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Florida Large Building Study
Polk County Administration Building

Final Report

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FOREWORD

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E. Timothy Oppelt, Director
National Risk Management Research Laboratory

ABSTRACT

This report describes a research study undertaken in support of the Florida Standard for Radon Resistant Construction in Large Footprint Structures, (currently under development by the Florida Department of Community Affairs). The project entailed an extensive characterization and parametric assessment study of a single large building located in Bartow, Florida with the purpose of assessing the impact on radon entry of design, construction, and operating features of the building, particularly, the mechanical subsystems.

As part of the study, the response of the structure to a range of HVAC operating conditions was continuously monitored with the purpose of determining the optimum HVAC conditions to reduce indoor radon within the envelope of acceptable operation as regards to energy, comfort and indoor air quality impacts on the structure.

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Chapter 1
Introduction

This document describes a research study undertaken in support of the Florida Standard for Radon Resistant Construction in Large Footprint Structures, (currently under development by the Florida Department of Community Affairs). The project entailed an extensive characterization and parametric assessment study of a single large building, the Polk County Administration building located in Bartow, Florida. The purpose of the study was to assess the impact on radon entry of design, construction, and operating features of the heating, ventilating and air-conditioning (HVAC) system. As part of the study, the response of the structure to a range of HVAC operating conditions was continuously monitored with the purpose of determining the optimum HVAC conditions to reduce indoor radon within the envelope of acceptable operation as regards to energy, comfort and indoor air quality impacts on the structure.

Specific objectives of the study included: determining the effect of HVAC operating cycles, (including Outdoor Air level and exhaust ventilation) on Radon-relevant parameters of the structures; assessing the effect of ground floor pressure imbalance on radon entry; monitoring the transport of air (and radon) between zones and floors; evaluating the effect of a larger extent slab on the driving pressures which promote radon entry; and assessing the effect of building features/faults on radon entry. The building was selected for this study as best representing the research criteria determined in a workshop review process by the Florida Radon Research Program (FRRP). These criteria represent specific information needs identified by the FRRP as important to the development of a definable construction standard for this class of structure. The building had elevated levels of radon gas, a large footprint (40,000 ft^2 first floor), multiple floors, floors with multiple zones being served by 13 airhandling units.

This report describes the building, study methodology, results, and lessons learned as a result of the project, which provided needed insight into the interaction of indoor radon and HVAC operation in a large building in the semitropical Florida climate zone. The study also resulted in methods to reduce the indoor radon concentrations in the building below the U. S. EPA action level of 4.0 pCi/L, while maintaining satisfactory and comfortable operation of the building.

Chapter 2
Conclusions and Recommendations

Results of the study provided solutions for both indoor radon and HVAC deficiencies at the building. Radon concentrations in the "as found" condition averaged approximately 8.1 pCi/L on first floor, 3.1 pCi/L on upper floors, yielding 4.1 pCi/L for the building as a whole. Based on inspection of the HVAC system and continuous monitoring, several deficiencies were noted which would be expected to adversely affect either radon levels, other indoor air quality factors, (such as elevated levels of CO_2) or energy consumption. Specifically, observations of the air handler operation indicate that the supply air flowrates were below design values (typically less than half of maximum flowrate), even at peak cooling demand times. Further, outdoor air flowrates were far below design values on the lower four floors. This is partly due to the outdoor air ductwork, which is undersized, and partly due to the low static pressure induced by the air handlers at the low supply volume used. The building was also found to have excessive pressure imbalance between zones, especially on the first floor. This imbalance caused air to flow between building zones and floors across fire rated walls.

The average indoor radon concentrations were not significantly changed by the changes in the Outdoor Air (OA) damper positions in Operating Cycles 1-3. Other measures of ventilation, including tracer gas air exchange measurements and peak CO_2 concentrations, were also unaffected. Apparently, the incremental changes in the low outdoor air flowrate were too small to cause any significant change to building ventilation. During periods of operation of the inline blowers in the OA duct, the indoor radon was reduced by an average of 18% with two fans operational (700 cfm added OA) and 40% with all three fans (1939 cfm) operational.

Due to the extent of constriction required we were unsuccessful in attempts to discover or seal areas on the first floor which might serve as paths for radon entry. One possible source, the main elevator shaft, did not prove to be a major factor in radon entry. Further, sealing of direct openings to the soil did not significantly reduce indoor radon. This experience is consistent with the spotty success record of sealing in other buildings. However, the significant depressurization of all three ground floor mechanical rooms, accompanied by infiltration into the air distribution systems and the excess radon concentrations in these rooms, indicate that they may be a major source of radon entry.

The experiments in this study demonstrate that when outdoor air was increased into the first floor HVAC system indoor radon concentrations reduced in the building, particularly on the first floor where the concentrations were highest. Our temporary fan installation produced significant reductions with flowrates of under 2000 cfm. We project that if first floor flowrates of 3000 cfm (nearer the design value of 3300 cfm) were used, adequate ventilation would be provided for the first floor auditorium and office space average radon concentrations would be completely below 4 pCi/L in the entire first floor and even lower in the remainder of the building. Added benefits of this level of outside air would be improved air quality throughout the building (as indicated by reduced peak CO_2 levels), and reduction or reversal of the overall building depressurization. Both design ratings and our observations indicate that the first floor air handling units have the capacity to handle the greater latent heat load.

Specifically, we recommend the following actions:

- Install induced air fans on the outdoor air intake lines of Air Handler Units 1-3 with capacity to deliver, respectively, the design values of 1500, 750, and 1050 cfm outdoor air flowrate in operation. Seal ductwork between fans and outdoor air intakes to insure against infiltration of indoor air. Configure each fan to operate continuously whenever the air handler is operating.

- Remove first floor air handler from current night setback cycle. We feel that the benefits of the added "Baseline" ventilation will justify round-the-clock operation of these units. This recommendation could be ignored if the OA fans operate only when the air handler is on, but the "occupancy" status on the control system should remain on ("occupied") even at night or weekends.

- Seal return ductwork in each mechanical room between air handler plenum and mechanical rooom fire walls to reduce or eliminate mechanical room depressurization and infiltration.

Certain other actions would seem beneficial to us in terms of overall comfort, energy, or indoor air quality. These actions include reducing the potential for first floor pressure imbalance, increasing supply air circulation rates, and increasing air handle duty cycles. However, we did not demonstrate a clear potential for reduction in radon from any of these actions. They were, therefore, omitted from our recommendations and left as suggestions to be considered if warranted by other considerations of the county.

Chapter 3
Description of Building

The Polk County Administration building located in Bartow, Florida, is a publicly owned building constructed in 1988. The site is located on what is likely reclaimed land from phosphate mining in years past. The building has 149,000 square feet of floor space distributed over five stories with an atrium that extends from the ground floor up to a glass skylight at roof level. Each of the first four floors open into a balcony around the atrium. The hallways and offices on each of these levels are isolated from the atrium by normally closed doorways. On the fifth floor, the atrium opening is enclosed completely and isolated from the occupied area. The building has a permanent occupancy of roughly 300 county employees and elected officials.

The foundation of the building is generally slab-on-grade with supporting pilings (or grade beams in some locations) under the slab. The slab thickness is nominally 6 inches thick with pilings that penetrate the sub-surface soil to an undetermined depth. The superstructure is supported by reinforced concrete columns resting on the driven pile foundations placed on a 30 ft by 30 ft grid over the slab profile. The ground floor slab is cast in place with isolation joints around the column penetrations. Control joints are set along column lines and midway between column lines, leaving a 15 ft by 15 ft spacing. Upper floors are cast in place concrete slabs over a precast structural concrete joist and beam system. Spacing between ground and second floors is 18 ft, that between the next 3 floors is 14 ft each, and the fifth floor to roof truss distance is 11.5 ft. Exterior building finish is a combination of aluminum curtain walls, glazing, and masonry. The building windows are operable, and while most windows were sealed, a few were capable of being opened and may possibly have been opened during the study period.

The building uses a Variable Air Volume (VAV) HVAC system with chilled water cooling and electrical resistance heating both in the 11 Air Handling Units (AHU) and the VAV boxes serving the exterior rooms. The two 150 ton centrifugal chiller units, located in an adjacent mechanical equipment building, operate in a lead-lag configuration. The Air Handler Units (AHU) are numbered numerically starting with the first floor in the North-West (NW) quadrant of the building and progressing counter-clockwise through the upper floors. There are two each on all floors except the first which has three units. The conditioned zones on the second through the fourth floors are similar in that the HVAC supply ductwork branches are divided into interior and exterior zones. One AHU supplies conditioning to the internal zone and the other supplies air to the exterior zone. On these floors both sets of ductwork liberally cross the fire-rated walls which generally border the main corridors. Therefore, the occupied portions of these floors and the open fifth floor are assumed to behave as well mixed zones surrounding and somewhat isolated from the central atrium area. The locations of the three air handlers and the areas of the first floor served by each are shown in Figure 1. Two of the units (AHU2 and AHU3) supply conditioning to the south and north office areas, respectively, of the building while the third system (AHU1) supplies conditioned air mainly to the Board Room and the Central Foyer. The fire-rated walls on this floor also lie along the corridor boundaries and show better correspondence to the HVAC ducting. However, considerable crossover mixing between zones in this floor is expected as well in view of the fact that each of the five zones shown in Figure 1 has return air windows into the plenum above the lobby/corridor area supplied from which AHU1 and 2 draw directly and which feeds return air into the plenum above the NE zone containing AHU3. Further mixing is provided by a distant branch from AHU2 which supplies a portion of the NE zone.

The 11 AHUs are controlled by a central Johnson Controller 8550 processing unit via local digital signal controller (DSC) units in each mechanical room. Control circuitry is included for chiller and chilled water system operation, HVAC fan and vane damper, smoke dampers, chilled water flowrate and reheat operation, and VAV settings including dampers, fans and heating strips. The zone temperature set points are controlled by the system rather than occupants. While the system is capable of several program operation cycles, it is typically operated in a programmed manual operation cycle, supplemented by manual overrides as required by building scheduled occupancy patterns. Since the pattern of setback and operation modes affects the data described in this report, each operating mode is described below in some detail. These three modes, designated as A, B and C, are described as follows:

Mode A: Normal occupancy mode: Weekdays from 6 a.m. to 9 p.m.; weekends from 6 a.m. to 2 p.m. All air handlers on; VAV supply dampers operating normally, temperature controlled by setpoints to sensors in rooms.

Mode B: Normal setback mode: Weekdays from 9 p.m. to 6 a.m.; weekends from midnight to 6 a.m. In this mode only one air handler is operating per floor, alternating between the two air handlers on each floor every 30 min; occupancy status flag is off, resulting in air handler vane dampers set to minimum condition and 7 degree setback of cooling zone setpoints.

Mode C: Weekend day setback: Weekends from 2 p.m. from midnight. One air handler operating per floor, alternating between the two air handlers on each floor every 30 min; occupancy status flag on, resulting in normal (demand-controlled) position of vane dampers and normal setpoints.

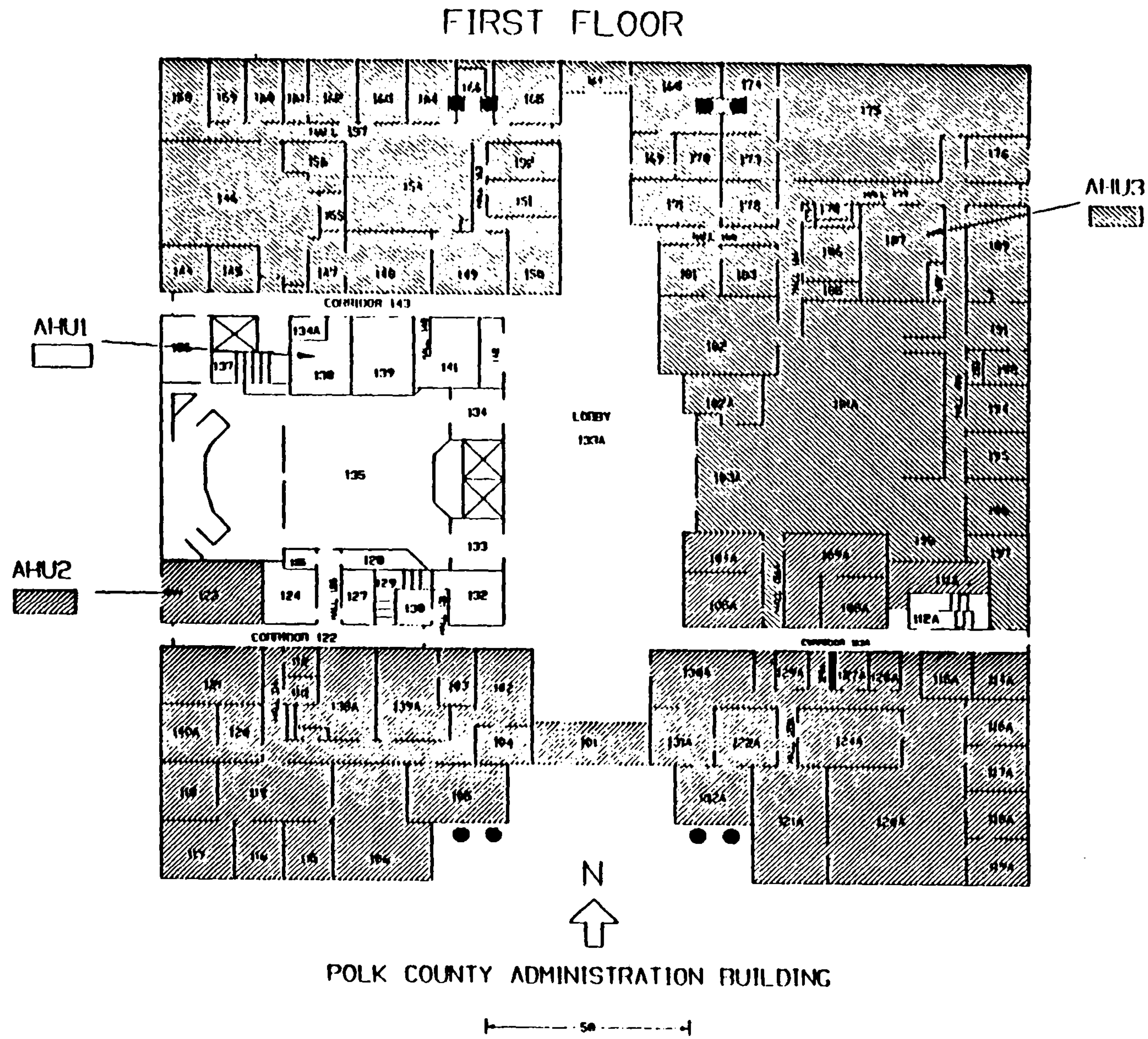


Figure 1. Locations of the first floor HVAC systems and the zones served by these units

Chapter 4
Experimental Plan

In the context of FRRP program needs, the overall goal of the present study was to define as much as possible in an operating building the potential impact of elements under consideration in a large building radon-resistant construction standard. Since structural elements (such as foundation radon barriers) and active soil depressurization systems were already being studied in new buildings, the primary focus of study in the Administration Building Study was the effects of HVAC system design and operation.

Specific objectives of the study are listed in the following paragraphs.

1. <u>To determine the effect of HVAC operating conditions on radon-relevant parameters of the structures</u>. These parameters included building pressure, ventilation rate, radon concentration, and radon entry rate (assuming a well-mixed building). The results were to be determined by a parametric study in which ventilation air and other HVAC operation settings were systematically varied.

2. <u>To assess the effect of ground floor pressure balance or imbalance on radon entry</u>. In other buildings, HVAC flow imbalances have been found to cause considerable pressure imbalances. The effect of inducing (or reducing) such pressure imbalances was to be investigated. If pressures on the ground floor were found to be balanced, it was planned to temporarily block fire dampers to partially isolate the return of 2 distant zones on first floor. An imbalance of ~5 Pa difference between near and far zones was targeted, and the ventilation rates, radon concentration and entry in the depressurized zones were to be examined.

3. <u>To monitor the transport of air (and radon) between zones and floors</u>. The NIST system primarily was set to measure whole building air change rates and the variations in rates under HVAC operating changes. In addition, some tracer experiments were planned to determine qualitative air mixing patterns between floors or between isolated zones on the first floor.

4. <u>To evaluate the effect of a larger extent slab on the driving pressures which promote radon entry</u>. In other FRRP studies, pressure differentials across the building slab have been found to track fluctuations in barometric pressure. Since entry of radon should follow these pressure differentials, the subslab pressure variations at this building were monitored with position and HVAC status. (It was anticipated that two superimposed effects would be observed, one dependent on position and the time derivative of the

barometric pressure and the other dependent on the HVAC cycle and possibly outside temperature.)

5. To assess the effect of building features/faults on radon entry. Some of the features thought to serve as enhanced entry points included elevators, stairwells, ground floor mechanical rooms, and visible penetrations. Several experiments were planned in which these areas were monitored for excess radon concentrations which would suggest enhanced radon entry.

6. To leave the building in an optimum operational configuration for minimum indoor radon. In respect for the needs for the Polk County Administrators and employees, after the parametric study had determined the appropriate level of ventilation air for reducing the radon in the structure, the building would be tested in that configuration, left in the optimum operating status, and the county would be given recommendations for future operation.

In order to meet these objectives, an experimental plan was developed that involved initial characterization of the building and its HVAC system, installation of data acquisition instrument packages, and monitoring building response during systematic variation of the HVAC system. Each of these elements will be described below, followed by a schedule of events in the study.

Characterization of HVAC System Operation
In order to assure a known state for the AHVs of the building HVAC system, thorough characterization of the HVAC was performed at the building. Before any measurements a team from Southern Research, EPA, and other research team members conducted a survey and inspection of the HVAC system. Several deficiencies in the HVAC installation and operation were noted and reported to the County Facilities Management staff. The most important of these included significant supply duct leakage in the attic areas above the 5th floor and total lack of ventilation (outdoor) air into both second floor air handlers due to obstruction of O/A intakes by building framing after installation. The county completed repair of these conditions before the experimental phase.

Measurements Conducted by TAB
A certified TAB company (Bay To Bay Balancing, Inc., Tampa, FL) had performed the initial test and balance of the HVAC systems in the building in December 1990. Additional measurements were conducted on the fifth floor in August 1992 following completion of this area of the building. As part of the present study, Bay-to-Bay was contracted to verify and spot check data from earlier balance reports of the system. These measurements included:

- Monitoring of total flow and trunk line supply flowrates from all air handlers at full open VAV conditions.

- Measurement of supply and outdoor air flowrate at each air handler at four demand flow conditions (nominally 60, 70, 85, and 100% of capacity) and at four positions of all operable outdoor air dampers (full open, closed, and nominally 50% and 75%).
- Measurement of exhaust fan flowrates.

All measurements were carried out using standard TAB techniques: for major duct flowrate measurements, pitot traverses were performed; for measurements at exhaust grills, a flow hood was used.

Characterization Measurements by FSEC

During two weekend periods during the study, a team from the Florida Solar Energy Center conducted several further tests of HVAC system operation and effects. These included: modified blower door testing of the airtightness of the total building, the lower four floors and the five first floor zones; confirmation measurements of supply flowrates on the first floor zones, and of exhaust and outdoor ventilation air flowrates on all floors; survey measurements of pressure differentials between first floor zones, upper floors, mechanical rooms, and other selected building areas for full and reduced VAV demand conditions. In addition to pitot traverses and flow hood measurements, FSEC used tracer dilution and modified blower door techniques to measure flow rates.

Continuous Data Monitoring Systems

Large buildings, being complex in character, raise imposing demands on data needs. Project demands to measure many data parameters over time made it necessary to either utilize numerous individual monitoring sensors or develop a new data collection station system. Individual sensor units would put large demands on field personnel in time and individuals needed to collect data, and would have created quality control concerns. A centralized data collection system was needed to reduce technical support time and streamline data collection. For continuous measurements 13 Indoor Air Quality Data Stations (IAQDS) were used, with internal and remote input sensors. Each of the IAQDS stored information via an internal microprocessor and transmitted this information by modem to a PC compatible computer. In addition to the IAQDS, weather station measurements were performed using a data logging system assembled by Southern Research, several other radon measurements were recorded using individual continuous radon monitors, and continuous tracer gas measurements were made using a system provided by the National Institute of Standards and Technology (NIST). The major systems are described below.

Description of IAQDS Locations and Parameters Measured

The EPA Indoor Air Quality Data Station is based on the Blue Earth Research Micro-440 micro controller system. This device is designed for compact, low power (or battery-operated) applications, and contains the core hardware and software in the main unit. The only additional required hardware units are the 4-input 12 bit A/D converter and a power supply. A 12-volt rechargeable battery pack is included in the power supply to provide for continued operation during short power failures. The built-in memory is large enough to save 20 days of data. If a longer period between downloading of data is desired, an additional memory module may be added to the system to give an extra 28 days of data storage. The devices are installed in a metal cage to give mechanical protection.

The microcomputer controlling the Blue Earth system uses the one-second clock interrupt to pace data acquisition. It counts to seven seconds and then reads each A/D converter and samples the input switch lines. The readings are added to averaging buffers which hold the intermediate values. After 256 loops the contents of the buffer are averaged and converted to one or two bytes of data. The 12 bit A/D converter values result in two bytes of data each, the 8 bit A/D converters and the switch registers produce one byte of data each, and the counter registers which are read at this time produce two bytes each. The elapsed time for the loop is 1792 seconds (7 X 256), so an added delay of 8 seconds before beginning the next loop produces sampling periods of 30 minutes (1800 seconds). The real time clock is read at this time and the month, day, hour, and minute values are used to form the header for the data block, which is stored in the battery-backed RAM which is available in the system. The four date/time numbers and the 20 data value numbers are stored as a block in the next available space in memory.

Each instrumentation node serves as a standalone system, requiring only electrical power to operate. The system contains rechargeable batteries which will provide about 8 hours of operation with the external power off. This will permit data acquisition to continue during short power outages. If the power is off for a longer interval, data acquisition will stop but the data taken up to that point will be saved in internal battery-backed RAM. When power is reapplied, the system will reset and start taking data from that time. The system will operate automatically without any operator intervention. For system control and data downloading, a computer configured as a terminal is connected to the RS-232 connector. The terminal operates at 2400 baud. Any one of the data channels can be checked for operation or calibrated via the RS-232 input. The channel number and the number of repetitions of the test are entered, and then that channel is exercised and the results printed out, with a delay between each repetition of the test.

Several input channels are dedicated to the internal instruments on the data station, including a continuous radon monitor (FemtoTech Model R210F), a carbon dioxide monitor, two differential pressure transducers (Modus, typically -25 to +25 Pa full-scale), temperature and relative humidity transducers. Additional pulse counting, A/D, and switch monitoring channels are available for other instruments if required.

As used at the Polk County Administration Building, the IAQDS measurements included indoor radon concentrations, two to four differential pressures, room temperature, relative humidity, and carbon dioxide concentrations in each of the 13 zones. In addition, percentage operation cycle time for selected air handlers, exhaust fans, and elevators were obtained via switches; duct air temperature and relative humidity in selected air handlers were monitored (for another project); and a particle counter in a single first floor zone provided indicative measurements of indoor particulate levels. The 13 IAQDS were distributed two per floor on the top four floors, with five stations distributed in several zones on the first floor. The locations of the IAQDS stations on the first floor are shown in Figure 2. Also shown in Figure 2 are the locations of additional radon monitors located externally to the data stations but whose outputs was logged and recorded by the data stations. A total of 10 monitors were located on the first floor to continually record the radon levels with adequate spatial resolution.

Tracer Gas System

The tracer gas testing of the Polk County Administration Building was conducted by personnel from the National Institute of Standards and Technology (NIST), Gaithersburg, MD. These tests consisted of automated measurements of whole building air change rates using the tracer gas decay technique and qualitative evaluations of interzone airflow patterns. This section of the report describes the tracer gas instrumentation, installation in the building and measurement procedures.

The tracer gas testing of the building employed an automated monitoring system with sulfur hexafluoride (SF_6) as a tracer gas. The system was installed in a room on the fourth floor of the building and consists of an SF_6 monitor, an air sampling system, a tracer gas injection system, and a microcomputer-based data acquisition and control system. The SF_6 monitor consists of a gas chromatograph (GC) equipped with an electron capture detector. The electron capture detector can determine SF_6 concentrations over a range of about 5 to 300 parts per billion (ppb) with an accuracy of roughly 5%. The tracer gas monitor contains a ten-port sample valve and can monitor up to ten sample locations, with the concentration determined at each location once every 10 minutes. There are ten air sampling pumps, one for each sampling port of the SF_6 monitoring system, that draw air from the sampling locations to the monitor. These air sampling pumps run continuously at an airflow rate of about 0.028 m^3/s (35 scfh) to provide a current air sample to the tracer gas monitor.

The tracer gas injection system consists of a cylinder of sulfur hexafluoride, a tracer gas distribution system, and a tracer gas injection panel. The distribution system consists of 3.2 mm (1/8 in.) outside diameter nylon tubing running from the injection panel to the tracer gas injection locations. The tracer gas injection panel consists of solenoid valves, relays and timers that enable computer control of the tracer gas injection. The tracer gas cylinder is connected to the normally-closed inlets of five electronically actuated solenoid valves, one for each of the building floors. The outlets of the valves serving the five floors are split off to two flow meters for floors 2 through 5 and three flow meters for the first floor. A 3.2 mm (1/8 in) diameter nylon tube runs from the outlet of each flow meter to the supply air duct in each of the eleven building

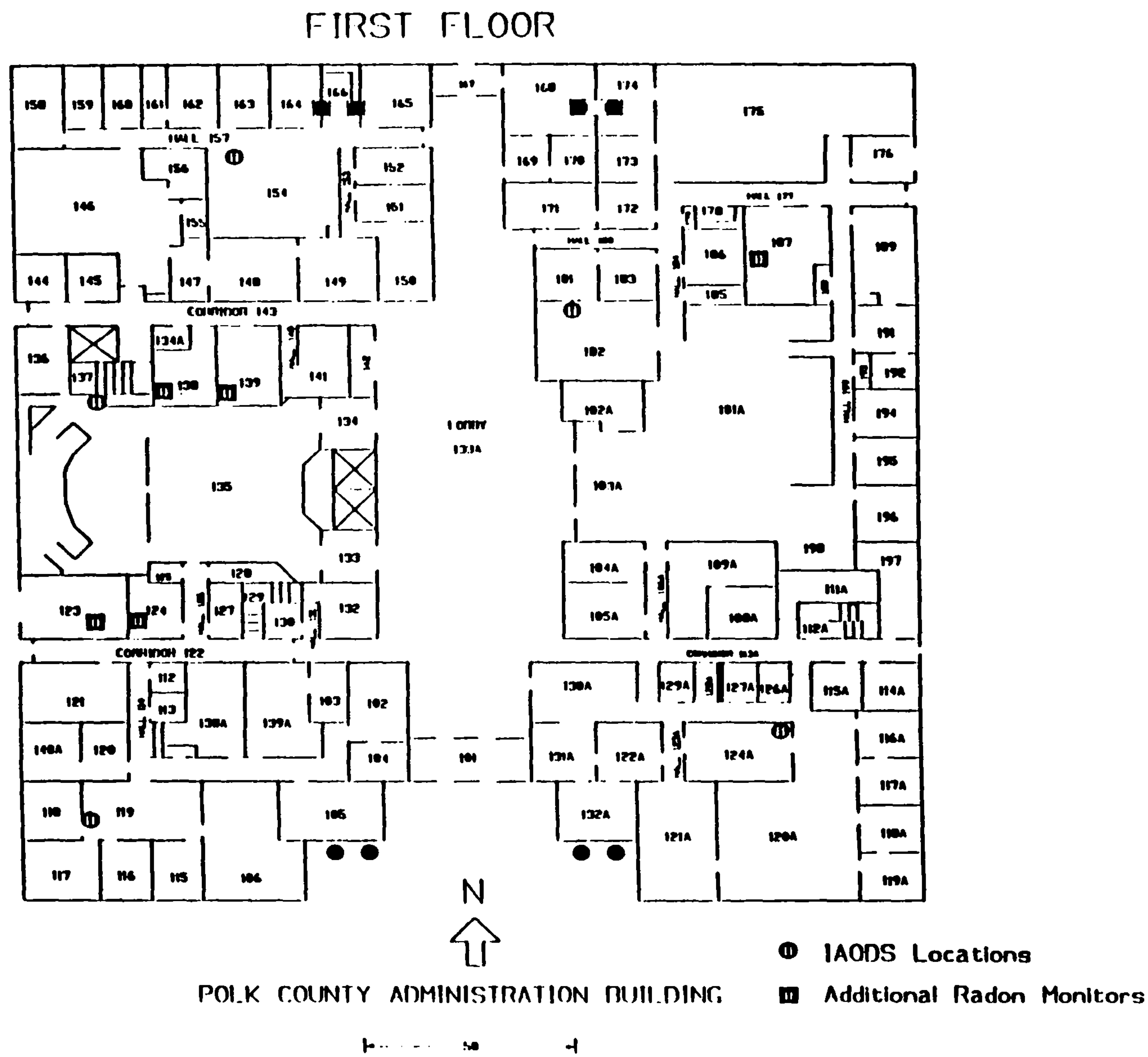


Figure 2. Locations of the first floor IAQDS units and the external radon monitors.

air handlers. In order to avoid injecting tracer gas into an air handler that is not operating, differential pressure transducers were installed in the supply air duct of each air handling system. These transducers provide a contact closure when a pressure differential of at least 38 Pa (0.15 inches of water) exists between the high and low pressure ports of the instrument. The low pressure side of the transducer is in the mechanical room, and the high pressure side is connected to a tube located inside the supply duct. Therefore, if an air handler is operating, a pressure differential will exist across the transducer producing a switch closure. Two-conductor wires from the fan status switches are wired to the injection panel so that at least one fan per floor is required to be running in order for SF_6 to be injected into the air handlers on that floor.

The microcomputer-based data acquisition and control system controls the air sampling, the timing of the injection of the tracer gas and the volume of the tracer gas injected. Tracer gas is injected into the supply air ducts of the building every twelve hours. The tracer gas concentrations at each of the ten sample locations are measured every ten minutes until the start of the next injection period. Tracer gas concentrations, the outdoor air temperature, and the number of seconds per hour that each fan was operating are all stored on a floppy disk. The system can operate unattended for up to one month.

As described earlier, the tracer gas system injects SF_6 into the building air handlers and samples the tracer gas concentration in the returns and outdoor air. Figure 3 is a schematic of the injection and sample tubing installation in the building. This schematic shows a pair of injection and sample tubes running to each mechanical room. The injection tube releases SF_6 into the supply duct of each air handler, and the sample tube is installed in the return air duct in each mechanical room. The two outdoor air sample lines on the fourth floor are also shown in the schematic.

Ten sample locations were connected to the SF_6 monitor, as follows:

1. Outdoor air, 4th floor west
2. Outdoor air, 4th floor east
3. 5th Floor return, blended air sample from air handlers 501 and 511
4. 4th Floor return, blended air sample from air handlers 454 and 414
5. 3rd Floor return, blended air sample from air handlers 364 and 316
6. 2nd Floor return, blended air sample from air handlers 211A and 238
7. Return from air handler 123
8. Return from air handler 138
9. Return from air handler 187
10. Room containing SF_6 monitor for diagnostics

The tracer gas system injected SF_6 to five ports, one for each floor, as follows:

1. 5th Floor, teed to air handlers 501 and 511
2. 4th Floor, teed to air handlers 454 and 414
3. 3rd Floor, teed to air handlers 364 and 316

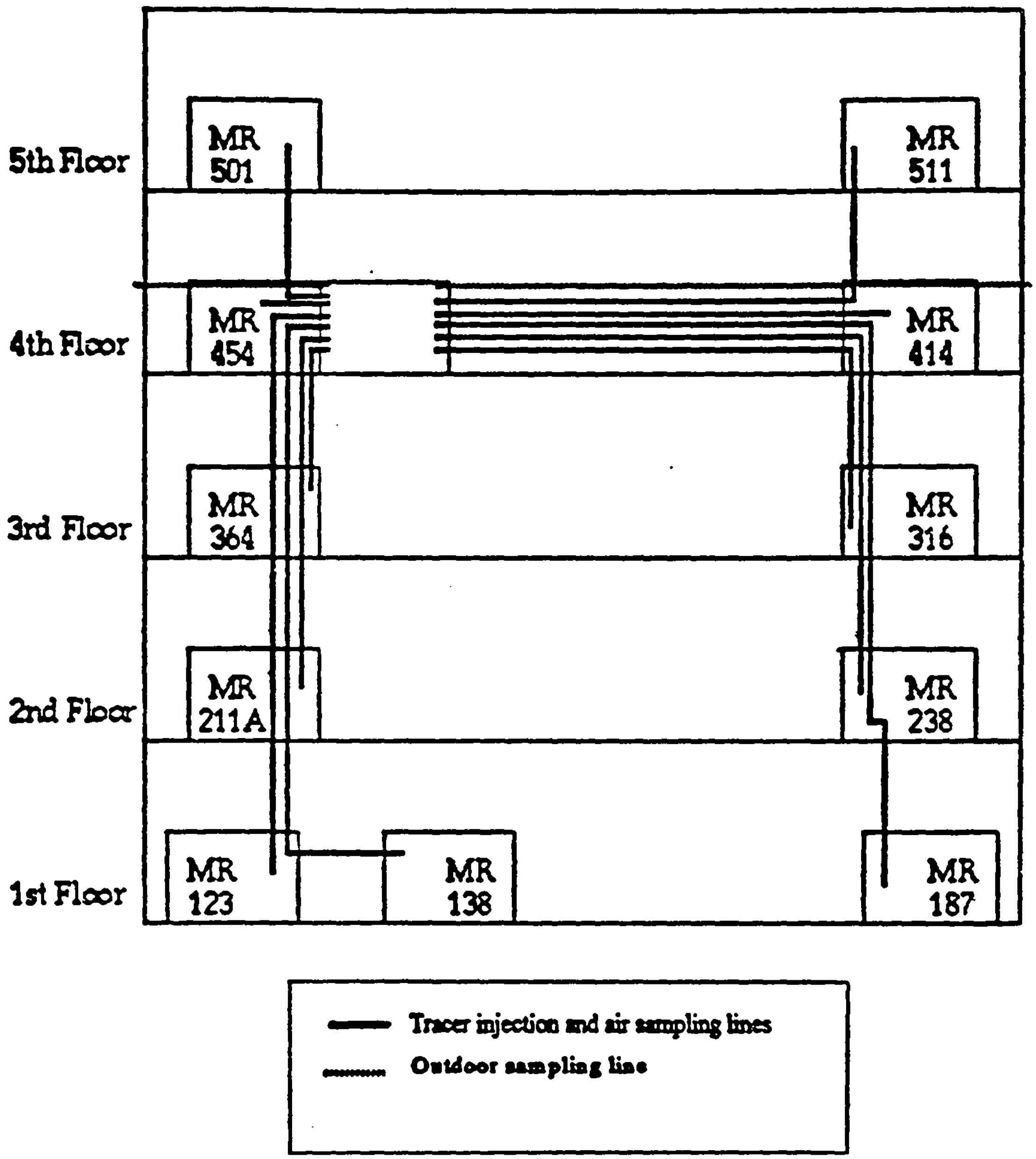


Figure 3. Schematic of tracer gas tubing layout in the Polk County Administration Building.

4. 2nd Floor, teed to air handlers 211A and 238
5. 1st Floor, teed to air handlers 123, 138 and 187.

Whole building air change rates were measured in the building using the tracer gas decay technique (ASTM 1993) during the period 5/9/94 through about 6/30/94. Unfortunately, the tracer gas system malfunctioned during the period when the OA fans were installed and operating and none of the data during this time period is of value. However for the periods in which the data quality was acceptable the following experimental strategy was used. Tracer gas was injected into the supply air ducts of the building air handlers every twelve hours and allowed to mix for about thirty minutes with the interior air. The decay technique requires that the tracer gas concentration be uniform throughout the building during the decay. When making these measurements, the uniformity of the tracer gas concentration depends on the tracer gas injection flow rates to the various building zones, the distribution of outdoor air ventilation within the building, and the air mixing patterns in the building. While the tracer gas injection flow rates can be controlled, the other factors affecting the uniformity of the indoor tracer gas concentration are a function of the ventilation system configuration and operation and other airflow characteristics of the building. The ability to achieve a sufficiently uniform tracer gas concentration will therefore vary from building to building. As will be discussed in the next chapter, it was difficult to achieve a uniform concentration in this building, and this increases the uncertainty of the measurement results. For conditions of good concentration uniformity, variations on the order of 10%, the whole building air change rates measured with the tracer gas decay technique have an uncertainty of about 10%. The measurements in this building, with much higher variations in concentration, have an uncertainty of about 25%.

During the tracer gas decays, the SF_6 concentrations at each of the ten sample locations were measured every ten minutes. The tracer gas decay rate in each zone was then determined from these concentrations by performing a linear regression of the logarithm of the tracer gas concentration versus time. Due to the very low air change rates in this building, on the order to 0.1 to 0.2 air changes per hour, the regressions were performed over 6 or 12 hour periods to increase the reliability of the results. Estimates of the whole building air change rate were then determined by averaging the decay rates determined for each of the returns. Only those decay rates with an uncertainty of 25% or less, based on the regression analysis, were included in the average. The average itself was weighted by the volumes of the various zones.

In addition to whole building air exchange rates, interzone airflow patterns were evaluated qualitatively by injecting tracer gas into an individual building zone and monitoring the concentration response in the building. While the results of these tests do not provide interzone airflow rates, they do provide an indication of the zones to which air flows from the injection zone. The results of these tests are presented in terms of the injection time and the maximum tracer gas concentration in the injection zone, along with the maximum concentration in the other building zones and the time of that maximum. The delay between the injection and the magnitude of the concentration response in the other zones indicates the relative degree of the airflow communication between the injection zone and the various building zones. All of the interzone airflow tests presented involved the release of tracer gas on the first floor of the building.

Experimental Schedule

Since it seemed clear from the beginning that the building as found had inadequate ventilation air, the primary condition varied was the position of the outdoor air intake dampers on the HVAC air handlers. The initial plan included one week each at "as-found", maximum, and minimum reversible damper settings, then a final week at an optimum position. (As will be seen, this plan was modified when it was discovered that the range of adjustment by the dampers was inadequate.) The plan also included adjustments to vary the pressure imbalance across first floor zones, but this portion of the plan was also deemphasized in practice in order to concentrate on the ventilation effects. Finally, after the mechanical systems were optimized, the effect of sealing the few observed openings in the slab were to be determined.

The actual building study schedule is summarized as follows:

Building Selection and Plan Development (1/15/94 - 3/25/94)--
The building was located, survey radon measurements were taken which indicated elevated radon (in the 4-15 pCi/l range). A draft study proposal was presented to the building owners (Polk County) and approval was obtained. Plans to the building were obtained and used to guide selection of measurements. Walk-through visits were conducted to confirm locations of the IAQDS continuous samplers, phone and electrical availability, and to obtain a survey of pressure difference between zones of the structure. Monitoring equipment was obtained from EPA, (AEERL, RTP, NC) calibrated and prepared for installation.

Installation of Continuous Monitoring Systems (4/6/94 - 4/15/94)--
A team from Southern Research, EPA, and Acurex installed 13 IAQDS as described in Appendix A. Most sensors, and the associated interconnecting wires and tubes, were placed in appropriate locations. A weather station was mounted on the fifth floor and monitored with a Campbell 21X data logger. Building features were inspected and modifications made to some measurement locations in response to on-site conditions.

Characterization of HVAC System (4/14/94 - 4/29/94)--
In addition to design survey and survey pressure measurements performed earlier, the certified TAB company (Bay-to-Bay) was contracted to verify and spot check data from earlier balance reports of the system. This work (planned the week of 4/11/94) was delayed by repairs to the ducting described above and by an outage of the central control computer system. HVAC operation was conducted on April 13, 25-28.

Installation of automated tracer gas system (4/5/94 - 5/4/94)--
Staff from the National Institute for Standards and Technology (NIST) installed the tracer gas injection and sampling lines during the week of 4/11/94. During the period 5/2/94 - 5/5/94, a computerized sample injection and g.c. detector system was installed, checked, and left in continuous operation. The system operated in a tracer decay mode using SF_6. The injection cycle was initially set at 4 injections per day; after observing the slow decay rates, NIST changed the cycle to 2 injections per day.

Operating Cycle 1 (OC1): Baseline (5/2/94 - 5/8/94)--
With all systems operational, a week of data in the "as found" condition (after the repairs noted above) were obtained.

Operating Cycle 2 (OC2): Maximum Outdoor Air (5/9/94 - 5/15/94)--
All operable outdoor air dampers were set to their full open position, and a week of data were obtained, downloaded, and analyzed. During this period, the data were surveyed frequently for indications of cooling system incapacity to meet the added latent heat load (inability to maintain set points, or excessive relative humidity in air zones). No such problems were observed.

Operating cycle 3 (OC3): Minimum outdoor air (5/16/94 - 5/22/94)--
Operable outdoor air dampers were set to a condition of low outdoor air consistent with occupant comfort and IAQ status. The target OA level were at most 50% of the baseline outdoor air flowrates. During the weekend of 5/21/95 - 5/22/94, the outdoor air supply was further reduced, to a level corresponding to less than 5 cfm/person at full building occupancy. During this period, the data were surveyed daily to determine if the outdoor supply needed to be increased. This need was to be determined by any of the following signs: CO_2 levels above twice the baseline level or 1500 ppm; reported occupant discomfort; any other indication of compromised indoor air quality. Again, no such problems were observed.

Extended operation in baseline condition (5/23/94 - 7/19/94)--
As a result of the measurements obtained during the previous cycles, it became apparent that modifications of the HVAC operating parameters had little or no effect upon the radon levels. It was concluded that too little induced outdoor air was coming into the building to significantly affect ventilation in comparison to the gains and losses through the building shell induced by depressurization and pressure imbalance. In consultation with the building owners, a temporary system of three inline fans was installed in the AHUs on the first floor to determine if forced outdoor air ventilation was feasible to increase the air exchange rate and decrease the radon entry on the first floor. During the intervening period, all units were returned to the baseline conditions.

Operation with outdoor air fans (7/19/94 - 8/2/94)--
On 7/19/94 three inline blowers were installed in the first floor air handlers. These fans were installed in the OA duct with flexible ducting, and were undersized for the application as the flowrate of all three systems was reduced by the restricted size and

torturous path of the temporary ductwork used. The prompt failure of the fan on AHU3 allowed three fan conditions to be studied, as a replacement fan of larger capacity was installed on 7/25/94. Measured flowrates for the OA fans on AHU1 through 3 were 533,172, and 1,234 cfm, respectively, for a total of 1,939 cfm in the final "3 OA fan" period (after 7/25/95), and 705 cfm in the "2 OA fan" period (7/22-7/25). We estimate a total flowrate of about 1000 cfm during the initial "3 OA fan" period.

Sealed penetrations to soil (8/1/94 - 8/5/94)--
In initial walk-throughs, several locations were discovered with significant pathways (i.e. several holes greater than 1 in^2 area) to soil. Some of these penetrations are in mechanical rooms or similarly vulnerable locations. At the beginning of this week, major penetrations were sealed with a suitable polymeric compound or expanding foam. Monitoring was carried out under HVAC configuration used in week 1.

On August 6, experiments were terminated and most of the equipment was removed from the building. To monitor radon concentrations in the building, four data stations were left until November 2, 1994.

Other events which occurred during the study period which may have had an impact on the data are noted below:

May 29-31: A team from FSEC and Southern Research performed HVAC characterization tests, including blower door testing of whole building (5/29-30), operation at VAV max, and opening and closing of fire damper sleeves.

July 10-11: A team from FSEC and Southern Research performed HVAC characterization tests, including further operation at VAV max, and opening and closing of fire damper sleeves.

July 20: The chiller water supply temperature was changed so that the discharge air temperature rose from 50°F to 57°F. This condition was reversed on August 2, at least for the lower three floors. Unfortunately, this change occurred within a day of installation of the outdoor air fans.

Chapter 5
Results and Discussion

Characterization of HVAC System

The characterization testing conducted by the TAB contractor (Bay to Bay) and by FSEC provides information relevant to system flowrates, and building pressure balancing.

HVAC System Flowrates

At the beginning of the study period, the certified test and balance (TAB) contractor measured actual flow distribution in the mechanical subsystems. These measurements, which were partly replicated by FSEC, are included in Table 1. Generally, the measurements of the TAB and FSEC are comparable, but some exceptions deserve mention. First, the supply air flowrates on the first floor were taken using flow hoods at the supply outlet grills in order to partition AHU supply flowrate into the zones into which the flow is actually delivered. With the exception of AHU1, the agreement is well within experimental uncertainty. Second, the listed OA flowrates measured by FSEC at the OA intake grill are typically lower than measured by the TAB (or FSEC) using pitot traverses within the ductwork. FSEC attributes the difference to inleakage of building air between the intake grill and the traverse plane. This hypothesis is supported by measurements in the ducts of AHU2, in which the temperature and relative humidity of the air in the duct matched those of building air better than outdoor air, indicating considerable inleakage of building air. Unfortunately, this implies that the "outdoor air" flowrates in Table 1, already below design values, are actually overstated by inclusion of recirculated indoor air. Similar evidence of duct leakage effects is seen in the exhaust air measurements, which in some cases does not originate in the intended rooms but presumably in the plenum above.

Based on the inspection of the HVAC system and measurements from Table 1 several deficiencies were noted which would be expected to adversely affect either radon levels, other indoor air quality factors, or energy consumption.

- Table 1 indicates that maximum supply air flowrates are below design values on all but the fifth floor. This is particularly true on the first floor where the measured flowrates are approximately 65% of the designed value. More significantly, observations of the air handler operation indicate that the supply air flowrates are typically less than half of maximum flowrate, even at peak cooling demand times. This is at least partially due to excess design capacity, low supply air temperature set points (50°F versus 57°F typical and design value) and absence of reheat. The combination of low supply air temperature and flowrate can have negative effects on occupant comfort, as rooms become sufficiently cool without adequate circulation and may seem "stuffy" to occupants.

Table 1. Summary of HVAC/AHU Operations in Polk County Administration Building, Bartow, Florida

HVAC AHU#	Location of Unit	Area of Building Served	Design Total Flowrate (cfm)	TAB Total Flowrate (cfm)	FSEC* Total Flowrate (cfm)	Design OA Flowrate (cfm)	Design Exhaust Flowrate (cfm)	TAB OA Flowrate (cfm)	FSEC* OA Flowrate (cfm)	FSEC* Exhaust Flowrate (cfm)	Fan** Assist OA Flowrate (cfm)
1	Room 138	Board Room Central Foyer	11,000	6,348	7447	1,500	520	663	580	72	533
2	Room 123	South Int./Ext.	17,100	10,696	10796	750	400	350	104	74	172
3	Room 187	North Int./Ext.	18,600	13,738	12670	1,050	350	1,914 ***	465	0	1,234
4	Room 211A	2nd Floor Exterior	21,100	11,456		675	230	935	303	120	303
5	Room 238	2nd Floor Interior	11,000	9,510		600	520	540	273	83	273
6	Room 364	3rd Floor Exterior	14,600	10,901		500	900	953	432	620	432
7	Room 316	3rd Floor Interior	9,000	7,296		650	900	952	965	603	965
8	Room 454	4th Floor Interior	8,400	6,524		1,050	500	537	497	510	497
9	Room 415	4th Floor Exterior	16,850	13,353		750	1200	599	330	1020	330
10	SW 5th	5th Floor SW	11,500	15,512		900	300	1,305		287	
11	NE 5th	5th Floor NW	11,500	15,434		900	600	1,430		578	
Totals			150,650	120,768	30,913	9,325	6,420	10,178	6,684	3,967	7,474

Notes:
*** Data taken on wrong duct
** Data taken with VAV Boxes at normal operation
* Data taken with VAV Boxes at maximum flow

- As is clear from Table 1, outdoor air flowrates were far below design values at all but one AHU on the first through fourth floors. This is partly due to the low static pressure induced by the air handlers at the lower supply volume used (see below). Low outdoor air intake (particularly on the ground floor) contributes to inadequate removal of indoor pollutants, especially radon. It also is a factor in building depressurization, discussed later. Further, the actual outdoor air flowrates are expected to be further reduced by up to a factor of two by the fact that the supply air flowrate is generally much less than the 100% capacity at which these measurements were made.

HVAC Pressure Balance
Figure 4 shows the trend of pressures in three first floor zones relative to the lobby. As can be seen, during the occupied hours there is an initial pressure surge as the air handlers leave setback mode, followed by a broad peak as cooling load increases the pressure difference between each zone and the lobby increases in magnitude through a maximum, then decreases in the afternoon. For some zones, notably the auditorium, the pressure difference can be 4-8 Pa. This effect is attributable to flow restrictions in the crossover windows in the fire-rated walls separating the first floor zones. Any flow imbalance among the three ground floor AHUs is converted into pressure imbalances at these restrictions. Such pressure imbalances are significant for radon entry in that they can create are as of local depressurization with respect to outdoors (or the subslab soil) even in buildings that are not depressurized overall. Two other mechanisms for local depressurization were also noted. During the setback periods (Modes B and C) fluctuation pressure differences of up to 4 Pa were induced between ground floor zones as alternate air handlers were switched off on the 30 minute duty cycle. These fluctuations are clearly seen in Figure 4 during the weekend Mode C times or the afternoon of July 2 and 3. In contrast, Figure 5 plots the pressure differential across the slab in three of the same rooms. Here the scatter in the data are greater and only two of the five pressure transducers (Rooms 124 and Auditorium) appear to be operational; however, two things are noteworthy. First, the pressure differences across the slab do not show the effects of the zone-to-zone imbalance in the building. The peak-to-peak variations are less than half that occuring within the building, and occur in synchronization with the 12 hour tidal pattern of fluctuations in the barometric pressure rather than the HVAC cycle.

Potentially more serious is the depressurization of the ground floor mechanical rooms due to net return duct leakage. FSEC measured the depressurization of the mechanical rooms for AHU1-3 to be -13.4, -10.6, and -14.6 Pa, respectively, relative to the lobby area for full VAV open conditions. Clearly, any radon drawn into the mechanical rooms will be immediately transferred throughout the ground floor by the HVAC system operation.

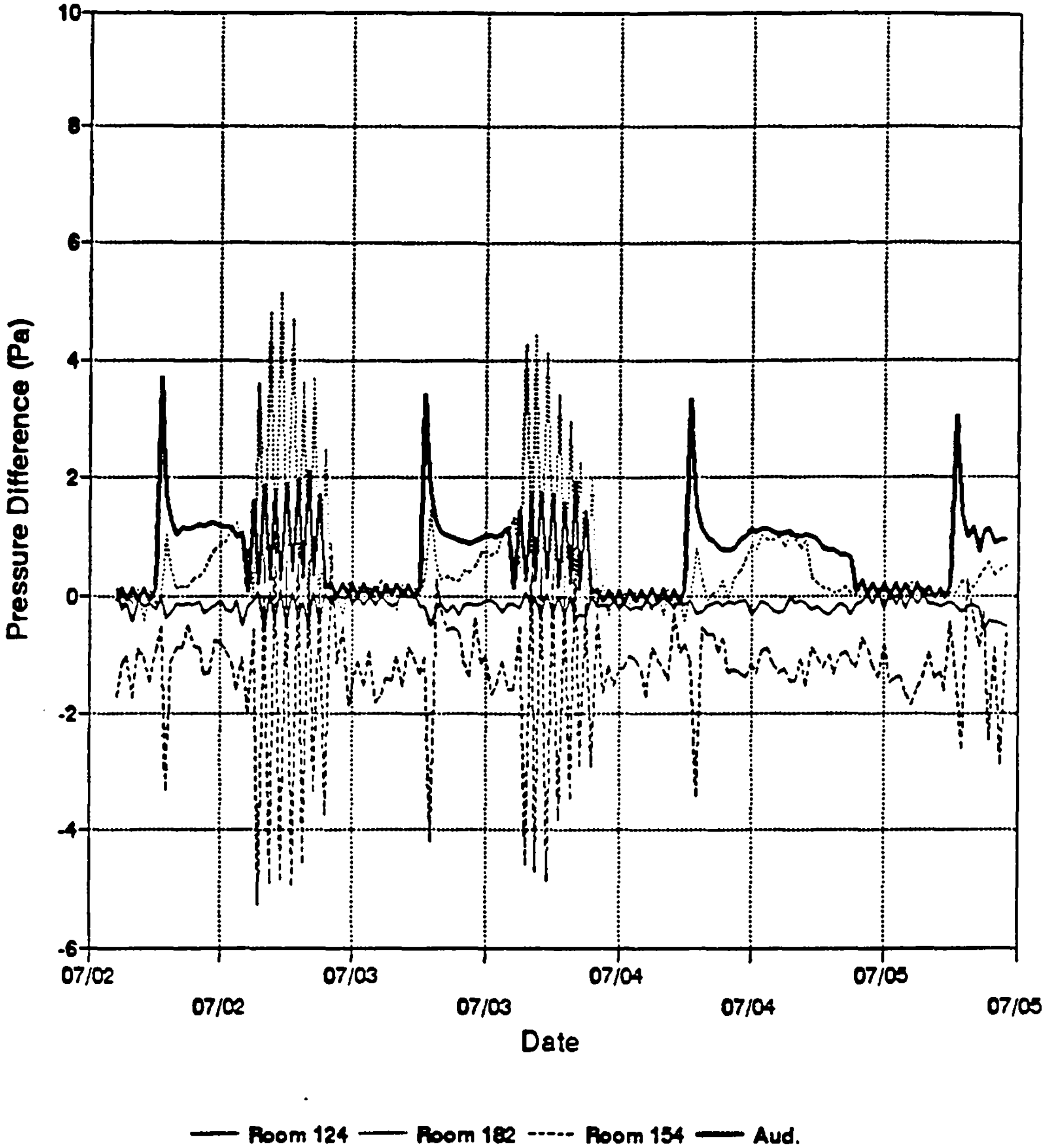


Figure 4. Pressures with respect to atrium of first floor rooms in Polk County Administration Building

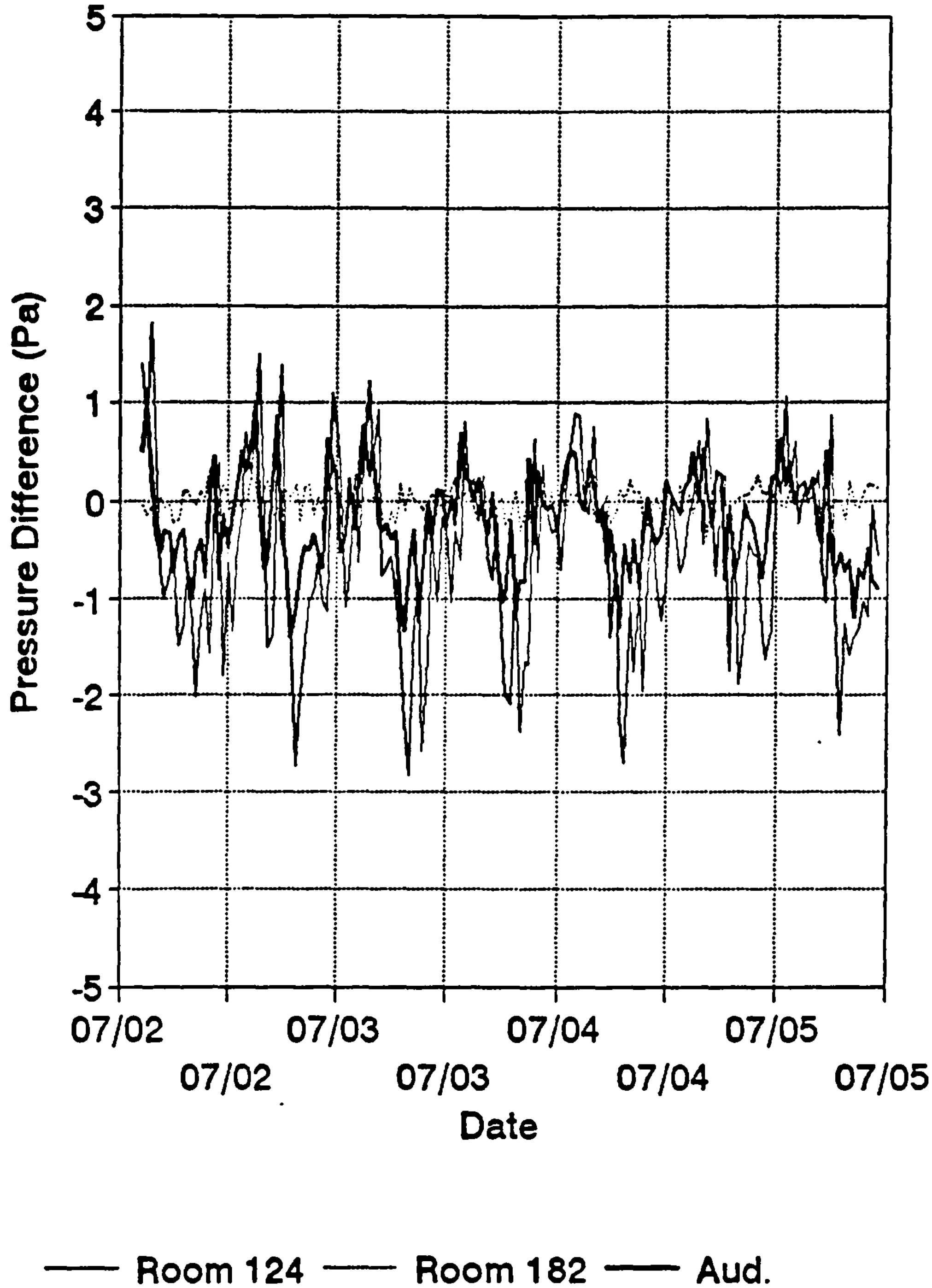


Figure 5. Pressure differences across slab of first floor rooms in Polk County Administration Building

Radon

Figure 6 depicts the trend of the radon concentrations during the first operating cycle tests in May. Figure 7 contains a similar plot of concentrations during the period beginning in July in which the inline fans were activated in the outdoor air ducts of AHU1 through 3. These figures were composited from individual data station measurements. The data from the 18 radon monitors fall into clusters by floor which vary together over long periods of time. For the purpose of simplicity in the figures, the two-hour average radon concentrations on the first, second, and three upper floors are averaged separately. The typical daily time course of radon concentrations on the first floor shows radon rising from a minimum shortly after midnight to a peak about 6:00 a.m., dropping to a second minimum around noon, rising to a second peak about 6:00 p.m., then falling the remainder of the day. This pattern is more pronounced in some rooms and on some periods of time, and is superimposed on cycles of rising and falling radon concentrations which tend to be 3-5 days in duration and are independent of the activities and operation of the building. On the third through fifth floors, the morning buildup of radon is relatively slower, and the secondary evening peak is absent. The radon concentration drops steadily from a peak about 8:00 a.m. to a minimum at roughly 9-10 pm, then begins to recover slightly in advance of the first floor. Radon concentrations on the second floor show an intermediate behavior, with suggestions of a secondary maximum in the early evening. The upper floors all show the same longer term variations of radon seen on the first floor rooms.

Averaged values of the radon levels in the individual locations of the building are shown in the figures of Appendix B. The 30 minute average radon values from each monitor have been further smoothed with a non-weighted moving average to remove some of the fine structure. The averaging period for these figures was 6 hours. The overall average radon levels in the various locations in the building are summarized in Table 2 and Figure 8. Here the values are averaged for each IAQDS location and over each distinct operation condition. Also shown in this table are the overall averages for the first floor, the building as a whole, and below the table the average level under the subslab in Room 187, and the average outdoor level as measured at the first floor level (outside Room 123 AHU2) and at the third floor level (outside Room 316 AHU7) of the building.

Radon concentrations in the "as found" condition averaged approximately 8.1 pCi/L on first floor, and 3.1 pCi/L on upper floors, yielding 4.1 pCi/L for the building as a whole. As can be seen in the table, radon concentrations were essentially unaffected by variation in the OA damper settings. As described below, tracer gas measurements of the building air change rate over this period (in the range 0.15-0.25 hr^{-1}) also show no significant variation, indicating that the damper settings are largely ineffectual in varying the ventilation rate.

This finding suggests that ventilation in this building is primarily by direct leakage across openings in the building shell and is driven by local pressure differentials

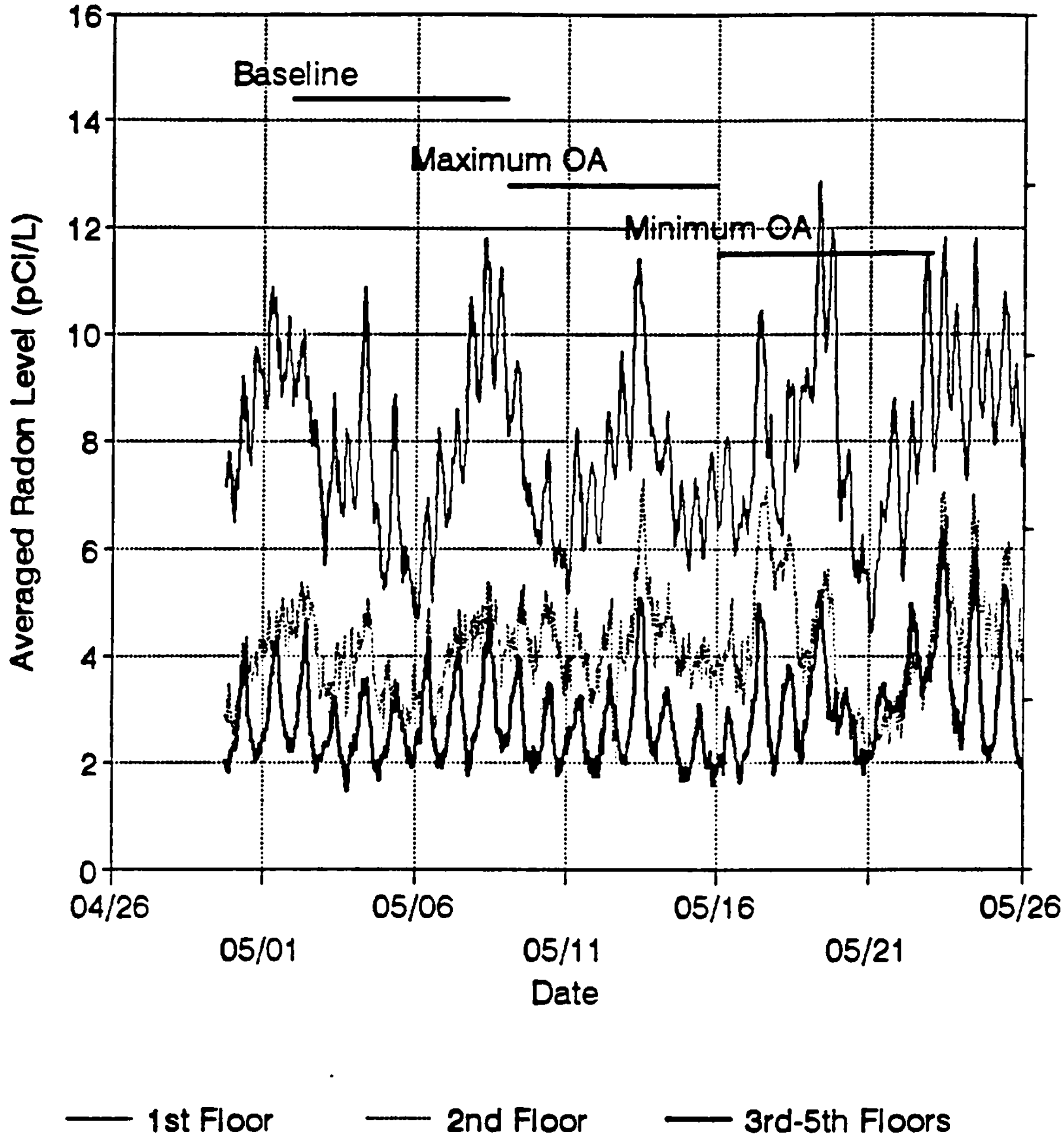


Figure 6. Average radon concentrations in Polk County Administration Building for three outdoor air changer settings

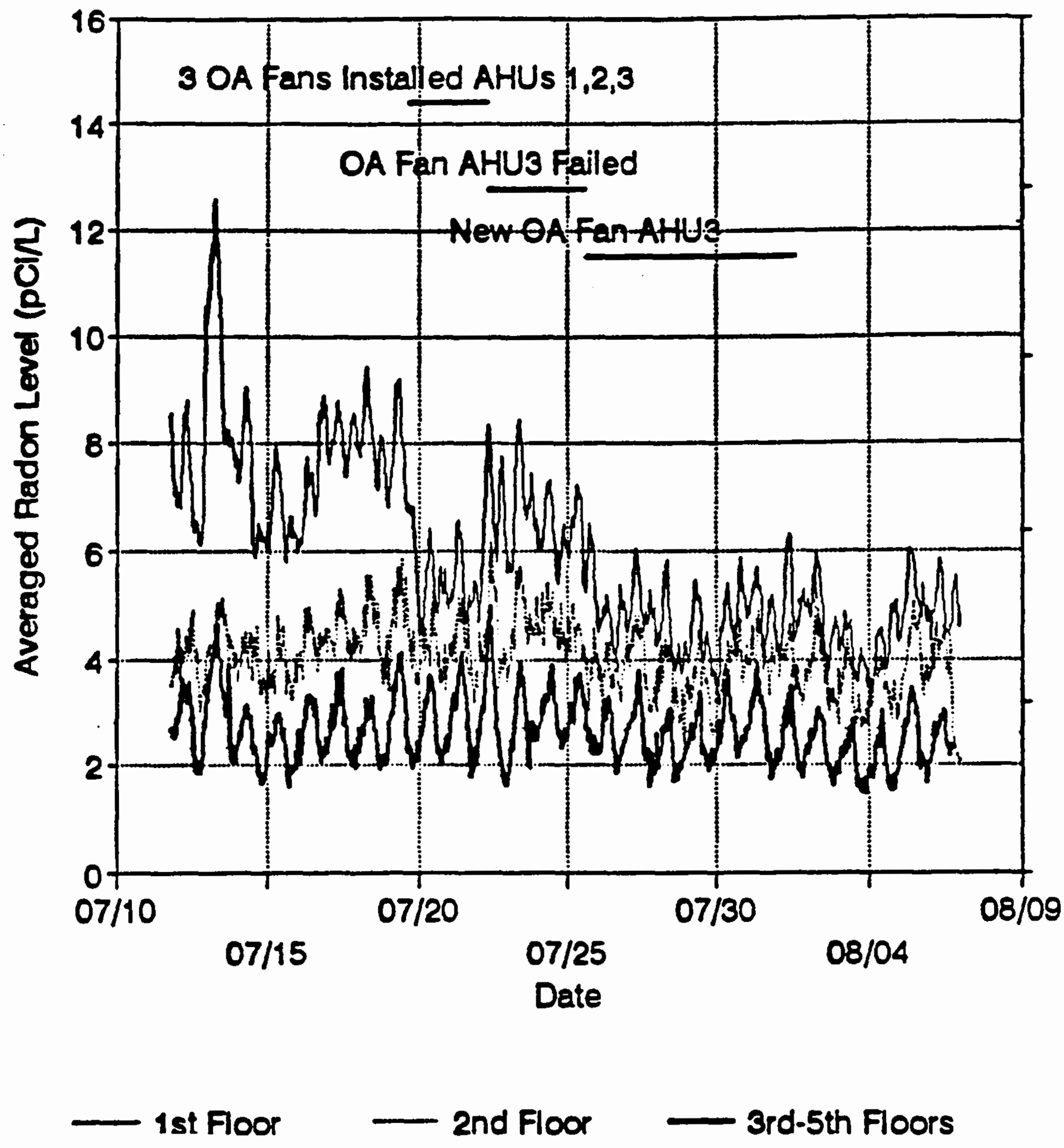


Figure 7. Average radon concentrations in Polk County Administration Building for three configurations of outdoor air fans

Table 2. Average Radon Levels in the Polk County Administration Building, Bartow, Florida.

Building Condition

Location	Baseline	Max OA	Min OA	Normal Operation (pCi/L)	3 OA Fans Level (pCi/L)	3 OA Fans (%)	2 OA Fans Level (pCi/L)	2 OA Fans (%)	3 OA Fans Level (pCi/L)	3 OA Fans (%)
Rm 124A	6.56	6.38	6.17	6.87	5.57	81.1	6.17	89.9	5.03	73.3
Rm 182	8.20	7.54	7.49	8.66	6.18	71.4	8.04	92.8	4.54	52.4
Rm 187	8.55	7.12	6.72	8.01	4.85	60.5	6.70	83.6	3.25	40.6
Rm 154	7.89	7.36	7.30	7.98	5.14	64.5	6.49	81.3	3.82	47.9
Rm 138	11.28	9.49	11.09	10.17	6.26	61.6	6.93	68.1	5.35	52.6
Rm 119	6.85	6.53	6.45	7.06	5.57	78.9	6.50	92.1	5.47	77.4
Rm 123	8.18	7.45	8.80	7.87	5.43	69.0	5.96	75.7	5.45	69.2
Rm 124	8.85	8.61	8.12	8.66	6.79	78.4	7.53	87.0	5.97	68.9
Board Rm	6.95	6.02	7.33	6.83	4.27	62.6	4.92	72.0	3.86	56.5
Rm 139	8.78	7.67	9.35	9.05	6.02	66.5	6.98	77.1	5.56	61.4
Rm 235	3.52	3.86	3.41	3.84	3.82	99.5	4.22	109.7	3.42	89.0
Rm 342	2.82	2.72	3.05	4.31	3.49	80.8	6.83	158.3	3.15	73.1
Rm 313		*	*	*	3.14		3.32		3.24	
SW 5th	3.04	3.05	3.37	2.88	2.97	103.1	3.06	106.1	2.77	96.3
NE 5th	2.17	2.12	2.50	2.05	2.27	110.7	2.54	124.0	2.04	99.5
Rm 289	4.38	4.80	4.72	4.63	4.58	98.8	5.11	110.3	4.26	91.9
Rm 415	2.97	2.70	3.30	2.57	2.56	99.5	2.59	100.5	2.29	89.2
Rm 445	2.71	2.50	3.08	2.43	2.50	102.8	2.60	107.1	2.21	90.8
1st Floor Average	8.21	7.42	7.88	8.12	5.61	69.1	6.62	81.6	4.83	59.5
Building Average	4.08	3.93	4.22	4.08	3.65	89.6	4.00	4.5	3.30	81.0

* -- Monitor Malfunction

Other Average Radon Levels Include:

Subslab Radon Level (Under Room 187) = 15,878 pCi/L
Bottom of Elevator shaft = 4.4 pCi/L
Outside of Building (Near Room 123) = 2.8 pCi/L
Outside of Building (Outside Room 316) = 0.7 pCi/L

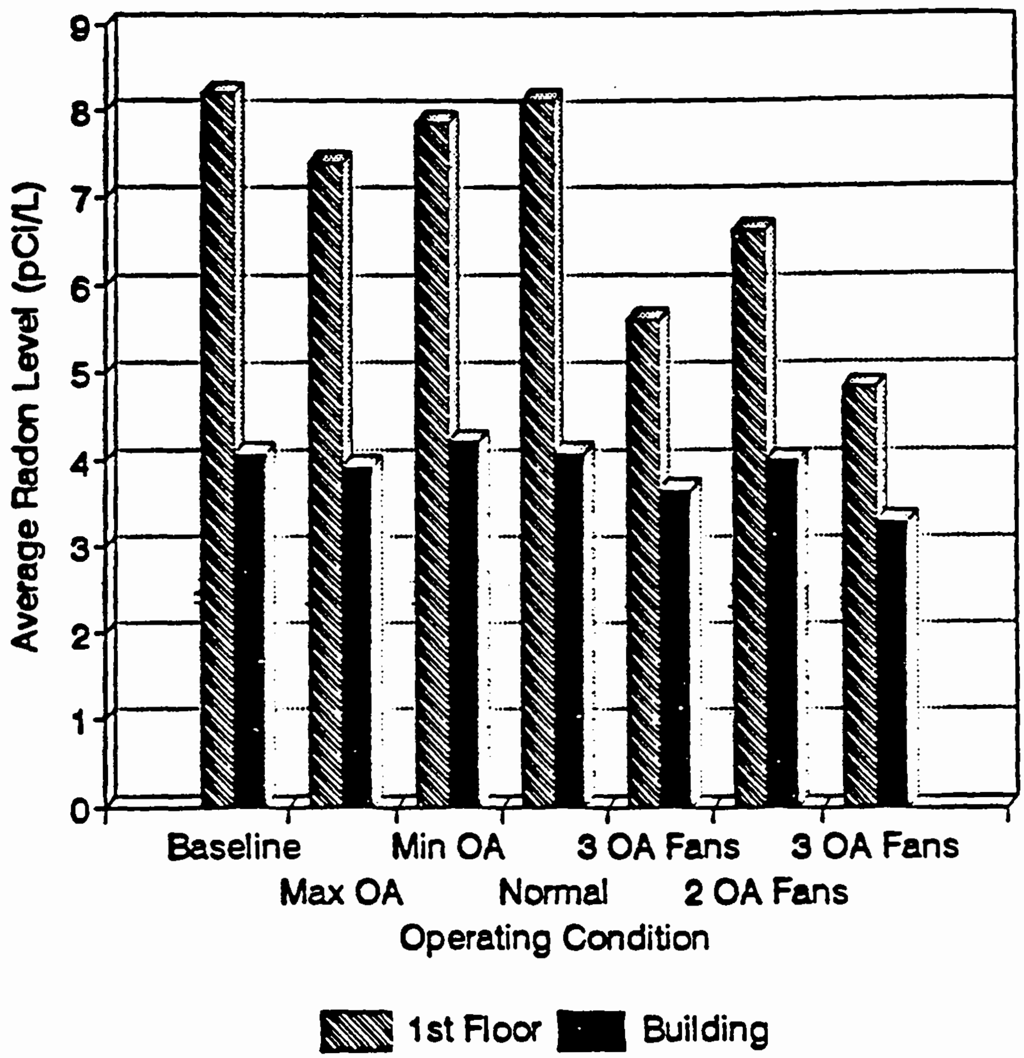


Figure 8. Average radon levels on the first floor and the entire building under various operating conditions at the Polk County Administration Building

between specific indoor zones and the adjacent outside environment. These pressure differentials can arise from natural forces on the building, such as wind pressure and stack effect; however, the observed magnitude of HVAC-induced pressure imbalance among the first floor zones is enough to expect that a significant portion of the observed infiltration/exfiltration is derived from this source.

As can be seen in the final three columns of Table 2, first floor radon concentrations were progressively reduced with addition of increased amounts of forced outdoor ventilation air. At the highest level of outdoor air, the first floor average radon had dropped to 4.8 pCi/L, approximately 60 percent of the original concentration. As might be expected, radon reductions on upper floors were not as dramatic as found on the first floor. Only at the highest outdoor air level was a clear decrease observed in the upper floor average; in fact, the upper floor radon appears to have increased slightly during the period before the final fan was replaced. This increase, if real, may be due to increased transport of radon upstairs by the added outdoor air into the first floor air handlers. Even if this redistribution of indoor radon is real, the volume-weighted building average radon is lower for all fan conditions than in the previous periods.

Other relevant radon levels are illustrated in Figure 9 where a portion of the average first floor levels is plotted along with the outside and subslab radon levels. The data were taken on a 30 minute time scale but has been averaged over a period of 3 hours to remove fine structure. It is seen in this figure that the outdoor radon levels track quite well with the averaged first floor levels. The subslab radon level has some structure that may or may not be related to building operation. It may also be more closely related to atmospheric conditions. As shown in Table 2 the average outdoor levels were 2.8 pCi/L at the first floor level and about 0.7 pCi/L at the 3rd floor level. The average subslab radon level was 15,878 pCi/L.

In an attempt to identify major radon entry routes into the building, a continuous radon monitor was placed in the maintenance pit at the bottom of the elevator shaft. The results are shown in Figure 10 where the radon levels in the shaft are plotted along with the averaged first floor levels. These measurements were carried out during more-or-less normal operating conditions of the building. The average level in the elevator shaft was about 4.4 pCi/L which is less than 50% of the level measured on the first floor over the same period. It can safely be concluded that the elevator shaft is not a major source of the building radon, if it is a source at all. One reason to question the elevator shaft as a major entry route is because the construction of the shaft is such that cracks and openings are minimized. The radon in the shaft probably originates from the building interior itself. Similar measurements in the telephone room and electrical room in the first floor shows radon levels comparable to the surrounding NE zone. On the other hand, inspection of the first four columns of Table 2 and the figures of Appendix B indicates that all three mechanical rooms (138, 123, and 187) have average radon concentrations above the averages of other rooms in the zones they serve for most of the study period. These results are highly suggestive that the highly depressurized

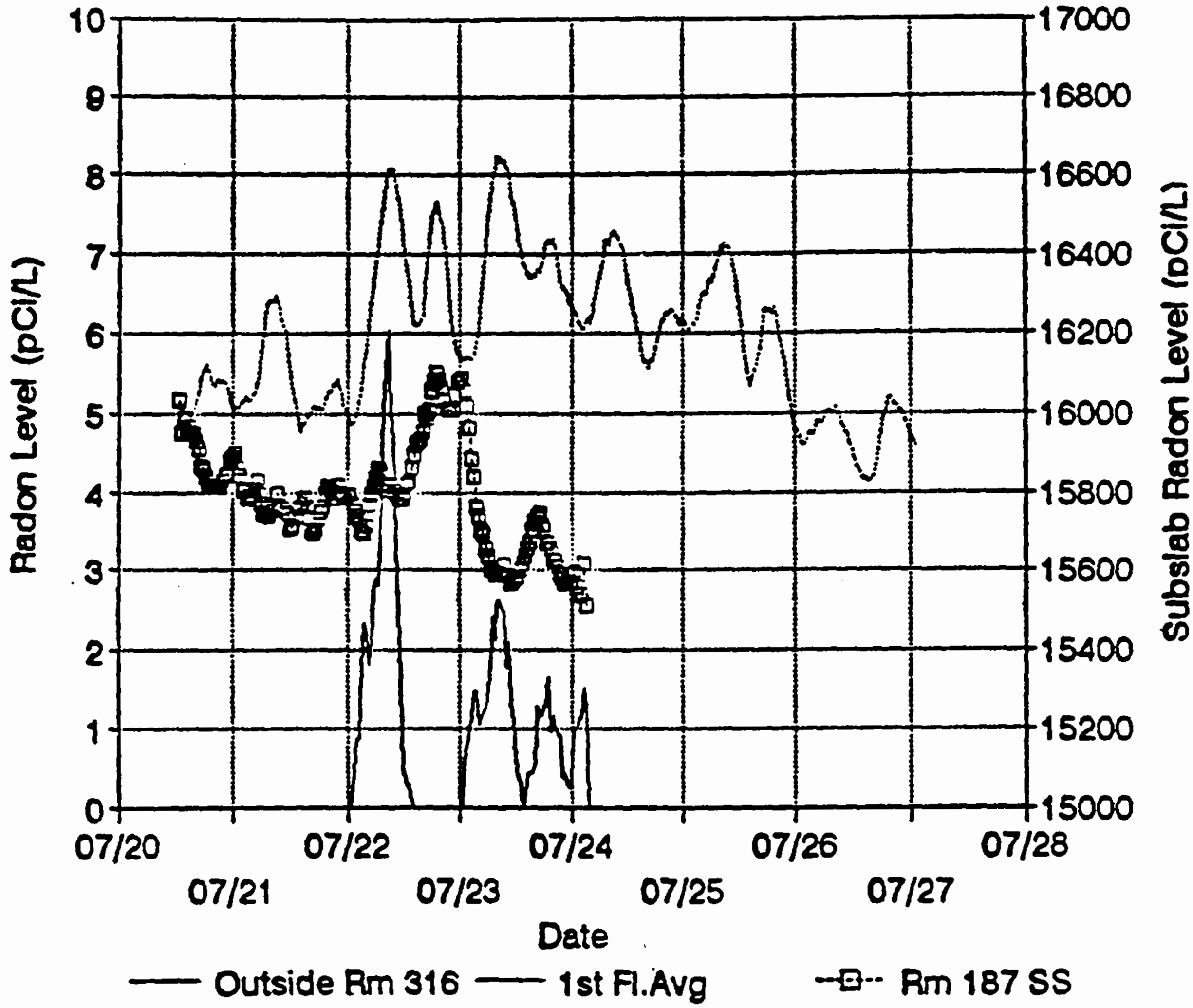


Figure 9. Comparison of radon levels outside the building and under the slab with the average of all first floor monitors at the Polk County Administration Building

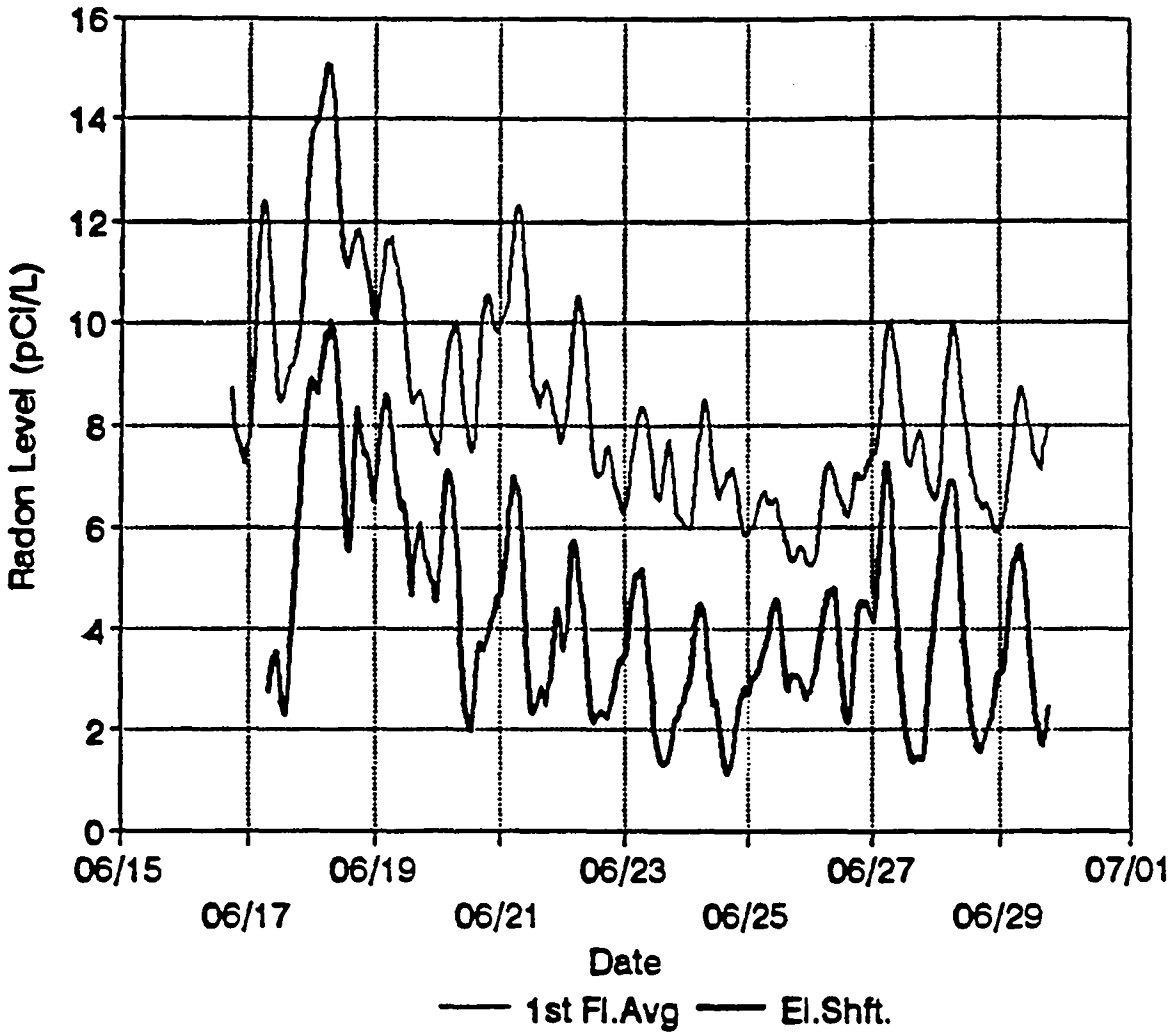


Figure 10. Comparison of first floor average radon levels with the levels measured in the maintenance pit of the elevator shaft at the Polk County Administration Building.

mechanical rooms form a major entry point for radon in the building, although the rapid redistribution of air in these rooms makes it difficult to place any estimate on radon entry rates into the mechanical rooms. Interestingly, the pattern of higher concentration in the mechanical rooms is reversed somewhat in the later study days with OA fans, demonstrating that the mechanical rooms, are not the only radon source for the building.

Tracer Gas Results

Whole Building Air Change Rates

The results of the whole building air change rate measurements are presented in Figure 16. This figure is a plot of the volume-weighted average of the tracer gas decay rates in each of the return air sample locations versus the outdoor air temperature in °C. As discussed later, this average is not strictly equal to the whole building air change rate and will be referred to as an estimated building air change rate. Results are presented for the three previously mentioned modes of operation as well as under varying outdoor air intake conditions. The three different modes of operation are distinguished in Figure 11 by three different shades of data markers; i.e., white indicates Mode A, black indicates Mode B, and shaded indicates Mode C. During air change rate measurements, four different outdoor air intake settings were utilized: 1) set-point: all outdoor air intake dampers at their normal settings, 2) OA open: all adjustable dampers opened completely, 3) 50% OA: all adjustable dampers approximately half open, and 4) VAV open: all variable air volume dampers of terminal units completely open. These four outdoor air intake settings are indicated by the different shapes of data markers in Figure 11; i.e., squares, circles, diamonds and triangles respectively.

As previously mentioned, a uniform tracer gas concentration between all zones of the building often could not be maintained during the tracer gas decay tests. One example of a nonuniform tracer decay test is shown in Figure 12. As shown in Figure 12, even though the concentrations in each sample location were very close to each other at the beginning of the decay period, the tracer gas concentration appeared to decay at two different rates. In this example, return air concentrations in the returns of the first and second floor air handlers decayed at a noticeably slower rate than those of the third, fourth and fifth floors. While nonuniform decay tests were typical, the pattern was not always the same. Due to the variation in tracer gas concentration between the zones, the tracer gas decays are not equal to the building air change rate. The estimated whole building air change rate based on the average tracer gas decay rate for all the zones has an uncertainty of roughly 0.05 air changes per hour.

As seen in Figure 11, the estimated building air change rate varied from about 0.05 air changes per hour (ach) to about 0.25 ach with the lower values occurring during the unoccupied modes of operation B and C, which is also when outdoor air temperatures were at their lowest. Higher air change rates occurred at higher outdoor temperatures. This increase may be caused by increased supply airflow rates in

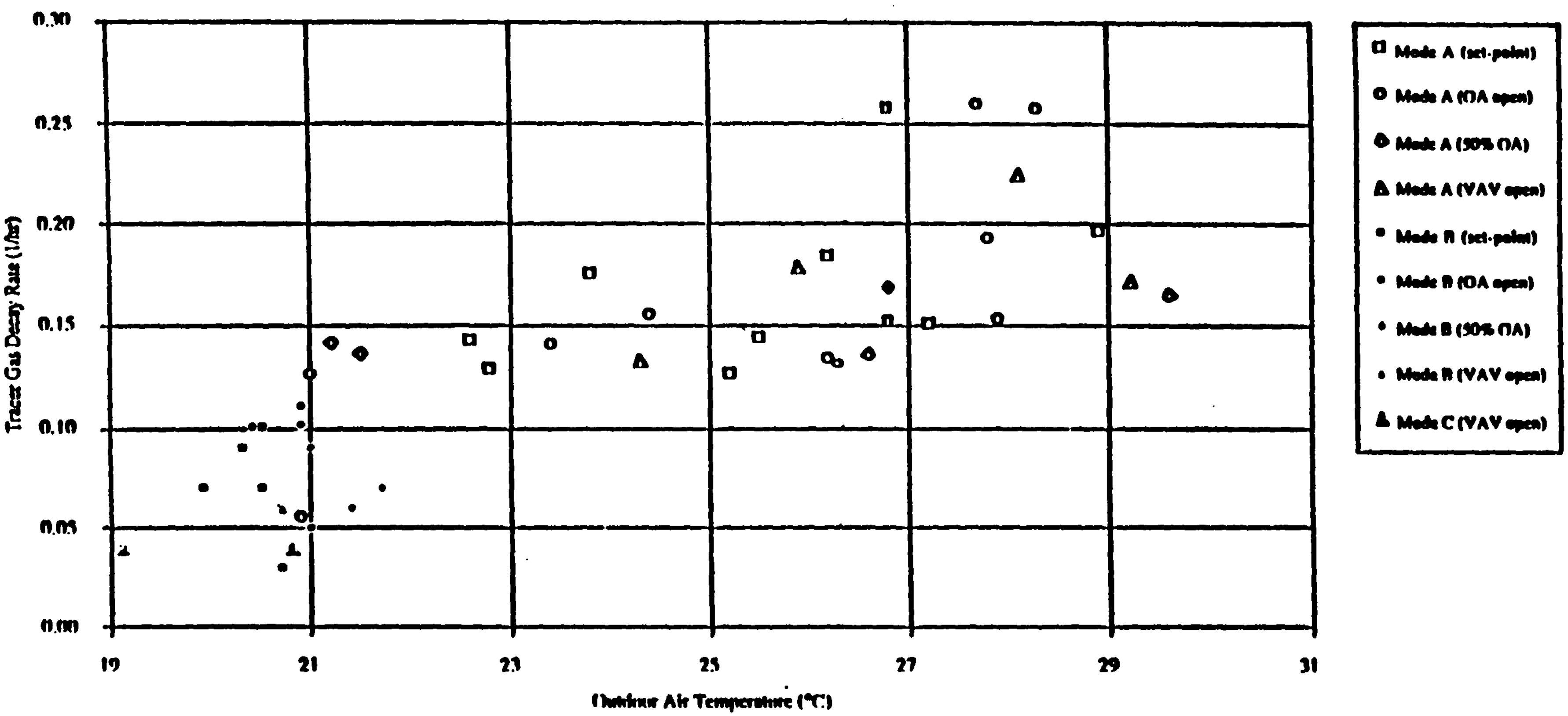


Figure 11. Whole building air change rates measured by NIST using SF_6 tracer gas in the Polk County Administration Building.

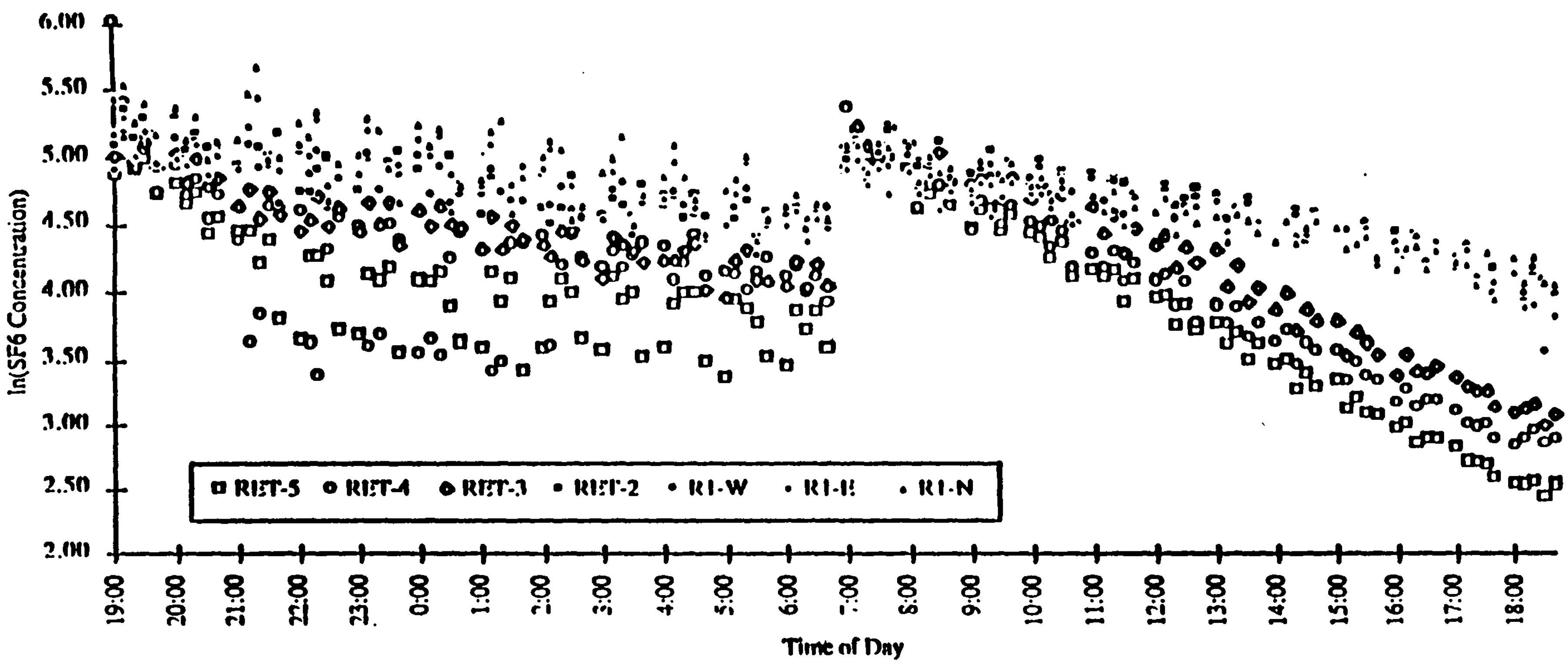


Figure 12. Sample tracer gas decay tests conducted by NIST on 6/1/94 in the Polk County Administration Building.

response to increased thermal loads, which may have in turn increased the rate of outdoor air intake and pressure-induced infiltration. Based on the building volume of approximately 60,000 m^3 and the maximum and minimum whole building air change rates, the air change rate is between 830 L/s (1,760 cfm) and 4,200 L/s (8,900 cfm) or between 2.8 L/s (5.9 cfm) per person and 14 L/s (30 cfm) per person based on a building occupancy of 300 people.

The variation of the air change rate during each of the first three operating cycles was greater than any systematic differences between 3 periods of damper adjustment, indicating that OA damper position was not the major determinant of air exchange rate in the building. Unfortunately, no reliable data were obtained during the period in which OA fans were installed.

Interzone Airflow Patterns

Interzone airflow patterns were evaluated qualitatively by injecting tracer gas into various locations on the first floor of the building and monitoring the time history of the tracer gas concentrations in the return air ducts of the air handlers. The results of the tests are presented in Table 3. This table indicates the location of the injection, the initial concentration prior to injection (C_0), the maximum concentration after injection (C_{max}), and the amount of time that had elapsed since injection when the maximum concentration occurred (Δt). Tracer gas was injected by the automated tracer gas injection system into the supply air ducts of each of the three air handlers serving the first floor individually and into all three at once. Values shown in bold text indicate a "notable" response in that zone. Table 4 is a summary of the injection zone and the corresponding return air streams in which a "notable" response was observed (excluding the injection zone).

Injecting into each zone of the first floor showed a notable response in the other first floor zones except when injecting into the supply air stream of AHU2 (Room 123) (1W) in which case there was no notable response in the zone served by AHU1 (Room 138) (1N). The second floor showed a notable response when tracer gas was injected into AHU3 (Room 187), and the third floor showed a notable response when tracer gas was injected into both AHU1 and AHU2. These responses are illustrated in Figure 13. Each time there was an automated injection, there was a quick response in the fourth floor sample locations. This was due to the close proximity of the automated injection system to an opening in the fourth floor return air plenum, and a small discharge of tracer gas from the injection system each time it performed an injection. This was verified by releasing a balloon full of tracer gas directly into the space served by each of the first floor air handlers. During these manual injections, no tracer gas was noted on the fourth floor.

Table 3. Interzone Tracer Gas Test Results

Date	Injection Location	Return Air Sample Location: 5			4			3			2			1E			1N			1W		
		Co [ppb]	Cmax [ppb]	Δt [min]	Co [ppb]	Cmax [ppb]	Δt [min]	Co [ppb]	Cmax [ppb]	Δt [min]	Co [ppb]	Cmax [ppb]	Δt [min]	Co [ppb]	Cmax [ppb]	Δt [min]	Co [ppb]	Cmax [ppb]	Δt [min]	Co [ppb]	Cmax [ppb]	Δt [min]
6/4/94	Supply 1E	15	16	22	18	81	13	16	17	224	27	62	24	44	142	37	40	84	138	26	50	206
6/5/94	(AHU 187)	19	10	32	10	61	13	10	12	154	18	60	15	40	142	27	33	78	118	19	39	236
6/6/94		18	9	32	10	37	13	9	9	194	14	41	15	34	114	27	30	65	138	18	32	196
6/7/94	Supply 1N	18	16	192	11	88	13	11	27	114	18	33	135	40	89	107	39	272	28	30	171	16
6/8/94	(AHU 138)	15	10	82	6	63	13	6	12	134	8	12	215	13	29	267	16	158	28	13	103	26
6/9/94	Supply 1W	2	4	132	3	41	13	6	78	14	8	11	175	16	30	177	13	19	298	15	74	36
6/10/94	(AHU 123)	3	4	72	4	38	13	6	80	14	7	11	135	12	27	137	10	15	208	15	72	46
6/11/94		3	3	-	3	25	13	5	56	14	6	8	235	9	16	137	7	10	208	12	50	46
6/15/94	1E, 1W & 1N	6	8	92	4	20	13	8	47	14	9	25	15	18	80	27	20	96	38	21	19	36
6/16/94		7	10	132	8	16	13	7	39	14	9	22	15	17	76	27	20	91	28	19	75	26
6/17/94		7	9	132	7	20	13	7	34	14	8	20	15	12	64	17	15	69	28	15	69	16

Table 4. Summary of Interzone Tracer Gas Test Responses

Injection Zone	Responding Zones
AHU-187 (1E)	AHU-138 (1N), AHU-123 (1W), 2nd Floor
AHU-138 (1N)	AHU-187 (1E), AHU-123 (1W), 2nd Floor, 3rd Floor
AHU-123 (1W)	AHU-187 (1E), 3rd Floor
All 1st Floor AHU's	2nd Floor, 3rd Floor

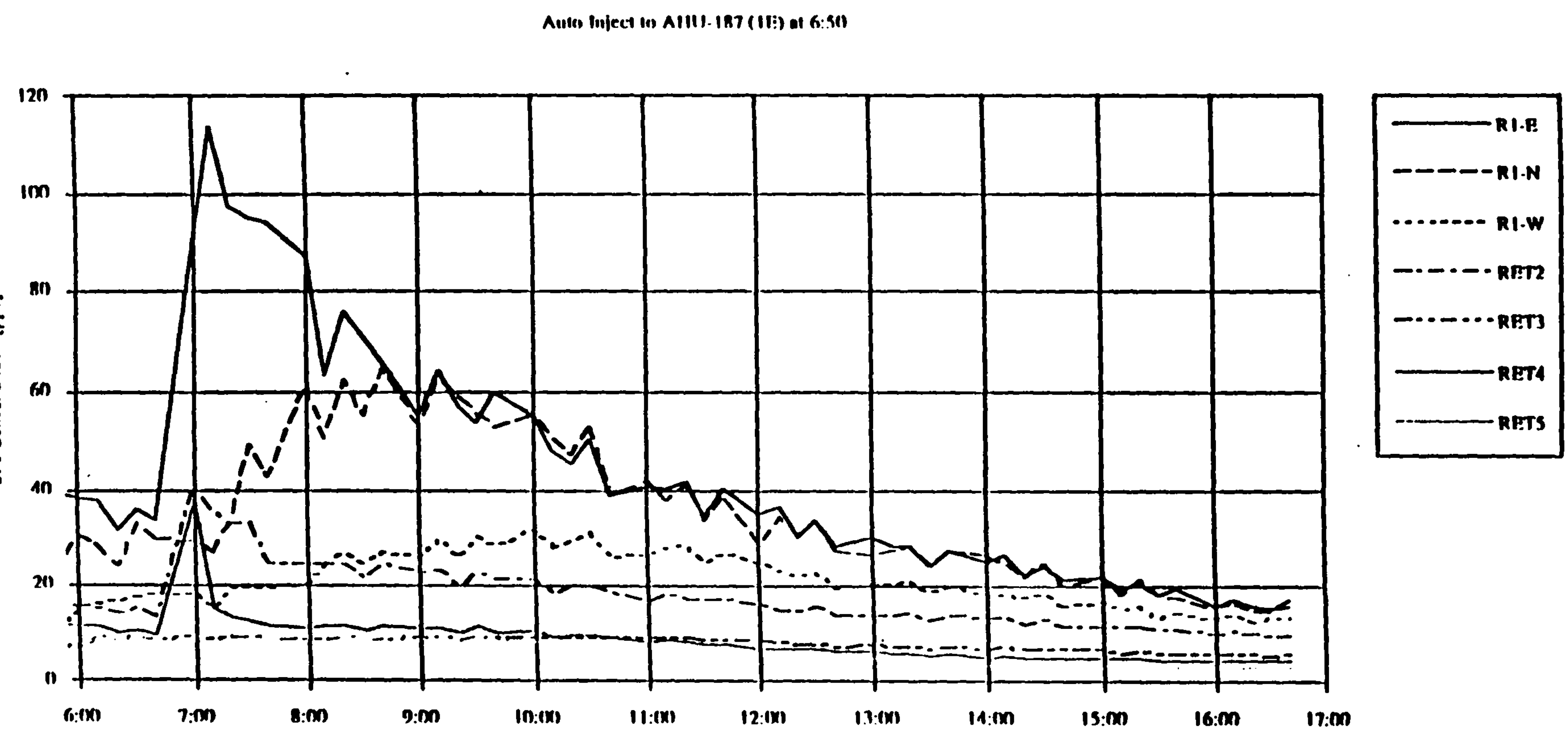


Figure 13. Plot of an interzone tracer gas injection conducted at the Polk County Administration Building.

Other IAQDS Measurements

Building Temperatures

The temperatures measured at the IAQDS locations showed very little change other than that produced by the cycling of the HVAC systems. The continuous temperature measurements are shown in the Figures in Appendix C. The values averaged over each operating condition and for each station are shown in Table 5. The first floor and building averages are plotted in Figure 14 where it is seen that the three OA fans did not appreciably change the building temperatures. Any tendencies to raise the building temperatures due to increasing the OA were more than compensated for by the HVAC systems.

Building Moisture (RH) Levels

The continuous indoor RH levels measured at the 13 IAQDS locations are shown in the Figures of Appendix D. Here it is seen that there were measurable increases in the RH levels of all five floors of the building when the OA fans were installed and operated on the AHUs on the first floor. It might appear that some of this increase was due to the increased OA supplied to the first floor. However, coincident with this increase, the supply air temperatures of all air handlers in the building were raised from 50°F to 57°F (via telephone conversations with Johnson Controls). Since the RH increase covered all floors and reversed itself while the fans were still operational, first floor OA fans do not appear to be a significant cause of the moisture increase.

The averaged values of RH are summarized in Table 6 where the values recorded by each of the IAQDS units were averaged for each of the building operating conditions. With the OA fans operating the RH levels at various locations increased by about 12% on the first floor and by about 14% for the entire building (with the larger OA fan on AHU3). Levels generally remained below 50% RH and within the recommended 20-60% RH range (ASHRAE Comfort Standard 55-74). These increases are shown graphically in Figure 15 where both the first floor and building averages are plotted as a function of the building operating condition. It would appear that bringing in the additional OA posed no problem for the HVAC systems and could be increased (as recommended to the County) without exceeding the recommended maximums.

Building Carbon Dioxide (CO_2) Levels

The continuous CO_2 levels as measured by the 13 IAQDS units are shown in Appendix E. The background levels as measured on Sunday evenings were generally about 400 parts per million (ppm). The maximum or peak CO_2 levels measured throughout the testing period are shown in Figure 16 where the peak levels generally were less than 1,500 ppm. One exception was a level of 2,798 ppm measured in the Auditorium (or Board Room) on 4/26/94 at about 10:00 pm, presumably during a County Commission meeting. The weekday average maximum CO_2 levels measured by the IAQDS stations are tabulated in Table 7. For the first floor of the building the average maximum during normal building operation was 1,333 ppm and the building average maximum was 1,115 ppm. These maximum levels were little affected by the

Table 5. Average Temperatures in the Polk County Administration Building, Bartow, Florida

	Building Condition									
Location	Baseline (oF)	Max OA (oF)	Min OA (oF)	Normal Operation (oF)	3 OA Fans Level (oF)	3 OA Fans % of Norm (%)	2 OA Fans Level (oF)	2 OA Fans % of Norm (%)	3 OA Fans Level (oF)	3 OA Fans % of Norm. (%)
Rm 124A	81.2	81.5	81.4	81.4	81.4	100.0	81.3	99.8	81.1	99.6
Rm 182	70.2	70.8	71.0	70.6	70.7	100.1	70.5	99.8	71.0	100.6
Rm 154	81.5	82.1	82.1	81.5	81.9	100.5	82.1	100.7	81.8	100.4
Rm 119	80.5	80.2	78.4	78.3	78.5	100.2	78.0	99.6	77.9	99.4
Board Rm	81.7	81.9	81.3	80.5	80.0	99.4	79.8	99.2	79.7	99.0
Rm 235	75.9	76.1	76.0	75.8	75.6	99.7	76.6	101.1	76.7	101.1
Rm 342	81.0	81.3	81.3	81.1	80.6	99.4	80.9	99.7	80.8	99.6
Rm 313	78.5	78.7	78.7	78.5	78.7	100.2	79.0	100.7	78.9	100.5
SW 5th	77.3	78.0	79.9	79.9	80.0	100.1	79.4	99.3	80.3	100.4
NE 5th	77.4	77.7	77.5	78.2	*	*	*	*	*	*
Rm 289	81.2	81.9	81.5	81.7	81.8	100.2	82.3	100.8	82.4	100.9
Rm 415	81.3	81.1	79.2	79.5	79.2	99.6	79.4	100.0	79.2	99.7
Rm 445	78.0	78.3	78.0	78.3	*	*	*	*	*	*
1st Floor Average	79.00	79.31	78.83	78.48	78.51	100.0	78.34	99.8	78.30	99.8
Building Average	78.89	79.21	78.94	78.88	78.96	100.1	79.04	100.2	79.06	100.3

* -- Monitor Malfunction

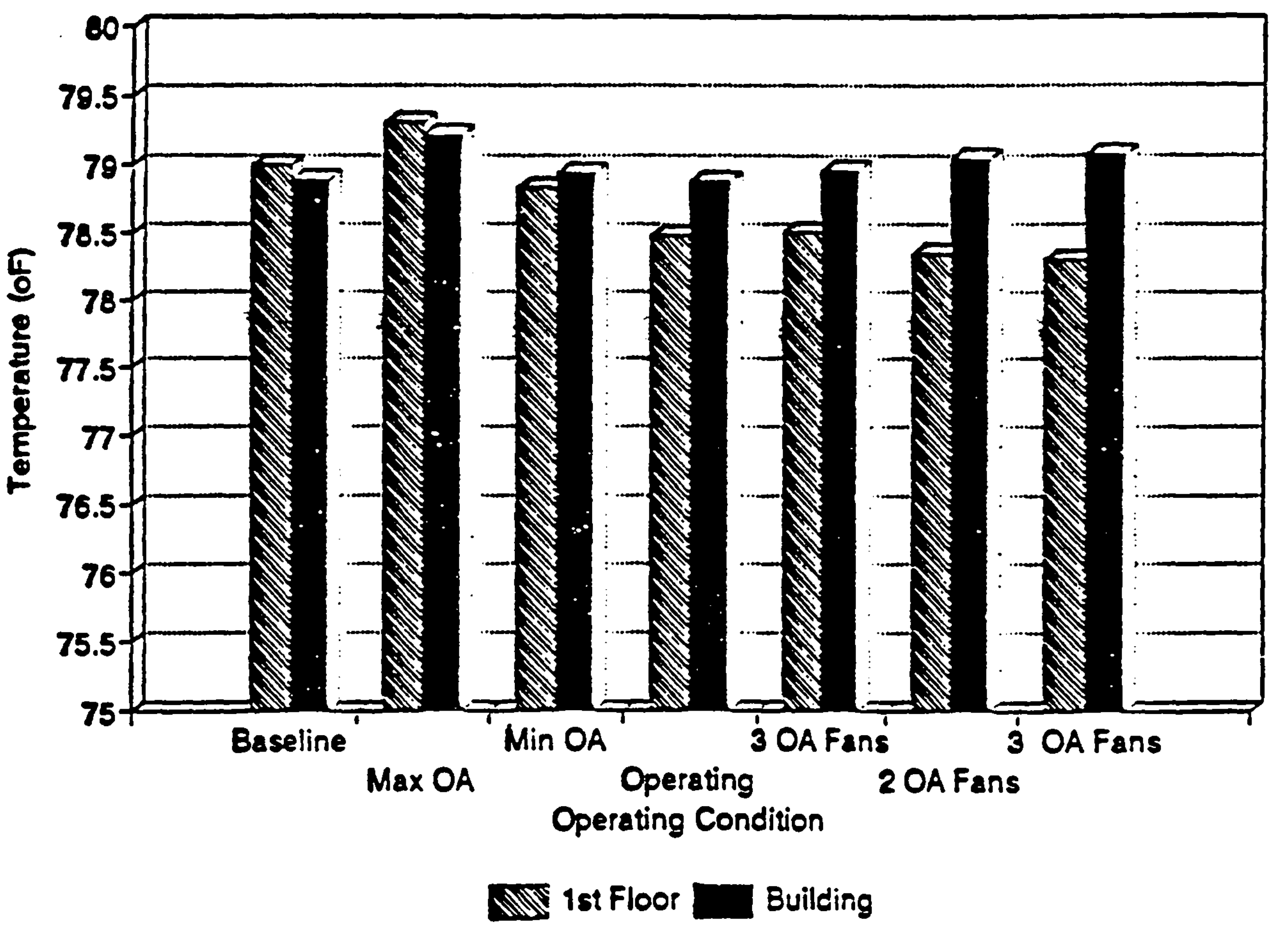


Figure 14. Average temperatures on the first floor and for the entire building under various operating conditions at the Polk County Administration Building.

Table 6. Average Relative Humidities in the Polk County Administration Building, Bartow, Florida

Location	Baseline (%)	Max OA (%)	Min OA (%)	Normal Operation (%)	3 OA Fans Level (%)	3 OA Fans % of Norm (%)	2 OA Fans Level (%)	2 OA Fans % of Norm (%)	3 OA Fans Level (%)	3 OA Fans % of Norm (%)
	Building Condition									
Rm 124A	29.8	28.8	29.2	30.2	32.4	107.3	34.5	114.2	34.8	115.5
Rm 182	32.1	30.6	30.6	32.2	34.3	106.5	36.1	112.2	34.6	107.7
Rm 154	32.3	31.5	31.8	33.1	36.0	108.7	37.2	112.3	37.0	111.7
Rm 119	31.9	31.7	34.3	36.4	38.7	106.2	41.1	112.8	41.3	113.3
Board Rm	32.5	31.8	32.1	34.5	37.0	107.1	38.2	110.5	38.8	112.6
Rm 235	37.5	38.1	37.8	35.6	40.7	114.5	45.3	127.3	44.3	124.4
Rm 342	32.8	32.7	32.2	33.8	36.2	106.9	39.6	117.0	39.7	117.4
Rm 313	35.2	35.1	34.7	36.3	36.9	101.6	41.0	113.0	40.1	110.6
SW 5th	36.9	35.8	33.9	37.2	38.0	101.9	41.9	112.4	41.6	111.6
NE 5th	37.7	37.1	36.7	40.4	50.1	124.0	54.3	134.5	54.8	135.9
Rm 289	35.2	35.1	34.5	34.9	39.8	114.1	45.9	131.3	45.0	128.7
Rm 415	34.9	35.2	33.5	37.0	38.4	103.5	42.1	113.6	41.2	111.3
Rm 445	36.4	36.6	35.1	39.1	30.8	78.8	33.0	84.4	33.7	86.3
1st Floor Average	31.73	30.87	31.61	33.28	35.65	107.1	37.39	112.4	37.32	112.1
Building Average	34.24	33.85	33.58	35.45	37.62	106.2	40.77	115.0	40.55	114.4

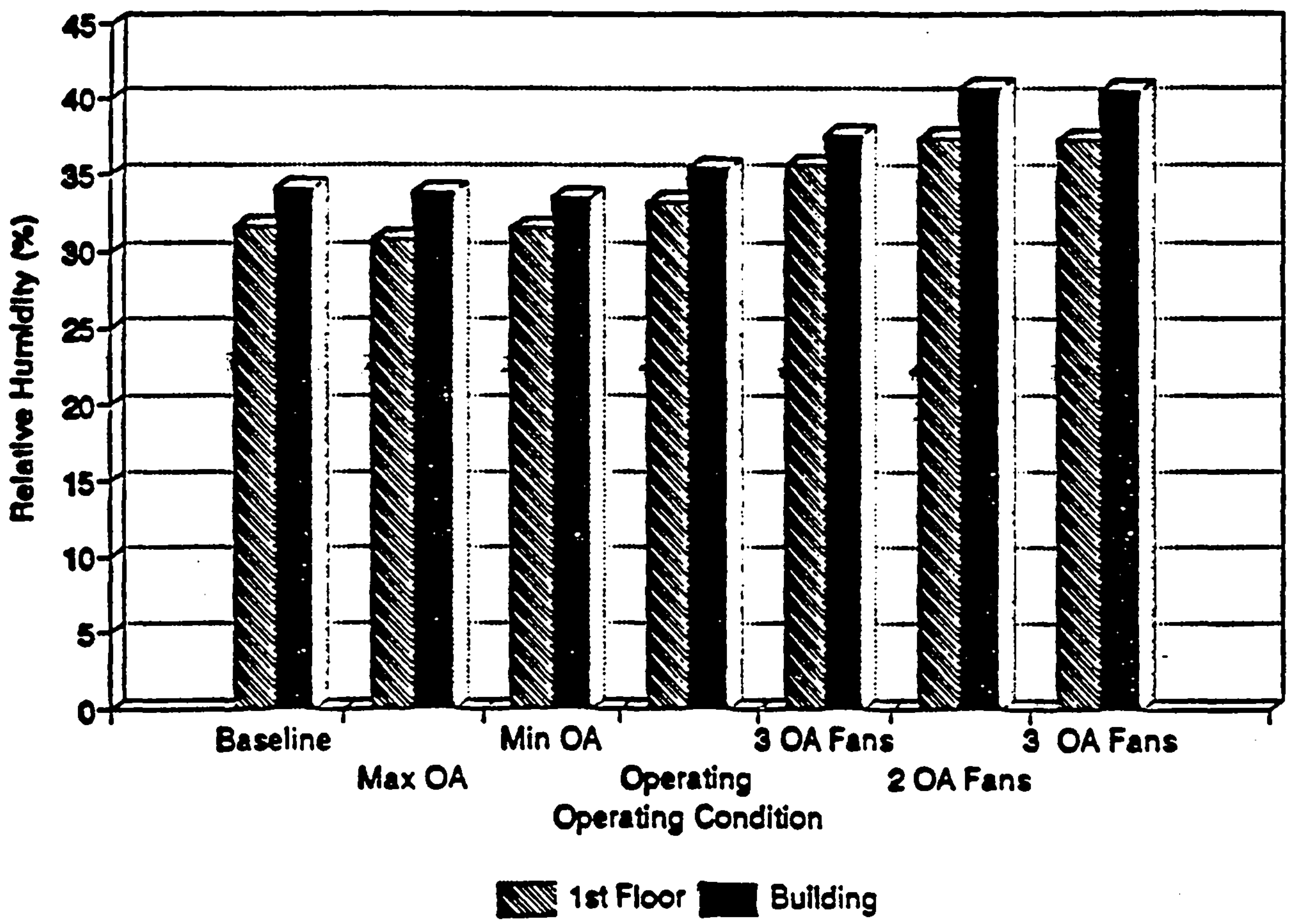


Figure 15. Average moisture levels (RH) on the first floor and the entire building under various operating conditions at the Polk County Administration Building

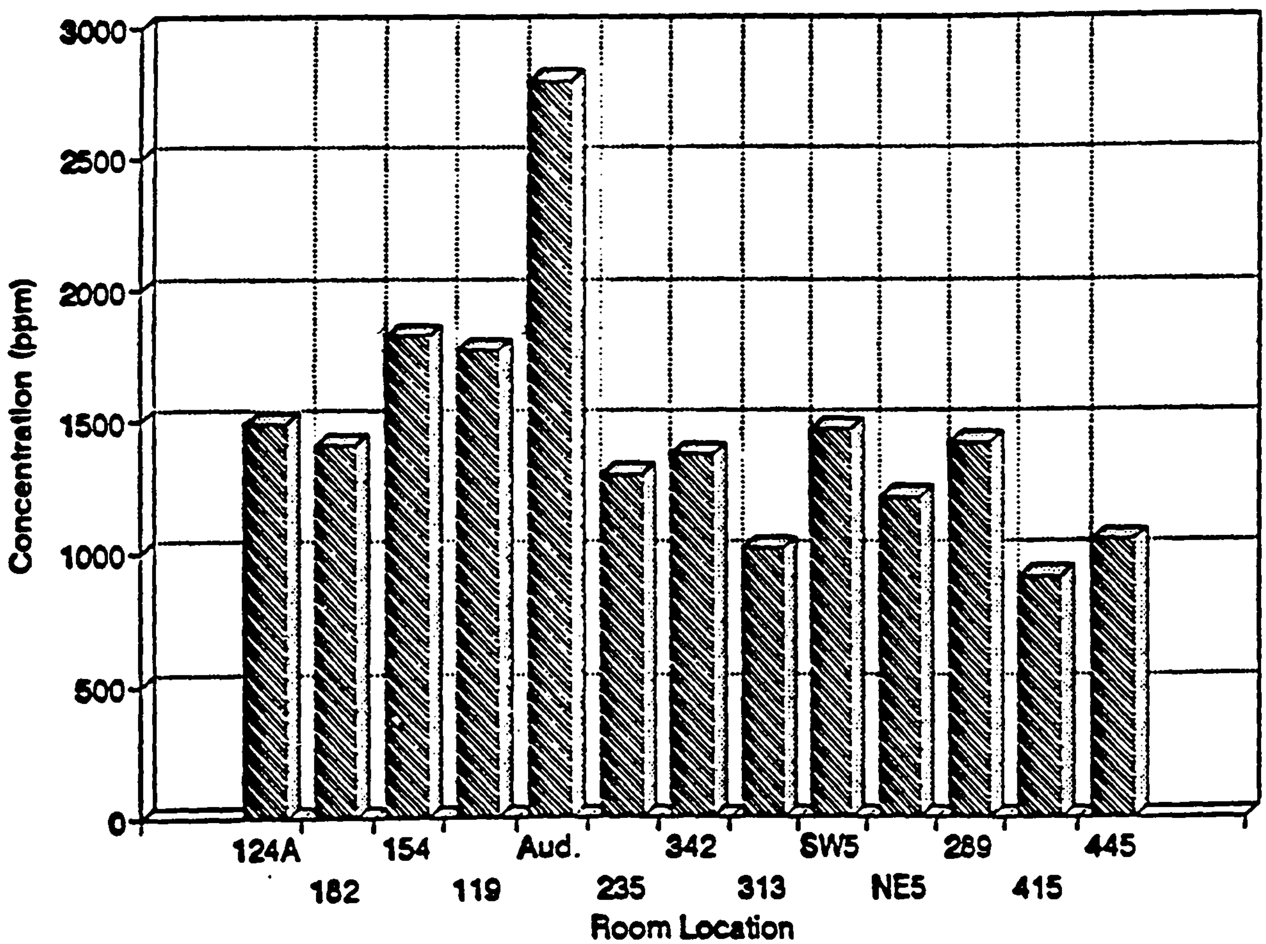


Figure 16. Maximum or peak weekday CO_2 levels measured at the IAQDS locations in the Polk County Administration Building

Table 7. Average Maximum CO_2 Levels in the Polk County Administration Building, Bartow, Florida

Building Condition

Location	Baseline (ppm)	Max OA (ppm)	Min OA (ppm)	Normal Operation (ppm)	3 OA Fans Level (ppm)	3 OA Fans % of Norm (%)	2 OA Fans Level (ppm)	2 OA Fans % of Norm (%)	3 OA Fans Level (ppm)	3 OA Fans % of Norm (%)
Rm 124A	1211	1270	1193	1189	1131	95.1	995	83.7	1013	85.2
Rm 182	1249	1266	1232	1219	1105	90.6	1068	87.6	993	81.5
Rm 154	1525	1564	1522	1512	1288	85.2	1170	77.4	1026	67.9
Rm 119	1455	1519	*	*	*	*	*	*	*	*
Board Rm	1432	1482	1412	1414	1237	87.5	1480	104.7	1109	78.4
Rm 235	1071	1162	1104	1139	1177	103.4	1033	90.7	1053	92.5
Rm 342	1011	1079	1079	1107	1067	96.4	941	85.0	949	85.7
Rm 313	775	854	833	816	843	103.4	745	91.4	767	94.0
SW 5th	1383	1399	1360	1325	1343	101.3	1321	99.7	1341	101.1
NE 5th	1105	1124	1090	1071	1054	98.4	1054	98.5	1027	95.9
Rm 289	1007	1182	1006	1168	1195	102.3	1066	91.2	1070	91.6
Rm 415	*	*	733	689	738	107.1	646	93.7	676	98.0
Rm 445	735	792	805	737	*	*	*	*	*	*
1st Floor Average	1374	1420	1340	1333	1190	89.6	1178	88.4	1035	78.3
Building Average	1183	1224	1114	1115	1107	97.3	1047	91.2	1002	88.4

* -- Monitor Malfunction

position of the passive OA dampers on the air handlers. However, installation of the OA fans on the first floor air handlers significantly reduced the maximum levels on the first floor. With the large fan on AHU3 the first floor maximum levels were reduced by more than 20% and the whole building levels by slightly more than 10%. These reductions are easily seen in Figure 17 where the averaged weekday peak CO_2 levels are plotted for both the first floor and the entire building as functions of the various operating conditions. Clearly, the additions of more outside air improved the indoor air quality as measured by the CO_2 levels.

Discussion of Study Objectives

The results described in this section allow some insight into the study objectives listed at the beginning of Chapter 4. First, the data has demonstrated a link between HVAC operation and radon entry, at least as related to the level of ventilation air in the structure. As described in the discussion of Table 2, the effect of forced air ventilation to bring the first floor closer to the design outdoor levels produced a dramatic decrease in first floor radon and a lesser decrease in whole building radon. While the original adjustments of the outdoor air dampers failed to have a clear effect on either radon, building pressures, or air exchange rate, fan-assisted ventilation provided a feasible and cost-effective means of reducing radon while resetting the building ventilation rates to the original specifications.

Second, the effects of ground floor pressure imbalances are less clear. While HVAC-induced pressure differentials of 1-4 Pa regularly occur in the building, they are not easy to relate to radon entry in that periods of maximum pressure imbalance do not appear to coincide with periods of maximum radon concentration. The observation from Figures 10-11 that the zone-to-zone pressure differentials do not appear to correlate with the pressure differences across the slab add further uncertainty to the anticipated impacts of pressure imbalance.

The third objective, monitoring air flow between zone and floors, was only partially met. Qualitative air flow pattern can be deduced from the tracer data summarized in Tables 3 and 4, and use of Table 2 with radon as a tracer indicates that roughly half the air on the second floor and 30 percent of the air on the upper floors originates on the ground floor. Further interzone measurements would have been desirable, and the failure of the tracer gas system before installation of the forced OA fans was especially disappointing.

Likewise, measurement difficulties were involved as no conclusive insight was obtained into the effects of slab size or driving pressures. The peak-to-peak pressure differences across the slab are not larger in magnitude than those previously observed in house-sized slabs, and insufficient valid data locations were available to relate the pressure differences to position on the slab. The time dependence of these pressure fluctuations does match that seen in earlier FRRP studies of slab-or-grade structures.

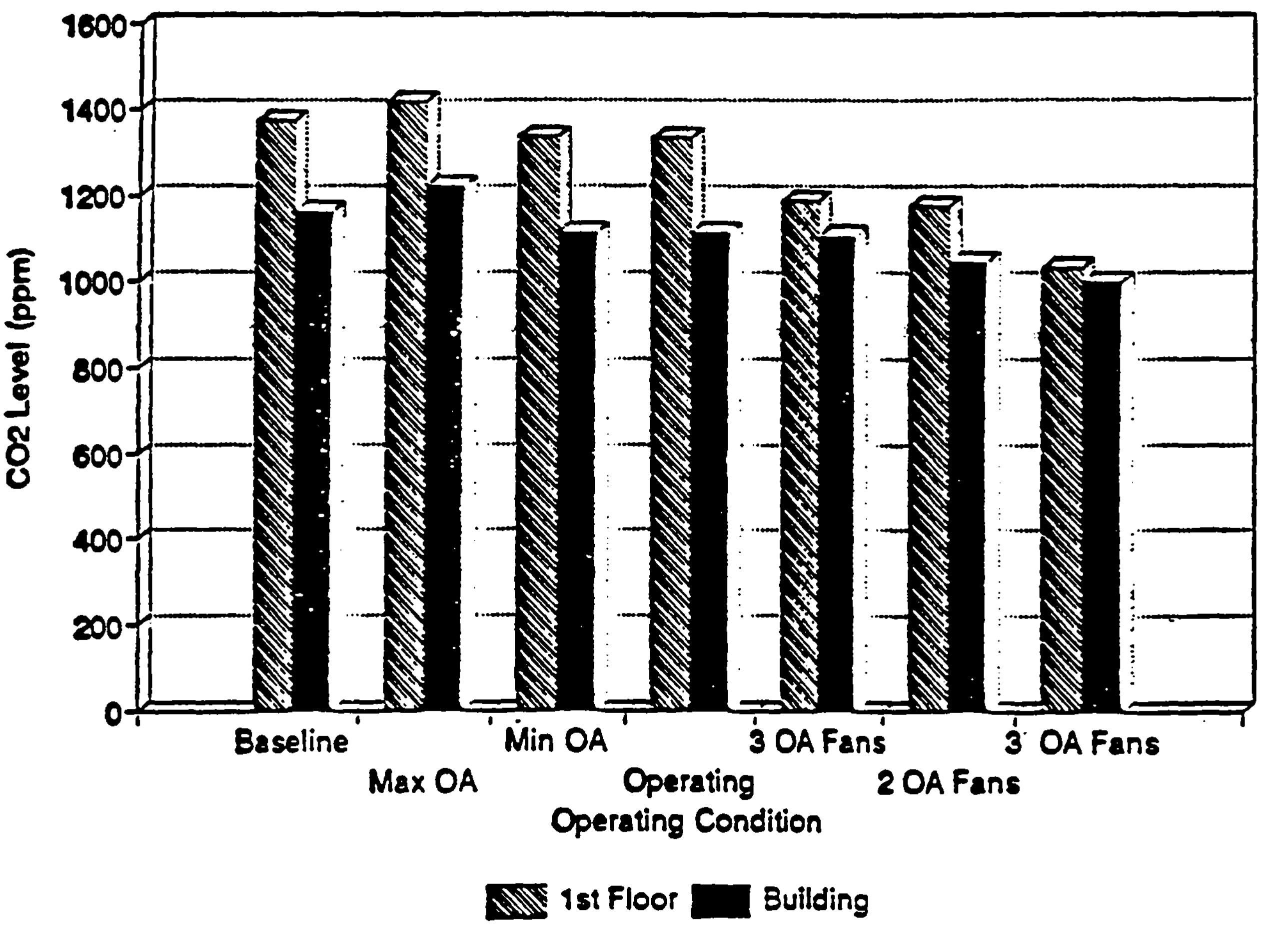


Figure 17. Averaged weekday peak CO_2 levels for the first floor and for the entire building under various operating conditions at the Polk County Administration Building

Fifth, in the course of the study some semiquantitative conclusions can be offered as to the vulnerability of certain building features to radon entry. The central elevator shafts were clearly not a significant point for radon entry, although they cannot be discounted as conduits for transport to the fifth floor. The visible penetrations in the electrical and telephone rooms were not demonstrated to be a measurable radon source. The excess radon concentrations in all three ground floor mechanical rooms, combined with their high depressurization and strong coupling to the HVAC supply systems, implicates them as probable entry locations for a substantial fraction of the indoor radon.

Finally, the study was able to leave the building owners, Polk County, a clear demonstration of measures which would reduce indoor radon to below the Florida radon standard while remaining within the mechanical design specifications for the building.

Chapter 6
Quality Assurance

In early 1994, the EPA approved a Quality Assurance (QA) Project Plan (QAPP) (#94036) for the "Large Building 1994 Demonstration" to develop suitable diagnostic and mitigation techniques for existing large buildings in Florida. This plan was used by the research teams to guide the study reported in this document for this building. The radon measurements were made in accordance with procedures found in the EPA's "Indoor Radon and Radon Decay Product Measurement Device Protocols" manual (U.S. EPA 1992). The differential pressure measurements were made using MODUS Instruments, Inc. pressure transmitters according to their operating instructions.

Data Quality Objectives and Achievements

The major objectives of this project were to determine the effect of HVAC operating cycles (including OA level and exhaust ventilation) on radon-relevant parameters of the structures, to evaluate the effect of a larger slab on the driving pressures which promote radon entry, to assess the effect of ground floor pressure balance or imbalance on radon entry, to monitor the transport of air and radon between zones and floors, and to assess the effect of building features/faults on response variables. Limited tests conducted with forced OA input on the first floor air handlers indicated that radon entry could be greatly reduced by increasing the amount of OA into the HVAC systems.

Data Quality Indicators

The data quality indicator (DQI) goals for precision, accuracy, and completeness are described in the QAPP (#94036) of March 1994. The precision goals for radon concentrations of 4 pCi/L or greater are given in terms of a coefficient of variation (CV) or relative standard deviation and are the 10% levels listed as achievable in the EPA's protocols (U.S. EPA 1992). The precision goal for differential pressure of 25% CV was set higher because many of the measurements are expected to be in the range of ±1 Pa, and this level of precision will be quite adequate in this range of measurements. The accuracy goal for radon concentrations was the criterion for a pass in the EPA's Radon Proficiency Program (RPP) (U.S. EPA 1995), ±25% bias for concentrations above 4 pCi/L. This bias was also considered adequate for the differential pressure measurements. The target completeness goal was 90% for each measurement parameter.

Continuous Radon Monitors

Precision--Before any continuous radon measurements were started in this building in April 1994, the 19 CRMs were placed in the same location and measured the radon concentration there simultaneously for two days. The resulting measurements from these monitors had a CV of 9%, less than the DQI goal for precision of 10% for radon concentrations greater than 4 pCi/L. Therefore, the precision of the CRMs was considered to be acceptable.

Accuracy--The 19 CRMs were exposed to 18.4 pCi/L in the EPA radon chambers at the National Air and Radiation Environmental Laboratory (NAREL) in Montgomery, Alabama, from 28 February until 2 March 1994. Using the last recorded calibration factors (CF) for each of these monitors (some had not been used in several years), the measured radon concentrations were calculated. The difference between the measured value and the actual concentration divided by the actual concentration is the bias or relative error (RE), usually given as a percentage. The DQI goal for accuracy was ±25% RE for concentrations greater than 4 pCi/L. Table 8 lists the results of the bias determination made for the CRMs based on this calibration run. The mean and the mean absolute relative error (MARE) (the mean of the absolute values of each of the individual REs) of the calibration measurements are given in the table. Each of the individual REs and the MARE were within the target bias of ±25%; therefore, the accuracies of the CRMs were considered to be quite adequate. Based on this exposure, a new CF was calculated for each monitor. The new CFs were used in the study.

Radon Grab Samples

Precision--Only five grab samples were taken in this building, and one of them represented a duplicate measurement. The CV for this duplicate measurement was less than the 10% DQI goal; so the precision of these grab samples was considered acceptable.

Accuracy--Approximately annually most of the grab sampling cells are routinely taken to the NAREL in Montgomery, Alabama, for checks of their calibration. During March 1994 before any of the grab samples were taken in this building, the grab sampling cells that were used in these measurements had calibration checks performed there. Air from one of the environmental control chambers was sampled by each of the cells. They were returned to Birmingham where they were counted at least twice. Later NAREL sent the actual concentration that was maintained in the chambers at the time of sampling. Then new CFs were calculated for each of the cells based on the actual chamber concentrations.

In 1995, after the measurements in this building were completed, most of the cells were returned to NAREL for another calibration check. (Unfortunately, cell 1.5 was in use on another project during that time.) The concentrations of radon measured by each of the cells were determined. When NAREL sent the actual concentrations of the chambers, the REs of the measured values and new CFs of the cells were determined. Table 9 lists the calibration results for these two exposures. As was the case with the CRMs, the measure that is used to compare the REs is the MARE. The individual REs for the various cells range from -7 to 10%, and the MARE for the calibration check was 5%.

Table 8. Results of the Bias Determinations for the CRMs

IAQDS #	CRM ID	Old CF	Counts	Radon	RE	New CF
I13	094	0.29	16818	20.1	9.4%	0.32
I10	131	0.29	17463	20.9	13.6%	0.33
I3A	395	0.29	14354	17.2	-6.6%	0.27
I4B	414	0.29	14263	17.1	-7.2%	0.27
I11	418	0.29	15621	18.7	1.6%	0.29
I5A	421	0.28	14114	17.5	-4.9%	0.27
I8	422	0.28	17534	21.7	18.2%	0.33
I4A	423	0.31	15471	17.3	-5.8%	0.29
I9	425	0.28	15078	18.7	1.6%	0.28
I14	427	0.30	14449	16.7	-9.1%	0.27
I6	428	0.29	14263	17.1	-7.2%	0.27
I7	532	0.29	14499	17.4	-5.7%	0.27
I12	533	0.29	14470	17.3	-5.8%	0.27
I3	534	0.29	14769	17.7	-3.9%	0.28
I2	535	0.29	14867	17.8	-3.3%	0.28
I5	536	0.30	19241	22.3	21.0%	0.36
I4	537	0.29	14210	17.0	-7.5%	0.27
I2A	538	0.29	14823	17.7	-3.5%	0.28
I1	539	0.29	14950	17.9	-2.7%	0.28
			Mean/MARE	18.3	7.3%	

All of these error measures were well within the DQI goal of ±25%; so the bias of the grab samples was considered to be acceptable.

Table 9. Calibration Results for the Grab Cells From 1994 and 1995

Cell No.	CF 1994	Background	Measured	Chamber	RE 1995	CF 1995
EPA 1.3	0.702	11.3	117.8	118.4	- 1%	0.697
EPA 1.5	0.646	4.9				
EPA 2.1	0.655	2.4	97.9	100.1	- 2%	0.640
EPA 2.2	0.659	6.6	129.7	118.4	10%	0.715
SRI 283	0.883	5.6	93.4	100.1	- 7%	0.815
Mean	0.709			MARE	5%	0.717

Before a cell was used in the field, a background count was generally made and recorded to ensure that the cell was relatively "clean." After a sample was collected and counted, the cell was flushed with clean ambient air and allowed to "relax" to allow the residual decay products to decay away before another background check was made. With the relatively high radon concentrations sampled in this study, especially, when taking soil and sub-slab samples, the cells were subjected to large potentials for increased backgrounds.

Completeness--All of the individual grab samples taken over the course of this study produced valid measurements, for a 100% completion rate, easily exceeding the 90% DQI goal for this measure of data quality.

Differential Pressure Measurements

Precision--Before the 28 pressure transmitters were placed in the building they were used to measure three pressures (of varying magnitudes) that spanned their ranges. On all 28 transmitters the ports were connected, for a pressure differential of 0 Pa, and the mV readings of the transmitters were compared. Their CV was 5%. The other pressures placed across their ports were near the transmitters' maximum and minimum values, but not all transmitters had the same pressures applied. Two to four transmitters each had one of six different positive and seven different negative pressures applied. (A few of the pressures had no replicated transmitters measuring them.) The resultant millivolt readings were processed with the nominal conversion factors of the transmitters. The calculated pressures of these 13 replicated measurements had CVs varying from 1 to 23%, all within the 25% DQI goal; therefore, the precision of these monitors was considered to be acceptable.

Accuracy--Digital micro manometers, which were routinely sent back to the manufacturer for their calibrations to be certified with National Institute of Standards and Technology (NIST) traceable test equipment, were used to calibrate the pressure transmitters. In April 1994, before the building was instrumented with the devices, all 28 transmitters were calibrated with these manometers using three values spanning their ranges. The middle value (0) should have registered a transmitter reading of 2000 mV. The REs of the 28 transmitters' readings at this pressure varied from -16 to 9%, with a MARE of 5%. At the low and high pressures, the transmitter readings in millivolts were converted to pressures in Pascals using the instruments' generic calibration factors, and the results were compared with the manometer readings. Forty-eight of the 56 resulting REs (86%) fell within the ±25% DQI goal, and the MARE of all 56 readings was 17%. Based on this information, the bias of these instruments was considered acceptable.

Linear regressions were run over these pressure ranges, producing slopes of Pascals/volt and intercepts of calculated pressures in Pascals. The use of these updated calibration factors for each device for the conversion of the millivolt output to pressure values should have made the field measurements even more accurate than the above numbers indicate. A second measure was taken to control for another type of bias that could be introduced over the course of the measurement period, namely zero drift of the transmitters. For five minutes at the beginning of each half hour's measurements the pressure signal sent to the transmitters was of zero pressure drop between the ports, and these readings were recorded by the data logger. The calculations of the measured pressures each half hour were made with this zero correction.

Data Reviews

Prior to the study, all of the radon and pressure measuring equipment was calibrated as described above. Generally QA personnel not directly involved with the actual field measurements made the calibration checks of the equipment. The CRMs and most of the pressure transmitters came from the EPA, and one of their contractors performed the calibrations and provided Southern with the results. The radon grab cells belonged to Southern. The calibration checks for these radon measuring devices were performed at the EPA's NAREL in Montgomery, Alabama, by Birmingham-based technicians and/or scientists. The calibration certification of the micro manometers was performed by the manufacturer. The results of all the calibration checks were reviewed by the project manager and the principal investigator and passed on to the on-site project coordinator for use in the field. This individual kept detailed project logs, copies of which were sent to Birmingham at least monthly. Here they were reviewed by both the manager and investigator for completeness. At least twice during the project, a field visit was made by Birmingham personnel to review the data set up and collection.

Identification of Corrective Actions

The data from the data logger were retrieved within the next working day of any changes to the system to ensure that their collection was complete and accurate as planned. If any data appeared to be faulty or missing, then immediate checks of the system were performed. For instance, if no data appeared in the output where some was expected, then the wiring, connections, and programming were inspected. If unreasonable data were detected, then sampling lines were checked for blockage, crimping, or leaks. Once the reliability of the data retrieval system appeared to be sufficient, then downloads were conducted approximately weekly, and another thorough review of the collected data was performed to ensure that the measurement and collection systems were operating as planned. Because this was an occupied and working facility throughout the time of this study, there were numerous potential interferences with consistent and continuous data collection. Moreover, there were frequent thunder storms and severe weather that caused power fluctuations. Generally the system was inspected as soon as possible after each such event occurred.

References

ASTM 1993. Standard Test Method for Determining Air Change in a Single Zone by Means of Tracer Gas Dilution, E741, American Society for Testing and Materials, Philadelphia, PA.

U.S. EPA, 1992. Indoor Radon and Radon Decay Product Measurement Device Protocols, EPA-402/R-92-004 (NTIS PB92-206176), U.S. Environmental Protection Agency, Washington, D.C., 104 pp.

U.S. EPA, 1995. Radon Proficiency Program (RPP) Handbook, EPA-402/R-95-013, U.S. Environmental Protection Agency, Washington, D.C., 120 pp.

Appendix A. IAQDS Data Station Locations and Configurations.

IAQDS1

Data Station Location: Rm 124A Label Colors: 1st:Lt.Blue
Station No.: 1 ' 2nd:Lt.Blue
Data Logger ID#: 1
Modem Jack ID No: J27 (in Rm120A)

Channel ID	Calib Menu ID#	Connect To	Function
ADC1	1	INT	Dp#1 Zone to Subslab +-0.1
ADC2	2	INT	Dp#2 Zone to Lobby +-0.1
ADC3	3	FP-2	Dp#3 Zone to Outside +-1.0
ADC4	4	FP-9	HVAC SA Temp AHU3
ADC5	5	INT	Zone Temp
ADC6	6	INT	Zone RH
ADC7	7	INT	Zone CO2
ADC8	8	FP-3	Climet Particle Counter
SW1	9	FP-6	
SW2	10	FP-13	
SW3	11	FP-7	
Cnt1	12	INT	Femto Zone Radon
Cnt2	13	FP-5	
Cnt3	14	FP-12	

Dp#1 High Subslab
Low Zone

Dp#2 High Lobby
Low Zone

Dp#3 High Outside
Low Zone

IAQDS2

Data Station Location: Rm 182 Label Colors: 1st:Lt.Blue
Station No.: 2 ' 2nd:Green
Data Logger ID#: 2
Modem Jack ID No: J14

Channel ID	Calib Menu ID#	Connect To	Function			
ADC1	1	INT	Dp#1	Zone to Subslab	+-0.1	
ADC2	2	INT	Dp#2	Zone to Lobby	+-0.1	
ADC3	3	FP-2	Dp#3	Zone to Outside	+-1.0	
ADC4	4	FP-9	Dp#4	RA Static Press AHU3 Rm187	0-3.0	
ADC5	5	INT	Zone Temp			
ADC6	6	INT	Zone RH			
ADC7	7	INT	Zone CO2			
ADC8	8	FP-3	HVAC SA RH AHU3			
SW1	9	FP-6	HVAC Pressure Switch Rm187			
SW2	10	FP-13				
SW3	11	FP-7				
Cnt1	12	INT	Femto	Zone Radon		
Cnt2	13	FP-5	Femto Radon in Rm 187			
Cnt3	14	FP-12				

Dp#1	High	Subslab
	Low	Zone
Dp#2	High	Lobby
	Low	Zone
Dp#3	High	Outside
	Low	Zone
Dp#4	High	MR Rm187
	Low	AHU3 RA Tap

IAQDS3

Data Station Location: Rm 154 Label Colors: 1st:Lt.Blue
Station No.: 3 ' 2nd:Red
Data Logger ID#: 3
Modem Jack ID No: J25

Channel ID	Calib Menu ID#	Connect To	Function
ADC1	1	INT	Dp#1 Zone to Subslab +-0.1
ADC2	2	INT	Dp#2 Zone to Lobby +-0.1
ADC3	3	FP-2	Dp#3 Zone to Outside +-1.0
ADC4	4	FP-9	Dp#4 RA Static Pressure AHU1 Rm 138 0 - 3.0
ADC5	5	INT	Zone Temp
ADC6	6	INT	Zone RH
ADC7	7	INT	Zone CO2
ADC8	8	FP-3	
SW1	9	FP-6	HVAC SA Pressure Switch AHU1 Rm 138
SW2	10	FP-13	
SW3	11	FP-7	
Cnt1	12	INT	Femto Zone Radon
Cnt2	13	FP-5	Femto Radon Rm 138
Cnt3	14	FP-12	

Dp#1 High Subslab
Low Zone

Dp#2 High Lobby
Low Zone

Dp#3 High Outside
Low Zone

Dp#4 High MR Rm138
Low AHU1 RA Tap

IAQDS4

Data Station Location: Rm 119 Label Colors: 1st:Lt.Blue
Station No.: 4 ' 2nd:Orange
Data Logger ID#: 4
Modem Jack ID No: J12

Channel ID	Calib Menu ID#	Connect To	Function			
ADC1	1	INT	Dp#1	Zone to Subslab +-0.1		
ADC2	2	INT	Dp#2	Zone to Lobby +-0.1		
ADC3	3	FP-2	Dp#3	Zone to Outside +-1.0		
ADC4	4	FP-9	Dp#4	RA Static Pressure AHU2 Rm123 0 - 0.5		
ADC5	5	INT	Zone Temp			
ADC6	6	INT	Zone RH			
ADC7	7	INT	Zone CO2			
ADC8	8	FP-3	HVAC SA Temp AHU2			
SW1	9	FP-6	HVAC SA Pressure Switch AHU2 Rm 123			
SW2	10	FP-13				
SW3	11	FP-7				
Cnt1	12	INT	Femto	Zone Radon		
Cnt2	13	FP-5	Femto	Radon in Rm 123		
Cnt3	14	FP-12	Femto	Radon in Rm 124		

Dp#1 High Subslab
Low Zone

Dp#2 High Lobby
Low Zone

Dp#3 High Outside
Low Zone

Dp#4 High MR Rm123
Low AHU2 RA Tap

IAQDS5

Data Station Location: Audtrum Label Colors: 1st:Lt.Blue
Station No.: 5 ' 2nd:White
Data Logger ID#: 5
Modem Jack ID No: J55 in Rm 139

Channel ID	Calib Menu ID#	Connect To	Function			
ADC1	1	INT	Dp#1	Zone to Subslab (Rm139) +-0.1		
ADC2	2	INT	Dp#2	Zone to Lobby +-0.1		
ADC3	3	FP-2	Dp#3	Zone to Outside +-0.5		
ADC4	4	FP-9				
ADC5	5	INT	Zone Temp			
ADC6	6	INT	Zone RH			
ADC7	7	INT	Zone CO2			
ADC8	8	FP-3				
SW1	9	FP-6				
SW2	10	FP-13				
SW3	11	FP-7				
Cnt1	12	INT	Femto	Zone Radon		
Cnt2	13	FP-5	Femto	Radon Rm 139		
Cnt3	14	FP-12				

Dp#1	High	Subslab (Rm139)
	Low	Zone
Dp#2	High	Lobby
	Low	Zone
Dp#3	High	Outside
	Low	Zone

IAQDS6

Data Station Location: Rm 235 Label Colors: 1st:Green
Station No.: 1 ' 2nd:Lt.Blue
Data Logger ID#: 6
Modem Jack ID No: J122

Channel ID	Calib Menu ID#	Connect To	Function
ADC1	1	INT	Dp#1 Zone to Lobby +-0.1
ADC2	2	INT	Dp#2 1st Lobby to 2nd Lobby +-0.1
ADC3	3	FP-2	Dp#3 Zone to Outside +-1.0
ADC4	4	FP-9	Dp#4 Annubar AHU5 Rm 238 0 - 0.5
ADC5	5	INT	Zone Temp
ADC6	6	INT	Zone RH
ADC7	7	INT	Zone CO2
ADC8	8	FP-3	HVAC RA Temp AHU3 Rm 187
SW1	9	FP-6	HVAC SA Pressure Switch AHU5 Rm 238
SW2	10	FP-13	
SW3	11	FP-7	
Cnt1	12	INT	Femto Zone Radon
Cnt2	13	FP-5	
Cnt3	14	FP-12	

Dp#1 High Lobby
Low Zone

Dp#2 High 2nd Floor Lobby
Low 1st Floor Lobby

Dp#3 High Outside
Low Zone

Dp#4 High MR Rm238
Low AHU5 RA Tap

IAQDS7

Data Station Location: Rm 342 Label Colors: 1st:Red
Station No.: 2 ' 2nd:Green
Data Logger ID#: 7
Modem Jack ID No: J87

Channel ID	Calib Menu ID#	Connect To	Function
ADC1	1	INT	Dp#1 Zone to Lobby +-0.1
ADC2	2	INT	Dp#2 Zone to Outside -0.67 to +2.0
ADC3	3	FP-2	HVAC SA Temp AHU8
ADC4	4	FP-9	HVAC SA RH AHU8
ADC5	5	INT	Zone Temp
ADC6	6	INT	Zone RH
ADC7	7	INT	Zone CO2
ADC8	8	FP-3	HVAC SA RH AHU2
SW1	9	FP-6	HVAC SA Press Switch AHU6 Rm 364
SW2	10	FP-13	
SW3	11	FP-7	
Cnt1	12	INT	Femto Zone Radon
Cnt2	13	FP-5	
Cnt3	14	FP-12	

Dp#1 High Lobby
Low Zone

Dp#2 High Outside
Low Zone

IAQDS8

Data Station Location: Rm 313 Label Colors: 1st:Red
Station No.: 1 ' 2nd:Lt.Blue
Data Logger ID#: 8
Modem Jack ID No: J127A(Rm314)

Channel ID	Calib Menu ID#	Connect To	Function
ADC1	1	INT	Dp#1 Zone to Lobby +-0.1
ADC2	2	INT	Dp#2 Zone to Outside -0.67 to +2.0
ADC3	3	FP-2	HVAC SA Temp AHU9 Rm414
ADC4	4	FP-9	HVAC SA RH AHU9 Rm 414
ADC5	5	INT	Zone Temp
ADC6	6	INT	Zone RH
ADC7	7	INT	Zone CO2
ADC8	8	FP-3	HVAC RA RH AHU3 Rm 187
SW1	9	FP-6	HVAC SA Press Switch AHU7 Rm 316
SW2	10	FP-13	
SW3	11	FP-7	
Cnt1	12	INT	Femto Zone Radon
Cnt2	13	FP-5	
Cnt3	14	FP-12	

Dp#1 High Lobby
Low Zone

Dp#2 High Outside
Low Zone

IAQDS9

Data Station Location: SW 5th Label Colors: 1st:White
Station No.: 2 ' 2nd:Green
Data Logger ID#: 9
Modem Jack ID No: J139

Channel ID	Calib Menu ID#	Connect To	Function
ADC1	1	INT	Dp#1 Zone to Elevator Shaft +-1.0
ADC2	2	INT	Dp#2 Zone to Outside -0.67 to +2.0
ADC3	3	FP-2	HVAC RA Temp AHU11 NE MR
ADC4	4	FP-9	HVAC RA RH AHU11 NE MR
ADC5	5	INT	Zone Temp
ADC6	6	INT	Zone RH
ADC7	7	INT	Zone CO2
ADC8	8	FP-3	HVAC SA RH AHU11
SW1	9	FP-6	HVAC SA Press Switch AHU10 SW MR
SW2	10	FP-13	N Elevator Operation Switch (R/B to #2 Right)
SW3	11	FP-7	S Elevator Operation Switch (G/W to #1 Left)
Cnt1	12	INT	Femto Zone Radon
Cnt2	13	FP-5	
Cnt3	14	FP-12	

Dp#1	High	Elevator Shaft
	Low	Zone
Dp#2	High	Outside
	Low	Zone

IAQDS10

Data Station Location: NE-5th Label Colors: 1st:White
Station No.: 1 ' 2nd:Lt.Blue
Data Logger ID#: 10
Modem Jack ID No: J90

Channel ID	Calib Menu ID#	Connect To	Function			
ADC1	1	INT	Dp#1 Zone to Top of Atrium +-0.1			
ADC2	2	INT	Dp#2 Zone to Attic +-0.1			
ADC3	3	FP-2	Dp#3 Zone to Outside -0.67 to +2.0			
ADC4	4	FP-9	Dp#4 4th Lobby to Top of Atrium +-0.1			
ADC5	5	INT	Zone Temp			
ADC6	6	INT	Zone RH			
ADC7	7	INT	Zone CO2			
ADC8	8	FP-3	HVAC SA Temp AHU11			
SW1	9	FP-6	HVAC SA Press Switch NE MR AHU11			
SW2	10	FP-13				
SW3	11	FP-7				
Cnt1	12	INT	Femto Zone Radon			
Cnt2	13	FP-5				
Cnt3	14	FP-12				

Dp#1 High Top of Atrium
Low Zone

Dp#2 High Attic
Low Zone

Dp#3 High Outside
Low Zone

Dp#4 High Top of Atrium
Low 4th Floor Lobby

IAQDS11

Data Station Location: Rm 289 Label Colors: 1st:Green
Station No.: 2 ' 2nd:Green
Data Logger ID#: 11
Modem Jack ID No: J41

Channel ID	Calib Menu ID#	Connect To	Function
ADC1	1	INT	Dp#1 Zone to Lobby +-0.1
ADC2	2	INT	Dp#2 RA Static Pressure AHU4 Rm211A 0 - 0.5
ADC3	3	FP-2	Dp#3 Zone to Outside +-1.0
ADC4	4	FP-9	Remote Dp Annubar AHU2 Rm 123 0 - 0.5 or HVAC RA RH AHU2 Rm 123
ADC5	5	INT	Zone Temp
ADC6	6	INT	Zone RH
ADC7	7	INT	Zone CO2
ADC8	8	FP-3	HVAC RA Temp AHU2 Rm 123
SW1	9	FP-6	HVAC SA Press Switch AHU4 Rm 211A
SW2	10	FP-13	
SW3	11	FP-7	
Cnt1	12	INT	Femto Zone Radon
Cnt2	13	FP-5	
Cnt3	14	FP-12	

Dp#1	High	Lobby
	Low	Zone
Dp#2	High	MR Rm211A
	Low	AHU4 RA Tap
Dp#3	High	Outside
	Low	Zone

IAQDS12

Data Station Location: Rm 415 Label Colors: 1st:Orange
Station No.: 1 ' 2nd:Lt.Blue
Data Logger ID#: 12
Modem Jack ID No: J62

Channel ID	Calib Menu ID#	Connect To	Function
ADC1	1	INT	Dp#1 Zone to Lobby +-0.1
ADC2	2	INT	Dp#2 4th Lobby to 2nd Lobby +-0.1
ADC3	3	FP-2	Dp#3 Zone to Outside +-1.0
ADC4	4	FP-9	HVAC RA Temp AHU9 Rm 414
ADC5	5	INT	Zone Temp
ADC6	6	INT	Zone RH
ADC7	7	INT	Zone CO2
ADC8	8	FP-3	HVAC RA RH AHU9 Rm 414
SW1	9	FP-6	HVAC SA Press Switch AHU9 Rm 414
SW2	10	FP-13	
SW3	11	FP-7	
Cnt1	12	INT	Femto Zone Radon
Cnt2	13	FP-5	
Cnt3	14	FP-12	

Dp#1 High Lobby
Low Zone

Dp#2 High 4th Floor Lobby
Low 2nd Floor Lobby

Dp#3 High Outside
Low Zone

IAQDS13

Data Station Location: Rm 445 Label Colors: 1st:Orange
Station No.: 2 ' 2nd:Green
Data Logger ID#: 13
Modem Jack ID No: J75

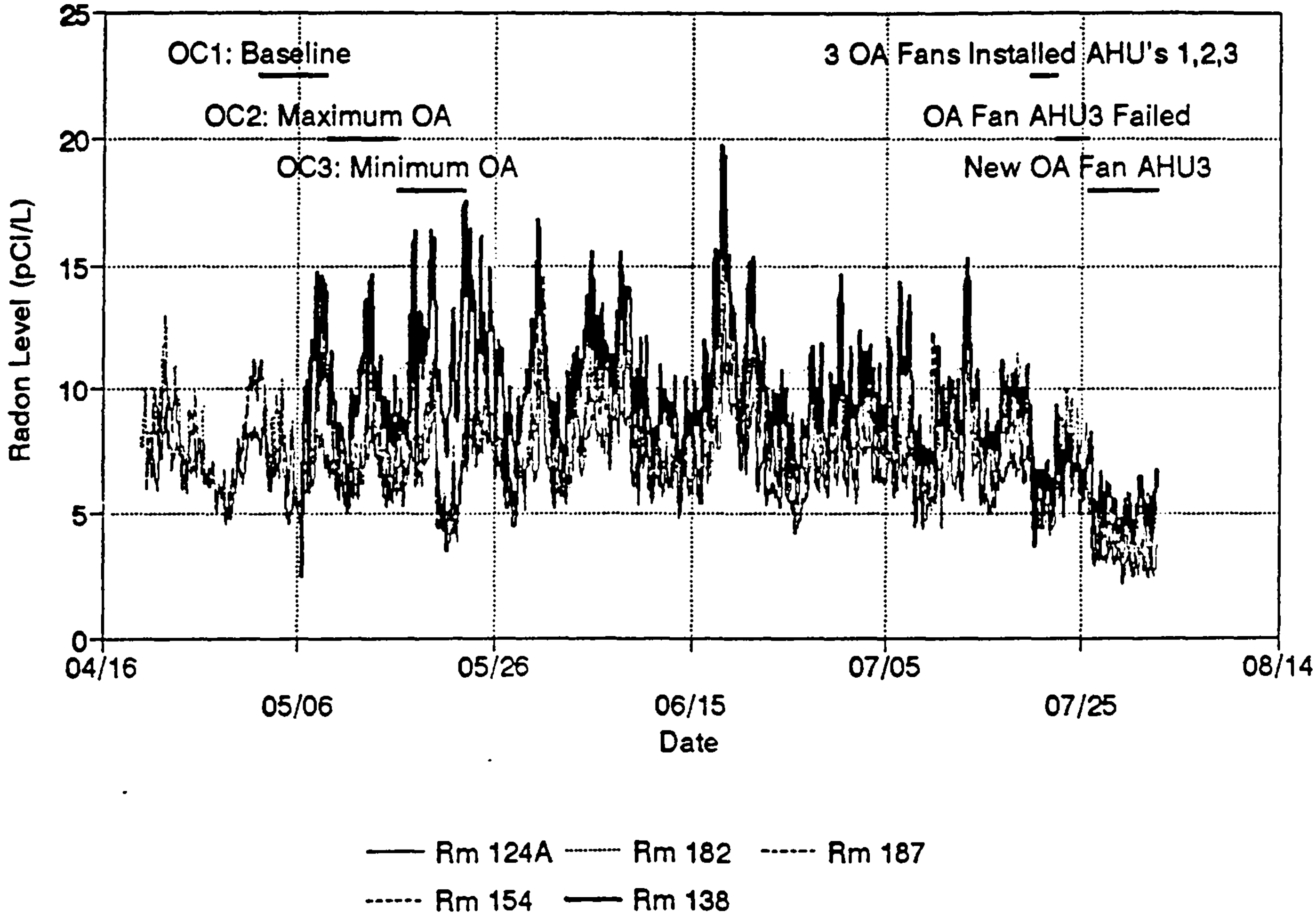
Channel ID	Calib Menu ID#	Connect To	Function
ADC1	1	INT	Dp#1 Zone to Lobby +-0.1
ADC2	2	INT	Dp#2 Zone to Outside +-1.0
ADC3	3	FP-2	HVAC RA Temp AHU8 Rm 454
ADC4	4	FP-9	HVAC RA RH AHU8 Rm 454
ADC5	5	INT	Zone Temp
ADC6	6	INT	Zone RH
ADC7	7	INT	Zone CO2
ADC8	8	FP-3	
SW1	9	FP-6	HVAC SA Press Switch AHU8 Rm 454
SW2	10	FP-13	
SW3	11	FP-7	
Cnt1	12	INT	Femto Zone Radon
Cnt2	13	FP-5	
Cnt3	14	FP-12	

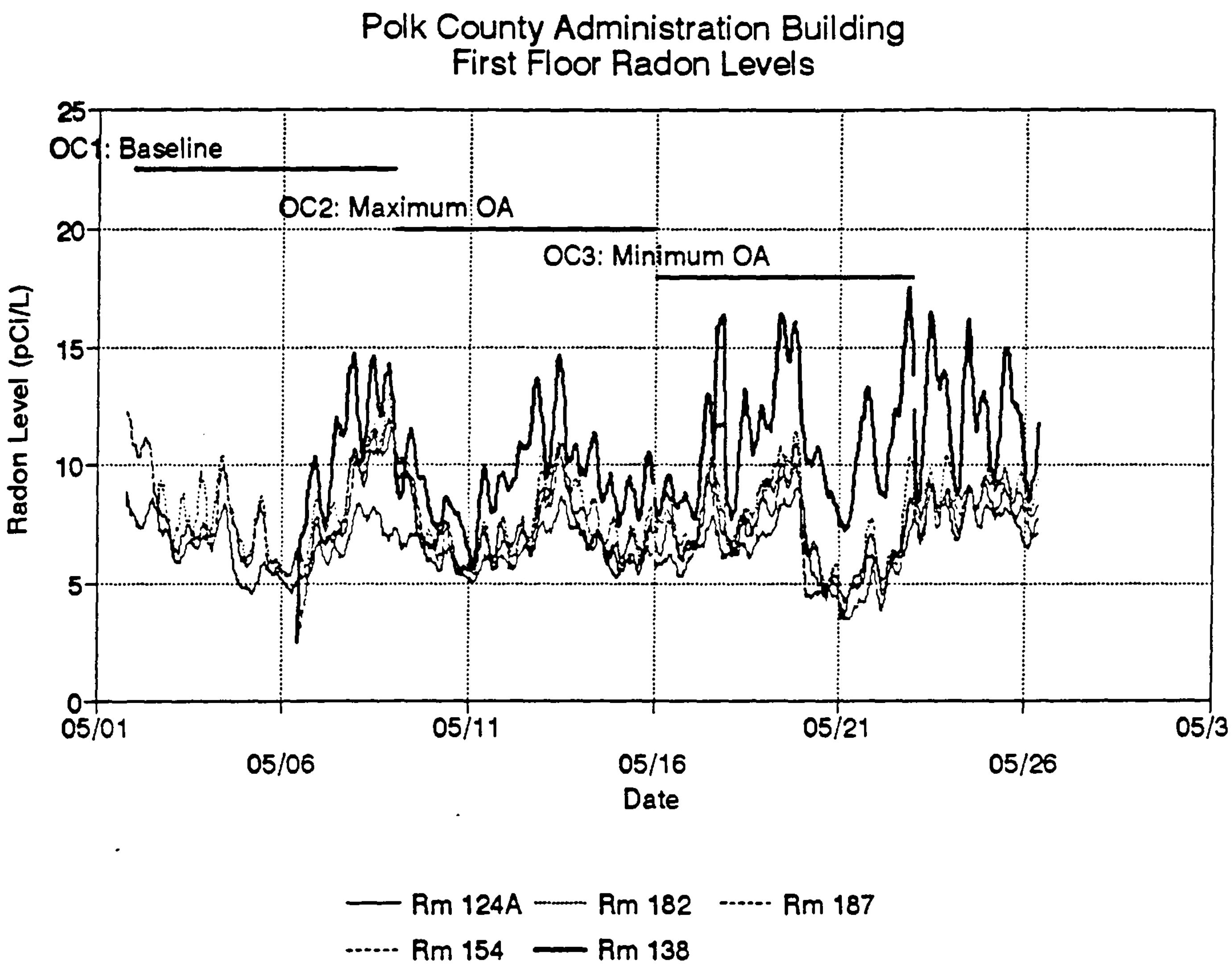
Dp#1 High Lobby
Low Zone

Dp#2 High Outside
Low Zone

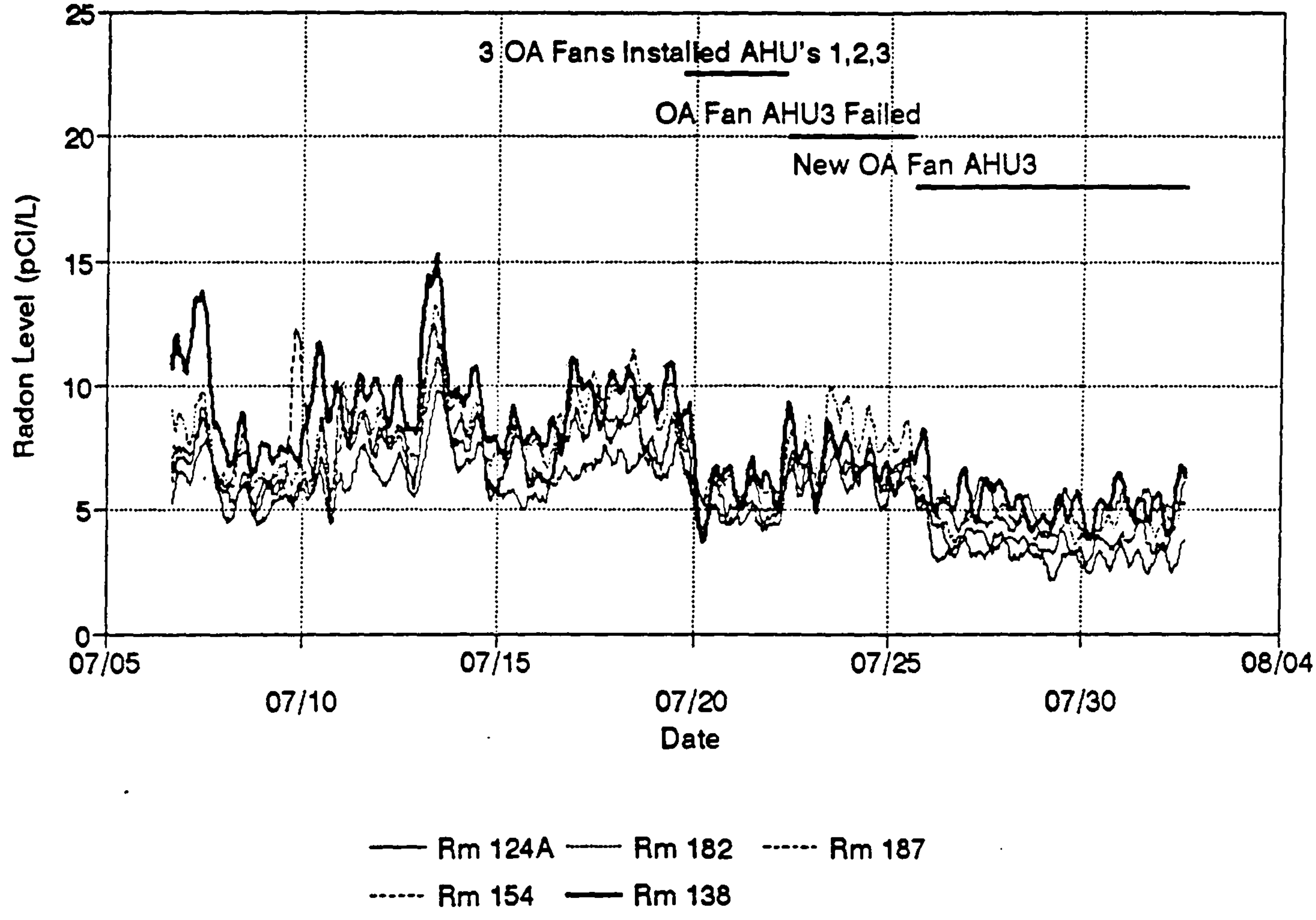
Appendix B. Average Continuous Radon Levels Measured With The IAQDS Units

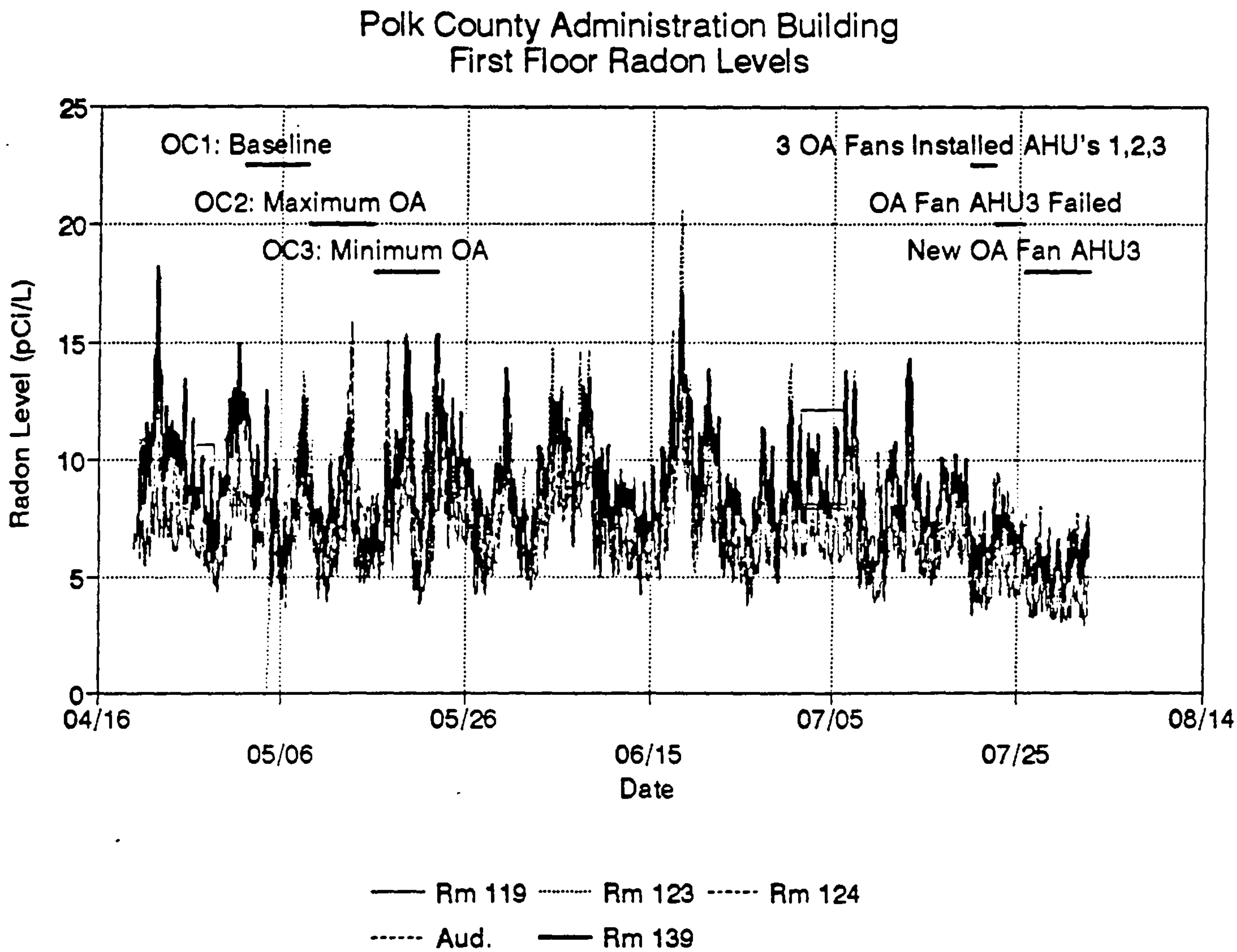
Polk County Administration Building
First Floor Radon Levels

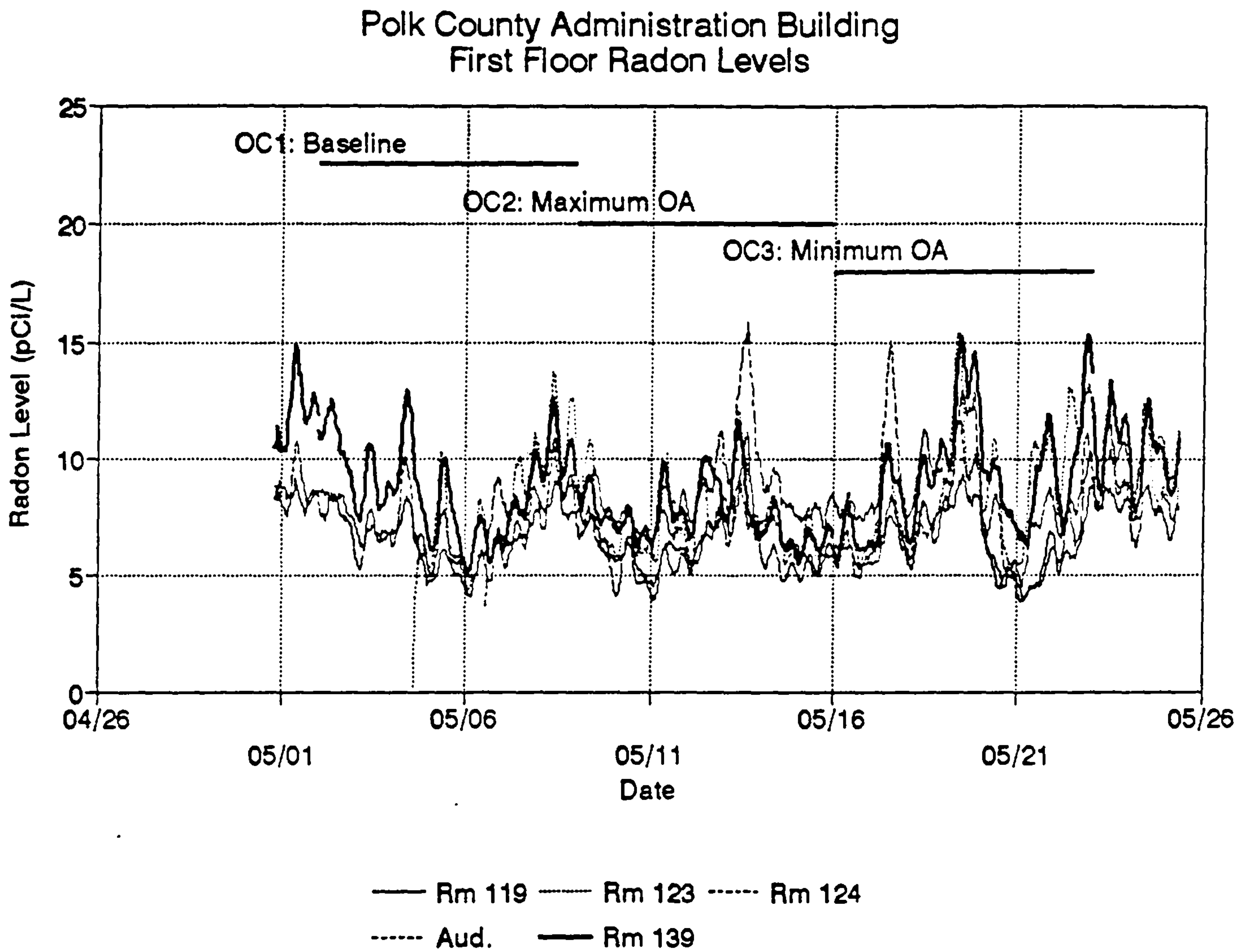



Polk County Administration Building
First Floor Radon Levels
25
OC1: Baseline
OC2: Maximum OA
20
OC3: Minimum OA
15
10
5
0
Radon Level (pCi/L)
05/01
05/06
05/11
05/16
05/21
05/26
05/31
Date
Rm 124A
Rm 182
Rm 187
Rm 154
Rm 138

Polk County Administration Building
First Floor Radon Levels

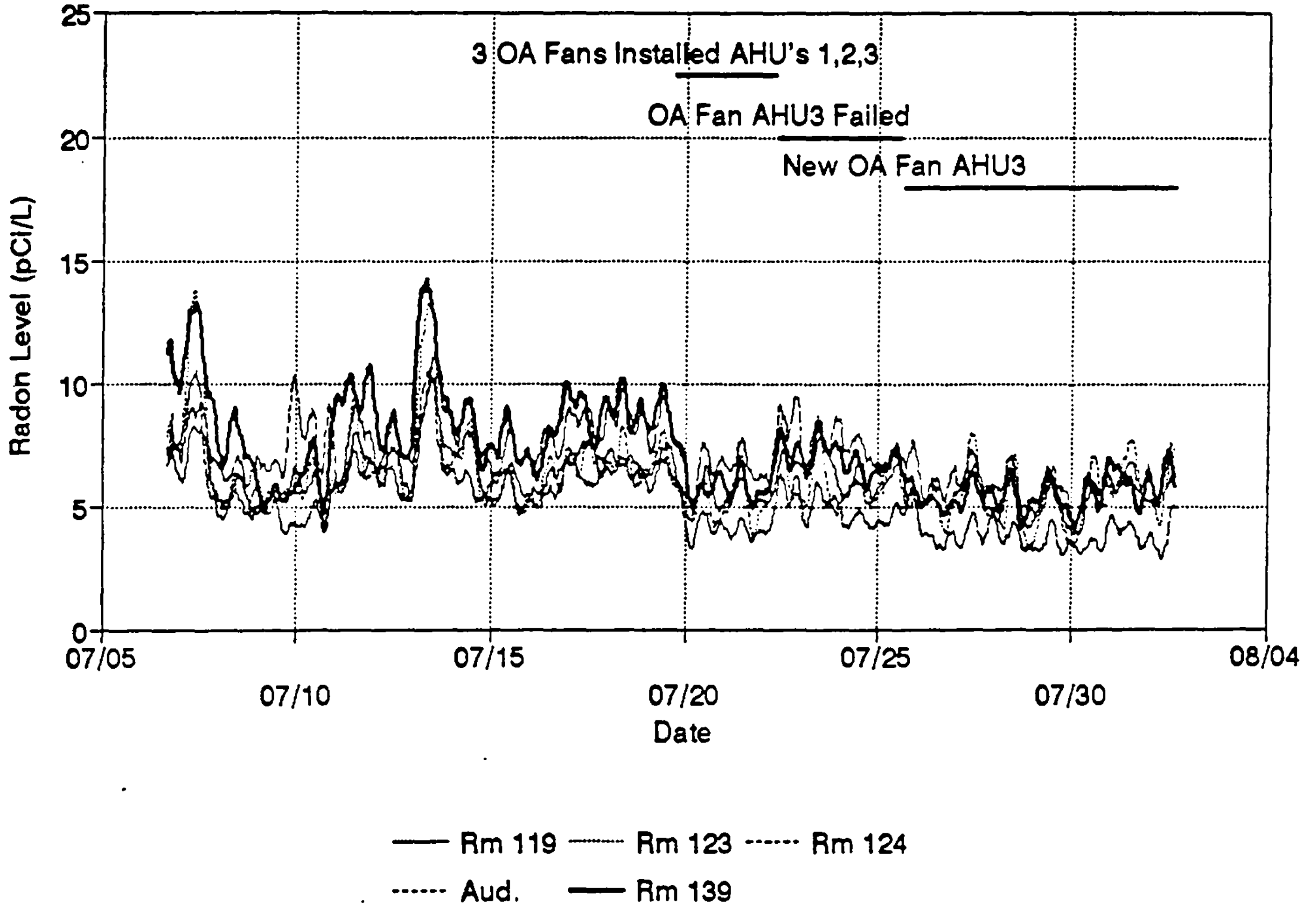


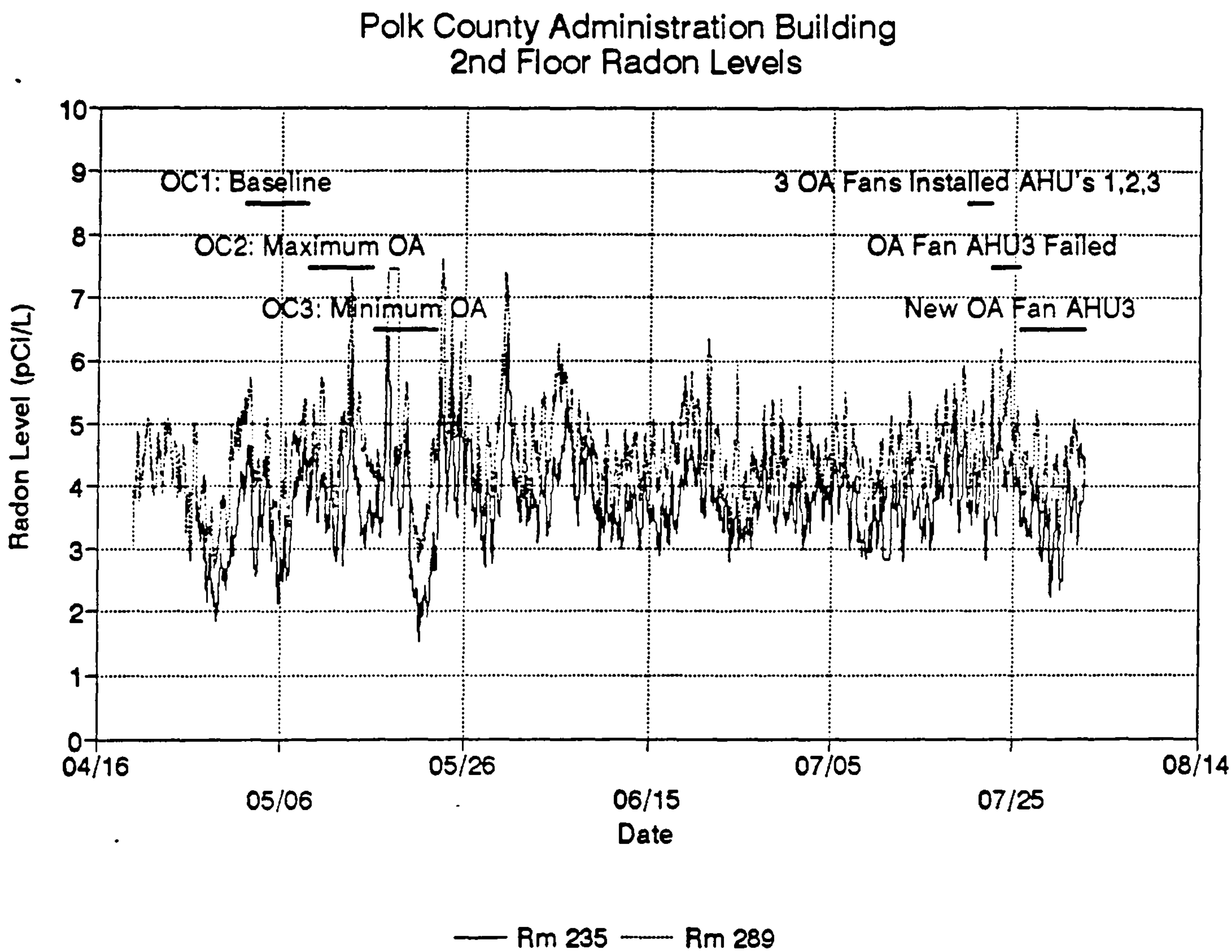

Polk County Administration Building
First Floor Radon Levels
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Radon Level (pCI/L)
25
20
15
10
5
0
04/16
05/06
05/26
06/15
07/05
07/25
08/14
Date
Rm 119
Rm 123
Rm 124
Aud.
Rm 139



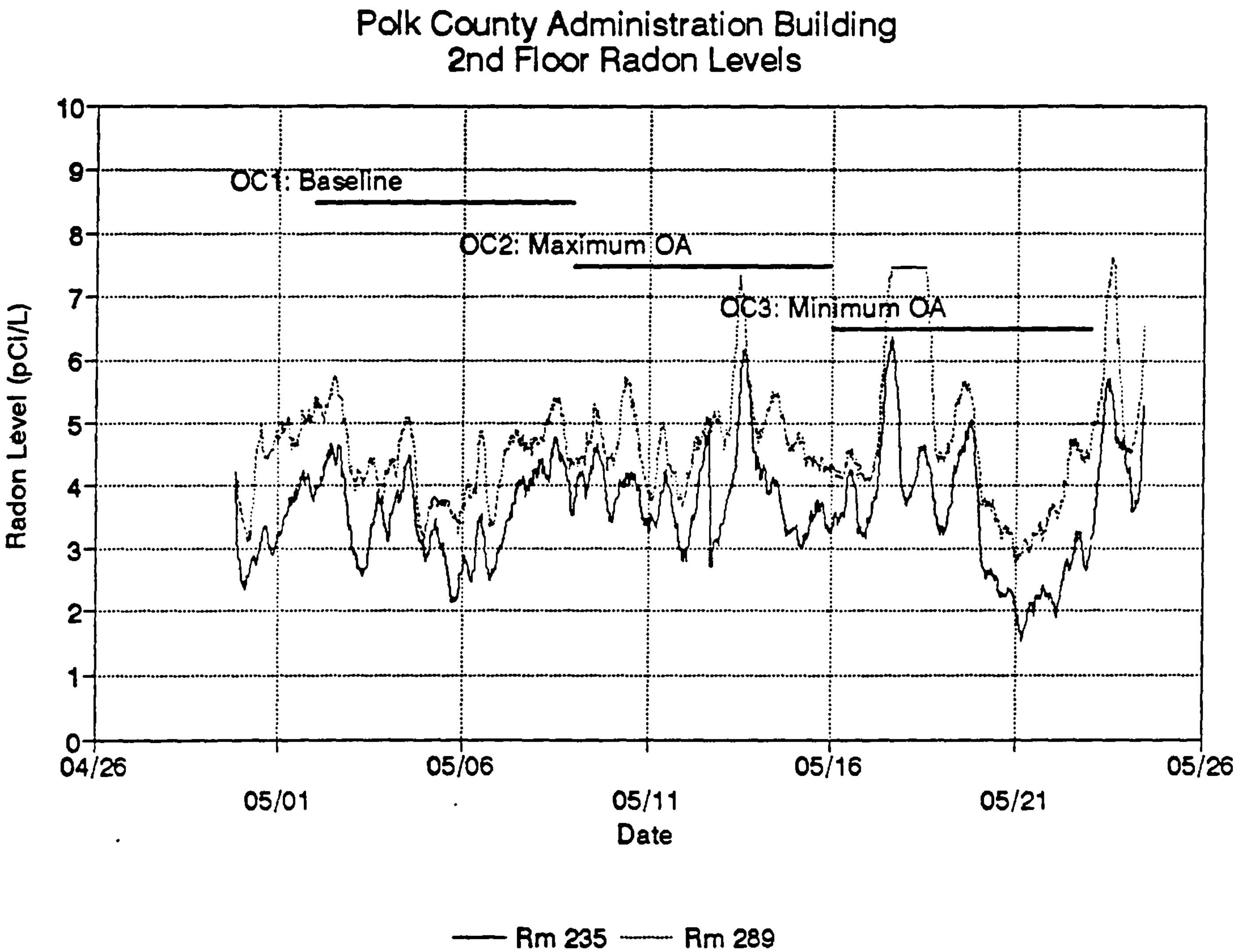
Polk County Administration Building
First Floor Radon Levels
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
25
20
15
10
5
0
Radon Level (pCi/L)
04/26
05/01
05/06
05/11
05/16
05/21
05/26
Date
Rm 119
Rm 123
Rm 124
Aud.
Rm 139

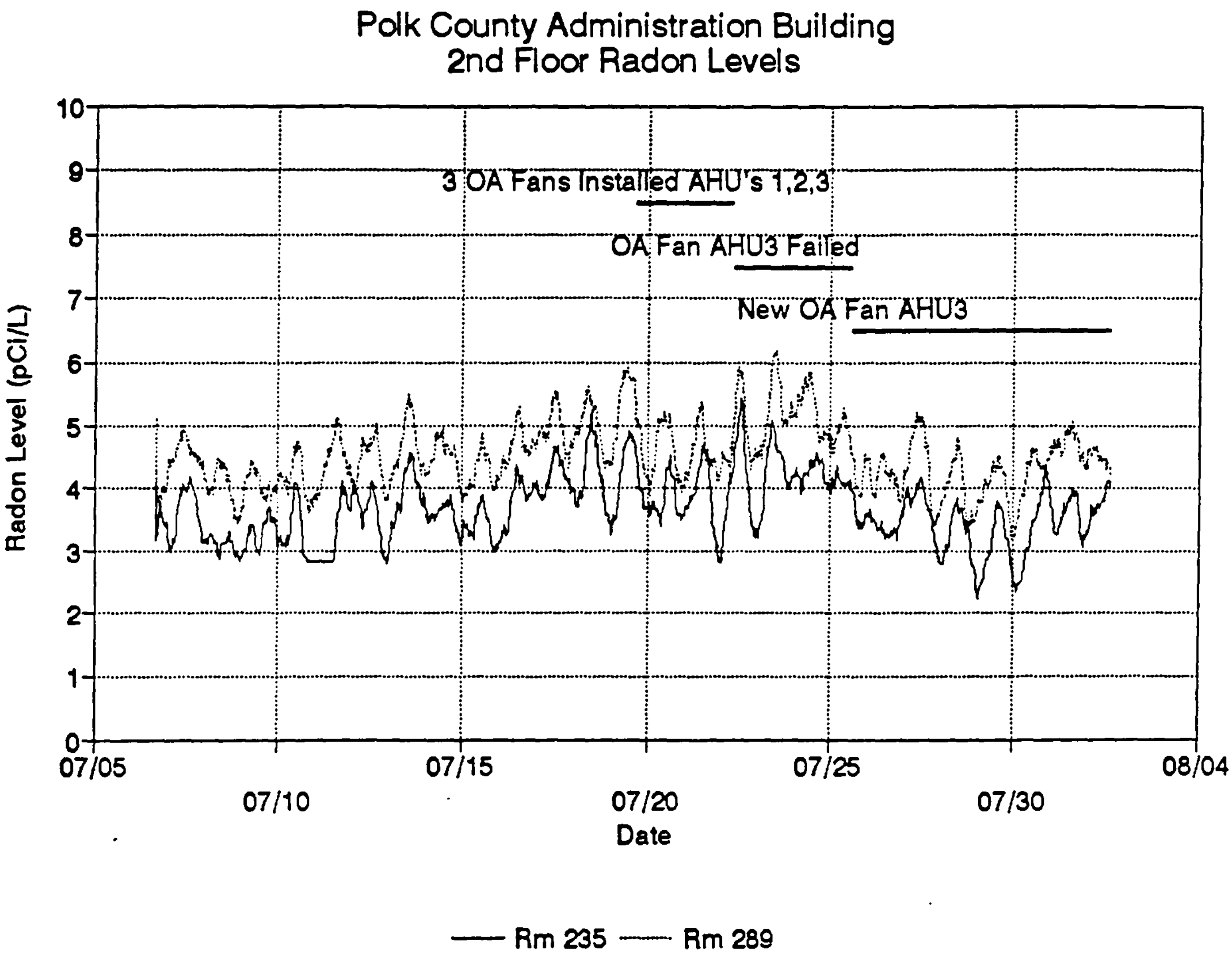
Polk County Administration Building
First Floor Radon Levels



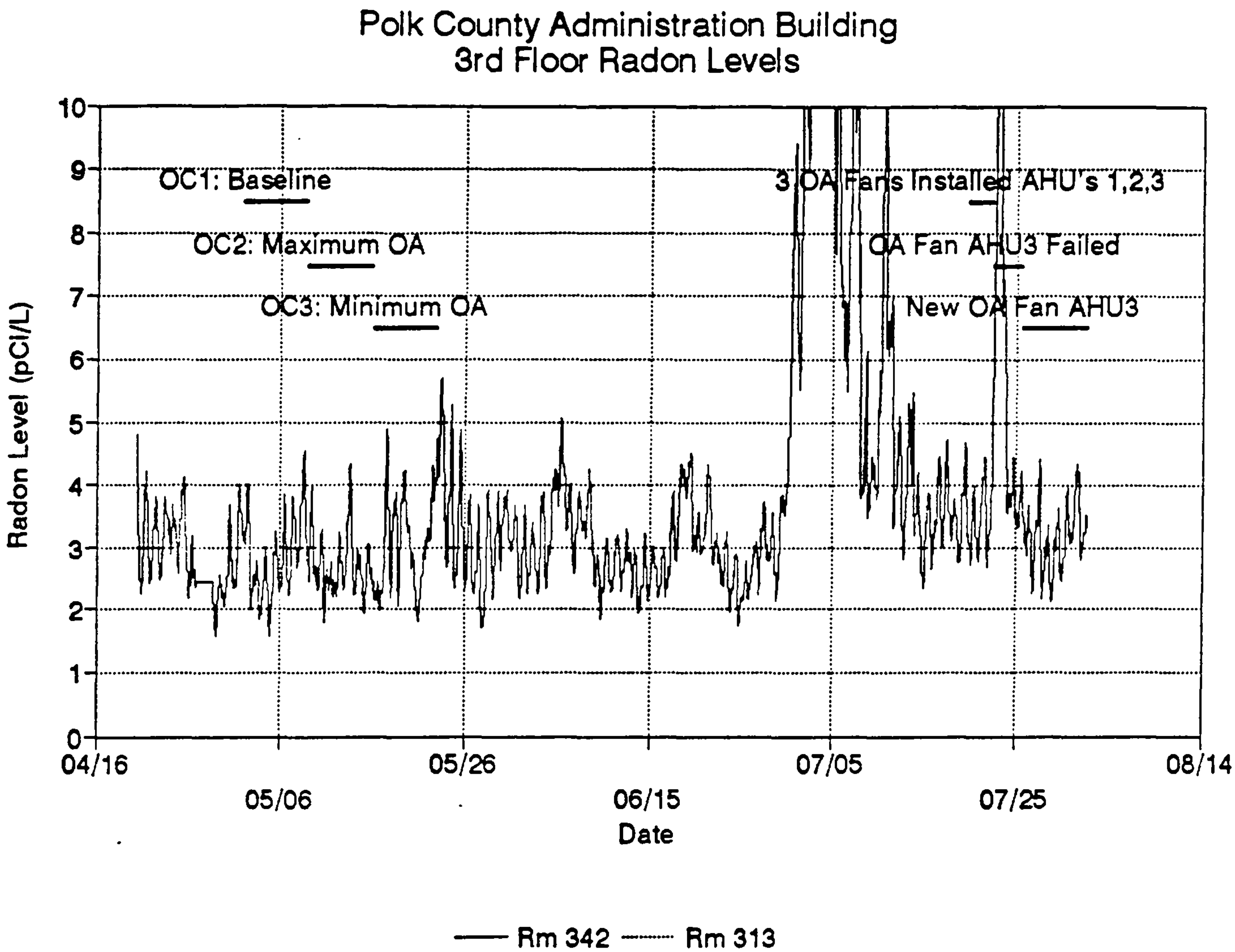


Polk County Administration Building
2nd Floor Radon Levels
Radon Level (pCi/L)
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
0
1
2
3
4
5
6
7
8
9
10
04/16
05/06
05/26
06/15
07/05
07/25
08/14
Date
Rm 235
Rm 289

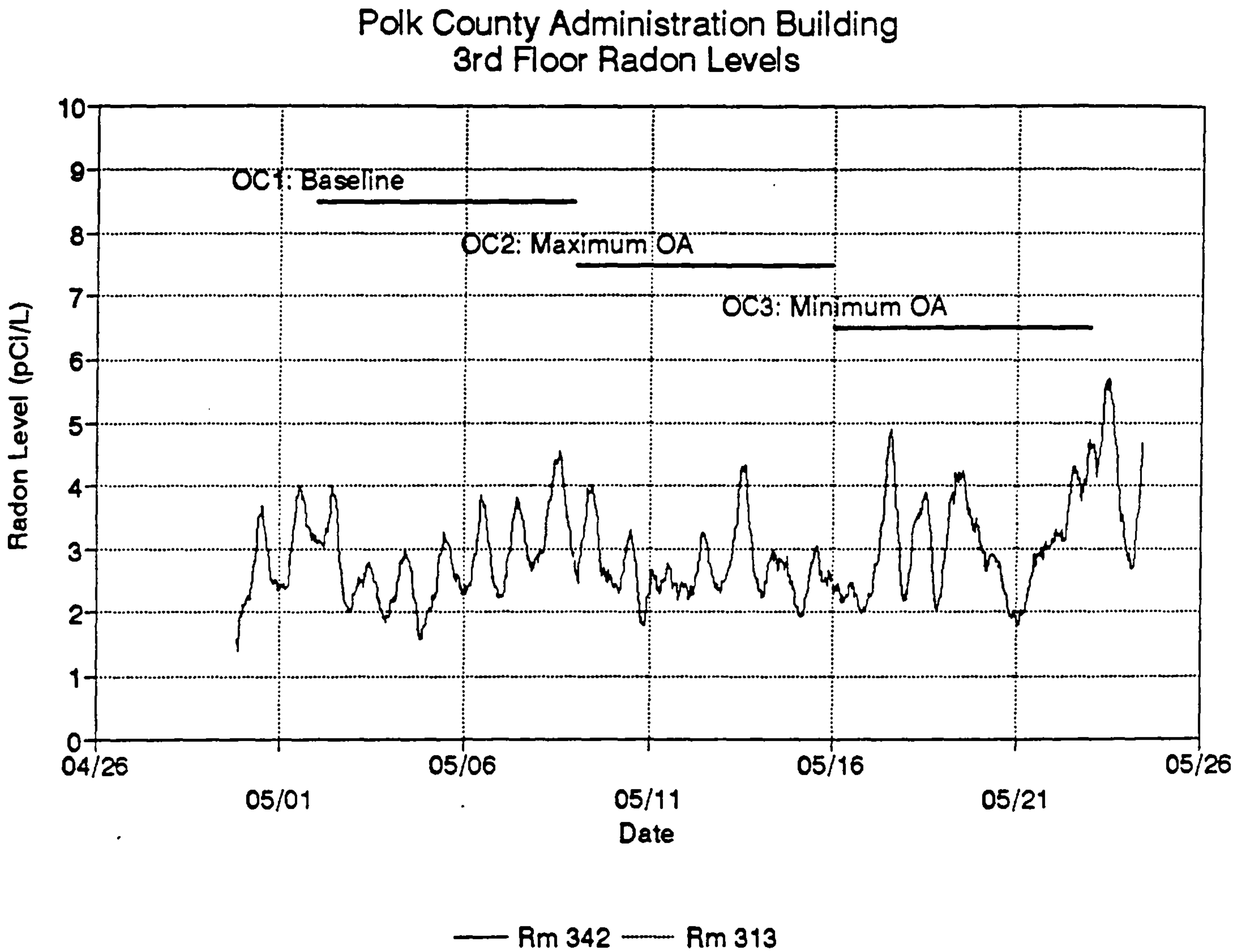

Polk County Administration Building
2nd Floor Radon Levels
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
Radon Level (pCi/L)
10
9
8
7
6
5
4
3
2
1
0
04/26
05/01
05/06
05/11
05/16
05/21
05/26
Date
Rm 235
Rm 289

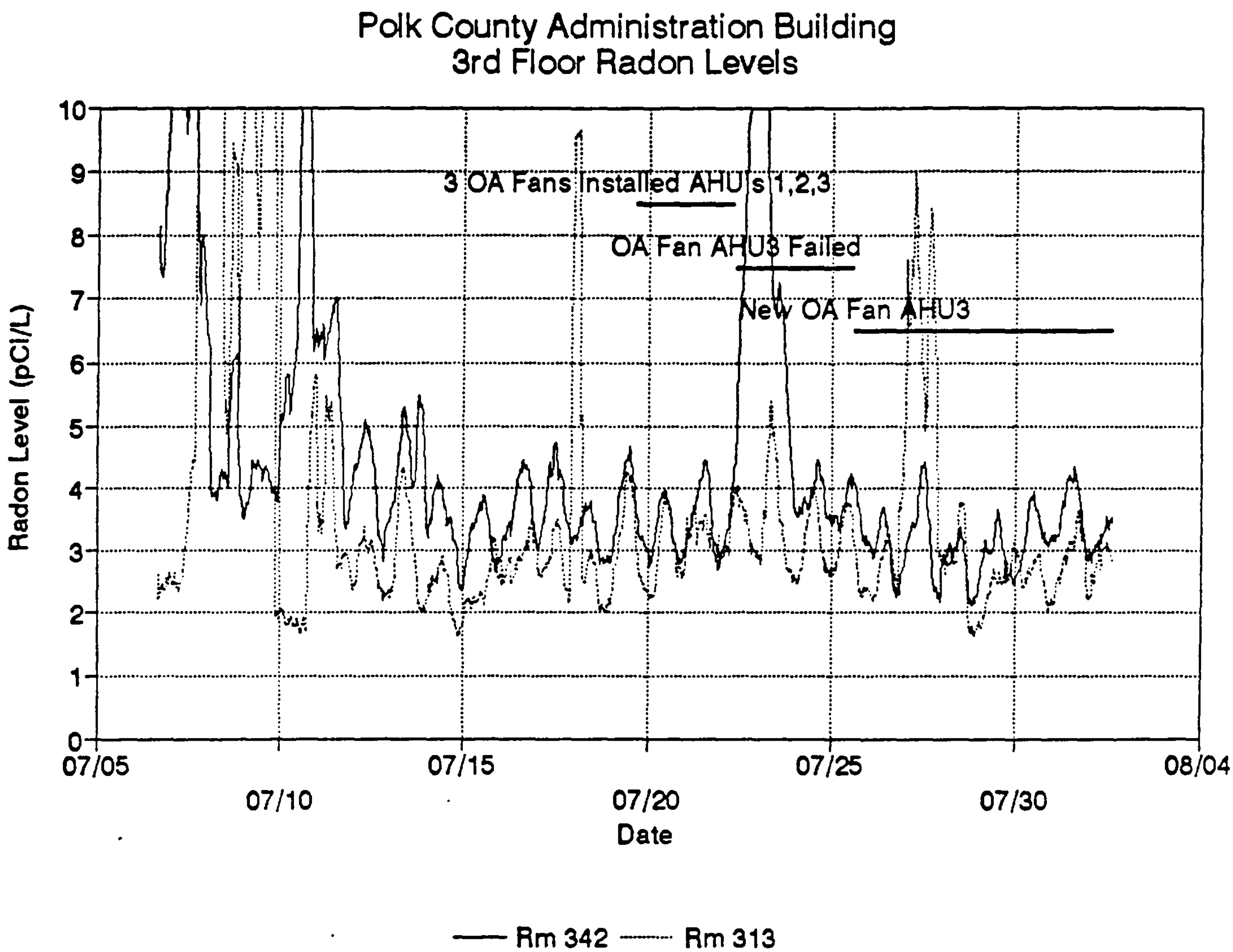


Polk County Administration Building
2nd Floor Radon Levels
Radon Level (pCI/L)
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
0
1
2
3
4
5
6
7
8
9
10
07/05
07/10
07/15
07/20
07/25
07/30
08/04
Date
Rm 235
Rm 289

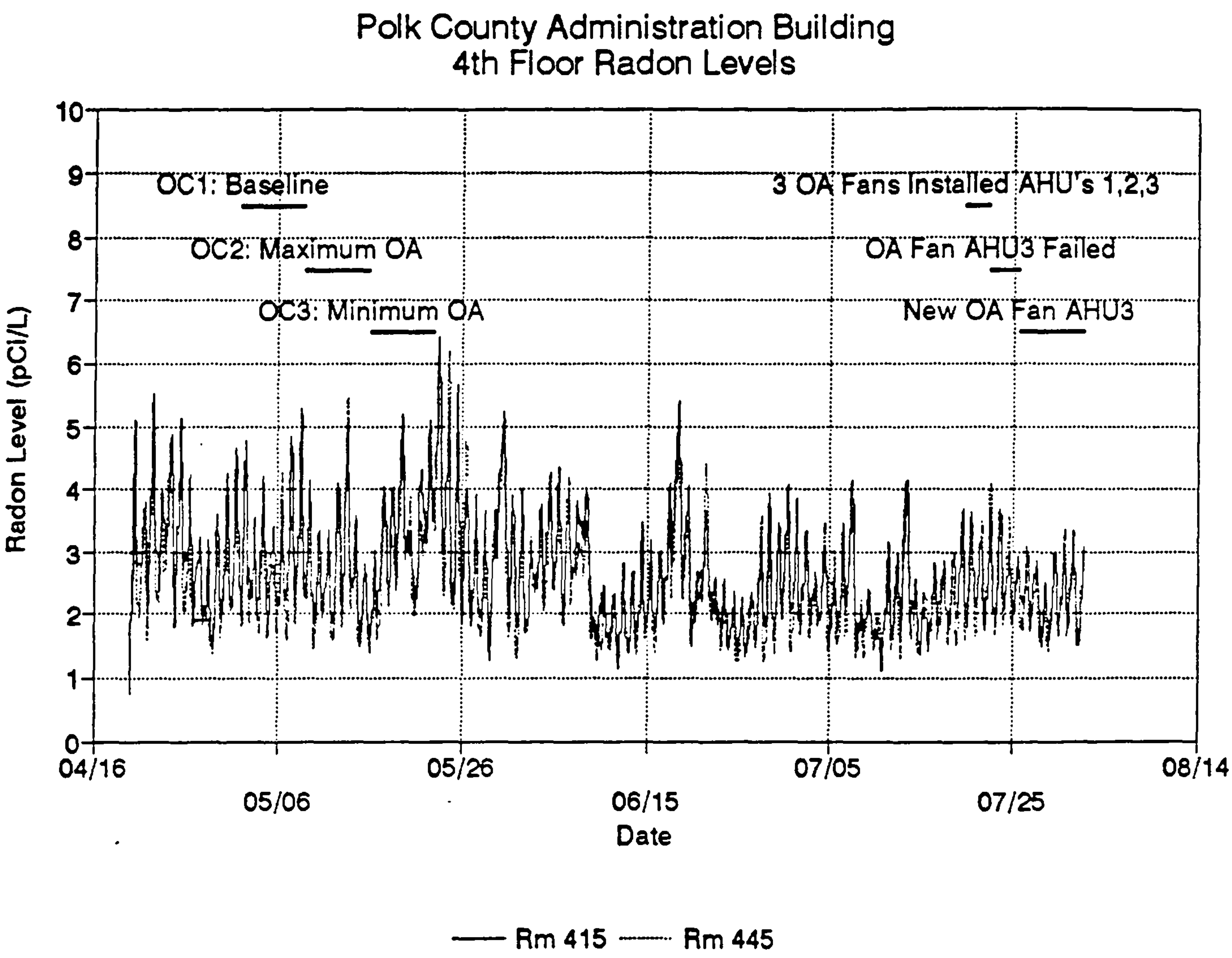


Polk County Administration Building
3rd Floor Radon Levels
10
9
8
7
6
5
4
3
2
1
0
Radon Level (pCi/L)
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
04/16
05/06
05/26
06/15
07/05
07/25
08/14
Date
Rm 342
Rm 313

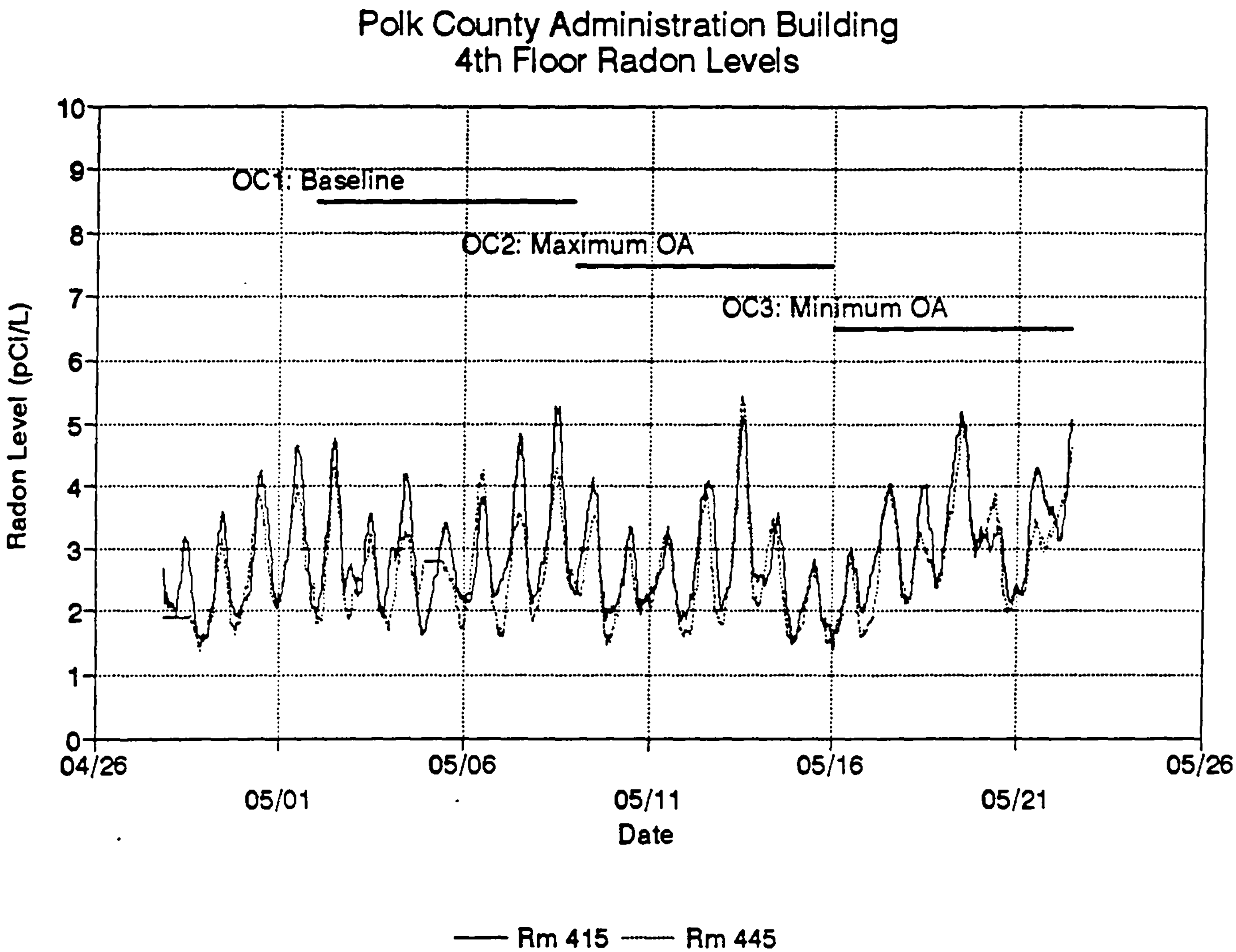

Polk County Administration Building
3rd Floor Radon Levels
Radon Level (pCi/L)
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
0
1
2
3
4
5
6
7
8
9
10
04/26
05/01
05/06
05/11
05/16
05/21
05/26
Date
Rm 342
Rm 313

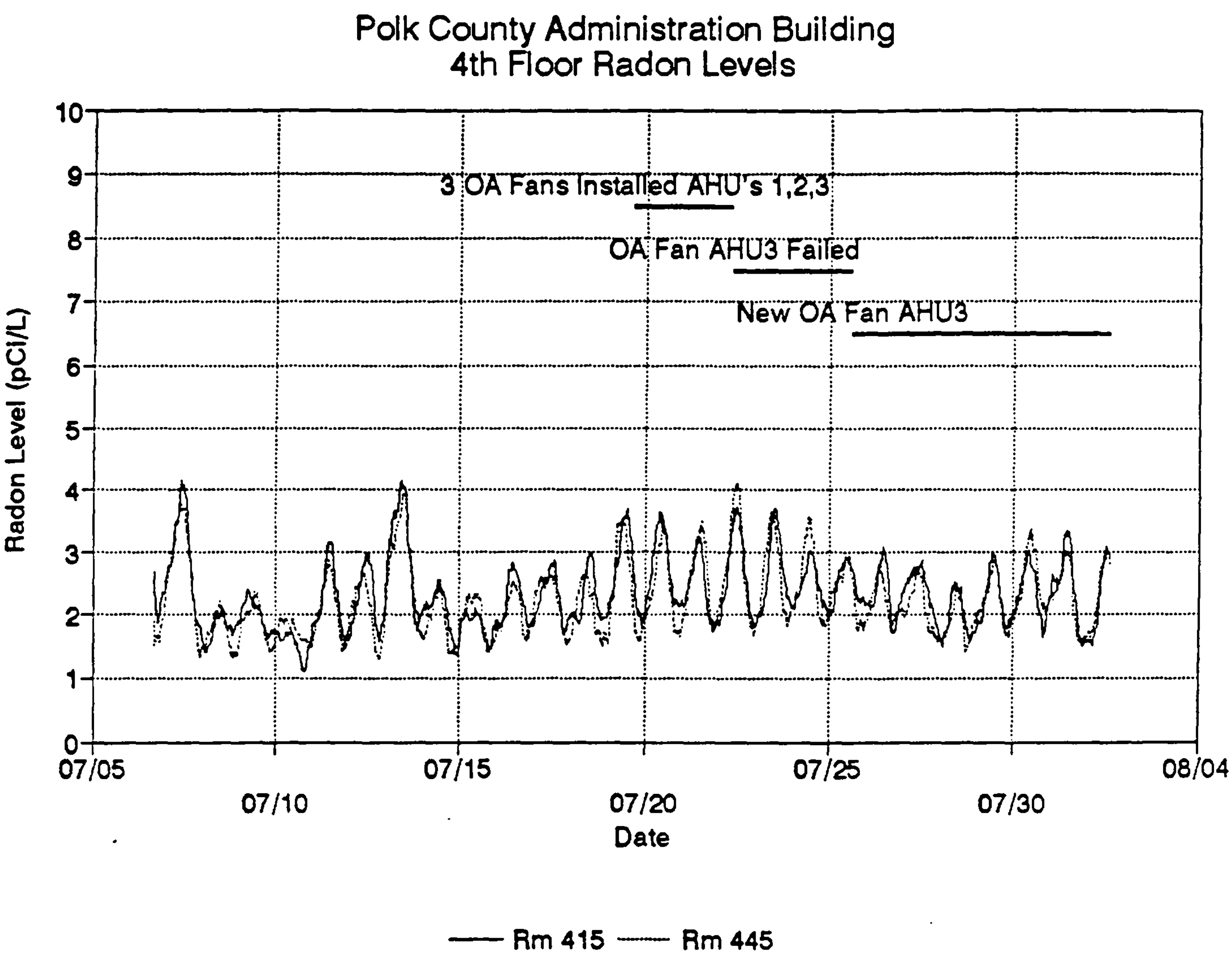


Polk County Administration Building
3rd Floor Radon Levels
Radon Level (pCi/L)
10
9
8
7
6
5
4
3
2
1
0
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
07/05
07/10
07/15
07/20
07/25
07/30
08/04
Date
Rm 342
Rm 313

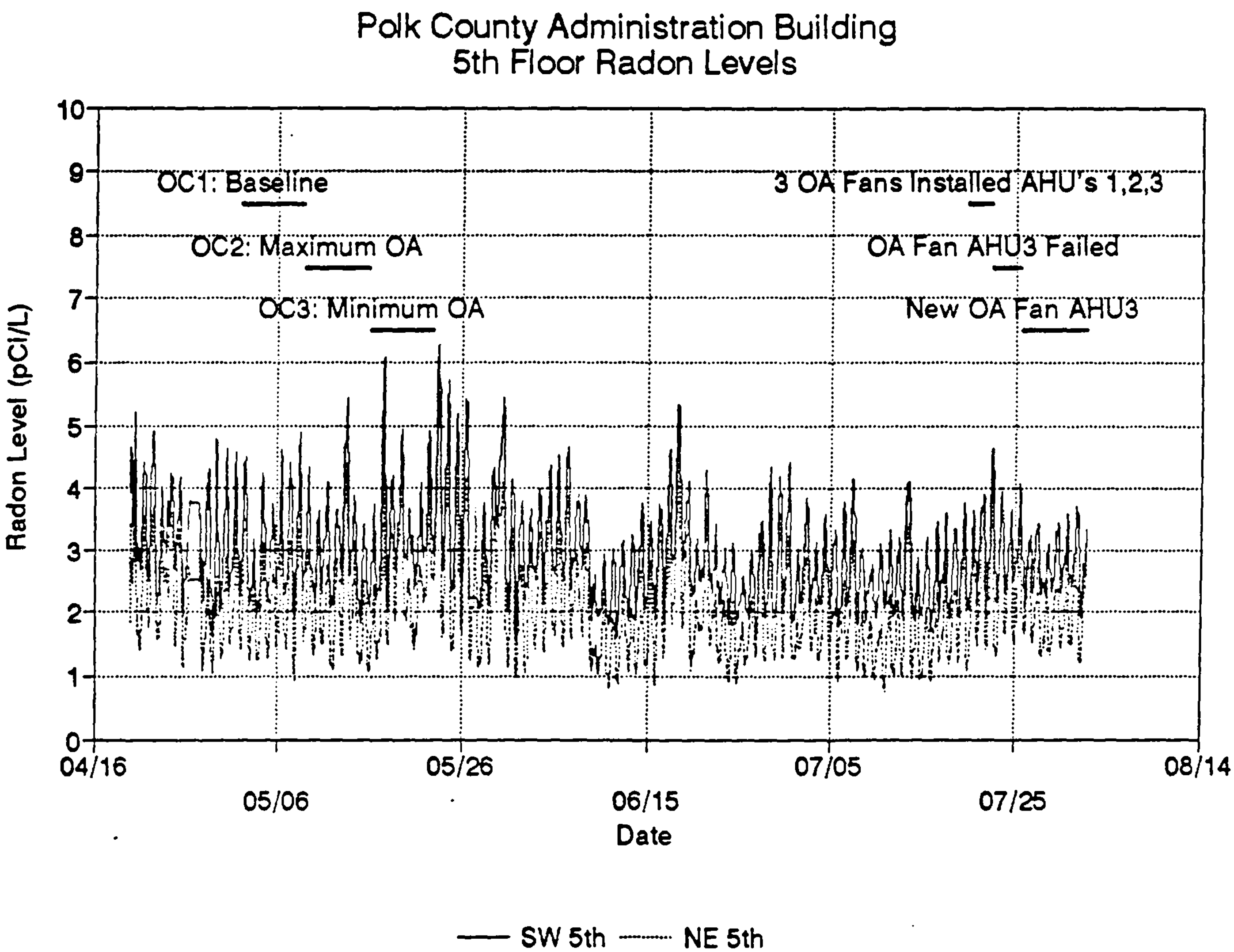


Polk County Administration Building
4th Floor Radon Levels
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Radon Level (pCi/L)
10
9
8
7
6
5
4
3
2
1
0
04/16
05/06
05/26
06/15
07/05
07/25
08/14
Date
Rm 415
Rm 445

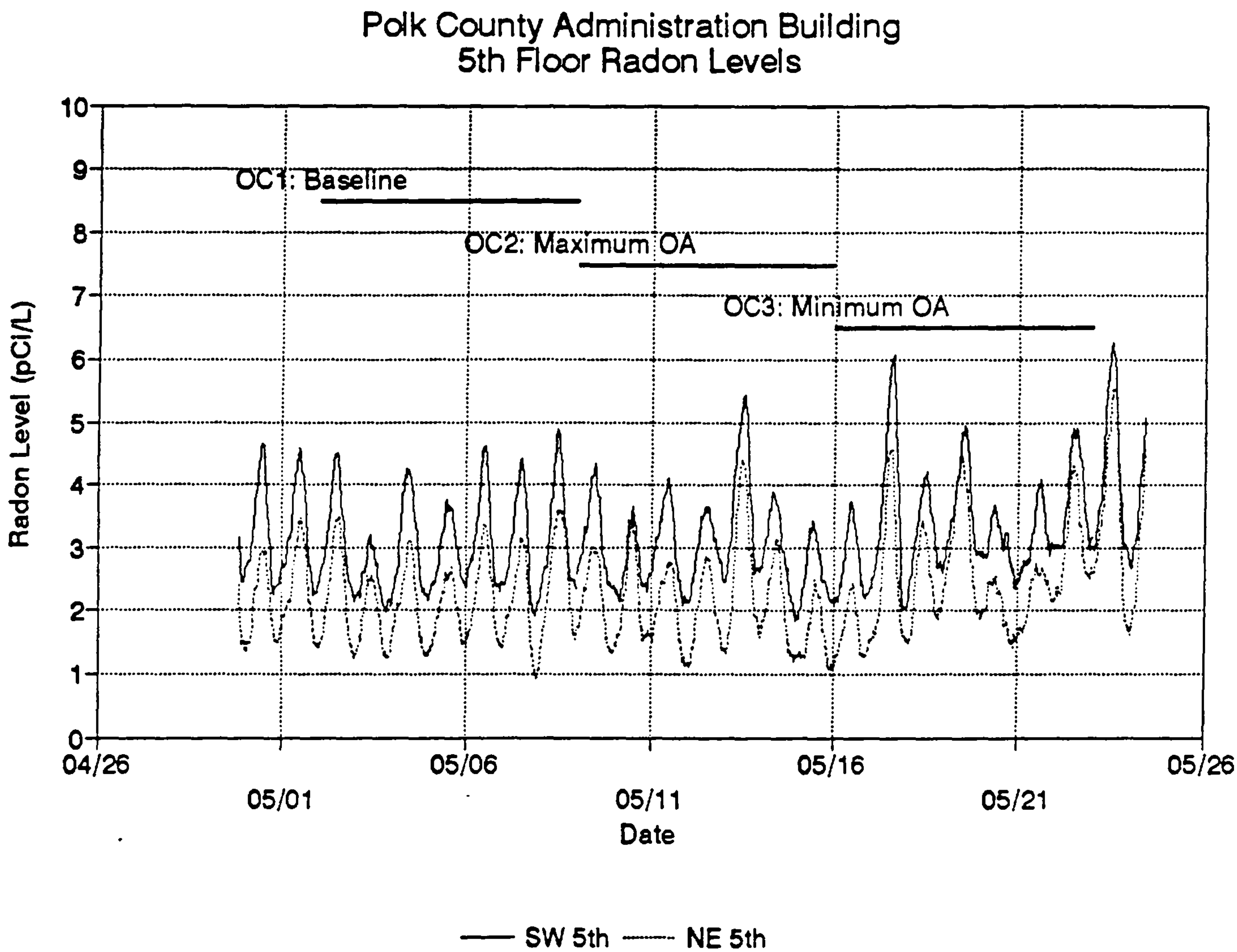

Polk County Administration Building
4th Floor Radon Levels
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
Radon Level (pCi/L)
10
9
8
7
6
5
4
3
2
1
0
04/26
05/01
05/06
05/11
05/16
05/21
05/26
Date
Rm 415
Rm 445



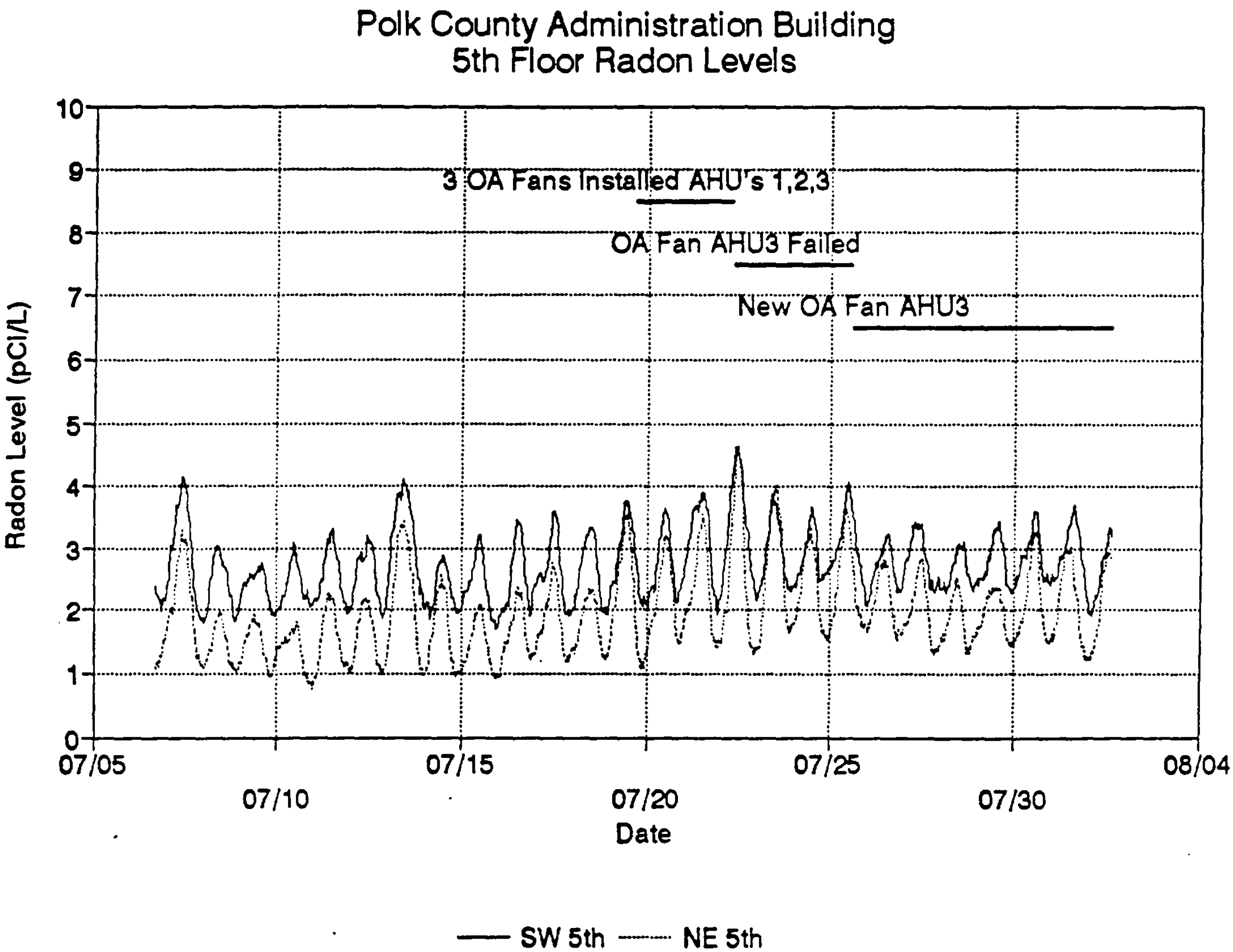
Polk County Administration Building
4th Floor Radon Levels
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Radon Level (pCi/L)
0
1
2
3
4
5
6
7
8
9
10
07/05
07/10
07/15
07/20
07/25
07/30
08/04
Date
Rm 415
Rm 445



Polk County Administration Building
5th Floor Radon Levels
Radon Level (pCi/L)
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
04/16
05/06
05/26
06/15
07/05
07/25
08/14
Date
SW 5th
NE 5th

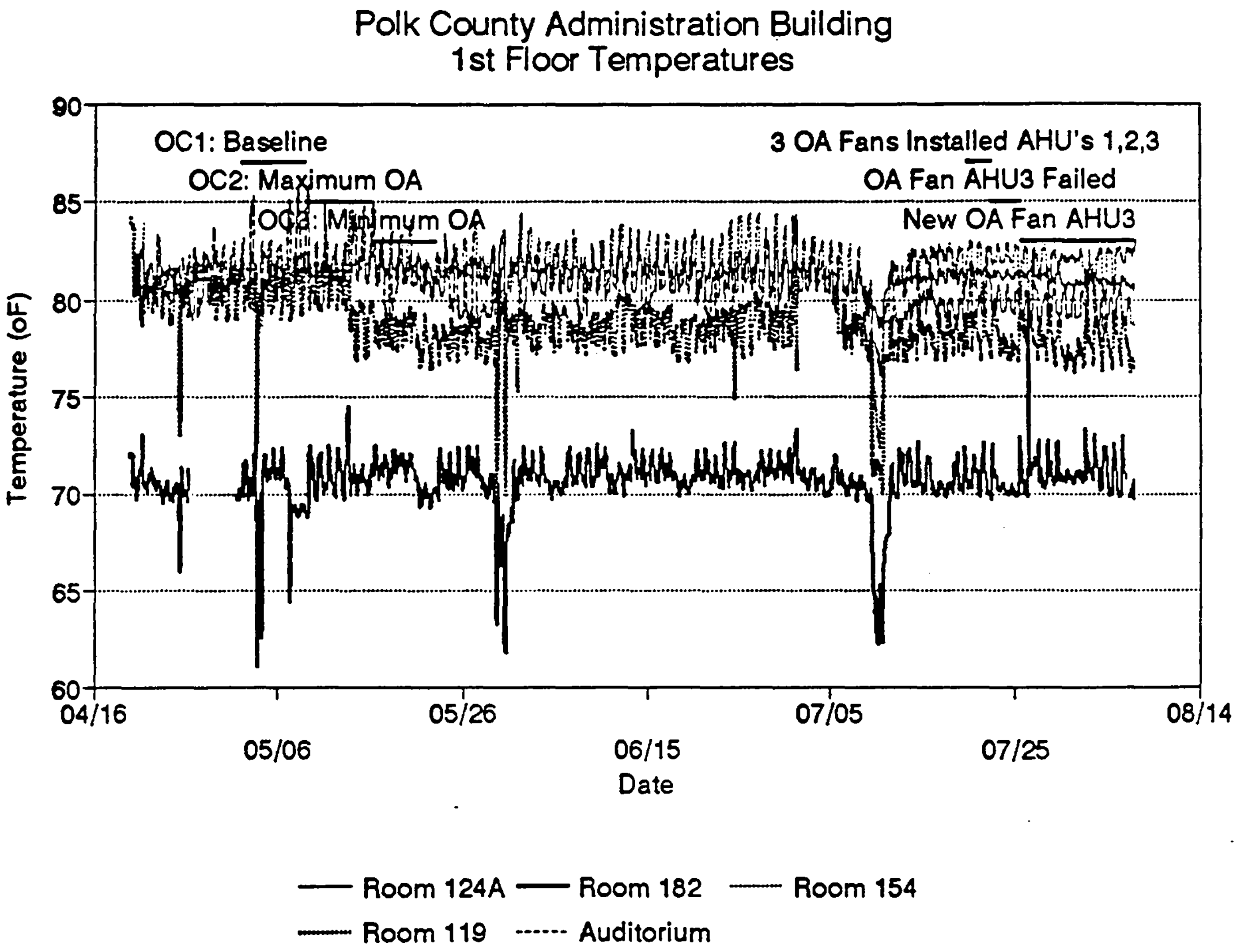


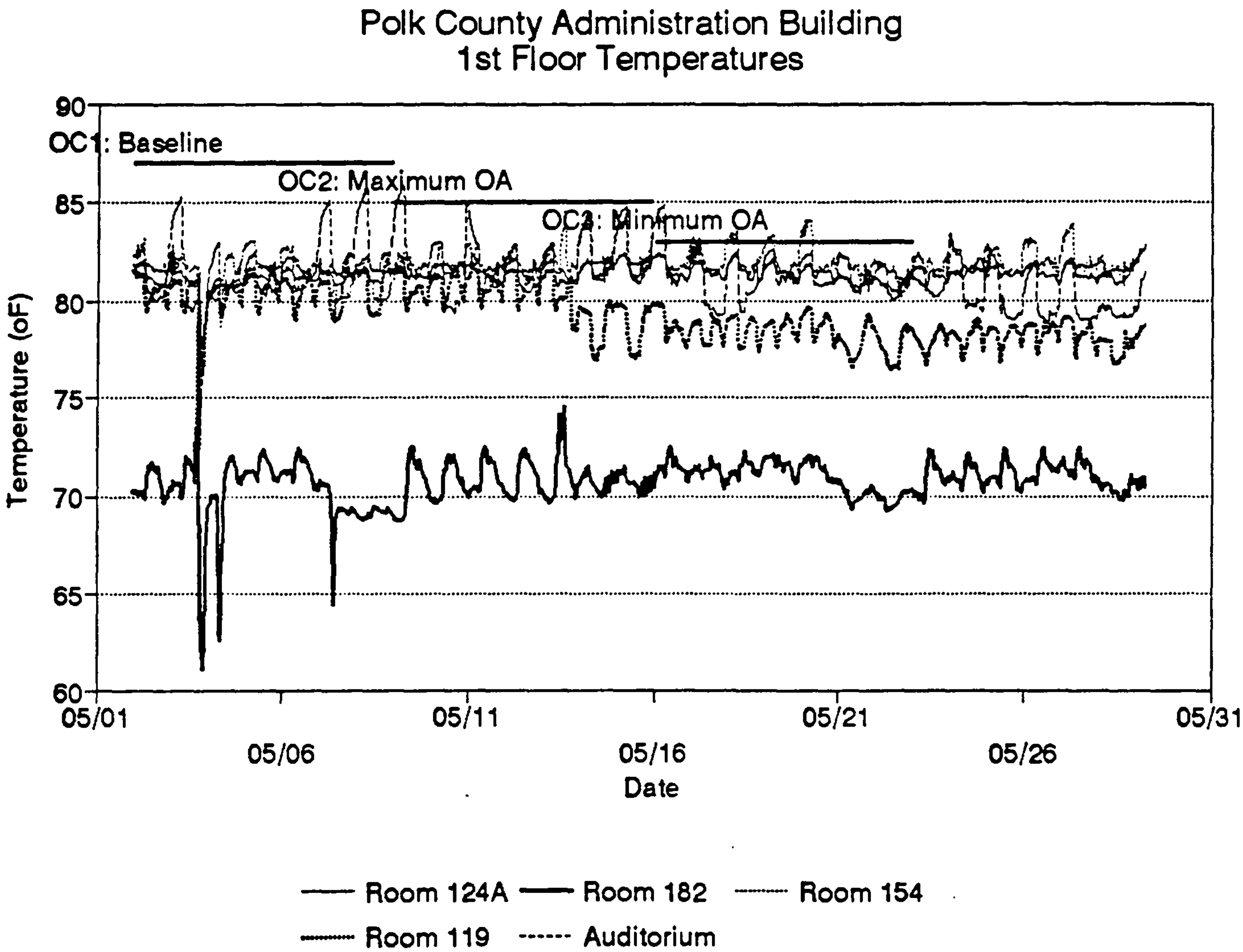
Polk County Administration Building
5th Floor Radon Levels
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
Radon Level (pCi/L)
0
1
2
3
4
5
6
7
8
9
10
04/26
05/01
05/06
05/11
05/16
05/21
05/26
Date
SW 5th
NE 5th

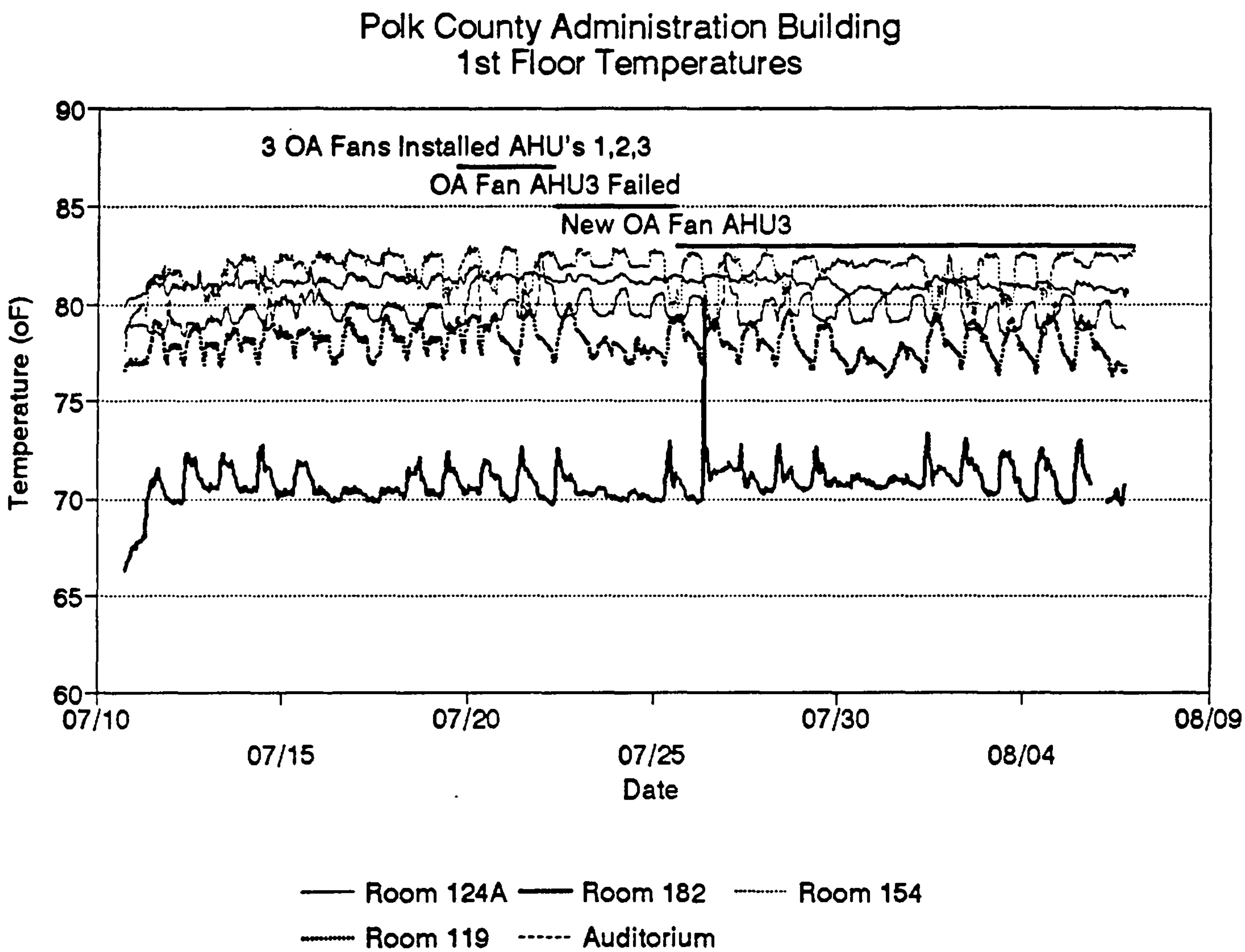


Polk County Administration Building
5th Floor Radon Levels
Radon Level (pCi/L)
10
9
8
7
6
5
4
3
2
1
0
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
07/05
07/10
07/15
07/20
07/25
07/30
08/04
Date
SW 5th
NE 5th

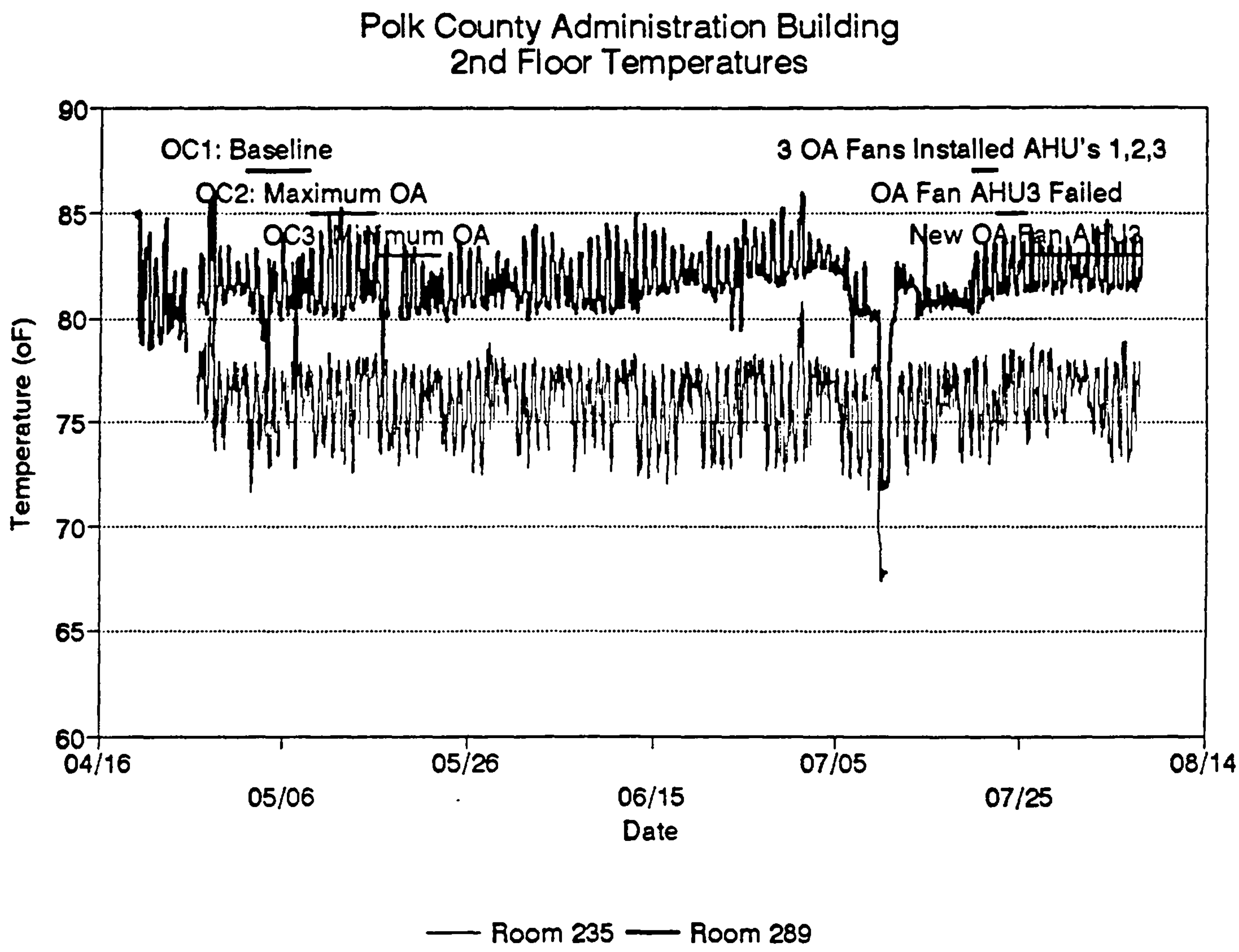
Appendix C. Average Continuous Temperatures Measured With the IAQDS Units

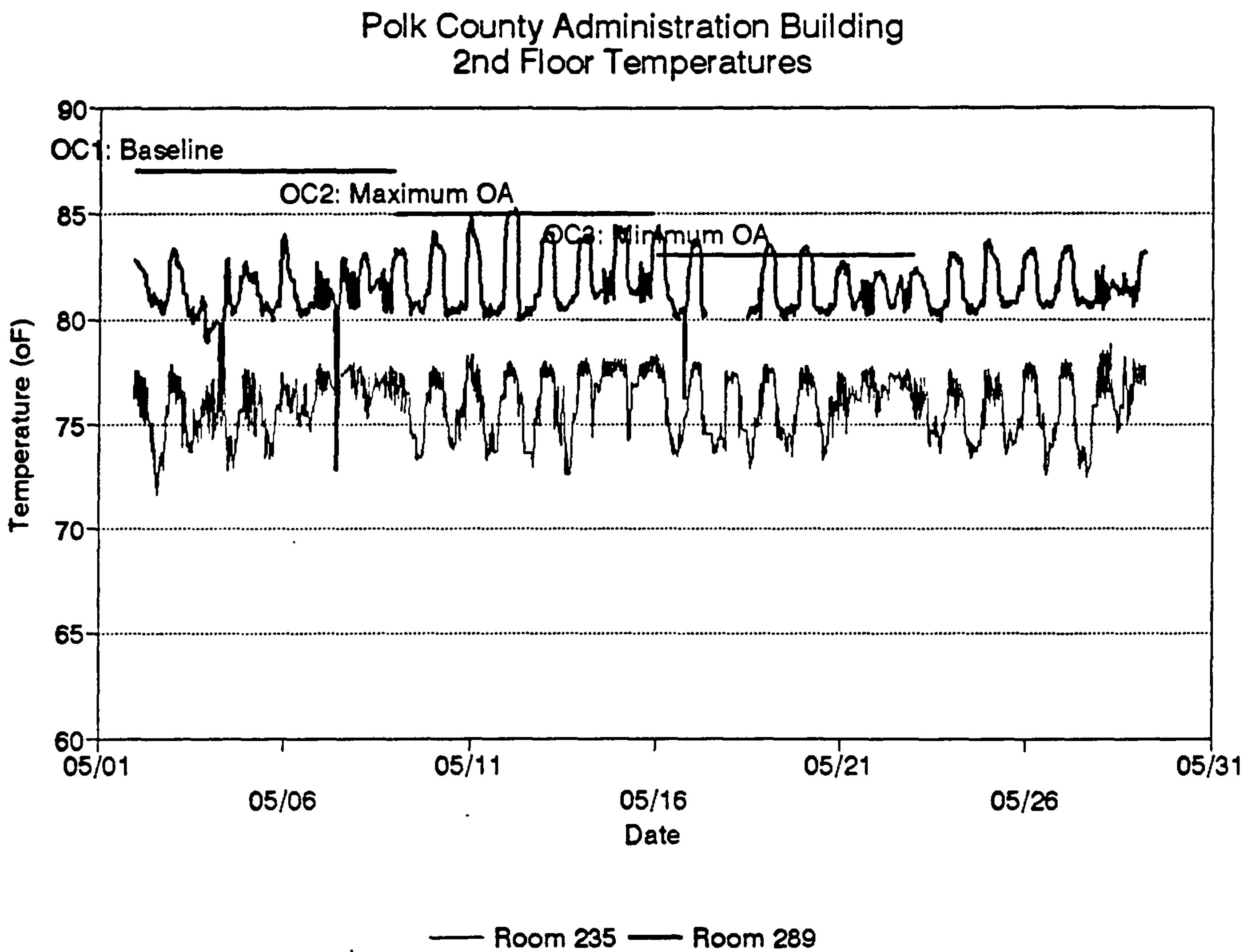

Polk County Administration Building
1st Floor Temperatures
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Temperature (oF)
90
85
80
75
70
65
60
04/16
05/06
05/26
06/15
07/05
07/25
08/14
Date
Room 124A
Room 182
Room 154
Room 119
Auditorium

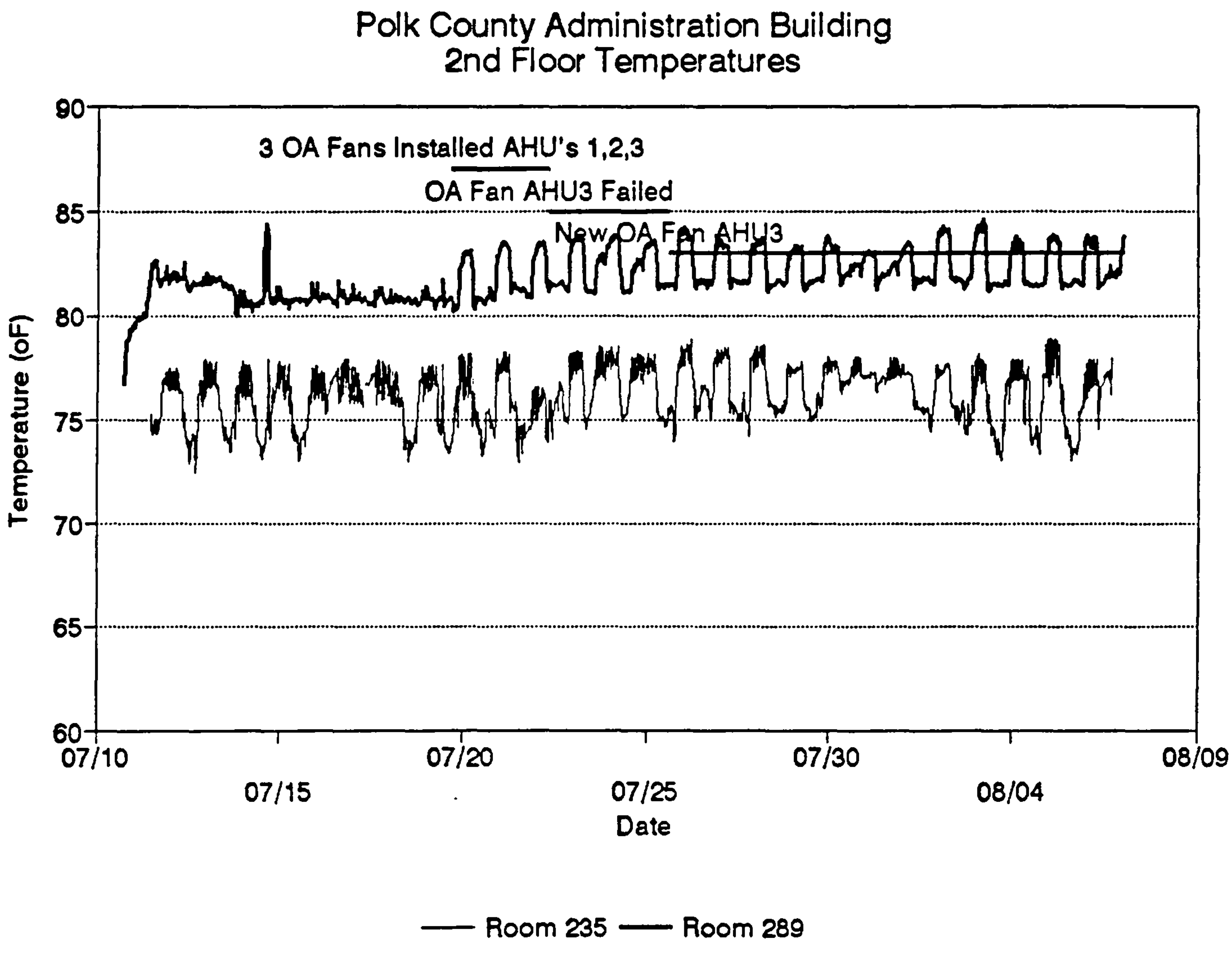

Polk County Administration Building
1st Floor Temperatures
90
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
85
80
75
70
65
60
Temperature (oF)
05/01
05/06
05/11
05/16
05/21
05/26
05/31
Date
Room 124A
Room 182
Room 154
Room 119
Auditorium



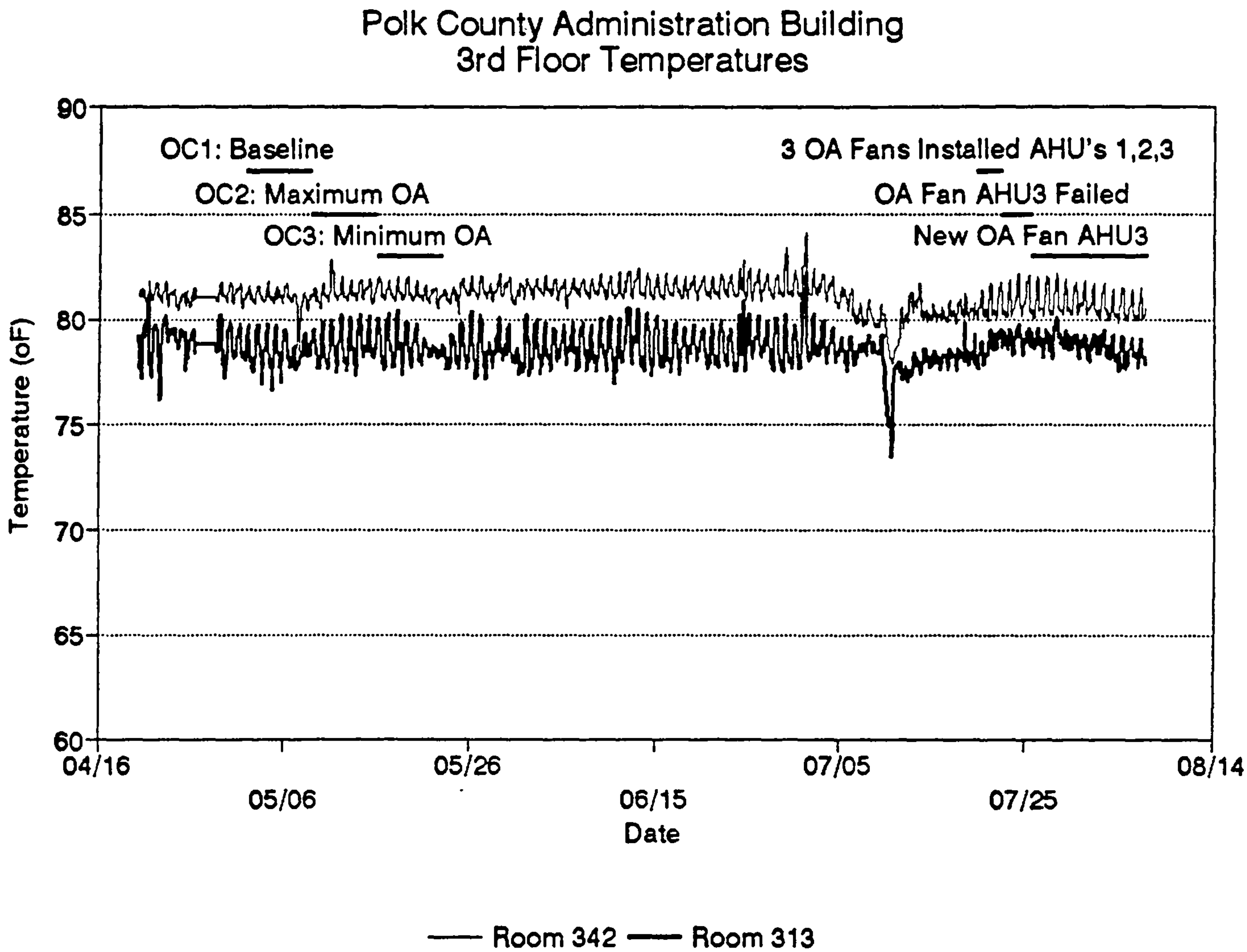
Polk County Administration Building
1st Floor Temperatures
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Temperature (oF)
90
85
80
75
70
65
60
07/10
07/15
07/20
07/25
07/30
08/04
08/09
Date
Room 124A
Room 182
Room 154
Room 119
Auditorium


Polk County Administration Building
2nd Floor Temperatures
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Temperature (oF)
90
85
80
75
70
65
60
04/16
05/06
05/26
06/15
07/05
07/25
08/14
Date
Room 235
Room 289

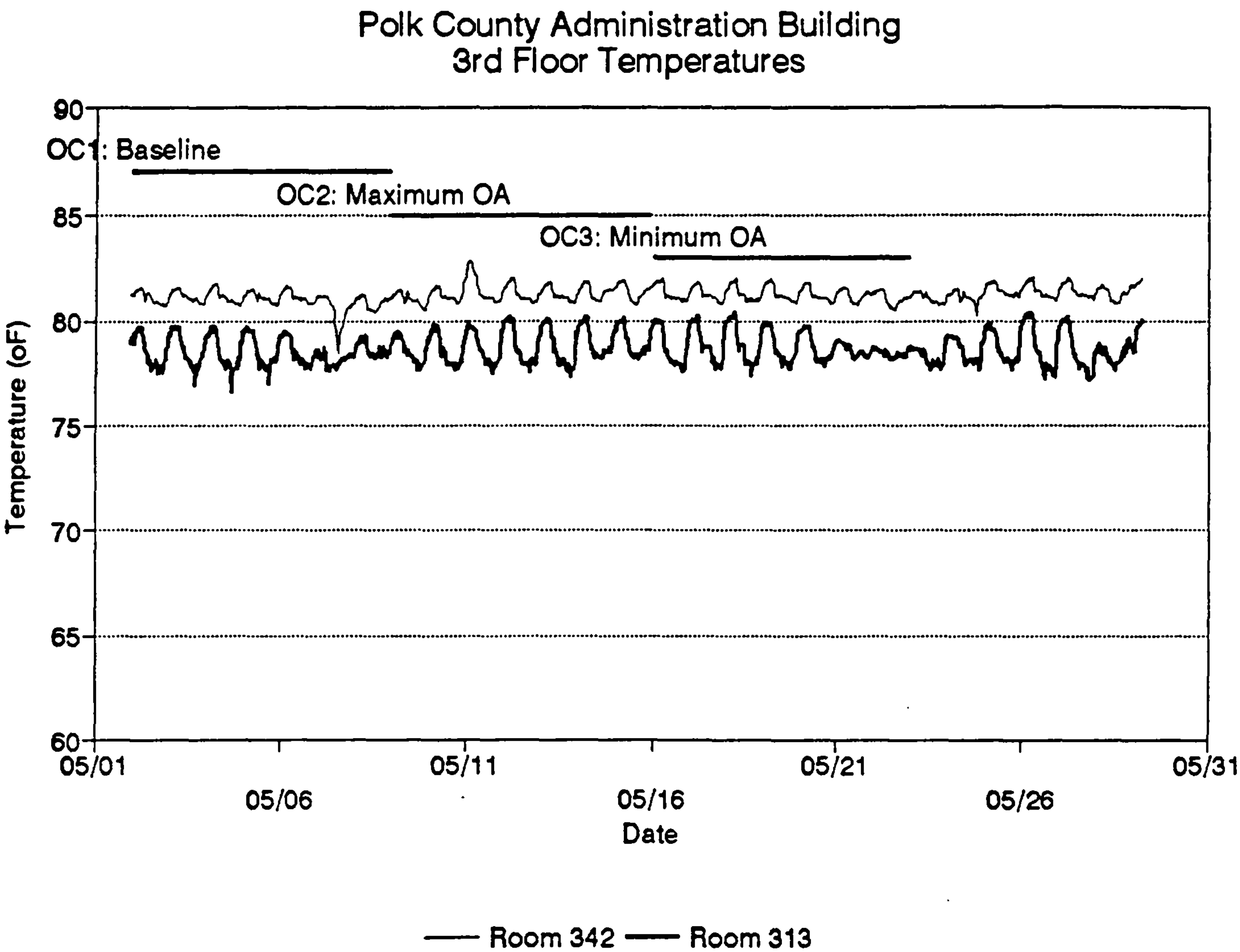

Polk County Administration Building
2nd Floor Temperatures
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
Temperature (oF)
90
85
80
75
70
65
60
05/01
05/06
05/11
05/16
05/21
05/26
05/31
Date
Room 235
Room 289

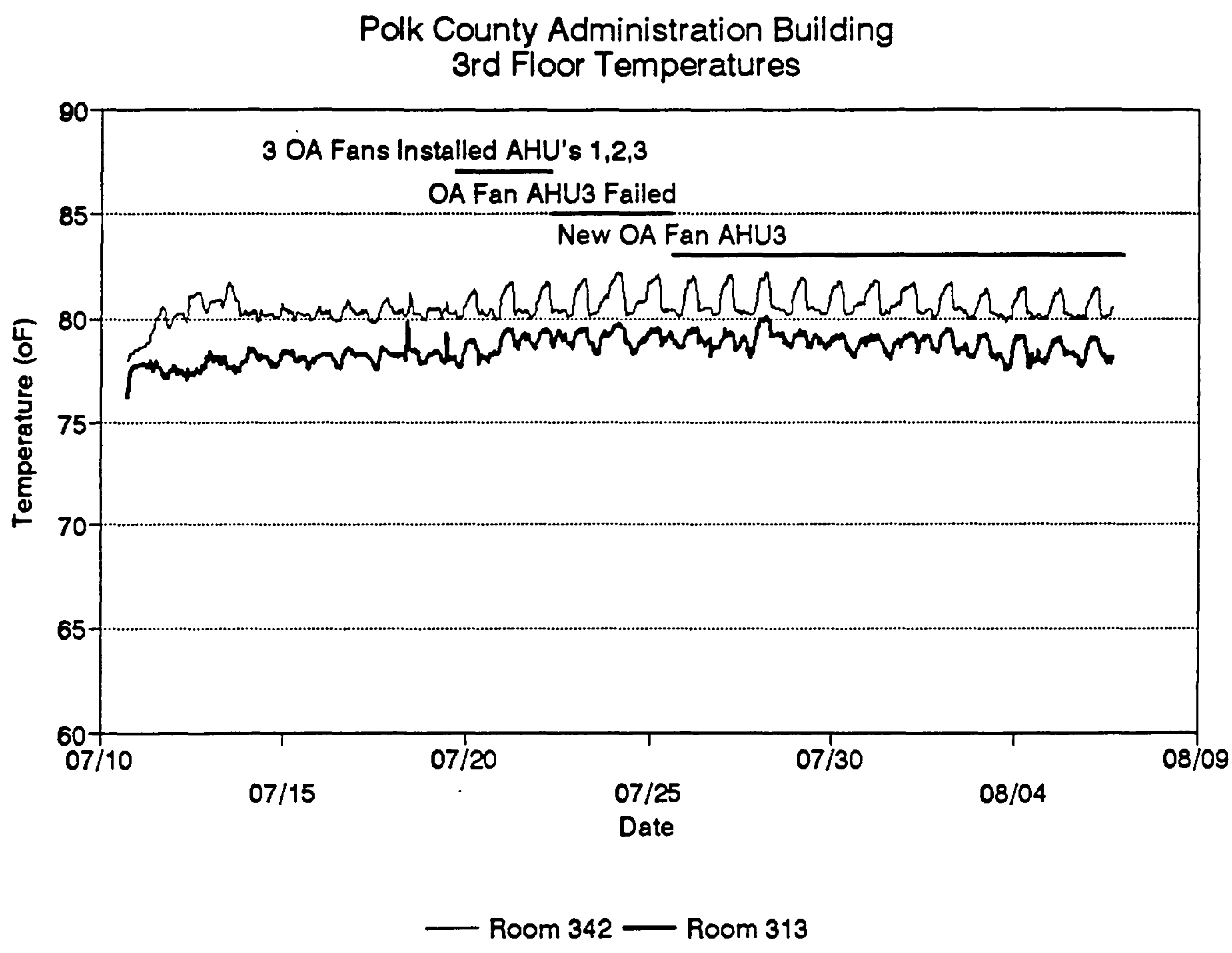


Polk County Administration Building
2nd Floor Temperatures
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Temperature (oF)
90
85
80
75
70
65
60
07/10
07/15
07/20
07/25
07/30
08/04
08/09
Date
Room 235
Room 289

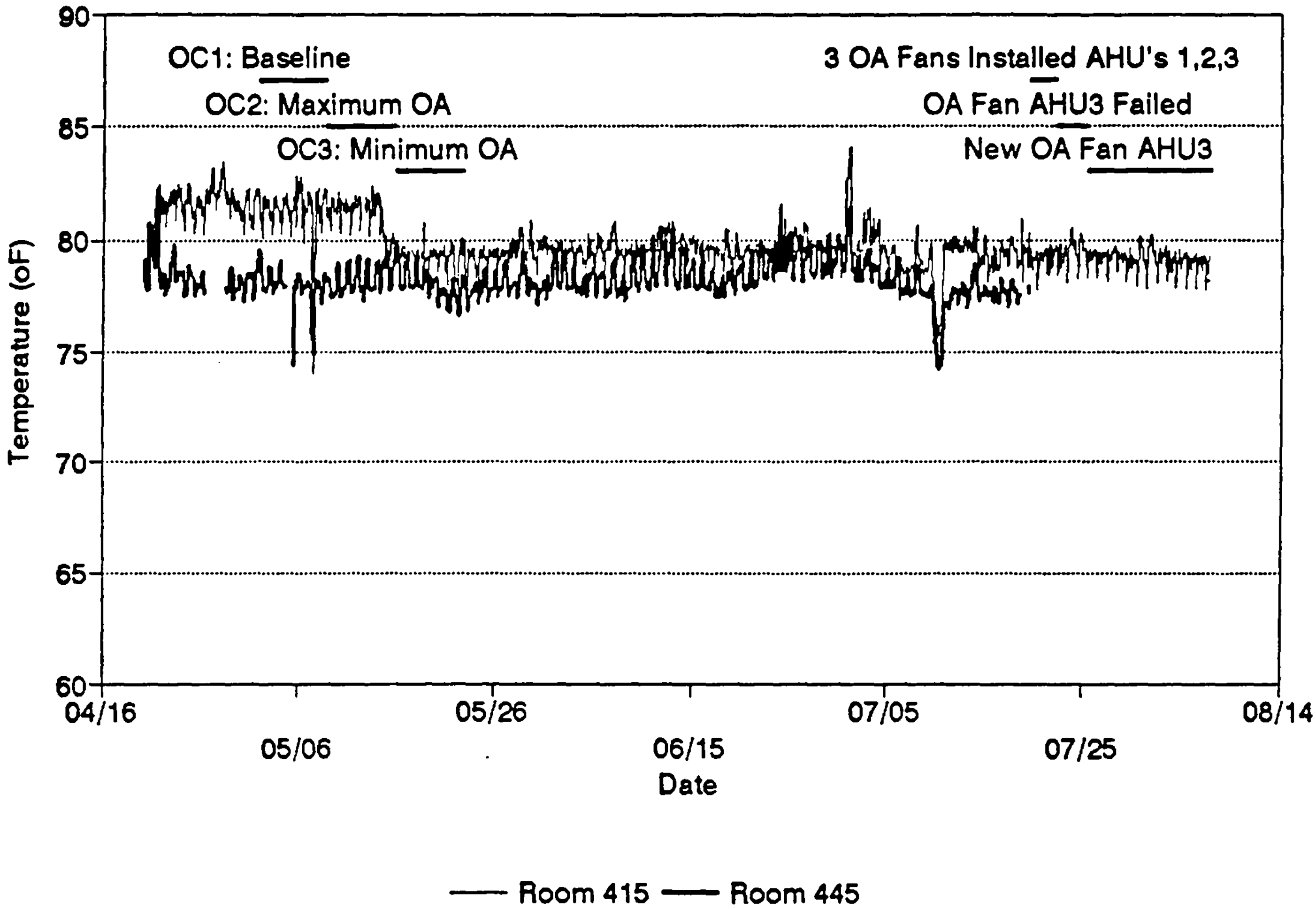


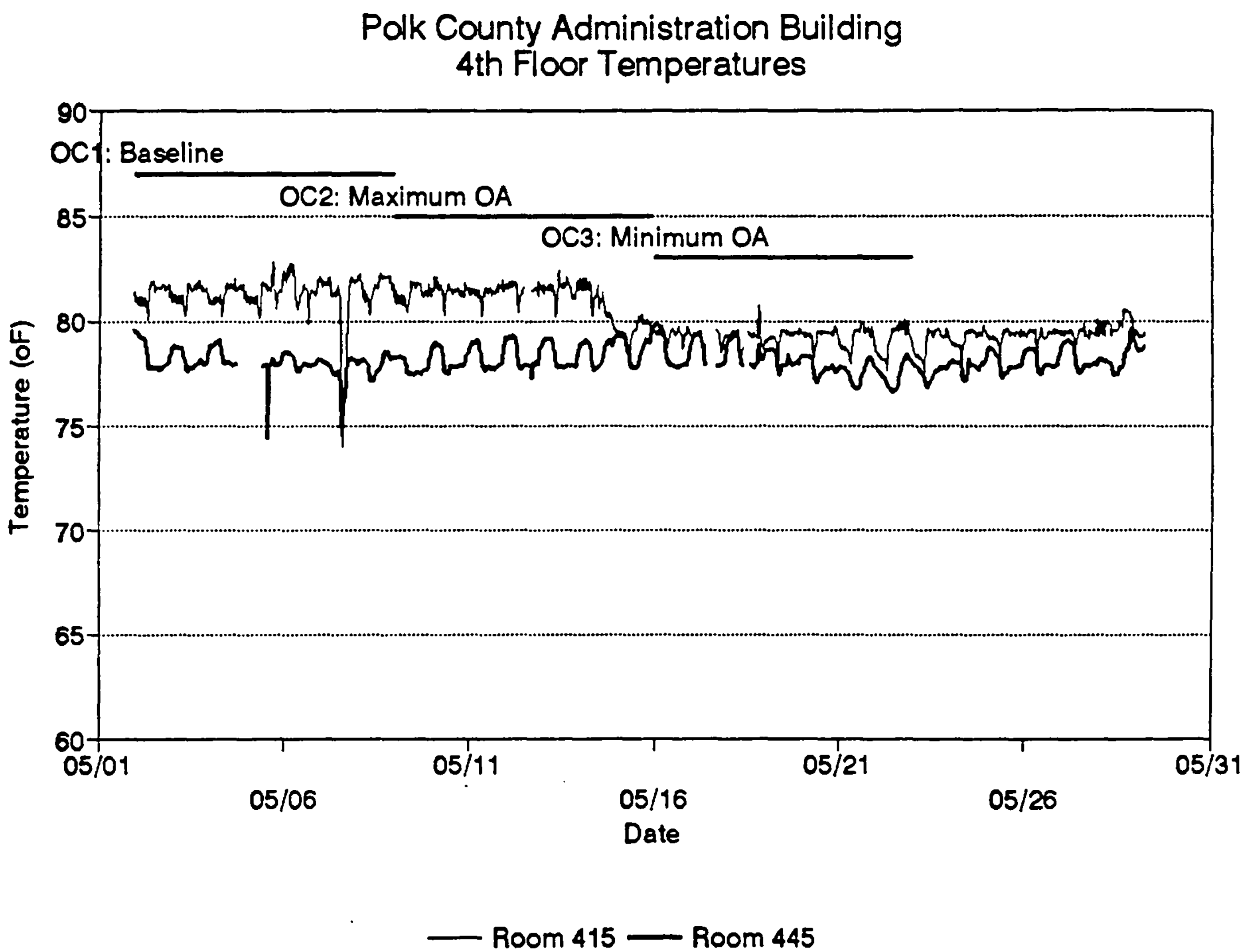
Polk County Administration Building
3rd Floor Temperatures
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
90
85
80
75
70
65
60
Temperature (oF)
04/16
05/06
05/26
06/15
07/05
07/25
08/14
Date
Room 342
Room 313

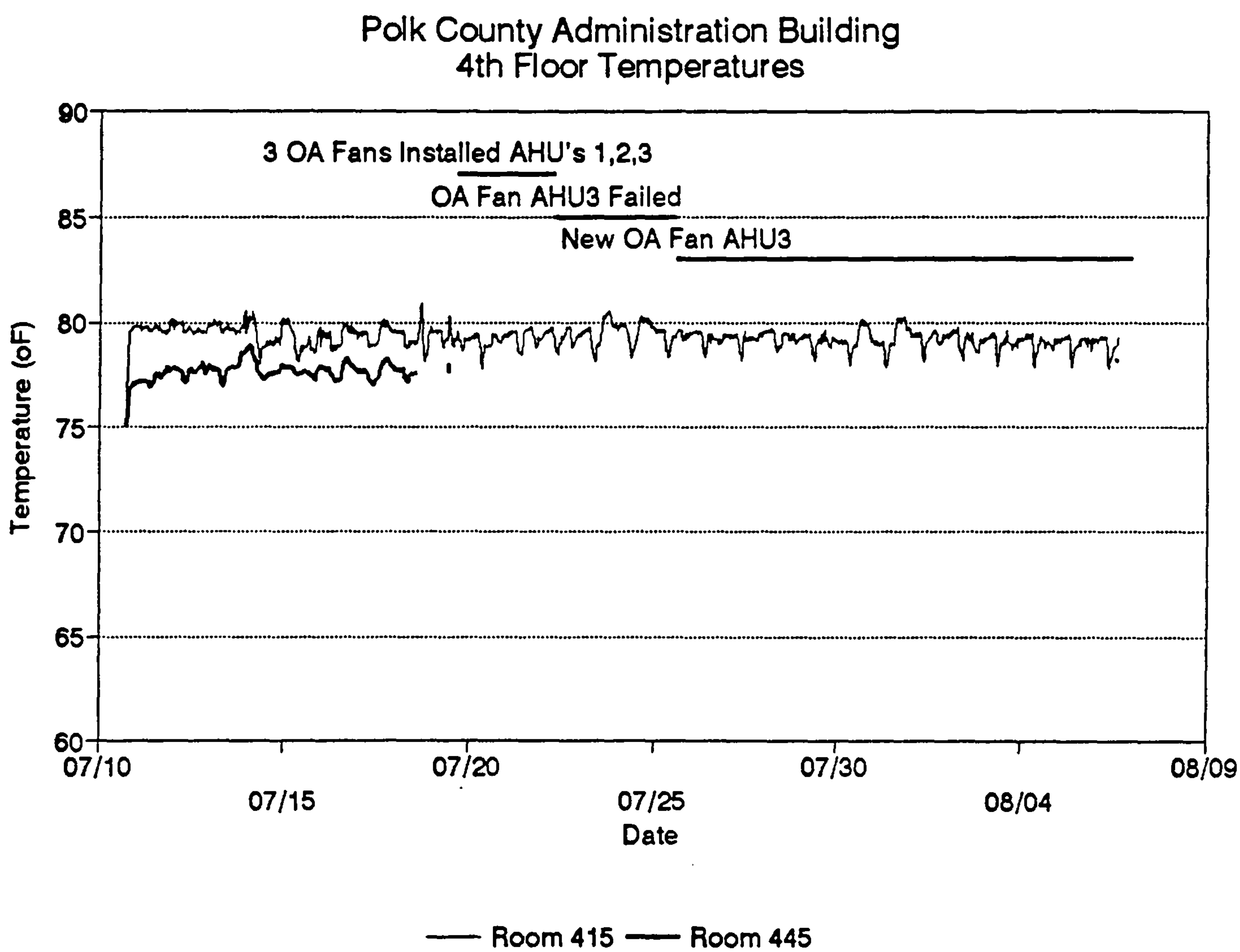

Polk County Administration Building
3rd Floor Temperatures
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
Temperature (oF)
90
85
80
75
70
65
60
05/01
05/06
05/11
05/16
05/21
05/26
05/31
Date
Room 342
Room 313

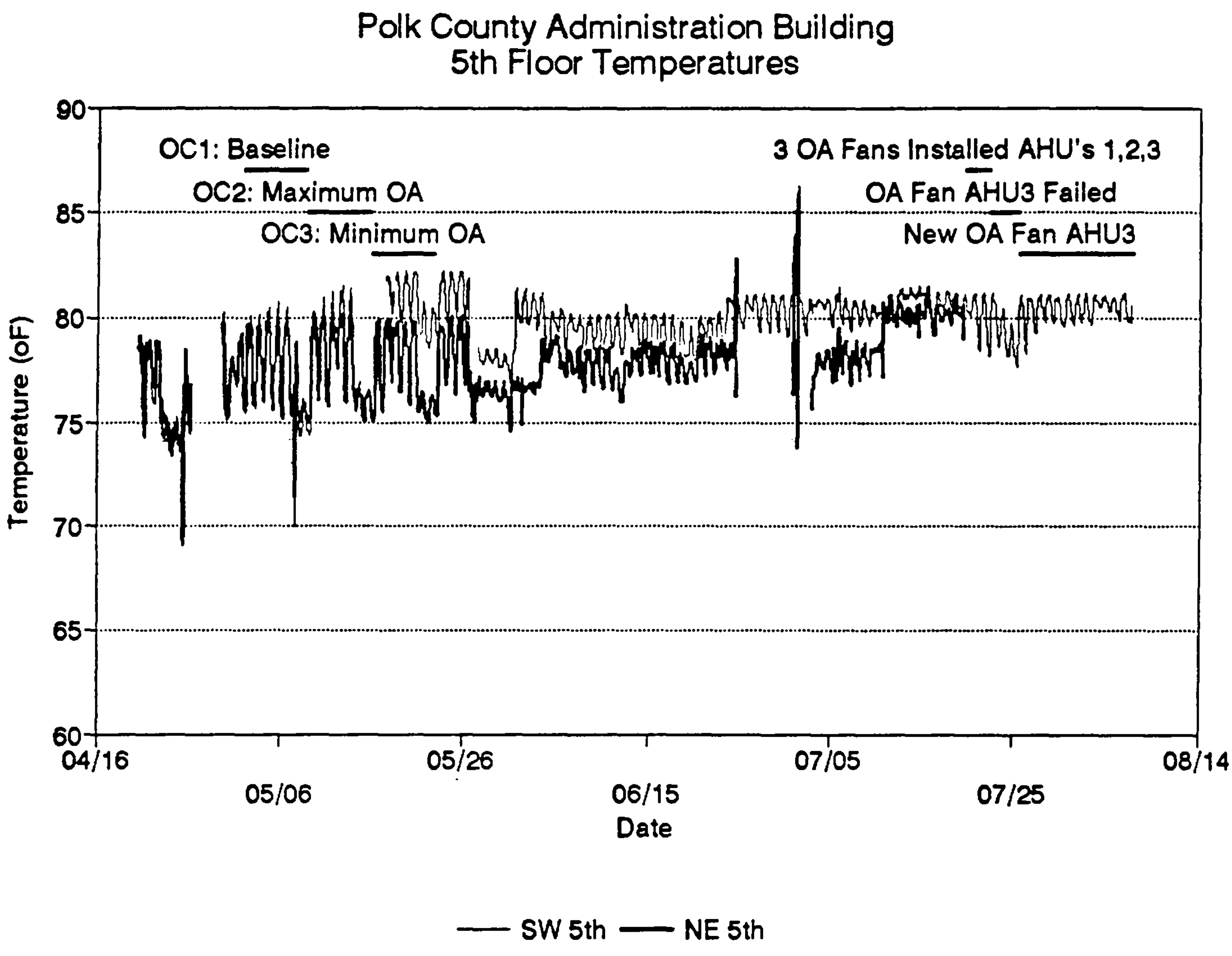

Polk County Administration Building
3rd Floor Temperatures
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Temperature (oF)
90
85
80
75
70
65
60
07/10
07/15
07/20
07/25
07/30
08/04
08/09
Date
Room 342
Room 313

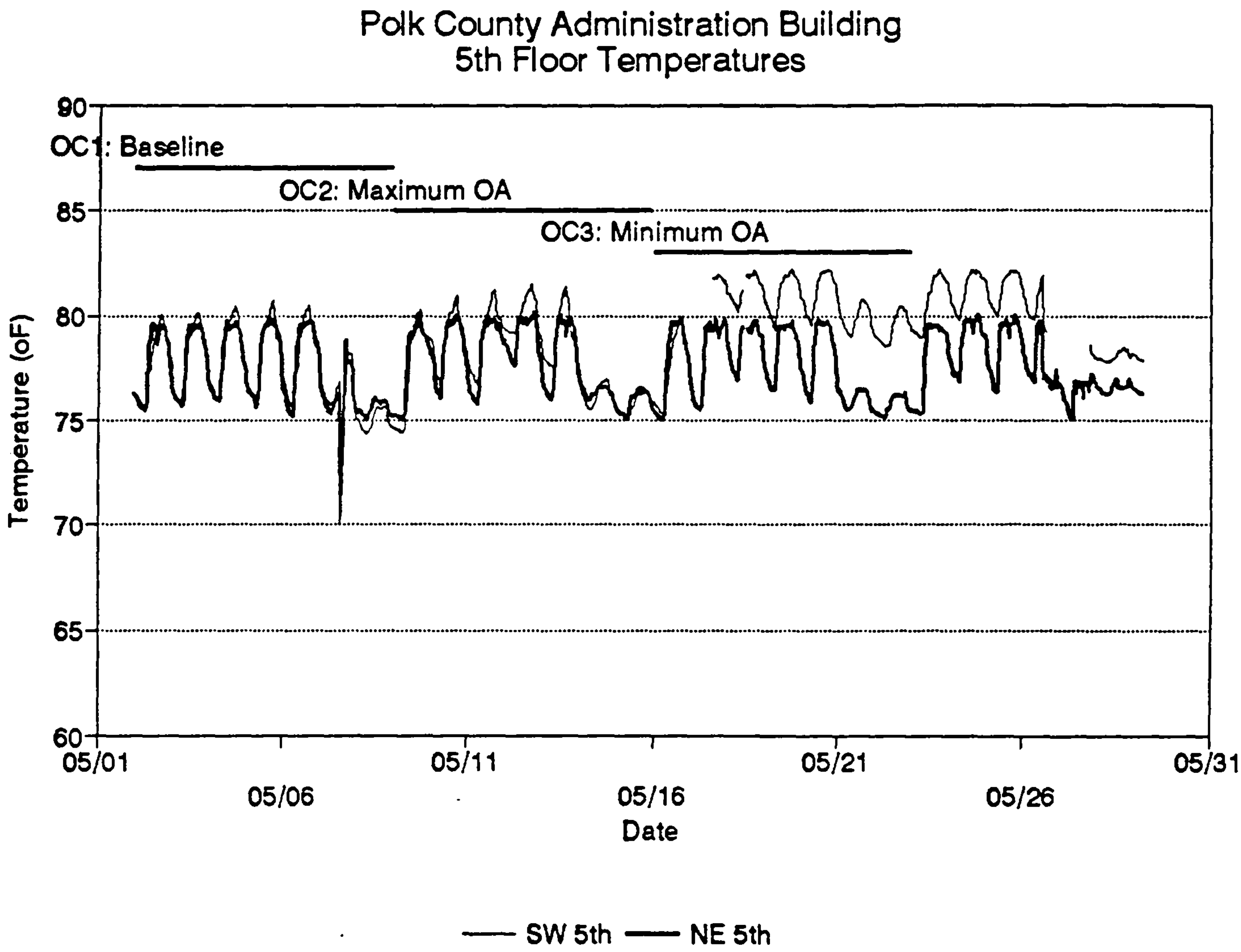
Polk County Administration Building
4th Floor Temperatures



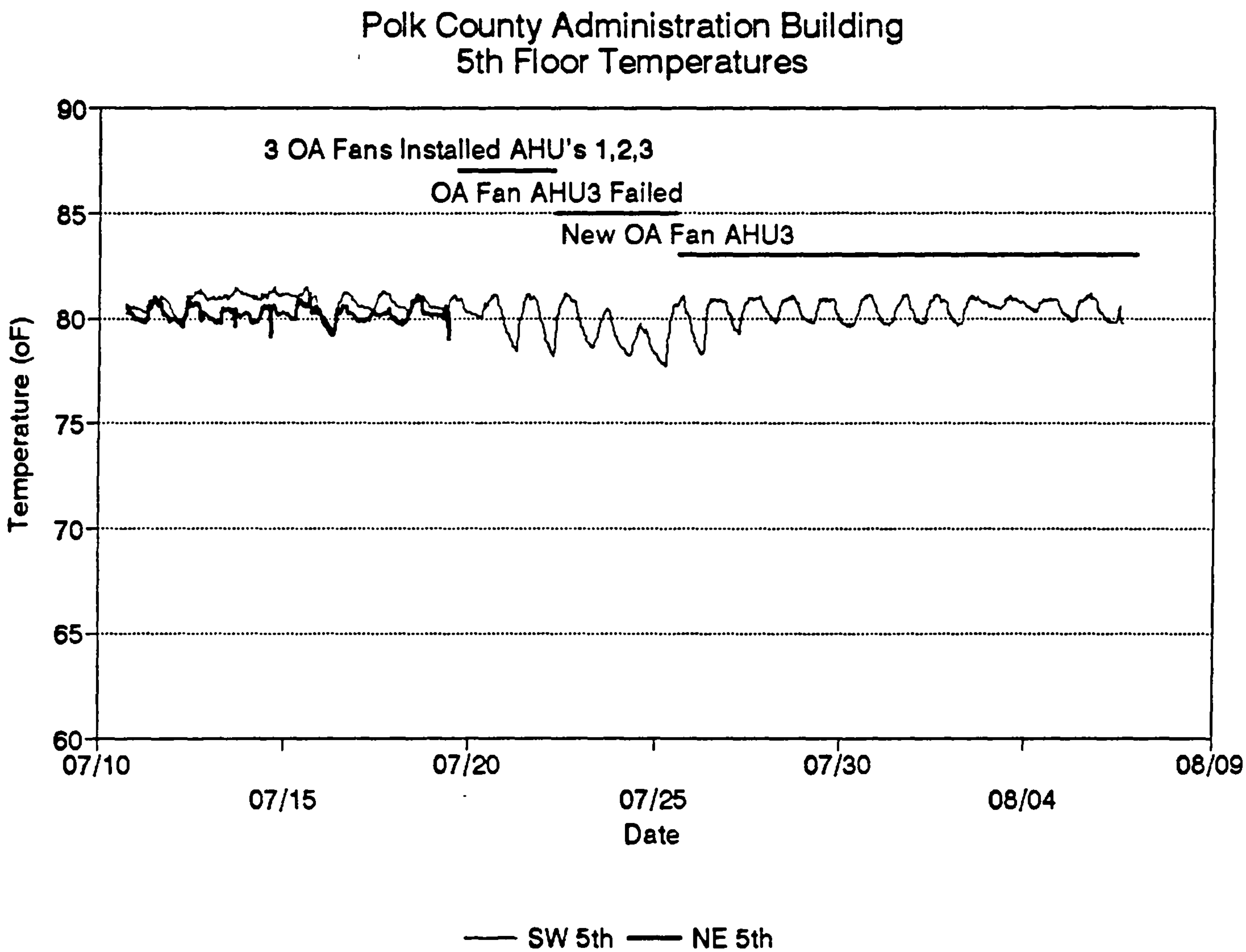

Polk County Administration Building
4th Floor Temperatures
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
Temperature (oF)
90
85
80
75
70
65
60
05/01
05/06
05/11
05/16
05/21
05/26
05/31
Date
Room 415
Room 445


Polk County Administration Building
4th Floor Temperatures
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Temperature (oF)
90
85
80
75
70
65
60
07/10
07/15
07/20
07/25
07/30
08/04
08/09
Date
Room 415
Room 445

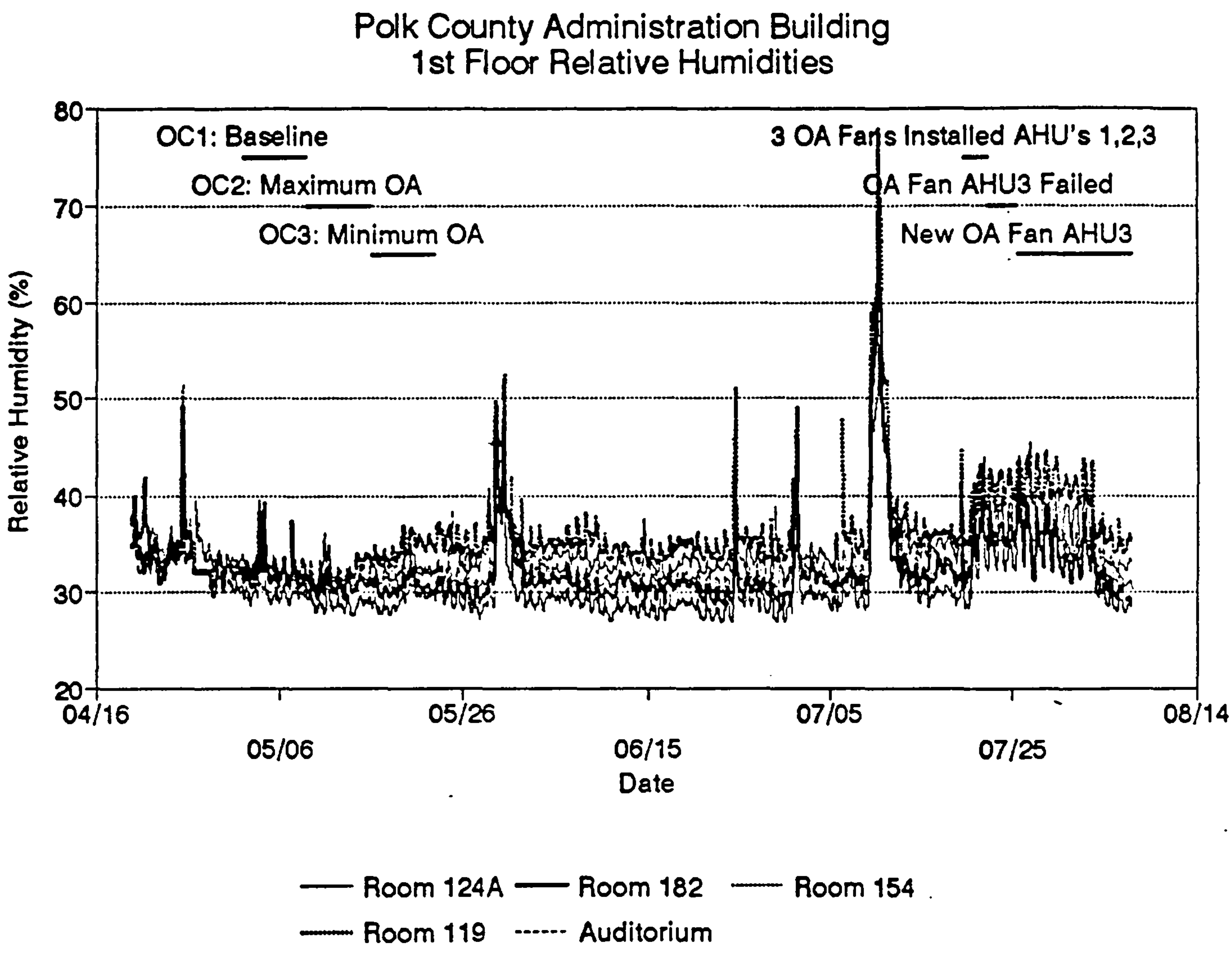

Polk County Administration Building
5th Floor Temperatures
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Temperature (oF)
90
85
80
75
70
65
60
04/16
05/06
05/26
06/15
07/05
07/25
08/14
Date
SW 5th
NE 5th

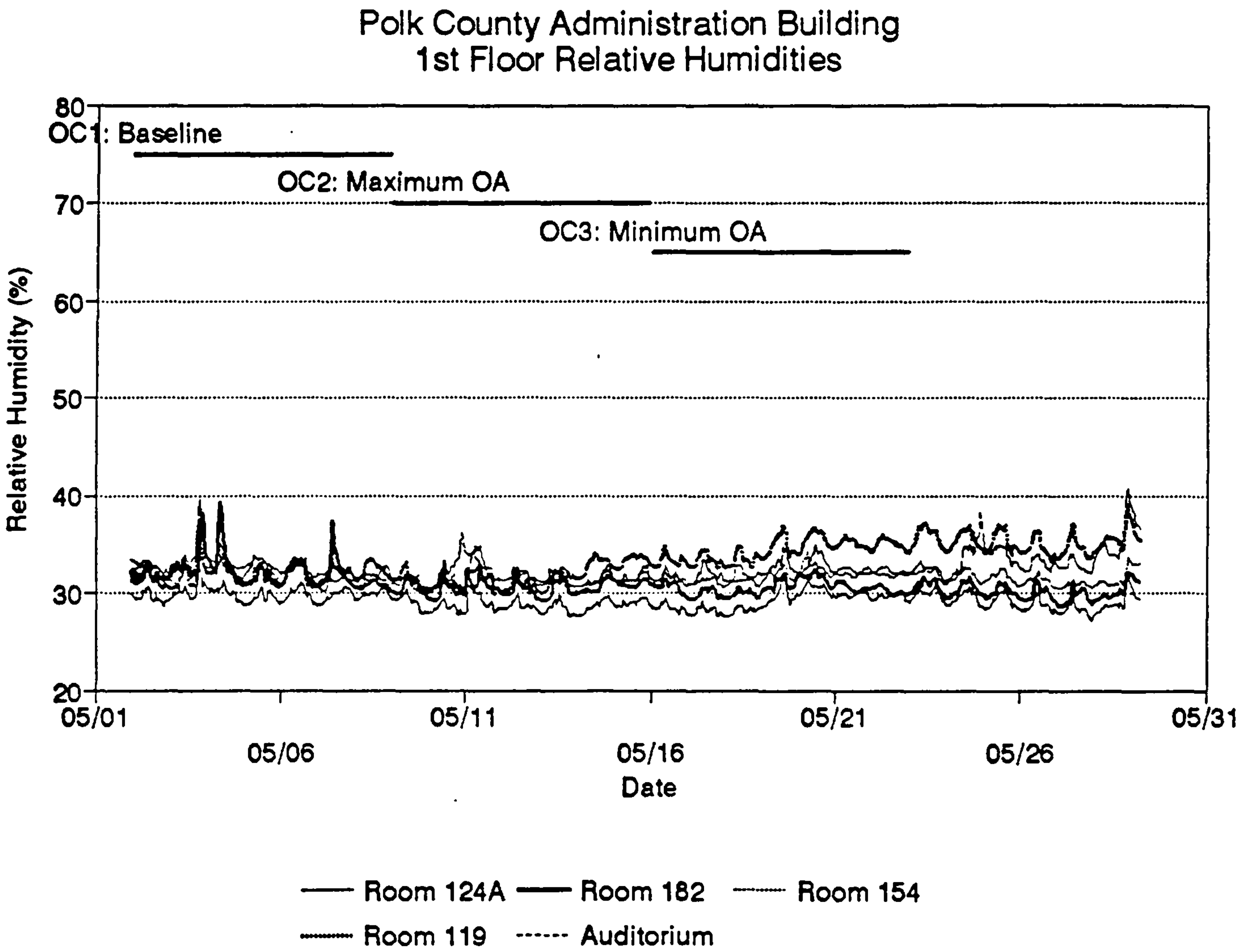


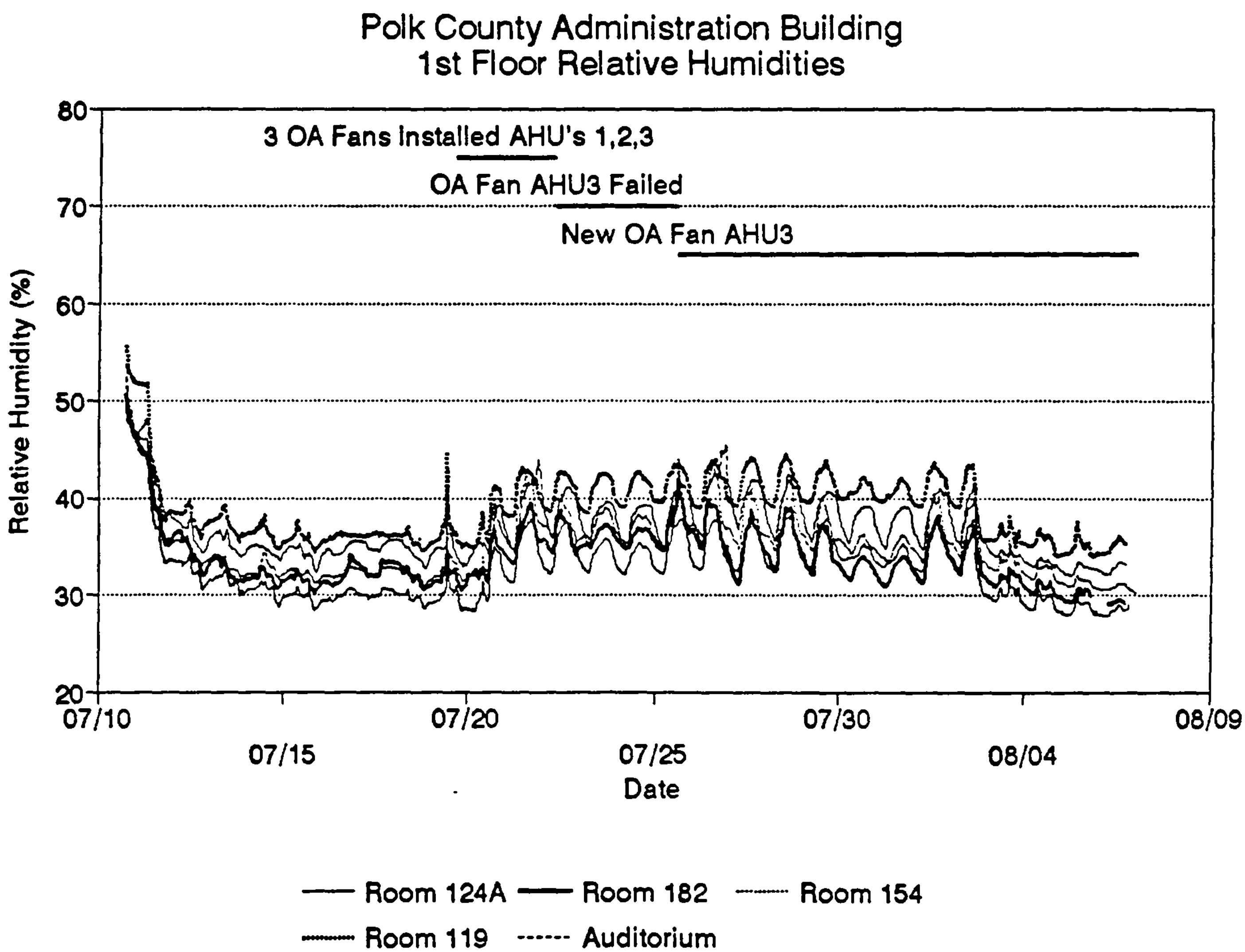
Polk County Administration Building
5th Floor Temperatures
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
Temperature (oF)
90
85
80
75
70
65
60
05/01
05/06
05/11
05/16
05/21
05/26
05/31
Date
SW 5th
NE 5th


Polk County Administration Building
5th Floor Temperatures
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Temperature (oF)
90
85
80
75
70
65
60
07/10
07/15
07/20
07/25
07/30
08/04
08/09
Date
SW 5th
NE 5th

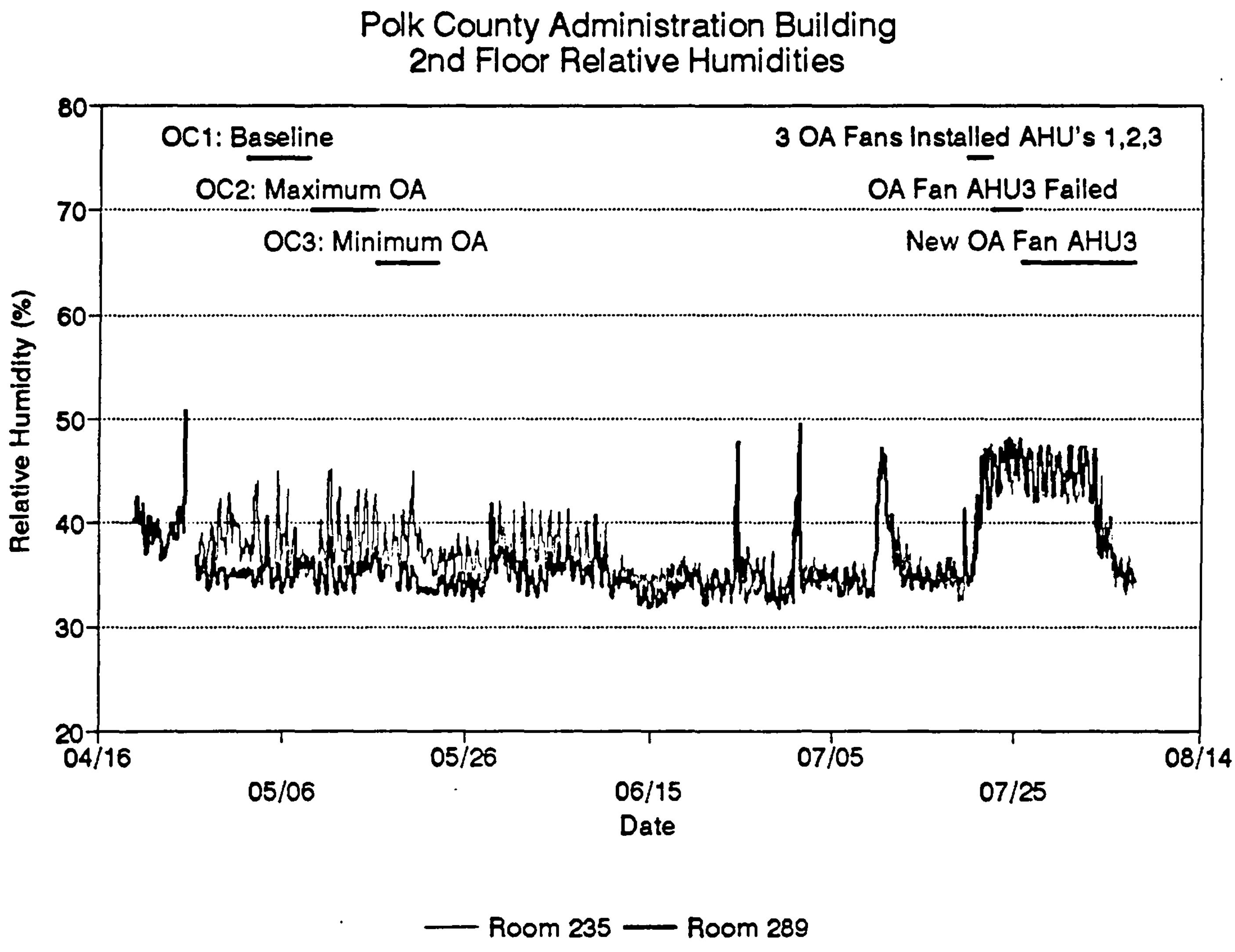
Appendix D. Average Continuous Relative Humidities Measured With The IAQDS Units

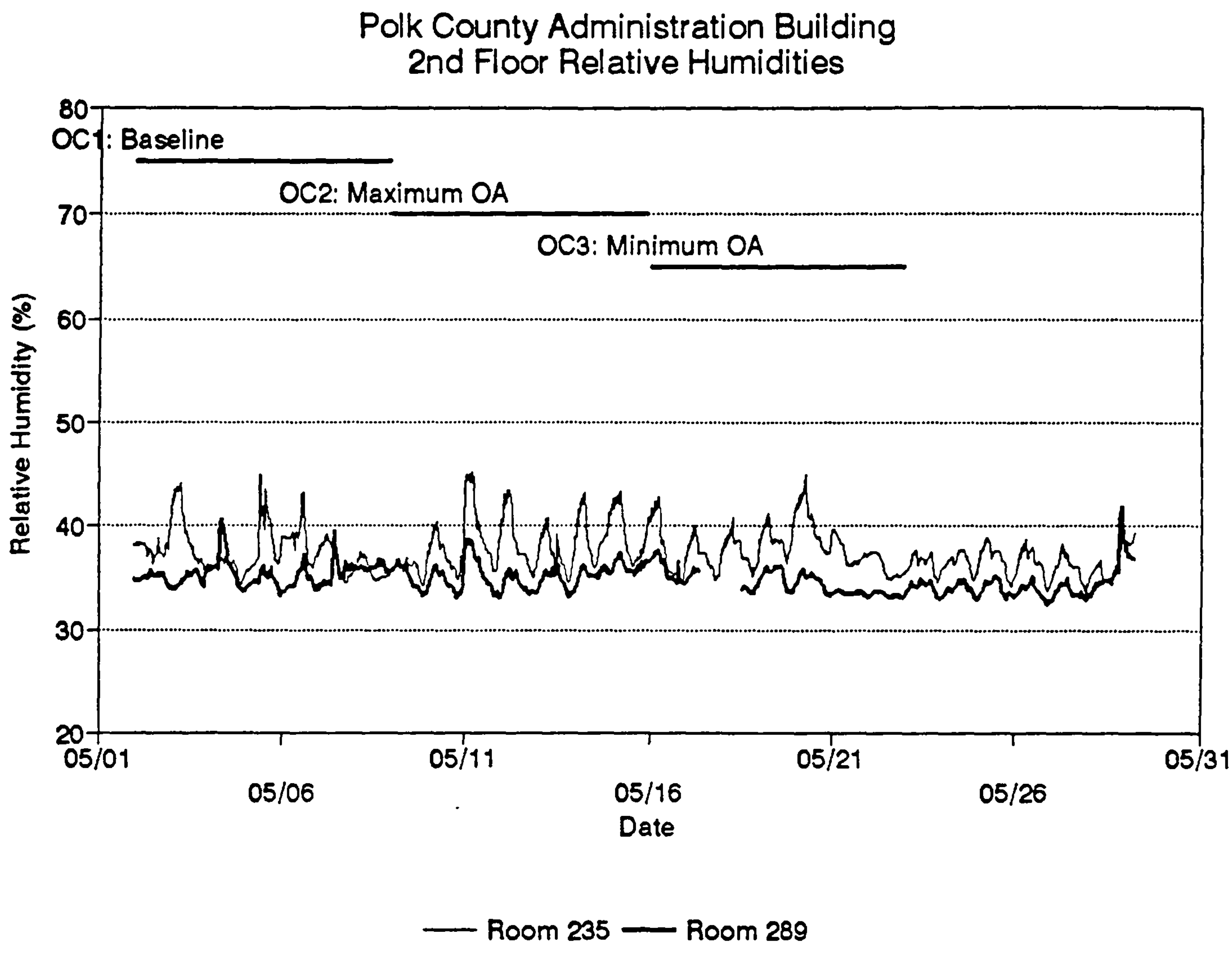

Polk County Administration Building
1st Floor Relative Humidities
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Relative Humidity (%)
80
70
60
50
40
30
20
04/16
05/06
05/26
06/15
07/05
07/25
08/14
Date
Room 124A
Room 182
Room 154
Room 119
Auditorium

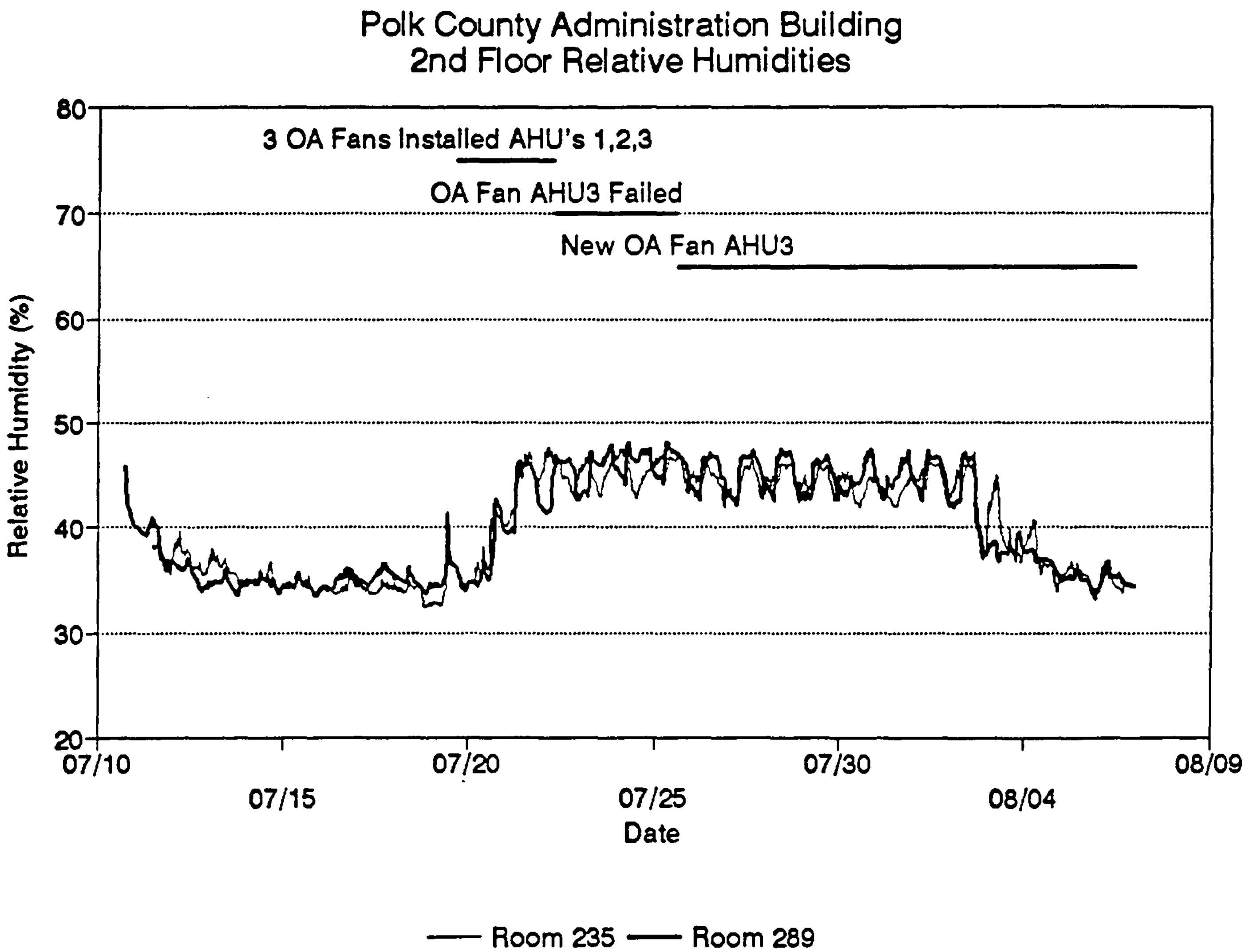

Polk County Administration Building
1st Floor Relative Humidities
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
Relative Humidity (%)
80
70
60
50
40
30
20
05/01
05/06
05/11
05/16
05/21
05/26
05/31
Date
Room 124A
Room 182
Room 154
Room 119
Auditorium



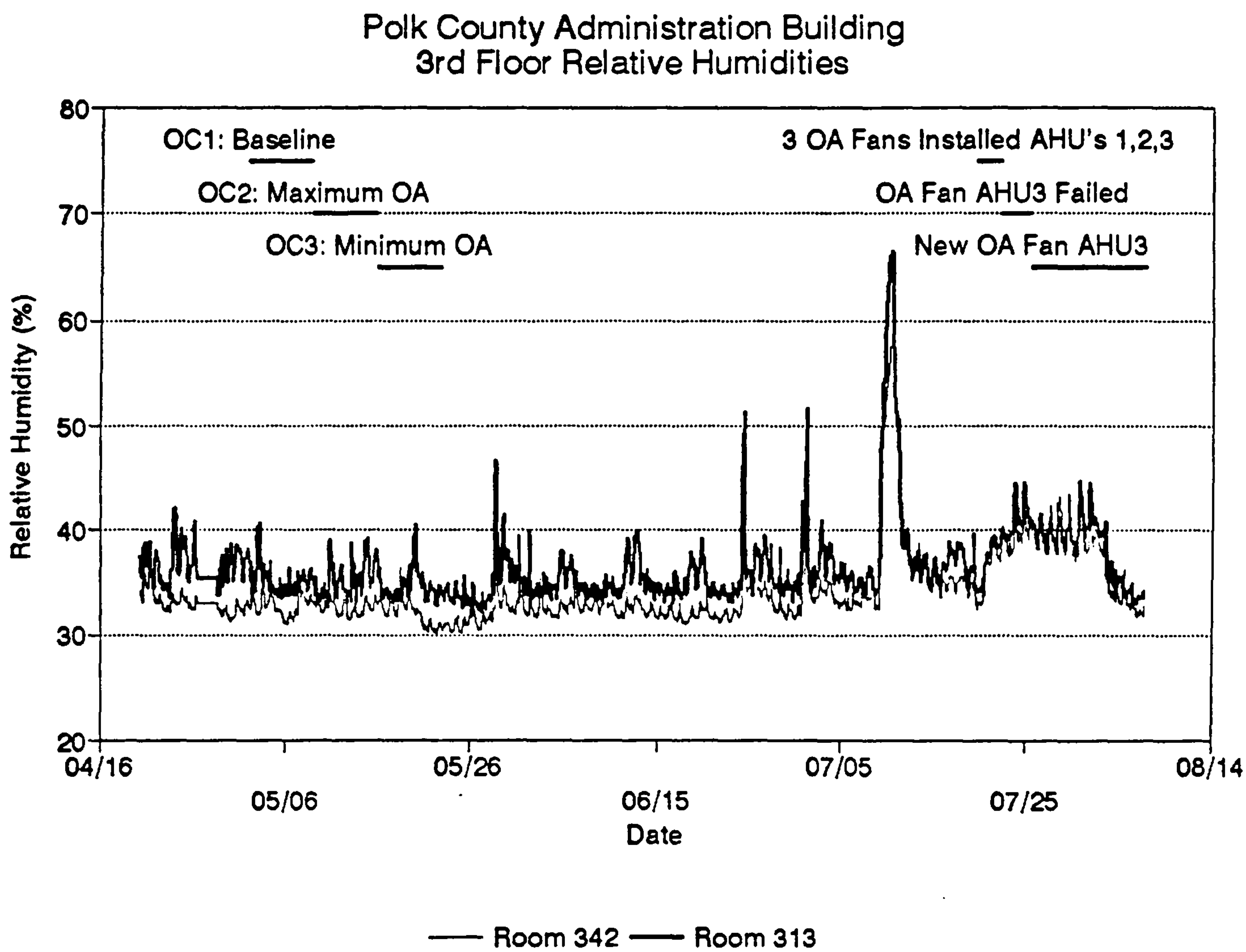
Polk County Administration Building
1st Floor Relative Humidities
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Relative Humidity (%)
80
70
60
50
40
30
20
07/10
07/15
07/20
07/25
07/30
08/04
08/09
Date
Room 124A
Room 182
Room 154
Room 119
Auditorium


Polk County Administration Building
2nd Floor Relative Humidities
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Relative Humidity (%)
80
70
60
50
40
30
20
04/16
05/06
05/26
06/15
07/05
07/25
08/14
Date
Room 235
Room 289

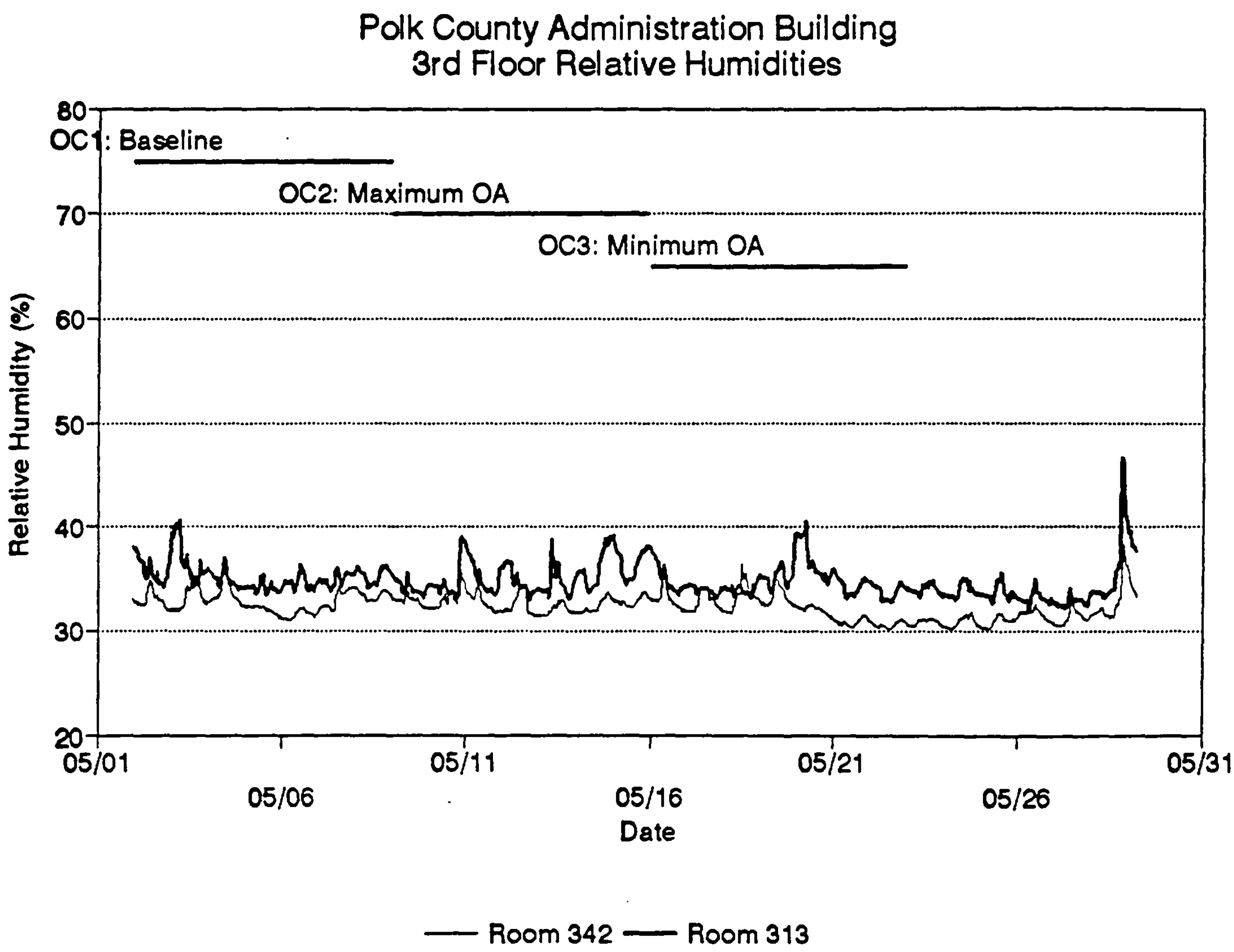

Polk County Administration Building
2nd Floor Relative Humidities
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
Relative Humidity (%)
80
70
60
50
40
30
20
05/01
05/06
05/11
05/16
05/21
05/26
05/31
Date
Room 235
Room 289



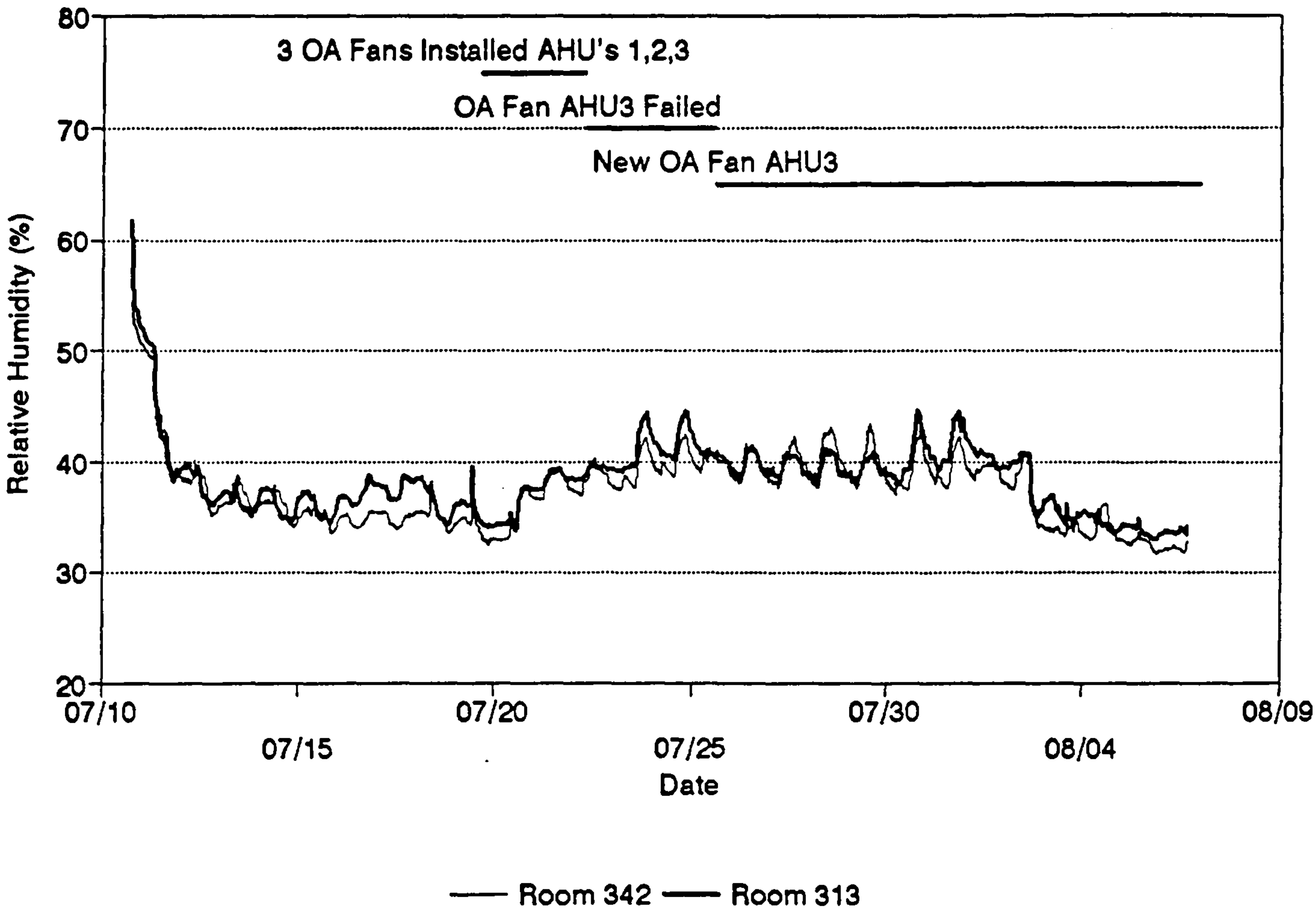
Polk County Administration Building
2nd Floor Relative Humidities
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Relative Humidity (%)
80
70
60
50
40
30
20
07/10
07/15
07/20
07/25
07/30
08/04
08/09
Date
Room 235
Room 289

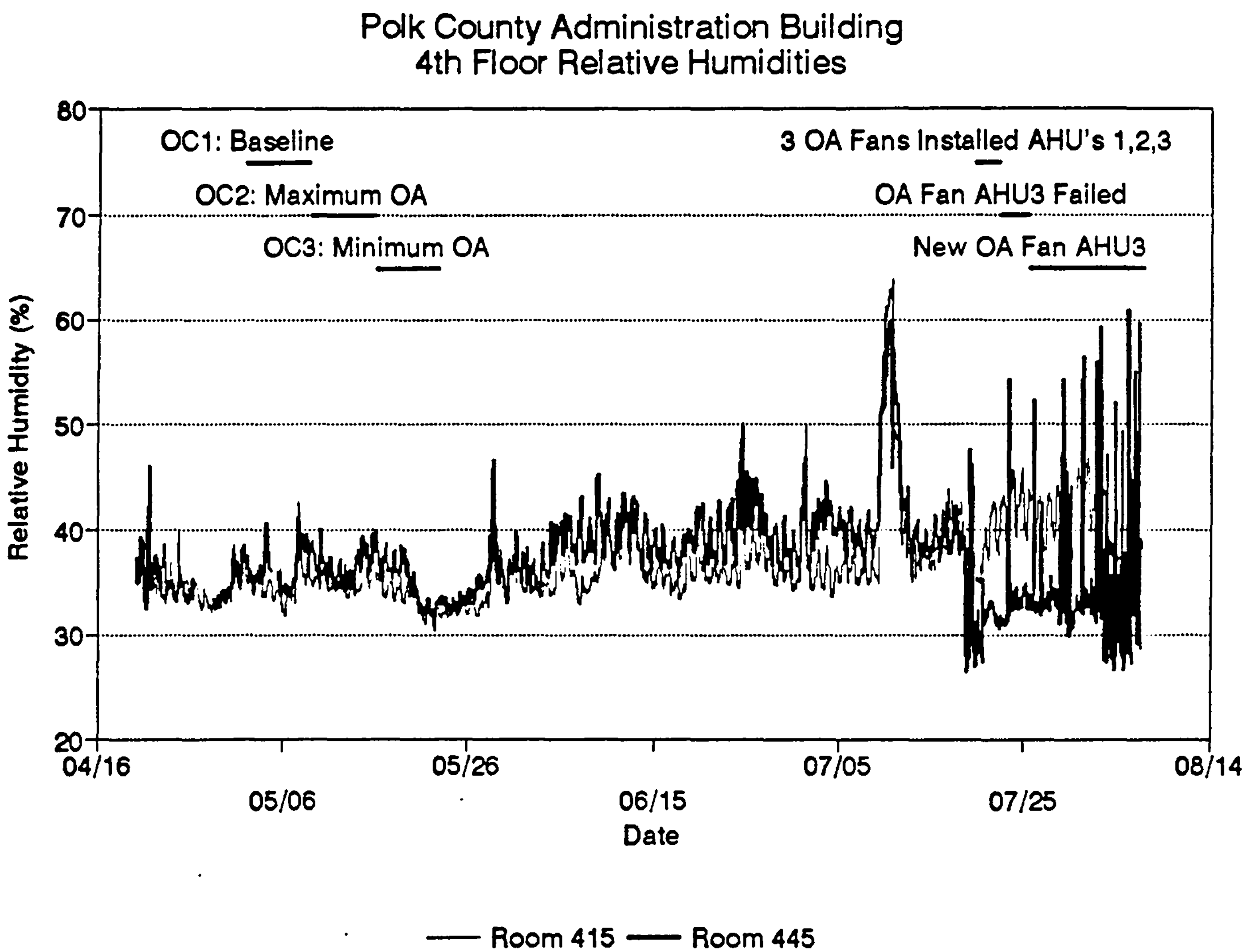


Polk County Administration Building
3rd Floor Relative Humidities
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Relative Humidity (%)
80
70
60
50
40
30
20
04/16
05/06
05/26
06/15
07/05
07/25
08/14
Date
Room 342
Room 313

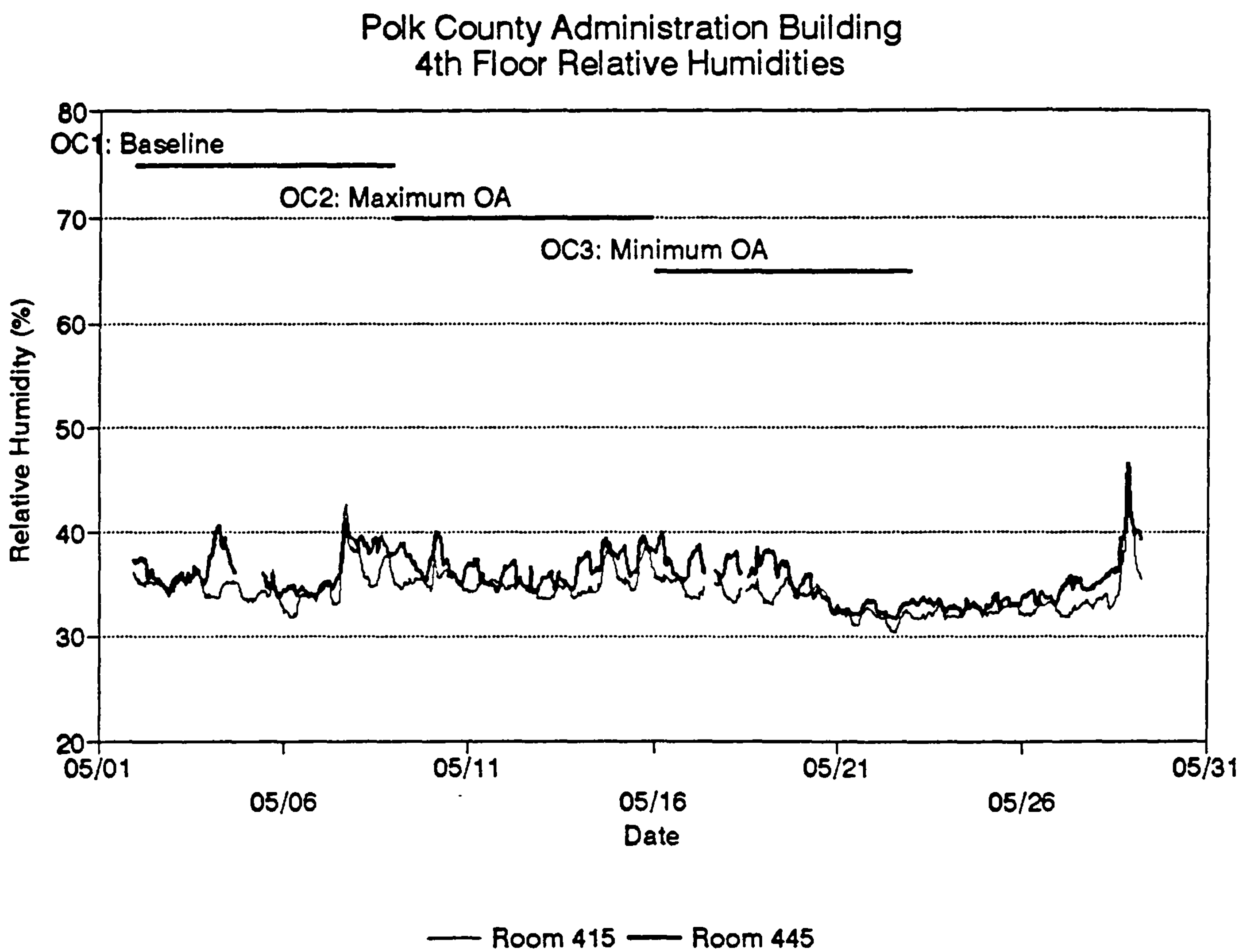

Polk County Administration Building
3rd Floor Relative Humidities
80
OC1: Baseline
OC2: Maximum OA
70
OC3: Minimum OA
60
50
40
30
20
Relative Humidity (%)
05/01
05/06
05/11
05/16
05/21
05/26
05/31
Date
Room 342
Room 313

Polk County Administration Building
3rd Floor Relative Humidities

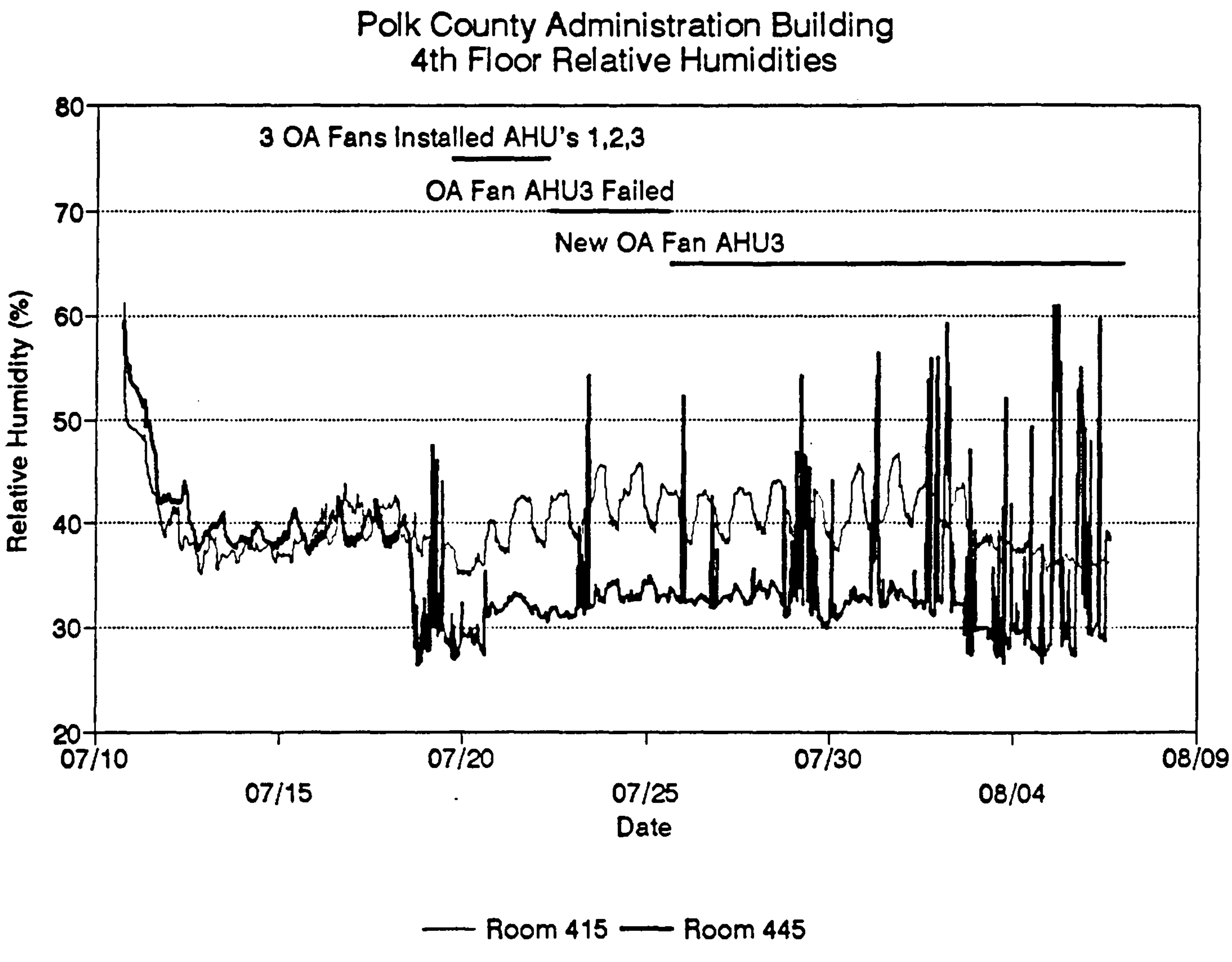


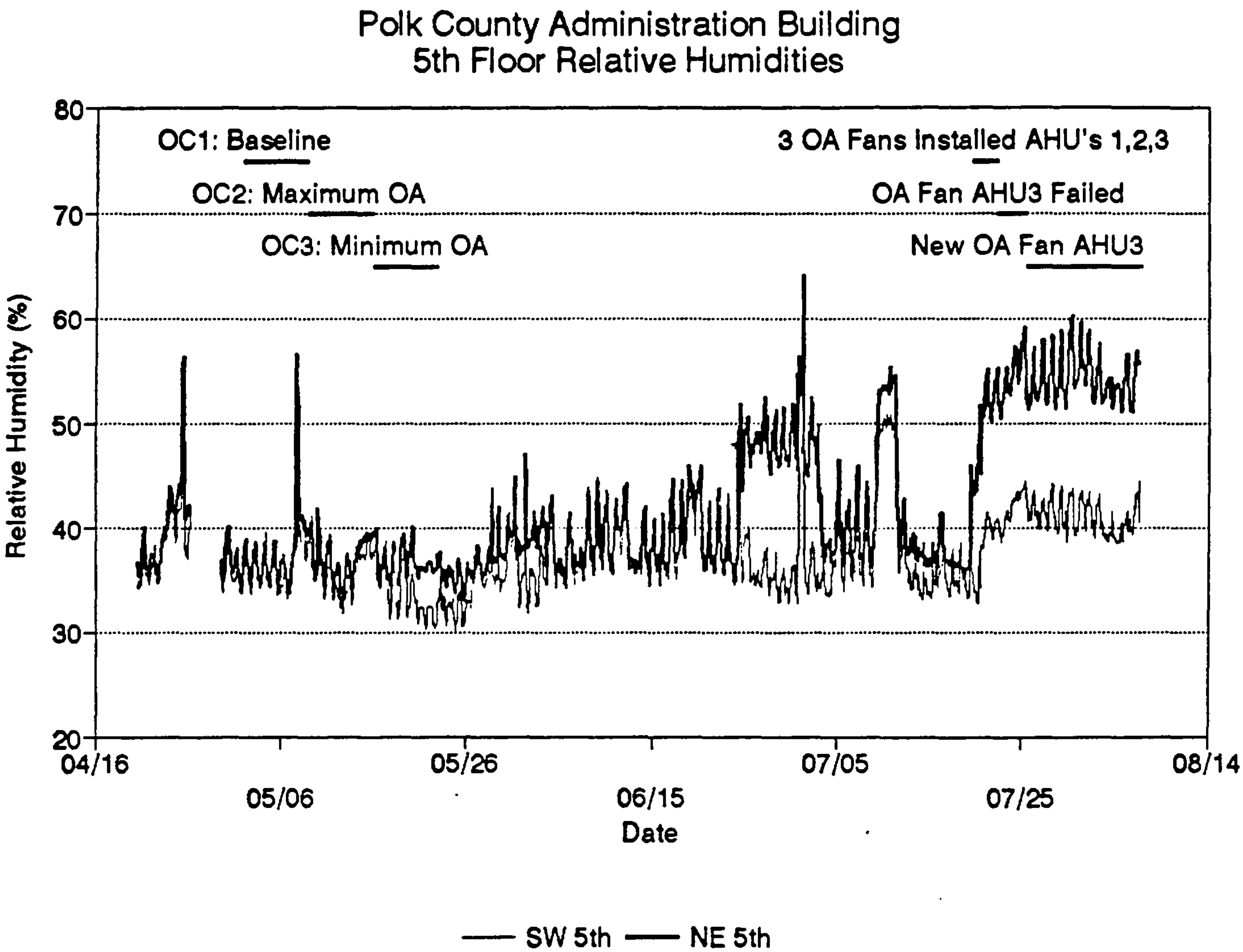


Polk County Administration Building
4th Floor Relative Humidities
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Relative Humidity (%)
80
70
60
50
40
30
20
04/16
05/06
05/26
06/15
07/05
07/25
08/14
Date
Room 415
Room 445

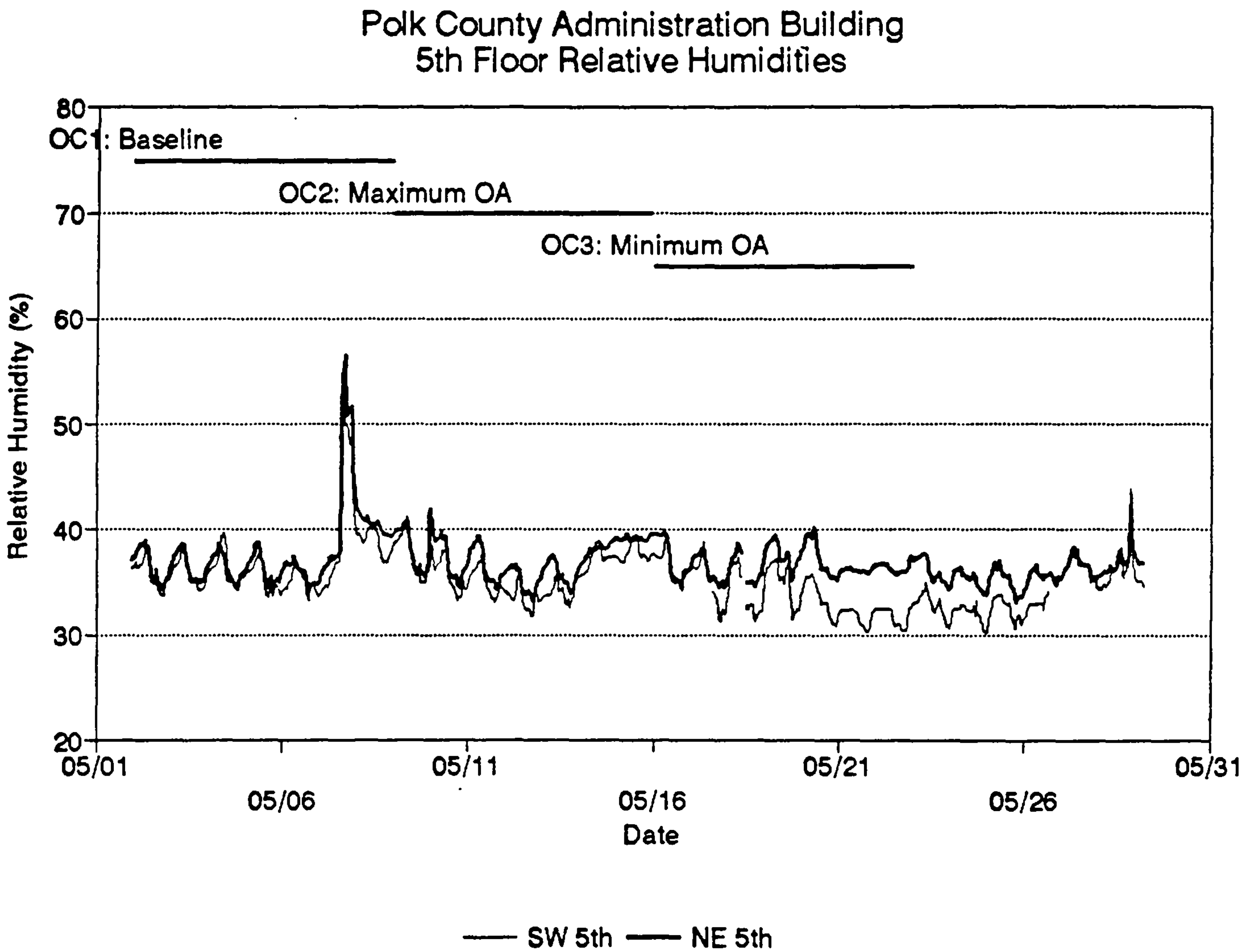


Polk County Administration Building
4th Floor Relative Humidities
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
Relative Humidity (%)
80
70
60
50
40
30
20
05/01
05/06
05/11
05/16
05/21
05/26
05/31
Date
Room 415
Room 445


Polk County Administration Building
4th Floor Relative Humidities
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
80
70
60
50
40
30
20
Relative Humidity (%)
07/10
07/15
07/20
07/25
07/30
08/04
08/09
Date
Room 415
Room 445

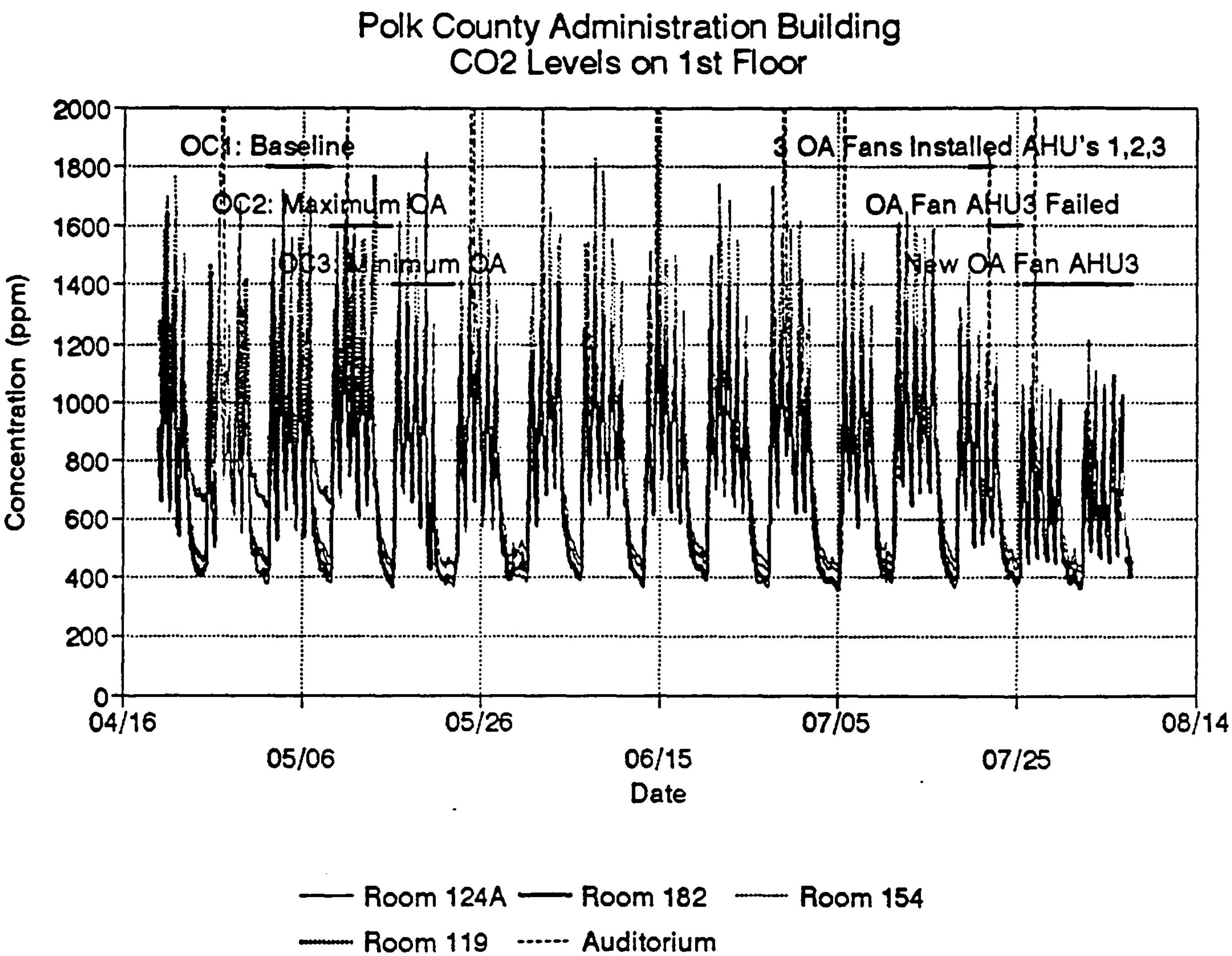


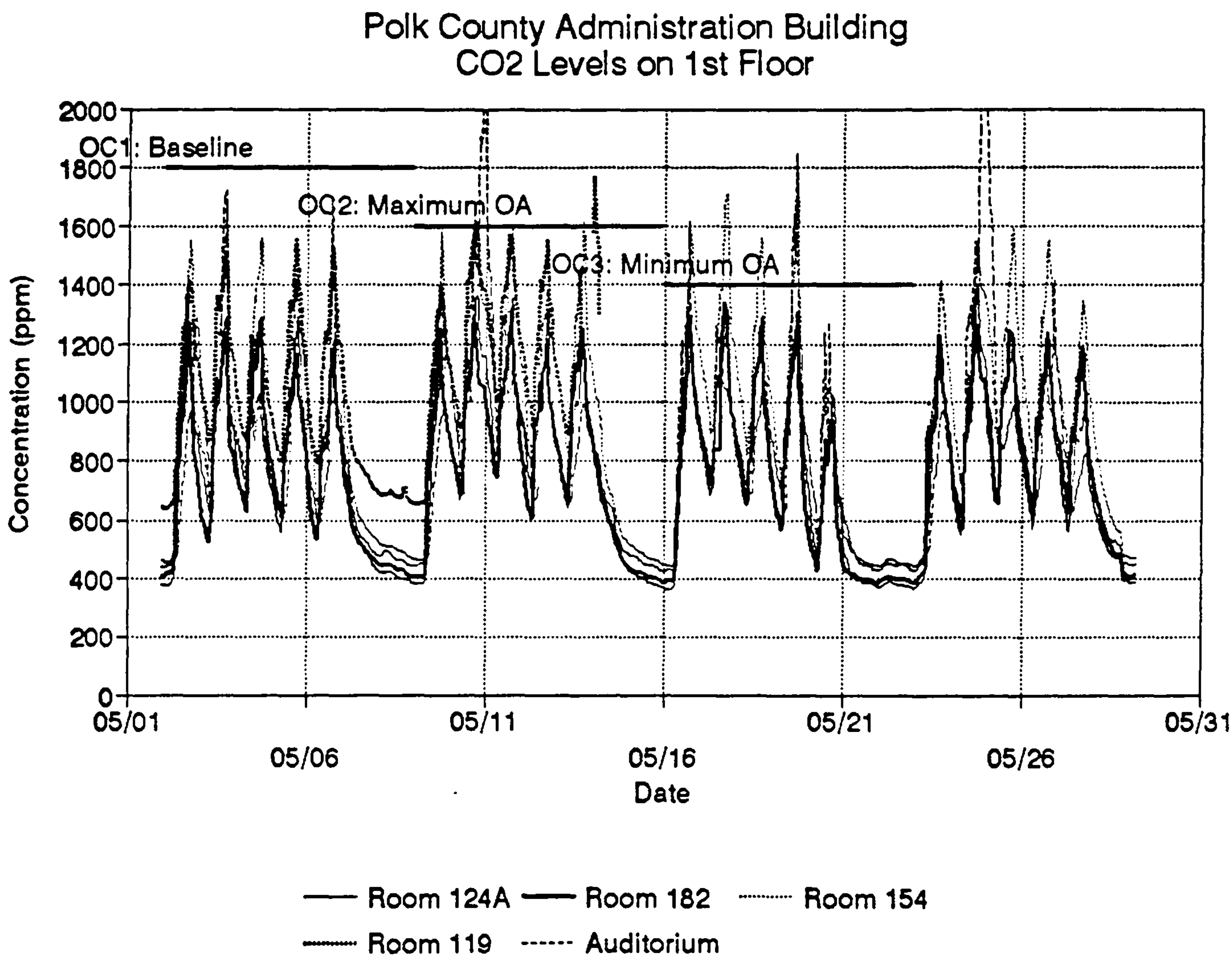
Polk County Administration Building
5th Floor Relative Humidities
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Relative Humidity (%)
80
70
60
50
40
30
20
04/16
05/06
05/26
06/15
07/05
07/25
08/14
Date
SW 5th
NE 5th



Polk County Administration Building
5th Floor Relative Humidities
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
Relative Humidity (%)
80
70
60
50
40
30
20
05/01
05/06
05/11
05/16
05/21
05/26
05/31
Date
SW 5th
NE 5th

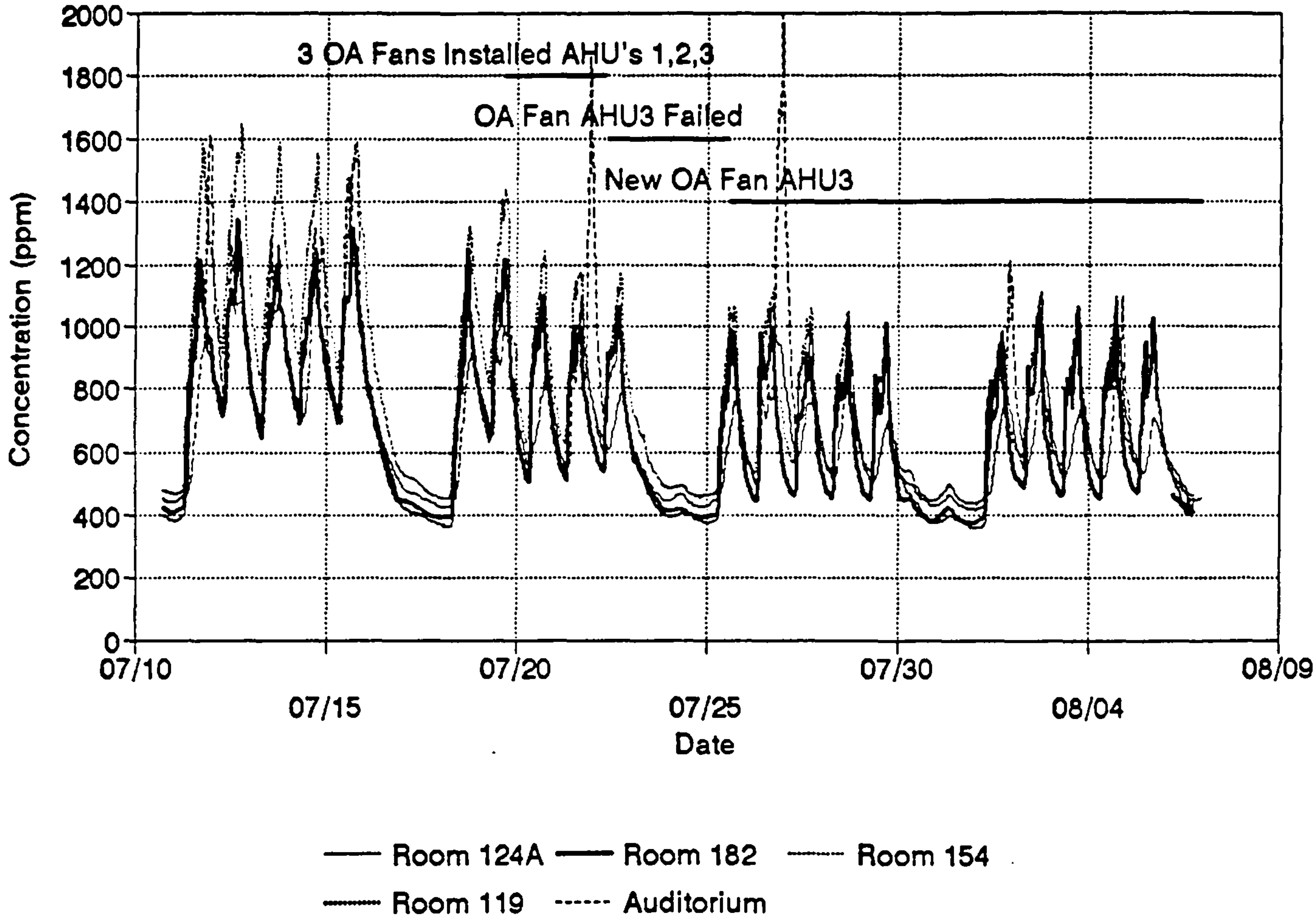
Appendix E. Average Continuous CO_2 Levels Measured With The IAQDS Units

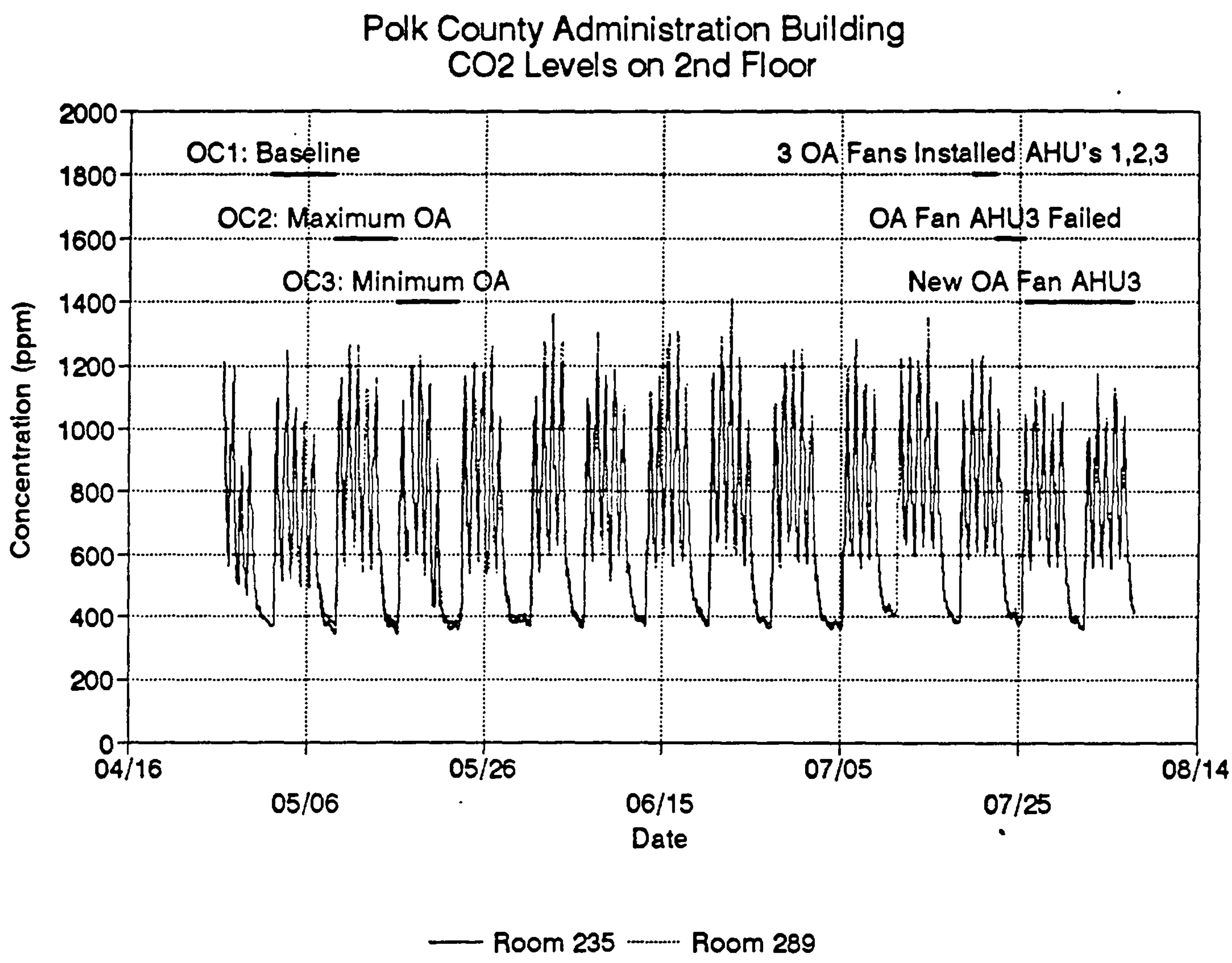

Polk County Administration Building
CO2 Levels on 1st Floor
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Concentration (ppm)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
04/16
05/06
05/26
06/15
07/05
07/25
08/14
Date
Room 124A
Room 182
Room 154
Room 119
Auditorium



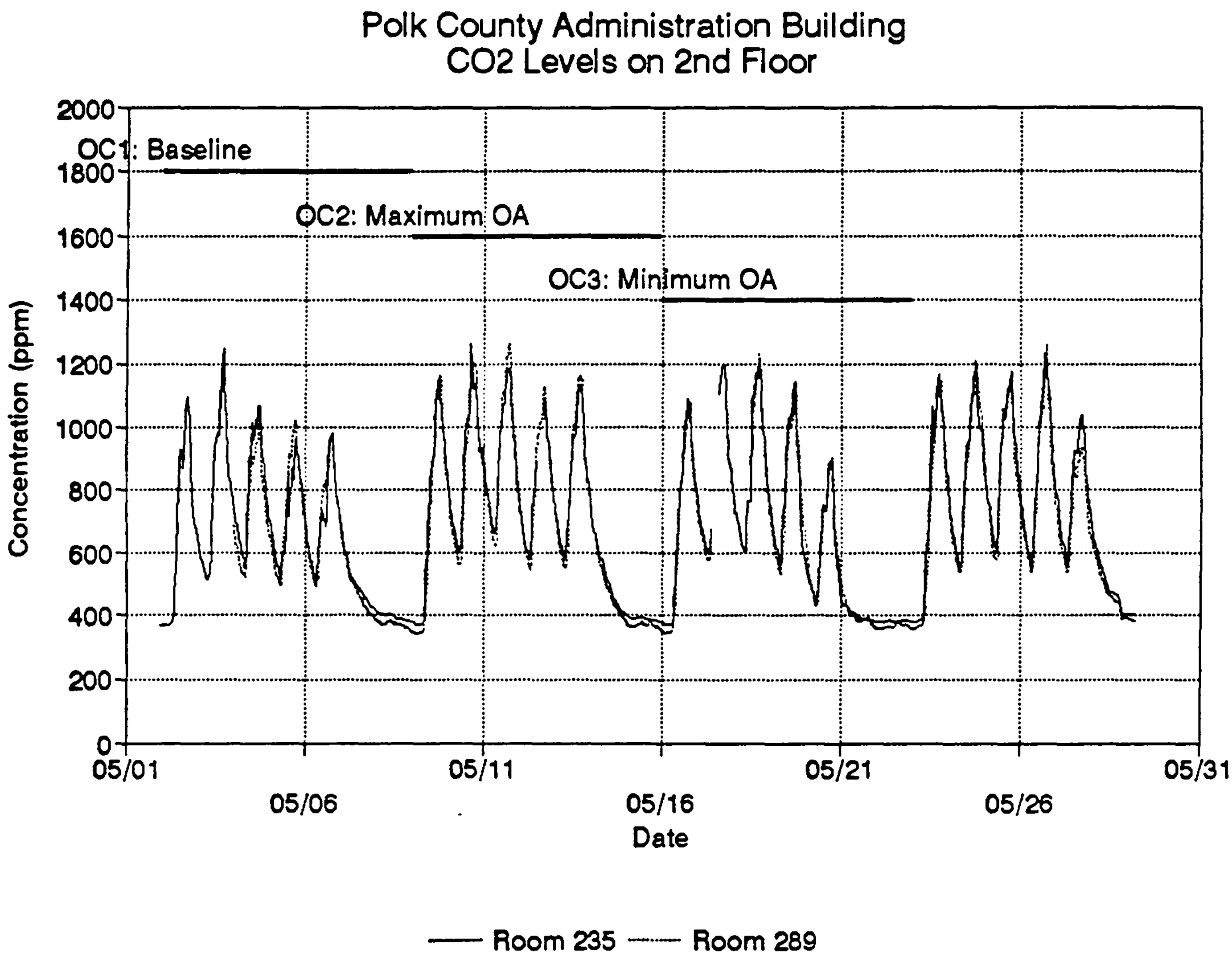
Polk County Administration Building
CO2 Levels on 1st Floor
2000
1800
1600
1400
1200
1000
800
600
400
200
0
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
Concentration (ppm)
05/01
05/06
05/11
05/16
05/21
05/26
05/31
Date
Room 124A
Room 182
Room 154
Room 119
Auditorium

Polk County Administration Building
CO2 Levels on 1st Floor

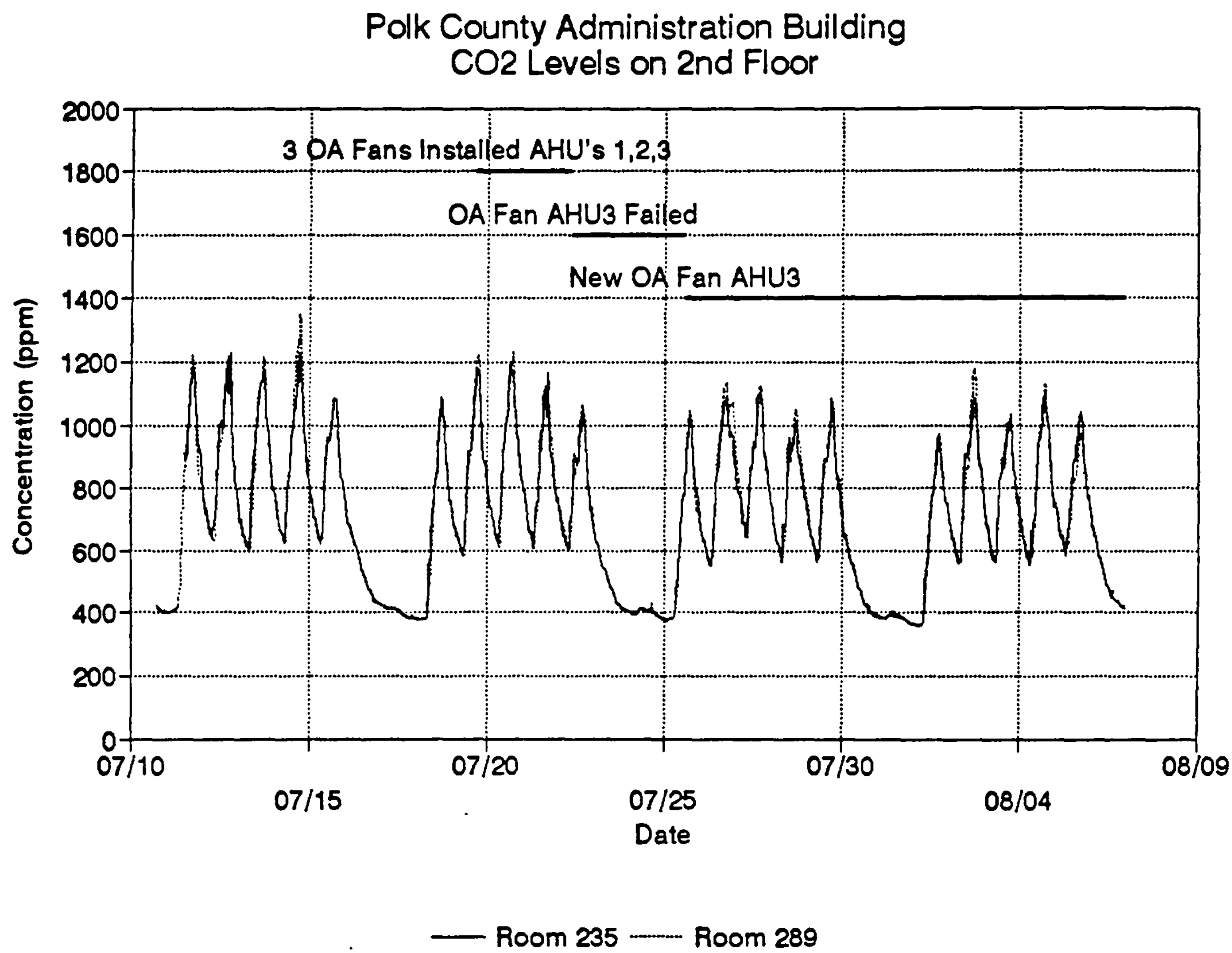


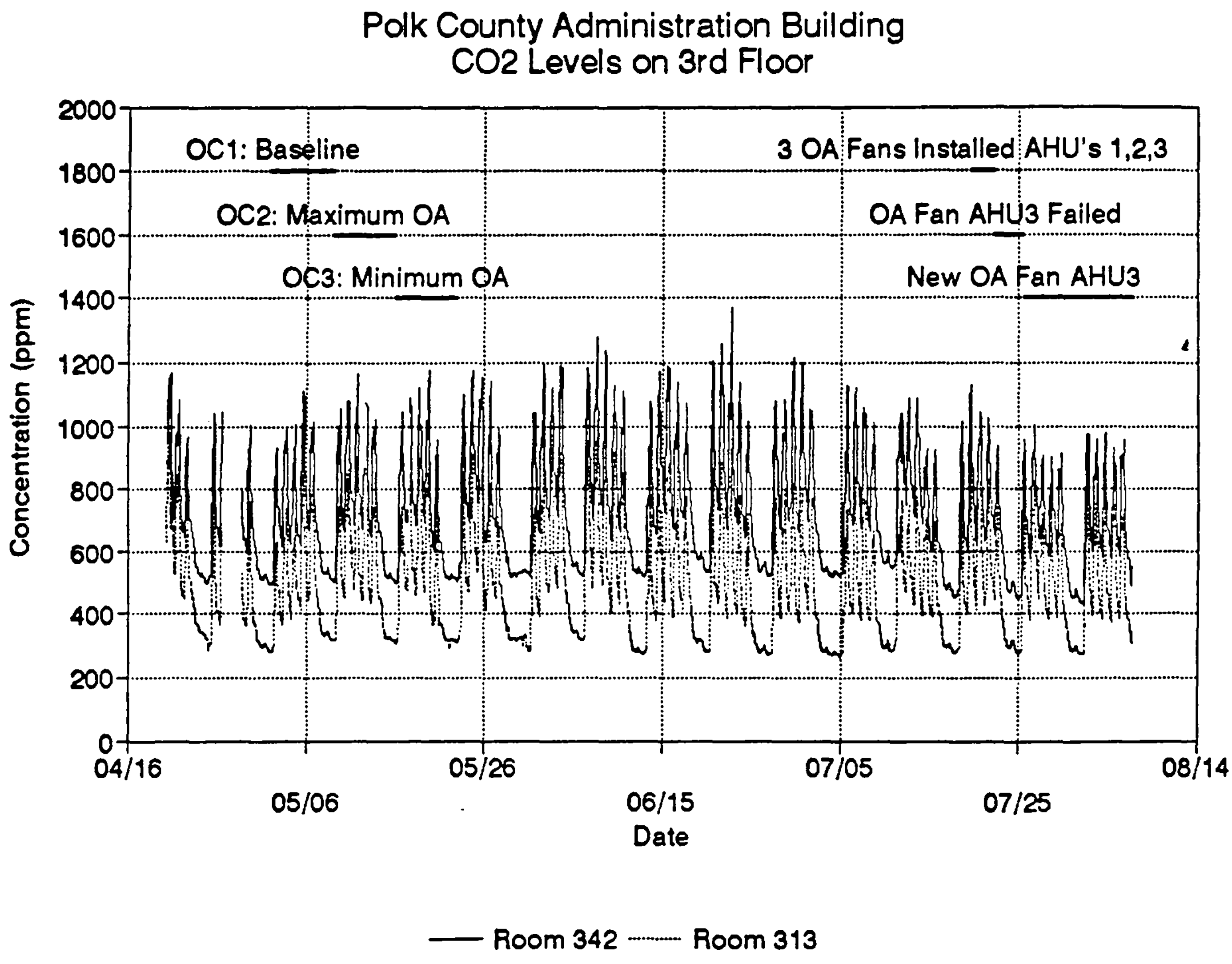


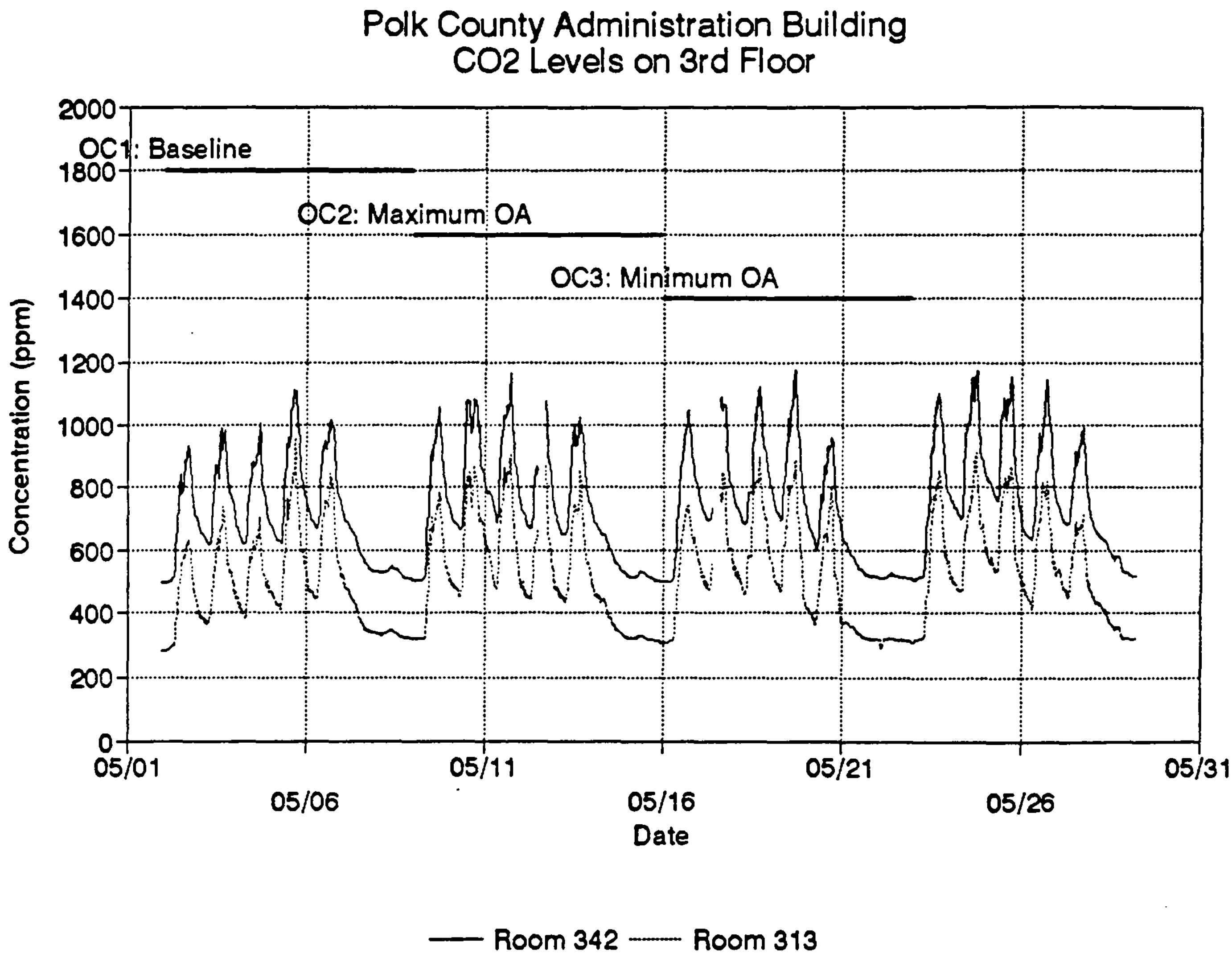
Polk County Administration Building
CO2 Levels on 2nd Floor
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Concentration (ppm)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
04/16
05/06
05/26
06/15
07/05
07/25
08/14
Date
Room 235
Room 289



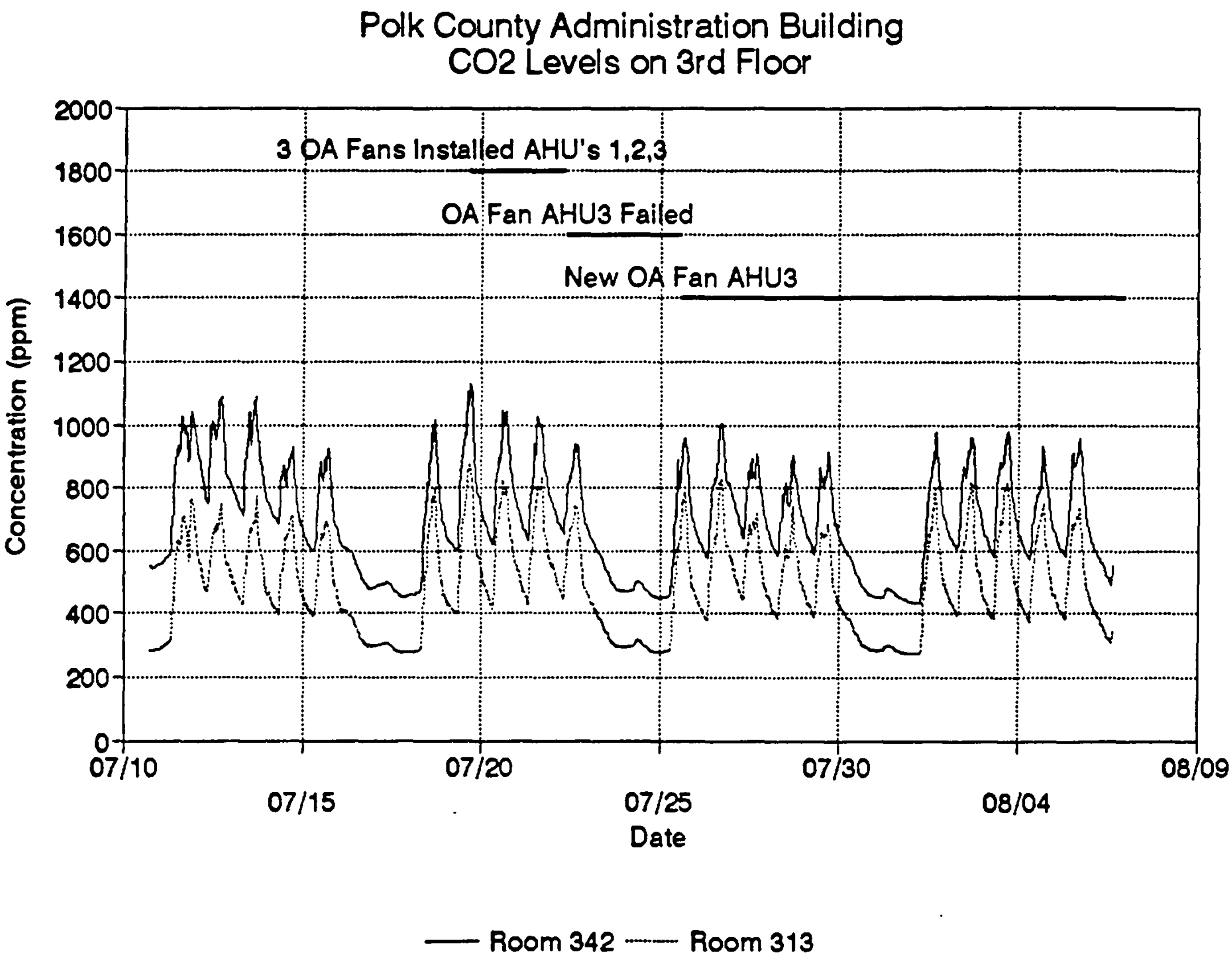
Polk County Administration Building
CO2 Levels on 2nd Floor
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
Concentration (ppm)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
05/01
05/06
05/11
05/16
05/21
05/26
05/31
Date
Room 235
Room 289

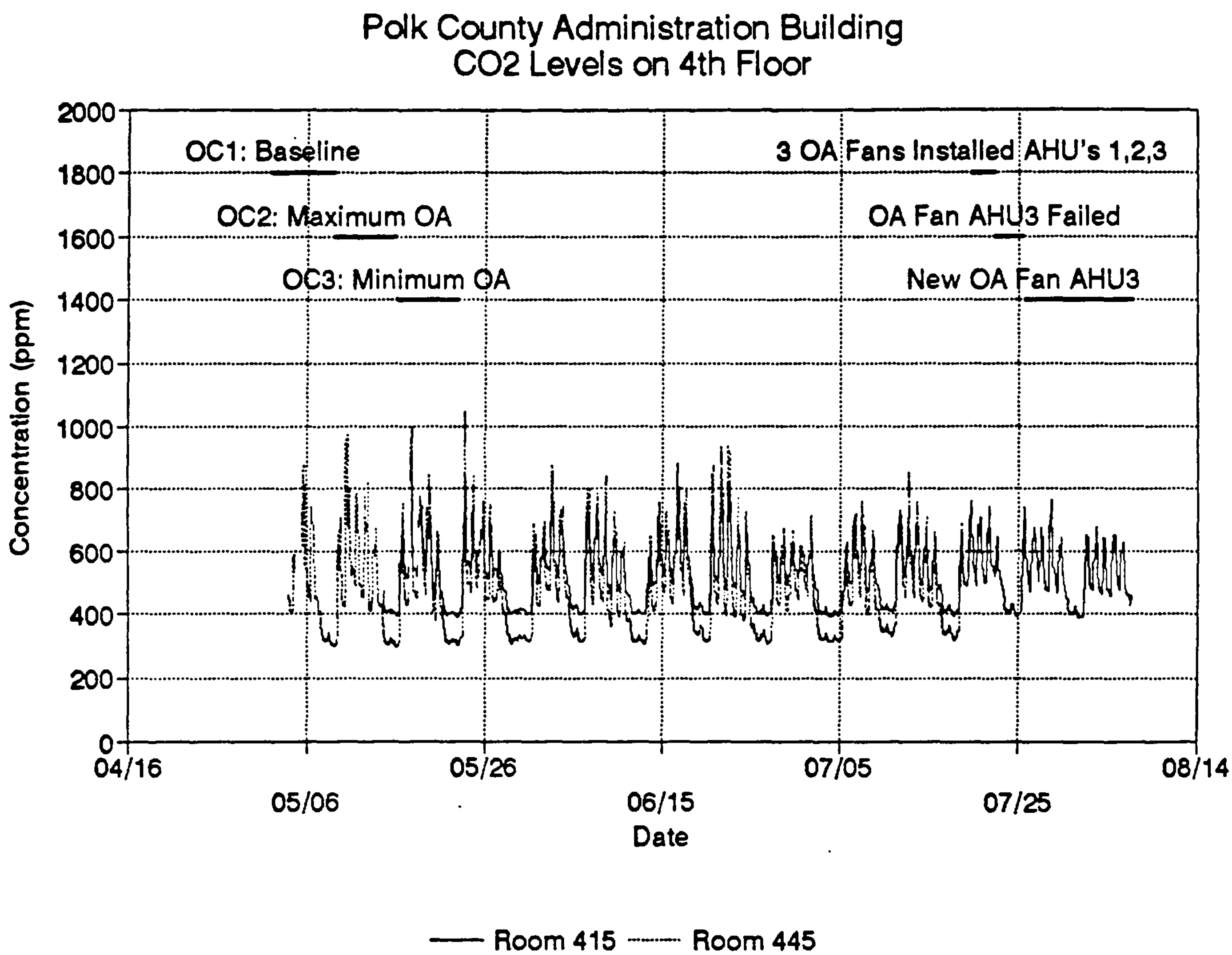

Polk County Administration Building
CO2 Levels on 2nd Floor
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Concentration (ppm)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
07/10
07/15
07/20
07/25
07/30
08/04
08/09
Date
Room 235
Room 289

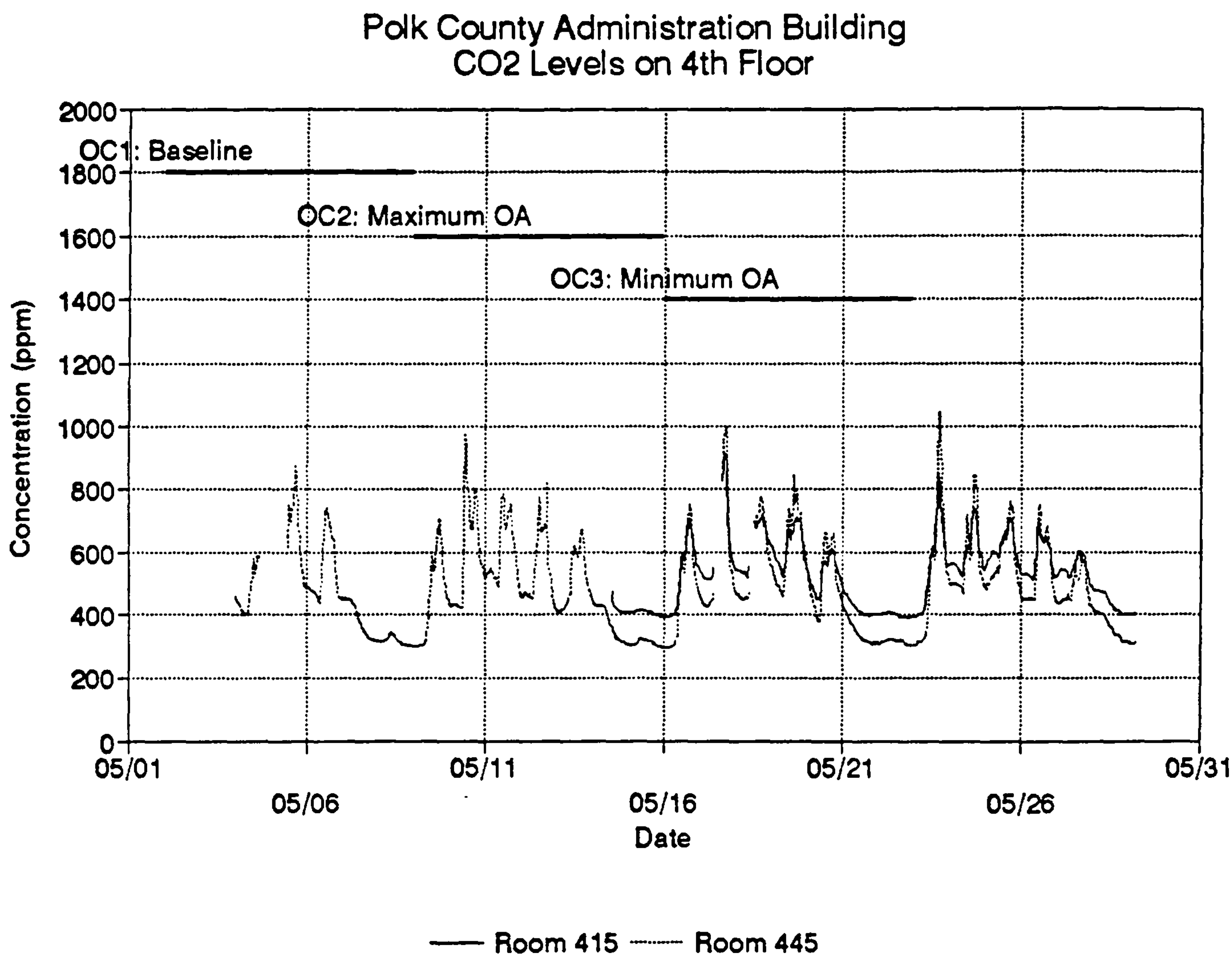

Polk County Administration Building
CO2 Levels on 3rd Floor
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Concentration (ppm)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
04/16
05/06
05/26
06/15
07/05
07/25
08/14
Date
Room 342
Room 313



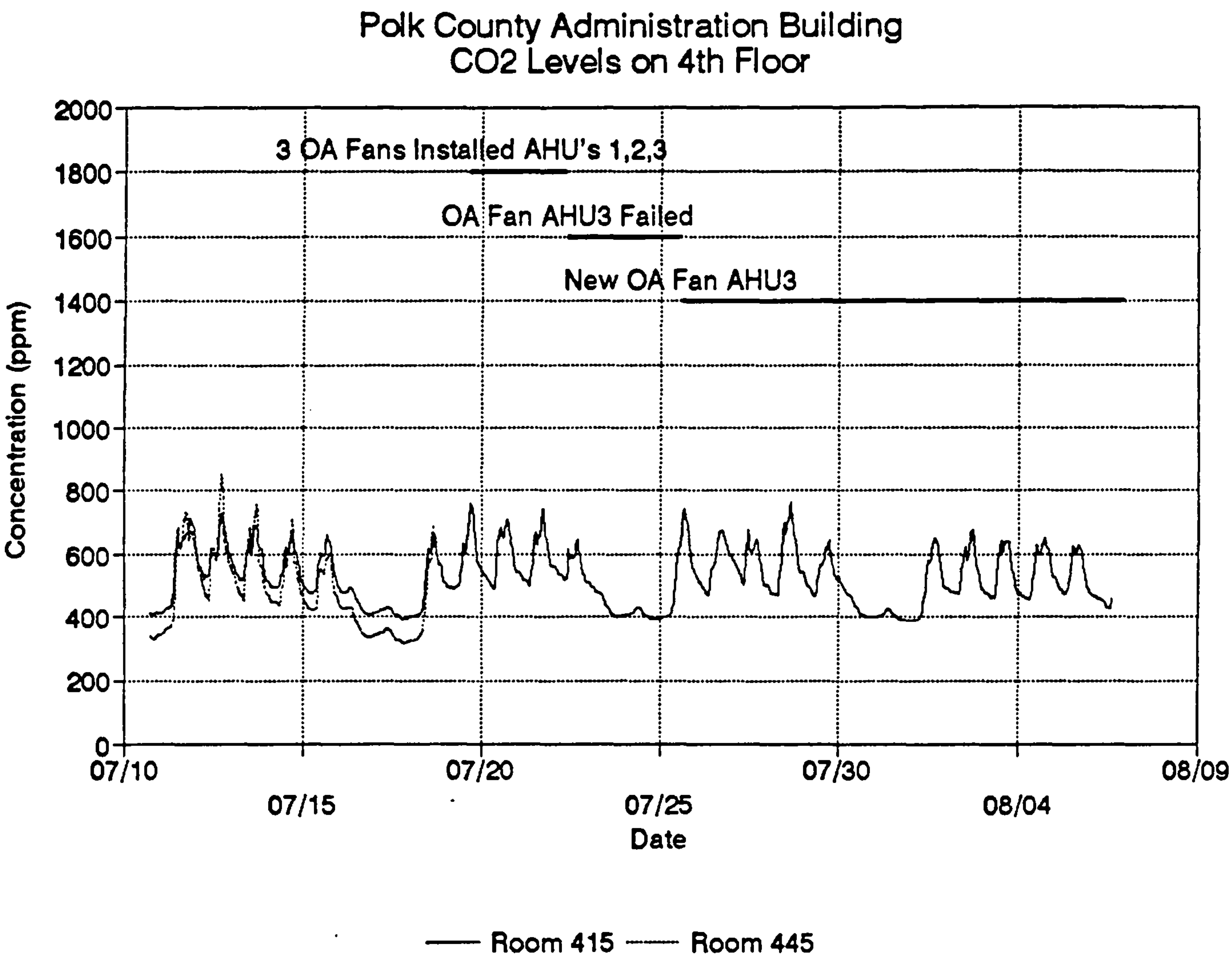
Polk County Administration Building
CO2 Levels on 3rd Floor
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Concentration (ppm)
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
05/01
05/06
05/11
05/16
05/21
05/26
05/31
Date
Room 342
Room 313

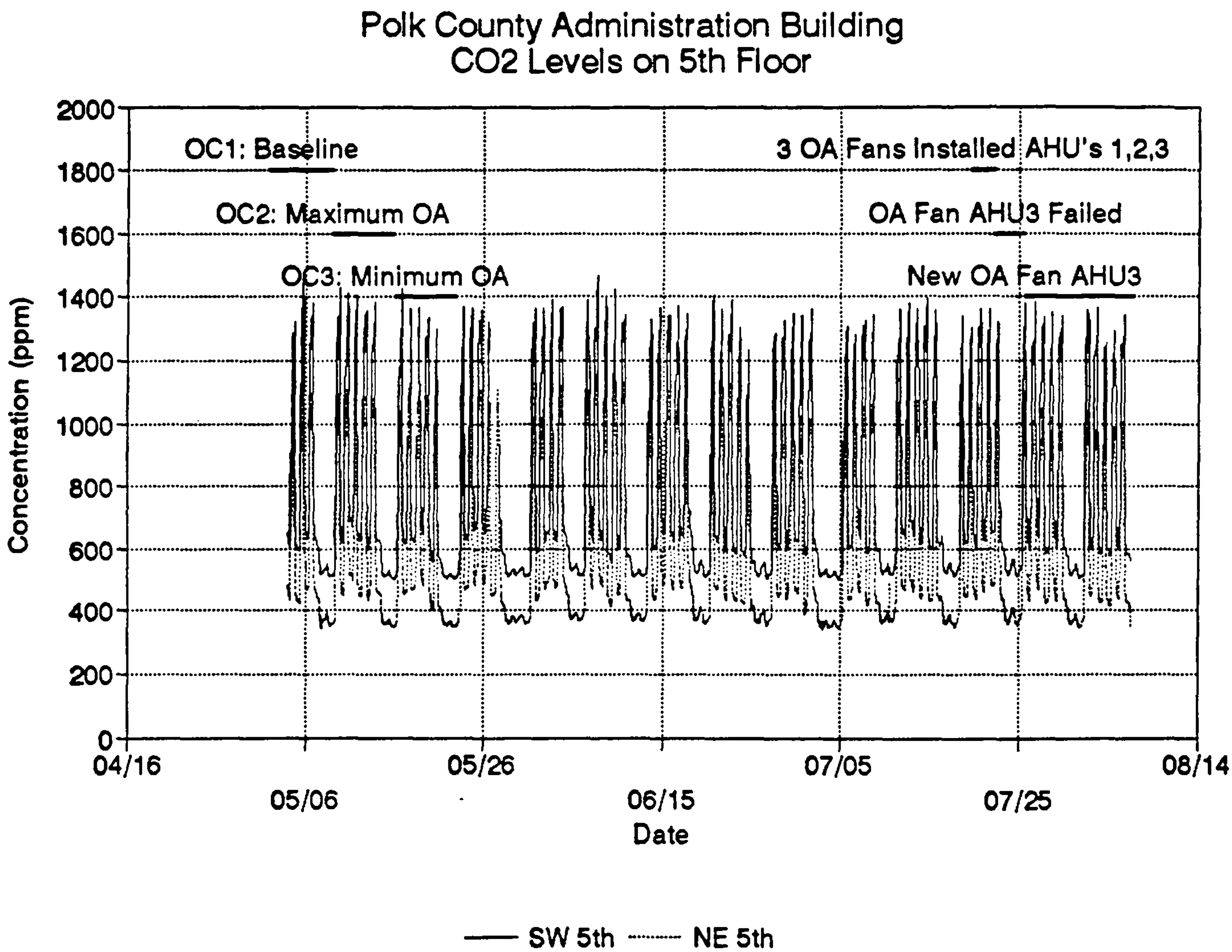

Polk County Administration Building
CO2 Levels on 3rd Floor
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Concentration (ppm)
07/10
07/15
07/20
07/25
07/30
08/04
08/09
Date
Room 342
Room 313


Polk County Administration Building
CO2 Levels on 4th Floor
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Concentration (ppm)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
04/16
05/06
05/26
06/15
07/05
07/25
08/14
Date
Room 415
Room 445

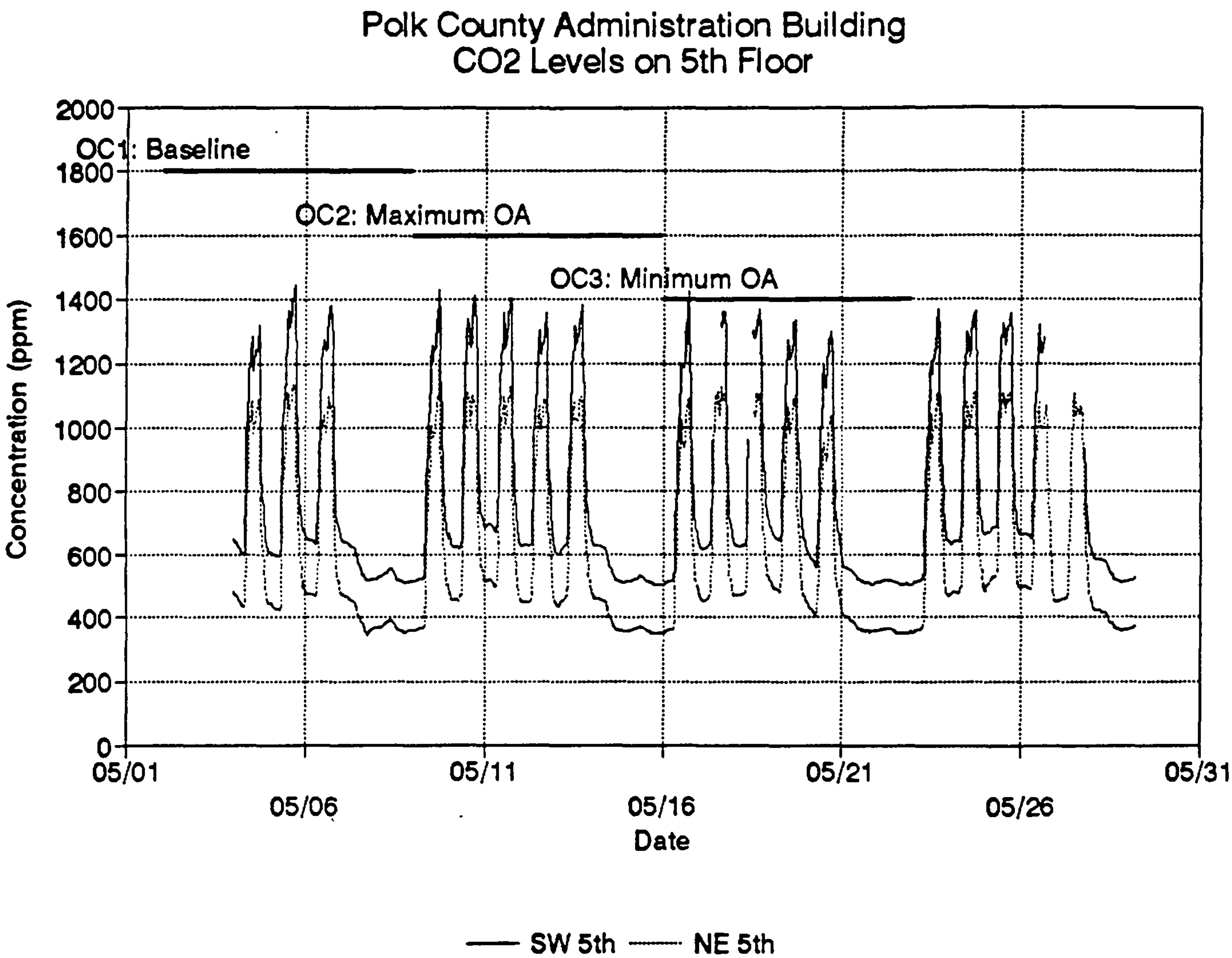


Polk County Administration Building
CO2 Levels on 4th Floor
2000
1800
1600
1400
1200
1000
800
600
400
200
0
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
Concentration (ppm)
05/01
05/06
05/11
05/16
05/21
05/26
05/31
Date
Room 415
Room 445

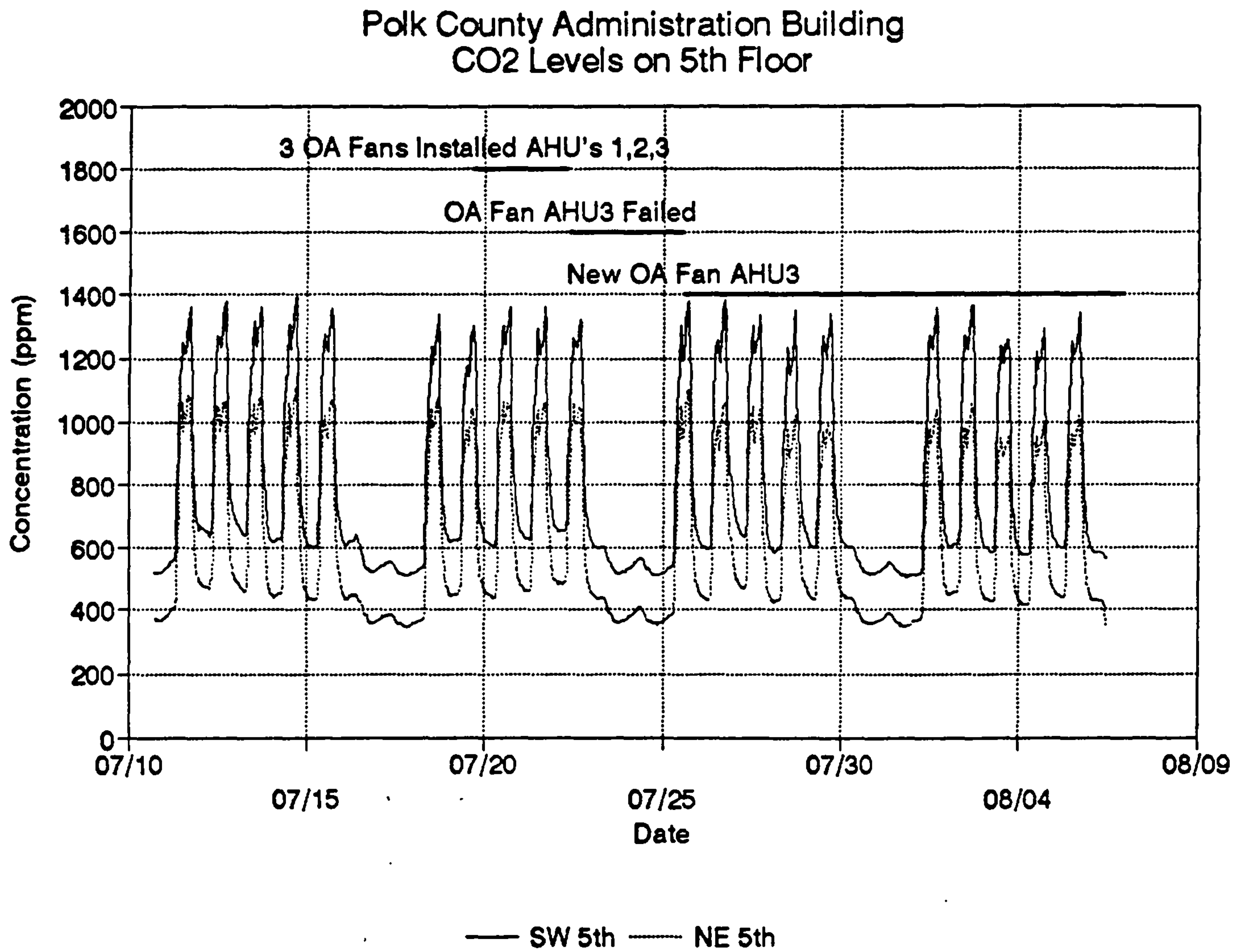

Polk County Administration Building
CO2 Levels on 4th Floor
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Concentration (ppm)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
07/10
07/15
07/20
07/25
07/30
08/04
08/09
Date
Room 415
Room 445



Polk County Administration Building
CO2 Levels on 5th Floor
2000
1800
1600
1400
1200
1000
800
600
400
200
0
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Concentration (ppm)
04/16
05/06
05/26
06/15
07/05
07/25
08/14
Date
SW 5th
NE 5th



Polk County Administration Building
CO2 Levels on 5th Floor
2000
1800
1600
1400
1200
1000
800
600
400
200
0
OC1: Baseline
OC2: Maximum OA
OC3: Minimum OA
Concentration (ppm)
05/01
05/06
05/11
05/16
05/21
05/26
05/31
Date
SW 5th
NE 5th


Polk County Administration Building
CO2 Levels on 5th Floor
3 OA Fans Installed AHU's 1,2,3
OA Fan AHU3 Failed
New OA Fan AHU3
Concentration (ppm)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
07/10
07/15
07/20
07/25
07/30
08/04
08/09
Date
SW 5th
NE 5th