RESEARCH REPORT

Log Walls Field Tests

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LOG WALLS FIELD TESTS

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DISCLAIMER

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EXECUTIVE SUMMARY

The effective RSI values of carefully selected sections of solid log wall houses were measured using a guarded calorimeter test apparatus commonly known as a "mimic box".

The five log houses that were included in the study consisted of the following:

i) three of standard round pine log wall construction
ii) one of square cedar log-chinked wall construction
iii) one of modified round pine log wall construction

All round log houses were less than three years old. The cedar log house was eight years old.

The effective RSI value of a wall section from a house of standard wood-frame construction (eight years old) was also measured to produce a baseline against which the performance of the log wall sections could be interpreted.

Testing was restricted to north facing walls only. Infrared thermography was used to ensure that the selected wall sections were representative of typical log wall construction practice (i.e. the wall sections were chosen so that no voids or discontinuities in the joints were present to bias the results).

The instrumentation package designed for this monitoring project was comprised of:

i) A mimic box complete with a 150W heating cable, controller, thermopile junction and high temperature safety cut-out.

ii) An electronic data acquisition system interfaced to a microcomputer.

iii) An array of thermocouples to measure various temperatures within the mimic box and ambient indoor and outdoor temperatures, all of which were interfaced to the data acquisition system.

iv) A pulse initiating kilowatt-hour meter interfaced to the data acquisition system.

Data was collected approximately every thirty seconds and stored on floppy disk in cumulative hourly functions.

Testing of each log wall section lasted a minimum of three weeks. All testing was performed during mid-winter to early spring, 1986. The test period chosen for analysis was carefully selected so as to minimize the effects of stored energy within the log walls.

The results revealed that the effective thermal resistance of the log walls sections included in the study ranged from a minimum of 1.87 $m^2 \cdot C/W$ (10.6 $hr.ft.^2 \cdot F/Btu$) to a maximum of 2.52 $m^2 \cdot C/W$ (14.3 $hr.ft.^2 \cdot F/Btu$). The effective thermal resistance of the wood frame wall section was found to be 2.41 $m^2 \cdot C/W$ (13.7 $hr.ft.^2 \cdot F/Btu$).

The effective resistivities of the log wall sections tested were found to range from 0.0063 $m^2 \cdot C/W$ per mm (.91 $hr.ft.^2 \cdot F/Btu$ per inch) to 0.0071 $m^2 \cdot C/W$ per mm (1.02 $hr.ft.^2 \cdot F/Btu$ per inch) for the round pine logs. The square cedar log wall section was found to have an effective resistivity of 0.0083 $m^2 \cdot C/W$ per mm (1.2 $hr.ft.^2 \cdot F/Btu$ per inch). These values are below the current value recognized by CMHC for log walls, which is 0.0087 $m^2 \cdot C/W$ per mm (1.25 $hr.ft.^2 \cdot F/Btu$ per inch) for pine logs and 0.0092 $m^2 \cdot C/W$ per mm (1.33 $hr.ft.^2 \cdot F/Btu$ per inch) for cedar logs.

Thermal bridging at the joints appears to be the major weak link in the log wall systems.

LOG WALLS FIELD TESTS

1.0 INTRODUCTION

For several years, the thermal resistance of solid log walls has been a subject of controversy between log home builders and CMHC since the thermal resistance calculated using standard reference data is less than the values CMHC requires in many parts of the country for housing financed under the National Housing Act. The issue remains unresolved partly due to the lack of adequate field data available to CMHC officials on the actual in-place thermal resistance of solid log walls.

Scanada Consultants was contracted to measure the effective RSI values of several solid log walls by measuring energy consumption through carefully selected sections of these walls using guarded calorimeters. The results obtained from this monitoring project are intended to provide sound field data which can be compared to theoretical RSI values.

Log home builders have argued that the actual net heat loss through log walls is less than would be calculated using simple heat conduction formulae because of the benefits of solar energy storage in the logs' mass. However, this aspect is best addressed through analytic studies rather than through short term field tests since the results of the latter would be affected in an unpredictable manner by the particular pattern of solar energy availability that occurred during the test period. Therefore, the tests described herein were limited to north walls only so as to limit the effect of stored solar energy. Thus the results do not include any solar storage benefits that might accrue from the massive nature of log walls.

2.0 OBJECTIVES

The field testing of the thermal resistance of log wall systems has three main objectives. These are -

1) To measure, for known inside/outside temperature conditions, the actual heat loss through several types of log walls and thence to determine their effective thermal resistance.

2) To compare the theoretical and actual thermal resistance values of log walls and, based on this comparison, recommend any required modifications to the present RSI values assigned to log wall construction.

3) To conduct similar measurements and comparisons for walls of standard frame construction in order to produce a baseline against which the performance of the log walls can be interpreted.

3.0 THE "MIMIC BOX" GUARDED CALORIMETER

3.1 General Principle

The "mimic box" is an insulated box Hm high by Wm wide by Dm deep with one of its HxW sides open. The open side is sealed against the wall to be tested. An electric heating element inside the box is controlled by an electronic device which senses any temperature difference between the interior of the box and the ambient room air and turns the element on to eliminate any such difference. Thus the temperature in the box "mimics" that in the room. Since the box is highly insulated and the difference between the air temperature in the box and the room is kept very small, essentially any heat loss from the box, which must be made up by the heating element, must be through the test wall. Thus the measured energy supplied to the heating element, is a proxy for energy flowing out through the test wall. The energy supplied to the heating element is measured using a kilowatt-hour meter.

The energy balance of the mimic box system can be expressed by the following equation which is an expression of the principle of conservation of energy[1]:

$$E_m = \frac{(T_{in} - T_{out})_{mean} \bullet A \bullet t}{RSI} + \Delta Q_s \qquad (1)$$

where -

E_m is the cumulative energy consumed by the heating element (Wh).

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1 This equation is a simplification of the more general one-dimensional heat conduction equation. Ref. Heat Transfer, J.P. Holman, McGraw-Hill Company, Fifth Edition, 1981, pp. 4.

$(T_{in} - T_{out})_{mean}$ is the average temperature difference between the interior and exterior air films of the metered wall section over the selected test period (°C). Note: T_{in} is the average temperature of the air in the mimic box (°C). T_{out} is the average outdoor temperature near the exterior wall (°C).

A is the area of wall under test (i.e. the area under the mimic box) (m^2).

t is the length of the test period (hours).

RSI is the effective thermal resistance of the portion of the wall under the mimic box, including the effect of heat loss at the log joints (or studs in the case of the wood frame wall). Since the temperature sensors are located outside the air films, the effective resistance also includes air films ($m^2 \cdot °C/W$).

ΔQ_s is the difference in the internal energy of the wall at the beginning of the test and at the end of the test (i.e. the net energy stored) (Wh)

Equation 1 can be re-arranged to solve for the resistance term as shown in Equation 2.

$$RSI = \frac{(T_{in} - T_{out})_{mean} \cdot A \cdot t}{E_m - \Delta Q_s} \qquad (2)$$

Equation 2 has two unknowns, RSI and ΔQ_s. Thus, in order to solve for RSI, test conditions must be chosen which will result in ΔQ_s being at or close to zero.

3.2 Minimizing the Effect of Stored Energy

The thermal resistance derived from Equation 2 was shown to be a function of ΔQ_S. One way to minimize the effect of this term is to select a period for analysis such that the final temperature of the log wall is the same as its initial temperature. In theory this would ensure that the difference in energy stored in the wall is zero. However, this criterion is difficult to satisfy in practice because it would require precise measurement of the average temperature of the logs themselves. A possible proxy for temperatures of the log wall might be the average of the inside and outside air temperatures. However, even this method is not likely to accurately assure that the internal energy within the log structure at the end of the test is the same as at the beginning of the test. As a result, using this method alone, although it reduces the effects of ΔQ_S, may still yield a result which is biased by the storage effects, either positively or negatively.

An examination of Equation 2 indicates that the significance of the stored energy is reduced if the heat loss through the wall is large (i.e. ΔQ_S is small in comparison to the overall heat loss through the wall). This can be achieved in two ways -

1) choosing test periods where the temperature differential across the wall section is maximized, or
2) utilizing the longest test period possible, since the quantity on heat loss increases with time and the amount of energy stored is independent of time.

Clearly the optimum monitoring strategy is to combine all the criteria discussed above; i.e. the best results will be obtained if one chooses a test period:

a) for which the inside and outside temperatures are the same at the beginning and end of the test;

b) during which the temperature differential across the wall is high;

c) which is quite long.

These criteria have been followed in choosing the test periods for analysis.

4.0 DESCRIPTION OF HOUSES

Testing was carried out in the following houses:

a) five log wall houses
b) one conventional wood frame house

The field testing was restricted to north facing walls so as to minimize the effects of solar energy stored in the walls. An infrared thermographic scan was performed on each wall section to ensure that there were no thermal anomalies (i.e. voids in the joints) in the test section that might bias the analysis.

The log wall houses can be further sub-divided into the following types of construction -

i) three of standard round log wall construction
ii) one of square log-chinked wall construction
iii) one of modified round log wall construction

All of the houses are two storey homes with a full basement. Only the first floor walls are made of logs. The second floor is conventional wood frame construction.

Each of these wall construction types is discussed briefly below.

<u>Standard Round Log Wall Construction</u>

The first three log houses tested in this project can be classified under this type of construction. These are referred to as Log House No. 1, Log House No. 2 and Log House No. 3 in the balance of the report. Each of these log houses is less than three years old.

The construction of the log walls in these three houses is based on a Scandinavian technique in which a longitudinal round groove is hewn into the bottom of each log. Each log is hand scribed so that the groove matches the contour of the log on which it is to be placed. A thin piece of mineral wool is placed in the groove to help fill voids between the logs. The corner detail in all houses is a double groove type.

The wall section that was tested in Log House No. 1 was comprised of alternating white and red pine logs ranging in diameter from 230 mm to 350 mm with an average diameter of 270 mm (based on on-site measurements of the ends of the logs used in the test section). The joints have an average depth (measured across the wall) of about 145 mm.

The joints of Log House No. 1 differ from the other two houses in that the interior and exterior surface of the joints were caulked using a rubber based caulking compound.

Log House No. 2 uses white pine exclusively in the log walls. The logs in the wall section that was tested in this house range in diameter from 250 mm to 400 mm with an average diameter of 310 mm. The average depth of the joints was 190 mm.

Log House No. 3 also uses white pine exclusively in the log walls. The logs in the wall section that was tested in this house range in diameter from 280 mm to 440 mm with an average diameter of 350 mm. The average depth of the joints was 210 mm.

Square Log-Chinked Wall Construction

This log house, referred to as Log House No. 4 in the balance of the report is about eight years old. The log walls of this house are comprised of 250 mm by 250 mm squared cedar logs tied together by steel bolts. The dovetail corner detail separates the logs vertically from each other creating a space about 50 mm high. This space is filled with mineral wool insulation. These insulated joints are then covered both inside and out with expanded metal lath and parged with concrete.

Modified Round Log Wall Construction

This house is about two years old and is referred to as Log House No. 5 in the balance of the report. The house was built using a construction technique similar to the squared log house discussed above but instead round logs were used. In this type of construction, the top and bottom of each log is flattened to create a flat face of about 250 mm. The logs are placed one on top of another separated by about 40 mm of semi-rigid fiberglass insulation. The logs are tied about every one meter by 30 mm round hardwood dowels. Corner detailing uses the "Butt and Pass" method. All joints are sealed on the interior and exterior surfaces with reenforced plastic cement. The logs range in diameter from 350 mm to 450 mm with an average diameter of 390 mm.

Conventional Wood Frame Construction

A single wood frame house was also included in the study to produce a baseline for comparison to the log wall measurements. This house, referred to as the "Control" house in the balance of the report is a conventional wood framed house about eight years old. The interior is finished with 13 mm drywall covering an 89 mm wood stud/insulation cavity. The cavity is insulated with 2.1 RSI (R 12) batt insulation. The exterior finish is 16 mm plywood panelling over building paper.

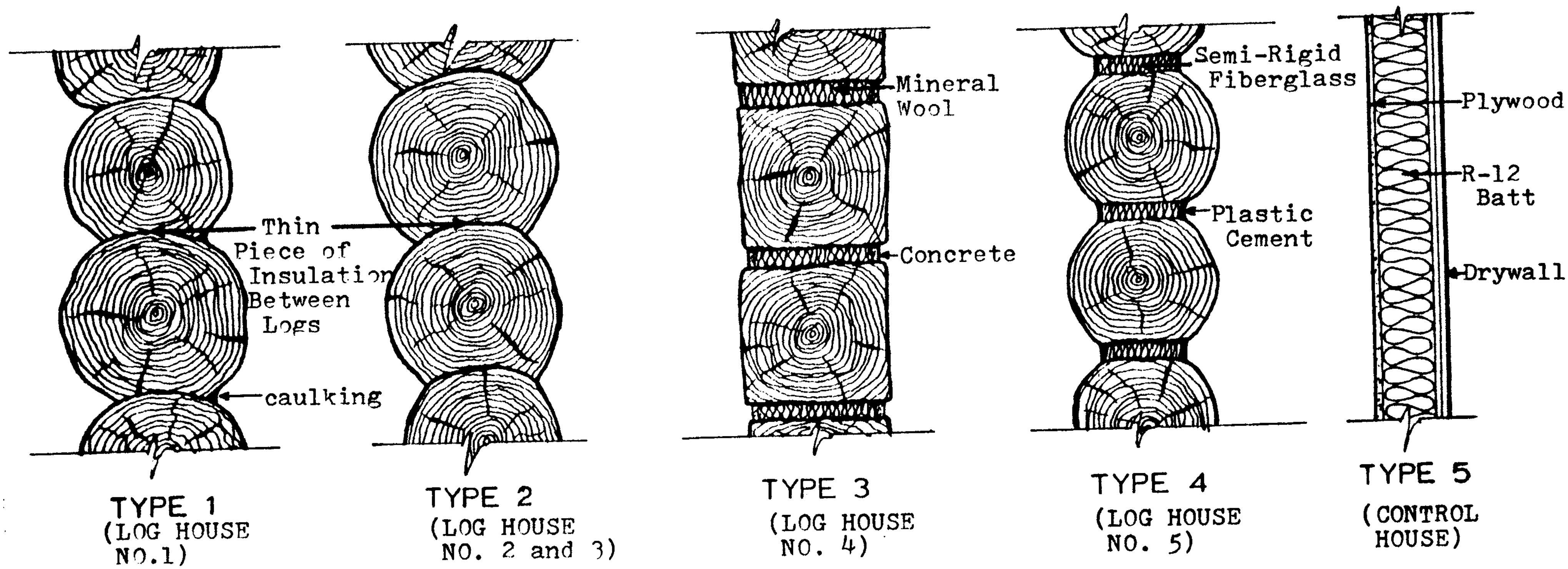
The wood studs are 400 mm o.c. Three wood studs were included in the test section.

Table 1 summarizes the dimensional features of each of the log wall sections tested in the study. Figure 1 shows cross-sections of each of the different types of log walls tested in the study.

Table 1: Summary of Dimensional Features of Log Houses Included in the Study

Log House No.	Age yrs	Log Size (mm) Max	Min	Avg	Joint Size (mm) Max	Min	Avg	Test Location	Test Period
1	3	350	230	270	180	100	145	Bathroom	22:00 Jan.21/86 - 10:00 Feb.15/86
2	3	400	250	310	220	180	180	Closet	21:00 Jan.27/86 - 19:00 Mar.03/86
3	2	440	280	350	260	180	210	Bedroom	13:00 Feb.07/86 - 24:00 Feb.23/86
4	8	250	250	250	250	250	250	Living Room	16:00 Feb.19/86 - 10:00 Mar.12/86
5	2	450	350	390	270	210	240	Living Room	19:00 Mar.03/86 - 10:00 Mar.25/86

Figure 1: Various Log Wall Construction Techniques Examined in the Study



5.0 INSTRUMENTATION

5.1 Mimic Box

The basic principle of the mimic box was discussed earlier. The mimic boxes used were supplied by the Institute for Research in Construction of the National Research Council. These mimic boxes are comprised of the following:

1) The basic five sided guarded calorimeter (mimic box) with one open side which is sealed to the test wall. The dimensions of the box are 1960 mm high by 1210 mm wide by about 200 mm deep. The section of wall under test thus has an area of 2.37 m^2.

2) A 150 W electrical heating cable looped within the mimic box so as to provide even distribution of heating.

3) A thermopile junction to measure the temperature difference between the air in the box and that in the room.

4) A controller to turn the 150 W heater cable on and off to maintain a negligible temperature difference across the mimic box walls.

5) A high temperature safety cut-out to shut off the heaters if the controller fails and temperatures inside the box exceed a preset upper limit.

6) A pulse initiating kilowatt-hour meter to measure the energy consumed by the heater cable.

5.2 Data Acquisition System

The data acquisition system was made up of the following components -

- Sciemetrics Instruments Model 8082A Electronic Measuring System capable of measuring 64 analog channels and 16 digital channels.

- Compaq portable MS-DOS computer with 256 K RAM, two floppy disk drives and a real time clock card.

- J type thermocouples capable of measuring temperatures in the range of -210°C to 760°C with an accuracy of 2.2°C.

- Pulse counter card to provide the interface between the pulse initiating kilowatt-hour meter and the Sciemetrics system.

The temperature sensors and the pulse initiating meter were connected to the Sciemetrics system. The Sciemetrics system was then connected to the microcomputer via a custom interface card. A compiled PASCAL program developed by Sciemetrics for this type of application was used to control the data acquisition system. The program continually reads each of the selected channels sequentially and stores the value in a cumulative average (thermocouples) or cumulative total (kilowatt-hour meter) function. These functions are stored on disk each hour.

In addition, the kilowatt-hour meter reading was recorded manually at the beginning and end of each test period to provide a suitable backup in case of a malfunction of the energy measuring component of the data acquisition system.

5.3 Sensor Placement Strategy

Figure 2 shows the placement of the temperature sensors used in the monitoring project. The placement of the sensors was designed to fully describe the thermal behaviour of the particular wall section. A degree of redundancy was introduced to provide back-up in case of failure of some sensors. The locations of the sensors are summarized in Table 2.

Also shown in Figure 2 are the locations of additional sensors designed to track the box/room temperature difference, ambient indoor and outdoor air temperatures, and temperatures on a wall section adjacent to the mimic box. These measurements are not essential to the determination of heat loss or RSI-value but do provide supplemental information that helps validate the operation of the mimic box and the experiment as a whole.

<u>Attachment of the Mimic Box to the Wall.</u>

The unevenness of the round log walls provided an additional challenge since it was imperative that an airtight seal between the mimic box and the log wall be achieved. The following describes the method used:

1) A square wooden frame 1.21 m by 1.96 m was fabricated using 12 mm by 25 mm wood framing.

2) The frame was attached to the selected wall section with duct tape. The frame was appropriately positioned such that the top and bottom portion of the frame could be attached to a log (i.e. the top and bottom portion of the frame were not placed directly opposite joints).

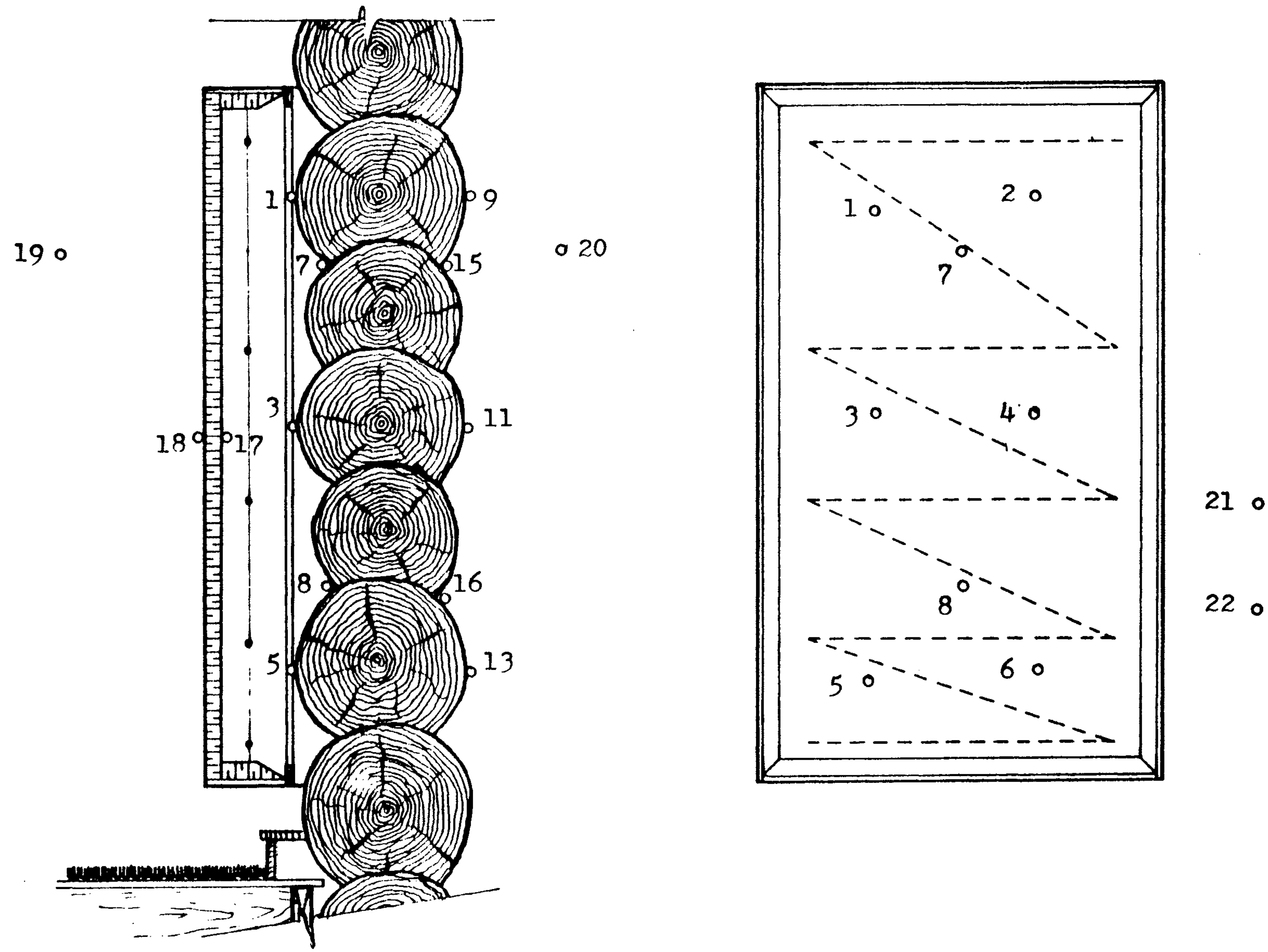
3) Semi-rigid fiberglass insulation was cut to fill in the voids between the log and the vertical framing members caused by the contours of the logs. All joints were sealed with duct tape.

4) The mimic box was braced against the wall with wooden framing members and all seams sealed with duct tape.

TABLE 2:DESCRIPTION OF SENSOR LOCATIONS USED IN MONITORING PROJECT

SENSOR NO.	DESCRIPTION/LOCATION
1	MIMIC BOX AIR TEMPERATURE #1
2	MIMIC BOX AIR TEMPERATURE #2
3	MIMIC BOX AIR TEMPERATURE #3
4	MIMIC BOX AIR TEMPERATURE #4
5	MIMIC BOX AIR TEMPERATURE #5
6	MIMIC BOX AIR TEMPERATURE #6
7	JOINT TEMPERATURE #1 (INSIDE MIMIC BOX)
8	JOINT TEMPERATURE #2 (INSIDE MIMIC BOX)
9	EXTERIOR TEMPERTURE #1 NEAR LOG
10	EXTERIOR TEMPERTURE #2 NEAR LOG
11	EXTERIOR TEMPERTURE #3 NEAR LOG
12	EXTERIOR TEMPERTURE #4 NEAR LOG
13	EXTERIOR TEMPERTURE #5 NEAR LOG
14	EXTERIOR TEMPERTURE #6 NEAR LOG
15	EXTERIOR JOINT TEMPERATURE #1
16	EXTERIOR JOINT TEMPERATURE #2
17	TEMPERATURE ON MIMIC BOX WALL(INSIDE MIMIC BOX)
18	TEMPERATURE ON MIMIC BOX WALL(ROOM SIDE)
19	ROOM AIR TEMPERTURE
20	OUTDOOR AIR TEMPERTURE
21	INDOOR AIR TEMPERATURE NEAR LOG(OUTSIDE MIMIC BOX)
22	INDOOR AIR TEMPERATURE NEAR JOINT(OUTSIDE MIMIC BOX)
23	EXTERIOR AIR TEMPERATURE NEAR LOG(OUTSIDE MIMIC BOX)
24	EXTERIOR AIR TEMPERATURE NEAR JOINT(OUTSIDE MIMIC BOX)

Figure 2: Location of Temperature Sensors



6.0 RESULTS

As pointed out under "Instrumentation", hourly temperature and power consumption data was stored to disk every hour.

A review of the data indicated that in four of the six houses, energy consumption recorded by the data acquisition system was between six to seven percent less than that recorded manually. All equipment was calibrated prior to monitoring. In these four cases, hourly energy consumption recorded by the datalogger was corrected by the discrepancy to bring the power consumption as recorded by the data acquisition system in line with that recorded manually.

In two of the cases, the energy consumption data recorded by the data acquisition system was clearly inconsistent with that recorded manually. In these two houses, the same monitoring equipment was used and hence the error is attributed to either the meter or the pulse reading board. However, since the final RSI value depends only on the total power consumption, the manual meter readings can still be used in lieu of data from the data acquisition system to yield the RSI for these two walls.

Hourly energy data provides an opportunity to measure the effects of stored energy on the final result. Calculation of the RSI value for a number of increasing time intervals from the beginning of a test highlights the error caused by neglecting stored energy in equation (2). This error is larger at the shorter intervals, and diminishes as the intervals get longer. The error will be positive or negative at any one time depending on whether the wall is cooler or warmer than at the start of the test.

For these cases where hourly energy data is available, the RSI value can be calculated for each hour of the test period. For each hourly calculation, the time interval is the duration of the time since the beginning of the test or analysis period and similarly the temperatures are the average temperatures over that same time interval. The average temperature inside the mimic box is based on the six temperature sensors located near the logs. A check of this average temperature against the room temperature for each of the set-ups confirmed that these six sensors were sufficiently far enough away from the wall to be outside the air film. Therefore, the thermal resistance of the interior air film should be considered to be included in the measured RSI value of the wall. Similarly, the outside wall temperature measurement was based on six sensors located near the exterior wall and directly opposite an interior wall sensor. Again, these sensors were far enough away from the wall that exterior air films were considered to be included in the measured RSI value.

Two temperature sensors located near two joints in each of the log wall systems were used to measure the degree of heat loss at the joint. The average value of these joint sensors was compared to the interior and exterior temperatures and a measure of the difference between temperatures near the log and near the joint was used to evaluate the degree of heat loss.

The performance of the control system of the mimic box was evaluated by measuring the box/room temperature differential (i.e. the temperature differential across the back side of the mimic box). The control system was considered to be operating satisfactorily if this temperature differential averaged less than 1°C.

A brief overview of the results for each house is presented in the following sections. The results for each house are summarized in Table 3 which follows this overview.

LOG HOUSE NO. 1

Testing in this house was conducted from 22:00 January 21, 1986 to 10:00 February 15, 1986, a duration of 589 hours. A review of the data indicated that a period from 08:00 January 23, 1986 to 07:00 February 15, 1986, a duration of 552 hours best satisfied the previously established criteria for minimizing the effects of stored energy.

The average outdoor temperature over this period was -13.7°C with a range from -27.2°C to 2.7°C. The average temperature of the room was 20.2°C with a range from 13.8°C to 25.9°C.

The mimic box/room temperature differential was tracked. The results show that the average temperature differential was -0.8°C over the test period, indicating that the box control system was working as intended.

The average air temperature inside the mimic box over the selected period was 19.9°C with a range from 14.1°C to 24.3°C. An examination of the data indicates that the difference between the average temperature measured near the joints and the average air temperature measured near the logs was about 1°C. The difference is small for this house compared to other log wall systems, as will be seen later. This may be attributed to the caulking the occupant performed on the joints which essentially eliminated air leakage through the joints.

Exterior temperatures near the logs over the selected period averaged -12.1°C with a range from -25.7°C to 3.2°C. No perceptible difference was observed between temperatures measured near the logs and temperatures measured near the joints. The temperature profiles for the wall section tested in this house is shown in Figure 3.

In Section 3, three methods of reducing the effects of stored energy in the logs were identified. These were -

a) ending the analysis period at a point having the same inside and outside temperature as at the beginning of the test;

b) maximizing the temperature differential across the wall;

c) utilizing the longest possible period that met a) and b).

Figure 4 shows the hourly RSI-value (using equation (2))for the wall section tested in this house for the period 08:00 January 23, 1986 to 07:00 February 15, 1986. The flattening out of the curves after about 300 hours indicates that the effects of stored energy have become sufficiently small compared to the cumulative conductive heat loss through the wall section. The horizontal line is the final result of 1.87 $m^2 \cdot C/W$ (10.6 hr. $ft.^2 \cdot F/Btu$) at 552 hours.

It is interesting to note that if the RSI calculation had been performed using the data over the full monitoring period, the RSI value would be have been 1.88 $m^2 \cdot C/W$ (10.7 hr.$ft.^2 \cdot F/Btu$). This value is almost the same as that calculated above. Thus, if the test period is sufficiently long, the importance of ending the analysis period at a point when the temperature is the same as at the start becomes smaller and smaller.

The advantage of using the full monitoring period is that the final result can be based on the total energy consumption derived from manual meter readings.

Thus, the effective RSI value for wall section tested in Log House No. 1, based on the monitored period 08:00 January 21, 1986 to 07:00 February 15, 1986 was found to be 1.87 $m^2 \cdot C/W$ (10.6 hr.$ft.^2 \cdot F/Btu$).

Figure 3

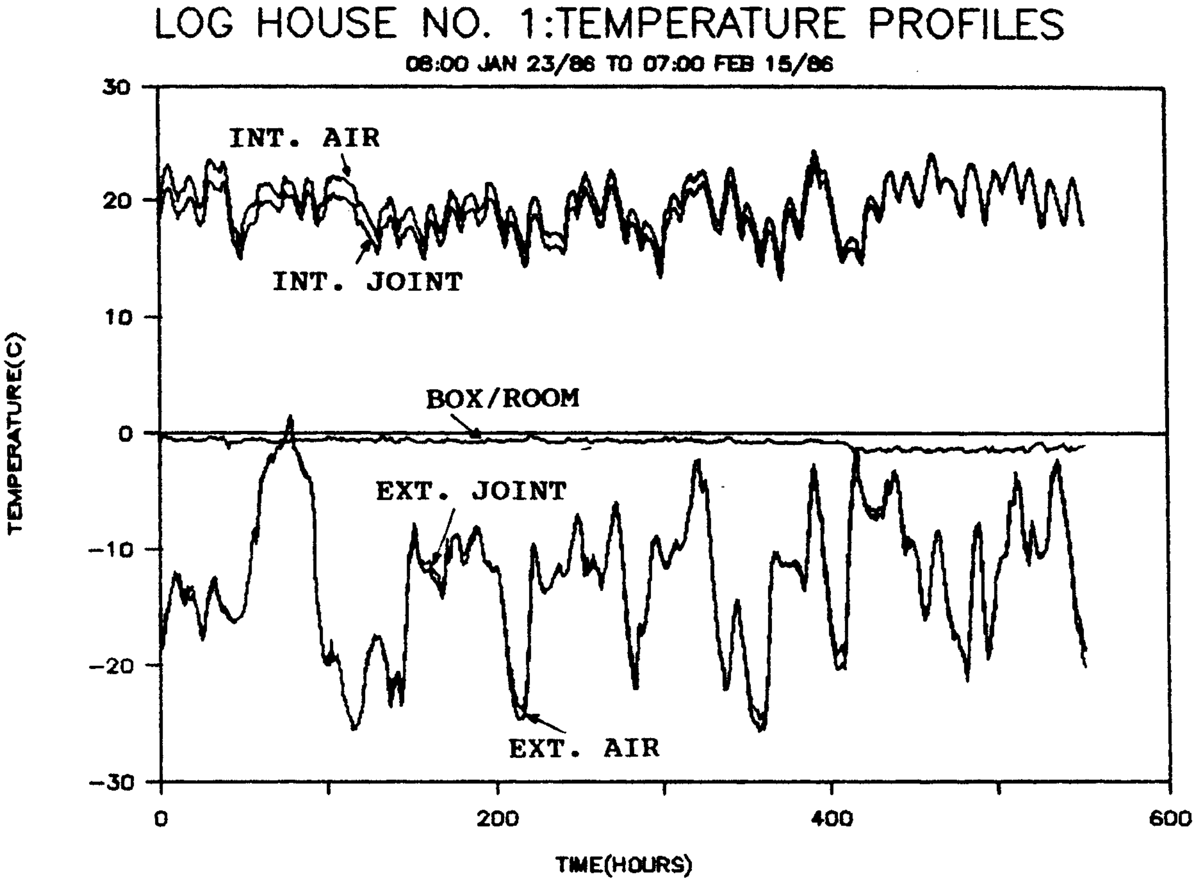
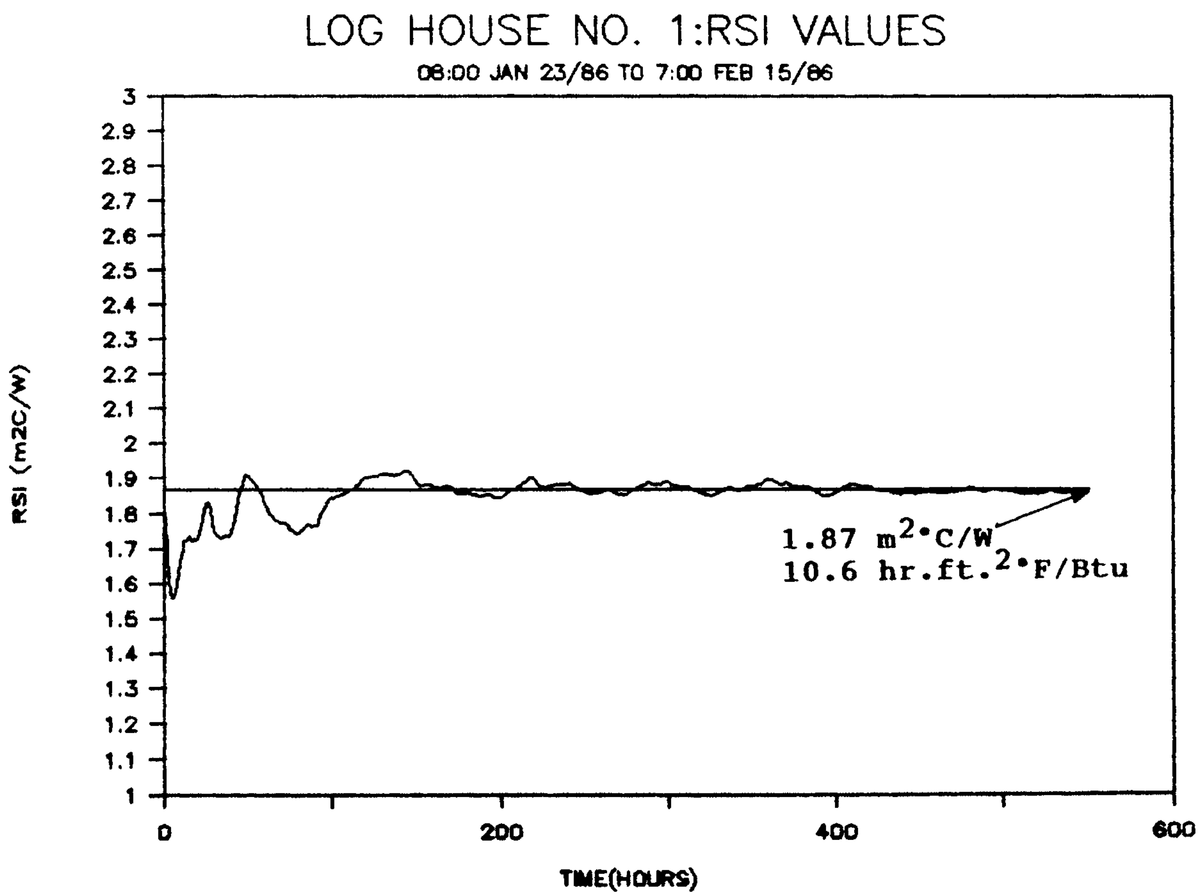


Figure 4



LOG HOUSE NO. 2

Testing in this house was conducted from 22:00 January 27, 1986 to 19:00 March 3, 1986, a duration of 838 hours.

During the monitoring period, the top of the mimic box pulled away from the log wall (i.e. the seal broke). This was first observed at 19:00 January 19, 1986, which was the scheduled termination date for this test. An examination of the mimic box indicated that the gap was small, less than 1 cm and restricted almost exclusively to the top left portion of the box. (The break was not apparent to an observer unless viewed from the top of the box.) Since the actual time that the box broke away from the log wall could not be determined on site, the box was resealed, braced against the opposite wall and the monitoring period extended a further 12 days to 19:00 March 3, 1986.

A review of the box/room temperature differential appears to indicate that the mimic box broke away from the wall sometime on February 17, 1986 since on that day the temperature differential changed from about 0.3°C to 2°C.

As a result of this break in the seal of the mimic box, two independent periods were selected for analysis. The first was from 03:00 January 30, 1986 to 02:00 February 17, 1986 (prior to when the box apparently broke its seal), a duration of 432 hours. The second period was from 00:00 February 20, 1986 (following the repair of the seal) to 19:00 March 3, 1986, a duration of 283 hours.

Test Period 1: 03:00 January 30, 1986 to 03:00 February 17, 1986

The data for this period shows the average outdoor temperature over the period was -11°C with a range from -24.7 to -1.3°C. The average temperature of the room was 24.5°C ranging from 23.1°C to 26.7°C.

The average box/room temperature differential over this selected period was 0.0°C.

The average air temperature in the mimic box was 24.1°C with a range from 22.4°C to 26.0°C. From the data it can be seen that the difference between the average air temperature in the box and that near the joints is about 2°C. This is larger than that observed in Log House No. 1 which had both its interior and exterior joints caulked, whereas Log House No. 2 had only its exterior joints caulked.

Exterior air temperatures near the logs averaged about -9.5°C with a range from -22.8°C to 0.6°C. The exterior air temperatures near the joints were observed to be about 1.7°C warmer. The temperature profiles for the wall section of this house for the first period are shown in Figure 5.

Figure 6 shows a plot of the hourly RSI value for the wall section tested in this house for this first test period. The curve shows that after 300 hours the effect of stored energy has become sufficiently small compared to the cumulative conductive heat loss through the wall section. This is indicated by the flattening out of the curve. Thus, based on the monitored data, the final result at 431 hours is the best result.

Thus, the effective RSI value for the test wall section of Log House No. 2, based on the monitored period 03:00 January 30, 1986 to 03:00 February 17, 1986 was found to be 2.19 m^2°C/W (12.4 hr.ft.^{2}°F/Btu).

<u>Test period 2: 00:000 February 20, 1986 to 19:00 March 3, 1986</u>

The data for this period shows the average outdoor temperature over the period was -8.1°C with a range from -21.1°C to 2.1°C. The average temperature of the room was 24.8°C with a range from 22.4°C to 27.2°C.

The average box/room temperature differential was 0.6°C over this period.

The average air temperature in the mimic box was 24.3°C with a range from 21.7°C to 26.8°C. From the data it can be seen that the air temperature measured near the joints was about 1.7°C cooler than the average air temperature in the mimic box. This difference is similar to observations made in the first test period.

Exterior air temperatures near the logs averaged about -6.7°C with a range from 5.6°C to 20.4°C. The average exterior air temperatures near the joints were observed to be about 1.2°C warmer than corresponding temperatures near the logs. The temperature profiles for this wall section for the second test period are shown in Figure 7.

Figure 8 shows a plot of the hourly RSI value for the wall section tested in the house during the second test period. An examination of the plot indicates that although the variations appear to have reduced, it is difficult to interpret if this final result is the best result. A longer period would have been preferred in order to fully verify if the final result has actually minimized the effects of stored energy. However, based on this data after 283 hours, the best RSI value for this second period was found to be 2.42 m^2°C/W (13.7 hr.ft.^{2}°F/Btu) after 283 hours.

The two test periods yield a difference in RSI value of about 10%. The lowest value was derived from a period in which the box integrity may be considered suspect (even though the data suggests that the seal broke sometime later). However, assuming that the seal was not perfect, the first test period would result in a higher heat loss from the box and hence bias the RSI value low. Conversely, the second test period probably represents the higher limit that can be expected for this wall section. Although the seal integrity was assured in this test period, the confidence in this result is limited by the shorter duration and lower energy consumption over the period. As discussed earlier, the effects of stored energy would bias the final RSI result unpredictably. It is probably appropriate to present a range of RSI value for this house based on the data collected.

Thus, the effective RSI value for this particular wall section can be estimated to be somewhere between 2.19 $m^2 \cdot C/W$ (12.4 $hr.ft.^2 \cdot F/Btu$) and 2.42 $m^2 \cdot C/W$ (13.7 $hr.ft.^2 \cdot F/Btu$).

Figure 5

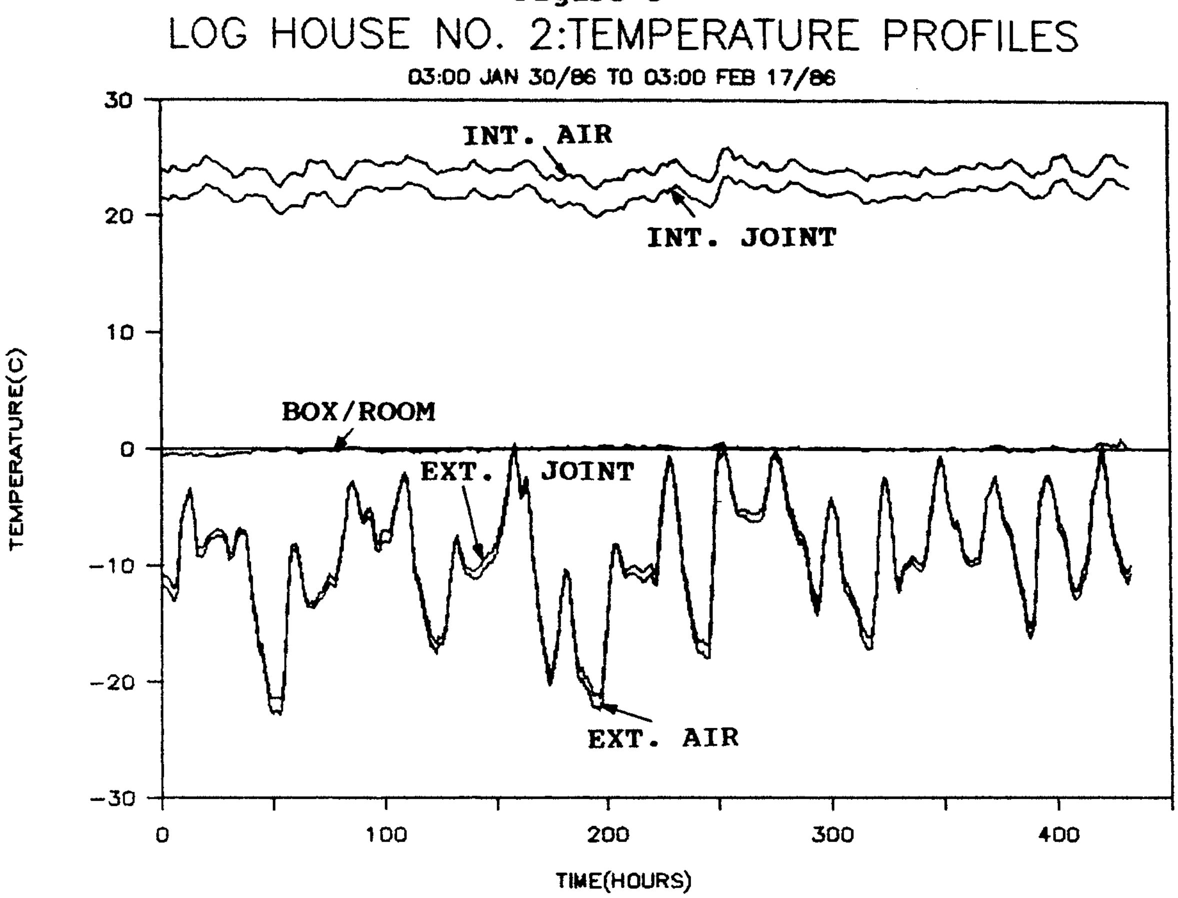


Figure 6

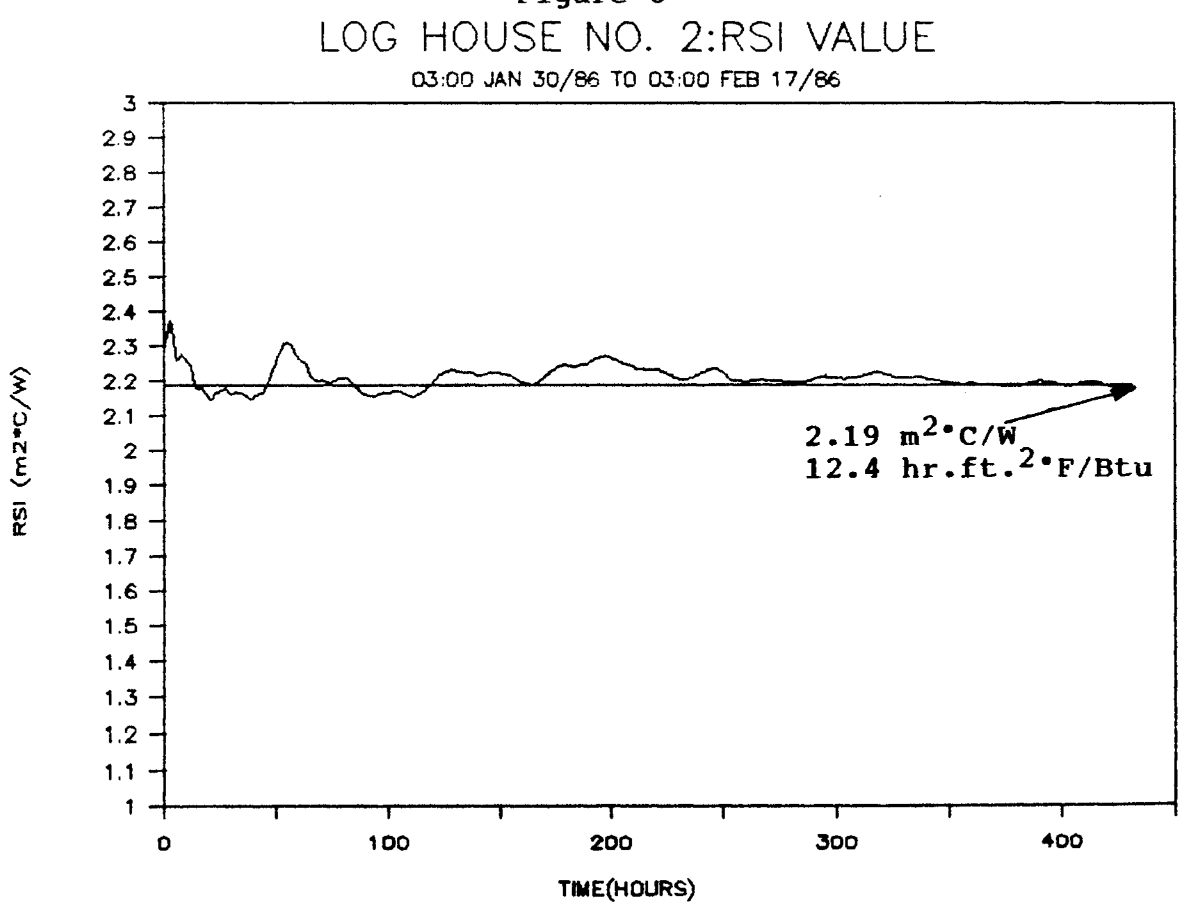


Figure 7

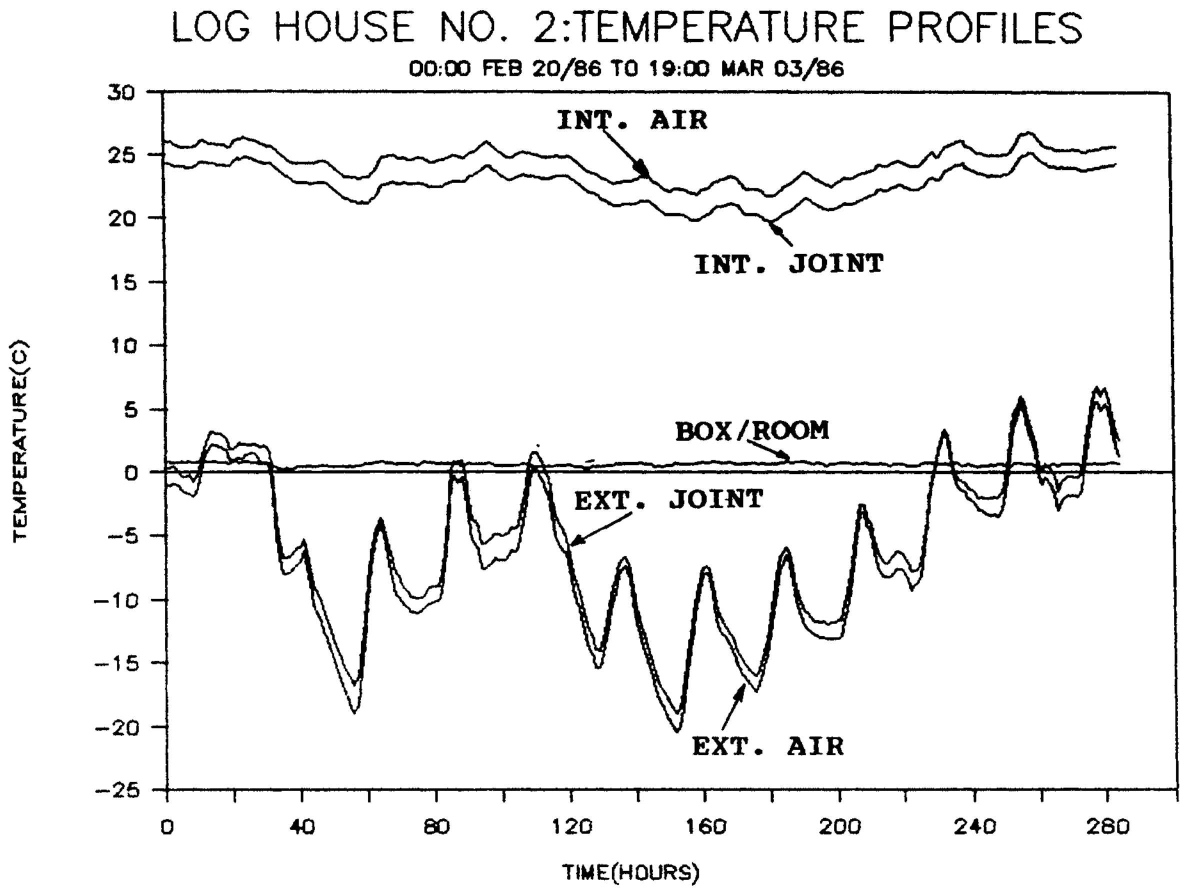
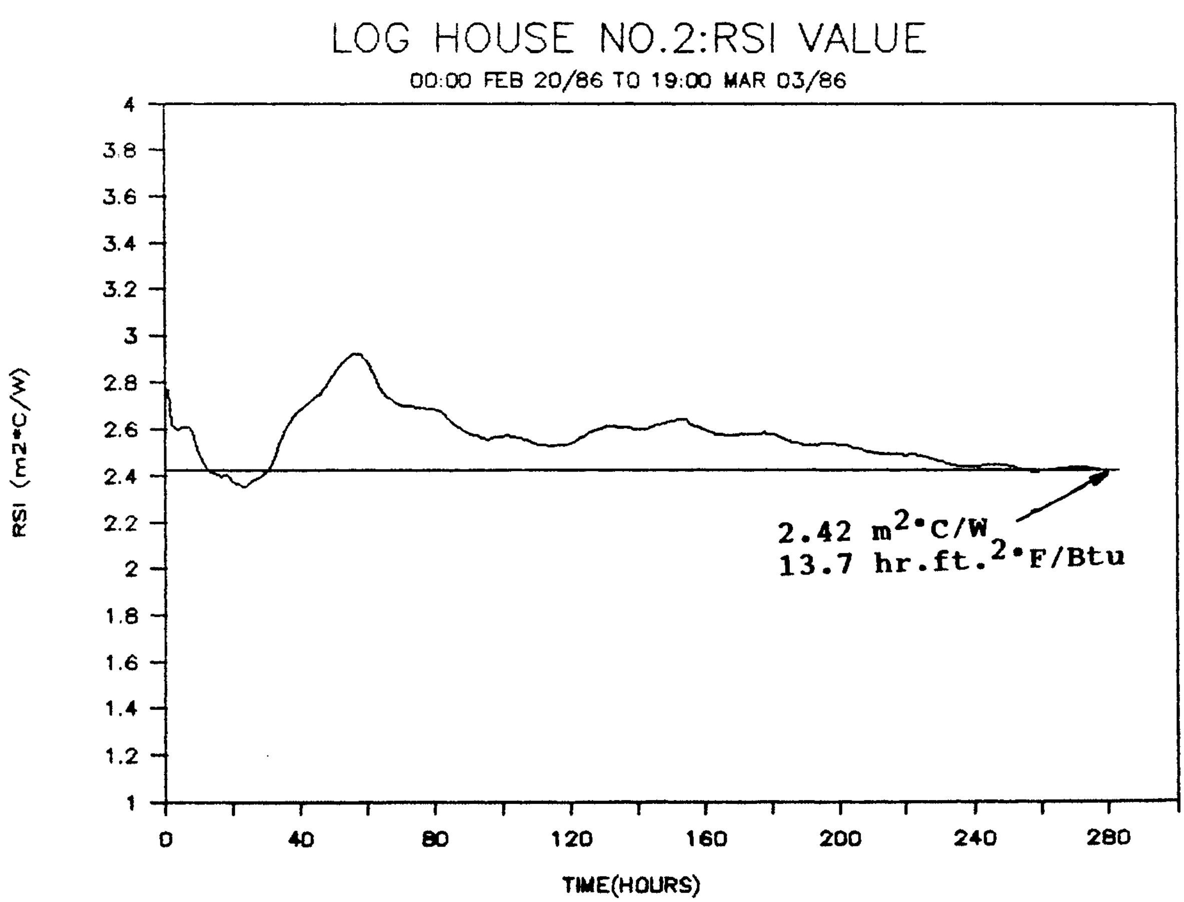


Figure 8



LOG HOUSE NO. 3

Testing in this house was conducted from 19:00 February 7, 1986 to 24:00 February 25, 1986, a duration of 396 hours.

A review of the data indicates that the criteria to minimize the effects of stored energy are satisfied by using the full monitoring period for analysis.

The data shows the average outdoor temperature over the period was -8.7°C with a range from -19.4°C to -0.2°C. The average temperature of the room was 17.3°C with a range from 15.1°C to 19.1°C.

The average box/room temperature differential was 0.1°C.

The average air temperature in the mimic box was 16.3°C with a range from 14.6°C to 17.9°C. The temperatures measured near the joints were about 2°C cooler than the average. Again, neither interior nor exterior joints were caulked in this house.

Exterior air temperatures averaged about -7.3°C with a range from -18.2°C to 2.1°C. The average exterior air temperature near the joints was found to be -5.7°C, slightly less than 2°C warmer than temperatures measured near the logs. Temperature profiles for the wall tested in this house are shown in Figure 9.

The monitoring period for this house was marred by an apparently defective component in the power measuring system. Thus, the plot of RSI vs. time is not available for the wall section of this house. However, as pointed out earlier, the final result relies only on the total power consumption over the analysis period, which in all cases can be derived directly from the manual readings of the kilowatt-hour meter. Since the plot of RSI vs. time is not available for this wall, the reduction of the effect of stored energy cannot be checked graphically. However, as the test period was as long as that used in Log House No. 1, it can be assumed with reasonable confidence that the effect of stored energy has been minimized.

Thus, the effective RSI value for the test wall section of Log House No. 3, based on the monitoring period 19:00 February 7, 1986 to 24:00 February 25, 1986, a duration of 396 hours, was found to be 2.18 $m^2 \cdot C/W$ (12.4 $hr.ft.^2 \cdot F/Btu$).

Figure 9

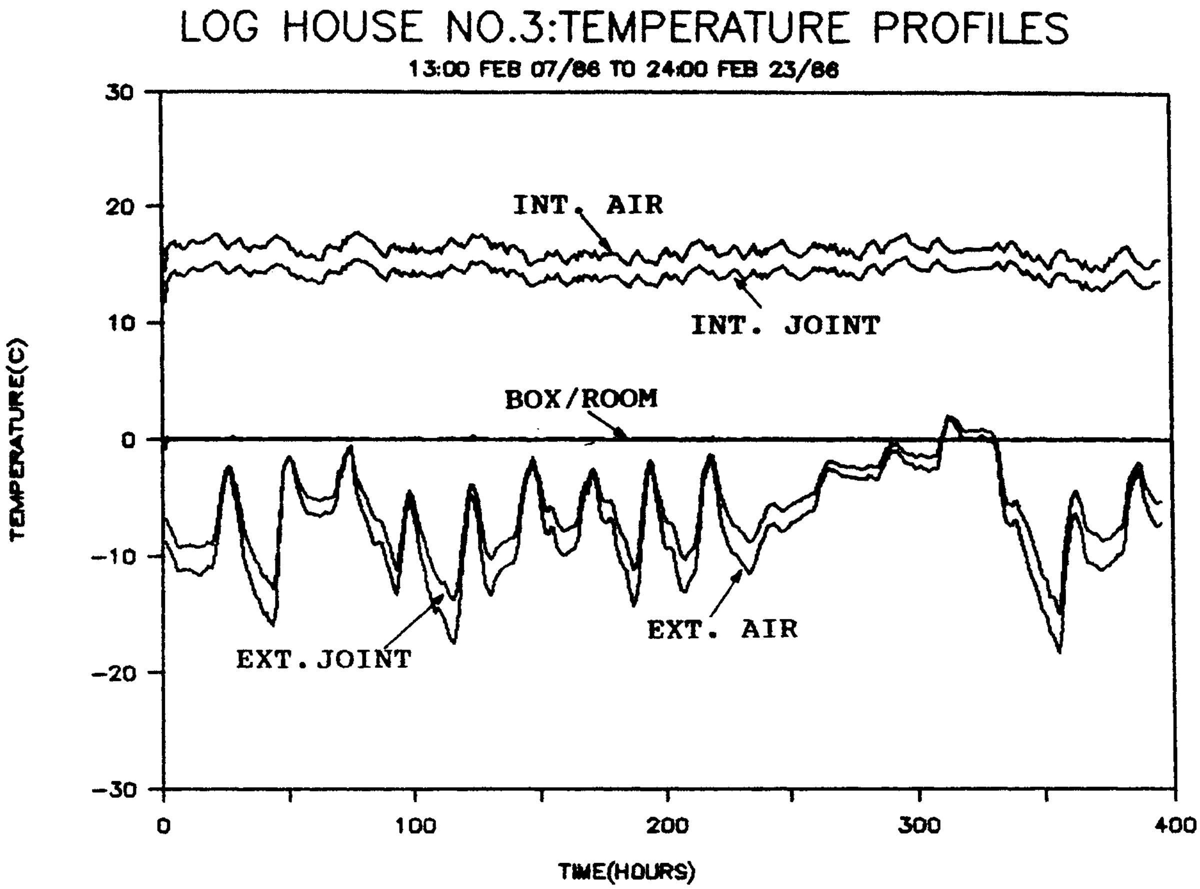
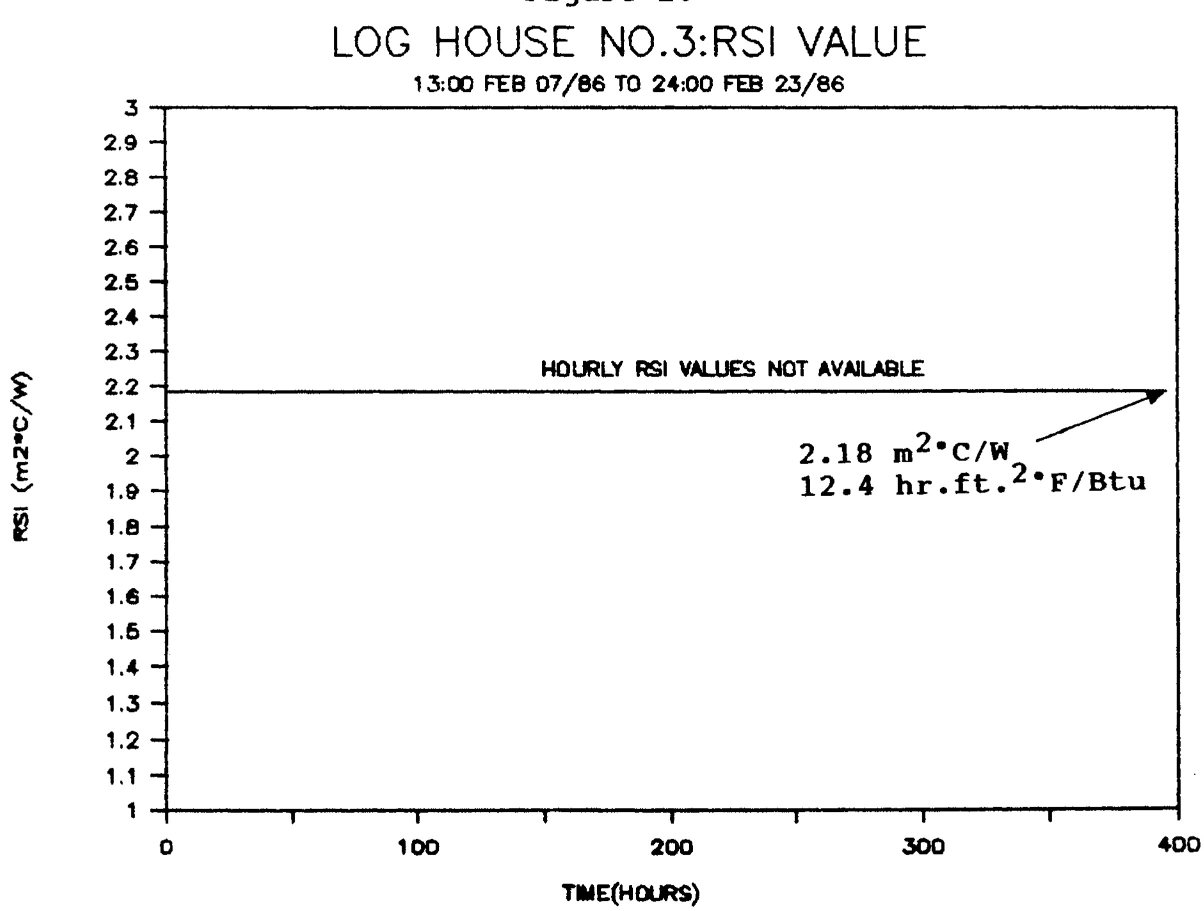


Figure 10



LOG HOUSE NO. 4

Testing in this house was conducted from 16:00 February 19, 1986 to 10:00 March 12, 1986, a duration of 499 hours.

Again, the data indicates that the full monitoring period adequately satisfied the criteria to minimize the effects of stored energy.

The data shows the average outdoor temperature over the period was -6.4°C with a range from -16.7°C to 2.8°C. The average temperature of the room was 17.1°C with a range from 9.4°C to 23.4°C.

The room temperatures varied significantly between day and night. This is attributed to the occupants' practice of setting the thermostat back to a very low temperature at night. Despite this variation the mimic box was able to track the house temperatures within 0.7°C.

The average air temperature in the mimic box was 15.3°C with a range from 8.8°C to 20.4°C. No perceptible difference was observed between the temperature measured near the joints and the average temperature in the box.

Exterior air temperatures averaged about -4.3°C with a range from -13.5°C to 3.5°C. Again, as with the interior joints, no perceptible difference was observed between the exterior air temperature near the joints and the exterior air temperature measured near the logs. This is interesting since the joints were parged, essentially eliminating the effects of lateral or through air leakage. The relative difference between box and joint temperatures is similar to that observed in Log House No. 1 which had its joints caulked. The temperature profiles for the wall section of this house are shown in Figure 11.

Plots of RSI vs. time for this wall section are shown in Figure 12. The curves clearly indicate that after 300 hours the effects of stored energy are sufficiently small compared to the cumulative conductive heat loss through the wall section that the final result at 499 hours is the best result.

Thus, the effective RSI value for the test wall section of Log House No. 4, based on the monitored period 16:00 February 19, 1986 to 10:00 March 12, 1986 was found to be 2.22 $m^2 \cdot C/W$ (12.6 $hr.ft.^2 \cdot F/Btu$).

Figure 11

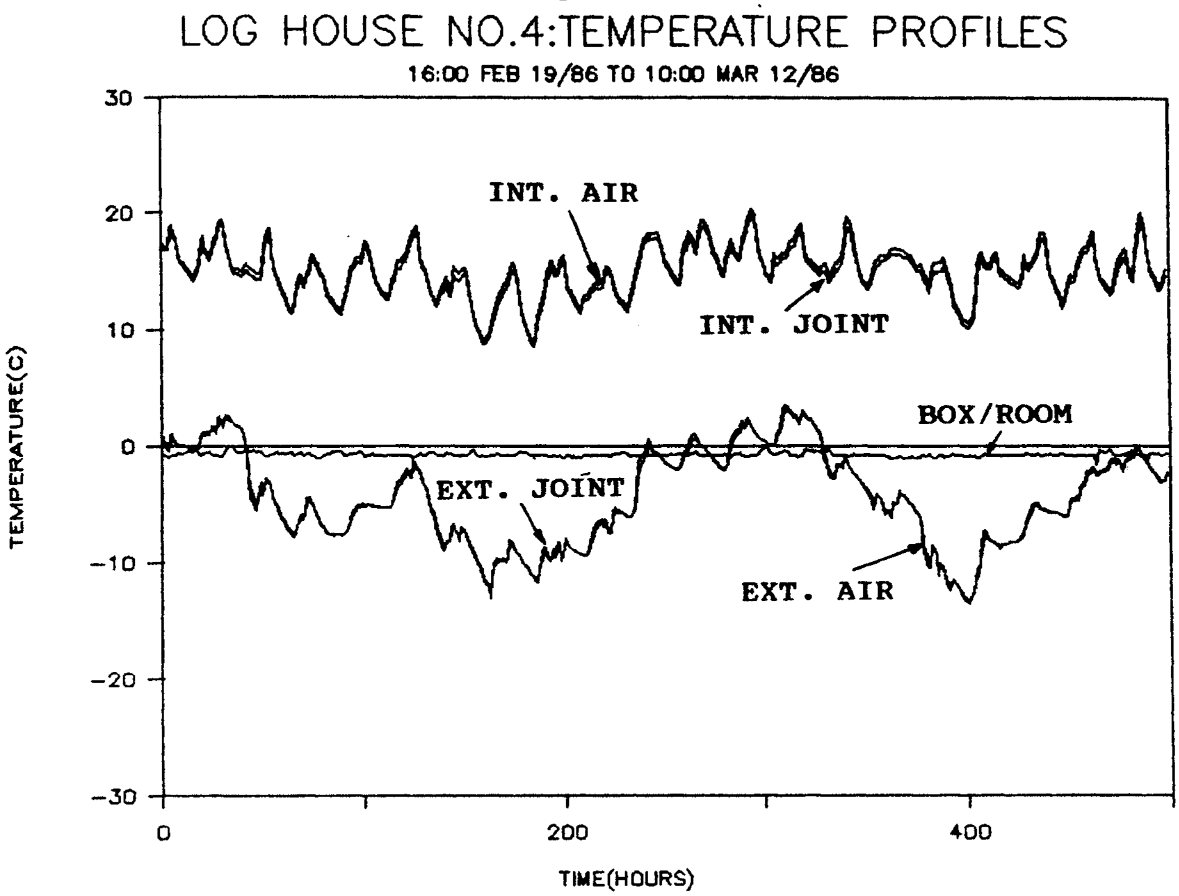
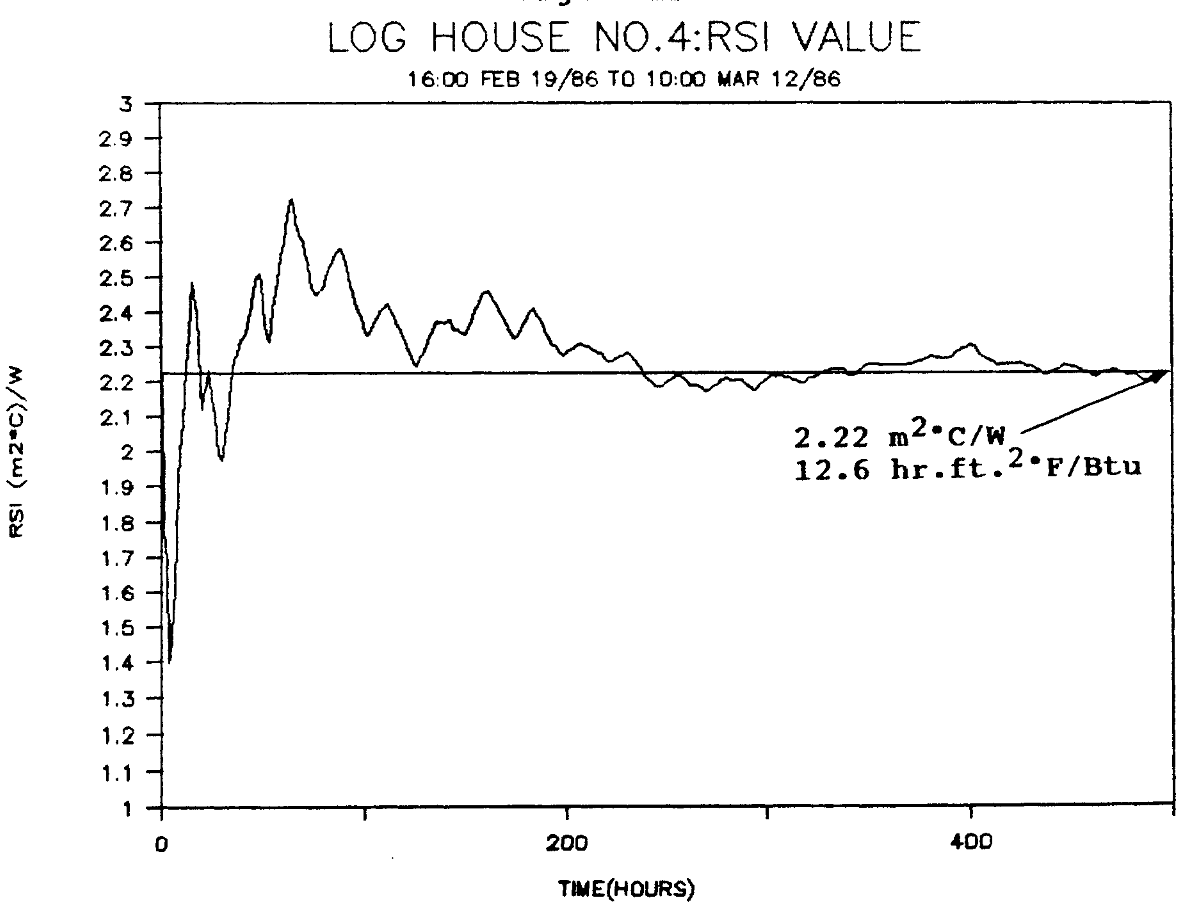


Figure 12



LOG HOUSE NO. 5

Testing in this house was conducted from 19:00 March 3, 1986 to 10:00 March 25, 1986, a duration of 509 hours.

The full monitoring period was found to satisfy the criteria to minimize the effects of stored energy.

Average outdoor temperature over the monitoring period was 0.4°C with a range from -9.9°C to 6.8°C. The average temperature of the room was 19.9°C with a range of 13.8°C to 24.9°C.

The average box/room temperature differential was 0.5°C for this period.

The average air temperature in the mimic box was 19.4°C with a range from 15.7°C to 23.3°C. Average temperature measured near the joints was found to be 18.1°C which is about 1.3°C cooler than the average air temperature in the box.

Average exterior air temperature for the monitoring period was 0.1°C with a range from -6.1°C to 6.8°C. Exterior air temperatures measured near the joints were about 0.5°C warmer than the temperatures measured near the logs. Both the interior and exterior joints of this house were sealed. Temperature profiles for the wall section of this house are shown in Figure 13.

The monitoring equipment used on Log House No. 3 was also used in this log house. As a result, hourly measurements of energy are unavailable for this house and hourly calculations of RSI are thus not possible. However, as in Log House No. 3, the final RSI result can still be calculated using the manual kilowatt-hour meter readings.

As with Log House No. 3 it is assumed that the duration of analysis for this house, 509 hours, is sufficiently long that any difference in stored energy is much smaller than the conductive heat loss through the wall section.

Thus, the effective RSI value for the test wall section of Log House No. 5, based on the monitored period 19:00 March 3, 1986 to 10:00 March 25, 1986, a duration of 509 hours, was found to be 2.52 $m^2 \cdot C/W$ (14.3 $hr.ft.^2 \cdot F/Btu$).

Figure 13

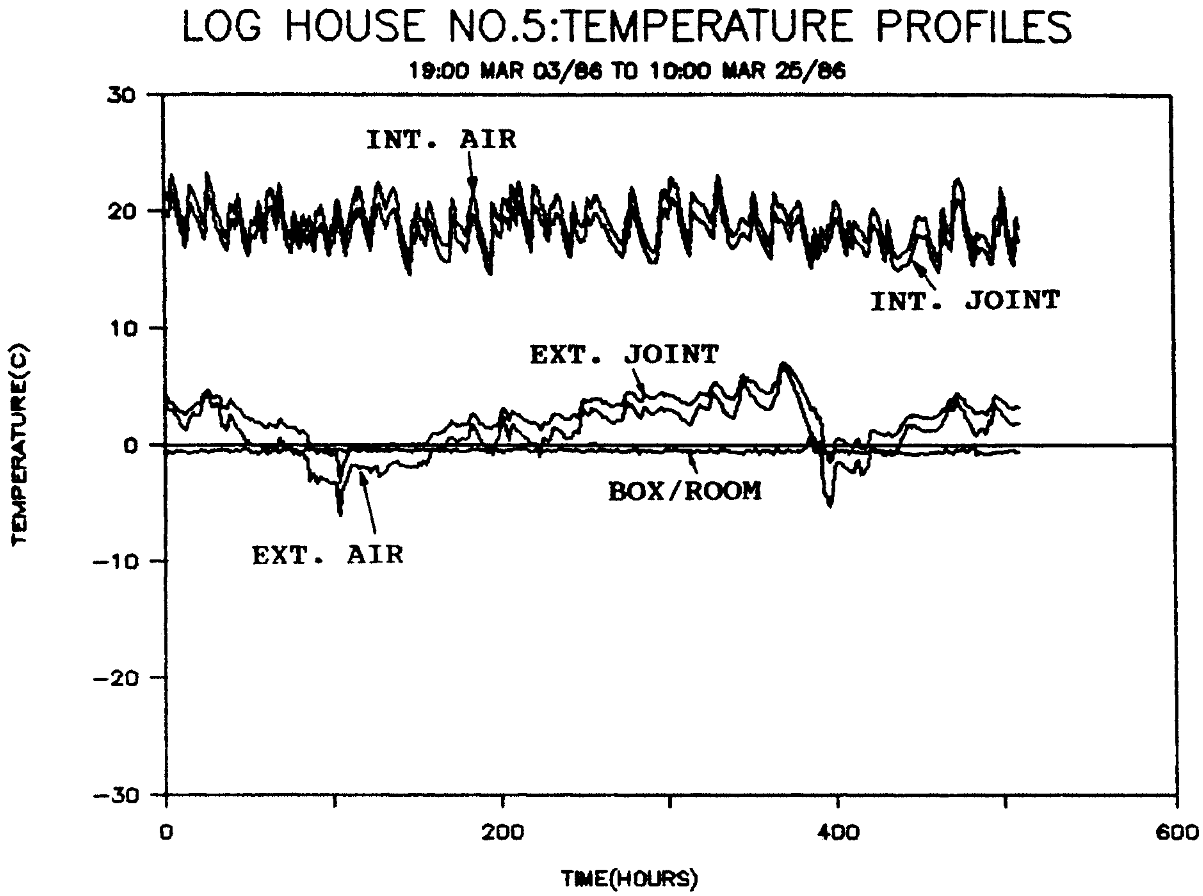
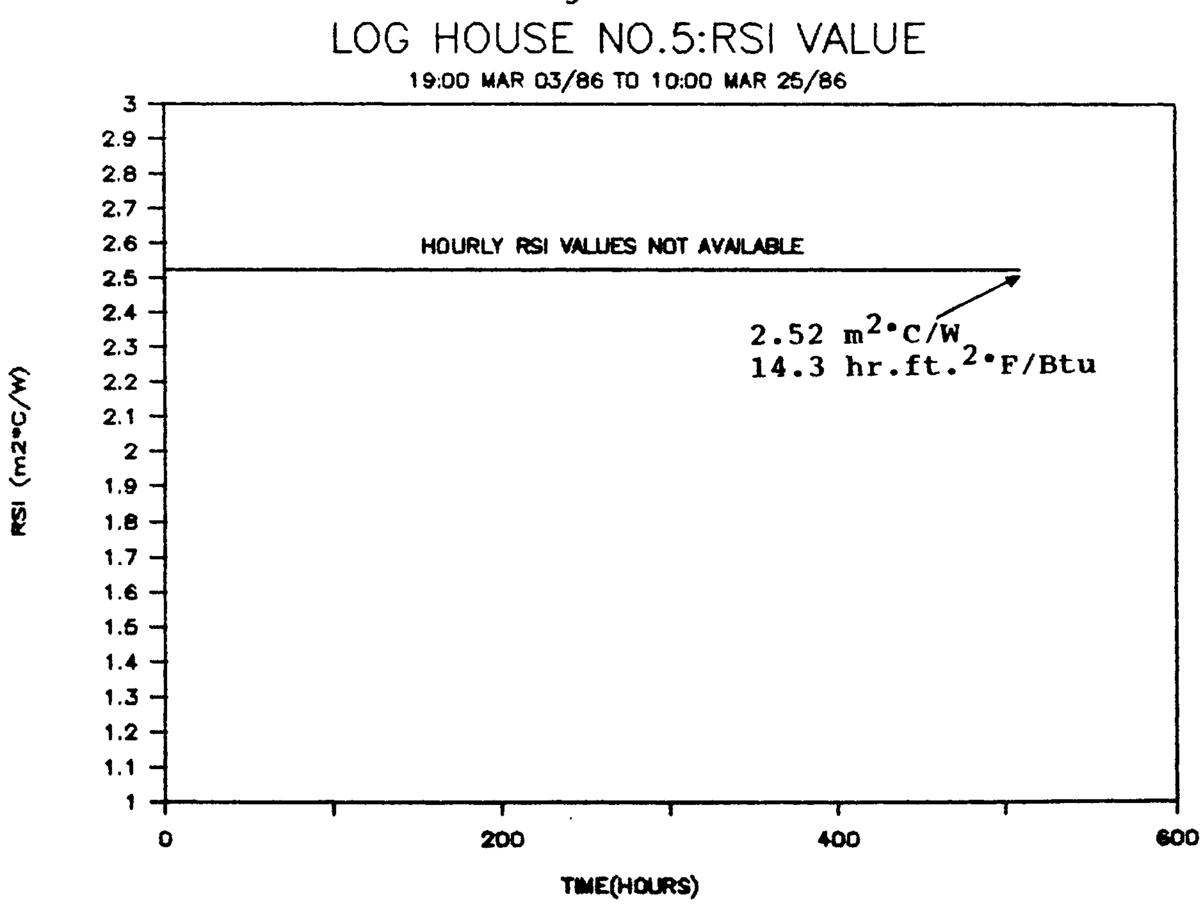


Figure 14



CONTROL HOUSE

Testing of the control house was conducted from 10:00 March 11, 1986 to 13:00 March 25, 1986, a duration of 321 hours.

Because of delays in the start of the monitoring project, the testing of the control house could not begin until March. Unfortunately, several periods of unseasonably mild weather occurred during this period resulting in extreme ranges between daytime and nighttime temperatures. In addition, the only wall with sufficient area on which to place the mimic box was oriented in a northwesterly direction. As a result, some degree of solar exposure resulted adding to the large temperature rises both inside and out.

Because of the large variation between day and night temperatures, it was decided to restrict the analysis periods to nighttime periods so as to net out any potential effects of stored energy. However, it should be noted at this point that since the temperature sensors were located close to the wall, their values are essentially what the wall "sees". As long as the criteria to minimize stored energy are adhered to, the effective RSI value will be essentially the same as that calculated for the night periods. The only limitation to this is if the exterior temperature exceeds the interior temperature. In this case the analytical basis for the mimic box is not applicable during these periods since the conductive heat loss becomes negative.

The net result is an analysis period limited from 22:00 to 08:00 hours over the period from March 11, 1986 to March 25, 1986, a duration of 136 hours.

The average outdoor temperature during these night periods was -2.1°C with a range of -17.3°C to 4.8°C. Indoor temperatures averaged 22.7°C with a range from 19.1°C to 23.7°C. Average temperature in the mimic box was 20.3°C with a range from 17.8°C to 23.5°C. Exterior air temperatures near the wall ranged from -16.5°C to 5.3°C with an average of -2.0°C

Average box/room temperature differential was 0.0°C.

Thus the effective RSI value for this control wall for the selected night periods from 22:00 March 11, 1986 to 00:00 March 25, 1986 was found to be 2.41 $m^2 \cdot C/W$ (13.7 $hr.ft.^2 \cdot F/Btu$).

The temperature profiles and RSI value for this wall section are shown in Figure 15 and 16 respectively.

Figure 15

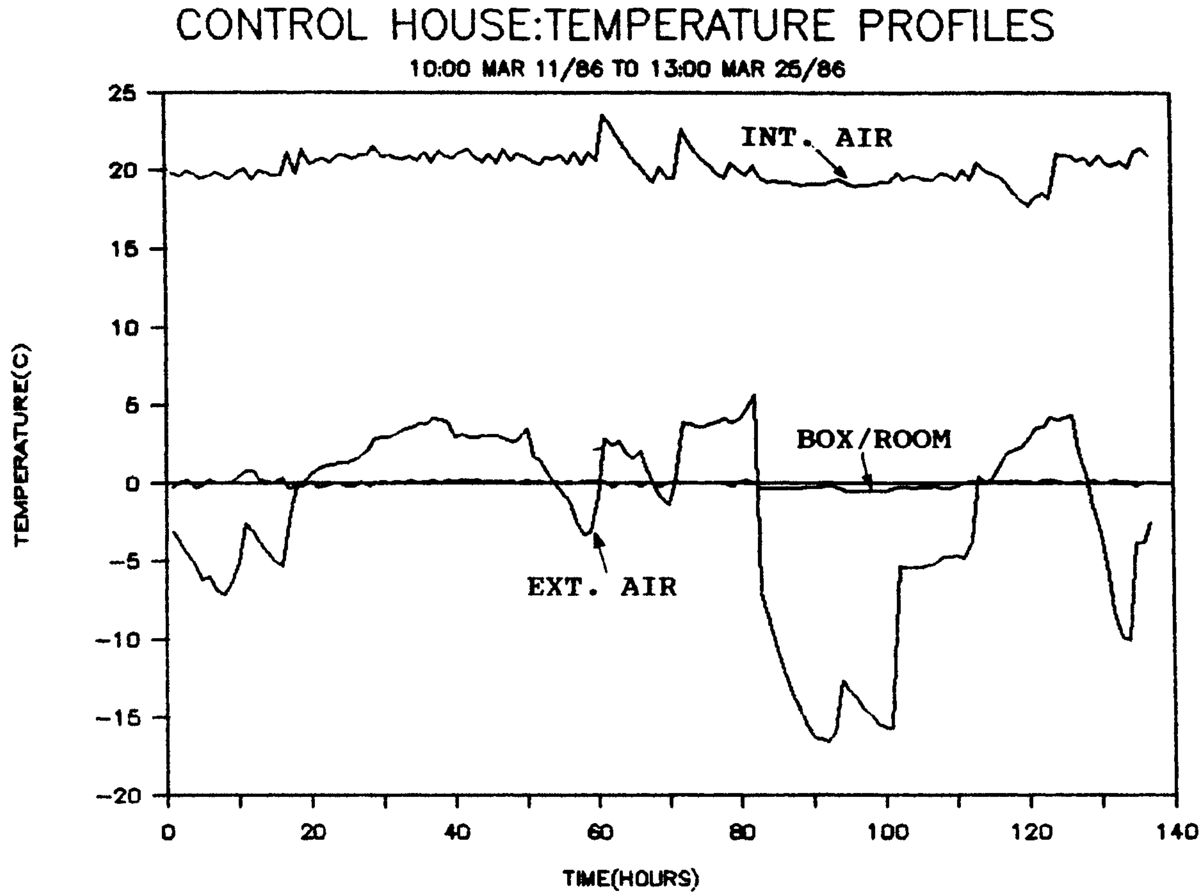


Figure 16

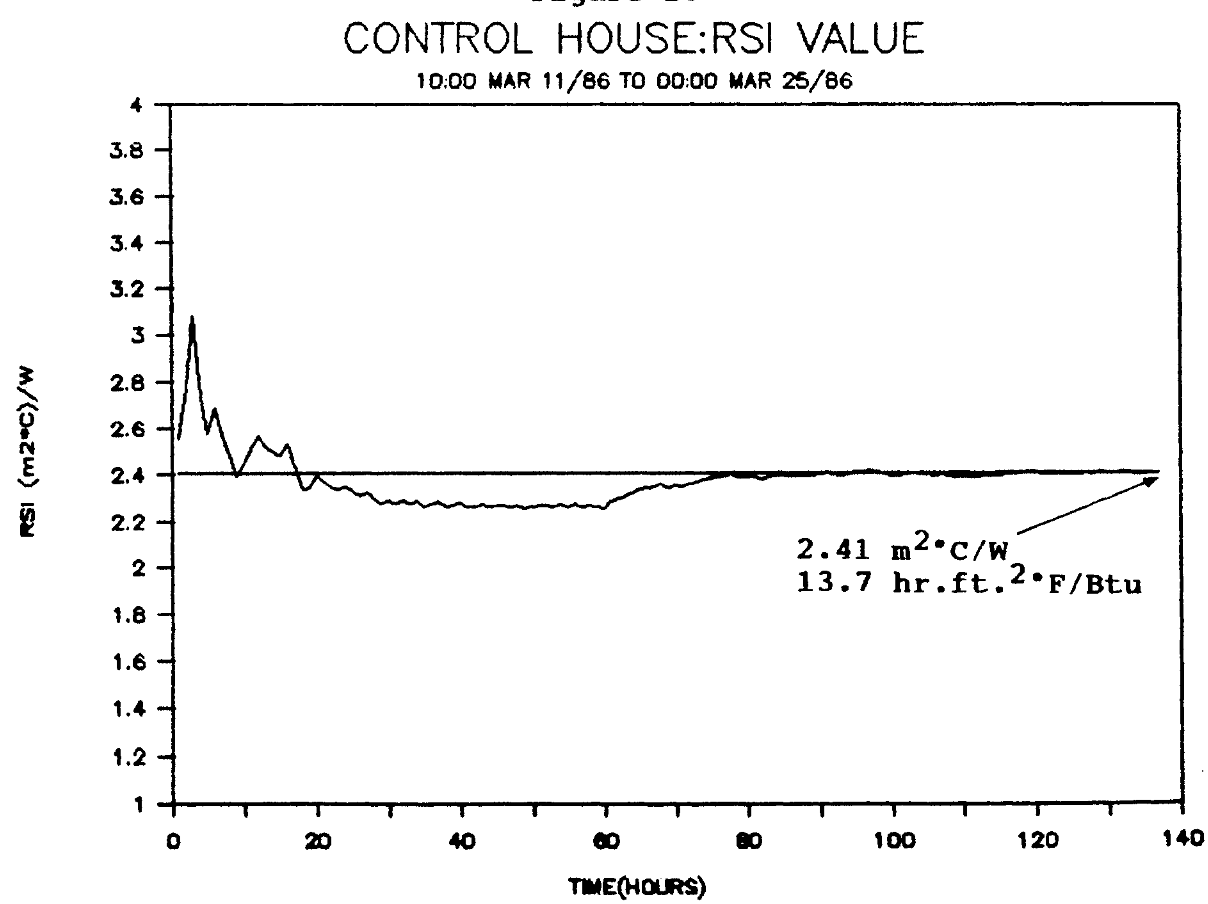


TABLE 3:SUMMARY OF RESULTS FOR THE ANALYSIS PERIODS SELECTED FOR EACH HOUSE.

TEMPERATURE AND ENERGY DATA FOR LOG HOUSE NO. 1-08:00 JANUARY 23/86 TO 07:00 FEBRUARY 15/86

	BOX AVERAGE DEGC	JOINT AVERAGE DEGC	BOX MIMICING DEGC	ROOM AVERAGE DEGC	EXTERIOR AVERAGE DEGC	EX. JOINT AVERAGE DEGC	OUTDOOR AVERAGE DEGC	TOTAL ENERGY CONSUMPTION WH
AVERAGE	19.94	18.95	-0.77	20.17	-12.56	-12.20	-13.65	
MAXIMUM	24.27	24.05	-0.10	25.90	1.33	1.50	0.30	22766.75
MINIMUM	14.12	13.25	-1.60	13.80	-25.65	-25.50	-27.20	

TEMPERATURE AND ENERGY DATA FOR LOG HOUSE NO. 2-03:00 JANUARY 30/86 TO 03:00 FEBRUARY 17/86

	BOX AVERAGE DEGC	JOINT AVERAGE DEGC	BOX MIMICING DEGC	ROOM AVERAGE DEGC	EXTERIOR AVERAGE DEGC	EX. JOINT AVERAGE DEGC	OUTDOOR AVERAGE DEGC	TOTAL ENERGY CONSUMPTION WH
AVERAGE	24.09	21.91	0.01	24.69	-9.53	-8.13	-10.96	
MAXIMUM	25.95	23.55	1.00	26.70	0.62	0.75	-1.30	15749.51
MINIMUM	22.42	20.00	-0.60	23.10	-22.83	-19.90	-24.70	

TEMPERATURE AND ENERGY DATA FOR LOG HOUSE NO. 2-00:00 FEBRUARY 20/86 TO 19:00 MARCH 03/86

	BOX AVERAGE DEGC	JOINT AVERAGE DEGC	BOX MIMICING DEGC	ROOM AVERAGE DEGC	EXTERIOR AVERAGE DEGC	EX. JOINT AVERAGE DEGC	OUTDOOR AVERAGE DEGC	TOTAL ENERGY CONSUMPTION WH
AVERAGE	24.33	22.56	0.59	24.88	-6.71	-5.52	-8.12	
MAXIMUM	21.73	19.75	0.20	22.40	-20.47	-19.00	-21.10	8605.10
MINIMUM	26.75	25.05	0.90	27.20	5.60	6.75	2.90	

TEMPERATURE AND ENERGY DATA FOR LOG HOUSE NO. 3-13:00 FEBRUARY 07/86 TO 24:00 FEBRUARY 23/86

	BOX AVERAGE DEGC	JOINT AVERAGE DEGC	BOX MIMICING DEGC	ROOM AVERAGE DEGC	EXTERIOR AVERAGE DEGC	EX. JOINT AVERAGE DEGC	OUTDOOR AVERAGE DEGC	TOTAL ENERGY CONSUMPTION WH
AVERAGE	16.31	14.33	0.09	17.31	-7.34	-5.67	-8.72	
MAXIMUM	17.85	15.80	0.40	19.10	2.12	2.15	-0.20	10170.00
MINIMUM	14.55	11.90	-0.80	15.10	-18.22	-14.95	-19.40	

TABLE 3(CONT):SUMMARY OF RESULTS FOR THE ANALYSIS PERIODS SELECTED FOR EACH HOUSE.

TEMPERATURE AND ENERGY DATA FOR LOG HOUSE NO. 4-16:00 FEBRUARY 19,1986 TO 10:00 MARCH 12,1986

	BOX AVERAGE DEGC	JOINT AVERAGE DEGC	BOX MIMICING DEGC	ROOM AVERAGE DEGC	EXTERIOR AVERAGE DEGC	EX. JOINT AVERAGE DEGC	OUTDOOR AVERAGE DEGC	TOTAL ENERGY CONSUMPTION WH
AVERAGE	15.29	14.82	-0.70	17.14	-4.34	-4.39	-6.37	
MAXIMUM	20.38	19.80	0.00	23.40	3.52	3.00	2.80	10440.00
MINIMUM	8.80	8.55	-1.60	9.40	-13.48	-13.35	-16.70	

TEMPERATURE AND ENERGY DATA FOR LOG HOUSE NO. 5-19:00 MARCH 03,1986 TO 10:00 MARCH 25,1986

	BOX AVERAGE DEGC	JOINT AVERAGE DEGC	BOX MIMICING DEGC	ROOM AVERAGE DEGC	EXTERIOR AVERAGE DEGC	EX. JOINT AVERAGE DEGC	OUTDOOR AVERAGE DEGC	TOTAL ENERGY CONSUMPTION WH
AVERAGE	19.42	18.07	-0.45	19.94	1.02	1.41	-0.35	
MAXIMUM	23.27	21.60	1.10	24.90	6.80	6.70	6.80	8800.00
MINIMUM	15.73	14.65	-0.90	13.80	-6.12	-6.10	-9.90	

TEMPERATURE AND ENERGY DATA FOR CONTROL HOUSE-11:00 MARCH 11,1986 TO 13:00 MARCH 25,1986

	BOX AVERAGE DEGC	BOX MIMICING DEGC	ROOM AVERAGE DEGC	EXTERIOR AVERAGE DEGC	OUTDOOR AVERAGE DEGC	TOTAL ENERGY CONSUMPTION WH
AVERAGE	20.31	0.00	22.74	-2.02	-2.12	
MAXIMUM	23.47	0.80	32.70	5.43	4.80	3017.30
MINIMUM	17.82	-0.50	19.10	-16.48	-17.30	

NOTE:BOX AVERAGE IS THE AVERAGE OF THE SIX SENSORS LOCATED IN THE MIMIC BOX OPPOSITE A LOG
NOTE:JOINT AVERAGE IS THE AVERAGE OF TWO SENSORS LOCATED OPPOSITE LOG JOINTS
NOTE:MIMICING REFERS TO THE BOX/ROOM TEMPERATURE DIFFERENTIAL
NOTE:ONLY PERIODS FROM 22:00 TO 08:00 WERE SELECTED FOR THE CONTROL HOUSE.

7.0 DISCUSSION

The RSI values determined in this monitoring project for each of the log wall sections tested are summarized in Table 4. The results show that the wall section tested in the modified round log house, Log House No. 5, has the highest effective RSI value (2.52 $m^2 \cdot C/W$ - 14.3 $hr.ft.^2 \cdot F/Btu$) while the wall section tested in the standard round log house, Log House No. 1, has the lowest effective RSI value (1.87 $m^2 \cdot C/W$ - 10.6 $hr.ft.^2 \cdot F/Btu$). The remainder of the log wall sections tested in the study all fit within this range. Note that the lower limit derived for the wall section tested in Log House No. 2 (i.e 2.19 $m^2 \cdot C/W$ - 12.43 $hr.ft.^2 \cdot F/Btu$) is almost identical to the result derived for the wall section of Log House No. 3 (i.e. 2.18 $m^2 \cdot C/W$ - 12.37 $hr.ft.^2 \cdot F/Btu$). This is interesting since both of these houses used the same construction technique, had similar size logs and similar degrees of heat loss as measured by temperatures near the joints. This provides further confidence that the lower limit of 2.19 $m^2 \cdot C/W$ (12.37 $hr.ft.^2 \cdot F/Btu$) that was derived for the wall section of Log House No. 2 is probably closer to the best result for this house. Consequently, this value will be used in the balance of the report.

The wall tested in the control house has an effective RSI value of 2.41 $m^2 \cdot C/W$ (13.7 $hr.ft.^2 \cdot F/Btu$). This result can be compared with the calculated value of 2.24 $m^2 \cdot C/W$ (12.7 $hr.ft.^2 \cdot F/Btu$) (calculation includes effect of thermal bridging through studs based on actual stud area within the test wall area) based on standard reference data, which yields a theoretical RSI value of 2.24 $m^2 \cdot C/W$ (12.7 $hr.ft.^2 \cdot F/Btu$). Thus the field result is within 7% of the theoretical value.

The effective RSI value for each of the log walls is plotted in Figure 17. To provide some perspective on these values the results determined from the monitoring project can be compared to the value prescribed by CMHC according to the 1978 Measures for Energy Conservation in New Buildings. This document defines the minimum effective RSI value for new housing for various degree day (DD) climates. These range from 2.5 $m^2 \cdot C/W$ (14.2 $hr.ft.^2 \cdot F/Btu$) for up to 3500 DD to 3.7 $m^2 \cdot C/W$ (21.0 $hr.ft.^2 \cdot F/Btu$) for 8000 DD and up. Interpolation is permitted. This standard however does not take into account the effects of thermal bridging between framing members. Thus, if these results are to be compared to the Measures, the RSI value recommended in the Measures should be corrected to take into account the reduction in RSI value due to thermal bridging in a normal frame wall. A typical 2 x 6, R-20-batt-insulated wood-frame wall that satisfies the Measures up to a climate of about 7000 DD would be reduced by a factor of about 11% due to the effects of thermal bridging at the framing members. Applying this factor to each of the minimum values in the Measures yields "adjusted minimum" values to which the results for each of the log walls can be compared. These adjusted minimum values are represented by the horizontal lines in Figure 17.

The results show that the measured RSI values of the walls of Log Houses Nos. 2, 3 and 4, (about 2.2 $m^2 \cdot C/W$ - 12.5 $hr.ft.^2 \cdot F/Btu$) satisfy the adjusted minimum value for a degree day climate up to about 3500 DD.

The measured RSI value of the wall of Log House No. 1 (1.87 $m^2 \cdot C/W$ - 10.6 $hr.ft.^2 \cdot F/Btu$), however, would only be recommended for a climate up to about 3000 DD. The value for the wall of Log House No. 5 and the control house, 2.52 $m^2 \cdot C/W$ (14.3 $hr.ft.^2 \cdot F/Btu$) and 2.41 $m^2 \cdot C/W$ (13.7 $hr.ft.^2 F/Btu$) respectively, satisfy the adjusted minimum value for up to about 4500 DD.

7.1 Comparison of Field Results to Calculated RSI

The measured RSI value determined in this project can also be compared to calculated RSI values for the log walls that were tested. The calculated values are based on the resistivity for softwood lumber.[2] The value recognized by CMHC for pine is 0.0087 $m^2 \cdot C/W$ per mm thickness (1.25 $hr.ft.^2 \cdot F/Btu$ per inch of thickness). For cedar logs this value is 0.0092 $m^2 \cdot C/W$ per mm thickness (1.33 $hr.ft.^2 \cdot F/Btu$ per inch of thickness). This resistivity is multiplied by an appropriate depth of wall, and values for indoor and outdoor air films are added. It should be noted here that the accuracy of this method is affected by the accuracy in the assumed R-value of the air films. For the purposes of this discussion, a value of 0.12 $m^2 \cdot C/W$ (0.68 $hr.ft.^2 \cdot F/Btu$) was used for the interior air film and a value of 0.03 $m^2 \cdot C/W$ (0.17 $hr.ft.^2 \cdot F/Btu$) was used for the exterior air film.

The depth of wall was calculated by first determining the volume of logs in the test section and converting this volume into an equivalent rectangular volume with the same height as the test area and with a depth 'd'. The steps to determine this depth are described below.

1) The face area of each log within the test section was calculated. The area was based on an on-site measurement of the diameter at the end of the logs. The distance of this measurement was generally less than two meters from the section that was tested so the diameter is probably representative of the area at the test section. All logs were assumed to be circular prior to

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2 Derived from several sources including ASHRAE Handbook of Fundamentals and Testing by National Research Council.

hewing, and the total volume of a 1m length of log was calculated.

2) The volumes of the hewn portions cut out of the logs were then calculated to find the net volume of each log.

3) A total volume of logs within the test height was then calculated. The equivalent depth of a rectangular cross section of width one mēter was then calculated by dividing this total volume by the height.

Once the equivalent depth was determined for each of the log walls, it was multiplied by the resistivity of wood used by CMHC for log walls and the appropriate air films added. The resultant RSI value was then compared to the measured results for each wall system. These results are also shown in Table 4 and Figure 17.

In all cases the measured RSI values are below the calculated RSI values. For the round pine logs, the measured RSI values were, on average, about 20% below the calculated RSI values. The cedar wall section was found to be only about 9% below the RSI value determined using the CMHC rating of 0.0092 $m^2 \cdot C/W$ per mm thickness (1.33 $hr.ft.^2 \cdot F/Btu$ per inch of thickness).

The equivalent depth calculated for each of the log wall systems can also be used to deduce the apparent resistivity of the wood in each wall system, to compare with the standard values used by CMHC. Again the accuracy of the measured (field-derived) resistivity is limited to the accuracy in the assumed interior and exterior air film RSI values, since these values must first be subtracted from the field results.

The results are also shown in Table 4. Figure 18 plots the apparent resistivity for each of the wall systems. These were calculated by dividing the measured RSI values (after subtracting the air films) by the equivalent depth of each of the wall systems.

From the results of this project it appears that the current CMHC rating for log walls is generous. Based on the results of this project, the RSI/mm value for the white pine round log systems ranged from 0.0063 $m^2 \cdot C/W$ per mm thichness (0.91 hr.ft.$^2 \cdot F$/Btu per inch of thickness) to 0.0071 $m^2 \cdot C/W$ per mm thickness(1.02 hr.ft.$^2 \cdot F$/Btu per inch of thickness) with an average for the round log systems of 0.0068 $m^2 \cdot C/W$ per mm thickness (0.98 hr.ft.$^2 \cdot F$/Btu per inch of thickness). The results indicate that the squared cedar log system had an apparent resistivity of 0.0083 $m^2 \cdot C/W$ per mm thickness (1.2 hr.ft.$^2 \cdot F$/Btu per inch of thickness). The reduction in the insulating value of the wood is apparently linked to increased heat loss at the joints. It is not clear how this should be taken into account when using the CMHC-recognized resistivity values.

There appears to be a correlation between the apparent resistivity of each of these log wall systems and the degree of heat loss observed near the joints. The walls of Log Houses Nos. 1, No. 4 and No. 5, all of which had their interior and exterior joints sealed, have the best apparent resistivity. The walls of Log House No. 2 (exterior joints caulked only) and Log House No. 3 (joints not caulked) had the highest degree of heat loss through the joints and had the lowest apparent resistivity. Caulking of the exterior joints may be the major reason why Log House No. 2 has an apparently higher resistivity compared to the wall of Log House No. 3 even though the overall RSI values for these two walls are almost identical.

The issue of air leakage may only be important in those wall sections where the joints were not caulked i.e. Log House No. 3 and to a lesser extent Log House No. 2. However, over time as the logs shrink and shift, the caulked joints may deteriorate making air leakage a much greater concern. This was already observed in Log House No. 1. It should be pointed out that the effects of through air leakage is virtually eliminated by the presence of the mimic box apparatus. Some air leakage may occur either through convective loops within the mimic box exacerbated by varying wind pressures or lateral air movement along the joints. The total heat loss, however, for those wall sections susceptible to air leakage, will thus be somewhat lower than without the mimic box, biasing the measured RSI values slightly high (but still lower than a perfectly sealed wall section).

(In addition to confirming the extra losses at log-to-log joints, the thermographic scans also pointed to some extra heat loss effects at wall corners. The extra losses there appear to be independent, or largely independent, of the degree of airtightness. The properties of the wood itself are apparently in full play: wood resistivity along the grain (i.e. along the log) is less than half the resistivity across the grain. Hence the losses at or near corners must be largely a matter of heat flow along the grain from indoors to outdoors. Perhaps the resulting reduction in indoor surface temperatures in the corners is significant in terms of dust marking or even condensation and mould potentials, especially since corners tend to have stagnation (poor heat distribution) in any case. More thermographic analysis might prove useful.)

Although the sample size was small and the number of types tested in the study was limited, it is believed that these systems are representative of good log wall construction practice since many of the houses were built by a reputable contractor.

As pointed out in the Introduction, log wall builders have argued that the actual net heat loss through log walls is less than would be calculated using simple heat conduction formulae mass in the logs' walls. This present project was designed to provide sound field data on the effective RSI values of typical log wall systems, exclusive of any mass effect. The results provide a foundation upon which the mass effect can now be evaluated.

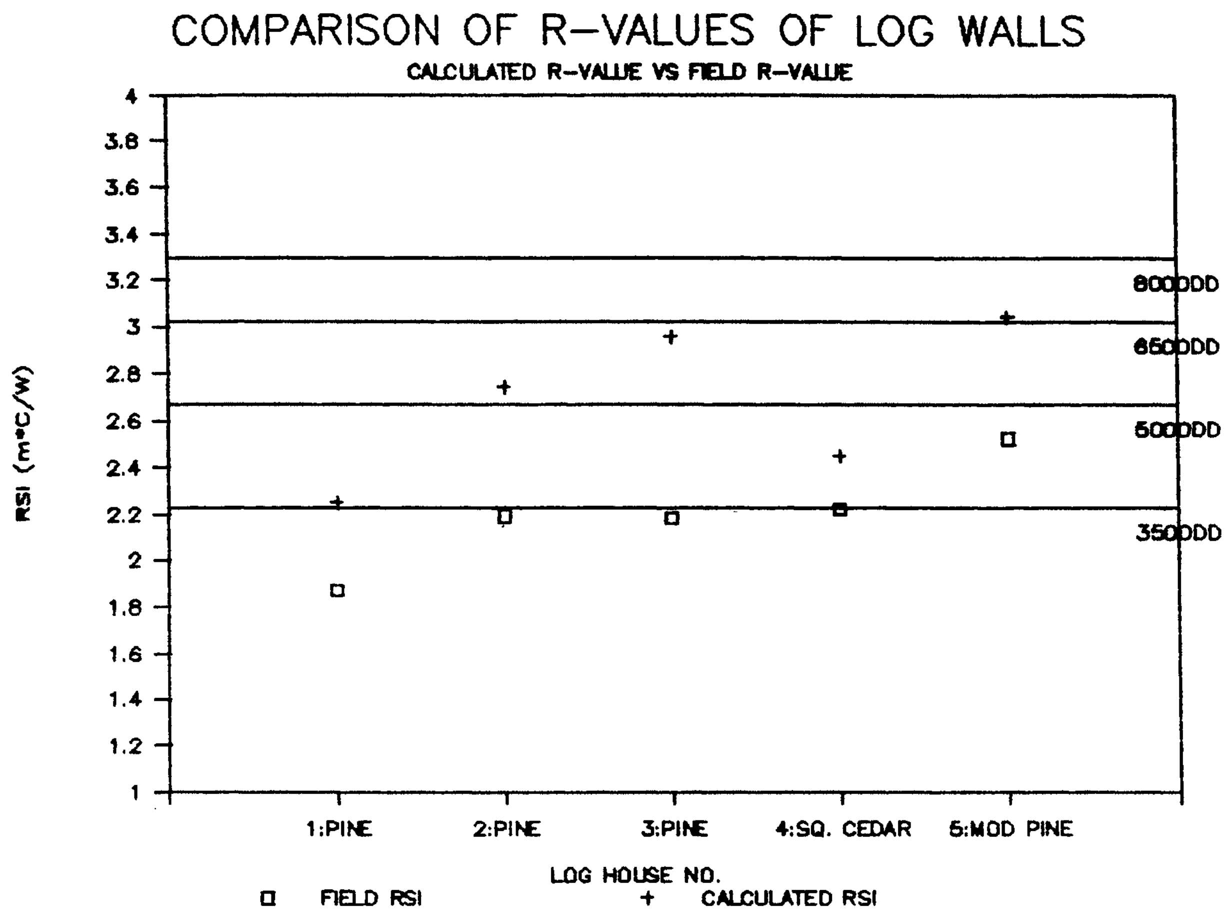
TABLE 4:SUMMARY OF RESULTS:FIELD VS. STANDARD VALUES

HOUSE NO	DESCRIPTION	DIAMETER cm	EQUIVALENT DEPTH cm	FIELD RSI m2C/W	CALCULATED RSI m2C/W	DIFFERENCE %	THEORETICAL VALUE/mm m2C/Wmm	FIELD RSI PER mm m2C/Wmm
-	-							
1	ROUND PINE	27	24.1	1.87	2.25	16.8%	0.0087	0.0071
2	ROUND PINE	32	29.8	2.19	2.74	20.1%	0.0087	0.0068
3	ROUND PINE	35	32.3	2.18	2.96	26.4%	0.0087	0.0063
4	SQUARE CEDAR	25	25	2.22	2.45	9.4%	0.0092	0.0083
5	MOD RND PINE	39	33.3	2.52	3.05	17.3%	0.0087	0.0071
6	CONTROL	12	12	2.41	2.24	-7.6%	-	-

NOTES:
CALCULATED VALUE IS BASED ON THEORETICAL RSI/mm MULTIPLIED BY EQUIVALENT DEPTH. THE RSI VALUE OF AIR FILMS ARE THEN ADDED TO THIS VALUE TO GIVE THE CALCULATED VALUE

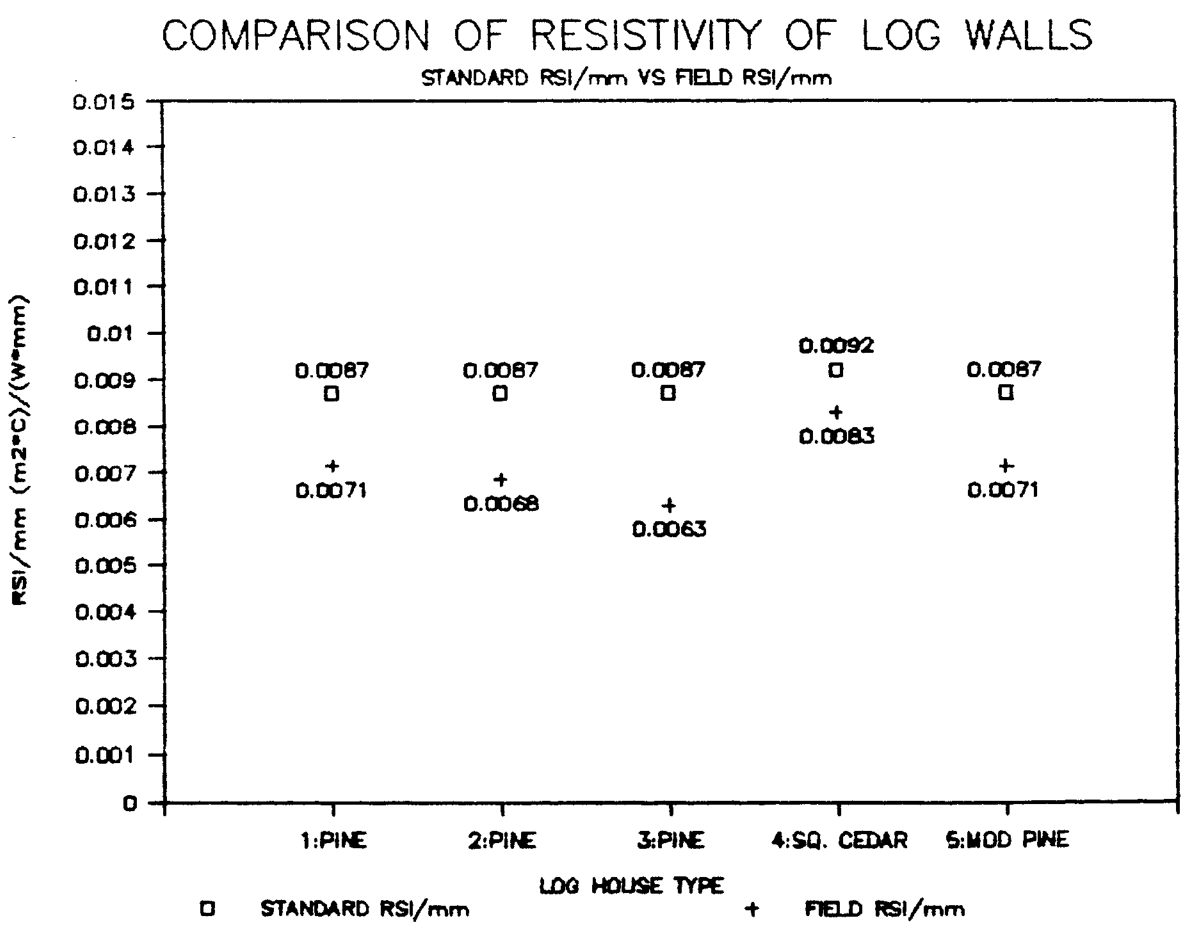
FIELD RSI/mm IS THE RSI VALUE DETERMINED IN THE FIELD MINUS RSI FOR AIR FILMS AND DIVIDED BY EQUIVALENT DEPTH

Figure 17



*DD=Degree Days

Figure 18



8.0 CONCLUSION

The heat loss through selected north wall sections of five log houses and one conventional wood frame house was monitored using a guarded calorimeter (mimic box) interfaced to a data acquisition system.

The results indicate a range of effective RSI values of the log walls from a minimum of 1.87 $m^2 \cdot C/W$ (10.6 $hr.ft.^2 \cdot F/Btu$) to a maximum of 2.52 $m^2 \cdot C/W$ (14.3 $hr.ft.^2 \cdot F/Btu$). The conventional wood frame house was found to have an effective RSI value of 2.41 $m^2 \cdot C/W$ (13.7 $hr.ft.^2 \cdot F/Btu$).

The highest RSI value measured would satisfy CMHC requirements for walls located in areas with up to 4500 DD. The lowest, RSI value measured would not satisfy the minimum CMHC requirement for areas with up to 3500 DD.

The results were also used to derive apparent resistivity values for the logs which were compared to the current resistivity value recognized by CMHC for logs, which is 0.0087 $m^2 \cdot C/W$ per mm thickness (1.25 $hr.ft.^2 \cdot F/Btu$ per inch of thickness) for pine logs and 0.0092 $m^2 \cdot C/W$ per mm thickness (1.33 $hr.ft.^2 \cdot F/Btu$ per inch of thickness) for cedar logs. All apparent resistivity values were found to be below the recognized values. The round pine logs were found to have an apparent resistivity in the range of 0.0063 $m^2 \cdot C/W$ per mm thickness (0.91 $hr.ft.^2 \cdot F/Btu$ per inch of thickness) to 0.0071 $m^2 \cdot C/W$ per mm thickness (1.02 $hr.ft.^2 \cdot F/Btu$ per inch of thickness) with an average of 0.0068 $m^2 \cdot C/W$ per mm thickness (0.98 $hr.ft.^2 \cdot F/Btu$ per inch of thickness). The square cedar logs were found to have an apparent resistivity of 0.0083 $m^2 \cdot C/W$ per mm thickness (1.2 $hr.ft.^2 \cdot F/Btu$ per inch of thickness).

Heat loss at the joints appears to be a major weak link in the log wall systems and efforts to seal these joints seemed to have a major influence on the insulating value of the wall system.

The effect of thermal mass was identified by all the occupants as a major contributor to the thermal comfort of these homes. However, this effect was not addressed in this project. Further study of this effect is recommended.

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