ENERGY RELATED PERFORMANCE TESTING OF MINNESOTA LOG HOMES

JUNE 1990

MINNESOTA DEPARTMENT OF PUBLIC SERVICE ENERGY DIVISION

Prepared by
Stephen R. Klossner
Advanced Certified Thermography
Lakeland Minnesota

SUMMARY

A survey of the air leakage characteristics of 24 Minnesota log homes was performed during the 1989-1990 heating season. The results of this research were originally published in June 1990; minor edits were made to post the document on the department Web site in May 2005.

The sample consisted of buildings from two to eight years old of three types: kit homes (8 examples), hard-scribed non-chinked homes (14 examples), and hand-scribed chinked homes (3 examples). The sample was identified by contacting long-time builders. Each home was blower door tested to quantify air tightness and surveyed by infrared thermography to identify major heat loss areas. Estimates of annual heat loss through envelope components were calculated. The homes were all occupied, but due to the confounding variable of wood heating, no data on historical energy use could be collected.

The results for these homes showed little air leakage between logs or at the rim joists. More air leakage was found at log corners and window and door frames. Most of the air leakage was through cathedral ceilings and at the tops of log walls (at the intersection with the roof). For this limited sample size, no definitive difference in air tightness was evident of the three types of log homes. However, three of the four homes that were identified as “owner built” had the greatest air leakage of the sample.

The infrared thermographic surveys indicated that under certain conditions, small sections of insulated 2x6 walls (such as dormers) had greater heat conductivity than the adjacent log walls, even though their theoretical conductivity is less. Similarly for cathedral ceilings, the presence of air leakage suggests that their thermal performance is considerably less than their design R-value would indicate. Calculations of annual heat loss indicated that infiltration is generally the largest heat loss of these buildings.

The identification of tight foundation and wall systems concurrent with considerable air leakage through cathedral ceilings and at the tops of walls could be conducive to conditions of combustion appliance back drafting. Combustion air inlets were not found at most of the sites.

OBJECTIVES

The objective of this study was to complete a preliminary survey of the air tightness of log homes built in Minnesota. Of particular interest was the location of the major leakage areas in relation to the different components of construction. Thermograms and photographs were used to document the major leakage areas. In addition to air leakage tests, data were collected on windows, foundations, mechanical systems, insulation values and space heating costs.

The homes included in this study were between two and eight years old, and representative of three different styles of construction.

SURVEY OF HOMES

Sample identification. Letters were sent to log builders, log home suppliers and kit suppliers listed in the St. Paul, Minneapolis, Moorehead and Duluth phone directories. In addition, a letter was sent to the Minnesota Log Crafters Association.

Copies of the Request for Proposals as well as the Advanced Certified Thermography proposal were sent to these companies, along with a cover letter asking for their help in identifying homes for the study. Letter recipients were asked to make the initial contact with the homeowner. This was done to facilitate cooperation from the homeowners because it was felt that the builders could minimize homeowner concerns about an unknown company asking for entry into the homes.

Each home identified received a cover letter from the Department of Public Service (now the Department of Commerce) explaining the study and identifying Advanced Certified Thermography as the contractor. Again it was thought that an official letter would help to ease homeowners concerns.

The letter also contained an application to participate in the study. Recipients were asked to complete and return. Of the 32 home applications that were returned, 24 were selected for testing.

The type of homes, number of homes and identifying code are shown in Table 1. The identifying codes are used throughout this report for comparison and discussions. The Heating Degree Days for homes in the study ranged from 7,500 to 10,500.

TABLE 1

Type of Home	Number of Homes Proposed	Number of Homes Tested	Identifying codes in Report
Kit	8	8	Kit-01 to 08
Hand Scribed			
Non-Chinked	8	14	HSNCH-01 to 15
Chinked	8	3	HSCH-01 to 03

One of these homes was identified as a non-log home only after it was scheduled. Because of the distance traveled, the home was tested and the results are included in the study. In addition, a second non-log home was located in close proximity to a log structure, and as time allowed it was also tested and the results are included in the study. These homes, Kit-01 and Kit-02, are marketed as log homes, however the construction is significantly different than what the original intent of the study covered. The first Kit-01 was 2"x 6" construction with a log façade attached to the exterior. The Kit-02 construction was 2"x 7" planks that sandwiched a 6 inch block of foam.

Testing. Each of the 24 homes in the study was tested for leakage using a calibrated blower door. The same blower door was used for each home. The blower door was calibrated to +/- 5 percent airflow rates. The blower door data was also corrected for the difference in interior and exterior temperatures.

Each home was tested according to ASTM E779, "Method for Determining air Leakage by Fan Depressurization" at both positive and negative pressures. In each home the maximum pressure difference induced was 60 Pascals (0.24 inches water column) of pressure difference. Not all homes could be depressurized to this level, and in those cases they were pressurized or depressurized to the maximum level attainable.

The homes were tested during winter operating conditions. All windows and doors were closed and latched. Accessible intentional openings were sealed. These openings included combustion air inlets, buoyancy vented appliances, wood burning stoves and fans. Observed gaps in windows, doors and other construction components were left in the condition found.

The homes were scanned with a Mikron 440, thermal imaging camera. In the majority of the homes the scanning was done from the interior with a room scan. Infrared scanning was done at an induced pressure of 30 Pascals. When the scanning was done from the interior the home was under an induced negative pressure. When the scanning was done from the exterior the home was pressurized. Thermograms and real photographs were taken of major airflow areas. Several thermograms and photographs were also taken of tight areas. Although thermograms are generally not taken of areas without problems, it was thought that a comparison of leaky to non-leaky areas would help give a better overall perspective of the buildings' leakage characteristics.

Data collected on site included building component surface area measurements and R-value estimates. An R-value of 1.25 per inch was assumed for the log portion of the homes. For areas that were not open to observe the insulation, estimates were based on information provided by the homeowner or builder.

An attempt to gather energy data on these homes was unsuccessful. This was largely a result of the wood bring appliances, and the fact that only one home was supplied by a utility that could provide that information on a monthly basis. Homes that were heated with wood did not keep track of the amount or type of wood burned.

RESULTS

The results of the blower door tests are shown in Table 2. This table shows the results of the negative and positive blower door tests, as well as the average of the two. This table also shows the Lawrence Berekly Laboratories and Canadian Leakage Areas, as well as their average values. All leakage areas are reported in square inches. *Due to limited population size these results should not be generalized to apply to all log homes***.**

TABLE 2
Blower Door Test Results

Log Home Code	Owner Built	ACH/50 Negative	ACH/50 Positive	ACH/50 Average	Leakage Area (LBL)	Leakage Area (CAN)	Leakage Area (Avg)
HSCH-01	Y	8.17	9.75	9.23	66	134	100
HSCH-02	N	3.78	4.94	4.36	167	316	242
HSCH-03	N	3.64	4.58	4.11	97	216	157
HSNCH-01	N	4.61	5.42	5.02	77	151	114
HSNCH-02	N	5.62	5.89	5.76	99	201	150
HSNCH-03	N	4.44	5.22	4.83	160	294	227
HSNCH-04	Y	10.18	10.01	10.10	358	702	530
HSNCH-05	N	6.40	8.08	7.24	221	377	299
HSNCH-06	N	3.47	3.53	3.50	79	151	115
HSNCH-07	N	6.85	6.38	6.62	272	512	392
HSNCH-08	N	9.23	10.27	9.75	237	431	334
HSNCH-09	Y	23.03	23.51	23.27	175	344	260
HSNCH-10	N	4.44	5.26	4.85	55	118	87
HSNCH-11	N	9.77	10.56	10.17	258	470	364
HSNCH-12	N	8.51	9.03	8.77	224	418	321
HSNCH-14	N	6.47	6.11	6.29	191	369	280
HSNCH-15	N	8.56	8.88	8.72	213	412	313
KIT-01*	N	4.66	5.13	4.90	83	171	127
KIT-02*	N	2.94	3.06	3.00	77	143	110
KIT-03	N	4.48	5.02	4.75	98	189	144
KIT-04	N	4.64	5.25	4.95	113	211	162
KIT-05	N	7.29	7.11	7.20	128	242	185
KIT-06	N	1.23	1.40	1.32	34	69	52
KIT-07	N	6.27	6.55	6.41	85	164	125
KIT-08	Y	25.71	23.34	24.53	152	291	222

* not true log homes

Average Value	Owner Built	ACH/50 Negative	ACH/50 Positive	ACH/50 Average	Leakage Area (LBL)	Leakage Area (CAN)	Leakage Area (Avg)
HSCH	1	5.38	6.42	5.90	110	222	166
HSNCH	2	7.97	8.44	8.20	187	354	270
KIT	1	7.15	7.11	7.13	96	185	141
TOTAL AVERAGE		7.40	7.77	7.58	149	284	216

Note: due to limited data, care must be taken not to generalize these results to a larger log home population.

A careful interpretation of Table 2 is advised. Because the volumes range from 9,212 to 44,157 cubic feet, Air Changes per Hour at 50 Pascals is not a comparable number. For example, 1 ACH/50 for the 9,212 cubic foot home would equate to 154 CFM of airflow at 50 Pascals. The same 1 ACH/50 for the 44,157 cubic foot home would equate to 736 CFM's.

A better method for home to home comparison is presented in Table 3 which compares the buildings' leakage ratios to their respective shell surface area. The result is reported as square inches of leaks per 100 square foot of surface area (calculated by both LBL and Canadian methods). This is considered a more accurate method to compare different volumes when using blower door data.

TABLE 3

Comparison of Leakage Ratio to the Building Shell Surface

Log Home Code	**Owner Built**	**100 Sq. Ft. Of Area/ Sq. In. Leaks (LBL)**	**100 Sq. Ft. Of Area/ Sq. In. Leaks (Can)**	**Cfm@ 50 Pa/ 20**
HSCH-01	Y	5.04	6.75	73
HSCH-02	N	4.15	5.43	157
HSCH-03	N	2.91	4.01	144
HSNCH-01	N	3.44	4.55	76
HSNCH-02	N	4.21	5.65	107
HSNCH-03	N	3.77	4.88	134
HSNCH-04	Y	9.17	12.14	364
HSNCH-05	N	7.12	8.97	156
HSNCH-06	N	2.64	3.47	74
HSNCH-07	N	5.57	7.27	243
HSNCH-08	N	7.60	9.81	191
HSNCH-09	Y	14.09	18.68	176
HSNCH-10	N	2.80	3.83	71
HSNCH-11	N	8.93	11.54	214
HSNCH-12	N	6.39	8.32	199
HSNCH-14	N	4.39	5.79	187
HSNCH-15	N	6.96	9.18	210
KIT-01*	N	2.87	3.86	96
KIT-02*	N	2.28	2.96	68
KIT-03	N	2.98	3.93	93
KIT-04	N	3.88	5.06	99
KIT-05	N	5.76	7.54	116
KIT-06	N	1.16	1.56	38
KIT-07	N	4.31	5.67	83
KIT-08	Y	11.24	14.76	144

*not true log homes

Log Home Code	**Owner Built**	**100 Ft.2 Of Area/ Sq. In. Leaks (Lbl)**	**100 Ft.2 Of Area/ Sq. In. Leaks (Can)**	**Cfm@ 50 Pa./ 20**
HSCH	1	4.03	5.40	125
HSCNH	2	6.22	8.15	179
KIT	1	4.31	5.67	92
TOTAL AVERAGE		5.35	7.02	141

Note: due to limited data, care must be taken not to generalize these results to a larger log home population.

Table 4 is a tabulation of the surface areas of the major structural components of each home and each home's computed volume.

TABLE 4

Surface areas in of the major structural components, sq. ft.

Log Home Code	Owner Built	Window Area	Log Area	2"X 6" Area	Attic Area	Foundation Area	Volume Cu. Ft.
HSCH-01	Y	186	629	82	1088	0	9527
HSCH-02	N	260	2028	0	2242	1288	43258
HSCH-03	N	193	1410	0	2240	1537	42000
HSNCH-01	N	138	1144	0	1075	960	18144
HSNCH-02	N	236	840	356	1225	903	22824
HSNCH-03	N	250	2119	640	1796	1224	33389
HSNCH-04	Y	110	1680	533	2170	1288	43283
HSNCH-05	N	256	1512	286	1140	1008	25012
HSNCH-06	N	272	1600	464	1372	640	25486
HSNCH-07	N	525	1640	660	2904	1312	44157
HSNCH-08	N	226	1300	523	1368	975	23546
HSNCH-09	Y	85	840	0	917	0	9212
HSNCH-10	N	189	1115	0	912	868	17472
HSNCH-11	N	411	1028	140	1383	1112	25272
HSNCH-12	N	315	1122	1200	1566	824	27237
HSNCH-14	N	556	1256	308	2706	1548	35581
HSNCH-15	N	228	1222	578	1120	1340	28532
KIT-01*	N	302	1376	0	1362	1386	23584
KIT-02*	N	645	0	1685	1337	1162	27000
KIT-03	N	325	1816	0	1534	1137	23500
KIT-04	N	177	993	264	1652	1086	23920
KIT-05	N	286	797	164	1058	905	19372
KIT-06	N	326	1214	0	1692	1197	34239
KIT-07	N	111	990	0	909	880	15624
KIT-08	Y	65	847	191	868	0	7068

*not true log homes

Average Value	Owner Built	Window Area	Log Area	2"X 6" Area	Attic Area	Foundation Area	Volume Ft. 3
HSCH	1	213	1356	27	1857	942	31595
HSNCH	2	271	1316	406	1547	1000	27082
KIT	1	280	1004	288	1302	969	21788
TOTAL AVERAGE		267	1221	323	1505	983	25930

Note: due to limited data, care must be taken not to generalize these results to a larger log home population.

The surface areas expressed as percentages for each component are listed in Table 5. The first column of windows is the percent of window to wall area; the percent for the other columns is the percent of total surface area. It is interesting to note the amount of window area in these homes. The average for all homes tested was 18 percent of wall area. The low was six percent and the high was 38 percent. As an aside to window area, mention should be made of orientation. All window orientation was site specific. If the "view" happened to be toward a lake, the windows were located to take advantage of this. If this direction was north, the windows may be more of a liability than the same amount of all south exposure.

TABLE 5

Surface Areas Expressed as Percentages

Log Home Code	Owner Built	Window % Of Walls	Log Percent	2"X 6" Percent	Attic Percent	Foundation Percent	Total Area
HSCH-01	Y	26%	32%	4%	55%	0%	1985
HSCH-02	N	13%	35%	0%	39%	22%	5818
HSCH-03	N	14%	26%	0%	42%	29%	5380
HSNCH-01	N	12%	34%	0%	32%	29%	3317
HSNCH-02	N	20%	24%	10%	34%	25%	3560
HSNCH-03	N	9%	35%	11%	30%	20%	6029
HSNCH-04	Y	5%	29%	9%	38%	22%	5781
HSNCH-05	N	14%	36%	7%	27%	24%	4202
HSNCH-06	N	13%	37%	11%	32%	15%	4348
HSNCH-07	N	23%	23%	9%	41%	19%	7041
HSNCH-08	N	12%	30%	12%	31%	22%	4392
HSNCH-09	Y	10%	46%	0%	50%	0%	1842
HSNCH-10	N	17%	36%	0%	30%	28%	3084
HSNCH-11	N	35%	25%	3%	34%	27%	4074
HSNCH-12	N	14%	22%	24%	31%	16%	5027
HSNCH-14	N	36%	20%	5%	42%	24%	6374
HSNCH-15	N	13%	27%	13%	25%	30%	4488
KIT-01*	N	22%	31%	0%	31%	31%	4426
KIT-02*	N	38%	0%	35%	28%	24%	4829
KIT-03	N	18%	38%	0%	32%	24%	4812
KIT-04	N	14%	24%	6%	40%	26%	4172
KIT-05	N	30%	25%	5%	33%	28%	3210
KIT-06	N	27%	27%	0%	38%	27%	4429
KIT-07	N	11%	34%	0%	31%	30%	2890
KIT-08	Y	6%	43%	10%	44%	0%	2971

*not true log homes

Average Value	Owner Built	Window % Of Walls	Log Percent	2"X 6" Percent	Attic Percent	Foundation Percent	Total Area
HSCH	1	18%	31%	1%	45%	17%	4394
HSNCH	2	20%	37%	8%	44%	25%	5482
KIT	1	21%	28%	7%	35%	24%	3842
TOTAL AVERAGE		18%	30%	7%	36%	22%	4299

Note: due to limited data, care must be taken not to generalize these results to a larger log home population.

The areas of leakage and their relative significance to the total leakage areas was noted during the infrared inspection. The major leakage areas were then compared for all homes. The frequency of their occurrence is shown in Table 6. On this table the category 2"x6" and interface includes the dormer walls and their connection to the cathedral ceiling. This was done because of the difficulty of separating the leakage areas during the infrared inspection. Areas that were listed last during the inspection were dropped from this list as they were considered an insignificant portion of the total infiltration. The listing of leakage areas included seven areas identified as leaks. These were:

1. Cathedral ceilings
2. Log tops
3. Purlins and support beams
4. 2"x6" construction and interface with ceiling
5. Horizontal log seams
6. Windows and doors
7. Rim joist

For each home tested, these areas were listed starting from the largest contributor to the least contributor to infiltration. The first three areas listed were meant to account for the majority of infiltration, and an attempt was made to include only the first 50% of the leaks into this category. By the time the list reached number 6, these were generally an insignificant part of the infiltration. These are shown in Table 6.

TABLE 6

Major Leakage Areas of Log Homes

Severity Of Leaks	**Horizontal Logs**	**Purlins-Beams**	**Log Top Interface**	**Log Corners***	**2"X6" Interface**	**Cathedral Ceilings**
#1	0	4	4	1	2	8
#2	0	4	2	3	3	3
#3	0	3	3	3	1	2
#4	2	0	1	4	2	2
#5	1	0	1	2	0	0
#6	0	0	1	2	0	0
#7	0	0	0	0	0	0
TOTALS	4	11	12	16	8	15

Notes: #1 is the worse leak

* Significant log corner leaks were all on tight homes and although they were rated as leaks, the amount of leakage was small

	Horizontal Logs	**Purlins-Beams**	**Log Top Interface**	**Log Corners**	**2"X6" Interface**	**Cathedral Ceilings**
Total of top 3	0	11	9	7	6	13
% top 3	0%	24%	15%	25%	13%	28%
% of total	6%	17%	18%	24%	12%	23%

Note: due to limited data, care must be taken not to generalize these results to a larger log home population.

Of interest in Table 6, is that 76% of the three worst leakage areas were not log related. Of all noted leaks, the majority occurred in the purlins and support beams. However, if the beam leaked at the ceiling line the leak was attributed to the ceiling. Only if the beam leaked at the outside wall was it attributed to the beam.

CONCLUSIONS

Far and away, the greatest leaks were found in the cathedral ceilings. This is partly related to the tongue and groove ceiling and partly related to the difficulty in maintaining a continuous vapor barrier (and air barrier) over the purlins. Also noted were three homes with no vapor barrier installed. In the majority of homes rigid insulation also acted as the vapor barrier. Although this system also leaked, it was not possible to inspect for the reason for this leakage because of inaccessibility. In two homes where access was available, one had the seams between the sheets sealed with duct tape, and the other had no sealing of the seams. Upon inspection, it was found that the duct tape was hanging away from the sheathing.

The infrared thermographic surveys indicated that under depressurized conditions, small sections of insulated 2x6 walls (dormers and connections to cathedral ceilings) had greater heat conductivity than the adjacent log walls, even though their theoretical conductivity is less. Similarly, given the leakage observed in all of the cathedral ceilings, it is almost certain that their thermal performance is considerably less than their design R-value would suggest.

Gaps in the vapor barrier also existed when two components of construction connected. Most notable were the cathedral ceiling and dormer wall interface, and the log top and cathedral ceiling interface.

Log corners were also noted as an area of leakage both during the testing and as comments from the occupants. The corners were not listed as a significant leak because they constitute a small percentage of area and they were not a significant part of the total infiltration.

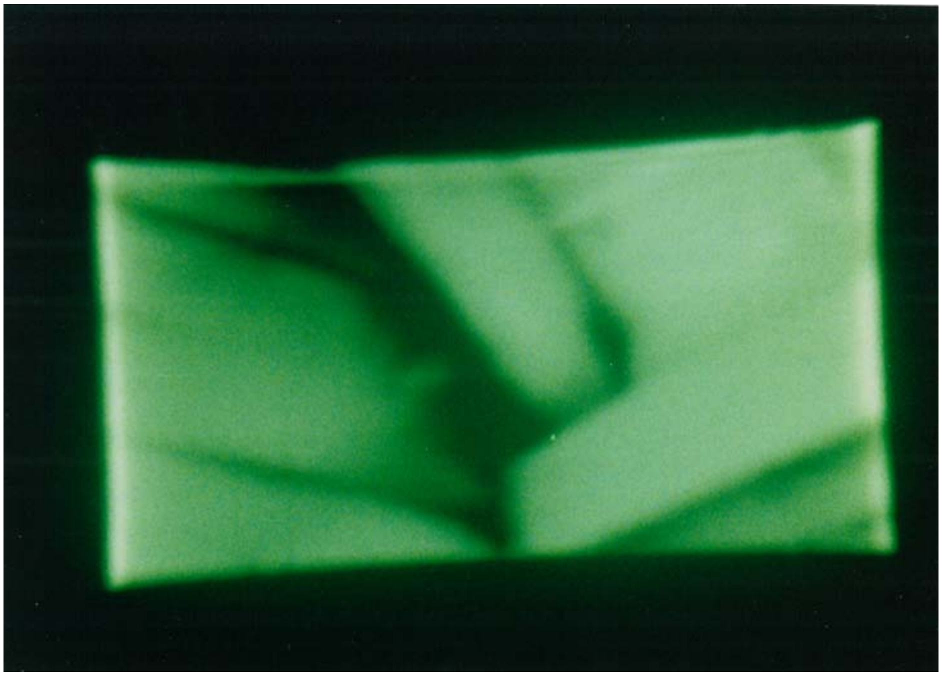
Also noted during the infrared inspection was the lack of leaks at the rim-joist area, a common source of significant leakage standard frame construction. This phenomenon was probably the result of the weight of the logs or the sealing method.

One final important observation made during the inspections was the lack of combustion air inlets for the furnaces and boilers. In 9 of 22 homes tested, no combustion air inlet was installed for the furnace/boilers as required by the Minnesota Building Code. This lack of combustion air is of particular concern because most of the leaks in these homes were in the upper rather than the lower portion of the building. During the winter, the natural stack effect will draw air out of the homes through the upper level. The furnace or boiler will be in competition for this same air. This raises the concern that there will be frequent difficulty in providing combustion/dilution air for these appliances and that backdrafting will result.

RECOMMENDATIONS FOR FUTURE RESEARCH

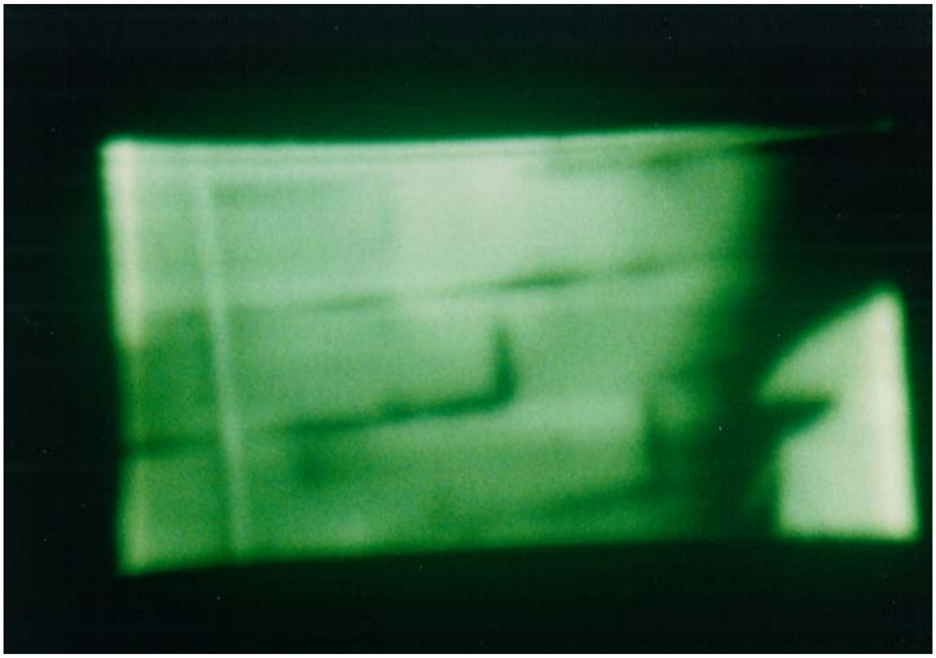
This study is an initial survey on a limited number of structures. As such, there are many questions that future research could be address:

- Additional data on the infiltration levels and locations, on a larger sampling of homes;
- To correlate actual measured energy consumption on log homes of different construction types;
- To correlate actual measured energy consumption with infiltration data and construction types;
- To investigate methods and alternatives to current vapor barrier installation;
- To investigate the relationship of leakage locations to both depressurization and actual energy consumption;
- To investigate techniques for reducing infiltration in non-log portions of these structures.



THERMOGRAM # 1
Dark area is cold. Shows air movement at an exterior wall support beam. Leak is at dormer and cathedral ceiling Interface.

PHOTOGRAPH # 1
Photograph of area shown in thermogram.

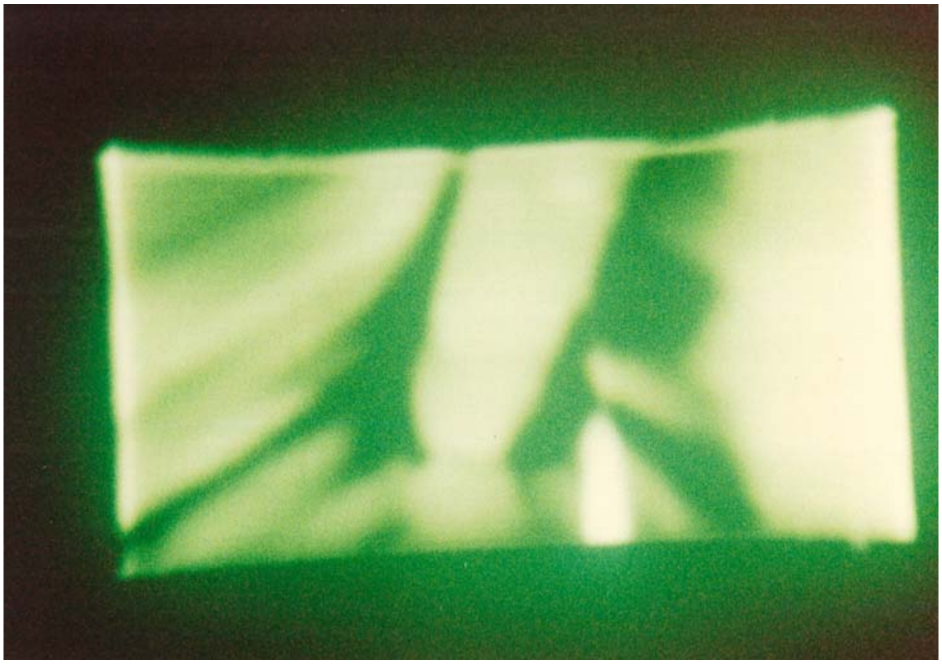


THERMOGRAM # 2

Dark area is cold. Shows air movement at an exterior wall support Beam. Leak is at dormer and cathedral ceiling interface.

PHOTOGRAPH # 1

Photograph of area shown in thermogram.



THERMOGRAM #3
Dark is cold. Shows air leakage above the main ridge beam. This Type of leak was attributed to the cathedral ceiling.

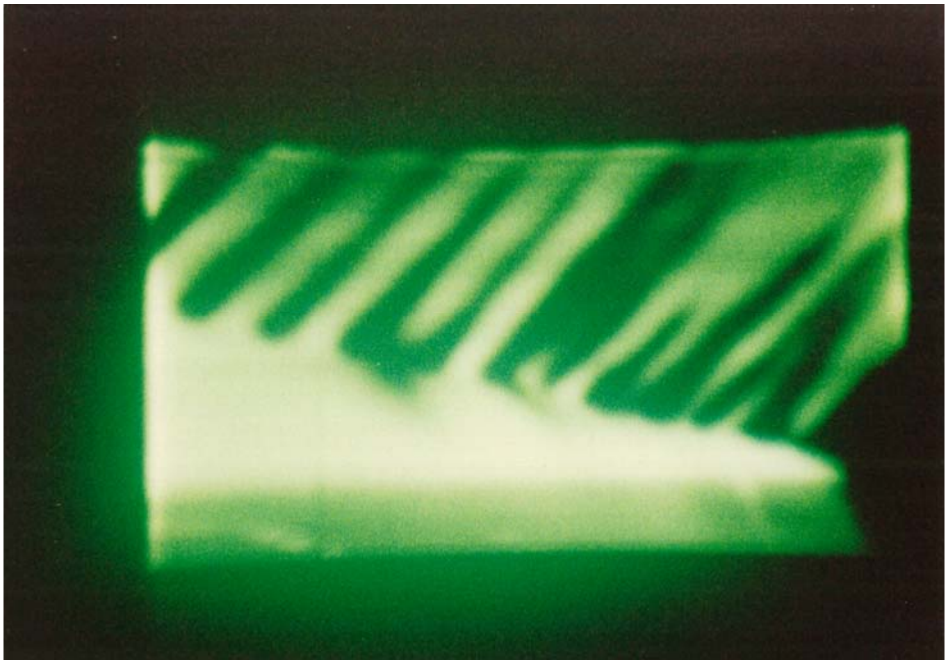
Photograph # 3
Photograph of area shown in thermogram.

THERMOGRAM # 4

Dark is cold. Shows air leakage at the purlin and wall interface. This Type of leak was attributed to purlins.

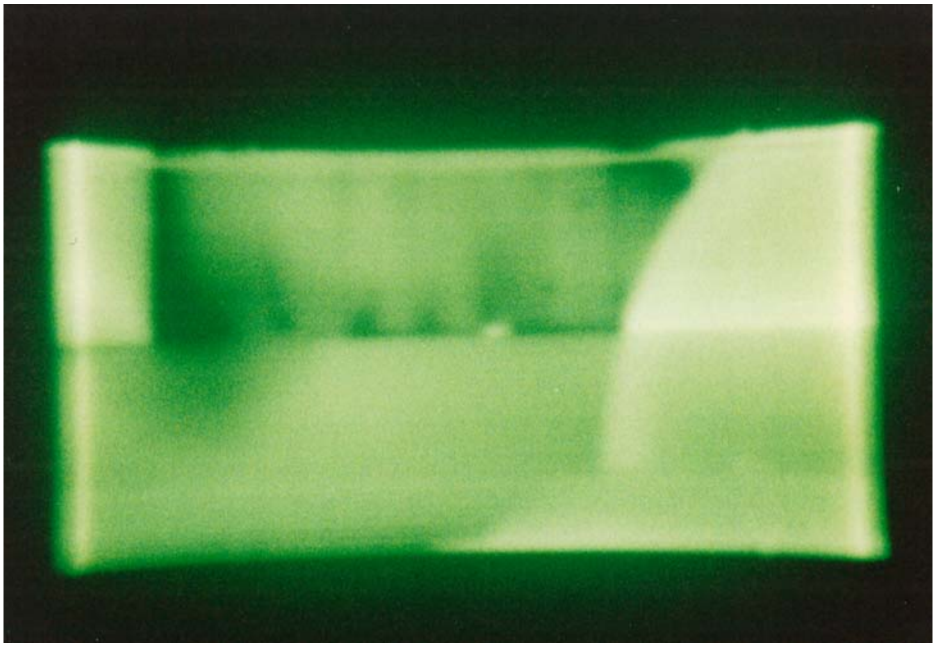
PHOTOGRAPH # 4

Photograph of area shown in thermogram.



THERMOGRAM # 5
Dark is cold. Shows air leakage between the tongue and groove Cathedral ceiling.

Photograph # 5
Photograph of area shown in thermogram.

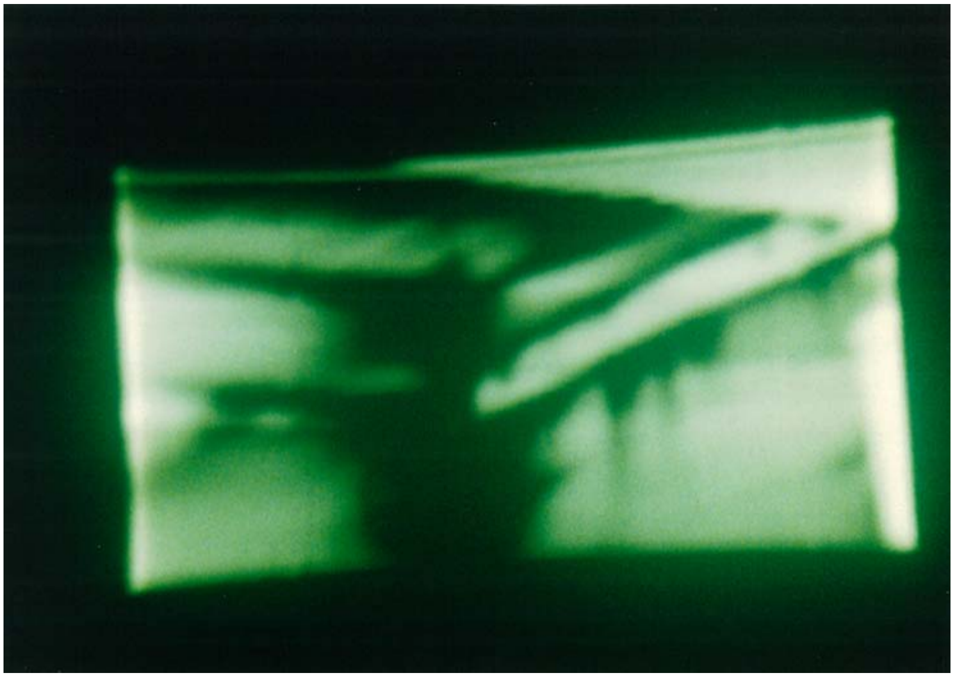


THERMOGRAM # 6

Dark is cold. Shows air leakage at the log top and window molding.

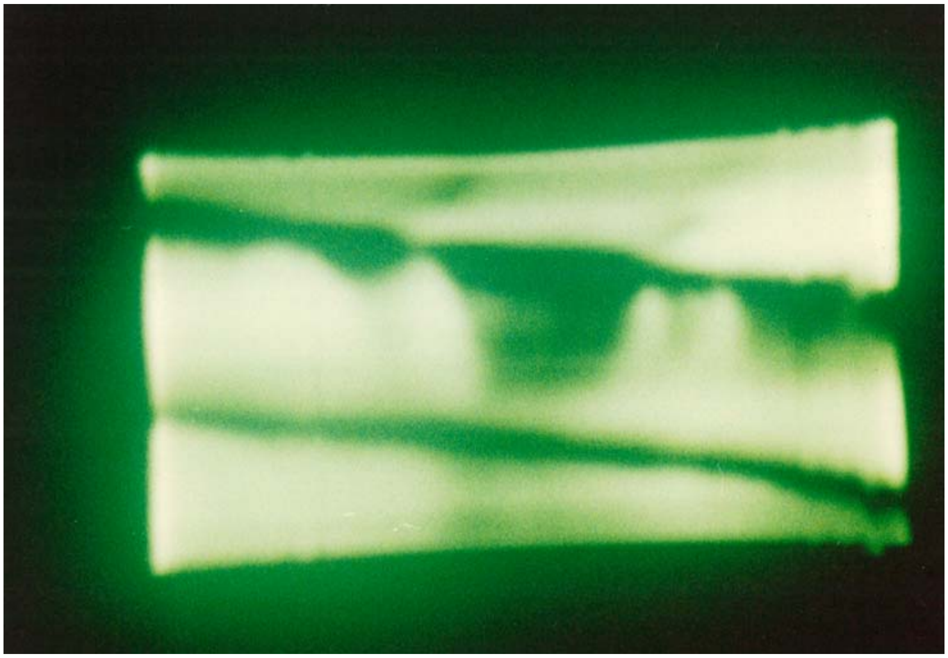
PHOTOGRAPH # 6

Photograph of area shown in thermogram.



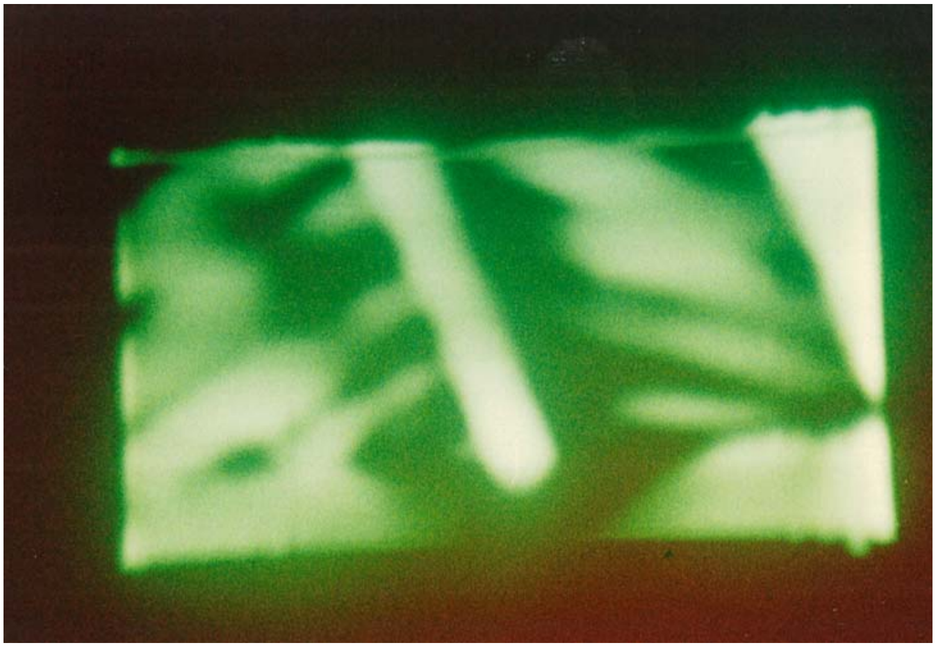
THERMOGRAM #7
Dark is cold. Shows air leakage at the log corners and dormer ceiling Interface.

PHOTOGRAPH # 7
Photograph of area shown in thermogram.



THERMOGRAM # 8
Dark is cold. Shows air leakage at log top and 2”x6” wall interface. Also can compare leaks at horizontal log and log top.

PHOTOGRAPH # 8
Photograph of area shown in thermogram.

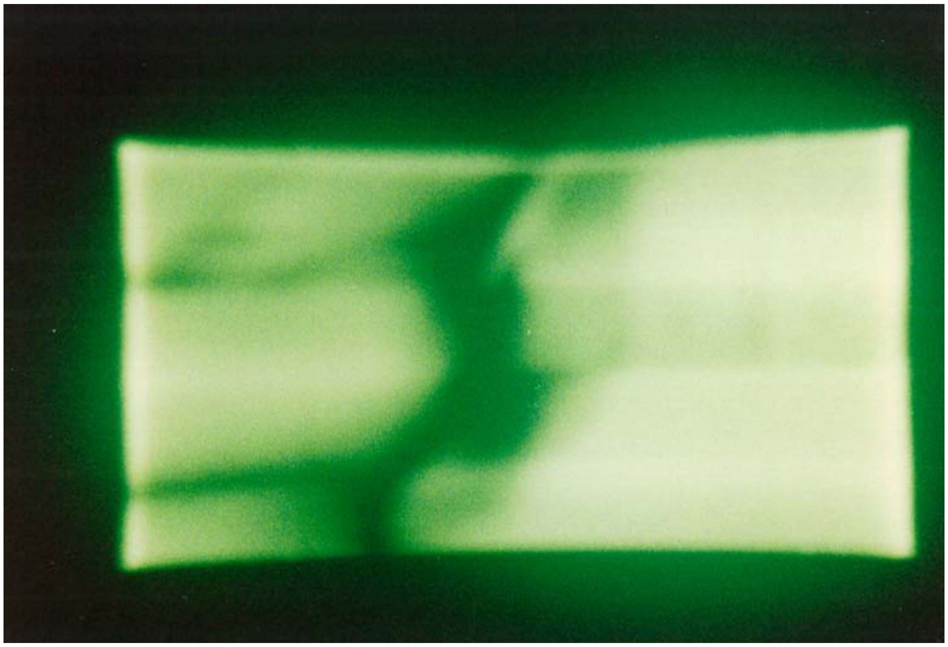


THERMOGRAM # 9

Dark is cold. Shows air leakage through the cathedral ceiling.

PHOTOGRAPH # 9

Photograph of area shown in thermogram.

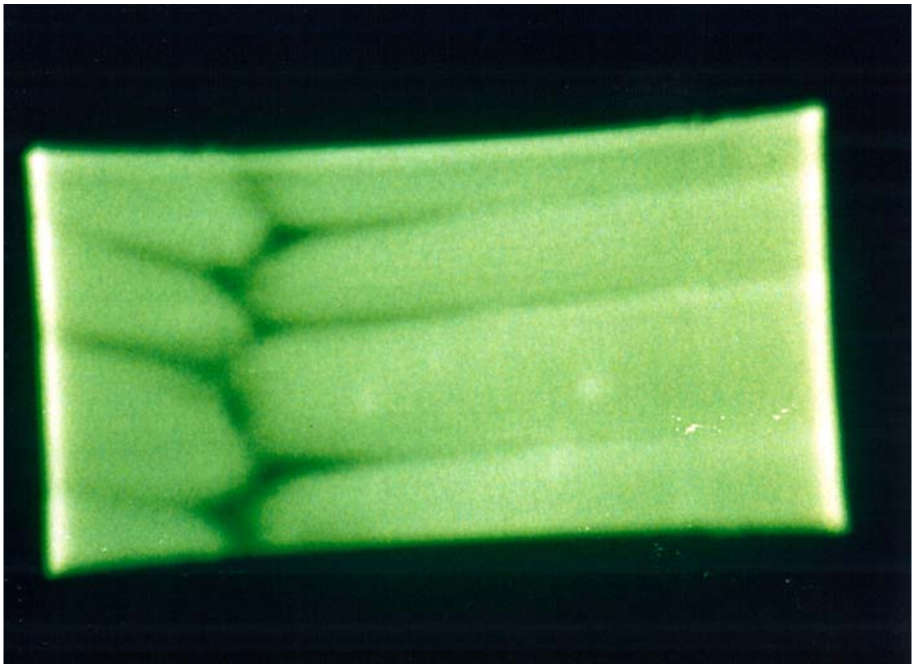


THERMOGRAM # 10

Dark is cold. Shows air leakage at corner, purlins and wall ceiling Interface.

PHOTOGRAPH # 10

Photograph of area shown in thermogram.



THERMOGRAM # 11

Dark is cold. Shows slight air leakage at corner and no leakage at horizontal log.

PHOTOGRAPH # 11

Photograph of area shown in thermogram above.