# MEASURED ENERGY CONSUMPTION OF A LOW ENERGY PASSIVE SOLAR TOWNHOUSE COMPLEX

R.S. DUMONT
Division of Building Research
National Research Council of Canada
Saskatoon, Saskatchewan
S7N 0W9



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ABSTRACT

Measured energy consumption figures are presented for a townhouse complex located in Regina, Saskatchewan. The complex consists of 8 two-storey wood frame structures incorporating low energy design principles and some passive solar features. A total of sixty-seven living units and one community centre are present in the complex. The complex is owned by the Meadowlark Housing Co-operative. The complex is believed to be the first in the Canadian prairie region incorporating low energy design principles which has been monitored for energy consumption.

The windows are triple glazed units on all non-south windows (double glazed on the south) and the ceilings, walls and basement walls have U values equal to 0.14, 0.2, and 0.29 $W/m^2K$ respectively. (The U value is the inverse of the R value $m^2K/W$.) The units are tightly sealed, and incorporate an exhaust air ventilation system.

The complex was completed in mid-1983, and energy consumption readings are presented for the period from August, 1983 to August, 1984. The units use natural gas forced air furnaces and natural gas storage-type water heaters.

The measured space heating for the first year of monitoring averaged 411 $MJ/m^2$ for all units. This figure is approximately 40% lower than the space heating consumption of typical non-low energy units in this area of Canada. The annual heating degree days for the first year of monitoring in Regina were 5383°C days (reference 18°C).

Comparisons between the measured space heating consumption of the living units and the calculations of a computer model called HOTCAN are also presented in the paper.

KEY WORDS

Energy

Measurements

Space Heating

Low Energy

Townhouse

Multi-Family

Cold Climate

Computer Calculation

HOTCAN

## INTRODUCTION

In the first half of 1983, a low energy townhouse complex was completed in Regina, Saskatchewan, Canada. This townhouse complex consisting of sixty-seven living units and one community centre is believed to be the first of its type in the prairie region of Canada. The complex incorporates high levels of energy conservation in its space heating design. The windows are triple glazed, the ceiling, walls and basement walls are very well insulated, with U values for the ceiling, walls and basement walls equal to 0.14, 0.2, and 0.29 $W/m^2K$ respectively. The units were tightly sealed and incorporate an exhaust air ventilation system.

Energy consumption readings are presented in this paper for a twelve month period beginning August, 1983.

Regina has a climate which is classed as "continental", with annual degree days (base 18°C) averaging 5920°C, and a January design temperature of -34°C. The annual average sunshine hours are 2331.

This monitoring project had several purposes: the first was to document the space heating and total energy consumption performance of the units in this townhouse complex and to compare this energy performance with that of conventional housing units built during the 1970s. A second purpose was to compare the measured energy performance of a group of the townhouses with calculations of the computer model HOTCAN 2.0.[3]

## DESCRIPTION OF PROJECT

The townhouse complex consists of 68 separate units, one of which is used as a community center. A plan view of the complex is presented in figure 1. A majority of the units have a major axis oriented east-west, allowing south window exposure. The complex consists of 18-two bedroom units and 50-three bedroom units. An elevation view of one complex is shown in figure 2.

There are three basic house modules used in the project:

Table 1. Description of Modules for Meadowlark Project

| | Number of Modules | Number of Units per Module | Description |
|---|---|---|---|
| MODULE A | 20 | 1 | Two-storey, single units with 3 bedrooms each and a full basement. Total floor area = 141 $m^2$ including basement. |
| MODULE C | 9 | 2 | Two-storey units with 2 bedrooms each. One floor unit on top and a separate unit with a basement below. Upstairs unit floor area = 87.1 $m^2$. Lower unit floor area = 174 $m^2$ including basement. |
| MODULE D | 15 | 2 | Two-storey units with 3 bedrooms each, one floor unit on top and a separate unit with a basement below. Upstairs unit floor area = 103.6 $m^2$. Lower unit floor area = 207.1 $m^2$ including basement. |
| | 44 | | |

Note: Modules C and D have two living units per module.

The particular design was adopted to facilitate access for handicapped persons. The handicapped-accessible units are all in the lower levels of the C and D modules. No elevators are used in the complex.

As there are basically only three types of living units within the complex, the opportunity arose for comparison of energy consumption levels of the similar units.

The units all have identical construction details. A wall section is shown in figure 3. Glass fiber batt insulation is used in the walls, with blown insulation in the attic space. The vapour barrier in the main floor and second floor wall section is sandwiched between a 38x64mm horizontal strapping and 38x140mm vertical studs. The vapour barrier is a 135 micrometer thick polyethylene sheet. All joints between the vapour barrier sheets were caulked using an acoustical sealant compound.

Pressure tests conducted on three of the Module A type end units using a fan pressurization unit[1] yielded the following results:

| | Air changes per hour at 50 pascals |
|---|---|
| Unit a. | 1.68 |
| b. | 1.74 |
| c. | 1.94 |

To prevent air leakage between adjacent units during the tests, the adjacent unit was pressurized to the same level as the unit under test.

The air tightness levels quoted above compare favourably with an average value of 3.6 air changes per hour at 50 pascals for conventionally constructed house units built over the period 1961-80 as reported by Dumont[2], Orr, and Figley.

Although inner units in the rows of housing were not tested, it would be expected that they would have a lower air leakage rate, as they have less surface area exposed to the outside.

The ventilation air for the houses is provided by a 125mm diameter duct which connects from outside to the return air plenum on the forced air furnace. A two-speed exhaust air fan with an installed capacity of approximately 65 litres/second maximum flow is connected to the bathroom, kitchen and laundry space in each unit.

Each unit is heated with a forced warm air furnace with intermittent ignition and an atmospheric vented chimney. The natural gas furnace sizes were 26 kW and 22 kW input for the 3 and 2 bedroom units respectively. A natural gas, atmospheric vented water heater was used in each unit. The presence of a separate furnace and water heater in each living unit facilitated energy consumption measurements.

Each living unit has a separate natural gas and electricity meter. The only devices using natural gas are the space and water heaters. There was no submetering present on either the appliances or water heater.

## Description of Monitoring

The monitoring consisted of manual readings of the natural gas, electricity and water meters once per month, during the first week of each month.

Weather records were gathered from the weather station at the Regina airport, which is located at the same elevation approximately 10 km from the housing project.

The meter readings were input to a computer program for analysis by staff at the Division of Building Research.

## Results of Monitoring

Energy Consumption per Unit Floor Area.

As there are variations between modules A, C and D in the amount of floor area, it was of interest to present the energy statistics normalized by the floor area.

The energy consumption values per unit floor area are presented in Table 2.

Table 2. Energy Consumption Values for Various Modules

August, 1983 - August, 1984

| | | No. of Living Units | Floor Area Including Basement $m^2$ | Nat Gas (GJ) | Elec (GJ) | Nat Gas ($MJ/m^2$) | Elec ($MJ/m^2$) | Total ($MJ/m^2$) |
|---|---|---|---|---|---|---|---|---|
| A Units | Middle | (13) | 141 | 73.5 | 29 | 521 | 206 | 727 |
| | End | (7) | 141 | 79.8 | 30.5 | 566 | 216 | 782 |
| C Units | Lower | (9) | 174 | 74.4 | 21.0 | 428 | 121 | 549 |
| | Upper | (9) | 87.1 | 64.2 | 17.5 | 737 | 201 | 938 |
| D Units | Middle Lower | (7) | 207.2 | 79.0 | 23.5 | 381 | 113 | 494 |
| | Middle Upper | (7) | 103.6 | 79.5 | 21.3 | 767 | 205 | 972 |
| | End Lower | (8) | 207.2 | 78.6 | 24.9 | 379 | 120 | 499 |
| | End Upper | (8) | 103.6 | 75.1 | 26.4 | 725 | 254 | 979 |
| AVERAGE | | | | 75.0 | 24.4 | 566 | 183 | 749 |

A histogram of the total energy consumption per square meter for the modules is presented in figure 4.

Relatively small differences existed between the end and middle units of the same size in terms of total energy consumption.

For the A and D block the results were as follows:

Table 3. Comparison of Energy Consumption of Middle and End Units

| | | Total Energy Consumption ($MJ/m^2$) | Ratio |
|---|---|---|---|
| A Units | Middle | 727 | 0.93 |
| | End | 782 | 1 |
| D Units | Middle Upper | 972 | 0.99 |
| | End Upper | 979 | 1 |
| | Middle Lower | 494 | 0.99 |
| | End Lower | 499 | 1 |

The C units were all located in the middle of a complex.

## Comparison of Measured Energy Consumption with Calculations of a Computer Model

The computer model HOTCAN 2.0[3] was used to compare calculations with the energy consumption of several of the townhouses.

In the Meadowlark complex there are five "A" units which face in the same direction and are end units. The house units are marked with an asterisk (*) in figure 1.

Plots of the total energy consumption rate versus degree-days per day were plotted for each of the five units. The plots are presented in figure 8 for the 8-month winter period from October to May. As may be seen from the graph, there is a considerable variation from unit to unit. However, the slope values are relatively uniform (within +10% and -14% of the mean slope).

The slope values for the five houses are presented below:

Table 4. Measured Slope Values for Five Identical Townhouses

| | Slope Value W/K | $R^2$ |
|---|---|---|
| House 1 | 142.3 | 0.9859 |
| 4 | 167.0 | 0.9821 |
| 33 | 165.5 | 0.9683 |
| 36 | 169.9 | 0.9817 |
| 56 | 182.1 | 0.9545 |
| Average = | 165.4 | |

A HOTCAN run was performed using the dimensions from the blueprints for the units. Values for the total energy consumption rate versus degree-days per day were plotted and the slope taken. As the units all used natural gas furnaces for space heating, a furnace efficiency had to be assumed. The natural gas furnaces are atmospheric vented, non condensing units, with intermittent ignition devices.

Using a value of 0.7 for furnace efficiency, the calculated slope using HOTCAN is equal to 164 W/K, which agrees very favourably with the average of 165 W/K for the measured performance of the five units.

The computer calculation is very sensitive to certain parameters, particularly the air change rate chosen for the units. A percentage breakdown of the heat loss from the units as calculated by HOTCAN is presented in Table 5.

Table 5. Percentage Breakdown of Seasonal Heat Loss from Module A End Units

| | |
|---|---|
| Ceiling | 4.9 |
| Walls & Doors | 20.8 |
| Basement Floor | 14.4 |
| Windows | 12.7 |
| Air Change (assuming 0.6 air changes/hr) | 47.2 |
| | 100.0% |

The air change rate of 0.6 air changes per hour constitutes about one half of the total heat loss of the unit. The figure of 0.6 air changes is high compared to most typical housing in this part of Canada. The reason for this high figure is the use of a continuously running exhaust fan in each unit. Based on tests in three of the units, the exhaust air flow rate averaged 56.9 litres/s, which is equivalent to 0.57 air changes per hour in a unit with a volume of 359 $m^3$. During the exhaust air flow tests, measurements were made of the air pressure difference between inside and outside at the ground floor. The houses were under a negative pressure of about 5 pascals.

Discussion

a. Energy Consumption Values

The energy consumption of the units was found to average 520 $MJ/m^2$ for natural gas and 170 $MJ/m^2$ for electricity for the period from August 1983 to August 1984. (Elapsed degree days = 5383 degree C-days)

Comparable energy statistics for townhouses built to conventional standards during the period before the energy crisis of the mid-1970's were not available.

Statistics for detached houses in Regina are available in a paper by Hedlin and Orr[4]. For 209 houses located in Glencairn, an area of Regina, with an average total floor area of 194 $m^2$ including basement, the mean natural gas consumption was 1034 MJ/$m^2$ and the mean electricity consumption was 159 MJ/$m^2$. These houses were constructed post 1970 and most are single storey.

A table comparing the two sets of houses is presented below:

Table 6. Energy Consumption Comparison of Meadowlark Units with Non-Low Energy Houses

| | Meadowlark | Non-low energy houses | Ratio |
|---|---|---|---|
| Year of Construction | 1983 | 1970-73 | |
| Degree-days of monitoring period (°C days) | 5383 | 5764 | |
| Annual total energy consumption (MJ/$m^2$) | 749 | 1192 | 0.628 |
| Annual space heating consumption (MJ/$m^2$) | 411 | 764 | |
| Annual space heating consumption per degree-day (kJ/$m^2$ °C day) | 76.4 | 133 | 0.574 |

As the townhouses at Meadowlark all have at least one surface attached to adjacent heated space, they would be expected to have reduced consumption compared to detached houses of the same size. However, as noted in Table 3, the adjacent heated structure seemed to have a small effect (less than 7%) on total energy consumption. A recent paper by Hedlin and Bantle[5] presents data for groups of houses located in Regina including detached houses and duplexes. Compared to houses of the same floor area, the duplexes consumed about twelve percent less natural gas compared with one storey houses with full basements. Both sets of houses had total floor areas in the range of 150-200 $m^2$. In the Meadowlark houses, air change constitutes a greater percentage of the total heat loss than in conventional houses, and consequently the presence of adjacent heated structures which reduce the surface losses would be expected to have a smaller percentage effect.

As may be seen from Table 2, the upper units in the C and D modules had the highest natural gas consumption on a unit area basis. It is believed that this high consumption is linked to the high air exchange rates in these units, as they have exhaust fans as large as those in other units. These upper units have one-half the volume of the lower units.

b. Possible Improvements

The townhouses achieved a relatively good energy performance compared to houses constructed 10 years earlier. However, a number of inexpensive improvements to the units are possible. As may be seen from Table 5, about 50% of the heat loss from the units is due to air change. If the air change rates were reduced from 0.6 air changes to approximately 0.3 air changes per hour by reducing the exhaust flow rate, the annual energy consumption for space heating would fall by 43%, based on the calculations of the computer model HOTCAN 2.0. A value of 0.3 air changes per hour would normally be sufficient to provide adequate ventilation. This value is also consistent with measurements of air change rates made in houses in this part of Canada. The ASHRAE Standard 62-1981 recommends a continuous ventilation rate of 5 L/s per room. In a living unit with a volume of 338 $m^3$ (Module A type) and 6 rooms, the ASHRAE recommended flow of 30 L/s would correspond to 0.32 air changes per hour.

Use of triple glazing on the south side would improve the performance further. The energy savings from these measures are presented in Table 7 for an end unit of Module A type.

Table 7. Annual Space Heating Requirment of a Module A Unit Under Three Different Assumptions

(Calculation performed Using HOTCAN 2.0)

| | Annual Space Heating Consumption (Natural Gas) (GJ) | Ratio |
|---|---|---|
| (1) House as is | 58.2 | 1 |
| (2) With air change reduced to 0.3 air changes/hr from 0.6 air changes/hr | 33.0 | 0.57 |
| (3) Same as (2), but with use of triple glazing on south side | 31.6 | 0.55 |

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| | |
|---|---|
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| Provincial Government Support: | Saskatchewan Power Corporation and Saskatchewan Housing Corporation. A financial contribution from these organizations through the Home Energy Loan Program (HELP) assisted with the energy conservation measures in the townhouses. |
| Construction Company: | Cairns Construction Ltd., Regina. |

**References**

1. Orr, H.W. and Figley, D.A., "Air Exhaust Fan Apparatus for Assessing the Air Leakage Characteristics of Houses" DBR, NRCC, Ottawa, BRN 156, 1980.

2. Dumont, R.S., Orr, H.W. and Figley, D.A., "Air Tightness Measurements of Detached Houses in the Saskatoon Area", Division of Building Research, National Research Council of Canada, Ottawa, BRN No. 178, 1981.

3. Dumont R.S., Lux, M.E. and Orr, H.W., "Hotcan: A Computer Program for Estimating the Space Heating Requirement of Residences", Computer Program No. 49, Division of Building Research, National Research Council of Canada, Ottawa, 1982.

4. Hedlin, C.P. and Orr, H.W., "A Study of the Use of Natural Gas and Electricity in Saskatchewan Houses", Proceedings, 91st Annual EIC Meeting, 1977. (National Research Council of Canada, Division of Building Research, NRCC 20416, 1982)

5. Hedlin, C.P. and Bantle, M., "A Statistical Study of the Thermal Performance of a Group of 1478 Houses on the Canadian Prairies", V.90, Pt.1, ASHRAE Transactions, 1984.

6. ASHRAE Standard 62-1981, "Ventilation for Acceptable Indoor Air Quality", 1791 Tullie Circle N.E., Atlanta, GA 30329, 1981.

List of Figures

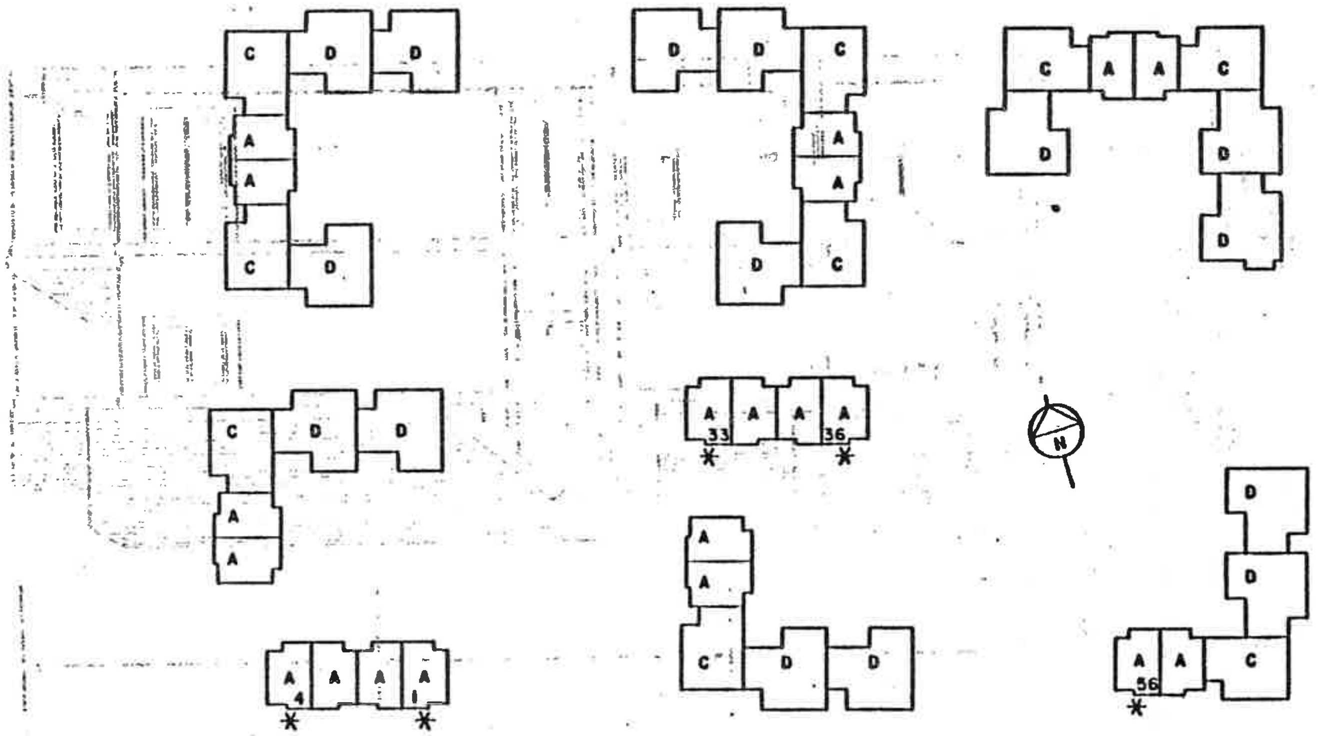
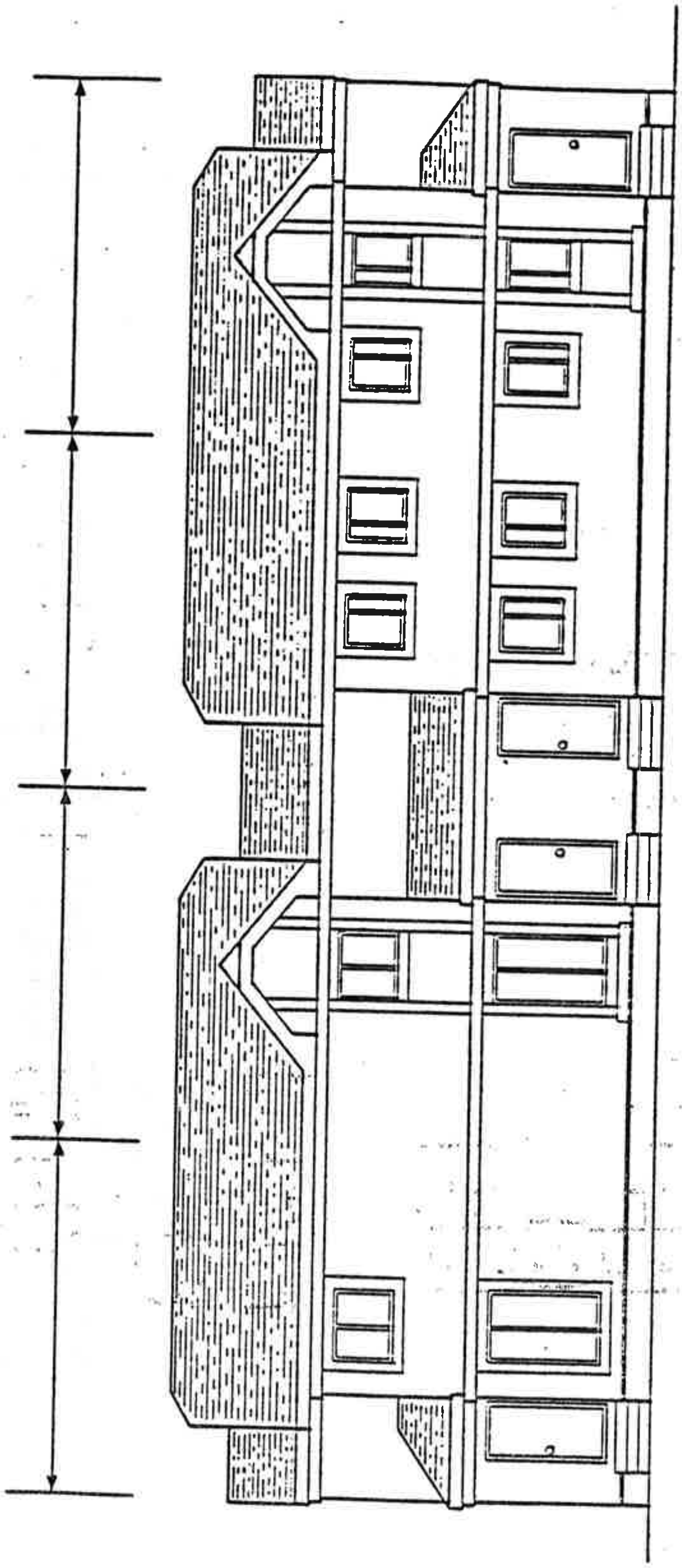



Figure 1. Plan view of Meadowlark Housing Co-operative



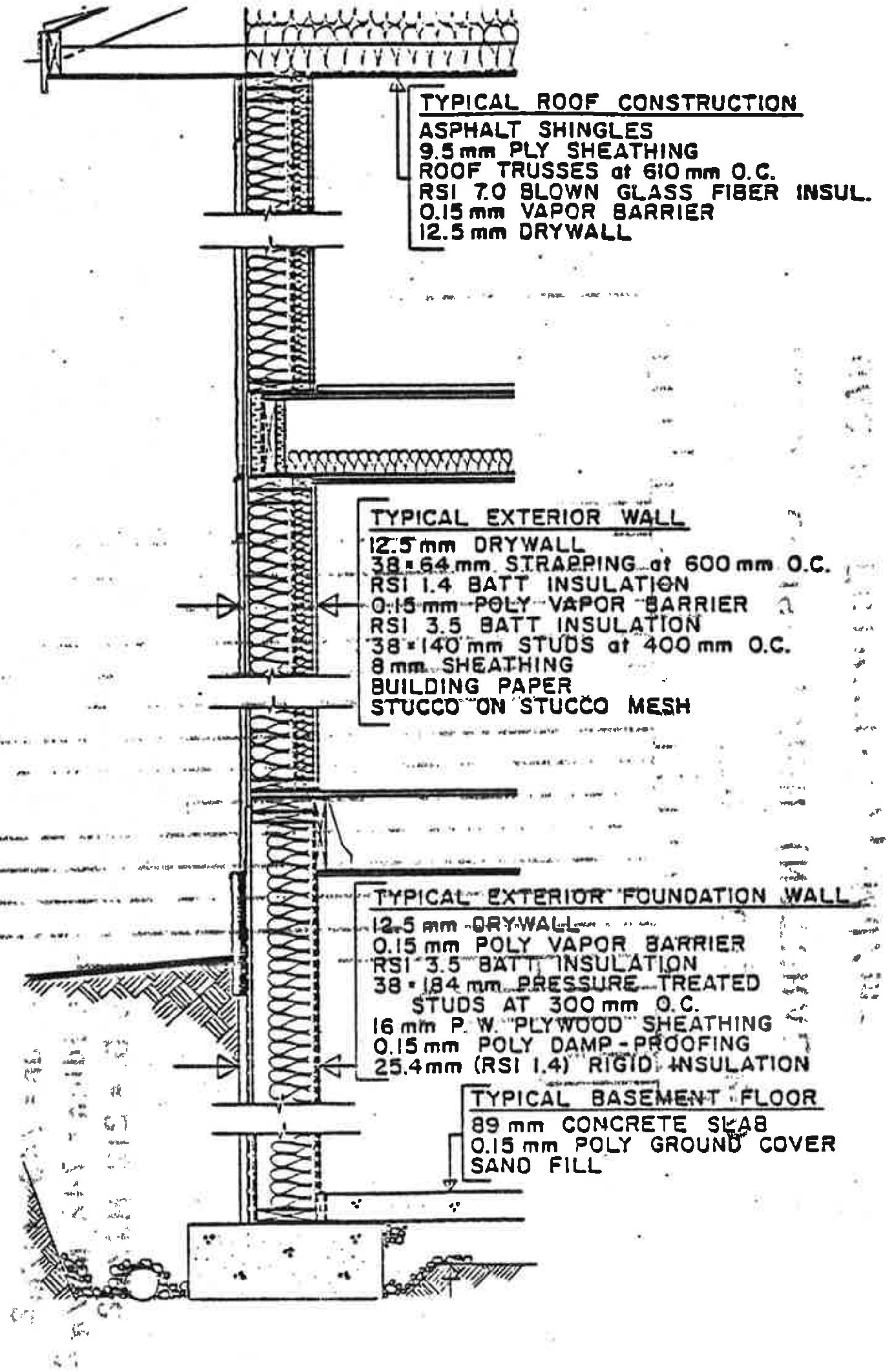



Figure 3. Section View of Wall Construction

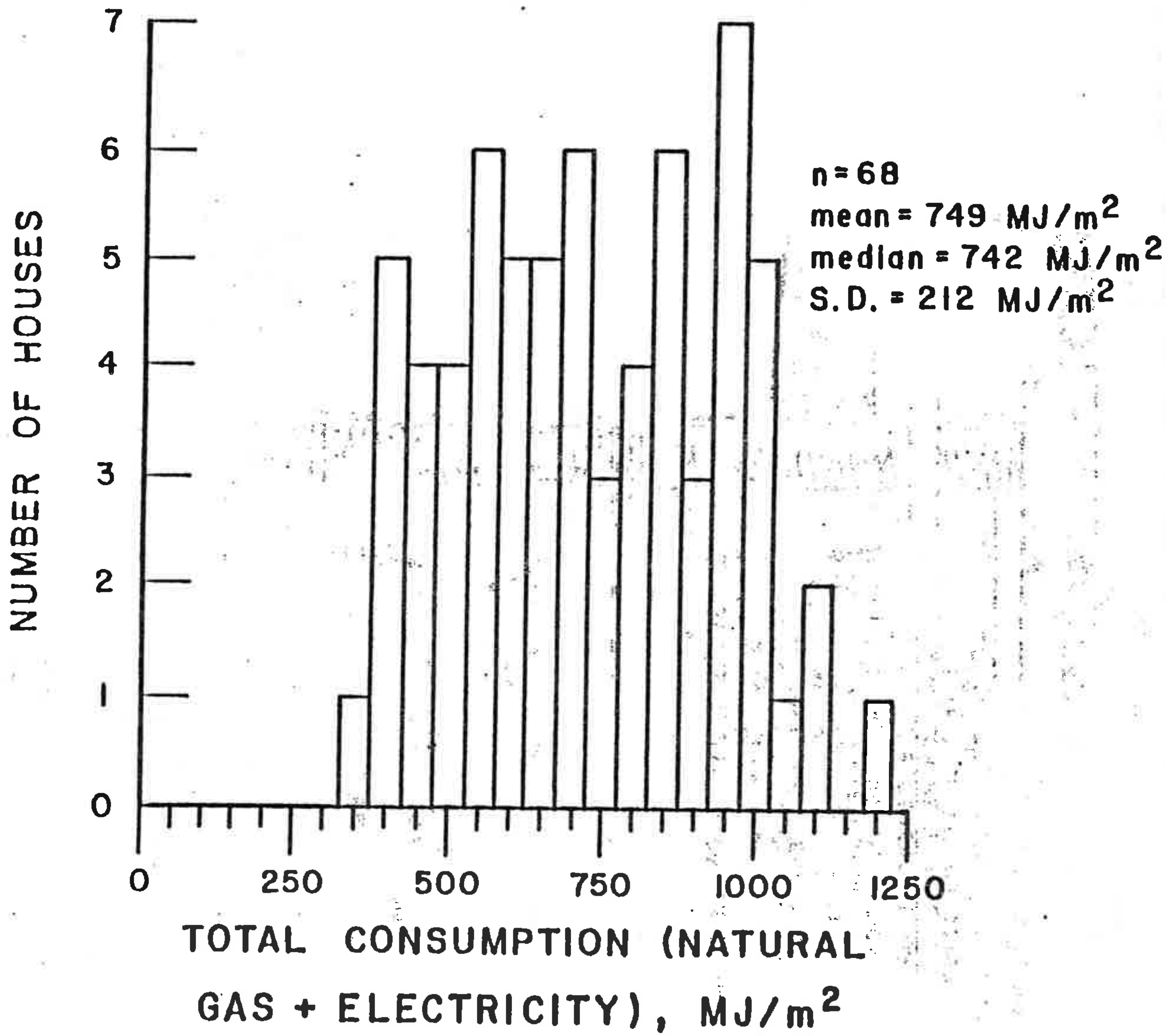



Figure 4. Histogram of Total Consumption of Sixty-Eight Units August,1983-August,1984.

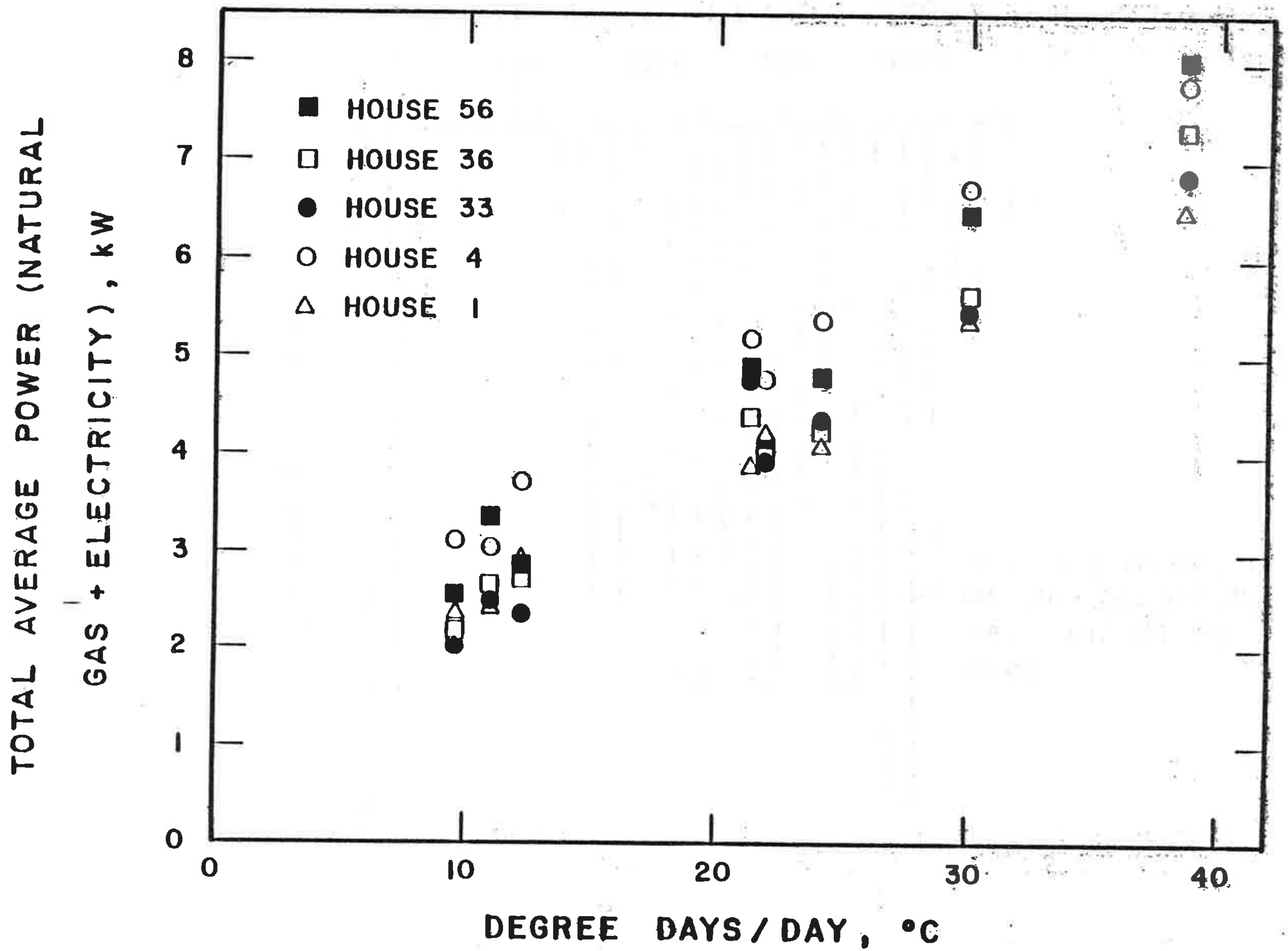



Figure 5. Measured total average power versus degree-days/day for five units at Meadowlark