CASE STUDIES IN ELECTRICAL HEATING

Donald E. Brotherson

Research Report 61-1
UNIVERSITY OF ILLINOIS
SMALL HOMES COUNCIL-
BUILDING RESEARCH COUNCIL
ABSTRACT

In order to more accurately estimate the seasonal heating requirements proposed for electrical resistance heating, the University of Illinois Small Homes Council—Building Research Council, under a cooperative agreement with the Commonwealth Edison Company, studied the heat requirements of ten electrically heated houses, located in northern Illinois. The attempt was made to establish a relationship between estimated and actual heat requirements and to evaluate the performance of the heating system.

The houses studied ranged in size from 1,025 square feet to 1,877 square feet. Four are of multi-level design and six are of single-floor design. Seven had full basements, one a partial basement, and two were built over crawl spaces. Four were heated with baseboard units and six with ceiling cable.

The standard formula for calculating fuel consumption for any period of time may be written as:

\[ F = \frac{HL \times DD \times C}{TD \times U \times E} \]

where:
- \( HL \) = calculated heat loss at design temperature differential in BTU's per hr
- \( DD \) = design days
- \( C \) = net heat load in BTU's
- \( TD \) = design temperature differential (usually 70°F - design outdoor temperature)
- \( U \) = heating value in BTU's per unit of fuel
- \( E \) = efficiency of fuel utilization

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February 1962

This publication is a report of a study performed by the University of Illinois Small Homes Council—Building Research Council pursuant to an agreement for cooperative investigation between the University and the Commonwealth Edison Company.

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Price: $1.50
ABSTRACT

In order to more accurately estimate the seasonal heating costs in homes proposed for electrical resistance heating, the University of Illinois Small Homes Council—Building Research Council, under a cooperative agreement with the Commonwealth Edison Company, studied the heat requirements of ten electrically heated houses, located in northern Illinois, during the heating season of 1960-1961. An attempt was made to establish a relationship between estimated and actual heat requirements and to evaluate the general effectiveness of the heating system.

The houses studied ranged in size from 1,025 square feet to 1,877 square feet. Four are of multi-level design and six are of single-floor design. Seven had full basements, one a partial basement, and two were built over crawl spaces. Four were heated with baseboard units and six with ceiling cable.

The standard formula for calculating fuel consumption for any period of time may be written as:

\[ F = \frac{HL \times DD \times C}{TD \times U \times E} \]

where:

- \( HL \) = calculated heat loss at design temperature differential in BTU's per hour
- \( DD \) = degree-days
- \( C \) = hours of operation
- \( TD \) = design temperature differential (usually 70°F - design outdoor temperature)
- \( U \) = heating value in BTU's per unit of fuel
- \( E \) = efficiency of fuel utilization

Since "C" is defined as operation hours, it should normally be 24. However, experience has shown that high estimates will result. An "apparent C-number" has been developed as a correction factor. Ranging from 10 to 24 for various systems, the average C-value recommended by the Federal Housing Administration and the National Electrical Manufacturers Association for electrical heating is 18.5. The results of this study indicated an average C-value of 19.0, with a range of 15.5 to 26.0. An attempt was made to correlate the variations to characteristics of the separate houses. The closest correlation was to the ratio of south glass area to total floor area, indicating that solar heat gain was a major factor in the variation. The multi-level houses as a group did not perform as well as the single-level houses.

The comfort data collected indicates that temperatures in these houses were controlled within acceptable limits. The temperature gradient from ceiling to floor was not significantly different between the ceiling cable and baseboard installations. The average temperature selected by the occupants of ceiling cable houses was generally lower than in those equipped with baseboard units. The humidity levels in the test houses were within acceptable limits during the field studies.
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**ACKNOWLEDGEMENT**

This study was made possible under a research grant from the Commonwealth Edison Company and the Illinois State Board of Healthy. The University Committee was composed of the following members:

- Professor Warren S. Harris
- Professor Howard A. Jones
- Mr. Harold L. Kneip

Their help and advice is gratefully acknowledged.

Acknowledgement is also due to Mr. William J. Oraham, Jr. of the Department of Mechanical Engineering for his assistance in the field studies.

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ACKNOWLEDGEMENT

This study was made possible under a research grant from the Commonwealth Edison Company of Chicago, Illinois. To provide guidance for this project, an Advisory Committee was formed composed of the following members:

Professor Warren S. Harris  
Department of Mechanical Engineering

Professor Rudard A. Jones  
Small Homes Council–Building Research Council

Mr. Harold L. Koenig  
Commonwealth Edison Company

Their help and advice is gratefully acknowledged.

Acknowledgement is also due to Mr. William J. Graham, Jr. of the Department of Mechanical Engineering for his assistance in the field studies.
I. INTRODUCTION

In 1957, 261,000 homes were reported to be heated with electrical heating in the United States (4). By 1959 this number had increased to almost 600,000 homes (1, 4). It is estimated that by 1968 there will be 2,000,000 houses heated electrically and by 1978 it is expected that this number will reach 10 to 20,000,000 homes (1).

In addition to resistance heating (baseboard units, ceiling cable, etc.) and heat pumps, developmental work is being carried on in the field of conductive films that can be applied to large areas, electric drapes, floor coverings, etc.

Electricity, when used for heating, must be considered as a fuel much the same as coal, oil or gas. It is a very refined fuel and, therefore, it will usually cost more per unit than other fuels. This will depend somewhat upon the area and the availability of other fuels.

In order to compete favorably with other fuels the suppliers of electricity have recommended better insulated houses and tighter houses to minimize heat losses and so decrease heating costs. In most parts of the country six inches of insulation in the ceiling, 4 inches in walls and 2 inches in floors is standard practice. In one area as much as 12 inches of insulation in the ceiling and 6 inches of insulation in walls and floors has been recommended (7).

Until the experience patterns of operating costs are well known by the public, the installer or utility company must be able to furnish a reasonably accurate estimate of the yearly fuel bill to the homeowner. With other fuels, there has not been too much emphasis on accuracy when estimating yearly fuel bills.

At best, a heat loss calculation is an estimate requiring judgement on the part of the engineer. Assumptions of indoor and outdoor temperatures must be made; judgement must be exercised in assuming temperatures of attics, basements, crawl spaces, and other unheated or partially heated spaces; and the amount of infiltration and ventilation air must be estimated. Usually no consideration is given to the effects of heat from lights and appliances, solar heat, metabolic heat from occupants, wind effects, etc. The outdoor design temperature and wind conditions are chosen to represent the most severe condition that might be imposed on the heating system except for isolated short-time conditions.

In houses with large heat losses, small inaccuracies in the initial estimate do not have any great effect on the total seasonal fuel consumption and in some cases tend to balance each other. However, as the heat loss is reduced by the addition of more insulation and the general improvement of construction techniques and details, the seasonal fuel consumption is reduced to the point where it becomes very sensitive to these normal inaccuracies. The variations in fuel consumption due to these inaccuracies become a significant percent of the total.
The equation for determining fuel consumption for any period of time may be written as:

\[ F = \frac{H \times C \times t}{E \times U} \]  \hspace{1cm} (1)

where:

- \( H = \) heat loss in BTU's per hour per degree temperature differential
- \( C = \) hours of operation
- \( t = \) average temperature differential (indoor-outdoor)
- \( E = \) efficiency of fuel utilization
- \( U = \) heating value in BTU's per unit of fuel
- \( F = \) quantity of fuel required

For seasonal fuel consumption, degree-days may be substituted for the average temperature differential. Daily degree-days are defined as the difference between 65°F and the mean daily temperature when it is less than 65°F. The mean temperature is the temperature midway between the highest and lowest hourly temperature recorded during the day. For example: if the daily temperatures varied between 60°F and 40°F, the mean daily temperature would have been 50°F and there would have been 65°F - 50°F or 15 degree-days. The total degree-days for the heating season are obtained by summing up the daily degree-days. While the mean daily temperature will not necessarily be the same as the average temperature for any one day, over a long period of time the average of the mean daily temperatures will very closely approximate the average seasonal temperature.

The 65°F base for accumulating degree-days is based on observations made by the American Gas Association that heating plant operation did not commence until the outdoor temperature dropped below 65°F when indoor temperatures were maintained in the 68°F to 72°F range. The 65°F is, then, only approximate and adds to the possible deviations when comparing estimated fuel consumption to actual fuel consumption. Since weather data is accumulated using this base, it is expedient to use this data as a means of estimating fuel consumption.

The term "H" in equation (1) may be written as:

\[ H = \frac{HL}{TD} \]  \hspace{1cm} (2)

where:

- \( TD = \) design temperature differential (usually 70°F - design outdoor temperature)
- \( HL = \) calculated heat loss at design temperature differential in BTU's per hour
Substituting equation (2) for H and degree-days (DD) for "t", equation (1) may then be written as:

\[
F = \frac{HL \times DD \times C}{TD \times U \times E}
\]  
(3)

which is the basic formula for estimating fuel consumption using the degree-day method. For electricity, the value of "U" is 3,413 BTU's per kilowatt-hour and E may be assumed to be 1.00, since all the power used is transformed into heat.

Equation (3) may then be further refined and written as:

\[
F = \frac{HL \times DD \times C}{TD \times 3,413 \times 1.00}
\]

or

\[
F = \frac{HL \times DD \times C}{TD \times 3,413}
\]

(4)

where:

\[F = \text{quantity of fuel required in kilowatt-hours}\]

Since "C" is defined as "operating hours," it is normally 24 hours. However, experience has shown that this will usually result in high estimates of fuel consumption (5, 6, 8).

As stated earlier, little consideration is given to extraneous heat gains in the calculation of seasonal fuel consumption. In order to get closer approximations, it has been the practice to use an "apparent C-number" in place of the 24 value, rather than to introduce a correction factor or to assume efficiencies greater than 100%. The problem is to select the apparent C-value.

It has been suggested in various publications that a C-value ranging from 10 to 24 should be used, (5, 6) depending on the infiltration rate assumed. The Federal Housing Administration and the National Electrical Manufacturers Association have recommended the use of 18.5 as the value of C for electrical heating.

The experience of several utility companies has indicated that the 18.5 value is not always dependable and that the apparent C-value may be greater or smaller in many instances.

In 1960 the Commonwealth Edison Company of Chicago, Illinois, and the Small Homes Council—Building Research Council of the University of Illinois entered into a cooperative investigation to study the relationship between estimated fuel consumption and actual fuel consumption in several family occupied, electrically heated homes served by the Commonwealth Edison Company and its Public Service Company divisions. The results of this study were to be used as a basis for exercising judgement in the estimation of seasonal fuel consumption.
As part of the program the study was to attempt to evaluate the general effectiveness of the heating systems and to ascertain any special factors relating to comfort and energy consumption.

This report summarizes the results of the study conducted during the 1960-1961 heating season.

1. Houses would be equipped with either baseboard heaters or ceiling cable.
2. Houses would be occupied by families including children.
3. During pre-selection interviews it would be ascertained that no abnormal activities would be carried on in the house that would modify influence its heating characteristics.
4. The houses selected would not be extremely large or small in area but would be representative of what could be considered average size and construction.

As shown in Table 1, the houses selected range in size from 1,025 square feet to 1,977 square feet. In multi-level houses the rooms partially below grade and heated continuously are included in the total area. Of the ten houses, four are of multi-level design and six are single-floor design. Seven of the houses have basements, one has a partial basement, and two are over crawl spaces. Heating equipment was installed in all of the basements but since heating is intermittent the basement was not included in the area of the house. The houses orient around the compass and half are considered to be protected. Protected is defined as having houses close by or sheltered by trees and plantings. Four houses are equipped with baseboard units and six with ceiling cable installations.

Photographs of the ten houses are shown in figures one through ten.
II. SELECTION OF HOUSES AND INSTRUMENTATION

Approximately twenty houses were made available by the sponsor for selection by the staff of the Small Homes Council-Building Research Council. Of these, ten houses were selected. Selection was influenced by the following factors:

1. Houses would be equipped with either baseboard heaters or ceiling cable.
2. Houses would be occupied by families including children.
3. From pre-selection interviews it would be ascertained that no abnormal activities would be carried on in the house that would unduly influence its heating characteristics.
4. The houses selected would not be extremely large or small in area but would be representative of what could be considered average size and construction.

As shown in Table I, the houses selected range in size from 1,025 square feet to 1,877 square feet. In multi-level houses the rooms partially below grade and heated continuously are included in the total area. Of the ten houses, four are of multi-level design and six are single-floor design. Seven of the houses have basements, one has a partial basement, and two are over crawl spaces. Heating equipment was installed in all of the basements but since heating is intermittent the basement was not included in the area of the house. The houses orient around the compass and half are considered to be protected. Protected is defined as having houses close by or sheltered by trees and plantings. Four houses are equipped with baseboard units and six with ceiling cable installations.

Photographs of the ten houses are shown in figures one through ten.

Each house was equipped with temperature recording devices to record indoor and outdoor temperatures. The bulbs of the outdoor recorders were located on the north side of the houses to provide shielding from the effects of direct sun. One indoor recorder was located in the living area of the house and one in the bedroom area. In multi-level houses, a third recorder was placed in the "lower-level" area. The recorders were equipped with seven-day charts and were changed weekly by the occupants of the house.

Sub-metering of the electrical system was accomplished by the installation of recording demand meters on the heating circuit and recording demand meters on the total house circuit. The demand meters recorded the electricity used each half-hour. The demand meter tapes were removed monthly and the data processed by computer to give half-hourly kilowatt-hour usage and total daily kilowatt-hours consumed.
<table>
<thead>
<tr>
<th>House No.</th>
<th>Sq. Ft.</th>
<th>1 floor or Multi-level</th>
<th>Bsmt.</th>
<th>Walls (1)</th>
<th>Roof (2)</th>
<th>Front Faces</th>
<th>Protected (3)</th>
<th>Equipment (4)</th>
</tr>
</thead>
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<td>1</td>
<td>1800</td>
<td>M. L.</td>
<td>Yes</td>
<td>F-L</td>
<td>L</td>
<td>E</td>
<td>No</td>
<td>BB</td>
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<td>1877</td>
<td>M. L.</td>
<td>No</td>
<td>F-L</td>
<td>L</td>
<td>S</td>
<td>Yes</td>
<td>BB</td>
</tr>
<tr>
<td>3</td>
<td>1745</td>
<td>M. L.</td>
<td>Yes</td>
<td>M-L</td>
<td>D</td>
<td>N</td>
<td>Yes</td>
<td>CC</td>
</tr>
<tr>
<td>4</td>
<td>1609</td>
<td>1 FL</td>
<td>Yes</td>
<td>F-L</td>
<td>L</td>
<td>E</td>
<td>No</td>
<td>CC</td>
</tr>
<tr>
<td>5</td>
<td>1555</td>
<td>1 FL</td>
<td>Yes</td>
<td>M-L</td>
<td>M</td>
<td>SW</td>
<td>No</td>
<td>CC</td>
</tr>
<tr>
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<td>1025</td>
<td>1 FL</td>
<td>Yes</td>
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<td>L</td>
<td>W</td>
<td>Yes</td>
<td>BB</td>
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<tr>
<td>7</td>
<td>1084</td>
<td>1 FL</td>
<td>Yes</td>
<td>M-L</td>
<td>M</td>
<td>S</td>
<td>Yes</td>
<td>CC</td>
</tr>
<tr>
<td>8</td>
<td>1583</td>
<td>M. L.</td>
<td>No</td>
<td>F-D</td>
<td>L</td>
<td>N</td>
<td>No</td>
<td>CC</td>
</tr>
<tr>
<td>9</td>
<td>1412</td>
<td>1 FL</td>
<td>Part</td>
<td>F-M</td>
<td>D</td>
<td>NW</td>
<td>No</td>
<td>BB</td>
</tr>
<tr>
<td>10</td>
<td>1560</td>
<td>1 FL</td>
<td>Yes</td>
<td>M-L</td>
<td>M</td>
<td>N</td>
<td>Yes</td>
<td>CC</td>
</tr>
</tbody>
</table>

(1) F-Frame; M-Masonry; L-Light Colored; M-Medium; D-Dark;

(2) L-Light Colored; M-Medium; D-Dark;

(3) Protected is defined as having houses close by or protected by trees and plantings.

(4) BB-Baseboard Units
     CC-Ceiling Cable
Figure 7, House No. 7

Figure 8, House No. 8

Figure 9, House No. 9

Figure 10, House No. 10
III. HEAT LOSS CALCULATIONS

For each house an estimate of heat loss was made using the standard procedure outlined in the Guide of the American Society of Heating, Refrigeration and Air-Conditioning Engineers, since this procedure is applicable to any structure regardless of fuel or heating system employed and is generally considered the best procedure currently available.

The following assumptions were used in the calculations:

1. Indoor design temperature: 70°F
2. Outdoor design temperature: -10°F
3. Ventilated attic spaces are at outdoor design temperature
4. Unheated basements or crawl spaces are at 50°F
5. Unheated garages are at outdoor design temperature
6. Ceiling temperatures in cable installations are at 100°F
7. Glass areas are taken as the sash opening with the U-value adjusted for the wood sections
8. Infiltration is calculated on the volume method at one air change per hour and at three-quarters of an air change per hour.

The calculated heat losses for the ten houses are listed in Table II. At one air change per hour the heat losses range from 25.2 BTUH/square foot (at design temperatures) to 31.6 BTUH/square foot. At three-quarters of an air change per hour, they range from 22.5 BTUH/square foot to 28.4 BTUH/square foot. This is less than the 40 BTUH/square foot maximum allowed by the Federal Housing Administration but is representative for houses with electric heating in the northern Illinois area.

During the selection of the houses it was established that the basement area in House Number 10 would be used and heated almost continuously. This is reflected in the heat loss calculation listed in Table II. For the other houses with basements no adjustment was made for basement heating and heat losses through the floor were calculated on the basis of assumption number 4 listed above.
### TABLE II

Calculated Heat Loss (1)

<table>
<thead>
<tr>
<th>House No.</th>
<th>Square Feet</th>
<th>One Air Change BTUH</th>
<th>BTUH per Square Foot</th>
<th>Three-Fourth Air Change BTUH</th>
<th>BTUH per Square Foot</th>
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<td>1</td>
<td>1800</td>
<td>51,737</td>
<td>28.7</td>
<td>46,432</td>
<td>25.8</td>
</tr>
<tr>
<td>2</td>
<td>1877</td>
<td>53,437</td>
<td>29.5</td>
<td>47,643</td>
<td>25.4</td>
</tr>
<tr>
<td>3</td>
<td>1745</td>
<td>54,058</td>
<td>31.0</td>
<td>48,893</td>
<td>28.0</td>
</tr>
<tr>
<td>4</td>
<td>1609</td>
<td>40,948</td>
<td>25.4</td>
<td>36,828</td>
<td>22.9</td>
</tr>
<tr>
<td>5</td>
<td>1555</td>
<td>41,735</td>
<td>26.8</td>
<td>37,355</td>
<td>24.0</td>
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<tr>
<td>6</td>
<td>1025</td>
<td>28,650</td>
<td>27.9</td>
<td>26,708</td>
<td>26.0</td>
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<tr>
<td>7</td>
<td>1084</td>
<td>33,227</td>
<td>30.6</td>
<td>30,097</td>
<td>28.4</td>
</tr>
<tr>
<td>8</td>
<td>1583</td>
<td>39,967</td>
<td>25.2</td>
<td>35,667</td>
<td>22.5</td>
</tr>
<tr>
<td>9</td>
<td>1412</td>
<td>40,927</td>
<td>28.8</td>
<td>37,426</td>
<td>26.4</td>
</tr>
<tr>
<td>10</td>
<td>1560</td>
<td>61,176</td>
<td>31.6(2)</td>
<td>53,166</td>
<td>26.4(2)</td>
</tr>
</tbody>
</table>

(1) Calculations based on 70 degrees indoor temperature and -10 degrees outdoor temperature.

(2) Loss per square foot - First floor
IV. NET FUEL CONSUMPTION

The data gathered over the 1960-1961 heating season was analyzed to make a comparison of estimated fuel consumption based on the calculated heat loss of the building and degree-days using equation (4) and the total fuel consumption for the season.

Table III summarizes the degree-days and average monthly temperatures for the period October 1, 1960, through April 30, 1961, for the areas where the houses are located. As seen in the last column of the table the average outdoor temperature ($t_o$) for this period derived from the summation of degree-days is very close to the actual average temperature as recorded for the period.

As stated earlier in this report, degree-days are accumulated using a base of 65°F. This assumes an indoor temperature of 70°F. Since the temperatures in all of the houses were not maintained at 70°F, the degree-days for each location were adjusted to reflect this difference. Table IV lists the adjusted degree-days for each house.

An estimate of fuel consumption was made for each house based on the calculated heat loss listed in Table II. These are listed in Table IV. Table IV also lists the actual kilowatt-hours used during this period and in the last two columns shows the "apparent C-value" i.e., the corrected or adjusted value of $C$ to be used in equation (4) that will give an estimated consumption equal to the actual fuel used.

The C-values for an assumed three-quarters of an air change per hour range from a low of 15.5 to a high of 26.0 with an average value of 19.0. This approximates very closely the 18.5 value suggested by the various agencies as discussed earlier.

The problem is to find some rational reason for the difference in the performance of the ten houses. As discussed earlier, the variables affecting house performance are numerous. Differences in quality of construction, exposure to winds, and the living habits of the occupants will affect infiltration rates considerably. However, this will not completely account for the wide range of performance experienced.

Gains from other electrical equipment and the metabolic gain from the occupants will also contribute to the variation from the calculated fuel consumption. Table IV lists the other electrical consumption in each of the houses. House Number 8 had the least consumption for the period (4,989 KWH) and House Number 3 the greatest (12,493 KWH), yet both houses had almost the same apparent C-value. It should be remembered that when estimating fuel consumption using the degree-day method, an allowance is made for extraneous gains.
### TABLE III

**Summary of Degree Days and Average Monthly Temperatures**

*(From ILLINOIS CLIMATOLOGICAL DATA)*

<table>
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<td>712</td>
<td>1243</td>
<td>1340</td>
<td>912</td>
<td>795</td>
<td>560(2)</td>
<td>5917(2)</td>
<td>28.4</td>
<td>36.6</td>
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<td></td>
<td></td>
<td>53.5</td>
<td>41.1</td>
<td>24.8</td>
<td>21.5</td>
<td>32.3</td>
<td>39.1</td>
<td>615</td>
<td>5972</td>
<td>28.2</td>
<td>36.8(1)</td>
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<td>Waukegan</td>
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<td>373</td>
<td>686</td>
<td>1240</td>
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<td>814</td>
<td>655</td>
<td>5992</td>
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<td>36.7(1)</td>
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<td></td>
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<td>52.8</td>
<td>41.8</td>
<td>24.9</td>
<td>22.1</td>
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<td>38.4</td>
<td>42.9</td>
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<td>6 &amp; 10</td>
<td>301</td>
<td>657</td>
<td>1225</td>
<td>1284</td>
<td>853</td>
<td>741</td>
<td>612</td>
<td>5673</td>
<td>26.8</td>
<td>38.2(1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>55.6</td>
<td>42.8</td>
<td>25.3</td>
<td>23.3</td>
<td>34.3</td>
<td>40.8</td>
<td>44.3</td>
<td></td>
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<td>38.0</td>
</tr>
<tr>
<td>Morrison</td>
<td>7</td>
<td>347</td>
<td>613</td>
<td>1237</td>
<td>1339</td>
<td>880</td>
<td>772</td>
<td>590</td>
<td>5778</td>
<td>27.2</td>
<td>37.8(1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>53.7</td>
<td>41.7</td>
<td>24.9</td>
<td>21.7</td>
<td>33.3</td>
<td>40.0</td>
<td>45.0</td>
<td></td>
<td></td>
<td>37.2</td>
</tr>
<tr>
<td>Dixon</td>
<td>8</td>
<td>350</td>
<td>687</td>
<td>1258</td>
<td>1331</td>
<td>893</td>
<td>802</td>
<td>607</td>
<td>5928</td>
<td>28.0</td>
<td>37.0(1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>53.8</td>
<td>41.9</td>
<td>24.2</td>
<td>21.7</td>
<td>33.0</td>
<td>39.0</td>
<td>44.6</td>
<td></td>
<td></td>
<td>36.9</td>
</tr>
</tbody>
</table>

(1) Based on Degree-Days

65° - DD/Day = t₀ Av.

(2) To April 27, 1961, (House No. 2).
<table>
<thead>
<tr>
<th>House No.</th>
<th>$t_{\text{Av}}$ (°F)</th>
<th>Degree Days</th>
<th>Estimated Seasonal Fuel Consumption</th>
<th>Actual Consumption</th>
<th>Apparent &quot;C&quot; Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 A.C. KWH</td>
<td>3/4 A.C. KWH</td>
<td>Heating KWH</td>
</tr>
<tr>
<td>1</td>
<td>70</td>
<td>5972</td>
<td>27,200</td>
<td>24,300</td>
<td>19,756</td>
</tr>
<tr>
<td>2(6)</td>
<td>68</td>
<td>5548</td>
<td>26,000</td>
<td>23,200</td>
<td>18,304</td>
</tr>
<tr>
<td>3</td>
<td>69</td>
<td>5788</td>
<td>27,500</td>
<td>24,900</td>
<td>19,195</td>
</tr>
<tr>
<td>4</td>
<td>69</td>
<td>5830</td>
<td>21,000</td>
<td>18,900</td>
<td>20,491</td>
</tr>
<tr>
<td>5</td>
<td>69</td>
<td>5385</td>
<td>19,710</td>
<td>17,650</td>
<td>12,816</td>
</tr>
<tr>
<td>6</td>
<td>75</td>
<td>6742</td>
<td>17,000</td>
<td>15,800</td>
<td>12,162</td>
</tr>
<tr>
<td>7</td>
<td>72</td>
<td>6190</td>
<td>18,100</td>
<td>16,400</td>
<td>10,576</td>
</tr>
<tr>
<td>8</td>
<td>69</td>
<td>5724</td>
<td>20,150</td>
<td>17,980</td>
<td>13,727</td>
</tr>
<tr>
<td>9</td>
<td>74</td>
<td>6890</td>
<td>24,800</td>
<td>22,700</td>
<td>16,646</td>
</tr>
<tr>
<td>10</td>
<td>68</td>
<td>5249</td>
<td>28,500</td>
<td>24,500</td>
<td>20,121</td>
</tr>
</tbody>
</table>

Average 7,857 17.1 19.0

(1) Period: October 1, 1960, to April 30, 1961
(2) $t_{\text{Av}}$ = average indoor temperature during heating season
(3) Adjusted for actual indoor temperature
(4) Calculated using equation (4) with "C" = 24
(5) Lights, appliances, etc.
(6) Through April 27, 1961
### TABLE V.

**Relationship of Glass Areas**

<table>
<thead>
<tr>
<th>House</th>
<th>Sq. Ft. Floor</th>
<th>Glass Sq. Ft.</th>
<th>% Wall</th>
<th>Glass Sq. Ft.</th>
<th>Glass % Total</th>
<th>x 10^-2 Glass - Ratio to Floor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1800</td>
<td>271.0</td>
<td>17.3</td>
<td>24.4</td>
<td>9.2</td>
<td>1.4 5.0 0.8 7.8</td>
</tr>
<tr>
<td>2</td>
<td>1877</td>
<td>285.7</td>
<td>17.8</td>
<td>130.9</td>
<td>45.7</td>
<td>7.0 0.8 4.8 2.6</td>
</tr>
<tr>
<td>3</td>
<td>1745</td>
<td>378.0</td>
<td>22.7</td>
<td>90.0</td>
<td>23.8</td>
<td>5.2 4.5 6.5 5.5</td>
</tr>
<tr>
<td>4</td>
<td>1609</td>
<td>197.1</td>
<td>16.1</td>
<td>65.7</td>
<td>0</td>
<td>0 4.1 1.8 6.4</td>
</tr>
<tr>
<td>5</td>
<td>1555</td>
<td>161.6</td>
<td>13.4</td>
<td>47.5</td>
<td>14.6</td>
<td>1.5 3.1 5.7 --</td>
</tr>
<tr>
<td>6</td>
<td>1025</td>
<td>160.7</td>
<td>14.7</td>
<td>20.2</td>
<td>22.8</td>
<td>3.7 2.0 4.1 6.1</td>
</tr>
<tr>
<td>7</td>
<td>1084</td>
<td>169.0</td>
<td>15.8</td>
<td>34.4</td>
<td>21.6</td>
<td>3.4 3.2 7.2 1.9</td>
</tr>
<tr>
<td>8</td>
<td>1583</td>
<td>155.2</td>
<td>9.8</td>
<td>48.6</td>
<td>31.3</td>
<td>3.1 1.0 3.2 2.5</td>
</tr>
<tr>
<td>9</td>
<td>1412</td>
<td>201.1</td>
<td>14.9</td>
<td>39.0</td>
<td>22.8</td>
<td>3.2 2.8 5.8 2.4</td>
</tr>
<tr>
<td>10</td>
<td>1560</td>
<td>204</td>
<td>14.6</td>
<td>48.1</td>
<td>23.6</td>
<td>3.1 4.4 1.5 4.0</td>
</tr>
</tbody>
</table>
Solar gain, as an extraneous heat source, will vary considerably from house to house and will be dependent, for the most part, on the orientation of the major glass areas of the building. Solar gain through roofs is not great during the winter months since high solar angles are never reached. Gains through solid walls are also generally low because of the low mass of the construction and the high reflectance of the usually light colored walls. (In the ten houses considered in this study all but one house had light colored exterior walls).

The fact that solar oriented houses will result in a reduction of heating requirements is not new. In 1946 F. W. Hutchinson, (2) reporting on the progress of the "solar house" at Purdue University indicated a savings of 10% over a conventional house. In the report on the Wood Conversion Test House (8) in Minnesota, approximately 9% of the heating required during the period February 5-23, 1960, was attributed to solar radiation.

Table V lists the glass areas of the ten houses investigated and the distribution of the glass areas around the houses. The last four columns of Table V give the ratio of the area of glass to the total floor area of the houses for the various orientations. If the houses are listed in order of the magnitude of the ratio of south glass to floor area, as is done in Table VI, it is evident that a strong influence on the variance of the apparent C-value can attribute to this ratio.

Pursuing this analysis, if the houses are listed in order of magnitude of the ratio of east plus south glass to floor area (Table VII), this same influence on the apparent C-value can be seen. If east, south, and west glass are considered (Table VIII), the results are more scattered. The data in Tables VI and VII are plotted in Figures 11 and 12 and regression lines are drawn for the points. It is not intended that these lines be used for design purposes but they serve only as an illustration of the relationship involved.

Further information on the effect of the orientation of major glass areas may be had by studying Figures 13, 14, and 15. The lower portions of these illustrations represent the electrical demand in half-hour periods for houses 4, 6, and 7 for December 22, 1960. The clear areas of the bar-graphs represent heating demand and the shaded areas represent other electrical demand.

House Number 4, with a south glass to floor ratio of 0.018, shows very little change in electrical demand during the twenty-four hour period except for the period between 5:00 p.m. and 7:00 p.m. where the other electrical input is high and is probably supplying part of the heating requirement. There is some indication of extraneous gain other than electrical input since the heating demand shows no increase during the evening hours (taking into consideration other electrical input) even though outdoor temperatures are falling and indoor temperatures are staying steady.

House Number 6 (ratio of 0.041) shows a more marked decrease in heating demand starting at 9:30 a.m. and carrying through until late in the evening. It is interesting to note that the high other electrical input between noon and 1:30 p.m. does not have as great an effect on heating demand as might be expected.
### TABLE VI
RELATION OF SOUTH GLASS TO "C" VALUE

<table>
<thead>
<tr>
<th>HOUSE NO.</th>
<th>EQUIP.</th>
<th>RATIO SOUTH GLASS TO FLOOR AREA (x10^{-2})</th>
<th>APPARENT &quot;C&quot; VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Multilevel Houses</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>BB</td>
<td>0.8</td>
<td>19.5</td>
</tr>
<tr>
<td>8</td>
<td>CC</td>
<td>3.2</td>
<td>18.4</td>
</tr>
<tr>
<td>2</td>
<td>BB</td>
<td>4.8</td>
<td>19.0</td>
</tr>
<tr>
<td>3</td>
<td>CC</td>
<td>6.5</td>
<td>18.5</td>
</tr>
<tr>
<td><strong>Single Level Houses</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>CC</td>
<td>1.5</td>
<td>19.7</td>
</tr>
<tr>
<td>4</td>
<td>CC</td>
<td>1.8</td>
<td>26.0</td>
</tr>
<tr>
<td>6</td>
<td>BB</td>
<td>4.1</td>
<td>18.4</td>
</tr>
<tr>
<td>5</td>
<td>CC</td>
<td>5.7</td>
<td>17.4</td>
</tr>
<tr>
<td>9</td>
<td>BB</td>
<td>5.8</td>
<td>17.6</td>
</tr>
<tr>
<td>7</td>
<td>CC</td>
<td>7.2</td>
<td>15.5</td>
</tr>
</tbody>
</table>

### TABLE VII
RELATION OF EAST PLUS SOUTH GLASS TO "C" NUMBER

<table>
<thead>
<tr>
<th>HOUSE NO.</th>
<th>EQUIP.</th>
<th>RATIO GLASS TO FLOOR AREA (x10^{-2})</th>
<th>APPARENT &quot;C&quot; NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Multilevel Houses</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>CC</td>
<td>4.2</td>
<td>18.4</td>
</tr>
<tr>
<td>2</td>
<td>BB</td>
<td>5.6</td>
<td>19.0</td>
</tr>
<tr>
<td>1</td>
<td>BB</td>
<td>5.8</td>
<td>19.5</td>
</tr>
<tr>
<td>3</td>
<td>CC</td>
<td>11.0</td>
<td>18.5</td>
</tr>
<tr>
<td><strong>Single Level Houses</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>CC</td>
<td>5.9</td>
<td>19.7</td>
</tr>
<tr>
<td>4</td>
<td>CC</td>
<td>5.9</td>
<td>26.0</td>
</tr>
<tr>
<td>6</td>
<td>BB</td>
<td>6.1</td>
<td>18.4</td>
</tr>
<tr>
<td>9</td>
<td>BB</td>
<td>8.6</td>
<td>17.6</td>
</tr>
<tr>
<td>5</td>
<td>CC</td>
<td>8.8</td>
<td>17.4</td>
</tr>
<tr>
<td>7</td>
<td>CC</td>
<td>10.4</td>
<td>15.5</td>
</tr>
</tbody>
</table>
Figure 11

South Glass Vs. C - Value

- Multilevel Houses
- Single Level Houses

APPARENT C-VALUE

RATIO SOUTH GLASS TO FLOOR AREA
Figure 12

- Multilevel Houses
- Single Level Houses

APPARENT C-VALUE

RATIO EAST PLUS SOUTH GLASS TO FLOOR AREA
Figure 13

House No. 4
12-22-60

INDOOR TEMPERATURE

$T_i$ av. = 67°

OUTDOOR TEMPERATURE

$T_o$ av. = -17

Heating KWH: 235.1
Other KWH: 45.2

12 2 4 6 8 10 12 2 4 6 8 10 12
a.m. p.m.

TIME VS. ELECTRICAL DEMAND
INDOOR TEMPERATURE

$T_i \text{ av.} = 74$

OUTDOOR TEMPERATURE

$T_o \text{ av.} = -12^\circ$

Heating KWH: 182.5
Other KWH: 46.6

Figure 14
House No. 7
12-22-60

INDOOR TEMPERATURE

\[ t_i \text{ av. } = 74^\circ \]

OUTDOOR TEMPERATURE

\[ t_o \text{ av. } = -15^\circ \]

Heating KWH: 141.7
Other KWH: 33.1

Figure 15
- 21 -
TABLE VIII

RELATION OF EAST PLUS SOUTH PLUS WEST GLASS TO "C" NUMBER

<table>
<thead>
<tr>
<th>HOUSE NO.</th>
<th>EQUIP.</th>
<th>RATIO GLASS TO FLOOR AREA x10^-2</th>
<th>APPARENT &quot;C&quot; NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Multilevel Houses</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>BB</td>
<td>6.2</td>
<td>19.0</td>
</tr>
<tr>
<td>8</td>
<td>CC</td>
<td>6.7</td>
<td>18.4</td>
</tr>
<tr>
<td>1</td>
<td>BB</td>
<td>13.6</td>
<td>19.5</td>
</tr>
<tr>
<td>3</td>
<td>CC</td>
<td>16.5</td>
<td>18.5</td>
</tr>
<tr>
<td><strong>Single Level Houses</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>CC</td>
<td>8.8</td>
<td>17.4</td>
</tr>
<tr>
<td>10</td>
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<td>19.7</td>
</tr>
<tr>
<td>9</td>
<td>BB</td>
<td>11.0</td>
<td>17.6</td>
</tr>
<tr>
<td>6</td>
<td>BB</td>
<td>12.2</td>
<td>18.4</td>
</tr>
<tr>
<td>7</td>
<td>CC</td>
<td>12.3</td>
<td>15.5</td>
</tr>
<tr>
<td>4</td>
<td>CC</td>
<td>12.3</td>
<td>26.0</td>
</tr>
</tbody>
</table>

House Number 7 (ratio of 0.072) shows the greatest reduction in heating demand with a considerable carryover into the evening hours even though outdoor temperatures were falling and indoor temperatures remained steady.

In the houses studied, House Number 4 has the greatest deviation from the performance of the group. A thorough investigation of the conditions affecting House Number 4 does not reveal any simple explanation for this deviation except for the following possibilities:

1. The assumption of three-quarters of an air change per hour may have been too low. The house is located in an exposed area and infiltration may have been greater.

2. In the houses with basements no consideration was given in the heat loss calculations for intermittent basement heating and in this case the basement may have been heated more often than in the other houses.

House Number 7 also shows a deviation from the performance of the group but in the opposite direction. An investigation of this house revealed humidities higher than in the other houses and evidence of condensation. This would indicate a lower infiltration rate than assumed, possibly one-half of an air change per hour or less.
The multi-level houses as a group did not perform quite as well as the single-level houses. This apparent lower efficiency is most likely due to the inadequate data available to the engineer for estimating heat losses from the lower levels and the possibility that solar gains are not as great through glass near grade level due to possible shading of the glass surfaces.

The question of whether the performance of these ten houses can be attributed to the type of fuel used requires some discussion. All other factors remaining equal, without the flue required by combustible fuels, less infiltration will result. However, the savings accrued through solar gains must be attributed to the system of control rather than to the fuel.

Inherent to the resistance heating installed in these houses is complete room control, since each room or area is provided with its own thermostat. This means that rooms receiving extraneous gains from solar radiation, occupants, or other electrical apparatus need not be heated as much or as often as other rooms not receiving these gains. The result is more even temperatures and less of a tendency to overheat or underheat areas of the house as is typical of installations with one thermostat controlling the heating equipment for the whole house. If these houses were equipped with a central system using electricity as a heating medium, it is doubtful that full advantage of the extraneous gains would have been achieved.

From the results of this study, it is recommended that for the purpose of estimating seasonal fuel consumption a C-value of 18.5 (at 3/4 of an air change per hour) be used. When it is evident that a high percentage of the glass area of the house faces south, the 18.5 figure may be lowered. Careful judgement must be used in each case and consideration must be given to the other factors affecting fuel consumption as discussed in this report. If the situation is in reverse with very little expectation of solar gains, then the C-value must be increased, again with careful judgement on the part of the engineer.
V. COMFORT AND TEMPERATURE CONTROL

During the investigation period one day was spent at each house and a detailed field study was conducted. For the study, thermocouple stands were set up in each room of the house. Each stand carried four thermocouples to give temperature readings at three inches, 30 inches, 60 inches and 90 inches above the floor. Readings at half-hour intervals were made on a portable potentiometer. (See Figures 16 and 17). A sling psychrometer was used at one hour intervals in each room to determine relative humidities.

The data collected during the field study is summarized in Table IX. The fifth column of the table lists the average floor to ceiling temperature difference throughout the house. The maximum difference is listed in the sixth column. The rooms in lower levels of multi-level houses were not considered in listing the maximum difference. This was done since floor temperatures in rooms partially underground are more influenced by ground temperatures and would not represent a true picture of the characteristics of the heating equipment.

The floor to ceiling temperatures in the lower levels were complicated by other conditions. In House Number 2, heating in the lower level was accomplished by cables buried in the floor slab. This resulted in warmer floor temperatures than in the rest of the house. In House Number 8, the heating equipment in the lower level was mounted four feet above the floor and distribution was poor, resulting in greater differentials than would be expected when using ceiling cable as is used in the rest of the house.

As a group, the baseboard installations show an average floor to ceiling differential of 4.18°F. The ceiling cable installations average 4.65°F, about one-half degree greater. This is to be expected because of the nature of panel heating.

House Number 3 showed the greatest floor to ceiling differentials and some discussion of the conditions in this house is warranted. The design of this multi-level house includes a cathedral ceiling over the living and dining areas. The upper level opens directly into the living area. The maximum differential occurred in a bedroom in the upper level. A recording voltmeter in the heating circuit for this room indicated that very little if any heating was done during the test period. The large differential and the heating of the upper level is probably attributable to the flow of heat from the lower and intermediate levels. This is verified by the temperatures on the landing of the upper level where no heating cable is installed but temperatures were the same as in the rooms with heating cable.

The seventh and eighth columns of Table IX list the fluctuation in temperature within the house. The fluctuation of temperature within the house averaged 1.1 degrees. It is uncertain if the 3.5 degrees variation listed as the maximum for House Number 3 can be attributed to the heating system or to the conditions discussed previously. A study of the temperature in the room where the 3.5 degree variation occurred seems to indicate a condition of overheating of the space rather than a condition of poor control.
Figure 16, Thermocouple Stand

Figure 17, Thermocouple Console
### TABLE IX

**Floor to Ceiling Temperature Differentials & Temperature Control**

The last column in Table IX lists the average relative humidities maintained in the houses during the field study. These are all within acceptable limits considering the indoor and outdoor test.

Three other items of interest were noted during the field investigations. In all of the houses, the voltage thermostats were used to control the cycling of the heating equipment. In each house three or four of the thermostats were opened as a routine matter. A number of the thermostats inspected showed evidence of malfunction in that one lag of the cycling was demonstrated. This does not affect the operation of the heating equipment but it does not affect the temperature differentials.

In two or three of the houses investigated, it was noted that a draft of cold air bypassed the heating box and the thermostats were removed. This would account for the fact that the thermostats in some rooms needed to be set at a lower position than the other thermostats to maintain comparable temperatures. It would also tend to make close temperature control difficult.

### Temperature Differentials

<table>
<thead>
<tr>
<th>House No.</th>
<th>Equip.</th>
<th>Average $t_i$ $^\circ F$</th>
<th>Average $t_o$ $^\circ F$</th>
<th>Average $t_{max}$ $^\circ F$</th>
<th>Maximum $t_{max}$ $^\circ F$</th>
<th>Control $^\circ F$</th>
<th>Maximum $^\circ F$</th>
<th>Average Relative Humidity %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BB</td>
<td>71.9</td>
<td>34.7</td>
<td>5.02</td>
<td>5.9</td>
<td>1.5</td>
<td>2.2</td>
<td>33</td>
</tr>
<tr>
<td>2</td>
<td>BB</td>
<td>72.6</td>
<td>38.6</td>
<td>4.11</td>
<td>6.2</td>
<td>0.9</td>
<td>1.3</td>
<td>37</td>
</tr>
<tr>
<td>3</td>
<td>CC</td>
<td>70.4</td>
<td>54.6</td>
<td>5.70</td>
<td>7.8</td>
<td>2.1</td>
<td>3.5</td>
<td>38</td>
</tr>
<tr>
<td>4</td>
<td>CC</td>
<td>69.6</td>
<td>42.0</td>
<td>3.68</td>
<td>4.4</td>
<td>0.9</td>
<td>1.0</td>
<td>32</td>
</tr>
<tr>
<td>5</td>
<td>CC</td>
<td>69.0</td>
<td>50.9</td>
<td>4.65</td>
<td>6.9</td>
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<td>2.0</td>
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</tr>
<tr>
<td>6</td>
<td>BB</td>
<td>72.3</td>
<td>41.1</td>
<td>2.91</td>
<td>4.6</td>
<td>1.1</td>
<td>1.8</td>
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</tr>
<tr>
<td>7</td>
<td>CC</td>
<td>70.1</td>
<td>36.7</td>
<td>4.46</td>
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<td>1.5</td>
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<tr>
<td>8</td>
<td>CC</td>
<td>73.0</td>
<td>41.4</td>
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<td>41.9</td>
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<td>50.5</td>
<td>4.30</td>
<td>6.9</td>
<td>(4)</td>
<td>(4)</td>
<td>45</td>
</tr>
</tbody>
</table>

(1) BB - Baseboard Units  
CC - Ceiling Cable

(2) Rooms above grade only considered

(3) Average of greatest temperature fluctuation in each room above grade

(4) Data not available
The last column in Table IX lists the average relative humidities maintained in the houses during the field study. These are all within acceptable limits considering the indoor and outdoor temperatures during the day of the test.

Three other items of interest were brought out during the field investigations. In all of the houses, line voltage thermostats were used to control the cycling of the heating equipment. In each house three or four of the thermostats were opened as a routine matter. A number of the thermostats inspected showed evidence of malfunction in that one leg of the circuit would not disconnect. While this does not affect the operation of the heating equipment, such a malfunctioning thermostat is not in compliance with a building code which requires the thermostat to provide a completely "off" position.

In two or three of the houses investigated, it was noted that a draft of cold air spilled out of thermostat mounting box when the thermostats were removed. This would account for the fact that the thermostats in some rooms needed to be set at lower positions than in other rooms to maintain comfortable temperatures. It would also tend to make close temperature control difficult.

In House Number 8, a thermocouple was placed under the kitchen table to investigate the shading effect of furniture when panel heating was used. During this test, the temperature under the table lagged less than one degree behind the temperature in the middle of the room, indicating very little, if any, shading effect.
VI. SUMMARY

1. The formulas and factors for computing heat loss as given in the ASHRAE Guide are applicable to electrically heated houses.

2. For the purposes of estimating seasonal energy requirements, a C-value of 18.5 may be used when infiltration is estimated at three-quarters of an air change per hour. Under certain circumstances, the value must be varied.

3. The data collected indicates that the temperatures in these houses were controlled within acceptable limits.

4. The average temperature selected by the occupants of ceiling cable houses was generally lower than in those equipped with baseboard units.

5. The temperature gradient from ceiling to floor was not significantly different between ceiling cable (panel) and baseboard installations.

6. The humidity levels maintained in the houses was within acceptable limits during the field studies.
BIBLIOGRAPHY

1. Carroll, J. Raymond
   Electrical Heating, Proceedings, 15th Annual Short Course in Residential
   Construction, Small Homes Council-Building Research Council, University

2. Hutchinson, F. W.
   The Solar House: A Research Progress Report Heating and Ventilating,
   March, 1946.

3. Linden, E. E.
   A Statistical Method for Determining Heat Losses in Electrically Heated
   Residences, AIEE Transactions Vol. 79, Part II, Paper No. 60-28,
   March, 1960.

4. Novak, W. J.
   "A Manual of Electric Space Heating 1960", Electrical Construction and

5. Novak, W. J.
   "Electric Heat Can Cost Less Than Conventional Estimates Indicate",
   Electrical Construction and Maintenance, April, 1960.

6. Smith, Howard S. and Olson, Floyd
   "Design Heat Loss and the NEMA Constant", Electrical Construction and

7. Thompson, H. S. and Simons, J. W.
   Some Effects of Construction and Climatic Factors on Heating Five Expansible
   Farm Houses, Agricultural Research Service, U. S. Department
   of Agriculture, ARS 42-46, April, 1961.

8. Wisconsin Power & Light Company

9. Wood Conversion Company
   Preliminary Test House Project Results, 1961.