NBSIR 83-2768

Interim Report on NBS Thermal Integrity Diagnostic Tests on Eight GSA Federal Office Buildings

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

September 1983

Prepared for:

ublic Building Service
ieneral Services Administration
/ashington, DC 20405

NBSIR 83-2768

INTERIM REPORT ON NBS THERMAL INTEGRITY DIAGNOSTIC TESTS ON EIGHT GSA FEDERAL OFFICE BUILDINGS

Richard A. Grot
Yui-May L. Chang
Andrew K. Persily
Jin B. Fang

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

September 1983

Prepared for:
Public Building Service
General Services Administration
Washington, DC 20405

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

Abstract

This report summarizes preliminary results of diagnostic tests to evaluate the thermal integrity of eight federal office buildings located throughout the country. The test results include tracer gas measurements of air infiltration rates, pressurization tests of the airtightness of the building shell, and inspections of the envelope employing infrared thermography. In addition, the thermal U-values of exterior walls were measured with both heat flow meters and a portable calorimeter box. The data collected on these buildings are still undergoing analysis and therefore are to be considered preliminary.

Key Words: air infiltration; building diagnostics; building thermal integrity; fan pressurization; field measurements; thermographic inspections; tracer gas techniques; U-value tests

Preface

This work was sponsored by the Public Building Service of the General Services Administration through an interagency agreement with the National Bureau of Standards, Interagency Agreement No. PBS-80-1.

TABLE OF CONTENTS

List of Tables

List of Figures

1. Introduction

In order to assess the usefulness of various diagnostic procedures for the assessment of the thermal integrity of the envelope of federal office buildings, the National Bureau of Standards performed a series of diagnostic tests on eight federal office builidngs during the period from September 1982 to May 1983. These buildings were located in Anchorage, AK, Columbia, SC, Norfolk, VA, Springfield, MA, Pittsfield, MA, Huron, SD, Ann Arbor, MI, and Fayetteville, AR. The tests which were performed on these buildings consisted of: fan pressurization to assess the tightness of the building envelope, tracer gas measurements of the natural air infiltration rates and ventilation rates of the buildings, ground based infrared thermography, aerial thermography, inspection of the buildings with spot radiometers, determination of the thermal conductance or U-value using heat flow meters and a portable calorimeter, and leakage testing of the components of the building. A detailed technical description of these test methods can be found in the report of the first phase of this project[1]. The purpose of the present report is to summarize the data collected and analyzed from the fan pressurization tests, the tracer gas tests, the thermographic inspections and the U-value tests. To date NBS has been able to carry out all tests envisioned in the first phase of this project with the exception of the use of the Envelope Thermal Testing Unit (ETTU) developed by Lawrence Berkeley Laboratories for measuring the dynamic response of walls. This device will not be available to NBS until the late summer of 1983.

2. Description of the Buildings

The eight federal office buildings are located in the cities shown in the map in figure 1. In general these are new buildings (less than 3 years old) constucted to the U.S. federal energy guidelines of less than 630 MJ/m^2 per year of on-site energy and less than 1200 MJ/m^2 per year of off-site energy. The building in Fayetteville, AR is 7 years old and was built before this energy guideline for new federal office buildings was in effect. Though these buildings tend to perform better than most existing federal office buildings, none has met the energy guidelines during its first few years of occupancy. For the purpose of this study the buildings in Anchorage, AK; Springfield, MA; Norfolk, VA; and Columbia, SC are considered large office buildings (over 10,000 m^2 of occupiable floor area). Columbia is 15 stories high, Norfolk 8 stories, Anchorage between 2 and 6 depending on the module, and Springfield 5 stories. The buildings in Pittsfield, MA; Huron, SD; Ann Arbor, MI; and Fayetteville, AR are considered small office buildings (less than 10,000 m^2 of floor area). These small office buildings range in height from 2 to 5 stories. Schematic diagrams and a photograph of each building are given in figures 2 through 9. All but two of the buildings have variable volume air handlers in the major zones of the buildings. They are heated by perimeter heating systems which are generally hydronic. The building in Columbia has two perimeter heating systems. In the Norfolk building, heaters and air conditioners have been added to the air system on floors which proved difficult to heat and cool. They all have central chiller systems for cooling the core spaces of the buildings. The buildings in Anchorage and Springfield have underground garages. The Norfolk building has an exterior garage.

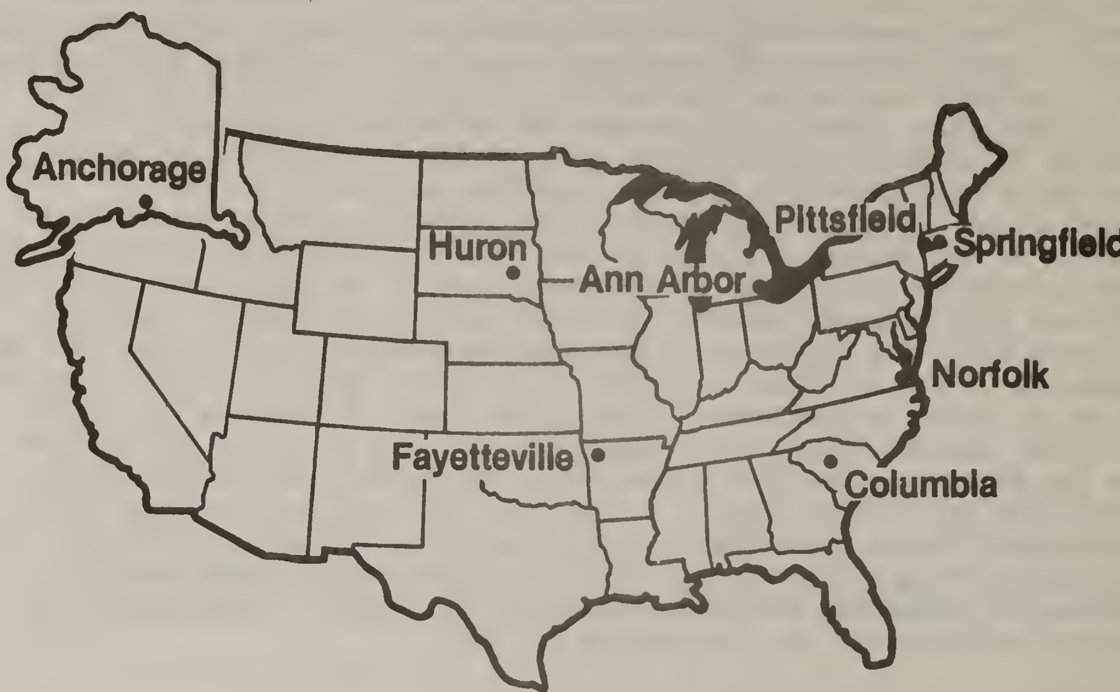


Figure 1. Location of the Eight Federal Office Buildings

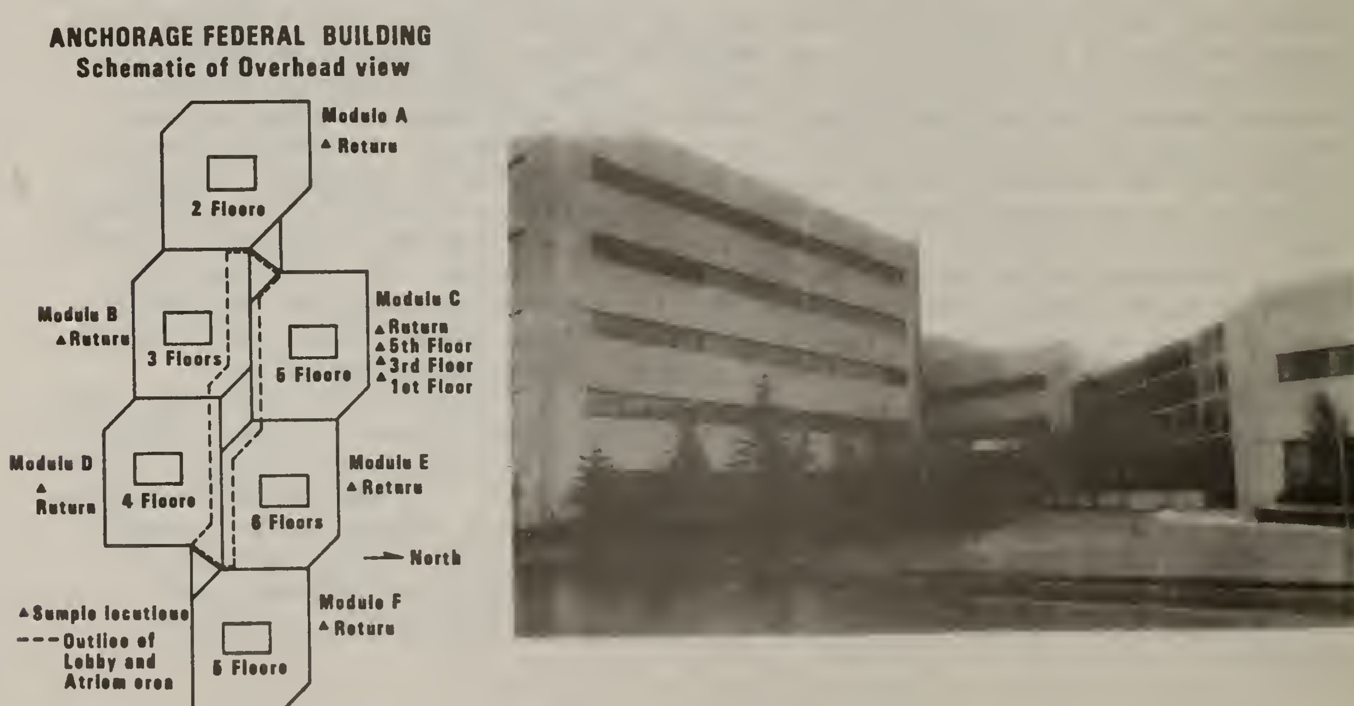


Figure 2. Schematic Diagram and Photograph of Federal Building in Anchorage, AK

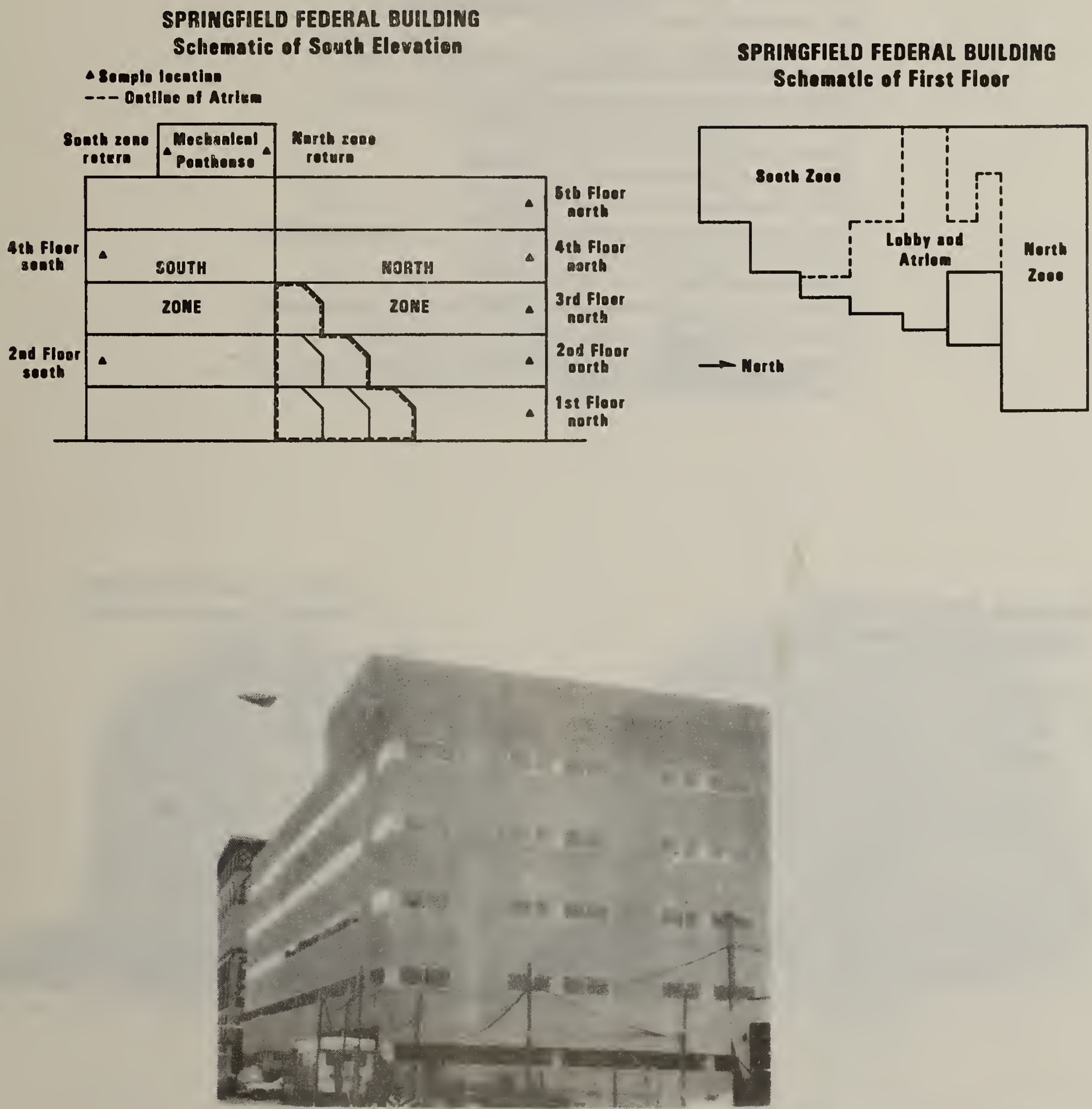
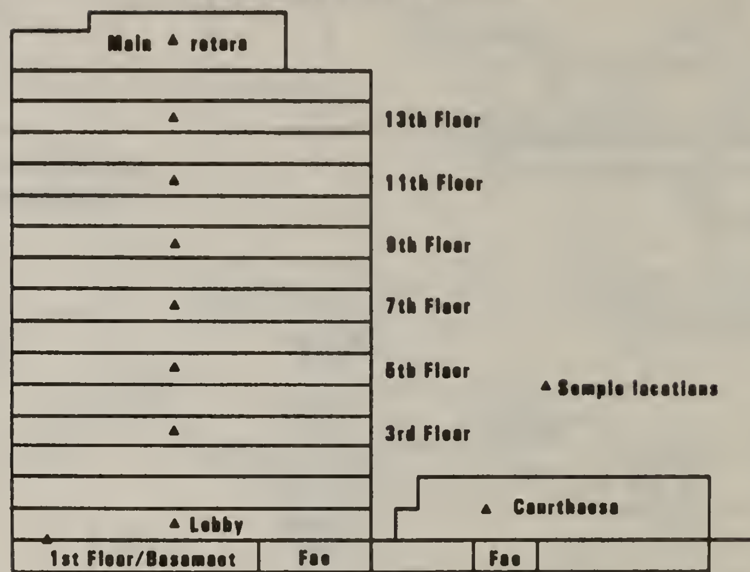


Figure 3. Schematic Diagram and Photograph of Federal Building in Springfield, MA

COLUMBIA FEDERAL BUILDING
Schematic of East Elevation



COLUMBIA FEDERAL BUILDING
Schematic of Overhead View

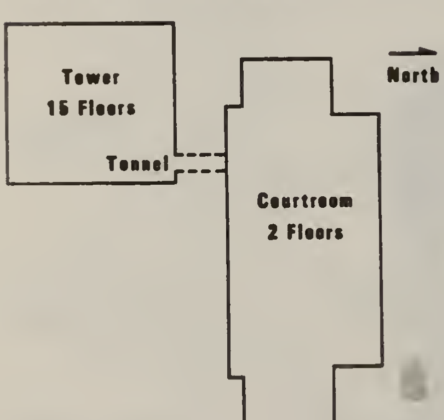


Figure 4. Schematic Diagram and Photograph of Federal Building in Columbia, SC

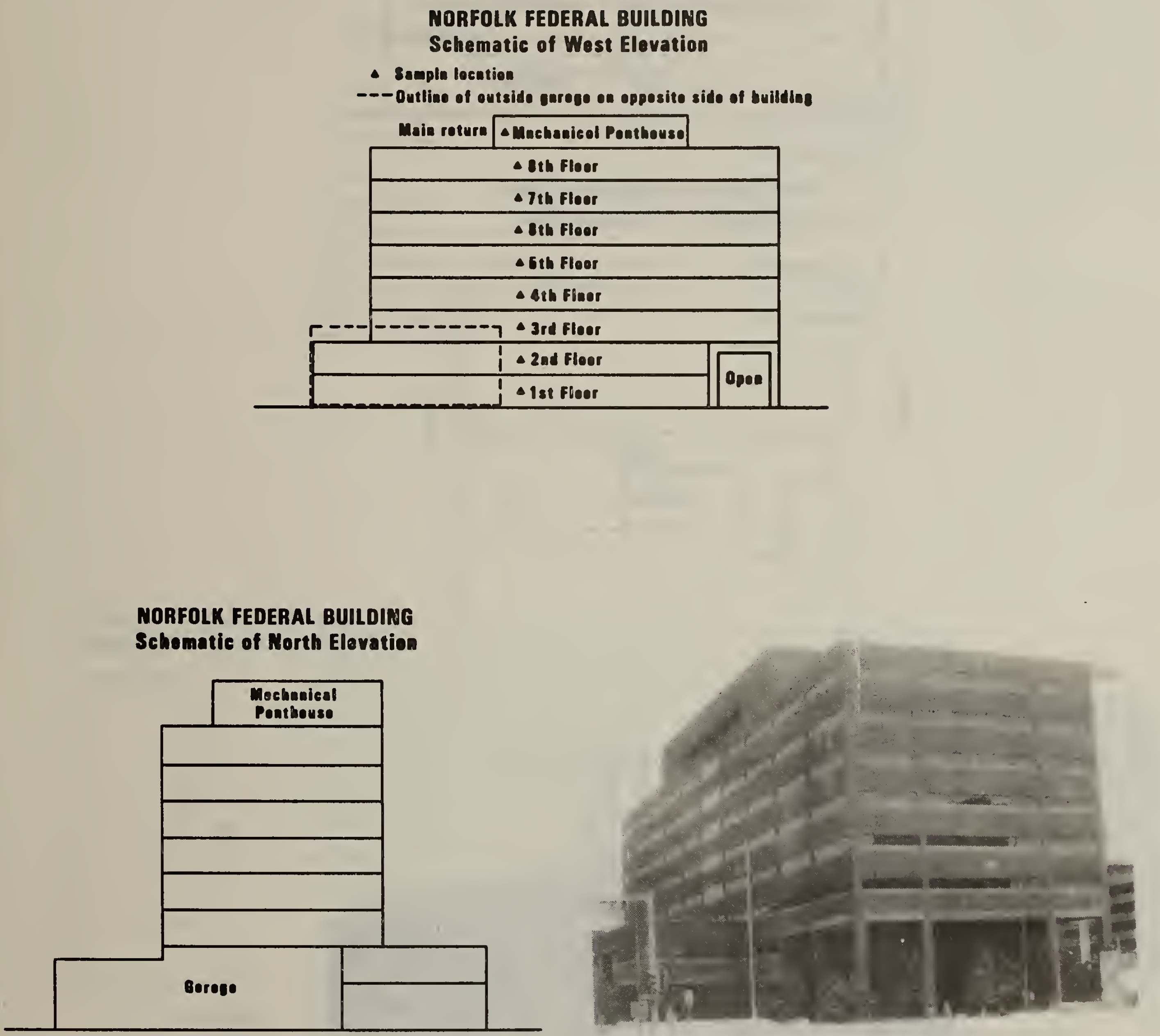


Figure 5. Schematic Diagram and Photograph of Federal Building in Norfolk, VA

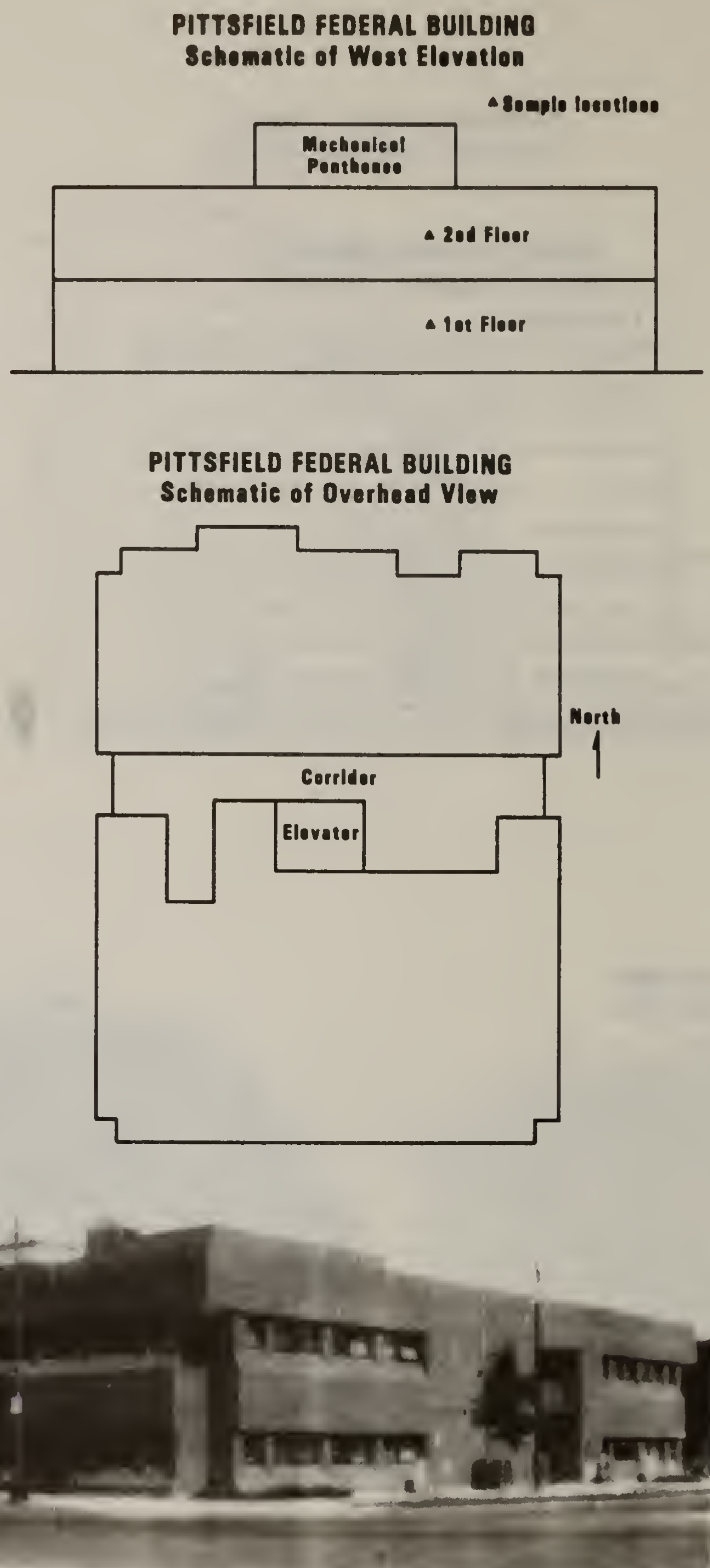


Figure 6. Schematic Diagram and Photograph of Federal Building in Pittsfield, MA

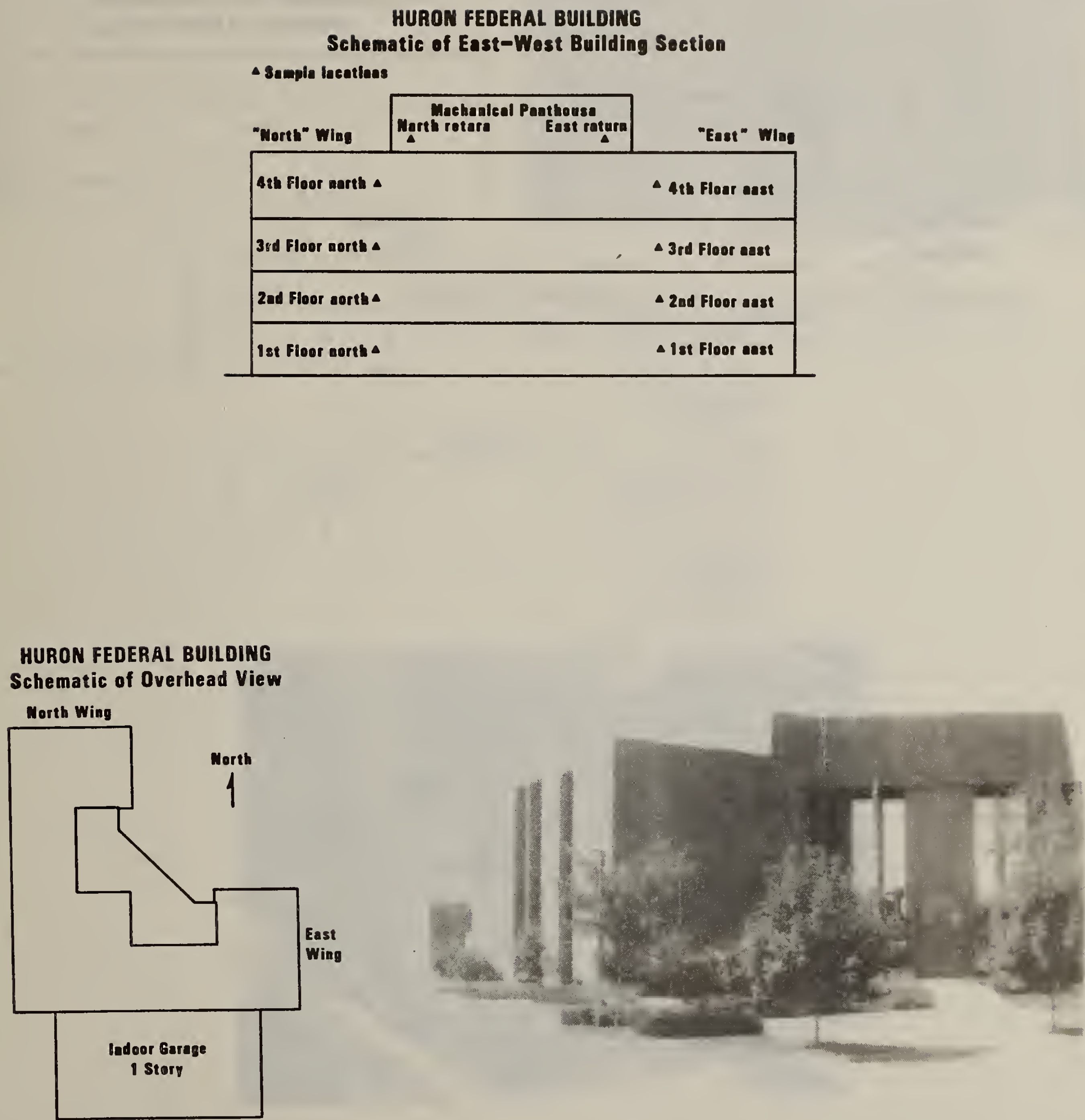


Figure 7. Schematic Diagram and Photograph of Federal Building in Huron, SD

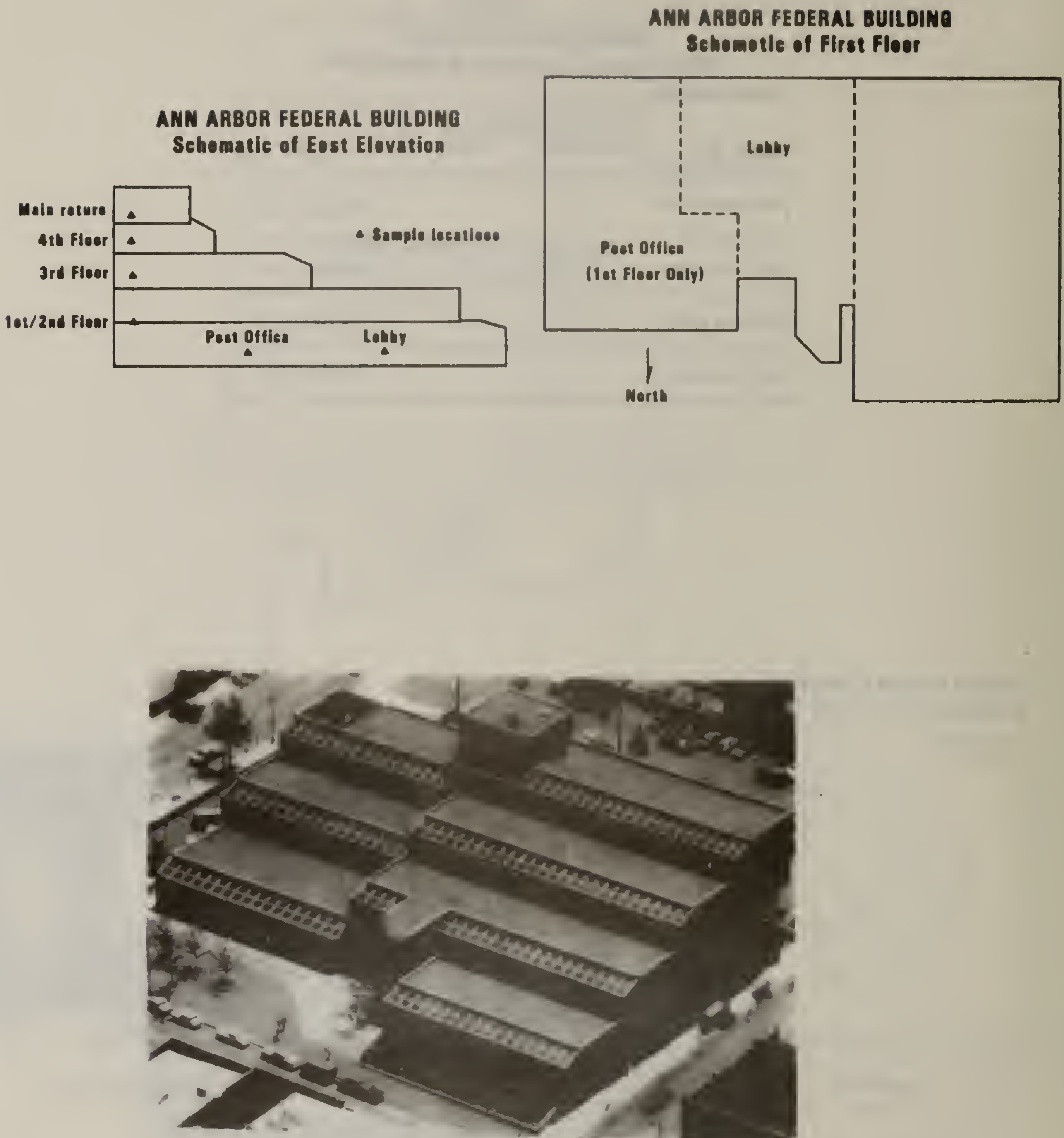
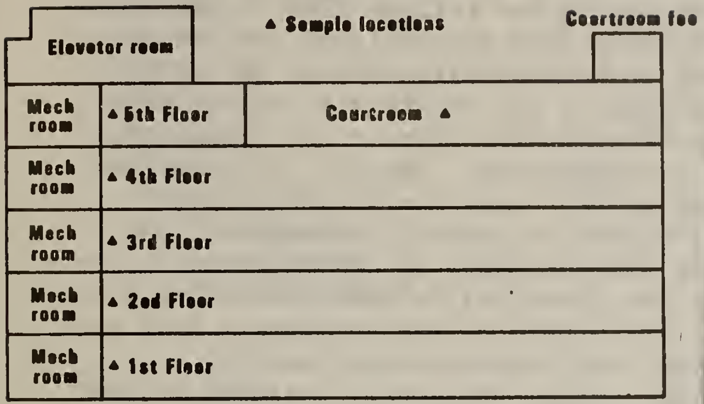
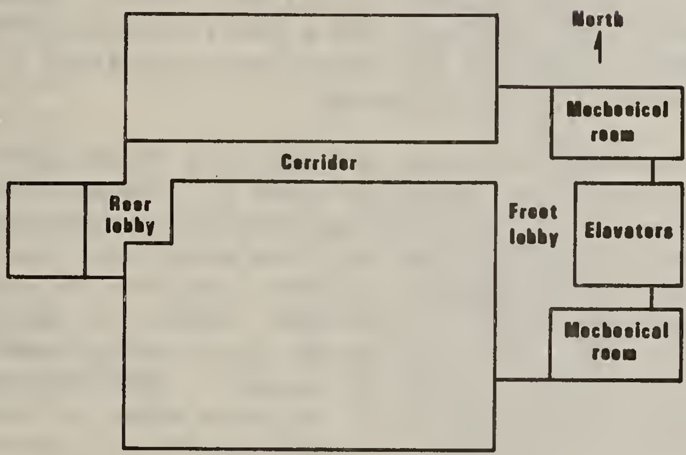


Figure 8. Schematic Diagram and Photograph of Federal Building in Ann Arbor, MI

FAYETTEVILLE FEDERAL BUILDING
Schematic of North Elevation



Schematic of First Floor



Schematic of Fifth Floor

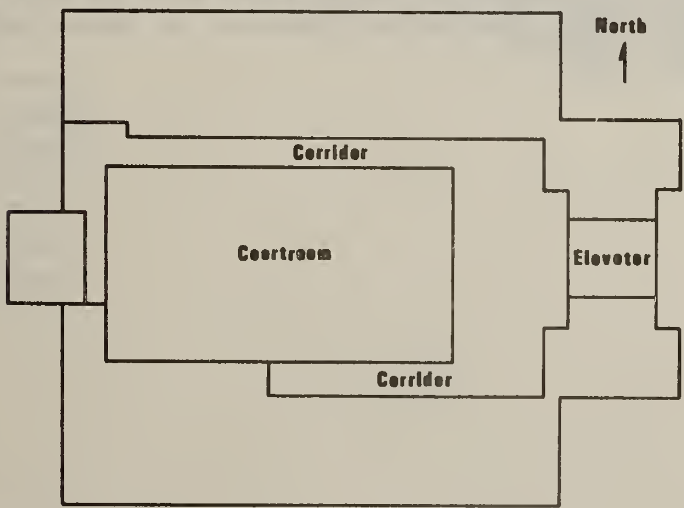


Figure 9. Schematic Diagram and Photograph of Federal Building in Fayetteville, AR

3. Air Infiltration and Building Tightness Tests

The air infiltration and building tightness of the eight federal office buildings were tested using whole building fan pressurization and tracer gas techniques. The fan pressurization tests were performed during the fall of 1982 on seven of the eight federal buildings using the building's HVAC system fans. It was not possible to pressurize the federal building in Fayetteville because the outside air duct could not bring in a sufficient volume of air due to its limited size. This building could be pressurized with an external fan however the shipment of this fan to Fayetteville was judged to be too expensive. The air infiltration under natural conditions was measured using sulfur hexafluoride (SF_6) as a tracer. This test was designed for each building to produce a measure of the total air infiltration rate of the building and the rates of the major zones of the building. Sample and injection tubing was installed in each zone along with wiring for measurng interior temperatures, the status of the building's HVAC fans and exterior weather conditions (wind speed, wind direction and exterior temperature). The automatic air infiltration system previously designed by NBS for large buildings was installed in each building for a period of about a week during the fall, winter and spring (three automated air infiltration systems were used on this project)[2]. Tests were performed both during periods of occupancy and non-occupancy, and with the dampers opened and closed. To date, tracer gas infiltration meaurements have been made for a total of about 200 hours in each building. The air sample locations for these tests are given in table 1, and shown in the schematics in figures 2 through 9.

The results of the pressurization tests and the fall tracer gas air infiltration measurements (dampers closed) are shown in table 2. The most notable aspect of these data is the tightness of the buildings from the pressurization measurements. The pressurization test results are the air flow rates into the buildings, in units of building volumes or exchanges per hour, required to sustain a 25 Pa pressure difference between inside and outside. These induced 25 Pa flow rates are significantly larger than the ventilation rates during normal building operation or infiltration rates induced by weather. The 50 Pa exchange rates of the buildings are roughly 1.5 times the 25 Pa rates shown in the table. These 50 Pa leakage rates are very low compared to those measured in homes. U.S. homes generally range from about 5 volumes per hour (tight) to greater than 20 (very leaky). Swedish and Canadian homes are being built with 50 Pa flow rates of less than 2 volumes per hour. Thus, the 50 Pa flow rates of these federal buildings correspond to very tight homes.

Table 1. Location of Tracer Gas Sampling

Anchorage
1. Module A
2. Module B
3. Module C
4. Module D
5. Module E
6. Module F
7. 5th Floor Module C
8. 3rd Floor Module C
9. 1st Floor Module C

Springfield
1. North Return
2. South Return
3. Atrium/Lobby
4. 5th Floor - North
5. 4th Floor - North
6. 3rd Floor - North
7. 2nd Floor - North
8. 1st Floor - North
9. 4th Floor - South
10. 2nd Floor - South

Ann Arbor
1. HVAC Return
2. 4th Floor Return
3. 3rd Floor Return
4. 1st & 2nd Floor Return
5. Lobby
6. Post Office

Huron
1. North Return
2. East Return
3. 4th Floor - North
4. 3rd Floor - North
5. 2nd Floor - North
6. 1st Floor - North
7. 4th Floor - East
8. 3rd Floor - East
9. 2nd Floor - East
10. 1st Floor - East

Columbia
1. HVAC Return
2. 13th Floor
3. 11th Floor
4. 9th Floor
5. 7th Floor
6. 5th Floor
7. 3rd Floor
8. 1st Floor & Basement
9. Lobby
10. Courthouse

Norfolk
1. HVAC Return
2. 8th Floor
3. 7th Floor
4. 6th Floor
5. 5th Floor
6. 4th Floor
7. 3rd Floor
8. 2nd Floor
9. 1st Floor

Fayetteville
1. 1st Floor
2. 2nd Floor
3. 3rd Floor
4. 4th Floor
5. 5th Floor
6. Courtroom - 5th Floor

Pittsfield
1. 1st Floor Return
2. 2nd Floor Return

Table 2. Airtightness Measurements on the Federal Buildings

Building Location	Floor Area (m^2)	Pressurization Flow at 25 Pa (volumes/hour)	Tracer Gas Decay* Infiltration Rate (volumes/hour)
Anchorage	45,490	0.80	0.20 to 0.30
Ann Arbor	4,900	0.86	0.55 to 0.65
Columbia	20,070	0.67	0.35 to 0.45
Fayetteville	3,400	----	0.35 to 0.45
Huron	6,420	0.45	0.10 to 0.20
Norfolk	17,250	1.36	0.45 to 0.55
Pittsfield	1,730	1.07	0.25 to 0.35
Springfield	13,530	1.00	0.30 to 0.40

* The values listed correspond to a range of measured infiltration rates with wind speeds less than 1.5 m/s and an outside temperature between 5 and 10 °C.

Table 1. Location of Tracer Gas Sampling

<u>Anchorage</u>

1. Module A
2. Module B
3. Module C
4. Module D
5. Module E
6. Module F
7. 5th Floor Module C
8. 3rd Floor Module C
9. 1st Floor Module C

<u>Springfield</u>

1. North Return
2. South Return
3. Atrium/Lobby
4. 5th Floor - North
5. 4th Floor - North
6. 3rd Floor - North
7. 2nd Floor - North
8. 1st Floor - North
9. 4th Floor - South
10. 2nd Floor - South

<u>Ann Arbor</u>

1. HVAC Return
2. 4th Floor Return
3. 3rd Floor Return
4. 1st & 2nd Floor Return
5. Lobby
6. Post Office

<u>Huron</u>

1. North Return
2. East Return
3. 4th Floor - North
4. 3rd Floor - North
5. 2nd Floor - North
6. 1st Floor - North
7. 4th Floor - East
8. 3rd Floor - East
9. 2nd Floor - East
10. 1st Floor - East

<u>Columbia</u>

1. HVAC Return
2. 13th Floor
3. 11th Floor
4. 9th Floor
5. 7th Floor
6. 5th Floor
7. 3rd Floor
8. 1st Floor & Basement
9. Lobby
10. Courthouse

<u>Norfolk</u>

1. HVAC Return
2. 8th Floor
3. 7th Floor
4. 6th Floor
5. 5th Floor
6. 4th Floor
7. 3rd Floor
8. 2nd Floor
9. 1st Floor

<u>Fayetteville</u>

1. 1st Floor
2. 2nd Floor
3. 3rd Floor
4. 4th Floor
5. 5th Floor
6. Courtroom - 5th Floor

<u>Pittsfield</u>

1. 1st Floor Return
2. 2nd Floor Return

Table 2. Airtightness Measurements on the Federal Buildings

Building Location	Floor Area (m^2)	Pressurization Flow at 25 Pa (volumes/hour)	Tracer Gas Decay* Infiltration Rate (volumes/hour)
Anchorage	45,490	0.80	0.20 to 0.30
Ann Arbor	4,900	0.86	0.55 to 0.65
Columbia	20,070	0.67	0.35 to 0.45
Fayetteville	3,400	----	0.35 to 0.45
Huron	6,420	0.45	0.10 to 0.20
Norfolk	17,250	1.36	0.45 to 0.55
Pittsfield	1,730	1.07	0.25 to 0.35
Springfield	13,530	1.00	0.30 to 0.40

* The values listed correspond to a range of measured infiltration rates with wind speeds less than 1.5 m/s and an outside temperature between 5 and 10 °C.

Table 7. Typical One-Hour Decay Tests for Columbia

FEDERAL BUILDING - COLUMBIA 11/19/82 0

MAX CURRENT = 1708 MIN CURRENT = 1660

EXTERIOR TEMP. = 14.6 C WIND SPEED = 1.0 M/S WIND DIR. = 157. DEG.

+/- .1 C +/- .6 M/S

INTERIOR TEMPERATURES

	M RET	13 FL	11 FL	9 FL	7 FL	5 FL	3 FL	1ST-B	LOBBY	COURT	
	27.6	27.7	27.2	27.5	27.2	26.6	26.3	22.2	21.7	24.3	C
+/-	.4	0.0	0.0	0.0	0.0	.1	0.0	0.0	.1	0.0	C

HVAC FAN OPERATION

TOWER	1ST-BAS	COURT	
0	0	0	SEC

TRACER CONCENTRATIONS

	M RET	13 FL	11 FL	9 FL	7 FL	5 FL	3 FL	1ST-B	LOBBY	COURT	
0:00	96.1	94.4	85.6	91.3	85.0	84.9	92.2	32.9	33.3	44.9	ppb
0:10	86.3	89.8	80.5	88.0	84.6	80.5	91.0	28.1	29.0	42.3	ppb
0:20	82.0	86.5	78.2	85.5	79.4	78.3	89.2	27.8	26.4	39.8	ppb
0:30	78.4	83.6	74.0	80.8	78.6	75.7	84.2	24.5	25.0	37.6	ppb
0:40	75.5	80.5	70.6	77.2	72.0	69.8	79.7	23.8	22.4	35.8	ppb
INFIL	.27	.22	.27	.27	.30	.28	.27	.37	.50	.34	/HR

Table 8. **Data Files for Ann Arbor Building with No Outside Air Intake**

CITY AND BUILDING : FEDERAL BUILDING - ANNARBOR

CONDITION : 0% OUTSIDE AIR
CONDITION : VENTS UNSEALED
CONDITION : WIND DATA

DATE	HOUR	W.SPEED	W.DIR	T.OUT	T.IN	T.DIFF	AI.AVE
2/ 4/83	18	1.4	270.0	1.4	22.9	21.5	.86

HVAC	=	.47
4TH F	=	.71
3RD F	=	.39
1&2 F	=	.57
LOB.	=	.76
P.O.	=	2.28

DATE	HOUR	W.SPEED	W.DIR	T.OUT	T.IN	T.DIFF	AI.AVE
2/ 4/83	19	1.1	270.0	1.8	22.7	20.9	.95

HVAC	=	1.24
4TH F	=	1.01
3RD F	=	.54
1&2 F	=	.52
LOB.	=	.97
P.O.	=	1.43

DATE	HOUR	W.SPEED	W.DIR	T.OUT	T.IN	T.DIFF	AI.AVE
2/ 4/83	20	1.0	270.0	1.5	22.5	21.0	.81

HVAC	=	.62
4TH F	=	.42
3RD F	=	.62
1&2 F	=	.58
LOB.	=	1.22
P.O.	=	1.37

DATE	HOUR	W.SPEED	W.DIR	T.OUT	T.IN	T.DIFF	AI.AVE
2/ 4/83	21	1.0	270.0	.8	22.3	20.8	.93

HVAC	=	.54
3RD F	=	.64
1&2 F	=	.66
LOB.	=	1.53
P.O.	=	1.26

DATE	HOUR	W.SPEED	W.DIR	T.OUT	T.IN	T.DIFF	AI.AVE
2/ 4/83	22	.8	270.0	1.4	22.1	20.7	.82

HVAC	=	.61
4TH F	=	.57
3RD F	=	.64
1&2 F	=	.62
LOB.	=	1.27
P.O.	=	1.23

Table 7. Typical One-Hour Decay Tests for Columbia

FEDERAL BUILDING - COLUMBIA 11/19/82 0

MAX CURRENT = 1708 MIN CURRENT = 1660

EXTERIOR TEMP. = 14.6 C +/- .1 C WIND SPEED = 1.0 M/S +/- .6 M/S WIND DIR. = 157. DEG.

INTERIOR TEMPERATURES

	M RET	13 FL	11 FL	9 FL	7 FL	5 FL	3 FL	1ST-B	LOBBY	COURT	
	27.6	27.7	27.2	27.5	27.2	26.6	26.3	22.2	21.7	24.3	C
+/-	.4	0.0	0.0	0.0	0.0	.1	0.0	0.0	.1	0.0	C

HVAC FAN OPERATION

TOWER	1ST-BAS	COURT	
0	0	0	SEC

TRACER CONCENTRATIONS

	M RET	13 FL	11 FL	9 FL	7 FL	5 FL	3 FL	1ST-B	LOBBY	COURT	
0:00	96.1	94.4	85.6	91.3	85.0	84.9	92.2	32.9	33.3	44.9	ppb
0:10	86.3	89.8	80.5	88.0	84.6	80.5	91.0	28.1	29.0	42.3	ppb
0:20	82.0	86.5	78.2	85.5	79.4	78.3	89.2	27.8	26.4	39.8	ppb
0:30	78.4	83.6	74.0	80.8	78.6	75.7	84.2	24.5	25.0	37.6	ppb
0:40	75.5	80.5	70.6	77.2	72.0	69.8	79.7	23.8	22.4	35.8	ppb
INFIL	.27	.22	.27	.27	.30	.28	.27	.37	.50	.34	/HR

Table 8. Data Files for Ann Arbor Building with No Outside Air Intake

CITY AND BUILDING : FEDERAL BUILDING - ANNARBOR

CONDITION : 0% OUTSIDE AIR
CONDITION : VENTS UNSEALED
CONDITION : WIND DATA

DATE	HOUR	W.SPEED	W.DIR	T.OUT	T.IN	T.DIFF	AI.AVE
2/ 4/83	18	1.4	270.0	1.4	22.9	21.5	.86

HVAC	=	.47
4TH F	=	.71
3RD F	=	.39
1&2 F	=	.57
LOB.	=	.76
P.O.	=	2.28

DATE	HOUR	W.SPEED	W.DIR	T.OUT	T.IN	T.DIFF	AI.AVE
2/ 4/83	19	1.1	270.0	1.8	22.7	20.9	.95

HVAC	=	1.24
4TH F	=	1.01
3RD F	=	.54
1&2 F	=	.52
LOB.	=	.97
P.O.	=	1.43

DATE	HOUR	W.SPEED	W.DIR	T.OUT	T.IN	T.DIFF	AI.AVE
2/ 4/83	20	1.0	270.0	1.5	22.5	21.0	.81

HVAC	=	.62
4TH F	=	.42
3RD F	=	.62
1&2 F	=	.58
LOB.	=	1.22
P.O.	=	1.37

DATE	HOUR	W.SPEED	W.DIR	T.OUT	T.IN	T.DIFF	AI.AVE
2/ 4/83	21	1.0	270.0	.8	22.3	20.8	.93

HVAC	=	.54
3RD F	=	.64
1&2 F	=	.66
LOB.	=	1.53
P.O.	=	1.26

DATE	HOUR	W.SPEED	W.DIR	T.OUT	T.IN	T.DIFF	AI.AVE
2/ 4/83	22	.8	270.0	1.4	22.1	20.7	.82

HVAC	=	.61
4TH F	=	.57
3RD F	=	.64
1&2 F	=	.62
LOB.	=	1.27
P.O.	=	1.23

The results of the tracer gas tests in table 2 indicate that the buildings in Pittsfield, Huron and Anchorage are experiencing relatively low natural leakage rates. The buildings with the highest natural rates are Ann Arbor and Norfolk. Tables 3 through 7 show the results of typical one-hour decay tests for the buildings in Anchorage, Springfield, Norfolk, Huron and Columbia. These tables indicate the extent of tracer gas mixing obtained in these tests, with good mixing being a requirement for accurate results. They also show zones of the building which exhibit high air exchange rates compared to the rest of the building - the lobby in Springfield, the 1st floor in Norfolk, and the lobby in Columbia. Similar high rates can also be shown for the 1st floor in Fayetteville and the lobby and post office in Ann Arbor. The lobbies generally exhibit larger exchange rates due to the exterior doors in these zones and the people moving in and out of the building. The post office in Ann Arbor has a large amount of such pedestrian traffic, and large doors for loading and unloading mail.

The data in tables 3 to 7 are checked for accuracy and then stored in separate files according to the condition of the vents and occupancy of the building. Tables 8 and 9 show data from these files for the Ann Arbor building. Note the large ventilation rates in table 9. These rates were measured under spring conditions in which the outdoor air is cool enough to condition the building without running the chillers.

From the data in table 2, it can be seen that there is correlation between the pressurization measurements and the tracer gas test results. Bearing in mind that the tracer gas results are preliminary and made only under approximately the same weather conditions, infiltration rates have been plotted against pressurization results in figure 10. The correlation between the two measurements appears to be fairly strong. The slope of a line passing through all the points is roughly 0.5. If one adjusts the 25 Pa flows to 50 Pa flows using the rough correction factor of 1.5, then the slope of infiltration against 50 Pa flow is about 1/3. This compares to the slope for residential buildings of about 1/20.

In comparing the pressurization test results of the federal buildings to each other and to residential buildings, the important factor of surface to volume ratio arises. Figure 11 shows the surface to volume ratios (S/V) in m^{-1} for the federal buildings and two sample homes. The 1-story house is assumed to have a 110 m^2 square floor area and 2.5 m ceilings. The 2-story home also has a square floor plan with 100 m^2 on each floor and a 5 m building height. We see in the figure that the large sizes of the federal buildings generally lead to lower values of S/V than for homes. The Ann Arbor building is an exception due to its particular design (see figure 8).

One may adjust the pressurization test results in table 1 to take into account the different values of S/V among the buildings. Table 2 gives the 25 Pa leakage rate in building volumes per hour. This number divided by S/V, yields the 25 Pa flow rate in m^3/hr per m^2 of exterior surface area. This second flow rate is more of a measure of "construction quality" than the first flow rate. Figure 12 compares these two measures of leakiness. The vertical scale on the left shows the 25 Pa flows in exchanges per hour for the seven federal buildings and the two sample houses (2.0 exchanges/hr at 50 Pa very tight). The vertical scale on the right shows the 25 Pa flows in $m^3/hr\text{-}m^2$ as discussed above. We see that in moving from exchanges/hr to $m^3/hr\text{-}m^2$ the tightness ranking of the buildings changes significantly. Also, the spread in the leakage values using the second measure is larger than the spread in exchanges per hour. The most significant change occurs in the Ann Arbor building which is of average tightness as measured by exchanges per hour but is the tightest building in terms of $m^3/hr-m^2$. Thus, the Ann Arbor building has the tightest construction per m^2 of wall area, but its design leads it to appear relatively leakier than many of the other buildings as measured by the flow in exchanges per hour.

Table 3. Typical One-Hour Decay Test for Anchorage

FEDERAL BLDG. - ANCHORAGE 1/ 7/83 12
MAX CURRENT = 1750 MIN CURRENT = 1708
EXTERIOR TEMP. = -18.2 C WIND SPEED = 3.9 M/S WIND DIR. = 135. DEG
+/- .1 C +/- .8 M/S

INTERIOR TEMPERATURES

	MOD A	MOD B	MOD C	MOD D	MOD E	MOD F	1ST C	3RD C	5TH C	
	22.5	22.3	0.0	0.0	23.3	23.5	22.6	22.7	22.7	C
+/-	.7	.1	0.0	0.0	0.0	0.0	.4	0.0	0.0	C

HVAC FAN OPERATION

MOD A	MOD B	MOD C	MOD D	MOD E	MOD F	
3599	3599	3599	3599	3599	3599	SEC

TRACER CONCENTRATIONS

	MOD A	MOD B	MOD C	MOD D	MOD E	MOD F	1ST C	3RD C	5TH C	
12:00	114.6	108.9	101.1	91.8	78.2	81.4	68.2	86.5	103.3	ppb
12:10	105.0	98.2	99.9	88.2	76.1	77.7	62.3	78.6	97.4	ppb
12:20	102.6	96.6	92.4	83.2	73.7	74.6	49.9	76.6	97.6	ppb
12:30	93.9	90.1	89.3	82.2	69.2	69.2	46.3	72.8	130.3	ppb
12:40	91.2	84.3	79.0	76.8	65.1	64.1	48.9	66.1	80.9	ppb
INFIL	.31	.32	.44	.26	.32	.39	.48	.34	.16	/HR

Table 4. Typical One-Hour Decay Test for Springfield

FEDERAL BLDG. - SPRINGFIELD, M 12/ 2/82 0
MAX CURRENT = 1862 MIN CURRENT = 1810
EXTERIOR TEMP. = 12.1 C WIND SPEED = 1.3 M/S WIND DIR. = 247. DEG.
+/- .1 C +/- .6 M/S

INTERIOR TEMPERATURES

	NORTH	SOUTH	LOBBY	N 5TH	N 4TH	N 3RD	N 2ND	N 1ST	S 4TH	S 2ND	
	23.4	24.3	27.8	24.7	23.7	23.4	23.0	24.3	24.5	24.3	C
+/-	.2	.1	0.0	.1	.1	.1	.1	.1	.1	0.0	C

HVAC FAN OPERATION

	NORTH	SOUTH	ATRIUM	
0	0	0	0	SEC

TRACER CONCENTRATIONS

	NORTH	SOUTH	LOBBY	N 5TH	N 4TH	N 3RD	N 2ND	N 1ST	S 4TH	S 2ND	
0:00	176.3	220.0	177.0	161.2	156.7	155.9	159.9	135.4	215.6	203.1	ppb
0:10	144.5	195.5	149.9	148.0	149.8	148.0	146.1	128.6	206.1	192.8	ppb
0:20	138.4	179.2	140.8	142.3	138.7	141.5	133.1	121.4	196.1	177.0	ppb
0:30	130.2	175.0	126.0	136.2	132.1	134.1	131.3	109.9	185.4	176.3	ppb
0:40	127.6	164.6	119.9	123.9	121.9	129.6	126.1	109.4	173.8	166.9	ppb
INFIL	.26	.32	.47	.35	.40	.27	.27	.35	.34	.26	/HR

Table 5. Typical One-Hour Decay Test for Norfolk

FEDERAL BUILDING - NORFOLK, VA 10/21/82 0

MAX CURRENT = 1665 MIN CURRENT = 1621

EXTERIOR TEMP. = 17.5 C +/- 0.0 C WIND SPEED = 2.0 M/S +/- .6 M/S WIND DIR. = 135. DEG.

INTERIOR TEMPERATURES

	RET	8TH F	7TH F	6TH F	5TH F	4TH F	3RD F	2ND F	1ST F	
	25.7	25.7	25.4	24.6	24.7	24.7	24.8	24.4	23.5	C
+/-	.1	0.0	.2	0.0	0.0	0.0	0.0	0.0	0.0	C

HVAC FAN OPERATION

M HVAC	1ST FL	
0	0	SEC

TRACER CONCENTRATIONS

	RET	8TH F	7TH F	6TH F	5TH F	4TH F	3RD F	2ND F	1ST F	
0:00	137.9	107.2	128.5	126.4	119.0	120.9	127.4	114.9	68.0	ppb
0:10	126.9	95.6	116.0	118.1	111.1	113.7	118.7	106.6	51.9	ppb
0:20	117.1	90.1	111.7	112.1	106.5	106.6	112.7	93.8	49.3	ppb
0:30	111.1	84.1	101.7	106.9	96.9	97.1	105.7	86.4	36.5	ppb
0:40	101.7	77.3	97.9	98.0	92.7	88.2	98.4	79.7	30.0	ppb
INFIL	.43	.42	.36	.36	.38	.51	.38	.57	1.17	/HR

Table 6. Typical One-Hour Decay Test for Huron

FEDERAL BUILDING - HURON, S.D. 10/ 8/82 11

MAX CURRENT = 659 MIN CURRENT = 611

EXTERIOR TEMP. = 10.2 C +/- .6 C WIND SPEED = 1.5 M/S +/- .9 M/S WIND DIR. = 135. DEG.

INTERIOR TEMPERATURES

	N RET	E RET	N 4TH	N 3RD	N 2ND	N 1ST	
	26.0	24.4	25.9	27.0	26.0	24.6	C
+/-	.6	0.0	.1	.3	.1	0.0	C

HVAC FAN OPERATION

ZONE 1	ZONE 2	
594	595	SEC

TRACER CONCENTRATIONS

	N RET	E RET	N 4TH	N 3RD	N 2ND	N 1ST	
11:00	99.8	121.4	99.5	95.2	96.9	93.1	ppb
11:10	89.8	88.8	89.9	87.9	86.0	86.9	ppb
11:20	82.7	77.6	83.5	84.8	82.9	84.4	ppb
11:30	82.1	76.1	82.1	81.3	82.4	81.6	ppb
11:40	78.6	75.1	81.4	80.9	80.8	78.3	ppb
INFIL	.24	.31	.19	.17	.12	.21	/HR

Table 7. Typical One-Hour Decay Tests for Columbia

FEDERAL BUILDING - COLUMBIA 11/19/82 0

MAX CURRENT = 1708 MIN CURRENT = 1660

EXTERIOR TEMP. = 14.6 C WIND SPEED = 1.0 M/S WIND DIR. = 157. DEG.

+/- .1 C +/- .6 M/S

INTERIOR TEMPERATURES

	M RET	13 FL	11 FL	9 FL	7 FL	5 FL	3 FL	1ST-B	LOBBY	COURT	
	27.6	27.7	27.2	27.5	27.2	26.6	26.3	22.2	21.7	24.3	C
+/-	.4	0.0	0.0	0.0	0.0	.1	0.0	0.0	.1	0.0	C

HVAC FAN OPERATION

TOWER	1ST-BAS	COURT	
0	0	0	SEC

TRACER CONCENTRATIONS

	M RET	13 FL	11 FL	9 FL	7 FL	5 FL	3 FL	1ST-B	LOBBY	COURT	
0:00	96.1	94.4	85.6	91.3	85.0	84.9	92.2	32.9	33.3	44.9	ppb
0:10	86.3	89.8	80.5	88.0	84.6	80.5	91.0	28.1	29.0	42.3	ppb
0:20	82.0	86.5	78.2	85.5	79.4	78.3	89.2	27.8	26.4	39.8	ppb
0:30	78.4	83.6	74.0	80.8	78.6	75.7	84.2	24.5	25.0	37.6	ppb
0:40	75.5	80.5	70.6	77.2	72.0	69.8	79.7	23.8	22.4	35.8	ppb
INFIL	.27	.22	.27	.27	.30	.28	.27	.37	.50	.34	/HR

Table 8. Data Files for Ann Arbor Building with No Outside Air Intake

CITY AND BUILDING : FEDERAL BUILDING - ANNARBOR

CONDITION : 0% OUTSIDE AIR
CONDITION : VENTS UNSEALED
CONDITION : WIND DATA

DATE	HOUR	W.SPEED	W.DIR	T.OUT	T.IN	T.DIFF	AI.AVE
2/ 4/83	18	1.4	270.0	1.4	22.9	21.5	.86

HVAC	=	.47
4TH F	=	.71
3RD F	=	.39
1&2 F	=	.57
LOB.	=	.76
P.O.	=	2.28

DATE	HOUR	W.SPEED	W.DIR	T.OUT	T.IN	T.DIFF	AI.AVE
2/ 4/83	19	1.1	270.0	1.8	22.7	20.9	.95

HVAC	=	1.24
4TH F	=	1.01
3RD F	=	.54
1&2 F	=	.52
LOB.	=	.97
P.O.	=	1.43

DATE	HOUR	W.SPEED	W.DIR	T.OUT	T.IN	T.DIFF	AI.AVE
2/ 4/83	20	1.0	270.0	1.5	22.5	21.0	.81

HVAC	=	.62
4TH F	=	.42
3RD F	=	.62
1&2 F	=	.58
LOB.	=	1.22
P.O.	=	1.37

DATE	HOUR	W.SPEED	W.DIR	T.OUT	T.IN	T.DIFF	AI.AVE
2/ 4/83	21	1.0	270.0	.8	22.3	20.8	.93

HVAC	=	.54
3RD F	=	.64
1&2 F	=	.66
LOB.	=	1.53
P.O.	=	1.26

DATE	HOUR	W.SPEED	W.DIR	T.OUT	T.IN	T.DIFF	AI.AVE
2/ 4/83	22	.8	270.0	1.4	22.1	20.7	.82

HVAC	=	.61
4TH F	=	.57
3RD F	=	.64
1&2 F	=	.62
LOB.	=	1.27
P.O.	=	1.23

Table 9. Data Files for Ann Arbor Building with Outside Air Intake

CITY AND BUILDING : FEDERAL BUILDING - ANN ARBOR

CONDITION : AIR INTAKE
CONDITION : VENTS UNSEALED
CONDITION : WIND DATA

DATE	HOUR	W.SPEED	W.DIR	T.OUT	T.IN	T.DIFF	AI.AVE
5/25/83	8	1.8	157.5	15.0	24.0	9.0	3.22

HVAC	=	3.19
4TH F	=	3.90
3RD F	=	3.38
2ND F	=	3.98
1ST F	=	2.94
LOB.	=	1.90

DATE	HOUR	W.SPEED	W.DIR	T.OUT	T.IN	T.DIFF	AI.AVE
5/25/83	9	1.5	247.5	14.3	23.8	9.5	2.11

HVAC	=	2.51
4TH F	=	1.82
3RD F	=	2.58
2ND F	=	2.51
1ST F	=	1.25
LOB.	=	1.97

DATE	HOUR	W.SPEED	W.DIR	T.OUT	T.IN	T.DIFF	AI.AVE
5/25/83	10	2.0	270.0	13.8	23.6	9.8	2.32

HVAC	=	3.00
4TH F	=	2.96
3RD F	=	2.78
2ND F	=	2.85
1ST F	=	.51
LOB.	=	1.83

DATE	HOUR	W.SPEED	W.DIR	T.OUT	T.IN	T.DIFF	AI.AVE
5/25/83	11	1.9	270.0	13.8	23.6	9.8	2.58

HVAC	=	3.24
4TH F	=	2.52
3RD F	=	3.00
2ND F	=	2.71
1ST F	=	1.86
LOB.	=	2.17

DATE	HOUR	W.SPEED	W.DIR	T.OUT	T.IN	T.DIFF	AI.AVE
5/25/83	12	1.9	270.0	14.2	23.5	9.3	2.73

HVAC	=	2.78
4TH F	=	3.34
3RD F	=	3.10
2ND F	=	3.71
1ST F	=	1.65
LOB.	=	1.79

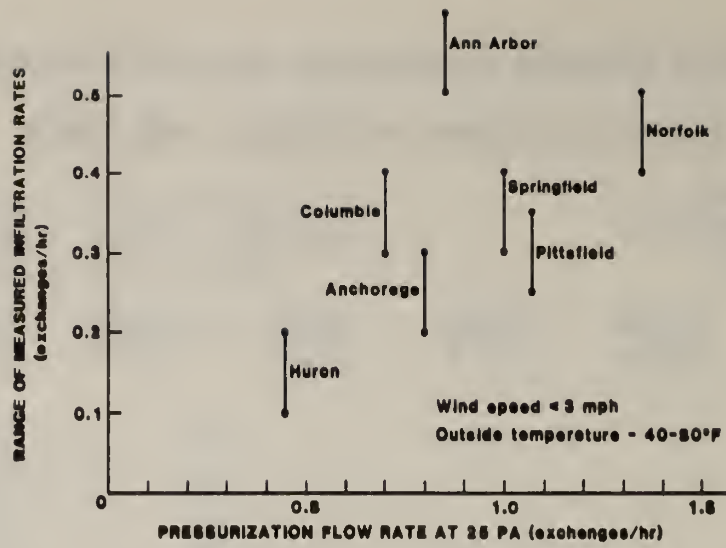


Figure 10. Natural Air Infiltration Rates Versus Induced Air Exchange Rates at 25 Pa

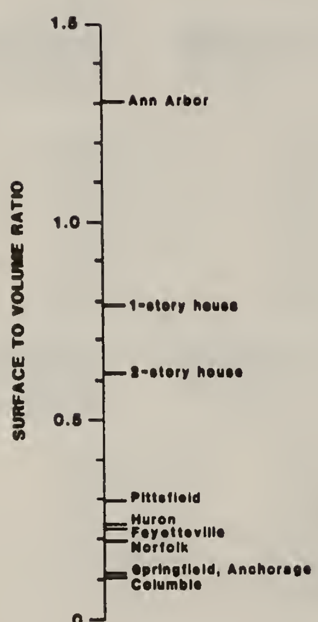


Figure 11. Distribution of Surface to Volume Ratio Among Federal Buildings and Residences

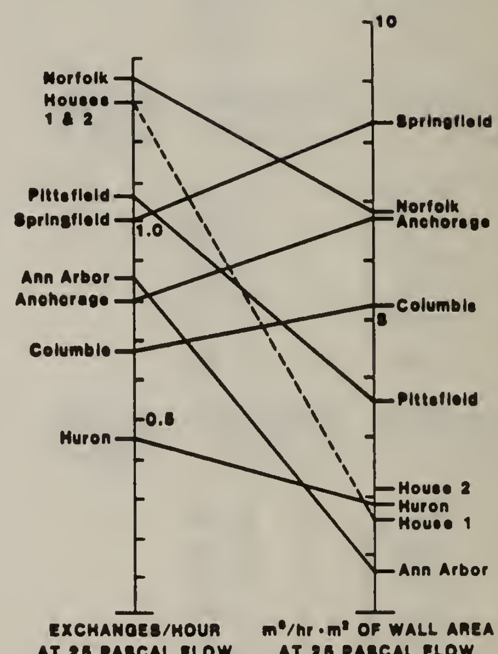


Figure 12. Comparison of Ranks of Pressurization Test Results

4. Ground Infrared Thermographic Surveys

4.1 Background

Thermographic inspection by use of infrared (IR) imaging systems is a diagnostic tool to locate thermal defects in a building envelope. IR thermography is a technique using non-contact scanning devices to convert the IR radiation from the object surface to visible light by providing the image of the surface intensity variation. The application of IR thermographic surveys to detect thermal anomalies and to determine insulation effectiveness in large buildings permits the selection of retrofit actions to be carried out to achieve energy conservation. During field measurements, IR thermographic inspections are usually carried out both internally and externally under suitable weather conditions. Thermographic data can be collected by photographing the thermal image display of the thermographic sensing system or by recording the video output of the system directly for subsequent reproduction. Information such as the temperature range of the sensing system and the environmental conditions during inspection are also required to accompany the thermographic data. A copy of such a thermal image, which corresponds to the apparent radiance temperature distribution along the surface, is called a thermogram. A typical thermogram of a surface will provide an intensity-modulated image where the bright and dark portions represent the hot and cold regions, respectively, and the grey shades show the intermediate range. Accordingly, the thermal integrity of the buildings can be analyzed and interpreted from the thermograms and the documentation.

4.2 Summary of Results

Thermographic surveys were conducted during the heating season of 1982-83 at all eight federal buildings. Since these are all large buildings, they were inspected thoroughly by exterior surveys with interior surveys at some regions where thermal anomalies were detected or suspected by outside inspections. A summary of thermal deficiencies interpreted from the thermographic inspection for all eight buildings is given in table 10. Note that the numerical calculations of the total wall area and percentage of wall area subject to thermal defects in table 10 exclude the glass and window areas of the outside surfaces. As indicated in table 10, the most severe thermal defects that occur in these buildings, besides defects in insulation, are air leakage through joints (wall-to-wall, ceiling-to-wall, and floor-to-wall) and window seals. Other common heat loss locations observed include shrinkage of insulation, and air penetration paths in walls and ceilings. The percentage of wall area subject to thermal defects in these buildings was found to be between 6 and 18 percent, also given in table 10. Descriptions of the thermal integrity and examples of defects observed in the thermograms are included in the following discussion.

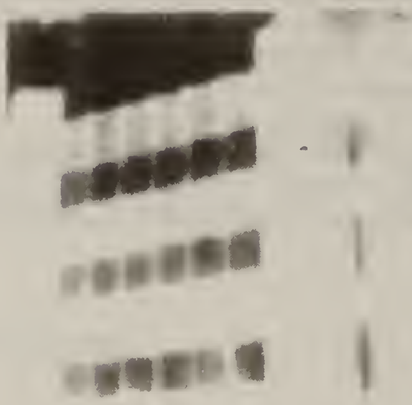
Table 10. Thermal Deficiencies Observed in Each Test Building

City	ANCHR	ANNAR	COLUM	FAYET	HURON	NORFK	PITFD	SPRFD
Total Wall Area (m^2)	7600	904	10584	1480	3561	6171	1013	4388
Defective Wall Area (m^2)	1405	159	1814	88	328	1067	187	303
% of Wall Area Subject to Thermal Defects	18	18	17	6	9	17	18	7
Defects Observed :								
Walls								
Lack of Insulation		*	*	*			*	*
Shrinkage or Fissures in Insulation	*	*	*		*	*	*	
Cross Braces		*				*	*	
Air Penetration	*	*	*		*	*	*	*
Ceilings								
Interior		*	*			*	*	*
Indentation or Overhang			*	*		*	*	*
Doors					*			
Windows	*	*	*	*	*	*	*	*
Seam Leakage								
Wall-Wall				*	*	*	*	
Floor-Wall			*	*	*		*	*
Wall-Panels	*	*	*					*
Basement			*					
Pipe or Duct			*				*	
Thermal Bridges	*	*			*	*		*

Description of Thermal Defects in the Anchorage Federal Building

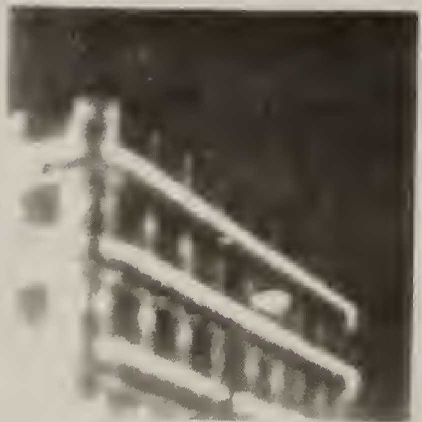
The Federal Building in Anchorage, AK, is rather uniform in its thermal anomalies, for the defects in the modules are consistant and regular and the modules are nearly identical to one another, discounting the differences in the number of floors. The major defects are the thermal bridging at the panel supports and the leakage that occurs at the seams of the interlocking panels, especially at the corners and along the edges of the adjoining mirror walls, as illustrated in the thermograms from figures 13-1, 13-2, and 13-3. The mirror walls in figure 13-1 appear with bands of light and dark as the light bands have one-way mirrors for the floors inside and the dark bands have walls behind them. The high rating, 18%, of wall area exposed to thermal defects is primarily due to this corner leakage and thermal bridging at the structural supports of the panels. Examples are the SW corner of the A module in figure 13-2 and the vertical seams in figures 13-3 and 13-4. (The bright spot in the center of figure 13-3 is the heat from a streetlight.) There also is extensive heat loss from the first floor windows that are on every module as illustrated by the west face of the A module in figure 13-4.

Figure 13. Thermal Defects Observed in the Anchorage Building



13-1
Mirror wall section

13-2
SW corner of
A module



13-3
SE corner with E wall,
upper floor F module

13-4
West face of the
A module

Description of Thermal Defects Observed in the Ann Arbor Federal Building

The Federal Building in Ann Arbor has many types of thermal anomalies, but the predominant defect is the lack of insulation in large rectangular sections in the east and west walls. Note the large heat loss areas in figures 14-2, 14-4, and 14-5. There are similar voids in the insulation in the wall outcroppings that face east in the top center of the building as seen in figure 14-6. Leakage in the seams is also a distinct problem in the building, as the heat loss is evident in the thermograms of the adjoining panels in figures 14-1 and 14-2. The floor-to-floor joints are sources of heat loss as well and are found in nearly all exterior wall areas. The strong flaring in the close-up of the east wall at the south end, as shown in figure 14-3, is indicative of serious thermal defects due to air leakage in the top seams. Note the cross-brace in the thermogram of the Post Office in figure 14-5 and some incompletely or unevely insulated walls in figures 14-2 and 14-6 which the irregular voids indicate.

Figure 14. Thermal Defects Observed in the Ann Arbor Building

14-1
Middle two floors of SW corner

14-2
Top floors of the W wall at the S end

14-3
E wall at the S end

14-4
E wall at the S end

14-5
E wall at the N end, first floor Post Office

14-6
N face above and to the left of the front entrance

Description of Thermal Defects in the Columbia Federal Building

The thermal anomalies observed in the Federal Building in Columbia, SC, consist primarily of leakage through defects in the window panels and voids in the insulation at the panel seams. The thermograms shown in figures 15-1 and 15-2 made by interior inspections illustrate some of the thermal defects, such as poor insulation, missing insulation, and compression of insulation around the window areas of this building. Figures 15-3 and 15-4 indicate the compression and voids in the insulation in the north wall of the fourth floor by interior and exterior thermograms, respectively. Similar defects over the entire building are the main contributors to the high percentage, 17%, of wall area subjected to thermal anomalies. Note the seam leakage in the panels that make up the solid edges in figure 15-4. The heat loss depicted in figure 15-5 which rises up the west edge of the south wall and across the top edge of the building is due to the perimeter zone HVAC system ducts. The thermal integrity of the courthouse adjacent to the tower is also imperfect. Figure 15-6 shows the leakage that occurs at the NW corner indent of the courthouse, which is typical of the leakage at those seams.

Figure 15. Thermal Defects Observed in the Columbia Building

15-1
N wall on the fourth floor of the tower (interior)

15-2
N wall on the fourth floor of the tower (interior)

15-3
SE corner of the fourth floor of the tower (int)

15-4
Lower west face of the tower at the N end

15-5
S face with W end

15-6
NW corner indent of the courthouse

Description of Thermal Defects Observed in the Fayetteville Federal Building

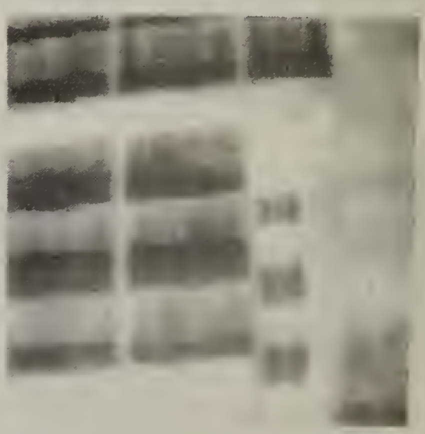
Of all the Federal Buildings inspected, the wall areas of the Fayetteville Building are observed to be relatively uniformly insulated, however this is actually due to a lack of insulation in the exterior wall envelope. This indicates the limitation placed on infrared methods when applied to uninsulated walls. The leakage of the floor-to-floor seams are the prominent defects. Examples are the seams of the elevator towers as shown in figures 16-1 and 16-3. This type of thermal defect is also evident in the east and west walls below the overhangs where the roof of the overhanging section appears to be a source of heat loss as seen by the flaring against the tower in figure 16-1. Note that the heat loss through the floor of the overhangs could be due to the corner seams, for the defect is well-defined along the edges of the overhanging floor. There are relatively few insulation voids which helps account for the low 6% thermal defects of the total wall area.

Figure 16. Thermal Defects Observed in the Fayetteville Building

16-1
NE corner with one
east face tower

16-2
NW corner with west
wall under overhang

16-3
E end with three
elevator towers



16-4
NW corner above N entrance
with view up to overhang

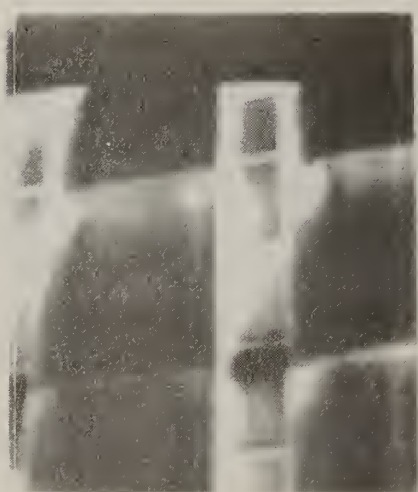
Description of Thermal Defects Observed in the Huron Federal Building

The Federal Building in Huron, SD, is relatively sound with respect to thermal integrity. The 9% thermal defects in wall area is primarily due to leakage through seams between floors and thermal bridges at intersections of walls, floors, and beams, as seen in figure 17-3. There is also an amount of flaring around and above the windows as shown in figures 17-1 and 17-3. Note how the seams appear to be more defective as they approach the windows, especially as seen in figure 17-3. The brightness in the leftmost side of figure 17-2 is due to the windows near the front entrance in the background. Figure 17-4 is an interior thermogram of the fourth floor indicating a beam which conducts cold air in on the right hand side. Figure 17-4 also depicts some shrinkage in the insulation in the third and fifth sections of the wall, as well as air leakage at the top and the bottom of the wall where it intersects the floor and ceiling.

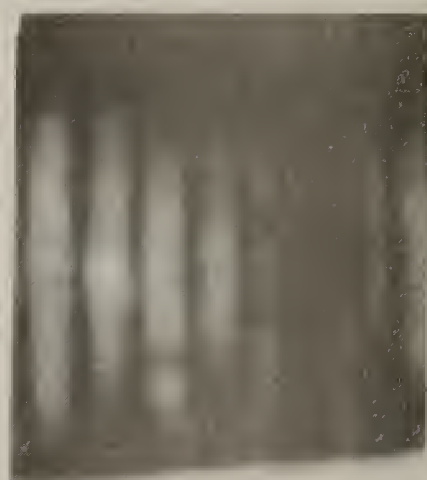
Figure 17. Thermal Defects Observed in the Huron Building

17-1
E wall with NE
entrance off to right

17-2
N face with NE
entrance on left



17-3
Close-up of middle
section on E wall as
shown in 5-2



17-4
Fourth floor interior
N wall of the E wing

Description of Thermal Defects in the Norfolk Federal Building

The thermal anomalies observed in the Federal Building in Norfolk, VA, consisted of two basic kinds, the leakage that occurred at the wall-to-floor seams and the leakage at the exterior panel seams. In figure 18-1, there is a great deal of heat loss shown at the panel seams in the middle of the east wall. The wall-to-post-to-floor seams are also sources of heat loss as illustrated in figures 18-2 through 18-5. Figure 18-2 shows an interior thermogram of the west wall at the south end. (The middle window does not have the blind pulled down and is not reflecting.) Note the vertical darker area in the center of the picture, which is a beam conducting cold inwards. Figures 18-3, 18-4, and 18-5 show leakage between the windows and from the panel seams in the solid wall sections below, which correspond to the horizontal, long, bright white areas across the entire length of the building. Other thermal defects observed include the floors of the third floor and second floor overhangs, as evidence of voids in insulation and leakage at the seams is identified in figures 18-5 and 18-6.

Figure 18. Thermal Defects Observed in the Norfolk Building

18-1
Lower wall section of E wall

18-2
W wall at S end on the third floor

18-3
W face at the N end

18-4
E wall at the SE corner

18-5
Third floor overhang of the N wall at the W end

18-6
NE overhang of second floor over garage

Description of Thermal Defects Observed in the Pittsfield Federal Building

The thermal integrity of the Federal Building in Pittsfield, MA, can be characterized by a large number of markedly undefined voids in the insulation. Many sections have insulation that is distributed unevenly, and there are areas where a whole section of wall is lacking insulation as shown in figure 19-2, where the top third of the wall next to the front entrance is distinctly warmer. The large percentage, 18%, of defective wall observed in the Pittsfield Building is due to these large rectangular voids, but the problems with all types of seams must also be taken into consideration. In figure 19-1 for example, note the leakage from the seam below the second floor windows and the wall-to-wall seam in the upper right-hand corner. The posts running through the walls also cause heat loss as shown in figures 19-4 and 19-6. These two thermograms are characteristic of those for every wall-to-post seam in the building. At each corner there is an indentation in which there is leakage as illustrated by the thermograms in figures 19-3 and 19-4, where the exterior and the interior of the NW corner on the first floor are shown. The dark line in figure 19-4 indicating the penetration of cold corresponds to the bright white regions in figure 19-3 which indicate heat loss to the outside. Other defects observed in this building include the possibility of a damaged pipe inside the north wall as shown in figure 19-5, where a flaring warm area near the top is detected.

Figure 19. Thermal Defects Observed in the Pittsfield Building

19-1
S end of E wall
(exterior)

19-2
The front entrance
on E wall (exterior)

19-3
NW corner with N
wall section and
indent (exterior)

19-4
NW corner with W
window and
indent (interior)

19-5
Center of N wall
(exterior)

19-6
Wall-post seams on E
wall first floor
(interior)

Description of Thermal Defects in the Springfield Federal Building

The Springfield Federal Building has a relatively low, 7%, rating of wall area subject to thermal anomalies. The main defect is the post-to-wall joints as seen in figures 20-1 through 20-6. Note the consistant pattern of the defect in figures 20-1 and 20-3. An exterior close-up of the post-to-wall seam is shown in figure 20-2 at the SW corner with an interior view in figure 20-4. The dimensions of the columns are defined in figures 20-1 and 20-2 by the heat loss that occurs at the edges as the column rises up the side of the building. The interior view shows the cold penetrating to the interior at the sides of the pillar at a single floor. The heat loss from the joints is also consistently evident at the corners, where there are small insulation voids above the windows as well which can be observed in figure 20-3 and 20-5. There is also a great deal of heat loss from the glass windows on the first floor and from the atrium which rises up the center of the east face of the building, as shown in figures 20-5 and 20-6.

Figure 20. Thermal Defects Observed in the Springfield Building

20-1
SE corner of
the N wing

20-2
Close-up of the floor-wall-
post seam on the E face of
the N wing

20-3
SW corner showing seams
at the second and third
floors

20-4
Interior thermogram of
the wall-post seam

20-5
S wall first floor
glass wall with metal
panel, W end

20-6
Atrium rising up
center of E face

5. Determination of the Thermal Resistances of the Building Envelope Using Heat Flow Meters and a Portable Calorimeter

In an attempt to determine the feasibility of directly measuring the thermal resistance of sections of the building envelope, NBS deployed a micro-computer based data acquisition system which could monitor the output of heat flow meters, thermistors for measuring temperature, and the electrical energy used by a portable calorimeter. Two of these systems were used in the project.

The heat flux transducers used for measuring the rate of heat transfer through the building components included heat flow meters and a portable calorimeter. The heat flow meter was a 10 cm diameter circular, wafer-type sensor with the hot and cold junctions of an embedded thermopile attached to its surfaces. The heat flow meters were attatched with masking tape to the selected locations on the interior surfaces of the building components including the exterior walls and the roofs, structural beams and columns, and the floors. The voltage signals produced by the heat flow meter were proportional to the heat flow through the cicular disk. The temperatures of the outdoor air and indoor air in the vicinity of the heat flow meters were measured with thermistors. A portable calorimeter was designed, constructed, and used for on-site measurement of the rate of heat loss through the external wall of the selected buildings. The calorimeter consisted of a five-sided box having dimensions of 124 cm wide by 198 cm high by 20 cm deep which was fabricated from semi-rigid fiber glass insulation board. The calorimeter contained an electric heater, which was controlled automatically to maintain the air temperature inside the calorimeter box equal to that of the guard room. The heat flow through the metered area was measured by monitoring the total electrical power consumption of the heater. A watt-hour meter equipped with an optical electronic device, which generated a pulse for each 1.8 Wh of electricity consumed by the heater, was installed in the circuit to the heater. These pulses were totaled by an electronic counter. The outputs from the device in the modified watt-hour meter, the heat flow meters, and thermistors, were acquired every two seconds and processed, and the test data were recorded at one hour intervals on a floppy disk by the micro-computer.

Construction details of the typical exterior walls on which heat flow measurements were made are summarized in table 11. Table 12 presents the thermal resistance values measured with heat flow meters and the portable calorimeter on the exterior walls for the test buildings. The measured wall resistance value was the average of R-values calculated by dividing the average temperature difference between the inside and outside air present across the building wall, by the average heat flow rate over a period of 24 hours. The steady-state thermal resistances of these walls for the test buildings were computed using the series resistancce method and published data on thermal properties of building materials. These predicted values are also presented in the table along with the corresponding measured indoor and outdoor air temperatures. The calibration of heat flow meters employed a standard guarded hot plate apparatus. The sensitivity of individual heat flow meters was determined by inserting them between the warm and cold plates maintained at constant temperatures and subjecting each meter to a unifrom heat flux at the mean temperatures experienced during the tests. Also shown in the table are the significantly high wall resistance measured by the calorimeter for the building in Columbia, SC, which may have resulted from additional heat laterally conducting into the measuring area from a nearby hot air duct.

Table 11. Construction of External Walls of Test Buildings

Building Location	Wall Description
Ann Arbor, Michigan	1.3 cm (0.5 in.) Quarry tile, 2.5 cm (1 in.) metal lath and motar bed, 25.4 cm (10 in.) concrete masonary unit, 3.8 cm (1.5 in.) semi-rigid glass fiber insulation board and 1.3 cm (0.5 in.) acoustic wall panel
Columbia, S. Carolina	5.1 cm (2 in.) granite siding, 22.9 cm (9 in.) concrete, 5.1 cm (2 in.) glass fiber blanket insulation, and 1.6 cm (0.625 in.) gypsum wallboard
Springfield, Massachusetts	14.0 cm (5.5 in.) precast concrete panel, 6.4 cm (2.5 in.) semi-rigid glass fiber insulation board, and 1.3 cm (0.5 in.) gypsum wallboard on 9.2 cm (3.625 in.) metal studs
Huron, S. Dakota	10.2 cm (4 in.) face brick, 15.2 cm (6 in.) light-weight concrete masonary unit, 7.6 cm (3 in.) semi-rigid glass fiber insulation board, and 1.6 cm (0.625 in.) gypsum wallboard
Norfolk, Virginia	10.2 cm (4 in.) face brick, 1.9 cm (0.75 in.) air space, 1.3 cm (0.5 in.) gypsum board sheathing, 10.2 cm (4 in.) glass fiber blanket insulation, and 1.3 cm (0.5 in.) gypsum wallboard
Pittsfield, Massachusetts	10.2 cm (4 in.) face brick, 5.1 cm (2 in.) semi- rigid glass fiber insulation board, and 10.2 cm (4 in.) brick
Anchorage, Alaska	12.7 cm (5 in.) precast concrete panel, 7.6 cm (3 in.) semi-rigid glass fiber insulation board, 10.2 cm (4 in.) glass fiber batt insulation, and 1.6 cm (0.625 in.) foil backed gypsum wallboard on 6.4 cm (2.5 in.) metal studs
Fayetteville, Arkansas	10.2 cm (4 in.) face brick and 30.5 cm (12 in.) concrete block

Table 12. Comparsion of Wall Thermal Resistances Measured With a Portable Calorimeter and Heat Flow Meters to Corresponding Predicted Values

Building Location	Air Temperature (°C)		Wall Thermal Resistance (m^2-°C/W)		
			Measured Values		
	Hot Side	Cold Side	Calorimeter	Heat Flow Meter	Predicted Value*
Ann Arbor, Michigan	20.1	4.1	1.95	2.03	1.87
Columbia, S. Carolina	21.3	8.8	2.66	1.90	1.98
Springfield, Massachusetts	20.8	5.5	1.20	2.22	2.29
Huron, S. Dakota	19.4	3.3	2.11	3.60	2.97
Norfolk, Virginia	25.1	9.1	--	1.46	2.76
Pittsfield, Massachusetts	25.4	3.7	--	1.81	1.80
Anchorage, Alaska	23.4	10.3	--	6.88	5.27
Fayetteville, Arkansas	--	--	--	--	0.56

* Note: These values include air films with thermal resistances 0.12 m^2-°C/W at inside surface and 0.70 m^2-°C/W at the outside surface. This is based on an air velocity of 0.3 m/s across the hot, and 0.2 m/s for the cold side surfaces, respectively.

6. Conclusions

This interim report has presented some preliminary findings of the building diagnostic tests of the eight GSA federal buildings. The air infiltration and pressurization measurements show that these buildings are not excessively leaky. In fact, they are tighter than most U.S. homes. The infrared inspections have located sites of air leakage and insulation defects in all the buildings. The percentage of wall area exhibiting thermal defects ranges from about 10 to 20% in the buildings. The U-value measurements show varying correlation with the calculated values. It is not clear whether any disagreement between these measurements and predictions arise from measurement techiques or predictive methods. Both estimates are based on assumptions of one-dimensional heat flow and this may not always be a good approximation. Further reports on this project will contain additional analysis of the infrared inspections and U-value measurements. Also, additional study of the air infiltration data, particularly weather dependence of infiltration, will be presented.

7. Acknowledgements

The authors would like to thank David Eakins and Erma Striner of GSA for their continued support, assistance and encouragement. The technical contributions of Douglas Pruitt and Steve Schweinfurth's assistance in data analysis must also be noted.

REFERENCES

1. Grot, R.A., Burch. D.M., Silberstein, S., and Galowin, L.S., "Measurement Methods for Evaluation of Thermal Integrity of Building Envelopes," NBSIR 82-2065, 1982.

2. Grot, R.A., Hunt, C.M., and Harrje, D.T., "Automated Air Infiltration Measurement in Large Buildings," Proceedings of First Air Infiltration Centre Conference, Windsor, October, 1980.

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET *(See instructions)*	1. PUBLICATION OR REPORT NO. NBSIR 83-2768	2. Performing Organ. Report No.	3. Publication Date September 1983

4. TITLE AND SUBTITLE

Interim Report on NBS Thermal Integrity Diagnostic Tests on Eight GSA Federal Office Buildings

5. AUTHOR(S)

Richard A. Grot, Yui-May Chang, Andrew K. Persily, Jin B. Fang

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

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.
Interagency Agreement PBS-80-1

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

Public Building Service
General Services Administration
Washington, D.C. 20405

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)*

This report summarizes preliminary results of diagnostic tests to evaluate the thermal integrity of eight Federal office buildings located throughout the country. The test results include tracer gas measurements of air infiltration rates, pressurization tests of the air tightness of the building shell, and inspections of the envelope employing infrared thermography. In addition, the thermal U-values of exterior walls were measured with both heat flow meters and a portable calorimeter box. The data collected on these buildings are still undergoing analysis and therefore are to be considered preliminary.

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

air infiltration; building diagnostics; building thermal integrity; fan pressurization; field measurements; thermographic inspections; tracer gas technique; U-value tests

13. AVAILABILITY

[X] Unlimited
[ ] For Official Distribution. Do Not Release to NTIS
[ ] Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.
[X] Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES
50

15. Price
$8.50

USCOMM-DC 6043-P80