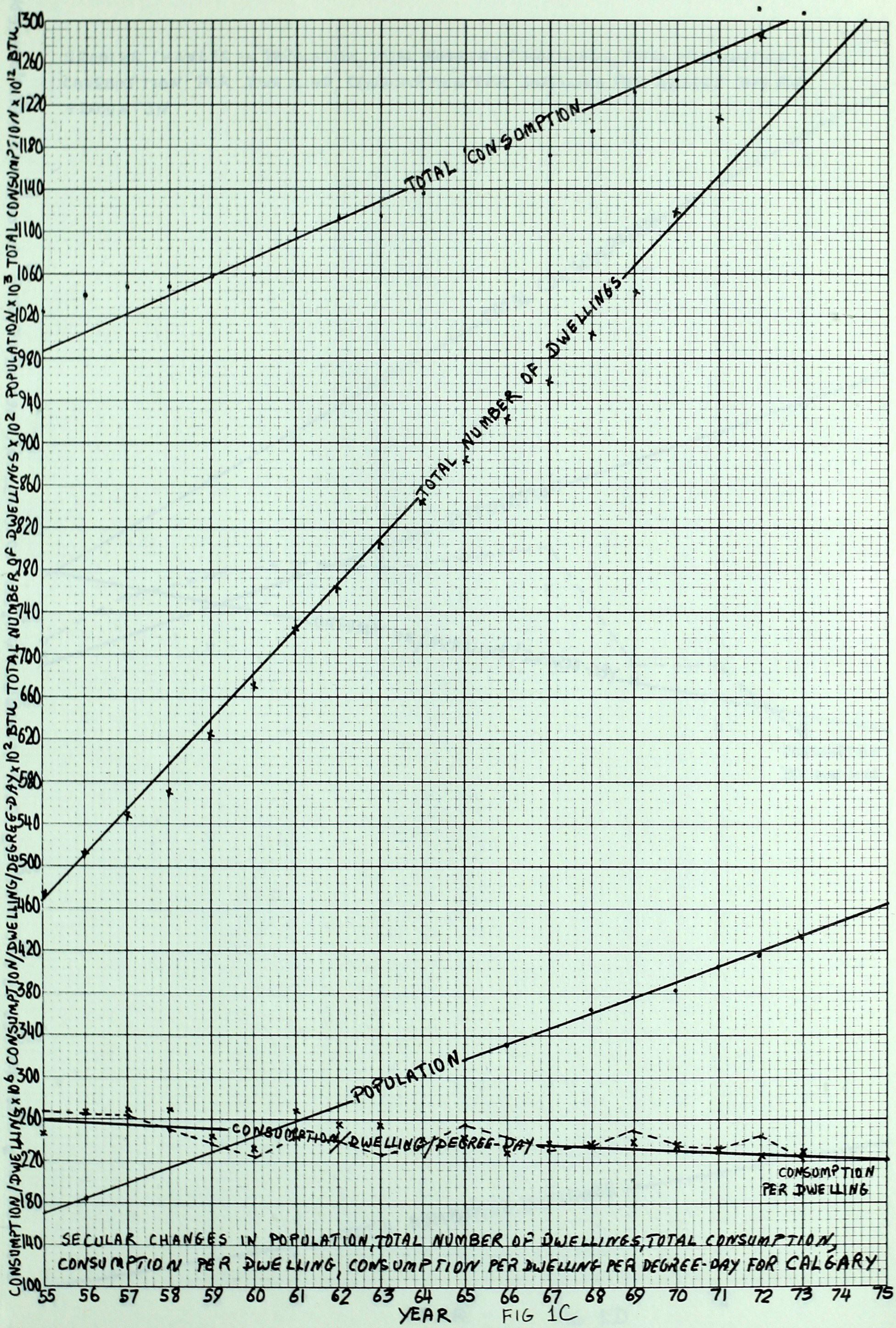
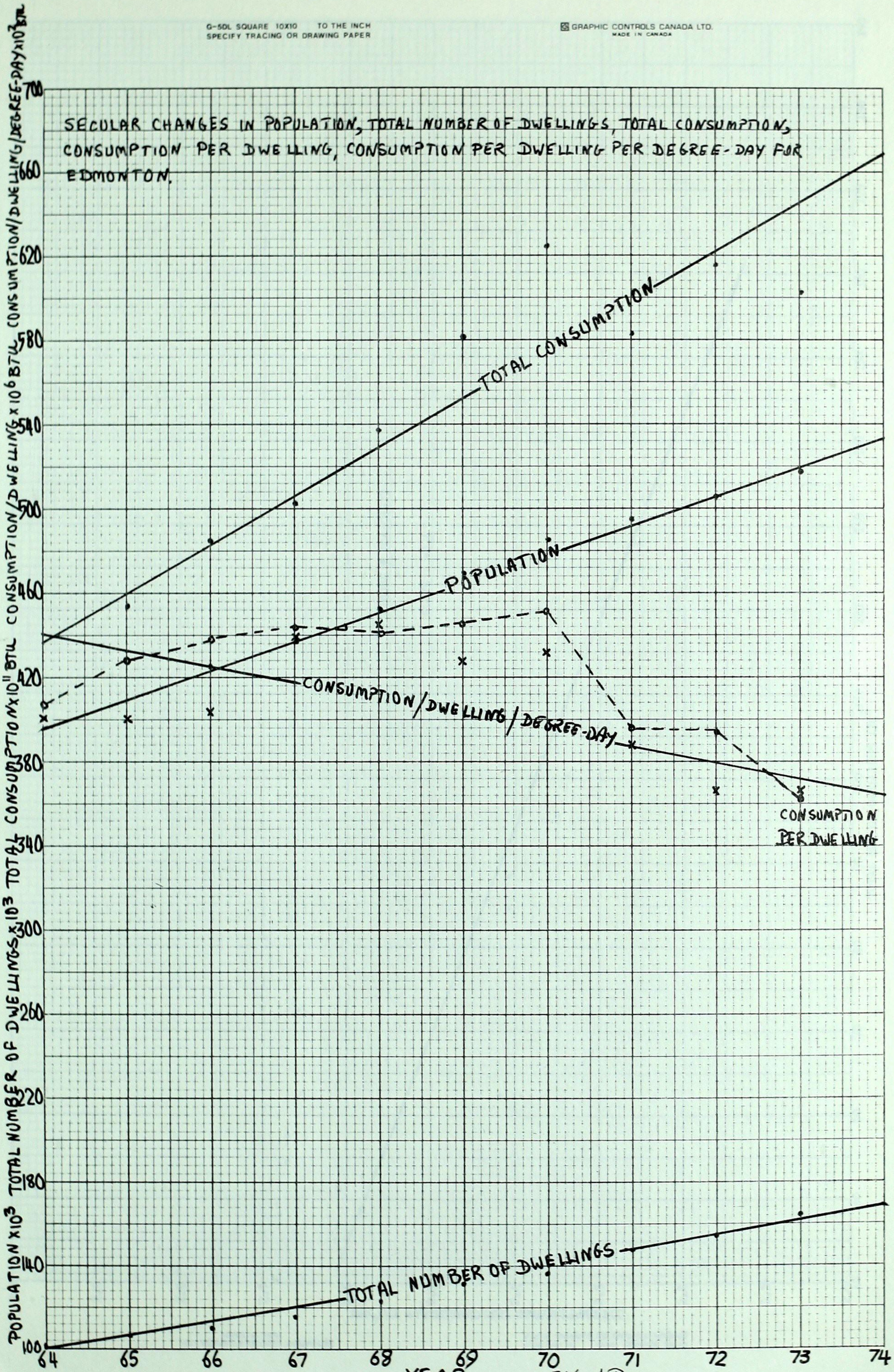


FIG 1C


G-50L SQUARE 10X10 TO THE INCH
SPECIFY TRACING OR DRAWING PAPER
GRAPHIC CONTROLS CANADA LTD.
MADE IN CANADA
SECULAR CHANGES IN POPULATION, TOTAL NUMBER OF DWELLINGS, TOTAL CONSUMPTION, CONSUMPTION PER DWELLING, CONSUMPTION PER DWELLING PER DEGREE-DAY FOR EDMONTON.
POPULATION x10³ TOTAL NUMBER OF DWELLINGS x10³ TOTAL CONSUMPTION x10¹¹ BTU CONSUMPTION/DWELLING x10⁶ BTU CONSUMPTION/DWELLING/DEGREE-DAY x10³ BTU
700
660
620
580
540
500
460
420
380
340
300
260
220
180
140
100
TOTAL CONSUMPTION
POPULATION
CONSUMPTION/DWELLING/DEGREE-DAY
CONSUMPTION PER DWELLING
TOTAL NUMBER OF DWELLINGS
64
65
66
67
68
69
70
71
72
73
74
YEAR
FIG 1D

G-SDL SQUARE 10X10 TO THE INCH
SPECIFY TRACING OR DRAWING PAPER

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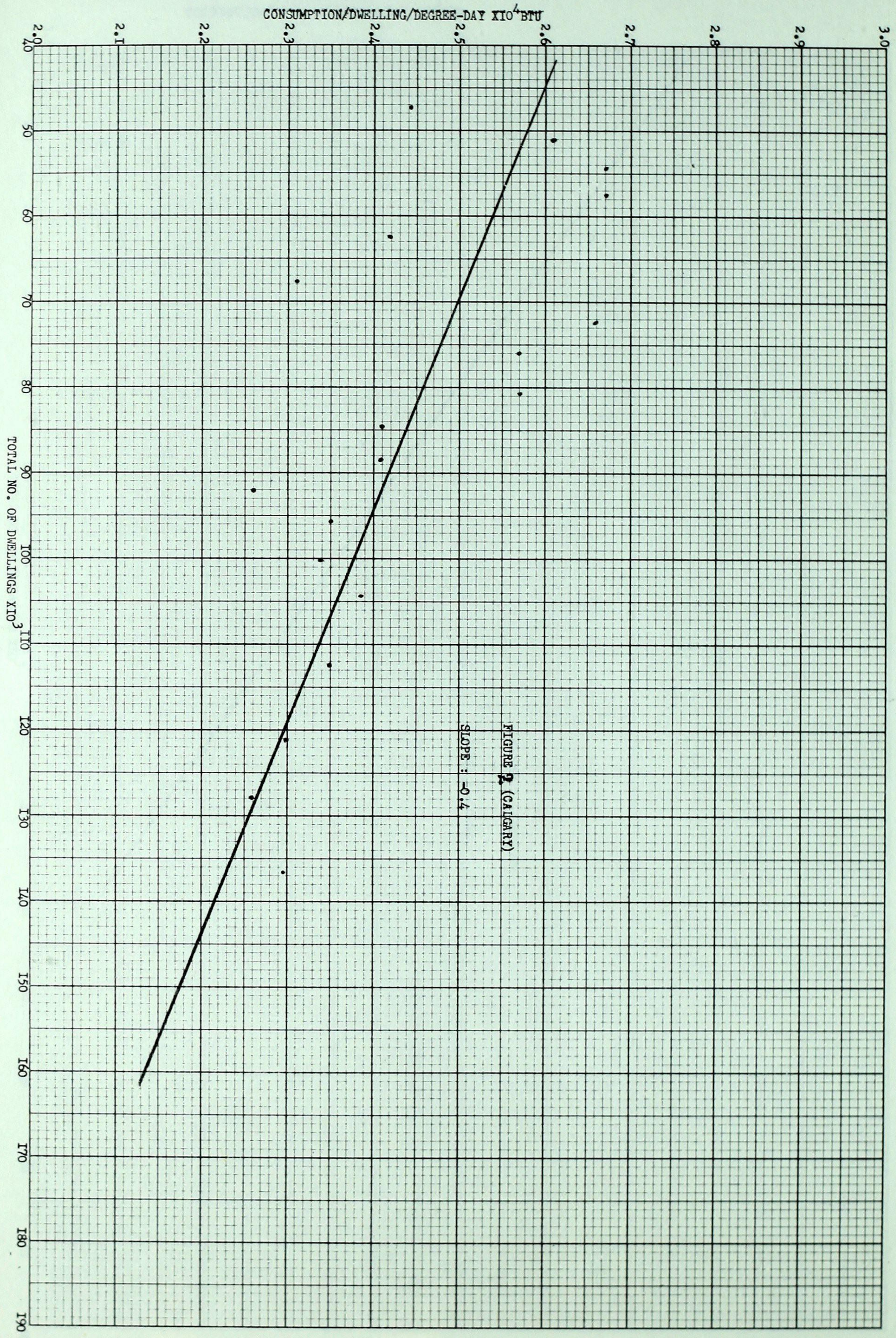

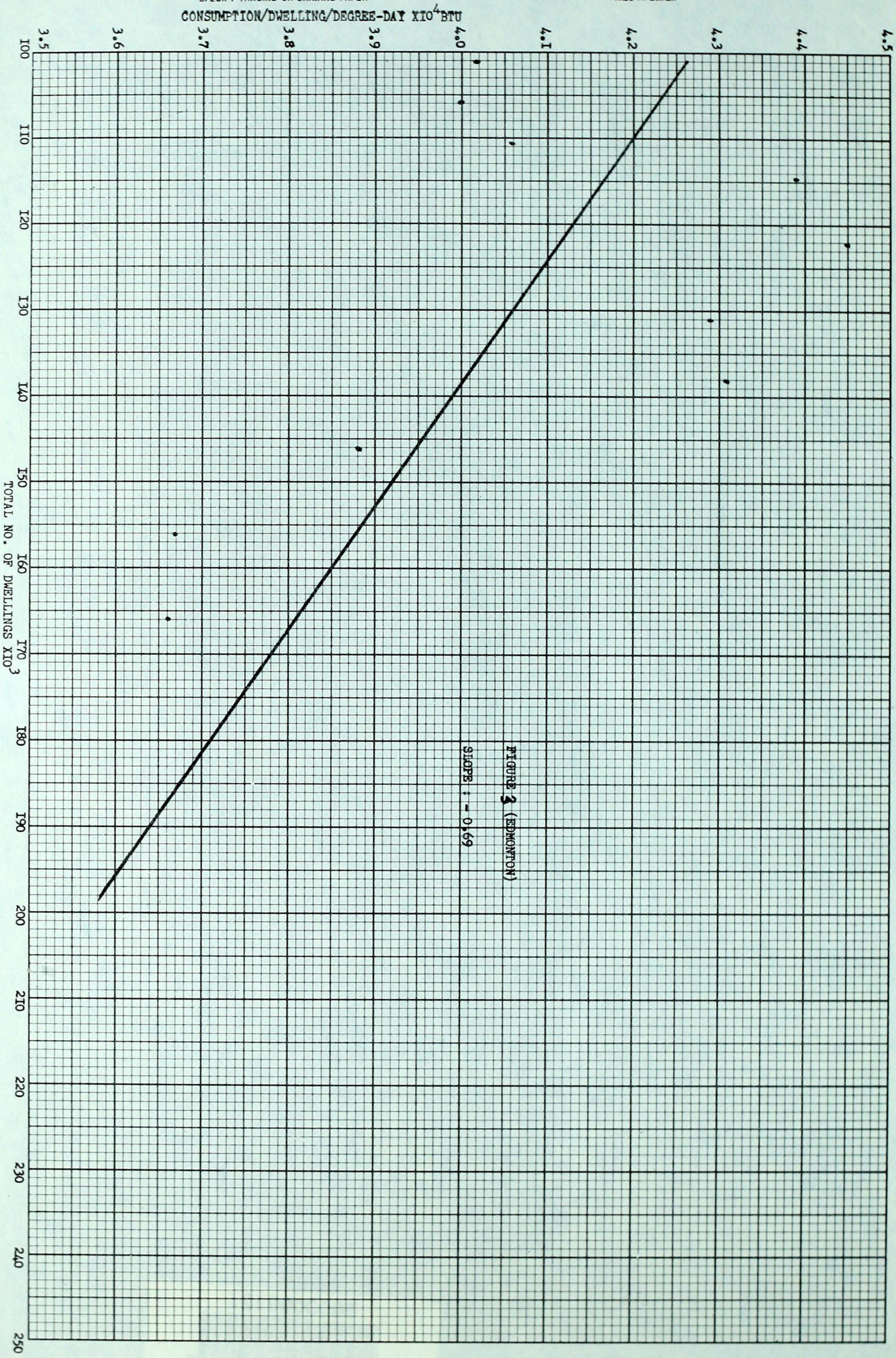

FIGURE 3 (EDMONTON)