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Quality of Inspections Utilizing Infrared Technology on Weatherization Retrofit Installations

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Building Technology
Washington, DC 20234

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Prepared for:
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QUALITY OF INSPECTIONS UTILIZING INFRARED TECHNOLOGY ON WEATHERIZATION RETROFIT INSTALLATIONS

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

ABSTRACT

A comparative evaluation of various portable infrared sensing systems used for detecting heat loss anomalies within building envelopes was performed. This is the second of a two-stage applied research program sponsored by the Department of Energy to assess the application and reliability of using infrared technology. Twelve single-family residences in three cities from the Weatherization Program of the Community Services Administration were employed as field samples. The results of infrared surveys carried out by thermographic surveying firms and those by the National Bureau of Standards were analyzed and compared in the categories of: completeness of scanning, identification of defects, weather condition of inspection, and method of equipment operation. The thermograms of uninsulated areas, sketches of observed thermal deficiencies, and total areas of defects for each dwelling are presented. Through the comparison, the degree of completeness of inspecting the residences thoroughly was evaluated to be the most important factor for defect identification. The results of thermographic inspection of the homes showed that serious thermal anomalies still existed in most of these 'weatherized' residences, with a majority exhibiting between 5 percent and 15 percent of the wall areas uninsulated, or defective. The total uninsulated areas observed by each surveyor was found to be affected by the quality of thermograms submitted.

Key Words: Building heat losses; comparison of inspections; infrared scanning systems; insulation voids; interpretation of thermograms; thermal deficiencies; thermographic inspections; weatherization retrofits

PREFACE

This report is one of a series documenting National Bureau of Standards research and analysis efforts in support of the Department of Energy/Oak Ridge National Laboratory/National Bureau of Standards" Building Thermal Envelope Systems and Insulating Materials" Program. The work covered in this report was performed under the "Laboratory Tests in Support of Thermographic Standards" project and under DOE/NBS Interagency Agreement No. DE-AI05-780R06113, Task No. 11.

ACKNOWLEDGMENT

This report is based on the data and analysis submitted to NBS by the New England Innovation Group (NEIG) under contract #NB80SBCA0337. The authors wish to acknowledge the professional efforts of Dr. Richard Munis and Mr. Rick Regan of NEIG, without which this work would not have been possible.

CONVERSION FACTORS TO METRIC (SI) UNITS

Physical Quantity	Symbol	To Convert From	To	Multiply By
Length	L	ft	m	3.05×10^{-1}
Area	A	ft^2	m^2	9.29×10^{-2}
Volume	V	ft^3	m^3	2.83×10^{-2}
Temperature	T	Fahrenheit	Celsius	TC = (TF-32)/1.8
Temp. Diff.	dT	Fahrenheit	Kelvin	K = (TF)/1.8
Wind Speed	W	ft/min	m/s	5.08×10^{-3}

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1. INTRODUCTION

The infrared radiation measurement to assess the energy loss in building structures has been shown as a viable technique for noncontact measurements of surface temperature distribution [1,2]. Based on the fact that insulation materials impede the flow of thermal energy, infrared thermography can be utilized to provide images of the temperature distribution along the surface of a building envelope and interpret the thermal defects of building envelopes. The thermal defect problems include missing insulation, voids or cracks within the insulation itself, improperly installed insulation, wet insulation, air leakage, air penetration, etc. Prior to the weatherization of buildings, this technique is capable of locating the regions having high heat loss in order to appraise more adequately the retrofit requirements of the building. Thermographic inspection can also be employed as a quality control tool to evaluate postweatherization retrofits [3,4].

Essentially, a thermographic survey is a tool to detect thermal abnormalities and to determine insulation effectiveness in buildings. In spite of the fact that the thermographic inspection involves only measurement of relative apparent surface temperature distribution instead of the profiles of surface heat flux, the thermal patterns produced are able to identify thermal anomalies within building envelopes. Thermography is an indispensable technique to locate and document heat loss anomalies in buildings that are not evident to the human eye. Further development of this technique will result in improved diagnostic procedures for determining building performance as well as building envelope energy efficiency.

The infrared equipment currently available and being used for energy surveys can be classified as:

(1) high resolution thermal image systems (HRIS);
(2) low resolution thermal image systems (LRIS);
(3) thermal line scanners; and
(4) spot radiometers.

In order to assess the potential of each of the foregoing classes of infrared equipment for locating defects in buildings, an attempt was made to conduct a comparative evaluation of portable infrared sensing devices for detecting heat loss in buildings. Accordingly, a two-stage program was developed to invite participants using the most common thermographic equipment employed in building inspections, to locate thermally defective areas in buildings.

Stage one consisted of a laboratory test undertaken by thermographic firms in a "cold room" at the U.S. Army Cold Regions Research and Engineering Laboratory (USACRREL) [5]. The conclusions of the laboratory tests indicate that when various classes of infrared scanning equipment were compared, the high resolution systems performed better than the low resolution systems and the line scanners. Furthermore, all systems did better in detecting defects than in determining regions of insulation levels, and the low resolution image system did not perform well at the lowest indoor/outdoor temperature differential.

Stage two involved a field evaluation of infrared inspection contractors, using residences inspected by NBS as part of the Community Services Administration (CSA) Weatherization Program [6] as a baseline. Simultaneously, cost effectiveness and quality of inspection services offered by thermographic firms could also be assessed. In order to confirm the validity of both laboratory and field tests, the same types of infrared devices were used to perform the scanning for both measurements. The field test of this project was coordinated by the New England Innovation Group, which also provided the interpretation of the data submitted by the thermographic inspection contractors. There were two phases of evaluation in the field tests. According to the types of data recorded by NBS during thermographic inspections, the dwellings used for field evaluation were divided into two groups. Phase one of the field evaluation consisted of those homes where thermograms were produced by NBS during inspection. Phase two would be those homes where videotapes were recorded by NBS during scanning. This report includes the comparison and analysis of thermograms for phase one of the field evaluation.

In phase one, the field evaluation was carried out in four cities: Portland, Maine; Fargo, North Dakota; Minneapolis-St. Paul, Minnesota; and St. Louis, Missouri. In these cities single-family, cavity frame wall, low-income housing had been retrofitted by the CSA with various types of wall insulation. Eight thermographic inspection firms were asked to inspect different dwellings in these four cities. The types of infrared sensing devices which were utilized included five high resolution thermal image systems (resolution less than 0.5°F), a low resolution thermal image system (resolution greater than 0.5°F), a thermal line scanner used in conjunction with a spot radiometer, and a pyroeletric vidicon. In the baseline inspection, NBS used a high resolution image system to scan each dwelling thoroughly for quality control of the weatherization retrofits. Using NBS infrared survey results as a baseline, comparisons were performed on the results of thermograms, photographs, and contractors' own interpretations of the data obtained by thermographic inspection contractors.

2. THERMOGRAPHIC INSPECTIONS AND INTERPRETATION FROM THERMOGRAMS SUBMITTED BY CONTRACTORS

Of the eight firms which participated in the comparative evaluation of thermographic inspections, the results of only six are analyzed and presented in this report. The data from the other two could not be compared with data from NBS and the other firms. One contractor using a spot radiometer submitted only general letter reports to describe the results of his inspection. Without documentation of any regions of voids, it was impossible to make direct comparison of void sizes with data from NBS and others. Documentation from another contractor, using a pyroelectric vidicon, only included a few locations having voids and air leakage paths and was not adequate for comparisons with data from NBS, as well as other contractors.

Due to the unfavorable weather conditions, contractors were unable to carry out inspections for residences in St. Louis. Hence analysis and comparison of inspections were performed for dwellings in only three cities - Fargo, Minneapolis-St. Paul, and Portland, with four residences in each city.

Since the void areas were estimated from documentation provided by each contractor, numerical data depend mainly on the quality of thermograms, area covered, interior furnishings which obstruct subject surface, and interpretation by contractors. The accuracy for estimating the size of void area was limited by random variables such as angles of viewing, equipment adjustments like sensitivity, and type of thermal anomaly.

The instructions given to each infrared inspection firm were to inspect the interior as well as exterior of each surveyed dwelling. They were also asked to submit reports documenting the location of all insulation voids, air infiltration paths, and other important building heat loss anomalies such as cracks, weatherstripping and caulking defects. However, only insulation voids in exterior walls were included in the comparative evaluation. Other sources of heat loss anomalies were only documented as recognitions.

In this report, thermographic inspection firms will be identified as contractors no. 1 through no. 6. Only contractor no. 1 was using a low resolution infrared system (LRIS) for scanning; the other five all used high resolution infrared systems (HRIS). Infrared contractor no. 1 covered the most dwellings in this program, four houses in Fargo and three houses in Minneapolis-St.Paul, for a total of seven houses. Although no thermograms were submitted, (the low resolution imaging system was not capable of producing hard copies of its display) sketches of walls with void areas in each room of every house furnished by contractor no. 1 provided a fairly complete documentation of the house condition. There was some difficulty by contractor no. 1 in using the low resolution scanning system to distinguish the differences in insulation performance levels in two houses located in Fargo and one house in Minneapolis-St. Paul. As a result, contractor no. 1 reported some partial void areas as "cool" areas instead, and the estimated void areas were substantially lower than results from NBS. Infrared contractor no. 2 surveyed six houses, four in Fargo and two in Minneapolis-St. Paul. Besides the interior photographs and thermograms of identical locations, no. 2 always included exterior photographs and orientation

of the house. Such documentation was very effective for analysis of the thermographic data. However, contractor no. 2 did not cover the whole envelope during the inspection of two of its houses (one in Fargo and one in Minneapolis-St. Paul) and thus gave a much lower estimation of the void area than NBS' data.

Contractors no. 3 through no. 6 inspected four houses in one city, which overlapped the work of the other contractors. In other words, there were at least two contractors carrying out inspections for each dwelling. In spite of the fact that both contractors no. 3 and no. 4 submitted photographs and thermograms of identical locations of the respective homes in their inspection, they missed significant uninsulated areas in their observations, with the exception of Minneapolis-St. Paul house #2, where 27 thermograms were produced by contractor no. 4. Other dwellings in Minneapolis-St. Paul had 4, 9 and 13 thermograms from contractor no. 4 and dwellings in Fargo had between 7 to 10 thermograms from contractor no. 3. With such a small number of thermograms available, the actual void area of each mentioned home cannot be interpreted accurately from these incomplete inspections. Furthermore, it seemed that the sensitivity of the scanning systems used for these two contractors (no. 3 and no. 4) was set incorrectly, thereby providing insufficient resolution for void detection. Hence the estimated void areas provided by these contractors were lower than those for the NBS survey.

Four houses in Portland were inspected thoroughly by contractors no. 5 and no. 6. Contractor no. 5 submitted the most elaborate documentation of envelope heat loss anomalies, with sketches provided for each house giving locations where the thermograms and observations were taken, stating the dimensions of voids, and giving the probable causes of the heat loss anomalies. Contractor no. 6 described in detail the weather conditions, interior temperature conditions, and other factors that might present a problem in interpreting the data from the scanning. Even though some thermograms taken by contractors no. 5 and no. 6 were not focused correctly, estimations of void area from their results were close to NBS' data, with exceptions of Portland house #2 from contractors no. 5 and no. 6, and Portland house #4 from contractor no. 5. The discrepancies in void estimation from these two cases were simply due to the failure to inspect the whole house by these contractors. Furthermore, none of the contractors seemed to include exterior thermographic scannings for any of these dwellings, as only interior thermograms were provided.

A detailed discussion of the analysis made, and comparisons of each dwelling's thermal defects are summarized in the following section.

3. DATA ANALYSIS AND SUMMARY

A detailed analysis for each dwelling surveyed by contractors and NBS personnel is presented separately in the appendix. General descriptions of these residences, insulation options, sketches of thermal deficiencies, some thermograms as examples to demonstrate the location of heat loss anomalies, and comparative evaluations are also included in the appendix. A typical thermogram of a surface will provide an intensity-modulated image where the light and dark portion respectively represent the hot and cold region, and the grey shades indicate temperatures between hot and cold.

According to the analysis of results from infrared inspections, a summary of void areas estimated from thermograms and documents submitted by each contractor is presented in table 1. The total area of known defects of each dwelling in table 1 is based on results from all inspections. Using the sum of known defects of each house inspected by individual survey contractor as the total area of voids to be detected, the percentage of overall void areas identified by each surveyor is calculated and presented in table 1.

NBS personnel employed the draft American Standard Test Method (ASTM) for infrared inspection and achieved the highest percentage, 93.5, of defective area observed. Furthermore, the defective regions in Fargo house #1 not recognized by NBS were due to camera malfunction and the result for Portland house #3 was provided by local staff of CSA. If the areas of these two houses were excluded, NBS would have 97.7 percent in defect detection.

Despite the difficulties with the use of LRIS at low temperature differentials, contractor no. 1 inspected and sketched every wall of each room in each house to indicate the locations and areas of defects. Hence it still recognized more than 70 percent of the existing voids. As for those using HRIS, contractors no. 2, no. 5, and no. 6 observed about 70 to 90 percent of existing voids. However, contractors no. 3, and no. 4 who could only find less than 50 percent of the total defects, in the authors' opinions, are considered to be questionable in terms of surveying performance.

A summary of thermal deficiencies interpreted from the thermograhic surveys for dwellings in these three cities is shown in table 2. As indicated in table 2, the most common heat loss locations observed in these dwellings are leakage paths around and through windows and doors; penetration from ceilings and walls; and infiltration paths at wall-to-wall joints. Furthermore, only one basement of a house was inspected in the survey and it was found to have heat loss in the regions above ground. It is also shown in the table that between 5 percent and 15 percent of the wall area defects have still remained in most of the dwellings after retrofit. Six of the dwellings surveyed had thermal defective areas accounted for 5 to 10 percent of total wall areas and three showed between 10 percent and 15 percent defective areas. Figure 1 illustrates the distribution of insulation voids among these houses. The average defective area of all dwellings is found to be 9.75 percent.

Table 1. Comparison of Insulation Voids Given in ft^2 Observed by Each Survey Contractor and NBS

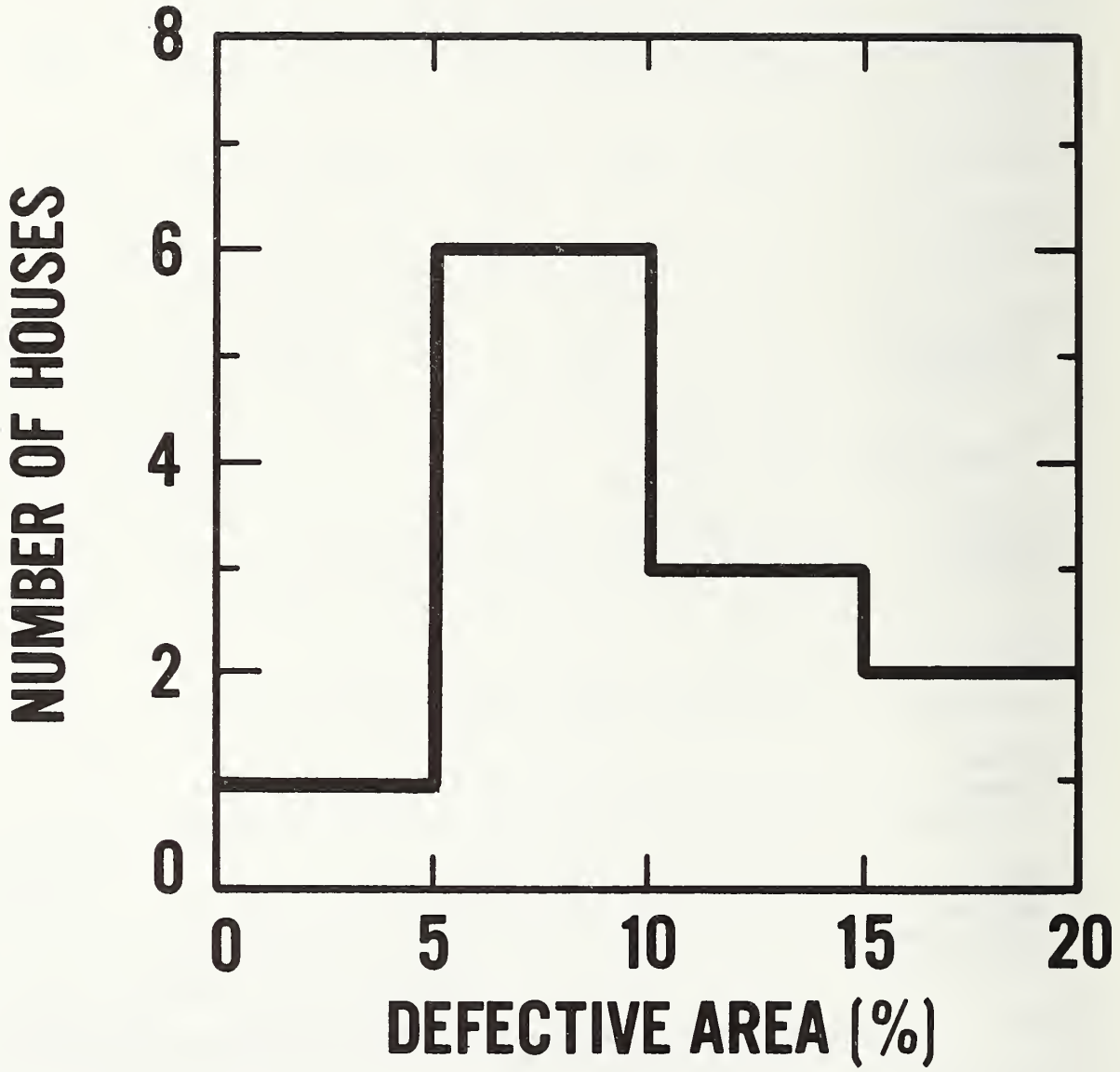
City - House No.		**	NBS	Survey Contractor No.1	No.2	No.3	No.4	No.5	No.6	Total Area of Known Defects*
FAR	1	(2)	70	35	17	18				70
FAR	2	(25)	42	78	78	50				78
FAR	3	(30)	75	60	59	23				75
FAR	4	(36)	63	34	63	38				67
MSP	1	(2)	85		30		31			89
MSP	2	(4)	169	125	142		144			174
MSP	3	(21)	310	277			118			310
MSP	4	(45)	75	24			21			75
POR	1	(16)	106					97	92	106
POR	2	(18)	97					43	67	97
POR	3	(20)	135					144	154	164
POR	4	(26)	105					68	110	119
Total Area of Voids Detected			1332	633	389	129	314	352	423	
Total Area of Voids to be Detected			1425	849	553	290	648	487	487	
Percentage of Voids Detected			93.5	74.6	70.3	44.5	48.4	72.3	86.8	

* Based on results of all surveys.

** Numbers in parenthesis denote corresponding house numbers in CSA program.

Table 2. Thermal Defects Observed in Each Dwelling

City House No.	FAR 1	FAR 2	FAR 3	FAR 4	MSP 1	MSP 2	MSP 3	MSP 4	POR 1	POR 2	POR 3	POR 4
Defective Wall Area (ft^2)	70	78	75	67	89	174	310	75	106	97	164	119
% of Defective Wall Area	7%	9%	10%	11%	6%	10%	20%	4%	8%	5%	20%	7%
Defects Observed:												
Walls												
Shrinkage or Fissures				*	*	*		*				
Air Penetration			*	*	*		*	*	*		*	*
Ceilings												
Sloped	*					*			*	*		
Flat	*	*	*	*		*	*		*	*	*	*
Doors												
Frames	*	*	*	*		*	*		*		*	
Air Leakage	*	*	*	*	*	*	*		*		*	*
Windows												
Frames	*	*	*	*			*	*		*	*	
Air Leakage	*	*	*	*	*	*	*		*		*	*
Joints												
Wall-Wall	*		*	*	*	*		*			*	*
Ceiling-Wall	*	*	*	*	*	*	*		*	*		*
Floor-Wall			*									*
Eaves	*			*	*			*			*	*
Basement or Crawl Space			*									



Number of houses = 12

Mean area = 9.75%

Figure 1. Distribution of Defective Areas in Houses Inspected

4. CONCLUSION

The field inspection results showed that the infrared survey contractors located approximately 45 percent to 86 percent of the known thermal defects during their inspections. The main cause of failure to locate defects is that contractors failed in many cases to inspect all exterior walls of each house involved. Thus the inspection procedures used by the infrared contractors are very important to the outcome of inpsections. The results of the interpretation of the thermographic data are affected by the quality of thermograms. With a higher operational cost, thermograms generated from contractors using HRIS are supposed to provide better documentations than sketches produced manually by the contractors using LRIS. However, many thermograms submitted by the contractors were quite poor in quality due to out of focus or lack of adequate thermal contrast. This causes uncertainty in the analysis and estimation of voids, and therefore causes a wide discrepancy in results among the contractors. There is a need to develop recommended measurement techniques, inspection procedures, and analysis methods to provide consistent results for infrared survey of buildings.

As for the quality of the installation of insulation into these dwellings, the results from this program indicated serious defects still existed in most of the houses after weatherization. Some defects, such as air penetration into ceilings, heat loss at soffits and eaves, and excessive heat loss from attics, are usually not considered as normal weatherization measures. However, defects such as missing insulation, shrinkage or fissures, air leakage at windows and doors, etc., are primarily due to a poor quality of workmanship.

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APPENDIX

ANALYSIS AND COMPARISON OF THERMOGRAPHICAL INSPECTIONS

I. Fargo House #1

This is a one-story, approximately 25 year old residence whose interior dimensions are 24 ft. in length, 25 ft. in width, and 7.4 ft. in wall height; located in Fargo, ND. There are 5 rooms of living space, with an attic and a basement. Its exterior construction contains metal siding and an asphalt shingle roof.

Prior to the weatherization program, this residence was insulated with 3 1/2" glass fiber batt insulation in the cavity walls. An insulation contractor was instructed to add UF foam to this existing insulation. After the retrofitted foam was injected into the walls, this dwelling was inspected by NBS personnel and IR contractors #1, #2, and #3. A sketch of the voids and the locations of heat loss obtained from thermograms and documents by NBS, as well as those by the IR contractors, is shown in figure Ia.

In general, the most common area of heat loss in this house were found at wall-ceiling joints, at corners (bridges), and also around the diagonal braces. This might be due to the defective sealing at eave junctions such that air leaked into the dwelling. Also, cold ceilings were found at the corners of the south and north sides on the main floor as well as in the attic.

Thermographic inspection by NBS observed most known defects of this residence so that its result can be used as a baseline for comparison. Due to the fact that UF foam was added on to the existing insulation, different performance levels of insulation could be observed in locations where the foam did not reach the intended locations.

Contractor #1, who used LRIS for inspection, had difficulties in identifying the partial insulation voids from different performance levels and sketched most of the locations of low temperatures as 'cool' areas instead of voids. This report will interpret these 'cool' areas as void areas.

Contractors #2 and #3 failed to inspect several regions in this house as compared with the inspection by NBS.

A detailed description of the defects observed by NBS as well as those by the IR contractors, is summarized in table Ia. Besides the total defective wall area in ft^2 found by each inspection, table Ia also includes each defective wall area in ft^2 of each room of the house, analyzed from available thermograms and sketches. The total estimates of void areas is approximately 70 ft^2, which represents about 7 percent of the gross wall area. Table Ib presents the environmental conditions documented from each inspection. Thermograms/sketches 1-1 to 1-9 are some examples which demonstrate the locations of heat loss anomalies, as they are referred to in the descriptions in table Ia.

Table Ia. Summary of Defects Observed in Fargo House #1

Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #1	#2	#3	Thermogram No. in Appendix
Front Entrance	S	Air Infiltration Underneath & Around 'Hollow' Door		No	No	Yes	Yes	1-1
	E	Air Infiltration or Void at Ceiling		No	No	Yes	No	
Living Room	S	Voids & Infiltration: Above & Below Window	6	Yes	Cool	Yes	No	1-2
		at Corner of SW & Ceiling		Yes	No	No	Yes	1-3
	W	Voids Around Diagonal Brace	7	Yes	Yes	No	No	1-4
		Thermal Bridge at SW Corner		Yes	No	No	No	1-5
Kitchen	W	Voids Below & Above Window; Partial Bay Cavity at NW Corner	6	Yes	Cool	Yes	No	
		Infiltration Around 'Hollow' Door & at Lower Left of Door		No	No	Yes	Yes	1-6
	N	Small Void above Refrigerator at Ceiling & in wall Behind Cabinets	2	Yes	No	No	No	
Bathroom	N	Voids Above & below Window; Penetration From Ceiling	6	Yes	No	No	No	1-7 1-8
Northeast Bedroom	N	Voids Below Window & Around the Diagonal Brace	4	Yes	No	No	Yes	
		Air Penetration From Ceiling at NE Corner		Yes	No	Yes	No	

Table Ia. Summary of Defects Observed in Fargo House #1

Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #1	#2	#3	Thermogram No. in Appendix
	E	1 Half Bay Cavity at NE Corner	7	Yes	Cool	Yes	No	
		Partial Voids in 2 Upper Bays and Below Window With Infiltration		Yes	No	No	No	
Southeast Bedroom	E	Voids Above and on Both Sides of Windows	12	Yes	Yes	No	No	
		1 Bay Cavity Above Diagonal Brace at S of Window		Yes	Yes	No	No	1-9
		Air Leakage at SE Corner		Yes	No	Yes	Yes	1-10
	S	Voids Below Window Partial Void at SE Corner	8	Yes	No	No	Yes	
		2 Upper Bay Cavities at W of Window		Yes	No	No	No	
		Air Penetration From Ceiling		Yes	Yes	Yes	Yes	
Attic	E	Voids Below Window	4	Yes	No	Yes	No	
		Partial Bay Cavity at NE Corner		Yes	No	No	Yes	
	S	Uninsulated Sloped Ceiling		Yes	No	No	Yes	
	W	Voids Above & at S Side of Window	8	Yes	No	No	No	
		Uninsulated Sloped Ceiling		Yes	No	No	Yes	1-11
	N	Uninsulated Sloped Ceiling		Yes	No	No	Yes	
Total Wall Area of Insulation Voids Detected Given in ft^2			70	70	35	17	18	

Table Ib. Environmental Conditions During Inspections of Fargo House #1

	NBS	Contractors #1	#2	#3
Date	3/1/79	4/10/79	4/25/79	4/17/79
Time	11:00 am	9:00-10:00 pm		10:00 am
Weather Condition			overcast	bright sunlight
Outside Temperature	10°F		47°F	49°F
Inside Temperature	68°F	55°F 60°F(attic)	68°F	67°F
Inside Humidity				54%
Wind Speed(MPH)	5-10		2-5	25-30
Wind Direction	NW		NW	SE

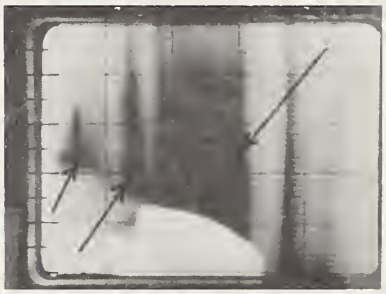
1-1
Solar Effect on
'hollow' front door.
(by contractor #3)

1-2
SE corner on S
of living room.
(by contractor #2)

1-3
SW corner on S
of living room.
(by NBS)

1-4
W corner on W
of living room.
(by NBS)

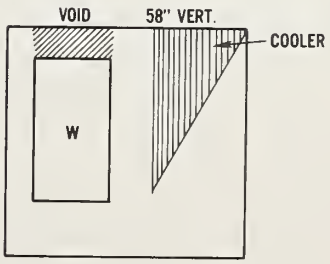
1-5
SW corner on W
of living room.
(by contractor #3)



1-6
'Hollow' side door
scanned at overcast.
(by contractor #3)

1-7
Above window & at
ceiling of bathroom.
(by NBS)

1-8
Below window
of bathroom.
(by NBS)



1-9
E wall of SE
bedroom. (by LRIS)

1-10
SE corner of
SE bedroom.
(by contractor #2)

1-11
Solar effect at
the attic ceiling.
(by contractor #3)

II. Fargo House #2

This is a one-story, approximately 50 year old residence whose interior dimensions are 36 ft. in length, 19 ft. in width, and 8 ft. in wall height; located in Fargo, ND. There are 6 rooms of living space, with an attic and a basement. Its exterior construction contains wood siding and a cedar shingle roof.

Prior to the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the walls of this house with UF foam. After the retrofitted foam was injected into the walls, this dwelling was inspected by NBS personnel and IR contractors #1, #2 , and #3. A sketch of the voids and the locations of heat loss obtained from thermograms and documents by NBS, as well as those by the IR contractors, is shown in figure IIa.

In general, the most common area showing heat loss in this house were found on both the east and west sides. The voids in these walls may be due to poor installation or extreme shrinkage of foam. The north wall enclosed by the porch was not insulated since insulation was supposed to be added to the outside walls of the house. The outer walls of the porch were not inspected because the porch was not heated. Hence this wall was omitted in area calculations.

Thermographic inspection by NBS missed the data on east walls of the bathroom and the northeast bedroom due to camera malfunction. Therefore, its results can not serve as a baseline for these two walls.

Contractors #1 and #2 identified all defective wall areas while contractor #3 missed a few locations. In addition, contractors #2 and #3 included inspections of the ceiling of the dining room and found that the insulation in the ceiling was not adequate.

A detailed description of the defects observed by NBS as well as thoe by the IR contractors, is summarized in table IIa. Besides the total defective wall area in ft^2 found by each inspection, table IIa also includes the defective wall areas in ft^2 of each room of the house, analyzed from available thermograms and sketches. The total estimates of void areas is approximately 78 ft^2, which represents about 9 percent of the gross wall area. Table IIb presents the environmental conditions documented from each inspection. Thermograms/sketches 2-1 to 2-7 are some examples which demonstrate the locations of heat loss anomalies, as they are referred to in the descriptions in table IIa.

Table IIa. Summary of Defects Observed in Fargo House #2

Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #1	#2	#3	Thermogram No. in Appendix
Living Room	E	Voids Above & Air Infiltration Below Window; Shrinkage of Insulation at Lower NE Corner	8	Yes	Yes	Yes	Yes	2-1
	S	Voids Above SW Corners of Door and SW Window	4	Yes	Yes	Yes	Yes	
		Air Infiltration at Lower Part of Door		No	Yes	Yes	Yes	
	W	Voids Above Windows	8	Yes	Yes	Yes	No	
		2 Upper Bay Cavities at NW Corner		Yes	Yes	Yes	Yes	
Dining Room	W	Voids Above Both Windows; Missing Insulation on Both Sides of SW Window and 4 Upper Bay Cavities	10	Yes	Yes	Yes	Yes	2-2
	Ceiling	Missing Insulation or Moisture Damage		No	No	Yes	Yes	2-3
East Bedroom	E	Voids Above Window and Partial Bay Cavities in Upper Wall	10	Yes	Yes	Yes	Yes	
	Ceiling	Missing Insulation or Moisture Damage		No	No	Yes	No	2-4
Bathroom	E	Voids in Upper Part of Whole Wall	20	No	Yes	Yes	Yes	2-5
		1 Partial Bay & Air Infiltration Below Window		No	Yes	Yes	No	
Northeast Bedroom	E	Voids Above Window and 1 Upper Bay Cavity at SE of Window	7	No	Yes	Yes	No	2-6

Table IIa. Summary of Defects Observed in Fargo House #2

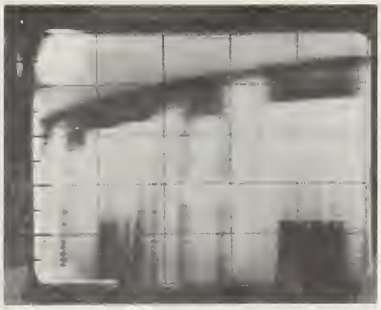
Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #1	#2	#3	Thermogram No. in Appendix
		Voids & Infiltration Below Window		No	Yes	Yes	No	2-7
	N	Small Void Above Window	2	Yes	Yes	Yes	No	
Kitchen	W	Voids Above Window & Under Cabinets at NW Corner	9	No	Yes	Yes	No	
Total Area Wall of Insulation Voids Detected Given in ft^2			78	42	78	78	50	

Table IIb. Environmental Conditions During Inspections of Fargo House #2

	NBS	Contractors #1	#2	#3
Date	3/2/79	4/10/79	4/26/79	4/17/79
Time	2:00 pm	8:15-9:15 pm		1:15 pm
Weather Condition			light snow	bright sunhine
Outdoor Temperature	15°F	37°F	38°F	59°F
Indoor Temperature	75°F	77°F	78°F	71°F
Indoor Humidity				53%
Wind Speed(MPH)	2-5		calm	20-25
Wind Direction	NW			SE

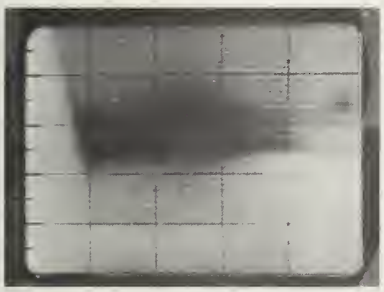
Thermal Anomalies Observed in Fargo House #2

2-1
E wall of
living room.
(by NBS)

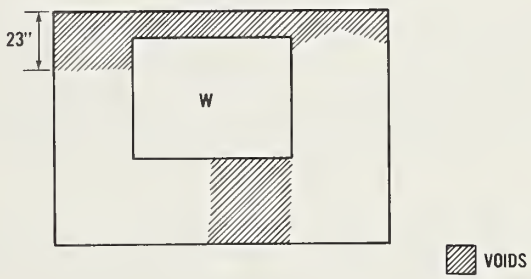


2-2
W wall of
dining room.
(by contractor #2)

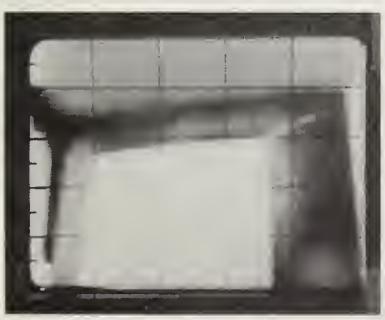
2-3
Dining room
ceiling.
(by contractor #3)



2-4
E bedroom
ceiling.
(by contractor #2)

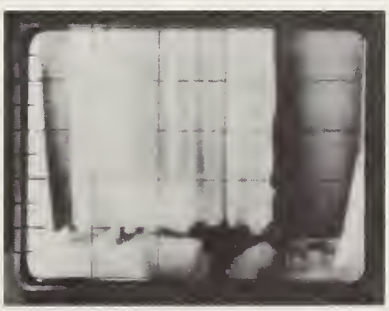


2-5
E wall of bathroom. (by LRIS)



2-6

Upper E wall of
NE bedroom.
(by contractor #2)



2-7

Lower E wall
of NE bedroom.
(by contractor #2)

III. Fargo House #3

This is a one-story, approximately 60 year old residence whose interior dimensions are 34 ft. in length, 24 ft. in width, and 8 ft. in wall height; located in Fargo, ND. There are 6 rooms of living space, with an attic and a basement. Its exterior construction contains wood frame with aluminum siding, and an asphalt shingle roof.

Prior to the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the walls of this house with UF foam. After retrofitted foam was injected into the walls, this dwelling was inspected by NBS personnel and IR contractors #1, #2, and #3. A sketch of the voids and the locations of heat loss obtained from thermograms and documents by NBS, as well as those by the IR contractors, is shown in figure IIIa.

In general, the most common area of heat loss in this house were found above windows, doors, and eaves as well as air leakage paths below windows.

Thermographic inspection by NBS identified most known defects of this residence so that its results can be used as a baseline for comparison. Furthermore, NBS included scanning of the basement walls which were colder at the top. Since the top part of the basement is above ground and the bottom part is under ground, there seemed to be cold air penetration to the basement from outside.

Contractors #1 and #2 each missed inspection of a few locations, but contractor #2 inspected the dining room ceiling and found some voids at the ceiling, the west partition wall of the dining room, and the north partition wall of the bathroom. However, these voids were not included in calculations for defects.

Contractor #3 scanned this dwelling under bright sunlight so that the high temperature areas do indicate void areas due to the high temperature from solar radition. Several locations were missed by contractor #3 which were identified by contractors #1 and #2 as well as NBS.

A detailed description of the defects observed by NBS as well as those by the IR contractors, is summarized in table IIIa. Besides the total defective wall area in ft^2 found by each inspection, table IIIa also includes the defective wall areas in ft^2, of each room of the house, analyzed from available thermograms and sketches. The total estimates of void areas is approximately 75 ft^2, which represents about 10 percent of the gross wall area. Table IIIb presents the environmental conditions documented from each inspection. Thermograms/sketches 3-1 to 3-12 are some examples which demonstrate the locations of heat loss anomalies, as they are referred to in descriptions in table IIIa.

Table IIIa. Summary of Defects Observed in Fargo House #3

Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #1	#2	#3	Thermogram No. in Appendix
Living Room	N	Voids Above Window and Door	10	Yes	Yes	Yes	No	3-1
		1 Upper Bay Cavity at NE of Window & Air Infiltration Around Door		Yes	Yes	Yes	Yes	
	E	Voids Above Window and 2 Upper Bay Cavities at SE of Window	8	Yes	Yes	Yes	Yes	3-2
Dining Room	E	Voids in Upper Part of the Entire Wall	17	Yes	Yes	Yes	No	3-3
		1 Bay Cavity at NE Corner & Infiltration Below Window		Yes	Yes	No	No	3-4
	W	Voids in Partition Wall & Cold Ceiling		No	No	Yes	No	3-5
Kitchen	E	Voids Above Window and Infiltration Below Window	7	Yes	No	No	No	
		Voids Above and at NE Side of Near Door; Air Infiltration at SE Corner		Yes	No	No	No	
	S	Air Penetration & Voids Below Window	2	Yes	No	No	No	
Northeast Bedroom	N	Voids Above Window and in 2 Upper Bays at NE Corner	8	Yes	Yes	Yes	No	3-6
	W	Voids in 1 Upper Bay	1	Yes	Yes	Yes	Yes	
		Air Penetration at Lower NW Corner		Yes	No	No	No	

Table IIIa. Summary of Defects Observed in Fargo House #3

Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #1	#2	#3	Thermogram No. in Appendix
Bathroom	W	Voids Above Window and in 2 Upper Bays at Both Sides of Window	10	Yes	Yes	Yes	No	
	N	Some Voids in Partition Wall		No	No	Yes	No	
Southwest Bedroom	W	Voids Above Window and in 3 Upper Bays at SW Corner	8	Yes	Yes	Yes	Yes	3-7 3-8 3-9
	S	Voids at SW Corner of Window	4	Yes	No	No	Yes	
Basement		Cold Air Penetrated From Outside at Top of Wall		Yes	No	No	No	3-10 3-11 3-12
Total Wall Area of Insulation Voids Detected Given in ft^2			75	75	60	59	23	

Table IIIb. Environmental Conditions During Inspection of Fargo House #3

	NBS	Contractors #1	#2	#3
Date	3/1/79	4/9/79	4/25/79	4/17/79
Time	2:00 pm	7:00-8:00 pm		12:00 noon
Weather Condition			cloudy	bright sunlight
Outdoor Temperature	15°F	35°F	41°F	56°F
Indoor Temperature	79°F	72°F	69°F	78°F
Indoor Humidity				40%
Wind Speed(MPH)	5-10		8-12	20-25
Wind Direction	NW		N	SE

Thermal Anomalies Observed in Fargo House #3

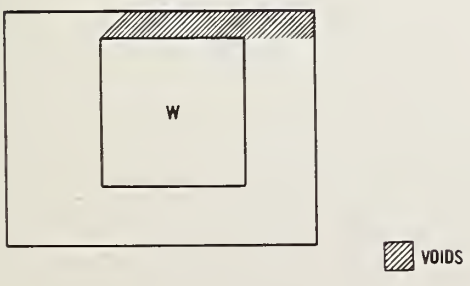
3-1
N wall of
living room.
(by NBS)

3-2
E wall of
living room.
(by contractor #2)

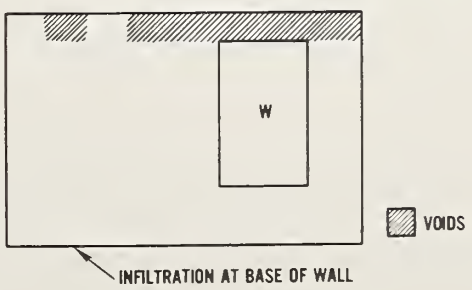
3-3
E wall of
dining room.
(by contractor #2)

3-4
NE corner on E
of dining room.
(by NBS)

3-5
Ceiling & W wall of
dining room.
(by contractor #2)



3-6
N wall of NW bedroom. (by LRIS)

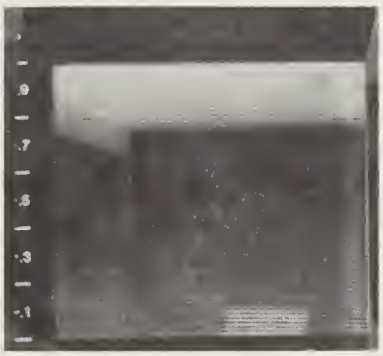


3-7
W wall of SW bedroom. (by LRIS)

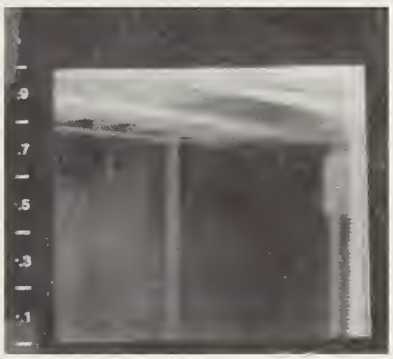
3-8
SW corner of SW bedroom.
(Scanned at overcast
by NBS)

3-9
SW corner of SW bedroom
(Scanned under bright sunlight
by contractor #3)

3-10
At basement door.
(by NBS)



3-11
NW corner of
basement.
(by NBS)



3-12
NE corner of
basement.
(by NBS)

IV. Fargo House #4

This is a one-story, approximately 15 year old residence whose interior dimensions are 23 ft. in length, 21 ft. in width, and 8 ft. in wall height; located in Fargo, ND. There are 4 rooms of living space with an attic and a basement. Its exterior construction contains wood frame with wood lap siding and an asphalt shingle roof.

Prior to the weatherization program, this house was insulated with 3 and 1/2'' glass fiber batt insulation in the cavity walls. An insulation contractor was instructed to add UF foam to the existing insulation. After the retrofitted foam was injected into the walls, this dwelling was inspected by NBS personnel and IR contractors #1, #2, and #3. A sketch of the voids and the locations of heat loss obtained from thermograms and documents by NBS as well as those by the IR contractors, is shown in figure IVa.

In general, the most common area of heat loss in this house were found above most windows and doors, and below most of the windows. The corner of the wall-ceiling joints were also defective with several vertical partially-voided corner bays. Problem areas may be due to the insulation defects at the eaves underneath the roof and compression of old insulation as well as missed foaming. These were loose fitting paneling in the bathroom and a moisture problem in the attic. Both doors were found to be uninsulated with severe air leakage around them.

Thermographic inspection by NBS observed most known defects of this residence except of the south entrance. Contractor #2 also included all defects except for the east wall of the living room. Therefore, from the combination of these two inspections, a baseline were established for comparison purposes.

From contractor #1's comment, the thermal pattern observed in this house was due to: (1) damp insulation, (2) uneven application of foaming (different density), and (3) foam mixed with other kind of insulation, providing areas of different R-values. Therefore, it claimed that no voids were found in this house. However, this house did have insulation before and the inspection should be locating voids in the foam retrofits. Hence the 'cool area' indicated by contractor #1 should be considered as defects, misses, or shrinkage of foaming. The cool areas found by contractor #1 were interpreted as voids in the house. However contractors #1 and #3 failed to inspect many areas in this dwelling.

A detailed description of the defects observed by NBS as well as those by the IR contractors, is summarized in table IVa. Besides the total defective wall area in ft^2 found by each inspection, table IVa also includes the defective wall areas in ft^2 of each room of the house, analyzed from available thermograms. The total estimates of void areas is approximately 67 ft^2, which represents about 11 percent of the gross wall area. Table IVb presents the environmental conditions documented from each inspection. Thermograms 4-1 to 4-8 are some examples which demonstrate the locations of heat loss anomalies, as they are referred to in the descriptions in table IVa.

Table IVa. Summary of Defects Observed in Fargo House #4

Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #1	#2	#3	Thermogram No. in Appendix
Living Room	E	Air Penetration from Ceiling and Infiltration Around 'Hollow' Door	5	Yes	Yes	Yes	Yes	
		Voids Above Window		Yes	Yes	No	No	
		1 Half Bay Cavity and Infiltration at NE Corner		Yes	No	No	Yes	
	N	1 Half Bay Cavity at NW Corner	12	Yes	Yes	Yes	Yes	4-1
		Voids Above Window; Missing Foam in Several Upper Bays and Infiltration at Ceiling-Wall Joint		Yes	No	Yes	Yes	4-2
Bathroom	E	Voids Below Window	6	Yes	Yes	Yes	Yes	4-3
		Voids Above Window and in 1 Upper Bay at NE Corner		Yes	No	Yes	No	
	S	Partial Bay Cavities at SE Corner; Missing a Good Deal of Foam in Wall	7	Yes	No	Yes	No	
South ENTRANCE	S	Voids Above Door & Air Penetration Through Attic Hatch	4	No	Yes	Yes	No	4-4
		Air Leakage Around & Penetration Tthrough 'Hollow' Door		No	No	Yes	Yes	4-5
Kitchen	W	Voids Above and Below Window		Yes	Yes	Yes	No	

Table IVa. Summary of Defects Observed in Fargo House #4

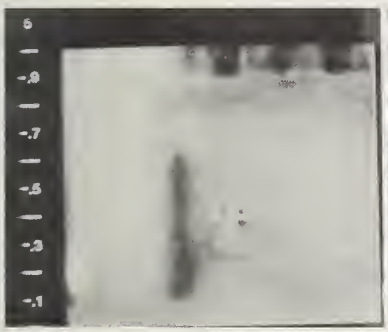
Room & Orientation	Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #1	#2	#3	Thermogram No. in Appendix
	Foam Missing Partially in Several Bays on Both Sides of window		Yes	No	Yes	Yes	
Ceiling	Possible Moisture Damage at 1 Spot		No	No	Yes	Yes	4-6
Bedroom W	Voids Above Window	10	Yes	Yes	Yes	No	
	2 Upper Bay Cavities and Air Penetration Through Ceiling at NW Corner		Yes	No	Yes	Yes	4-7
	Foam Missing Partially in 2 Upper Bays at SW of Window		Yes	No	Yes	No	4-8
N	Air Penetration at NW Corner & Around Window	10	Yes	No	Yes	Yes	
	Voids Above Window & Foam Missing Partially in Some Bays on Both Sides of Window		Yes	Cool	Yes	No	
	1 Partial Bay Cavity at NE Corner		Yes	Yes	Yes	No	
Total Wall Area of Insulation Voids Detected Given in ft^2		67	63	34	62	38	

Table IVb. Environmental Conditions During Inspection of Fargo House #4

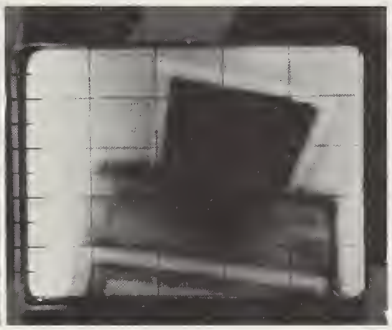
	NBS	Contractors #1	#2	#3
Date	3/2/79	4/9/79	4/25/79	4/17/79
Time	4:00 pm	8:15-9:15 pm		2:45 pm
Weather Condition			overcast	bright sunshine
Outdoor Temperature	13°F	35°F	37°F	59°F
Indoor Temperature	75°F	75°F	76°F	79°F
Indoor Humidity				51%
Wind Speed(MPH)	5-10		3-5	25-35
Wind Direction	NW		S	SE

4-1
NW corner on N of living room.
(Different density levels of insulation by NBS)

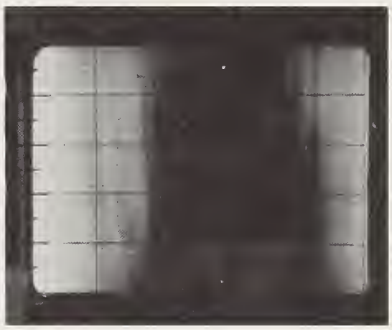
4-2
N wall of living room.
(Different density levels of insulation by contractor #2)



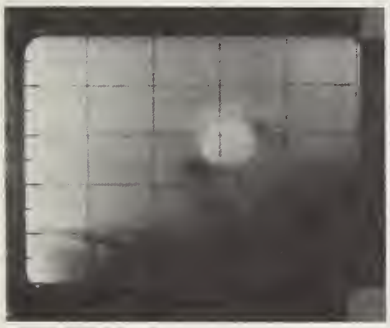
4-3
Below window on E of bathroom.
(by contractor #3)



4-4
Attic hatch & above side door.
(by contractor #2)



4-5
Infiltration around & underneath side door.
(by contractor #2)



4-6
Problems at kitchen ceiling.
(by contractor #2)

4-7
NW corner on W of bedroom.
(by NBS)

4-8
SW corner on W of bedroom.
(by NBS)

V. Minneapolis-St. Paul House #1

This is a two-story, approximately 60 year old residence whose interior dimensions are 33 ft. in length, 30 ft. in width, and 9 ft. in wall height on the first floor, and 8 ft. in wall height on the second floor; located in Minneapolis-St. Paul, MN. There are 8 rooms of living space, with an attic and a basement. Its exterior construction contains wood frame with stucco siding and an asphalt shingle roof.

Prior to the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the walls of this dwelling with UF foam. After retrofitted foam was injected into the walls, this dwelling was inspected by NBS personnel and IR contractors #2, and #4. A sketch of the voids and locations of heat loss obtained from thermograms and documents by NBS as well as those by the IR contractors, is shown in figures Va and Vb.

In general, voids in this house were found above most of the windows and doors, and these locations were also sites of air leakage. The wall and ceiling joints have thermal bridges with infiltration, and bay cavities were also found at wall-to-wall joints. Several walls on the second floor were found to have foam shrinkage.

Thermographic inspection by NBS revealed most of the defects of this residence, except for those in the north upstairs room. Furthermore, NBS carried out both interior and exterior inspections of this house. Besides giving the correct location of the fireplace chimney, the exterior thermograms illustrated some defects on the west wall of the southwest bedroom where no interior thermograms were produced. Therefore, results of NBS' inspection were used as a baseline for comparison purposes.

Contractors #2 and #4 employed HRIS to observe defects in this dwelling by producing thermograms and visual photographs of identical locations. However, they failed to recognize many uninsulated areas. Neither contractor inspected all of the walls, as they submitted only nine thermograms each, covering different areas of the house. There were also some questionable interpretations from the contractors. Both contractors observed the east wall of the living room and the southeast bedroom upstairs; and considered the 'cool' areas as voids. These areas are locations of the fireplace chimney, which are always cold except during use. Contractor #2 did identify this area as a fireplace chimney for the bedroom upstairs, without also considering the cold area in the living room, which is just behind the fireplace. NBS' interior and exterior thermograms gave a clear indication of the chimney location.

A detailed description of the defects observed by NBS as well as those by the IR contractors, is summarized in table Va. Besides the total defective wall area in ft^2 found by each inspection, table Va also includes the defective wall areas in ft^2 of each room of the house, analyzed from available thermograms and sketches. The total estimates of void areas is approximately 89 ft^2, which represents about 6 percent of the gross wall area. Table Vb presents the environmental conditions documented from each inspection. Thermograms 5-1 to 5-9 are some examples which demonstrate the locations of heat loss anomalies, as they are referred to in the descriptions in table Va.

Table Va. Summary of Defects Observed in Minneapolis-St. Paul House #1

Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #2	#4	Thermogram No. in Appendix
Living Room	E	Small Voids Above Both Windows	2	Yes	No	No	
		Cold Air Penetration from Chimney of Fireplace; Infiltration Through Both Windows		Yes	Yes	Yes	5-1
	S	Voids Above Window and in 1 Upper Bay at SW of Window; Warm Area at SE Indicating Solar Loading; Air Penetration Through Ceiling	6	Yes	Yes	No	5-2
		Small Voids Above Door		Yes	No	No	
	W	Voids Above & Below Window	4	Yes	No	No	
Stairway (1st Floor)	W	1 Partial Bay Cavity at Side Door and Infiltration or Leakage Through Door	3	Yes	No	No	
Kitchen	W	Voids Above Window and Pantry	8	Yes	No	Yes	
		Voids Below Pantry		Yes	Yes	No	
		1 Partial Bay Cavity at SW Corner		Yes	No	No	
	N	Voids Above Window and Behind Cabinets	6	Yes	Yes	No	5-3
Dining Room	N	Voids Above Window and Partially in 1 Bay at NW of Window	6	Yes	Yes	Yes	5-4

Table Va. Summary of Defects Observed in Minneapolis-St. Paul House #1

Room & Orientation	Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #2	#4	Thermogram No. in Appendix
	Small Voids at NE Corner		Yes	Yes	No	
	Air Infiltration Around & Below Window		Yes	Yes	No	
E	Voids Above SE Corner of Window and 1 Partial Bay Cavity at SE Corner	8	Yes	No	No	
Stairway W (2nd Floor)	Voids Above Window and Infiltration at Ceiling	4	Yes	No	Yes	5-5
Bathroom W	Voids Above Window and Infiltration at NW Corner	3	Yes	No	Yes	
N	Small Void and Infiltration Above Shower Area	1	Yes	No	No	
Northroom N	Voids Above Window	4	No	No	Yes	
Northeast N Bedroom	Voids Above Window	4	Yes	Yes	Yes	
	Partial Bay Cavities on Both Sides of Window		Yes	Yes	No	
	Shrinkage of Foam		Yes	Yes	Yes	
E	Voids Above Window and in Upper Part of Wall at SE of Window	4	Yes	Yes	No	
	Shrinkage of Foam at NE Side of Window and Infiltration at Ceiling-Wall Joint		Yes	No	No	5-6

Table Va. Summary of Defects Observed in Minneapolis-St. Paul House #1

Room & Orientation	Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #2	#4	Thermogram No. in Appendix
Southeast E Bedroom	Cold Air Penetration at NE of Window Through Fireplace Chimney; Missing Insulation at Both Sides of Window	8	Yes	Yes	Yes	5-7
S	1 Half Bay Cavity at SE Corner	10	Yes	No	Yes	
	Voids Above Window and in Partial Bays at SW of Window; Shrinkage of Foam		Yes	No	No	5-8
Southwest S Bedroom	Voids Above Window and in 2 Upper Bays at SE Corner; Some Shrinkage of Foam	3	Yes	No	No	
W	Voids in Upper on Both Sides of Windows		Yes	No	No	5-9
Total Wall Area of Insulation Voids Detected Given in ft^2		89	85	30	31	

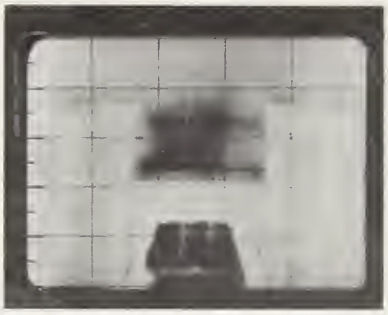
Table Vb. Environmental Conditions During Inspection of Minneapolis-St. Paul House #1

	NBS	CONTRACTORS #2	#4
Date	2/14/79	4/27/79	4/4/79
Time	10:00 am		12:25 pm
Weather Conditions		partly cloudy	
Outdoor Temperature	13°F	49°F	42°F
Indoor Temperature	75°F	75°F	74°F
Wind Speed(MPH)	5-10	6	
Wind Direction	NW	N	

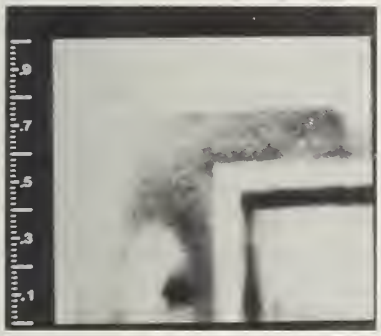
Thermal Anomalies Observed in Minneapolis-St. Paul House #1

5-1
E wall of
living room.
(by contractor #2)

5-2
S wall of
living room.
(by contractor #2)

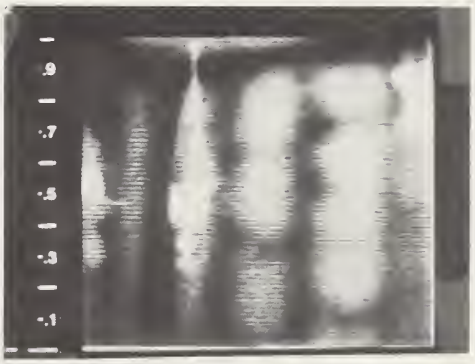


5-3
N wall of
kitchen.
(by contractor #2)



5-4
N wall of
dining room.
(by contractor #4)

5-5
W of stairway
on 2nd floor.
(by NBS)



5-6
E wall of
NE bedroom.
(by NBS)

5-7
E wall of
SE bedroom.
(by NBS)

5-8
S wall of
SE bedroom.
(by NBS)

5-9
W wall of
SW bedroom.
(exterior by NBS)

VI. Minneapolis-St. Paul House #2

This is a two-story, approximately 80 year old residence whose interior dimensions are 45 ft. in length, 24 ft. in width, and 8 ft. in wall height on each floor; located in Minneapolis-St. Paul, MN. There are 9 rooms of living space, with an attic and a basement. Its exterior construction contains wood siding and an asphalt shingle roof.

Prior to the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate this house with UF foam. After the retrofitted foam was injected into the walls this dwelling was inspected by NBS personnel and IR contractors #1, #2, and #4. A sketch of the voids and the locations of heat loss obtained from thermograms and documents by NBS as well as those by the IR contractors, is shown in figures VIa and VIb.

In general, the insulation on the first floor of this house is better than that on the second floor. Furthermore, all doors were found to be uninsulated and voids were observed at stairwells and ceilings. On the first floor, many void areas were found in the living room, family room, dining room, and kitchen. On the second floor, pitched ceilings were found to be uninsulated, many walls have voids, windows have voids above them, and air was leaking from joints of pitched ceilings and walls.

Thermographic inspection by NBS identified most of the defects, except for those in the wall area underneath the uninsulated pitched ceiling at north of the west bedroom upstairs. Besides the interior inspection, NBS made a fairly complete exterior thermographic survey of this dwelling and observed most of the voids. There were some locations where only exterior thermograms were taken, such as the east wall on the left side of the window in the family room and above the north door of the dining room. The results of the NBS survey were used as a baseline for comparison purposes.

This is the only house in Minneapolis-St. Paul that was inspected by all three contractors, two contractors (#2 and #4) used HRIS to produce thermograms and one (#1) used LRIS to sketch locations of missing locations. Contractors #2 and #4 produced 26 and 27 thermograms respectively and gave detailed locations of each wall. Even though they missed some defects during inspection, their results are considered to be fairly good. Contractor #1 provided 16 sketches of which some did not show uninsulated areas. Hence its performance was not as good as that of the other contractors.

A detailed description of the defects observed by NBS, as well as IR those by the contractors, is summarized in table VIa. Besides the total defective wall area in ft^2 found by each inspection, table VIa also includes the defective wall areas in ft^2 of each room of the house, analyzed from available thermograms and sketches. The total estimates of void areas is approximately 174 ft^2, which represents about 10 percent of the gross wall area. Table VIb presents the environmental conditions documented from each inspection. Thermograms/sketches 6-1 to 6-17 are some examples which demonstrate the locations of heat loss anomalies, as they are referred to in the descriptions in table VIa.

Table VIa. Summary of Defects Observed in Minneapolis-St. Paul House #2

Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #1	#2	#4	Thermogram No. in Appendix
Kitchen	W	Voids Above Window and in Several Upper Bays Air Infiltration From Ceiling	10	Yes	Yes	Yes	Yes	6-1
	N	Voids Above Refrigerator & Above Door; Air Leakage Around the Door	5	Yes	Yes	Yes	Yes	6-2
	E	Voids Above Window And in Lower Bays at SE of Window	10	Yes	No	No	No	
		Voids Below Cabinets and Infiltration Around Window		Yes	Yes	No	No	
Family Room	E	Voids Above Window	13	Yes	No	No	Yes	
		Voids at Upper Part of Whole Wall Air Infiltration From Floor		Yes	No	No	No	6-3
Living Room	E	Air Infiltration or Leakage Around Window		Yes	Yes	No	No	
	S	Air Leakage Through Door	10	Yes	Yes	No	No	
		Voids Above Window and in Several Bays Partially at SE of Window		Yes	Yes	Yes	Yes	6-4
		Small Void Below Window & Infiltration Around Window; Uneven Application of Foam		Yes	Yes	Yes	No	

Table VIa. Summary of Defects Observed in Minneapolis-St. Paul House #2

Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #1	#2	#4	Thermogram No. in Appendix
	W	No Defects		Yes	Yes	No	No	
Dining Room	W	Voids Above Window and in 2 Bays Partially at SW of Window	18	Yes	Yes	Yes	Yes	6-5
		Insulation Shrinkage and Fissure in Several Bays at NW of Window		Yes	Yes	Yes	No	6-6
	N	Small Voids Above Door	9	Yes	No	No	No	6-7
		Air Leakage Through Door		Yes	No	Yes	Yes	
		Missing Insulation in 1 Lower Bay in Stairwell		Yes	Yes	Yes	Yes	
		Missing Insulation at Ceiling of Stairway		Yes	Yes	Yes	No	
North Bedroom	W	Uninsulated Pitched Ceiling	6	Yes	No	Yes	Yes	6-8
		Voids Above Window and in 1st Bay at NE and NW Corners Partially		Yes	No	Yes	No	6-1
	N	Voids Below Pitched Ceiling and above Window	10	Yes	Yes	Yes	Yes	6-2
		Voids in 1st Bay Cavities at NE and NW Corners		Yes	No	Yes	Yes	

Table VIa. Summary of Defects Observed in Minneapolis-St. Paul House #2

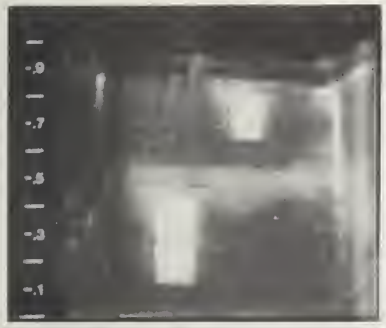
Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #1	#2	#4	Thermogram No. in Appendix
	E	Voids Above Window and in Half Bay Cavity at NE of Window	7	Yes	Yes	Yes	Yes	
		Uninsulated Pitched Ceiling With Air Penetration Through Ceiling		Yes	No	Yes	Yes	
Bathroom	E	Missing Insulation in the Upper Part of the Wall	25	Yes	Yes	Yes	Yes	6-9 6-10 6-3
	S	Air Leakage at Ceiling-Wall Joint Under Pitched Ceiling		No	No	Yes	No	
Sewing Room	E	Missing Insulation Above Window at SE Corner	8	Yes	Yes	Yes	Yes	
	S	Voids Above Window and at SE of Window Under Ceiling	7	Yes	Yes	No	Yes	6-11 6-12
South Bedroom	S	Uninsulated Bay Cavities in the Upper Part of the Entire Wall	20	Yes	Yes	Yes	Yes	6-13
		Air Infiltration Below SE Window		Yes	Yes	Yes	Yes	
	W	Uninsulated Pitched Ceiling and Air Leakage Underneath Small Voids Above Window	1	Yes	Yes	Yes	Yes	6-14

Table VIa. Summary of Defects Observed in Minneapolis-St. Paul House #2

Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #1	#2	#4	Thermogram No. in Appendix
West Bedroom	W	Voids Above Window & Under the Ceiling at NW and SW Corners	10	Yes	Yes	Yes	Yes	6-15
	N	Uninsulated Pitched Ceiling and Wall Area Underneath	5	No	No	Yes	No	6-16
	S	Uninsulated Pitched Ceiling		No	No	Yes	Yes	
Total Area of Insulation Voids in ft^2			174	169	125	142	144	

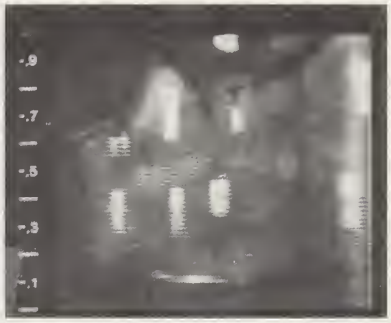
Table VIb. Environmental Conditions During Inspection of Minneapolis-St. Paul House #2

	NBS	Contractors #1	#2	#4
Date	2/13/79	4/12/79	4/27/79	4/4/79
Time	11:00 am	8:45-9:30 pm		9:30 am
Weather Conditions			overcast	
Outdoor Temperature	16°F	43°F	43°F	38°F
Indoor Temperature	75°F	76°F	73°F	77°F
Wind Speed (MPH)	5-10	15-20	6	
Wind Direction	NW		N	



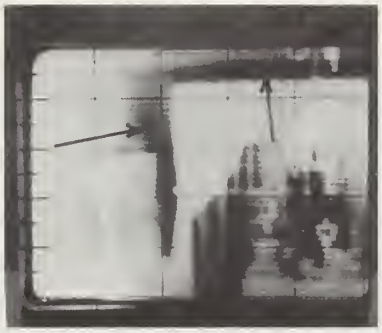
6-1
W side of kitchen
& N bedroom.
(exterior by NBS)

6-2
N side of kitchen
& N bedroom.
(exterior by NBS)

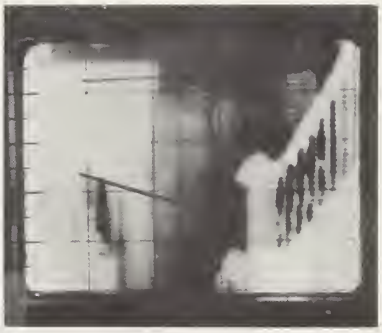


6-3
E side of family
room & bathroom.
(exterior by NBS)

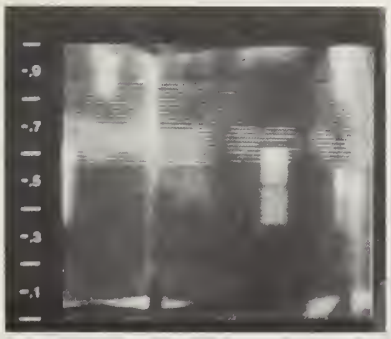
6-4
S wall of
living room.
(by NBS)



6-5
SW corner on W
of dining room.
(by contractor #2)

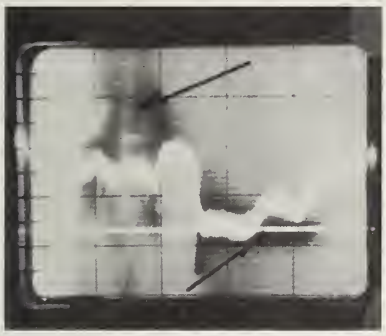


6-6
NW corner on W
of dining room.
(by contractor #2)

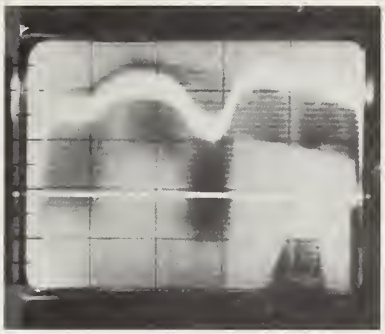


6-7
N side of
dining room.
(exterior by NBS)

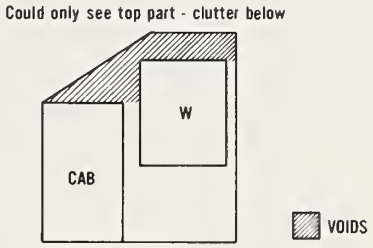
6-8
W pitched ceiling
of N bedroom.
(by contractor #4)



6-9
NE corner on E
of bathroom.
(by contractor #2)

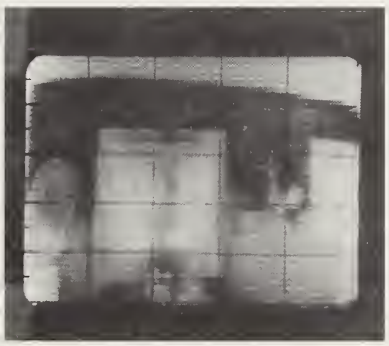


6-10
SE corner on E
of bathroom.
(by contractor #2)



6-11
S wall of
sewing room.
(by LRIS)

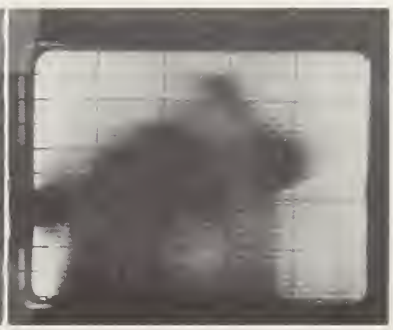
6-12
S side of sewing
room & S bedroom.
(exterior by NBS)



6-13
S wall of
S bedroom.
(by contractor #2)

6-14
W pitched ceiling
of S bedroom.
(by contractor #4)

6-15
W side of W
bedroom.
(exterior by NBS)



6-16
N pitched ceiling
of W bedroom.
(by contractor #2)

VII. Minneapolis-St. Paul House #3

This is a two-story, approximately 45 year old residence whose interior dimensions are 36 ft. in length, 24 ft. in width, and 8 ft. in wall height on each floor; located in Minneapolis-St. Paul, MN. There are 7 rooms of living space, with an attic and a basement. Its exterior construction contains wood frame with steel siding and an asphalt shingle roof.

Prior to the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the walls of this house with UF foam. After retrofitted foam was injected to the walls, this dwelling was inspected by NBS personnel and IR contractors #1, and #4. A sketch of the voids and the locations of heat loss obtained from thermograms and documents by NBS as well as those by the IR contractors, is shown in figures VIIa and VIIb.

The quality of the insulation job for this dwelling is questionable since there are about 15 whole bay cavities, 25 half bay cavities, and 17 one third bay cavities still without insulation in the house. The overall defects of this dwelling were found to be worse on the west and the north sides; with voids in the walls, and air penetration under the ceiling insulation. The east side was found to have missed insulation in about half of the walls on the second floor, with air penetration at the joint under the pitched ceiling. The first floor exhibited voids around windows and doors. The south side was shown to have one bay cavity and a few small voids on the second floor.

Thermographic inspection by NBS observed most of the known defects of this residence so that its results were used as a baseline for comparison purposes. In addition, NBS depicted the ceiling defects of the den/kitchen, showing some cold spots that may be damaged by moisture from condensation or a leaking roof.

Contractor #1 conducted a rather complete inspection of this house, missing only a few voids, while contractor #2 failed to observe several voids, as it produced only seven thermograms. The quality of these thermograms was quite poor and the area of scanning was often incomplete.

A detailed description of the defects observed by NBS as well as those by the IR contractors is summarized in table VIIa. Besides the total defective wall area in ft^2 found by each inspection, table VIIa also includes the defective wall areas in ft^2 of each room of the house, analyzed from available thermograms and sketches. The total estimates of void areas is approximately 310 ft^2, which represents about 20 percent of the gross wall area. Table VIIb presents the environmental conditions documented from each inspection. Thermograms/sketches 7-1 to 7-11 are some examples which demonstrate the locations of heat loss anomalies, as they are referred to in the descriptions in table VIIa.

Table VIIa. Summary of Defects Observed in Minneapolis-St. Paul House #3

Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #1	#4	Thermogram No. in Appendix
Living Room	S	Voids Above Window, Voids Above Door & in 1 Upper Bay Between Window and Door	10	Yes	Yes	Yes	
	W	Voids Above Window And in 1 Bay Cavity at NW of Window; Foam Shrinkage or Voids on Both Sides of Window	30	Yes	Yes	Yes	7-1 7-2
Dining Room	W	Partial Voids Above Window and in Bay Cavities at Both Sides of Window, Missing Insulation in the Upper Part of the Entire Wall	38	Yes	Yes	No	
	N	Partial Voids Above Window and in Bay Cavities on Both Sides of Window	35	Yes	Yes	No	
		Missing Insulation at the NW Side of Window		Yes	Yes	Yes	
Den & Kitchen	W	Air Penetration from Ceiling	5	Yes	No	No	7-4
		Foam Shrinkage or Voids in Upper Bays Partially		Yes	No	No	7-5
	N	Voids Above Window and in Upper Bay Cavity at NW Corner	13	Yes	No	No	7-6

Table VIIa. Summary of Defects Observed in Minneapolis-St. Paul House #3

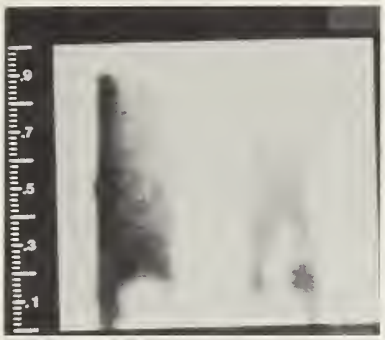
Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #1	#4	Thermogram No. in Appendix
		Air Penetration from Ceiling and Some Defects at Lower SW Corner of Window		Yes	Yes	Yes	
	E	Small Voids Above Door & Some Spots at Ceiling	5	Yes	Yes	No	
Ceiling Stairway	E	Defective Ceiling Some Voids Around Window & at Upper SE Corner on 1st Floor; Voids Also in Several Partial Bay Cavities on the 2nd Floor	26	Yes	No	No	7-7
				Yes	Yes	Yes	7-8
Southeast Bedroom	E	Voids Above Window, in 1 Lower Bay Cavity at NE Corner, & in the Upper Part of the Entire Wall at SE of Window	15	Yes	Yes	No	7-9
	S	Voids Above Window & in 1 Lower Bay Cavity of SE Corner	7	Yes	Yes	No	
Southwest Bedroom	S	Voids in Partial Bay Cavities at Upper SW Corner & at SE Side of Window	7	Yes	No	No	7-10
	W	Voids in 1 Bay Cavity at SW Corner	18	Yes	Yes	Yes	
		Voids in Upper Part of the Entire Wall		Yes	Yes	No	

Table VIIa. Summary of Defects Observed in Minneapolis-St. Paul House #3

Room & Orientation	Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #1	#4	Thermogram No. in Appendix
Northwest W Bedroom	Voids in 1 Bay Cavity at SW Side of Window and in the Upper Part of the Entire Wall	30	Yes	Yes	Yes	
N	Voids in 1 Bay Cavity at NW of Window & in the Upper Part of the Entire Wall	26	Yes	Yes	No	7-11
Bathroom N	Uninsulated Upper Part of the Entire Wall	20	Yes	Yes	No	
	Voids at Ceiling-Wall Joint with Air Penetration from the Ceiling		Yes	Yes	Yes	
E	Voids Above Window and in Several Upper Bay Cavities	25	Yes	Cool	No	
S	Voids Suspected in Partition Wall		Yes	No	No	
Total Wall Area of Insulation Voids Detected Given in ft^2		310	310	277	118	

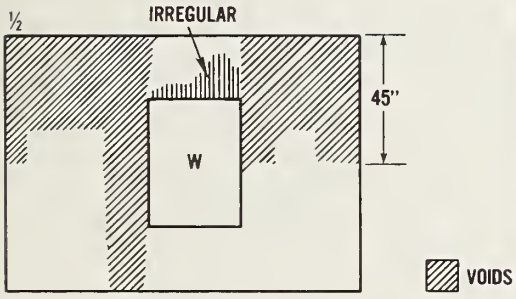
Table VIIb. Environmental Conditions During Inspection of Minneapolis-St. Paul House #3

	NBS	Contractors #1	#4
Date	2/14/79	4/11/79	4/4/79
Time	5:00 pm	7:30-8:45 pm	11:00 am
Outdoor Temperature	10°F	39°F	43°F
Indoor Temperature	75°F	75°F	78°F
Wind Speed(MPH)	5-10	30+	
Wind Direction	NW		



7-1
SW on W of
living room.
(by contractor #4)

7-2
NW on W of
living room.
(by contractor #4)



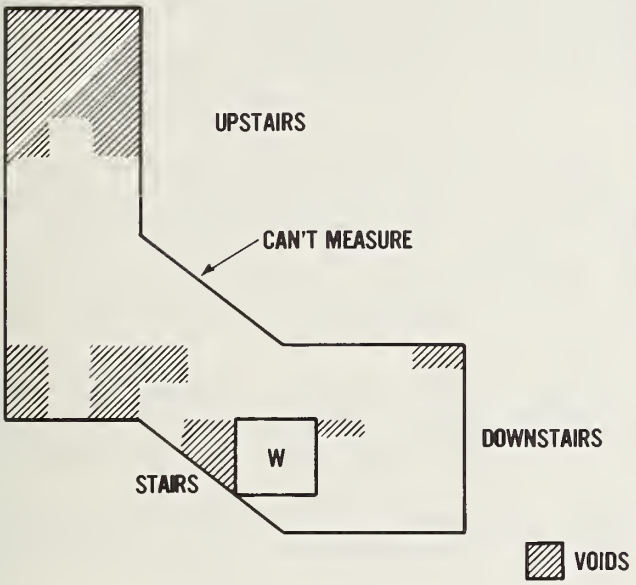
7-3
W wall of
dining room.
(by LRIS)

7-4
Ceiling on W of
den/kitchen.
(by NBS)

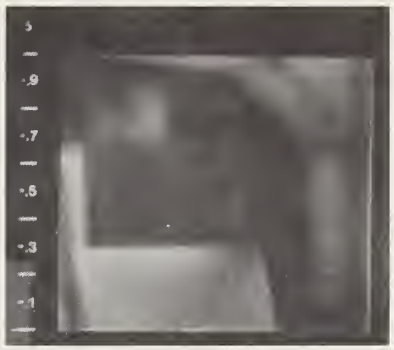
7-5
W wall of
den/kitchen.
(by NBS)

7-6
N wall of
den/kitchen
(by NBS)

7-7
Ceiling of
den/kitchen
(by NBS)

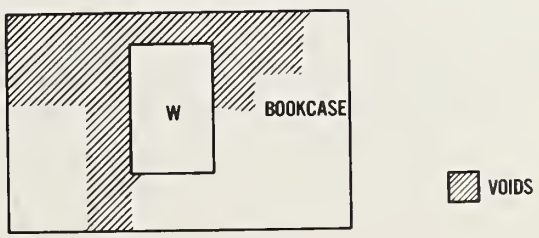


7-8
W wall of stairway.
(by LRIS)



7-9
E wall of
SE bedroom.
(by NBS)

7-10
SW corner of
SW bedroom.
(by NBS)



7-11
N wall of NW bedroom.
(by LRIS)

VIII. Minneapolis-St. Paul House #4

This is a two-story, approximately 50 year old residence whose interior dimensions are 42 ft. in length, 30 ft. in width, and 8 ft. in wall height on each floor; located in Minneapolis-St. Paul, MN. There are 7 rooms of living space, with an attic and a basement. Its exterior construction contains wood siding and an asphalt shingle roof.

Prior to the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the walls of this house with UF foam. After retrofitted foam was injected into the walls, this dwelling was inspected by NBS personnel and IR contractors #1, and #4. A sketch of the voids and the location of heat loss obtained from thermograms and documents by NBS, as well as those by the IR contractors, is shown in figures VIIIa and VIIIb.

In general, the insulation job for this dwelling was considered to be fairly good except for both the north side and the east wall of the northeast bedroom on the second floor, and the west wall of the living room on the first floor.

Thermographic inspection by NBS located most known defects of this residence so that its results were used as a baseline for comparison purposes.

Contractor #4 submitted only four thermograms of the living room and the north wall of the northeast bedroom. On the other hand, contractor #1 seemed to inspect every room of the house; but reported that many walls were satisfactory, and interpreted many low temperature regions as cool areas instead of defects. Therefore, the estimated number of voids from contractor #4's thermograms, and from contractor #1's sketches, were considered to be low.

A detailed description of the defects observed by NBS as well as those by the IR contractors, is summarized in table VIIIa. Beside the total defective wall area in ft^2 found by each inspection, table VIIIa also includes the defective wall areas in ft^2 of each room of the house, analyzed from available thermograms and sketches. The total estimates of void areas is approximately 75 ft^2, which represents about 4 percent of the gross wall area. Table VIIIb presents the environmental conditions documented from each inspection. Thermograms/sketches 8-1 to 8-8 are some examples which demonstrate the locations of heat loss anomalies, as they are referred to in the descriptions in table VIIIa.

Table VIIIa. Summary of Defects Observed in Minneapolis-St. Paul House #4

Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Observed by Contractors #1	Observed by Contractors #4	Thermograms No. in Appendix
Kitchen	W	Small Void at N of Window and Air Infiltration at NW Corner	3	Yes	No	Yes	
	N	Small Voids Above Window & Door, Also in Half Bay Cavity at NE Corner	5	Yes	No	No	
Dining Room	N	Small Void Below Window and at NW Upper Corner Air Infiltration Around Window & at NE Corner	5	Yes	No	No	
	E	Voids Above Window & Missing Insulation at Both Sides of Window	16	Yes	No	No	8-1 8-2
Living Room	E	Only Some Infiltration Underneath Window		Yes	No	Yes	
	S	Some Voids Above Door	8	Yes	Yes	Yes	
		Partial Voids Above Window & 1 Upper Bay at SE Corner		Yes	No	Yes	
	W	Voids Above Window and in Partial Bay Cavities at Both Sides of Window	8	Yes	Yes	No	8-3 8-4
Stairway (2nd Floor)	W	Voids Above Window and in 1 Partial Bay Cavity at S of Window	6	Yes	Yes	No	8-5 8-6
Northwest Bedroom	W	Small Void at NW Corner Under Ceiling; Air Penetration From Ceiling, and Above & Below Window	2	Yes	No	No	

Table VIIIa. Summary of Defects Observed in Minneapolis-St. Paul House #4

Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #1	#4	Thermograms No. in Appendix
	N	Small Voids at NW and NE Corners; Air Penetration From Ceiling	4	Yes	No	No	
Bathroom	N	Air Penetration at Top & Around Window		Yes	No	Yes	
Northeast Bedroom	N	Voids Above Window and Across the Top at E Side of Window with Shrinkage of Insulation or Fissure; Air Infiltration Around Window	10	Yes	Yes	Yes	8-7 8-8
	E	Voids Above Window and in Partial Bay Cavity at NE Corner	6	Yes	No	No	
South Bedroom	S	Voids in Partial Bay Cavity at SE Corner	2	Yes	No	No	
		Air Penetration at Floor & Above Window		Yes	No	Yes	
Total Wall Area of Insulation Voids Detected Given in ft^2			75	75	24	21	

Table VIIIb. Environmental Conditions During Inspection of Minneapolis-St. Paul House #4

	NBS	Contractors #1	#4
Date	2/13/79	4/12/79	4/4/79
Time	3:00 pm	7:30-8:15 pm	11:55 am
Outdoor Temperature	15°F	44°F	43°F
Indoor Temperature	75°F	74°F	75°F
Wind Speed(MPH)	5-10	20	
Wind Direction	W		

Thermal Anomalies Observed in Minneapolis-St. Paul House #4

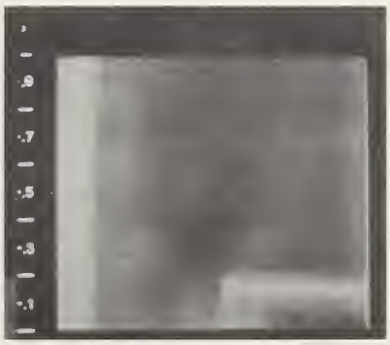
8-1
NE on E wall
of dining room.
(by NBS)

8-2
Above window on
E wall of dining room
(by NBS)

8-3
Above window &
at bottom of stairs
on W of living room.
(by NBS)

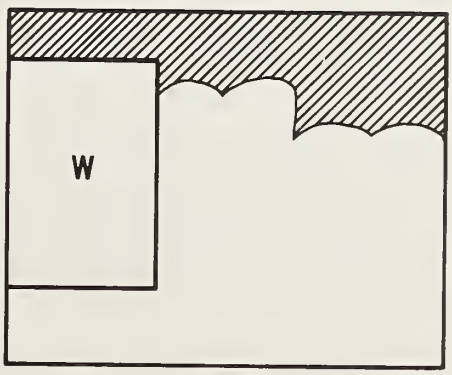
8-4
W wall & stairway
of living room.
(by NBS)

8-5
Below window on
W of stairway upstairs.
(by NBS)



8-6
Above window on
W of stairway
upstairs.
(by NBS)

8-7
NE corner on N
of NE bedroom.
(by contractor #4)



8-8
E wall of
NE bedroom.
(by LRIS)

IX. Portland House #1

This is a two-story, approximately 23 year old residence whose interior dimensions are 32 ft. in length, 25 ft. in width, and 7 ft. in wall height on each floor; located in Portland, ME. There are 8 rooms of living space with an attic and a basement. Its exterior construction contains wood frame siding and an asphalt shingle roof.

Prior to the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the walls and attic with cellulose, and install storm windows and storm doors. After retrofitted options were completed this dwelling was inspected by NBS personnel and IR contractors #5, and #6. A sketch of the voids and the locations of heat loss obtained from thermograms and documents by NBS, as well as those by the IR contractors, is shown in figures IXa and IXb.

In general, the most common heat loss areas in this house were found at at locations around most windows and above the windows upstairs. There are many ceiling areas with defects. At the bottom of the stairway, missed insulation was depicted at the upper right of the window and at the ceiling. Also the ceiling over the stairs, on the second floor showed an uneven temperature distribution at the surface, indicating defective insulation. Moreover, variable insulation at the pitched ceiling at the north side of the northeast bedroom is probably the result of the insulation not being installed at full density. The north wall of this room seemed to have air penetration as well.

Thermographic inspection by NBS observed most known defects of this residence so that its results were used as a baseline for comparison purposes.

Contractors #5 and #6 seemed to identify most of the defective areas of this dwelling, by submitting thermograms and/or statements.

A detailed description of the defects observed by NBS as well as those by the IR contractors, is summarized in table IXa. Besides the total defective wall area in ft^2 found by each inspection, table IXa also included the defective wall areas in ft^2 of each room of the house, analyzed from available thermograms and statements. The total estimates of void areas is approximately 106 ft^2, which represents about 8 percent of the gross wall area. Table IXb presents the environmental conditions documented from each inspection. Thermograms 9-1 to 9-13 are some examples which demonstrate the locations of heat loss anomalies, as they are referred to in the descriptions in table IXa.

Table IXa. Summary of Defects Observed in Portland House #1

Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #5	#6	Thermo-grams No. in Appendix
Kitchen	N	Small Void Above W Window; Air Leakage Under Windows	1	Yes	Yes	Yes	
	E	Small Void Between Door & Cabinet; Air Leakage Around Door & Below Cabinet	1	Yes	Yes	Yes	
Dining Romm	E	Voids Above Window, Around Window, & in 1 Partial Bay Cavity at NE Corner; Air Infiltration Under-Neath Window	14	Yes	Yes	Yes	9-1
	S	Air Infiltration at Both SE & SW Corners		Yes	Yes	Yes	
Front Entrance	S	Voids Under Light Switch at W of Door; Air Infiltration Around Door and at Both SE & SW Corners	4	Yes	Yes	No	9-2 9-3
Living Room	S	Cold Vertical Area Behind Picture,(May be Outside Crack) Air Infiltration on W of Window and at Both SE and SW Corners		Yes	Yes	No	9-4
	W	Voids in 1 Bay Cavity at SW Corner, 1 Bay Cavity at S of SW Window, Between SW & Center Windows, and Partially Center & NW Windows; Air Leakage From Ceiling	35	Yes	Yes	Yes	9-5 9-6

Table IXa. Summary of Defects Observed in Portland House #1

Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #5	#6	Thermo-grams No. in Appendix
	N	Small Voids at Top of NE Corner; Air Infiltration at E Side of Window	3	Yes	Yes	Yes	
Stairway (1st Floor)	N	Voids at Bottom of Stairs and Air Penetration from Ceiling	3	Yes	Yes	Yes	9-7
	E	Small Void in Partition Wall	1	Yes			
Stairway (2nd Floor)	N	Defective Ceiling Over Stairway		Yes	Yes	Yes	9-8
Northeast Bedroom	N	Defective Pitched Ceiling (May be Due to Shrinkage or Moisture Damage)		Yes	Yes	Yes	9-9
	E	Insulation Missing Below Window & Inside Closet; Air Leakage on S Side of Window	5	Yes	Yes	Yes	
Southeast Bedroom	E	Voids at SE Corner of Window; Air Penetration from Ceiling	5	Yes	Yes	Yes	
	S	Defective Sloped Ceiling	12	Yes	Yes	Yes	9-10
		Voids Above Windows, in 1 Partial Bay Cavity at E of Windows; Air Infiltration Below W Window at SE Corner		Yes	Yes	Yes	
Bathroom	S	Voids Above Window and in Upper Part of Wall	2	Yes	No	No	9-11

Table IXa. Summary of Defects Observed in Portland House #1

Room & Orientation	Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #5	#6	Thermo-grams No. in Appendix
Southwest S Bedroom	Voids Above Window	4	Yes	Yes	Yes	
	Voids at Both Upper SE and SW Corners		Yes	Yes	No	
W	Voids in Upper Wall at S of Window and Also in NW Corner	9	Yes	Yes	Yes	
Northwest W Bedroom	Small Voids at Both SW and NW Upper Corners	3	Yes	Yes	Yes	
N	Defective Sloped Ceiling at W Side of Window	4	Yes	Yes	Yes	9-12
	Voids Above Window and at West Side of Window		Yes	No	Yes	9-13
Total Wall Area of Insulation Voids Detected Given in ft^2		106	106	97	92	

Table IXb. Environmental Conditions During Inspection of Portland Hours #1

		Contractors	
	NBS	#5	#6
Date	3/15/79	4/10/79	4/12/79
Time	10:00 am	7:45-9:30 pm	9:00 pm
Outdoor Temperature	35°F	37°F	45°F
Indoor Temperature	68°F	67-68°F	
Wind Speed(MPH)	0-5	0-10	
Wind Direction	W		

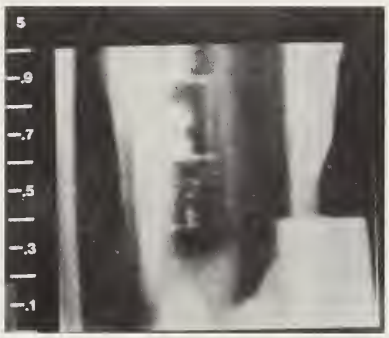
Thermal Anomalies Observed in Portland House #1

9-1
E wall of
dining room.
(by NBS)

9-2
SW corner of
S entrance.
(by NBS)

9-3
SE corner of
S entrance.
(by NBS)

9-4
SE corner on S
of living room.
(by contract #5)

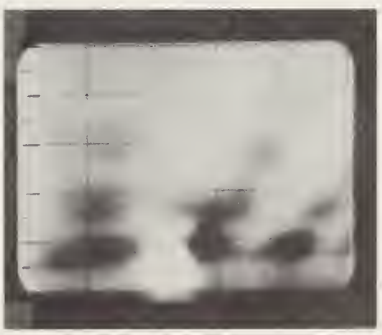


9-5
SW corner on W
of living room.
(by contractor #5)

9-6
W wall of
living room.
(by contractor #6)

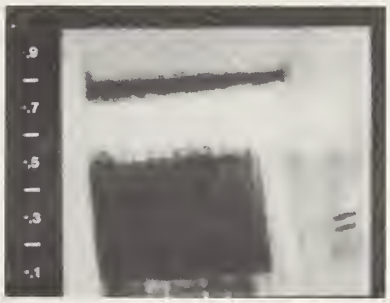
9-7
Bottom of stairway
on N of 1st floor.
(by contractor #5)

9-8
Over stairway
on N of 2nd floor.
(by NBS)



9-9
N pitched ceiling
of NE bedroom.
(by contractor #5)

9-10
S pitched ceiling
of SE bedroom.
(by contractor #5)



9-11
Above window
on S of bathroom.
(by NBS)

9-12
W pitched ceiling
of NW bedroom.
(by NBS)

9-13
Above and on
W side of window
of NW bedroom.
(by contractor #6)

X. Portland House #2

This is a two-story, approximately 80 year old residence whose interior dimensions are 24 ft. in length, 42 ft. in width, and 9 ft. in wall height on the first floor, and 8 ft. in wall height on the second floor; located in Portland, ME. There are 7 rooms of living space, with an attic and a basement. Its exterior construction contains wood siding and an asphalt shingle roof.

Prior to the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the walls and the attic with cellulose. After retrofitted options were completed this dwelling was inspected by NBS personnel and IR contractors #5, and #6. A sketch of the voids and the locations of heat loss obtained from thermograms and documents by NBS, as well as those by the IR contractors, is shown in figures Xa and Xb.

In general, the most common heat loss areas in this house were found at the ceilings. Very large uninsulated areas were found in pitched ceilings upstairs as well as in flat ceilings downstairs. Some of these uninsulated sloped ceilings extended to the walls underneath; e.g., the south wall of the east bedroom. Due to the fact that the exact dimensions of these walls were unknown and the thermograms only showed the part of these voids which extended from the ceiling, the estimated wall area of voids for this dwelling will only be an approximation.

Thermographic inspection by NBS identified most known defects in this residence so that its results were used as a baseline for comparison purposes.

Contractors #5 and #6 failed to inspect several areas to identify the defective locations.

A detailed description of the defects observed by NBS as well as those by the IR contractors, is summarized in table Xa. Besides the total defective wall area in ft^2 found by each inspection, table Xa also includes the defective wall areas in ft^2 of each room of the house, analyzed from available thermograms. The total estimates of void areas, without taking into account void areas of any ceilings, is approximately 97 ft^2, which represents about 5 percent of the gross wall area. Table Xb presents the enviremental conditions documented from each inspection. Thermograms 10-1 to 10-10 are some examples which demonstrate the locations of heat loss anomalies, as they are referred to in the description in table Xa.

Table Xa. Summary of Defects Observed in Portland House #2

Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #5	#6	Thermo-grams No. in Appendix
Kitchen & Laundry Room	E	Missing Insulation at Top: on N of Door	1	Yes	Yes	Yes	10-1
		On S of Door		Yes	Yes	No	
	S	Missing Insulation at Top: On E of Window	5	Yes	No	Yes	10-2
		On W of Window		Yes	Yes	Yes	
		Air Leakage at SE Corner		Yes	Yes	Yes	
	W	Small Void at Top of NW Corner; Air Penetration From Ceiling	1	Yes	Yes	Yes	
Bathroom	W	Air Infiltration at Top & NW Corner		Yes	No	No	
	N	Small Void at E Side of Window; Air Penetration From Ceiling	3	Yes	No	No	
Dining Room	N	Air Penetration from Ceiling	7	Yes	No	Yes	10-3
		Small Void at E Side of Window		Yes	No	Yes	
	S	Small Void at Top of SW Corner of Window	1	Yes	No	No	10-4

Table Xa. Summary of Defects Observed in Portland House #2

Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #5	#6	Thermograms No. in Appendix
Living Room	E	Small Void at Top of SE Corner of Window	1	Yes	Yes	Yes	10-5
		Air Penetration from Ceiling & Infiltration Around Window & Door, and at NE & SE Corners		Yes	Yes	Yes	
Stairway (1st Floor)	N	Missing Insulation Around Light Switch Area		Yes	Yes	Yes	10-6
Hallway (2nd Floor)	W	Missing Insulation in 4 Upper Bay Cavities	14	Yes	Yes	Partial	10-7
	N	Missing Insulation at Top of Window	4	Yes	Yes	Yes	10-8
		Air Penetration from Ceiling		Yes	Yes	Yes	
East Bedroom	N	Uninsulated Pitched Ceiling		Yes	Yes	Yes	
	E	Voids Above Window; Voids Under & at N Side of Window	12	Yes	Yes	Yes	
		Defective Pitched Ceiling		Yes	Yes	No	
	S	Uninsulated Pitched Ceiling	38	Yes	No	Yes	10-9
		Uninsulated Entire Wall Area		Yes	No	Yes	10-10
West Bedroom	S	Uninsulated Sloped Ceiling	6	Yes	Yes	Yes	10-11
		Some Shrinkage of Insulation in Wall		Yes	No	No	

Table Xa. Summary of Defects Observed in Portland House #2

Room & Orientation	Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #5	#6	Thermo-grams No. in Appendix
W	Same Void at Top of NW Corner	4	Yes	Yes	Yes	
	Defective Pitched Ceiling		Yes	Yes	Yes	
N	Uninsulated Pitched Ceiling		Yes	Yes	Yes	
Total Wall Area of Insulation Voids Detected Given in ft^2		97	97	43	67	

Table Xb. Environmental Conditions During Inspection of Portland House #2

	NBS	Contractor #5	#6
Date	3/15/79	4/10/79	4/12/79
Time	1:00 pm	6:15-7:30 pm	7:00 pm
Outdoor Temperature	38°F	40°F	45°F
Indoor Temperature	73°F	70°-75°F	
Wind Speed(MPH)	0-5	5	
Wind Direction	W		

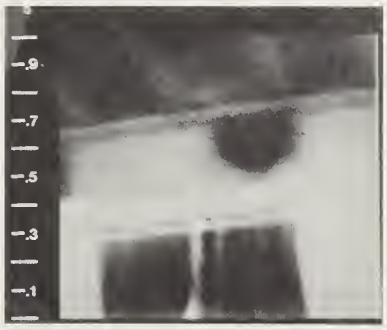
THERMAL ANOMALIES OBSERVED IN PORTLAND HOUSE #2

10-1
Above door on E of kitchen. (by contractor #5)

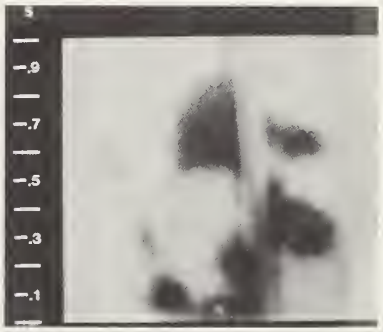
10-2
SE corner of kitchen (by NBS)

10-3
Ceiling on N side dining room. (by contractor #6)

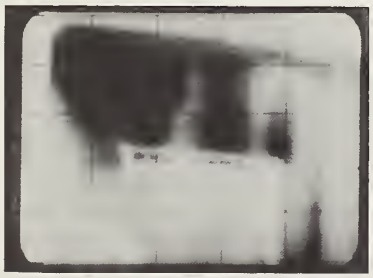
10-4
Above window on S of dining room. (by NBS)



10-5
Above window on E of living room. (by contractor #6)



10-6
Around light switch on N wall of stairway on 1st floor (by contractor #6)



10-7
W wall of hallway on 2nd floor. (by contractor #5)

10-8
N wall of hallway on 2nd floor. (by contractor #5)

10-9
S pitched ceiling of E bedroom (by NBS)

10-10
S side of W bedroom. (by NBS)

XI. Portland House #3

This is a one-story, approximately 40 year old residence whose interior dimensions are 30 ft. in length, 33 ft. in width, and 8 ft. in wall height; located in Portland, ME. There are 6 rooms of living space, with an attic and a basement. Its exterior construction contains wood frame siding and an asphalt shingle roof.

Prior to the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the walls and the attic with cellulose. After retrofitted options were completed, this dwelling was inspected by IR contractors #5, #6, and the local staff of CSA, as representatives for NBS. A sketch of the voids and the locations of heat loss obtained from thermograms and documents by NBS, as well as those by the IR contractors, is shown in figure XIa.

Generally speaking, the quality of insulation work in this dwelling was relatively poor, as the house was observed to have more than ten bay cavity voids, voids above most windows, air infiltration, and air penetration.

Thermographic inspection by local staff of CSA to represent NBS did not cover all of the rooms of this residence. Comparison of area of defects should rely only on thermograms submitted by contractors. Results from NBS can only be considered as supporting documents, as it failed to inspect the kitchen, the bathroom, the east side of the living room, and the east side of the northeast bedroom. Hence, the discrepency in estimated void areas between NBS and contractors (or the combined areas) can be expected.

Contractors #5 and #6 failed to recognize some defective areas as well.

A detailed description of the defects observed by NBS as well as those by the IR contractors, is summarized in table XIa. Besides the total defective wall area in ft^2 found by each inspection, table XIa also includes the defective wall areas in ft^2 of each room of the house, analyzed from available thermograms. The total estimates of void areas is approximately 165 ft^2, which represents about 20 percent of the gross wall area. Table XIb presents the environmental conditions documented from each inspection. Thermograms 11-1 to 11-16 are some examples which demonstrate the locations of heat anomalies, as they are referred to in the descriptions in table XIa.

Table XIa. Summary of Defects Observed in Portland House #3

Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #5	#6	Thermo-grams No. in Appendix
Living Room	E	Missing Insulation:		(Partial)			
		Above & Around Door;	31	Yes	Yes	Yes	11-1
		Above Window		Yes	Yes	Yes	11-2
		in 1 Bay Cavity at S of Window		Yes	No	Yes	11-3
	S	Voids Above E Window and in 1 Bay Cavity at W Side of E Window; Air Penetration from Fireplace Chimney	16	Yes	Yes	Yes	11-4
		Voids Above W Window		Yes	No	No	
	Ceiling	Defective Ceiling, May be Due to Moisture Damage		No	Yes	No	11-5
Dining Room	S	Missing Insulation: Above Window	26	Yes	Yes	No	
		Below Window & Bay Cavities at SE and SW Corner		Yes	Yes	Yes	11-6 11-7
Kitchen	S	Voids Above Door & Air Leakage Above & Underneath Door	2	No	Yes	Yes	11-8 11-9
	W	Voids Above Window and in 2 Partial Bay Cavities at N & S of Window	12	No	Yes	Yes	
Northwest Bedroom	W	Voids Above, Below, and in Partial Bay Cavities at N & S of Window	23	Yes	Yes	No	11-10
		Missing Insulation Inside Closet		Yes	Yes	Yes	11-11

Table XIa. Summary of Defects Observed in Portland House #3

Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #5	#6	Thermo-grams No. in Appendix
	N	Voids Above Window Voids in 1 Bay Cavity	13	Yes	Yes	Yes	11-12
		Between Window and Closet		Yes	No	Yes	
Bathroom	N	Voids Above Window	15	Yes	Yes	Yes	
		Voids in 1 Bay Cavity in Tub Area		No	Yes	Yes	11-13
		Voids in Lower SW Corner of Window; Air Infiltration at NW Corner		No	Yes	Yes	11-14
Northeast Bedroom	N	Voids Above Window & in 2 Bay Cavities at Both E & W Sides of Window; Air Infiltration at NW Corner	23	Yes	Yes	Yes	11-15 11-16
	E	Voids Above Window	3	No	No	Yes	
Total Wall Area of Insulation Voids Detected Given in ft^2			- 164	135	144	154	

Table XIb. Environmental Conditions During Inspection of Portland House #3

	NBS	Contractors #5	#6
Date	3/16/79	4/9/79	4/11/79
Time	2:00 pm	7:00-8:15 pm	7:30 pm
Outdoor Temperature	25°F	36°F	40°F
Indoor Temperature	68°F	68°F	
Wind Speed(MPH)	0-5	5	
Wind Direction	NW		

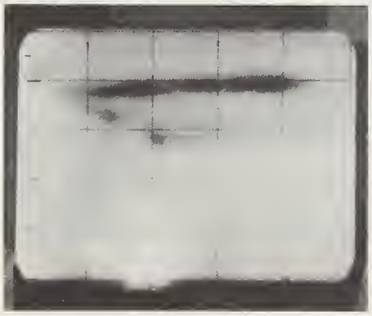
Thermal Anomalies Observed in Portland House #3

11-1
At top & both
sides of E door
in living room.
(by NBS)

11-2
Above window on
E of living room.
(by contractor #6)

11-3
SE corner on E
of living room.
(by contractor #6)

11-4
S wall of
living room.
(by NBS)

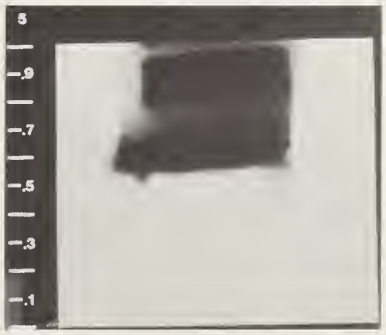


11-5
Ceiling of
living room.
(by contractor #5)

11-6
SE corner on S
of dining room.
(by NBS)

11-7
SW corner on
S of dining room.
(by NBS)

11-8
Above S door
in kitchen.
(by contractor #6)



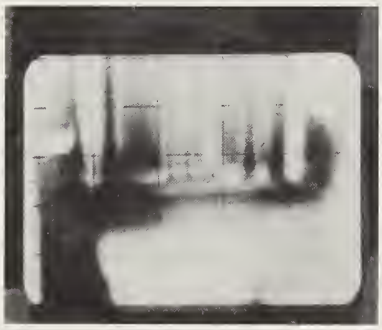
11-9
Underneath S
door in kitchen.
(by contractor #6)

11-10
Around window on
W of NW bedroom.
(by contractor #5)

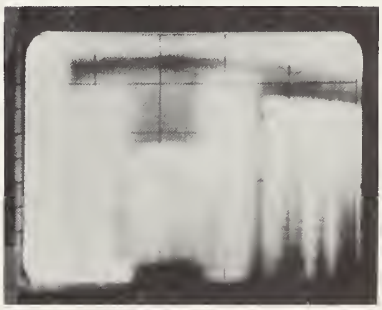
11-11
Inside closet on
W of NW bedroom.
(by contractor #5)

11-12
N wall of
NW bedroom.
(by NBS)

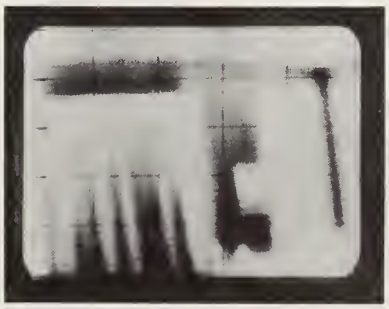
11-13
Tub area on N
of bathroom.
(by contractor #5)



11-14
NW corner on
N of bathroom.
(by contractor #5)



11-15
NW corner on N of
NE bedroom.
(by contractor #5)



11-16
NE corner on N
of NE bedroom.
(by contractor #5)

XII. Portland House #4

This is a two-story, approximately 100 year old, L-shaped residence whose interior dimensions are 43 ft. in length, 31 ft. in width, and 8 ft. in wall height on the first floor, and 7 ft. in wall height on the second floor; located in Portland, ME. There are 8 rooms of living space with an attic and a basement. Its exterior construction contains wood frame siding and an asphalt shingle roof.

Prior to the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the walls and the attic with cellulose, and to install storm doors. After retrofitted options were completed this dwelling was inspected by NBS personnel and IR contractors #5, and #6. A sketch of the voids and the locations of heat loss obtained from thermograms and documents by NBS, as well as those by the IR contractors, is shown in figures XIIa and XIIb.

Among three independent inspections, this dwelling seemed to be covered quite thoroughly. Insulation on the first floor is considered to be adequate except for the northeast corner and the southwest of the kitchen's west wall. Infiltration was found around most of the windows and door. Air leakage existed at most wall-to-wall and wall-to-ceiling joints. At the time of thermographic inspections, the second floor was unoccupied and its interior temperature was very low. This condition made it difficult to collect meaningful data especially in the room above the kitchen. Consequently, the entire kitchen ceiling was found to be very cold. On the second floor, the most common area of voids found by both contractors and NBS is above the windows and below the pitched ceiling.

This residence was inspected thoroughly by both contractors and NBS, except for a few areas that were missed by each group. The discrepency in estimating defective areas between contractor #5 and the others, was the east wall at the northeast corner of the northeast sitting room downstairs, where contractor #5 did not inspect. According to the report from contractor #6, due to sunshine throughout the day and the overheated radiator in the room, the room temperature was so high that the upper portion of the thermogram was obscured. Even though the upper wall portion of the northeast corner appeared to be warm, the studs were warmer than the bay areas. Hence it suggested that all bays around this corner were completely uninsulated. Nevertheless, inspection by NBS supported contractor #6's statement of an overheated radiator as it exhibited the identical phenomena of the studs being warmer than the bays. However, contractor #5 only observed the north side of this corner, without inspecting the east side; and, as a result, the defective wall area was estimated to be much less than the findings of contractor #6 and NBS.

Another area that demonstrated the same phenomena of the studs being warmer than the bay areas was the south side of the kitchen. This finding might be due to the sun loading on the south side of the house, which did not imply uninsulated bays. Some thermograms from NBS' inspection indicated a cold ceiling in this room, which was caused by the unheated room upstairs.

A detailed description of the defects observed by NBS as well as those by the IR contractors, is summarized in table XIIa. Besides the total defective wall area in ft^2 found by each inspection, table XIIa also includes the defective wall areas in ft^2 of each room of the house, analyzed from available thermograms and statements. The total estimates of void areas is approximately 119 ft^2, which represents about 7 percent of the gross wall area. Table XIIb presents environmental conditions documented from each inspection. Thermograms 12-1 to 12-11 are some examples which demonstrate the locations of heat loss anomalies, as they are referred to in the descriptions in table XIIa.

Table XIIa. Summary of Defects Observed in Portland House #4

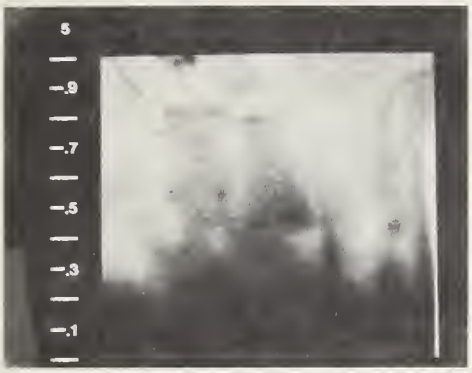
Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #5	#6	Thermograms No. in Appendix
Front Entrance	N	Small Void in Upper NW Corner; Air Leakage Under and Around Door	1	Yes	Yes	Yes	
Northeast Sitting Room (1st Floor)	N	Missing Insulation in a Lot of Bay Cavities, E of Window; 1 Partial Bay Cavity at W of Window	28	Yes	Yes	Yes	12-1
	E	Missing Insulation in 3 Bay Cavities at NE Corner; Air Infiltration Around Windows	30	Yes	No	Yes	
Kitchen	E	Small Voids Above Window	1	Yes	No	Yes	12-2
		Cold Ceiling Indicating Unheated Room Upstairs		Yes	No	Yes	12-3
	S	Cold Ceiling; Effect of Sun Loading to Show Warmer Studs in Uninsulated Wall		Yes	No	Yes	12-4
	W	Missing Insulation in 1 Bay Cavity at SE	23	Yes	No	Yes	
		Voids Behind Cabinet and in 1 Lower Bay Cavity Air Penetration from Lower NW Corner		Yes	Yes	Yes	
Northwest Bedroom (1st Floor)	W	Small Voids Above Window and at Upper NW Corner Air Infiltration at Both NW and SW Corners	6	Yes	Yes	Yes	

Table XIIa. Summary of Defects Observed in Portland House #4

Room & Orientation		Description of Defects	Defective Wall Area in ft^2	Observed by NBS	Contractors #5	#6	Thermo-grams No. in Appendix
	N	Small Void Above Window; Air Infiltration at Both NE and NW Corners	1	Yes	No	No	
Northeast Bedroom (2nd Floor)	N	Air Infiltration and Penetration		Yes	Yes	No	
	E	Small Void at S Side of Window; Air Infiltration at SE and NE Corners	3	Yes	Yes	No	12-5
	S	Small Void at SW Corner	4	Yes	No	No	12-6
SothH Bedroom (2nd Floor)	E	Voids Above Window and in Some Partial Bay Cavities; Air Leakage from Ceiling	15	No	Yes	Yes	12-7 12-8 12-9
	W	Air Penetration from Ceiling		Yes	Yes	No	
Bathroom (2nd Floor)	W	Voids Below Pitched Ceiling and at NW Corner	4	Yes	No	Yes	12-10
Northwest Bedroom (2nd Floor)	N	Small Void at NE Corner Under Pitched Ceiling	3	Yes	Yes	Yes	12-11
	S	Cold Pitched Ceiling		Yes	Yes	No	
Total Wall Area of Insulation Voids Detected Given in ft^2			119	105	68	110	

Table XIIb. Environmental Conditions During Inspection of Portland House #4

	NBS	Contractors #5	#6
Date	3/17/79	4/9/79	4/11/79
Time	3:00 pm	8:45-10:15 pm	9:00 pm
Outdoor Temperature	35°F		40°F
Indoor Temperature	69°F	69°F	
Wind Speed(MPH)	0-5	5	
Wind Direction	NW		
Weather Condition			sunshine throughout the day
Indoor Condition			over-heated radiation at NE sitting room



12-1
NE corner of
sitting room.
(by contractor #6)

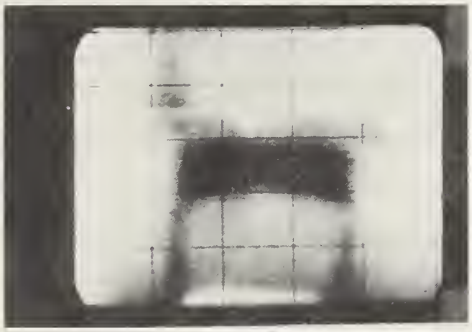
12-2
E wall of
kitchen.
(by NBS)

12-3
Cold ceiling on E
of kitchen.
(by NBS)

12-4
S wall of
kitchen.
(by contractor #6)

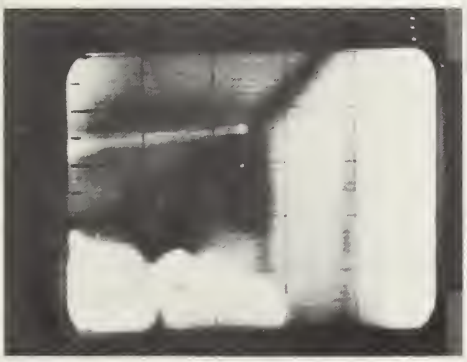
12-5
E wall of
NE bedroom.
(by contractor #5)

12-6
S wall of
NE bedroom.
(by NBS)

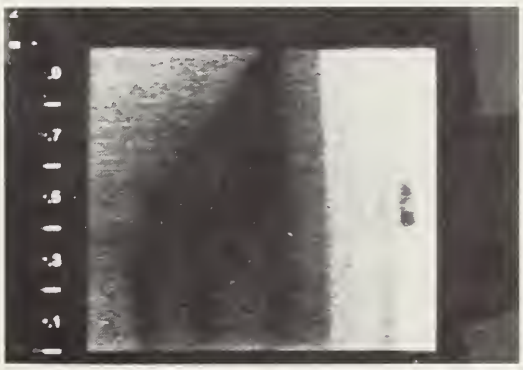


12-7
Above window on
E of S bedroom.
(by contractor #5)

12-8
Below pitched
ceiling on E of
S bedroom.
(by contractor #5)



12-9
SE corner of
S bedroom.
(by contractor #5)



12-10
W wall of bathroom.
on 2nd floor.
(by NBS)

12-11
NE corner of NW
bedroom on 2nd floor.
(by NBS)

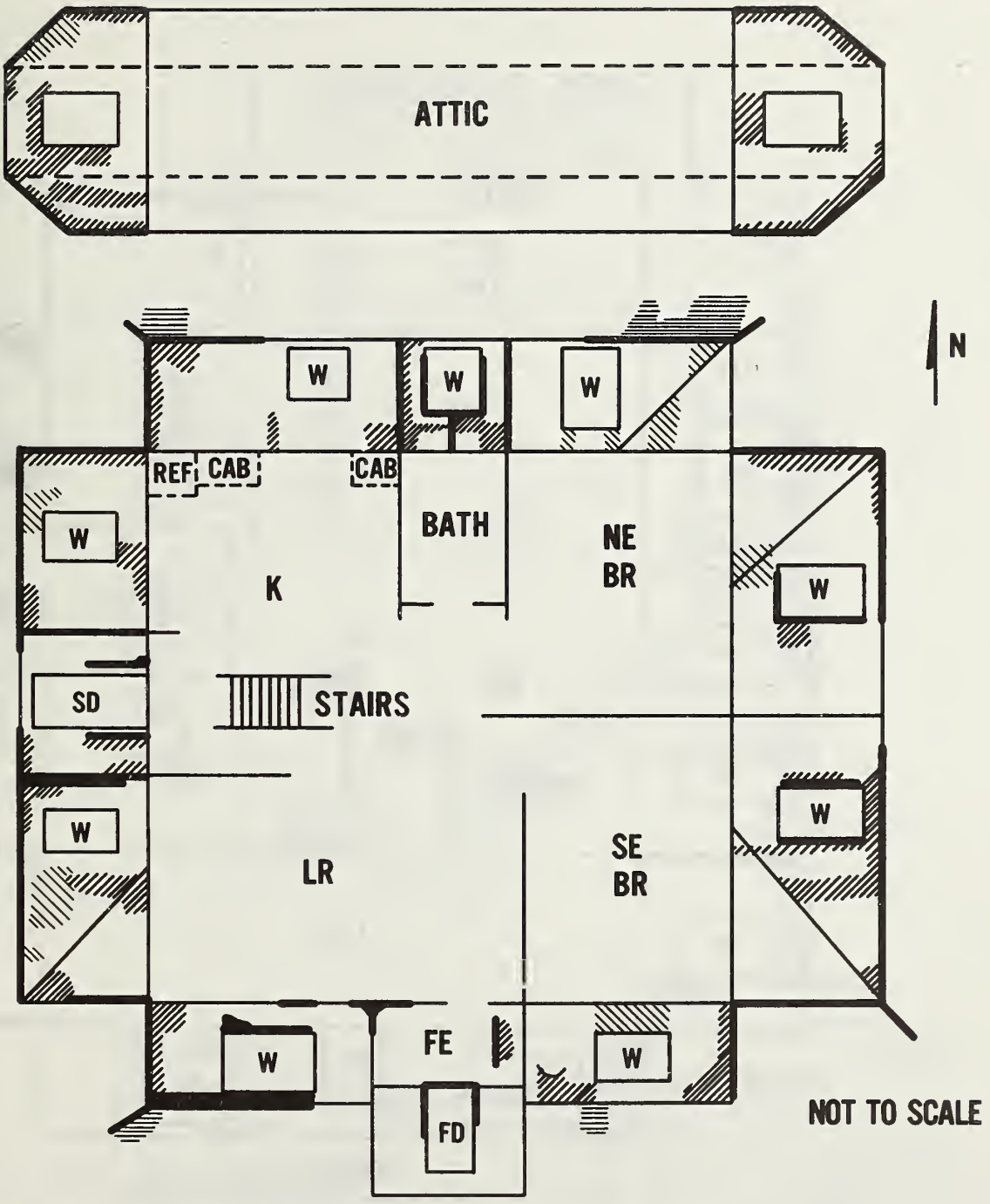


Figure I. Thermal deficiencies observed in Fargo house #1

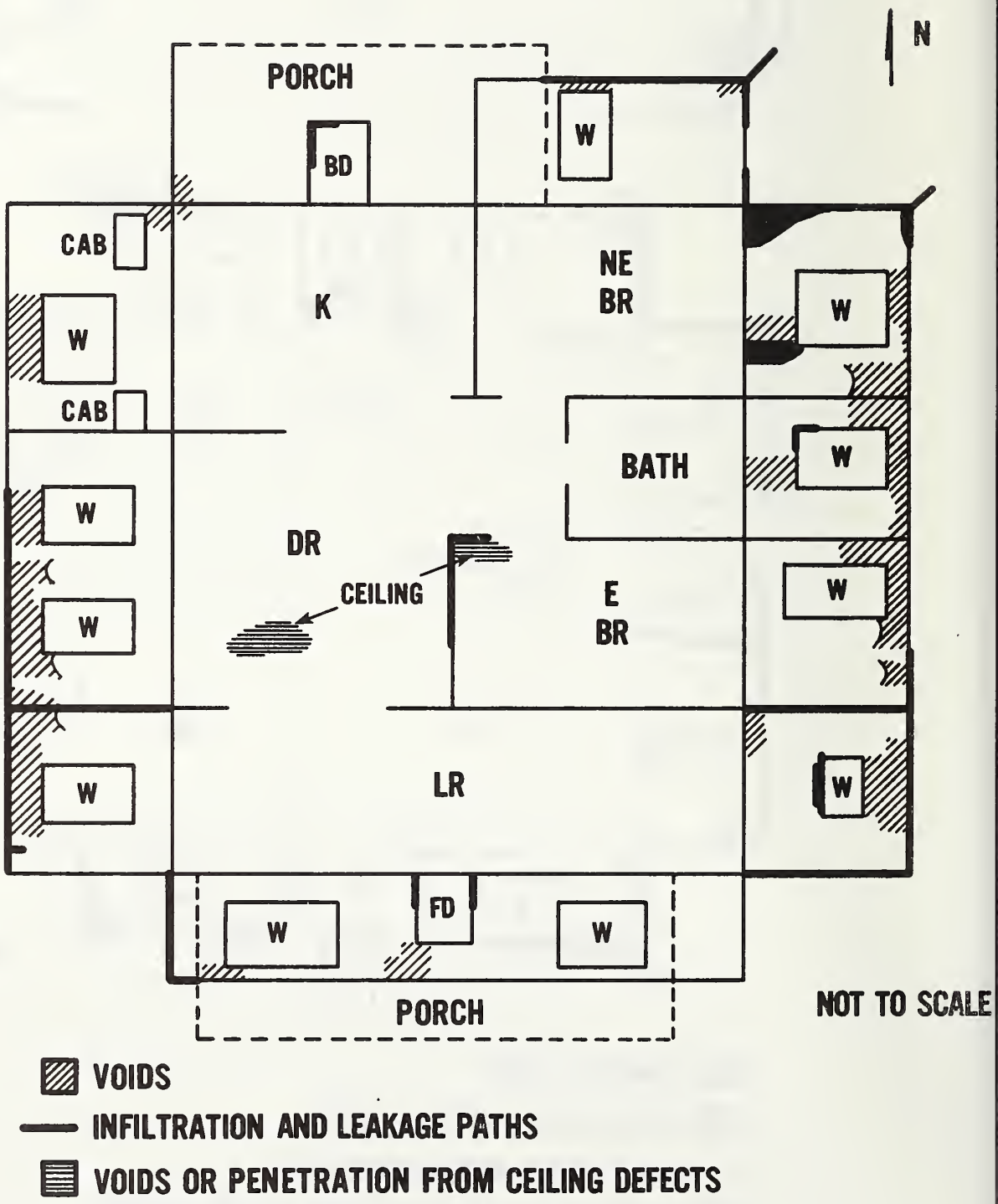


Figure II. Thermal deficiencies observed in Fargo house #2

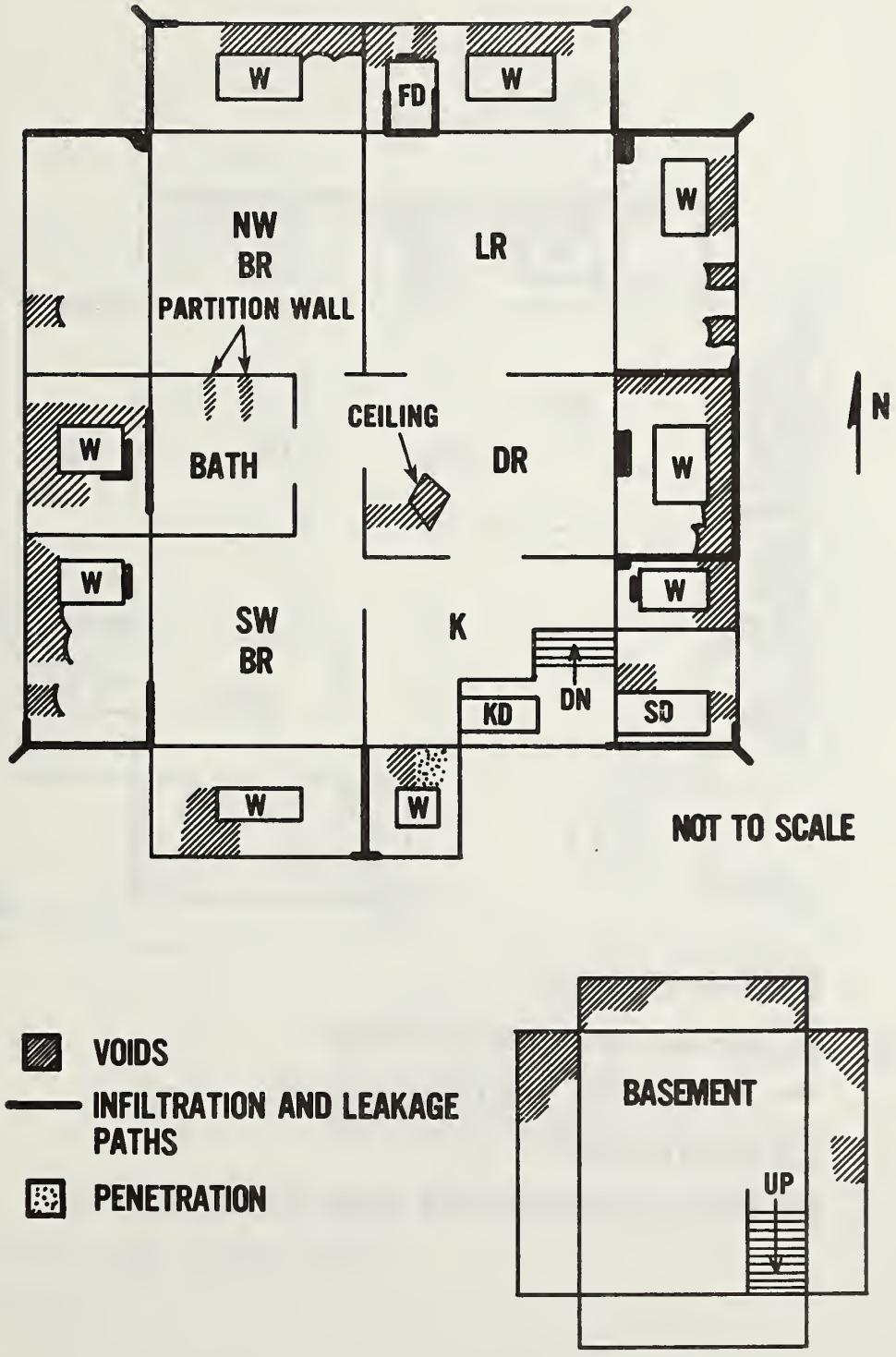


Figure III. Thermal deficiencies observed in Fargo house #3

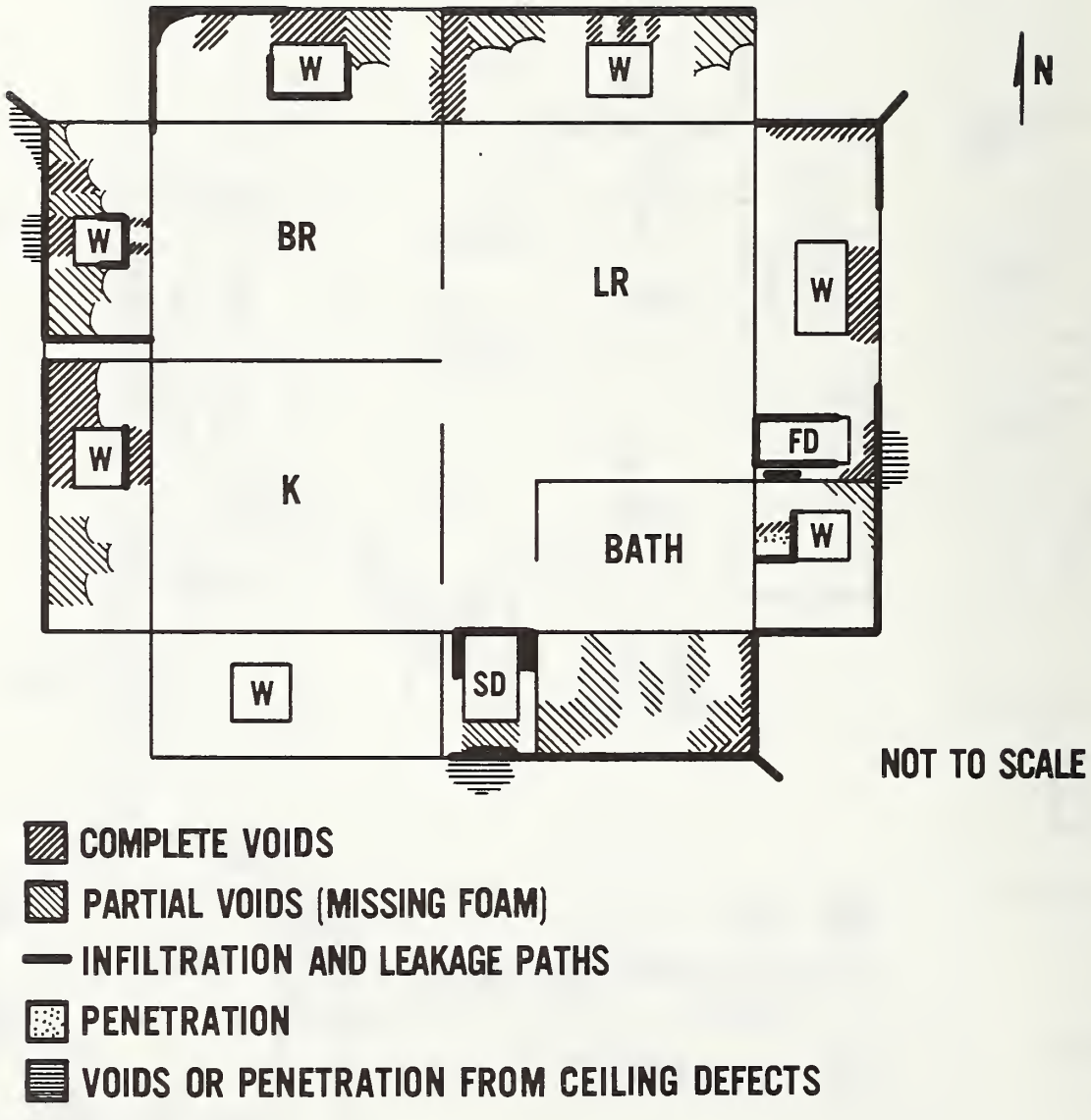


Figure IV. Thermal deficiencies observed in Fargo house #4

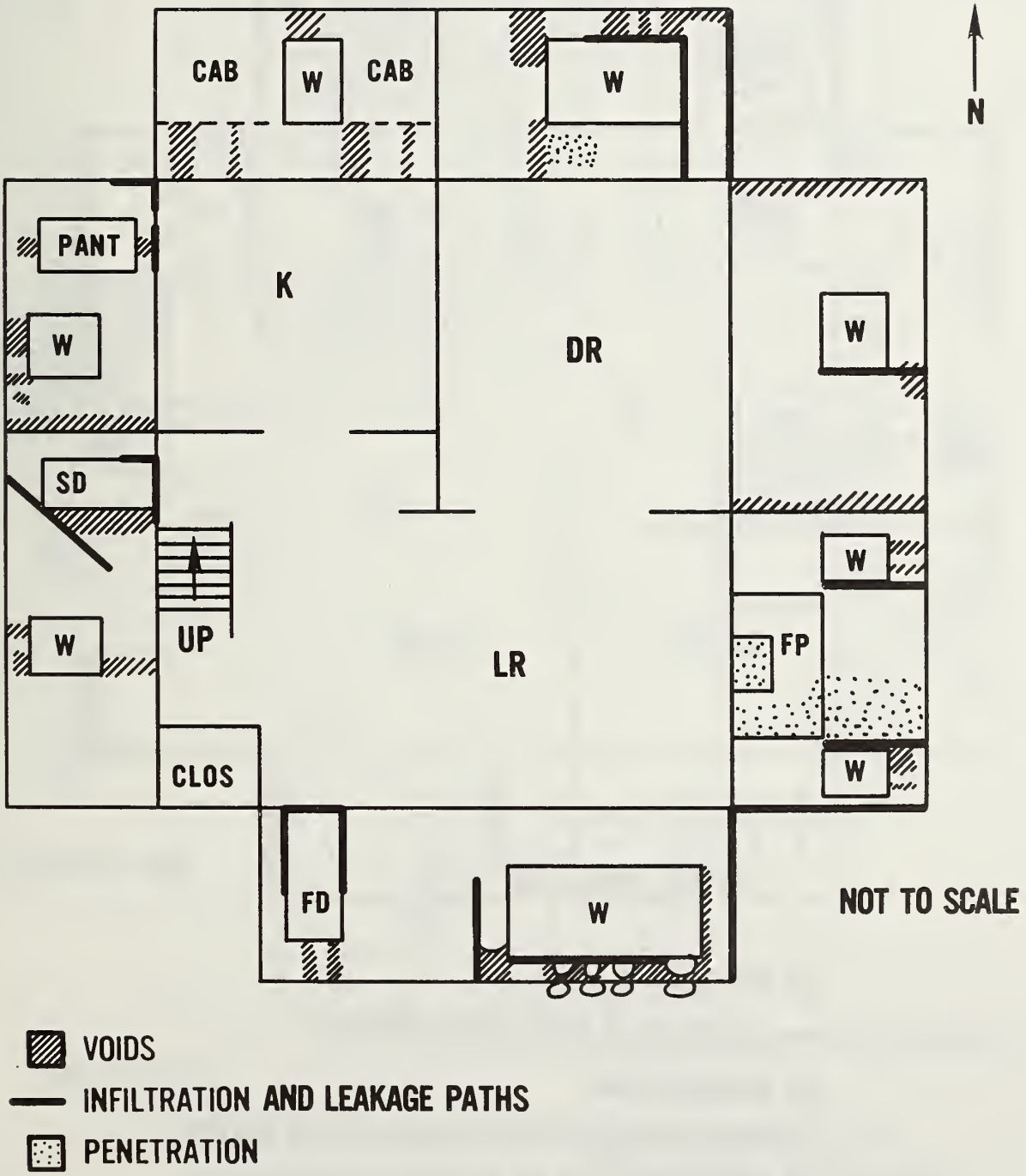


Figure Va. Thermal deficiencies observed on the first floor in Minneapolis-St. Paul house #1

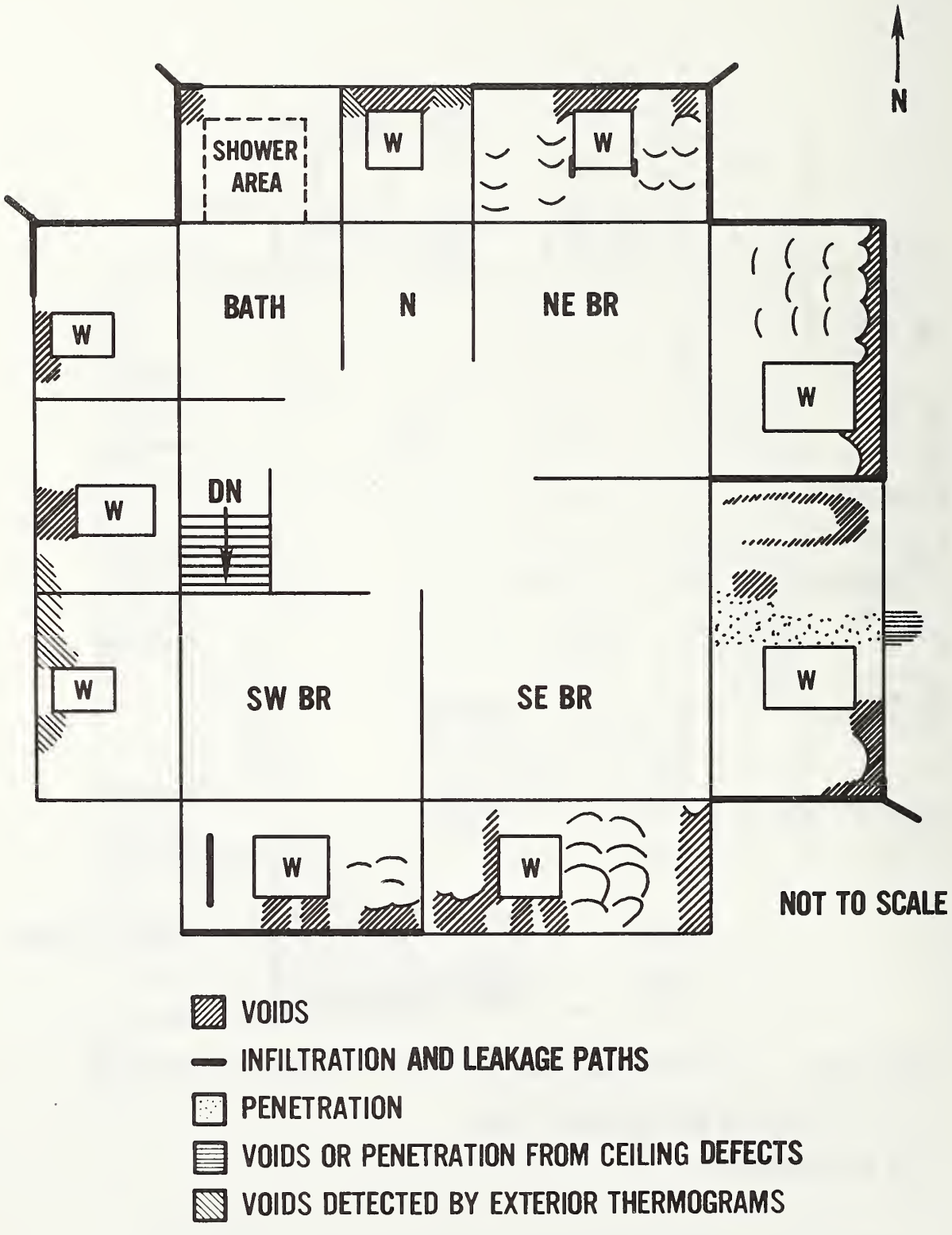


Figure Vb. Thermal deficiencies observed on the second floor in Minneapolis-St. Paul house #1

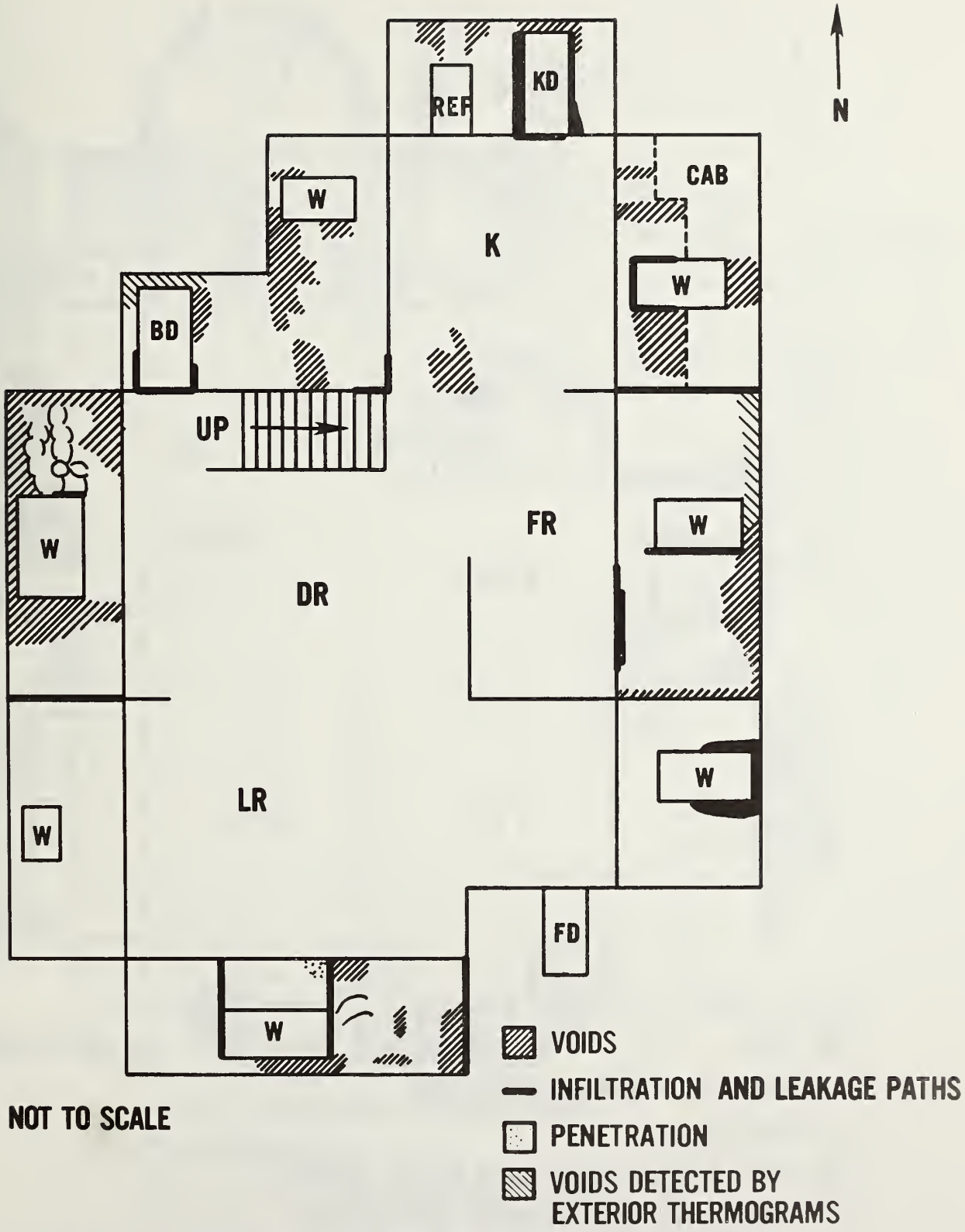


Figure VIa. Thermal deficiencies observed on the first floor in Minneapolis-St. Paul house #2

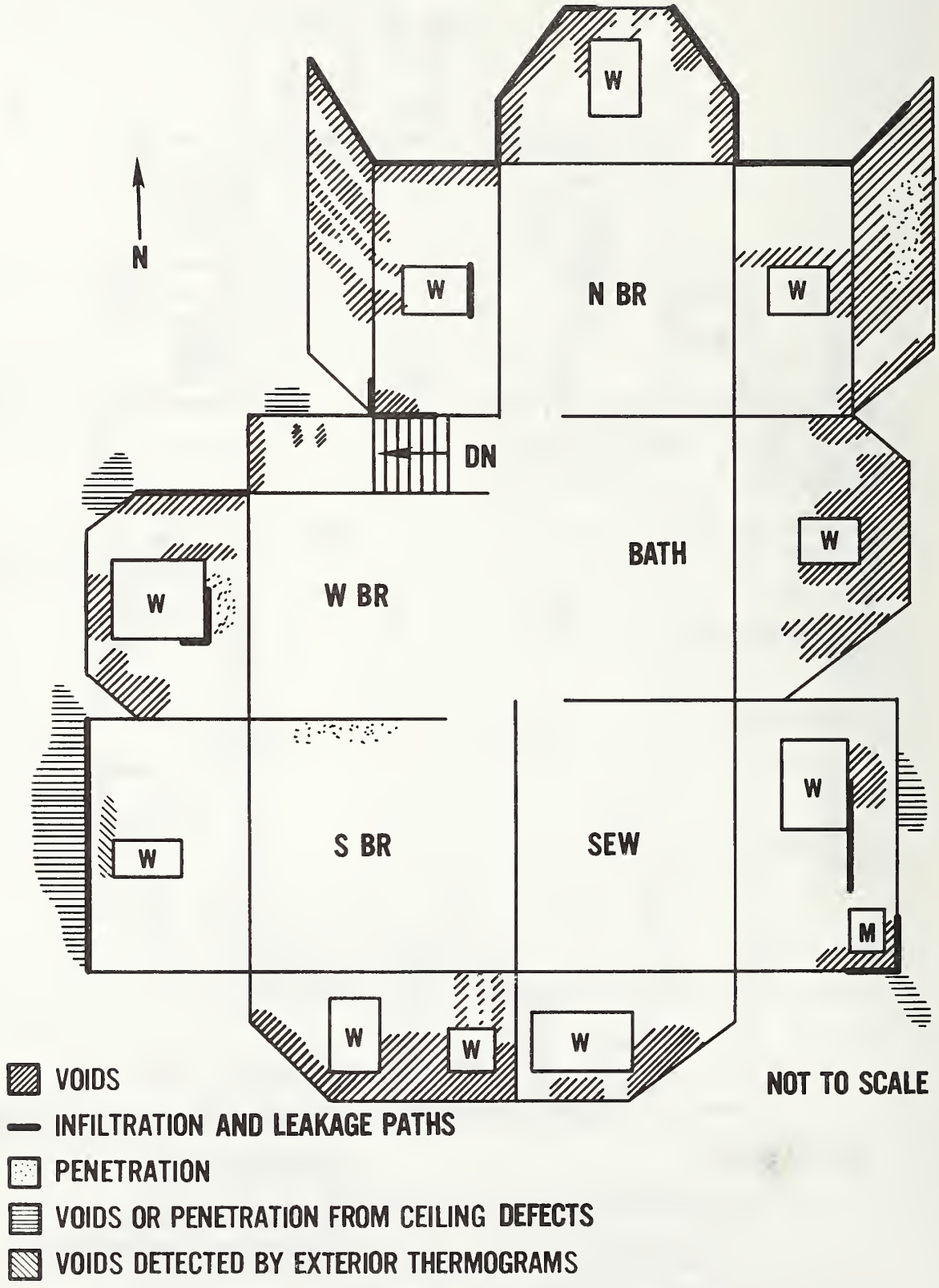


Figure VIb. Thermal deficiencies observed on the second floor in Minneapolis-St Paul house #2

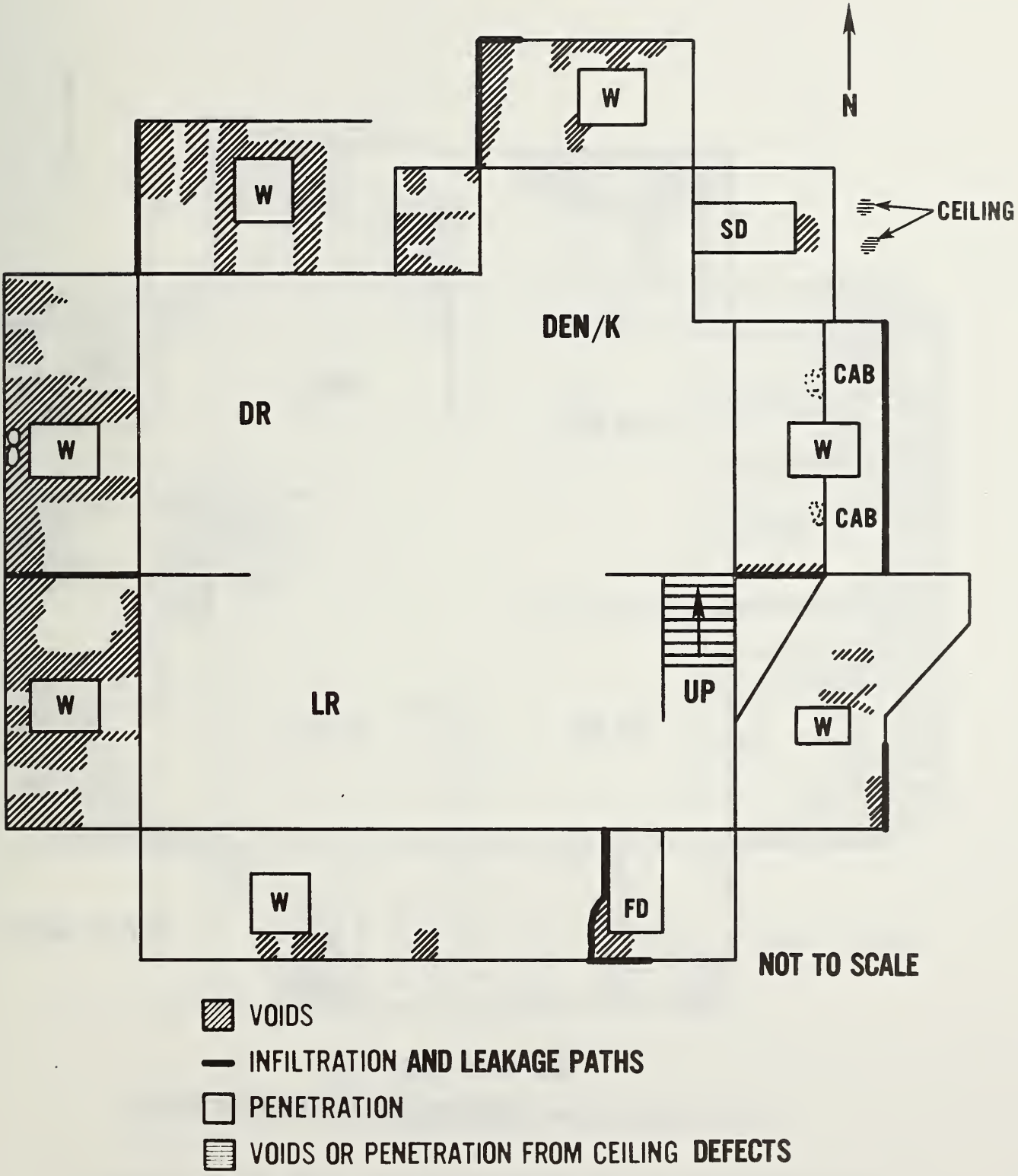


Figure VIIa. Thermal deficiencies observed on the first floor in Minneapolis-St. Paul house #3

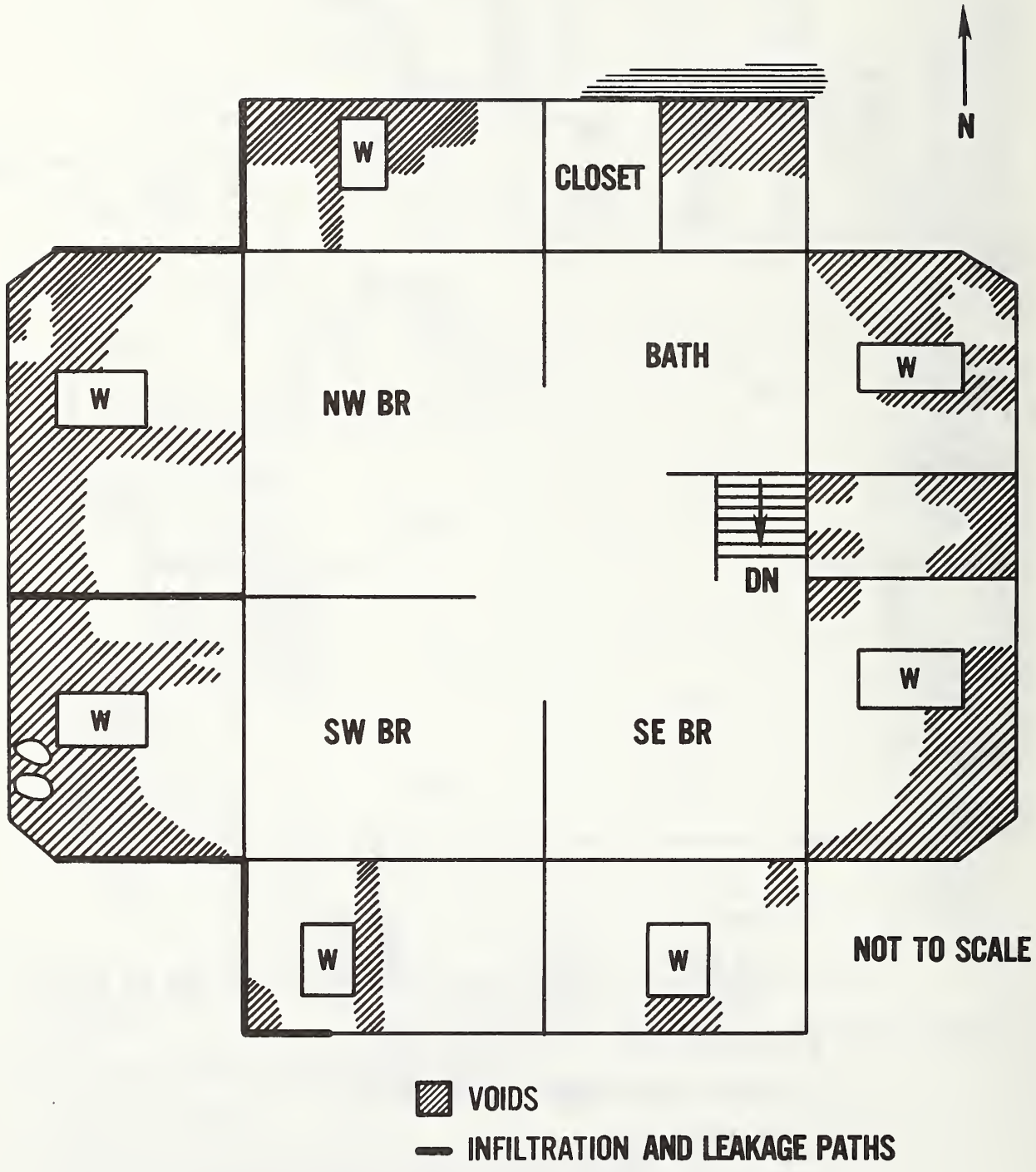


Figure VIIb. Thermal deficiencies observed on the second floor in Minneapolis-St. Paul house #3

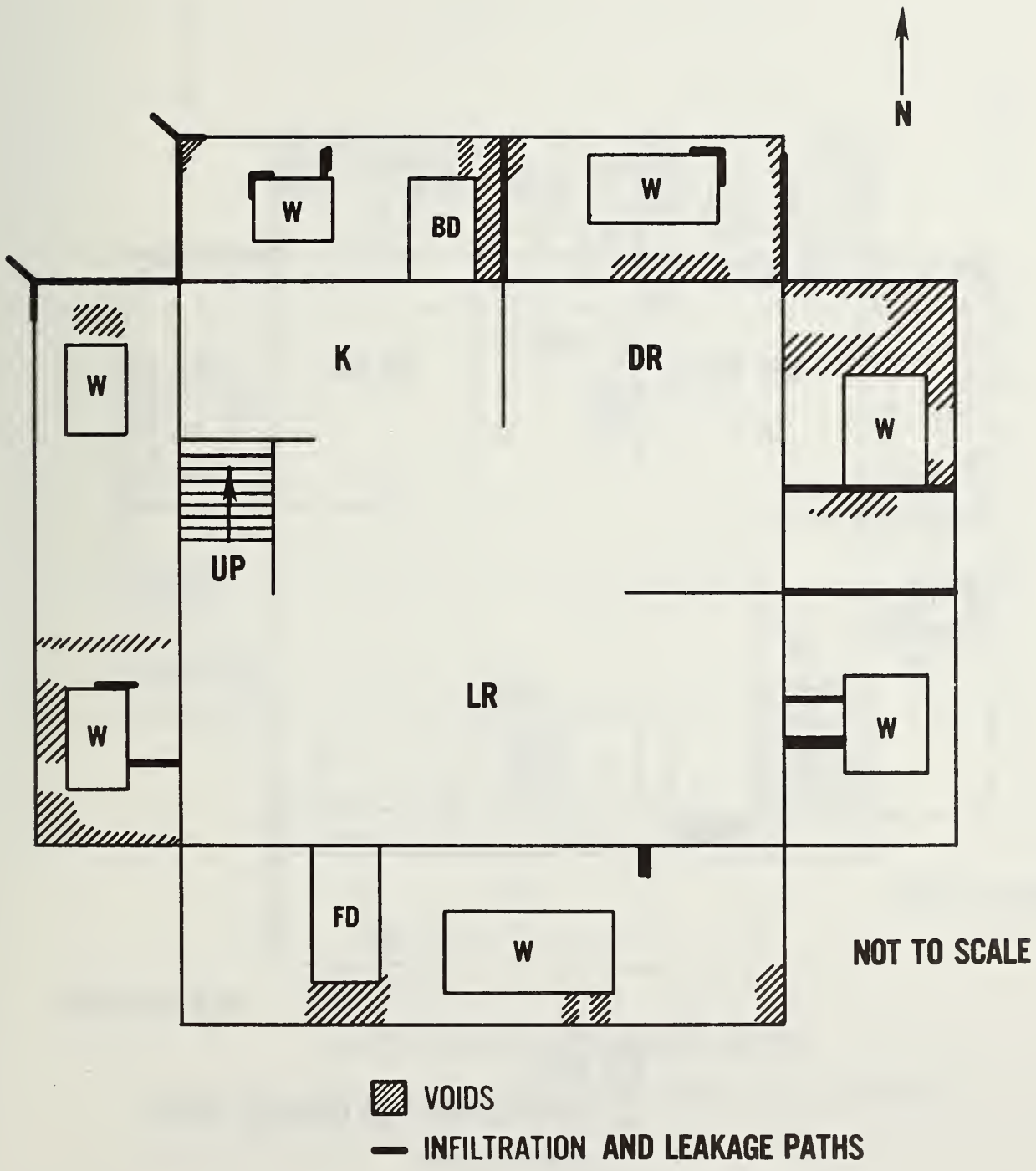


Figure VIIIa. Thermal deficiencies observed on the first floor in Minneapolis-St.Paul house #4

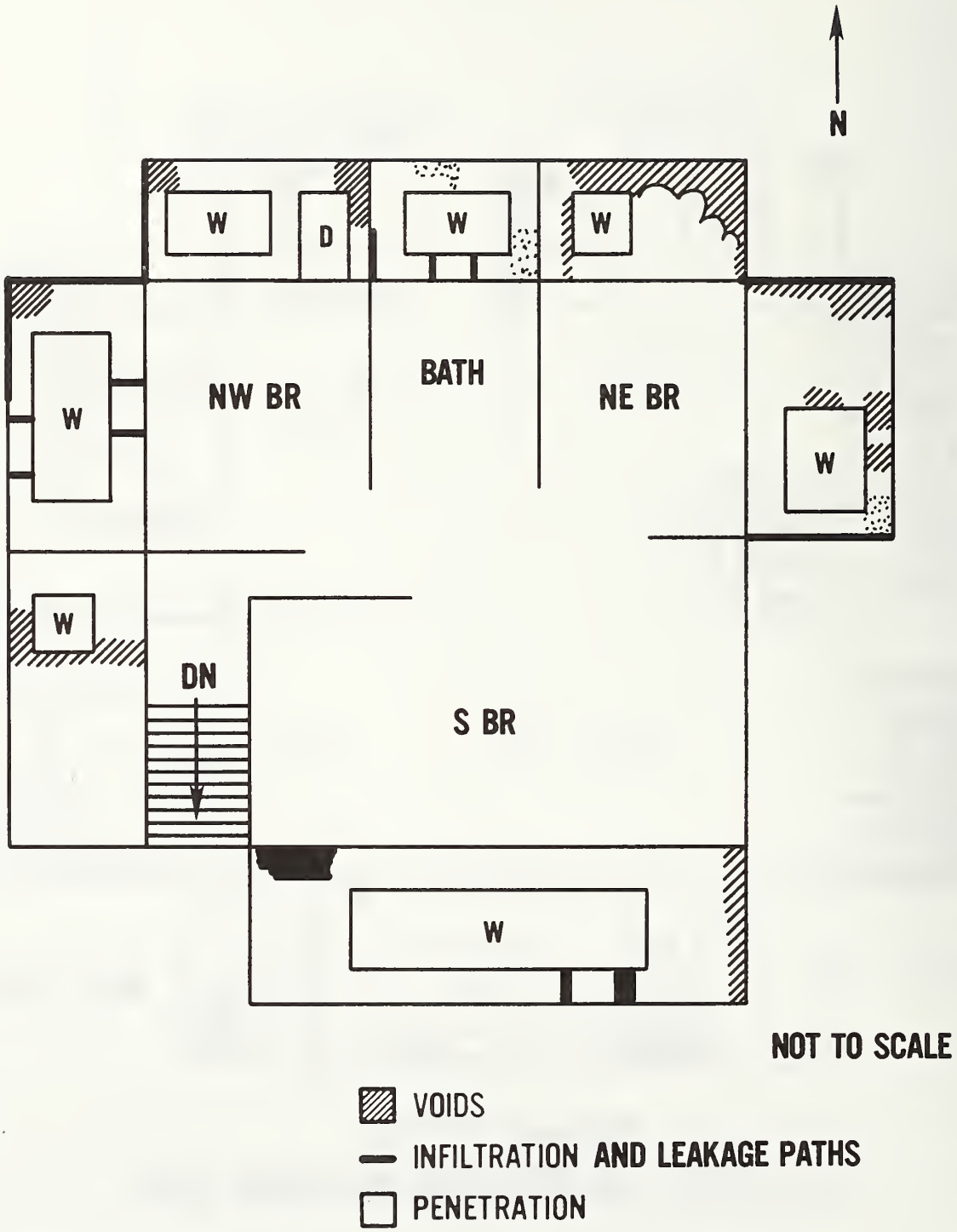


Figure VIIIb. Thermal deficiencies observed on the second floor in Minneapolis-St. Paul house #4

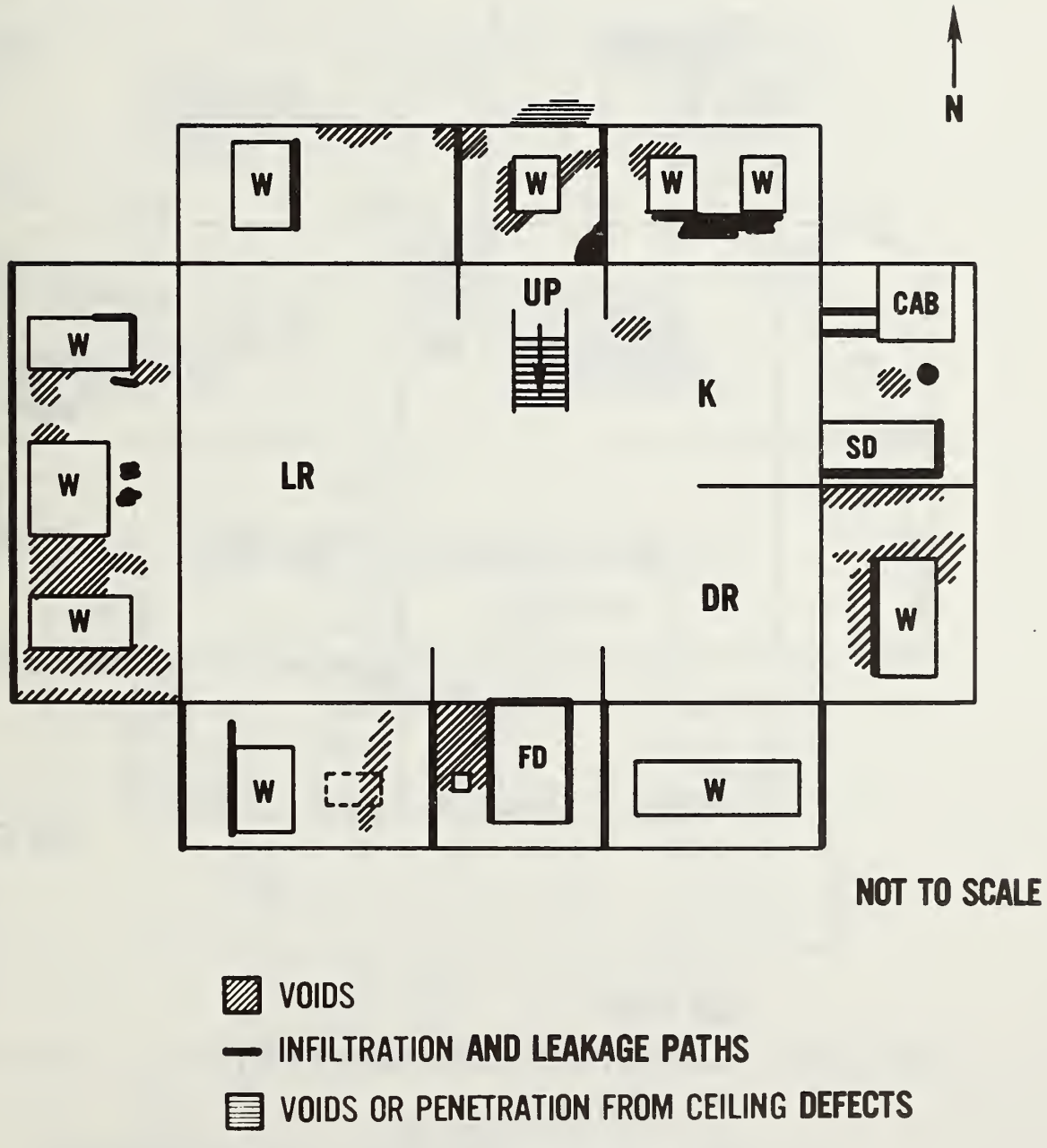


Figure IXa. Thermal deficiencies observed on the first floor in Portland house #1

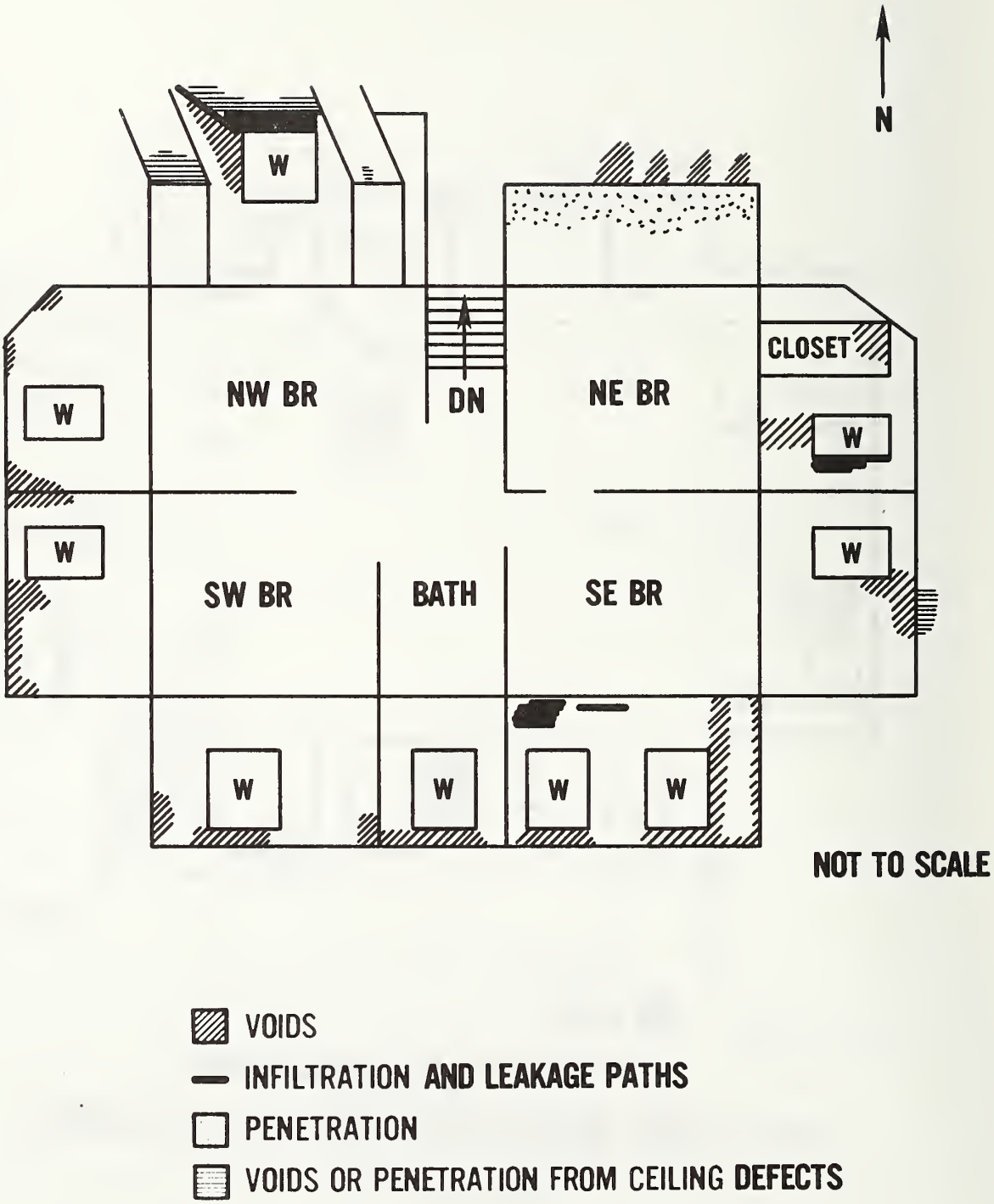


Figure IXb. Thermal deficiencies observed on the second floor in Portland house #1

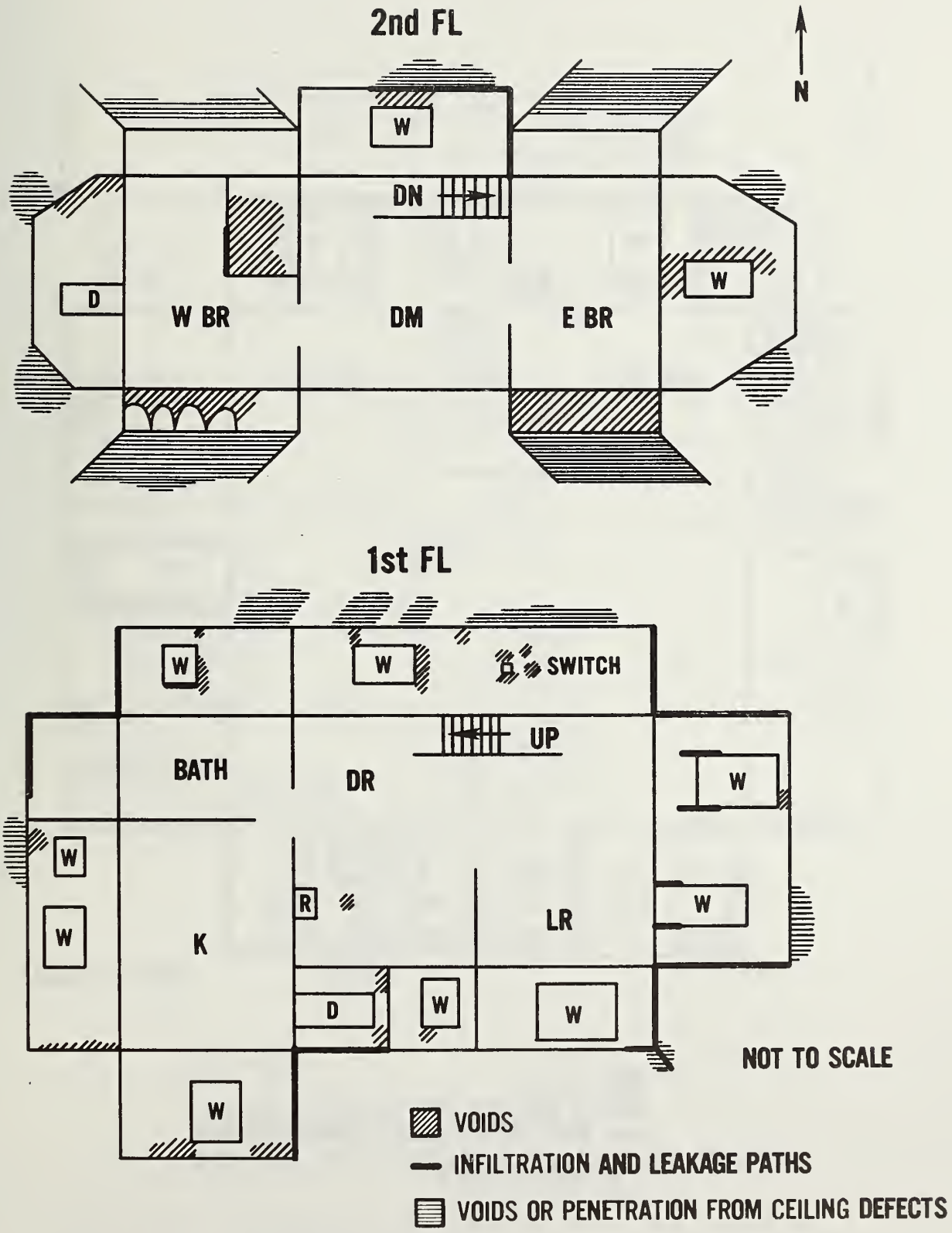


Figure X. Thermal deficiencies observed in Portland house #2

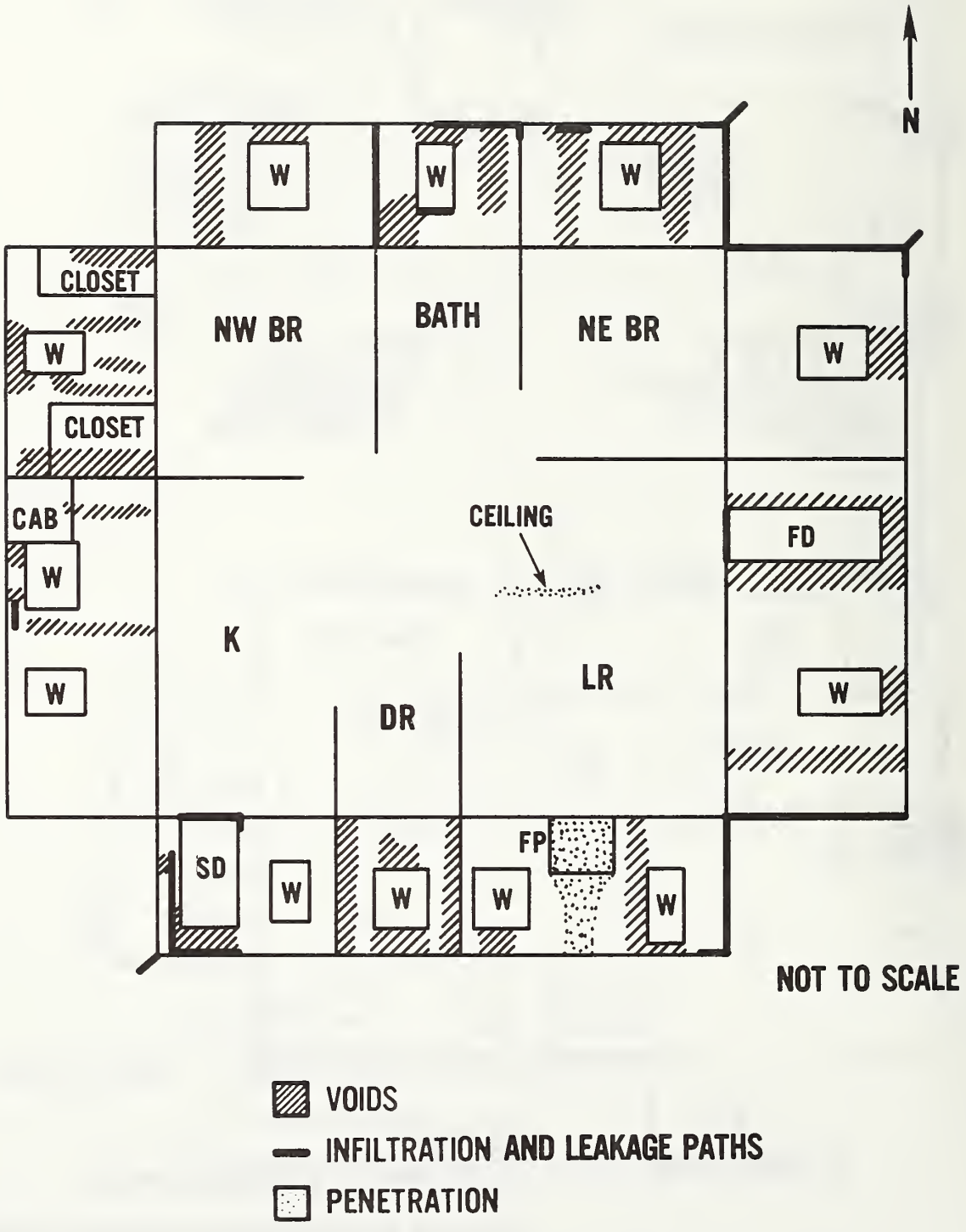


Figure XI. Thermal deficiencies observed in Portland house #3

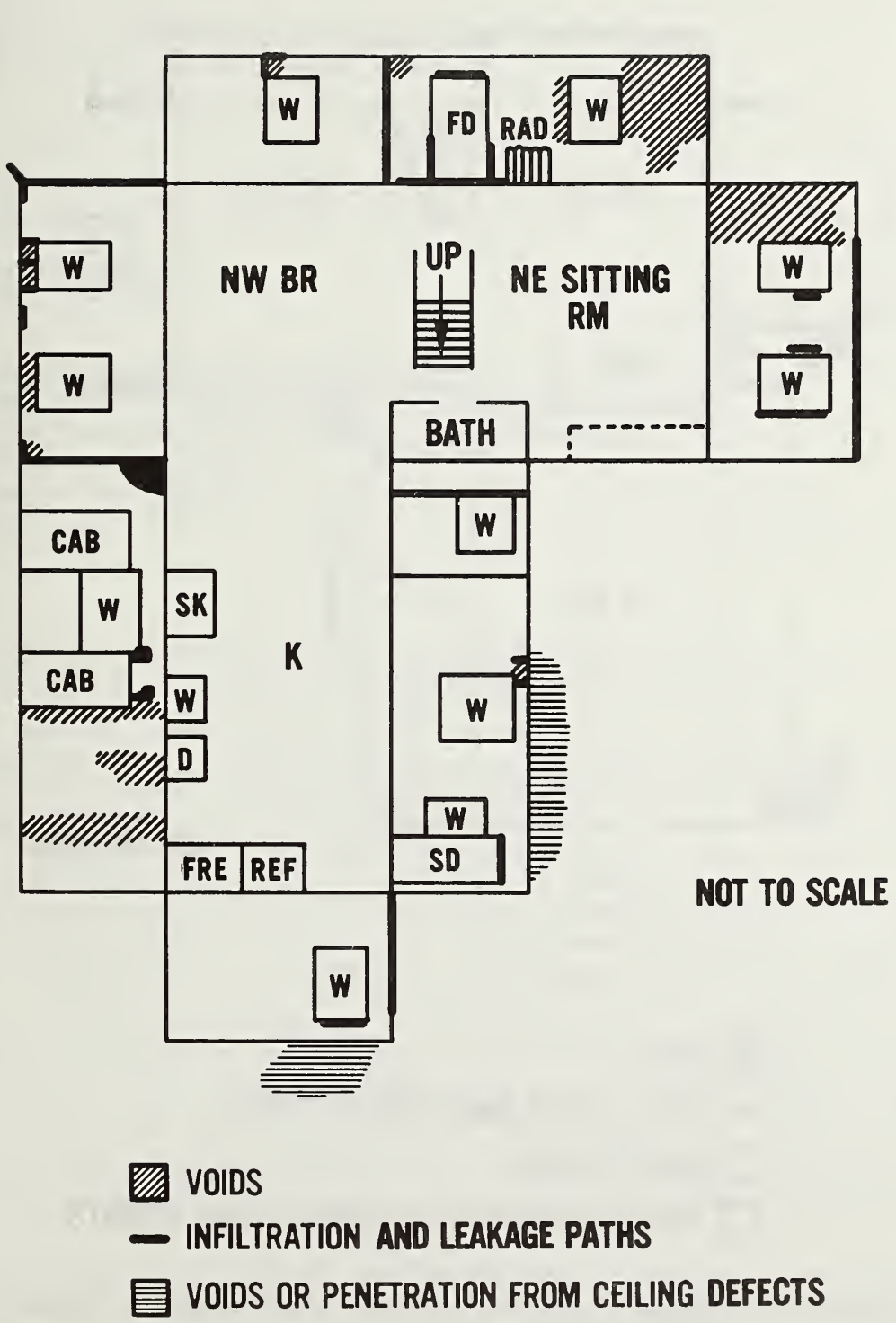


Figure XIIa. Thermal deficiencies observed on the first floor in Portland house #4

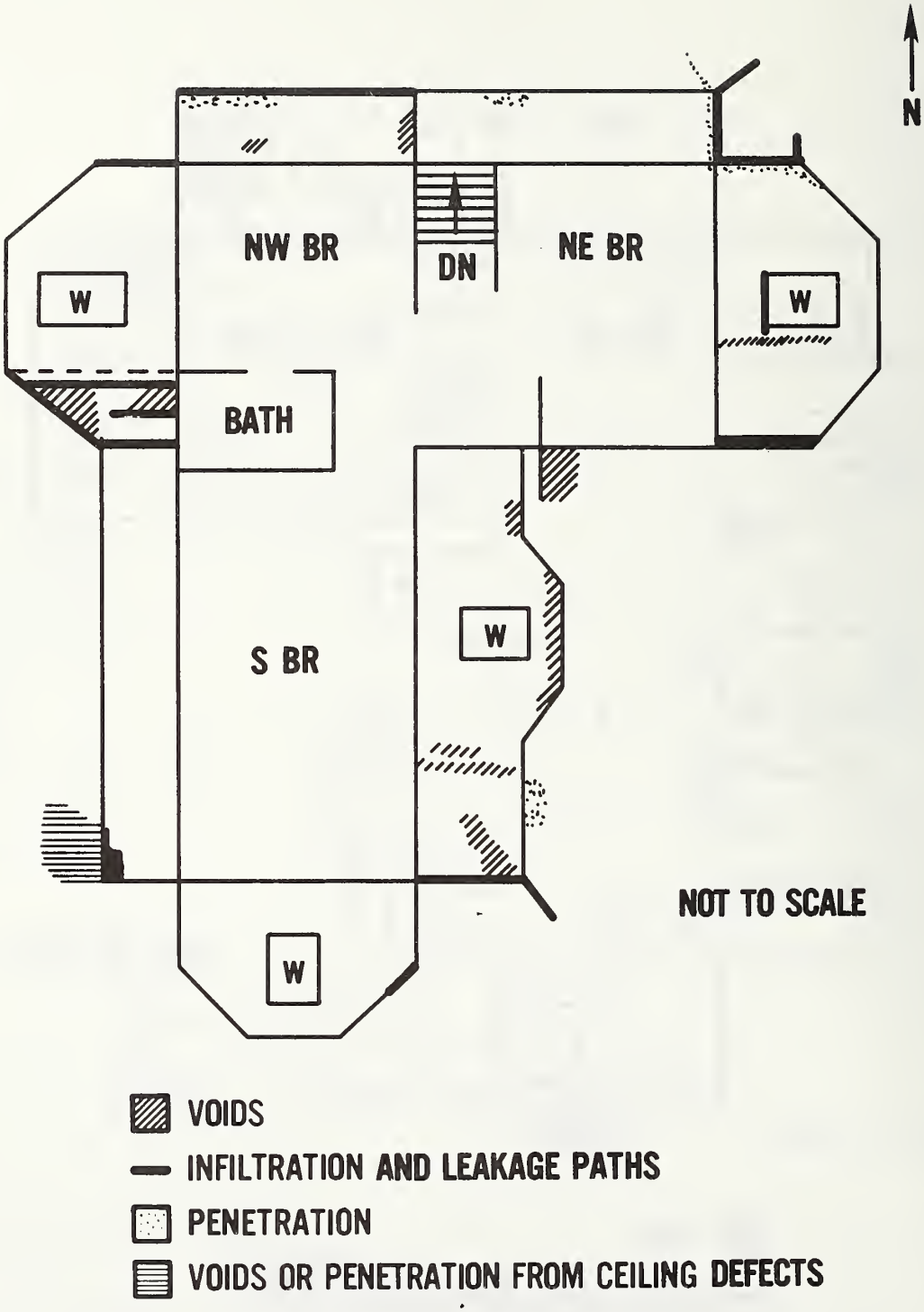


Figure XIIb. Thermal deficiencies observed on the second floor in Portland house #4

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (*A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here*)

A comparative evaluation of various portable infrared sensing systems used for detecting heat loss anomalies within building envelopes was performed. This is the second of a two-stage applied research program sponsored by the Department of Energy to assess the application and reliability of using infrared technology. Twelve single-family residences in three cities from the Weatherization Program of the Community Services Administration were employed as field samples. The results of infrared surveys carried out by thermographic surveying firms and those by the National Bureau of Standards were analyzed and compared in the categories of: completeness of scanning, identification of defects, weather condition of inspection, and method of equipment operation. The thermograms of uninsulated areas, sketches of observed thermal deficiencies, and total areas of defects for each dwelling are presented. Through the comparison, the degree of completeness of inspecting the residences thoroughly was evaluated to be the most important factor for defect identification. The results of thermographic inspection of the homes showed that serious thermal anomalies still existed in most of these 'weatherized' residences, with a majority exhibiting between 5 percent and 15 percent of the wall areas uninsulated, or defective. The total uninsulated areas observed by each surveyor was found to be affected by the quality of thermograms submitted.

12. KEY WORDS (*Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons*)

Building heat losses; comparison of inspections; infrared scanning systems; insulation voids; interpretation of thermograms; thermal deficiencies; thermographic inspections; weatherization retrofits.

13. AVAILABILITY

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