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Field Hydraulic Performance of One- and Two-Story Residential Plumbing Systems With Reduced-Size Vents

Robert S. Wyly

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and

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U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
Center for Building Technology
Building Equipment Division
Gaithersburg, MD 20899

May 1984

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

ABSTRACT

This report describes hydraulic tests of drain-waste-vent systems with reduced-size vents installed in single-family housing units at Andrews Air Force Base, Camp Springs, Maryland. The vent systems of six field units were sized according to a procedure based on findings in prior laboratory investigations. The tests reported were conducted on three of the units before occupancy. Principal measurements made were trap-seal reduction and pneumatic pressure excursions in selected vents, using laboratory test procedures adapted to field conditions. Results of the preocupancy tests showed satisfactory performance with the reduced-size vents. A procedure for the design of reduced-size vent systems is presented that provides methods for plumbing designers and groups engaged in updating plumbing codes.

ACKNOWLEDGMENTS

The program described in this report originated in response to a technical implementation proposal prepared by Robert S. Wyly[1] for Paul Land, Directorate of Civil Engineering, U.S. Air Force. The work was conducted under the administrative direction of Lawrence S. Galowin. Mary Jane (Orloski) Phillips[2] directed activities relating to the design, and installation of the reduced-size vents, planned and conducted the preoccupancy tests, and prepared a draft report presenting the results. The design, development and installation of the automated data acquisition system and instrumentation package was directed by Richard A. Grot, assisted by Lynn Schuman. Robert W. Beausoliel, Grover C. Sherlin, Jr. and Robert S. Wyly contributed recommendations on instrumentation design and measurement procedures. Members of the NBS Instrument Shop are acknowledged for their work in constructing some of the special sensors. Assistance in the evaluation of the as-built systems to determine conformance of the drainage piping to the appropriate model plumbing code was provided by George Williams, Chief Plumbing Inspector, Fairfax County, VA., and by Dee Rathbone, Plumbing Engineer. Capt. Kenneth Hanna (USAF) provided liaison between the NBS project staff, the Andrews Air Force Base Civil Engineering Office, the plumbing contractor, and the occupants of the test houses.

Robert S. Wyly and Lawrence S. Galowin expanded the initial draft report prepared by Mary Jane (Orloski) Phillips and consolidated the design criteria in the appendices from other NBS reports.

The work was first sponsored by the Directorate of Civil Engineering, U.S. Air Force and later by the Building Research Committee of the Tri Services. A significant portion of the project costs to obtain field data on water usage and frequency of fixture operation was borne by the NBS Center for Building Technology. The preparation of this report was sponsored by the Department of Housing and Urban Development.

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[1] Currently Plumbing Consultant.

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DEFINITIONS

In this report, a number of terms are used that require specialized definition beyond the dictionary meaning of the words. Some terms used are adequately defined in plumbing codes, but others are used in such a sense as to require modified definition for the purposes of this report. Therefore, the following definitions are provided as an aid to understanding.

Blowback - the ejection of suds, air, or other gases through the trap-seal to the room side of a trap as a result of excessive positive pressure on the drain side of the trap.

Branch - any part of the piping system other than a main, riser, or stack.

Branch vent - a vent pipe to which two or more fixture vents are connected and which terminates by connection to a vent stack or a stack vent.

Building drain - that part of the lowest piping of a drainage system which receives the discharge from soil, waste, and other drainage pipes inside the walls of the building and conveys it to the building sewer.

Common vent - a fixture vent connecting at the junction of two fixture drains and serving as a vent for both fixtures.

Cumulative dH - trap-seal reduction of an idle trap after a series of fixture discharges without refilling the idle trap between such discharges.

dH - the amount of decrease in trap-seal depth from full-seal depth of an idle trap following the discharge of other fixture(s) into the system.

Dip of trap - the highest point on the internal vertical cross section of the trap at the lowest portion of the bend (inverted siphon).

dP - peak vent pressure (positive or negative) occurring during the discharge of fixtures into the system.

Dry vent - any vent that does not carry water or waterborne wastes.

Fixture vent - a vent that provides the primary ventilation for one or two traps located in the proximity of the base of the vent.

Flood-level rim - the top edge of a receptacle or fixture bowl from which water can overflow in the absence of or malfunction of an overflow device at a lower elevation.

Frost closure - the partial or complete closure of a roof vent in cold weather by the formation of a layer of frost on the inner surface of the vent.

Individual vent - a fixture vent installed to vent a single fixture and so connected with the vent system or with the open air that free movement of air is possible at all times.

Induced siphonage - the process whereby a reduction in the surface level of the trap-seal of an idle fixture is caused by the discharge of other fixtures on the system, such discharge resulting in transient local pressure fluctuations that siphon, or otherwise remove, water from the idle trap.

Reduced size venting (RSV) - a specially designed vent system (or the procedure for such design) that contains dry vents smaller in size than allowed by the applicable plumbing code for standard venting.

Soil stack - a stack intended to convey sewage containing fecal matter.

Stack - general term for the vertical main of the soil, waste, or vent piping system.

Stack vent - a stack vent is the extension of a soil or waste stack above the highest connection of a horizontal drain to the stack.

Trap - a fitting or device placed below a fixture outlet and constructed so as to provide a water seal for protection against the emission of sewer gases, without significantly retarding the flow of water through it.

Trap-seal - the vertical distance between the trap weir and the dip of the trap.

Trap-seal reduction - same as dH.

Trap-seal retention - the amount of trap-seal retained following the discharge of fixture(s) into the system.

Trap weir (crown weir) - the lowest point in the vertical cross section of the horizontal waterway at the exit of the trap.

Vent - a pipe installed to provide a flow of air to or from a drainage system or element thereof so as to provide protection of trap-seals from siphonage and back pressure.

Vent header - a generally horizontal vent that joins together two or more stack vents and/or vent stacks, and terminates outside the building in the atmosphere.

Vent stack - a vertical vent pipe extending through two or more stories, installed to provide circulation of air between elements of the DWV system. Usually, the vent stack is the vertical main of the vent system, to which branch vents are connected.

Vent terminal - that portion of the vent piping extended outside the building and open to the atmosphere.

Waste - liquid waste not including fecal matter.

Waste stack - a stack that conveys only waste.

1. INTRODUCTION

1.1 OBJECTIVE AND SCOPE OF PROGRAM

The principal objective of the research program described herein was to evaluate field performance of reduced-size vents (RSV). Laboratory-based vent-sizing criteria were applied to the modification of selected standard drain-waste-vent (DWV) designs and measurements made to determine the field hydraulic and pneumatic performance of the test units. In addition, the broad overall scope of the program undertaken called for the acquisition of post-occupancy data on the magnitude and time distribution of hot and cold water by fixture and of energy consumption by the water heater. Samples of the type of data obtained in the post-occupancy study are presented in appendix B.

Laboratory-based criteria [1] were applied to resize the dry vents of two living units each of three different standard DWV plans (a total of six units). Sensors, transmission wiring, and a data acquisition system were installed for the primary purpose of automatically monitoring, subsequent to occupancy: (1) the hydraulic and pneumatic performance of the DWV system, (2) distribution of fixture operations, (3) water consumption, and (4) energy used by the water heaters.

Preoccupancy field tests were made in three of the six units, in which trap-seal reductions for idle traps and pneumatic pressure changes in vents were measured when selected plumbing fixtures were discharged manually. Figure 1 is an aerial view of the test houses.

This report includes recommended design procedures, installation guidelines and preoccupancy field test performance data for RSV systems.

1.2 BACKGROUND

Before the present study was initiated several reports describing laboratory investigations of reduced-size venting had been issued [1, 2, 3, 4], and one field study had been reported [5]. Reduced-size venting was used in one single family, one-story DWV design used in HUD's Operation Breakthrough Program [6] apparently with satisfactory results. Those investigations showed the adequacy of hydraulic and pneumatic performance of selected one- and two-story DWV systems with reduced-size vents under the conditions described. The principal explanations offered for the satisfactory performance of those systems not conforming to traditional vent sizing requirements were:

(a) Traditional sizing of vent stacks and stack vents is based on maximum air flow rates associated with conditions in a tall building [7], where both the waste loading rates and the accompanying air flow rates might be expected to be much greater than occur in a one- or two-story building. Laboratory data confirmed this, showing relatively low air demands in one- and two-story systems.

(b) Scientific criteria for the traditional sizing of individual and common fixture vents and for branch vents could not be identified; analysis of installation practices and laboratory measurements indicated such vents, at least in one- and two-story systems are capable of carrying much greater air flow rates that normally occur in service when sized by plumbing code requirements.

(c) Traditional vent sizing was developed with an awareness of the tendency of ferrous pipes to acquire, under some conditions, surface corrosion deposits which could, over a period of time, reduce the effective diameter of the pipe. But if modern piping materials not subject to corrosion are used, this effect should be negligible.

As a result of these findings suggesting potential for the demonstration of of RSV as a viable type of venting, the U.S. Air Force and the Tri Services, together with NBS, funded the field study described in this report. The demonstration was intended to provide a basis for possible later general application of RSV, with economic benefits, in the Tri Services family housing construction programs. The highly instrumented homes were to provide field data on water use and distribution of fixture operations needed for updating the widely used Hunter method for sizing water supply piping. It was also intended to provide a practical, generalized sizing procedure for use by plumbing code organizations that may consider the inclusion of RSV criteria in their codes.

Economic analyses of the impact of reduced-size venting [8] concluded that under some conditions and methods of cost estimating, significant savings can be anticipated from the installation of RSV. In these analyses, potential savings in single family, one- and two-story residential installations ranged from $24 to $151 per dwelling unit (1975 dollars). Cost reductions from RSV are affected primarily by: (1) the specifics of the DWV system design including pipe sizes, configuration, complexity, fixture locations, etc., (2) types and availability of necessary piping materials, and (3) the nature of cost estimating procedures used and other business practices of the plumbing contractor. These are essentially the principal factors that generally affect the cost of plumbing. The studies showed that, while the unit savings from the lower materials costs of smaller pipes and fittings may be relatively small, installation labor, overhead, and profit generally amplify this margin so that, for example, a one dollar saving on the material cost of a length of pipe may result in much more than a one dollar saving in the completed installation.

1.3 PERFORMANCE CONCEPTS AND GENERAL APPROACH

Performance concepts for plumbing in general, and sanitary DWV systems in particular, have been treated at length in previous studies [9, 10, 11, 12] so the criteria and requirements will not be discussed here in detail. Let it suffice to state that the performance criteria of particular interest in this study were: (a) trap-seal retention in idle traps subjected to suction, and (b) absence of emissions of water or suds through idle trap-seals subjected to back pressure. Attention was also given to the principal phenomenon which might produce the results measured by criteria (a) and (b): the fluctuating suction or back pressure within the vent system pipe network itself.

In the preoccupancy tests, the general approach was to impose test loads considered somewhat more severe than would be expected in normal service, and to measure trap-seal reduction (the complement of trap-seal retention) and pressure fluctuations in the vents. At the same time, test personnel listened for noises indicating air flow through idle trap-seals which could indicate excessive levels of back pressure or suction.

Figure 1. Aerial view of test houses

2. SIZING OF VENTS

2.1 SIZING CRITERIA

2.1.1 Traditional Criteria

The traditional code requirements for sizing of stack vents and vent stacks (main vents) are based on data from laboratory studies with multistory test systems, applied conservatively [7, 13, 14]. The traditional criteria for sizing individual, common and branch vents are more or less "rule-of-thumb," based on experience with ferrous vent piping materials (commonly used when these rules were being formulated), which, under some conditions, can be subject to gradual diameter reduction and increased surface roughness as a result of corrosion. Also, it is recognized that intermittent discharge of a fixture may, under some conditions, deposit a layer of particulate matter inside the lower portion of a vent, further contributing to gradual closing of the vent over a period of time, regardless of the piping material used.

A review of this information indicated that in many systems dry vents sized by traditional criteria are considerably larger than would be required to accomodate the air flow with an acceptable pressure drop. The review suggested that dry vent size reduction would be appropriate in low-rise systems, particular one- and two-story residences, and that such reduced-size venting should be constructed of corrosion-resistant piping.

2.1.2 Criteria for RSV

The essential features of the RSV criteria applied in this study were presented in an earlier publication [1]. The criteria used were technically similar to those presently recommended in appendix C using an updated format.

In applying the criteria, the principal parameters to be considered are: (1) "free-fall" distance for water discharge, (2) fixture unit load values(s) of fixture(s) served by a particular vent, and (3) type or function of vent, e.g., individual vent, branch vent, vent stack, etc. In addition, certain limitations are critical, e.g., no size reductions are permitted wherever wastewater might reasonably be expected to rise into the vent due to fouling or blockage of a drain, and no reductions of wet vent or drainage piping sizes are permitted below code minimums. See appendix C for further details.

2.2 APPLICATION OF RSV CRITERIA TO THREE DWV DESIGNS

The first step in sizing the vents for the study was to apply the RSV criteria to the DWV schematics furnished by the sponsor prior to the beginning of construction. Figures 2 through 4 are floor plans showing the plumbing layouts taken from the original design drawings. Figures 5 through 8 are soil, waste, and vent piping riser diagrams showing vent sizes as originally specified by the Air Force and as initially recommended by NBS on the basis of the RSV criteria [1]. Appendix C presents the criteria and a recommended procedure for applying them.

The second step was to make revisions to the initially recommended RSV designs to provide consistency with modifications to the installations due to onsite contractor practices or other alterations dictated by field conditions differing from the assumptions made in producing the initial schematics (see 3.1). The "as-built" schematics are shown in figures 9 through 11.

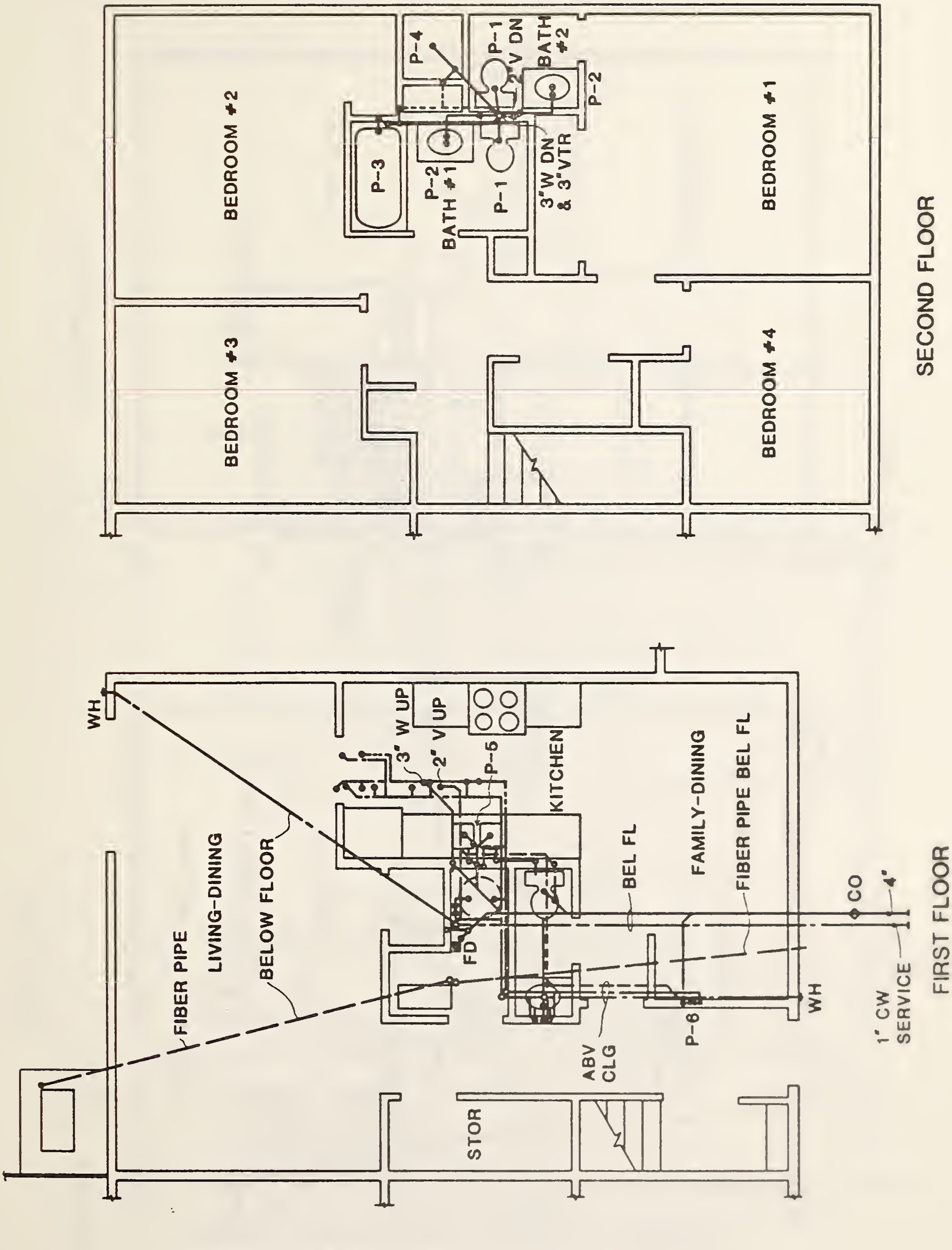

Figure 2. Floor plan for D-house (as designed)

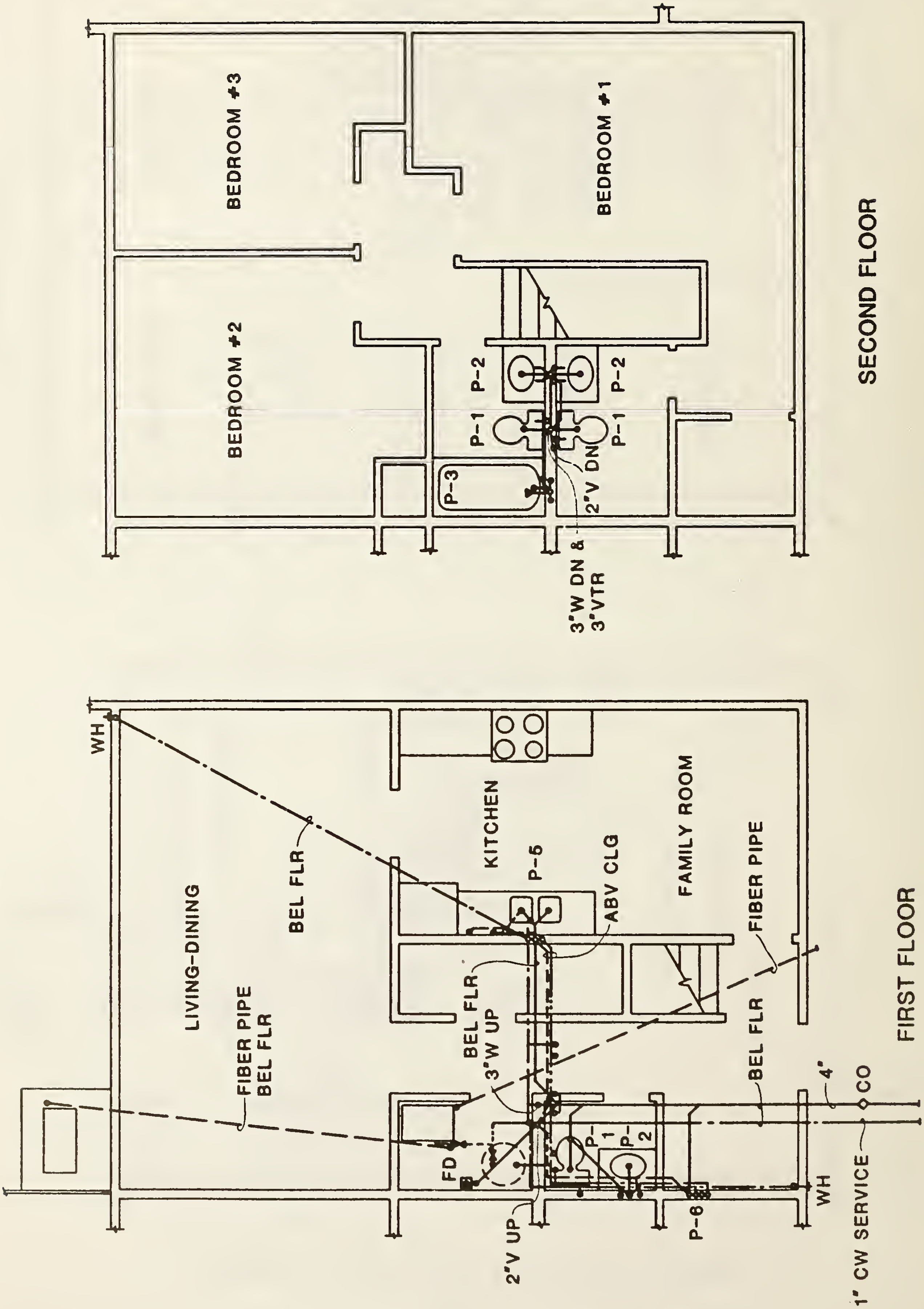

Figure 3. Floor plan for E-house (as designed)

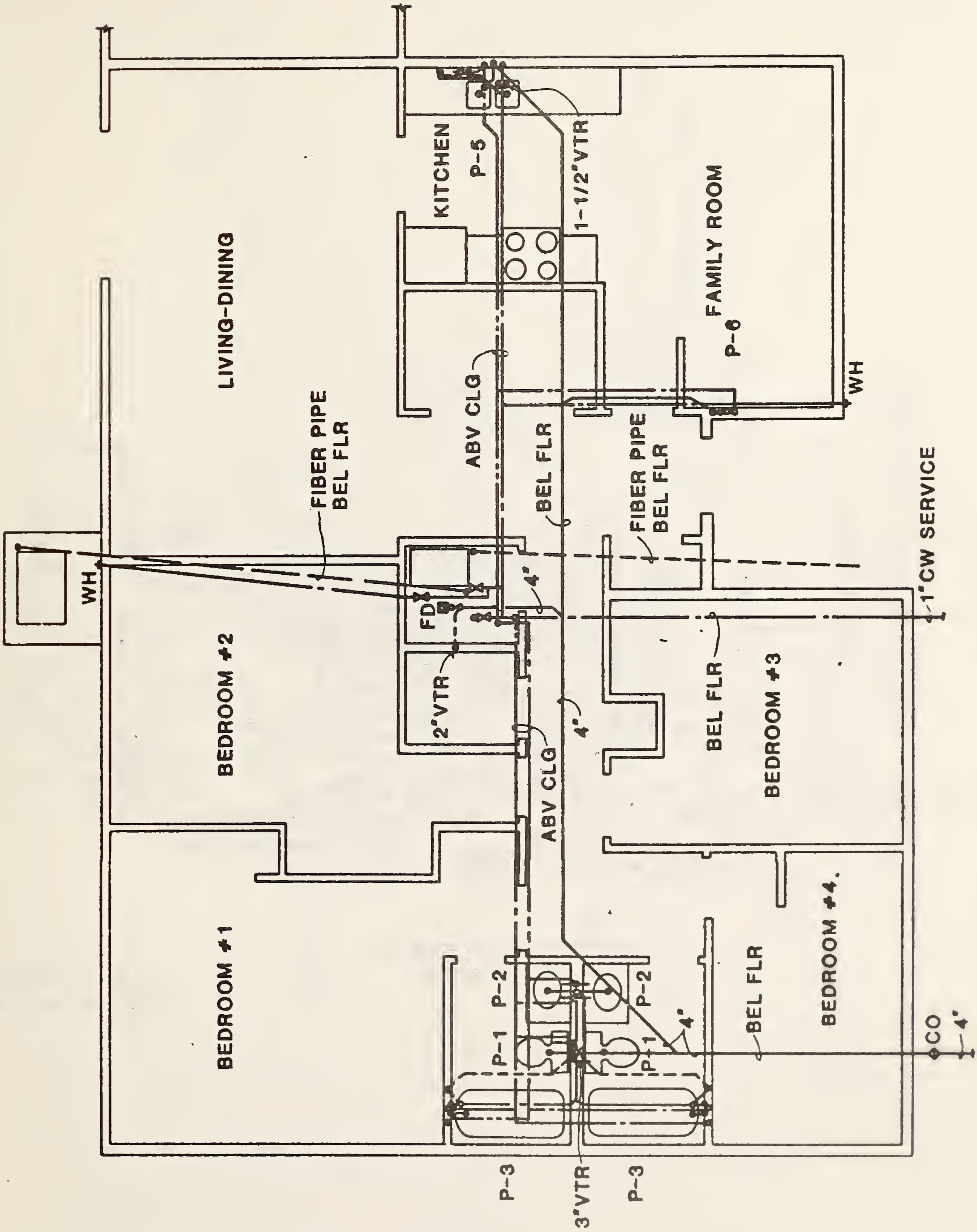

Figure 4. Floor plan for F-house (as designed)

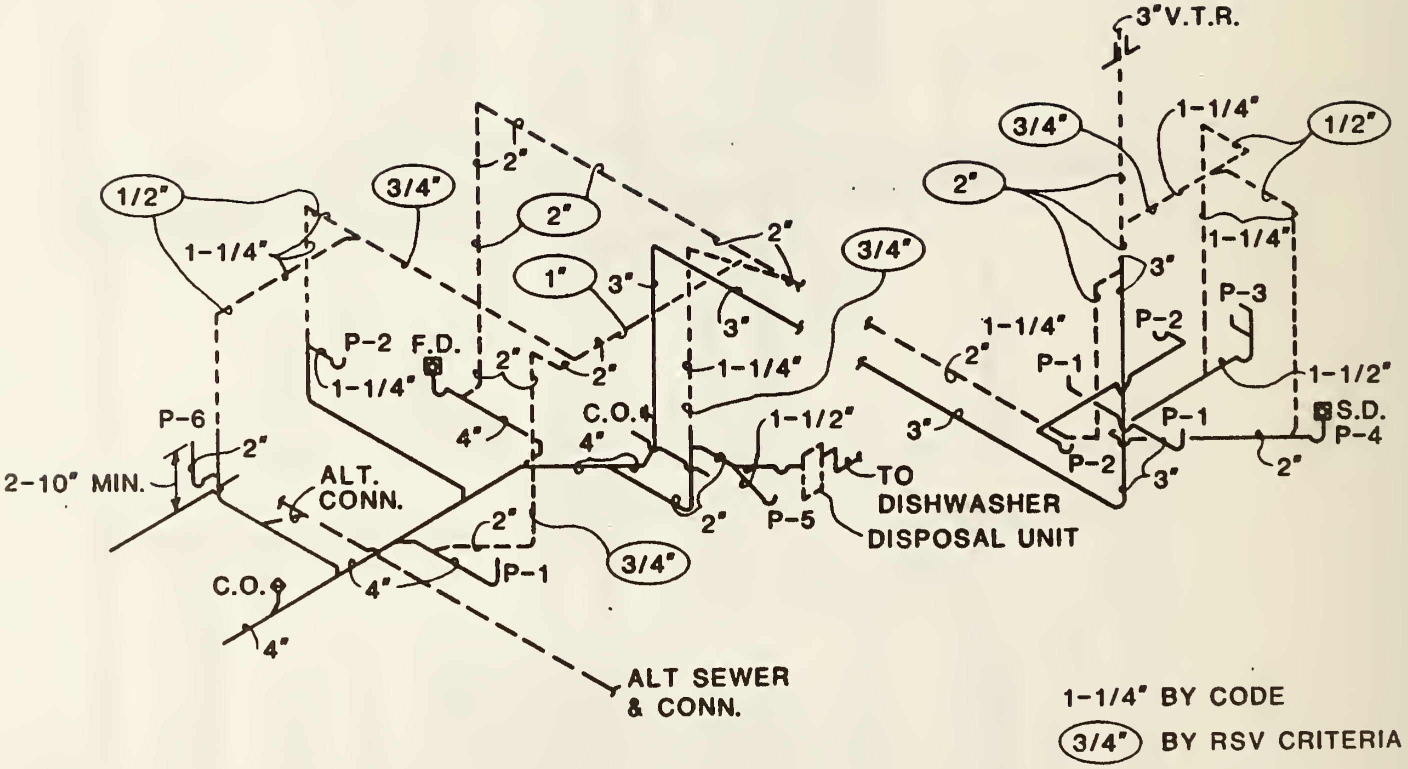

Figure 5. Original design, D-house soil, waste, and vent piping, showing vent size reductions obtainable from RSV criteria

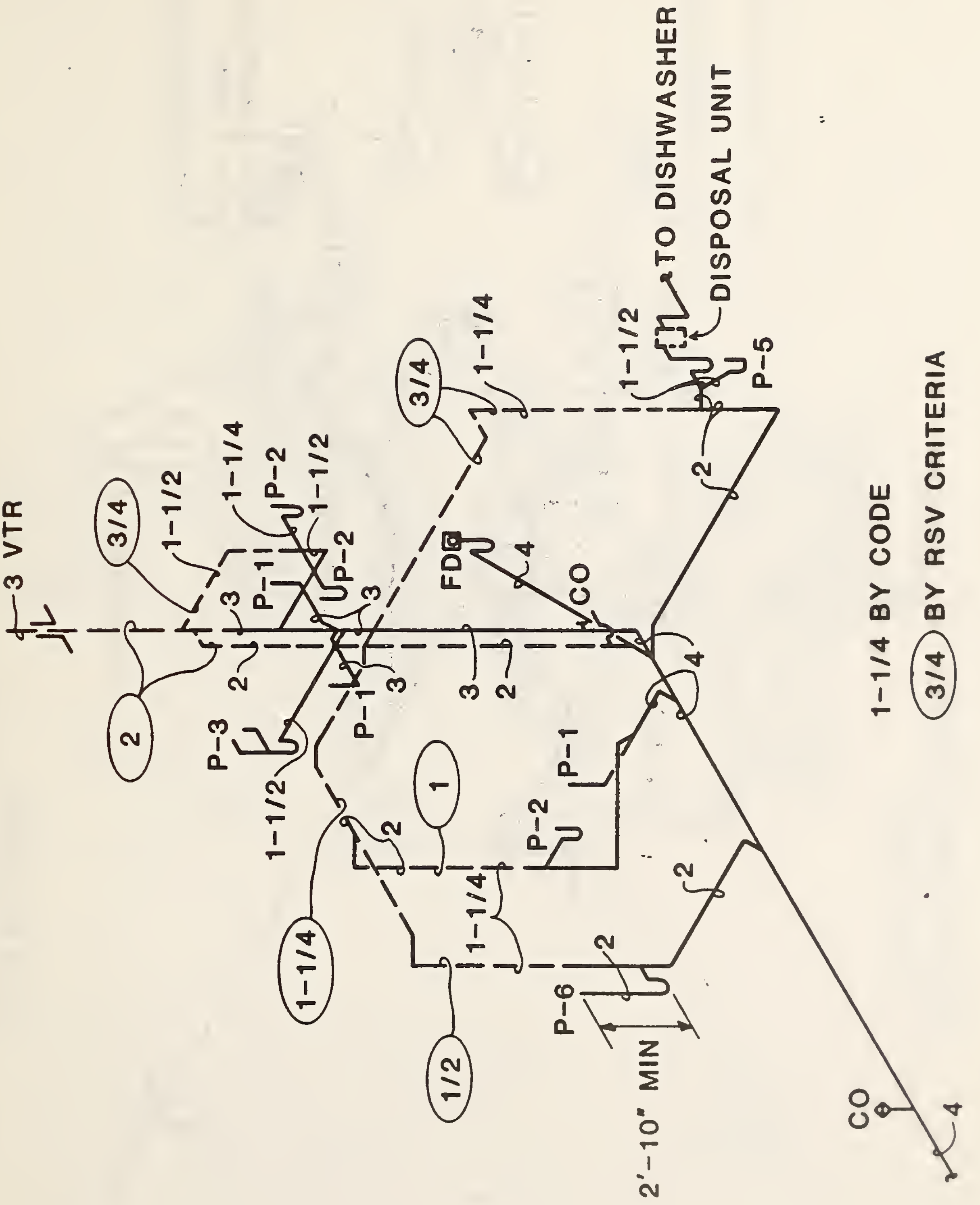

Figure 6. Original design, E-house soil, waste, and vent piping, showing vent size reductions obtainable from RSV criteria

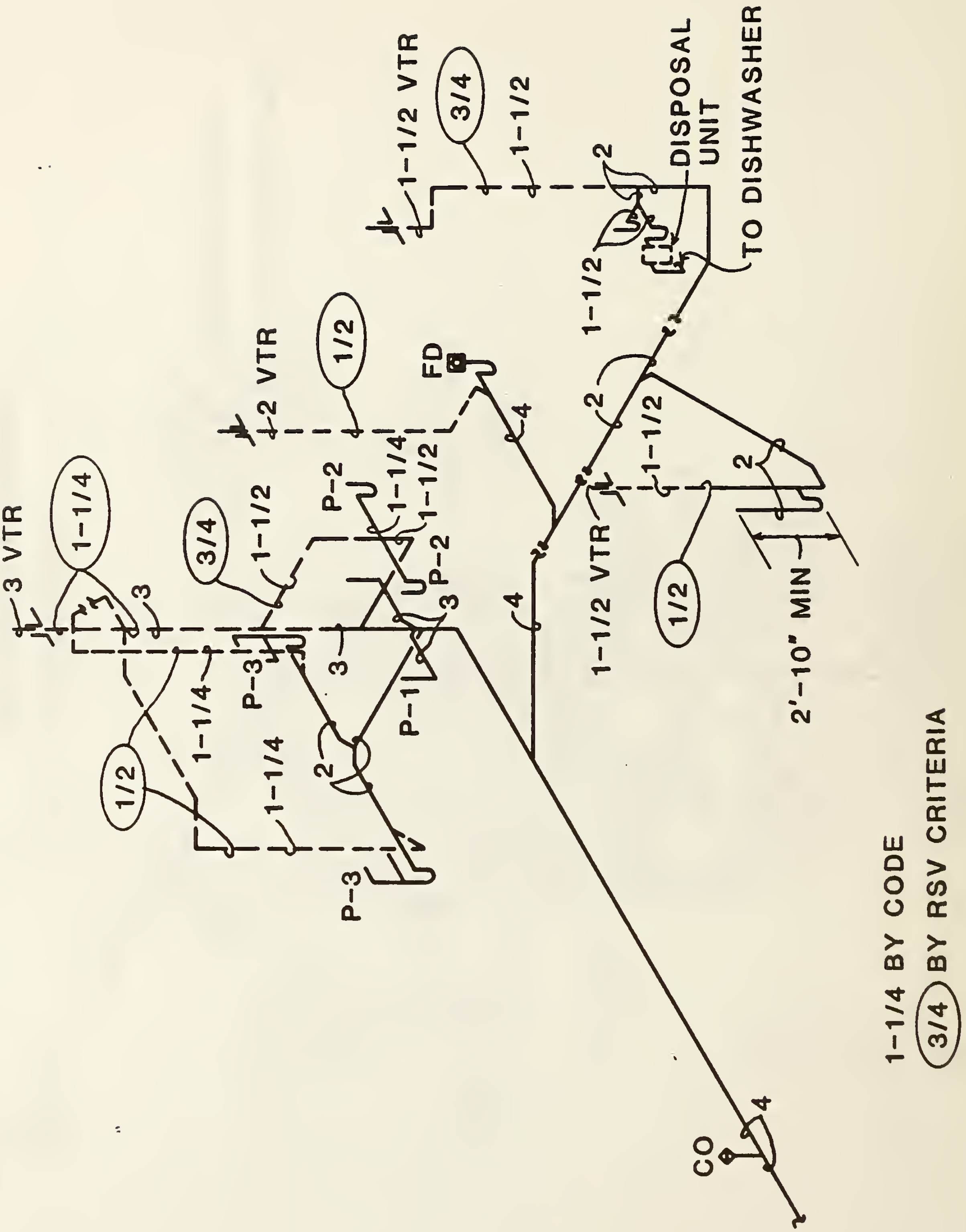

Figure 7. Original design, F-house soil, waste, and vent piping, showing vent size reductions obtainable from RSV criteria

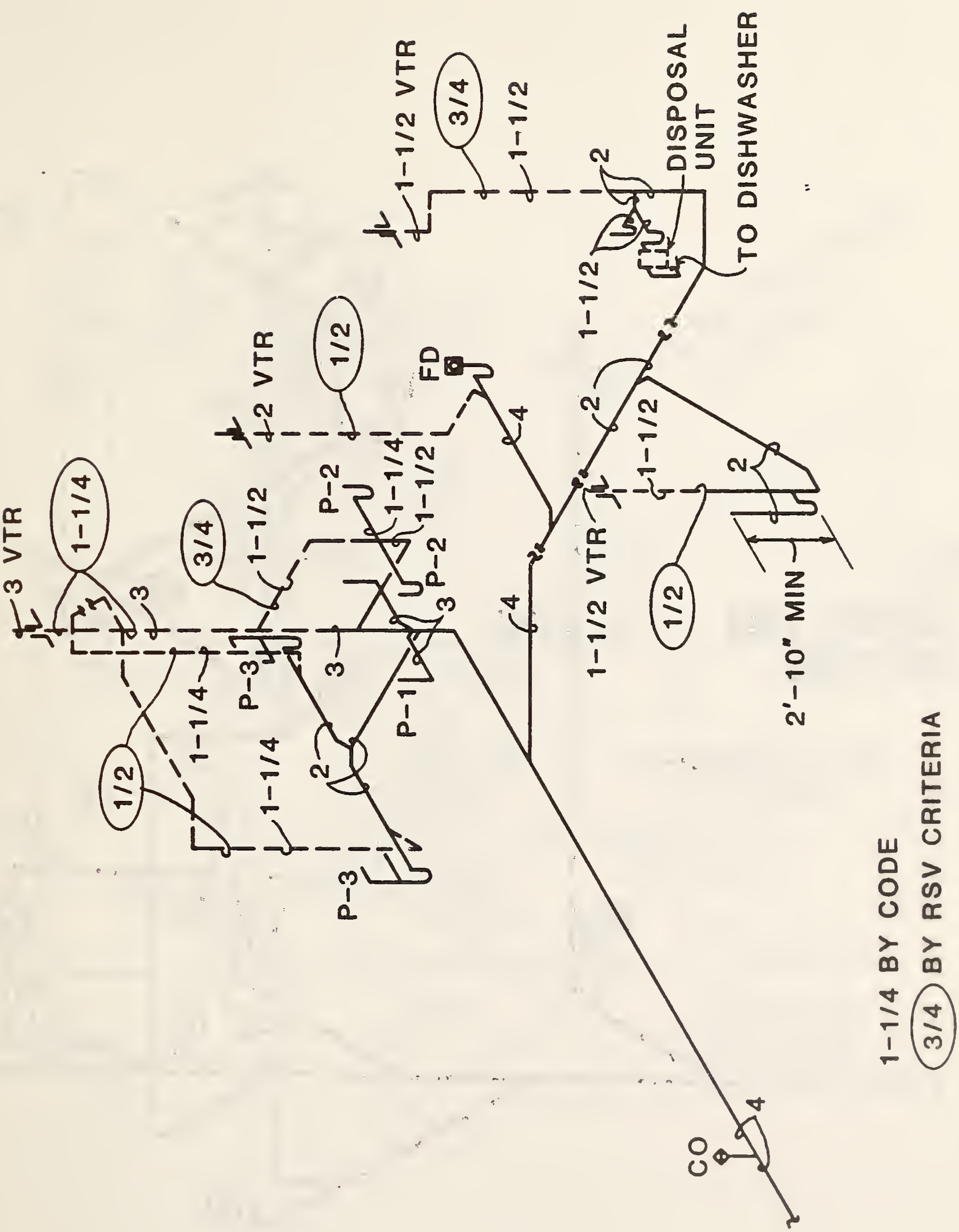

Figure 8. Modified original design, F-house soil, waste, and vent piping, showing manifolding of vent terminals and vent size reductions obtainable from RSV criteria

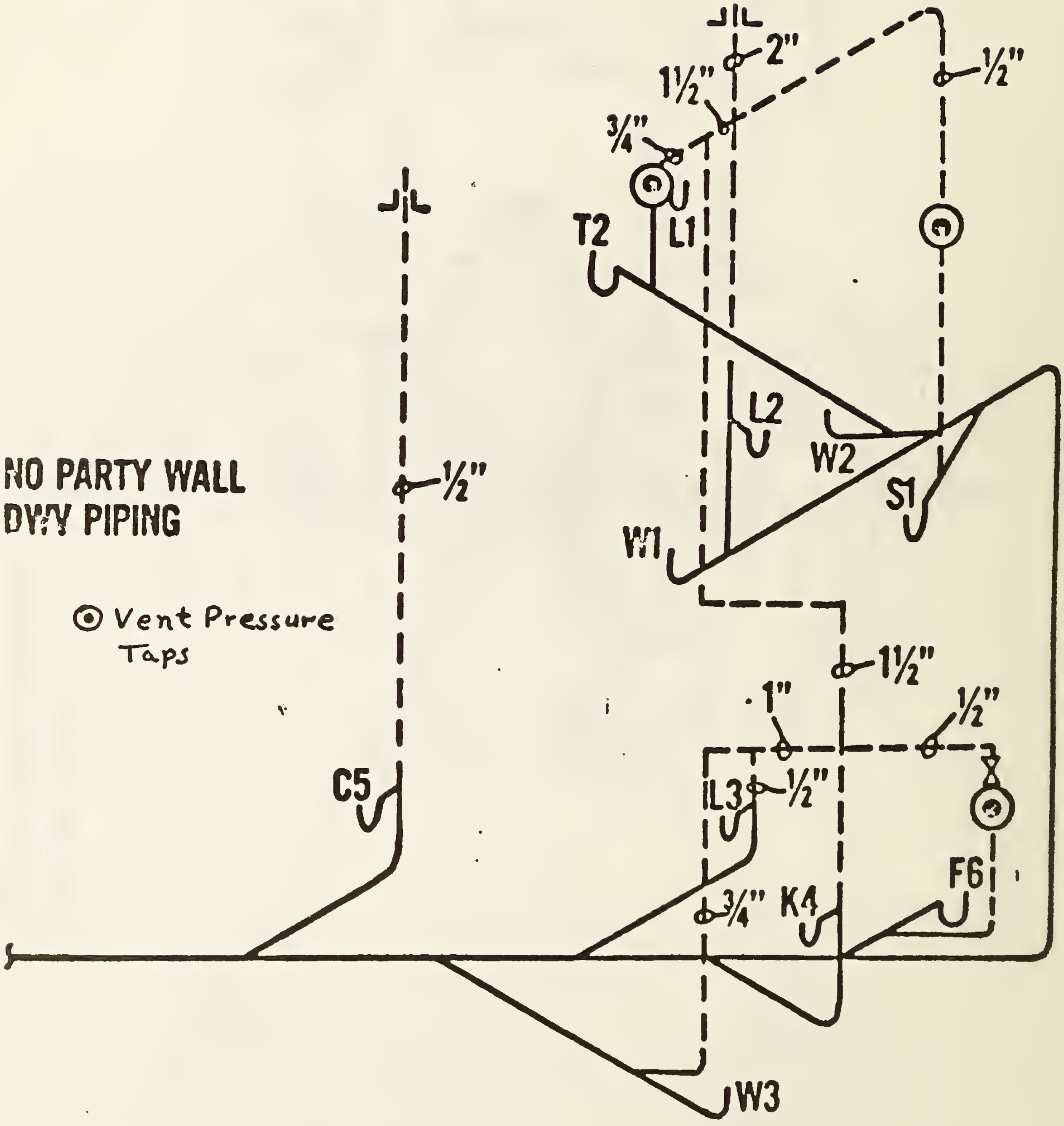

Figure 9. As-built design, D-house soil, waste, and vent piping, showing vent sizes obtained from RSV criteria

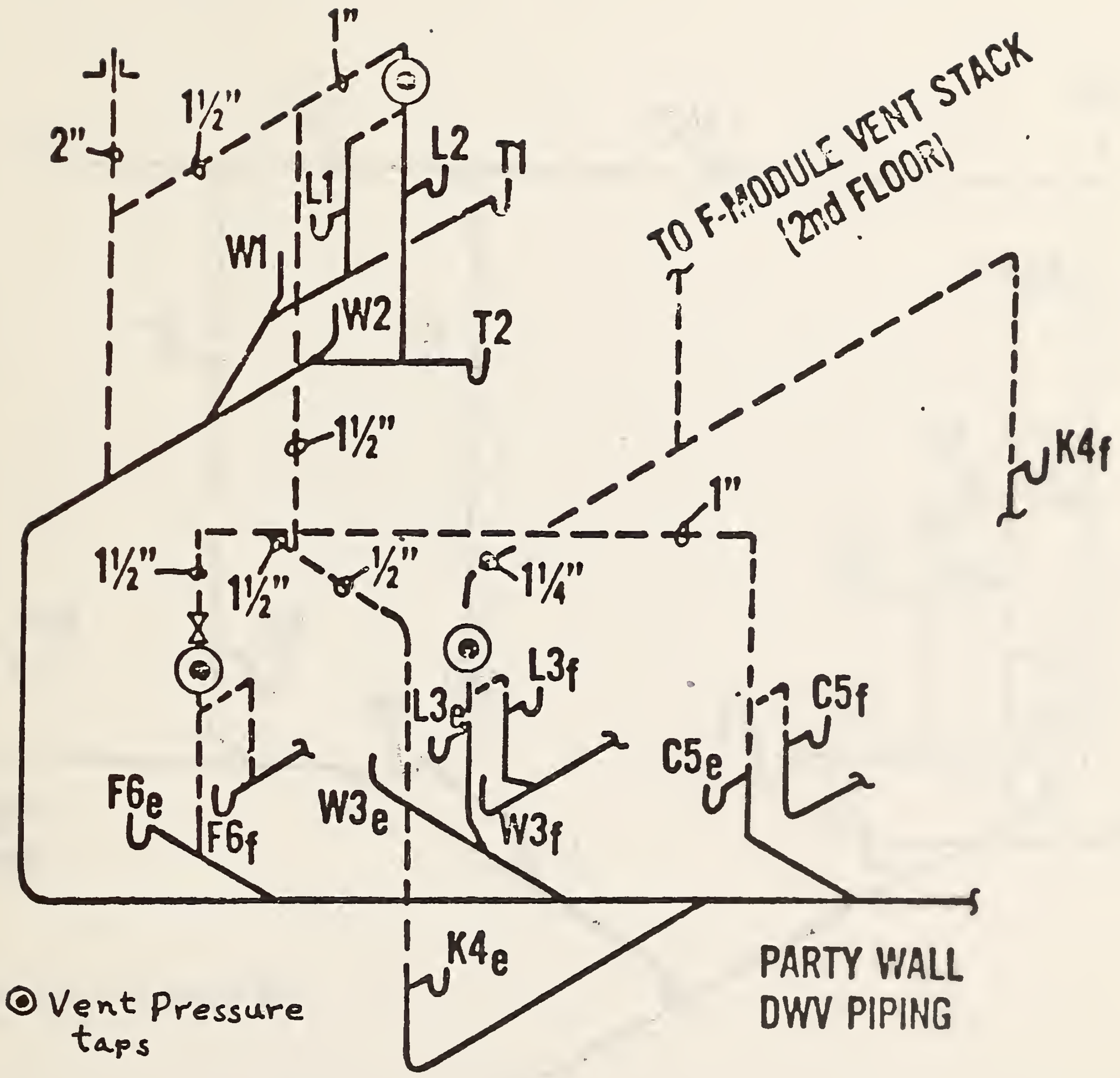

Figure 10. As-built design, E-house soil, waste, and vent piping, showing vent sizes obtained from RSV criteria

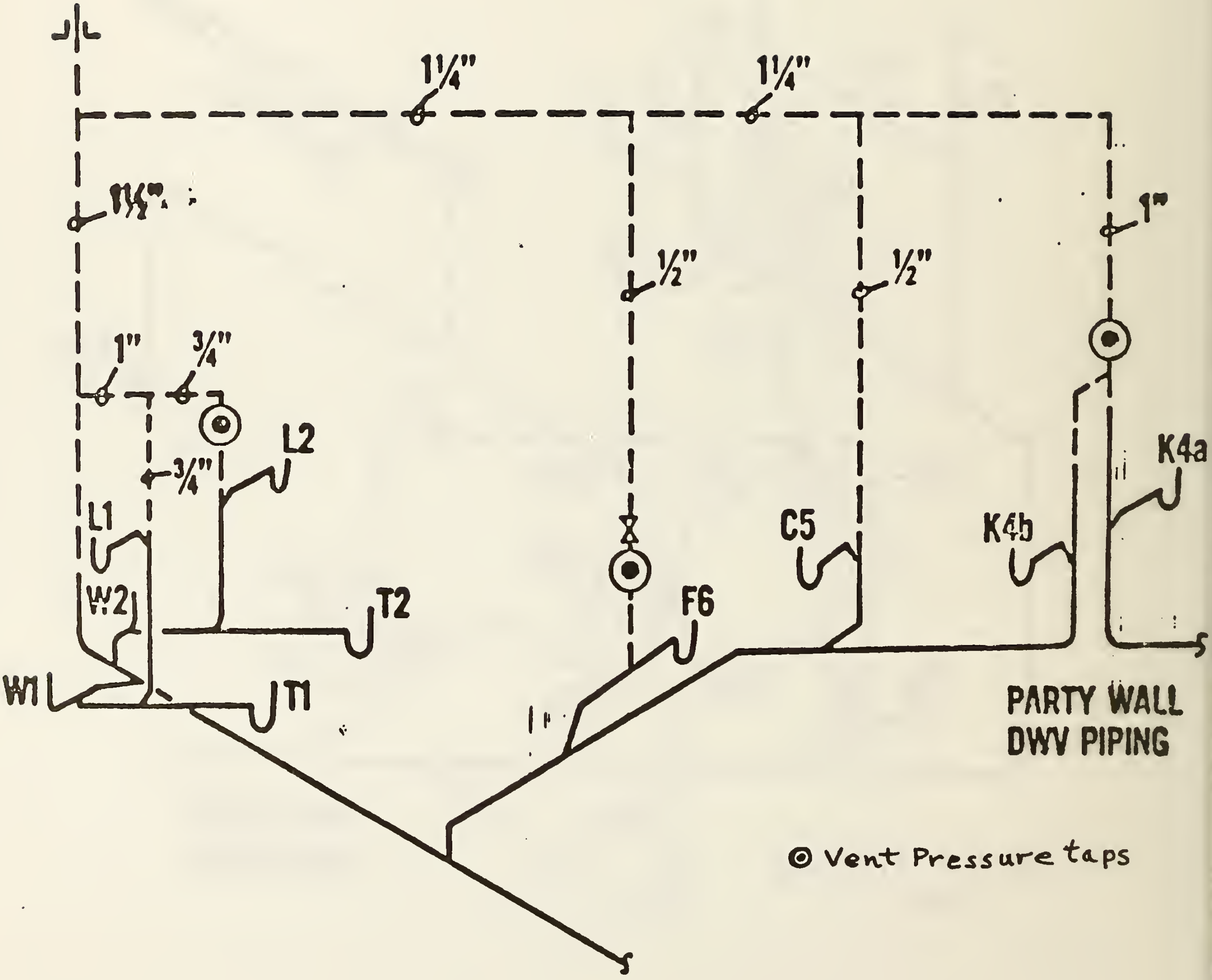

Figure 11. As-built design, F-house soil, waste, and vent piping, showing vent sizes obtained from RSV criteria

3. INSTALLATION AND TESTING OF RSV SYSTEMS IN THE FIELD

3.1 ORGANIZATION AND SEQUENCE OF PROJECT ACTIVITIES

At the outset it was necessary to consider the nature and sequence of project activities in relation to the construction and occupancy schedules. Some activities would have to be planned and/or completed before groundbreaking, others during construction, and still others after completion of construction but before occupancy of the test housing units. Table 1 shows the guide used as an aid to the management and monitoring of these activities.

3.2 INSTALLATION OF INSTRUMENTATION AND REDUCED SIZE VENTS

Figure 1 shows the locations of the test units in a family housing development at Andrews Air Force Base. During the early construction phase, underground cable was laid connecting each test unit with the DAS central control unit placed in a closet in the D/a module. In this terminology, e.g., D/a, the capital letter refers to the house type and the lower case letter refers to a particular module as designated in the architectural drawings (see figure 1). Within each of the test dwelling units, wires were run within the walls between the measurement points (primary sensors) and a centrally located closet selected for housing the "satellite" DAS equipment cabinet. The DAS central unit (recorder and printer), placed in the equipment closet of the D/a module, is shown in figure 12.

Pressure taps were provided at selected points in the venting systems during the installation of the DWV systems, and 3/8 in. O.D. diameter copper tubing was run within the walls and floor-ceiling cavities to the equipment closet in each test module. These tubes were continuously graded downward from the highest point to assure moisture drainage. Each equipment cabinet contained, among other things, three magnetically coupled differential pressure gages connected to the tubing from the pressure taps.

Flow switches were installed in the individual hot and cold water supply lines of lavatories, tubs and/or showers, kitchen sink, clothes washer, and in the cold water supply to the water closets. Water meters were installed in the water service pipe and in the cold water branch to the hot water heater of each instrumented housing unit.

The monitoring traps designed for automatically detecting trap-seal reductions were installed for the bath tubs, clothes washers, and shower stalls in the test units at appropriate times before drywall installation. Monitoring traps for the lavoratories and kitchen sinks were installed after completion of the drywall, and access panels to the clothes washer traps and flow switches were also provided after completion of the drywall installation.

Connections were made to telephone transmission lines from the data acquisition system on the housing site. The telephone lines could be used to carry data directly to the NBS site in Gaithersburg, an air distance of approximatly 47 km (29 miles).

At the appropriate time during the installation of the rough piping, the reduced-size vents were installed. Ideally, that would have been done simply in accordance with the original design schematics as modified for RSV (see figures 5 through 8). However, some modifications in the planned DWV configurations and sizes were necessitated because of building site conditions, and because of field changes in the drainage piping systems introduced by the plumbing contractor, (not an unusual situation). Before preoccupancy testing was initiated, it was established that the as-built drainage (wet) systems complied with the appropriate model plumbing code. In making the necessary design revisions for the reduced-size vents of the as-installed, field test systems, the sizing criteria were the same as previously applied for the first modifications to the original design drawings. The "as-built" designs are shown in figures 9 through 11.

3.3 EVALUATION METHODOLOGY

3.3.1 Instrumentation

The project plan called for three types of data: (1) DWV system performance, (2) water usage (distribution of fixture operations and volume of water used, by time and fixture), and (3) energy usage (for each water heater). The instrumentation developed for these measurements is described briefly in table 2 and figures 12 and 13. See also appendix B.

The automated instrumentation designed for collection of post-occupancy DWV system data, as well as other temporary installed instrumentation, was utilized during the preoccupancy tests. This provided for an opportunity for verification of the operational readiness of the automated system. Comparisons of the trap-seal levels directly measured from piezometers or portable depth-detector probes were made with those measured by means of the data acquisition system receiving the electrical signals from instrumented traps. Three magnetically-coupled differential pressure gauges in each of three test modules were utilized during the preoccupancy tests to observe visually the peak vent pressure excursions in selected tests for comparison with the corresponding values recorded in the automated operation mode. The gauges were equipped to automatically measure cumulative elapsed time over which vent pressure fluctuations fell outside a preselected pressure range; e.g., ± 25 mm WG (see figure 13).

Water seal depth changes in some of the bathtub or shower traps were measured in the preoccupancy tests by means of the portable depth-detector probe (figure 12); the traps were also instrumented for post-occupancy automatic data acquisition. Floor drain traps, however, were not instrumented for post-occupancy automatic data collection because only relatively mild changes in water level in the traps were expected during normal loading. This was confirmed in the preoccupancy tests using the portable probe.

The flow switches on the hot and cold water supply lines to the fixtures together with the two water meters (one in the house service pipe and the other in the supply pipe to the water heater) provided a means of monitoring the time distribution of water usage by fixture and the cumulative consumption of water.

It was planned that in the post-occupancy tests the data from the flow switches and the traps would be processed to identify which fixture(s) were operated to produce a water flow registered by the water meter(s), and to provide data on the time distribution of the fixture operations.

In the preoccupancy tests, piezometers were utilized to read the water levels in some of the instrumented traps. Peak vent pressures were observed visually on the magnetically-coupled gauges for selected tests (see figure 13) while the data acquisition system was automatically recording the cumulative time outside the range ± 0.25 kPa. Locations of pressure measurement taps are shown schematically in figures 9 through 11.

3.3.2 Test Procedures: Preoccupancy Tests

The test plan covered four areas: organization of project activities; the discharge characteristics of the fixtures; a selection of test conditions (including specific test loads); and definitive test procedures.

Each of the fixtures in each of the houses was given an abbreviated identification code (symbol) that would apply in all the houses. (See table 3).

Water depths for the waste fixtures (fixtures other than water closets) were established, a selection of loading patterns was made, certain conditions of test were selected, and the scope of measurements decided. Tables 4 through 6 and the following discussion describe these areas in greater detail.

The selection of hydraulic test loads for DWV system evaluation has not been standardized. But preliminary analysis of the piping schematics showed that specific hydraulic loads should be imposed to test the adequacy of particular types of vents, and of the vent system as a whole. For example, appropriate individual fixture discharges would test the fixture vents; simultaneous discharge of two or more fixtures served by a particular branch vent would test the branch vent; and generally three or more fixtures discharged simultaneously would test the main vents and overall venting system. Some tests would be necessary to evaluate the effect of detergents as used in the clothes washer and the kitchen sink.

A review was made of several earlier reports on DWV testing. The load selection guide, shown as table 5, for selecting test loads in the RSV preoccupancy field study was based on [15] for single-branch interval portions of plumbing systems and on other general requirements for hydraulic loading. The loads actually used were considered equal, or greater, in effect than those indicated by table 5. The effects of the loads used are believed to have been at least as severe as might have been expected from service loadings imposed by building occupants.

Table 5 indicates the number of fixtures to be discharged. Judgment is required to select which fixtures should be discharged when several are served by the system or component being tested. Experience in performance evaluation of DWV systems has shown that, generally, it is wise to choose two or three different combinations so as to produce effects more or less representative of service conditions.

In any bathroom group of three fixtures, it is reasonable to discharge two fixtures and observe the effect on the third or idle fixture. In any back-to-back bathroom arrangement, it is logical to test each group separately (as immediately above), and also to discharge two fixtures in one bathroom and observe the effect on the fixtures in the opposite bathroom or to discharge two in one room and one in the other, observing any effects in either room. A loading comprising two fixtures in each room would represent a very unusual concentration of simultaneous operation and is precluded by table 5.

When the fixtures are distributed on two or three different levels, table 5 may be used to aid in selecting test loads, using an approach similar to that given above for back-to-back bathrooms on the same level. If some but not all of the discharging fixtures are on the lowest level, measurable back pressure may be produced at this elevation.

A "test" was defined to consist of four successive runs under conditions as identical as possible. Detergent, used in some of the tests, was introduced on the first and third runs of a test (clean water used on runs two and four). Four successive runs with detergent additives were not considered a realistic test cycle. Readily available testing materials were used: 1-1/4 c. TIDE laundry detergent in the clothes washer according to the manufacturer's directions; for the kitchen sink, 1/4 c. PALMOLIVE detergent (sink bowls filled to 15 cm level as established in the fixture calibration determination). (The designation c. is used for "cup" and products were selected due to availability.)

After a run was initiated, the peak readings on one or two selected pressure gauges were observed visually. This information was correlated, where applicable, with the elapsed time in seconds outside the range of ± 0.25 kPa clocked by the DAS (see figure 13).

Trap-seal elevations were read manually on the piezometers after each run. In almost all cases, the trap monitor voltage values from the DAS were recorded after each run (as a convenient means of comparing the changes in water level in the traps as indicated by the DAS against level changes observed on the trap piezometers). The traps were not filled between runs, so the value recorded by the DAS after the fourth run corresponded to the cumulative trap-seal reduction determined visually from the piezometer, within the limits of resolution of the depth measurement electrode pins in the traps.

In the D and F houses, tests were first run with the vent terminal open, and then with it taped shut, in accordance with the plan indicated in table 6. If the first run produced a trap-seal reduction of more than 25 mm with the terminal closed, the fixtures were refilled after each run. The four values of trap-seal reduction obtained in this way yielded an average "single-run" dH, as depicted in figure 14.

In all six of the houses, gate valves were installed in the vent lines of the floor drain (F6 figures 9, 10, and 11). These were shut before the preoccupancy tests. In the original test plan (see table 6), tests were to be made with the floor drain vent valve both closed and open. Tests were first run with the valve closed. Because of the small floor drain trap-seal reductions observed, the series was not repeated with the valve open. These valves remained closed after occupancy.

The piezometers used for the preoccupancy tests were removed before occupancy and the installed DAS system was to monitor the performance.

3.4 DATA SUMMARY AND DISCUSSION

The data tabulations presented are from the records prepared by visual/manual readings. The pre-occupancy testing provided opportunity for check-out of the DAS instruments and automated data compilations. The cumulative times for pressure excursions in the over range periods were obtained from the DAS. The precision of the visual/manual instrument readings were less than the resolution capability of the automated systems; general agreement was found between the sets of data compared.

3.4.1 Discharge Characteristics of Fixtures

The results of the fixture calibrations are given in tables 7 and 8. For the waste fixtures, the average values were as follows:

Fixture Type	Discharge Duration Seconds	Volume Discharge Liters (gal)	Discharge Rate Liters/second (gpm)
Lavatory	17.0	6.56 (1.73)	0.39 (6.1)
Bathtub	166.2	82.9 (21.9)	.50 (7.9)
Kitchen Sink	29.4	37.7 (10.0)	1.28 (20.3)
Clothes washer	52.6	56.0 (14.8)	1.06 (16.9)

For the water closets in the D/a unit (see table 8), the average water consumption per flush was 14.7 liters (3.9 gal).

3.4.2 Trap-Seal Reduction and Vent Pressure with Vent Terminal Open

The principal and typical results from the tests with the vent terminal open are summarized in tables 9 and 10. The detailed data are given in appendix A.

In a few instances an apparent rise in temperature level appeared and are noted by the + readings (e.g., tables A.1.1, A.2.2, A.2.3). Such readings may occur as a result of: positive pressures or fluctuating miniscus and inadequate time for the system to stabilize prior to the piezometer reading; capability to read the miniscus wetting the wall within a limit of 1 mm or a depth probe to 2.5 mm limit (as noted in table 2); combinations of capillary effects with dirt in the tubing introducing a small error.

Results of all the tests with the vent terminal open show that the reduced-size vents provided satisfactory performance in terms of trap-seal retention and vent pressure.

The greatest trap-seal reduction in the D house was 10 mm, in the E house 7 mm, and in the F house 5 mm (tables 9 and A.1.1). The greatest vent suction was 40 mm WG (E house) and the greatest vent back pressure was 20 mm WG (F house). See table 10 and section A.1.

The greatest trap-seal reductions in the E house, 7 mm, occurred for discharges of W1 + W2 + W3 + C5, and for W1 + W2 + L1. Of special interest in the E house was the shared (party wall) vent serving the first floor half baths (water closets and lavatories). For a discharge of both these water closets and one of the lavatories, the greatest seal reduction in the trap of the idle lavatory was only 2 mm. See table A.1.1(B).

For the RSV installation in the F house, the largest trap-seal reduction, 5 mm, occurred for discharges of W1 + W2 + L; W1 + W2 + T1; and W1 + W2 + K4. See table A.1.1(C).

For all tests with the vent terminal open, the largest trap-seal reduction was 10 mm, in a P-trap in the D/a unit (see table A.1.1). It it is assumed that the seal depth of the full-trap is 50 mm, then the trap-seal retention is given by:

$$\text{P-trap-seal rentention} = 100 - \left(100\,\frac{\Delta H}{H}\right) = 100 - 100\left(\frac{10\ \text{mm}}{50\ \text{mm}}\right) = 80\ \text{percent}$$

This means that P-trap-seal retention was at least 80 percent after four runs (without filling of traps between runs).

A 10 mm reduction in the level of the water closet trap yielded a greater trap-seal retention percentage because the full trap-seal depth of the water closet was 75 mm:

$$\text{WC-trap-seal rentention} = 100 - \left(100\,\frac{\Delta H}{H}\right) = 100 - \left(100\,\frac{10\ \text{mm}}{75\ \text{mm}}\right) = 87\ \text{percent}$$

Generally, the idle P-traps exhibited greater trap-seal reductions than the W.C. traps. This has also been observed in other laboratory studies where idle P-traps were subjected to transient, fluctuating suction. Probably a major factor in this phenomenon is the relatively larger mass and inertia of the W.C. trap, which minimizes the effect of transient pressure fluctuations such as those associated with suction.

However, in studies of high-rise systems subject to back pressure, failures of W.C. traps have been observed near the bottom (lower floors) of the system due to blowback while no failures of nearby P-traps occurred. Analysis of the geometry of the respective trap types provides a plausible explanation: with back pressure, the water head resisting air passage (blowback) is least for the W.C. case because the trap seal volume on the room side is much greater than the volume on the sewer side of the seal.

Limited measurements relating to vent pressure fluctuations were made. The DAS could automatically record the cumulative time that the pressure was outside the preselected range of ± 0.25 kPa, the generally accepted design range for DWV systems. The pressure values observed were within these limits in idle trap vents for nearly all of the tests with the vent terminal open.

Because the vent pressure excursion peaks on the magnetically-coupled differential pressure gauges were read manually, it is estimated that the maximum error could be in excess of 0.02 kPa (2 percent of full-scale of manufacturer's claimed accuracy). See table 2.

Studies [1,3,10] of the relationship of peak suction in the vent and the associated trap-seal reduction under normal conditions showed that a 25 mm cumulative trap-seal reduction occurred only when the peak transient suction in the vent was on the order of -0.40 kPa. A similar result was found in the pre-occupancy field test, based on the pressure gauge peak readings observed visually and the corresponding trap-seal reductions actually measured with the vent terminal open.

3.4.3 Trap-Seal Reduction and Vent Pressure with Vent Terminal Closed

Data from load tests with vent terminal closed, some of which produced trap-seal reductions near failure (≈25 mm), presented an additional opportunity to examine, in this critical area of unusually severe conditions, the relationship between the traditional ± 25 mm pressure criterion and the more meaningful criterion: trap-seal reduction not exceeding 25 mm together with the absence of adverse back pressure effects. These data are also presented in detail in appendix A.

The data support the earlier laboratory findings that a repetitive peak suction of 38 mm (1 1/2 in WG) is roughly comparable to a cumulative P-trap seal reduction of 25 mm (1 in WG). Also, the trap-seal failures or near-failures observed in some instances, with closed vent terminals and heavy hydraulic loads, indicate the general desirability of keeping the vent terminals open, although this may not be essential for every system and is dependent on system configuration and location of fixtures.

Table 1. Organization and Sequence of Activities Relating to Preoccupancy Hydraulic Tests

I. BEFORE GROUNDBREAKING

1. Select plumbing systems to be studied and size the reduced-size vents using design drawings submitted by sponsor.

2. Select sensors and decide scope of measurements within each test unit; design data collection system for post-occupancy measurements; and order equipment.

II. DURING EARLY STAGES OF CONSTRUCTION (BEFORE DRYWALL)

3. Underground cable connections to be made between units and building sewer pressure tap to be installed.

4. Assemble instrumentation and make the appropriate modifications to "off-shelf" items.

5. Install reduced-size vents and vent pressure taps as appropriate for as-built wet system.

6. Arrange inspection of wet system for code compliance.

7. Verify RSV sizes taking into account wet-piping field changes, and make modifications as necessary to satisfy (6).

8. Install wiring (for individual sensors) within walls, install "hidden" traps (laundry, bathtub, shower); and install "hidden" flow switches (laundry, bathtub, shower). Install tubing between equipment closets and pressure taps in the vent system.

III. DURING LATER STAGES OF CONSTRUCTION (AFTER DRYWALL)

9. Install "external" traps (lavatories, kitchen sink).

10. Install DAS, connect sensor wires to transmission wires, and connect pressure tubes to pressure gauges.

11. Check all instruments and the Data Acquisition System for operational readiness.

IV. AFTER COMPLETION OF CONSTRUCTION (BEFORE OCCUPANCY)

12. Determine fixture discharge characteristics, install piezometers and assemble portable probes for preoccupancy measurements of trap-seal elevation.

13. Conduct preoccupancy tests according to test plan. Subsequently remove piezometers and portable test instrumentation in preparation for occupancy of the housing units.

Table 2. Characteristics of Instruments and Purposes for Which Used

Instrument	Range or Size of Instrument	Utilization	Resolution of System
In Preoccupancy Tests			
Rulers/Piezometers	30 cm	To measure depth of water in fixtures and in traps	1 mm
Stopwatch	30 min	To measure duration of discharge	0.1 s
Graduated cylinders	100, 500 ml	To measure volume of discharge of fixtures and to calibrate larger containers (2 and 4 liter beakers, and 8 liter bucket used for filling fixtures)	
Depth probe	1 in	To measure trap-seal reductions	0.1 in (2.5 mm)
In Pre- and Post-Occupancy Tests			
100-channel DAS	100 channels (25 channels per unit)[a]	To collect post-occupancy data; also to record pressure overrange duration and trap-seal reduction in preoccupancy tests	"single scan" for millivolt changes every 5 seconds
Instrumented traps and trap printed circuit cards	+ 2 cm to − 7 cm[b]	To detect water depth in trap	5 mm
Magnetically coupled differential pressure gauges	10 cm of water	To measure time outside preselected pressure range	0.5 cm[c]
Printed circuit timer cards	--	To measure time	0.1 s
In Post-Occupancy Tests			
Water meters	100,000 gal	To measure volume of water used	1/350 gal[d] (0.011 liter)
Volume counter card	--	To register water used	0.1 gal[d] (0.38 liter)
Magnetic flow switches	10 cm of water	To detect occurrence of water flow in fixture supply pipes	1 s[d]

[a] Four housing units could be monitored concurrently by the DAS by means of switches but all six units were instrumented.

[b] Zero level = water surface level of full trap-seal.

[c] This was read visually during manual tests and it is estimated that the readings made this way would be accurate to within 0.5 cm water gauge. This is 2-1/2 times the manufacturer's claimed accuracy.

[d] For a flow duration greater than 5 s. Water meter resolution 1/350 gal; with counter card 0.1 gal.

Table 3. Symbols for Fixtures

Symbol	Fixture	Location
W1	Water closet	Master bathroom
L1	Lavatory	Master bathroom
T1	Bathtub	Master bathroom
S1[a]	Shower stall	Master bathroom
W2	Water closet	Common (second) bathroom
L2	Lavatory	Common (second) bathroom
T2	Bathtub	Common (second) bathroom
K4	Kitchen sink	Kitchen, laundry, utility
C5[b]	Clothes washer	Kitchen, laundry, utility
F6	Floor drain	Kitchen, laundry, utility

[a] The D house had a shower stall in the master bathroom instead of a bathtub.

[b] A clothes washer was not furnished with these units, although laundry piping was installed in the units. A clothes washer used in earlier NBS laboratory tests was taken to each house in turn for the preoccupancy tests.

Table 4. Water Level in Waste Fixtures for Discharge Rate Measurements

Fixture Type	Initial Water Level when Discharge Initiated
Lavatory	Filled to overflow weir
Bathtub	Filled to 15 cm depth, measured at stopper rim
Kitchen sink	Filled to 15 cm depth, measured at stopper rim
Clothes washer	Filled to level at which water is automatically shut off and agitation begins - factory preset

Table 5. Guide for Selecting Test Loads for Residential Plumbing Systems

Number of Fixtures Served by System or Component Being Tested	Maximum Reasonable Number of Concurrently Operating Fixtures to Comprise Test Load
1	1
2-5	2*
6-12	3
13-32	4

* For a two fixture system or component, also discharge each fixture individually.

Table 6. Plan for Testing Sequence and Certain Test Conditions in Preoccupancy Hydraulic Tests

Sequence	Conditions of Test		
	Status of Gate Valve in Floor Drain Vent	Status of Vent Terminal	Use of Detergent as an Additive
1	Closed	Open	In some tests
2[a]	Open	Open	In some tests
3	Closed	Closed	In some tests

[a] In conducting the tests, step 2 was omitted because satisfactory performance was attained in step 1 with the floor drain vents closed. These vents remained closed during both preoccupancy and post-occupancy testing.

Table 7. Waste Fixture Discharge Characteristics Determined from Field Calibrations of Fixtures In Place

Fixture Symbol[1]	Volume Liters	Duration s	Rate Liters/s	Volume Liters	Duration s	Rate Liters/s
	D/a Unit[2]			D/b Unit		
L1	6.7	17.2	0.39	6.5	17.7	0.36
L2	6.7	16.6	0.39	6.5	17.2	0.38
L3	6.9	21.9	0.31	6.5	16.4	0.39
T1	83.3	170.2	0.49	86.9	176.8	0.40
K4	39.2	31.5	1.24	38.1	28.4	1.34
	E/e Unit			E/f Unit		
L1	6.4	14.6	0.44	6.6	17.6	0.38
L2	6.4	17.4	0.37	6.6	20.5	0.32
L3	6.6	16.8	0.39	6.7	15.7	0.42
T1	84.8	205.8	0.41	82.2	184.3	0.45
T2	75.8	195.6	0.39	82.8	152.5	0.54
	F/a Unit			F/b Unit		
L1	6.4	14.2	0.45	6.6	15.6	0.42
L2	6.5	17.0	0.38	6.4	15.2	0.42
T1	83.8	152.6	0.55	82.8	121.7	0.68
T2	82.8	133.5	0.62	83.8	168.6	0.50
K4	36.4	28.6	1.28	37.0	29.3	1.26
	All Units Tested					
C5	56.0	52.6	1.06			

[1] See table 3 for fixture symbol identification

[2] Code: Capital letter indicates house type, lower case letter the module; e.g., D house, a module = D/a unit.

Table 8. Water Closet Water Consumption Measured in D/a Unit

Run	Water Consumption for One Flush[1]		
	W1	W2	W3
	Liters (gal)	Liters (gal)	Liters (gal)
1	14.8 (3.9)	14.8 (3.9)	15.1 (4.0)
2	14.0 (3.7)	15.5 (4.1)	13.6 (3.6)
3	14.8 (3.9)	15.9 (4.2)	13.2 (3.5)
4	15.1 (4.0)	15.5 (4.1)	13.6 (3.6)
AVG.	14.7 (3.9)	15.4 (4.1)	13.9 (3.7)

[1] Values obtained from water meter readings

Table 9. Summary of Findings on Trap-Seal Reductions D, E, and F Houses with Vent Terminals Open

A. Trap-seal reductions after four runs for a discharge of W1 + W2 + C5 in the D/a unit

Test No.	Lavatories and Bathtub					Kitchen and Floor Design	
	L1	L2	L3	TI	T2	K4	F6
	mm	mm	mm	mm	mm	mm	mm
1	8	5	6	5	10	5	5
2	10	4	7	5	5	6	2.5
3*	7	3	6	5	10	4	5
4*	7	3	4	5	7.5	5	5
AVG	8	4	6	5	8	5	4

* Detergent in C5 runs 1 and 3.

B. Trap-seal reduction after four runs for two different leads in the E/e unit

Lavatories			Bathtubs		Kitchen and Utility	
L1	L2	L3	T1	T2	K4	F6
mm	mm	mm	mm	mm	mm	mm
Discharge of W1 + W2 + W3 + C5						
5	2	4	0	2.5	7	0
Discharge of W1 + W2 + W3						
3	2	3	2	2.5	6	2

C. Trap-seal reduction after four runs for a discharge of W1 + W2 + K4b + C5 in the F/b unit

Test No.	Lavatories		Bathtubs		Kitchen
	L1	L2	T1	T2	K4a
	mm	mm	mm	mm	mm
1	1	5	2.5	2.5	3
2	0	5	2.5	2.5	2
AVG.	1	5	2.5	2.5	3

---

[1] See table A.1.1 for additional data.

Table 10. Summary of Findings on Vent Pressures in D, E, and F Houses with Vent Terminals Open[1]

Fixtures Discharged[1]	Pressure Tap Location[2] and Vent Size	Peak Pressure Excursions
	D/a Unit Tests	
W1 + W2 + W3 + W5	S1(1/2")	-2 cm W.G. (199 Pa) +1/2 cm W.G.
W1 + W2 + W3 + W5	W3(3/4")	-1.5 cm W.G. (149 Pa) +1 cm W.G. (96 Pa)
	E/e Unit Tests	
W1 + W2 + W3	K4(1/2")	-2 cm W.G. (199 Pa) +0
W3(e) + W3(f) + L3(f)	L3(e,f) and W3 (e,f) (1 1/4")	-1/2 cm W.G. (50 Pa) +0
	F/b Unit Tests	
W1 + W2 + L2	L1(3/4")	-1 cm W.G. (100 Pa)
K4(a) + K4(b)	K4(a,b) (1")	-3 cm W.G. (299 Pa) +0
W1 + W2 + K4(b)	C5 (1/2")	-1 cm W.G. (100 Pa.) +2 cm W.G. (199 Pa)

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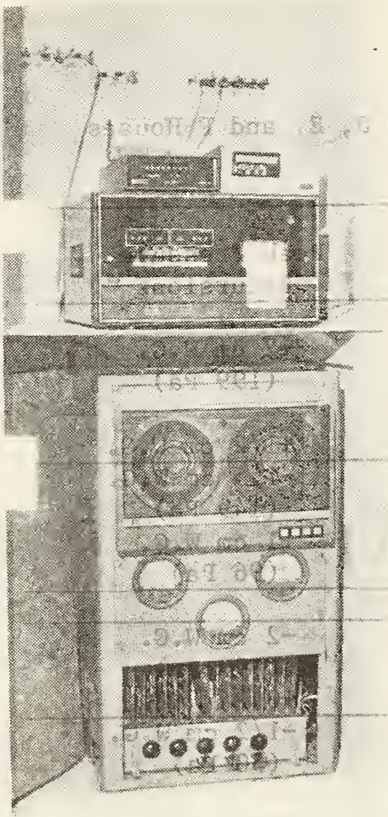
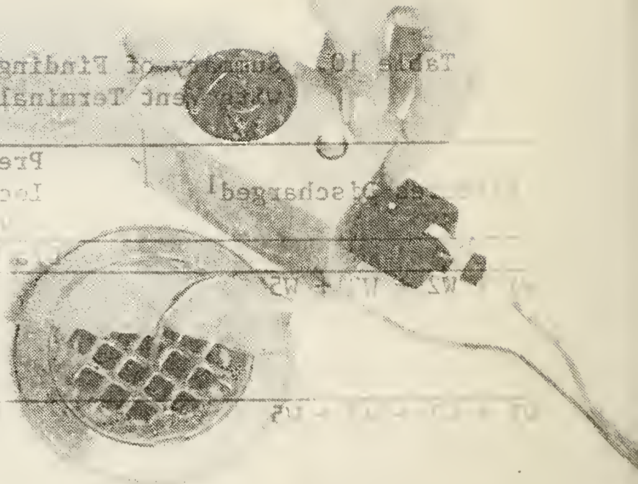
[1] See section A.1 for additional data.

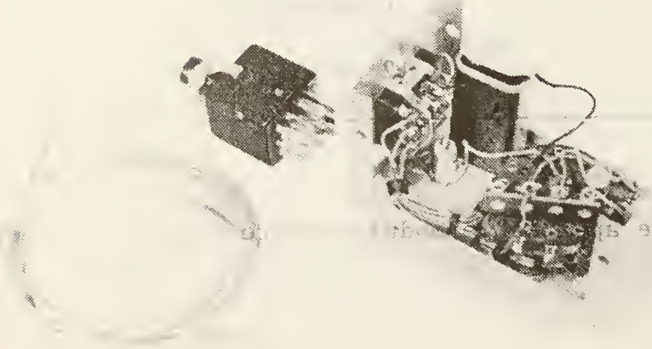
[2] Lower case letters in parenthesis indicate the applicable modules where party wall DWV piping existed.



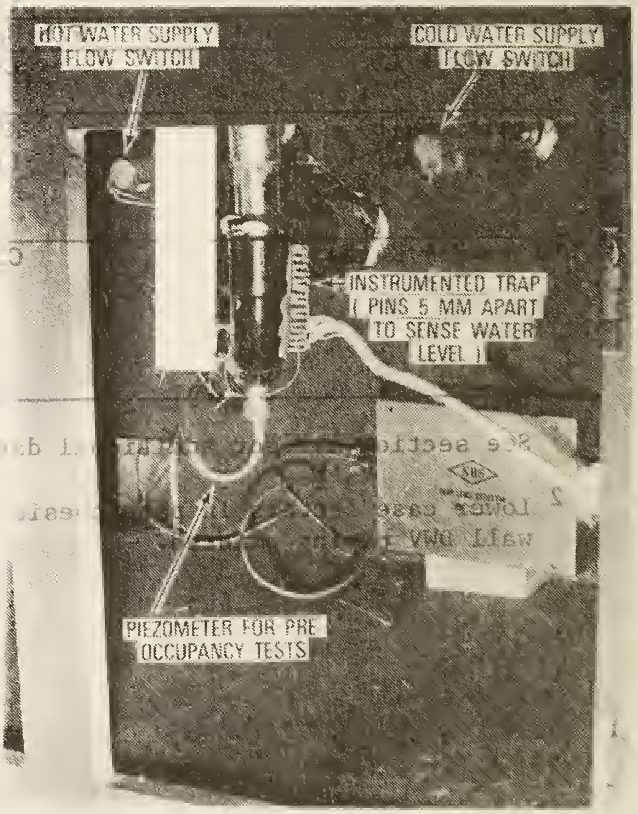
Data Aquisition Console



Portable Trap Seal Level Detector
Placed In Floor Drain



Portable Trap seal
Level Detector



Instrumented Trap and Fixture
Supply Pipe Flow Switches

Figure 12. Instrumentation and data acquisition system

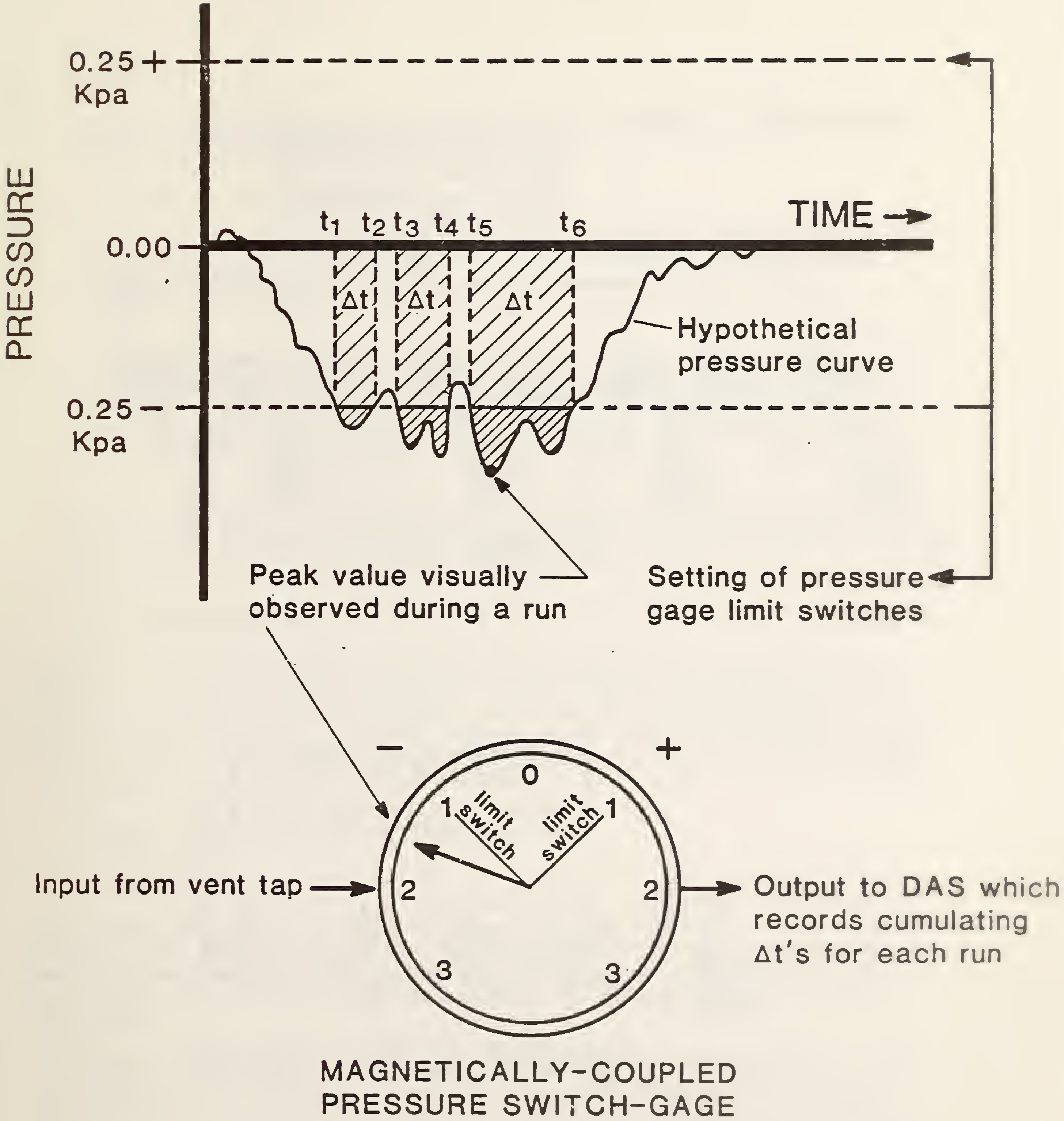
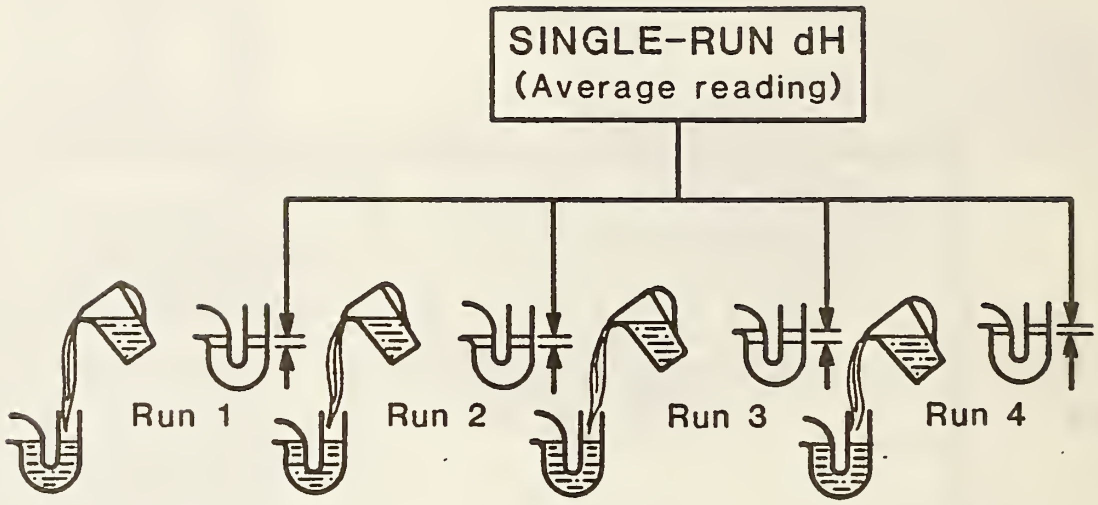
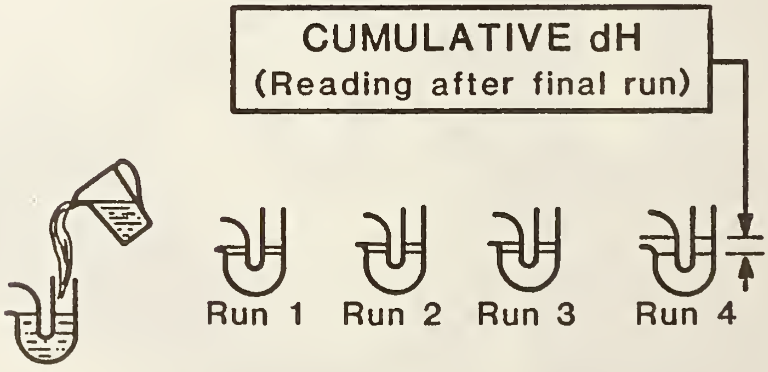


Figure 13. Method for measurement of cumulative time outside preset pressure range



Trap filled before each run



Trap filled only before first run

Figure 14. Definition of trap-seal reductions for testing purposes

4. CONCLUSIONS

4.1 ADEQUACY OF PERFORMANCE OF THE RSV SYSTEMS AT ANDREWS AIR FORCE BASE AND ADEQUACY OF THE RSV CRITERIA

From the study it is concluded that:

1. The data show the adequacy of performance of properly designed and installed RSV systems for one- and two-story residential designs connected to a standard drainage system, conforming to the criteria presented in appendix C.

2. The RSV criteria can be successfully applied to vent design modification from standard DWV plans for one- and two-story systems conforming to a recognized model code. The formulation of proposed code changes and/or design/installation practices could be based upon the approach defined and discussed in this report.

3. The data support the elimination of requirements for floor drain vents in one- and two-story residential housing designs at typical building sites. Some current codes recognize that such vents may be omitted under specified conditions.

4.2 COST CONSIDERATIONS

Published results from studies on the economics of RSV are limited [8]. A review of such information available to the investigation described herein indicated potential savings ranging up to about $150 per dwelling unit, expressed in 1975 dollars. In many situations, RSV does in fact offer significant potential for savings. The actual extent of savings in a given situation depends on a number of factors.

4.3 RESIDUAL ISSUES AND CODE ACCEPTANCE

4.3.1 Residual Issues

Among lingering issues are: (a) what is the impact of frost closure of vent terminals, and (b) are reduced-size dry vents really subject to a significantly greater risk of blockage than are standard size vents? If so, can opening the vents be satisfactorily accomplished through simple maintenance procedures?

On the frost closure issue, the present recommendation is to conform to local code requirements in minimum size of vent terminals where frost closure is recognized as a problem with standard DWV systems. However, in the light of the results of one study of frost closure [16] it seems this would be a significant problem only in areas with extended periods of freezing temperatures (below 0°F (-18°C)). Even in these areas the use of materials with low thermal conductivity, insulating shields, electrical heating or shortened extension above the roof line could minimize closure. A "frost closure map" of the United States based on available weather data and a model representative of heat transfer in roof vents is needed as a guide for the design of roof vents in very cold regions. Probably only a very small proportion of the U.S. would require special precautions.

No frost closure or other types of blockage of the reduced-size vents at Andrews Air Force Base have been observed by the investigators or reported by the Air Force since the installations were completed more than seven years ago.

While neither of the issues appears to be highly critical if the recommended design procedures are followed, the widespread acceptance and implementation of RSV under plumbing codes would be expedited and enhanced if further applicable data were to be provided. Perhaps the most straightforward and meaningful approach would be to monitor field demonstrations, possibly in military family housing, in accordance with a plan developed by a committee of interested groups, and to publicize the findings.

Realization of widespread benefits from utilization of RSV depends on code recognition of the method as an alternative, engineered design by referencing of a uniform design procedure in the codes; the general availability (from manufacturers) of the smaller sizes of pipe and fittings for venting at reasonable cost; and working familiarity with the method among contractors, engineers, and inspectors.

4.3.2 Formulation of Code Changes and Generally Accepted Design Procedures

The current design procedures recommended by the American Society of Plumbing Engineers [17], together with the material provided herein as appendix C, should be considered by appropriate established code change committees, professional engineers and others as the basis for formulation of realistic code changes and guidelines for the design of engineered systems employing RSV.

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APPENDIX A. PREOCCUPANCY TESTS: DETAILED INFORMATION

A.1 DATA WITH VENT TERMINAL OPEN

Tests with the vent terminal open were described and the findings summarized in section 3.3.1. Detailed data on trap-seal reductions are presented in table A.1.1.

With the vent terminal open, the greatest trap-seal reductions of the idle traps after four runs with the most severe loads (see tables A.1.1(a), A.1.1(b) and A.1.1(c)) were:

Unit Tested	Greatest Reduction		
	Load	Trap	ΔH mm
D/a	W1 + W2 + L1	T_2	10
	W1 + W2 + W3	T_2	10
	W1 + W2 + W3 + C5	T_2	10
	W1 + W2 + W3 + C5 + DET	T_2	10
E/e	W1 + W2 + L1	T_2	5
F/b	W1 + W2 + L1	T_2	5
	W1 + W2 + T1	T_2	5

[a] The designation DET means that detergent was used in the indicated detergent-using fixture.

The greatest trap-seal reduction observed in these tests, 10 mm, is less than one-half of the generally accepted limit of 25 mm.

The greatest vent pressure fluctuations measured in the tests with the vent terminal open (see table 13) were:

Unit Tested	Greatest Pressure Fluctuations (Suction)		
	Vent;Size	Load	ΔP mm
D/a	S1;1/2/1-1/2/1/2"	W1 + W2 + W3 + C5	-20
E/e	L1,2;1"	W1 + W2 + W3	-40
F/b	K4(a,b);1"	K4(a) + K4(b)	-30

The maximum positive pressures observed did not exceed 25 mm.

Although one test load in the E/e unit produced an instantaneous peak suction of 40 mm, the greatest trap-seal reduction shown for this load was only 10 mm. In other studies, it has been found that with a repeated application of suction to an idle trap-seal, a 25 mm cumulative trap-seal reduction may be expected from a fluctuating, transient suction level of about 40 mm WG [1,3,10].

Therefore, the data with the vent terminal open show entirely satisfactory trap-seal performance, with a safety factor of at least 2.5. Although two loadings produced vent suction levels somewhat exceeding the generally accepted level of 25 mm WG, this is not considered significant since no corresponding excessive trap-seal reductions occurred.

A.2 DATA WITH VENT TERMINAL CLOSED

Tests with the vent terminal closed were described briefly in section 3.3.3. The data on trap-seal reductions and vent pressures with closed terminal are presented in tables A.2.1, A.2.2, A.2.3, and A.2.4.

Analysis of the pattern of trap-seal failure associated with data presented for the D/a unit with vent terminal closed (see table A.2.3) has been aided by the construction of figure A.2.1. Twelve replicate tests were made, each test consisting of four runs without replenishment of water in the idle trap-seals between runs. From figure A.2.1 it is apparent that some traps were more subject to failure than others, that there was a variance in results from test to test, and that the cumulative number of failed traps increased with the number of runs made. In considering these data, it should be remembered that the vent terminal was completely closed, and the load was a severe one. In addition, the likelihood of four successive replicate runs with the same loading seems very remote under service conditions. Therefore, it seems that if under service conditions the vent terminal should become fully closed, most of the traps would be replenished after the first "run" of a particular loading, because of the probable random composition of successive loadings. Therefore, it might be expected that representative results would more nearly resemble those after run 1 than after run 4. Under this condition, there was only one trap failure, L2. This occurred only once in 12 replicate tests (see table A.2.3), and the failure was very marginal (27 mm vs 25 mm). The average trap-seal reduction (in 12 tests) for trap L2 after the first run was 17.5 mm, a value appreciably less than the generally accepted 25 mm.

Table A.1.1 Trap-Seal Reduction with Vent Terminal Open

A. D/a Unit[a]

				Idle trap-seal reductions after four runs								
Test No.	Fixtures Discharged	K4 mm	L3 mm	L2 mm	T2 mm	C5 mm	L1 mm	S1 mm	F6 mm	W1 mm	W2 mm	W3 mm
1	L1	0	0	0	0.0	0	A[a]	0.0	0.0	0	2	0
2	L1 + L2	0	0	A	2.5	0	A	5.0	0.0	0	4	0
3	L1 + W2	2	2	2	5.0	+1	A	5.0	2.5	1	A	0
4	W1 + W2 + L1	3	3	2	10.0	0	A	5.0	2.5	A	A	0
5	W1 + W2 + L2	5	6	A	5.0	0	5	7.5	2.5	A	A	1
6	W3	3	2	3	5.0	1	4	2.5	0.0	1	0	A
7	W3 + L3	3	A	3	5.0	0	2	2.5	0.0	1	2	A
8	W1 + W2 + W3	0	5	3	10.0	0	7	7.5	-	A	A	A
9	W1 + W2 + W3	4	7	4	7.5	6	6	6.0	0.0	A	A	A
10	W1 + W2 + W3 + C5	5	6	5	10.0	A	8	5.0	5.0	A	A	A
11	W1 + W2 + W3 + C5 + DET	4	6	3	10.0	A	7	5.0	5.0	A	A	A
12	W1 + W2 + W3 + K4	A	7	4	5.0	4	6	3.0	0.0	A	A	A
13	W1 + W2 + W3	5	5	3	5.0	6	6	5.0	5.0	A	A	A
14	W1 + W2 + W3	4	4	2	7.5	5	5	5.0	5.0	A	A	A
15	W1 + W2 + W3 + C5	6	7	4	5.0	A	10	5.0	2.5	A	A	A
16	W1 + W2 + W3 + C5 + DET	5	4	4	7.5	A	7	1.0	5.0	A	A	A
17	W1 + W2 + W3 + K4	A	4	3	5.0	7	7	3.0	2.5	A	A	A

[a] The symbol A indicates an active (discharging) fixture.

Table A.1.1 Trap-Seal Reduction With Vent Terminal Open (continued)

B. E/e Unit

Test No.	Fixtures Discharged	Idle trap-seal reductions after four runs													
		K4 mm	L3(e) mm	L2 mm	T2 mm	C5 mm	L1 mm	T1 mm	F6 mm	W1 mm	W2 mm	W3(e) mm	W3(f) mm	L3(f) mm	C5(f) mm
1	W1 + W2		3	2	2.5	1	5	3	0	A[a]	A	4	-[b]	-	0
2	W1 + W3	3	2	5	2.5	0	5	3	0	A	3	A	-	-	0
3	W1 + W2 + W3 + K4	A	3	3	2.5	0	4	4	0	A	A	A	-	-	0
4	W1 + W2 + W3 + C5	7	4	2	2.5	A	5	0	0	A	A	A	-	-	0
5	W1 + W2 + W3	6	3	2	2.5	2	3	2	-	A	A	A	-	-	0
6	W1 + W2 + L1	7	3	2	5.0	3	A	2	-	A	A	4	-	-	0
7	W1 + W2 + T2	6	4	2	A	2	4	2	+2.5	A	A	5	-	-	0
8	W3(e) + W3(f) + L3(e)	-	A	-	-	-	-	-	-	-	-	A	A	1	-
9	A3(e) + W3(f) + L3(f)	-	2	-	-	-	-	-	-	-	-	A	A	A	-

[a] The symbol A indicates an active (discharging) fixture.

[b] Dash marks indicate that no data were obtained for the indicated traps. Generally, these traps were subjected to milder pressure fluctuations than the traps for which data are reported.

Table A.1.1 Trap-Seal Reduction with Vent Terminal Open (continued)

C. F/b Unit

Test No.	Fixtures Discharged	Idle trap-seal reductions after four runs									
		K4(b) mm	L2 mm	T2 mm	C5 mm	L1 mm	T1 mm	F6 mm	W1 mm	W2 mm	K4(a) mm
1	K4(b)	A[a]	0	0.0	1	0	0.0		0	0	1
2	K4(a)	3	0	0.0	2	0	0.0		0	0	A
3	C5(b)	3	0	0.0	A	0	0.0		0	0	0
4	K4(a) + K4(b)	A	0	0.0	1	0	0.0		0	0	A
5	W1 + W2 + C5	2	2	2.5	A	1	2.5		A	A	2
6	W1 + W2 + C5	1	3	0.0	A	1	2.5		A	A	4
7	W1 + W2 + K4	A	5	0.0	+1	1	0.0		A	A	3
8	W1 + W2 + K4 + C5	A	5	2.5	0	1	2.5		A	A	1
9	W1 + W2 + K4 + C5	A	5	2.5	A	1	2.5		A	A	3
10	W1 + W2 + K4 + C5	A	5	2.5	A	0	2.5		A	A	2
11	L2 + W2	0	A	2.5	0	1	2.5		0	A	—[b]
12	W1 + W2	1	1	2.5	1	0	2.5		A	A	—
13	L2 + L1	0	1	0.0	0	A	0.0		A	0	—
14	L2 + W1	0	A	2.5	0	0	2.5		A	0	—
15	W1 + W2 + L1	1	2	5.0	1	A	0.0		A	A	—
16	W1 + W2 + L2	0	A	2.5	0	0	0.0		A	A	—
17	W1 + W2 + T1	0	1	5.0	0	0	A		A	A	—

[a] The symbol A indicates an active (discharging) fixture.

[b] Observations not made of the K4(a) trap for tests 11 through 17, as indicated by dash marks.

Table A.2.1 Summary of Findings on Trap-Seal Reductions[a] in D and F Houses with Vent Terminal Closed

Unit D: Trap-seal reductions after four runs with W1 + W2 + T2 discharged

Lavatories			Shower	Kitchen, Laundry, Utility		
L1	L2	L3	S1	K4	C5	F6
mm	mm	mm	mm	mm	mm	mm
21	20	20	25	16	15	8

Unit D: Trap-seal reductions after four runs with W1 + W2 + W3 discharged

Lavatories			Shower, Tub		Kitchen, Laundry, Utility		
L1	L2	L3	S1	T2	K4	C5	F6
mm	mm	mm	mm	mm	mm	mm	mm
45	39	29	24	25	38	28	24

Unit F/b: Trap-seal reductions[b] after four runs with K4(a) + K4(b) discharged

Water Closets		Lavatories		Bathtubs		Laundry,	Utility
W1	W2	L1	L2	T1	T2	C5	F6
mm	mm	mm	mm	mm	mm	mm	mm
42	44	21	12	13	22	24	c
30	44	25	2	15	18	24	c
(0)[d]	(0)	(0)	(0)	(0)	(0)	(1)	c

[a] 12 test average.

[b] The vent terminals of both the F/a and F/b units were closed.

[c] Equipment malfunction; level not read.

[d] Numbers in parentheses in last line are corresponding trap-seal reductions after four runs with the vent terminal open.

Table A.2.2 Trap-Seal Reduction with Vent Terminal Closed

A. D/a unit[a]

Test No.	Fixtures Discharged	Idle trap-seal reductions after four runs										
		K4 mm	L3 mm	L2 mm	T2 mm	C5 mm	L1 mm	S1 mm	F6 mm	W1 mm	W2 mm	W3 mm
13	W1 + W2 + W3	38	29	39	25	28	45	24	24.0	A[b]	A	A
14	W1 + W2 + K4	A	10	39	25	16	31	25	7.0	A	A	11
15	W1 + W2 + W3 + K4	A	23	42	25	22	41	25	6.0	A	A	A
16	W1 + W2 + W3 + C5	32	29	35	25	A	36	25	6.0	A	A	A
17	W1 + W2 + W3	23	25	27	23	25	30	22	17.5	A	A	A
18	W1 + W2 + K4	A	17	30	23	16	26	21	2.0	A	A	12
19	W1 + W2 + W3 + K4	A	17	30	23	16	26	21	0.0	A	A	A
20	W1 + W2 + W3 + C5	26	26	31	25	A	35	25	3.0	A	A	A

[a] F6 vent closed.

[b] Symbol A indicates active (discharging) fixtures. Virtually zero seal reductions occurred in the traps of such fixtures, due to refill provided by trailing flow at the end of the discharge.

Table A.2.2 Trap-Seal Reduction with Vent Terminal Closed (continued)

B. F/b Unit

Test No.	Fixtures Discharged	Idle trap-seal reductions after four runs									
		K4(b) mm	L2 mm	T2 mm	C5 mm	L1 mm	T1 mm	F6 mm	W1 mm	W2 mm	K4(a) mm
1	K4(b)	A[a]	2	0.0	0	1	0.0		0	2	2
2	K4(a)	1	7	--	6	7	0.0		12	12	A
3	C5(b)	3	2	0.0	A	1	2.5		2	3	1
4	K4(a) + K4(b)	A	12	22.5	24	21	12.5		42	44	A
5	W1 + W2 + C5	+1	8	7.5	A	7	2.5		A	A	4
6	W1 + W2 + C5	3	10	10.0	A	9	2.5		A	A	4
7	W1 + W2 + K4	A	8	5.0	2	9	0.0		A	A	4
8	W1 + W2 + K4	A	3	5.0	2	7	0.0		A	A	3
9	W1 + W2 + K4 + C5	A	5	2.5	A	5	2.5		A	A	2
10	W1 + W2 + K4 + C5	A	5	5.0	A	5	2.5		A	A	0
11	L2 + W2	2	A	0.0	1	2	0.0		2	A	-
12	W1 + W2	2	1	5.0	2	2	2.5		A	A	-
13	L1 + W1	2	1	0.0	1	A	0.0		A	5	-
14	L2 + W1	1	A	0.0	1	0	0.0		A	3	-
15	W1 + W2 + L1	8	8	5.0	5	A	0.0		A	A	-
16	W1 + W2 + L2	2	A	2.5	2	4	2.5		A	A	-
17	W1 + W2 + T1	2	4	2.5	3	5	A		A	A	-
18	K4(a) + K4(b)	A	2	17.5	24	25	15.0		30	44	A
19	W1 + W2 + K4(b)	A	15	12.5	28	15	2.5		A	A	15

[a] Symbol A indicates active (discharging) fixtures. Virtually zero seal reductions occurred in the traps of such fixtures.

Table A.2.3 Effect on Idle Trap-Seal Reduction of Repeated Loading without Refilling Traps between Runs, with Vent Terminal Closed

Test unit: D/a Unit
Test load: W1 + W2 + T2 discharged

	Idle Trap-Seal Reductions							
Test No.	L1	L2	L3	W3	S1	K4	C5	F6
	mm	mm	mm	mm	mm	mm	mm	mm
				After first run				
1	16	17	16	11	17.5	12	13	12.5
2	19	18	16	10	22.5	15	15	12.5
3	20	27	17	16	18	16	14	0
4	13	13	11	5	8	11	7	0
5	20	20	18	14	18	17	16	+2.5
6	23	22	20	17	19	19	16	0
7	15	16	16	11	16	16	14	0
8	19	17	18	16	18	16	17	0
9	19	16	16	11	13	10	15	0
10	20	18	18	11	20	16	16	0
11	15	13	16	11	15	15	15	0
12	15	13	12	7	10	11	10	0
AVG	17.8	17.5	16.2	11.7	16.2	14.5	14.0	1.9
				After second run				
1	20	17	18	16	20	14	15	7.5
2	20	19	16	12	22.5	15	16	12.5
3	20	29	18	19	18	18	14	0
4	20	18	18	15	18	16	16	0
5	24	20	21	21	22	20	22	0
6	24	23	20	20	19	19	18	0
7	23	20	19	19	22	19	18	0
8	25	20	21	21	19	20	20	2.5
9	24	20	21	18	19	19	17	0
10	25	20	24	20	20	21	19	0
11	17	16	17	15	15	16	15	0
12	19	18	17	15	16	15	14	0
AVG	21.8	20.0	19.2	17.6	19.2	17.7	17.0	1.9
				After third run				
1	20	19	20	19	55.5	15	15	2.5
2	20	19	17	13	22.5	16	16	12.5
3	21	29	18	20	19	18	15	0
4	16	23	20	20	20	19	19	0
5	22	23	23	27	28	22	22	0
6	25	23	21	25	25	21	21	2.5
7	24	20	21	22	22	21	21	5
8	25	23	24	26	25	22	22	25
9	26	23	23	25	26	22	21	5.0
10	19	16	17	15	16	16	15	0
11	19	18	17	16	16	16	15	2.5
AVG	21.5	21.4	20.1	20.7	25.0	18.9	18.4	5.0
				After fourth run				
1	21	20	20	20	25	16	15	2.5
2	20	19	17	15	25	16	18	17.5
3	21	30	18	20	20	18	16	0
4	29	28	26	29	26	26	25	7.5
5	22	25	24	28	29	22	22	2.5
6	25	23	21	25	25	23	21	0
7	25	23	23	26	27	23	24	5
8	27	25	25	28	26	23	22	5
9	27	23	24	26	26	23	22	5
10	26	24	25	26	29	25	24	2.5
11	19	18	17	15	16	16	16	0
12	20	18	17	16	16	17	16	2.5
AVG	23.5	23.0	21.4	22.8	24.2	20.7	20.1	4.2

Table A.2.4 Vent Pressure Data for the D/a Unit with Vent Terminal Closed, W1 + W2 + T2 Discharged (see also table A.2.3 and figure A.2.1)

		K4		S1		W3	
Test Number/ Run Number	Limit Switch Setting	Peak Suction Observed	Time Beyond Suction Limit	Peak Suction Observed	Time Beyond Suction Limit	Peak Suction Observed	Time Beyond Suction Limit
	kPa	kPa	s	kPa	s	kPa	s
1/1	0.50	0.45[a]	[b]	[c]	[b]	[c]	[b]
2/		[c]	[b]	0.60	[b]	[c]	[b]
3/[d]		[c]	0.00	0.60	0.08	[c]	0.00
4/1		[c]	0.00	0.30	0.00	[c]	0.00
5/1		[c]	0.07	0.60	0.00	0.55	0.00
6/1		[c]	0.11	0.70	0.24	0.60	0.06
7/1	0.25	[c]	2.30	0.50	4.00	0.45	1.85
8/1		[c]	4.19	0.50	6.03	0.50	4.21
8/2		[c]	3.57	0.70	4.87	0.60	3.62
9/1		[c]	2.56	0.55	3.45	0.45	2.31
10/1		[c]	3.37	0.75	3.52	0.55	3.43
10/2		[c]	3.86	0.60	5.10	0.60	3.80
11/1		[c]	3.33	0.50	4.47	0.45	3.07
12/1		[c]	0.60	0.50	1.76	0.35	0.66

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[a] This suction value was also observed for the clothes washer for this run.

[b] DAS not recording.

[c] Peak suction not observed.

[d] The first run of test 3 produced the only trap-seal reduction (L2) exceeding 25 mm in the 12 test series.

PATTERN OF TRAP FAILURES

W1 + W2 + T2 DISCHARGED, D/A UNIT, VENT TERMINAL CLOSED

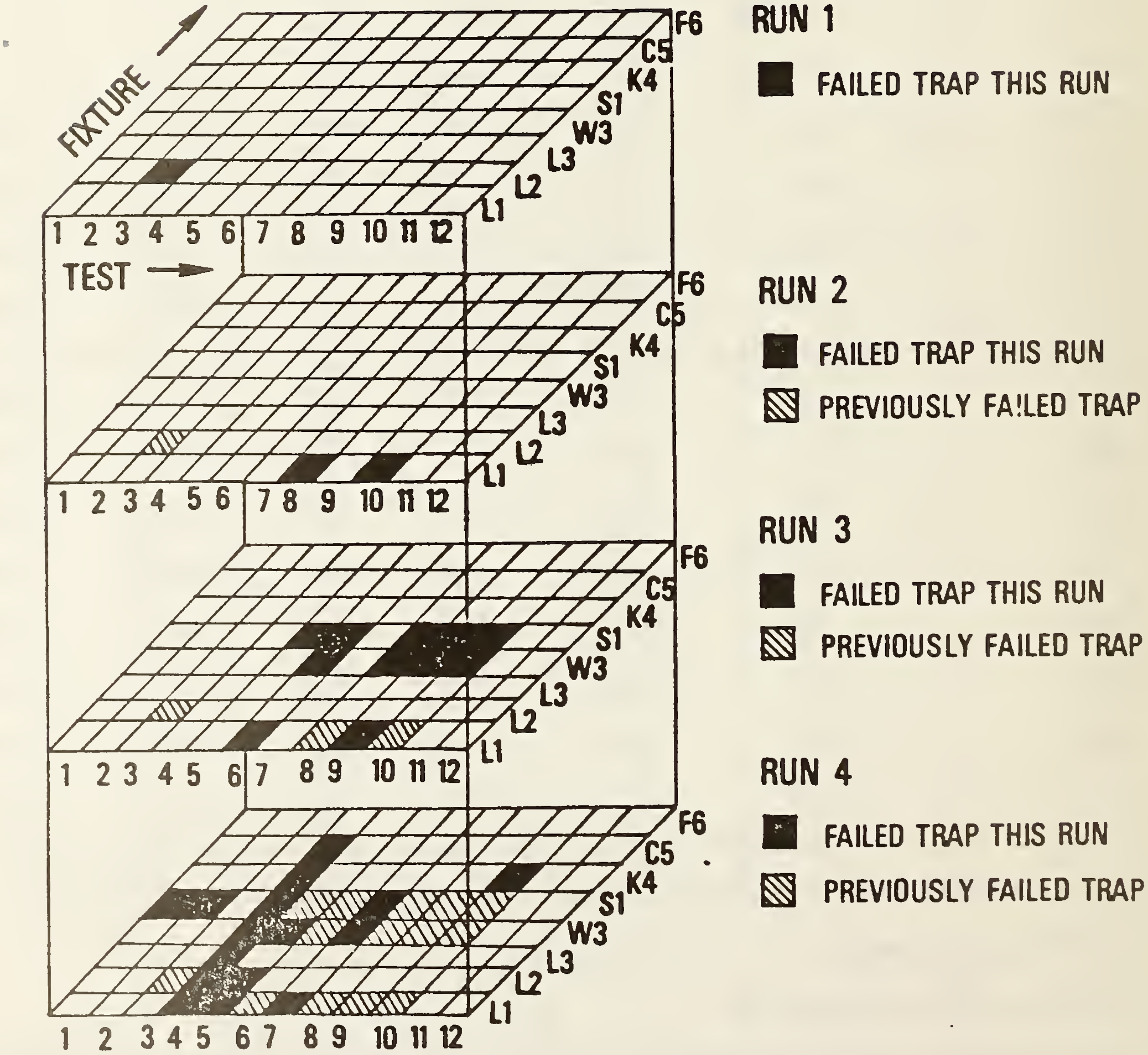

Figure A.2.1 Pattern of trap failures with repetitive, heavy loading and closed vent terminal

APPENDIX B. POST OCCUPANCY STUDY

B.1 APPROACH AND OBJECTIVE

As indicated in foregoing sections of the report describing the preoccupancy tests, the program was designed to monitor the performance of the plumbing systems in a military family housing project after occupancy of the test units, utilizing the sensors and data acquisition system described briefly in section 3 and also shown in figures B.1.1 and B.1.2. The data acquisition system was a medium speed, expandable system, with initial capability of storing data from sensors at 100 points. Data were recorded on magnetic tape with a paper printout option. Scan speed was 20 channels per second for magnetic tape recording and 5 channels per second using the printout option. The DAS was remotely controlled and had provisions for data transmission by telephone data lines. The system was interfaced with a computer for either control and/or data storage purposes. Special sensing instrumentation was installed for measuring the performance of the plumbing systems. Trap-seal depth changes were sensed by means of electrically conductive pins inserted through the walls of the plastic traps at 5 mm intervals of elevation. Vent pressure changes were sensed by combination pressure switch-gages that could be preset to maintain a closed circuit during time periods where the pressure fluctuations exceeded the preset range. See table 2 for further detail. Among parameters measured on real-time basis (clock timer data) were trap-seal changes, the existence of vent pressures outside a preset range, occurrence of flow in individual fixture supply pipes, volume of water delivered to the dwelling unit and volume delivered to the water heater, and electrical energy consumed by the water heater.

It was expected that the data obtained by the method outlined here would be useful in future analysis and updating of existing water supply pipe sizing procedures that have been in use for over 40 years.

The primary objectives of the post-occupancy study were:

1. To verify under the actual service conditions the adequacy of performance of the reduced-size vents, which had been found adequate by preoccupancy tests (described in foregoing sections of this report). In particular, data on trap-seal reduction and vent pressure were to be compared with the accepted plumbing standards of 1.0 inch maximum allowable trap-seal reduction and ± 1.0 inch WG maximum allowable vent pressure fluctuation.

2. To correlate the measured trap-seal depth changes, the associated pressure excursions in the vents; and the occurrence of specific fixture operations in normal service loading by the occupants.

Other objectives were:

1. To obtain data on time distribution of water use in individual fixture types, and on hot and cold water consumption and peak delivery rates in individual dwelling units. From such data, characteristic periods of time between fixture operations on frequency of use can be derived. Such data

are essential to the rational updating of traditional procedures for the design of water service and distribution piping, which are based on the Hunter method.

2. To obtain energy consumption data, such as the quantity and time distribution of energy consumed in heating water. Such data are needed for comparison with current estimates and with recent data obtained in civilian housing projects, as one element in the improvement of energy management programs.

B.2 RESULTS

Data were obtained intermittently and stored on magnetic tape, covering various periods of time over a space of approximately 3 years. Sample analyses of the data were made, from which it was concluded that vent pressure fluctuations were negligible[1] and trap-seal retention was adequate. Inspections of the roof vents after a period of nearly 3 years showed no evidence of blockage. No plumbing problems or complaints were reported to the Andrews Air Force Base housing maintenance office that could be attributed to the existence of the reduced-size vents. Any problems reported were for normal plumbing maintenance or as a result of the presence of sensors installed for experimental purposes.

After about three years, the instrumented traps and the flow switches, as well as exposed wiring and tubing, were removed to restore the wet piping systems to an unaltered condition. Where appropriate, standard plumbing and building materials were used to replace instrumented components and to repair damaged elements. As had been expected, deterioration of the trap pins from electrolytic corrosion ultimately resulted in some of the traps leaking.

Because of the great quantity of data that were recorded, and because of the need to edit the records to remove spurious data, the resources available to the program proved inadequate to complete the reduction, analysis, and reporting of the data. The data are retained by NBS in anticipation of some future opportunity to complete the analysis and report the detailed results.

Figures B.2.1 through B.2.8, and tables B.2.1 and B.2.2 show samples of data extracted from the tapes, giving the distribution of hot and cold water flow rates and consumption by fixture/outlet in two test units over a 5 day period.

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[1] In fact, essentially no data were obtained on the existence of vent pressures outside the range of ± 1 in W.G. By resetting the range to ± 0.5 in. WG, some data were obtained. This indicated that vent pressures outside the range ± 1 in WG, the accepted norm, almost never occurred with the reduced-size vents.

Based on the experience gained in this study, the following recommendations are offered to future researchers:

1. It is very important to avoid the recording of nonessential data, because a very large quantity of data is produced.

2. The parameters measured should relate directly to the corresponding parameters addressed in plumbing codes, standards and generally accepted design practice, and in currently accepted mathematical models.

3. Sensors should be very carefully selected or designed to minimize malfunction and maintenance. Preliminary field trials of candidate sensors should be made to check their reliability and general suitability before final selection for a research program. Sticking flow switches caused false data storage on the magnetic tape of the DAS and depleted the tape available for recording actual usage events.

Tables B.2.1 and B.2.2 give the cumulative hot and cold (and combined hot and cold) water consumption recorded over a period of 5 days for tests units D/a and F/a. These data also show the distribution of the water consumption of fixture and outlet.

Figures B.2.1 through B.2.8 show the distribution of hot and cold (and combined hot and cold) water flow rates by fixture and proportion of flow occurrences over a period of 5 days for test units D/a and F/a.

Table B.2.1 Water Consumption in Occupied Test Unit D/a and Distribution by Fixture and Outlet (data sample covering a 5 day period).

	Water Usage by Fixture					
	Cold Water		Hot Water		Total	
Fixtures	Gallons	Percent	Gallons	Percent	Gallons	Percent
Kitchen Sink	50.85	3.74	87.90	14.34	138.75	7.08
Powder Room Lavatory	29.07	2.14	17.07	2.78	46.14	2.34
Common Bath Lavatory	11.10	.82	6.67	1.09	17.76	.90
Common Bath Tub	84.24	6.20	112.63	18.38	196.87	9.98
Common Bath Shower	1.33	.10	.00	.00	1.33	.07
Clothes Washer	199.52	14.68	204.50	33.37	404.02	20.49
Master Bath Lavatory	19.70	1.45	8.44	1.38	28.14	1.43
Master Bath Shower	45.99	3.38	59.78	9.75	105.77	5.36
Front Sillcock	18.11	1.33	.00	.00	18.11	.92
Rear Silcock	10.74	.79	.00	.00	10.74	.54
Furnace Humidifier	.00	.00	.00	.00	.00	.00
Powder Room Toilet	461.59	33.96	.00	.00	461.59	23.40
Common Bath Toilet	261.02	19.20	.00	.00	261.02	13.23
Master Bath Toilet	166.06	12.22	.00	.00	166.07	8.42
Dishwasher	.00	.00	115.91	18.91	115.91	5.88
Total	1359.32	100%	612.89	100%	1972.21	100%

Table B.2.2 Water Consumption in Occupied Test Unit F/a and Distribution by Fixture and Outlet (data sample covering a 5 day period).

Fixtures	Water Usage by Fixture					
	Cold Water		Hot Water		Total	
	Gallons	Percent	Gallons	Percent	Gallons	Percent
Kitchen Sink	40.94	3.49	149.75	18.68	190.69	9.65
Common Bath Lavatory	37.05	3.16	26.31	3.28	63.37	3.21
Common Bath Tub	30.97	2.64	60.50	7.55	91.47	4.63
Common Bath Shower	.00	.00	.00	.00	.00	.00
Clothes Washer	149.45	12.73	100.82	12.58	250.28	12.67
Master Bath Lavatory	24.91	2.12	18.76	2.34	43.67	2.21
Master Bath Tub	150.38	12.81	221.20	27.59	371.58	18.81
Master Bath Shower	73.15	6.23	104.94	13.09	178.09	9.02
Front Sillcock	29.92	2.55	.00	.00	29.92	1.51
Rear Silcock	.00	.00	.00	.00	.00	.00
Furnace Humidifier	.00	.00	.00	.00	.00	.00
Common Bath Toilet	207.52	17.68	.00	.00	207.52	10.50
Master Bath Toilet	429.42	36.59	.00	.00	429.42	21.74
Dishwasher	.00	.00	119.46	14.90	119.46	6.05
Total	1173.72	100%	801.74	100%	1975.46	100%

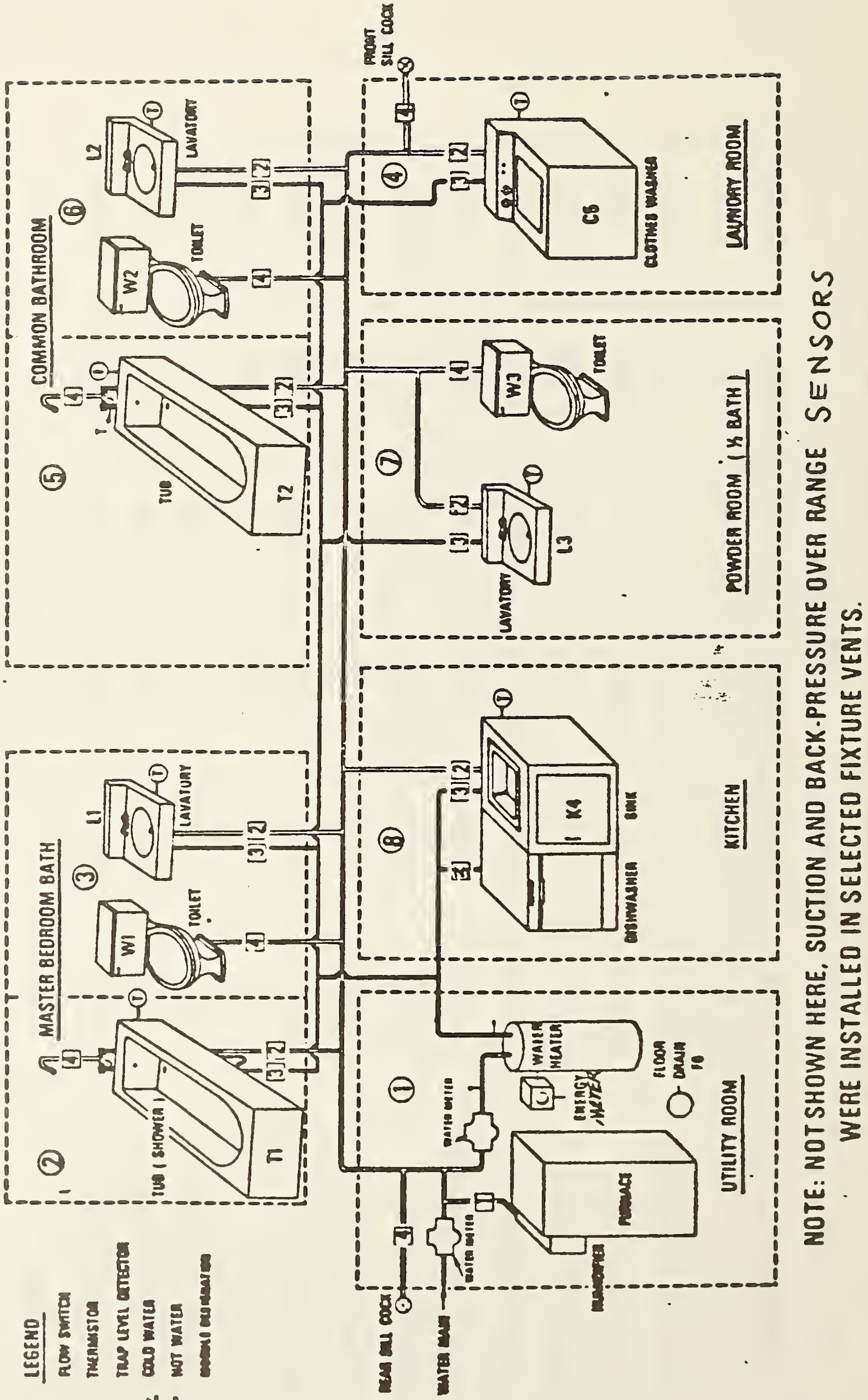

Figure B.1.1 Schematic of automatic monitoring instrumentation for post-occupancy tests

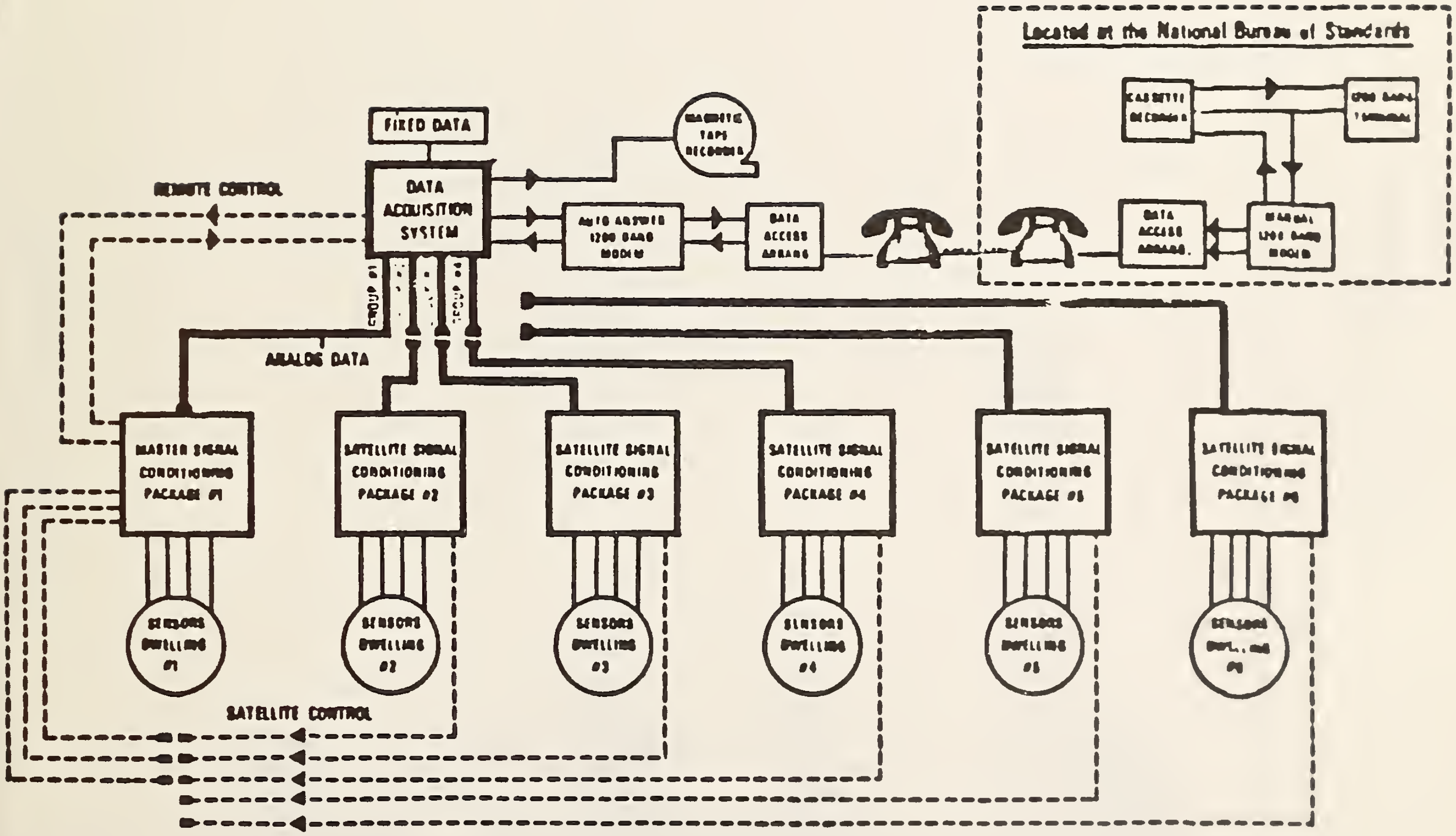

Figure B.1.2 Schematic of post-occupancy field data acquisition system

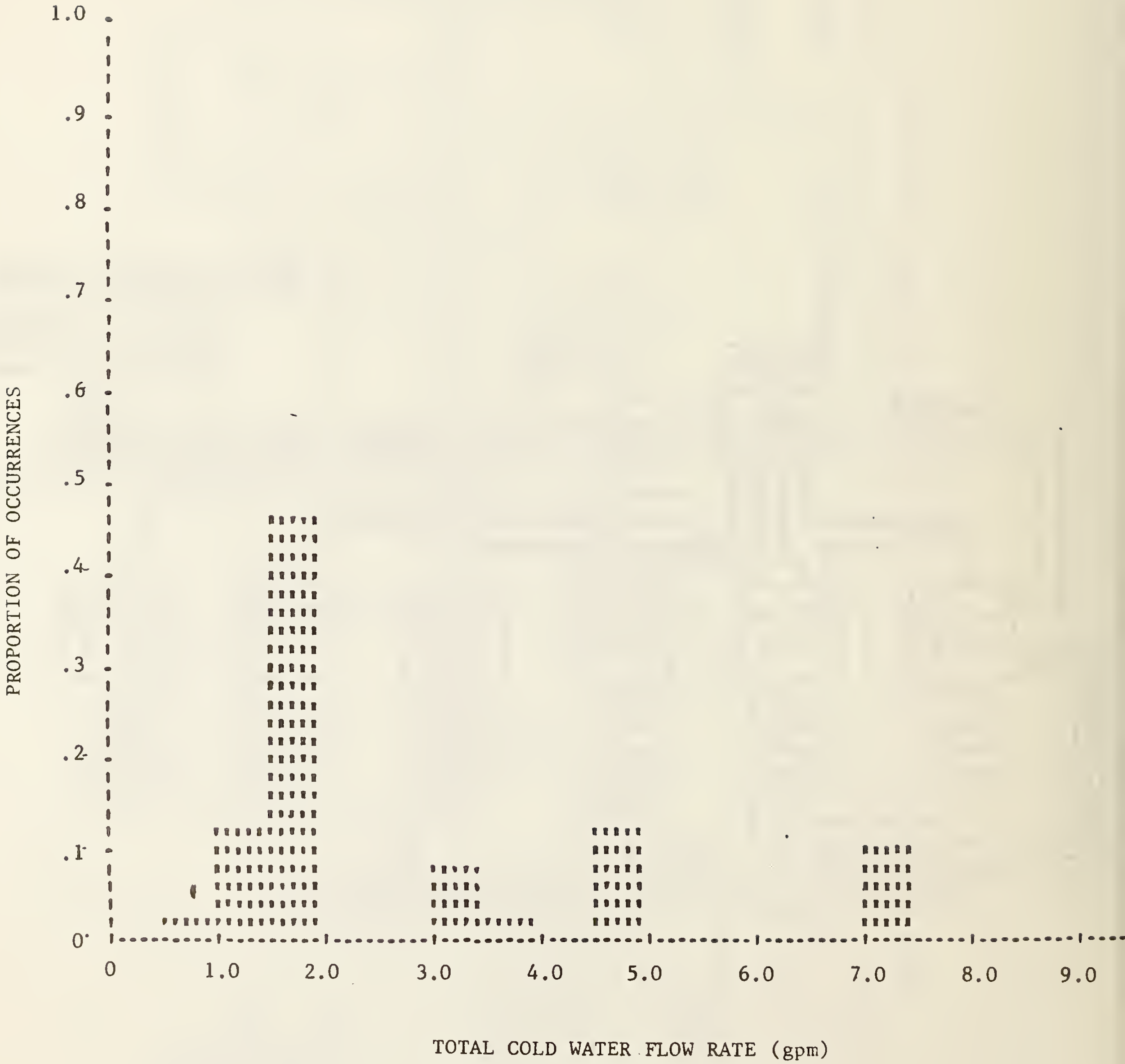

Figure B.2.1 Distribution of cold water flow rates in master bath shower, D/a unit (data sample covering a 5 day period)

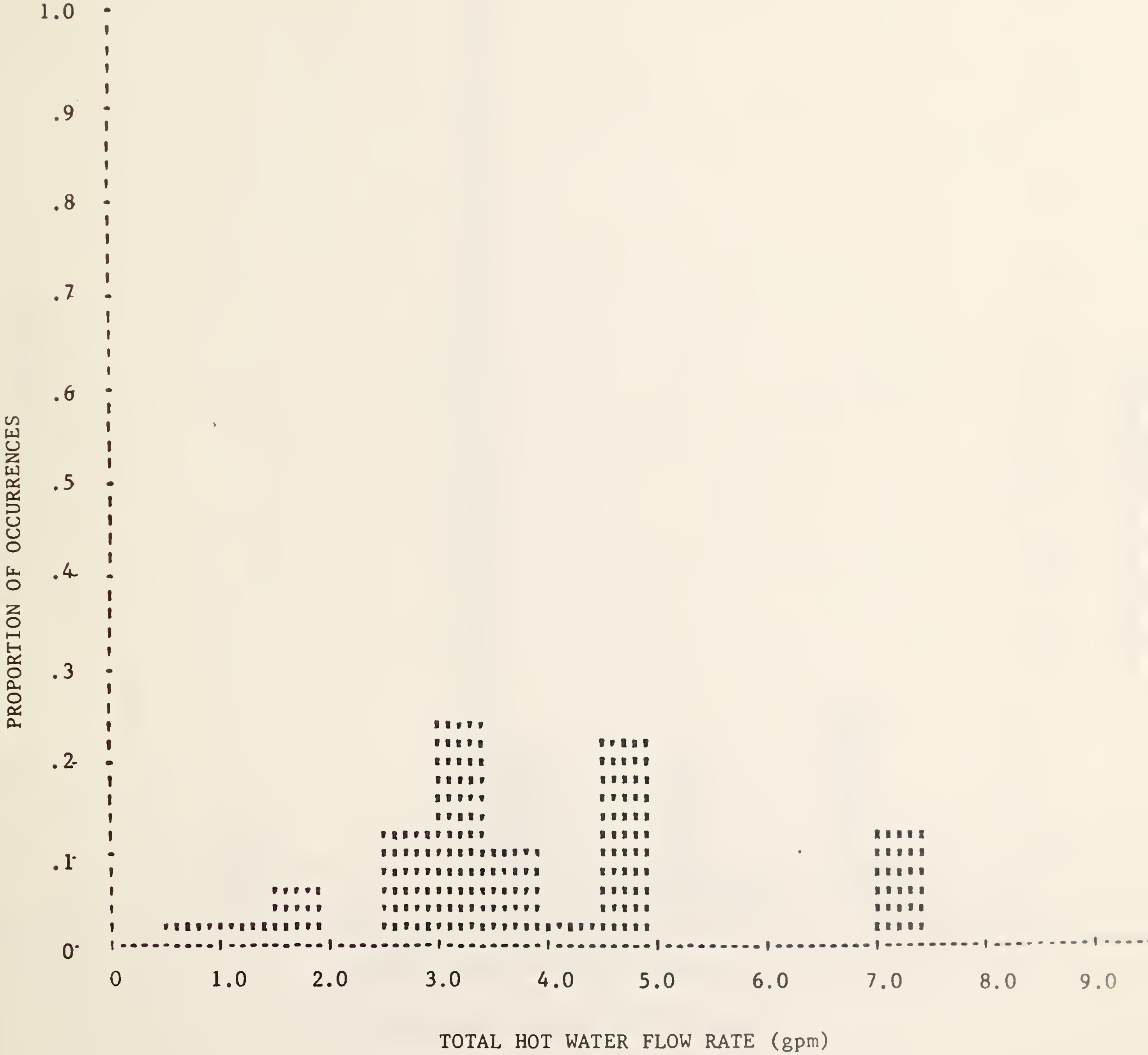

Figure B.2.2 Distribution of hot water flow rates in master bath shower, D/a unit (data sample covering a 5 day period)

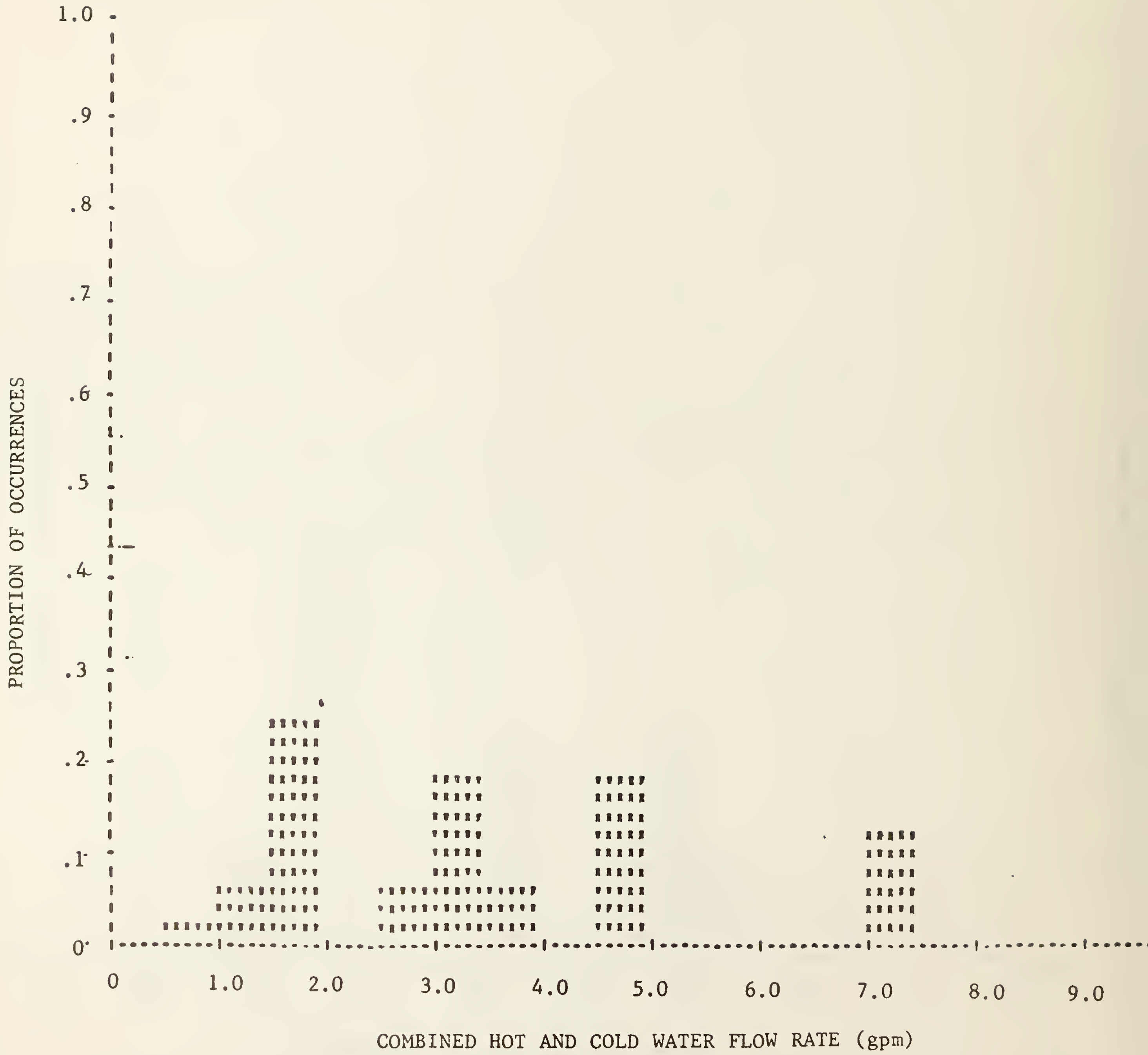

Figure B.2.3 Distribution of combined hot and cold water flow rates in master bath shower, D/a unit (data sample covering a 5 day period)

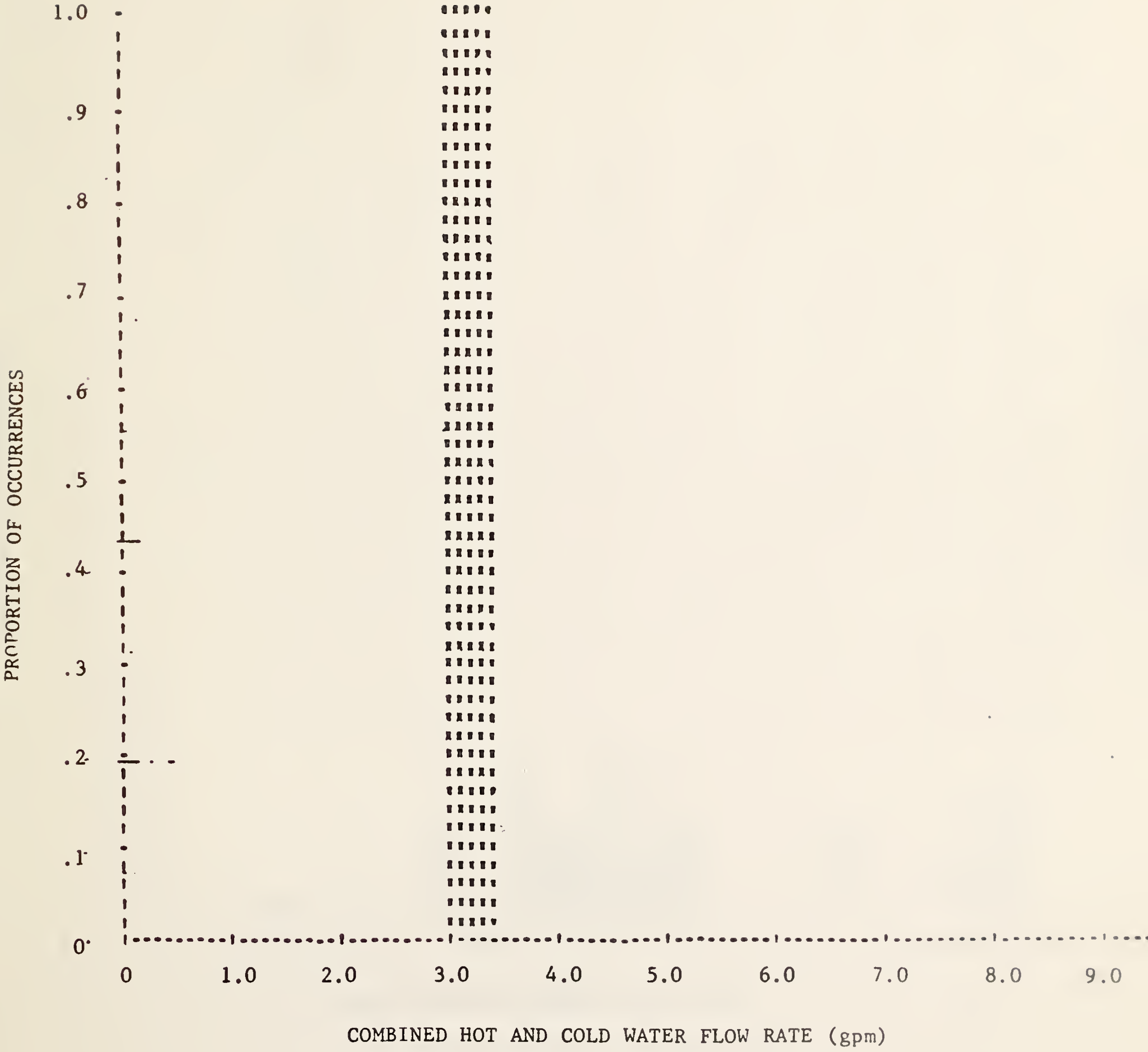

Figure B.2.4 Distribution of combined hot and cold water flow rates in common bath shower head, D/a unit (data samples covering a 5 day period)

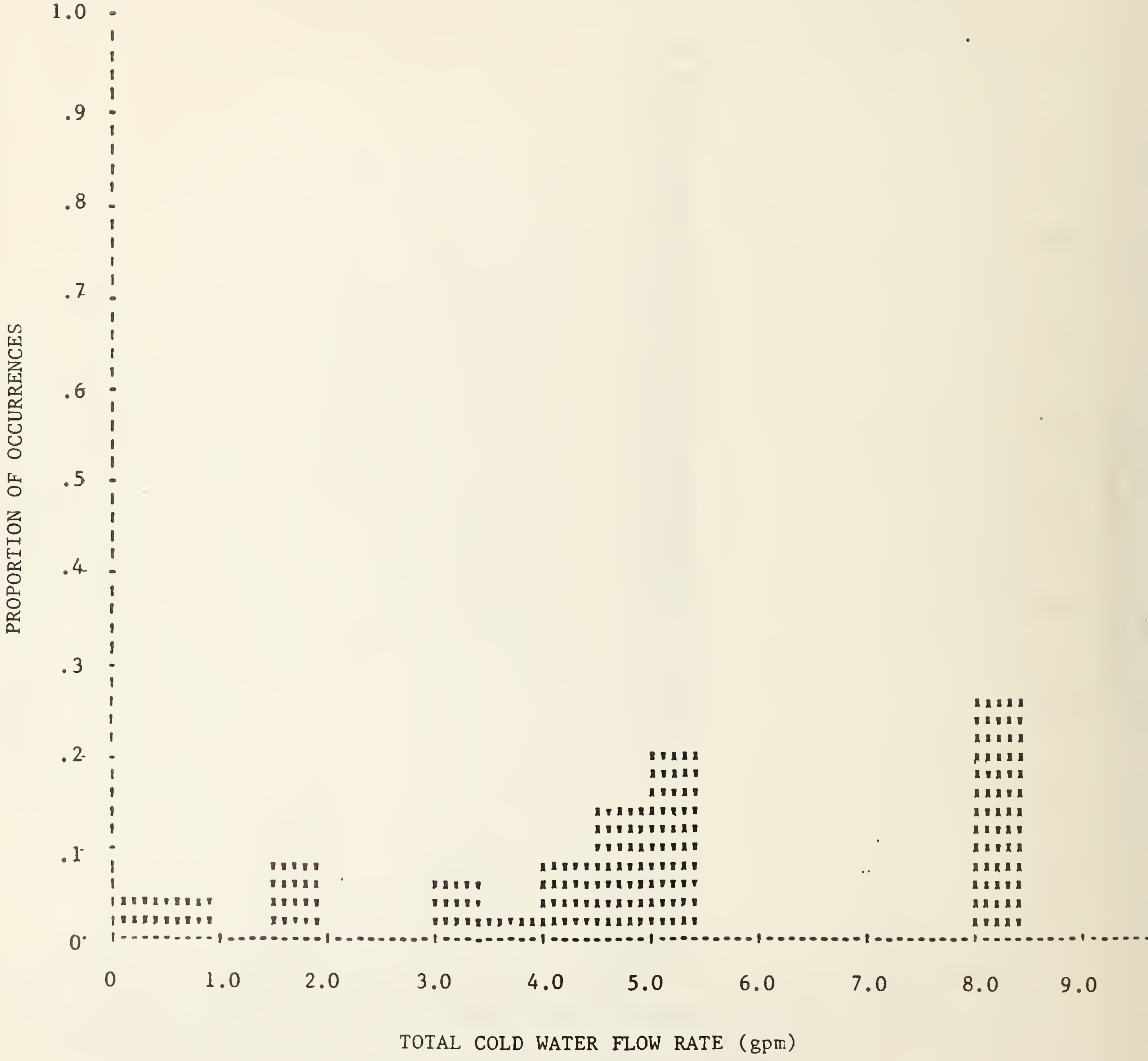

Figure B.2.5 Distribution of cold water flow rates in master bath shower, F/a unit (data sample covering a 5 day period)

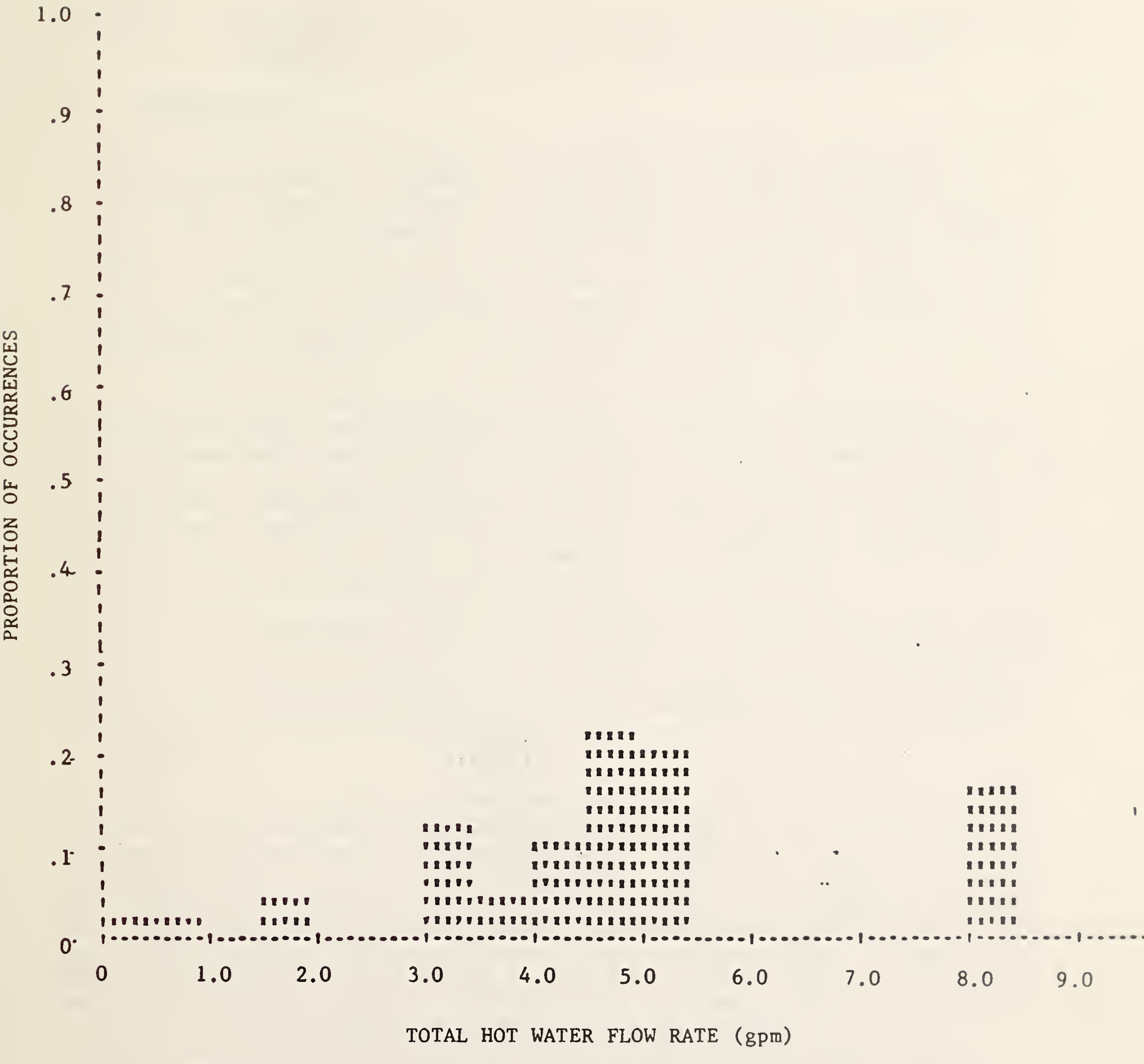

Figure B.2.6 Distribution of hot water flow rates in master bath shower, F/a unit (data sample covering a 5 day period)

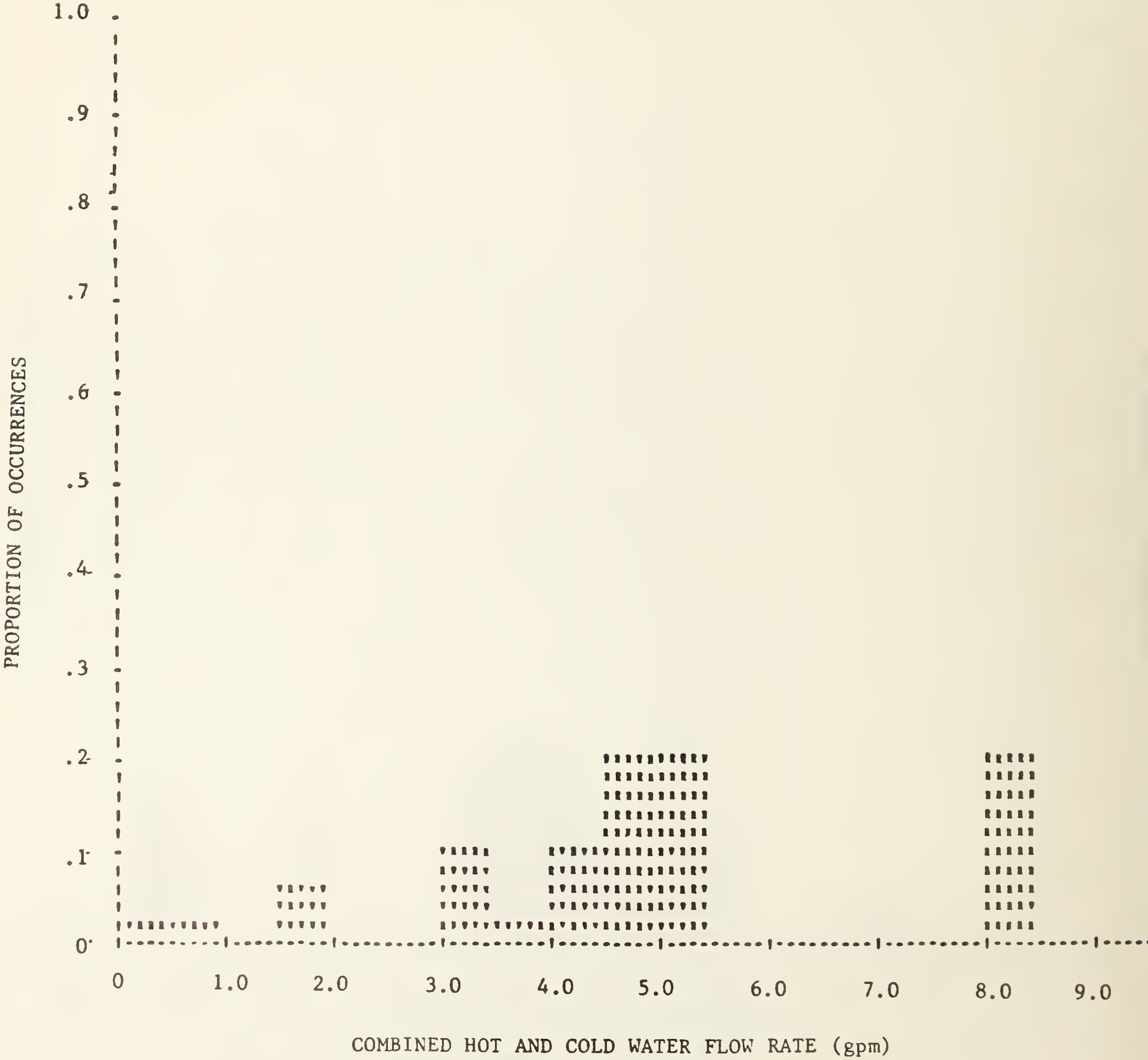

Figure B.2.7 Distribution of combined hot and cold water flow rates in master bath shower, F/a unit (data sample covering a 5 day period)

APPENDIX C. RECOMMENDED CRITERIA AND GUIDELINES FOR THE DESIGN AND INSTALLATION OF REDUCED-SIZE VENTS FOR ONE- AND TWO-STORY HOUSING UNITS

C.1 INTRODUCTION

Standard design of sanitary drain-waste-vent (DWV) systems in accordance with conventional plumbing code requirements provides ventilation piping as an integral part of the DWV system. The principal function of the vent piping is to protect the trap-seals against excessive depletion from suction or against blowing from back pressure. Other functions commonly ascribed to vent piping include the facilitation of rapid and silent drainage from the fixtures, ventilation of gases from the public sewer or septic tank, and the minimization of the buildup of concentrations of gases in the DWV system that may be corrosive to some piping materials.

The variables that determine safe, economic vent design and sizing are numerous, difficult to define, and intricately related. Among these variables are the time dependent air flow in the DWV pipe network. The interdependence of the drains and vents for functional adequacy, the likelihood of random simultaneous or concurrent (overlapping) discharge of two or more fixtures, the hydraulic discharge characteristics of the drainage from the individual fixtures, the heights of the drainage stacks, the geometry of the drainage fittings, drain pipe sizes, and the specific configuration of the DWV system.

Various research programs to study the hydraulics and pneumatics of DWV systems have been conducted; some have provided semi-scientific, more or less empirical, bases for relaxing specification of some of the stringent requirements (e.g., unnecessarily large stack sizes and individual venting of each and every fixture) in plumbing practice as regulated by the early plumbing codes in the United States.

Among the mitigating effects of this research have been the gradual recognition by codes of certain cost-saving practices such as wet venting, stack venting, common venting, and the use of 3 inch diameter soil stacks and building drains under many conditions. Based on a combination of research findings and empirical or practical judgments, codes have, from time-to-time, updated the requirements for sizing and configuration of vent systems. Generally, this evolutionary process has resulted in requirements less restrictive than they were before the research was conducted. However, many codes still require a considerable amount of ventilation piping, undoubtedly more than necessary for many systems.

In the 1960s and 1970s feasibility studies were conducted, in response to interest and support by home builders and by family housing branches of the agencies of the U.S. Department of Defense, to reduce the minimum sizes of dry vents prescribed by codes, as they might relate to one- and two-story residential systems. It was hypothesized that size reductions for such systems might be based on initial considerations as follows:

1. Traditional criteria for sizing main vents (stack vents and vent stacks) were derived from research data obtained under hydraulic test

conditions which were more severe than those normally occuring in actual service, especially in one- and two-story residential buildings.

2. The traditional criteria for sizing fixture vents and branch vents were purely empirical and based on practical experience and collective opinion.

3. Analysis indicated that air flow demands in the vents of the DWV systems of one- and two-story buildings are substantially less than those provided for by the prescriptive sizing requirements of plumbing codes.

4. Traditional criteria were based on the assumption that a substantial diameter reduction in vent pipes occurred during service from the accumulation of corrosion products. With pipe materials not significantly subject to corrosion the assumption can be challenged.

The results of the several RSV studies have confirmed the hypothesis that reduced-size vents may perform adequately and have provided certain new design criteria and installation guidelines to facilitate the utilization of reduced-size venting as a viable technique.

In reduced-size venting design, trap-seal retention and absence of blow-back is the criterion of performance rather than suction and back pressure. When the application of RSV is limited to specific conditions, significant savings in piping can be made, with safety and health still maintained.

The magnitude of savings obtainable is affected significantly by the total length of pipe and the number and types of fittings. In general, it can also be stated that it costs less to use small piping than to use large piping, if factors other than size are assumed equal.

Among the principal variables affecting the cost of any system are the following:

1. Relative locations and positioning of the fixtures and appliances.

   The following design objectives should be sought, where possible, so as to minimize costs:

   (a) the fixtures and appliances should be grouped to limit the number of fittings and the amount of horizontal piping.
   (b) where possible, the design should provide for back-to-back bathrooms.
   (c) In two-story systems, an attempt should be made to place bathrooms and plumbing walls one above the other ("stacked").

2. Complexity of the vent system.

   The system configuration and amount of piping is affected by code requirements on venting. For example, stack venting and wet venting designs provide for simpler configurations and less piping than individual venting.

3. Field changes.

   The nature and extent of field changes can affect overall costs significantly. In general, field changes should be made only in response to architectural or site constraints, to reduce complexity and/or the amount of piping, or to avoid inadvertant violation of the code.

4. Cost estimating procedures used by the plumbing contractor.

   There appears to be wide differences by different contractors in the variables they consider and in their procedures for taking the variables into account in estimating costs for an installed system. Thus, cost estimates may vary considerably between contractors, and experience suggests this variability may be accentuated when an innovative design is presented.

C.2 GENERAL LIMITATIONS

Reduced-size venting considerations herein have been limited to DWV system elements where (1) the waterfall distance from fixtures through their stacks or vertical waste pipes to the next lower vented horizontal drain (building drain or horizontal fixture branch drain) does not exceed 18 ft[1], (2) to residential occupancies and (3) to residential-type fixtures.

This would limit RSV to systems or components with a maximum of three floors of plumbing fixtures with connections distributed over a vertical distance not exceeding 18 ft. This would generally include all one-story residences with or without basements or crawl spaces, most split level designs, and two-story Colonial designs conforming to the 18 ft distribution rule. This would preclude RSV in two-story designs with full basement and sewer below basement in which plumbing connections are made in each of the three branch intervals to a stack running the full height of the building.

Reduced-size venting is limited to DWV systems, the wet-piping of which fully complies with the applicable plumbing code, and the dry vent system configuration and general design of which fully complies with the applicable plumbing code with the exception of sizing.

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[1] Applications to systems of greater height may be feasible if adequate provision is made for pipe and fitting friction losses in design. Preliminary research in this area has provided encouragement. (See item 3 in C.7.)

Reduced-size vents sized in accordance with C.4 shall be made of corrosion-resisting materials, such as copper or approved thermoplastics.[1]

Reduced-size vents shall not be used for fixture and stack vents below an elevation 6 inches above the flood rim of the highest fixture served by the vent, nor for any portion of a vent subject to intermittent wetting; e.g., by water rise due to a drain blockage or pressure that could be exerted by a pumped discharge.

See Section C.5 for important installation guidelines for reduced-size venting.

C.3 PRELIMINARY DATA

In considering the utilization of reduced-size venting, it is essential that the proponent (designer, contractor, builder, etc) consult with the local plumbing code enforcement agency, or other governmental department having jurisdiction before designing the system. This is essential for assuring that this sizing method will be acceptable under the applicable ordinance and to ascertain what plans, specifications, and other information may be required by the Administrative Authority prior to granting approval.

In resizing standard dry vent systems in accordance with the specific procedures given in section C.4, certain preliminary data should be obtained before applying the RSV criteria. Among these are the following:

1. Site and Geographic Conditions

The likelihood of abnormal pressures in and surcharging (overloading) of the public sewer should be estimated based on consultation with the local sewer authority. Where surcharged sewers are known to occur frequently RSV sizing may be increased by one pipe size to provide additional venting capacity. Under intermittent surcharged sewer conditions at infrequent intervals relief may be provided from man hole venting, or increased for each ten living units (at continuous site locations) as discussed in C.5. Also, the incidence of frost closure of vent terminals should be evaluated based on discussions with the Administrative Authority for plumbing and with local plumbing contractors who have had some period of experience in the particular

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[1] For materials subject to corrosion, prudent allowances for gradual diameter reduction would have to be made. Recommendations for such allowances have not been developed.

geographical area. Weather records[2], ASHRAE criteria[3] and other available data[4] may be helpful in estimating the likelihood of frost closure. Vent terminals should probably be enlarged in accordance with the local plumbing code in localities having minimum winter design temperatures of less than 0°F (97-1/2 percent Column of the ASHRAE Criterion for the time during December, January, and February). The critical areas in which frost closure is likely, according to this criterion, are largely in some portions of the Northern Rocky Mountains, upper Midwest and upper New England.

2. Piping Materials and Standard DWV Design Data

Since the RSV design procedures are intended for application to standard plumbing plans and specifications, a set of such plans and specifications acceptable to or approved by the Administrative Authority should be reviewed, together with the applicable plumbing code or portions thereof, as a basis for applying the RSV criteria. Among the types of information that should be obtained from this review are the following:

a) Piping materials and joining methods, specified and alternate materials and methods that may be acceptable as well as any specifications relating to installation procedures.

b) Specific physical arrangements of fixtures and DWV piping, as indicated particularly by plan drawings showing the locations of all plumbing fixtures and by isometric schematics showing the proposed arrangement and sizing of the DWV piping (both wet and dry elements) which is acceptable as standard by the code.

C.4 SIZING PROCEDURE

C.4.1 Activity Sequence and Sizing Criteria

A logical sequence of steps should be employed in modifying standard plans and specifications for the dry vents of sanitary DWV systems. The following sequence is suggested:

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[2] Evaluated Weather Data for Cooling Equipment Design, 1963 and Addendum No. 1 Summer and Winter Data, Fluor Products Company, Santa Rosa, Calif., 1964. Engineering Weather Data, Army, Navy, and Air Force Manual TM 5-785, 1963.

[3] Weather Data and Design Conditions. ASHRAE Handbook of Fundamentals, Chapter 33, Table 1, Climatic Conditions for United States and Canada, American Society of Heating, Refrigerating and Air Conditioning Engineers, 1972.

[4] Part 3, Technical Section. National Plumbing Code Handbook, McGraw Hill, 1957. Frost Closure of Roof Vents. National Bureau of Standards BMS 142, 1954.

1. Obtain preliminary data on site and geographic conditions, piping materials, and specific plans and specifications for a standard DWV design acceptable to or approved by the Administrative Authority (see section C.3). Based on these data, review the general limitations applicable to RSV (see section C.2) before proceeding to step 2.

2. Prepare isometric schematics showing DWV piping arrangements, fixture unit loads and pipe sizes in accordance with the following procedure:

   a) Label each dry vent with a letter designation, and the fixture unit load served according to table C.4.1. Then determine the appropriate classification of each dry vent: (1) individual or common fixture vent, or waste stack vent, (2) soil stack vent, (3) branch vent or vent header, if any, and (4) vent stack, if any.

   b) Label each dry vent with the appropriate size determined in accordance with the following sequence and criteria:

      (i) Fixture and stack vents - table C.4.2.

      (ii) Branch vents, beginning with elements connected to the fixture vents most distant from and proceeding toward the main vent, according to tables C.4.3, C.4.4, and C.4.5.

      (iii) Vent stacks - table C.4.6.

      (iv) Vent headers - size as a branch vent, considering each element connecting to the header as a fixture vent, according to tables C.4.3, C.4.4, and C.4.5.

      (v) Vent terminals - if frost closure is likely in accordance with preliminary data (section C.3), size according to the requirements of the applicable plumbing code.

   c) Label all wet-pipe (drainage) elements with the appropriate standard sizes approved by or acceptable to the Administrative Authority.

C.4.2 Illustrative Examples

Case 1. Assume a two-story townhouse design, figure C.4.1, that has been determined acceptable under the applicable plumbing code. Preliminary investigation reveals that PVC plastic is acceptable for all DWV pipe and fittings, and that sewer surcharging and frost closure is unlikely, based on site conditions, geographical location, and local experience.

To apply the RSV sizing criteria, each dry vent is labeled with a letter designation, and classified and sized as illustrated in table C.4.7. The loads served and the RSV sizes are then transferred to the schematic (figure C.4.2). Both standard and reduced-sizes may be shown here for comparison if desired.

Summarizing, table C.4.7 and figure C.4.2 show the results of the classification and sizing of the dry vents according to the RSV criteria.

Case 2. Assume a one-story slab-on-grade ranch house design, figure C.4.3, that has been determined acceptable under the applicable plumbing code. Other assumptions are as in case 1.

Table C.4.8 and figure C.4.4 show the results of the classification and sizing of the dry vents according to the RSV criteria.

The system shown in figures C.4.3 and C.4.4 requires five roof penetrations for the five vents. A vent header might provide some overall cost reduction and certainly would improve the appearance of the roofline. Table C.4.9 and figure C.4.5 show the results of the application of the RSV criteria (table C.4.3) to the sizing of the vent header.

C.5 INSTALLATION GUIDELINES AND DATA FOR BUILDING OWNER

The plumbing designer should maintain close contact with the installing contractor before and during installation of the DWV system. The designer should explain the special requirements of the reduced-size venting method to the installer, who may be unfamiliar with them. To facilitate understanding by the installer, the designer should review the basic design drawings and specifications with the installer and when necessary to describe the system fully, should provide more detailed drawings. This can enhance the potential economies and level of performance obtainable from RSV installations.

The designer should make regular field inspections to be sure that the design conditions are met. This is particularly important in the event field changes are introduced by the contractor (as is often done for legitimate reasons in typical plumbing work). The designer's early cognizance and review of the plans for field changes is essential to assure conformance of the field changes with the RSV criteria, and to assure that any RSV design changes necessitated by the field piping changes are made in a timely fashion.

The owner should be given copies of the plumbing drawings for permanent record so that any future additions can be properly designed and sized, and that the location of all piping elements and drain cleanouts can be readily determined in the event future maintenance, repairs or remodeling should be required.

Ideally, this coordination between installer and designer should be employed in all plumbing work, not just for RSV. However, plumbing contractors are generally quite familiar with traditional code approved designs, so that the need for close monitoring of the installation process is reduced in comparison with that required for innovative designs.

In relation to installation requirements, the designer and the installing contractor should be familiar with the general limitations given in section C.2, so that compliance will be assured in the field. The following detailed guidelines should be reviewed by both designer and installer.

If single bowl kitchen sinks (or double bowl sinks with separate traps and waste pipes) are equipped with food waste grinders, the shutoff head of the grinder unit, in height of water column, should be ascertained. The sink vent serving the compartment with the grinder should not be reduced in size below an elevation 6 inches (15 centimeters) above the level corresponding to the shutoff head of the unit.

This limitation does not apply to a grinder in a double-bowl sink with a single trap and waste. A similar precaution should be observed in relation to any fixture with a pumped discharge not having a drain air gap or air break. Because most dishwashers and clothes washers are installed with a drain air gap or break, they do not usually pose a potential problem in this respect.

The DWV system design should be reviewed to evaluate the possibility of sewage rising into any of the vents in case of a typical drain blockage occurring anywhere in the system followed by the discharge of fixtures. In most cases, it will be apparent that the rise in a given vent will be limited to the flood rim level of a particular fixture. No portion of a vent at an elevation up to 6 inches (15 cm) above the floor rim level or any higher elevation that could be wetted from such occurrences should be reduced in size.

Since reduced-size vents may not be suitable for the entry of standard drain cleaning tools, care should be taken to assure that drain cleanouts or cleanout equivalents are adequate to assure compliance with the cleanout requirements of the code.

In the selection of fittings for size reduction, the most economical available fitting or combination of fittings should be used. Generally, the fewest number of fittings should be used that will accomplish the necessary size reductions.

Pipe and fittings customarily used in DWV work are not now manufactured in sizes less than 1-1/4 inches. In sizes of 1 inch and less, therefore, it will be necessary to use pipe and fittings manufactured for other applications, such as water supply; for example, type M copper tube, or SDR PR or Schedule 40 PVC plastic pressure pipe. Probably DWV type fittings would be manufactured in these small sizes if RSV design becomes more generally accepted in plumbing codes and were more widely specified.

Care should be taken to follow the recommendations and specifications of the applicable manufacturers for the design, selection and installation of joints and joining materials.

Requirements for pitch and support of reduced-size vent piping are identical to those for standard venting, except that closer support spacing for horizontal runs of the sizes smaller than 1 1/4 in may be required in accordance with the pipe manufacturer's recommendations since standard venting does not recognize nor specify support spacing for such smaller vent sizes.

Vent terminals of 1 inch size and less should be fitted with durable, corrosion resistant, enlarged screen caps of 1/8 to 3/16 inch mesh having an open area at least 150 percent of that of the terminal. Where approved by the Administrative Authority, vents may terminate through a wall or beneath an overhang, provided that the end is turned down and that such terminals are located at least 2 feet above any openable window, door, or ventilation opening within 10 feet horizontally, and are located at least 10 feet horizontally from the property line except for adjacent townhouse units. No vent shall terminate in a wall space, floor-ceiling cavity, or attic.

Vent terminals in frost closure prone localities shall be sized according to the requirements of the applicable plumbing code. However, the preliminary evaluation of the likelihood of frost closure in a particular geographic area (see section C.3) may provide a basis for a waiver on this requirement.

In tract housing, or townhouse rows in which RSV is planned for all the units, a soil stack should extend full size to the atmosphere for each ten living units or fraction thereof exceeding four units connected to the street sewer between sewer manholes. This full size stack should be for the unit furthermost downstream in each ten such units or fraction thereof exceeding four units.

C.6 APPROVAL OF RSV DESIGN

The designer should assemble and organize the information required by the Administrative Authority, using an acceptable or agreed-upon format. The designer should be available to review this information with the Administrative Authority. Generally, this would include drawings and specifications relating to the RSV design. Other data may be requested by the Administrative Authority and the designer should prepare such data as a part of the submittal. If this supplemental data will be required, this fact should be ascertained from the preliminary discussion with the Administrative Authority (section C.3).

C.7 CHRONOLOGICAL BIBLIOGRAPHY ON RSV

1. Minimum Venting for Plumbing Systems. National Bureau of Standards Tech. News Bulletin, May 1966.

2. Performance of Reduced-Size Venting in Residential DWV Systems. NAHB Research Foundation, Inc. Publication LR210-17, 1971.

3. An Investigation of the Adequacy of Performance of Reduced-Size Vents Installed on a Ten-Story Drain, Waste and Vent System. Stevens Institute of Technology Report SIT-DL-73-1708, July, 1973. T. Jackson and T. P. Konen.

4. Studies of Reduced-Size Venting of Sanitary Drainage Systems in the U.S.A. Paper 13, Proceedings of the CIB Commission W62 Symposium On Drainage and Water Supply for Buildings, Stockholm, September 1973. R. S. Wyly and M. J. Orloski.

5. *Laboratory Studies of the Hydraulic Performance of One-Story and Split-Level Residential Plumbing Systems with Reduced-Size Venting*. National Bureau of Standards Building Science Series BSS 49, March 1974. R. S. Wyly, et al.

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8. *The Evolution of the Performance Approach in Plumbing*. NBS Special Publication 473, Proceedings of the First NBS/NCSBCS Joint Conference on Research and Innovation in the Building Regulatory Process, Providence, R. I., September 1976. R. S. Wyly, et al.

9. *Potential Savings from Using Reduced-Size Venting on the United States*. NBS Special Publication 553, Proceedings, CIB Commission W62 Symposium, Washington, September 1976. H. E. Marshall, et al.

10. *All's Well that Vents Well -- Pre-Occupancy Performance of Field Units with Reduced-Size Vents*. Yearbook of the American Society of Sanitary Engineering, 1976. M. J. Orloski.

11. *Economic Aspects of the Installation of Reduced-Size Vents and Various Standard Venting*. Contractor's report to National Bureau of Standards, 1976. George Kauffman.

12. *Cost Savings from Reduced-Size Venting*. Plumbing Engineer, July-August and September/October 1977. Harold E. Marshall, et al.

13. *Reduced Size Venting Design*. Plumbing Engineer, May/June 1978. E. Brownstein.

14. *Performance Criteria and Plumbing System Design*. National Bureau of Standards Technical Note Series TN 966, August 1978. M. J. Orloski and R. S. Wyly.

15. *Reduced-Size Venting Design*. ASPE Data Book, Vol. 1 Fundamentals of Plumbing Design, Section II, Chapter 1, Sanitary Drainage Systems, 1979-80; also Vol. 1, Sec. II, Chapter 17, Vents and Venting, 1983-84, American Society of Plumbing Engineers.

Table C.4.1 Drainage Fixture Unit Load Ratings For Various Plumbing Fixtures[1]

Fixture or Group	Drainage Fixture Units (dfu)
Bathtub with or without shower head	2
Clothes washer standpipe	3
Dishwasher on separate trap	2
Floor drain	2
Kitchen sink only or kitchen sink with food waste grinder	2
Kitchen sink with dishwasher and with or without food waste grinder	3
Laundry tub	2
Lavatory	1
Show stall	2
Water closet	4
Bathroom group	6
Half-bath group	4
Laundry group	4

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[1] These are suggested ratings, subject to change from plumbing code modifications resulting from amendment procedures. It is believed that the RSV criteria will remain valid with modest changes in fixture unit ratings from the values suggested here.

Table C.4.2 Minimum Sizes for Individual and Common Fixture Vents and for Stack Vents

Type of Vent	Water Fall Distance[1] (ft)	Load Served by Vent[2] (dfu)	Vent Size[3] (in)
Individual fixture vent	up to 8	3 and less	1/2
		4	3/4
	over 8 through 18	3 and less	3/4
		4	1
Common fixture vent or waste stack vent	up to 8	3 and less	3/4
		4 through 6	1
	over 8 through 18	6 and less	1
Soil stack vent	up to 8	6 and less	1
		7 through 15	1-1/4
		15 through 30	1-1/2
	over 8 through 18	6 and less	1-1/4
		7 through 15	1-1/2
		16 through 30	2

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[1] The vertical distance the water from the highest fixture (served by the vent) falls before being diverted by the first vented horizontal drain in its path, i.e., a vented horizontal branch drain or the building drain.

[2] Fixture unit loadings for the usual fixtures are given in table C.4.1.

[3] Increase one pipe size over listed value if vent length exceeds 25 ft.

Table C.4.3 Minimum Sizes for Branch Vents[1]

Number of Fixture Vents Served	Rule for Sizing[2]
Two	One pipe size larger than the largest fixture vent served
Three	Usually one pipe size larger than the largest fixture vent served; exceptions requiring a two pipe size increase given in table C.4.4.
Four or more	Compute from the formula:[3] $A_B = \sqrt{A_L} \times \sqrt{\Sigma A_{vs}}$ Where A_B = minimum cross sectional area of branch vent, A_L = area of largest fixture vent served by branch vent, and ΣA_{vs} = sum of areas of all fixture vent served by branch vent. See table C.4.5 for cross sectional areas for various nominal pipe sizes.

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[1] To apply procedure to vent headers, consider each vent connected to header as a fixture vent and size header as a branch vent.

[2] A branch vent need not be larger than would be required by table C.4.6 for a vent stack serving a DWV system with the same total fixture unit loading as the system for which the branch vent is being sized.

Table C.4.4 Combinations of Three Fixture Vent Sizes Requiring a Branch Vent Two Pipe Sizes Larger than Largest Fixture Vent Served by Branch Vent[1]

Sizes of the Three Fixture Vents Served by Branch Vent			Branch Vent Size Required[2]
Largest	Intermediate	Smallest	
in	in	in	in
1	1	1	1-1/2
1-1/4	1	3/4	2
1-1/4	1	1	2
1-1/4	1-1/4	3/4	2
1-1/4	1-1/4	1	2
1-1/4	1-1/4	1-1/4	2
1-1/2	1-1/2	1-1/4	3
1-1/2	1-1/2	1-1/2	3

---

[1] All other likely combinations of three fixture vent sizes require a branch vent one pipe size larger than the largest fixture vent served by branch vent.

[2] A branch vent need not be larger than would be required by table C.4.6 for a vent stack serving a similar DWV system with the same total fixture unit

Table C.4.5 Internal Cross Sectional Areas of Various Nominal Sizes of Pipe

Nominal Diameter	Internal Cross-Sectional Areas[a]		
	Schedule 40 Pipe Metallic or Non-Metallic	Copper Tube	
		Type M	Type DWV
in	in^2	in^2	in^2
1/2	0.304	0.254	
3/4	.533	.517	
1	.864	.874	
1-1/4	1.495		1.317
1-1/2	2.036		1.865
2	3.355		3.272
3	7.393		7.235

---

[a] Areas for other piping materials and wall thicknesses may be obtained or calculated from the respective ASTM Standards or the manufacturers' specifications.

Table C.4.6 **Minimum Sizes and Maximum Lengths for Vent Stacks**

Total Load on Soil or Waste Stack Served by Vent Stack (dfu)	Length of Vent Stack (ft)	Minimum size of[1] Vent Stack Size (in)
10 and less	36 and less	1-1/4
10 and less	37 or more	1-1/2
11 through 30	30 and less	1-1/4
11 through 30	31 or more	1-1/2

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[1] Increase one pipe size if frequent flooded sewer conditions are anticipated.

Table C.4.7 Classification and Sizing of Dry Vents (Figure C.4.2, Example 1)

Letter Designation	Vent Classification	Applicable RSV Criterion	Fixture Unit Load Served	Wall Fall Distance (ft)	Std. Size (in)	RSV Size (in)	Reduction (Pipe Sizes)
A	Waste stack vent	Table C.4.2	3	2	1-1/2	3/4	3
B	Individual vent	Table C.4.2	1	2	1-1/4	1/2	3
C	Individual vent	Table C.4.2	2	2	1-1/2	1/2	4
D	Individual vent	Table C.4.2	2	0	1-1/2	1/2	4
E	Individual vent	Table C.4.2	2	1	1-1/2	1/2	4
F	Individual vent	Table C.4.2	2	1	1-1/2	1/2	4
G	Individual vent	Table C.4.2	1	2	1-1/2	1/2	4
H	Soil stack vent	Table C.4.2	20	10	3	2	1
I	Branch vent	Table C.4.3	NA	NA	1-1/2	3/4	3
J	Branch vent	Table C.4.3	NA	NA	1-1/2	3/4	3
K	Branch vent	Table C.4.3	NA	NA	1-1/2	3/4	3
L	Vent stack	Table C.4.6	23	NA	2	1-1/4	2

Table C.4.8 Classification and Sizing of Dry Vents (Figure C.4.4, Example 2)

Letter Designation	Vent Classification	Applicable RSV Criterion	Fixture Unit Load Served	Water Fall Distance (ft)	Std. Size (in)	RSV Size (in)	Reduction (Pipe Sizes)
A	Individual vent	Table C.4.2	2	1	1-1/2	1/2	4
B	Soil Stack vent	Table C.4.2	8	2	2	1-1/4	2
C	Individual vent	Table C.4.2	2	1	1-1/2	1/2	4
D	Individual vent	Table C.4.2	2	0	1-1/2	1/2	4
E	Individual vent	Table C.4.2	2	2	1-1/2	1/2	4
F	Individual vent	Table C.4.2	3	2	1-1/2	1/2	4

Table C.4.9 Sizing of Vent Headers[a] (Figure C.4.5, Example 2)

Header Element	Fixture Vents Served	A_L (in^2)	ΣA_{VS} (in^2)	A_B (in^2)	Nominal Diameter Required (in)
G	E, F	0.254	0.508	0.358	3/4
H	D, E, F	.254	.762	.438	3/4
I	A, D, E, F	.254	1.016	.509	3/4
B	A, C, D, E, F	.254	1.270	.570	1[b]

[a] Using rule for branch vents, table C.4.3.

[b] Element B was previously sized 1-1/4 in as a soil stack vent, so will not be reduced below 1-1/4 in.

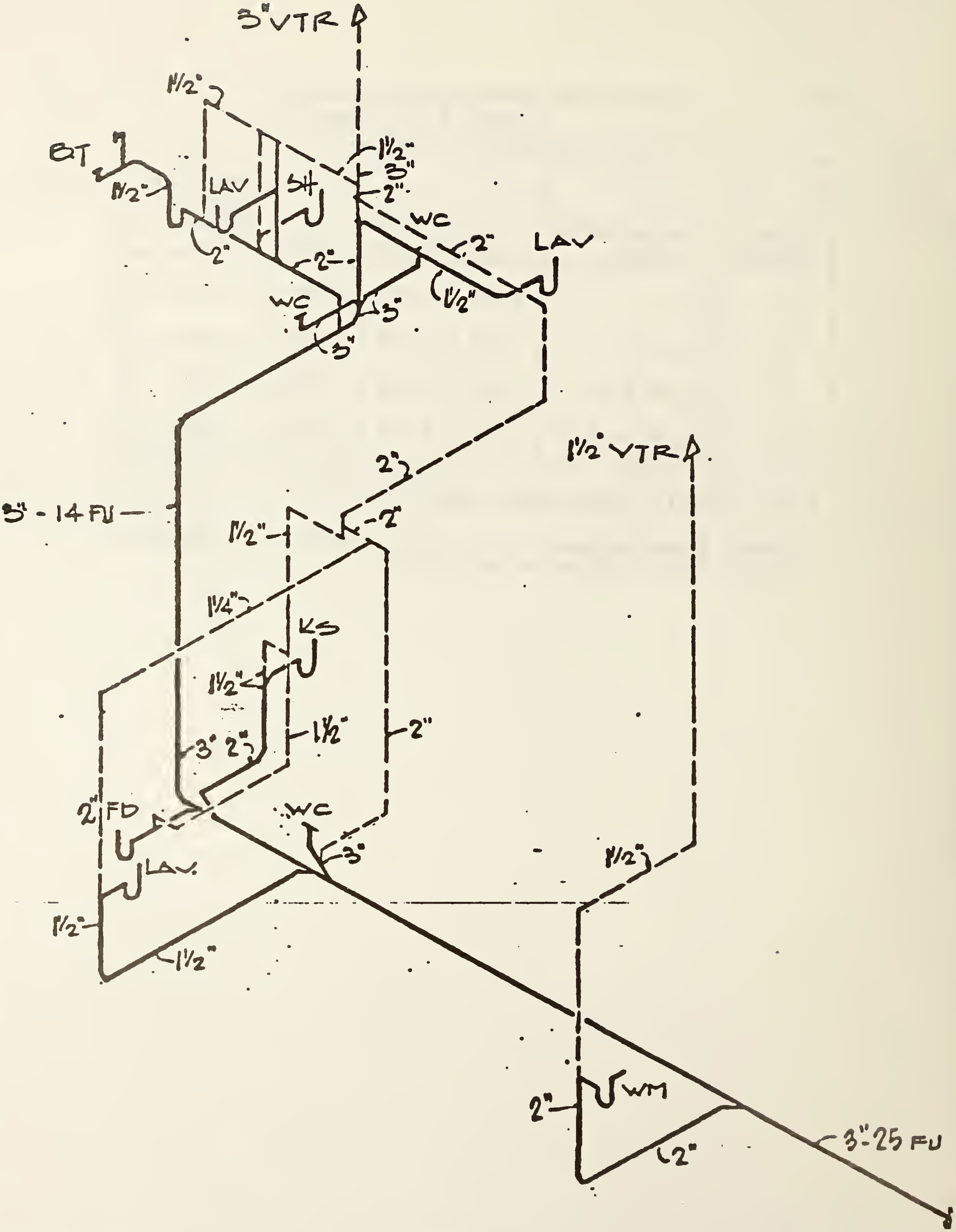

Figure C.4.1 Soil-waste-vent piping for 2-story single family townhouse, showing a standard DWV design conforming to the applicable plumbing code (compare with figure C.4.2 for RSV)

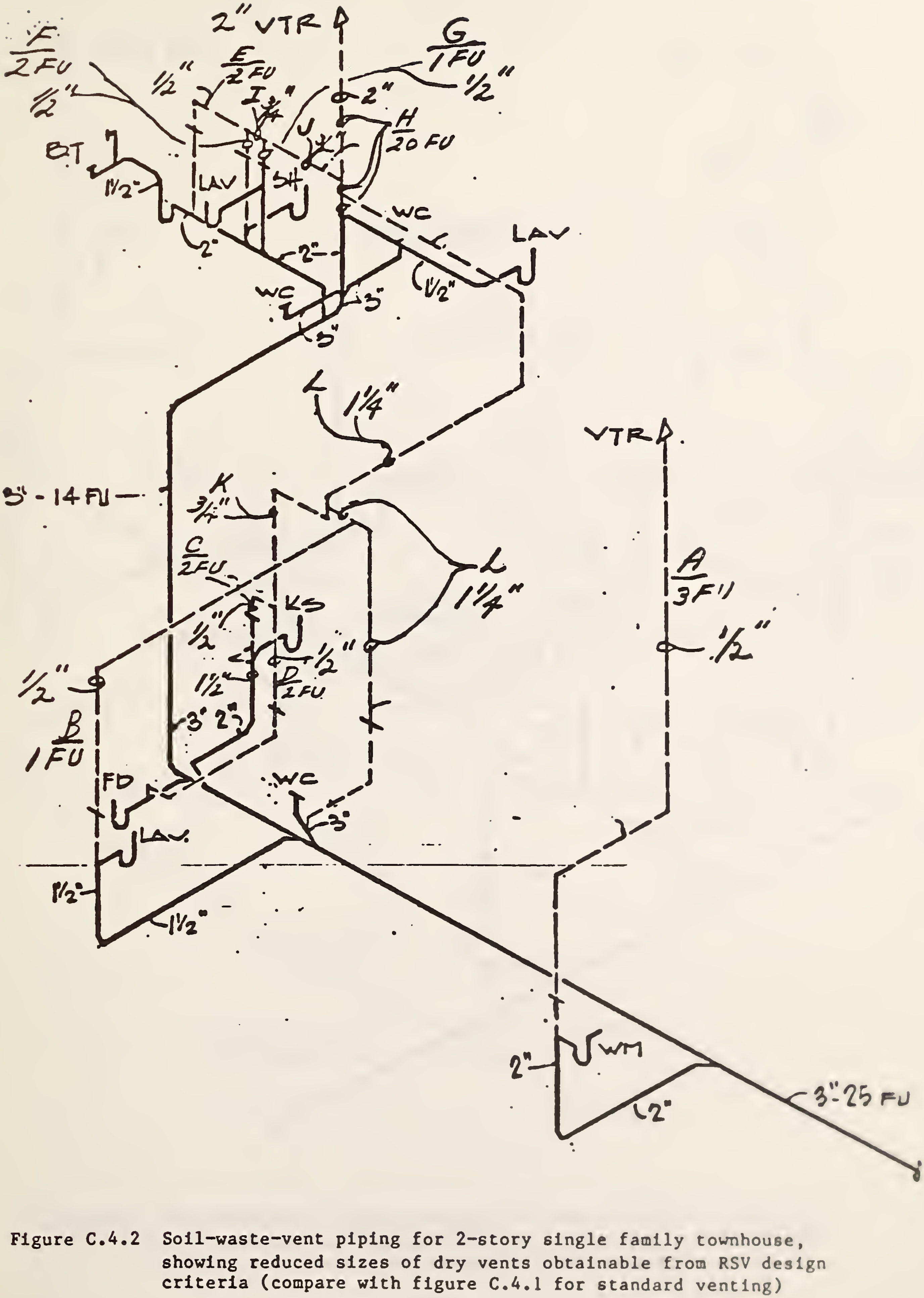

Figure C.4.2 Soil-waste-vent piping for 2-story single family townhouse, showing reduced sizes of dry vents obtainable from RSV design criteria (compare with figure C.4.1 for standard venting)

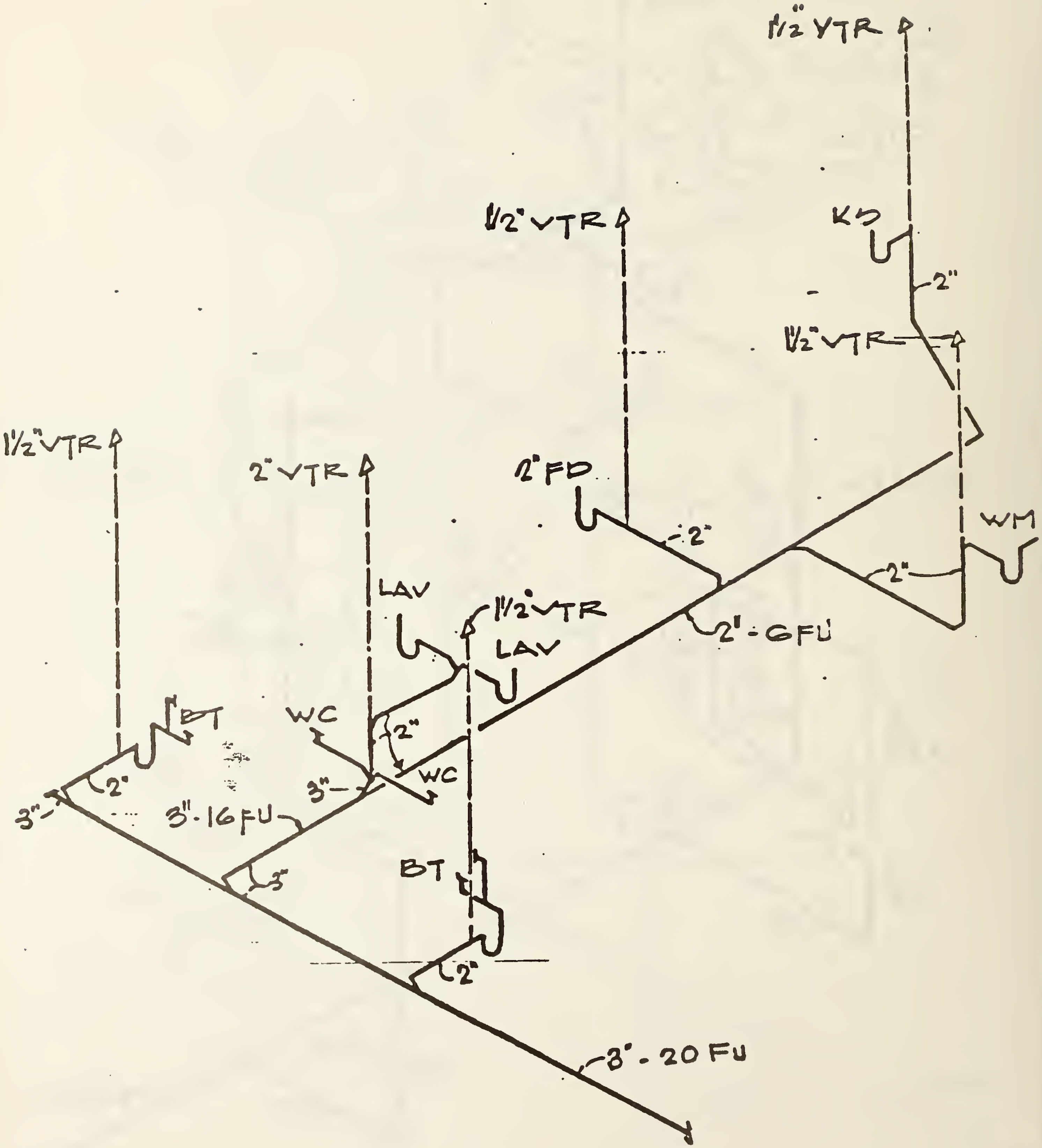

Figure C.4.3 Soil-waste-vent piping for 1-story single family residence, showing a standard DWV design conforming to the applicable plumbing code (compare with figure C.4.4 for RSV)

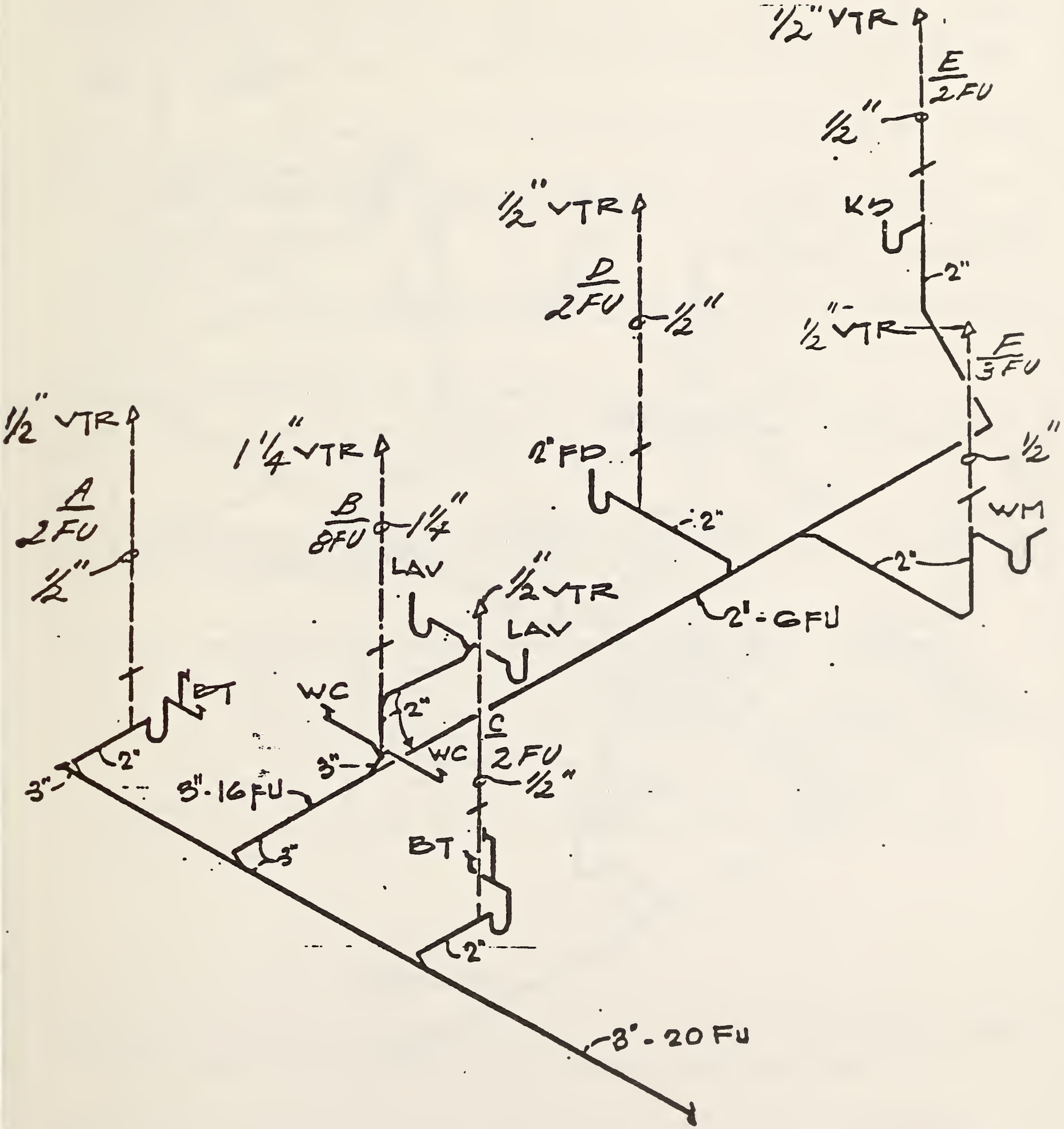

Figure C.4.4 Soil-waste-vent piping for 1-story single family residence, showing reduced sizes of dry vents obtainable from RSV design criteria (compare with figure C.4.3 for standard venting)

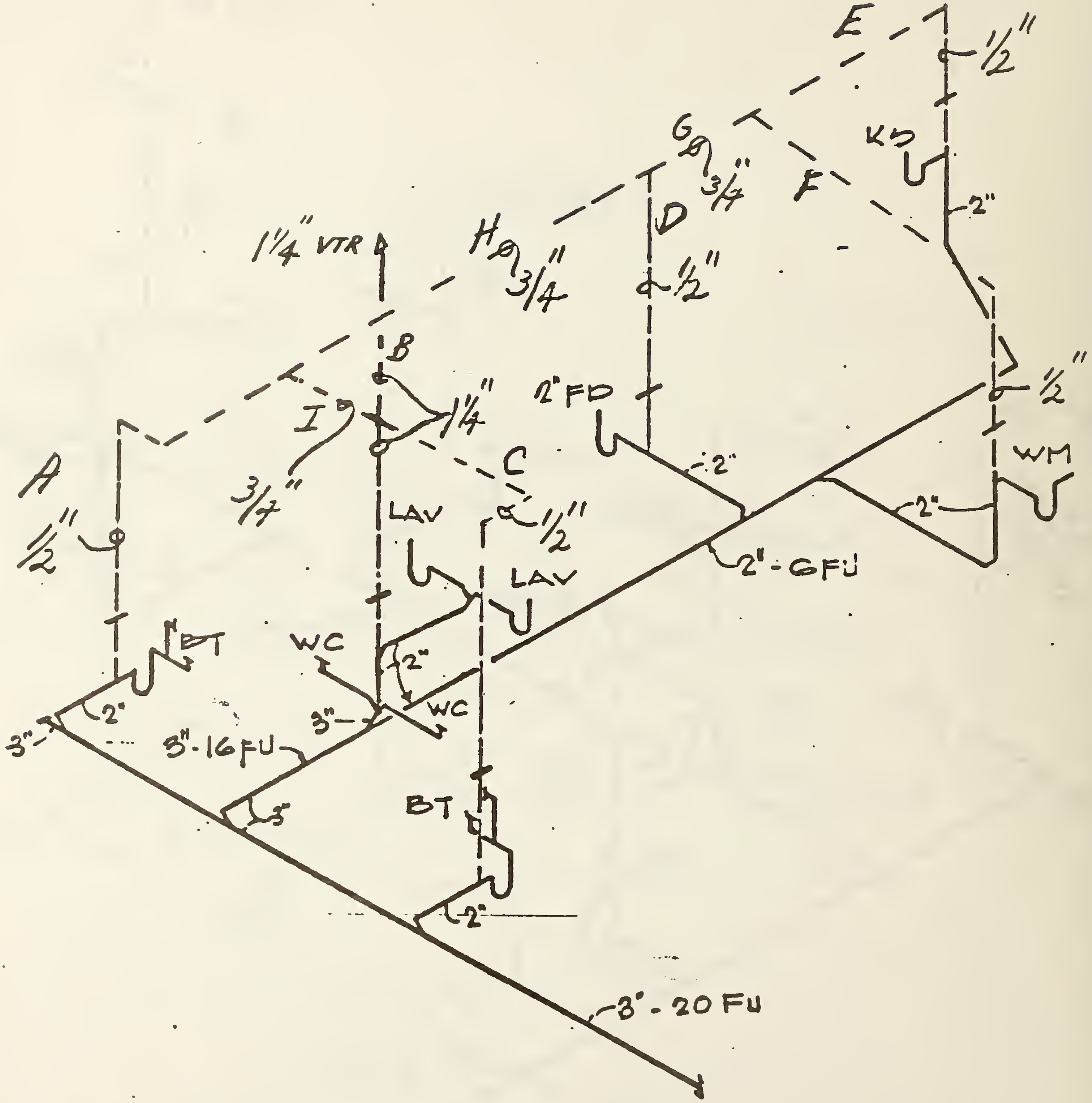

Figure C.4.5 Soil-waste-vent piping for 1-story single family residence, showing the use of a vent header to reduce the number of roof penetrations (compare with figures C.4.3 and C.4.4 showing five penetrations)

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This report describes hydraulic tests of drain-waste-vent systems with reduced-size vents installed in single-family housing units at Andrews Air Force Base, Camp Springs, Maryland. The vent systems of six field units were sized according to a procedure based on findings in prior laboratory investigations. The tests reported were conducted on three of the units before occupancy. Principal measurements made were trap-seal reduction and pneumatic pressure excursions in selected vents, using test procedures developed in the laboratory and adapted to field conditions. Results of the preoccupancy tests showed adequate performance with the reduced-size vents. A procedure for the design of reduced-size vent systems is presented that should be of interest to plumbing designers and groups engaged in updating plumbing codes.

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

plumbing; reduced size vents; residential plumbing; vent-system; vents

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