NBSIR 83-2701

Comparative Analysis of Thermographic Inspections Performed on Retrofitted Homes

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

May 1983

Prepared for:
Building Systems Division
Office of Building Energy Research
and Development
U.S. Department of Energy
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COMPARATIVE ANALYSIS OF THERMOGRAPHIC INSPECTIONS PERFORMED ON RETROFITTED HOMES

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

ABSTRACT

An applied research program was sponsored by the Department of Energy to analyze and compare the results from inspections that utilized infrared sensing systems to identify thermal deficiencies in buildings. This research consisted of both the laboratory evaluation of the commonly used infrared sensing equipment for building inspections and the field evaluation of the accuracy and consistency of the results of thermographic surveys performed by various thermographic inspectors. The field evaluation of thermographic inspection performed by infrared contractors was undertaken using residences previously inspected by the National Bureau of Standards (NBS) as part of the Community Services Administration Weatherization Program. The results of the first phase was carried out in 1978-79 and published in a previous report. The present report contains the analysis and comparison of thermal anomalies detected by NBS and infrared contractors, during the second phase of this research program, on twenty single-family residences in five cities in 1980-81.

A substantial improvement was apparent in the style of reporting by infrared contractors, under phase two, as compared with phase one. However, contractors' surveys still have problems related to completeness of inspection, quality of hard-copy documentations, interpretation of thermal defects, and utilization of equipment. Consequently, contractors generally identified only about 50 percent of the total defects.

Key words: comparison of inspections; infrared sensing systems; insulation voids; interpretation of thermograms; location of heat loss; quality controls; thermal deficiencies; thermographic inspections.

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. It is based on data and analysis submitted to NBS by the New England Innovation Group (NEIG) under contract #NB80SBCA0337.

The conclusions and recommendations in this report were made in response to a request by the Department of Energy that the National Bureau of Standards evaluate, using the material submitted by NEIG, the effectiveness of surveys performed by contractors using infrared imaging systems in determining thermal anomalies. The contractors noted in this report were not retained by nor under the supervision of NBS; their equipment and techniques were not perscribed by nor approved by NBS.

ACKNOWLEDGMENT

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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^3	m^3	9.29×10^{-2}
Volume	V	ft^3	m^3	2.83×10^{-3}
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}

1. INTRODUCTION

The application of infrared (IR) thermal sensing systems to energy conservation in building envelopes of residential, commercial, and industrial buildings has been significantly increased in recent years. Using thermography as a building diagnostic tool, thermal anomalies can be observed from IR inspection performed on these buildings [1,2]. In general, the most common building defects are thermal insulation problems such as insulation voids, improper installation of insulation, cracks within insulation, moisture damage of insulation, air infiltration and leakage, moisture damage to roofs, thermal bridges, and excessive heat loss from unconditioned spaces such as eaves, crawl spaces, and attics.

The images generated from thermographic surveying equipment correspond to thermal variations in surface temperature distributions. These images are displayed in the form of thermograms where the bright portions represent high temperatures, dark portions represent low temperatures, and grey shades indicate temperatures between hot and cold. Since anomalies in the thermal properties of the building envelopes cause variation in the surface temperature, IR thermographic inspections have the capability of identifying heat loss in problem areas which normally appear to be efficient in retaining heat within buildings. Consequently, IR equipment has been utilized as a tool in assessing the thermal performance of building envelopes to locate thermal defects and to identify areas where weatherization retrofits would increase the energy efficiency of their homes [3]. This thermographic technology is also valuable during construction of new buildings or during the retrofit of an existing building for providing a thermal quality control of construction and assessing retrofit work. Thermography can also be used during periodical inspections of a building for preventive maintenance such as roof inspections. Paramount to each of these applications is the accuracy and consistency of thermographic inspections in locating and identifying thermal defects. In order to compare the quality of inspections using IR thermographic technology, a laboratory and field program was undertaken to analyze and compare the results from inspections by utilizing thermographic equipment to identify thermal deficiencies in buildings.

The initial laboratory assessment, conducted in 1978, involved an evaluation of various classes of thermographic equipment for the thermal inspections of buildings performed by major manufacturers of portable IR sensing systems in a "cold room" at the U.S. Army Cold Regions Research and Engineering Laboratory (USACRREL) [4]. The equipment used for the laboratory evaluation included two high resolution imaging systems (resolution less than 0.5°F), one low resolution imaging system (resolution greater than 0.5°F), and a line scanner (a single straight-line scanned on the target [5]). The result showed that all systems did better in detecting defects than in determining regions of insulation levels, and the high resolution imaging systems (HRIS) performed better than the low resolution imaging system (LRIS) and the line scanner. Furthermore, the LRIS did not perform well at the lowest temperature differential. Currently, the National Bureau of Standards (NBS) is constructing an infrared imaging system evaluation laboratory for measuring the pertinent parameters of infrared imaging systems for the detection of thermal defects in buildings [6].

The field evaluation consisted of a two-phase evaluation of IR inspection contractors, using residences inspected by NBS as part of the Community Services Administration (CSA) Weatherization Program [7] as a baseline. In order to confirm the validity of both the laboratory and field tests, the same types of IR devices were selected to perform the scanning for both measurements. The field test of this project was coordinated by the New England Innovation Group (NEIG), which also handled and provided interpretation of the data submitted by the IR contractors [8].

In the first phase of the field test, carried out during the heating season of 1978-79 at 12 homes in three cities, NBS used a HRIS to scan each wall of the residences and a 35-mm camera to photograph the thermal patterns on the oscilloscope screen [9]. The field test indicates that most of the IR contractors failed to cover the entire house in their inspections and located between 45 percent and 86 percent of the total defects in wall areas. Many thermograms submitted by the IR contractors were poor in quality, causing uncertainties in the analysis and wide discrepancy in results.

In the second phase of the field evaluation, conducted during the heating season of 1980-81 at 20 homes in five cities, NBS used a HRIS to scan the dwellings and a video tape recorder to collect the data while some IR contractors used HRIS and others used LRIS in performing inspectors. This report presents the results from the analysis and comparison of thermal anomalies detected by the inspections.

2. RECOMMENDATIONS FOR CONTRACTORS

Results of the field surveying by the IR contractor of Phase I indicated that the degree of completeness of inspection was the most important factor for defect identification. IR contractors of Phase I were unrestrained in the selection of the method of inspection, documentation, and data interpretation. As a result, data submitted by these contractors had tremendous variations. In two cases the data were inadequate for performing meaningful analysis and incomparable with these from other firms and NBS [8].

In order to reduce the variability of data encountered under Phase I, the Residential Thermographic Inspection Form (RTIF) (see appendix A) was developed by NEIG to aid the IR contractors in data collection, recordation, and documentation during field inspections. The RTIF contained standard formats for environmental conditions, floor plan sketch with orientations, and data sheet for location, estimated size, and description of each uninsulated area. Also furnished were instructions for use of RTIF and a example to illustrate the recordation of informations on the data sheet. However, the utilization of the RTIF was a recommendation, not a requirement, to IR contractors in the process of data gathering during their inspections. To further improve the quality and the accuracy of data submitted, NEIG also amended the service agreements with IR contractors to include the double verification of retrofitted areas with NEIG as well as CSA personnel, and the amended requirement of carrying out interior IR inspection of the entire house.

3. THERMOGRAPHIC INSPECTIONS BY CONTRACTORS

In the second phase of the field evaluation, 18 IR contractors were selected to perform IR inspections on 20 residences, with four in each of the following five cities: Atlanta, GA; Colorado Springs, CO; Hughesville, MD (suburb of Washington, D.C.); Minneapolis-St. Paul, MN; and Providence, RI. Each IR contractor was assigned to four homes in the same city. Therefore, all dwellings in the same city were inspected by the same four contractors; except those in Colorado Springs to which only two contractors were assigned. Ten of the IR contractors operated HRIS; the rest operated LRIS; with NBS performed baseline inspections using a HRIS to scan the dwellings and a video tape recorder to collect the data. Again, with the exception of those homes in Colorado Springs, all dwellings were inspected by both HRIS and LRIS.

In this report, thermographic inspection firms will be identified according to the first letter of the city name such that contractors A1 through A4 are firms surveying residences in Atlanta, contractors C1 and C2 are firms surveying residences in Colorado Springs, and so forth.

As mentioned previously, prior to the execution of the service agreement with IR inspection firms, NEIG had established recommendations to assist the IR contractors in providing a more accurate and detail documentation of their findings. However, only 78 percent IR contractors submitted RTIF and 72 percent verified retrofitted areas with CSA and NEIG prior to their IR thermographic inspections. Furthermore, most of them did not cover the entire interior wall areas of the dwellings in their IR surveyings with 25 percent of the IR contractors reported incorrect orientations of the houses inspected. Based on the hard-copy documentation of thermal anomalies of those homes, it seemed that a few IR contractors with HRIS did not fully utilize their equipment to collect data in order to provide much more concise information in clear documents from their inspections. Thus it would cause the discrepancies in estimation and in identification of uninsulated areas. Another problem encountered was the unrecognized solar reversal patterns by one IR contractor during his daytime IR inspections. Such patterns would show the uninsulated area at a higher surface temperature rather than a lower surface temperature.

4. DATA ANALYSIS AND SUMMARY

A detailed description of thermal deficiencies in each dwelling from the comparative analysis of documents produced by individual thermographic inspections is presented separately in appendix B. General descriptions of these residences, retrofitted options, sketches of thermal anomalies, comparative evaluations, and some thermograms as examples to illustrate the location of heat loss area are also included in appendix B. Of the 20 homes selected for IR surveys, 10 were eliminated from the CSA weatherization program after retrofitted options were completed. Thus the house data, such as the dimensions of rooms, windows, and doors, were unavailable for the calculation of the total insulated wall area. In some residences, informations of neither the floor plan nor the dimension of the house itself were given. Since the purpose of this field test is mainly a comparative evaluation of five independent surveys of each dwelling, the analysis based on the combined documents can still be considered as a baseline reference in a qualitative comparison among them. Without detailed information of the house, the estimates of the percentage of defective wall areas with respect to the entire wall areas of these residences will not be able to perform. Therefore, the comparative analysis of thermographic inspections of dwellings is divided into two groups: group A are those dwellings remained in the CSA program so that complete house data are available; and group B are those homes dropped from the CSA program without detailed informations of house data.

The IR equipment employed by NBS personnel during thermographic inspection consisted of a high resolution imaging system of a scanner and a monitor, connected to a video tape recorder. The data were collected on video cassettes by scanning each wall of every room inside the house in a continuous format by going through the entire home, including the stairways and ceilings. Simultaneously, the surveyor, who was accompanied by the home owners during inspections, would speak into a microphone to record the environmental conditions, orientations, and the problem areas encountered. By communicating with the home owner, correct orientations, retrofitted options, and special problems of the house can be obtained by the surveyor. Furthermore, completeness of inspection would easily be achieved because the home owners were anxious to verify the quality of the insulation work, which effected their energy savings directly. As a result, NBS inspected each house thoroughly and observed most of the defective wall areas except in two houses where only two small void areas were missing. Moreover, even though exterior surveying is not a requirement for the IR firms, NBS personnel carried out both interior and exterior thermographic inspections for 15 of the total 20 residences. The exterior inspection includes views of the entire sidewall area of the house to contrast the surveyor's findings from interior inspection, and to identify additional thermal anomalies and by-pass heat loss locations. Therefore, results from NBS' inspections will be used as a baseline for comparison.

The numerical estimation of defective wall areas in appendix B was based on the analysis of data and documentations submitted by each IR firm, with video tapes by NBS, from their thermographic inspections. Due to the variability of estimated sizes for the same defects reported by different IR contractors, one common value of area size will be given in this report for each defective area

found by NBS, by any IR contractor with hard-copy documentation and estimated size, or by any two IR contractors with estimated size. Tables 1A through 1E are the summaries of results from appendix B. Using the result from NBS as a baseline, the percentages of overall void areas identified by each surveyor are calculated and are presented in tables 1A through 1E.

The extent to which defective wall areas identified by each IR contractor differ is very great, ranging from 10 to 90 percent, with an average of 48.7 percent. Of the 18 IR contractors, only ten located more than 50 percent of the total defective wall areas. In general, it appears that those IR firms using HRIS out performed those using LRIS in each city. Based on the results in tables 1A through 1E, figures 1 and 2 illustrate the distributions of percentage of uninsulated wall areas in dwellings identified by IR contractors using HRIS and using LRIS, respectively. As shown in figure 1, most IR firms with HRIS observed more than 40 percent of defects and two of them only recognized between 20 to 40 percent of the total defects. Both of these contractors, M1 and M2, were assigned to inspect dwellings in Minneapolis-St. Paul. According to their documents, they missed the entire uninsulated east wall in the kitchen of house no. 1, and reported no defects or only a small void on top of the front door in house no. 3. Consequently, they only observed about one fourth of the total defective wall areas. As for the IR firms with LRIS, half of them located 20 percent or less of the total defects, as shown in figure 2. This is mainly due to incomplete inspections and lack of documentations during their scannings. Furthermore, the hard copies produced by the LRIS are of such poor quality that difficulties arise in performing analysis. The remaining half of the IR firms with LRIS observed the high percentage of defects (in one case over 80 percent) indicating that reasonably accurate data can be achieved when the surveyor fully utilizes the equipment to scan, and documents sufficiently the problem areas with detailed sketches and estimated sizes during his inspection.

Summary results of thermal deficiencies interpretated from the thermographic inspections for all dwellings are given in tables 2A and 2B. As indicated in these two tables, the most severe thermal anomalies, besides uninsulated wall areas, are defective ceilings with air penetration paths found at wall-to-ceiling and wall-to-wall joints. Other common heat loss locations observed in these residences are leakage paths around windows and doors. Table 2A also includes the percentage of uninsulated wall area in ten dwellings of group A. It can be seen that between 2 percent and 23 percent defective wall areas were found in the houses of this group. Since the house data of group B are not available only defectve wall areas are given without the percentage values.

5. DISCUSSION

Use of the RTIF (appendix A) was recommended to IR firms for data documentation by NEIG in the hope of improving uniformity and reducing omissions, both of which are necessary for a reliable assessment of locating thermal defects within dwellings. Overall, the analysis of results from field inpsections performed under Phase II (use of RTIF) showed only a slight improvement over those conducted in Phase I (without RTIF). The style of reporting and the quality of data submitted by some IR contractors from Phase II seemed to be better than those from Phase I, however, the recommendations of the RTIF were not followed completely.

With the aid of the RTIF, all IR contractors documented the data, the time, and the environmental conditions during their surveys. They also gave floor plan sketches of the residences, but none of them would provide the dimensions of the rooms; with a few of them gave incorrect orientations of the houses. Even though the locations and sizes of defective areas were given by some IR contractors, the description and estimation of identical void areas given by individual contractors were quite diversified. As for the hard copy documentations submitted, some IR contractors included visual pictures with thermograms of the same region to indicate areas of thermal defects, and some contractors provided clear thermograms to show thermal patterns of insulation voids. However, a number of IR contractors provided no hard copies at all, or the thermograms attached were in extremely poor condition and no images could be observed.

Due to the inconsistencies of the data submitted by IR contractors from their field measurements, it is necessary to establish effective surveying methodology to improve the existing techniques for thermographic inspections. Based on the findings of data analysis of field evaluations in both Phase I and Phase II, the following are suggested for consideration as requirements for thermographic inspections.

1. Completeness of inspections.
2. Sketches of floor plans with approximate sizes and correct orientations.
3. Understanding of the characteristics of the IR equipment used.
4. Suitable environment to perform IR inspection.
5. Understanding the existing environmental condition.
6. Verification of regions to be inspected.
7. Interpretation of thermal anomalies from thermal pattern displayed at site.
8. Additional scanning of doubtful areas.
9. Hard copies of photographs and thermograms of the same regions.

Presently, the implication of thermographic standards to promote the proper application of thermographic inspection of building envelopes has been developed by several working groups; such as the International Standards Organization (ISO), the American Society for Testing and Materials (ASTM), and the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) [10-12]. The standards activities of these professional societies and organization are mainly to specify guidelines such as inspection procedures, proper

environmental conditions, equipment requirement, and method of inspection in order to assist IR surveyors to obtain reasonable accuracy from thermographic inspections.

6. CONCLUSION

Analysis of the data collected by IR contractors in Phase II (voluntary utilization of RTIF) produced a variety of inadequacies ranging from failure in detecting a majority of the thermal deficiencies within a dwelling to the incorrect reporting of house orientation. A substantial improvement was apparent in the style of reporting and in documentation of environmental conditions under Phase II, as compared with those under Phase I. In some instances, due to lack of training or understanding in the thermographic inspecting methods, it appears that some IR contractors tried to perform surveys with a minimal effort resulting in the failure to depict a majority of thermal deficiencies in the dwellings. Moreover, it seems that some IR contractors with HRIS did not utilize the full potential of their equipment to produce better hard-copy documents, and some contractors included no thermograms in their reports. The result of the overall percentage estimation of defect identification under Phase II is even lower than that under Phase I.

Other inadequacies of voluntary utilization of RTIF are revealed from the data submitted by IR contractors. Incompleteness of inspection seems to be the major problem. The given instructions for inspection were not totally followed such as contacting NEIG to verify the areas of homes to be inspected. Incorrect reporting of the orientations of the house inspected and problems of thermal interpretation also occurred.

To obtain adequate results from thermographic inspection of building envelopes, it is necessary to establish and mandate guidelines for IR firms to perform IR inspections. Training programs for surveyors are considered to be equally important for IR contractors to provide a complete and accurate thermographic inspection of buildings.

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Table 1A. Comparison of Insulation Voids in Wall Areas Given in ft^2 Observed in Each Surveying Contractor and by NBS in Atlanta, GA*

City	House No.	NBS	Survey Contractor A1(HRIS)	A2(HRIS)	A3(LRIS)	A4(LRIS)
ATL	2 (31)**	36	36	7	36	6
ATL	3 (32)	52	25	21	8	8
ATL	4 (33)	221	147	135	93	25
Total Area of Voids Detected		309	208	162	137	39
Percentage of Voids Detected***			67.3	52.4	44.3	12.6

* House No. 1 is excluded from comparison because only one room was insulated and no major defects were observed.

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

*** Based on results of all surveys.

Table 1B. Comparison of Insulation Voids in Wall Areas Given in ft^2 Observed by Each Surveying Contractor and by NBS in Colorado Springs, CO

City	House No.	NBS	Survey Contractor C1(HRIS)	Survey Contractor C2(HRIS)
CSP	1 (17)*	65	5	31
CSP	2 (34)	230	140	116
CSP	3 (43)	111	24	52
CSP	4 (47)	124	66	110
Total Area of Voids Detected		530	235	309
Percentage of Voids Detected**			44.3	58.3

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

** Based on results of all surveys.

Table 1C. Comparison of Insulation Voids in Wall Areas Given in ft^2 Observed by Each Surveying Contractor and by NBS in Minneapolis-St. Paul, MN

City	House No.	NBS	Survey Contractor M1(HRIS)	M2(HRIS)	M3(HRIS)	M4(LRIS)
MSP	1 (151)*	157	36	42	134	21
MSP	2 (152)	40	28	30	42	23
MSP	3 (174)	103	0	5	89	4
MSP	4 (200)	69	34	18	53	11
Total area of Voids Detected		369	98	95	318	59
Percentage of Voids Detected**		99.2	26.3	25.5	85.5	15.9

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

** Based on results of all surveys, 372 ft^2.

Table 1D. Comparison of Insulation Voids in Wall Areas Given in ft^2 Observed by Each Surveying Contractor and by NBS in Providence, RI

City	House No.	NBS	Survey Contractor P1(LRIS)	P2(HRIS)	P3(LRIS)	P4(LRIS)
PRO	1 (28)*	93	37	37	82	13
PRO	2 (37)	184	161	139	151	153
PRO	3 (219)	252	204	226	203	157
PRO	4 (287)	155	114	139	136	89
Total Area of Voids Detected		684	516	541	572	412
Percentage of Voids Detected**			75.4	79.1	83.6	60.2

* Numbers in parentheses denote corresponding house numbers in CAS program.

** Based on results of all surveys.

Table 1E. Comparison of Insulation Voids in Wall Areas Given in ft^2 Observed by Each Surveying Contractor and by NBS in Washington, D.C.

City	House No.	NBS	Survey Contractor W1(LRIS)	W2(HRIS)	W3(LRIS)	W4(HRIS)
WAS	1 (2)*	26	2	7	3	9
WAS	2 (8)	126	13	44	17	101
WAS	3 (44)	189	36	86	9	39
WAS	4 (47)	352	93	180	68	309
Total area of Voids Detected		693	144	317	97	458
Percentage of Voids Detected**			20.8	45.7	14.0	66.1

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

** Based on results of all surveys.

Table 2A. Thermal Defects Observed in Each Dwelling in Group A

City House No.	ATL 2	ATL 3	CSP 1	CSP 2	CSP 3	CSP 4	WAS 1	WAS 2	WAS 3	WAS 4
Defective Wall Area (ft^2)	36	52	65	230	111	124	26	126	189	352
% of Defective Wall Area	2	6	9	17	17	21	4	15	15	23
Defects Observed:										
Walls										
Shrinkage or Fissues		*			*	*			*	
Cross Braces			*	*			*		*	*
Air Penetration		*	*	*			*		*	
Ceilings										
Sloped				*			*			*
Flat	*	*	*		*	*	*	*	*	*
Air Penetration	*	*	*	*	*	*	*		*	*
Doors										
Frames	*			*			*		*	*
Air Leakage	*	*	*	*	*	*	*	*	*	*
Windows										
Frames		*						*		*
Air Leakage	*	*	*	*	*	*				*
Joints										
Wall-Wall	*		*	*	*		*	*	*	*
Ceiling-Wall	*		*	*	*			*	*	*
Floor-Wall				*	*				*	
Floor		*							*	
Heat Loss										
Eaves			*	*						
By-Pass				*	*			*		*
Basement or Crawl Space					*		*			

Table 2B. Thermal Defects Observed in Each Dwelling in Group B

City House No.	ATL 1	ATL 4	MSP 1	MSP 2	MSP 3	MSP 4	PRO 1	PRO 2	PRO 3	PRO 4
Defective Wall Area (ft^2)		221	157	40	103	69	93	184	252	155
Defects Observed:										
Walls										
Shrinkage or Fissures		*			*				*	
Corner Braces									*	
Air Penetration			*							
Ceilings										
Slope			*			*	*		*	
Flat	*	*	*	*			*	*	*	*
Air Penetration		*	*	*		*	*	*	*	*
Doors										
Frames			*			*				*
Air Leakage		*	*		*	*	*			*
Windows										
Frames				*				*		*
Air Leakage	*		*	*	*	*		*	*	*
Joints										
Wall-Wall		*	*	*	*	*	*	*	*	*
Ceiling-Wall		*	*	*	*	*	*	*	*	*
Floor-Wall			*				*	*	*	*

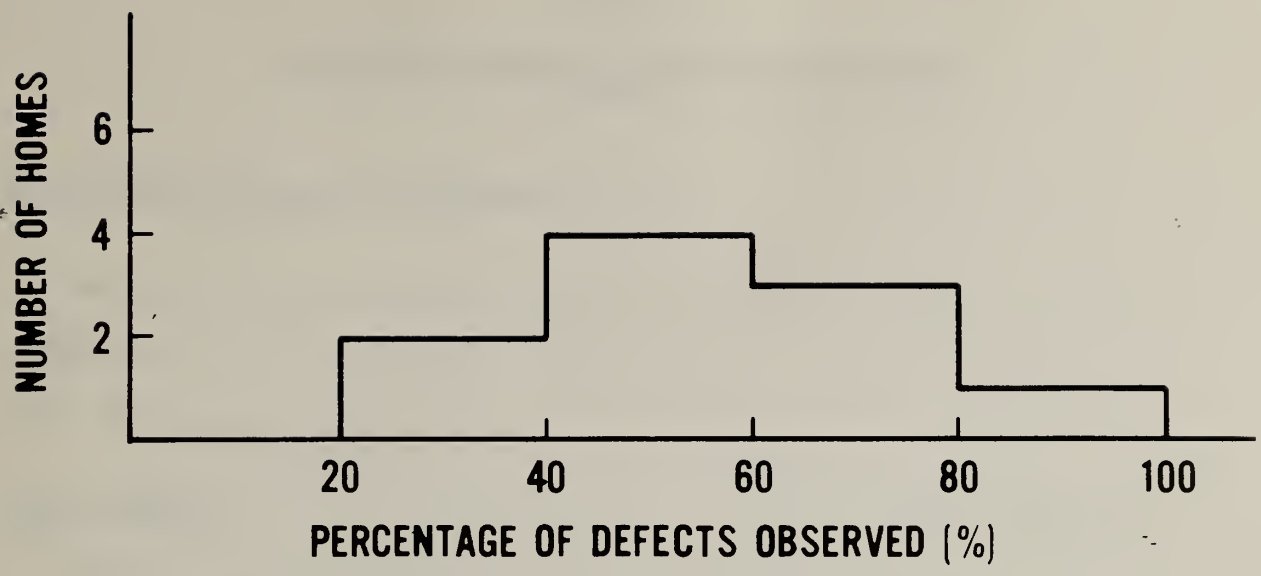


Figure 1. Distribution of percentage defects remaining in homes observed by IR contractors using HRIS

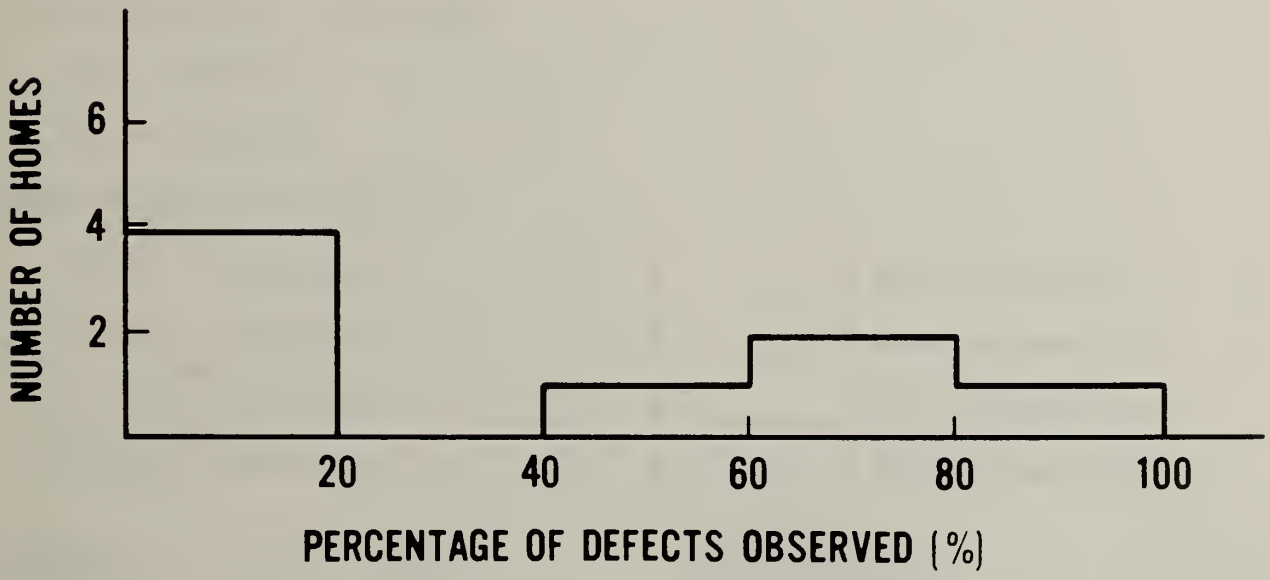


Figure 2. Distribution of percentage defects remaining in homes observed by IR contractors using LRIS

APPENDIX A

RESIDENTIAL THERMOGRAPHIC INSPECTION FORM (RTIF)

Thermographic Inspection Contractor:

Name: _____

Address: _____

Tel. No: _____

Home Inspected: Date Inspected: _____

City: _____

Address: _____

House #: _____

Time Started: _____ Time Finished: _____

Outside Ambient Air Temperature:

Start Inspection: _____ ^{o}F

Finish Inspection: _____ ^{o}F

Inside Ambient Air Temperature:

Basement Temperature: _____ ^{o}F @ _____ % Relative Humidity

1st Story Temperature: _____ ^{o}F @ _____ % Relative Humidity

2nd Story Temperature: _____ ^{o}F @ _____ % Relative Humidity

3rd Story Temperature: _____ ^{o}F @ _____ % Relative Humidity

Wind Speed: _____ mph Wind Direction: _____

Weather Conditions: _____

FLOOR PLAN SKETCH

INSUFFICIENTLY INSULATED AREAS

DATA SHEET

Document Number	Story	Room	Wall Orientation	Location	Area (ft^2)

MOISTURE CONTAMINATED AREAS

DATA SHEET

Document Number	Story	Room	Wall Orientation	Location	Area (ft^2)

UNINSULATED AREAS

DATA SHEET

Document Number	Story	Room	Wall Orientation	Location	Area (ft^2)

DAMAGED INSULATION AREAS

DATA SHEET

Document Number	Story	Room	Wall Orientation	Location	Area (ft^2)

Instructions for Use of

Residential Thermographic Inspection Form
(RTIF)

The following ancillary equipment is recommended for making environmental and meteorological measurements required on Page 1 of RTIF:

1. Thermometer
2. Compass
3. Air Current Velocity Meter*
4. Hygrometer

*Measurement of wind speed and direction at the site of inspection are preferred. Recording from nearest measurement site, of wind speed and direction, will be acceptable if measurement at site is not possible.

Weather Conditions

The most appropriate of the following examples should be used to best identify existing weather conditions during inspection at site: Clear, Partly Clear, Overcast, Snow, Rain, Sleet, Fog.

Floor Plan Sketch

Each story which is either partially or fully inspected by the infrared contractor must be identified in a floor plan sketch which includes the following:

1. Orientation
2. Story and Room Identificiation
3. Window and Door Identification
4. Number Each Room in Sequence of Inspection
5. Identify and Give Temperature of Non-Heated Rooms

Data Sheets

Document numbers listed on individual Data Sheets should coincide with numbers indicated on hard copy documentation. In addition story, room identification, and room number in sequence of inspection should be taken from floor plan sketch and recorded in appropriate areas on data sheets.

An example of how information is to be posted on the Data Sheets is given on the reverse side of this page.

UNINSULATED AREA

DATA SHEET

Document Number	Story	Room	Wall Orientation	Location	Area (ft^2)
3	2	Bedroom (6)	North/East	Void above window	3 ft^2

Void size

Identified location of void area

Indicates wall orientation of void area

Indicates sequential number of room inspection

Indicates room of void area location

Indicates story of void area location

Indicates hard-copy documentation number

APPENDIX B

ANALYSIS AND COMPARISON OF THERMOGRAPHICAL INSPECTIONS

1. Atlanta House #1

This is a single story residence whose interior dimensions are 38 ft. in length, and 36 ft. in width; located in Atlanta, GA. There are totally 6 rooms as living space with 2 porches and an attic. Its exterior construction consists of concrete-block walls and an asphalt shingle roof.

Prior to the implementation of the weatherization program, this house had no insulation. The only insulation added to this house was to install rigid board to the inside of the exterior walls of the southeast bedroom, and to blow rockwool into the attic. After retrofitted options were completed, this dwelling was inspected by NBS personnel and by IR contractors A1, A2, A3, and A4. Figure I is a sketch of voids and locations of heat loss of the ceiling and the southeast bedroom obtained from video tapes by NBS, and thermograms and documents by IR contractors.

Generally speaking, the wall areas of the southeast bedroom of this house were considered to be well insulated, except for some cold spots on the east wall. This might be due to mechanical fastening of the board to the sheetrock wall surface. If this were the case, then they should not be considered as defects. However, a great deal of mottling was observed at the ceiling, indicating uneven placement of the blown in rockwool insulation. Furthermore, a rectangular pattern of insufficient insulation was also found in the corners of the ceilings, indicating thermal deficiencies in the voids between the joists.

Thermographic inspection by NBS was carried out for both the exterior and the interior of this residence. Besides the southeast bedroom, the thermograms by NBS revealed that the wall area above all of the windows was also insulated. However, NBS only inspected part of the ceilings of this house, where a lot of defects in the entire ceiling were found by the contractors. Contractors A1 and A2 employed HRIS to inspect this dwelling by producing 8 and 6 thermograms respectively. Contractor A1 provided visual photographs as well as thermograms of identical locations to cover all major defects of this house. Although this contractor did not submit the documentation sheets supplied by NEIG, his report contained detailed description of defect location and commentary to support his findings. Contractor A2 observed mostly the defective ceilings by submitting very clear copies of thermograms. Contractors A3 and A4, who used LRIS for inspection, also identified the ceiling defects by producing 6 and 4 thermograms respectively. The qualities of the thermograms produced by the LRIS are very poor, thus making it difficult to perform analysis.

A detailed description of ceiling defects observed by IR contractors is summarized in table Ia. No summary of defective wall areas will be included because only one room of this house was insulated and no major defects were observed. Furthermore, this house will be excluded from calculations of total area of defective walls observed by each contractor. Table Ib presents the environmental conditions documented by each IR contractor. Thermograms 1-1 to 1-6 are some examples to demonstrate locations of heat loss anomalies, as they are referred to in the descriptions in table Ia.

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

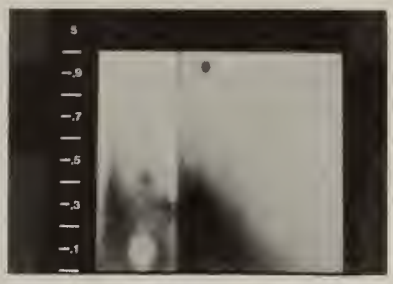
Room & Orientation		Description of Ceiling Defects	Observed by NBS	Contractors A1	A2	A3	A4	Thermogram No. in Appendix
Southeast Bedroom	SE	Missing Insulation at Corner	Yes	Yes	Yes	Yes	Yes	1-1 1-2 1-3
Southwest Bedroom	S & SW	Mottling to Show Uneven Insulation	No	Yes	Yes	Yes	Yes	
Living Room	W	Large Area of Mottled Pattern to Show Deficiencies of Insulation	Yes	Yes	Yes	No	Yes	1-4
Dining Room	NW	Missing Insulation at Corner and along N Side	No	Yes	Yes	Yes	Yes	1-5
Kitchen	N	Missing Insulation in Area Above Window	No	Yes	Yes	Yes	No	
East Bedroom	E	Lack of Insulation in Area Above Window	No	Yes	Yes	Yes	Yes	1-6

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

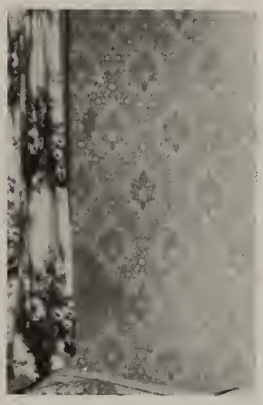
	Contractors			
	A1	A2	A3	A4
Date	3-11-81	3-9-81	3-11-81	3-5-81
Time	11:10 - 11:35 pm	9:25 - 9:40 pm	11:25 pm - 12:15 am	9:45 - 10:35 pm
Weather Condition	clear & cold	clear	clear	partly clear
Outside Temperature	44°F	50°F	51°F	48°F
Inside Temperature	75°F	77°F	74°F	72°F
Relative Humidity	26%	35%	60%	51%
Wind Speed(MPH)	15-18	calm	calm	13
Wind Direction	NW			NW

Thermal Anomalies Observed in Atlanta House #1

1-1
Ceiling defects observed at SE corner of SE bedroom (by NBS)



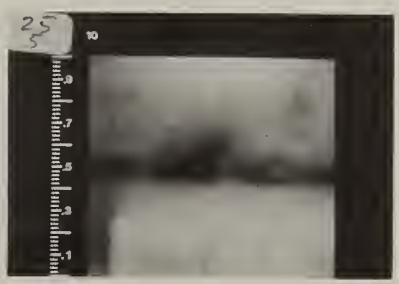
1-2
Air leakage along window on E wall of SE bedroom (by contractor A1)



1-3
E of SE bedroom (by contractor A1)

1-4
Ceiling defects observed in living room (by NBS)

1-5
Dining room ceiling defects (by contractor A1)



1-6
Ceiling defects and voids observed in E bedroom (by contractor A2)

II. Atlanta House #2

This is a single story, approximately 23 years old residence whose interior dimensions are 30 ft. in length, 30 ft. in width, and 8 ft. in wall height; located in Atlanta, GA. There are totally 5 rooms as living space with an attic and a crawl space. Its exterior construction consists of concrete-block walls and an asphalt shingle roof.

Prior to the implementation of the weatherization program, this house had no insulation. Aninsulation contractor was instructed to insulate the walls of this dwelling with styrofoam covered with sheetrock, and fill the cavities of the cinder blocks with vermiculite; also to blow rockwool in the attic, and install fiberglass batts in the floor joists. After retrofitted options were completed, this dwelling was inspected by NBS personnel and IR contractors A1, A2, A3, and A4. Figure II is a sketch of voids and locations of heat loss obtained from video tapes by NBS, thermograms and documents by IR contractors.

Generally speaking, the wall areas of this house were considered to be well insulated, except in the bathroom whose exterior wall was observed to be completely uninsulated. Furthermore, insufficient insulation was found in the corners of the ceilings. Other defects included an uninsulated attic hatch, lack of vermiculite in the northwest corner of the kitchen west wall, mottled thermal pattern on kitchen floor indicating moisture problems, and no insulation in the bathroom floor.

Thermographic inspection by NBS observed most defects of this residence except the kitchen and bathroom floors and the small sealing problem above the northeast corner of the north window of living room. Contractors A1 and A2 employed HRIS to inspect this dwelling by producing 8 and 4 thermograms , respectively. Contractor A1 provided visual photographs as well as thermograms of identical locations to cover all major defects of this house except the bathroom floor. Although this contractor did not submit the documentation sheets supplied by NEIG, his report had detailed description of defect location and commentary to support his findings. However, this contractor had some problems to identify the correct orientations of defects found in the bathroom wall from thermograms produced by the interior and the exterior inspections. Contractor A2 observed mostly the defective ceilings. This contractor claimed that he could not have good results from inspection of the bathroom wall because this small wall is covered with tiles. Contractors A3 and A4, who used LRIS for inspection, observed all the defects in the ceiling by producing 4 thermograms each. Furthermore, contractor A3 inspected the bathroom thoroughly to identify the entire uninsulated exterior wall and indicate that the floor has no insulation neither. Contractor A4 only reported the infiltration problems in the bathroom without mentioning the exterior wall and the floor. However, this contractor did not verify with NEIG the areas within this house which were insulated and to be inspected. The qualities of the thermograms produced by the LRIS are very

poor, thus makes it difficult to perform analysis.

A detailed description of defects observed by NBS as well as 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 video tapes, available thermograms and documentation. The total estimates of void areas is approximately 36 ft^2 which represents about 2% of the gross wall area. Table IIb presents the environmental conditions documented by each IR contractor. Thermograms 2-1 to 2-6 are some examples to demonstrate locations of heat loss anomalies, as they are referred to the descriptions in table IIa.

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

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors A1	A2	A3	A4	Thermogram No. in Appendix
Living Room	N	Insufficient Insulation at Ceiling		Yes	Yes	Yes	Yes	Yes	
		Sealing Problem Above NE Corner of Window	(1)	No	Yes	No	No	No	
	NE	Lack of Insulation in Ceiling and Air Leakage at Wall-Wall Joint		Yes	Yes	Yes	Yes	Yes	2-1
Southeast Bedroom	E	Air Leakage Underneath Window		Yes	No	No	No	No	
	SE	Insufficient Insulation in Ceiling and Air Leakage at Wall-Wall Joints		Yes	Yes	Yes	Yes	Yes	2-2
	S	Air Leakage Underneath Window		Yes	No	No	No	No	
Southwest Bedroom	SW	Air Leakage From Ceiling and Wall-Wall Joint		Yes	Yes	Yes	Yes	Yes	
Bathroom	W	Missing Insulation in the Entire Wall	30	Yes	Yes	No	Yes	No	2-3 2-4
		No Insulation in Floor		No	No	No	Yes	No	
Kitchen	W	Air Leakage on Both Sides of Back Door		Yes	Yes	No	No	No	2-5
		Small Voids at NW Corner	6	Yes	Yes	Yes	Yes	Yes	
		Moisture in Insulation Below Floor		No	Yes	No	No	No	
	NW	Lack of Insulation in Ceiling and Air Leakage at Wall-Wall Joint		Yes	Yes	Yes	Yes	Yes	2-6

Table IIa. Summary of Defects Observed in Atlanta House #2 (Cont'd)

Room & Orientation	Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors A1	A2	A3	A4	Thermogram No. in Appendix
Hallway W	Missing Insulation at Attic Hatch	(2)	Yes	Yes	No	No	No	
Total Wall Area of Insulation Voids Detected Given in Ft^2		36	36	36	7	36	6	

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

	Contractors A1	A2	A3	A4
Date	3-11-81	3-9-81	3-11-81	3-5-81
Time	10:10-10:40 pm	9:00-9:15 pm	10:50-11:30 pm	9:00-9:30 pm
Weather Condition	clear sky	clear	clear	partly clear
Outside Temperature	47°F	51°F	53°F	48°F
Inside Temperature	76°F	90°F	77°F	72°F
Relative Humidity	24%	35%	50%	51%
Wind Speed(MPH)	15-20	calm	calm	13
Wind Direction	NW			NW

2-1
Lack of insulation in NE ceiling of living room (by contractor A2)

2-2
Insufficient insulation in ceiling at SE corner of SE bedroom (by contractor A1)

2-3
Uninsulated W wall of bathroom (by contractor A1)

2-4
Uninsulated W wall of bathroom (by contractor A1)

2-5
Air leakage at back door, W of kitchen (by NBS)

2-6
Lack of insulation at NW corner and ceiling of kitchen (by contractor A2)

III. Atlanta House #3

This is a single story, approximately 10 years old residence whose interior dimensions are 31 ft. in length, 37 ft. in width, and 8 ft. in wall height; located in Atlanta, GA. There are totally 5 rooms as living space with an attic and a crawl space. Its exterior construction consists of wood sidings with a brick veneered front an asphalt shingle roof.

Prior to the implementation of the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the walls of this dwelling with cellulose; also to blow rockwool in the attic, and install fiberglass batts in the floor joists. After retrofitted options were completed, this dwelling was inspected by NBS personnel and IR contractors A1, A2, A3, and A4. Figure III is a sketch of voids and locations of heat loss obtained from video tapes by NBS, thermograms and documents by IR contractors.

Generally speaking, the insulation work in the wall areas of this house was considered to be fair, except some uninsulated partial bay cavities along the windows and cross braces on the east and west walls. Furthermore, air leakage from the ceiling were found at the corners, and on south and north sides. Other locations of thermal anomalies observed were penetration of cold air underneath the kitchen and living room floors, and inside the partition wall between kitchen and bathroom; indicating a possibility of heat loss due to by-pass.

Thermographic inspection by NBS was carried out for both exterior and interior of this residence. The exterior inspection revealed the phenomenon of sun loading on both south and west sides of the house. The solar patterns observed on the south wall were due to heat stored in the moisture portion of the studs; not uninsulated areas. Furthermore, the attic was warm, indicating it was well insulated. Contractors A1 and A2 employed HRIS to inspect this dwelling by producing 18 and 16 thermograms, respectively. Contractor A1 provided visual photographs as well as thermograms of identical locations to cover most defects of this house except the uninsulated wall areas of bathroom, living room, and south bedroom. Moreover, this contractor gave detailed descriptions of the thermal deficiencies of the kitchen and living room floors; and was the only one to identify the uninsulated attic hatch in the hallway. Although contractor A1 did not submit the documentation sheets supplied by NEIG, his report had detailed description of defect location and commentary to support his findings. Contractor A2 observed mostly the defective ceilings and missed about 60% of the uninsulated wall areas. This contractor did not found the thermal deficiencies of the floors neither. Contractors A3 and A4, who used LRIS for inspection by producing 12 and 7 thermograms, respectively. However, they missed a lot of thermal anomalies and observed about 15% of the defective wall areas, without identifying the cold floors. Contractor A3 did not verify with NEIG the areas within this home which were insulated and to be inspected. The qualities of the

thermograms produced by the LRIS are very poor, thus makes it difficult to perform analysis.

A detailed description of defects observed by NBS as well as 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 video tapes, available thermograms and documentation. The total estimates of void areas is approximately 52 ft^2 which represents about 6% of the gross wall area. Table IIIb presents the environmental conditions documented by each IR contractor. Thermograms 3-1 to 3-9 are some examples to demonstrate locations of heat loss anomalies, as they are referred to the descriptions in table IIIa.

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

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors A1	A2	A3	A4	Thermogram No. in Appendix
Living Room	E	Voids in 2 Partial Bay Cavities Along Both Edges of Window	10	Yes	No	No	No	No	
		Air Leakage Above Window; and at SE Corner of Wall-Wall and Wall-Floor Joints		Yes	No	Yes	No	No	
		Small Void on S of Window	2	Yes	No	Yes	No	Yes	
	S	Insufficient Insulation at Ceiling From SE Corner and Extended to Area Above Window		Yes	Yes	Yes	Yes	No	
		Small Void on E of Front Door and Air Leakage Under Front Door	2	Yes	No	No	No	No	
		Missing Insulation in 2 Floor Joints From N to S Between the Living Room Floor		Yes	Yes	No	No	No	3-1 3-2
Hallway	W	Missing Insulation at Attic Hatch	(4)	No	Yes	No	No	No	
South Bedroom	S	Small Void Along W Side of Window	3	Yes	No	No	No	No	
		Insufficient Insulation at Edge of Ceiling		Yes	No	Yes	Yes	No	
Southwest Bedroom	S	Insufficient Insulation at S Edge of Ceiling		Yes	Yes	Yes	Yes	No	3-3
	W	Small Voids at SW Corner and on S of Window	4	Yes	Yes	Yes	Yes	No	3-4

Table IIIa. Summary of Defects Observed in Atlanta House #3 (Cont'd)

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors A1	A2	A3	A	Thermogram No. in Appendix
		Insulation Void at SW Corner of Ceiling		Yes	Yes	Yes	Yes	Yes	
Northwest Bedroom	W	Some Voids at the Stud Brace at SW Corner	3	Yes	Yes	Yes	No	No	
		Small Void at NW Corner	2	Yes	Yes	Yes	No	No	
	N	Small Voids on W of Window	2	Yes	No	Yes	No	No	
		Partial Bay Cavity Along E Side of Window	4	Yes	Yes	No	No	No	
		Insufficient Insulation at N Edge of Ceiling and Air Leakage at NW Corner		Yes	Yes	Yes	Yes	Yes	
Bathroom	N	Small Voids Below Window	4	Yes	No	Yes	Yes	No	
		Insufficient Insulation in Ceiling W of Window		Yes	Yes	Yes	Yes	Yes	
Kitchen/ Dining Room	W	This Partition Wall Has Cold Air Coming From Attic, due to Missing Insulation		Yes	Yes	No	No	No	3-5 3-6 3-7
	N	Insufficient Insulation at Ceiling Along N Edge of Wall		Yes	Yes	Yes	Yes	Yes	
		Partial Bay Cavity on W of Back Door	6	Yes	Yes	No	No	No	
		Some Voids on E of Back Door and Air Leakage at NE Corner	4	Yes	No	Yes	No	No	3-8 3-9
		Missing Insulation in 1 Floor Joint		Yes	Yes	No	No	Yes	

Table IIIa. Summary of Defects Observed in Atlanta House #3 (Cont'd)

Room & Orientation	Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors A1	A2	A3	A4	Thermogram No. in Appendix
NE	Insufficient Insulation in Ceiling at NE Corner		Yes	Yes	Yes	No	Yes	
E	1 Partial Bay Cavity at N of Window & Small Voids on S of Window	6	Yes	Yes	No	No	Yes	
Total Wall Area of Insulation Voids Detected Given in Ft^2		52	52	25	21	8	8	

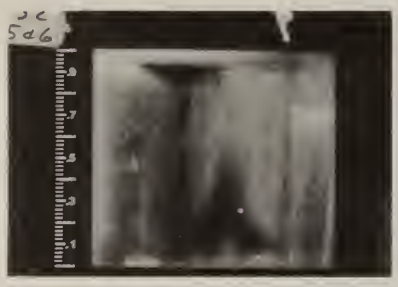
Table IIIb. Environmental Conditions During Inspections of Atlanta House #3

	Contractors A1	A2	A3	A4
Date	3-11-81	3-9-81	3-11-81	3-5-81
Time	7:15-8:30 pm	7:15-8:00 pm	8:15-9:11 pm	7:15-8:00 pm
Weather Condition	clear sky	clear	clear	partly clear
Outside Temperature	55°F	51°F	54°F	49°F
Inside Temperature	77°F	84°F	81°F	81°F
Relative Humidity	23%	35%	46%	56%
Wind Speed(MPH)	15-28	calm	5-8	14
Wind Direction	NW		NW	NW

3-1
Living room floor facing S (by contr. A1)

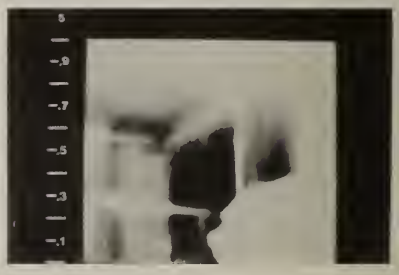
3-2
Missing insulation in living room floor (by contractor A1)

3-3
Solar patterns observed on the S wall of SW bedroom (by NBS)



3-4
Void areas on SW corner of SW bedroom (by contractor A2)

3-5
E (partition) wall of bathroom (by contractor A1)



3-6
Cold area in partition wall of 3-5 (by contractor A1)

3-7
Same cold area of 3-6 shown in the opposite side, W wall of kitchen (by NBS)

3-8
Insulation voids around back door in kitchen, interior (by NBS)

3-9
Insulation voids around back door in kitchen, exterior (by NBS)

IV. Atlanta House #4

This is a single story residence whose interior dimensions are 24 ft. in length, and 42 ft. in width; located in Atlanta, GA. There are totally 6 rooms as living space with an attic. Its exterior construction consists of brick walls and an asphalt shingle roof.

Prior to the implementation of the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the walls of this dwelling with UF foam, and to add fiberglass batts on top of the existing loose fiberglass insulation to the attic. After retrofitted options were completed, this dwelling was inspected by NBS personnel and IR contractors A1, A2, A3, and A4. Figure IV is a sketch of voids and locations of heat loss obtained from video tapes by NBS, thermograms and documents by IR contractors.

Generally speaking, the insulation work to this house was considered to be very poor, as a lot of regions was observed to have missing insulation, such as on the upper portion of the walls, and above and around the windows. Further, partial voids under the window and insufficient foam insulation or shrinkage were found on the north wall of northwest bedroom. The panel wall on the north side of the middle bedroom had low temperature differential which made it difficult to observe defects. Cold air was also leaking from the ceiling , indicating a severe problem in the attic insulation.

Thermographic inspection by NBS observed most defects of this residence except some difficulties to scan the south walls due to sun loading. NBS also locate the voids above and on east side of the window in the outside portion of the east wall of middle bedroom. None of the contractors inspected this wall which is partially an interior wall. Contractors A1 and A2 employed HRIS to inspect this dwelling by producing 11 thermograms each, mostly on defective ceilings; and they identified about 70% of the total defective wall areas. Contractor A1 provided visual photographs as well as thermograms of identical locations to exhibit the defects of this house. Although this contractor did not submit the documentation sheets supplied by NEIG, his report had detailed description of defect location and commentary to support his findings. Contractor A2 detected mostly the defective ceilings, and stated that approximately 20% of the wall areas were voided. Contractors A3 and A4, who used LRIS for inspection, located mostly the defects in the ceiling by producing 13 and 6 thermograms, respectively. Neither contractors inspected this house thoroughly as they identified between 10% and 40% of the total defective wall areas. Contractor A3 did not verify with NEIG the areas within this home which were insulated and to be inspected. The qualities of the thermograms produced by the LRIS are very poor, thus makes it difficult to perform analysis.

A detailed description of defects observed by NBS as well as 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 video tapes, available thermograms and documentation. The total estimates of void areas is approximately 221 ft^2. Since the dimensions of the windows and doors of this dwelling were not available the percentage defective wall area of the gross wall area would not be presented. Table IVb presents the environmental conditions documented by each IR contractor. Thermograms 4-1 to 4-8 are some examples to demonstrate locations of heat loss anomalies, as they are referred to the descriptions in table IVa.

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

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors A1	A2	A3	A4	Thermogram No. in Appendix
Living Room	N	Voids Above Front Door	5	Yes	Yes	Yes	Yes	Yes	4-1
		1 Bay Cavity Along E Side of Front Door	10	Yes	Yes	Yes	No	No	
		2 Upper Bay Cavities Between Door and Window	10	Yes	No	Yes	No	No	
		Voids Above Window	6	Yes	No	No	No	No	
		1 Upper Bay Cavity at NW Corner	4	Yes	Yes	Yes	Yes	No	
		Defective Insulation at Ceiling and Air Leakage at Ceiling-Wall Joint		Yes	Yes	Yes	Yes	Yes	
	NE	Missing Insulation at Ceiling & Air Leakage at Wall-Wall Joint		Yes	Yes	Yes	Yes	Yes	4-2 4-3 4-4
	E	1 Full Bay and 2 Upper Bay Cavities at NE Corner	20	Yes	Yes	Yes	No	No	
		Voids Above Window	4	Yes	No	Yes	No	Yes	
		Small Voids Scattering on E Wall Between Living Room and Dining Area	6	Yes	No	Yes	No	No	
Kitchen/ Dining Room	SE	Missing Insulation in Ceiling & Around Both Windows	16	Yes	Yes	Yes	Yes	No	
	S	Voids Above Back Door & Missing Insulation in Ceiling Above	2	Yes	Yes	No	Yes	Yes	4-5 4-6
		1 Bay Cavity Between Back Door and Window	10	Yes	No	No	No	No	

Table IVa. Summary of Defects Observed in Atlanta House #4 (cont'd)

Room	Orientation	Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors A1	A2	A3	A4	Thermogram No. in Appendix
Bathroom	S	Voids Above Window	3	Yes	Yes	Yes	Yes	No	4-7
		Voids Below Window	6	Yes	No	No	No	Yes	
		Defective Ceiling Above Window		Yes	Yes	Yes	Yes	No	
Southwest Bedroom	SW	Defective Ceiling		Yes	Yes	Yes	Yes	Yes	4-8
		2 Upper Bay Cavities on S Side	8	Yes	Yes	No	No	No	
	W	Upper Portion of the Entire Wall Uninsulated	35	Yes	Yes	Yes	No	No	
		Voids Above Window	3	Yes	No	No	Yes	No	
Northwest Bedroom	W	Missing Insulation at the Upper portion of the Wall	22	Yes	Yes	No	Yes	No	
		Defective Ceiling		Yes	Yes	Yes	Yes	Yes	
	NW	Defective Ceiling & Voids in Some Upper Bay Cavities on N	4	Yes	Yes	Yes	Yes	Yes	
	N	Voids and Shrinkage All Over the Wall	20	Yes	No	No	Yes	No	
Middle Bedroom	N	1 Full Bay and 1 Upper Bay Cavity on W of Window	14	Yes	Yes	Yes	Yes	No	
		Voids Above Window	4	Yes	Yes	Yes	No	No	
		Small Void at NE Corner	4	Yes	No	No	No	Yes	
		Defective Ceiling		Yes	Yes	Yes	Yes	Yes	

Table IVa. Summary of Defects Observed in Atlanta House #4 (cont'd)

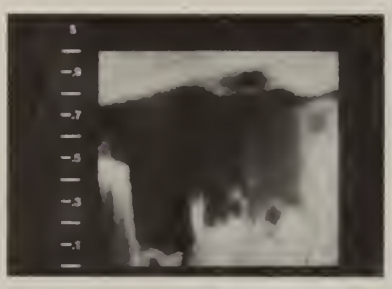
Room & Orientation	Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors A1	A2	A3	A4	Thermogram No. in Appendix
E'	Voids Above and on E Side of Window on the Portion of the Outside Wall	5	Yes	No	No	No	No	
Total Wall Area of Insulation Voids Detected Given in Ft^2		221	221	147	135	93	25	

Table IVb. Environmental Conditions During Inspections of Atlanta House #4

	Contractors A1	A2	A3	A4
Date	3-11-81	3-9-81	3-11-81	3-5-81
Time	8:50-9:35 pm	8:10-8:40 pm	9:30-10:25 pm	8:10-8:45 pm
Weather Condition	clear sky	clear	clear	partly clear
Outside Temperature	50°F	50°F	53°F	49°F
Inside Temperature	71°F	76°F	75°F	71°F
Relative Humidity	26%	35%	55%	54%
Wind Speed(MPH)	15-28	calm	5-8	13
Wind Direction	NW		NW	NW

4-1
Voids above front door, defective ceiling, and air leakage on N wall of living room (by contractor A2)

4-2
NE corner of living room (by contractor A1)



4-3
Uninsulated wall and ceiling areas at NE corner of living room (by contractor A1)

4-4
Thermal defects observed at NE corner of living room as shown in 4-3 (by NBS)

4-5
S wall of kitchen (by contractor A1)

4-6
Voids above back door and missing insulation in S ceiling of kitchen (by contractor A1)

4-7
Voids above window and defective ceiling on S wall of bathroom (by contractor A1)

4-8
Missing insulation in wall and ceiling areas on SW corner of SW bedroom (by NBS)

V. Colorado Springs House #1

This is a single story, approximately 65 years old residence whose interior dimensions are 33 ft. in length, 30 ft. in width, and 8 ft.in wall height; located in Colorado Springs, CO. There are totally 5 rooms as living space with 2 unheated porches, an attic, and a basement/crawl space. Its exterior construction consists of frame sidings and a tar paper roof.

Prior to the implementation of the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the walls and ceiling of this dwelling with cellulose, and basement/crawl-space ceiling with rockwool batts. After retrofitted options were completed, this dwelling was inspected by NBS personnel and IR contractors C1, and C2. Figure V is a sketch of voids and locations of heat loss obtained from video tapes by NBS, and from thermograms and documents by IR contractors.

In general, the insulation work to the exterior walls of this house was considered to be fair with voids above most of the windows and doors, and uninsulated bay cavities along some windows. Furthermore, the wall-to-wall joints have uninsulated corner braces at the bottom and heat loss from the eaves. However, the ceiling insulation was observed to be very poor as almost the entire ceiling was not insulated except 3 ft. from the west wall. Neither the northeast bedroom nor the northeast corner of the kitchen had any insulations in their ceilings. According to results from all inspections the area of uninsulated ceiling was estimated to be about 75% of the entire ceiling.

Thermographic inspection by NBS was carried out for both interior and exterior of this house, in two consecutive winters. Therefore, the results from both inspections would give a more accurate estimation. The exterior inspection revealed the cold basement even though the entire basement was supposed to be insulated, and also the location of heat loss from the eaves. Moreover, NBS observed some cold air leaking into the partition wall between the bathroom and the northeast bedroom from the interior inspections.

Both contractors C1 and C2 employed HRIS to inspect this dwelling and they did not provide enough hard-copy documentations to support their findings by producing 5 and 2 thermograms, respectively. Neither did they contact NEIG for areas to be inspected. They identified the defective ceiling but failed to recognize a lot of uninsulated wall areas. Besides that, contractor C1 did not follow instructions to submit documentation sheets, given by NEIG, of thermal anomalies as he only mentioned the uninsulated corner braces by including only one colored thermogram of one corner. Both thermograms provided by contractor C2 were locations of defective ceilings. The qualities of these thermograms were not clear, thus increased the uncertainties on analysis.

A detailed description of defects observed by NBS as well as 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 video tapes, thermograms, and sketches. The total estimates of void areas is approximately 65 ft^2 which represents about 9% of the gross wall area. Table Vb presents the environmental conditions documented by each IR contractor. Thermograms 5-1 to 5-5 are some examples to demonstrate locations of heat loss anomalies, as they are referred to the descriptions in table Va. The colored thermograms submitted by contractor C1 were not included due to the high cost for reproduction.

Table Va. Summary of Defects Observed In Colorado Springs House #1

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors C1	C2	Thermogram No. in Appendix
Living Room	S	Voids Above Window and Front Door	(4)	Yes	No	Yes	
		Voids in Lower SW Corner Brace	(2)	Yes	Yes	Yes	
		Air Leakage at Front Door and Infiltration at SW Corner		Yes	Yes	Yes	
	W	Small Voids Above and Misses Below Window	3	Yes	No	No	
		Voids in Lower SW Corner Brace	2	Yes	Yes	Yes	
		Lack of Insulation in Ceiling Beginning Three Feet From The W Wall		Yes	Yes	Yes	5-1 5-2
Northwest Bedroom	W	Voids Above Window and in 1 Whole Bay Cavity at N of Window	12	Yes	No	Yes	
		Voids in Lower NW Corner Brace	2	Yes	No	Yes	5-3 5-4
		Lack of Insulation in Ceiling Beginning Three Feet From W Wall		Yes	Yes	Yes	5-5
	N	Voids in Lower NW Corner Brace	2	Yes	No	Yes	
		Voids Above Window & on E Side of Window	10	Yes	No	Yes	
		Defective Ceiling		Yes	Yes	Yes	
Bathroom	N	Missing Insulation Above & Below Window, and in 1 Whole Bay Cavity at NE Corner	14	Yes	No	No	

Table Va. Summary of Defects Observed In Colorado Springs House #1 (Cont'd)

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors C1	C2	Thermogram No. in Appendix
	E	Air Penetration in Bay Cavity and Some Partial Bays of the Partition Wall	1 (12)	Yes	No	No	
		Defective Ceiling		Yes	Yes	Yes	
Northeast Bedroom	N	Small Voids in Bay Cavities at NE Corner and at the W of Window	3	Yes	Yes	Yes	
		Defective Ceiling		Yes	Yes	Yes	
	E	Small Voids at S of Window	1	Yes	No	No	
		Cold Spot on Ceiling		Yes	No	No	
Kitchen	E	Voids Above S Window	2	Yes	No	No	
		Some Cold Spots		Yes	Yes	No	
	S	Voids Above Window and in 1 Whole Bay Cavity at W of Window	14	Yes	No	No	
		Uninsulated Ceiling		Yes	Yes	Yes	
Total Wall Area of Insulation Voids Detected Given in Ft^2			65	65	5	31	

Table Vb. Environmental Conditions During Inspections of Colorado Springs House #1

	Contractors C1	C2
Date	3-9-81	3-16-81
Time	10:00 - 11:30 pm	9:00 - 9:50 pm
Weather Condition	clear sky & calm wind	partly cloudy
Outside Temperature	33°F	46°F
Inside Temperature	65°F	70°F
Relative Humidity	below 20%	33%
Wind Speed(MPH)	calm	0

5-1
Lack of insulation in living room ceiling (by contractor C2)

5-2
Lack of insulation in living room ceiling facing W (by NBS)

5-3
Voids in NW corner brace of NW bedroom shown in interior thermogram (by NBS)

5-4
Voids in NW corner of NW bedroom shown in exterior thermogram (by NBS)

5-5
Lack of insulation ceiling of NW bedroom (by NBS)

VI. Colorado Springs House #2

This is a two-story, approximately 40 years old residence whose interior dimensions are 38 ft. in length, 28 ft. in width, 9 ft. in wall height on the first floor, and 7.4 ft. in wall height on the second floor; located in Colorado Springs, CO. There are totally 6 rooms as living space with an unheated porch, an attic, and a crawl space. Its exterior construction consists of frame sidings and an asphalt shingle roof.

Prior to the implementation of the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the walls and ceilings of this dwelling with cellulose, and the floor joists with fiberglass batts. After retrofitted options were completed, this dwelling was inspected by NBS personnel and IR contractors C1, and C2. Figure VI is a sketch of voids and locations of heat loss obtained from video tapes by NBS, and from thermograms and documents by IR contractors.

In general, the insulation work to the exterior walls of this house was considered to be quite poor as voids above most of the windows and doors, and uninsulated bay cavities were observed at wall-to-wall joints. The bath room on the first floor was shown to have a defective ceiling as well as several uninsulated partial bay cavities on both the south and east walls. The insulation work on the second floor was even worse as the entire pitched ceiling and regions behind the kneewalls were found to be void of insulation. Moreover, heat loss from the eaves, uninsulated bay cavities on east and west walls and corner braces, were also observed from inspections upstairs.

Thermographic inspection by NBS was carried out for both interior and exterior of this house, in two consecutive winters. Therefore, the results from both inspections would give a more accurate estimation. The exterior inspection revealed the warm attic with leaking eaves, and the uninsulated bay cavities at wall-to-wall joints, which were not detected from interior inspections. Moreover, NBS also observed some warm air leaking down into the uninsulated crawl space from the exterior inspections.

Both contractors C1, and C2 employed HRIS to inspect this dwelling and they did not provide enough hard-copy documentations to support their findings by producing 1 and 2 thermograms, respectively. Neither did they contact NEIG for areas to be inspected. They gave general information of the defective ceiling and kneewalls without any detailed descriptions by submitting one thermogram each, but failed to recognize a lot of uninsulated wall areas on the second floor. Besides that, contractor C1 did not follow instructions to submit documentation sheets, given by NEIG, of thermal anomalies as he only mentioned the uninsulated regions of the kitchen, the bathroom, and the southeast bedroom on the first floor. Contractor C2 did not inspect the bathroom and submitted thermograms with poor qualities, thus increased the

uncertainties on analysis.

A detailed description of defects observed by NBS as well as IR 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 video tapes, thermograms, and sketches. The total estimates of void areas is approximately 230 ft^2 which represents about 17% of the gross wall area. Table VIb presents the environmental conditions documented by each IR contractor. Thermograms 6-1 to 6-6 are some examples to demonstrate locations of heat loss anomalies, as they are referred to the descriptions in table VIa. The colored thermograms submitted by contractor C1 were not included due to the high cost for reproduction.

Table VIa. Summary of Defects Observed in Colorado Springs House #2

Room & Orientation		Description of Defects	Defective Wall Area In Ft^2	Observed by NBS	Contractors C1	C2	Thermogram No. in Appendix
First Floor:							
Living Room	S	Voids Above Window & in 1 Bay Cavity on East of Window; Air Infiltration at SW Corner	12	Yes	No	No	
	W	Voids Above Window and Above Door;	6	Yes	No	Yes	
		Air Leakage Underneath Door and at Side of Door and Window		Yes	Yes	No	
Dining Room	W	Voids at Top of Several Bays & Partial Void of 1 Bay Cavity at NW Corner	10	Yes	No	Yes	
		Voids Below Window	3	Yes	No	No	
	N	Voids Above and Below Window	4	Yes	No	No	
		1 Bay Cavity Missed Completely (From Exterior Inspection)	12	Yes	No	No	
Kitchen	N	Voids in Bay Cavities Behind Cabinets and Counter Tops	8	Yes	Yes	Yes	6-1 6-2
		Missing Insulation Also Found Below Ceiling & Below Window on E Side of Cabinets	6	Yes	Yes	No	
	E	Missing Insulation in the 1st Bay of NE Corner; Air Leakage Around Door and on S Side of Window	3	Yes	No	No	

Table VIa. Summary of Defects Observed in Colorado Springs House #2 (Cont'd)

Room & Orientation		Description of Defects	Defective Wall Area In Ft^2	Observed by NBS	Contractors C1	C2	Thermogram No. in Appendix
Southeast Bedroom	E	Voids at Top of Several Bays and in 1 Whole Bay Cavity Behind the Electric Box Outside	16	Yes	Yes	Yes	6-3
	S	Voids Above & Below Window, and 1 Whole Bay Cavity on E Side of Window	18	Yes	No	No	
Bathroom	E	1 Whole Bay and 2 Partial Bays Found Uninsulated From Exterior Inspections	24	Yes	Yes	No	6-4
	S	Voids in Several Bay Cavities	10	Yes	Yes	No	
		Defective Ceiling		Yes	No	No	
Second Floor:							
Utility Room	N	Voids Above Window & on W Side of Window	3	Yes	No	No	
		Lack of Insulation at Ceiling		Yes	No	No	
	E	Closet Found Uninsulated Inside	15	Yes	No	No	
East Bedroom	N	Missing Insulation at Upper Corners & on W Side of Attic Door of Knee-Wall	4	Yes	Yes	Yes	
		Lack of Insulation in Sloped Ceiling		Yes	Yes	Yes	
	E	Voids in 1 Bay at NE Corner and Below the Sloped Ceiling	8	Yes	Yes	Yes	6-5

Table VIa. Summary of Defects Observed in Colorado Springs House #2 (Cont'd)

Room & Orientation		Description of Defects	Defective Wall Area In Ft^2	Observed by NBS	Contractors C1	C2	Thermogram No. in Appendix
	S	Several Uninsulated Bay Cavities Found in Knee-Wall	18	Yes	Yes	Yes	6-6
		Lack of Insulation in Sloped Ceiling, (Showing Sun Loading)		Yes	Yes	Yes	
Stairwell	S	Voids in 2 Partial Bays	4	Yes	No	No	
West Bedroom	S	Voids in Corner Brace at SW Corner	4	Yes	Yes	Yes	
		Uninsulated Opening for Batt Insulation Behind Knee-Wall	7	Yes	Yes	Yes	
		Lack of Insulation in Sloped Ceiling		Yes	Yes	Yes	
	W	Voids in 2 Bay Cavities and Under Sloped Ceiling, Also in Some Partial Bays	18	Yes	Yes	Yes	
	N	Voids in 1st 2 Bay Cavities From W Corner	10	Yes	Yes	Yes	
		Uninsulated Opening for Batt Insulation Behind Knee-Wall	7	Yes	Yes	Yes	
		Lack of Insulation in Sloped Ceiling		Yes	Yes	Yes	
Total Wall Area Of Insulation Voids Detected Given in Ft^2			230	230	140	116	

Table VIb. Environmental Conditions During Inspections of Colorado Springs House #2

	Contractors C1	C2
Date	3-10-81	3-16-81
Time	10:00 - 11:30 pm	8:15 - 8:50 pm
Weather Condition	clear sky & calmwind	partly cloudy
Outside Temperature	27°F	48°F
Inside Temperature	53°F	61°F
Relative Humidity	below 20%	30%
Wind Speed(MPH)	calm	0

Thermal Anomalies Observed in Colorado Springs House #2

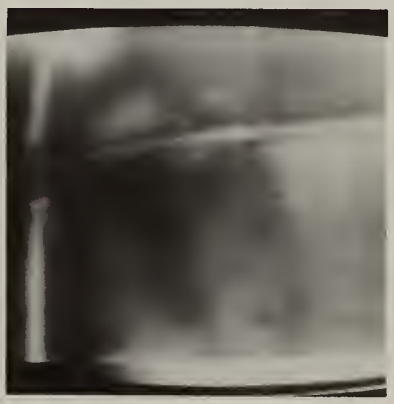
6-1
Void on N rear wall of kitchen (by NBS)

6-2
Poor quality of documantation to show defects on N wall of kitchen (by contractor C2)

6-3
Voids in one bay cavity and upper E wall of SE bedroom (by NBS)

6-4
Insulation voids in three bay areas on E wall of bathroom shown in exterior thermogram (by NBS)

6-5
Defective pitched ceiling and insulation voids in E wall at NE corner of E bedroom on the second floor (by NBS)



6-6
Defetive pitched ceiling and insulation voids in wall area on S of E bedroom (by NBS)

VII. Colorado Springs House #3

This is a single story, approximately 15 years old residence whose interior dimensions are 32 ft. in length, 30 ft. in width, and 8 ft. in wall height; located in Colorado Springs, CO. There are totally 5 rooms as living space with a garage, an attic, and a finished basement. Its exterior construction consists of frame sidings and an asphalt shingle roof.

Prior to the implementation of the weatherization program, this residence was insulated with 2" fiberglass batt insulation. An insulation contractor was instructed to add UF foam to the walls, and cellulose to the attic on top of the existing insulations of this dwelling. Also, he was to insulate the basement walls with fiberglass batts to about 3 ft. below grade. After retrofitted options were completed, this dwelling was inspected by NBS personnel and IR contractors C1, and C2. Figure VII is a sketch of voids and locations of heat loss obtained from video tapes by NBS, and from thermograms and documents by IR contractors.

Since UF foam was blown into the walls on top of the existing batt insulation, different density levels of insulations were shown from the inspections of the wall areas. In general, the insulation work to the exterior walls of this house was considered to be poorly done as a lot of regions in the south wall were observed with foam insulation hung up, indicating shrinkage or missing insulations. Furthermore, air leakage from ceiling on both east and west sides of the house exhibited the same patterns as in the south wall. The north wall of the living room is facing the garage which was not insulated. Mottled areas found over the entire wall might be due to the low temperature differential. This wall will be excluded from calculations of defective wall areas because it is not an exterior wall. Also, the corner at the garage door was observed to have air leakage. The basement walls also exhibited some voids above and around the windows and the entire bathroom wall was found to be uninsulated. The insulation contractor was supposed to open the basement walls and install fiberglass batt insulations in them. Therefore, these thermal deficiencies indicated the insulation work was questionable. The basement walls will form seperate calculation from the defective wall areas on the main floor.

Thermographic inspection by NBS was carried out for both interior and exterior of this house, in two consecutive winters. Therefore, the results from both inspections would give a more accurate estimation. The exterior inspection showed that the attic was insulated very well. However, it also revealed the warm brick foundation on the west side, indicating the possibility of heat loss through by-pass.

Both contractors C1, and C2 employed HRIS to inspect this dwelling and they did not provide enough hard-copy documentations to support their findings by producing 5 and 2 thermograms, respectively. Neither did they contact NEIG for areas to be inspected. It seemed that both contractors had trouble to determine the defects of the walls from the different density levels of insulations as they recorded mostly ceiling defects and infiltrations, and failed to report foam shrinkage or voids of the walls of the main floor. Contractor C1 did not follow instructions to submit documentation sheets, given by NEIG, of thermal anomalies as he identified only 20% of the defective wall areas on the main floor and located about half of the voids in the basement with colored thermograms. Contractor C2 inspected the entire basement and found all the thermal deficiencies. However, he only located about 40% of the defective wall areas on the main floor.

A detailed description of defects observed by NBS as well as 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 video tapes, thermograms, and sketches. The total estimates of void areas is approximately 111 ft^2 which represents about 17% of the gross wall area. Table VIIb presents the environmental conditions documented by each IR contractor. Thermograms 7-1 to 7-6 are some examples to demonstrate locations of heat loss anomalies, as they are referred to the descriptions in table VIIa. The colored thermograms submitted by contractor C1 were not included due to the high cost for reproduction.

Table VIIa. Summary of Defects Observed in Colorado Springs House #3

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors C1	C2	Thermogram No. in Appendix
Front Entrance	W	Small Void Above and Air Infiltration Around Front Door	1	Yes	No	No	
Living Room	W	Voids Below Window and Mottled Area Over the Entire Wall	15	Yes	No	Yes	
Ceiling		Cold Pattern at Wall-Ceiling Joint Indicating Uninsulated Eave Vent, or Air Currents Under the Insulation		Yes	Yes	Yes	7-1 7-2
	N	Mottled Area Over the Entire Wall.(Excluded in Area Calculation)		Yes	No	No	
		Cold Corner at Garage Door and Air Leakage at Wall-Floor Joint					7-3
Kitchen	N	Small Void or Air Leakage Above and on W of Side Door	3	Yes	No	No	
	E	Partial Voids at Lower N Corner, Around the Cabinets and Above Window	12	Yes	Yes	Partial	
Ceiling		Cold Pattern at Wall-Ceiling Joint Indicating Uninsulated Eave Vent or Air Penetration Under the Insulation		Yes	Yes	Yes	
Bathroom	E	Voids Above Window and Void or Shrinkage Below Window	4	Yes	No	Yes	

Table VIIa. Summary of Defects Observed in Colorado Springs House #3 (Cont'd)

Room & Orientation	Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors C1	C2	Thermogram No. in Appendix
Southeast E Bedroom	Voids Above Window, Missing Insulation, Shrinkage or Fissures on Both Sides of Window	12	Yes	Yes	Yes	
Ceiling	Cold Pattern at Wall-Ceiling Joint Indicating Uninsulated Eave Vent,-		Yes	No	Yes	
	or Air Penetration Under Insulation		Yes	Yes	Yes	
S	Missing Foam, Shrinkage, or Fissures Over the Entire Wall	30	Yes	No	No	7-4
	Heat Loss at Both Corners of Wall-Wall Joints and Also at Wall-Floor Joint		Yes	Yes	No	
Southwest S Bedroom	Missing Foam, Shrinkage or Fissures, Over the Entire Wall	15	Yes	No	No	7-5
	Voids at Lower E Corner	2	Yes	No	Yes	
	Heat Loss at Both Corners of Wall-Wall Joints		Yes	Yes	No	
W	1 Partial Bay Cavity and Voids on Top at S of Window	9	Yes	No	Yes	
	Some Voids on N of, and Below Window	8	Yes	No	No	
	Heat Loss at SW Corner of Wall-Wall and Wall-Floor Joints		Yes	Yes	No	7-6

Table VIIa. Summary of Defects Observed in Colorado Springs House #3 (Cont'd)

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors C1	C2	Thermogram No. in Appendix
Ceiling		Cold Pattern at Wall-Ceiling Joint Indicating Uninsulated Eave Vent or Air Penetration Under Insulation		Yes	Yes	Yes	
Total Wall Area of Insulation Voids Detected Given in Ft^2			111	111	24	52	
Basement	W	Small Void at S Corner	2	Yes	No	Yes	
Family Room		Missing Insulation on Both Sides of Windows	6	Yes	Yes	Yes	
	N	1 Bay Cavity at W Corner	3	Yes	No	Yes	
Bathroom	E	No Insulation on the Entire Wall	5	Yes	No	Yes	
Bedroom	E	Voids Above Window	2	Yes	Yes	Yes	
Total Wall Area of Insulation Voids Detected Given in Ft^2 (basement)			18	18	8	18	

Table VIIa. Summary of Defects Observed in Colorado Springs House #3 (Cont'd)

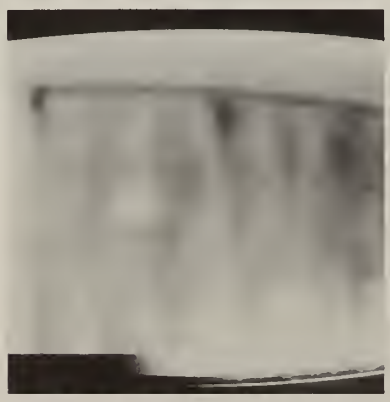
Room & Orientation	Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors C1	C2	Thermogram No. in Appendix
Southeast E Bedroom	Voids Above Window, Missing Insulation, Shrinkage or Fissures on Both Sides of Window	12	Yes	Yes	Yes	
Ceiling	Cold Pattern at Wall-Ceiling Joint Indicating Uninsulated Eave Vent,-		Yes	No	Yes	
	or Air Penetration Under Insulation		Yes	Yes	Yes	
S	Missing Foam, Shrinkage, or Fissures Over the Entire Wall	30	Yes	No	No	7-4
	Heat Loss at Both Corners of Wall-Wall Joints and Also at Wall-Floor Joint		Yes	Yes	No	
Southwest S Bedroom	Missing Foam, Shrinkage or Fissures, Over the Entire Wall	15	Yes	No	No	7-5
	Voids at Lower E Corner	2	Yes	No	Yes	
	Heat Loss at Both Corners of Wall-Wall Joints		Yes	Yes	No	
W	1 Partial Bay Cavity and Voids on Top at S of Window	9	Yes	No	Yes	
	Some Voids on N of, and Below Window	8	Yes	No	No	
	Heat Loss at SW Corner of Wall-Wall and Wall-Floor Joints		Yes	Yes	No	7-6

7-1
Defective ceiling at W of living room (by NBS)

7-2
Defective ceiling as shown in 7-1 (by contractor C2)

7-3
Air leakage at corner of garage on E side (by NBS)

7-4
Shrinkage of foam insulation on S wall of SE bedroom (by NBS)



7-5
Shrinkage of foam insulation on S wall of SW bedroom (by NBS)

7-6
Warm brick foundation on W side indicating by-pass heat loss (by NBS)

VIII. Colorado Springs House #4

This is a single story, approximately 70 years old residence whose interior dimensions are 34 ft. in length, 18 ft. in width, 8 ft. in wall height; located in Colorado Springs, CO. There are totally 5 rooms as living space with an attic, an unheated porch, and a crawl space. Its exterior construction consists of frame sidings and an asphalt shingle roof.

Prior to the implementation of the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the upper walls and ceiling of this dwelling with cellulose, lower walls with UF foam, and the crawl space with fiberglass batts. After retrofitted options were completed, this dwelling was inspected by NBS personnel and IR contractors C1, and C2. Figure VIII is a sketch of voids and locations of heat loss obtained from video tapes by NBS, and from thermograms and documents by IR contractors.

In general, the insulation work to the exterior walls of this house was considered to be quite poor as voids above most of the windows and doors, and uninsulated bay cavities were observed along the windows and at wall-to-wall joints. Furthermore, the UF foam in the lower part of the living room walls exhibited shrinkage, or the original insulation work was poorly done that it never reached the bottom of the cellulose insulation.

Thermographic inspection by NBS was carried out for both interior and exterior of this house, in two consecutive winters. Therefore, the results from both inspections would give a more accurate estimation. The exterior inspection revealed the uninsulated bay cavities in south wall of kitchen, which were not detected from the interior inspection due to the obstruction by the cabinets. Moreover, NBS also observed some warm air leaking down into the uninsulated crawl space from the exterior inspections.

Both contractors C1, and C2 employed HRIS to inspect this dwelling and they did not provide enough hard-copy documentations by producing 4 and 2 thermograms, respectively. Neither did they contact NEIG for areas to be inspected. They identified the regions of missing insulation between the UF foam and the cellulose, and other areas of thermal deficiencies. However, they failed to observe some locations of heat loss, and detected between 50 to 80 percent of the total defective wall areas. Besides that, contractor C1 did not follow instructions to submit documentation sheets, given by NEIG, of thermal anomalies as he only included colored thermograms showing the defects of the living room. Contractor C2 submitted thermograms with poor qualities, thus increased the uncertainties on analysis.

A detailed description of defects observed by NBS as well as IR contractors is summarized in table VIIIa. Besides 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 video tapes, thermograms, and sketches. The total estimates of void areas is approximately 124 ft^2 which represents about 21% of the gross wall area. Table VIIIb presents the environmental conditions documented by each IR contractor. Thermograms 8-1 to 8-6 are some examples to demonstrate locations of heat loss anomalies, as they are referred to the descriptions in table VIIIa. The colored thermograms submitted by contractor C1 were not included due to the high cost of reproduction.

Table VIIIa. Summary of Defects Observed in Colorado Springs House #4

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors C1	C2	Thermogram No. in Appendix
Living Room	N	1 Bay Cavity at W Corner and a Half Bay Cavity on E of Window	15	Yes	Yes	Yes	8-1 8-2
		Missing Foam at Upper Part of the Bottom Portion of the Entire Wall	16	Yes	Yes	Yes	
		Small Void at Top	2	Yes	No	Yes	8-3
		Air Leakage at E Corner		Yes	No	Yes	
	E	Voids Above N Window, Above and on E of Front Door	8	Yes	Yes	Yes	
		Missing Insulation in 2 Upper Bay Cavities At S Corner	10	Yes	Yes	Yes	
Dining Room	S	1 Bay Cavity at W Corner and Voids Above Window	12	Yes	No	Yes	
Kitchen	S	Voids Above Window and Above Cabinet	4	Yes	Yes	Yes	
		Partial Bay Cavities at Edges of Window, and on W of Window	15	Yes	No	Yes	8-4
	W	Small Voids Above Side Door and Above Window	4	Yes	No	Yes	8-5
		Air Leakage Around Side Door		Yes	No	No	
Bedroom	W	Voids Around Electric Outlet on S	4	Yes	Yes	Yes	

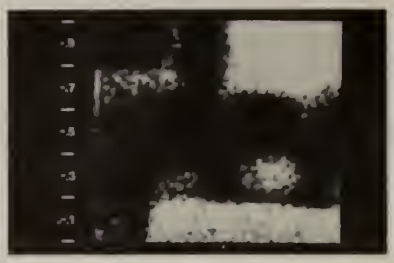
Table VIIIa. Summary of Defects Observed in Colorado Springs House #4 (cont'd)

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors C1	C2	Thermogram No. in Appendix
		Missing Insulation on S of Window	6	Yes	No	Yes	
		Air Leakage at Lower N Corner		Yes	No	No	
	N	1 Bay Cavity at W Corner	10	Yes	No	Yes	8-6
		Partial Voids Above Window	4	Yes	No	Yes	
		Voids Along Both Sides of Window	6	Yes	No	No	
Bathroom	N	Voids Above and Along E Side of Window, and on Lower E of Window	8	Yes	Yes	No	
Total Wall Area of Insulation Voids Detected Given in Ft^2			124	124	66	110	

Table VIIIb. Environmental Conditions During Inspections of Colorado Springs House #4

	Contractors C1	C2
Date	3-10-81	3-16-81
Time	7:30 - 9:30 pm	6:15 - 7:20 pm
Weather Condition	clear sky & calm wind	partly cloudy with intermittent slight breeze
Outside Temperature	33°F	54°F
Inside Temperature	81°F	76°F
Relative Humidity	below 20%	31%
Wind Speed(MPH)	calm	0-3
Wind Direction		W

8-1
Missing insulation in upper wall, shrinkage of foam in lower wall on NW of living room (by NBS)



8-2
Defects in N wall of living room as shown in 8-1 (by contractor C2)

8-3
Shrinkage of foam in lower wall and small void above on NE of living room (NBS)

8-4
Uninsulated bay cavities on S of kitchen shown in exterior thermogram (by NBS)

8-5
Defective areas on W side shown in exterior thermogram (by NBS)

8-6
Missing insulation on N wall of bedroom (by NBS)

IX. Minneapolis-St. Paul House #1

This is a two-story residence located in Minneapolis-St. Paul, MN. There are totally 5 and 4 rooms as living space on the first and second floors, respectively, with an attic and an unheated porch.

Prior to the implementation of the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the sidewalls and the attic of this dwelling with cellulose. After retrofitted options were completed, this dwelling was inspected by NBS personnel and IR contractors M1, M2, M3, and M4. Figure IX is a sketch of voids and location of heat losses obtained from video tapes by NBS, thermograms and documents by IR contractors.

In general, the insulation work in the wall areas of this house was considered to be fair except the completely uninsulated east wall of the kitchen, and some voids around the windows and at wall-to-wall joints. However, the insulation work in the attic was not too good as defective pitched ceilings were observed. Furthermore, both the bathroom and the kitchen on the first floor were found to have cold air leaking from their ceilings. Other locations of thermal anomalies included air penetration into the partition walls in the north wall of the west bedroom on the first floor and in the east wall of the living room on the second floor.

Thermographic inspection by NBS was carried out for both interior and exterior of this dwelling and observed most defects except the partition wall in the west bedroom on the first floor. Contractors M1, M2, and M3 employed HRIS to observe defects in this dwelling by producing thermograms and visual photographs of identical locations. Both contractor M1 and M2 failed to recognize the uninsulated east wall of the kitchen. Even though they provided 19 and 18 thermograms, respectively, they only identified between 20 to 30 percent of the total defective wall areas. Contractor M1 inspected this house with two different pieces of equipment (a raster scanner and a HRIS with data on video tapes) and submitted hard-copy photographs of the results from both systems. However, the quality of the hard copies made from the video tapes was not good enough to identify locations of heat loss, only could be used as supporting materials. This contractor also stated that video tapes from the inspection were available for analysis. However, he still missed a lot of uninsulated areas. Neither did contractors M2 and M3 submitted the documentation sheets supplied by NEIG, but their reports had description of defect locations and comments to support their findings. Contractor M3 provided 18 thermograms and was the only contractor who identified the uninsulated east wall in the kitchen. Contractor M4 who used the LRIS to inspect this dwelling seemed to have trouble to locate thermal defects of this house. Although this contractor provided 10 thermograms he observed less than 15% of the total defective wall areas. The qualities of the thermograms produced by the LRIS are very poor in contrast, thus

makes it difficult to perform analysis.

A detailed description of defects observed by NBS as well as IR contractors is summarized in table IXa. According to NEIG, all IR contractors were supposed to contract NEIG prior to performing IR inspections to verify areas to be inspected. However, contractors M2 and M4 failed to follow this particular instruction. This might be one of the reasons that they did not recognize a lot of thermal deficiencies. Besides the total defective wall area in ft^2 found by each inspection, table IXa also includes the defective wall areas in ft^2 of each room of the house, analyzed from video tapes, available thermograms and documentations. The total estimates of void areas is approximately 157 ft^2. Table IXb presents the environmental conditions documented by each IR contractor. Thermograms 9-1 to 9-16 are some examples to demonstrate locations of heat loss anomalies, as they are referred to the descriptions in table IXa.

Table IXa. 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 M1	M2	M3	M4	Thermogram No. in Appendix
First Floor:									
Living Room	N	Small Void Under Ceiling	1	Yes	Yes	Yes	No	No	
	E	Small Void Above N Window and Heavy Infiltration at NE Corner	1	Yes	No	No	Yes	No	
	S	Small Void Above Front Door to Porch (Excluded)	(2)	Yes	Yes	Yes	Yes	No	
Southwest Bedroom	S	Missing Insulation Below Windows & Area Between Windows	8	Yes	No	No	No	No	
	SW	Void Above W Window at SW Corner	2	Yes	No	No	Yes	Yes	
		1 Partial Bay Cavity and Air Leakage at SW Corner	8	Yes	No	Yes	No	No	9-1 9-2
West Bedroom	W	Void Above Window	5	Yes	Yes	Yes	Yes	No	
		Air Leakage From Ceiling		Yes	No	Yes	Yes	No	
	N	Some Air Penetration in Partition Wall at NE Corner		No	No	No	Yes	No	
Bathroom	W	Voids Above Window & Along N Side Half Way Down	4	Yes	No	No	Yes	No	
		Some Defects in Ceiling Insulation and Air Leakage From Ceiling		Yes	No	Yes	Yes	No	
Kitchen	N	Air Penetration From Floor Under Cabinet		Yes	No	Yes	No	No	9-3 9-4

Table IXa. Summary of Defects Observed in Minneapolis-St. Paul House #1 (Cont'd)

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors M1	M2	M3	M4	Thermogram No. in Appendi
	E	Missing Insulation in the Entire Wall With Air Infiltration Along Side Door and Window	90	Yes	No	No	Yes	No	9-5 9-6 9-7
		Large Area of Uninsulated Ceiling		Yes	No	Yes	Yes	No	
Second Floor:									
Living Room	E	Some Air Leakage at Corner of Stairwell		Yes	No	No	No	No	
	S	1 Partial Bay Cavity at SE Corner	5	Yes	Yes	No	Yes	Yes	9-8
		Small Voids Above Window and 1 Partial Bay Cavity on W of Window	5	Yes	Yes	No	Yes	No	
	SW	Small Void at Corner	3	Yes	Yes	Yes	Yes	No	
	W	Void at Top Under Pitched Ceiling and Also Defective Ceiling	5	Yes	Yes	Yes	Yes	No	9-9
	NW	Missing Insulation and Air Infiltration at Ceiling-Wall Joint	4	Yes	Yes	Yes	Yes	Yes	
West Bedroom	W	Void Above Window	2	Yes	Yes	Yes	Yes	Yes	
		Missing Insulation at Pitched Ceiling		Yes	Yes	Yes	Yes	No	
Bathroom	NW	Air Infiltration From Ceiling		Yes	Yes	Yes	No	No	
	N	Voids Above Window & along Both Sides of Window	6	Yes	Yes	Yes	No	No	9-10

Table IXa. Summary of Defects Observed in Minneapolis-St. Paul House #1 (Cont'd)

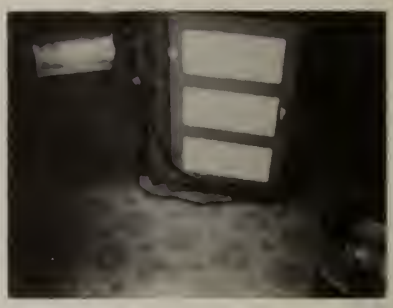
Room & Orientation	Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors M1	M2	M3	M4	Thermogram No. in Appendix
Kitchen NW	Void in Lower Portion of Corner	8	Yes	No	Yes	Yes	Yes	9-11 9-12 9-13
NE	Defective Pitched Ceiling		Yes	Yes	Yes	Yes	Yes	9-14 9-15
E	Air Infiltration From Pitched Ceilings		Yes	Yes	Yes	Yes	Yes	
Total Wall Area of Insulation Voids Detected Given in Ft^2		157	157	36	42	134	21	

Table IXb. Environmental Conditions During Inspections of Minneapolis - St. Paul House #1

	Contractors M1	M2	M3	M4
Date	3-19-81	3-2-81	3-11-81	3-3-81
Time	8:31-9:30 pm	11:05 am-12:20 pm	8:18-9:30 am	11:30 am-1:30 pm
Weather Condition	clear	clear	clear	partly clear
Outside Temperature	34°F	25°F	34°F	28°F
Inside Temperature	70°F	77°F	67°F	68°F
Relative Humidity	62%	71%	62%	30%
Wind Speed(MPH)	2	calm	2-3	10-12
Wind Direction	N		NW	S

9-1
Partial bay cavity at SW corner of SW bedroom on 1st floor (contr.M2)

9-2
Partial bay cavity at SW corner shown in 9-1 (by contractor M2)



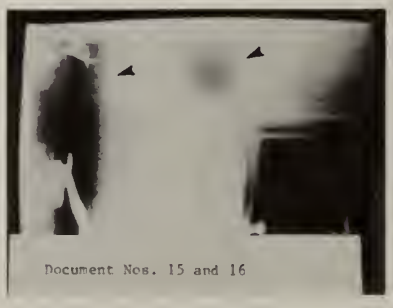
9-3
area under cabinet N of kitchen on 1st floor (by contr.M2)

9-4
Air penetration from floor under cabinet, N of kitchen on 1st floor (by contractor M2)

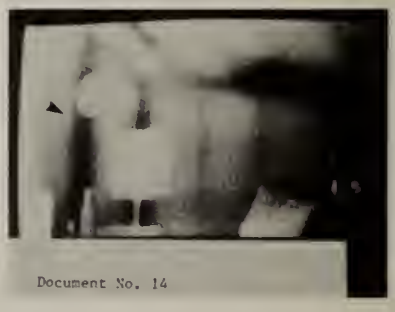
9-5
E wall of kitchen on first floor (by contractor M2)

9-6
Uninsulated E wall of kitchen on first floor (by contr.M3)

9-7
Void areas above window in E wall of kitchen on 1st floor (by contr.M2)



9-8
Uninsulated bay cavity and voids above window at SE corner of living room on 2nd floor (by contractor M1)

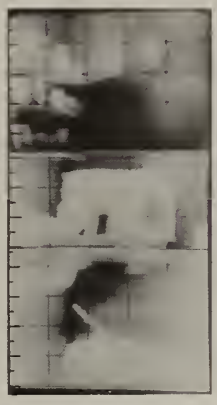


9-9
Unisulated bay cavities and defective pitched ceiling at SW corner of living room on 2nd floor (contr.M1)

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

9-10
Voids above window and defective pitched ceiling in N wall of bathroom on 2nd floor (by NBS)

9-11
N wall (with junction box) of kitchen on 2nd floor (by contractor M3)



9-12
Cold area of junction box in 9-11, shown in interior thermogram (contractor M3)

9-13
Cold area of junction box in 9-11, shown in ext. thermogram (by NBS)

9-14
Uninsulated bay cavity in pitched ceiling at NE corner of kitchen on 2nd floor (by contractor M2)

9-15
Uninsulated bay cavity in pitched ceiling at NE corner of kitchen on 2nd floor (by contractor M2)

X. Minneapolis-St. Paul House #2

This is a two-story residence located in Minneapolis-St. Paul, MN. There are totally 7 rooms as living space on the second floor with an attic. The first floor was not included as area of IR inspection for the contractors, thus no comparison of results on the first floor will be performed.

Prior to the implementation of the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the sidewalls and the attic of this dwelling with cellulose. After retrofitted options were completed, this dwelling was inspected by NBS personnel and IR contractors M1, M2, M3, and M4. Figure X is a sketch of voids and location of heat losses obtained from video tapes by NBS, thermograms and documents by IR contractors.

In general, the insulation work in the wall areas of this house was considered to be fairly good except some voids above the windows and doors, and slight air infiltration at some wall-to-wall and wall-to-ceiling joints. The insulation work in the attic was also good with only a small area in the north bedroom ceiling found to have non-uniform application of insulations.

Thermographic inspection by NBS was carried out for both interior and exterior of this dwelling and observed most defects except the the voids in the north wall of the north bedroom; and air protection in the partition walls at north of kitchen and at east of southeast bedroom. Furthermore, NBS included the inspection of the first floor. Contractors M1, M2, and M3 employed HRIS to observe defects in this dwelling by producing thermograms and visual photographs of identical locations. Both contractor M1 and M2, who provided 8 and 5 thermograms, respectively, did not inspect the north bedroom and failed to recognize the uninsulated areas on the east exterior wall of the house. Contractor M1 inspected this house with two different pieces of equipment (a raster scanner and a HRIS with data on video tapes) and submitted hard-copy photographs of the results from both systems. However, the quality of the hard copies made from the video tapes was not good enough to identify locations of heat loss, only could be used as supporting materials. This contractor also stated that video tapes from the inspection were available for analysis. However, he still missed a lot of uninsulated areas. Neither did contractors M2 and M3 submit the documentation sheets supplied by NEIG, but their reports had description of defect locations and comments to support their findings. Contractor M3 provided 11 thermograms and observed all the major defects of this house except a small void on the southwest corner of the north bedroom west wall. Contractor M4 used the LRIS to inspect this dwelling by including 7 thermograms, and identified about 50% of the total defective wall areas. The qualities of the thermograms produced by the LRIS are very poor in contrast, thus makes it difficult to perform analysis.

A detailed description of defects observed by NBS as well as IR contractors is summarized in table Xa. According to NEIG, all IR contractors were supposed to contract NEIG prior to performing IR inspections to verify areas to be inspected. However, contractors M2 and M4 failed to follow this particular instruction. This might be one of the reasons that they did not recognize a lot of thermal deficiencies. 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 video tapes, available thermograms, and documentations. The total estimates of void areas is approximately 45 ft^2. Table Xb presents the environmental conditions documented by each IR contractor. Thermograms 10-1 to 10-9 are some examples to demonstrate locations of heat loss anomalies, as they are referred to the descriptions in table Xa.

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

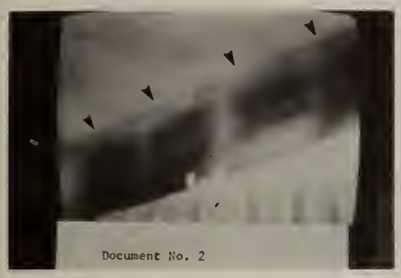
Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors M1	M2	M3	M4	Thermogram No. in Appendix
Entrance	E	Small Void at Top of Stairwell	2	Yes	No	No	Yes	No	
Southeast Bedroom	E	Air Penetration at Middle of Partition Wall		No	No	Yes	No	Yes	
	S	Voids at Top of SE Corner & Above Small Door	8	Yes	No	No	Yes	No	
Southwest Bedroom	S	Missing Insulation at Top of SE Corner and Above Both Windows	10	Yes	Yes	Yes	Yes	Yes	
	SW	Air Leakage at Wall-Wall Joint		Yes	No	No	Yes	No	
	W	Void Above Window	10	Yes	Yes	Yes	Yes	Yes	10-1
Living Room	W	Small Void at Top of 2nd Bay Cavity From SW Corner	2	Yes	Yes	Yes	Yes	Yes	
		Voids Above Both Windows	6	Yes	Yes	Yes	Yes	No	10-2
	NW	Air Leakage at Wall-Ceiling and Wall-Wall Joints		Yes	No	No	Yes	No	10-3 10-4
Kitchen	N	Air Penetration at Top of NW Corner on Partition Wall		No	Yes	Yes	Yes	Yes	10-5 10-6 10-7
North Bedroom	W	Small Void at Top of SW Corner	1	Yes	No	No	No	Yes	
	N	Small Voids Above W Corner, and Along W Side of Window	3	No	No	No	Yes	No	10-8 10-9
Ceiling		Non-Uniform Application of Insulation		No	No	No	Yes	No	

Table Xa. Summary of Defects Observed in Minneapolis-St. Paul House #2 (Cont'd)

Room & Orientation	Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors M1	M2	M3	M4	Thermogram No. in Appendix
Hallway E	Void Above Rear Door on N Side	1	Yes	No	No	Yes	No	
Bathroom E	Small Void Along N Side of Window and Air Infiltration at Ceiling-Wall Joint	2	Yes	No	No	No	No	
East Bedroom E	Air Infiltration Along S Side of Window and at Ceiling-Wall and Wall-Wall Joints		Yes	No	No	No	Yes	
Total Wall Area of Insulation Voids Detected Given in Ft^2		45	42	28	30	42	23	

Table Xb. Environmental Conditions During Inspections of Minneapolis - St. Paul House #2

	Contractors			
	M1	M2	M3	M4
Date	3-19-81	3-19-81	3-10-81	3-3-81
Time	10:15-11:00 pm	8:00-9:15 pm	7:29-8:25 pm	10:15-11:15 am
Weather Condition	clear	partly cloudy	clear	partly clear
Outside Temperature	32°F	34°F	33°F	25°F
Inside Temperature	72°F	72°F	73°F	74°F
Relative Humidity	61%	62%	65%	30%
Wind Speed(MPH)	4	5-8	0-1	8-10
Wind Direction	N	NNW	NW	S



10-1
Interior thermogram of voids above window in W wall of SW bedroom (by contr.M1)

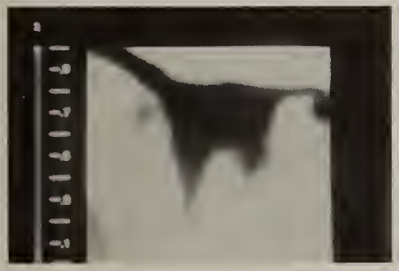
10-2
Exterior thermogram exhibits defects on W wall of living room SW bedroom (by NBS)

10-3
NW corner of living room with voids above window at W and warm areas at N partition wall from stove behind (by NBS)

10-4
Exterior thermogram of 10-3, warm areas above window and at corner (by NBS)

10-5
N partition wall of kitchen (by contractor M3)

10-6
Air penetration in N partition of kitchen (by contractor M3)



10-7
Air penetration in N partition wall of kitchen (by contr.M2)

10-8
N wall of N bedroom (by contractor M3)

10-9
Defects in N wall of N bedroom (by contractor M3)

XI. Minneapolis-St. Paul House #3

This is a single-story residence located in Minneapolis-St. Paul, MN. There are totally 7 rooms as living space with an attic.

Prior to the implementation of the weatherization program, this house had no insulation and contained only 4 rooms. An insulation contractor was instructed to insulate the sidewalls and the attic of this dwelling (of 4 rooms) with cellulose. After retrofitted options were completed, a construction of three rooms was added to this home. Afterward, this house was inspected by NBS personnel and IR contractors M1, M2, M3, and M4. Figure XI is a sketch of voids and location of heat losses obtained from video tapes by NBS, thermograms and documents by IR contractors. Since the addition of the house was not retrofitted according to the weatherization plan they will not be included in the IR inspections.

In general, the insulation work in the wall areas of this house was considered to be fairly poor as a lot of voids above windows and uninsulated bay cavities were observed all over the house. However, the insulation work in the attic seemed to be good except some leakage at the wall-to-ceiling and wall-to-wall joints.

Thermographic inspection by NBS was carried out for both interior and exterior of this dwelling and observed all major defects. Both contractors M1 and M2 employed HRIS to inspect this house but failed to observe the thermal anomalies. Contractors M1 reported no defects were found even though he used two different pieces of equipment (a raster scanner and a HRIS with data on video tapes) for inspection. This contractor also stated that video tapes from the inspection were available for analysis but no hard copies were included. Contractor M2 only located the small void at top of the front door by submitting only 3 thermograms. Contractor M3, who also used HRIS for inspection, provided 13 thermograms and visual photographs of identical locations. This contractor observed most thermal defects of this dwelling except the east side of the house and a small void on the west of the northwest corner of the living room. Although contractor M3 did not submit the documentation sheets supplied by NEIG, but his report had description of defect locations and comments to support their findings. Contractor M4 who used the LRIS to inspect this dwelling seemed to have trouble in the floor plan such that the sketch was a different floor plan provided by NEIG. This contractor documented that he only encountered two small voids in the walls of the southwest bedroom by including two thermograms. The qualities of the thermograms produced by the LRIS are very poor in contrast, thus makes it difficult to perform analysis.

A detailed description of defects observed by NBS as well as IR contractors is summarized in table XIa. According to NEIG, all IR contractors were supposed to contract NEIG prior to performing IR inspections to verify areas to be inspected. However, contractors M2 and M4 failed to follow this particular instruction. This might be one of the reasons that they did not recognize a lot of thermal deficiencies. 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 video tapes, available thermograms and documentations. The total estimates of void areas is approximately 103 ft^2. Table XIb presents the environmental conditions documented by each IR contractor. Thermograms 11-1 to 11-9 are some examples to demonstrate locations of heat loss anomalies, as they are referred to the descriptions in table XIa.

Table XIa. 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 M1	M2	M3	M4	Thermogram No. in Appendix
Living Room	W	Void at Top and on N Side of Front Door	5	Yes	No	Yes	Yes	No	11-1
		Partial Void in Bay Cavities Between Front Door & Window, & Voids Above Window	18	Yes	No	No	Yes	No	11-2 11-3
		Heavy Infiltration Underneath Front Door		Yes	No	Yes	Yes	No	11-4
		Small Void at Top of NW Corner and Air Leakage at Wall-Wall & Ceiling-Wall Joints	2	Yes	No	No	No	No	
Bathroom	E	Missing Insulation at Bottom of Entire Wall and Small Voids at SE Corner	12	Yes	No	No	No	No	11-5
Southeast Bedroom	E	Voids Above Window	5	Yes	No	No	No	No	
		Partial Bay Cavities and Small Void at Top at SE Corner	10	Yes	No	No	Yes	No	11-6 11-7
	S	Void Above Window and on E of Window	8	Yes	No	No	Yes	No	11-8
		Air Infiltration at Ceiling-Wall and Wall-Wall Joints		Yes	No	No	Yes	No	11-9
Southwest Bedroom	S	Partial Bay Cavity Along W Side of Window, and Voids Above and on Both Sides of Window	30	Yes	No	No	Yes	No	
		Small Void at Top of SW Corner	2	Yes	No	No	Yes	Yes	
	W	Small Void at SW Corner	2	Yes	No	No	Yes	Yes	

Table XIa. Summary of Defects Observed in Minneapolis-St. Paul House #3 (Cont'd)

Room & Orientation	Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors M1	M2	M3	M4	Thermogram No. in Appendix
	Voids at NW Corner Along S Side of Window, and on S of Window	14	Yes	No	No	Yes	No	
Total Wall Area of Insulation Voids Detected Given in Ft^2		103	103	0	5	89	4	

Table XIb. Environmental Conditions During Inspections of Minneapolis - St. Paul House #3

	Contractors M1	M2	M3	M4
Date	3-19-81	3-2-81	3-10-81	3-3-81
Time	6:55-7:38 pm	9:30-10:25 am	6:20-7:12 pm	9:30-10:15 am
Weather Condition	clear	clear	clear	partly clear
Outside Temperature	35°F	23°F	30°F	25°F
Inside Temperature	70°F	75°F	69°F	66°F
Relative Humidity	61%	67%	71%	35%
Wind Speed(MPH)	6	calm	0-1	8-10
Wind Direction	NW		NW	S

11-1
Voids at top and on N side of front door on W of living room (by NBS)

11-2
W wall of living room (by contractor M3)

11-3
Voids N of front door on W of living room (by contractor M3)

11-4
Air infiltration under front door (by contractor M2)

11-5
Missing insulation at bottom of bathroom, E wall (by NBS)

11-6
Voids in partial bay cavities, E wall of SE bedroom (by contractor M3)

11-7
SE corner of SE bedroom (by contractor M3)

11-8
Defective areas in S wall of SE bedroom (by contractor M3)

11-9
Defective area observed at SE corner of SE bedroom, as shown in 11-6, 11-8 (by NBS)

XII. Minneapolis-St. Paul House #4

This is a two-story residence located in Minneapolis-St. Paul, MN. There are totally 4 rooms as living space on each of the first and second floors, with an attic and an unheated porch.

Prior to the implementation of the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the sidewalls and the attic of this dwelling with cellulose. After retrofitted options were completed, this dwelling was inspected by NBS personnel and IR contractors M1, M2, M3, and M4. Figure XII is a sketch of voids and location of heat losses obtained from video tapes by NBS, thermograms and documents by IR contractors.

In general, the insulation work in the wall areas of this house was considered to be fair except some voids above and around the windows, and air infiltration at wall-to-wall and wall-to-ceiling joints. The insulation work in the attic was also good as only one uninsulated bay cavity was observed in the pitched ceiling. Other locations of thermal anomalies included uninsulated wall areas in south and west walls of both kitchens on each floor.

Thermographic inspection by NBS was carried out for both interior and exterior of this dwelling and observed all major defects except the the small void above front door in the north wall of living room. Since this wall and the east wall of the north bedroom are the interior walls of the unheated porch, they will be excluded from the calculation of defective wall areas. Contractors M1, M2, and M3 employed HRIS to observe defects in this dwelling by producing thermograms and visual photographs of identical locations. Both contractor M1 and M2, who submitted 8 and 7 thermograms, respectively, failed to recognize a lot of the uninsulated wall areas as they only identified between 25 to 50 percent of the total defective wall areas. Contractor M1 inspected this house with two different pieces of equipment (a raster scanner and a HRIS with data on video tapes) and submitted hard-copy photographs of the results from both systems. However, the quality of the hard copies made from the video camera was not good enough to identify locations of heat loss, only could be used as supporting materials. This contractor also stated that video tapes from the inspection were available for analysis. However, he still missed a lot of uninsulated areas. Neither did contractors M2 and M3 submitted the documentation sheets supplied by NEIG, but their reports had description of defect locations and comments to support their findings. Contractor M3 provided 18 thermograms and identified about 80% of the defective wall areas. Contractor M4 who used the LRIS to inspect this dwelling seemed to have trouble to locate thermal defects of this house. This contractor provided 7 thermograms and observed only 15% of the total defective wall areas. The qualities of the thermograms produced by the LRIS are very poor in contrast, thus makes it difficult to perform analysis.

A detailed description of defects observed by NBS as well as IR contractors is summarized in table XIIa. According to NEIG, all IR contractors were supposed to contract NEIG prior to performing IR inspections to verify areas to be inspected. However, contractors M2 and M4 failed to follow this particular instruction. This might be one of the reasons that they did not recognize a lot of thermal deficiencies. 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 video tapes, available thermograms and documentations. The total estimates of void areas is approximately 69 ft^2. Table XIIb presents the environmental conditions documented by each IR contractor. Thermograms 12-1 to 12-7 are some examples to demonstrate locations of heat loss anomalies, as they are referred to the descriptions in table XIIa.

Table XIIa. 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 M1	M2	M3	M4	Thermogram No. in Appendix
First Floor:									
Living Room	N	Void Above Front Door to Porch (Excluded)	(3)	No	No	Yes	Yes	No	
	E	Void Above N Corner of S Window	2	Yes	No	Yes	Yes	Yes	
		Air Infiltration at Ceiling-Wall and Wall-Wall Joints		Yes	No	No	No	No	
Bathroom	E	Missing Insulation Above and on N Side of Window	8	Yes	No	No	Yes	No	
		Infiltration at Wall-Wall Joints		Yes	No	No	No	No	
Kitchen and Entrance Hall	E	Void Above Window	3	Yes	No	Yes	Yes	No	
		Void at Top of NE Corner	2	Yes	No	No	Yes	No	
		Air Infiltration Around Side Door, at Ceiling-Wall and Wall-Wall Joints		Yes	No	No	No	No	
	S	Void and Infiltration at Top of SE Corner of Entrance Hall	5	Yes	No	No	Yes	Yes	
		Small Void at Top of SW Corner of Stairway Wall and Infiltration at Wall-Wall Joints	2	Yes	No	No	No	No	
	W	Small Voids at Top of NW Corner of Stairway Wall	2	Yes	Yes	No	No	No	
		Void Above Window	4	Yes	Yes	Yes	Yes	No	12-1 12-2

Table XIIa. Summary of Defects Observed in Minneapolis-St. Paul House #4 (Cont'd)

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors M1	M2	M3	M4	Thermogram No. in Appendix
		Missing Insulation in Several Partial Bay Cavities at Upper Portion of Wall	16	Yes	Yes	No	Yes	No	
North Bedroom	N	Small Void on E Side of Window and Infiltration Around Window	2	Yes	No	No	No	No	
2nd Floor:									
North Bedroom	N	Small Void on E of Window	2	Yes	No	No	No	Yes	
	NE	Missing Insulation in 1 Bay Cavity in Pitched Ceiling		Yes	No	No	Yes	No	12-3 12-4 12-5
		Air Infiltration at Ceiling-Wall and Wall-Wall Joints		Yes	No	No	No	No	
Middle Bedroom	E	Small Void Above Window & Infiltration at Ceiling-Wall Joints	2	Yes	No	No	No	No	
Bathroom	E	Voids & Infiltration Above Window at NE Corner & Below Window	5	Yes	No	No	Yes	No	
Kitchen	E	Heavy Infiltration From Ceiling & Between Walls		Yes	No	No	Yes	No	
	S	Void Above Window	3	Yes	Yes	No	Yes	No	12-6 12-7
		Void Above Door to Porch	3	Yes	Yes	Yes	Yes	No	
		Void Between Window and Door	2	Yes	Yes	Yes	Yes	Yes	

Table XIIa. Summary of Defects Observed in Minneapolis-St. Paul House #4 (Cont'd)

Room & Orientation	Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors M1	M2	M3	M4	Thermogram No. in Appendix
	Some Infiltration From Pitched Ceiling		Yes	Yes	No	No	No	
W	Small Void at SW Corner	2	Yes	No	No	No	No	
	Void Above Window and at NW Corner	4	Yes	Yes	Yes	No	No	
Total Wall Area of Insulation Voids Detected Given in Ft^2		69	69	34	18	53	11	

Table XIIb. Environmental Conditions During Inspections of Minneapolis - St. Paul House #4

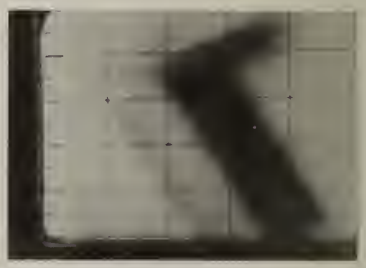
	Contractors M1	M2	M3	M4
Date	3-19-81	3-19-81	3-10-81	3-3-81
Time	9:25-10:40 am	6:00-7:30 pm	8:43-11:00 pm	1:40-2:15 pm
Weather Condition	clear	partly cloudy	clear	partly clear
Outside Temperature	40°F	37°F	31°F	32°F
Inside Temperature	74°F	70°F	75°F	74°F
Relative Humidity	66%	65%	58%	25%
Wind Speed(MPH)	1-variable	8-10	2-3	12-14
Wind Direction	W	NW	NW	S

12-1
Voids above window at W and insulation hung up at NW corner of kitchen of 1st floor (NBS)

12-2
Same defective areas as observed in 12-1 (by contractor M1)

12-3
Missing insulation in bay cavity in pitched ceiling at NE corner upstairs (by NBS)

12-4
NE corner in N bedroom upstairs (by contractor M3)



12-5
Missing insulation in pitched ceiling as observed in 12-3 (by contractor M3)

12-6
Voids above window and door and in area with electric box on back wall, observed on S wall of kitchen on second floor (by NBS)

12-7
Defective areas observed on S wall of kitchen on second floor as in 12-6 (by contractor M2)

XIII. Providence House #1

This is a two-story residence located in Providence, RI. There are totally 6 and 3 rooms as living space on the first and second floors, respectively, with an attic and an unheated porch.

Prior to the implementation of the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the exterior walls, except the dormer walls in the upstairs bathroom, and the attic of this dwelling with cellulose. After retrofitted options were completed, this dwelling was inspected by NBS personnel and IR contractors P1, P2, P3, and P4. Figure XIII is a sketch of voids and location of heat losses obtained from video tapes by NBS, thermograms and documents by IR contractors.

In general, the insulation work in the wall areas of this house was considered to be fair except the uninsulated kneewalls in the den on the second floor. Furthermore, some voids above and around the windows, and at wall-to-wall and wall-to-ceiling joints were also observed. The insulation work in the attic was also fairly good as only a small portion of the pitched ceilings above the kneewalls exhibited defective. Other locations of thermal anomalies in this dwelling included air penetration in the flat ceilings above the stairway and the north side of living room on the first floor, and air infiltration at the wall-to-wall and wall-to-ceiling joints.

Thermographic inspection by NBS was carried out for both interior and exterior of this dwelling and observed most defects except the void areas above and along both sides of the window in the east wall of living room. Since this wall and the north wall of the entrance are the interior walls of the unheated porch, they will be excluded from the calculation of the defective wall areas. Contractor P2 employed HRIS to inspect this dwelling, but he only submitted the documentation sheet with locations and areas of defects without any thermograms. Thus the analysis was only based on the contractor's descriptions. Moreover, this contractor also reversed his decision on the west kneewall of the den upstairs to state that this wall was insulated. According to the inspections of another contractor as well as NBS, this kneewall was uninsulated indeed. As a result, contractor P2 only located less than 40% of the total defective wall areas.

Contractors P1, P3, and P4 used LRIS to observe defects of this house by submitting different kinds of documentations. Contractor P1 included 3 thermograms with visual photographs of identical locations, and 7 sketches with descriptions of defects; but he did not include the documentation sheet provided by NEIG. This contractor also failed to observe the uninsulated kneewall on the west side of the den on the second floor.Therefore, he identified about 40% of the total defective wall areas. Contractor P3 provided the documentation sheets with detailed description of each location of thermal deficiencies by producing 9 thermograms to identify 90% of the total defective wall areas. Besides

identifying the uninsulated west kneewall in the den upstairs, this contractor put in additional effort to scan the bathroom also, even though this room was not excluded from the inspections. It seemed that this contractor fully utilized his equipment to inspect the house, even the qualities of the thermograms produced by the LRIS are not too good in contrast, as expected. Contractor P4 did not submit any thermograms, only the documentation sheet provided by NEIG by reporting a few locations of thermal anomalies on the first floor and a small void under the window in the north wall of the den on the second floor. Again, the analysis was only based on this contractor's interpretations, and only 15% of the total defective wall areas was observed.

A detailed description of defects observed by NBS as well as IR contractors is summarized in table XIIIa. Besides the total defective wall area in ft^2 found by each inspection, table XIIIa also includes the defective wall areas in ft^2 of each room of the house, analyzed from video tapes, available thermograms and documentations. The total estimates of void areas is approximately 93 ft^2. Table XIIIb presents the environmental conditions documented by each IR contractor. Thermograms / sketches 13-1 through 13-4 are some examples to demonstrate locations of heat loss anomalies, as they are referred to the descriptions in table XIIIa.

XIII. Providence House #1

This is a two-story residence located in Providence, RI. There are totally 6 and 3 rooms as living space on the first and second floors, respectively, with an attic and an unheated porch.

Prior to the implementation of the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the exterior walls, except the dormer walls in the upstairs bathroom, and the attic of this dwelling with cellulose. After retrofitted options were completed, this dwelling was inspected by NBS personnel and IR contractors P1, P2, P3, and P4. Figure XIII is a sketch of voids and location of heat losses obtained from video tapes by NBS, thermograms and documents by IR contractors.

In general, the insulation work in the wall areas of this house was considered to be fair except the uninsulated kneewalls in the den on the second floor. Furthermore, some voids above and around the windows, and at wall-to-wall and wall-to-ceiling joints were also observed. The insulation work in the attic was also fairly good as only a small portion of the pitched ceilings above the kneewalls exhibited defective. Other locations of thermal anomalies in this dwelling included air penetration in the flat ceilings above the stairway and the north side of living room on the first floor, and air infiltration at the wall-to-wall and wall-to-ceiling joints.

Thermographic inspection by NBS was carried out for both interior and exterior of this dwelling and observed most defects except the void areas above and along both sides of the window in the east wall of living room. Since this wall and the north wall of the entrance are the interior walls of the unheated porch, they will be excluded from the calculation of the defective wall areas. Contractor P2 employed HRIS to inspect this dwelling, but he only submitted the documentation sheet with locations and areas of defects without any thermograms. Thus the analysis was only based on the contractor's descriptions. Moreover, this contractor also reversed his decision on the west kneewall of the den upstairs to state that this wall was insulated. According to the inspections of another contractor as well as NBS, this kneewall was uninsulated indeed. As a result, contractor P2 only located less than 40% of the total defective wall areas.

Contractors P1, P3, and P4 used LRIS to observe defects of this house by submitting different kinds of documentations. Contractor P1 included 3 thermograms with visual photographs of identical locations, and 7 sketches with descriptions of defects; but he did not include the documentation sheet provided by NEIG. This contractor also failed to observe the uninsulated kneewall on the west side of the den on the second floor.Therefore, he identified about 40% of the total defective wall areas. Contractor P3 provided the documentation sheets with detailed description of each location of thermal deficiencies by producing 9 thermograms to identify 90% of the total defective wall areas. Besides

identifying the uninsulated west kneewall in the den upstairs, this contractor put in additional effort to scan the bathroom also, even though this room was not excluded from the inspections. It seemed that this contractor fully utilized his equipment to inspect the house, even the qualities of the thermograms produced by the LRIS are not too good in contrast, as expected. Contractor P4 did not submit any thermograms, only the documentation sheet provided by NEIG by reporting a few locations of thermal anomalies on the first floor and a small void under the window in the north wall of the den on the second floor. Again, the analysis was only based on this contractor's interpretations, and only 15% of the total defective wall areas was observed.

A detailed description of defects observed by NBS as well as IR contractors is summarized in table XIIIa. Besides the total defective wall area in ft^2 found by each inspection, table XIIIa also includes the defective wall areas in ft^2 of each room of the house, analyzed from video tapes, available thermograms and documentations. The total estimates of void areas is approximately 93 ft^2. Table XIIIb presents the environmental conditions documented by each IR contractor. Thermograms / sketches 13-1 through 13-4 are some examples to demonstrate locations of heat loss anomalies, as they are referred to the descriptions in table XIIIa.

Table XIIIa. Summary of Defects Observed in Providence House #1

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors P1	P2	P3	P4	Thermogram No. in Appendix
First Floor:									
Dining Room	E	Missing Insulation in Ceiling Above Middle Window and Some Infiltration Around S Window		Yes	No	No	No	No	
Southeast Bedroom	E	Small Void at Upper NE Corner	2	Yes	No	Yes	Yes	No	
		Air Infiltration at Wall-Floor Joint and at SE Corner		Yes	No	No	No	No	
Kitchen	S	Voids Above Back Door	3	Yes	No	Yes	Yes	No	
		Voids Above Window	3	Yes	Yes	Yes	Yes	Yes	13-1
		Missing Insulation in Stairway to Basement	5	Yes	No	No	No	No	
	W	Air Infiltration at Floor-Wall Joint Under Window and Wall-Wall Joints at Both Corners		Yes	No	No	No	No	
Bathroom	W	Voids Above Window at N	1	Yes	Yes	Yes	Yes	Yes	
		Voids and Air Infiltration Under Window	5	Yes	Yes	Yes	Yes	No	13-2
West Bedroom	W	Voids Above Both Windows	6	Yes	Yes	Yes	Yes	Yes	13-3
		Small Void Along N Side of N Window	2	Yes	Yes	Yes	Yes	No	
Living Room	W	Voids Above Window at S	2	Yes	Yes	Yes	Yes	Yes	

Table XIIIa. Summary of Defects Observed in Providence House #1 (Cont'd)

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors P1	P2	P3	P4	Thermogram No. in Appendix
	NW	Air Infiltration at Corner		Yes	No	No	No	No	
	N	Void in Ceiling Above Middle Window and Air Infiltration on E Side of E Window		Yes	Yes	No	No	No	13-4
	E	Voids Above Window	(3)	No	Yes	Yes	Yes	No	
		Voids Along Both Sides of Window	(2)	No	Yes	Yes	Yes	Yes	
Foyer	N	Voids Above Front Door to Porch	(3)	Yes	Yes	Yes	Yes	Yes	
		Small Void at Upper NE Corner	(1)	Yes	Yes	Yes	Yes	No	
		Air Leakage Underneath the Door		Yes	No	No	No	No	
	E	Voids Above Window on the E Side	4	Yes	Yes	Yes	Yes	No	13-5
		Defective Ceiling and Air Infiltration at Floor-Wall Joint		Yes	No	No	No	No	
Second Floor:									
Stairway	E	Missing Insulation in Sloped Ceiling		No	No	Yes	Yes	No	13-6
Bedroom	S	Voids Under Sloped Ceiling on Both Sides of Window	5	Yes	No	Yes	Yes	No	
		Air Infiltration at Wall-Wall and Wall-Ceiling Joints		Yes	No	Yes	Yes	No	
Bathroom (dormer)		All Exterior Walls are Not Insulated	(80)	Yes	No	No	Yes	No	

Table XIIIa. Summary of Defects Observed in Providence House #1 (Cont'd)

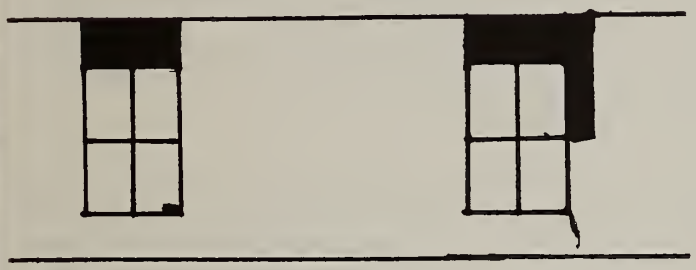
Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors P1	P2	P3	P4	Thermogram No. in Appendix
Den	W	Small Void Inside Closet	2	Yes	No	Yes	No	No	
		Defects Found in Both Sloped & Flat Ceilings		Yes	No	No	Yes	No	
		Missing Insulation in the Entire Knee Wall	32	Yes	No	No	Yes	No	
	N	Voids Above Window	2	Yes	No	Yes	No	No	
		Voids Under Window	1	Yes	No	No	Yes	Yes	
		Small Voids at Both Corners Under the Pitched Ceiling	2	Yes	No	Yes	No	No	
	E	Missing Insulation in 4 Bay Cavities	16	Yes	Yes	No	Yes	No	
		Defects Found in Sloped Ceiling		Yes	No	No	No	No	
Total Wall Area of Insulation Voids Detected Given in Ft^2			93	93	37	37	82	13	

Table XIIIb. Environmental Conditions During Inspections of Providence House #1

	Contractors			
	P1	P2	P3	P4
Date	3-10-81	3-10-81	3-12-81	3-3-81
Time	9:10-10:20 pm	7:30-8:30 pm	8:05-9:15 pm	6:58-7:20 pm
Weather Condition	cloudy, humid	partly clear-clear	clear	clear
Outside Temperature	34°F	39°F	37°F	32°F
Inside Temperature	66°F	70°F	68°F	67°F
Relative Humidity	45%	39%	41%	40%
Wind Speed(MPH)	light	calm	9	10
Wind Direction	W		WSW	NW

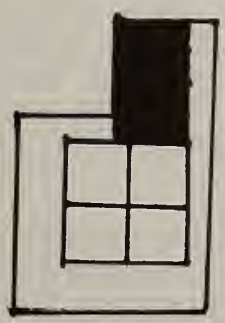
13-1
Voids above window on S wall and air infiltration at SW corner of kitchen on first floor (by NBS)

13-2
Voids and air infiltration under window on W wall of bathroom on first floor (by NBS)



13-3
Voids over both windows and in first half bay cavity to right of N window on W wall of W bedroom (by contractor P1)

13-4
Voids in ceiliing above middle window on N wall of living room on first floor (by NBS)



13-5
Voids above window on E wall of stairway (by contractor P1)

13-6
Missing insulation in ceiling above stairway (by NBS)

XIV. Providence House #2

This is a two-story residence located in Providence, RI. There are totally 3 and 4 rooms as living space on the first and second floors, respectively, with an attic and an unheated porch used as the foyer with a closet.

Prior to the implementation of the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the exterior walls, and the attic stairway of this dwelling with cellulose. After retrofitted options were completed, this dwelling was inspected by NBS personnel and IR contractors P1, P2, P3, and P4. Figure XIV is a sketch of voids and location of heat losses obtained from video tapes by NBS, thermograms and documents by IR contractors.

Generally speaking, the insulation work in the wall areas of this house was considered to be fairly poor as voids were observed above every window and below some windows, and also at some areas of wall-to-ceiling joints. Besides uninsulated areas above the window on first floor,the north wall of stairway was found to have unfilled cavities that continued up to the areas below the second floor window. The insulation work in the attic was fairly good as only a small portion of the ceilings on the west side above the foyer and the bathroom exhibited defective. Other locations of thermal anomalies in this dwelling included air penetration at the wall-to-floor joints, and air infiltration at the wall-to-wall and wall-to-ceiling joints.

Thermographic inspection by NBS observed most defects of this dwelling except some voids areas in the foyer. However, NBS did indicated that the entire porch seemed to be uninsulated and the contractors identified a lot of defects among them. Since the porch is unheated, retrofitted insulation work might not be included in this areas, even it is used as the foyer. Therefore, the thermal deficiencies of the porch will be excluded from calculations of total defective wall areas. As for the contractors, all four of them seemed to inspect this house thoroughly and located between 75% and 90% of the total defective wall areas. Contractor P2 employed HRIS to inspect this dwelling, but he only submitted the documentation sheet with locations and areas of defects without any thermograms. Thus the analysis was only based on the contractor's interpretations. It seemed that this contractor did not inspect the north wall of the stairway at all because he identified the rest of the thermal deficiencies of this house without mentioning this wall.

Contractors P1, P3, and P4 used LRIS to observe defects of this house by submitting different kinds of documentations. Contractor P1 included 3 thermograms with visual photographs of identical locations, and 12 sketches with descriptions of defects; but he did not include the documentation sheet provided by NEIG. This contractor was the only one to indicate that the west wall of living room had voids above the windows and a large area of insufficient insulation on the north of windows. However, without

supporting hard-copy documentation or any corroboration by either contractors or NBS, it is difficult to sustain this finding. Therefore, no thermal anomalies was considered in this wall. Contractor P3 provided the documentation sheets with detailed description of each location of thermal deficiencies by producing 14 thermograms to support his findings. Although this contractor did miss surveying some areas, it seemed that he fully utilized his equipment to inspect the house, even the qualities of the thermograms produced by the LRIS are not too good in contrast, as expected. Contractor P4 did not submit any thermograms, only the documentation sheet provided by NEIG by reporting locations of thermal anomalies. Again, the analysis was only based on this constractor's interpretations.

A detailed description of defects observed by NBS as well as IR contractors is summarized in table XIVa. Besides the total defective wall area in ft^2 found by each inspection, table XIVa also includes the defective wall areas in ft^2 of each room of the house, analyzed from video tapes, available thermograms and documentations. The total estimates of void areas is approximately 184 ft^2. Table XIVb presents the environmental conditions documented by each IR contractor. Thermograms / sketches 14-1 through 14-9 are some examples to demonstrate locations of heat loss anomalies, as they are referred to the descriptions in table XIVa.

Table XIVa. Summary of Defects Observed in Providence House #2

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors P1	P2	P3	P4	Thermogram No. in Appendix
First Floor:									
Living Room	S	Voids Above Windows & Leakage Along Both Sides of Windows	6	Yes	Yes	Yes	Yes	Yes	
	SW	Air Leakage at Ceiling-Wall Joint		Yes	Yes	No	No	No	
Foyer	S	Voids Above Window	(3)	No	No	Yes	Yes	No	
	W	Voids Above Door and on N of Door	(13)	Yes	No	Yes	Yes	No	
		Air Leakage Through Ceiling-Wall, Wall-Wall, and Wall-Floor Joints		Yes	No	No	No	No	
	N	Voids Above Closet Window and NE Upper Corner	(3)	Yes	Yes	Yes	Yes	No	
		Air Infiltration Below Window and at NW Wall-Wall Joint		Yes	No	No	No	No	
Stairway	N	Voids in NW Corner and Above Window in Stairway	5	Yes	Yes	No	Yes	Yes	14-1
		Horizontal Void Along the Stairway About 3 ft. High	35	Yes	Yes	No	Yes	Yes	14-2 14-3
Kitchen	N	Air Leakage Around Side Door		Yes	No	No	No	No	
		Small Voids Under and Along W Side of Window	3	Yes	No	Yes	No	No	
	NE	Air Infiltration at Wall-Wall & Ceiling-Wall Joints		Yes	No	No	No	No	

Table XIVa. Summary of Defects Observed in Providence House #2 (Cont'd)

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors P1	P2	P3	P4	Thermogram No. in Appendix
	E	Voids Above Window	3	Yes	Yes	Yes	Yes	Yes	
		Voids Along N Side of Window	3	Yes	Yes	No	No	No	
		Missing Insulation at Upper Portion of 2 Bay Cavities at SE Corner	4	Yes	Yes	Yes	No	Yes	14-4
		Air Leakage From Wall-Wall and Wall-Ceiling Joints		Yes	No	No	No	No	
Dining Room	E	Missing Insulation at Top of Entire Wall; Leakage at Wall-Wall & Wall-Ceiling Joints	15	Yes	Yes	Yes	Yes	Yes	14-5
	S	Unfilled Bay Cavities at Top of Entire Wall	20	Yes	Yes	Yes	Yes	Yes	
		Air Leakage at Wall-Wall and Ceiling-Wall Joints		Yes	No	No	No	No	
Second Floor:									
Hallway	W	Void at Top Between Partition Wall and Exterior Wall	10	Yes	No	Yes	No	No	
	NW	Air Leakage at Wall- & Wall-Ceiling Joints		Yes	No	Yes	No	No	
	N	Air Leakage Above and Along Both Sides of Window		Yes	No	Yes	No	No	
		Voids Below Window (Included in 1st Floor Stairway)							14-6

Table XIVa. Summary of Defects Observed in Providence House #2 (Cont'd)

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors P1	P2	P3	P4	Thermogram No. in Appendix
Northeast Bedroom	N	Missing Insulation Above & Below Window, and at Top on Both Sides of Window	24	Yes	Yes	Yes	Yes	Yes	
		Air Leakage at Wall-Wall, Ceiling-Wall, and Wall-Floor Joints		Yes	No	No	No	No	
	E	Voids Above Window & in Upper Portion of 2nd Bay Cavity on N of Window	5	Yes	Yes	Yes	Yes	Yes	
		Small Void at Top on S of Window	2	Yes	Yes	No	No	No	
		Air Leakage at Wall-Wall and Ceiling-Wall Joints		Yes	Yes	Yes	No	No	
Southeast Bedroom	E	Voids Above Window and at Top on S Side of Window	4	Yes	Yes	Yes	Yes	Yes	14-7
		Voids at Top on N of Window	1	Yes	No	Yes	Yes	Yes	
	SE	Air Leakage at Joints (Double Studs Shown on S Wall)		Yes	No	No	No	No	
	S	Voids Above Window & at Top Between Windows	15	Yes	Yes	Yes	Yes	Yes	
		Voids Below Window	5	Yes	Yes	Yes	No	Yes	
Southwest Bedroom	S	Voids Above Window	6	Yes	Yes	Yes	Yes	Yes	14-8
		Voids Below Window	6	Yes	Yes	Yes	No	No	
	SW	Air Leakage at Corner		Yes	No	Yes	No	No	
	W	Voids Above Window	3	Yes	Yes	Yes	Yes	Yes	

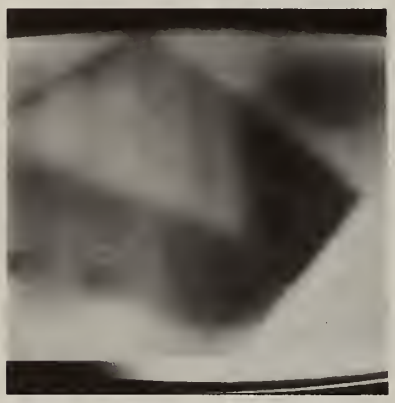
Table XIVa. Summary of Defects Observed in Providence House #2 (Cont'd)

Room & Orientation	Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors P1	P2	P3	P4	Thermogram No. in Appendix
Bathroom W	Voids Above Window & at Top of the Entire Wall	9	Yes	No	Yes	Yes	No	
	Air Penetration at Wall-Floor joint and in Partition Wall		Yes	No	Yes	No	No	14-9
Total Wall Area of Insulation Voids Detected Given in Ft^2		184	184	161	139	151	153	

Table XIVb. Environmental Conditions During Inspections of Providence House #2

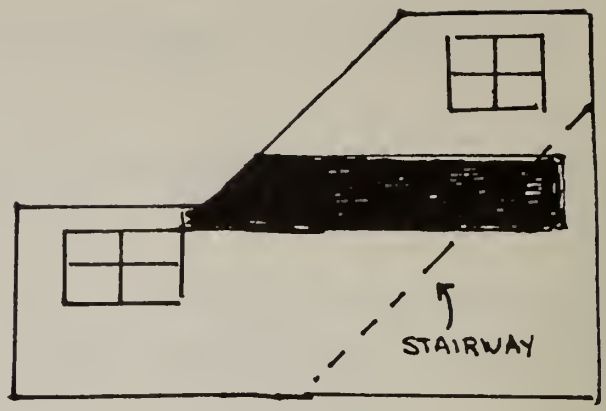
	Contractors P1	P2	P3	P4
Date	3-5-81	3-10-81	3-11-81	3-5-81
Time	8:30-10:15 pm	8:40-10:10 pm	8:20-9:35 pm	8:00-8:30 pm
Weather Condition	overcast	clear	partly cloudy	cloudy
Outside Temperature	39°F	37°F	36°F	36°F
Inside Temperature	68°F	71°F	68°F	72°F
Relative Humidity	52%	41%	48%	42%
Wind Speed(MPH)	extremely light	calm	7	10
Wind Direction			NW	N

14-1
Defective ceiling and insulation voids at NW corner of stairway on first floor (by NBS)



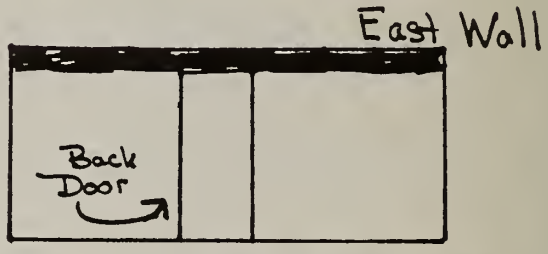
14-2
Horizontal void area along the stairway and up to the second floor on N wall of stairway (NBS)

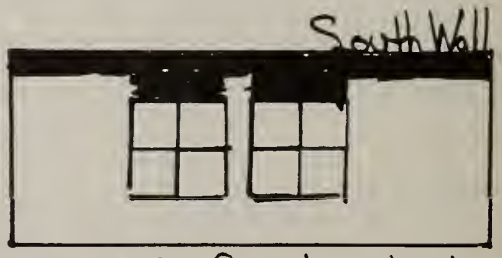
14-4
Defective areas in the E wall and warm area of the pipe along S of window in the kitchen (by NBS)



Horizontal void most likely due to framing change
Approx area - 30 FT²

14-3
Horizontal void observed on N of stairway as shown in 14-2 (by contractor P1)





severe draft along baseboard

14-5
Voids at upper parts of walls observed in dining room on 1st floor (by contractor P1)

14-6
Voids below window as shown in 14-2 from stairway up to second floor (by NBS)

14-7
Thermal deficiencies observed in SE bedroom on second floor (by contractor P1)

14-8
Voids above window and location of fireplace chimney on S wall of SW bedroom, 2nd floor (by NBS)

14-9
Air penetration at wall-floor joint on W of bathroom (by NBS)

XV. Providence House #3

This is a two-story residence located in Providence, RI. There are totally 6 and 4 rooms as living space on the first and second floors, respectively, with an attic, a basement, and an unheated porch.

Prior to the implementation of the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the exterior walls of this dwelling with UF foam. After retrofitted options were completed, this dwelling was inspected by NBS personnel and IR contractors P1, P2, P3, and P4. Figure XV is a sketch of voids and location of heat losses obtained from video tapes by NBS, thermograms and documents by IR contractors.

In general, the insulation work of the first floor of this house was considered to be fair except small voids above and around some windows, and uninsulated partial bay cavities along some windows and at wall-to-wall and joints were observed. Furthermore, foam shrinkage or fissures were also existed. However, the insulation work on the second floor was much worse than the first floor as the upper halves of both the north and south kneewalls were found to be uninsulated. Moreover, lack of insulations were also observed in a lot of wall areas under the ceiling on both east and west sides. The pitched ceiling and the flat ceiling downstairs are having problems as cold air is leaking in, although the contractors are not required to survey the ceilings. Other locations of thermal anomalies in this dwelling included some sealing problems at the corners of wall-to-wall joints on the first floor with air infiltration.

Thermographic inspection by NBS was carried out for both interior and exterior of this dwelling and observed all major defects including the ceilings. The exterior scanning also revealed some insulation in the upper part below grade of the basement walls. The east wall of the music room is the interior walls of the unheated porch, and it will be excluded from the calculation of the defective wall areas. Contractor P2 employed HRIS to inspect this dwelling, but he only submitted the documentation sheet with locations and areas of defects without any thermograms. Thus the analysis was only based on the contractor's interpretations. However, according to this contractor's documentation, it seemed that he inspect this house thoroughly as more than 90% of the total defective wall areas was reported.

Contractors P1, P3, and P4 used LRIS to observe defects of this house by submitting different kinds of documentations. Contractor P1 included 1 thermograms with visual photographs of identical locations, and 17 sketches with descriptions of defects; but he did not include the documentation sheet provided by NEIG. The sketches submitted by this contractor are very clear, but the areas of defective walls was not estimated correctly. As a result, contractor P1 located about 80% of the total defective wall areas. Contractor P3 who provided the documentation sheets

with detailed description of each location of thermal deficiencies by producing 17 thermograms, also identified 80% of the total defective wall areas. Although this contractor did miss surveying the bathroom, south of kitchen, and east of living room, it seemed that he fully utilized his equipment to inspect the house, even the qualities of the thermograms produced by the LRIS are not too good in contrast, as expected. Contractor P4 did not submit any thermograms, only the documentation sheet provided by NEIG by reporting a few locations of thermal anomalies, and both defective kneewalls on the second floor. Again, the analysis was only based on this contractor's interpretations and 60% of the total defective wall areas was observed.

A detailed description of defects observed by NBS as well as IR contractors is summarized in table XVa. Besides the total defective wall area in ft^2 found by each inspection, table XVa also includes the defective wall areas in ft^2 of each room of the house, analyzed from video tapes, available thermograms and documentations. The total estimates of void areas is approximately 252 ft^2. Table XVb presents the environmental conditions documented by each IR contractor. Thermograms / sketches 15-1 through 15-10 are some examples to demonstrate locations of heat loss anomalies, as they are referred to the descriptions in table XVa.

Table XVa. Summary of Defects Observed in Providence House #3

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors P1	P2	P3	P4	Thermogram No. in Appendix
First Floor:									
Living Room	N	Voids Under Window	8	Yes	Yes	No	No	No	
		Some Defects in Ceiling and Air Infiltration Along E Side of Window		Yes	No	No	No	No	15-1
	E	Some Voids in the 1st 2 Bay Cavities at N and Air Leakage at NE Wall-Wall Joint	5	Yes	No	Yes	Yes	Yes	
		Small Voids Above All 3 Windows	6	Yes	No	No	No	No	
		Insulation Shrinkage at the S 2 Bay Cavities of Windows	6	Yes	Yes	Yes	No	No	
Music Room	E	Small Voids at Upper N Corner	(1)	Yes	Yes	Yes	Yes	Yes	
		Voids Above Front Door & on N Side of Front Door with Infiltration Underneath	(3)	Yes	No	No	No	No	
		Small Voids at Upper S Corner of Front Door	(1)	Yes	No	Yes	Yes	No	
	SE	Shrinkage and Crack of Insulation in 4 Bay Cavities of Corner and Also Sealing Problem at Corner		Yes	Yes	No	Yes	No	15-2
	S	Small Void at Top of Window	1	Yes	No	Yes	Yes	No	
Bathroom	S	Missing Insulation Above & Along W Side of Window	8	Yes	Yes	No	No	No	15-3

Table XVa. Summary of Defects Observed in Providence House #3 (Cont'd)

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors P1	P2	P3	P4	Thermogram No. in Appendix
		Small Voids Under Window	2	Yes	No	No	No	No	
Kitchen	S	Missing Insulation at Upper SE Corner and Voids Above W Window	4	Yes	Yes	Yes	Yes	Yes	
		Some Shrinkage in the Wall and Leakage at Wall-Floor Joint		Yes	No	No	No	No	
	W	Small Void Above Window	1	Yes	No	Yes	No	No	
Stairway	SW	Small Voids at Corner Above Both Side and Back Doors	2	Yes	Yes	No	No	No	
Den	W	Voids in 4 Upper & 2 Lower Portion of Bays, and in 1 Partial Bay Cavity on N Side of Window	10	Yes	Yes	Yes	Yes	Yes	15-4
	NW	Sealing Problem at Corner, and Leakage at Wall-Wall, Wall-Ceiling, and Wall-Floor Joints		Yes	Yes	No	No	No	
	N	Small Void Under Window	1	Yes	No	Yes	No	No	
Dining Room	N	Voids in Upper W Bay Cavity, Above Windows, and Below Windows	8	Yes	Yes	Yes	Yes	No	
		Some Shrinkage in the Wall		Yes	No	No	No	No	

Table XVa. Summary of Defects Observed in Providence House #3 (Cont'd)

Room & Orientation	Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors P1	P2	P3	P4	Thermogram No. in Appendix
Second Floor:								
Northeast Bedroom N	Missing Insulation in the Upper Portion of the Entire Wall	40	Yes	Yes	Yes	Yes	Yes	15-5
	Problems Found in Pitched Ceiling		Yes	No	No	No	No	
E	Voids in Upper Portion of Wall on N Side of Window	4	Yes	Yes	Yes	Yes	No	
	Voids Above and Under Window	4	Yes	No	Yes	No	No	
	Shrinkage or Missing Insulation in 1st S Bay Cavity	3	Yes	No	Yes	Yes	No	
Southeast Bedroom E	Missing Insulation at Upper Portion of 1st N Bay Cavity and Above Window	8	Yes	No	Yes	Yes	Yes	
	Voids or Shrinkage at Top of the S 5 Bay Cavities	6	Yes	Yes	Yes	No	No	15-6
S	Missing Insulation in Upper Portion of 6 Bay Cavities	20	Yes	Yes	Yes	Yes	Yes	
	Defective Pitched Ceiling		Yes	No	No	No	No	
Southwest Bedroom S	Missing Insulation in Upper Portion of 5 Bay Cavities & Above the Window	15	Yes	Yes	Yes	Yes	Yes	15-7
	Defective Pitched Ceiling		Yes	No	No	No	No	

Table XVa. Summary of Defects Observed in Providence House #3 (Cont'd)

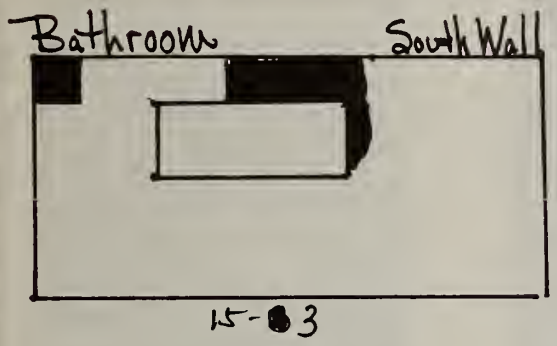
Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors P1	P2	P3	P4	Thermogram No. in Appendix
		Missing Insulation in Upper Portion of Wall Inside Closet	15	Yes	Yes	Yes	Yes	No	
	W	Voids in 1st Bay Cavity at SW Corner	5	Yes	No	Yes	No	No	
Hallway	W	Voids in Upper Portion of 1st Bay Cavities at S and Above Window	8	Yes	Yes	Yes	Yes	Yes	15-8
		Voids in Lower Portion of 3 Bay Cavities at N and Below Window	10	Yes	No	Yes	Yes	No	
		Shrinkage of Insulation and Air Leakage Along S Side of Window, at Ceiling-Wall and Wall-Floor Joints		Yes	No	No	No	No	
Northwest Bedroom	W	Missing Insulation at N Under Pitched Ceiling	5	Yes	Yes	Yes	Yes	No	
		Voids Above Window	2	Yes	No	Yes	Yes	No	
	N	Missing Insulation in Upper Half of Knee Wall Including the Wall in the Closet	45	Yes	Yes	Yes	Yes	Yes	15-9 15-10
		Defective Pitched Ceiling		Yes	No	No	No	No	
Total Wall Area of Insulation Voids Detected Given in Ft^2			252	252	204	226	203	157	

Table XVb. Environmental Conditions During Inspections of Providence House #3

	Contractors P1	P2	P3	P4
Date	3-10-81	3-10-81	3-11-81	3-5-81
Time	5:55-7:40 pm	10:30-11:30 pm	6:20-7:50 pm	6:30-7:36 pm
Weather Condition	overcast	clear	partly cloudy	cloudy
Outside Temperature	43°F	30°F	37°F	33°F
Inside Temperature	69°F	67°F	68°F	68°F
Relative Humidity	53%	42%	45%	40%
Wind Speed(MPH)	extremely light	calm	8	10
Wind Direction			NW	N

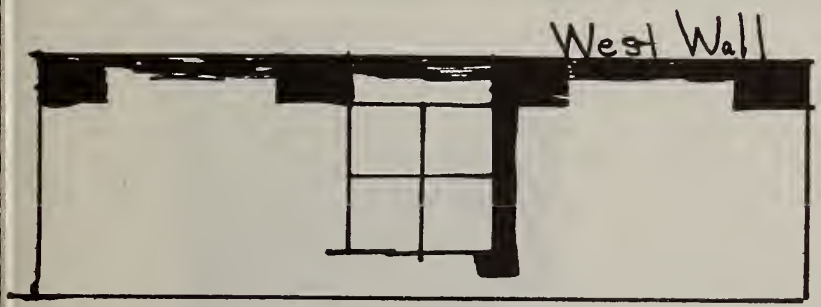
15-1
Cold air leaking in the ceiling on N of living room (by NBS)

15-2
Shrinkage and crack of insulation in 4 bay cavities and sealing problem at SE corner of front door (by NBS)



Small void in east corner as shown 1 ℄ft²
Insufficient insulation above & to right of window, shrinkage. 4 ℄ft²

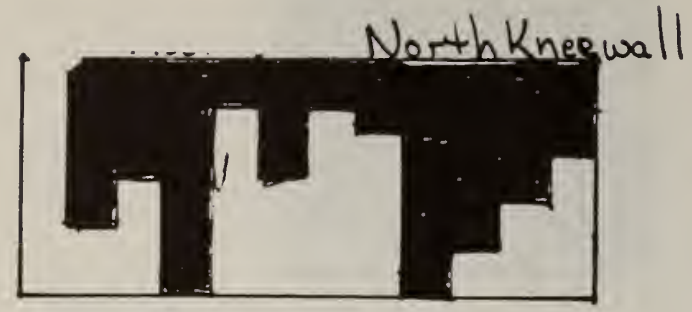
15-3
Voids and shrinkage observed in S wall of bathroom (by contractor P1)



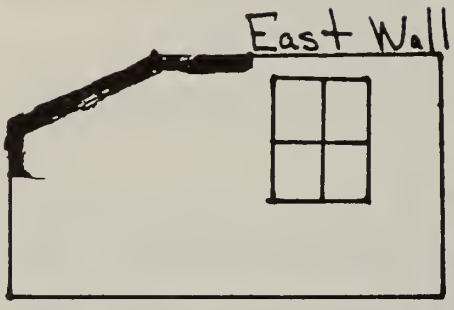
Voids & shrinkage as shown.

Shrinkage around right of window frame resulting in void. 14 ℄ft²

15-4
Voids and shrinkage observed in W wall of den (by contractor P1)



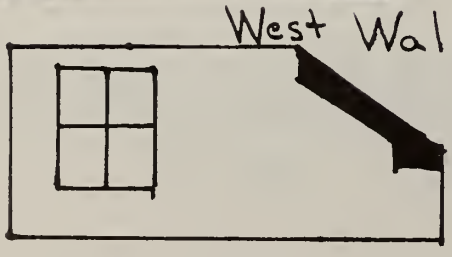
15-6
Voids or shrinkage at top of 5 bay cavities at SE corner and also defective pitched ceiling on S of SE bedroom (by NBS)



15-5
Missing insulaion observed in NE bedroom on 2nd floor (by contr. P1)

15-7
Missing insulation in upper portion of 5 bay cavities and defective pitched ceiling on S of of SW bedroom (by NBS)

15-8
Voids in upper portion of 1st bay cavity at SW corner and some shrinkage of insulation on W wall of the 2nd floor hallway (by NBS)



15-9
Missing insulation observed in NW bedroom on the 2nd floor (by contractor P1)

15-10
Missing insulation in upper half of kneewall and in pitched ceiling on N of NW bedroom (by NBS)

XVI. Providence House #4

This is a two-story residence located in Providence, RI. There are totally 5 rooms as living space on each of the first and second floors, with an attic.

Prior to the implementation of the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the exterior walls and the attic of this dwelling with blown fiberglass. After retrofitted options were completed, this dwelling was inspected by NBS personnel and IR contractors P1, P2, P3, and P4. Figure XVI is a sketch of voids and location of heat losses obtained from video tapes by NBS, thermograms and documents by IR contractors.

In general, the insulation work in the wall areas on the first floor of this house was considered to be fair except voids above and around some windows, and the front door. Furthermore, air penetration problem was also observed at ceilings of the kitchen and the dining room. Other locations of thermal anomalies on the first floor included air leakage along windows and front door, and at the wall-to-wall joints. During the time period of infrared scanning, the family room had heavy drapes covering both the east and south exterior walls with windows. Therefore, it would be difficult to identify uninsulated regions, if existed, except the paths of air leakage at the corners. The insulation work on the second floor was considered to be worse than the first floor as a lot of uninsulated bay cavities was found on the east and west sides of the house, and voids above most windows. However, from all inspections, the attic seemed to be well insulated without showing any indications of thermal deficiencies.

Thermographic inspection by NBS was carried out for both interior and exterior of this dwelling and observed all the major defects in it. The exterior scanning revealed the location of the fireplace chimney, which is not an indication of defective areas. Contractor P2 employed HRIS to inspect this dwelling, but he only submitted the documentation sheet with locations and areas of defects without any thermograms. Thus the analysis was only based on the contractor's interpretations. By comparing his results with those of others, this contractor seemed to cover this house thoroughly in his survey and located about 90% of the total defective wall areas.

Contractors P1, P3, and P4 used LRIS to observe defects of this house by submitting different kinds of documentations. Contractor P1 included 5 thermograms with visual photographs of identical locations, and 11 sketches with descriptions of defects; but he did not include the documentation sheet provided by NEIG. This contractor also failed to report the uninsulated regions of the foyer, the kitchen, and the mud room; plus other locations of thermal anomalies as he observed about 80% of the total defective wall areas. Contractor P3 provided the documentation sheets with detailed description of each location

of thermal deficiencies by producing 18 thermograms to identify 90% of the total defective wall areas. It seemed that this contractor fully utilized his equipment to inspect the house, even the qualities of the thermograms produced by the LRIS are not too good in contrast, as expected. Contractor P4 did not submit any thermograms , only the documentation sheet provided by NEIG by reporting some locations of thermal anomalies on the first and second floors. This contractor also missed the inspection of the kitchen, the mudroom, the foyer, and all three bathrooms. Again, the analysis was only based on this contractor's interpretations and about 60% of the total defective wall areas was observed.

A detailed description of defects observed by NBS as well as IR contractors is summarized in table XVIa. Besides the total defective wall area in ft^2 found by each inspection, table XVIa also includes the defective wall areas in ft^2 of each room of the house, analyzed from video tapes, available thermograms and documentations. The total estimates of void areas is approximately 155 ft^2. Table XVIb presents the environmental conditions documented by each IR contractor. Thermograms / sketches 16-1 through 16-8 are some examples to demonstrate locations of heat loss anomalies, as they are referred to the descriptions in table XVIa.

Table XVIa. Summary of Defects Observed in Providence House #4

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors P1	P2	P3	P4	Thermogram No. in Appendix
First Floor:									
Dining Room	W	Voids Above Window	4	Yes	Yes	Yes	Yes	Yes	
		Some Air Penetration Problems at Ceiling & Along N Side of Window		Yes	No	No	No	No	
	NW	Air Penetration From Ceiling to Wall-Wall Joint		Yes	No	No	No	No	
		Voids in 2 Partial Bay Cavities at Corner	4	Yes	No	Yes	No	No	
	N	Voids Above All 3 Windows	9	Yes	Yes	Yes	Yes	Yes	
		Defective Ceiling		Yes	No	No	No	No	
Foyer	N	Missing Insulation Above Front Door and Along Both Sides of Door	14	Yes	No	Yes	Yes	No	16-1
		Air Infiltration Underneath Front Door		Yes	No	No	No	No	
Living Room	N	Voids Above All Windows	8	Yes	Yes	Yes	Yes	Yes	16-2
	NE	Air Leakage at Wall-Wall and Wall-Floor Joints		Yes	No	No	No	No	
	E	Voids in 1 Bay Cavity Along S Side of S Window	5	Yes	Yes	Yes	Yes	Yes	16-3
		Voids Above Both Windows	6	Yes	No	Yes	Yes	No	
		Air Leakage Along Window Side Between Fireplace and Window		Yes	Yes	No	No	No	16-4

Table XVIa. Summary of Defects Observed in Providence House #4 (Cont'd)

Room & Orientation	Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors P1	P2	P3	P4	Thermogram No. in Appendix
Family Room E&S	Only Some Air Leakage at Wall-Wall Joints & Under Windows (Both Walls Were Covered by Heavy Drapes)		Yes	No	Yes	No	No	
Bathroom S	Voids Above Window	2	Yes	Yes	Yes	Yes	No	
	Voids Below and Along Side of Window	8	Yes	Yes	No	No	No	
Mud Room S	Small Voids at Bottom of SW Corner	3	Yes	No	Yes	Yes	No	
	Air Leakage at Wall-Wall and Wall-Floor Joint		Yes	No	No	No	No	
Kitchen W	Some Voids Found Between Cabinets and Counter Tops	3	Yes	No	Yes	No	No	16-5
	Defective Ceiling		Yes	No	No	No	No	
Second Floor:								
Master Bedroom N	Voids Above Window & on W of Window	4	Yes	Yes	Yes	Yes	Yes	16-6
	1 Upper Portion Bay Cavity on E of Window	2	Yes	Yes	Yes	Yes	No	
E	Missing Insulation in 1st 2 Full Bay Cavities at NE Corner	20	Yes	Yes	Yes	Yes	Yes	16-7 16-8
	Voids Above Both Windows and in 1 Full Bay Cavity Along S Side of Window	15	Yes	Yes	Yes	Yes	No	
	Air Leakage at NE Corner at Wall-Floor Joint		Yes	No	No	No	No	

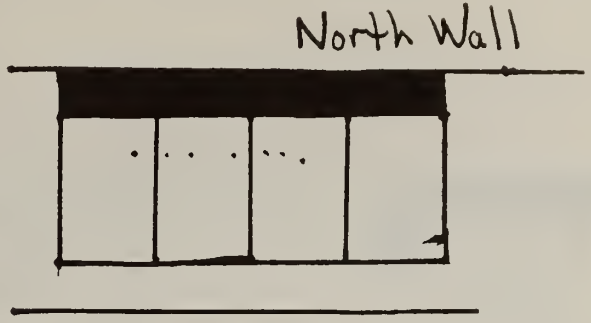
Table XVIa. Summary of Defects Observed in Providence House #4 (Cont'd)

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors P1	P2	P3	P4	Thermogram No. in Appendix
Bathroom (#2)	W	Small Void Under Window	2	Yes	No	No	No	No	
South Bedroom	S	Some Voids at E of Window	4	Yes	Yes	Yes	Yes	Yes	
		Voids Above Window	2	Yes	No	Yes	Yes	Yes	
	W	1 Bay Cavity at SW Corner	10	Yes	Yes	Yes	Yes	Yes	
		Voids Above Window & at Both Sides of Window	5	Yes	No	Yes	Yes	Yes	
North Bedroom	W	1 Bay Cavity at NW Corner	10	Yes	Yes	Yes	Yes	Yes	
		Voids Above Window & on Both Sides of Window	5	Yes	Yes	Yes	Yes	No	
	N	Voids Above Window & at Both Sides of Window	8	Yes	Yes	Yes	Yes	Yes	
Closet	N	Voids Above Window	2	Yes	No	Yes	No	No	
Total Wall Area of Insulation Voids Detected Given in Ft^2			155	155	114	139	136	89	

Table XVIb. Environmental Conditions During Inspections of Providence House #4

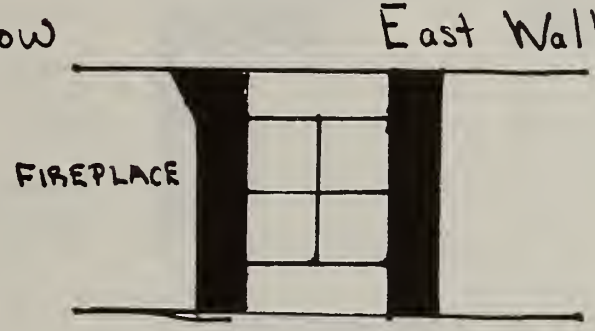
	Contractors			
	P1	P2	P3	P4
Date	3-5-81	3-10-81	3-12-81	3-3-81
Time	6:10-8:15 pm	6:00-7:15 pm	6:00-7:40 pm	6:00-6:45 pm
Weather Condition	cloudy & humid	partly clear	clear	clear
Outside Temperature	33°F	42°F	39°F	34°F
Inside Temperature	70°F	72°F	70°F	68°F
Relative Humidity	52%	29%	45%	40%
Wind Speed(MPH)	light	9	15	10
Wind Direction	W	NW	WSW	NW

16-1
Missing insulation above and along both sides of front door on N wall (by NBS)



Bay between window and fireplace plus bay to right of window void. 23 ft²

Area above picture window uninsulated

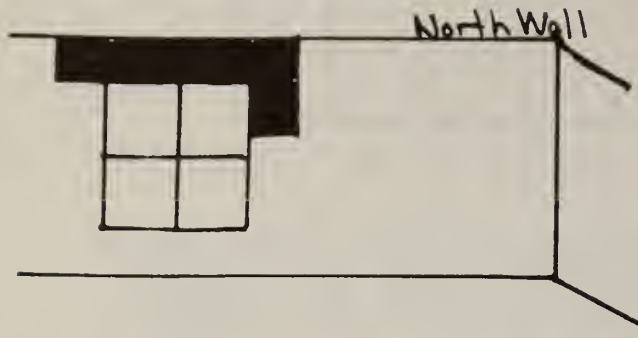


16-2
Uninsulated areas observed in living room (by contractor P1)

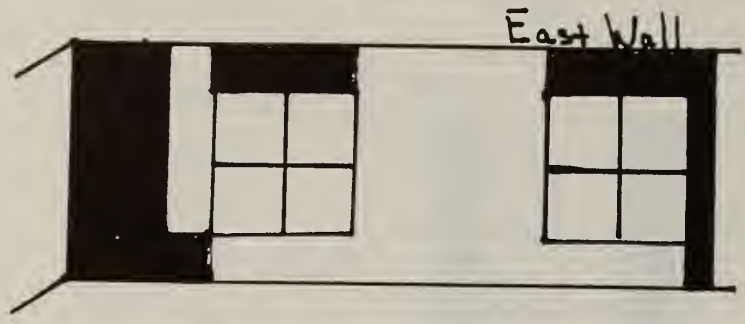
16-3
Voids above window and 1 bay cavity along S side of S window on E wall of living room, & cold area of fireplace chimney on 1st floor (by NBS)

16-4
Exterior thermogram shows the voids above N window on E wall of living room, and area of fireplace chimney (by NBS)

16-5
Small void area observed between cabinets and counter top in wall of kitchen (by NBS)



1st bay to right of window - top 2½ feet void. Over window and to left, as shown, appear insufficiently insulated



1st two bays in north corner and first bay to right of south window void.

Areas over windows appear insufficient.

Total uninsulated area approx 26FT²

16-6
Insufficient insulation areas observed in master bedroom on the second floor (by contractor P1)

16-7
Missing insulation in 1st two bay cavities on E wall at NE corner of master bedroom on the second floor (by NBS)

16-8
Exterior thermogram shows the same defects as shown in 16-7 and portions of the fireplace chimney (by NBS)

XVII. Washington, D.C. House #1

This is a two-story, approximately 29 years old residence whose interior dimensions are 34 ft. in length, 31 ft. in width, and 8 ft. in wall height on the first floor; located in the suburb of Washington, D.C. area. There are totally 5 rooms as living space with an unheated porch, an unheated attic as the second floor, and a basement. Its exterior construction consists of wood subsidings with asbestos shingles, and an asphalt shingle roof.

Prior to the implemetation of the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the walls and attic of this dwelling with cellulose, and basement walls with combinations of fiberglass, cellulose, and styrofoam. After retrofitted options were completed, this dwelling was inspected by NBS personnel and IR contractors W1, W2, W3, and W4. Figure XVII is a sketch of voids and locations of heat losses obtained from video tapes by NBS, thermograms and documents by IR contractors.

Generally speaking, the wall areas of this house were considered to be well insulated, except some shrinkage or fissures, some uninsulated cross braces and stud braces, a few partial bay cavities, and two uninsulated doors. However, severe problems of air penetration from defective ceilings and in the partition wall between kitchen and living room were observed. During the time of inspection, the entire attic on the second floor and the enclosed porch on north side were unheated. This condition makes it difficult to collect meaningful data so the exterior walls of these areas will be excluded from calculation of defective wall areas.

Thermographic inspection by NBS observed most defects of this residence except the bathroom and the basement. Contractors W2 and W4 employed HRIS to inspect this dwelling by producing 3 and 8 thermograms , respectively, to cover different areas of the house. Thermograms submitted by contractor W2 are sharp, but they only represented a few of the uninsulated regions. Contractor W4 is the only one to inspect and to locate insulation defects in the attic and in the basement, even though the quality of the thermograms produced is not too good. Contractors W1 and W3, who used LRIS for inspection, failed to observe a lot of defects on the first floor. Contractor W3 identified only infiltration paths rather than uninsulated areas. It seemed that this contractor did not follow the given instructions for inspection. Furthermore, the number of thermograms submitted is not corresponding to the number in the documentation sheet. This would increase the uncertainties in analysis. Contractor W1 gave detailed sketches of the interior of the house with indication of locations of defects. However, most thermal deficiencies were not included as only two locations were shown in thermograms and in documentation.

A detailed description of defects observed by NBS as well as IR contractors is summarized in table XVIIa. Besides the total defective wall area in ft^2 found by each inspection, table XVIIa also includes the defective wall areas in ft^2 of each room of the house, analyzed from video tapes, available thermograms and documentation. The total estimates of void areas on first floor is approximately 26 ft^2 which represents about 4% of the gross wall area. The uninsulated areas on the unheated attic will be excluded from calculation of total void areas. Table XVIIb presents the environmental conditions documented by each IR contractor. Thermograms 17-1 to 17-6 are some examples to demonstrate locations of heat loss anomalies, as they are referred to the descriptions in table XVIIa.

Table XVIIa. Summary of Defects Observed in Washington, D.C. House #1

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed By NBS	Contractors W1	W2	W3	W4	Thermogram No. in Appendix
First Floor:									
Living Room	S	No Insulation Around Front Door	3	Yes	No	No	Yes	No	
		Voids Around Electric Switches	2	Yes	Yes	No	No	Yes	17-1
		Leakage Along Both Sides of Window		Yes	No	No	No	No	
	W	Voids in 1st Half Bay Cavity at N	5	Yes	No	Yes	No	No	
		Some Small Voids Scattered Over the Entire Wall	3	Yes	No	No	No	No	
	N	Air Penetration into Partition Wall Between Kitchen & Living Room		Yes	No	No	No	No	17-2
Kitchen	W	Air Leakage Through the Side Door		Yes	No	No	Yes	No	
		Some Insulation Voids Below Window	1	Yes	No	Yes	No	No	17-3
Pantry	W	Partial Voids at NW Corner	5	Yes	No	No	No	No	
	N	Ceiling Problem							
Bathroom	N	Some Insulation Missed in Wall Over Tub	(1)	No	No	Yes	No	No	
Middle Bedroom (Ceiling)		Air Penetration from Ceiling Severely		Yes	No	No	No	No	17-4
East Bedroom	E	Uninsulated Cross Brace and Stud Brace Shrinkage or Fissures at N Corner	3	Yes	No	No	No	Yes	

Table XVIIa. Summary of Defects Observed in Washington, D.C. House #1 (Cont'd)

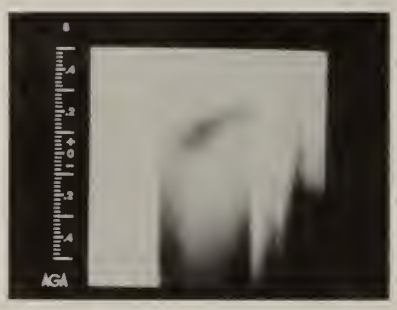
Room & Orientation	Description of Defects	Defective Wall Area in Ft^2	Observed By NBS	Contractors W1	W2	W3	W4	Thermogram No. in Appendi
S	Voids Below and Above Window, Shrinkage or Fissures at E Corner	4	Yes	No	No	No	Yes	17-5
Ceiling	Air Penetration from Ceiling Severely		Yes	No	No	No	Yes	17-6
Second Floor:								
N	Voids Above Window & 2 Partial Uninsulated Bay Cavities at NE of Dormer	(8)	Yes	No	No	Yes	Yes	
E	Small Void on N of Window	(1)	Yes	No	No	No	Yes	
S	Voids Above & Below Window	(3)	Yes	No	No	No	No	
W	Small Voids Above Window	(1)	Yes	No	No	No	No	
Ceiling	Defective Pitched and Flat Ceilings by Moisture Problems		Yes	No	No	Yes	Yes	
Total Wall Area Of Insulation Voids Detected Given in Ft^2		26	26	2	7	3	9	
Basement S	Voids in Wall on Left and Right of Window	9	No	No	No	No	Yes	
Total Wall Area Of Insulation Voids Detected Given in Ft^2		9					9	

Table XVIIb. Environmental Conditions During Inspections of Washington, D.C. House #1

	CONTRACTORS			
	W1	W2	W3	W4
Date	3-6-81	3-3-81	2-26-81	3-9-81
Time	12:01-1:15 pm	10:04-10:45 am	1:45-4:30 pm	11:40-12:30 pm
Weather Condition	clear	clear	sunny, mild, gusty wind	overcast occasional sun
Outside Temperature	41°F	38°F	52°F	52°F
Inside Temperature	64°F	69°F	75°F	70°F
Relative Humidity	74%	60%	38%	39%
Wind Speed(MPH)	17-29	5	15-25	0-8.5
Wind Direction	NW	NE	NW	W

17-1
Voids around electric switch along front door on S wall of living room (by conttactor W4)

17-2
NW corner of living room; half bay cavity at corner and air penetration into N partition wall (by NBS)



17-3
Shrinkage of insulation on W wall of kitchen (by contr.W2)

17-4
Defective ceiling in middle bedroom (by NBS)

17-5
Shrinkage or fissures at E corner of S wall in SE bedroom (by contr.W4)

17-6
Defective ceiling in SE bedroom (by NBS)

XVIII. Washington, D.C. House #2

This is a single story, approximately 40 years old residence whose interior dimensions are 24 ft. in length, 36 ft. in width, and 8 ft. in wall height; located in the suburb of Washington, D.C. area. There are totally 7 rooms as living space with an unheated porch, an attic, and a basement. Its exterior construction consists of German lap sidings and an asphalt shingle roof.

Prior to the implementation of the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the walls with UF foam, the attic with cellulose, and the floors joists with fiberglass batts to this dwelling. After retrofitted options were completed, this dwelling was inspected by NBS personnel and IR contractors W1, W2, W3, and W4. Figure XVIII is a sketch of voids and location of heat losses obtained from video tapes by NBS, thermograms and documents by IR contractors.

In general, the insulation work in this house was not too good as voids were found above most of the windows and doors, and these locations were also sites of air leakage. Some wall and ceiling joints have thermal bridges with infiltration, and bay cavities were also found at wall-to-wall joints.

Thermographic inspection by NBS was carried out for both interior and exterior of this residence. The exterior inspection revealed cold air penetrating from the old chimney into the west wall of the northwest bedroom where not much insulation was blown in due to its height. It also showed the contrast of different insulation levels in the walls between the dining room and the southwest bedroom, a cold room. Contractor W2 and W4 employed HRIS to observe defects in this dwelling by producing 14 and 33 thermograms, respectively, to cover a fair amount of areas of the house. Contractor W4 identified most thermal anomalies of this dwelling and included detailed documentations of their locations. Furthermore, this contractor also inspected the exterior of this dwelling and submitted exterior thermograms as well as interior thermograms for some regions to identify the defects. It appears that contractor W2 had some difficulties to record the correct orientation of the walls of some rooms, and observed only about one third of the defect areas. Contractors W1 and W3, who used LRIS for inspection, failed to observe a lot of defects by producing only 5 and 3 thermograms, respectively. According to the documentation contractor W3 identified most infiltration paths rather than uninsulated areas. It seemed that this contractor did not follow given instructions for inspection. Contractor W1 gave detailed sketches of the interior of this house with indication of locations of defects. However, a lot of thermal deficiencies were not included as only five locations were shown in thermograms and in documentations.

A detailed description of defects observed by NBS as well as IR contractors is summarized in table XVIIIa. Besides the total defective wall area in ft^2 found by each inspection, table XVIIIa also includes the defective wall areas in ft^2 of each room of the house, analyzed from video tapes, available thermograms, and sketches. The total estimates of void areas is approximately 126 ft^2 which represents about 15% of the gross wall area. Table XVIIIb presents the environmental conditions documented by each IR contractor. Thermograms 18-1 to 18-8 are some examples to demonstrate locations of heat loss anomalies, as they are referred to the descriptions in table XVIIIa.

Table XVIIIa. Summary of Defects Observed in Washington D.C. House #2

Room & Orientation	Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors W1	W2	W3	W4	Thermogram No. in Appendix
Entrance E	Narrow Voids on S Side of Window	3	Yes	No	Yes	No	Yes	
	Air Leakage on S of Window		Yes	No	No	No	No	
Kitchen E	Voids at SE corner Below & Above Cabinet	6	Yes	No	Yes	No	No	
S	Uninsulated Side Door		Yes	No	No	No	No	
Bathroom S	Voids Above and on W Side of Window	4	Yes	No	No	No	No	
Southwest Bedroom S	Voids Above & Along Lower E Side of Window	3	Yes	No	No	No	No	
	Small Void on W Side of Window	1	Yes	No	No	No	Yes	
Ceiling	Some Leakage at SE Corner		Yes	No	No	No	Yes	
W	Small Voids at N of Window and at NW Corner from Ceiling	3	Yes	Yes	No	No	Yes	
Ceiling	Voids in Ceiling Insulation		Yes	No	No	No	Yes	18-1
Dining Room W	Voids at Top of Studs on S and N of Window	6	Yes	Yes	Yes	No	Yes	18-2
	Voids Above Window	4	Yes	No	Yes	Yes	Yes	
Northwest Bedroom W	Unfilled Bay Cavities at Top of Wall Above & Under Cross Braces and Around the Old Chimney Area	50	Yes	No	No	No	Yes	18-3
N	Voids at Top of 3 Studs on W of Window	3	Yes	No	Yes	No	Yes	

Table XVIIIa. Summary of Defects Observed in Washington D.C. House #2 (Cont'd)

Room & Orientation	Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors W1	W2	W3	W4	Thermogram No. in Appendix
	Voids Above Window	2	Yes	No	No	Yes	Yes	18-4 18-5
	Voids at Top of 2 Studs of NE Corner	2	Yes	No	No	No	No	
	Small Voids on Both Sides of Window	3	Yes	No	Yes	Yes	Yes	18-6
Living Room N	Voids at Top & Bottom of 1st 2 Bays of W	4	Yes	No	Yes	No	Yes	
	Voids Above and on Both Sides of Window	4	Yes	No	Yes	Yes	Yes	
	Two Partial Bay Cavities at NE corner	10	Yes	No	Yes	No	Yes	
	Air Leakage at Both NE and NW Corner's Wall-Wall Joints		Yes	No	No	No	No	
E	Voids Above and on S Side of Window	4	Yes	Yes	Yes	Yes	Yes	18-7
	1 Partial Bay Cavity at NE Corner and 1 Full Bay Cavity at SE Corner Behind Porch	14	Yes	No	No	No	No	18-8
Total Wall Area of Insulation Voids Detected Given in Ft^2		126	126	13	44	17	101	

Table XVIIIb. Environmental Conditions During Inspections of Washington D.C. House #2

	Contractors W1	W2	W3	W4
Date	3-6-81	3-3-81	2-27-81	3-9-81
Time	3:40-4:35 pm	12:40-1:10 pm	10:30-12:45 pm	9:30-11:20 am
Weather Condition	clear	clear	sunny, cool, gusty winds	cloudy, overcast
Outside Temperature	44°F	44°F	50°F	49°F
Inside Temperature	66°F	70°F	72°F	72°F
Relative Humidity	74%	50%	40%	54%
Wind Speed(MPH)	18-30	5	5-10	0-5.5
Wind Direction	WNW	NE	NW	W

18-1
Voids in W ceiling of SW bedroom (by NBS)

18-2
Exterior thermogram depicts the different insulation levels between dining room and SW bedroom from W wall (by NBS)

18-3
Exterior thermogram shows the unfilled areas and air penetration from old chimney on W of NW bedroom (by NBS)

18-4
Voids above window in N wall of NW bedroom (by NBS)

18-5
Defects observed as in 18-4 (by contractor W4)

18-6
Defects observed as in 18-4 and 18-5, from the exterior (by contractor W4)

18-7
Voids above and on S side of window in E wall of living room (by contr. W2)

18-8
1 full bay cavity at SE corner in E wall of living room (by NBS)

XIX. Washington, D.C. House #3

This is a two-story residence whose interior dimensions are 28 ft. in length, 26 ft. in width, and 8 ft. in wall height on both the first and second floors; located in the suburb of Washington, D.C. area. There are totally 7 rooms as living space with an unheated porch, an attic, and a basement. Its exterior construction consists of aluminum sidings with backings and a metal shingle roof.

Prior to the implementation of the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the walls and attic of this dwelling with cellulose, and basement walls with combinations of fiberglass, cellulose, and styrofoam. After retrofitted options were completed, this dwelling was inspected by NBS personnel and IR contractors W1, W2, W3, and W4. Figure XIX is a sketch of voids and locations of heat losses obtained from video tapes by NBS, thermograms and documents by IR contractors.

Generally speaking, the insulation work of this house were considered to be better on the first floor than on the second floor. However, voids were found above most of the windows and doors in this house. Some wall and ceiling joints have thermal bridges with infiltration, and bay cavities were also found at wall-to-wall joints. On the first floor, air leakage was observed as it leaked into the wall from the electric box, into the ceiling from south side, and also into the partition wall between kitchen and the foyer. The north walls were not insulated since they are the inside walls of the enclosed porch; and they will be excluded from calculation of defective wall areas. The second floor has a lot of uninsulated cross braces, stud braces, and bay cavities. The bathroom floor was found to be cold. This may due to the cold air leaking in between first and second floor. Furthermore, moisture problems of ceiling above hallway and fissures in the wall areas were also observed.

Thermographic inspection by NBS observed most defects of this residence except the basement. Contractors W2 and W4 employed HRIS to inspect this dwelling by producing 20 and 9 thermograms, respectively, to cover different defective areas of the house. They did not inspect the first floor of this dwelling thoroughly expect for the living room ceiling. Contractor W2 identified the uninsulated north walls, but they will be excluded from the analysis. The only other defective area observed by contractor W2 was the south wall of the living room. Contractor W4 did not have the correct orientations of the house and submitted poor documentation of his findings, thus it is difficult to perform analysis from his results. However, this contractor reported that the hot water heater in the basement required insulation, which was not the objective of this analysis. Both contractors W2 and W4 inspected only the north and south walls of the second floor of this house, except the west wall of the northwest bedroom and the southwest corner of the bathroom.

Contractors W1 and W3, who used LRIS for inspection, failed to observe a lot of defects of this house. Contractor W3 did not include any thermograms and reported only infiltration paths rather than uninsulated areas. It seemed that this contractor did not follow the given instructions for inspection. Contractor W1 gave detailed sketches of the interior of the house with indication of locations of defects by including 12 thermograms. Furthermore, this contractor also inspected the basement to locate the uninsulated wall areas at the southeast corner. However, a lot of thermal deficiencies were not identified by this contractor as only west wall of kitchen, south wall of living, south wall of southeast bedroom, north side of second floor, and the second floor ceiling were shown in thermograms and in documentation.

A detailed description of defects observed by NBS as well as IR contractors is summarized in table XIXa. Besides the total defective wall area in ft^2 found by each inspection, table XIXa also includes the defective wall areas in ft^2 of each room of the house, analyzed from video tapes, available thermograms and documentation. The total estimates of void areas is approximately 189 ft^2 which represents about 15% of the gross wall area. Table XIXb presents the environmental conditions documented by each IR contractor. Thermograms 19-1 to 19-7 are some examples to demonstrate locations of heat loss anomalies, as they are referred to the descriptions in table XIXa.

Table XIXa. Summary of Defects Observed in Washington D.C. House #3

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors W1	W2	W3	W4	Thermogram No. in Appendix
First Floor:									
Foyer	S	One partial Bay Cavity on W of Front Door, and Small Void Above Front Door	6	Yes	No	No	No	No	
		Air Leakage From Front Door and Electric Outlet on W		Yes	No	No	No	No	
Ceiling		Cold Air Leaking From Ceiling		Yes	No	No	No	No	
Kitchen	W	Small Void at NW Corner Below Ceiling	3	Yes	Yes	No	No	No	
		Small voids at Bottom of NW Corner and at SW Corner Above Window	5	Yes	No	No	No	No	
	S	Cold Wall May be Caused by Stove		Yes	No	No	No	No	
	N	Uninsulated Wall and Air Leakage Around Door and NW Corner (Excluded From Calculation)		Yes	No	Yes	Yes	No	
Dining Room	N	Uninsulated Wall (Excluded From Calculation)		Yes	Yes	Yes	Yes	No	
	E	1 Bay Cavity Along the N Side of Window and Small Void Above Window	12	Yes	No	No	No	No	
Living Room	E	1 Bay Cavity Along S Side of Window and Small Voids on N of Window	12	Yes	No	No	No	No	

Table XIXa. Summary of Defects Observed in Washington D.C. House #3 (Cont'd)

Room & Orientation	Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors W1	W2	W3	W4	Thermogram No. in Appendix
S	1 Partial Bay Cavity at SW Corner	6	Yes	Yes	Yes	No	No	
	Voids Above Window and Along W Side of Window	6	Yes	No	Yes	No	Yes	
Ceiling	Uninsulated Ceiling Joints From N to S Above Window		Yes	No	Yes	No	Yes	19-1
Second Floor:								
Hallway W	Voids Around Window Air Leakage at N Corner	5	Yes	No	No	Yes	No	
Ceiling	Air Leakage From Ceiling Above and Inner Wall on N Indicating Defective Insulation		Yes	Yes	No	Yes	Yes	
Northwest W Bedroom	Missing Insulation at Stud Brace on S of Window	6	Yes	No	No	No	No	
	1 Bay Cavity Along N Side of Window and Voids Above Window	12	Yes	No	No	No	No	
	Voids Below Window	4	Yes	No	Yes	No	No	
N	2 Bay Cavities at W Corner (1st & 3rd)	20	Yes	Yes	Yes	No	Yes	19-2 19-3
	Small Void Below Window	1	Yes	No	Yes	No	No	
	Air Leakage Across Top of Wall from Ceiling and Also from Both Corners		Yes	Yes	No	Yes	No	

Table XIXa. Summary of Defects Observed in Washington D.C. House #3 (Cont'd)

Room & Orientation	Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors W1	W2	W3	W4	Thermogram No. in Appendix
Northeast N Bedroom	Missing Insulation at Cross Braces on W of Window	4	Yes	Yes	No	No	Yes	19-4
	Voids Above Window	2	Yes	No	Yes	No	Yes	
	Voids Below Window	4	Yes	No	Yes	No	No	
	Voids Along E Side of Window	2	Yes	No	No	Yes	No	
	Small Void or Fissures on E of Window	2	Yes	Yes	Yes	No	Yes	
	Air Leakage at Both Corners		Yes	No	No	No	No	
E	1 Partial Bay Cavity Along N Side of Window, 1 Partial Cavity at S Corner, and Voids Share Window	14	Yes	No	No	No	No	
Southeast E Bedroom	1 Partial Bay Cavity at N Corner, 1 Partial Bay Cavity Along S Side of Window, and Voids Above Window	12	Yes	No	No	No	No	
S	1 Bay Cavity at E of E Window	10	Yes	No	Yes	No	Yes	
	Voids Above E Window	2	Yes	No	Yes	No	No	
	Voids Below E Window	4	Yes	No	Yes	No	No	
	Partial Bay Cavities Between Windows	10	Yes	No	No	No	No	
	Small Voids Above W Window	1	Yes	Yes	Yes	No	Yes	

Table XIXa. Summary of Defects Observed in Washington D.C. House #3 (Cont'd)

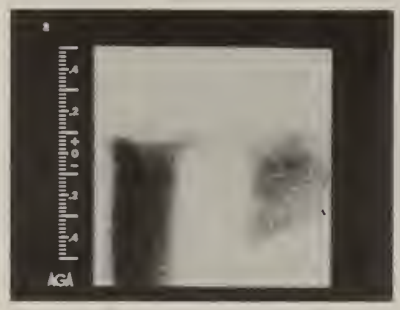
Room & Orientation	Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors W1	W2	W3	W4	Thermogram No. in Appendix
Bathroom S	Voids Above Window	2	Yes	No	Yes	Yes	No	19-5
	Missing Insulation on W of Window and at Corner Braces	14	Yes	No	Yes	No	No	
	Air Penetration into Floor in Tub Area		Yes	No	No	No	No	19-6
W	Missing Insulation at Corner Braces Above Tub Area and at Top of SW Corner	8	Yes	No	Yes	No	No	19-7
Total Wall Area of Insulation Voids Detected Given in Ft^2		189	189	36	86	9	39	

Table XIXb. Environmental Conditions During Inspections of Washington, D.C. House #3

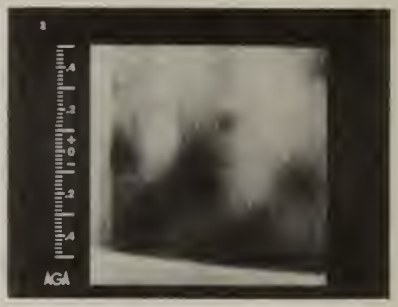
	Contractors W1	W2	W3	W4
Date	3-6-81	3-2-81	2-26-81	3-9-81
Time	1:27-2:49 pm	6:50-8:35 pm	5:00-7:15 pm	3:05-4:30 pm
Weather Condition	clear	partially cloudy	sunny, cool, gusty winds	overcast
Outside Temperature	42°F	41°F	51°F	48°F
Inside Temperature	68°F	73°F	71°F	73°F
Relative Humidity	61%	40%	31%	35%
Wind Speed(MPH)	21-34	10	10-15	0-9.5
Wind Direction	NW	NE	NW	N

19-1
Uninsulated ceiling joints from N to S in living room (by contractor W4)

19-2
Two uninsulated bay cavities at W corner in N wall of NW bedroom (by NBS)

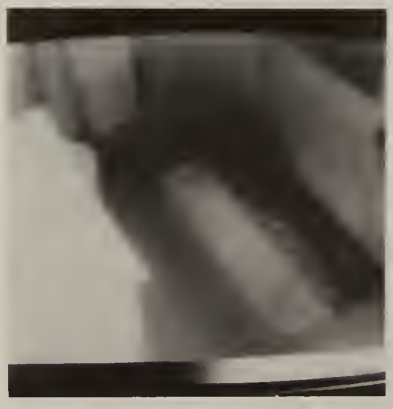


19-3
Defects observed as in 19-2 (by contractor W2)



19-4
Missing insulation at cross braces W of window in N wall of NE bedroom on the second floor (by contractor W2)

19-5
Voids above window and W of window in S wall of bathroom (by NBS)



19-6
Cold floor posssibly due to air penetration between floors in the tub area of bathroom (by NBS)

19-7
Missing insulation at NW corner above tub area in bathroom (by NBS)

XX. Washington, D.C. House #4

This is a two-story residence whose interior dimensions are 30 ft. in length, 24 ft. in width, and 8 ft. in wall height on both the first and second floors; located in the suburb of Washington, D.C. area. There are totally 5 rooms as living space and 2 rooms as storage with an attic and a basement. Its exterior construction consists of asbestos shingles with beveled sidings and a metal roof.

Prior to the implementation of the weatherization program, this house had no insulation. An insulation contractor was instructed to insulate the walls with UF foam, and the attic with cellulose to this dwelling . After retrofitted options were completed, this dwelling was inspected by NBS personnel and IR contractors W1, W2, W3, and W4. Figure XX is a sketch of voids and location of heat losses obtained from video tapes by NBS, thermograms and documents by IR contractors.

In general, the insulation work in this dwelling was considered to be poor as voids were found above and around most of the windows and doors, and uninsulated bay cavities were observed above the cross braces. Since the walls of this house have a lot of cross braces it makes the insulation work difficult to complete. Furthermore, heat-loss problems also existed as cold air leaking into the dining room ceiling and into the pitched ceiling upstairs, and foam penetrating into the partition wall of dining room and southwest bedroom.

Thermographic inspection by NBS was carried out for both interior and exterior of this residence. The exterior inspection not only showed the uninsulated portion of the walls with cross braces, but also revealed the warm attic from the west side indicating some kind of by-pass mechanism existed. Furthermore, the thermal deficiencies of the storage rooms on the second floor were also identified from the exterior alone as these rooms were not open for interior inspection.

Contractors W2 and W4 employed HRIS to observe defects in this dwelling by producing 12 and 30 thermograms, respectively, to cover a fair amount of areas of the house. Contractor W4 identified most thermal anomalies of this dwelling and included detailed documentations of their locations. Even though this contractor did not give correct orientations of the house, the corresponding directions were easily identified to perform analysis. Moreover, this contractor also observed the uninsulated upper portion of the east wall of the storage room #1. Contractor W2 only inspected the north and west walls on the first floor and the northeast bedroom on the second floor of this house, and observed about half of the defective areas. This contractor also had some difficulties to record the orientation of the walls in some rooms.

Contractors W1 and W3, who used LRIS for inspection, failed to observe a lot of defects by producing only 6 and 5 thermograms, respectively. According to the documentation contractor W3 identified most infiltration paths rather than uninsulated areas. It seemed that this contractor did not follow given instructions for inspection. However, this contractor was the only one that scanned the basement to report that the basement door had air leakage. Contractor W1 gave detailed sketches of the interior of this house with indication of locations of defects, including the survey of storage room #2. However, a lot of thermal deficiencies were not included as no inspections were made in the living room and the southwest bedroom.

A detailed description of defects observed by NBS as well as IR contractors is summarized in table XXa. Besides the total defective wall area in ft^2 found by each inspection, table XXa 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 352 ft^2 which represents about 23% of the gross wall area. Table XXb presents the environmental conditions documented by each IR contractor. Thermograms 20-1 to 20-9 are some examples to demonstrate locations of heat loss anomalies, as they are referred to the descriptions in table XXa.

Table XXa. Summary of Defects Observed in Washington, D.C. House #4

Room & Orientation		Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	W1	W2	W3	W4	Thermogram No. in Appendix
First Floor:									
Living Room	E	Missing Insulation in Studs on N and S of, Along Both Edges, and Above Window	20	Yes	No	No	No	Yes	
		Voids in Cross Braces at Both Lower Corners	4	Yes	No	No	No	No	
		Air Leakage Along Ceiling-Wall and Wall-Wall Joints		Yes	No	No	Yes	No	
	S	Missing Insulation on E of Window and in Cross Brace at Lower E Corner	10	Yes	No	No	No	Yes	
		Missing Insulation Above and Around Door	12	Yes	No	No	No	Yes	
Southwest Bedroom	S	2 Bay Cavities at E Corner	20	Yes	No	No	No	Yes	
		Voids Above and Along Both Edges of Window	10	Yes	No	No	No	Yes	
		Missing Insulation in 3 Bays at Upper W Corner	12	Yes	No	Yes	No	No	
	W	1 Bay Cavity at S Corner & Small Voids on S and Above Window	14	Yes	No	No	No	Yes	20-1
Dining Room	W	Missing Insulation in 2 Bay Cavities Above Cross Brace at S Corner	16	Yes	No	Yes	No	Yes	20-2
		Missing Insulation in 2 Bay Cavities Above Cross Brace at N Corner	16	Yes	Yes	No	No	Yes	20-3

Table XXa. Summary of Defects Observed in Washington, D.C. House #4 (Cont'd)

Room & Orientation	Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors W1	W2	W3	W4	Thermogram No. in Appendix
	Voids Above N Window and Between Windows	4	Yes	Yes	No	Yes	Yes	
Ceiling	Air Leakage From Ceiling		Yes	No	No	No	Yes	
S	Foam Penetration into Partition Wall		Yes	No	No	No	No	
N	Missing Insulation in 4 Bay Cavities Above Cross Braces at W and E Corners	32	Yes	Yes	Yes	No	Yes	
	Voids on Both Sides and Above Door	6	Yes	No	No	No	Yes	
Ceiling	Air Leakage From Ceiling		Yes	No	No	No	Yes	
Northeast Bedroom N	Missing Insulation in 2 Bay Cavities Above Cross Braces at W Corner	16	Yes	Yes	Yes	No	Yes	
	Missing Insulation in 2 Bay Cavities Above Cross Braces at E Corner	16	Yes	No	Yes	No	Yes	
	Air Leakage or Voids Above Windows		Yes	No	No	Yes	No	
E	Small Void Below N Window and in Cross Brace at S Corner	6	Yes	Yes	No	No	No	
	Air Penetration From Location of Chimney and Above Windows Along Ceiling-Wall Joint		Yes	No	No	No	No	

Table XXa. Summary of Defects Observed in Washington, D.C. House #4 (Cont'd)

Room & Orientation	Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors W1	W2	W3	W4	Thermogram No. in Appendix
Second Floor:								
Northeast W Bedroom	Voids in 1 Bay Cavity at S Corner	10	Yes	No	Yes	No	Yes	20-4
	Voids Above Window and in 2 Partial Cavities on S of Window	14	Yes	No	Yes	No	Yes	20-5
	Small Voids on N of Window	4	Yes	No	No	No	Yes	
N	Missing Insulation in 2 Bay Cavities Above Corner Braces at N Corner	16	Yes	Yes	Yes	Yes	Yes	20-6
	Missing Insulation in 2 Bay Cavities Above Corner Brace at E Corner	16	Yes	No	Yes	Yes	Yes	
Ceiling	No Insulation on Ceiling		Yes	No	No	No	Yes	20-7
E	2 Partial Bay Cavities at N Corner and Small Void Above N Window	18	Yes	No	Yes	Yes	No	
	2 Partial Bay Cavities at S Corner and Small Voids Above S Window	14	Yes	NO	Yes	Yes	Yes	
	Air Penetration From Chimney		Yes	No	No	No	No	
Storage Room #1 E	Upper Part of Entire Wall Not Insulated	35	Yes	No	No	No	Yes	20-8
S	Voids Above Window and 1 Partial Bay Cavity on E of Window	8	Yes	No	No	No	Yes	

Table XXa. Summary of Defects Observed in Washington, D.C. House #4 (Cont'd)

Room & Orientation	Description of Defects	Defective Wall Area in Ft^2	Observed by NBS	Contractors W1	W2	W3	W4	Thermogram No. in Appendix
Storage Room #2 S	Voids Above Window	3	Yes	Yes	No	No	No	
W and N	Exterior Inspection Showed Warm Paths up to Attic Indicating By-Pass Heat Loss		Yes	No	No	No	No	20-9
Total Wall Area of Insulation Voids Detected Given in Ft^2		352	352	93	180	68	309	

Table XXb. Environmental Conditions During Inspections of Washington, D.C. House #4

	Contractors W1	W2	W3	W4
Date	3-6-81	3-3-81	2-27-81	3-9-81
Time	10:21-11:50 am	11:05 am	1:10-3:30 pm	1:50-3:00 pm
Weather Condition	clear	clear	sunny, cool, gusty winds	overcast, occasional sun
Outside Temperature	40°F	40°F	58°F	52°F
Inside Temperature	68°F	65°F	74°F	76°F
Relative Humidity	61%	55%	12%	30%
Wind Speed(MPH)	17-25	15+	10-15	0-8
Wind Direction	NW	NE	NW	NE

Thermal Anomalies Observed in Washington, D.C. House #4

20-1
Missing insulation above cross braces and W window and 1 bay cavity at SW corner of SW bedroom (by NBS)

20-2
Missing insulation above cross braces at SW corner, and foam penetration into partition wall on S of dining room (by NBS)

20-3
Missing insulation in bay cavities above corner braces at NW corner of dining room (by NBS)

20-4
Thermal deficiencies observed at SW corner by exterior thermogram (by NBS)

20-5
Voids above window and in 2 partial bay cavities on S of window of W wall of NE bedroom on 2nd floor (by contractor W2)

20-6
Exterior thermogram shows defects at N of dwelling (by NBS)

20-7
Voids and ceiling defects at NE bedroom on second floor (by contr.W4)

20-8
Missing insulation in upper part of entire E wall on second floor shown by exterior thermogram (by NBS)

20-9
Exterior thermogram showing warm paths up to attic at NW corner indicating by-pass heat loss (by NBS)

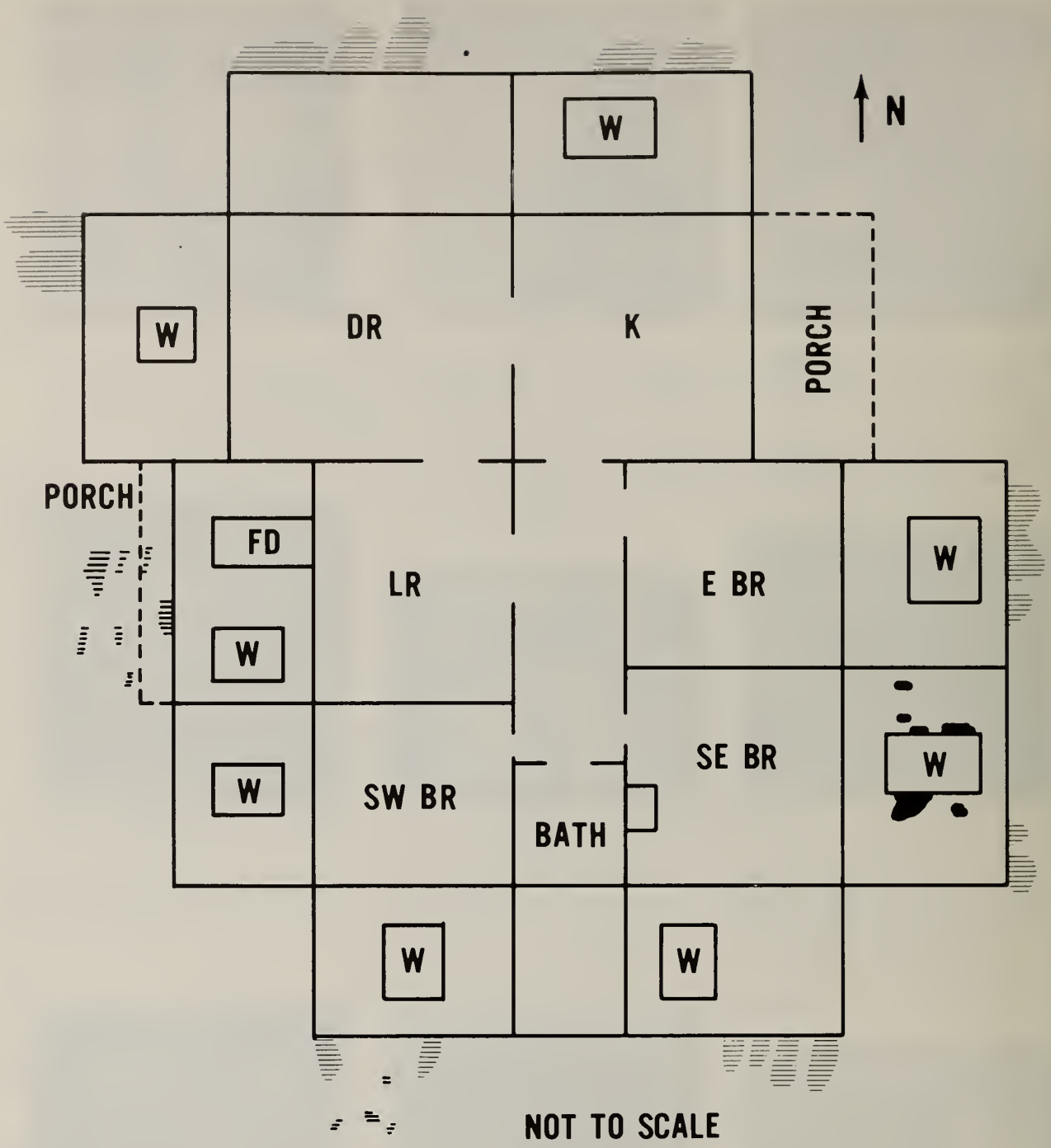


Figure I. Thermal deficiencies observed in ceiling and southeast bedroom of Atlanta house #1

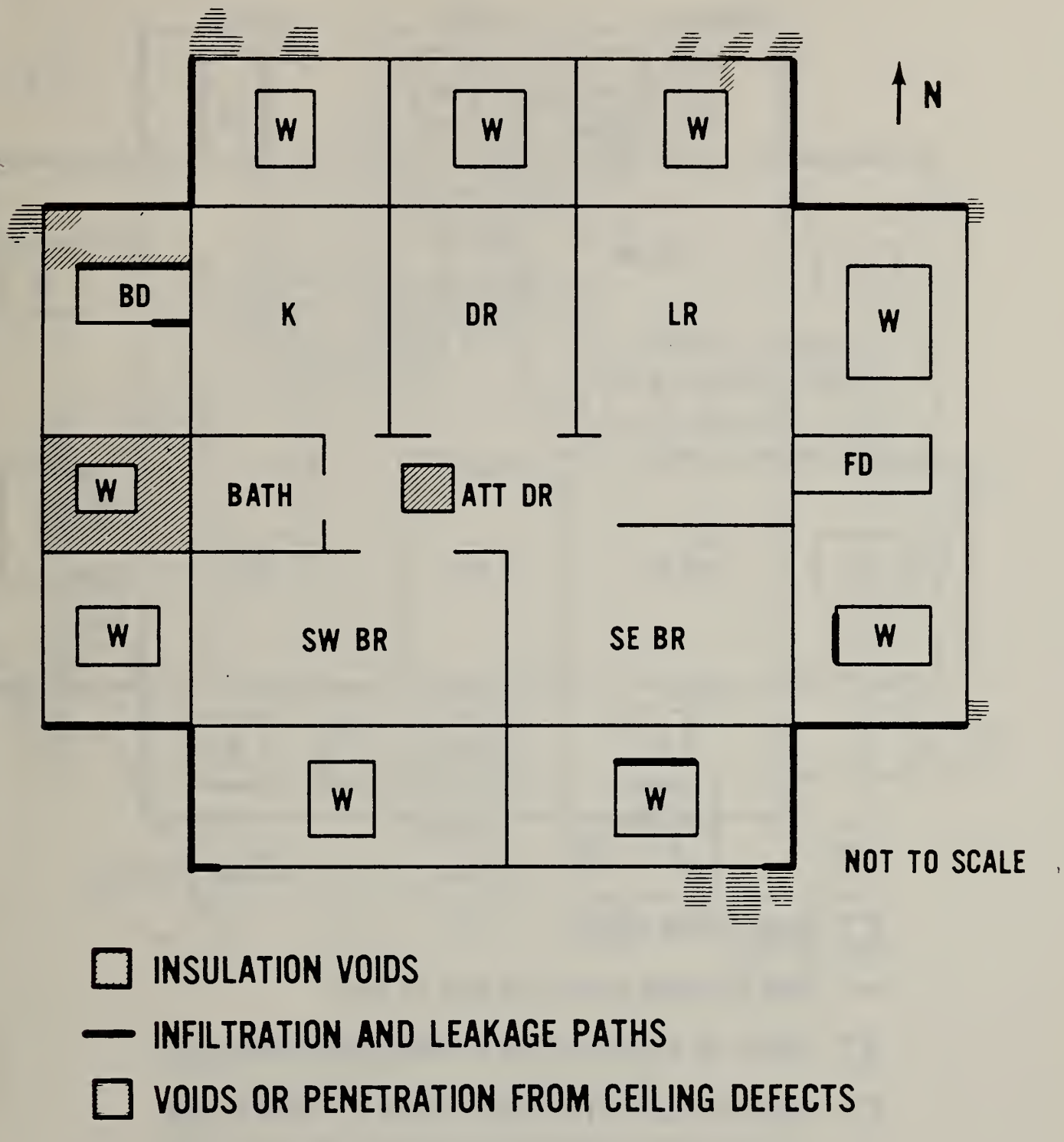


Figure II. Thermal deficiencies observed in Atlanta house #2

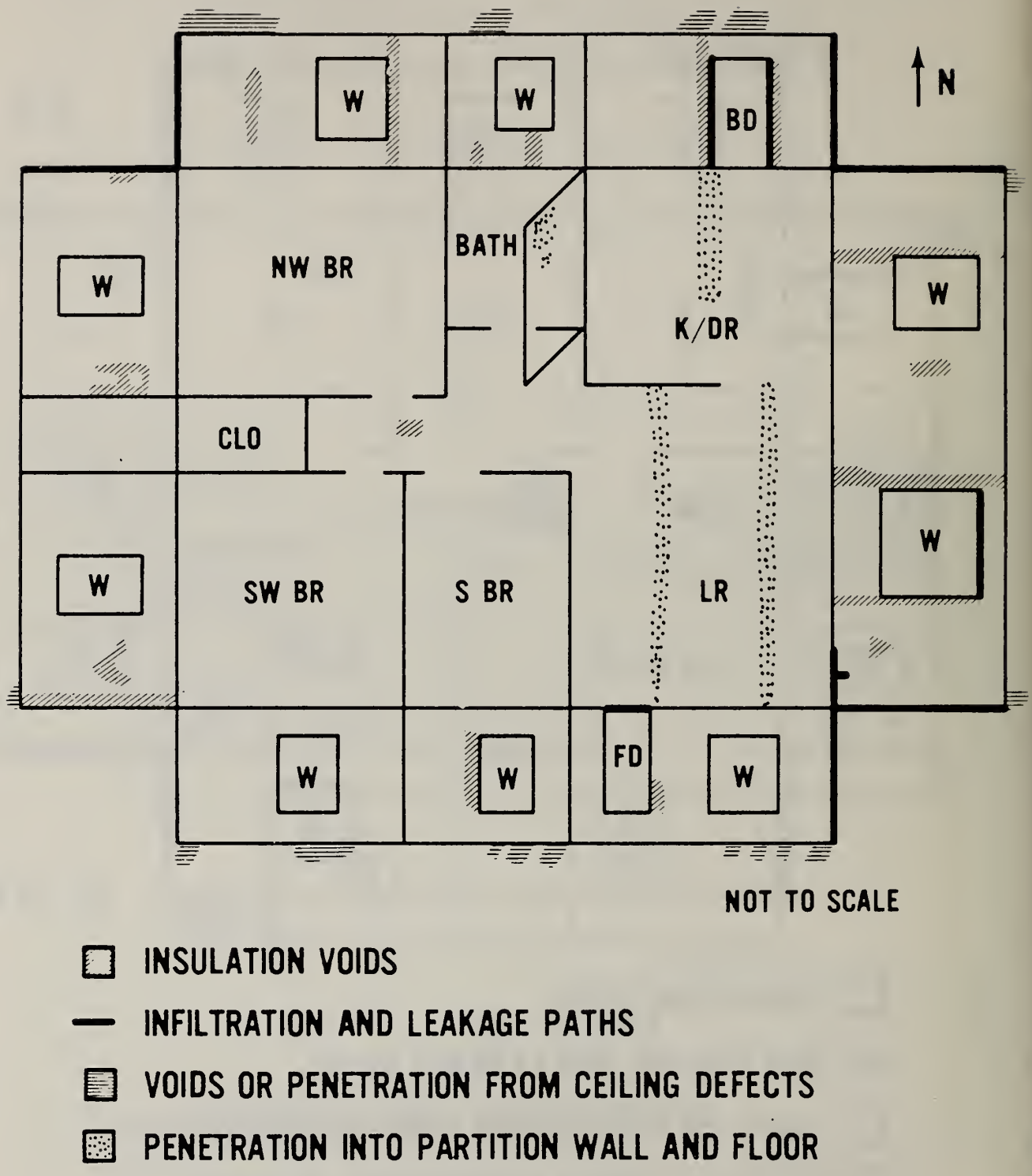


Figure III. Thermal deficiencies observed in Atlanta house #3

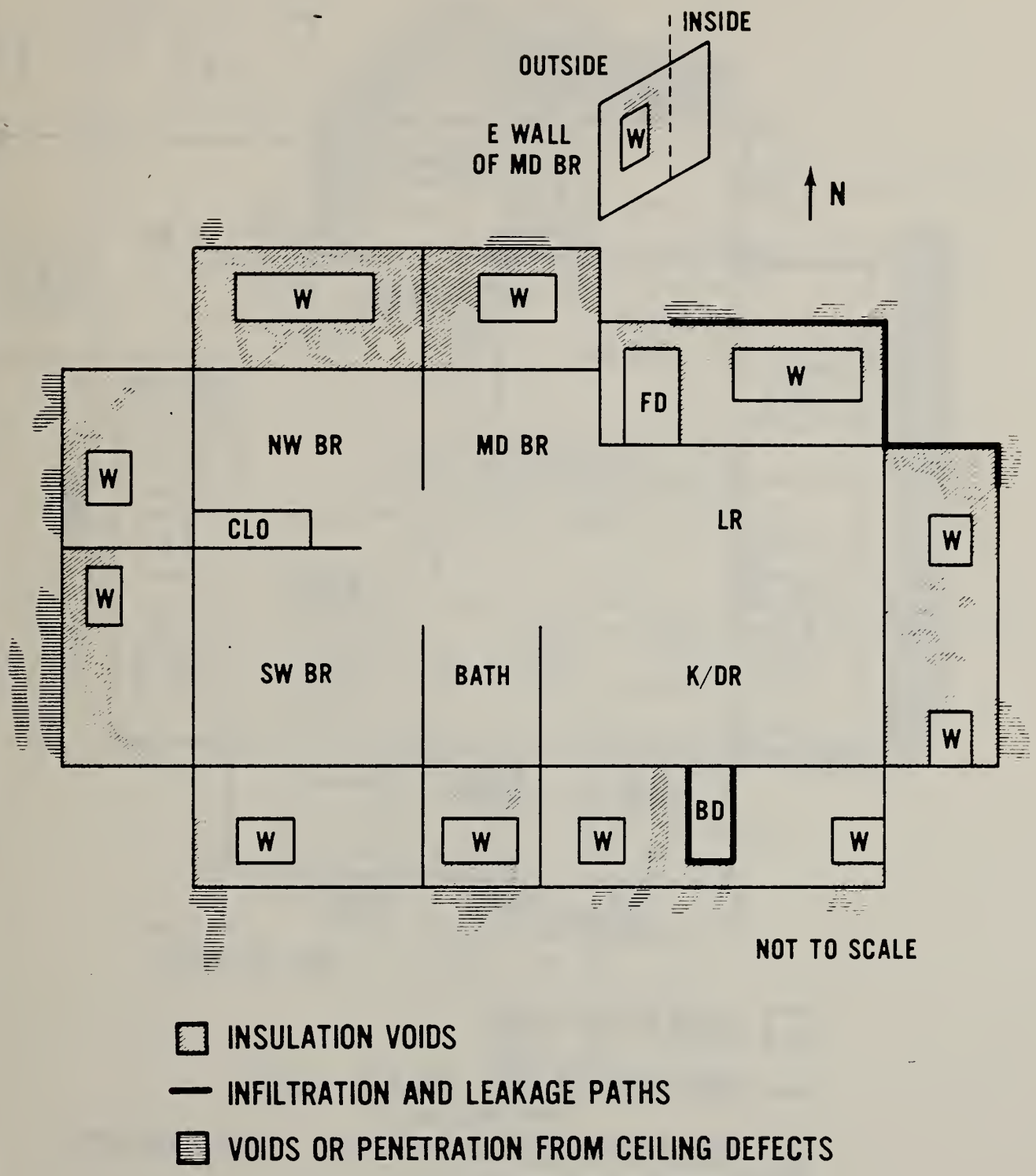


Figure IV. Thermal deficiencies observed in Atlanta house #4

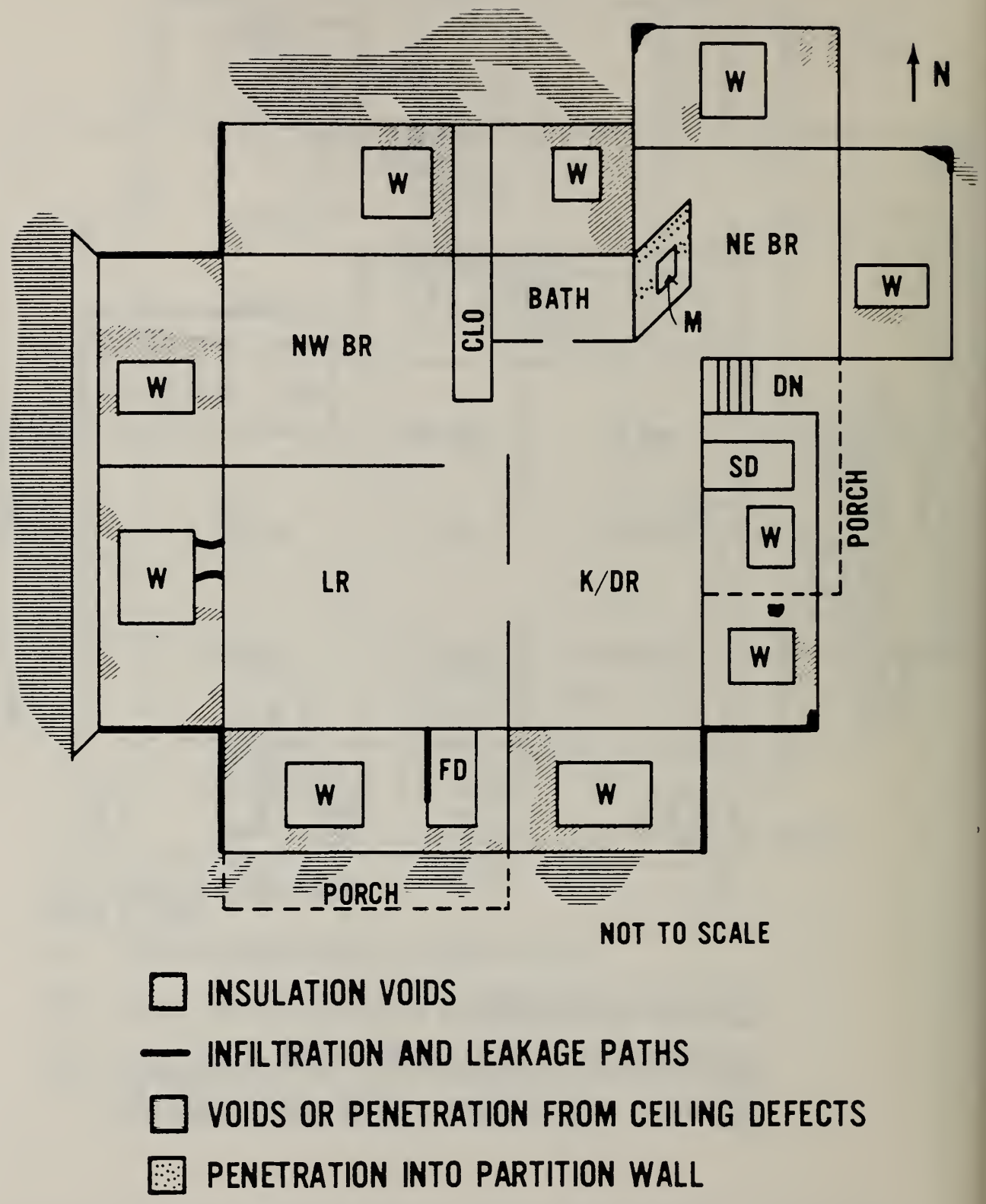


Figure V. Thermal deficiencies observed in Colorado Springs house #1

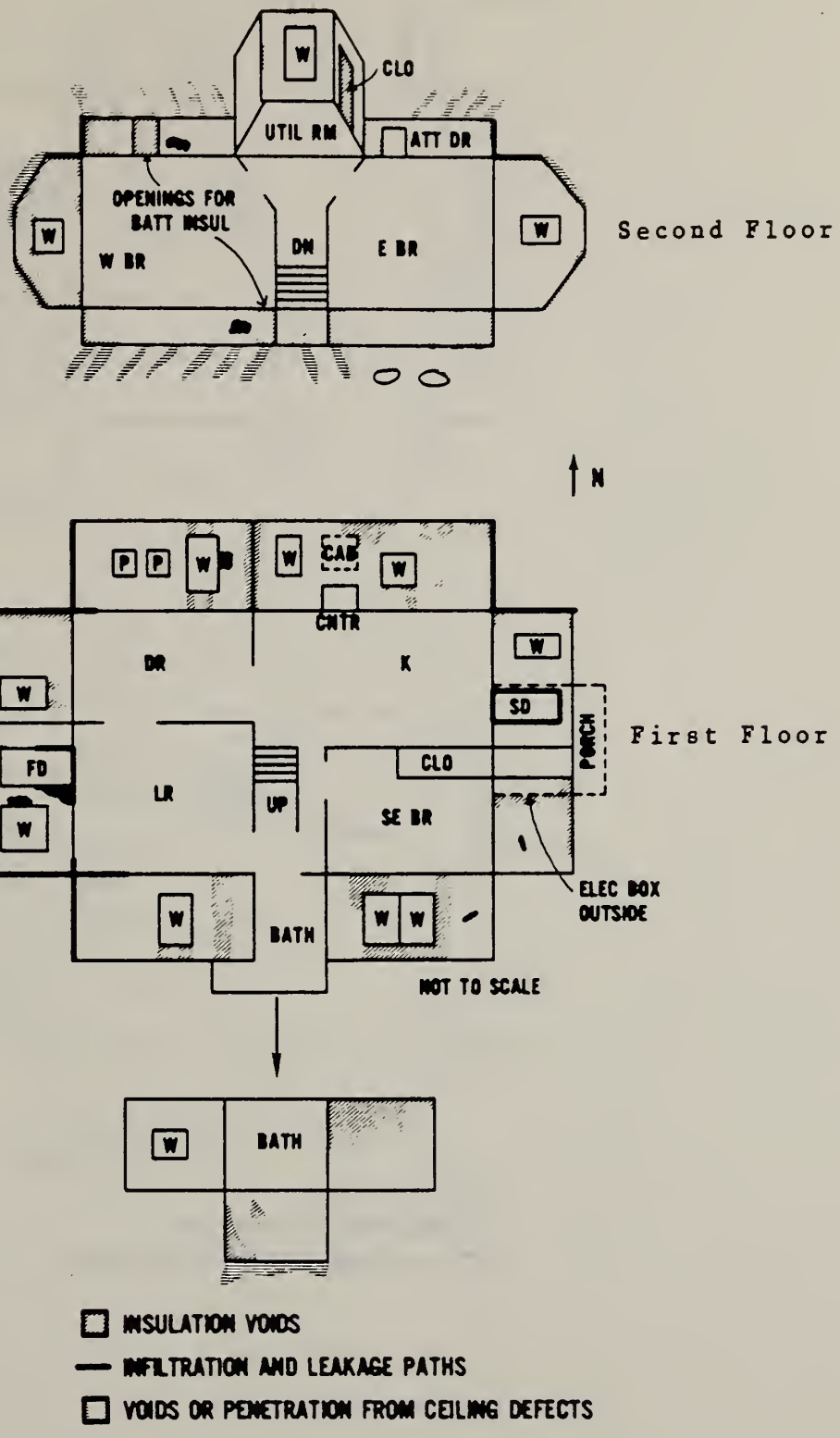
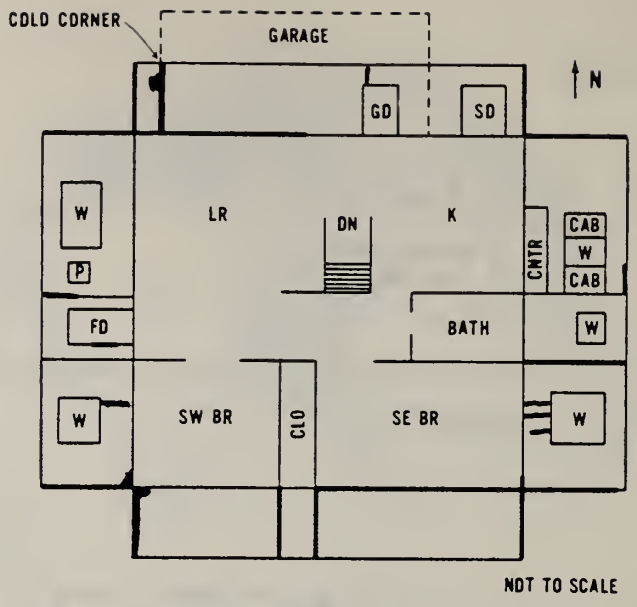
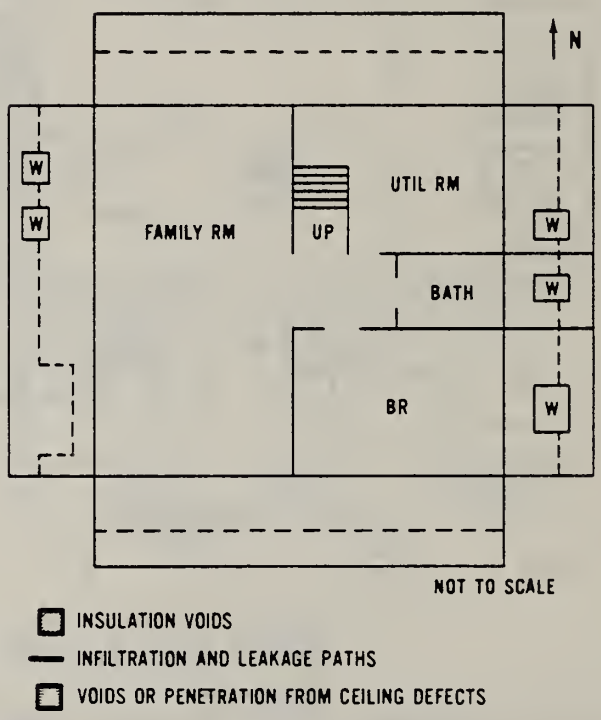


Figure VI. Thermal deficiencies observed in Colorado Springs house #2



Main Floor



Basement

Figure VII. Thermal deficiencies observed in Colorado Springs house #3

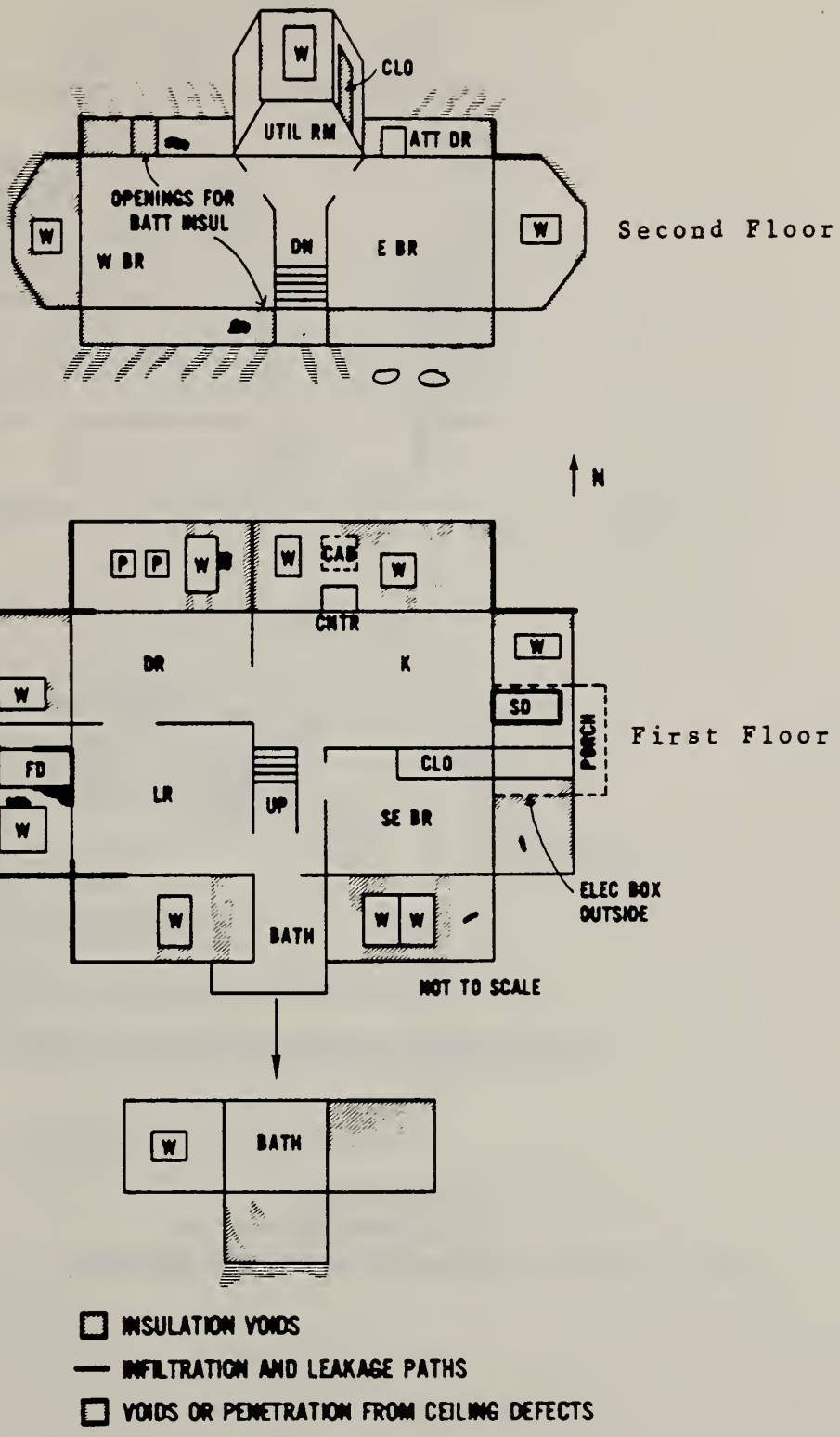


Figure VI. Thermal deficiencies observed in Colorado Springs house #2

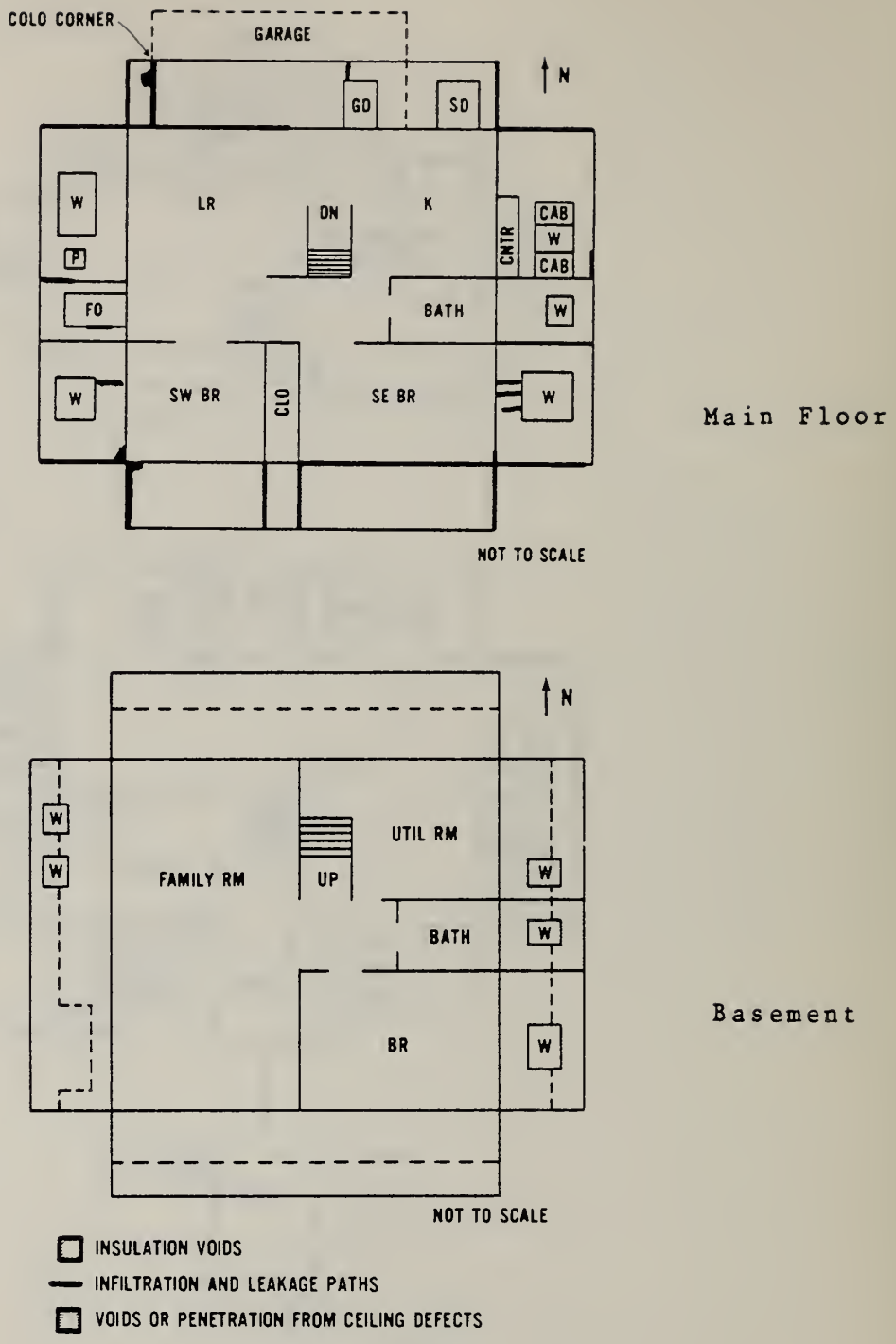


Figure VII. Thermal deficiencies observed in Colorado Springs house #3

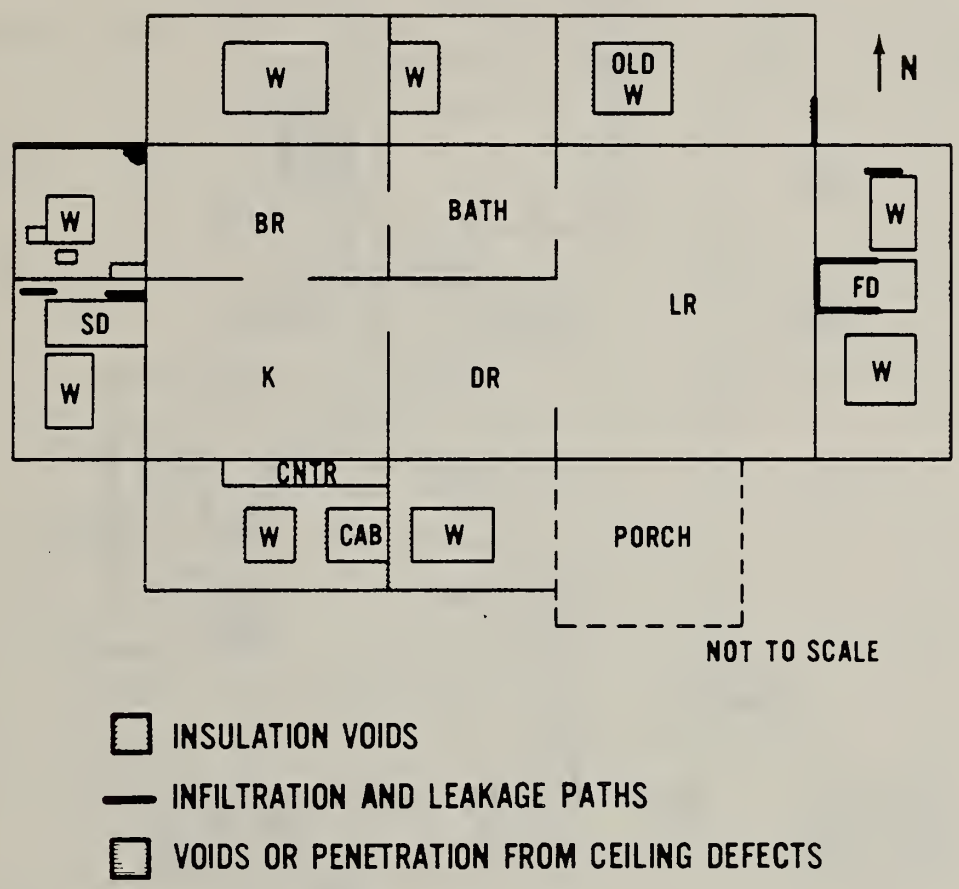
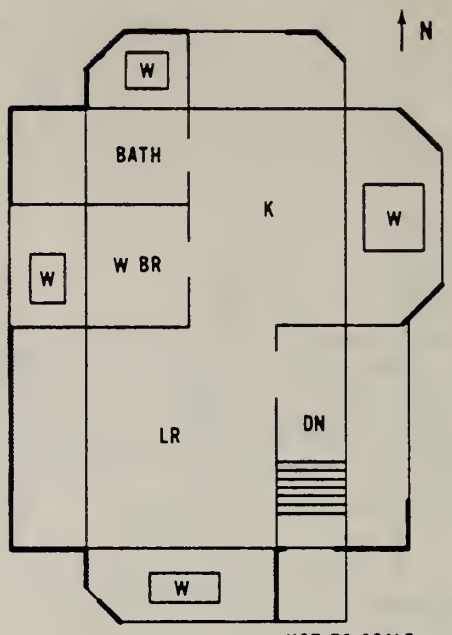
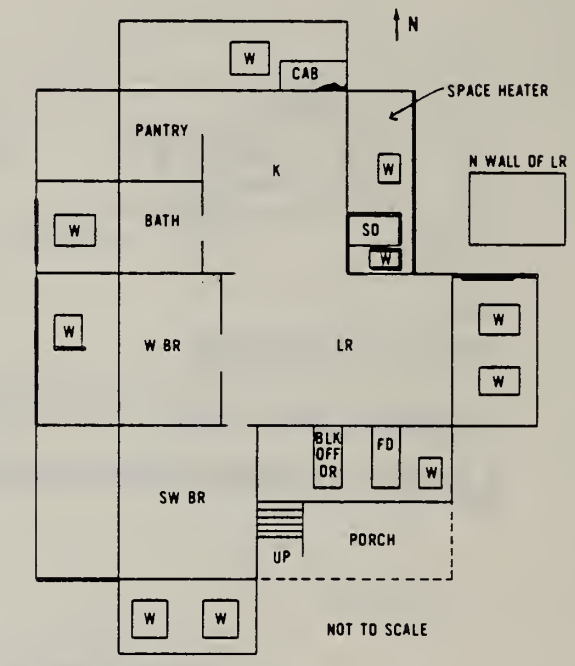


Figure VIII. Thermal deficiencies observed in Colorado Springs house #4



Second Floor



First Floor

Figure IX. Thermal deficiencies observed in Minneapolis-St. Paul house #1

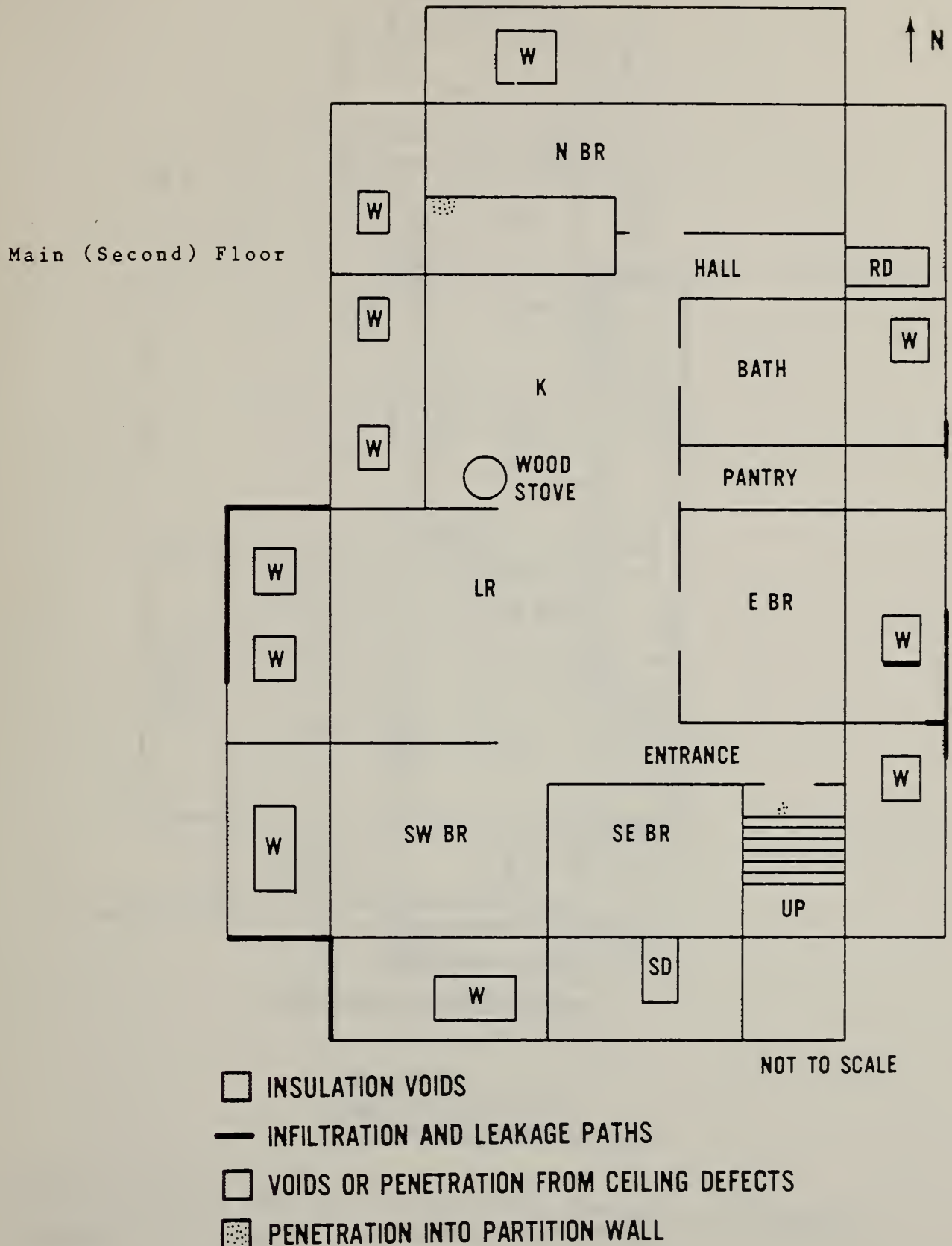


Figure X. Thermal deficiencies observed in Minneapolis-St. Paul house #2

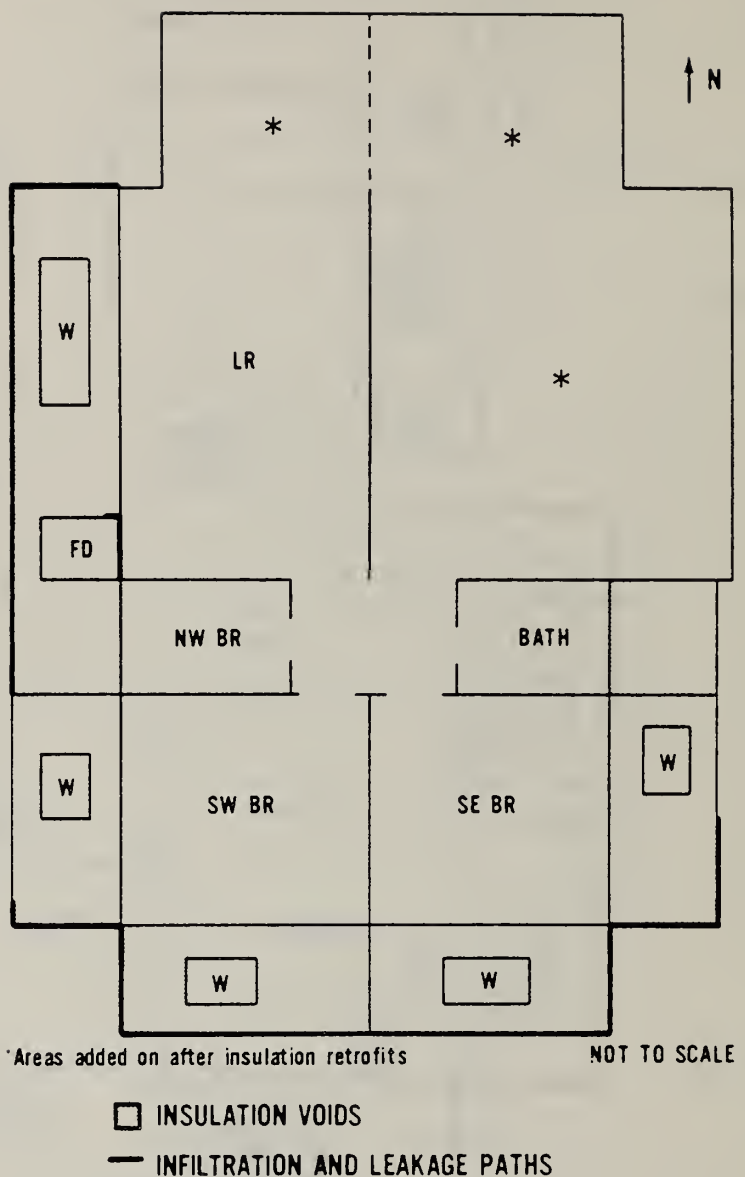


Figure XI. Thermal deficiencies observed in Minneapolis-St. Paul house #3

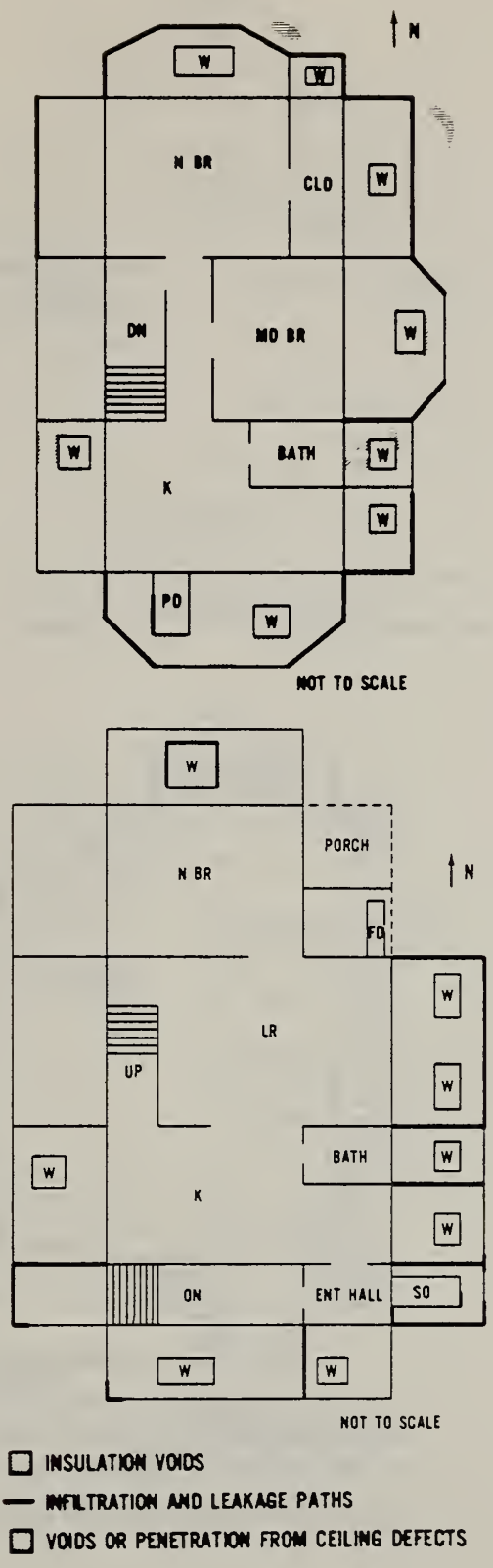
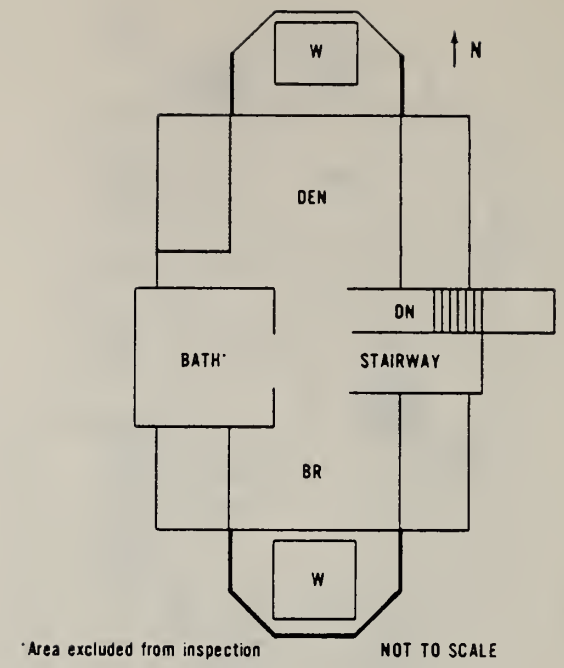
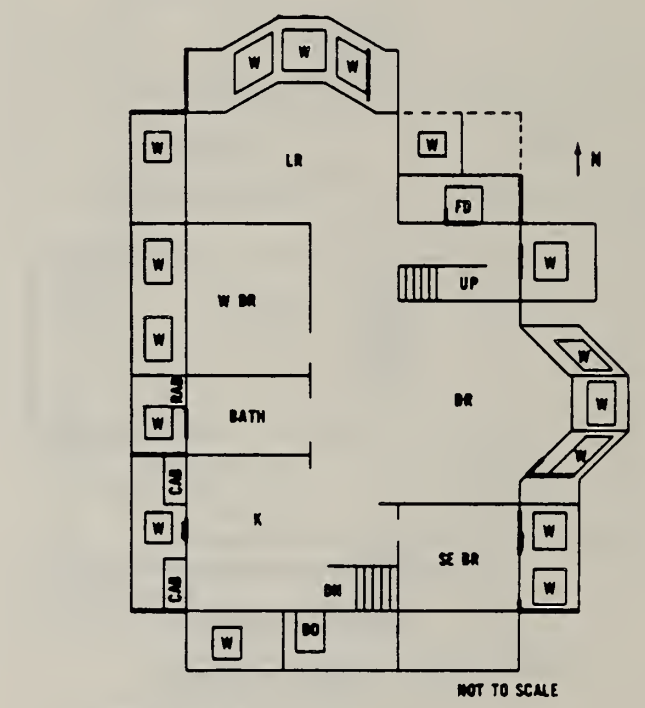


Figure XII. Thermal deficiencies observed in Minneapolis-St. Paul house #4

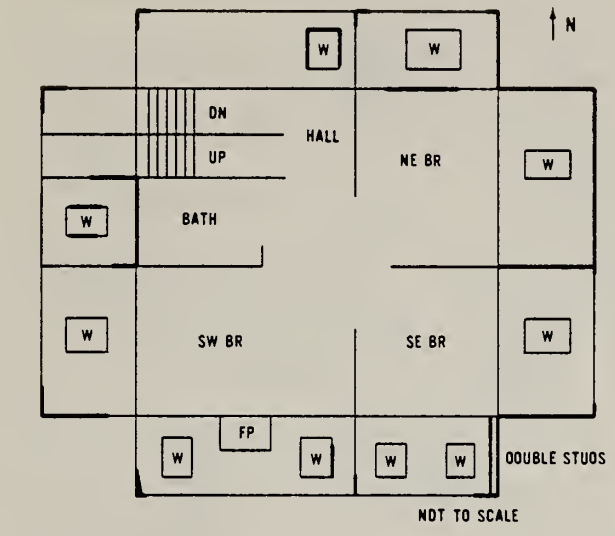


Second Floor

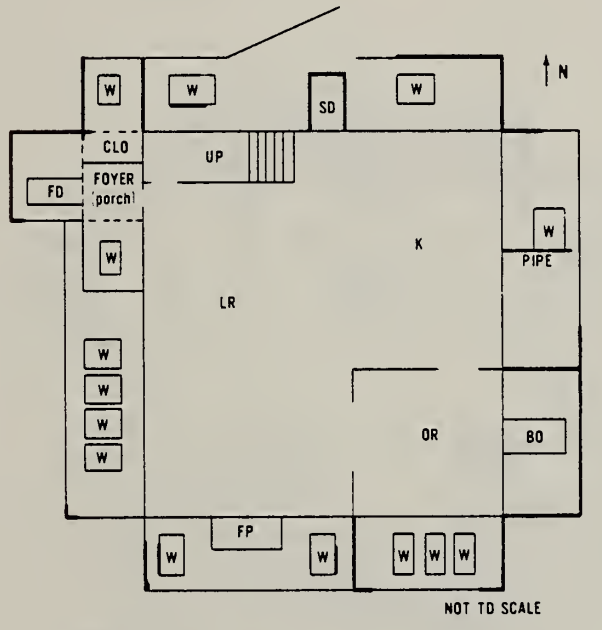


First Floor

Figure XIII. Thermal deficiencies observed in Providence house #1



Second Floor



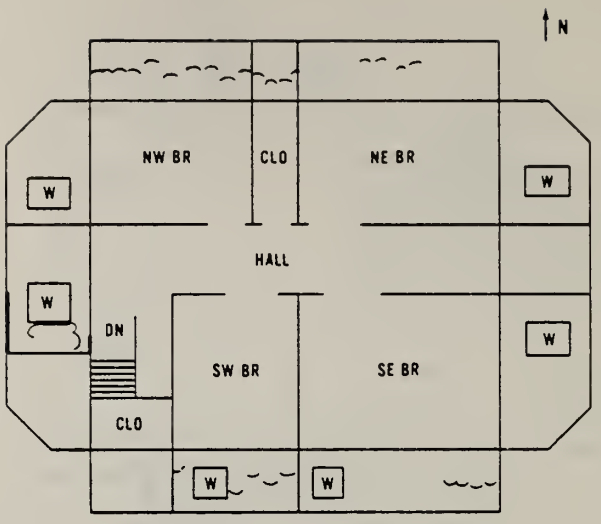
First Floor

INSULATION VOIDS

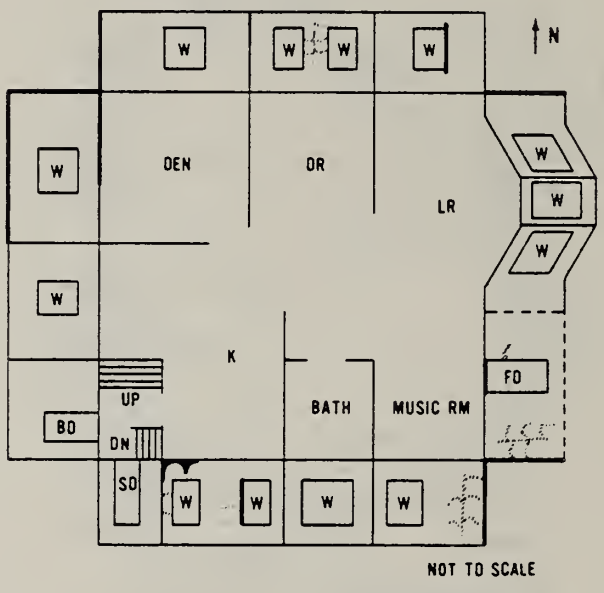
INFILTRATION AND LEAKAGE PATHS

VOIDS OR PENETRATION FROM CEILING DEFECTS

Figure XIV. Thermal deficiencies observed in Providence house #2



Second Floor



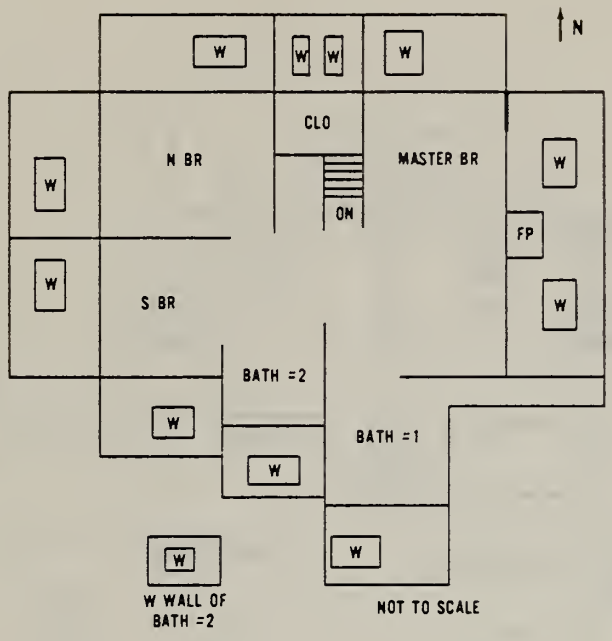
First Floor

INSULATION VOIDS

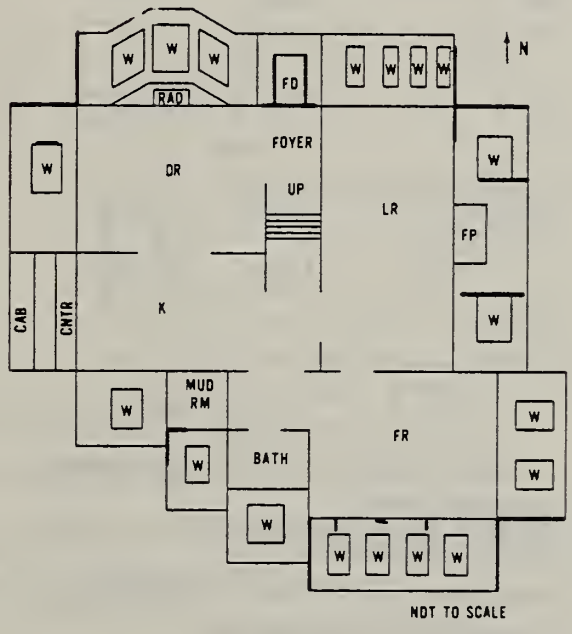
INFILTRATION AND LEAKAGE PATHS

VOIDS OR PENETRATION FROM CEILING DEFECTS

Figure XV. Thermal deficiencies observed in Providence house #3



Second Floor



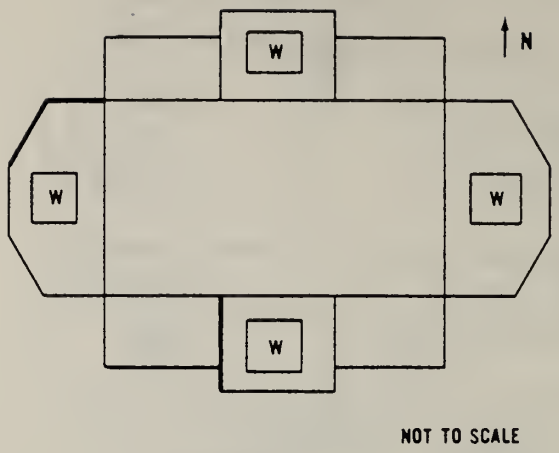
First Floor

☐ INSULATION VOIDS

— INFILTRATION AND LEAKAGE PATHS

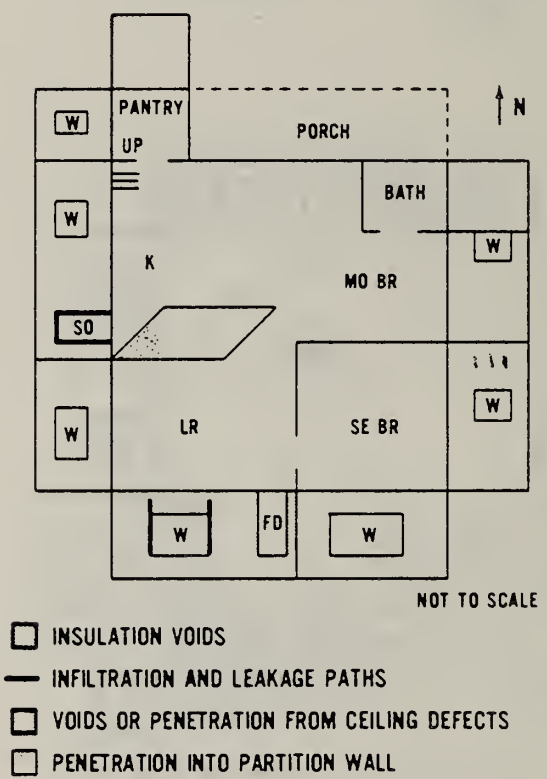
☐ VOIDS OR PENETRATION FROM CEILING DEFECTS

Figure XVI. Thermal deficiencies observed in Providence house #4



Second Floor

NOT TO SCALE



First Floor

NOT TO SCALE

- INSULATION VOIDS
- INFILTRATION AND LEAKAGE PATHS
- VOIDS OR PENETRATION FROM CEILING DEFECTS
- PENETRATION INTO PARTITION WALL

Figure XVII. Thermal deficiencies observed in Washington, D.C. house #1

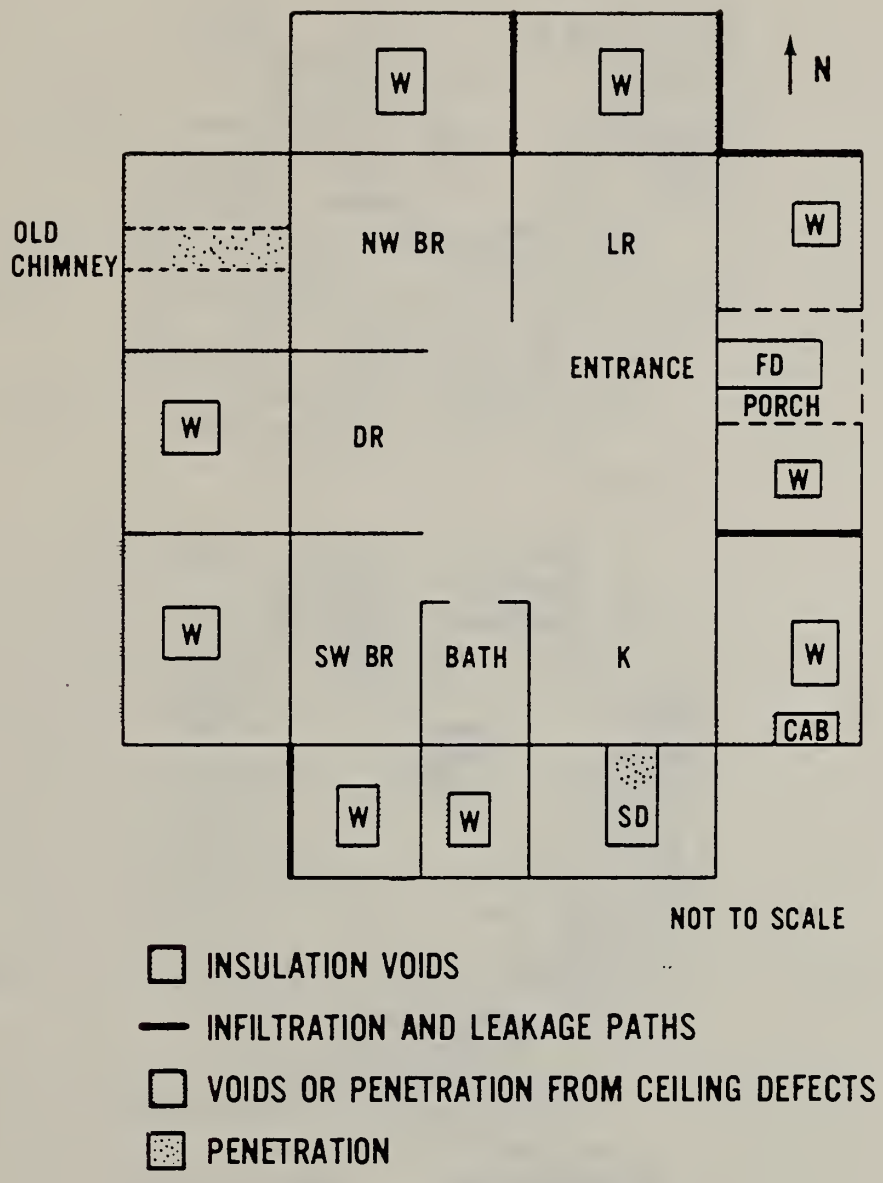
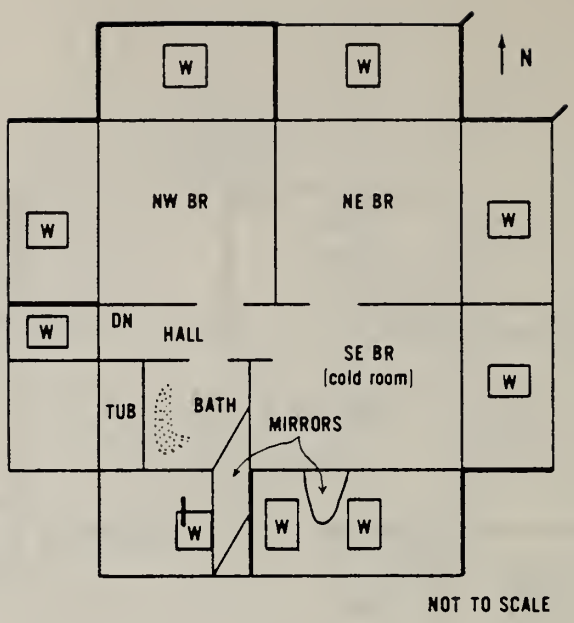
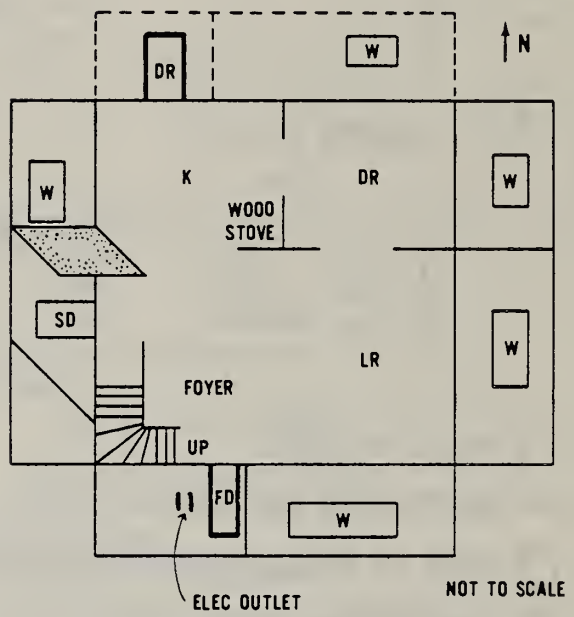


Figure XVIII. Thermal deficiencies observed in Washington, D.C. house #2



Second Floor



First Floor

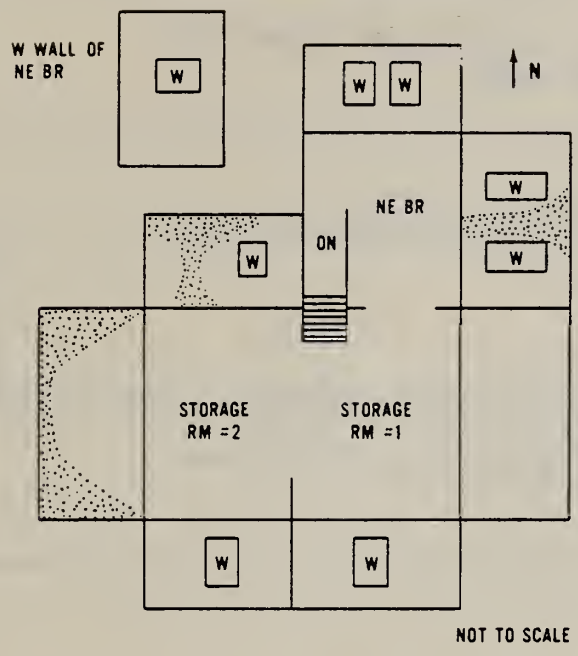
INSULATION VOIDS

INFILTRATION AND LEAKAGE PATHS

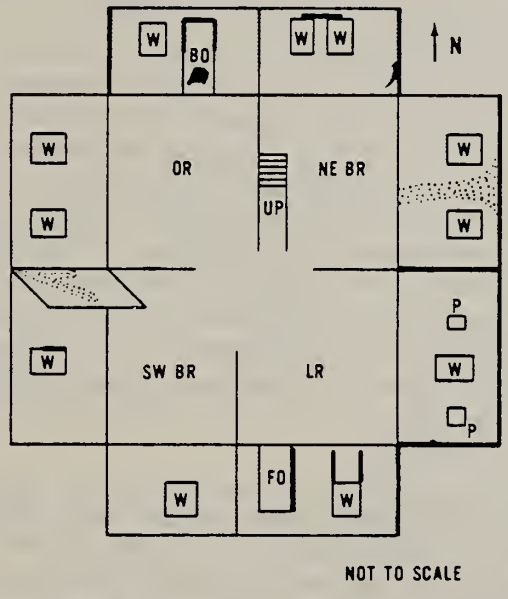
VOIDS OR PENETRATION FROM CEILING DEFECTS

PENETRATION INTO PARTITION WALL AND FLOOR

Figure XIX. Thermal deficiencies observed in Washington, D.C. house #3



Second Floor



First Floor

- INSULATION VOIDS
- INFILTRATION AND LEAKAGE PATHS
- VOIDS OR PENETRATION FROM CEILING DEFECTS
- PENETRATION INTO PARTITION WALL AND BYPASS HEAT LOSSES

Figure XX. Thermal deficiencies observed in Washington, D.C. house #4

NBS-114A (REV. 2-8C)

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5. AUTHOR(S)

Yui-May L. Chang and Richard A. Grot

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

NATIONAL BUREAU OF STANDARDS
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WASHINGTON, D.C. 20234

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Building Systems Division
Office of Building Energy Research and Development
U.S. Department of Energy
Washington, DC 20585

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)

An applied research program was sponsored by the Department of Energy to analyze and compare the results from inspections that utilized infrared sensing systems to identify thermal deficiencies in buildings. This research consisted of both the laboratory evaluation of the commonly used infrared sensing equipment for building inspections and the field evaluation of the accuracy and consistency of the results of thermographic surveys performed by various thermographic inspectors. The field evaluation of thermographic inspection performed by infrared contractors was undertaken using residences previously inspected by the National Bureau of Standards (NBS) as part of the Community Services Administration Weatherization Program. The results of the first phase was carried out in 1978-79 and published in a previous report. The present report contains the analysis and comparison of thermal anomalies detected by NBS and infrared contractors, during the second phase of this research program, on twenty single-family residences in five cities in 1980-81.

A substantisl improvement was apparent in the style of reporting by infrared contractors, under phase two, as compared with phase one. However, contractors' surveys still have problems related to completeness of inspection, quality of hard-copy documentations, interpretation of thermal defects, and utilization of equipment. Consequently, contractors generally identified only about 50 percent of the total defects.

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

Comparison of inspections; infrared sensing systems; insulation voids; interpretation of thermograms; location of heat loss; quality controls; thermal deficiencies; thermographic inspections.

13. AVAILABILITY

☒ Unlimited

☐ For Official Distribution. Do Not Release to NTIS

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☒ Order From National Technical Information Service (NTIS), Springfield, VA. 22161

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