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PRELIMINARY RESULTS OF REMOTE TEST SITE CONTROL AND MONITORING OF REDUCED INDOOR RADON LEVELS DUE TO AN INNOVATIVE BASEMENT PRESSURIZATION-HEAT RECOVERY SYSTEM

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ABSTRACT

Preliminary experimental results of a Wisconsin State Indoor Radon Grant (SIRG) are presented. A state-of-the-art PC-data acquisition and control system (PC-DACS) is currently employed to monitor and control the effectiveness of an innovative basement pressurization-heat recovery system at a remote test site. A Wisconsin home that initially exhibited elevated radon levels was installed with an automated PC-DACS that included data acquisition and control software as well as various sensors to measure radon gas concentrations, differential pressures, indoor air quality as well as indoor and outdoor environmental conditions. The isolated PC-DACS is connected to a university laboratory PC 45 miles away via a modem and a communications software package. Experimental data is monitored and saved to the remote PC in real time and then downloaded to the lab computer at selected intervals.

A description of this innovative radon mitigation-energy conservation system is provided. Field data on the relationships between specific meteorological conditions and radon gas entry are documented. Preliminary data on the control of fresh supply air (rate and intake location) to the basement pressurization-heat recovery system and its effect on radon reduction is reported. The documentation of the instrumentation, setup, procedures, PC Script code and listing of batch files produced by this research "opens-up doors" for radon and environmental investigations requiring modern remote monitoring applications.

INTRODUCTION

The consequences of humans contracting lung cancer from being continuously exposed to high levels of radon gas are documented in the literature (U.S. EPA, 1989). Since the mid-1980's, needed attention has been given to methods that decrease radon infiltration into residential buildings. Because of recent indoor air quality (IAQ) fascination by the Environmental Protection Agency, the American Lung Association, the Surgeon General, the Home Builders Association, etc., to indoor radon exposure, a number of innovative techniques to mitigate indoor entry have been developed by the scientific community (U.S. EPA, 1991; U.S. EPA, 1992a; U.S. EPA 1992b; Nazaroff and Nero, 1988). Such popular methods of radon entry control include: active soil depressurization (ASD), passive soil depressurization (PSD), submembrane depressurization (SMD), and heat recovery ventilation (HRV) to name a few. Although these methods have been found to be very successful, they also possess reduction limitations and do not usually address the issue of cost effectiveness with regards to associated energy penalties and operational costs.

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More recently, an innovative radon mitigation method that addressed energy conservation was successfully field tested by Renken and Konopacki (1993). The system used the concept of radon reduction by basement pressurization and dilution in combination with a secondary heat exchanger that recovered heat normally lost through conventional gas-fired furnace flue gas chimney exhaust. This radon mitigation-energy conservation retrofit system was found to actively reduce indoor radon levels caused by pressure driven flow by as much as 97%. The system appeared to be a more effective and less expensive alternative than conventional ASD systems and current house (basement) pressurization techniques.

This paper describes the "follow-up" work that is being conducted by the University of Wisconsin-Milwaukee Radon Research Laboratory to verify the original SIRG project's results and to optimize the basement pressurization-heat recovery system with respect to radon reduction and energy conservation. A more superior system was designed, fabricated, and installed at a remote test site which accommodated a modern PC-DACS. Preliminary field data of the reduction in radon levels due to the operation of this redesigned system is presented. Also, the dependence of radon gas entry with environmental conditions (e.g., barometric pressure, solar radiation, temperature, precipitation, etc.) is discussed.

DESCRIPTION OF EXPERIMENTAL SETUP

The following is a short description of the experimental setup which was installed at the test site and within the university laboratory. Complete details of the equipment, materials and supplies as well as operations and procedures can be found in Coursin (1994).

Test Site

The objective of our Wisconsin SIRG was: (1) to install an innovative radon mitigation-heat recovery system in a residential single family home and optimize the radon reduction and heat recovery effectiveness and (2) to perform automated remote data acquisition and control of radon levels and environmental parameters that affect radon entry dynamics. The basic requirements for test site selection were: an elevated indoor radon concentration, a conventional low efficiency gas-fired furnace, a tight shell, a full basement with slab, no exposed earth in the basement, and no small children or pets. After investigating potential test site candidates via county surveys and our own radon measurements and inspections, the chosen test site was a residence located in Colgate, Wisconsin which contained two adult homeowners and two teenage children. The home is a 19 year old ranch style house with full basement and an attached two car garage forming an "L" shape as illustrated in Fig. 1. The house is slightly shielded by trees, a tool shed on the north side, and a patio fence on the west side. The attached garage also shields part of the house's west side. The south (front) and east sides of the home are fairly exposed to the environment. The basement was sealed from the first floor by a plywood sub-floor, while the basement foundation consisted of poured concrete floor with cinder block walls which had been unsuccessfully sealed against radon by the previous owner. In the basement, there exists one sump well in the southeast corner and the original gas-fired furnace with a 110,000 BTU/hr input and a 88,000 BTU/hr bonnet capacity with a 1/3 hp blower. The initial average radon level in the basement was > 35 pCi/L.

Basement Pressurization-Heat Recovery System

Fig. 2 displays a schematic of the radon mitigation-heat recovery system used in this project. The system consists of a stainless steel secondary heat exchanger, a flue gas blower, a fresh air blower, two damper actuators, various sensors and electrical components, as well as HVAC ducting. The radon mitigation is accomplished by the pressurization and the dilution of the basement by the controlled amounts of makeup air being deposited into the environment after it is heated by the secondary heat exchanger. A variable speed radial drive blower imparts sufficient pressure to the heated makeup air relative to the soil pressure to prevent the entry of radon laden soil gas. The makeup air was delivered by two sources: fresh outside air and inside upstairs air. Each source was tested independently and jointly in prescribed mixtures to determine optimal performance. The heat recovery occurs because of the utilization of energy from the wasted flue gas which normally is exhausted by the chimney. In this fashion, the system is able to provide an effective alternative radon mitigation system without a severe energy penalty. The operational costs are also minimized because the system is on for selected intervals; unlike the common ASD systems which have fans operating continuously. Indoor air quality is also improved by the system, since fresh outside air is circulated throughout the living environment.

The system operates as follows: when the house thermostat calls for heat, a signal is sent to the flue gas blower to initiate operation. Then, a relay signal is sent to the furnace to ignite the burners and start the furnace blower. Once the hot flue gas inlet temperature to the heat exchanger reaches a prescribed temperature, the fresh air blower begins operation and draws air in from either the outside, the upstairs or a mixture of both depending on damper positions. The air is heated by the heat exchanger which has an unmixed, transitional, cross flow configuration with "turbulators." The heated air is then deposited into the basement where it provides dilution and a positive pressure as compared to the surrounding foundation soil pressure. Once sufficient heating is provided, the furnace and the flue gas blower shut off, while the fresh air blower continues to operate until minimal heat recovery persists. During the heating season, the cycle is repeated every time the thermostat calls for heat. Modifications to the system have been made so that operation during the cooling season is permissible. These tests are presently being conducted.

PC-Data Acquisition and Control System

The PC-DACS consisted of a combination of computer, data acquisition unit, plug-in cards, transducers and software packages. The two main hardware components were a portable computer and a data acquisition mainframe. More specifically, the PC contained a 80486 processor operating at 33 MHz with 8 MB RAM, 200 MB hard drive, a 1.44 MB 3.5" drive, and a color VGA monitor. In the PC was an internal data/fax modem which was connected to a second household telephone line that was installed just for this project. The external data acquisition cardcage was linked to the PC by an interface bus cable. It was equipped with four plug-in modules which supplied the interface for the instrumentation. The cards included a 5 1/2 digit multimeter which connected two 16-channel thermocouple relay multiplexers used to interface continuous voltage output sensors to the mainframe, a 3-channel universal counter employed to connect the voltage pulse output sensors, and a digital to analog converter to provide a variable 0-11 V.

The digital to analog capability of the system was used to control the radon mitigation system's main blower, the inlet air source, and the flue gas exhaust outlet as shown in Fig. 3. Three elements were needed to control the main blower: a solid state relay, a silicon controlled rectifier, and a permanent magnet DC motor. The solid state relay switched the 120 VAC power line to the silicon controlled rectifier (SCR) based on a control signal from the PC-DACS. The SCR converted the 120 VAC to 0-90 VDC in proportion to the 0-10 V control signal. The DC voltage was then fed to the motor to allow a variable flow rate.

The inlet air source and the flue exhaust outlet control was accomplished with a damper actuator. The actuators move to a specific angular position according to a 2-10 V control signal. The actuators were coupled to round dampers to achieve flow control. The inlet air source dampers were linked by a connecting arm such that a mixture of outside and inside upstairs air could be directed into the heat exchanger. The flue exhaust outlet actuator was constrained to a range of 50-100% open.

One interesting feature of the PC-DACS was that it was "self-powered". More specifically, the system was powered by three car batteries, an automatic battery charger and two DC power inverters. In this fashion, the loss of precious data due to electrical power company blackouts or blown fuses in the house was prevented. This independent power supply system additionally provided a means of not having to travel to the test site to reset the PC-DACS setup if there was a loss of power.

The popular menu-driven data acquisition software package *Labtech Notebook Version 6.2*[3] performed all the necessary data collection, internal conversions of sensor outputs to true engineering units and executed calculations between channels. During operation, this software elegantly controls the scanning rate, channel

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[3] Laboratories Technologies Corporation, 400 Research Drive, Wilmington, MA 01887.

selection, display of data in real time and logging of data into a compatible spreadsheet file. The ICONview graphical interface portion of Labtech Notebook permits the creation of data acquisition setups by moving and connecting icons. The user can graphically structure the application by using the icons as building blocks and connect them to show the relationships and data flow between functions.

The key ingredient to the automated remote data acquisition was the communications software package *The Norton pcAnywhere Host and Remote Version 4.5.*[4] This software package allows any PC to access and control a host PC for remote computing and complete general communications via a modem connection. Features include bi-directional high speed file transfer in the foreground or background, automated dial directory, call logging, session record and playback functions and built-in process control language (scripting) for automating repetitive functions. A detailed description of the procedure necessary to successfully complete the automated remote data acquisition and control from the test site PC-DACS to the lab PC for subsequent analysis is detailed in Coursin (1994).

Instrumentation

Table 1 gives a description of the sensors that were used in this project, their locations at the test site, and their true engineering output units. The number of sensors that can be utilized by our automated PC-DACS is unlimited. Currently, the system has 44 individual sensors, of which 22 are transducers that provide an analog voltage, six are transducers that provide a 4-20 mA current, 13 are type-T thermocouples that provide a mV input, and three provide a voltage pulse to the universal counter card.

Fig. 4 displays the instrumentation location. The indoor radon concentrations were measured by two calibrated *Pylon Model AB-5 continuous radon monitors*[5] which used 300 ml scintillation cells. The units (one located in the first floor family room and the other in the basement) were connected to the 3-channel universal counter cards of the data acquisition mainframe.

The pressure transducers were very low differential pressure sensors which could accurately detect differential pressures in the range of +/- 62.5 Pa. Five of the pressure measurements were between the basement and the soil probes placed around the house foundation. The remaining three sensors measured the differential pressure between the basement and the upstairs living area, the outside atmosphere relative to the basement, and between two locations in the basement.

Duct flow rates in the radon mitigation-heat recovery system were monitored by three averaging pitot tubes connected to differential pressure transducers and one hot wire anemometer. The pitot tubes had multiple ports on the air stream side of the probe at precise locations to give an average flow rate in the duct. The differential pressure between the static and dynamic ports was fed to a pressure transducer providing 0-5 V in proportion to the flow rate. The hot wire anemometer had a small heated element placed in the center of the air stream. Electric current was provided to the heating element to keep it at uniform temperature as the moving air dissipates heat away. The onboard circuitry monitors the amount of current being drawn by the heating element and converts it to a 0-5 V signal.

The other transducers used in conjunction with the PC-DACS are fully described in Coursin (1994). Their descriptions are not repeated here for brevity.

DISCUSSION OF RESULTS

Pre-Mitigation Data

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[4] Symantec Corporation, 10201 Torre Avenue, Cupertine, CA 95014-2132.

[5] Pylon Electronics Inc., 147 Colonnade Road, Ottawa, Ontario K2E 7L9.

Pre-mitigation data was collected from December 1992 to May 1993. Figs. 5 - 8 present an overview of the data for the week of March 22-31, 1993, which is representative of the pre-mitigation data. Each figure shows the radon concentration in the basement and first floor living area on the axis (basement radon concentration is always greater). The environmental parameters that affect radon entry are shown below the radon concentration levels in each figure for comparison. These environmental factors are grouped as relating to weather, pressure differentials, temperatures, and indoor air quality parameters.

Seen on a weekly time scale it is obvious that the radon levels vary widely. The variations are separated into overall trend information and noise. The noise component stems the high sensitivity of the scintillation cells. Throughout the pre-mitigation period the radon level is far in excess of the EPA action level of 4 pCi/L. The basement radon level remained 10 to 40 pCi/L above the first floor living area, which varied between 5 and 15 pCi/L.

An interesting effect can be seen from the solar radiation graph in Fig. 5. It has been theorized that radon concentrations in residential structures follow a diurnal pattern (Sheets, 1992). On most of the days registering strong sunlight, the radon level peaks when the solar radiation climaxes, albeit after a small time delay. This link to solar radiation could have many avenues since sunlight affects temperature, wind, barometric pressure, and home heating requirements.

The pressure differentials observed between the soil and basement as shown in Fig. 6 were positive at almost all times indicating that the flow of radon laden soil gas was pressure driven. The individual pressure differentials did fluctuate up and down due to wind effects, but on average the levels balanced out to a positive value. The upstairs to basement differential confirms that the basement was in a state of depressurization on a nearly continuous basis. The differential between outside and basement showed prolonged periods of positive and negative readings. This is a good indication that the house was exchanging some air via natural ventilation. The measurement of natural ventilation rate was based on the wind speed and the temperature difference between the inside and outside. Shielding factors such as trees and nearby obstructions were taken into account and the effective leakage area, which was measured in an initial whole house blower door test, was also factored into the calculation.

The outside temperature in Fig. 7 showed signs of following the sun as would be expected. The temperature differential between the outside air and the basement was close to the mirror image of the outside temperature since the basement temperature was nearly constant. The average soil temperature showed the least variance of any measured parameter except oxygen concentration, remaining between 40 and 50°F. The upstairs temperature fluctuates wildly due to the proximity of the thermocouple to the heating register. The natural ventilation rate is shown here since its major driving component was the temperature difference between the inside and outside of a structure (along with wind speed). The values of the natural ventilation rate indicated the house was exchanging air despite it's tight shell.

Fig. 8 presents the variation of indoor radon concentrations with indoor air quality parameters. The level of oxygen, carbon monoxide and carbon dioxide are recorded. The oxygen concentration was not observed to vary more than a few tenths of a percent from 20.5. The carbon monoxide level, measured in parts per million, rarely registered at all. Fig. 8 shows some indication of carbon monoxide on March 26 and 27. The carbon dioxide level varied from 600 to 1100 ppm. The oxygen and carbon dioxide content can be seen to follow the natural ventilation rate to some degree.

Post-Mitigation Data

The post-mitigation data was collected with optimization of the system in mind. Detailed in Table 2 are the configurations of supply air used during the mitigation period of September 15, 1993 to December 31, 1993. The ability to draw air from the first floor allowed the system to be configured such that the basement temperature was not significantly lowered on extremely cold days. Control was open loop in order to establish a baseline of information on the amount of warm indoor air needed to keep the basement temperature comfortable. Balanced against the need for temperature control was the adverse effect on mitigation of circulating radon laden air.

During period 1, the mitigation-heat recovery system was not consistently in operation due to the initiation of the heating season. The reduction of radon levels was quite apparent during several intervals in this period. The transition from period 1 (100% outside air) to period 2 (50% outside, 50% upstairs air) measured increases in radon levels. Here, the reduction of incoming fresh air was limiting the effectiveness of the system. Moving into period 3 (100% inside air) the system had become even less effective in mitigating. This was attributed to the minimization of the dilution. Finally, in period 4 (100% outside air) there was again a dramatic decrease (approximately 50%) in the average basement radon level. Experimental raw data depicting the variation of supply air configuration is found in Coursin (1994).

The post-mitigation period of October 22 - 31, 1993 is presented in Figs. 9 - 12, organized in a similar fashion with parameters grouped by weather, pressure, temperature and indoor air quality, with the addition of mitigation-heat recovery system operation immediately below radon concentration. The most striking difference in the radon and pressure differentials as compared to pre-mitigation data is a peak and trough pattern superimposed on the diurnal pattern caused by the operation of the radon mitigation-heat recovery system. Here, we find that the radon concentration in the house is solely dependent on the system operation. A more defined cycle is produced whereby radon levels are immediately decreased when the thermostat called for heat and the system turned on There also exists positive basement pressure relative to both the soil and upstairs pressures, indicating that basement pressurization is cyclically sustained. Oxygen levels within the basement also increased/decreased following the on/off operation.

CONCLUSIONS

Preliminary experimental data of an innovative radon reduction system that provided basement pressurization, dilution, and energy conservation in a residential structure was presented. A description of the basement pressurization-heat recovery system and the state-of-the-art PC-DACS, which monitored and recorded data as well as controlled the radon mitigation effectiveness, was also detailed. It was shown that the system can actively control residential radon levels in homes that have basements with conventional gas-fired furnaces. Also, observed was a direct dependence of indoor radon concentration with solar radiation level. Modifications of the current system for summer operation are being tested during the summer of 1994. More qualitative year-round results are expected by the spring of 1995.

ACKNOWLEDGMENTS

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Fig. 12 Exemplary post-mitigation data: radon concentration versus indoor air quality parameters for October 22-31, 1993.

Table 1. Description of sensors utilized with automated remote PC-DACS.

Channel	Instrument	Units	Location
1	Time	s	Computer (internal)
2	$\Delta P_{\text{soil south}}$	Pa	Soil Probe (South)/Basement
3	$\Delta P_{\text{soil southeast}}$	Pa	Soil Probe (Southeast)/Basement
4	$\Delta P_{\text{soil northeast}}$	Pa	Soil Probe (Northeast)/Basement
5	$\Delta P_{\text{soil north}}$	Pa	Soil Probe (North)/Basement
6	$\Delta P_{\text{soil west}}$	Pa	Soil Probe (West)/Basement
7	$\Delta P_{\text{upstairs}}$	Pa	Upstairs Family Room
8	$\Delta P_{\text{outdoor}}$	Pa	Radiation Shield Box
9	$\Delta P_{\text{basement}}$	Pa	Basement
10	AC Line Monitor	V	Basement Pressurization -Heat Recovery System
11	Barometer	in Hg	Basement/Radiation Shield Box
12	Wind Velocity	mph	Flagpole
13	Wind Direction	°	Flagpole
14	Indoor Relative Humidity	%	Upstairs Family Room
15	Basement Relative Humidity	%	Basement
16	Outdoor Relative Humidity	%	Radiation Shield Box
17	Precipitation Cumulative	inches	Flagpole
18	Precipitation Incremental	inches	Flagpole
19	Radon Upstairs Cumulative	pCi/L	Upstairs Family Room
20	Radon Upstairs Incremental	pCi/L	Upstairs Family Room
21	Radon Basement Cumulative	pCi/L	Basement
22	Radon Basement Incremental	pCi/L	Basement
23	T_{outdoor}	°F	Radiation Shield Box
24	$T_{\text{soil north}}$	°F	Soil Probe (North)
25	$T_{\text{soil south}}$	°F	Soil Probe (South)
26	$T_{\text{soil east}}$	°F	Soil Probe (East)
27	$T_{\text{soil west}}$	°F	Soil Probe (West)
28	T_{upstairs}	°F	Upstairs Family Room
29	T_{basement}	°F	Basement
30	$T_{\text{hrv air in}}$	°F	Secondary Heat Exchanger
31	$T_{\text{hrv air out}}$	°F	Secondary Heat Exchanger
32	$T_{\text{hrv flue in}}$	°F	Secondary Heat Exchanger
33	$T_{\text{hrv flue out}}$	°F	Secondary Heat Exchanger
34	Pyranometer	W/m^2	Flagpole
35	Furnace Monitor	°F	Furnace Duct
36	Oxygen	%	Basement
37	Carbon Monoxide	ppm	Basement
38	Carbon Dioxide	ppm	Basement
39	Main Air Volume	CFM	Basement Pressurization-Heat Recovery System
40	Outside Air Volume Flow	CFM	Basement Pressurization-Heat Recovery System
41	Upstairs Air Volume Flow	CFM	Basement Pressurization-Heat Recovery System
42	Flue Gas Volume Flow	CFM	Basement Pressurization-Heat Recovery System
43	Main Blower Power	W	Basement Pressurization-Heat Recovery System
44	Flue Blower Power	W	Basement Pressurization-Heat Recovery System
45	$T_{\text{up air supply}}$	°F	Upstairs Bedroom

Table 2. Basement pressurization-heat recovery system supply air configuration.

	Start	End	% Outside air	% Upstairs air
1	September 15, 1993	December 1, 1993	100	0
2	December 2, 1993	December 8, 1993	50	50
3	December 9, 1993	December 20, 1993	0	100
4	December 21, 1993	December 31, 1993	100	0

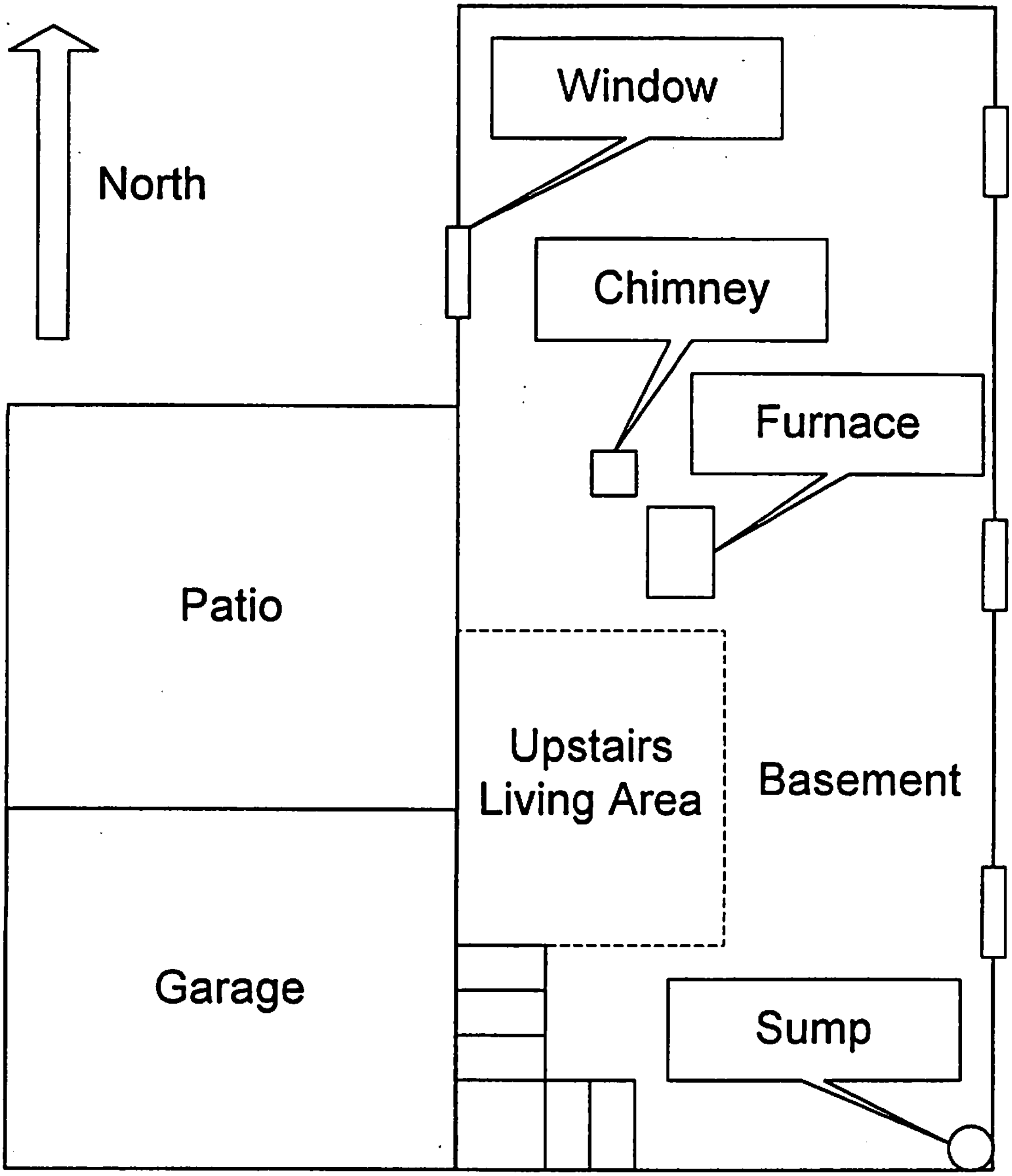
North
Window
Chimney
Furnace
Patio
Upstairs
Living Area
Basement
Garage
Sump

Fig. 1

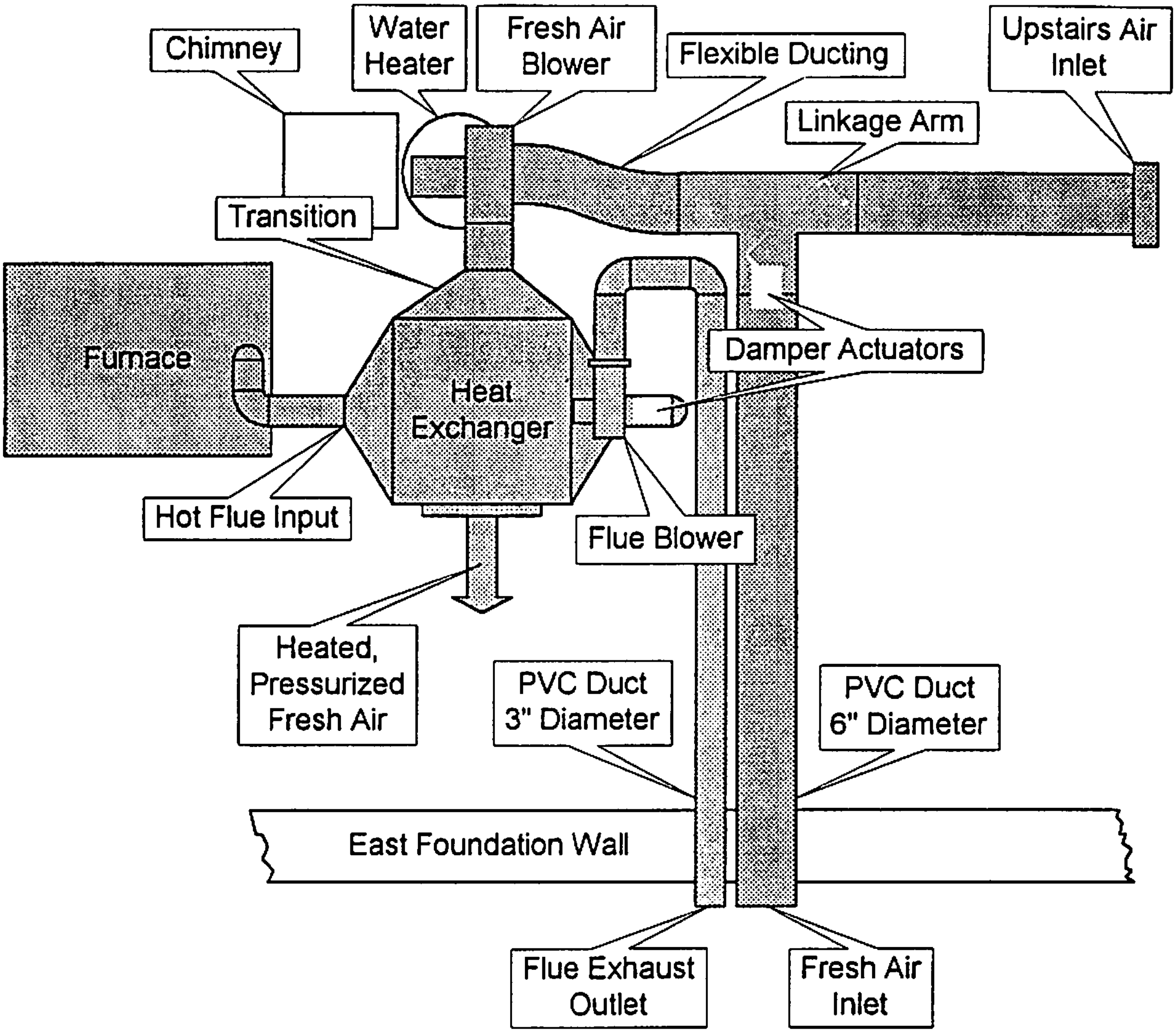
Chimney
Water Heater
Fresh Air Blower
Flexible Ducting
Upstairs Air Inlet
Linkage Arm
Transition
Furnace
Heat Exchanger
Damper Actuators
Hot Flue Input
Flue Blower
Heated, Pressurized Fresh Air
PVC Duct 3" Diameter
PVC Duct 6" Diameter
East Foundation Wall
Flue Exhaust Outlet
Fresh Air Inlet

Fig. 2

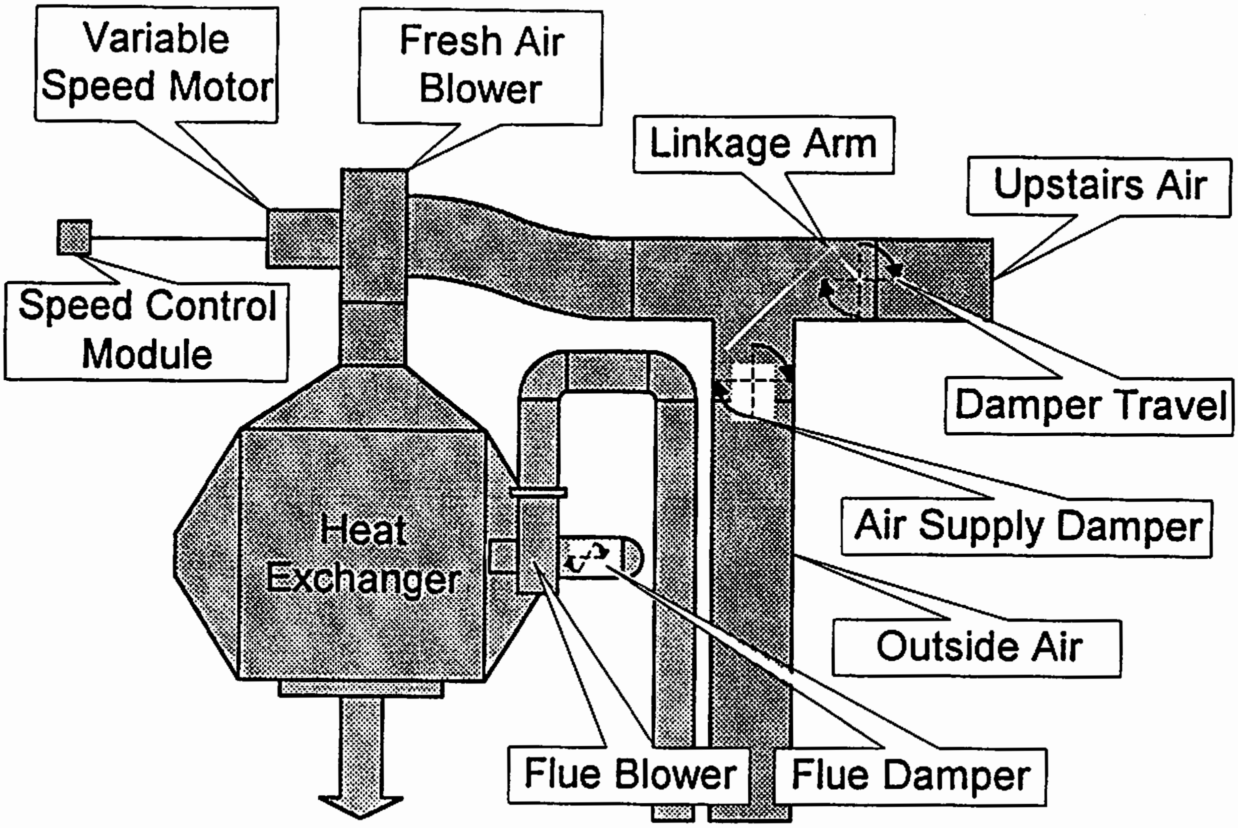
Variable Speed Motor
Fresh Air Blower
Linkage Arm
Upstairs Air
Speed Control Module
Damper Travel
Air Supply Damper
Heat Exchanger
Outside Air
Flue Blower
Flue Damper

Fig. 3

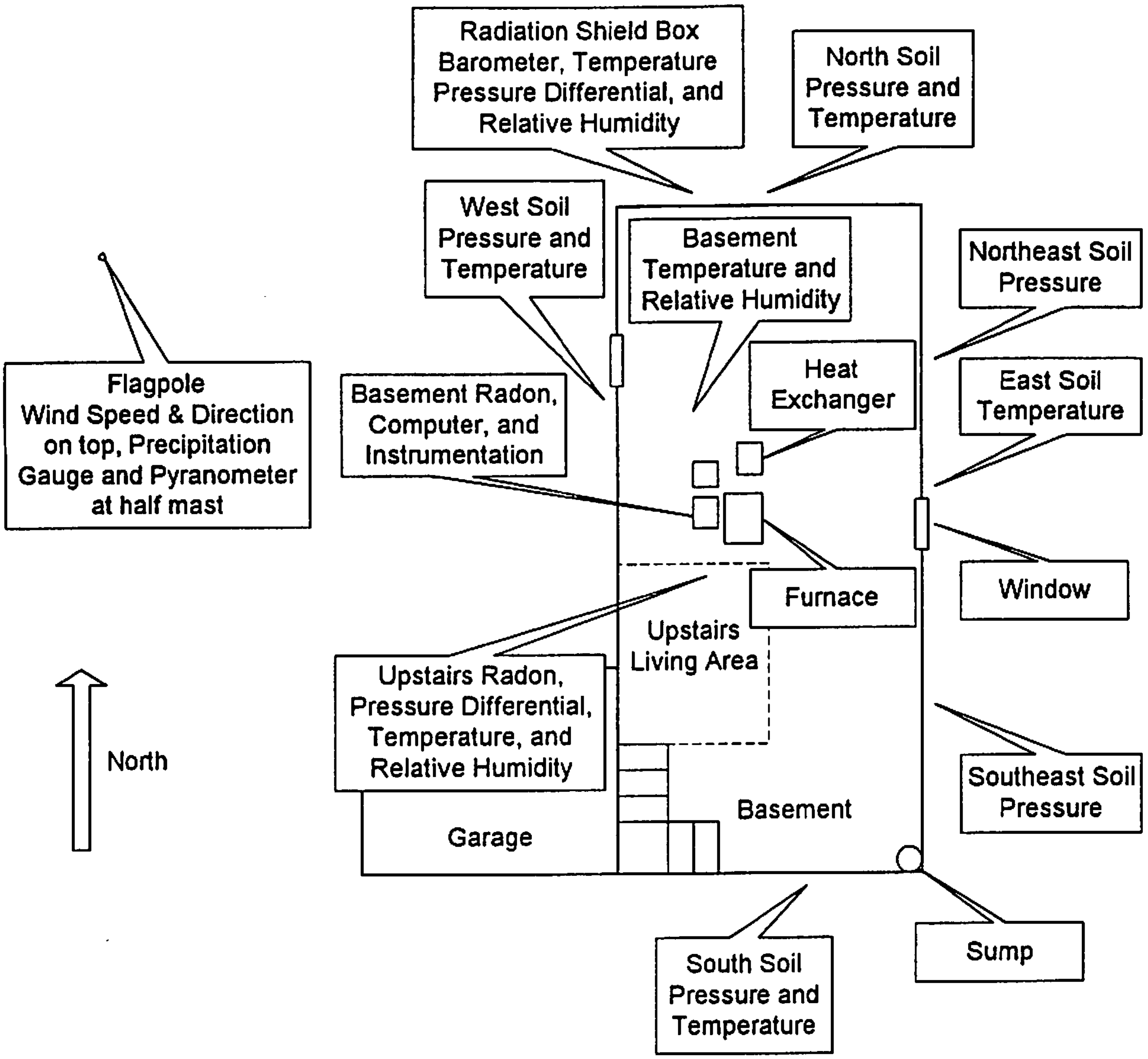
Radiation Shield Box
Barometer, Temperature
Pressure Differential, and
Relative Humidity
North Soil
Pressure and
Temperature
West Soil
Pressure and
Temperature
Basement
Temperature and
Relative Humidity
Northeast Soil
Pressure
Flagpole
Wind Speed & Direction
on top, Precipitation
Gauge and Pyranometer
at half mast
Basement Radon,
Computer, and
Instrumentation
Heat
Exchanger
East Soil
Temperature
Furnace
Window
Upstairs
Living Area
Upstairs Radon,
Pressure Differential,
Temperature, and
Relative Humidity
North
Southeast Soil
Pressure
Garage
Basement
Sump
South Soil
Pressure and
Temperature

Fig. 4

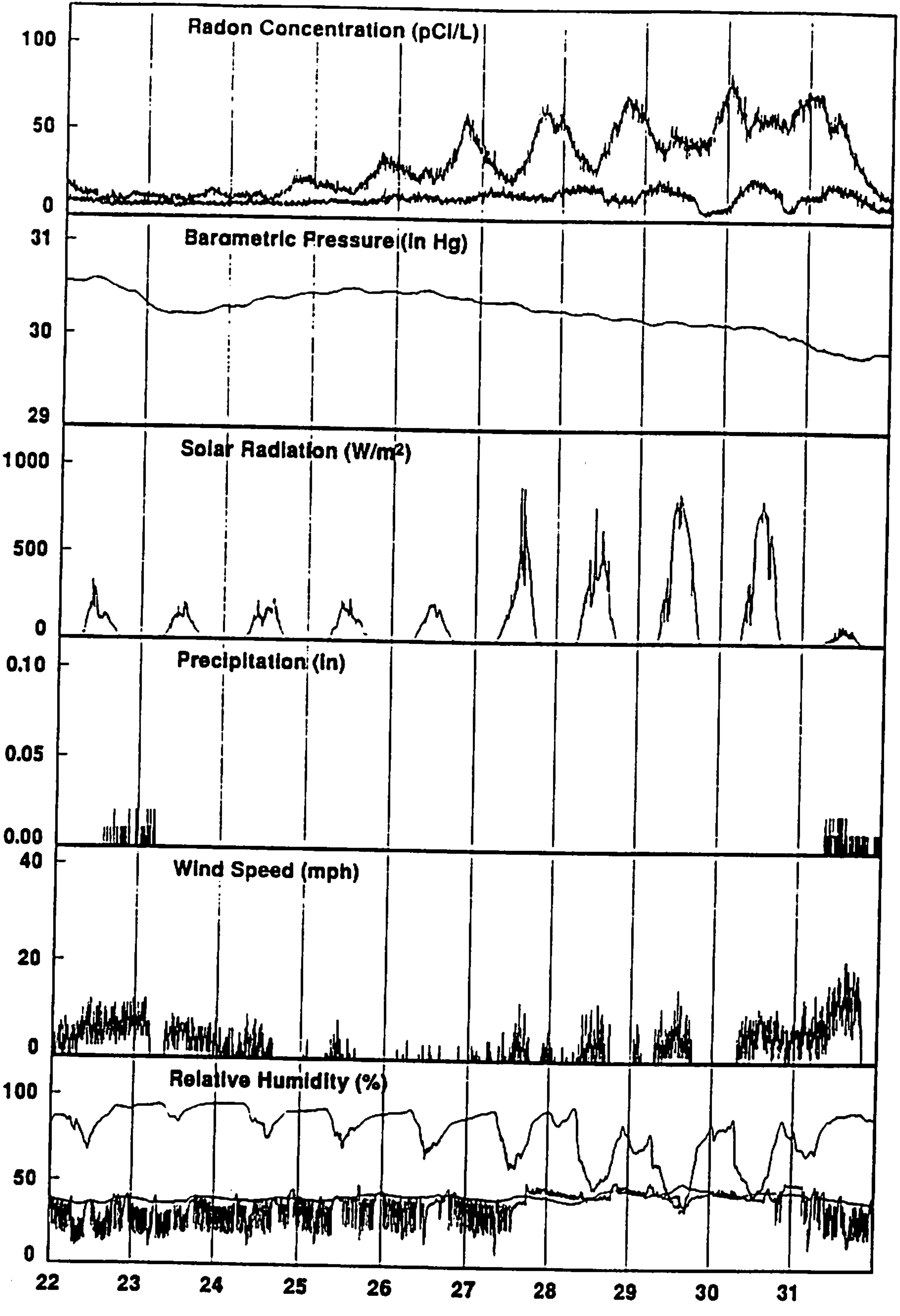
Radon Concentration (pCi/L)
100
50
0
Barometric Pressure (in Hg)
31
30
29
Solar Radiation (W/m²)
1000
500
0
Precipitation (in)
0.10
0.05
0.00
Wind Speed (mph)
40
20
0
Relative Humidity (%)
100
50
0
22
23
24
25
26
27
28
29
30
31

Fig. 5

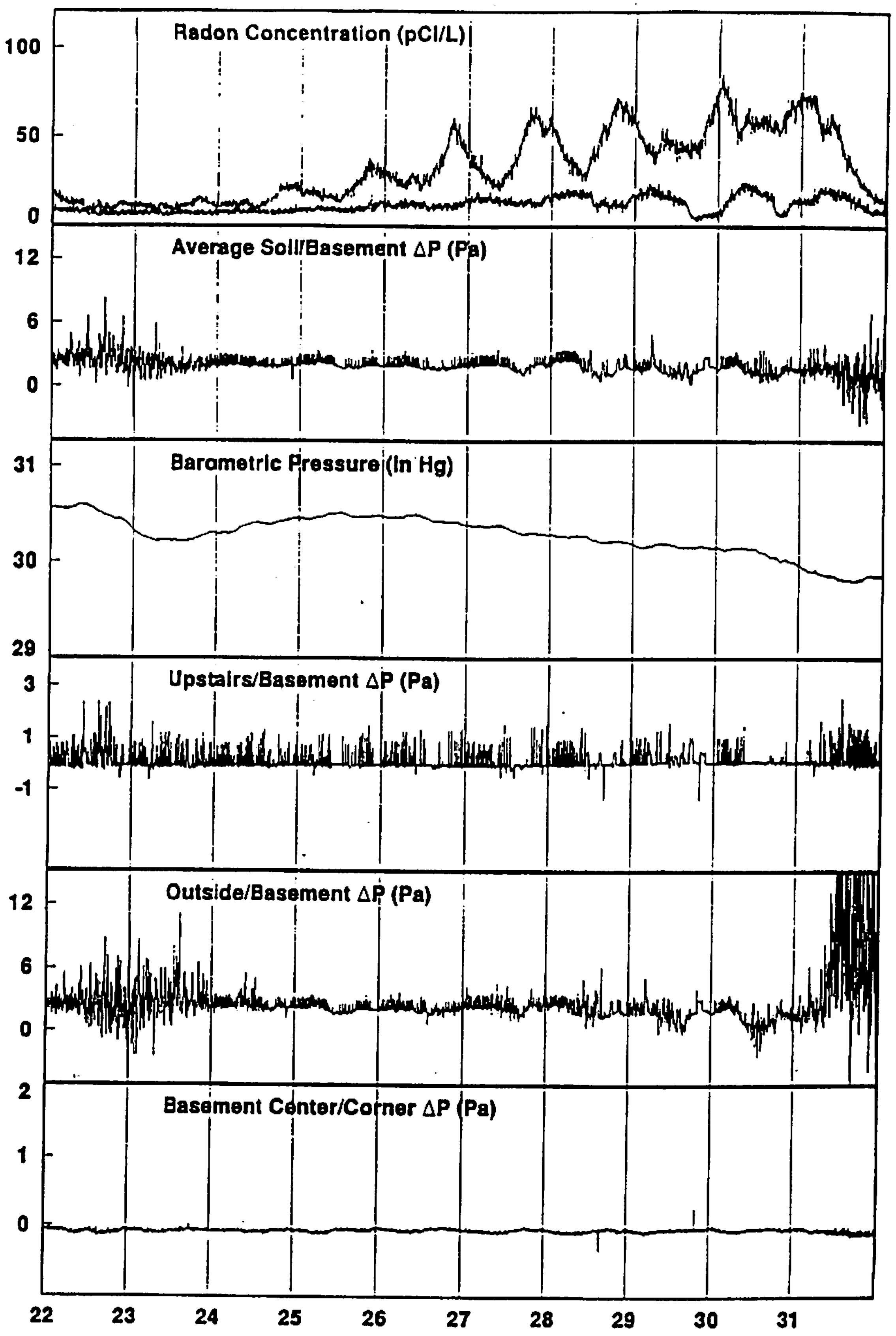
Radon Concentration (pCi/L)
100
50
0
Average Soil/Basement ΔP (Pa)
12
6
0
Barometric Pressure (in Hg)
31
30
29
Upstairs/Basement ΔP (Pa)
3
1
-1
Outside/Basement ΔP (Pa)
12
6
0
Basement Center/Corner ΔP (Pa)
2
1
0
22
23
24
25
26
27
28
29
30
31

Fig. 6

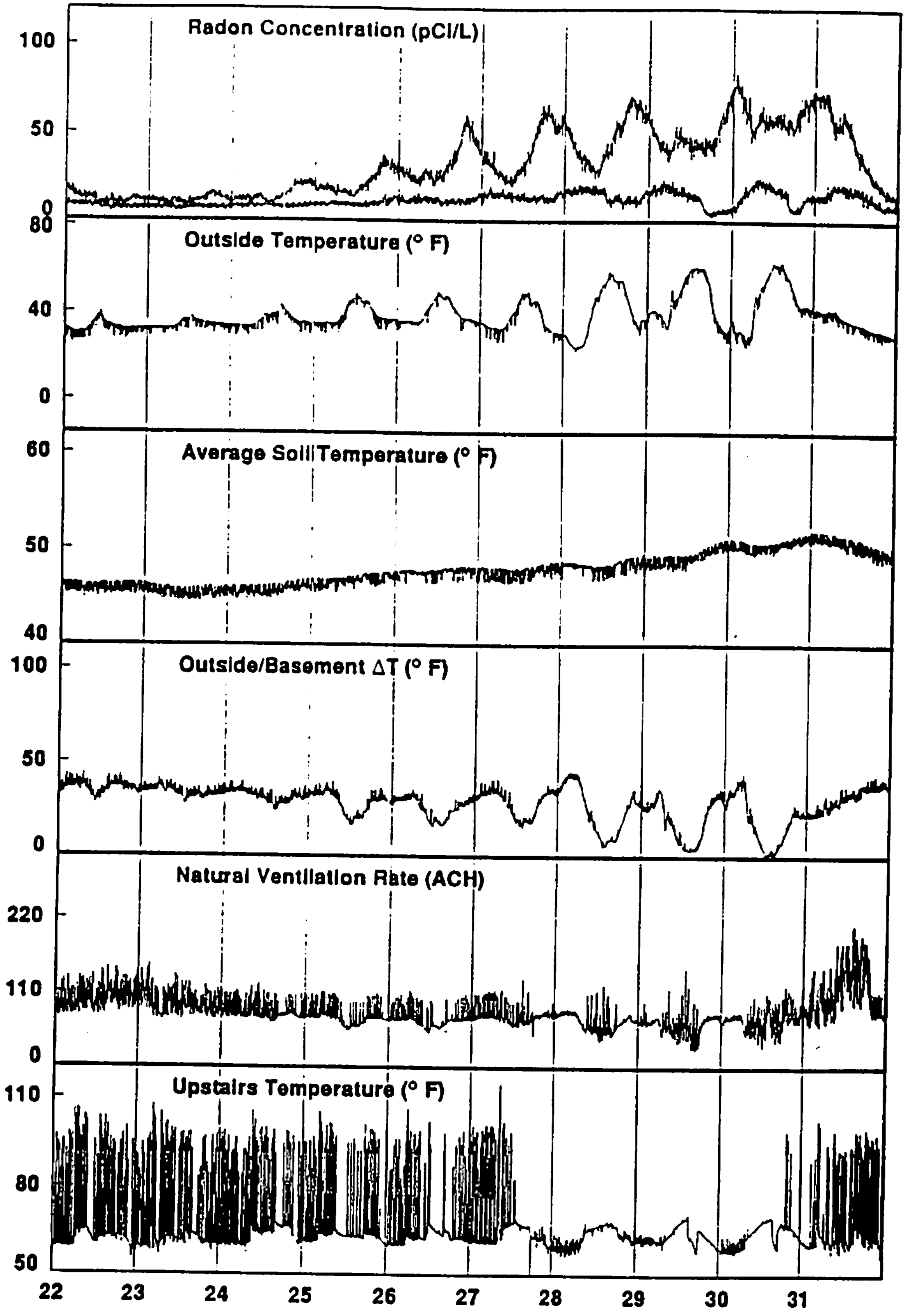
Radon Concentration (pCi/L)
100
50
0
Outside Temperature (° F)
80
40
0
Average Soil Temperature (° F)
60
50
40
Outside/Basement ΔT (° F)
100
50
0
Natural Ventilation Rate (ACH)
220
110
0
Upstairs Temperature (° F)
110
80
50
22
23
24
25
26
27
28
29
30
31

Fig. 7

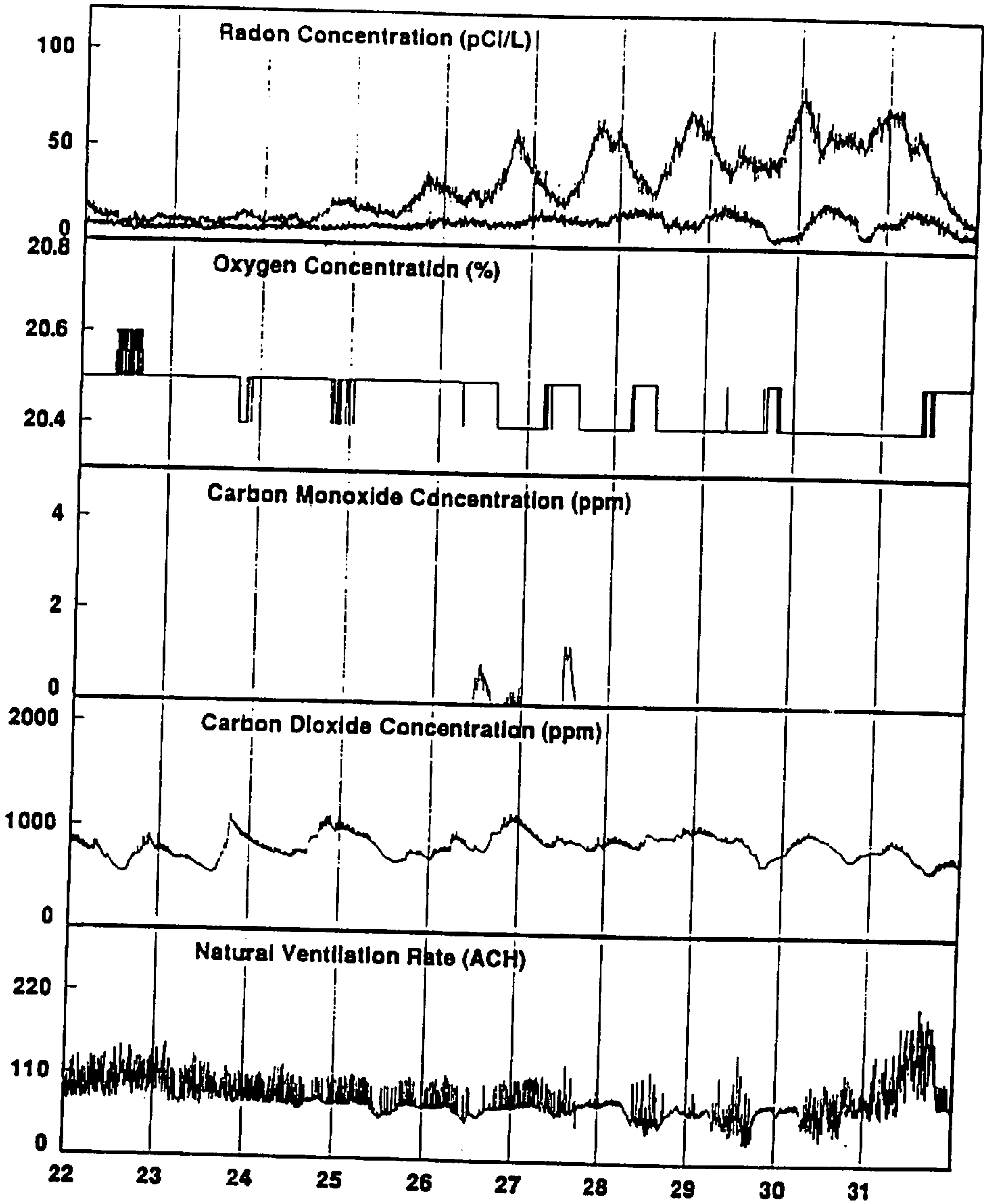
Radon Concentration (pCi/L)
100
50
0
Oxygen Concentration (%)
20.8
20.6
20.4
Carbon Monoxide Concentration (ppm)
4
2
0
Carbon Dioxide Concentration (ppm)
2000
1000
0
Natural Ventilation Rate (ACH)
220
110
0
22
23
24
25
26
27
28
29
30
31

Fig. 8

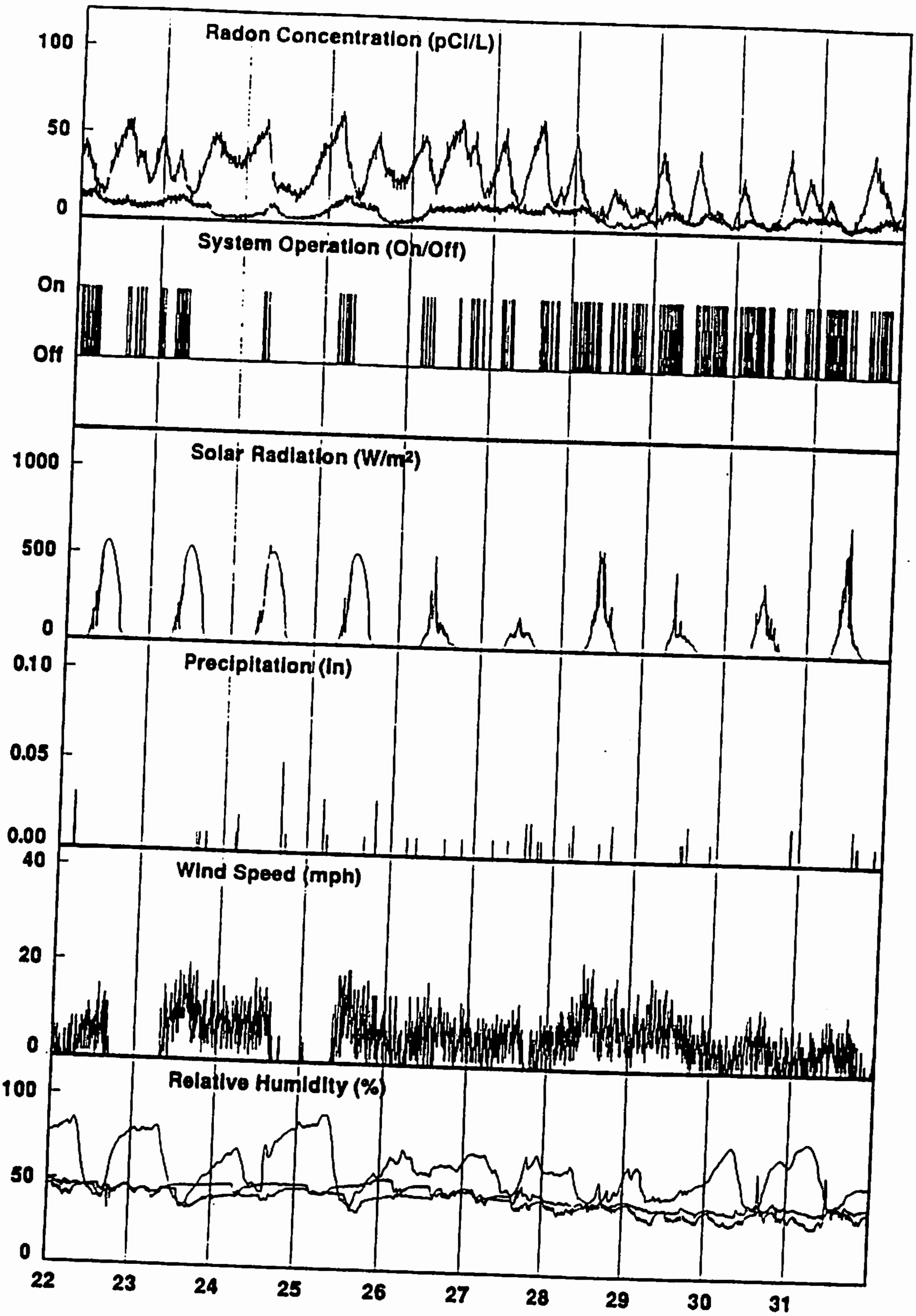
Radon Concentration (pCi/L)
100
50
0
System Operation (On/Off)
On
Off
Solar Radiation (W/m²)
1000
500
0
Precipitation (in)
0.10
0.05
0.00
Wind Speed (mph)
40
20
0
Relative Humidity (%)
100
50
0
22
23
24
25
26
27
28
29
30
31

Fig. 9

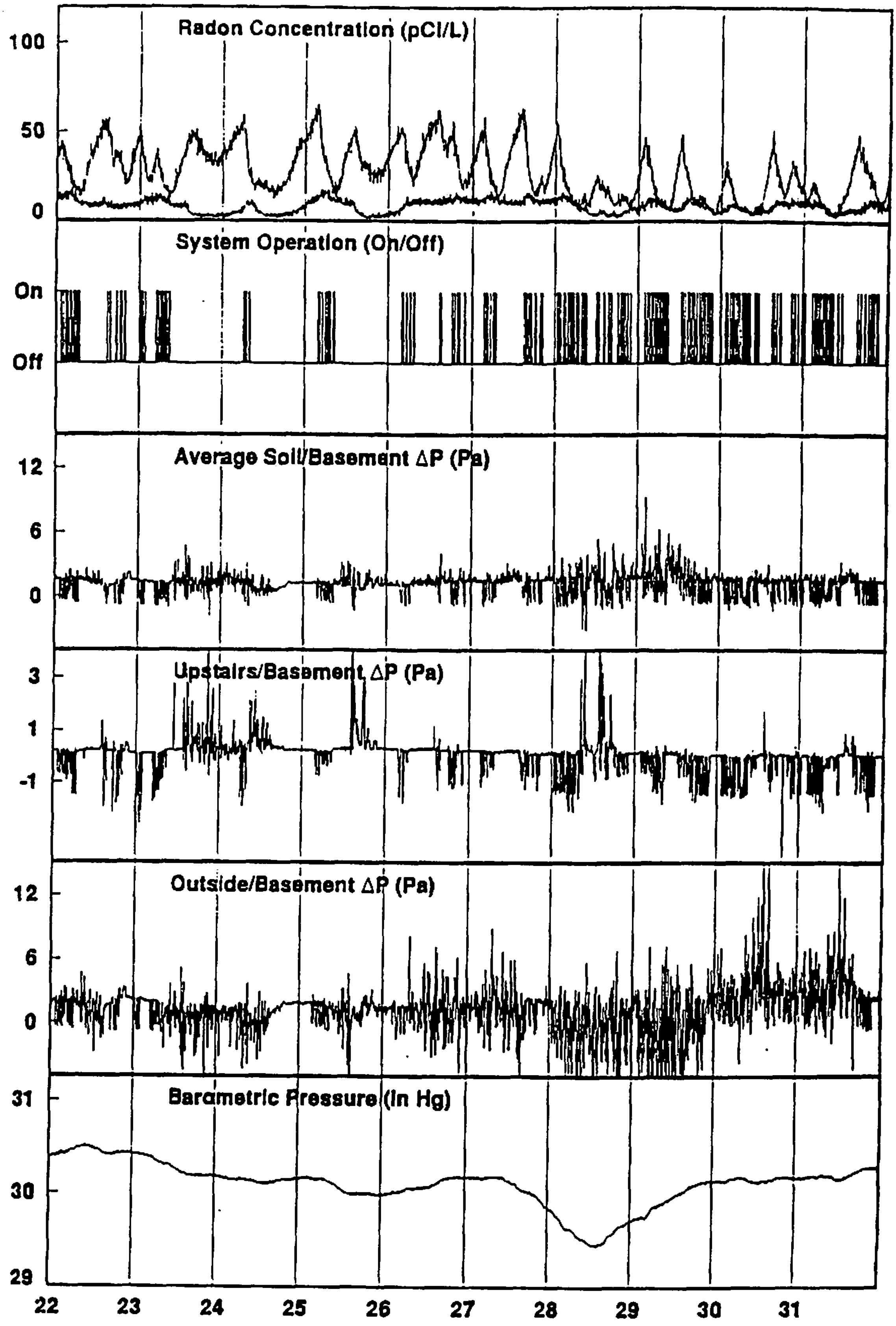
Radon Concentration (pCi/L)
100
50
0
System Operation (On/Off)
On
Off
Average Soil/Basement ΔP (Pa)
12
6
0
Upstairs/Basement ΔP (Pa)
3
1
-1
Outside/Basement ΔP (Pa)
12
6
0
Barometric Pressure (in Hg)
31
30
29
22
23
24
25
26
27
28
29
30
31

Fig. 10

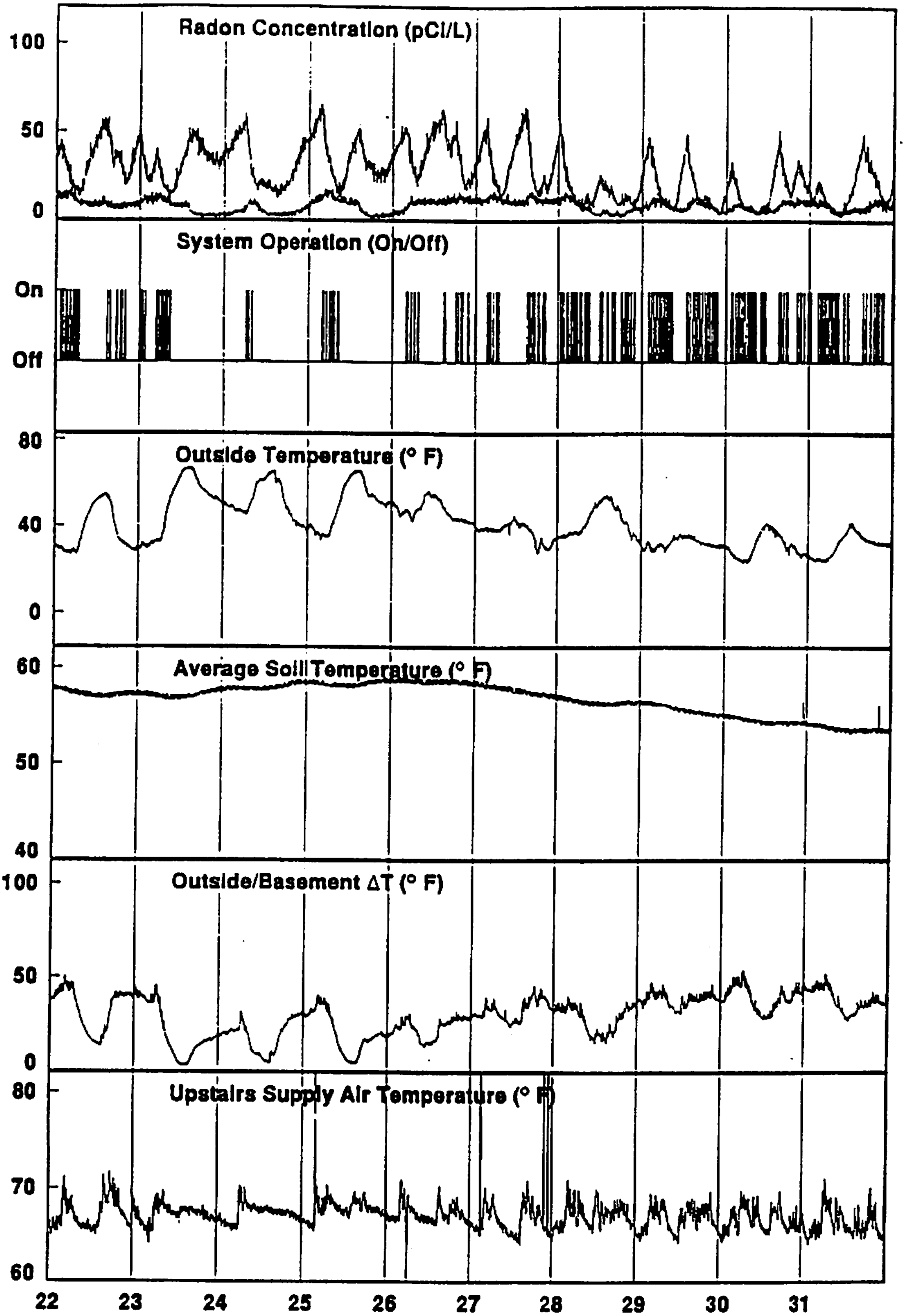
Radon Concentration (pCi/L)
100
50
0
System Operation (On/Off)
On
Off
Outside Temperature (° F)
80
40
0
Average Soil Temperature (° F)
60
50
40
Outside/Basement ΔT (° F)
100
50
0
Upstairs Supply Air Temperature (° F)
80
70
60
22
23
24
25
26
27
28
29
30
31

Fig. 11

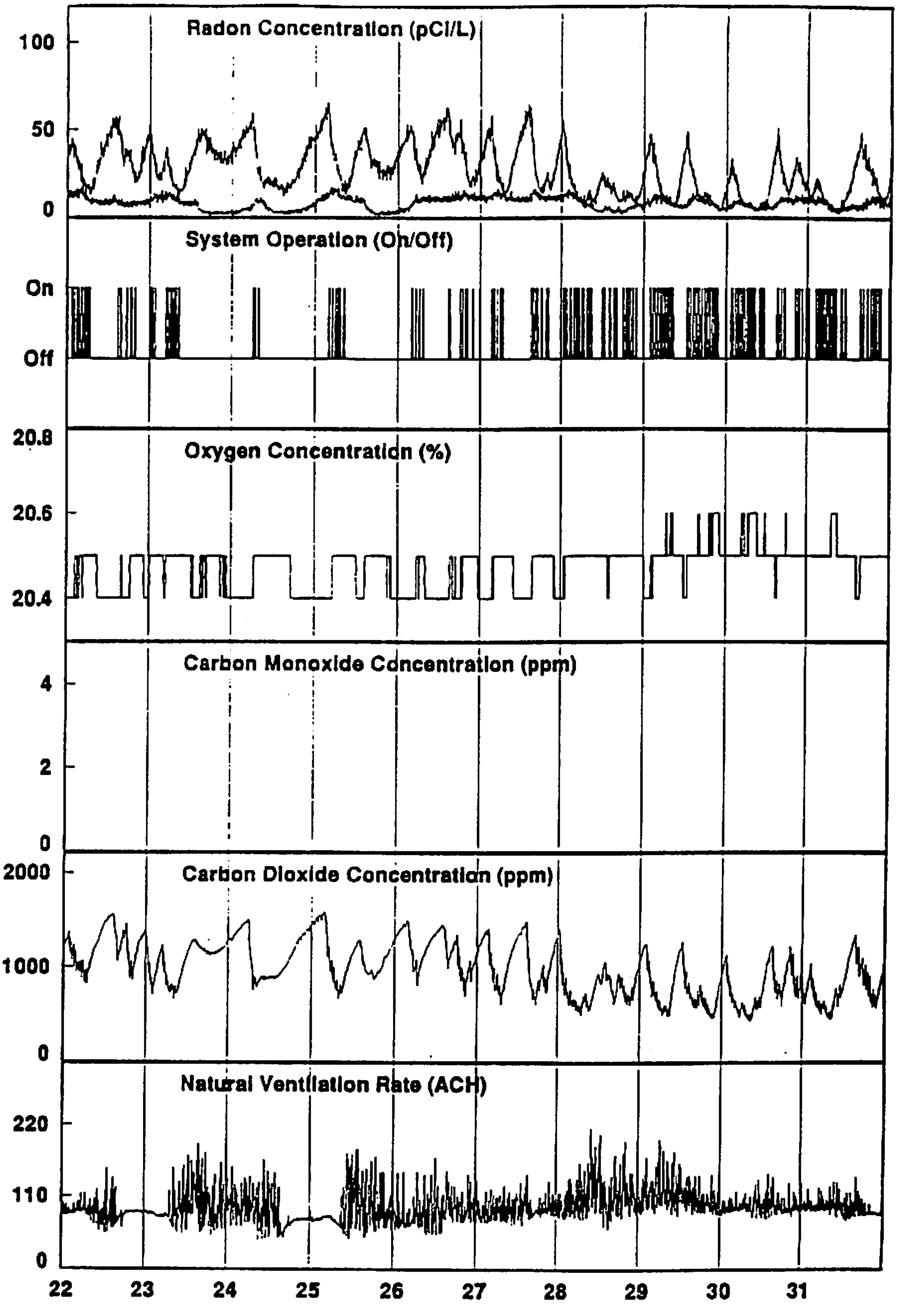
Radon Concentration (pCi/L)
100
50
0
System Operation (On/Off)
On
Off
20.8
Oxygen Concentration (%)
20.6
20.4
Carbon Monoxide Concentration (ppm)
4
2
0
2000
Carbon Dioxide Concentration (ppm)
1000
0
Natural Ventilation Rate (ACH)
220
110
0
22
23
24
25
26
27
28
29
30
31

Fig. 12