#3892

IN SITU TESTING OF THE THERMAL PERFORMANCE OF WALL SECTIONS IN N.W.T.

REPORT FOR CANADA MORTGAGE AND HOUSING CORPORATION

In Situ Testing of the Thermal Performance of Wall Sections in N.W.T.

FILE: 9287/92870726

Prepared by:

G. K. YUILL AND ASSOCIATES LTD.

1441 Pembina Highway
WINNIPEG, Manitoba
R3T 2C4

AUGUST 1 , 1989

TABLE OF CONTENTS

EXECUTIVE SUMMARY

A project to evaluate the thermal performance of composite wall sections in Arctic housing was carried out over the 1988/89 heating season in Rankin Inlet, Northwest Territories. The project involved in situ testing in four housing units that were of different styles and constructed in different years. The purpose of the project was to determine if significant reductions in the insulating value of otherwise physically sound composite wall sections have occurred as a result of wall degradation caused by exposure to the harsh Arctic environment.

The performance testing included inspections using infrared thermography equipment and continuous monitoring using guarded hot box calorimetry instrumentation. The infrared thermography scans were first conducted to ensure that the wall sections selected were properly insulated and of typical construction practise. Effective RSI values of the wall sections were determined from the data obtained from continuous monitoring with the calorimetry instrumentation. These measured values were then compared to theoretical values which were calculated using individual component thermal resistance values and accounting for thermal bridging of studs and strapping.

The housing units tested in this project were of the following types:

House No. 1: 1984 Nineplex
House No. 2: 1985 Duplex
House No. 3: 1986 Single Detached Retrofit (Constructed in 1976)
House No. 4: 1986 Duplex

The theoretical RSI values for the wall sections in these housing units were estimated to be 3.23 m^2K/W, 4.50 m^2K/W, 3.63 m^2K/W, and 4.77 m^2K/W, respectively.

The effective thermal resistance values of the wall sections tested were measured to be 3.56 m^2K/W, 5.09 m^2K/W, 2.11 m^2K/W, and 5.36 m^2K/W, respectively.

The results from testing wall sections in four housing units suggest that significant reductions in insulating value of composite wall sections have not occurred. The measured RSI values in three of the four houses were found to be in line with theoretical calculations.

For House No. 3 where the measured effective RSI value was significantly lower than the theoretical RSI value, speculation on the causes for the lower measured value were made.

1.0 INTRODUCTION

In recent years, heat loss from houses in the Canadian Arctic has become of increased concern. Fuel oil, which is used to heat most houses in the remote northern communities, is costly. Thus, bringing about the need for houses that are energy efficient and capable of sustaining the harsh climate conditions associated with extended winters and cold temperatures. While efforts have been made to construct houses with wall sections that are less susceptible to deterioration, building officials within Northwest Territories Housing Corporation (NWTHC) and Yukon Housing Corporation (YHC) remain concerned about the long term performance of building components exposed to the Arctic environment.

It has been suggested that the severe climate in the Arctic creates a unique environment that may, overtime, reduce the insulating value of composite wall sections. Factors include shrinkage of wood members, shifting of structures, and degradation of individual components within composite wall sections. Such occurrences may create air spaces between the insulation and the studs, allowing for convective loops to form. Actual degradation of individual building components may be the result of moisture migration.

To investigate the concerns raised by building officials in the Arctic, a project to carry out in situ testing of the thermal performance of wall sections in houses in the Northwest Territories was initiated by Canada Mortgage Housing Corporation (CMHC). G.K. Yuill and Associates Ltd. was contracted to conduct the investigation which involved infrared thermography scans and measurements of heat loss through wall sections using guarded hot box calorimetry instrumentation. The findings of this project were intended to investigate housing official's concerns that wall sections in Arctic housing undergo accelerated deterioration causing reductions in insulating value. They were also intended for use in the speculation on reasons for wall deterioration.

2.0 OBJECTIVES

Following are the three main objectives in conducting in situ thermal performance testing of wall sections of housing in the Arctic:

1. To determine if there is any appreciable reduction in the insulation value of composite wall sections exposed to harsh Arctic conditions for several years compared to theoretical values.

2. To speculate on the mechanisms that may be causing reductions in insulating value.

3. To recommend further field tests to measure those mechanisms causing reductions in insulating value.

3.0 HEAT LOSS MEASUREMENT THEORY

To measure the heat loss through a wall section, the use of a guarded hot box calorimeter is a common measurement technique. The energy balance equation for an apparatus of this type is of the following:

$$E_m = \frac{(T_{in} - T_{out})_{mean}\ A\ T}{RSI} + \Delta Q_s$$

where,

E_m = cumulative energy consumed by the heating element inside the calorimeter for the monitoring period (Wh);

$(T_{in} - T_{out})_{mean}$ = mean temperature difference across the metered wall section (air film to air film) for the monitoring period (^oC);

A = metered area or area under the guarded hot box calorimeter (m^2);

t = length of monitoring period (hrs);

RSI = effective thermal resistance value of the wall section tested (m^2K/W);

ΔQ_s = net energy stored in the wall section over the test period (W).

To solve for thermal resistance value, the above equation when rearranged, is of the following:

$$RSI = \frac{(T_{in} - T_{out})_{mean} \, A \, t}{E_m - \Delta Q_s}$$

The only unknown in the above equation is the stored energy term. Because this variable is difficult measure, it is desirable to reduce the effects of stored energy to a point where its presence is insignificant in the equation. The most practical means of accomplishing this is to utilize the longest test period possible such that the net stored energy in the test section becomes as small as possible compared to the cumulative energy conducted through the wall.

The effective thermal resistance values which are presented in this report, were determined using the theory stated above.

4.0 DESCRIPTION OF HOUSES

Four houses were tentatively selected for testing. Preferably, each house was to have been of a different type, and constructed in a different year. The purpose of selecting houses that were constructed in different years was to determine if wall sections in older houses show signs of increased deterioration. Because NWTHC officials already know that many of the older houses (constructed prior to 1980) have deteriorated wall sections, slightly newer houses were selected for this project. More specifically, the houses selected were either constructed or retrofitted within the last five years. The houses tested were of the following:

House No. 1: 1984 Nineplex Unit
House No. 2: 1985 Duplex Unit

House No. 3: 1986 Single Detached Retrofit (Constructed in 1976)
House No. 4: 1986 Duplex Unit

Originally, one of the tentatively selected houses was a 1986 4-plex unit. However, it was replaced with another duplex unit as it did not have a wall section of large enough surface area to accommodate a guarded hot box calorimeter. Although considerable effort was made in obtaining a replacement house that was different from the first three, the attempt was unsuccessful as the alternative wall sections also did not have large enough surface areas. Space was limited, primarily due to baseboard heating which covered most of the exterior wall sections in the houses. Three of the four wall sections tested were in houses that had baseboard heating on all exterior walls. The floor-to-ceiling heights in these houses were sufficient for accommodating the guarded hot box calorimeters.

Following are descriptions of the wall sections tested.

House No. 1: 1984 Nineplex

The nineplex was a multi-unit structure that consisted of nine separate dwelling units. The units were situated side-by-each, forming a long complex with the end units having three exterior walls, and the middle units having two exterior walls. The walls were of typical wood frame construction with 38 mm x 140 mm studs, 400 mm O.C. The walls (from interior to exterior) were composed of 12.7 mm gypsum board, vapour barrier, R.S.I. 3.5 batt insulation in the wall cavity, and 15.5 mm cedar siding. Figure 1 shows the cross section of the exterior wall in the nineplex.

The unit tested was a three-bedroom dwelling, located at one end of the structure. The wall section that the guarded hot box calorimeter was mounted to had a north-east exposure.

Figure 1. Exterior Wall Section of House No. 1

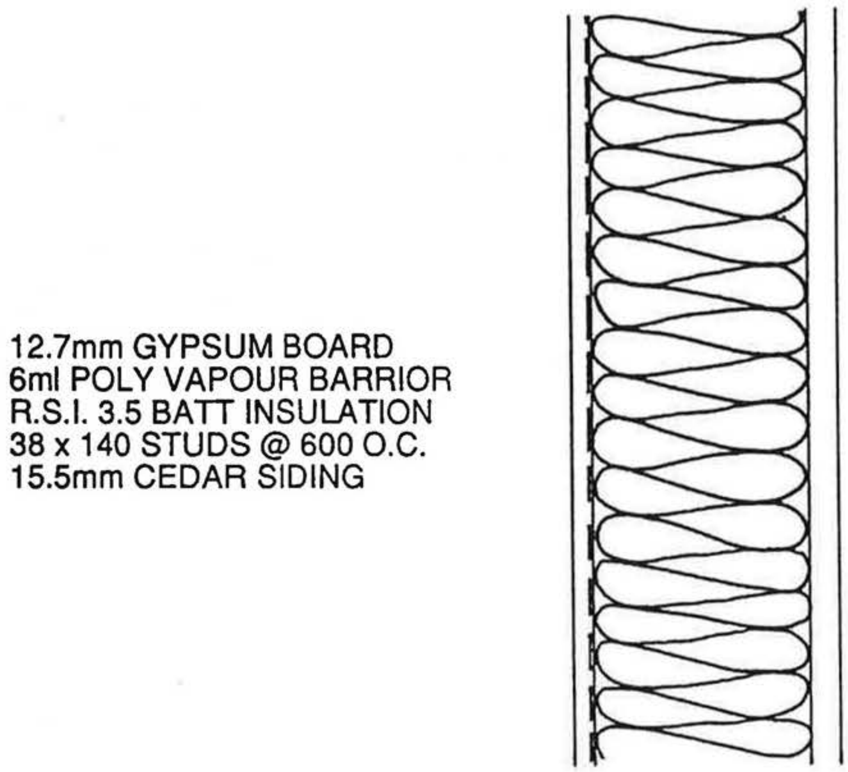
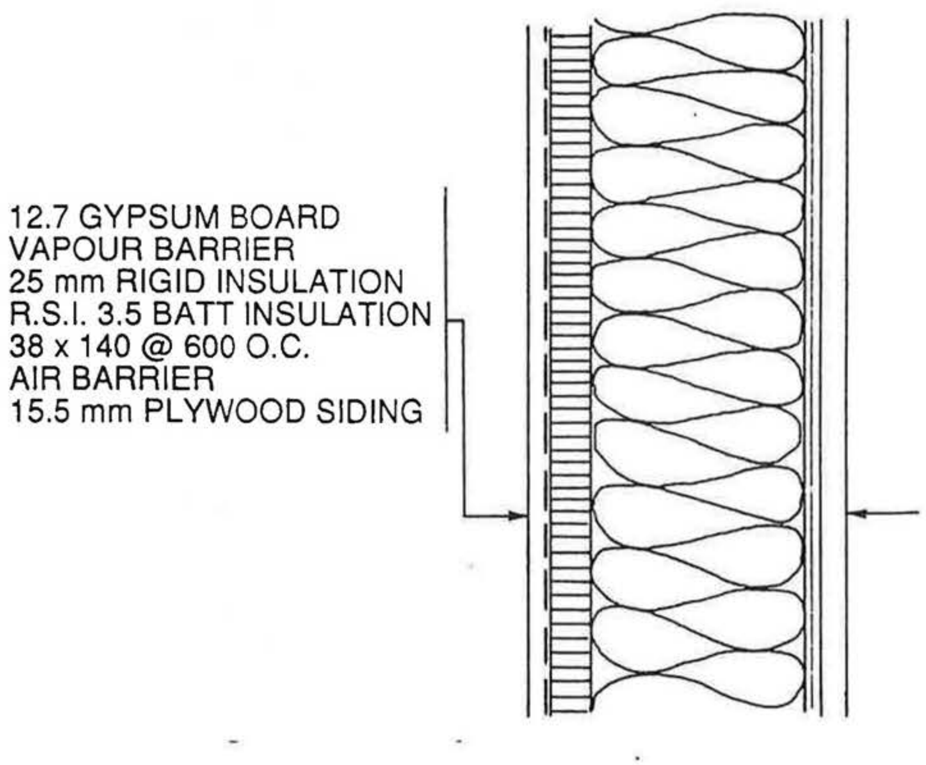


Figure 2. Exterior Wall Section of House No. 2



House No. 2: 1985 Duplex

The duplex was a two-dwelling structure with each unit having two stories. The walls were of typical wood frame construction with 38 mm x 140 mm studs, 600 mm O.C. The walls (from interior to exterior) were composed of 12.7 mm gypsum board, vapour barrier, 25 mm rigid insulation, R.S.I. 3.5 batt insulation in the wall cavity, air barrier, and 15.5 mm plywood siding. Figure 2 shows the cross section of the exterior wall in the duplex.

The wall section tested in House No. 2 was on the first level, and had a north exposure.

House No. 3: 1986 Retrofit

House No. 3 was a single detached dwelling unit that was constructed in 1976, and retrofitted in 1986. The original walls were of typical wood frame construction with 38 mm x 89 mm studs, 400 mm O.C. The wall cavity was insulated with R.S.I. 2.1 batt insulation. The retrofitted wall section had a gypsum board wall, horizontal strapping, and vapour barrier on the interior side of the original wall assembly, and 38 mm glas-clad complete with air barrier paper, and prefinished plywood siding on the exterior side of the original wall assembly. Figure 3 shows the cross section of the exterior wall in the 1986 retrofit.

The wall section tested had a north exposure. This house was the only house where the guarded hot box calorimeter was mounted on a wall that did not have a baseboard heater.

House No. 4: 1986 Duplex

The duplex was a two-dwelling structure with each unit having two stories. The walls were of typical wood frame construction with 38 mm x 140 mm studs, 600 mm O.C. The walls (from interior to exterior) were composed of 12.7 mm gypsum board, vapour barrier, 9.5 mm plywood, R.S.I. 3.5 batt insulation in wall cavity, and 38 mm glas-clad complete with air barrier paper, and prefinished

Figure 3. Exterior Wall Section of House No. 3

GYPSUM BOARD WALL FINISH ON 1 x 3 WOOD STRAPPING @ 16" O/C 6 mil POLY VAPOUR BARRIER ON EXISTING WALL ASSEMBLY c/w 2 x 2 VERT. WOOD STRAPPING @ 4'-0" O/C WITH $1^1/_2$" GLAS-CLAD BETWEEN c/w AIR BARRIER PAPER c/w PREFINISHED PLYWOOD SIDING

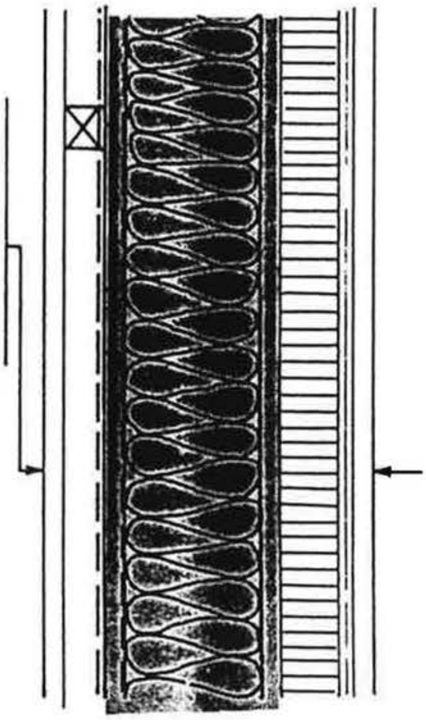
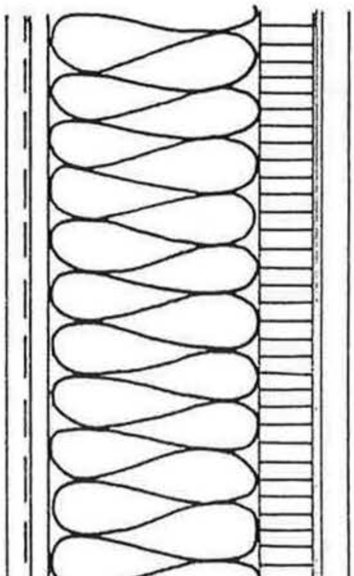


Figure 4. Exterior Wall Section of House No. 4

12.7mm GYPSUM BOARD
6ml POLY VAPOUR BARRIER
9.5mm PLYWOOD
R.S.I. 3.5 BATT INSULATION
38 x 140 @ 600 O.C.
38mm GLAS-CLAD
AIR BARRIER
15.5mm PLYWOOD SIDING



plywood siding. However, unlike that of the testing in House No. 2, the guarded hot box calorimeter was mounted on a wall having a south-east exposure.

5.0 MONITORING INSTRUMENTATION

5.1 Introduction

Testing the thermal performance of wall sections of housing in the Northwest Territories involved two important tasks. The first task was to conduct infrared thermography scans on the wall sections selected. The second task was to measure the heat loss through the wall sections using guarded hot box calorimeters, appropriately interfaced to microcomputer based data acquisition equipment.

The following sections describe the instrumentation used in carrying out this project.

5.2 Infrared Thermography Equipment

The infrared thermography equipment was obtained from Insight Infrared Energy Inspections in Winnipeg. This equipment consisted of a Model 750 AGA Infrared Scanner and a 35 mm camera complete with mount and light shield for photographing images on the monitor.

5.3 Portable Guarded Hot Box Calorimeters

Two portable guarded "hot box" calorimeters with control instrumentation were obtained from the Institute for Research in Construction of the National Research Council to measure the heat loss through the wall sections of interest. Each set-up consisted of three major components. Following is a description of each component.

a) Portable Hot Box Calorimeter. The portable hot box calorimeter is a five-sided, insulated box with one open side that is sealed to the test wall. Inside the hot box which is 1.96 meters high, 1.21 meters wide and 0.20 meters deep, is a 150 W heating element. The hot box is calibrated in the vertical position with the heating element oriented such that there is a relatively uniform distribution of heating. A thermopile junction to measure the differential temperature across the back wall of the calorimeter is also contained in the unit.

b) Pulse Generating Kilowatt-Hour Meter. A pulse generating kilowatt-hour meter which consists of a standard meter, optical card and a 12 volt power supply for powering the optical card, generates one pulse for every 0.1 watt-hours of energy consumed by the heating element.

c) Controller. The controller senses the temperature difference across the wall of the hot box by means of the thermopile junction. When the temperature in the house is greater than the temperature in the hot box, the controller turns on the heating element until the two temperatures are equal. Basically, the controller attempts to maintain the temperature in the hot box the same as the air temperature in the house.

Prior to the employment of the portable hot box calorimeter equipment in the specified application, the equipment was first calibrated at NRC. Details about the calibration are contained in Appendix A.

5.4 Data Acquisition Instrumentation

The monitoring equipment for each installation consisted of the following components:

a) Compaq or IBM/PC complete with a 20 MB hard disk and a battery backed time clock;
b) Sciemetric Instruments Model 8082A Electronic Measuring System with an IBM interface card;

c) Sciemetric Instruments PC-8 pulse counter card;
d) type T thermocouple wire suitable for indoor use; and
e) type T nylon coated thermocouple wire suitable for exposure to the outdoor temperatures in the Arctic climate region.

6.0 INSTALLATION

6.1 Sensor Placement

To carry out the guarded hot box calorimetry tests, 16 analog channels of the Sciemetric Instruments measurement system were utilized. 15 channels were used for measuring the various indoor and outdoor temperatures; 1 channel was used for measuring the analog output from the pulse counter card which counted pulses from the pulse generating kilowatt-hour meter.

The sensor placement strategy included the following temperature measurements:

1. Room Temperature (#1)
2. Room Temperature (#2)
3. Outside Temperature (#1)
4. Outside Temperature (#2)
5. Mimic Box Wall Temperature (Room Side)
6. Mimic Box Wall Temperature (Inside)
7. Exterior Wall Air Film Temperature Inside Mimic Box (Upper, Non-stud)
8. Exterior Wall Air Film Temperature Inside Mimic Box (Middle, Non-stud)
9. Exterior Wall Air Film Temperature Inside Mimic Box (Lower, Non-stud)
10. Exterior Wall Air Film Temperature Inside Mimic Box (Upper, Over Stud)
11. Exterior Wall Air Film Temperature Inside Mimic Box (Lower, Over Stud)
12. Outside Exterior Wall Air Film Temperature (Non-stud)
13. Outside Exterior Wall Air Film Temperature (Over Stud)
14. Inside Wall Cavity
15. Beneath Exterior Siding

All indoor temperature sensors were shielded with aluminum foil. Outdoor temperature sensors that were located on the north wall of the house were not shielded.

The temperature inside the wall cavity was measured by a thermocouple that was inserted three inches into the wall through a small hole in the wall board. This small hole, located approximately mid-way between two studs, was sealed with duct tape. To measure the temperature beneath the exterior siding, a thermocouple was inserted through a small hole where the wood siding overlapped.

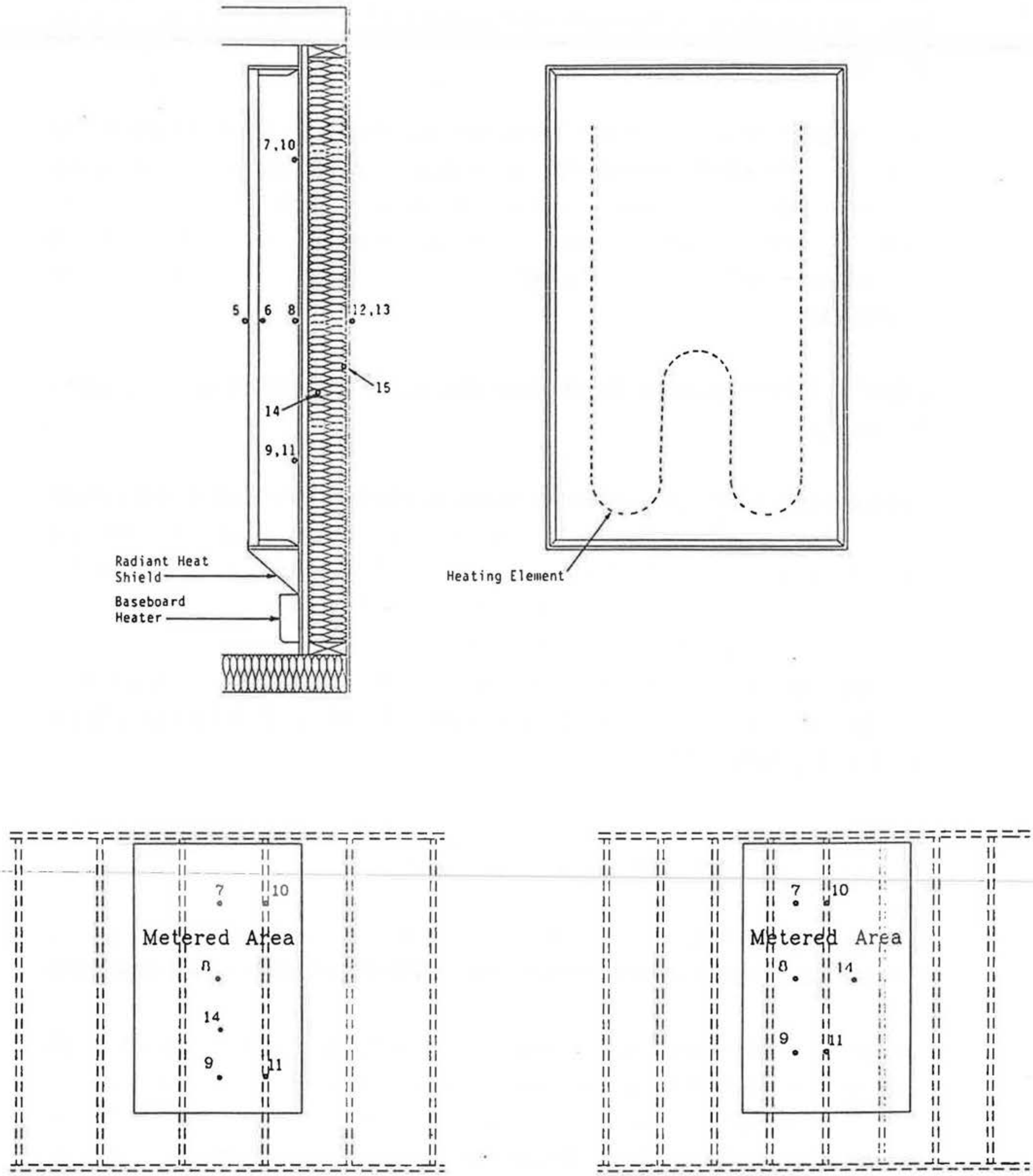
Figure 5 shows the approximate placement of the temperature sensors during monitoring.

The data acquisition system was controlled by the Sciemetric Instruments Level-5 software. Each channel was scanned once every 16 seconds and the cumulative average of the various temperatures and the cumulative total of the power consumed by the 150 W heater element were stored on disk every hour. At the end of the day, the data file was closed and a new data file was opened for the new day. Thus, a separate data file was created each day. The software also generated an error message file to indicate times of power failures and out of range measurements.

6.2 Installation of Guarded Hot Box Calorimeters

Locating wall sections of sufficient surface area for accommodating the guarded hot box calorimeters was a difficult task. Most of the houses had baseboard heaters on all exterior walls, leaving little room between the top of the baseboard heaters and the ceiling. In other houses where the baseboard-to-ceiling height was sufficient, the width of the wall space was insufficient due to windows or surface mounted electrical outlets. Three out of the four houses, finally selected, had baseboard heaters on the same wall as the guarded hot box calorimeters. Because this was the case, it was important that provisions were made to minimize the effects of the heaters immediately below the calorimeters.

Figure 5 Temperature Sensor Placement



38 x 140 Stud Wall 600 O.C.

38 x 140 Stud Wall 400 O.C.

Two steps were taken to ensure that the baseboard heaters did not affect the calorimeter testing. The first step was to mount the hot box as high as possible above the baseboard heater. In the three installations made in the present project, the hot box calorimeters were mounted 6 to 8 inches above the baseboard heaters. The second step was to shield the underside of the hot box with aluminum foil. This involved running aluminum foil from the wall at the top of the baseboard to the base of the hot box approximately 0.2 m out from the wall. Thus, there was an air space between the hot box calorimeter and the shield. This provision is portrayed in Figure 5.

The guarded hot box calorimeters were attached to the wall sections with four eye hooks, 0.25" nylon rope and duct tape. Two eye hooks were fixed to studs on each side of the hot box, and the nylon rope was used to strap the box to the wall. To keep the box from sliding down the wall, the rope was run from the lower eye hook on one side, under the short length of the box which faces the floor and back up to the lower eye hook on the other side. Duct tape was then used to make an airtight seal at the hot box/test wall interface.

The above described method of securing the guarded hot box calorimeters to the test walls proved to be successful. There was no sign of hot box separation from the wall on any of the installations. While efforts were made to shield the bases of the hot box calorimeters from the baseboard heaters, there is some uncertainty as to how the baseboard heaters may have affected the final results.

7.0 RESULTS

7.1 Introduction

In this section the results from testing wall sections in each of the four selected housing units are presented. Included are the findings from the guarded hot box calorimetry tests and comments on the infrared thermography scans. Following are a few points with regards to the measurements made by the microcomputer based data acquisition system, before going into the presentation of the results.

The sensor placement strategy in monitoring the heat loss through the selected wall sections is described in Section 6.1 of this report. As mentioned, several temperatures were measured including, indoor temperature, outdoor temperature, air film temperatures on the inside of the exterior wall section (over-stud and non-stud) and air film temperatures on the outside of the exterior wall section (over-stud and non-stud). In the analysis of the acquired data to determine thermal resistance values (RSI values), two temperatures were used. These two temperatures were the average of the various indoor air film temperatures and the average of the various outdoor air film temperatures. The proportionate studded and non-studded areas were taken into account when determining these average temperatures. Because the temperatures used in the analysis were air film temperatures rather than indoor air and outdoor air temperatures, the calculated RSI values are approximately representative of the wall sections (excluding air films).

The amount of energy released by the heating element in the guarded hot box calorimeter was recorded by the data acquisition system on an hourly basis. By recording this parameter hourly, presentation of the effects of stored energy in the wall sections tested was made possible. For each wall section a figure has been used to show the measured RSI values. The RSI value has been calculated for increasing time intervals starting from the beginning of the test. This technique shows how the error due to the effects of stored energy reduces with increasing time intervals.

The results from testing in each of the four housing units have been presented in the following four sub-sections.

7.2 House No. 1: Results from Testing

Thermal performance testing in the 1984 nineplex unit involved an initial infrared thermography scan followed by continuous monitoring with the guarded hot box calorimetry equipment. The infrared thermography scan was conducted on February 7, 1989. Continuous monitoring commenced on February 8, 1989 and was completed on March 6, 1989. During this time interval, approximately 620 hours of hourly data were collected with no breaks in the interval. Of the four houses tested in this project, this house was the only house where the monitoring period was unbroken.

The infrared thermography scan was conducted from inside the house where low lighting made for ease in viewing the black and white monitor of the scanner. From this view point, grey or black images on the monitor represented cold spots on the wall. No apparent cold spots were observed in the vicinity of the metered area on the wall section selected. One cold spot was observed on an adjacent wall in the first wall cavity from where the two walls met.

The net result from continuous monitoring is shown in Figure 6 where measured RSI value is plotted against time. A review of this figure indicates that the effects of stored energy were minimized after approximately 180 hours of monitoring. The effective RSI value for the selected wall section in House No. 1 was measured to be 3.66 m^2K/W.

A log of selected temperatures is shown in Figure 7. Indoor air temperatures fluctuated between 15.2^oC and 30.6^oC with the average being 24.3^oC. Outdoor air temperatures fluctuated between -9.5^oC and -39.9^oC with the average being -30.2^oC. Over the entire monitoring period, the average differential temperature across the wall section (air film to air film) was 51.2^oC.

In previous studies using similar monitoring instrumentation, the control system for maintaining the hot box air temperature the same as the room air temperature was considered to be operating satisfactorily if the temperature differential across the back wall of the calorimeter averaged less than 1^oC. The average box/room temperature differential, when monitoring the wall section in House No. 1, was 0.3^oC (a positive value indicates that the temperature in the hot box was slightly warmer than in the room).

7.3 House No 2: Results from Testing

Thermal performance testing in the 1985 duplex unit involved an initial infrared thermography scan followed by continuous monitoring with the guarded hot box calorimetry equipment. The infrared thermography scan was conducted on

Figure 6

HOUSE NO.1: 1984 NINEPLEX

February 8/89 to March 6/89

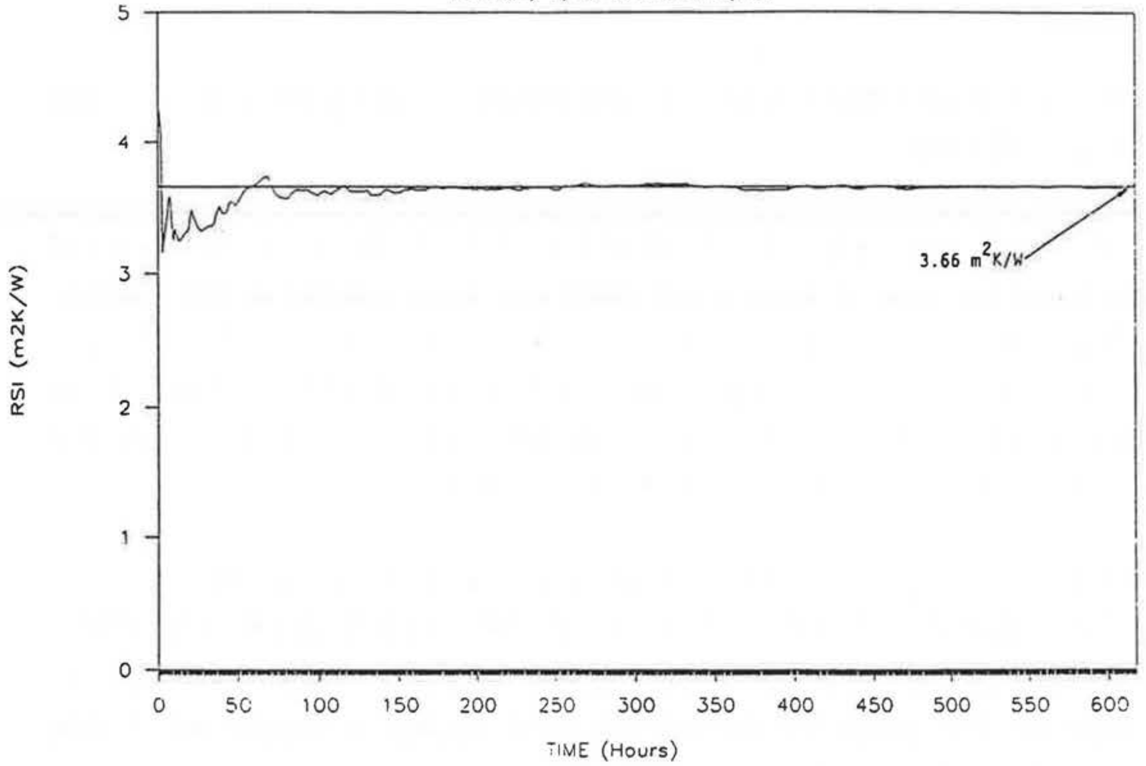
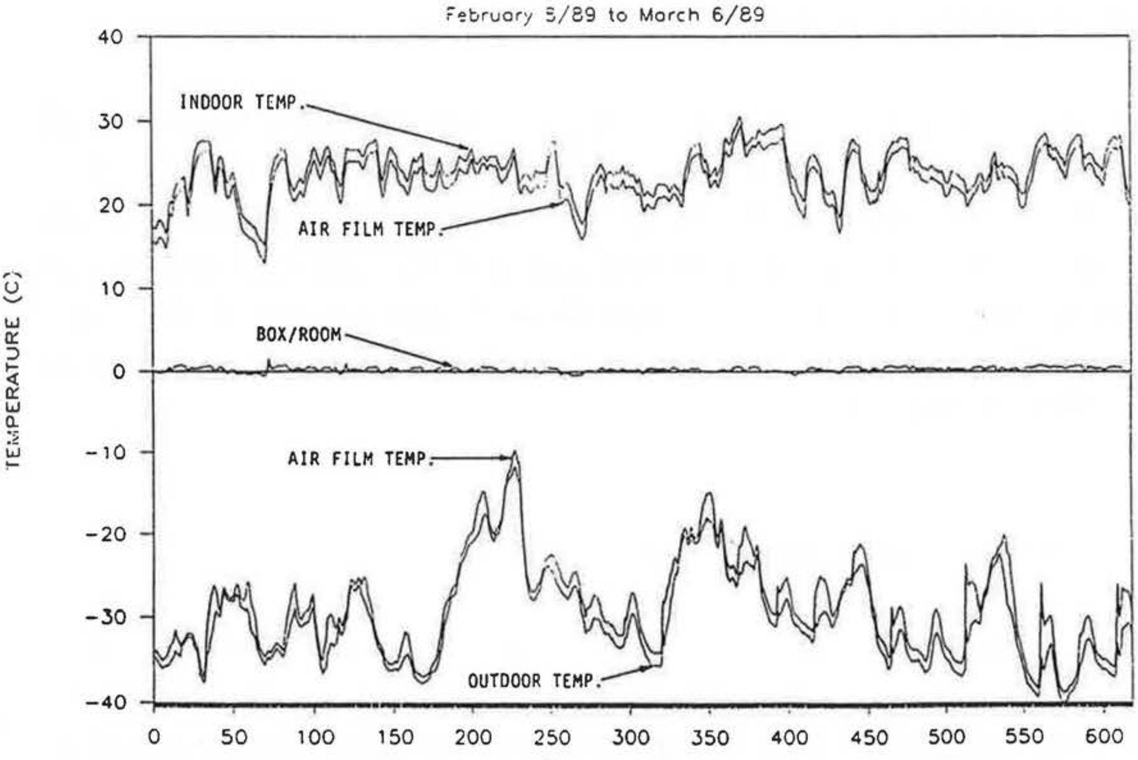


Figure 7

HOUSE NO.1: TEMPERATURE LOG

February 8/89 to March 6/89



February 7, 1989. Continuous monitoring commenced on February 8, 1989 and was completed on March 7, 1989. Approximately 400 hours of hourly data were collected. For the first half of the monitoring period the house was unoccupied.

An infrared thermography scan of the selected wall section showed no signs of wall deterioration.

Figure 8 shows the measured RSI value versus time plot. A review of this figure indicates that the effects of stored energy were minimized after approximately 60 hours of monitoring. The effective RSI value for the selected wall section in House No. 2 was measured to be 5.09 m^2K/W.

A log of selected temperatures is shown in Figure 9. Indoor air temperatures fluctuated between 18.3^oC and 31.0^oC with the average indoor air temperature being 24.0^oC. Outdoor air temperatures fluctuated between -18.0^oC and -38.8^oC. The average outdoor temperature was -30.8^oC. For the monitoring period in House No. 2, the average differential temperature across the wall section was 53.0^oC.

The average box/room temperature was 0.9^oC. For the first half of the monitoring period this average temperature was approximately 0.6^oC. For the second half of the monitoring period this average temperature was approximately 1.4^oC. Interestingly, the two average values stated above correspond to unoccupied and occupied monitoring. The presence of occupants in this house during the monitoring period caused the indoor temperatures to fluctuate dramatically, thus affecting the control system's ability to maintain the box temperature the same as the room temperature.

7.4 House No. 3: Results from Testing

As with the first two houses, thermal performance testing in the 1986 retrofit unit involved an initial infrared thermography scan followed by continuous monitoring with the guarded hot box calorimetry equipment. The infrared thermography scan was conducted on February 9, 1989. Continuous monitoring commenced

Figure 8

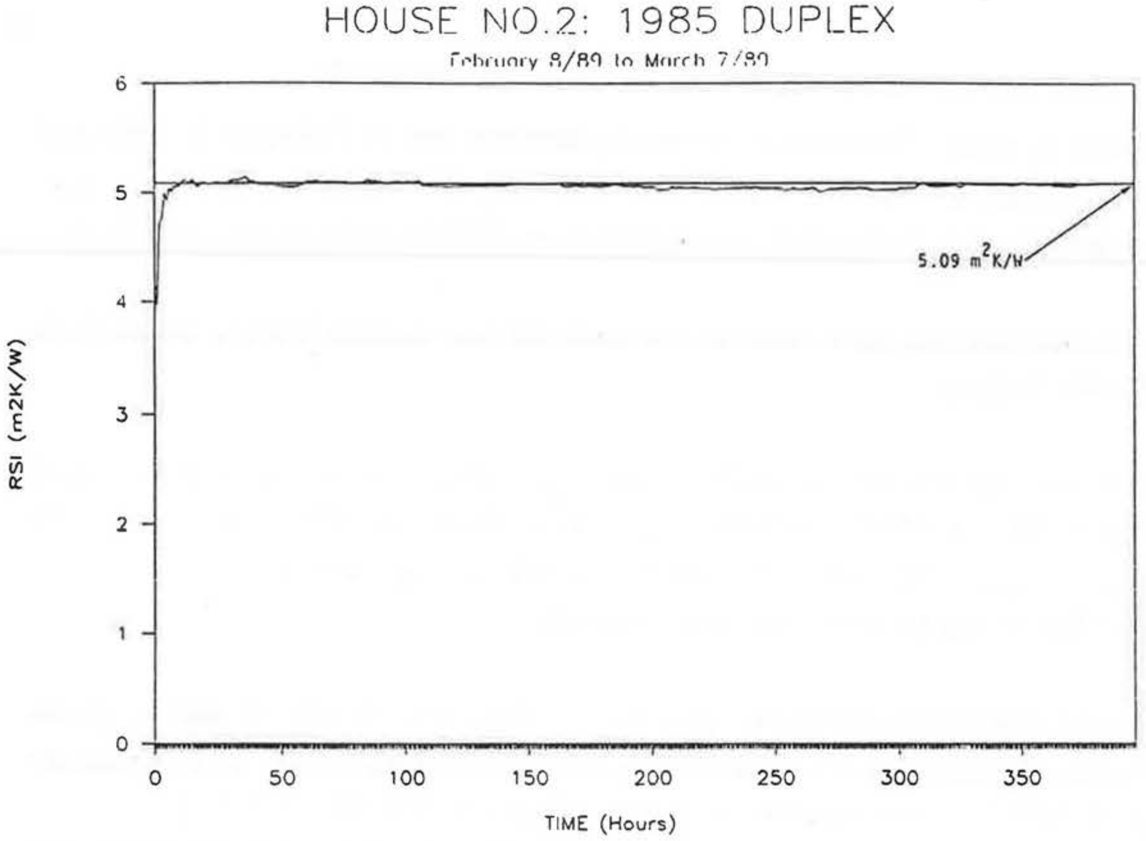
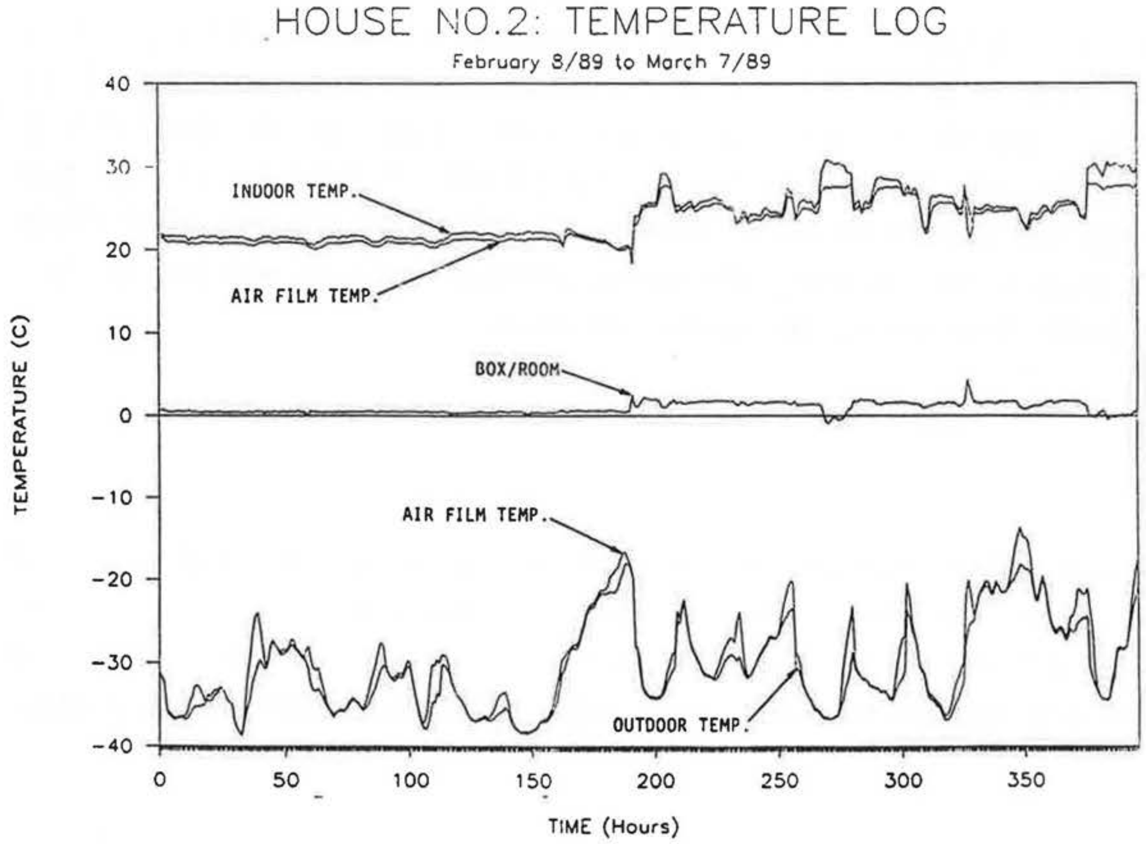


Figure 9



on March 9, 1989 and was completed on April 5, 1989. Over this time span, only 170 hours of hourly data were collected.

Unlike the other three houses tested, the retrofit unit had a considerable amount of space on the north wall for accommodating the guarded hot box calorimeter. This was due to fewer windows and no baseboard heating on the selected wall section. The infrared thermography scan on this wall revealed several cold spots. Most were at the ceiling/wall and floor/wall interfaces. However, because the north wall was quite large an area showing essentially no cold spots was identified for locating the guarded hot box calorimeter. In this area, only the strapping behind the gypsum board wall appeared dark on the monitor of the infrared scanner.

Figure 10 shows a plot of the measured RSI value versus time. A review of the plot indicates that the effects of stored energy may not have been completely minimized. However, the rate of change of the effective RSI value at the end of the monitoring period was small enough to postulate that the final result is reasonably close to that which would be measured after a longer monitoring period. The effective RSI value for the selected wall section in House No. 3 was measured to be 2.11 m^2K/W.

A log of selected temperatures is shown in Figure 11. Indoor air temperatures fluctuated between 22.2^oC and 30.5^oC. The average indoor air temperature was 25.6^oC. Outdoor air temperatures fluctuated between -15.5^oC and -36.7^oC. The average outdoor air temperature was -29.6^oC. For the monitoring period, the average differential temperature across the wall section was 50.9^oC.

The average box/room temperature was measured to be 0.2^oC. This value indicates that the control system functioned satisfactorily throughout the monitoring period.

7.5 House No. 4: Results from Testing

Thermal performance testing in the 1986 duplex unit involved only continuous monitoring of the heat loss through the selected wall section using the guarded

Figure 10

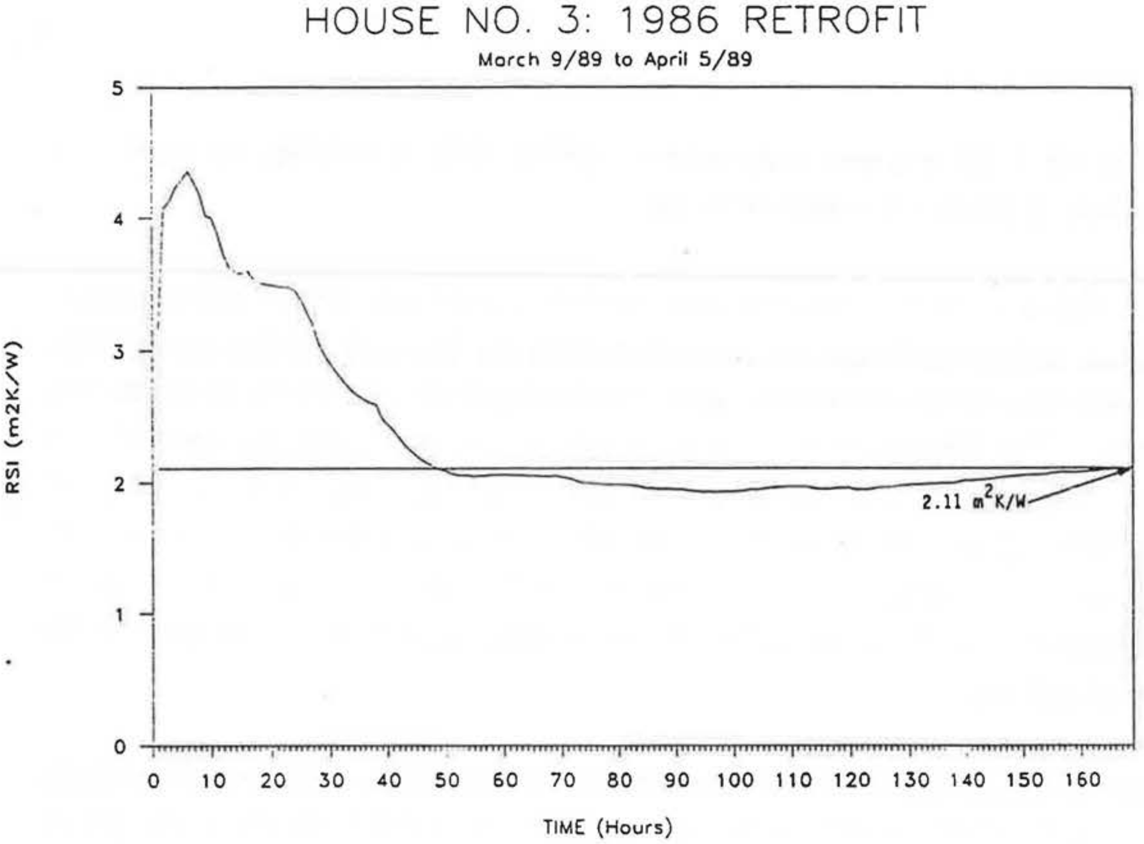
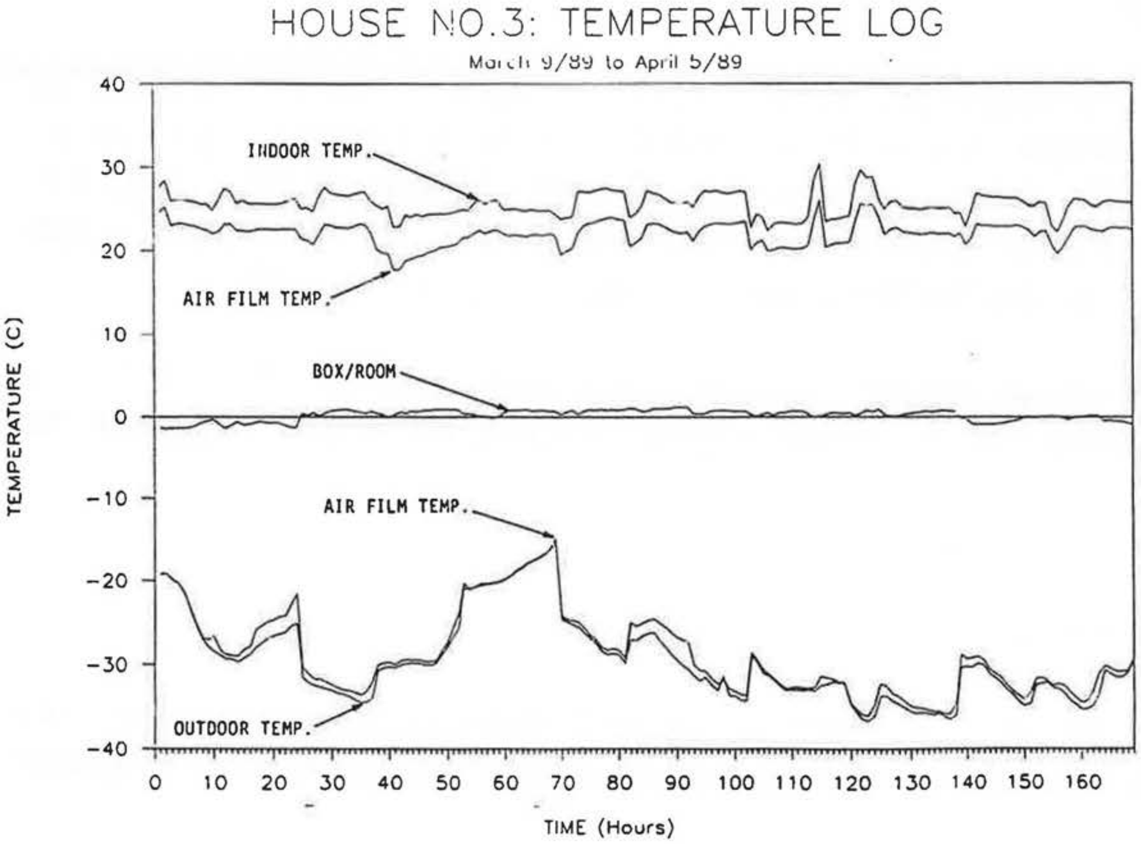


Figure 11



hot box calorimetry instrumentation. Monitoring commenced on March 9, 1989 and was completed on April 5, 1989. Approximately 200 hours of hourly data were obtained.

An infrared thermography scan was not conducted in House No. 4 as this house was not selected for testing until the second visit to Rankin Inlet. As mentioned earlier in this report, the tentatively selected house could not accommodate the guarded hot box calorimetry instrumentation.

As shown in Figure 12, the effects of stored energy in the selected wall section were minimized after approximately 135 hours of monitoring. The effective RSI value was measured to be 5.36 m^2K/W.

It is important to note that the selected wall section was part of a south-facing wall. Thus, there were large fluctuations in the exterior surface temperature of this wall due to solar radiation during the day and extreme cold temperatures overnight. In the analysis of the logged data to determine the effective RSI value of the wall section in this house, only nighttime data, obtained several hours after sunset, were used.

Two temperature logs are shown in Figures 13 and 14. The first is of selected temperatures used in the analysis to determine the effective RSI value. The second is of the temperatures measured throughout the entire monitoring period, including daytime values. From Figure 13, the indoor air temperature fluctuated between 20.6^oC and 26.2^oC with the average temperature being 24.6^oC. The outdoor temperature fluctuated between -14.5^oC and -37.0^oC with the average temperature being -27.9^oC. For the monitoring period, excluding daytime data, the average differential temperature across the wall section was 51.6^oC.

The average box/room temperature was 1.6^oC. This value indicates that the differential temperature sensing control system for the hot box calorimeter may have drifted slightly out of calibration.

Figure 12

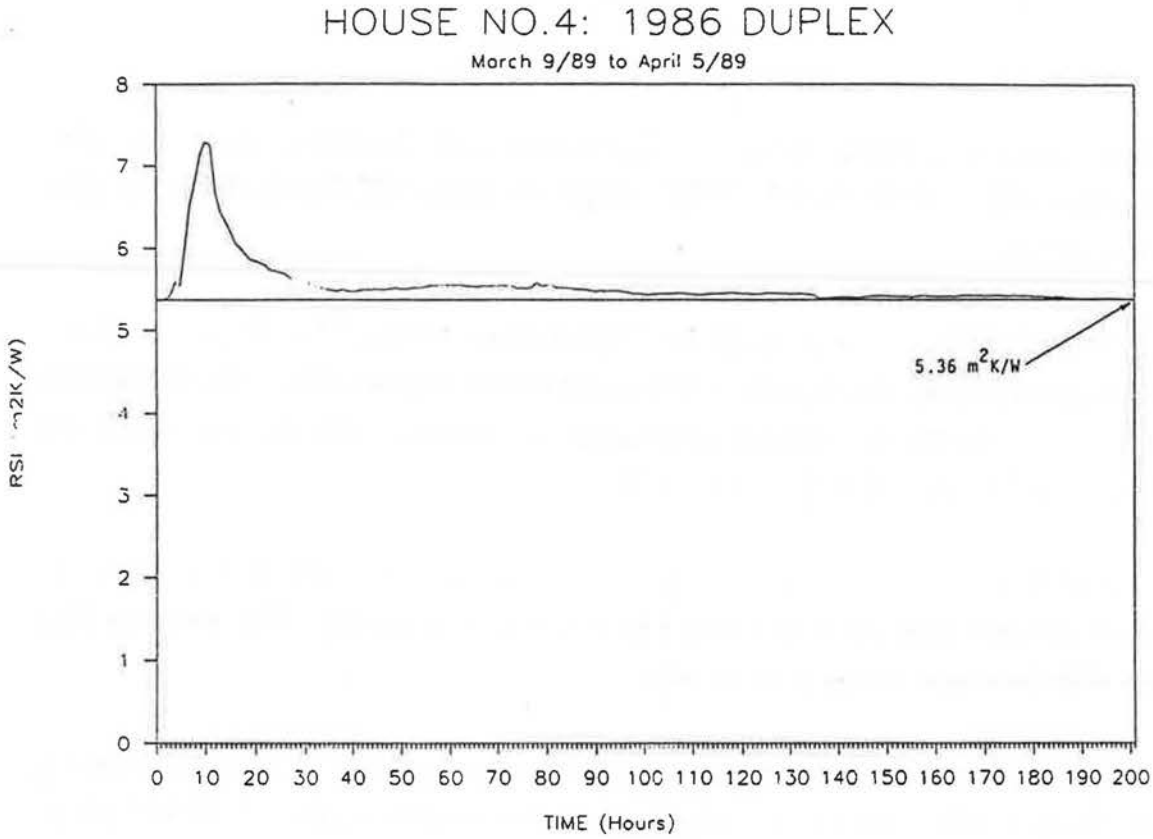


Figure 13

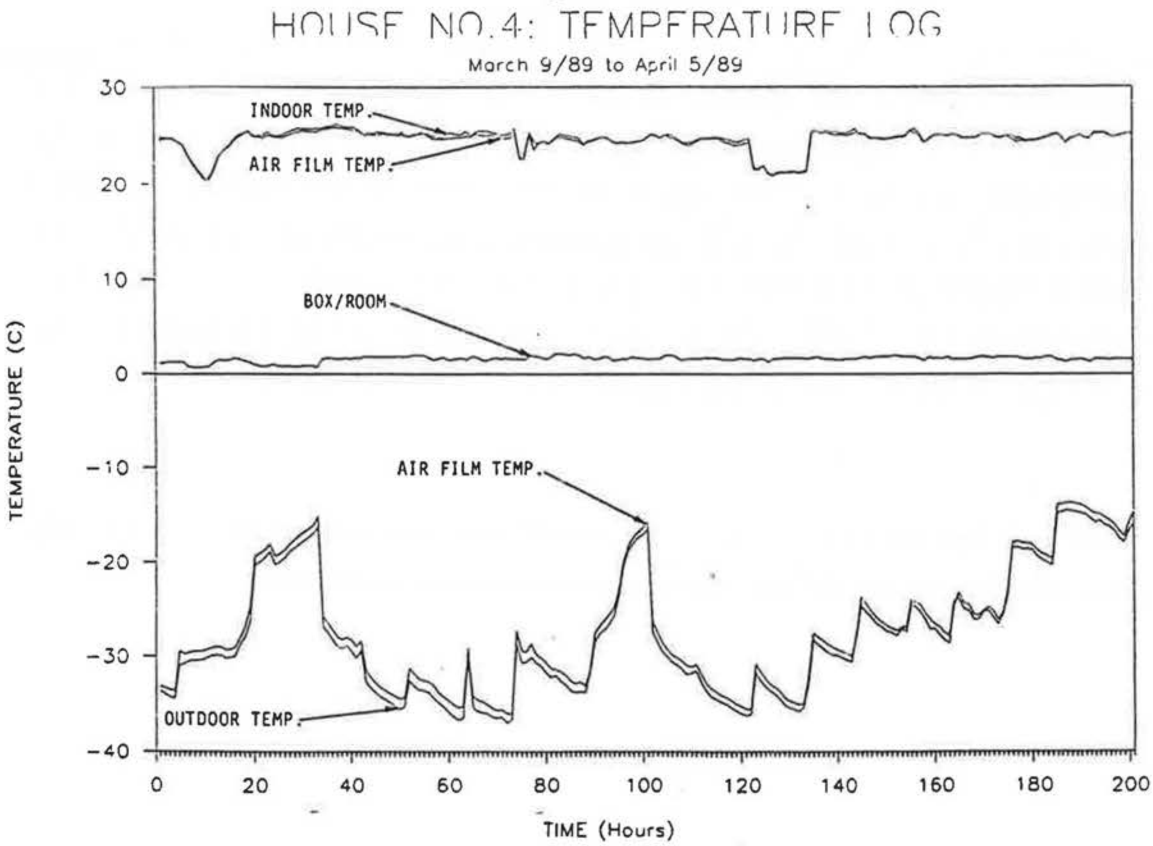
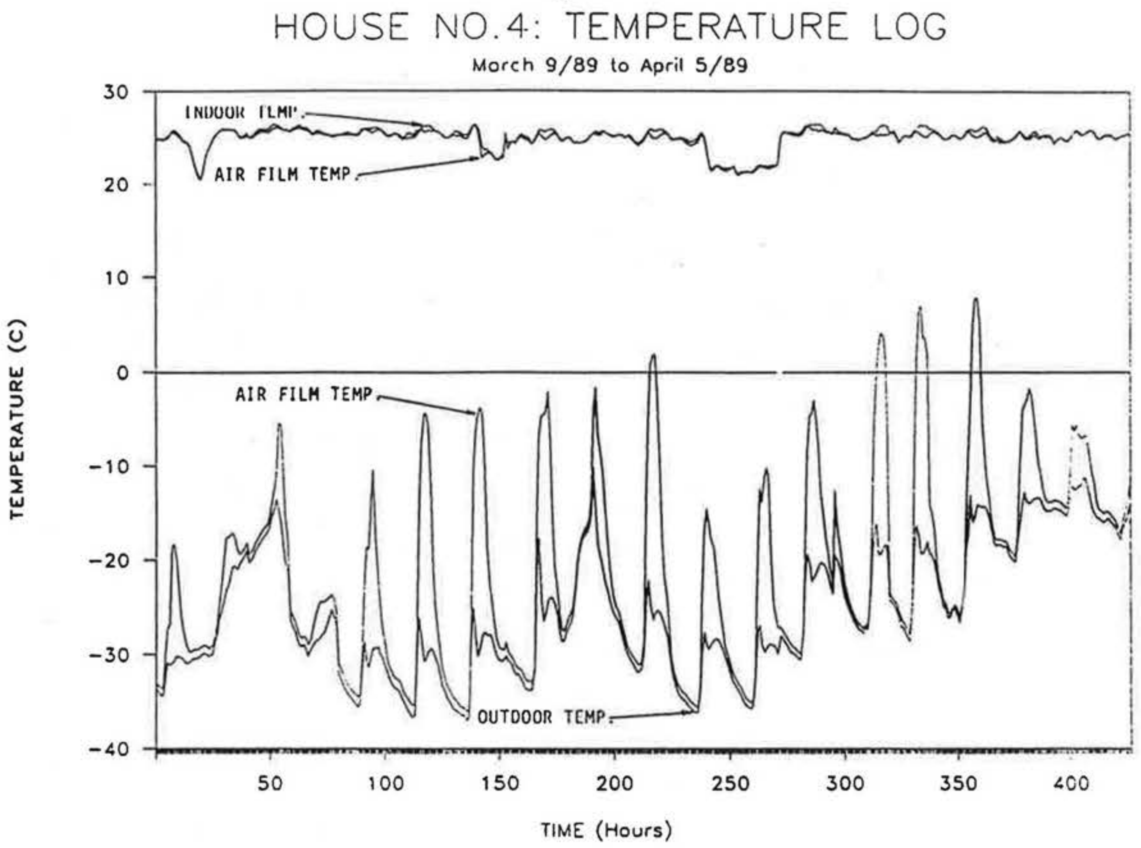


Figure 14


HOUSE NO.4: TEMPERATURE LOG
March 9/89 to April 5/89
INDOOR TEMP.
AIR FILM TEMP.
AIR FILM TEMP
OUTDOOR TEMP.
TEMPERATURE (C)
TIME (Hours)
30
20
10
0
-10
-20
-30
-40
50
100
150
200
250
300
350
400

8.0 DISCUSSION OF RESULTS

The effective RSI values measured in four northern housing units are presented in Table 1. Wall sections in the two duplex units that were similar in design but constructed in different years were found to have the highest thermal resistance values. For the 1985 duplex unit (House No. 2) and the 1986 unit (House No. 4), the measured effective RSI values were 5.09 m^2K/W and 5.36 m^2K/W, respectively. The wall section in the 1986 retrofit unit (House No. 3) was found to have the lowest RSI value of the four wall sections tested; 2.11 m^2K/W was measured for this wall section. The effective RSI value of the wall section in the 1984 nineplex unit (House No. 1) was measured to be 3.66 m^2K/W.

The effective RSI values that were measured in the four housing units are more meaningful when they are compared to their corresponding theoretical values, also listed in Table 1. Corresponding theoretical values were calculated using the cross-sectional drawings shown in Figures 1, 2, 3, and 4 and the individual component thermal resistance values obtained from the ASHRAE Fundamentals Handbook. Thermal bridges which include wood frame members and strapping were accounted for in the calculations.

As indicated in Table 1, the measured thermal resistance values of the wall sections tested are, in general, reasonably close to their respective theoretical values. The wall sections in the nineplex unit (House No. 1) and the two duplex units (House No. 2 and House No. 4) had measured thermal resistance values within 15 percent of their theoretical values. In all three cases, the measured values were higher than the theoretical values. Conversely, the measured thermal resistance value of the wall section in the 1986 retrofit unit (House No. 3) was 42 percent lower than its theoretical value. It is important to note, however, that this lower measured RSI value may not necessarily be due to the wall section's greater length of exposure to the Arctic environment. The type of wall construction in the retrofit unit differed from the types in the other three units. However, to truly substantiate whether or not type of construction is a factor, length of exposure to the Arctic environment would have to be the same for all wall sections investigated.

The measured effective RSI values of the wall sections in Houses No. 1, No. 2, and No. 4 were found to be approximately 13 percent higher than the calculated theoretical values. There are three major possibilities for this occurrence. Firstly, the baseboard heaters, immediately below the guarded hot box calorimeters, may have decreased the load on the heating elements within the calorimeters. Secondly, there was likely a certain degree of experimental error. Finally, the insulating materials in the wall sections may have performed better than expected, since the component RSI values used in the calculations were based on laboratory measurements made approximately 24°C. As temperatures decrease, the insulating value of materials generally increases.

The measured effective RSI value of the wall section in House No. 3 was found to be 42% lower than the calculated theoretical value. Housing officials in Rankin Inlet indicated that the existing wall sections in many of the retrofitted houses were damaged by moisture. However, the infrared thermography scan did not indicate signs of moisture damage. It is important to note that there was an air space behind the gypsum board wall which the guarded hot box calorimeter was attached to. Cold spots that were close to the metered area but not immediately behind it may have provided a route for heat to escape from the adjoining air space.

It should be noted that the number of houses tested represents a relatively small sample. Thus, the results obtained cannot necessarily be considered representative of Arctic housing.

TABLE 1

HOUSE NO.	HOUSE TYPE	CONSTRUCTION YEAR	MEASURED RSI VALUE m^2K/W	CALCULATED RSI VALUE m^2K/W	PERCENTAGE DIFFERENCE m^2K/W
1	NINEPLEX UNIT	1984	3.66	3.23	-13.3
2	DUPLEX UNIT	1985	5.09	4.50	-13.1
3	1986 RETROFIT (Single Detached)	1976	2.11	3.63	41.9
4	DUPLEX UNIT	1986	5.36	4.77	-12.4

9.0 RECOMMENDATIONS AND CONCLUSIONS

In situ testing of the thermal performance of wall sections in the Northwest Territories involved infrared thermography inspections and continuous monitoring of heat loss through four selected wall sections. There were three objectives in the project. The first objective was to substantiate housing officials concerns that insulating values in composite wall sections decrease with long term exposure to the Arctic environment. The second objective was to speculate on the mechanisms that may be causing reductions in insulating value. The third objective was to recommend further field tests to measure the mechanisms causing reductions in insulating value.

The results from testing wall sections in four housing units suggest that significant reductions in insulating value of composite wall sections in houses constructed in the last five years have not occurred. The measured RSI values for the houses in this category appear to be in line with theoretical calculations.

The oldest house tested was constructed in 1976 and retrofitted in 1986. It was the only house where the insulating value of the wall section tested was significantly lower than the theoretical value. Mechanisms responsible for this lower insulating value were not clearly identified in this project. However, speculations were made. As mentioned earlier in this report, a longer monitoring period would have been desirable as the effects of stored energy within this wall section may not have been adequately minimized. The monitoring period for this wall section was broken on several occasions. It is difficult to predict how this may have affected the final result.

It is important to note that the conclusions made in this project are based on the small sample consisting of four housing units. To further substantiate concerns regarding wall degradation with length of exposure to the Arctic environment, it is recommended that detailed infrared thermography inspections be conducted in many houses, encompassing a wide variety of wall construction types.

If further testing is to be carried out using guarded hot box calorimeters, it is recommended that smaller calorimeters be used. (It must be certain, however, that accuracy in measurement is not severely affected with smaller calorimeters. The ones used in this project could not be accommodated in most housing units because of their size.)

REFERENCES

ASHRAE. 1985. "Chapter 23: Design Heat Transmission Coefficients". ASHRAE Handbook of Fundamentals, Third Draft Revision, Atlanta: American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc.

Brown, W. C. and Schuyler, G. D. 1979. "A Calorimeter for Measuring Heat Flow Through Walls". DBR Paper No. 1004, Division of Building Research, NRCC.

Brown, W.C. and Schuyler, G. D. 1982. "In Situ Measurements of Frame Wall Thermal Resistance". DBR Paper No. 1075, Division of Building Research, NRCC.

Scanada Consultants Limited. 1986. "Log Walls Field Tests". Prepared for Canada Mortgage and Housing Corporation.

APPENDIX A

Calculated R.S.I. Values for Wall Sections Tested

Nineplex Wall section

Layer	Material	RSI per mm	Cavity RSI	Stud RSI
1	12.7 mm W.B	.0062	.08	.08
2	6mil Poly	0	0	0
3	Cavity(38x140@400OC)	0.0087 for stud	3.5	1.22
4	Tyvek Air Barrier	0	0	0
5	Cedar Siding(15.5mm)	.0092	.14	.14
			3.72	1.44

$$Reff = \frac{100}{\frac{90.55}{3.72} + \frac{9.45}{1.44}} = 3.23$$

1985 Duplex #2

Layer	Material	RSI per mm	Cavity RSI	Stud RSI
1	12.7 mm W.B	.0062	.08	.08
2	6 mil Poly	0	0	0
3	25 mm Rigid Ins.	.042	1.05	1.05
4	Cavity(38x140@600OC)	0.0087 for stud	3.5	1.22
5	Tyvek Air barrier	0	0	0
6	Plywood Siding(15.5mm)	.0087	.13	.13
			4.76	2.48

$$Reff = \frac{100}{\frac{93.71}{4.76} + \frac{6.29}{2.48}} = 4.5$$

1976 Retrofit

Layer	Material	RSI per mm	Cavity RSI	Stud RSI
1	12.7 mm W.B	.0062	.08	.08
	1x3@400mmOC Air Space	.12	.12	.12
2	6 mil Poly	0	0	0
3	12.7 mm W.B	.0062	.08	.08
4	Cavity(38x89@400mmOC)	0.0087 for stud	2.1	.77
5	Plywood Siding(15.5mm)	.0087	.13	.13
6	Glasclad(38mm)	.0305	1.16	1.16
7	Plywood Siding(15.5mm)	.0087	.13	.13
			3.80	2.47

$$Reff = \frac{100}{\frac{90.55}{3.80} + \frac{9.45}{2.47}} = 3.61$$

1986 Duplex #4

Layer	Material	RSI per mm	Cavity RSI	Stud RSI
1	12.7 mm W.B	.0062	.08	.08
2	Plywood Backing(9.5mm)	.0087	.083	.083
3	6 mil Poly	0	0	0
4	Cavity(38X140@600OC)	0.0087 for stud	3.5	1.22
5	Glas Clad(38mm)	.0324	1.23	1.23
6	Plywood Siding(15.5mm)	.0087	.13	.13
			5.023	2.743

$$Reff = \frac{100}{\frac{93.71}{5.02} \quad \frac{6.29}{2.74}} = 4.77$$

APPENDIX B

NRC Report
Calibration of Two Portable Hot Boxes

National Research Council Canada | Conseil national de recherches Canada
Institute for Research in Construction | Institut de recherche en construction

CLIENT REPORT

for

Canada Mortgage and Housing Corporation
Ottawa, Ontario, Canada K1A 0P7

Calibration of Two Portable Hot Boxes

Author ______________
W.C. Brown

Approved ______________
R.P. Bowen
Section Head

Approved ______________
W.A. Dalglicsh
Head, Quality Assurance

Report No: CR5831.1
Report date: 17 January 1989
Contract No. CR5831
Reference: Agreement dated 12 December 1988
Section: Building Performance

5 pages
Copy No. 5 of 5 copies

Canada

SUMMARY

Two portable hot boxes (PHB), each nominally 1.2 m x 2.0 m, were calibrated under steady-state conditions in the guarded hot box (GHB) facility of the Institute for Research in Construction (IRC). The heat flow measured by each PHB was within 2% of that predicted by a GHB measurement.

EXPERIMENTAL SETUP

A test specimen, 2.44 m x 2.44 m, was constructed of 100 mm thick expanded polystyrene with 12 mm gypsum board glued to the warm face and 12 mm plywood glued to the cold face. The specimen was installed in the IRC guarded hot box facility and the air temperatures on the warm and cold faces of the specimen was set to 21°C and -20°C respectively. After a steady-state heat transfer condition had been reached, the thermal resistance of the specimen was determined to be 3.13 $m^2 \cdot K/W$ from the measured heat flux and surface temperatures.

Two portable hot boxes (PHB #1 and PHB #2) were constructed approximately as described in "A calorimeter for Measuring Heat Flow Through Walls" by Brown and Schuyler[1]. Each PHB was nominally 1.2 m x 2.0 m with a test area of 2.38 m^2.

The two portable hot boxes were each separately mounted to the warm face of the test specimen to measure the heat transfer through the test specimen. The perimeter of the PHB was taped to the test specimen to eliminate any air leakage into the PHB. Test temperature conditions were set to approximately 21°C and -20°C, i.e. similar to those existing when the specimen thermal resistance was measured. Energy to the PHB heater was controlled by a three-mode controller and measured by a modified watt-hour meter. After a steady-state condition had been reached, the temperatures on the surface of the specimen and the energy supplied to the PHB were recorded.

RESULTS

The temperature and heat flux data recorded for the two calibration tests are tabulated in Table 1. The heat flux measured by each PHB deviated by less than 2% from the heat flux predicted from the GHB result. Temperatures measured in and around the test area of each PHB are shown in Figures 1 and 2. The wiring diagram for the heater, watt-

---

1 Brown, W.C. and Schuyler, G.D. *A Calorimeter for Measuring Heat Flow Through Walls*. ASHRAE/DOE-ORNL Conference on "Thermal Performance of the Exterior Envelopes of Buildings", Kissimmee, FL, December 1979.

hour meter and controller are shown schematically in Figure 3.

It should be noted that the results shown in Table 1 were obtained from a homogeneous specimen under optimum test conditions. Larger deviations would be anticipated when measuring heat flux through a nonhomogeneous specimen under field conditions. A number of factors, including variation of outdoor temperature and especially variation of indoor temperature, will increase the uncertainty of the measurement. While an accuracy of 5% has been quoted for the PHB under field conditions[1], an accuracy of 10-20% is more likely and then only when reasonable care and caution is exercised in the application.

Table 1. Results of Calibration Tests on PHB #1 and PHB #2.

	PHB #1	PHB #2
Avg. Warm Air Temperature, °C	20.7	20.6
Avg. Warm Surface Temperature, °C	19.5	19.5
Avg. Cold Surface Temperature, °C	-19.5	-19.6
Avg. Cold Air Temperature, °C	-20.1	-20.1
Measured Heat Flux, W/m^2	12.3	12.4
Predicted Heat Flux, W/m^2	12.5	12.5
Deviation From Predicted, %	1.6	0.8

NOTES: Avg. Warm & Cold Surface Temperatures are the average of five thermocouples located in the PHB test area.

Figure 1. Temperatures measured on warm and cold surfaces of test specimen with PHB #1 installed.
- viewed from room side
- T_h = 21°C; T_c =-20°C
- cold surface temperatures in brackets

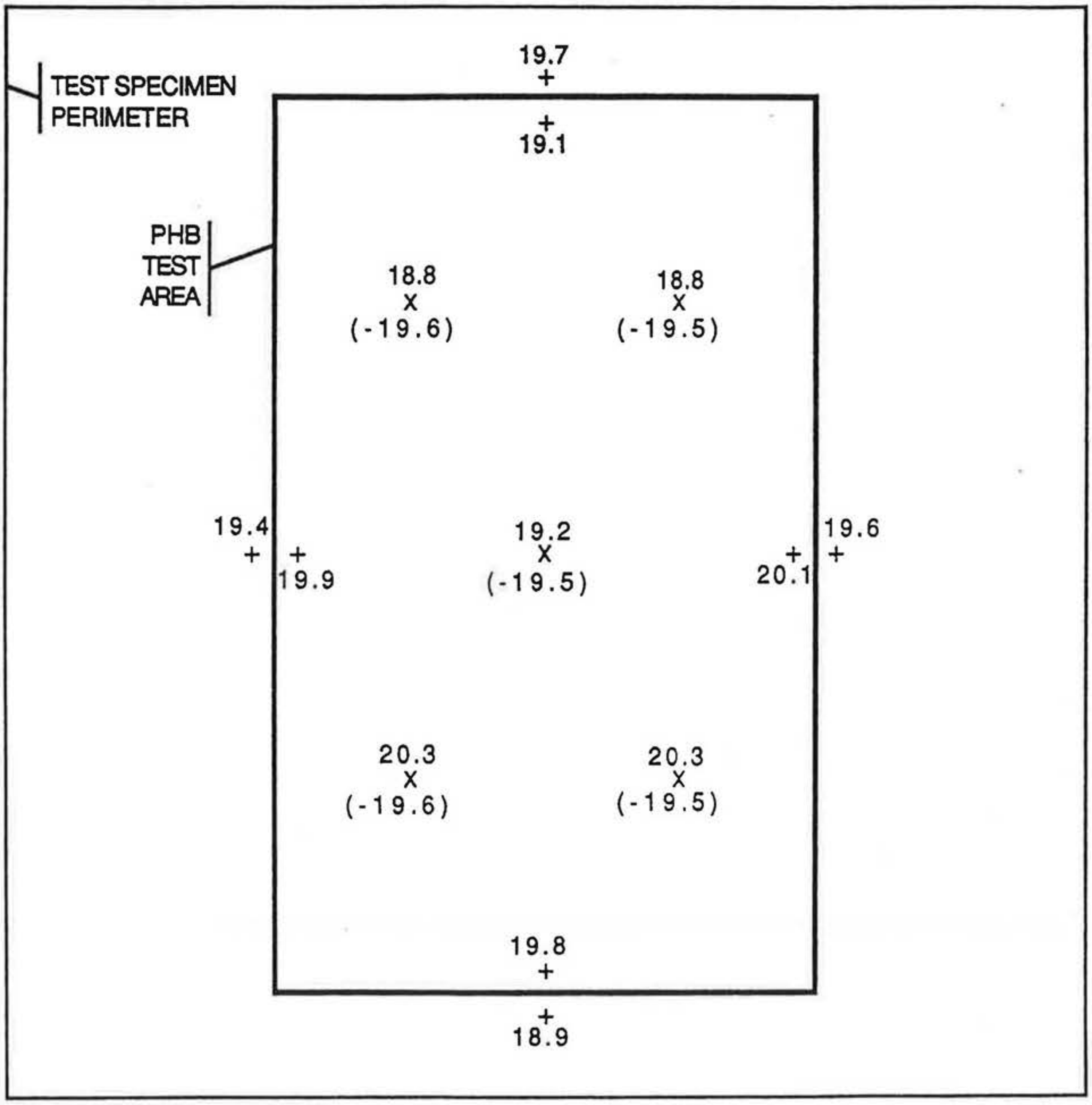


Figure 2. Temperatures measured on warm and cold surfaces of test specimen with PHB #2 installed.
- viewed from room side
- T_h = 21°C; T_c =-20°C
- cold surface temperatures in brackets

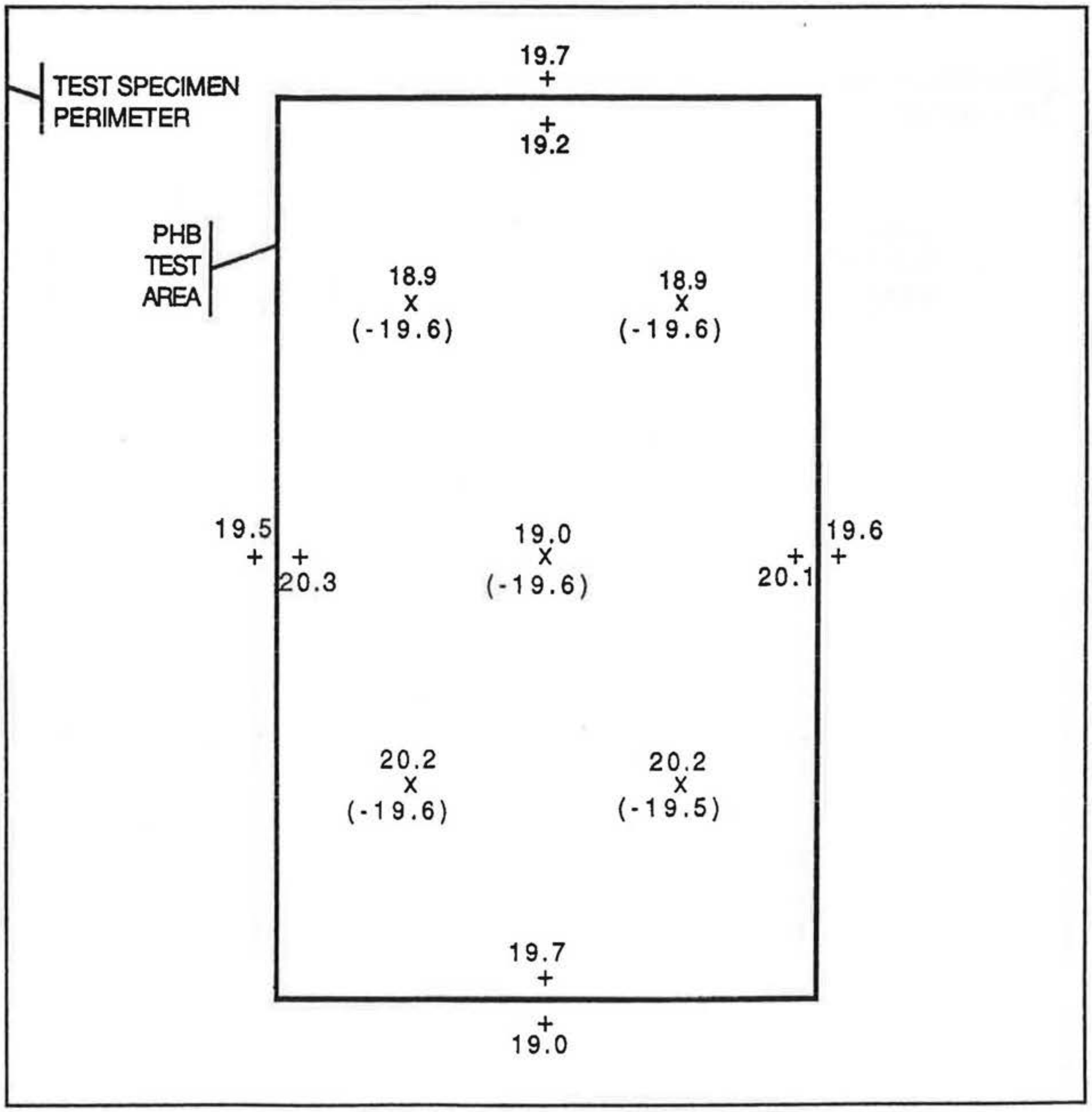
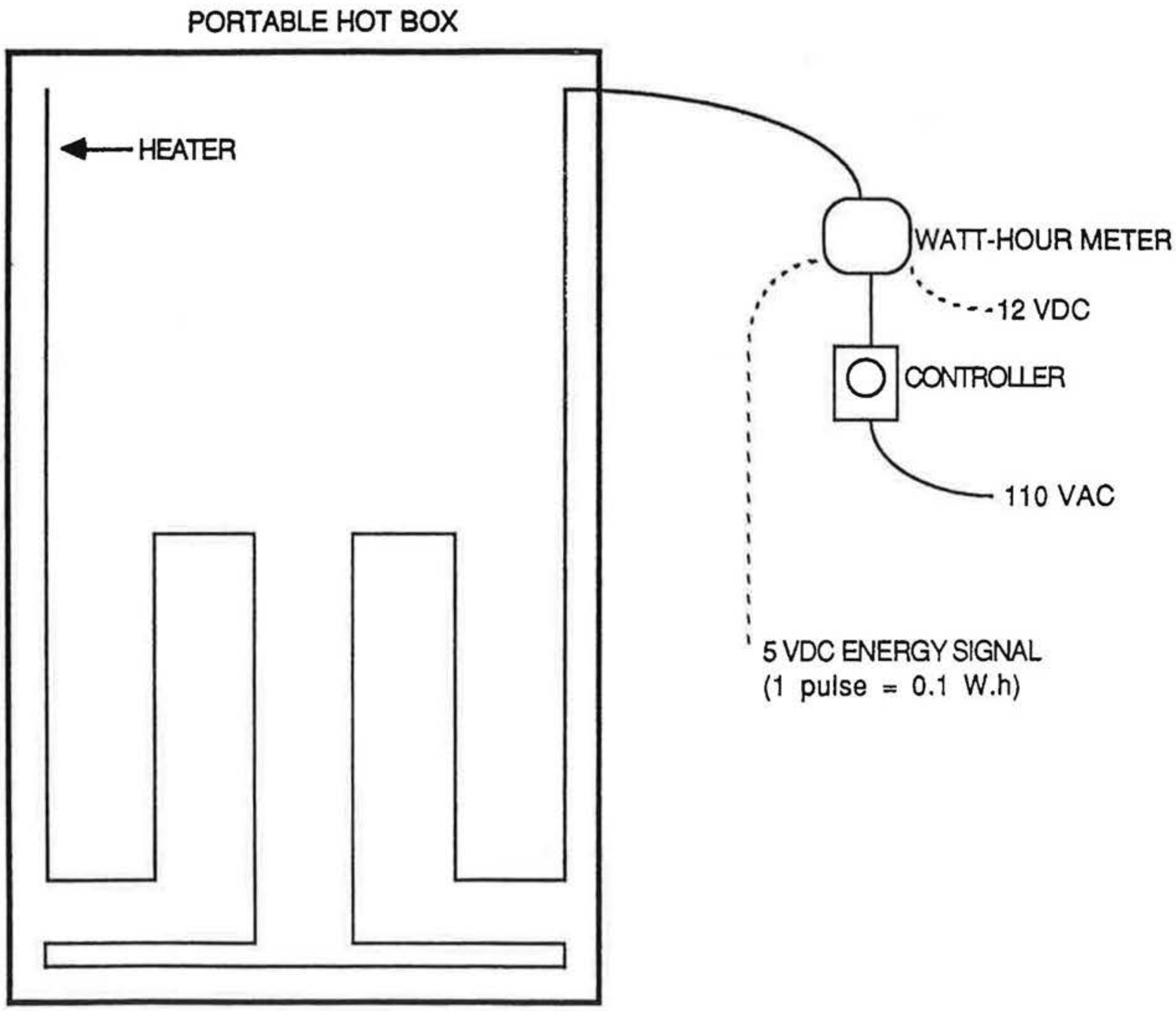


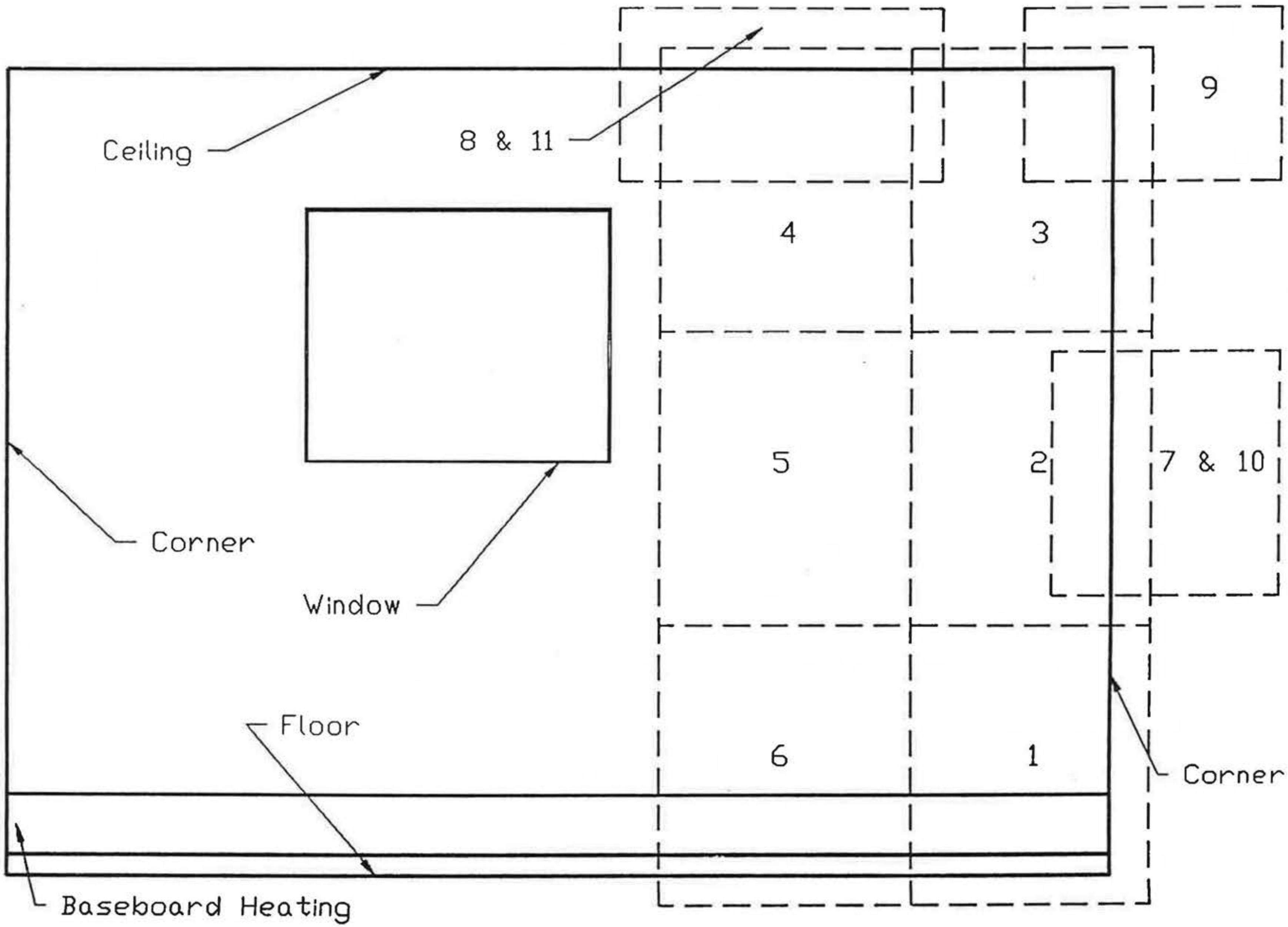
Figure 3. Schematic of portable hot box wiring diagram.



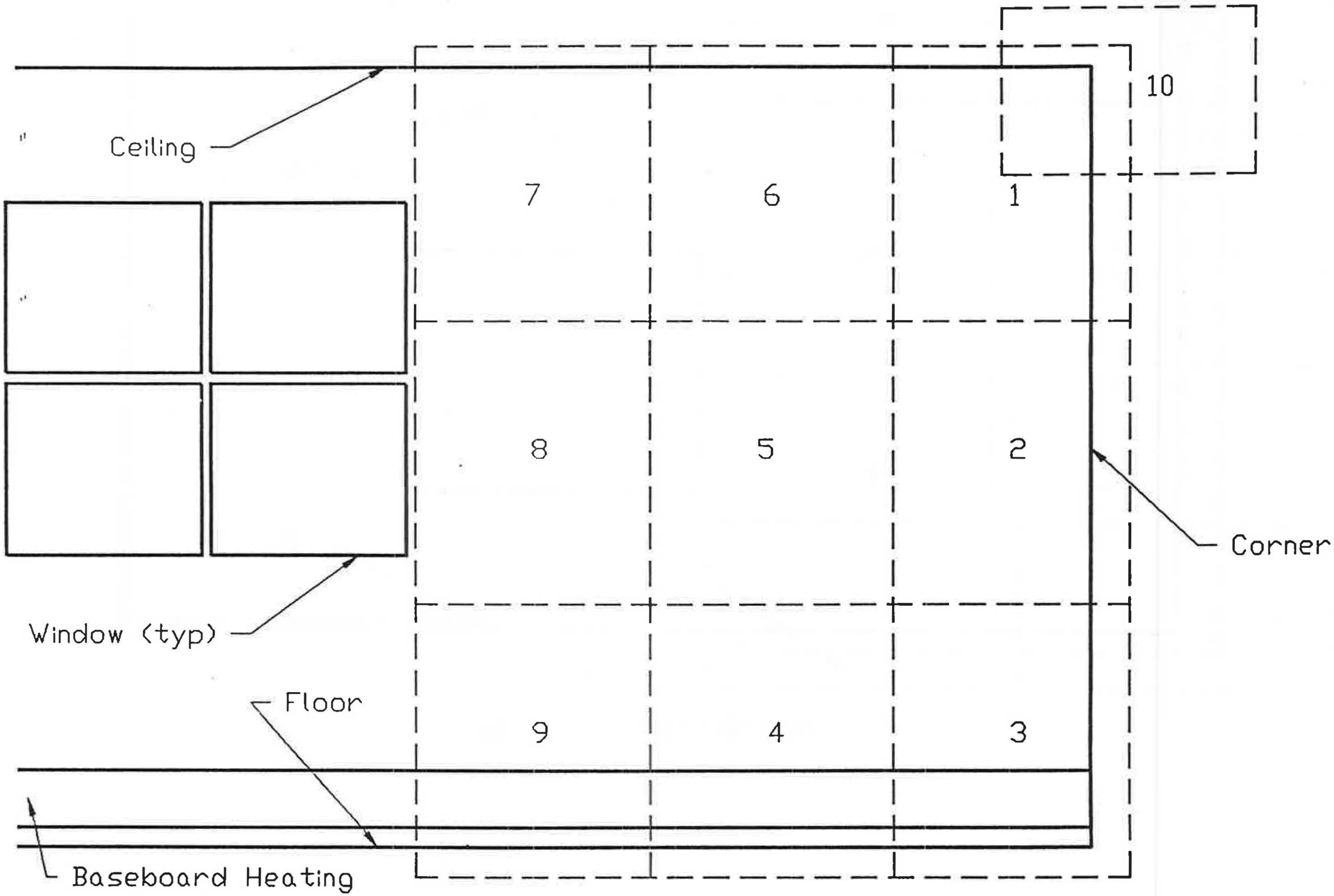
APPENDIX C

Sketches of Wall Sections and Locations
of Photographs from Infrared Scans
(Photographs Bound Separately)

House No. 1: 1984 Nineplex Unit



House No. 2: 1986 Duplex Unit



House No. 3: 1986 Retrofit Unit