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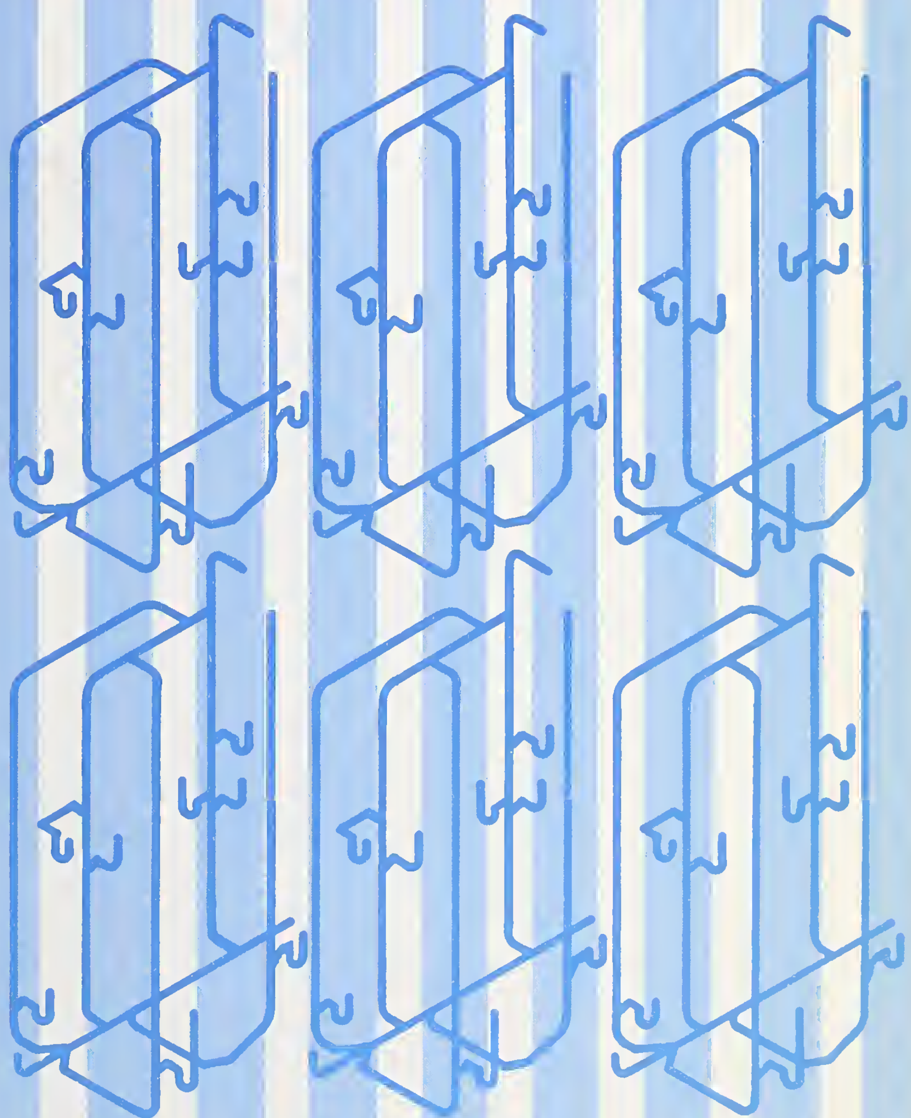
HYDRAULIC PERFORMANCE of a FULL-SCALE TOWNHOUSE DRAIN-WASTE-VENT SYSTEM with REDUCED-SIZE VENTS



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Hydraulic Performance of a Full-Scale Townhouse Drain- Waste- Vent System With Reduced-Size Vents

NBS Building Science Series

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Foreword

Housing research has been a major concern at NBS since its establishment in the early 1900's. Today, our modern research facilities include a plumbing laboratory that provides both great flexibility of measurement and a basis for improving the evaluation methodology in this field.

For example, recent measurements made with this facility have related the present design criteria for vent sizing to performance criteria for the first time under representative dynamic conditions. This work has shown that in many cases plumbing vents of reduced size perform quite well, providing a basis for resource conservation by use of smaller vent pipes. Such information will be useful to regulatory authorities when considering code changes, and to the plumbing engineering profession.

Ernest Ambler, *Acting Director*

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*Degrees of vent restriction were not necessarily the same (setting of the butterfly valve) in tables 4–8.

Hydraulic Performance of a Full-Scale Townhouse Drain-Waste-Vent System With Reduced-Size Vents**

M. J. Orloski and R. S. Wyly

This report describes the experimental findings of tests on a full-scale two-story plumbing system with reduced-size vents under a range of operating conditions including tests with the vent terminals closed and the building drain submerged. Results indicate that dry vent piping in 1–2 story housing units can safely be smaller than presently allowed by design without jeopardizing the trap seals. On the basis of the current investigation and from earlier work on full-scale systems of substantially different geometry, criteria for sizing reduced-size vents are given for general application to conventional 1–2 story housing units. In addition to the practical evidence in terms of acceptable trap performance, the current study provided fundamental evidence of the excessive present design criteria. For the first time measurements were obtained which relate traditional design criteria (air flow and vent pressure) to presently recommended performance criteria (trap-seal retention) under dynamic conditions. These findings indicate that the vents can be sized on the basis of 1.5 in water gage (equals 372.2 pascals) suction in the vent rather than the 1.0 in W.G. (equals 248.8 Pa) presently specified in the plumbing codes. Also air demands measured were significantly less than assumed in current practice for short stacks and for systems with vent networks.

Key words: DWV; performance testing; reduced-size vents; trap-seal retention; venting; venting criteria; vents, reduced size.

1. Introduction

1.1. General

Gravity sanitary drain-waste-vent (DWV)[1] systems in buildings utilize water-filled traps to prevent sewer gas, fumes, or foul odors from escaping into occupied spaces. Venting of the traps prevents the hydraulic action of the discharging fixtures from generating pneumatic pressures that would either cause excessive reductions of the trap seals or that would produce ejection of waste water, suds, etc., into idle fixtures. Optimum vent length or diameter (one of these must be assumed to find the other) is computed by means of an equation relating air demand, vent pressure excursion, and a material-dependent roughness factor [1].[2] Vent sizing tables in current plumbing codes are based on this computation.

Air demand estimates which are utilized for sizing main vents in the current plumbing codes are based on limited data from studies of components of plumbing systems. For example, National Bureau of Standards Monograph 31 [1] presents data for air flow in simple stacks of multi-story height with the water all being introduced at the top in most of the tests. Also, air demand estimates drawn from these data were based on the simplified assumption that air and water fall down a stack at the same mean velocity, and did not adequately account for reduced air demand rates at vent pressures below atmospheric or for air circulation in a typical vent network as a source of air for venting. Moreover, because of the absence of adequate data or mathematical models for venting systems, branch vents of a vent network and individual vents have been traditionally sized by rule-of-thumb with respect to air demand.

In the case of vent pressure excursion, a 1-in W.G. (248.8 Pa) [3] value has been specified over the years in plumbing codes as the value to be used in the design computation [2]. Under service conditions however, a 1-in reduction in trap seal of a trap with a full-seal depth of 2-in has traditionally been considered the basic criterion of performance [3, 4]. In other words, limiting the maximum pressure excursion in the vent by *design* is intended to assure that in actual *performance* no trap seal will be reduced by more than 50 percent of its full depth from representative fixture operation and from evaporation. It is widely believed that the design criterion of 1-in W.G. pressure excursion (along with the conservatively determined air demands described in the preceding paragraph) results in vent pipe sizes larger than needed for 50 percent trap-seal retention. However, the relationship between air demand rate, vent pressure excursion, and trap-seal reduction has not previously been demonstrated by laboratory studies of full-scale systems under representative dynamic conditions.

**This study is one element of a current program on RSV supported by the Tri-Services Investigational Committee on Building Materials of the Department of Defense, and by the Directorate of Civil Engineering, HQUSAF.

[1] Definitions, acronyms, and symbols used in this paper e.g. additives, pascal, *dH*, P-traps are given in appendix E.

[2] Figures in brackets indicate literature references on page 29

[3] U.S. customary units are used throughout this paper since these are the units most frequently used in plumbing design work in the U.S. Conversions to SI units can be found in appendix C.

1.2 Background of Present Study

In the mid 1960's, a laboratory investigation of reduced-size vents, conducted under joint sponsorship of the National Association of Home Builders (NAHB) and NBS, was carried out on two full-scale systems (one a slab-on-grade and the other a split-level having three levels) and several partial DWV systems [5]. The principal measurement on the full-scale systems was trap-seal retention. Principal measurements in tests on the partial DWV system were peak air flow rate and the corresponding pneumatic pressure in the vent.

The data from the partial systems showed air demand rate to be affected by the (water) fall distance and by small deviation of the vent pressure from atmospheric (within the 1-in W.G. specified in the codes) [6]. Air demand rate in a test stack with a fall distance of about 3½ ft was significantly less than that from a stack with a fall distance of 20 ft, which in turn was less than that predicted by NBS Monograph 31 for tall stacks (having a fall distance of 30–40 ft). In addition, a significant finding was that a slight reduction from atmospheric pressure substantially reduced the air demand in short stacks (fall distance up to 20 ft) such as those tested. These findings from tests on partial DWV systems helped to explain the surprisingly good performance of full-scale DWV systems with reduced-size vents (RSV). They were tested in the NBS laboratory and in a field test program subsequently carried out by NAHB involving DWV systems of 10 single-family housing units.

The NBS–NAHB investigation provided an empirical basis for broadening the vent-sizing criteria to include individual and branch vents, and a distinction between 1–2 story systems. As a result of these findings, in 1970 NAHB proposed to the three model code bodies, Building Officials Conference of America (BOCA), International Association of Plumbing and Mechanical Officials (IAPMO), and the Southern Building Code Congress (SBCC), to allow RSV in 1–2 story houses, and offered the sizing table developed from the laboratory tests at NBS [5]. For several years, these regulatory groups have been studying proposals to incorporate provisions on reduced-size venting in the codes. Some of the groups have indicated that they need further research data, particularly with respect to the details of the experimentation, and to the consideration given to some of the service parameters not adequately covered in the early work.

This need provided a basis for the present study. The purpose of the present study is to confirm and expand the RSV criteria developed in the earlier study with primary emphasis on their applicability to 1–2 story housing systems under service conditions. The current overall program, supported by Tri-Services, includes a comprehensive analysis of the early data, published separately [7], as well as laboratory tests on the system described in this report, and on a 10-story high-rise RSV system reported separately [8].

The current program is one interim step towards the long-range goal for development and application of a general computational method to the design of plumbing systems. The continuing work on venting criteria represents one portion of NBS's broad long-range program on hydraulic design criteria, intended to furnish a mathematical model on which the general computational method for venting could ultimately be based.

1.3. Objective, Approach, and Scope

The present laboratory investigation, utilizing new capability for dynamic measurement and incorporating new tests believed representative of the service environment, is an extension of the earlier laboratory work at NBS on 1–2 story RSV systems. The primary objectives in the current laboratory study were twofold. The first was to provide the sponsor with needed data regarding the practicability of building 1–2 story RSV systems, and the second to study the performance characteristics of the system in terms of the test conditions and measurable parameters, particularly at failure (1-in trap-seal reduction in any trap). These objectives were also important to confirm and expand the criteria developed earlier, from systems of very different geometric configuration, for general application to 1–2 story housing units. For these reasons, the tests selected covered a wide range of operating conditions, from normal to severe loadings, including some tests with the vent terminals closed and a few tests with the building drain submerged. (Tests with the building drain submerged and an adequate range of tests with additives were not included in the NBS–NAHB program.)

In gravity drainage systems with water-sealed traps, satisfactory trap-seal retention and unretarded fixture drainage along with the absence of blowback and crossflow are the fundamental measures of performance. Recently acoustical criteria have been proposed as an addititional consideration [9]. The experimental approach in this investigation was to evaluate the performance of the full-scale system principally on the basis of trap-seal retention. Audiovisual observations for blowback and fixture operation, particularly air aspiration through idle traps, were made in a number of instances. Due to the geometry of the full-scale system, crossflow and retarded fixture drainage were not considered likely. (Flow from only one branch interval was introduced on any one stack and individual fixture drains were neither back-to-back nor joined together.)

A secondary objective of the present investigation was to compare the present design criteria (1-in W.G. pressure excursion and air flow rates predicted in Monograph 31) with the fundamental criterion of performance intended in service (minimum 50% trap-seal retention) by means of an in-depth study of a simple one-stack system. The earlier work [7] examined air demand rate and vent suction in some of the tests and trap-seal retention in other tests. However, a better understanding of the simultaneous dynamie relationship between the three parameters: air flow rate, vent suction, and trap-seal retention is an important aspect of the development of a rational basis for a general computational method for venting.

In the present study, dynamic measurements of air demand and vent pressure were made on a selective basis in the full-seale system and for all the work on the eomponent system. Key to the capability for making a wide range of dynamic air demand and vent pressure measurements was the programmable data acquisition system (DAS). The DAS can average readings of rapidly changing phenomena for a preselected time period and report one value, presently for up to 64 channels simultaneously. This system is an integral part of the NBS facility and replaeed the need for manual examination and interpretation of dynamic curves for eaeh measurement made—a very time eonsuming process. The data are stored on magnetic tape, indexed, and can be systematically retrieved by means of a data analysis program.

2. Plan of Experimental Work

The simple one-staek system was studied first; then the tests on the full-scale two-story DWV system were carried out. A list of instruments used and their utilization in the experimental work is given in table 1. An averaging period of 0.2 s (for the DAS) was seleeted for transducers measuring air flow rate and pneumatic pressure in all tests, based on a calculation (given in Appendix D) of ¼ the frequency

TABLE 1. *Instruments and utilization in full-scale townhouse (TH) system and/or component stack (CS)*

Utilization	Instrument description	Range or size of instrument	Engineering variable resolution of system [a]
Air flow rate in stack vent, CS	Mass flowmeter hot wire type	2.3 lb/min full scale	0.23 gpm.
Vent pressure, CS	Strain-gage, bidirectional, wet-dry transducer (gage).	+5 to −5 in W.G	0.01 in W.G.
Pressure drop across Venturi in water supply line, CS.	Strain-gage, bidirectional wet-wet transducer (differential).	+5 to −5 in W.G	0.1 in W.G.
Water supply flow rate CS	Venturi	1½ in, β=563	1–3 gpm.
Trap reduction, CS	Strain-gage, unidirectional wet-dry transducer (gage).	0 to +5 in W.G	0.01 in.
Spent water weight, CS, and calibration of fixtures, CS.	Load cell, strain-gage type with indicator.	(four) 500-lbf capacity	5 lbf.[b]
Air flow rate in main vent terminal, TH.	Venturi	1½ in, β=427	1–3 gpm.
Air flow rate in sink vent terminal, TH.	Loop centrifugal meter, air	1 in, β=698	1–3 gpm.
Pressure drop across Venturi in main vent terminal, TH. Pressure drop across loop meter in sink vent terminal, TH. Vent pressure except sink vent, TH.	Variable-range capacitance-type transducers bidirectional dry-dry (differential/gage). (Four ranges used)	Range 1, ±0.5 in W.G Range 2, ±1.6 in W.G Range 3, ±5.3 in W.G Range 4, ±16.05 in W.G	0.00005 in W.G. 0.00016 in W.G. 0.0005 in W.G. 0.0016 in W.G.
Vent pressure, sink vent, TH Building drain water depth, TH.	Strain-gage, bidirectional wet-dry transducer (gage).	+5 to −5 in W.G	0.01 in.
Trap seal reduction, TH	Piezometers for L1, B1, L2, S3, C4, L5.	6 in	1/16 in.
Trap seal reduction, TH	Rulers for W1, W2, W5	12 in	1/16 in.
Transducer calibration, CS and TH.	Water manometer (6½ in diam.) with Digital voltmeter	±10 in W.G 10 V	0.001 in W.G. 0.001 V.

[a] "System" includes computer if computer was used.
[b] Amplified transducer output would improve resolution by computer. The resolution of the indicator, which was used to calibrate the fixtures, was 0.1 lbf.

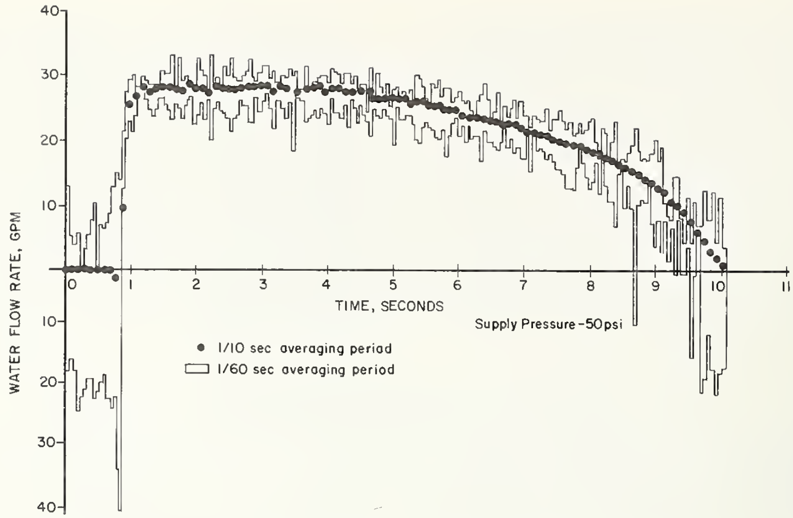


FIGURE 1. *Example of averaging period selections for water flow rate through a flushometer valve to show data smoothing.*

of "slosh" in a trap. An example of the data smoothing achieved by selection of a suitable averaging period is shown in figure 1. Smoothing the data to some degree permits meaningful comparison of maximum and minimum values (which can systematically be retrieved from the magnetic tape by means of an analysis program).

Strictly interpreted, a 50 percent trap-seal reduction varies from 1 in for 2-in-depth seals of P-traps, found on fixtures such as lavatories, to 1½ in for 3-in-depth seals, characteristic of water closets. In the present investigation, a 1-in reduction in the depth of any trap was assumed a failure for the experimental work on both systems.

The simple one-stack system, or component stack, designed for this study consisted of an 18-ft length of 3-in PVC with two back-to-back flushometer type water closets at the top, as shown in figure 2. Both water closets were calibrated before the tests to deliver 4 gal per flush in accordance with Federal Specification WW–P–541b [10].

For the experimental work on the component stack, measurements taken on pneumatic pressure in the vent stack, air flow rate, water flow rate, and trap-seal reduction were made by means of the programmable DAS. The computer flushed the water closet(s) by means of a solenoid actuator immediately after a start value ("zero") was recorded by the DAS for all the transducers. Measurement locations on the simple system are shown in figure 2.

A strain-gage type pressure transducer was used to sense the pneumatic pressure in the stack vent. Trap-seal reduction measurements were made by means of strain-gage pressure transducers (tapped into the bottom of the trapways to measure the head of water). Water flow rate was measured by means of differential strain-gage type pressure transducers used in conjunction with 1½-in Venturi meters in the water supply lines. An air mass flowmeter was located at the top of the stack vent. By means of different settings, a butterfly valve in the vent was

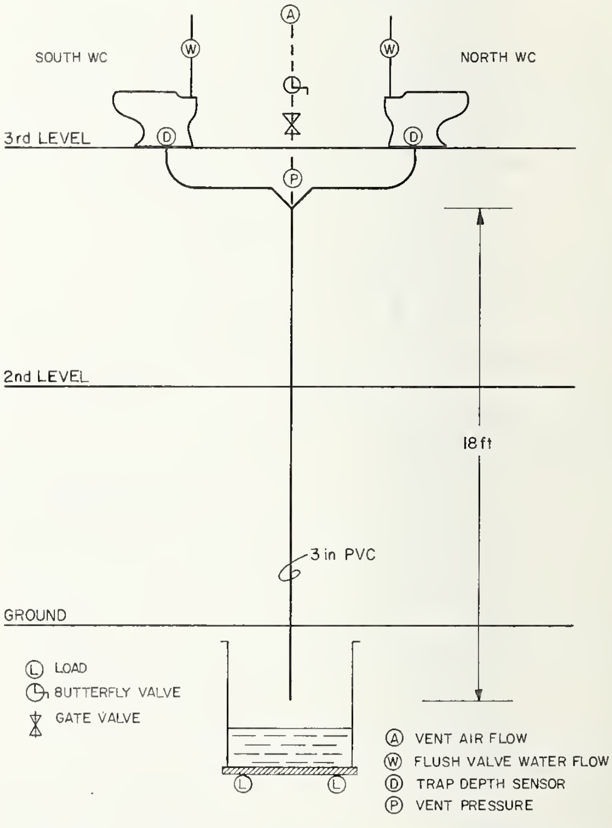


FIGURE 2. *Component stack schematic showing locations and types of measurements. (See Section 2 for discussion of the instrumentation.)*

used to simulate varying air demand/restriction of different sizes of vent pipes. Load cells situated under the tank, where the spent water was collected, were used to monitor the weight of water in the tank which was periodically emptied, and to check that the volume (by weight) of water delivered from each flush was close to the 4 gal per water closet determined by the calibration.

The full-scale townhouse system constructed in the laboratory was selected from several family housing plans submitted by the sponsor. The system had nine fixtures distributed among: one full bath, two half baths, a kitchen equipped with a two-compartment sink (food-waste-disposal-unit in one compartment), and a laundry area equipped with an automatic clothes washer. The system had five drainage stacks with four tied together in a common vent header. The fifth stack (kitchen sink) was vented individually. Discharge characteristics of the fixtures in the townhouse system are given in table 2.

TABLE 2. *Discharge characteristics of the fixtures in the townhouse system (4-run average)*

Fixture	Volume discharged	Duration of discharge	Average discharge rate
	(gal)	*(s)*	*(gpm)*
B1	22.2	158	8.4
L1	1.6	12	7.9
W1 [a]	4.5	11	24.6
L2	1.6	12	7.7
W2 [a]	4.5	11	24.6
S3 w/fwdu operating	3.6	6	35.5
C4	14.8	53	16.9
L5	1.6	12	7.9
W5 [a]	4.5	11	24.6

[a] From a calibration of the same model tank/type water closet. 1-s peak rate=32 gpm.

The building drain was turned 90 degrees from the original design, as shown in figure 3, to permit the system to fit into the laboratory. The sizes of the vents in the original design are shown in figure 4. The reduced-size vents were sized according to the criteria from the earlier study [7]. The vent header was sized by an arbitrary square root relationship (see appendix A). A schematic of the townhouse system as constructed in the laboratory is shown in figure 5.

The townhouse system was instrumented with transducers compatible (putting out a voltage between ±10V dc to the computer) with the DAS for measurement of vent pressure in the stacks, air flow in the main terminal and the sink vent terminal, and the depth (static head) of the water in the building drain. Measurement locations in the townhouse system are shown in figure 6. Three variable-capacitance type pressure transducers were used for

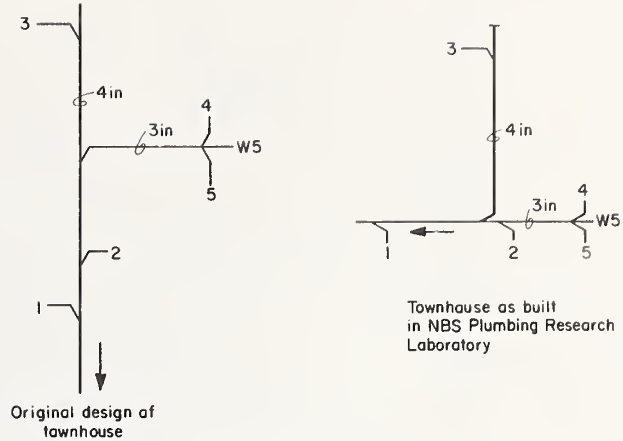
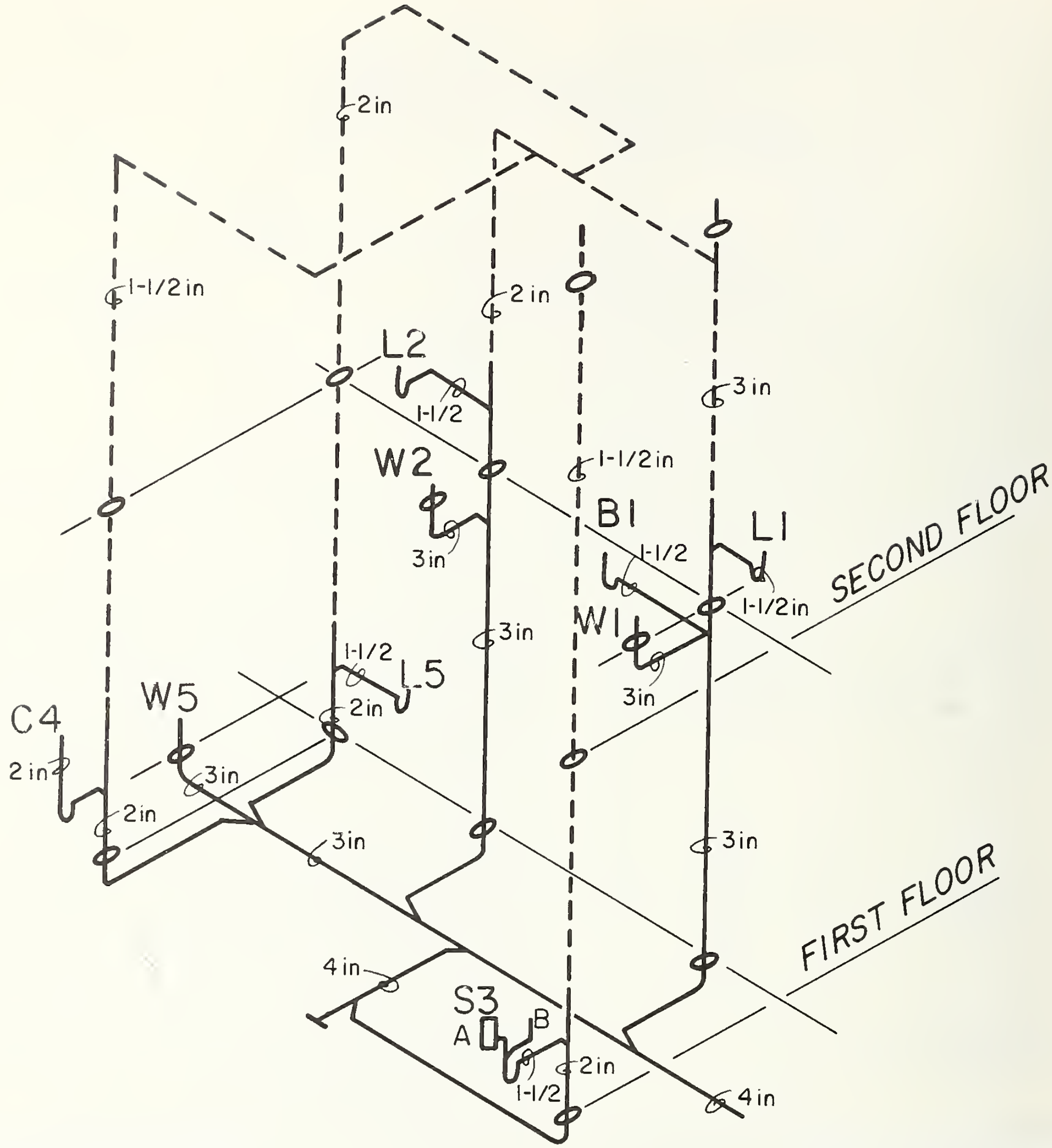


FIGURE 3. *Plan view of stack connections (by stack number designation) to building drain of townhouse system.*

measurement of vent pressure in four of the five stacks: one each for stacks 1 and 2 separately, and the third for stacks 4 and 5 together. In each case, the pressure to be measured, as shown in figure 6, was selected by means of a manifold with valve-select pneumatic connections to the stack. A strain-gage type transducer was used to sense the pressure in stack 3. Air flow rates in the main vent terminal and in the sink vent terminal were each measured by means of a variable-capacitance type pressure transducer. In the main vent terminal, a 1½-in Venturi meter was used as the differential-pressure sensing element; in the sink vent terminal, a ½-in loop (centrifugal) meter was used as the differential-pressure sensing element. The depth of the building drain flow was monitored by means of a strain-gage type transducer (one side tapped into the bottom of the drain to sense the head of water and the other side tapped into the top to sense the air pressure). The traps of all the fixtures except the water closets were equipped with piezometers connected to (the cleanout plugs of) the P-traps equipped with scales graduated in the U.S. customary and SI units. Rulers graduated in U.S. customary units were installed in the traps of idle water closets before a test. For all runs, fixtures were discharged manually at a verbal signal given immediately after a run was initiated on the DAS. Trap-seal depths were read manually at the end of a run.

The fixture-discharge loads for the townhouse tests were based on guidelines recommended for single-branch-interval systems, using table 1A of BSS 41 [11]. Reasons for selection of the test loads are summarized briefly in table 3. For the experimental work described in subsequent sections of this report, a "test" was defined to consist of four successive runs under conditions as identical as possible. Additives (e.g. paper diapers, bubble bath) used in some of the tests on the townhouse, were introduced on the first and third runs of a test.



SECOND FLOOR FIXTURES
↓—— STACK NUMBER
B1 BATHTUB
L1 LAVATORY
W1 WATER CLOSET
L2 LAVATORY
W2 WATER CLOSET

FIRST FLOOR FIXTURES
↓—— STACK NUMBER
S3 SINK (A AND B COMPARTMENTS)
C4 CLOTHES WASHING MACHINE
L5 LAVATORY
W5 WATER CLOSET

FIGURE 4. *Standard vent sizes originally specified for townhouse before vent size reductions.*

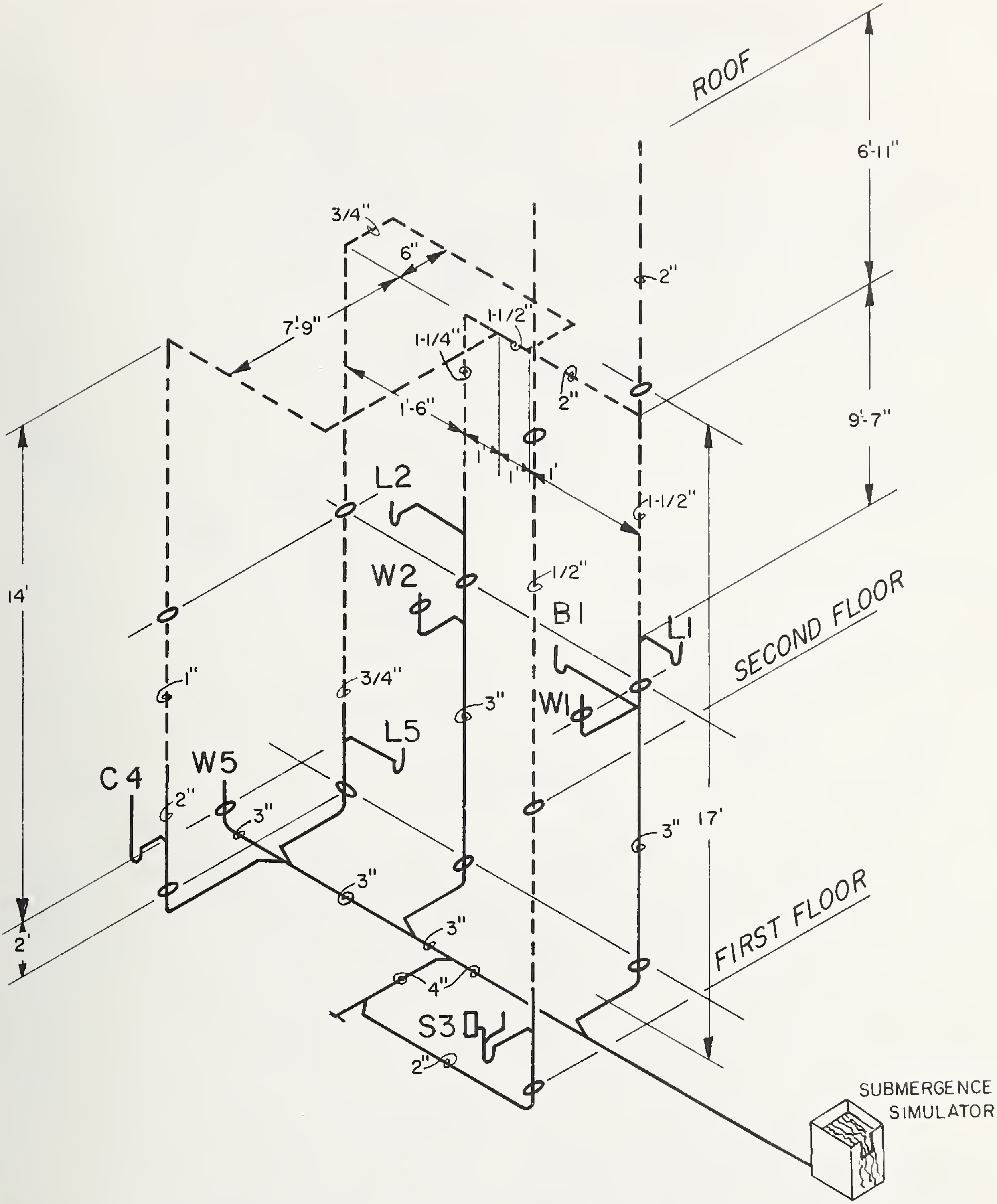
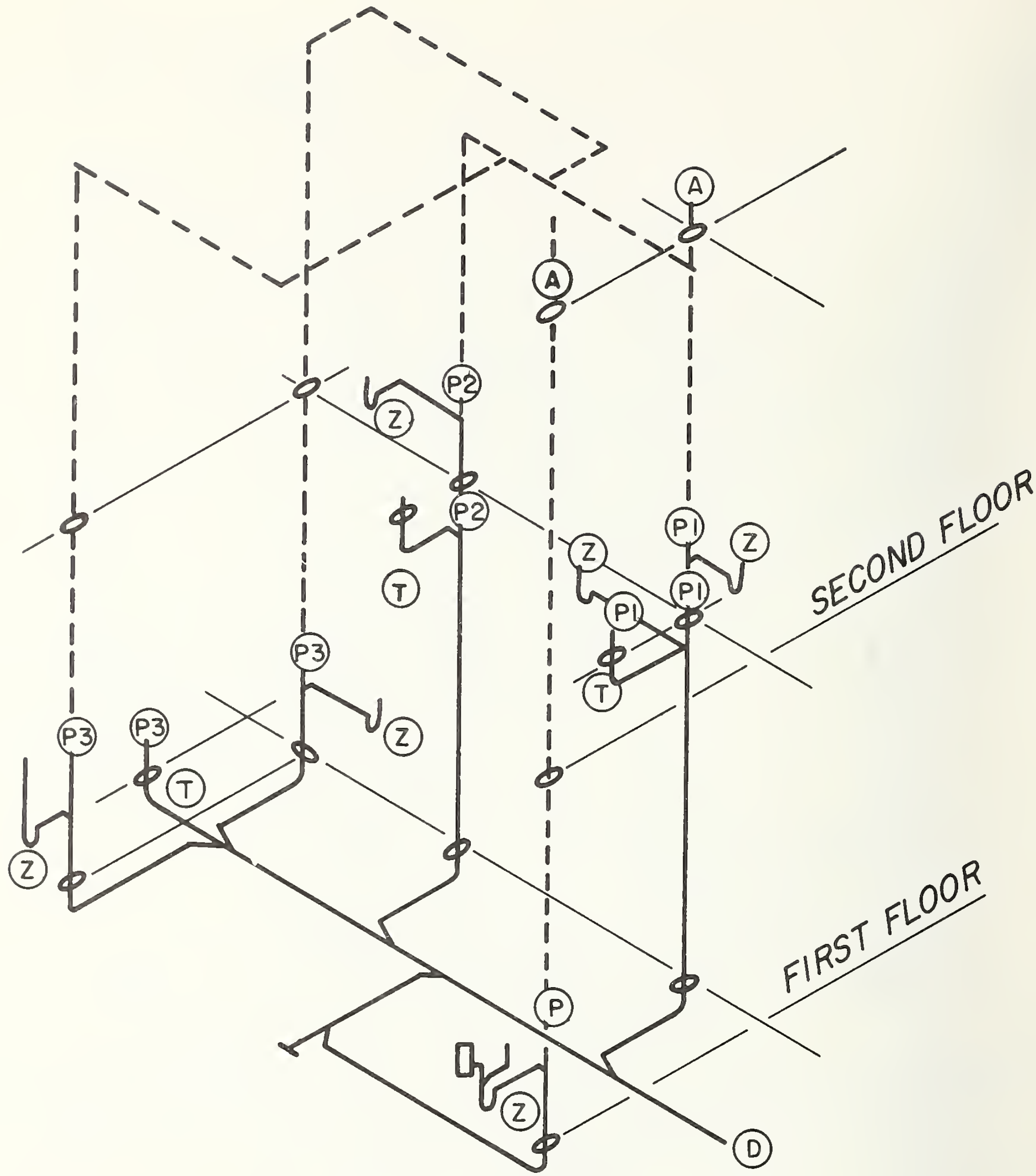


Figure 5. *Schematic showing townhouse system as built in NBS Plumbing Research Laboratory, with reduced-size vents.*



(A) AIR FLOW

(P) VENT PRESSURE (P1, P2, P3, VALVE SELECT)

(D) DRAIN DEPTH MONITOR

(T) TRAP RULER

(Z) PIEZOMETER

FIGURE 6. *Townhouse schematic showing locations and types of measurements. (See section 2 for discussion of the instrumentation.)*

TABLE 3. *Principal rationale for selection of test loads in townhouse system*

Stacks considered (by number designation)	Total fixtures available to discharge	Number of concurrently operating fixtures to comprise test load [a]	Fixture load selected	Principal rationale
3	1	1	S3	To examine self-siphonage and pneumatic effects.
2	2	1 (or 2)	W2 (second floor)	To examine effect of height of water fall.
5	2	1 (or 2)	W5 (first floor)	To examine effect of height of water fall.
1	3	2	W1+B1 W1+L1 B1+L1	To observe in a group of 3 fixtures the discharge of 2 at a time to determine greatest loading effect.
4 and 5	3	2	W5+C4	To observe interaction between 2 drainage stacks taking fixtures expected to produce greatest loading effect.
1 and 2	5	3	W1+W2+B1	To observe interaction between 2 soil stacks taking fixtures expected to produce greatest loading effect.
1, 2, and 3	6	3	W1+W2+S3	To observe interaction between 3 drainage stacks taking fixtures expected to produce greatest loading effect.
1, 2, and 4	6	3	W1+W2+C4 B1+W2+C4	To observe interaction between 3 drainage stacks taking fixtures expected to produce greatest loading effect.
1, 2, 3, 4, and 5	9	4	W1+W2+W5+S3 W1+W2+W5+C4	To observe interaction between 4 drainage stacks taking fixtures expected to produce greatest loading effect.

[a] These numbers of fixtures to be discharged together are taken from Table 1A of BSS41 [11].

3. Component Stack

3.1. Procedure

Tests were run with a water supply static pressure of 30, 50, and 70 psi while varying air demand (by means of five settings of the butterfly valve in the vent from open to closed) for flushes of each of the two water closets in turn (single-fixture flushes) and for both water closets together (back-to-back flushes). Initial level of trap-seal surface was that furnished by the automatic refill of the flushometer valve. Maximum drop in the line pressure during a flush was about 10 psi measured 2 ft upstream from the flushometer stop. When tests were run with the butterfly valve closed, the gate valve was closed also. The idle trap was not plugged in the tests, thus air was sucked through the idle trap in runs that produced high levels of vent suction.

Next tests were run at a water supply static pressure of 50 psi for varying air demand for single flushes of each of the two water closets in turn with the idle trap plugged with rags so that no air could be pulled through the idle trap. The purpose of these tests was to determine if appreciably more air flow occurred in the vent when air could not enter the system through the idle trap.

Then some series of runs were carried out at three settings of the vent valve (open and two different partially closed settings) up until the sound of air was heard being pulled through the idle trap during some runs. The purpose of these runs was to study experimentally the relationship between vent suction (dP), air demand rate in the vent (Q_a), and trap-seal reduction (dH) at the point of vent restriction when the sound of air being sucked through the idle trap was just audible during a flush of the active fixture. It was felt this might provide a basis for relating acoustical performance criteria to the traditional hydraulic and pneumatic criteria for plumbing systems [9].

3.2. Results

Values of peak air flow rate, peak vent suction and idle trap-seal reduction for tests at a supply static pressure of 30 psi are given in table 4, 50 psi in table 5, and 70 psi in table 6. Data obtained at 50 psi for peak air flow rate and suction in the vent with the idle trap plugged are given in table 7. Data for peak air flow, vent suction and trap-seal reduction with increasing restriction of the vent valve up to the sound of air being sucked through the idle trap at a supply pressure of 50 psi are given in table 8.

TABLE 4. *Component stack, single-fixture and back-to-back flush tests: peak air demand, peak vent suction and single run idle trap-seal reduction for conditions of vent open, 3 degrees of vent restriction and vent closed (idle trap not plugged)*

Supply pressure was 30 psi.

	(Vent open)			(Nominal ¾ open)			(Nominal ½ open)			(Nominal ¼ open)			(Vent closed)		
Single-fixture flush (North)															
Run No.	Q_a	dP	dH	Q_a	dP	dH	Q_a	dP	dH	Q_a	dP	dH	Q_a	dP	dH
	gpm	*in W.G.*	*in*	*gpm*	*in W.G.*	*in*	*gpm*	*in W.G.*	*in*	*gpm*	*in W.G.*	*in*	*gpm*	*in W.G.*	*in*
1	130.0	1.58	0.06	100.0	3.04	0.41	59.5	3.33	0.64	35.0	3.55	0.60	0.	3.76	0.64
2	138.0	1.72	.03	94.5	2.66	.26	61.0	3.36	.58	37.0	3.96	.81	8.	4.62	.86
3	136.0	1.71	.02	95.0	2.74	.28	60.0	3.29	.37	38.5	3.93	.94	8.	5.24	.97
4	130.5	1.52	.01	95.5	2.65	.35	56.0	2.95	.12	38.0	4.14	1.11	2.	5.65	1.05
Average	134	1.63	.03	96	2.77	.32	59	3.23	.43	37	3.90	.87	5	4.82	.88
Single-fixture flush (South)															
Run No.	Q_a	dP	dH	Q_a	dP	dH	Q_a	dP	dH	Q_a	dP	dH	Q_a	dP	dH
	gpm	*in W.G.*	*in*	*gpm*	*in W.G.*	*in*	*gpm*	*in W.G.*	*in*	*gpm*	*in W.G.*	*in*	*gpm*	*in W.G.*	*in*
1	121.5	1.31	0.19	88.0	2.36	0.41	60.0	3.37	0.93	40.0	4.48	1.01	3.	5.97	1.15
2	113.0	1.19	.10	96.0	2.69	.21	61.0	3.50	.55	40.0	4.41	.86	8.	5.80	1.03
3	112.0	1.13	.07	88.0	2.30	.13	58.5	3.09	.49	39.5	4.36	.83	0.	5.20	.93
4	111.0	1.15	.02	85.5	2.12	.18	61.5	3.52	.59	40.0	4.37	.80	6.	5.48	.93
Average	114	1.20	.10	89	2.37	.23	60	3.37	.64	40	4.41	.88	4	5.61	1.01
Back-to-back flush (North and South)															
Run No.	Q_a	dP		Q_a	dP		Q_a	dP		Q_a	dP		Q_a	dP	
	gpm	*in W.G.*		*gpm*	*in W.G.*		*gpm*	*in W.G.*		*gpm*	*in W.G.*		*gpm*	*in W.G.*	
1	156.0	2.26	....	102.5	3.09	....	67.5	4.30	....	43.0	5.21	....	0.	8.45	....
2	149.5	2.10	....	107.5	3.42	....	66.0	4.05	....	42.0	4.73	....	0.	6.62	....
3	162.5	2.44	....	103.0	3.15	....	64.5	3.83	....	41.0	4.61	....	17.	6.55	....
4	154.5	2.22	....	105.5	3.43	....	64.5	3.87	....	43.0	4.88	....	0.	7.00	....
Average	156	2.26	....	105	3.27	....	66	4.01	....	42	4.86	....	4	7.16	....

TABLE 5. *Component stack, single-fixture and back-to-back flush tests: peak air demand, peak vent suction and single run idle trap-seal reduction for conditions of vent open, 3 degrees of vent restriction and vent closed (idle trap not plugged).*

Supply pressure was 50 psi.

Run No.	(Vent open)			(Nominal ¾ open)			(Nominal ½ open)			(Nominal ¼ open)			(Vent closed)		
Single-fixture flush (North)															
Run No.	Q_a	dP	dH	Q_a	dP	dH	Q_a	dP	dH	Q_a	dP	dH	Q_a	dP	dH
	gpm	*in W.G.*	*in*	*gpm*	*in W.G.*	*in*	*gpm*	*in W.G.*	*in*	*gpm*	*in W.G.*	*in*	*gpm*	*in W.G.*	*in*
1..........	136. 5	1. 58	0. 02	94. 5	2. 55	0. 22	65. 5	3. 79	1. 02	57. 0	3. 89	1. 11	0.	5. 86	1. 03
2..........	143. 5	1. 68	. 01	107. 5	3. 09	. 59	68. 5	4. 10	. 81	57. 5	3. 87	0. 93	0.	6. 98	1. 23
3..........	144. 5	1. 75	. 02	99. 5	2. 70	. 43	67. 0	3. 90	. 94	58. 5	4. 20	. 95	0.	6. 45	1. 09
4..........	134. 5	1. 50	. 01	100. 5	2. 71	. 71	70. 0	4. 22	. 99	58. 5	4. 12	. 97	0.	5. 57	1. 33
Average..	140	1. 63	0. 02	101	2. 76	0. 49	68	4. 00	0. 94	58	4. 02	0. 99	0	6. 22	1. 17
Single-fixture flush (South)															
Run No.	Q_a	dP	dH	Q_a	dP	dH	Q_a	dP	dH	Q_a	dP	dH	Q_a	dP	dH
	gpm	*in W.G.*	*in*	*gpm*	*in W.G.*	*in*	*gpm*	*in W.G.*	*in*	*gpm*	*in W.G.*	*in*	*gpm*	*in W.G.*	*in*
1..........	126. 0	1. 37	0. 04	100 0	2. 83	0. 56	69. 0	4. 11	0. 84	60. 0	4. 47	0. 83	9.	6. 29	1. 09
2..........	120. 0	1. 19	. 01	95. 5	2. 62	. 72	63. 0	3. 38	1. 02	54. 0	3. 62	1. 19	0.	6. 46	1. 09
3..........	134. 0	1. 51	. 02	98. 5	2. 72	. 95	61. 5	3. 33	1. 30	58. 5	4. 11	. 89	3.	6. 14	1. 15
4..........	139. 0	1. 63	. 02	102. 0	2. 82	. 25	61. 5	3. 33	1. 03	56. 5	3. 84	. 99	0.	6. 39	1. 14
Average..	130	1. 43	0. 02	99	2. 75	0. 62	64	3. 54	1. 05	57	4. 01	0. 98	3	6. 32	1. 12
Back-to-back flush (North and South)															
Run No.	Q_a	dP		Q_a	dP		Q_a	dP		Q_a	dP		Q_a	dP	
	gpm	*in W.G.*		*gpm*	*in W.G.*		*gpm*	*in W.G.*		*gpm*	*in W.G.*		*gpm*	*in W.G.*	
1..........	152. 5	1. 91	....	121. 0	4. 11	....	78. 0	5. 36	....	67. 0	5. 48	....	0.	8. 85	....
2..........	165. 5	2. 45	....	117. 0	4. 13	....	74. 0	4. 47	....	65. 0	5. 12	....	0.	7. 40	....
3..........	164. 0	2. 26	....	120. 0	4. 13	....	73. 5	4. 63	....	63. 0	4. 65	....	0.	7. 67	....
4..........	167. 0	2. 28	....	121. 5	4. 27	....	73. 5	4. 64	....	63. 5	4. 99	....	6.	7. 46	....
Average..	162	2. 23	....	120	4. 16	....	75	4. 78	....	65	5. 06	....	2	7. 85	....

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TABLE 6. *Component stack, single-fixture and back-to-back flush tests: peak air demand, peak vent suction and idle trap seal reduction for conditions of vent open, 3 degrees of vent restriction and vent closed (idle trap not plugged)*

Supply Pressure was 70 psi.

Single-fixture flush (North)

	(Vent open)			(Nominal ¾ open) [b]			(Nominal ½ open) [b]			(Nominal ¼ open) [b]			(Vent closed)		
Run No.	Q_a	dP	Cumulative dH	Q_a	dP	Cumulative dH	Q_a	dP	Cumulative dH	Q_a	dP	Single run dH	Q_a	dP	Single run dH
	gpm	in W.G.	in	gpm	in W.G.	in	gpm	in W.G.	in	gpm	in W.G.	in	gpm	in W.G.	in
1 [a]	129.0	1.40	0.00	130.0	1.64	0.01	120.0	1.74	0.02	112.0	2.90	0.86	4.	8.15	1.64
2	136.0	1.55	.01	136.0	1.81	.03	122.0	1.82	.03	108.0	2.64	.43	0.	8.33	1.19
3	136.0	1.51	.01	127.0	1.55	.03	120.0	1.74	.04	117.0	3.15	.67	3.	7.65	1.19
4	127.0	1.31	.01	131.0	1.64	.04	127.0	1.92	.06	116.0	3.07	.62	7.	7.03	1.07
Average	132	1.44		131	1.66		122	1.81		113	2.94	0.65	4	7.79	1.27

Single-fixture flush (South)

Run No.	Q_a	DP	Cumulative dH	Q_a	dP	Cumulative dH	Q_a	dP	Cumulative dH	dP	Q_a	Single run dH	Q_a	dP	Single run dH
	gpm	in W.G.	in	gpm	in W.C.	in	gpm	in W.G.	in	gpm	in W.G.	in	gpm	in W.G.	in
1 [a]	121.0	1.19	0.00	111.0	1.17	0.00	111.0	1.47	0.01	110.0	2.94	0.96	0.	7.06	0.96
2	116.0	1.11	.00	113.0	1.19	.00	106.0	1.35	.02	111.0	2.81	.90	0.	8.74	1.25
3	124.0	1.30	.00	111.0	1.14	.00	119.0	1.71	.06	104.0	2.48	.81	0.	8.62	1.17
4	119.0	1.20	.00	111.0	1.17	.00	119.0	1.69	.08	101.0	2.33	.74	0.	8.62	1.21
Average	120	1.20		112	1.17		114	1.56		107	2.64	0.85	0	8.26	1.15

Back-to-back flush (North and South)

Run No.	Q_a	dP		Q_a	dP		Q_a	dP		Q_a	dP		Q_a	dP	
	gpm	in W.G.		gpm	in W.G.		gpm	in W.G.		gpm	in W.G.		gpm	in W.G.	
1 [a]	157.0	2.12	....	147.0	2.08	....	143.0	2.50	....	138.0	4.65	....	0.	8.82	....
2	159.0	2.24	....	153.0	2.20	....	139.0	2.42	....	134.0	4.01	....	4.	8.81	....
3	151.0	2.03	....	153.0	2.15	....	142.0	2.60	....	141.0	4.67	....	0.	8.79	....
4	147.0	1.99	....	151.0	2.10	....	154.0	3.04	....	147.0	5.01	....	0.	8.81	....
Average	154	2.10		151	2.13		145	2.64		140	4.59		1	8.81	

[a] Both traps were filled for the first run. For "cumulative dH", the idle trap was not refilled between runs, and the dH values given are cumulative after each successive run. For "single run dH", the traps were refilled after each run, and the dH values given are for the 4 individual runs. The "average dH" value is the 4-run average of single run dH.

[b] The butterfly valve settings used in these tests were arbitrarily determined from preliminary runs. Subsequently (for data in tables 4, 5, and 7), different settings were used to more evenly divide the peak air flow values obtained between the "vent open" and "vent closed" settings.

TABLE 7. *Component stack, single-fixture flush tests: peak air demand and peak vent suction for conditions of vent open, 3 degrees of vent restriction and vent closed (idle trap plugged)*

Supply Pressure was 50 psi

Single-fixture flush (North)

Run No.	(Vent open)		(Nominal ¾ open)		(Nominal ½ open)		(Nominal ¼ open)		(Vent closed)	
	Q_a	dP	Q_a	dP	Q_a	dP	Q_a	dP	Q_a	dP
	gpm	*in W.G.*	*gpm*	*in W.G.*	*gpm*	*in W.G.*	*gpm*	*in W.G.*	*gpm*	*in W.G.*
1	148.5	2.02	89.5	2.68	63.5	4.21	38.5	4.79	4.	5.05
2	134.0	1.64	98.5	2.98	59.0	3.53	38.0	4.51	0.	5.62
3	132.0	1.56	96.0	2.84	66.0	4.26	37.5	4.29	0.	5.06
4	128.0	1.52	101.0	3.13	64.5	4.05	40.0	4.85	0.	5.05
Average	136	1.69	96	2.91	63	4.01	39	4.61	1	5.20

Single-fixture flush (South)

Run No.	Q_a	dP	Q_a	dP	Q_a	dP	Q_a	dP	Q_a	dP
	gpm	*in W.G.*	*gpm*	*in W.G.*	*gpm*	*in W.G.*	*gpm*	*in W.G.*	*gpm*	*in W.G.*
1	121.0	1.33	89.5	2.52	60.5	3.87	35.5	3.63	3.	4.18
2	125.5	1.46	96.5	2.88	60.0	3.44	34.0	3.36	0.	4.43
3	128.5	1.52	98.5	2.92	60.0	3.62	36.0	3.61	0.	4.49
4	136.0	1.80	96.0	2.83	58.5	3.46	34.0	3.36	6.	4.22
Average	128	1.53	95	2.79	60	3.60	35	3.49	2	4.33

TABLE 8. *Component stack, single-fixture flush tests: peak air demand, peak vent suction and cumulative trap-seal reduction of conditions of vent open and 2 degrees of vent restriction up to onset of aspiration of air through idle trap*

Supply Pressure was 50 psi.

Single-fixture flush (North)

Run No.	(Vent open)				(Partial flow restriction, level one)				(Partial flow restriction, level two)			
	Q_a	dP	dH	Cum. dH	Q_a	dP	dH	Cum. dH	Q_a	dP	dH	Cum. dH
	gpm	*in. W.G.*	*in*	*in*	*gpm*	*in W.G.*	*in*	*in*	*gpm*	*in W.G.*	*in*	*in*
1[a]	129.5	1.66	0.38	0.38	135.0	2.05	0.60	0.60	128.5	2.41	0.69	0.69
2	140.0	2.04	.03	.41	131.0	1.96	.00	.60	127.5	2.47	.00	.69
3	129.0	1.72	.01	.42	136.0	2.16	.00	.60	129.5	2.51	.00	.69
4	139.5	1.96	.04	.46	134.5	2.10	.00	.60	127.0	2.34	.00	.69
5	143.0	2.14	.02	.48					130.0	2.52	.00	.69
6	127.5	1.63	.00	.48					129.0	2.34	.00	.69
7	138.0	1.88	.00	.48					125.5	2.37	.00	.69
8	128.5	1.60	.00	.48					119.0	2.03	.00	.69
1[a]									[b]127.0	2.45	.80	.80
2									[b]118.5	2.13	.01	.81
3									[b]121.5	2.21	.02	.83
1[a]									[b]126.5	2.36	.76	.76
1[a]									[b]132.5	2.56	.76	.76

[a] Both traps filled for first run to trap weir.

[b] Air was heard sucked through the idle trap in these runs.

3.3. Discussion

Although prevailing code language limits the pneumatic pressure excursion in the vent to ±1-in W.G., data in tables 4, 5, and 6 indicate that trap-seal reductions in the idle water closet trap did not exceed the 1-in reduction permitted in present practice until beyond a peak (0.2 s) suction in the vent of 3 in W.G. For a *dH* of 1 in, peak (0.2 s) *dP* was 3 in W.G. for 4-run cumulative *dH* (determined by extrapolation) and 4 in W.G. for single run *dH*. Although the greatest trap-seal reduction occurs in the first run of a four-run set, cumulative *dH* is also of interest as an example of the effect on an idle trap (as in a multi-family living unit where occupants are away but next-door neighbors are not) when the active trap is flushed again and again.

Air demand rates measured, whether or not the idle trap was plugged, were well below the theoretical prediction of NBS Monograph 31 for a one-stack system with all the air being pulled in from the top. For example, equation (56) in NBS Monograph 31 [1] predicts air demand rates (at atmospheric pressure) of the order of 200 to 250 gpm for a 3-in plastic drainage stack, depending on the magnitude of the hydraulic load. In tests on the component stack with the vent open (minimum diameter of 1.05 in at the smallest part of the passageway through the air flowmeter), air demand rate ranged from a low of 111 gpm (single-fixture flush) to a high of 167 gpm (back-to-back flush). These lower values are partly attributable to the occurrence of vent suction greater than 1 in W.G., as measured in these tests. The data for the idle trap plugged given in table 7, are plotted in figure 7, along with comparable data obtained from a similar RSV system, with one water closet, studied earlier at NBS [6]. The present data are in good agreement with the earlier work with the exception of the point with the vent closed. The more primitive instrumentation used in the earlier study may have been a factor in the difference between the two values. (Data reported herein do not contain measurements in the low *dP*-high Q_a range because of the relatively high resistance to flow through the small air flowmeter available when the measurements were made.)

Direct correlation of peak pneumatic pressure in the vent and its associated trap-seal reduction, made possible by the laboratory capability for dynamic measurement, is shown in figure 8. The data, taken from table 5, are for single-fixture flush tests of each of two water closets at a static supply pressure of

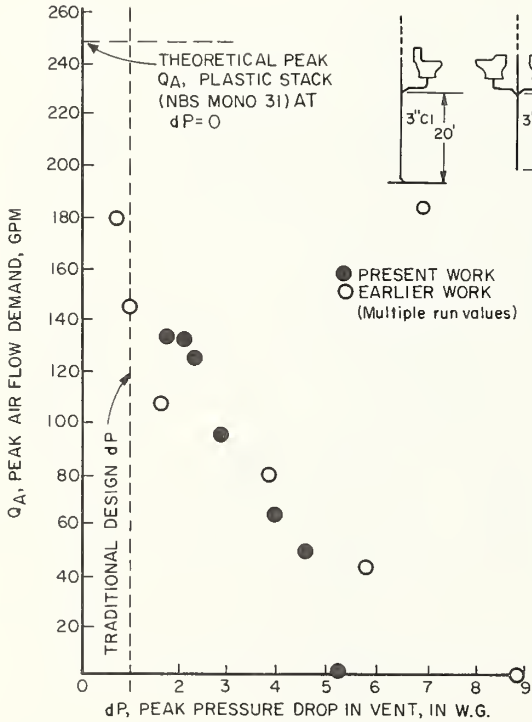


FIGURE 7. *Relationship between vent pressure and air demand rate, comparing results of two component stack investigations with one WC discharges. (Data for present study is from single-fixture flush tests in table 7.)*

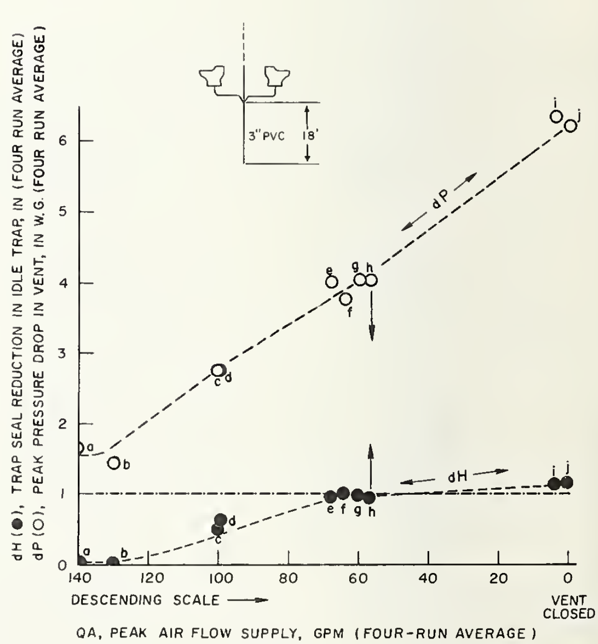


FIGURE 8. *Relationship between* dP *(peak 0.2 s suction),* dH *(trap-seal reduction) in the idle water closet trap, and* Q_a *(peak 0.2 s air demand) for single-fixture flush tests in the component stack investigation. (Data is from table 5 for single-fixture flush tests.)*

50 psi. Each data point in the figure represents a 4-run average value plotted against the corresponding 4-run average peak air flow rate. More exactly, each lettered pair is a 4-run average of dP and (single run) dH, and the pair is plotted on the intercept (x axis) of the Q_a (average) for the same 4 runs—to show a three-way correlation between Q_a, dP, and dH. The data show that the idle trap-seal reductions did not exceed 1 in at a peak (0.2 s) vent suction close to 4 in W.G. (pairs *e, f, g,* and *h*). Another important finding, illustrated in figure 8, is that the rate of increase in trap-seal reduction, as the air flow was reduced by restricting the vent butterfly valve, was much less than the accompanying rate of increase in the vent suction. With an excessive peak (0.2 s) vent suction of 6.3 in W.G., obtained with the vent completely closed, the trap-seal reduction in the idle trap was only 1.1 in (pairs *i* and *j*).

Thus adequate trap-seal retention in the idle water closet traps for peak (0.2 s) vent suction exceeding 3 in W.G. and the small air demand required relative to the traditional theoretical predictions clearly indicate that vent piping in 1–2 story housing units can safely be smaller than presently allowed by design without jeopardizing the integrity of the trap seals in service performance. On the basis of these findings, vents for water closets with full trap-seal depths of not less than 3 in can be sized for 2.0 in W.G. vent suction rather than the 1.0 in W.G. suction presently allowed in the plumbing codes. Criteria for back-pressure (positive pressure in the vent) were not studied in the component stack tests.

4. Townhouse

4.1. Procedure

Two series of tests were run in the experimental work on the townhouse. In the first, Series I, a total of seven fixture-discharge loads were tested and in the second, Series II, six additional fixture-discharge loads were tested along with two repeated from Series I. In the Series II tests, a few tests were made with the building drain submerged.

As in the procedure for the experimental work on the component stack, data in the townhouse work were taken in 4-run sets. Some tests (sets) were repeated to include additives on the 1st and 3rd runs or to compare the results of idle traps being filled or not filled between runs. The additives used were paper diapers, detergent, and bubble bath; operation of the food-waste-disposal-unit was also considered an additive in the tabulation of the data. In Series I, each discharge combination was applied both with the main vent terminal open and closed. In both series, all fixtures were manually discharged simultaneously at the beginning of a run just as (after) the computer recorded an initial value from all the transducers. No time sequencing of loads was used.

4.2. Results

Results of all measurements taken in Series I are given in table 9. These results show corresponding peak air demand rate Q_a, peak vent suction dP, and trap-seal reduction dH for the first time in a full-scale system (see tests 17–22, 28–30, 33, 37–40 in table 9). Results of the trap-seal reduction measurements for Series II are given in table 10. The largest idle trap-seal reduction with the vents open and the drain not submerged was 0.4 in (for C4 in test 37 and L5 in tests 34 and 38 of table 9 for a discharge of S3+W1+W2+W5, and S3 in test 16 of table 10 for a discharge of C4+W1+W2+W5). Discharge of C4+W1+W2 (test 18 of table 9) produced the largest values of peak (0.2 s) suction in the (Stack 4) vent, 0.56 in W.G. (2-run average) and of peak air demand rate, 83 gpm (2-run average) that were measured with the vent terminals and the building drain open. The largest idle trap-seal reduction with the vent terminal open and the drain submerged was 0.4 in (for W5 in test 9 of table 10) which occurred for a discharge of B1+W1+W2.

A short description of the loads, conditions of test, and number of trap-seal failures for both Series I and II is given in table 11. Data in this table show that in all the tests run, trap failure(s) occurred only when main or both vent terminals were closed and at least three fixtures were discharged. In one case, a discharge of three fixtures with the vent terminals closed did not produce a trap failure (test 30 of table 9), but did produce trap-seal failures when the drain was submerged in addition (test 15 of table 10). There were no trap-seal failures with the building drain submerged and the vent terminals open.

For a discharge of B1+W1+W2 with the vents closed, tests made without refilling the traps between runs produced a 4-run cumulative dH about twice the magnitude of the single run dH, where the traps were filled between runs, but still less than 1 in (see tests 30 and 33 in table 9 and also figure 9). Lack of significant difference between single run dH and cumulative dH for a discharge of B1+W1 with the vent terminals open (tests 8–11 in table 9) is attributed to the inability to detect very small changes by means of manual measurement of trap-seal depth with a ruler.

Table 9 also gives water depth measurements in the building drain (peak 0.2-s value) for Series I tests of 3 or more fixtures discharged, indicating that the depth did not exceed 2.4 in in the 4-in drain for any of the loads (see tests 37–39 in table 9).

TABLE 9. *Tabulation of Series I tests showing air flow rates, trap seal reductions, vent pressures and water depths in building drain, for various test conditions applied to the townhouse DWV system*

Test No.	Test conditions			Air flow, Q_a (0.2-s)		Vent pressures, dP (0.2-s)	
	Fixture discharge loads [a]	Additives [b]	Vent terminals [c]	Main vent	Sink vent	Stack 1	Stack 2
				gpm	*gpm*	*in W.G.*	*in W.G.*
1	[d] S3A	DET/fwdu in S3A		....	26	....	....
		fwdu		....	27	....	....
2	[d, e] S3A	fwdu	both closed	[g] X	X	....	....
		none	both closed	X	X	....	....
3	[e] W5	none		9	....	....	....
4	[d] W5	PD in W5		8	....	....	....
		none		7	....	....	....
5	W5	none	main closed	X	....	....	....
6	[d] W2	PD in W2		27	....	....	−0.31
		none		25	....	....	−0.24
7	W2	none	both closed	X	X	....	−0.25
8	[e] B1+W1	none		44	....	−0.20	....
9	[e] B1+W1	none		44	....	−0.21	....
10	B1+W1	none		40	....	−0.20	....
11	B1+W1	none		45	....	−0.22	....
12	[d] B1+W1	PD in W1		41	....	−0.19	....
		none		44	....	−0.25	....
13	[d] B1+W1	BB in B1		42	....	−0.21	....
		none		29	....	−0.12	....
14	B1+W1	none	main closed	X	....	−0.39	....

TABLE 9. *Tabulation of Series I tests showing air flow rates, trap seal reductions, vent pressures and water depths in building drain, for various test conditions applied to the townhouse DWV system*—Continued

Test No.	Vent pressures, *dP* (0.2-s)			Cumulative idle trap seal reductions, *dH*									Water depth in open bldg. drain (0.2-s)
	Stack 3	Stack 4	Stack 5	B1	L1	W1	L2	W2	S3	C4	L5	W5	
	in W.G.	*in W.G.*	*in W.G.*	*in*	*in*	*in*	*in*	*in*	*in*	*in*	*in*	*in*	*in*
1	−1.56 −1.45	... ...	... ...	...	...	...	...	...	[g]A	...	...	...	...
2	−5.95 −0.14	... ...	... ...	...	[e]0.0	...	[e]0.0	...	A	...	[e]0.0	...	...
3	...	...	−0.05	...	...	...	...	...	...	...	0.0	A	...
4	... ...	... ...	−0.04 −0.03	...	...	...	...	...	...	...	0.0	A	...
5	...	...	−0.02	...	0.1	...	0.0	...	...	...	0.0	A	...
6	... ...	... ...	... ...	...	...	...	0.0	A	...	...	...	...	...
7	...	...	...	...	0.1	...	0.1	A	...	...	0.1	...	...
8	...	...	...	A	[e]0.0	A	...	...	...	...	...	...	...
9	...	...	...	A	[e]0.1	A	...	...	...	...	...	...	...
10	...	...	...	A	0.0	A	...	...	...	...	...	...	...
11	...	...	...	A	0.0	A	...	...	...	...	...	...	...
12	... ...	... ...	... ...	A	0.0	A	...	...	...	...	...	...	...
13	... ...	... ...	... ...	A	0.0	A	...	...	...	...	...	...	...
14	...	...	...	A	0.1	A	0.1	...	...	...	0.2	...	...

TABLE 9. *Tabulation of Series I tests showing air flow rates, trap seal reductions, vent pressures and water depths in building drain, for various test conditions applied to the townhouse DWV system*—Continued

Test No.	Test conditions			Air flow, Q_a (0.2-s)		Vent pressures, dP (0.2-s)	
	Fixture discharge loads [a]	Additives [b]	Vent terminals [c]	Main vent	Sink vent	Stack 1	Stack 2
				gpm	*gpm*	*in W.G.*	*in W.G.*
15	[d] C4+W1+W2	DET in C4		66	....	....	....
		none		65	....	....	....
16	C4+W1+W2	none	both closed	X	X	....	....
17	C4+W1+W2	none		79	5	−0.43	−0.50
18	[d] C4+W1+W2	DET in C4		76	9	−0.43	−0.42
		none		83	4	−0.45	−0.54
19	[f] C4+W1+W2	none	both closed	X	X	−2.92	−2.83
						−0.95	−0.96
20	C4+W1+W2	none	sink closed	79	X	−0.40	−0.27
21	[f] C4+W1+W2	none	main closed	X	9	−2.34	−2.48
						−1.62	−1.54
22	[e] C4+W1+W2	none	both closed	X	X	−2.10	−2.29
23	[d] B1+W1+W2	PD in W1		68	....	....	....
		none		67	....	....	....
24	[d] B1+W1+W2	PD in W1		72	....	−0.54	....
		none		69	....	−0.33	....
25	[d] B1+W1+W2	BB in B1		64	....	....	....
		none		51	....	....	....
26	[d] B1+W1+W2	BB in B1		70	....	....	....
		none		70	....	....	....
27	[d] B1+W1+W2	BB in B1		64	....	−0.31	....
		none		57	....	−0.24	....
28	B1+W1+W2	none		72	6	−0.35	−0.43
29	[d] B1+W1+W2	BB in B1		65	7	−0.28	−0.42
		none		61	7	−0.25	−0.39
30	B1+W1+W2	none	both closed	X	X	−1.41	−1.38
31	B1+W1+W2	none	both closed	X	X	....	....
32	B1+W1+W2	none	both closed	X	X	−0.35	....
33	[e] B1+W1+W2	none	both closed	X	X	−1.32	−1.48

TABLE 9. *Tabulation of Series I tests showing air flow rates, trap seal reductions, vent pressures and water depths in building drain, for various test conditions applied to the townhouse DWV system*—Continued

Test No.	Vent pressures, *dP* (0.2-s)			Cumulative idle trap seal reductions, *dH*									Water depth in open bldg. drain (0.2-s)
	Stack 3	Stack 4	Stack 5	B1	L1	W1	L2	W2	S3	C4	L5	W5	
	in W.G.	*in W.G.*	*in W.G.*	*in*	*in*	*in*	*in*	*in*	*in*	*in*	*in*	*in*	*in*
15	... ...	... ...	−0.36 −0.44	0.0	0.1	A	0.3	A	0.1	A	0.3	...	...
16	...	...	...	0.0	1.1	A	1.3	A	0.1	A	1.1	...	...
17	−0.15	−0.48	...	0.2	0.1	A	0.2	A	0.1	A	0.2	0.1	1.9
18	[b] OSC	−0.49 −0.56	... ...	0.2	0.1	A	0.3	A	0.1	A	0.2	0.1	[d]2.1 2.0
19	−0.31 −0.25	−3.01 −0.96	... ...	1.9 0.0	1.0 0.0	A A	2.1 0.4	A A	0.0 0.1	A A	0.9 0.0	... ...	1.8
20	[b] OSC	−0.47	...	0.3	0.1	A	0.3	A	0.1	A	0.2	0.1	1.9
21	−0.55 −0.48	−2.49 −1.65	... ...	1.2 0.1	1.1 0.1	A A	1.3 1.0	A .A	0.1 0.2	A A	0.9 0.1	0.6 0.3	1.7
22	...	−2.12	...	[e]0.9	[e]0.7	A	[e]1.0	A	[e]0.1	A	[e]0.8	[e]0.5	...
23	... ...	... ...	−0.21 −0.19	A	0.1	A	0.1	A	0.1	...	...	...	...
24	... ...	... ...	... ...	A	0.1	A	0.2	A	0.1	...	...	...	...
25	... ...	... ...	... ...	A	0.1	A	0.3	A	0.1	...	...	...	1.7
26	... ...	... ...	−0.28 −0.28	A	0.1	A	0.1	A	0.1	...	...	...	...
27	... ...	... ...	... ...	A	0.1	A	0.1	A	0.0	...	...	...	...
28	[b] OSC	−0.30	...	A	0.0	A	0.1	A	0.1	0.1	0.3	0.1	1.7
29	[b] OSC ...	[b] OSC ...	... ...	A	0.1	A	0.1	A	0.2	0.2	0.3	0.1	1.6
30	−0.85	−0.95	...	A	0.6	A	0.8	A	0.4	0.6	0.6	0.4	1.5
31	...	...	−0.75	A	0.6	A	0.8	A	0.3	0.3	0.4	...	...
32	...	...	...	A	0.4	A	0.6	A	0.3	0.0	0.5	...	...
33	−0.87	−0.83	...	A	[e]0.3	A	[e]0.5	A	[e]0.2	[e]0.3	[e]0.3	[e]0.2	...

TABLE 9. *Tabulation of Series I tests showing air flow rates, trap seal reductions, vent pressures and water depths in building drain, for various test conditions applied to the townhouse DWV system*—Continued

Test No.	Test conditions			Air flow, Q_a (0.2-s)		Vent ressures, *dP* (0.2-s)	
	Fixture discharge loads [a]	Additives [b]	Vent terminals [c]	Main vent	Sink vent	Stack 1	Stack 2
				gpm	*gpm*	*in W.G.*	*in W.G.*
34	[d] S3A+W1 +W2+W5	DET/fwdu in S3A........ fwdu....................	....	....	....	....	−0.44 −0.44
35	[f] S3A+W1 +W2+W5	none....................	both closed.............	X	X	....	−2.69 −1.09
36	[d] S3A+W1 +W2+W5	DET/fwdu in S3A........ fwdu....................	....	....	....	....	−0.48 −0.41
37	[d] S3A+W1 +W2+W5	fwdu in S3A............	....	74	7	−0.47	−0.38
38	[d] S3A+W1 +W2+W5	DET/fwdu in S3A and PD in W1......... fwdu....................		 76 77	 23 25	 −0.41 −0.50	 −0.42 −0.46
39	[f] S3A+W1 +W2+W5	none....................	botb closed.............	X	X	−2.84 −1.02	−2.80 −1.01
40	[e] S3A+W1 +W2+W5	none....................	both closed.............	X	X	−2.69	−2.93

[a] Fixtures are identified by a letter and a number: B1=bathtub on Stack 1, C4 is the clothes washer on Stack 4. Likewise, there are lavatories L1, L2, and L5; water closets W1, W2, and W5; and a 2-Compartment sink, S3, with S3A the compartment having the food-waste-disposal-unit and S3B the otber compartment.

[b] Additives are identified by:

fwdu=food-waste-disposal-unit operating, an early model having a shut-off pressure of 20 psi.

PD=paper diaper, a commercially available "paper" diaper made of an absorbent pad adhering to a porous inner liner and covered on the outside with a waterproof plastic sheet. The absorbent pad was sloshed in the water closet to free it from the inner liner which was not flushed, in accordance with the manufacturer's recommendation. The size was identified by the manufacturer as for overnight use by babies over 11 lb.

DET=granulated detergent, a commercially available product containing 8.7 percent phosphorus in the form of phosphates. The surfactants in the products are reported to be biodegradable. When used in the sink, ¼ c. was stirred into the water, and for the clothes washer, 1 c. was stirred into the water.

BB=Bubble bath, a granulated bubble bath preparation stated by the manufacturer to be biodegradable and to contain no phosphates. In the bathtub, a sudsy condition was created by adding to warm water ¼ c. of the bubble bath.

[c] Open unless otherwise indicated.

[d] Additives, when used, were added on the first and tbird runs of a test. (In tests 1, 34, 36, 37, and 38 the fwdu was utilized in all 4 runs.) Where additives were used, the average peak air flow rate and vent pressure (and building drain depth in test 18) are tabulated for the first and third runs in the upper position and the second and fourth runs in tbe lower position.

[e] Before each of four successive runs, the traps were filled to the weir level. These trap seal reductions are single run dH 4-run average values.

[f] For these tests, the peak air demand rate, peak vent suction, and trap-seal reduction for the FIRST run is tabulated in the upper position. The peak air demand rate and vent pressure suction is averaged for runs 2, 3, and 4 and tabulated in the lower position. Cumulative additional *dH* for runs 2, 3, and 4 is tabulated in the lower position.

[g] Active trap, A; vent terminal closed, X.

Table 9. *Tabulation of Series I tests showing air flow rates, trap seal reductions, vent pressures and water depths in building drain, for various test conditions applied to the townhouse DWV system*—Continued

Test No.	Vent pressures, dP (0.2-s)			Cumulative idle trap seal reductions, dH									Water depth in open bldg. drain (0.2-s)
	Stack 3	Stack 4	Stack 5	B1	L1	W1	L2	W2	S3	C4	L5	W5	
	in W.G.	*in W.G.*	*in W.G.*	*in*	*in*	*in*	*in*	*in*	*in*	*in*	*in*	*in*	*in*
34	....	....	[h] OSC	0.0	0.1	A	0.1	A	A	0.3	0.4	A	....
	....	....	....										
35	....	....	−2.48	0.0	1.3	A	2.3	A	A	1.1	1.3	A	....
	....	....	−1.17	0.0	0.0	A	0.1	A	A	0.1	0.0	A	....
36	....	....	....	0.1	0.1	A	0.3	A	A	0.1	0.1	A	....
	....	....	....										
37	[h] OSC	[h] OSC	....	0.3	0.1	A	0.2	A	A	0.4	0.3	A	2.4
38	[h] OSC	[h] OSC	....	0.3	0.1	A	0.3	A	A	0.3	0.4	A	2.4
	....	....	....										
39	[h] OSC	−2.75	....	1.9	1.1	A	2.1	A	A	1.1	2.1	A	2.3
	....	−0.87	....	0.1	0.0	A	0.2	A	A	0.0	0.1	A	
40	[h] OSC	−0.89	....	[e] 1.8	[e] 1.1	A	[e] 2.2	A	A	......	[e] 1.4	A	....

[h] Vent pressure excursion oscillating such that both positive and negative values were determined significant. These values are tabled below:

Test No.	Stack No.	Runs of test	Positive and negative peaks	Vent terminals		Test No.	Stack No.	Runs of test	Positive and negative peaks	Vent terminals	
				Main	Sink					Main	Sink
			in W.G.						*in W.G.*		
18	3	1 and 3.	+0.37 to −0.09...	......	......	36	5	1 and 3.	+0.23 to −0.46...	......	......
		2 and 4.	+0.10 to −0.21...	......	......			2 and 4.	+0.23 to −0.46...	......	......
20	3	1–4....	+0.11 to −0.10...	......	X	37	3	1–4....	+0.29 to −0.33...	......	......
28	3	1–4....	+0.09 to −0.12...	......	......	37	4	1–4....	+0.22 to −0.52...	......	......
29	3	1 and 3.	+0.14 to −0.14...	......	......	38	3	1 and 3.	+0.29 to −2.24...	......	......
		2 and 4.	+0.35 to −0.12...	......	......			2 and 4.	+0.56 to −2.49...	......	......
29	4	1 and 3.	+0.04 to −0.30...	......	......	38	4	1 and 3.	+0.33 to −0.42...	......	......
		2 and 4.	+0.22 to −0.18...	......	......			2 and 4.	+0.26 to −0.50...	......	......
34	5	1 and 3.	+0.17 to −0.40...	......	......	39	3	1......	+0.77 to −0.48...	X	X
		2 and 4.	+0.25 to −0.38...	......	......			2, 3, 4	+0.76 to −0.55...	X	X

TABLE 10. *Tabulation of Series II tests showing cumulative idle trap-seal reductions for various test conditions applied to the townhouse DWV system*

Test No.	Test conditions				Cumulative idle trap seal reductions, *dH*								
	Fixture discharge loads [a]	Additives [b] (first and third runs)	Vent terminals [c]	Building drain [c]	B1	L1	W1	L2	W2	S3	C4	L5	W5
					in	*in*	*in*	*in*	*in*	*in*	*in*	*in*	*in*
1	S3B	None			0.0	0.0	0.0	0.0	0.0	[d] A	0.0	0.0	0.0
2	S3B	DET in S3B			0.0	0.0	0.0	0.0	0.0	A	0.0	0.0	0.0
3	L1+W1	PD in W1			0.0	A	A	0.0	0.0	0.0	0.0	0.1	0.0
4	L1+W1	PD in W1		Submerged six inches	0.0	A	A	0.0	0.1	0.2	0.0	0.1	0.0
5	B1+L1	BB in B1			A	A	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	C4+W5	PD in W5			0.0	0.0	0.0	0.1	0.0	0.0	A	0.2	A
7	C4+L5	DET in C4			0.0	0.0	0.1	0.0	0.0	0.0	A	A	0.1
8	[b] S3A+W1+W2	DET/fwdu in S3A			0.2	0.0	A	0.1	A	A	0.0	0.0	0.0
9	[b] S3A+W1+W2	DET/fwdu in S3A		Submerged two inches	0.1	0.0	A	0.0	A	A	0.0	0.1	0.4
10	B1+C4+W2	DET in C4			A	0.0	0.0	0.1	A	0.0	A	0.2	0.2
11	B1+C4+W2	DET in C4		Submerged two inches	A	0.0	0.0	0.0	A	0.1	A	0.1	0.1
12	B1+C4+W2	DET in C4		Submerged six inches	A	0.0	0.0	0.0	A	0.0	A	0.1	[e] +.4
13	B1+C4+W2	DET in C4	Both Closed		A	0.8	1.3	1.1	A	0.0	A	0.8	0.3
14	B1+W1+W2	None		Submerged two inches	A	0.0	A	0.0	A	0.1	0.0	0.0	0.1
15	B1+W1+W2	None (only 1 run)	Both Closed	Submerged two inches	A	1.1	A	2.2	A	0.0	1.0	1.8	0.1
16	C4+W1+W2+W5	DET in C4, PD in W1			0.0	0.1	A	0.0	A	0.4	A	0.2	A

[a] Fixtures are identified by a letter and a number: B1=bathtub on Stack 1, C4 is the clothes washer on Stack 4. Likewise, there are lavatories L1, L2, and L5; water closets W1, W2, and W5; and a 2-Compartment sink, S3, with S3A the compartment having the food-waste-disposal-unit and S3B the other compartment.

[b] Additives, when used, were added on the first and third runs of a test. (In tests 8 and 9 DET was utilized in runs 1 and 3 but fwdu was utilized in all 4 runs.)

For these tests hot water was used in the bathtub, the sink, and the clothes washer when these were discharged. Hot and cold water was mixed randomly and was found to be in the range of 113–140 °F (45–60 °C). This is called hot water because it is uncomfortable to the hands of many persons.

Additives are identified by:

fwdu=food-waste-disposal-unit operating, an early model having a shut-off pressure of 20 psi.

PD=paper diaper, a commercially available "paper" diaper made of an absorbant pad adhering to a porous inner liner and covered on the outside with a waterproof plastic sheet. The absorbant pad was sloshed in the water closet to free it from the inner liner which was not flushed, in accordance with the manufacturer's recommendation. The size was identified by the manufacturer as for overnight use by babies over 11 lb.

DET=granulated detergent, a commercially available product containing 8.7 percent phosphorus in the form of phosphates. The surfactants in the products are reported to be biodegradable. When used in the sink, ¼ c. was stirred into the water, and for the clothes washer, 1 c. was stirred into the water.

BB=bubble bath, a granulated bubble-bath preparation stated by the manufacturer to be biodegradable and to contain no phosphates. In the bathtub, a sudsy condition was created by adding to warm water ¼ c. of the bubble bath.

[c] Open unless otherwise indicated.

[d] Active trap.

[e] This increase in the trap-seal level from initial depth was accompanied by suds in the W5 bowl. This phenomenon might have been the result of air trapped in the horizontal branch serving W5.

TABLE 11. *Summary table: (compiled from tables 9 and 10) Trap-seal performance as affected by various degrees of loading and other test conditions in the Series I and II townhouse tests*

Fixture discharge load	No. of trap seals failed [a]	Severity of loading	Test conditions: Vent terminals [b]	Test conditions: Building drain [b]	Test conditions: Additives [c] (first and third runs)
[d,e] S3A	0	Normal			DET/fwdu in S3A.
S3A	0	Unlikely	Both closed		fwdu in S3A.
[d] S3B	0	Normal			
S3B	0	Normal			DET in S3B.
W5	0	Normal			
W5	0	Normal			PD in W5.
W5	0	Unlikely	Main closed		
W2	0	Normal			PD in W2.
W2	0	Unlikely	Both closed		
L1+W1	0	Normal			PD in W1.
L1+W1	0	Unlikely		Submerged 6 inches.	
B1+L1	0	Normal			BB in B1.
C4+W5	0	Normal			PD in W5.
C4+W5	0	Normal			DET in C4.
B1+W1	0	Normal			
B1+W1	0	Normal			
B1+W1	0	Normal			
B1+W1	0	Normal			
B1+W1	0	Normal			PD in W1.
B1+W1	0	Normal			BB in B1.
B1+W1	0	Unlikely	Main closed		
[e] S3A+W1+W2	0	Unlikely		Submerged 2 inches.	DET/fwdu in S3A.
[e] S3A+W1+W2	0	Unusual			DET/fwdu in S3A.
C4+W1+W2	0	Unusual			
C4+W1+W2	3	Unlikely	Both closed		
C4+W1+W2	0	Unusual			
C4+W1+W2	0	Unusual			DET in C4.
C4+W1+W2	0	Unlikely	Both closed		
C4+W1+W2	0	Unlikely	Sink closed		
C4+W1+W2	2	Unlikely	Main closed		
C4+W1+W2	1	Unlikely	Main closed		
B1+W1+W2	0	Unusual			PD in W1.
B1+W1+W2	0	Unusual			PD in W1.
B1+W1+W2	0	Unusual			BB in B1.
B1+W1+W2	0	Unusual			BB in B1.
B1+W1+W2	0	Unusual			BB in B1.
B1+W1+W2	0	Unusual			
B1+W1+W2	0	Unusual			BB in B1.
B1+W1+W2	0	Unlikely	Both closed		
B1+W1+W2	0	Unlikely	Both closed		
B1+W1+W2	0	Unlikely	Both closed		
B1+W1+W2	0	Unlikely		Submerged 2 inches.	
B1+W1+W2	2	Unlikely	Both closed	Submerged 2 inches.	
B1+W1+W2	0	Unlikely	Both closed		
B1+C4+W2	0	Unusual			DET in C4.
B1+C4+W2	0	Unlikely		Submerged 2 inches.	DET in C4.
B1+C4+W2	0	Unlikely		Submerged 6 inches.	DET in C4.
B1+C4+W2	2	Unlikely	Both closed		DET in C4.
[e] S3A+W1+W2+W5	0	Unlikely			DET/fwdu in S3A.
S3A+W1+W2+W5	4	Unlikely	Both closed		
[e] S3A+W1+W2+W5	0	Unlikely			DET/fwdu in S3A.
[e] S3A+W1+W2+5	0	Unlikely			fwdu in S3A.
[e] S3A+W1+W2+W5	0	Unlikely			DET/fwdu in S3A, PD in W1.
S3A+W1+W2+W5	5	Unlikely	Both closed		
S3A+W1+W2+W5	4	Unlikely	Both closed		
C4+W1+W2+W5	0	Unlikely			DET in C4, PD in W1.

[a] Reduced by 1 in from full-seal depth.
[b] Open unless otherwise noted.
[c] fwdu = food-waste-disposal-unit.
DET = granulated detergent.
PD = paper diaper.
BB = bubble bath.
[d] S3A = fwdu compartment of double-bowl sink.
S3B = non-fwdu compartment of double-bowl sink.
[e] fwdu utilized all four runs.

4.3. Discussion

Performance of the trap-seals with reduced-size vents and with both the main and sink vent terminals open was completely satisfactory. As mentioned in the last section and shown in tables 9 and 10, the trap-seal reduction did not exceed 1 in except for loads of at least three fixtures with the vent terminals closed—a case of severe loading that would be unlikely to occur under normal conditions. The low air flow rates and associated mild suctions measured are further evidence that actual air demands in the various elements of the venting network were less than commonly assumed, even for heavy loads. The highest (2-run average) rate measured in the main vent terminal in the present study was only 83 gpm (test 18 of table 9).

Significant trap-seal reduction i.e., failures or near failures, were observed only in the tests where both vent terminals were closed. The data on failures, when they occurred, show that the P-traps were more subject to failure than the water closet traps. The direct correlation for peak (0.2 s) vent suction and the trap-seal reduction dH is given in figure 9 for single-run and cumulative dH for P-traps. The greater total effect for cumulative dH was expected. The results show that peak (0.2 s) vent suction of about 1.8 in W.G. produced a cumulative dH of about 1 in. The data support the use of a design pressure drop in vents of 1.5 in W.G. for P-traps subject to suction, rather than the 1.0 in W.G. suction specified in the current codes.

The severity of the pneumatic effects in some tests with the vent terminals closed was dependent not only on the magnitude of the discharge rate of water, but also on the number of potential air circulation paths (within the network comprised of the various vents and the building drain) that were restricted by the concurrent discharges of the fixtures (see figure 9). For example, a discharge of B1+W1+W2 that had not produced a failure with the vent terminals closed or with the drain submerged did produce a failure (see test 15 of table 10) when the drain was submerged and the vent terminals were closed at the same time. This indicates that both the vents and the building drain of this system were important elements of the air circulation network. Other tests indicated that significant venting could have taken place through the building drain. For a discharge of four fixtures, the most fixtures used in a test, the measured water depth in the building drain did not exceed 2.4 in (see tests 37–39 in table 9). Most importantly, none of the tests with the building drain submerged produced a failure, showing that flooding the building drain in service to the level produced in these tests, would not affect the satisfactory operation of this particular system as long as the vent terminals were open.

Height of water fall as a factor in air demand produced by an operating fixture is shown by data (see tests 3, 4, 6 in table 9) where a second-story water closet produced an air flow rate in the main vent terminal of 26 gpm, but the first-story water closet in a separate test produced only 8 gpm in the same terminal. The effect of stack length (height of water fall) on air demand has also been observed in other studies [6, 12]. In the present investigation, air circulation within the vent-drain network, with the main vent terminal closed, is thought to have furnished the air required by the operating fixture since the suction in the vent was not significantly different than that measured for the same fixture with the vent terminal open (see tests 3–5, for a W5 first-story discharge, and 6 and 7 for a W2 second-story discharge).

As expected, closing the individual vent terminal serving the sink did not have an effect on the performance of the fixtures served by the main vent network. This is shown by tests 18–21 in table 9 where closing only the main vent terminal produced trap-seal failures whereas closing only the individual vent terminal serving the sink did not.

Although a high peak (0.2 s) value, 5.95 in W.G. (2-run average) of vent suction was measured right at the beginning of the run(s) in the individual sink vent when the food-waste-disposal-unit was operated with the terminal closed, trap-seal retention was nevertheless adequate (see test 2 of table 9). This is attributable to the discharge from the relatively flat-bottomed sink which would have refilled the (active) trap. Also, modern food-waste-disposal-units produce lower discharge rates than the early-model one which was used, and hence the momentary peak suction would be less.

Thus, results on the two-story full-scale system are a clear indication of the adequacy of trap performance with reduced-size vents. The fact that four of the discharge combinations of 1, 2, and in one case 3 fixtures, produced no excessive trap-seal reduction even with the vent terminals closed shows that there was sufficient air in the vent network to satisfy operation of the fixtures as long as not more than two vents were blocked by discharging fixtures. There were no failures among the tests run with the building drain submerged except for the case where both vent terminals were closed also. The results indicate that with realistic loads, the system would have performed adequately with even smaller vents except when the vent terminals were closed.

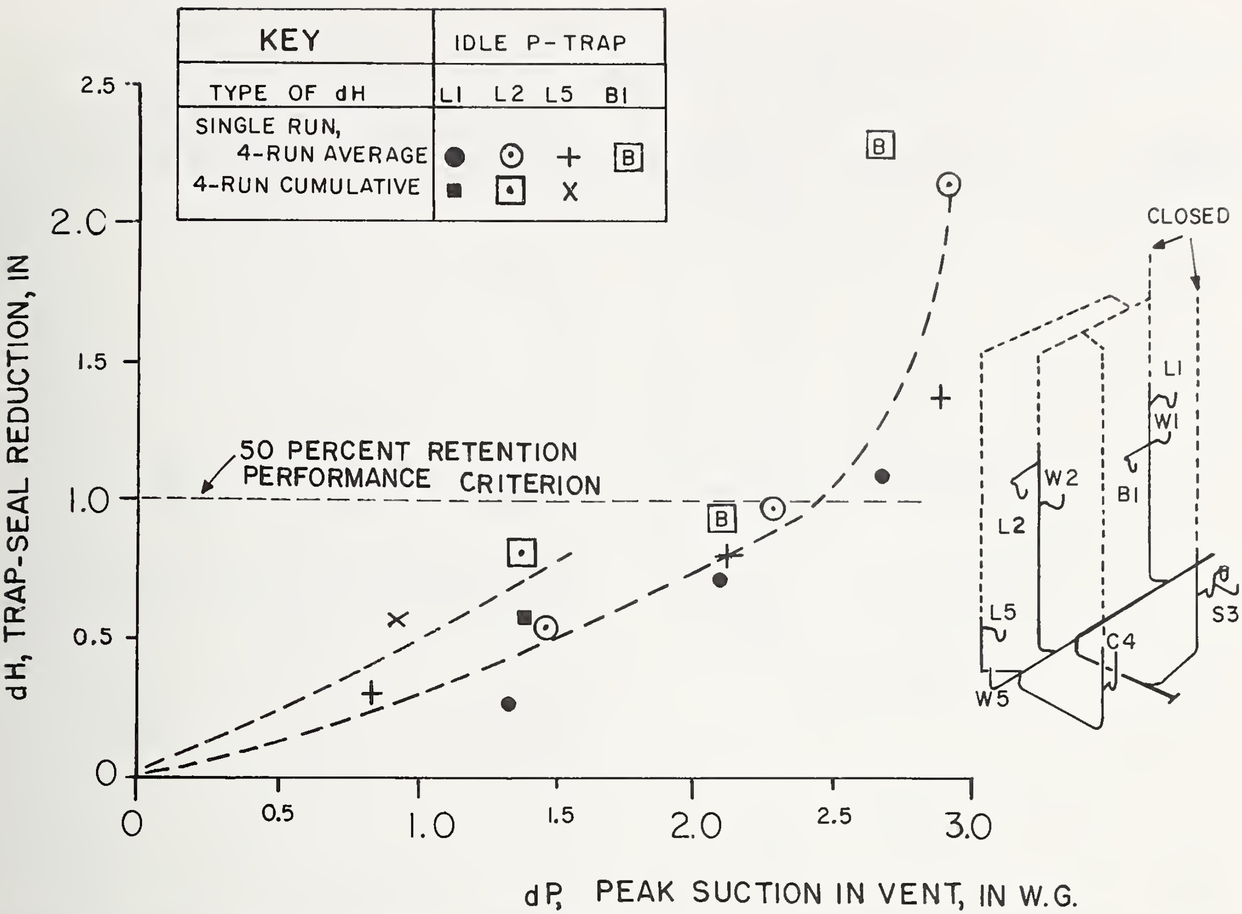


FIGURE 9. *Relationship between* dP *(peak 0.2 s suction) and* dH *(trap-seal reduction) in idle P-traps in the townhouse DWV system, with closed vent terminals. (Data is taken from table 9: tests 22, 30, 33, and 40.) The six* dH *data points below* dP=*1.5 in W. G. are results from two tests of a hydraulic load of B1+W1+W2 (involves two stacks); the four* dH *data points between* dP=*2.0 and 2.5 in W. G. are results from a test of a hydraulic load of C4+W1+W2 (involves three stacks); the four* dH *data points above* dP=*2.5 in W. G. are results from a test of a hydraulic load of S3+W1+W2+W5 (involves four stacks).*

5. Summary and Conclusions

In this study, the hydraulic and pneumatic performance of a two-story full-scale DWV system with RSV has been evaluated utilizing modern measurement techniques in a wide variety of tests. On the basis of this investigation and the earlier NBS work (see [13] and Section 4 of [7]), criteria for sizing dry vents for general application in 1–2 story housing systems are given in table 12. In the utilization of the recommended criteria, engineering judgment may be required in some special instances to carry out the intent of the criteria. Appendix A should be reviewed, also. It describes the procedure for application of table 12, and shows the results of its utilization with the system studied in this investigation. In addition, the sizing criteria in table 12 are recommended for RSV installation under competent engineering direction. For a detailed discussion involving climate and important details of installation, see Appendix B.

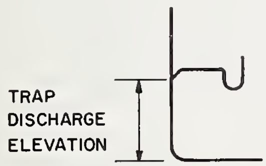
TABLE 12. *Recommended criteria for selecting dry-vent sizes for 1-2 story sanitary drainage system* [a]

SIZING SEQUENCE	SELECTION CRITERIA			MINIMUM VENT SIZE (nominal pipe diameter)
	Function of vent	Elevation of trap [b] (determines distance of water fall)	Maximum load [c] (served by vent)	
First	[d] *FIXTURE VENTS:*	*ft*	*FU*	*in*
	Individual (serves single trap).	Up to 8	1 to 3	½.
			4 to 6	¾.
		8 to 16	1 to 3	¾.
			4 to 6	1.
	Common (serves two traps).	Up to 8	1 to 3	¾.
			4 to 6	1.
		8 to 16	1 to 6	1.
	Stack vent (Main vent at top of a soil or waste stack).	Up to 8	1 to 6	1.
			7 to 15	1¼.
			16 to 30	1½
		8 to 16	1 to 6	1¼.
			7 to 15	1½.
			16 to 30	2.
Next	[e] *CONFLUENT VENTS:*			
	For two fixture vents	Not applicable	Not applicable	One pipe size larger than the largest fixture vent served.
	For three fixture vents	Not applicable	Not applicable	[f] In most cases. increase one pipe size over largest fixture vent served.
	For four or more fixture vents.	Not applicable	Not applicable	[g] Area of pipe selected must equal or exceed the value computed from: $A_{CONFLUENT} = \sqrt{A_{LARGEST} \cdot \Sigma A_{SERVED}}$
Last	[h] *ARTERIAL VENT:*			
	Vent stack, or Stack vent serving as a relief vent	Not applicable	10	1¼ (36 ft max).
			10	1½ (120 ft max).
			30	1¼ (30 ft max).
			30	1½ (100 ft max).

[a] This table may also be applied to 3-level split configurations in which the total height of water fall between the highest fixture and the main building drain does not exceed 16 ft.

[b] Elevation of trap above first lower (vented) horizontal fixture branch, (vented) soil or waste stack offset, or building drain branch that serves the trap.

Figure A



[c] Fixture unit values for usual plumbing fixtures found in residences [2]. For consistency, these values should be used for sizing the dry vents. The applicable code values, even if different from those given below, may be used for sizing the wet piping.

Common symbol	Fixture	Load
		FU
P–1	Tank WC	4
P–2	Lavatory	1
P–3	Bathtub	2
P–4	Shower	2
P–5	Sink w/fwdu and DWM	3
P–6	Clothes washer	3
F.D	Floor drain	3

[d] *Fixture vent:* Any single vent that provides the sole or primary ventilation for a trap or group of traps located at the base of the vent. These sizes are valid for vent lengths up to 25 ft. For longer lengths, increase by one pipe size.

[e] *Confluent vent:* A vent pipe that serves two or more fixture vents.

[f] Exceptions requiring two pipe size increase:

(Three) fixture vents served			Confluent vent
in	*in*	*in*	*in*
1	1	1	1½
1¼	1¼	1¼	2
¾	1	1¼	2
¾	1¼	1¼	2
1	1	1¼	2
1	1¼	1¼	2
1½	1½	1¼	3
1½	1½	1½	3

[g] Cross-sectional areas by which to calculate confluent vent size using the square-root formula are as follows:

Nominal diameter pipe	Internal cross-sectional areas		
	Schedule 40	Copper tube	
		M	DWV
in	*in*^{2}	*in*^{2}	*in*^{2}
½	0. 304	0. 254	
¾	0. 533	0. 517	
1	0. 864	0. 874	
1¼	1. 495	....	1. 317
1½	2. 036	....	1. 865
2	3. 355	....	3. 272
3	7. 393	....	7. 235

[h] These sizes (a one-pipe-size reduction derived from table 14 of [1]) are on the basis that significant pressure relief occurs through the building-drain and building-sewer route, significant circulation occurs in the branches of the vent network, and air demand is minimal in short stacks. If flooded sewer conditions are anticipated, the arterial vent size, obtained as indicated, should be increased one pipe size.

Because the sizing and installation procedures for reduced-size venting are unlike those now used for the venting of traditional DWV systems, the procedures (see table 12, its footnotes, Appendix A, and Appendix B) should be thoroughly understood by designers and installers responsible for applying the recommendations to a set of conventional specifications and drawings. The sizes of the "dry" fixture and confluent vents obtained from the recommended procedures are intended to apply to either a wet vented, individually vented, or stack vented system, upward from an elevation at least 6 in above the flood rim of the highest fixture served by the vent. If analysis of the system indicates significant potential for the rise of waste water to a higher level in the event of drain-pipe stoppage, then the vent should be standard size to this elevation (e.g. possibly in the case of a single-bowl kitchen sink with a food-waste-disposal-unit).

In the (table 12) sizing sequence, the primary elements, or *fixture vents*, are sized first. A fixture vent provides the primary or sole ventilation for a trap or group of traps located at the base of the vent. Where two or more fixture vents are connected, the joint pipe is sized in the next step as a *confluent vent* by means of a square-root formula which relates the sum of the areas of the fixture vents served to that of the confluent vent. Last in the sizing sequence is a consideration of the air circulation in the system as a WHOLE. The *arterial vent* sizing criteria apply to DWV systems more than one story and are intended to provide circulation and back-pressure relief in multi-story systems. The arterial vent may be one of the stack vents of a system comprising two or more drainage stacks, that is chosen to serve as a (building drain back-pressure) relief vent; or it may be a separate vent stack, depending on the particular overall configuration of the DWV piping.

It is recognized that further laboratory work on air circulation patterns along with a better correlation of *design* air flow rates and pressure limits with system *performance* in terms of trap-seal stability and system geometric variations (e.g. horizontal offsets in drainage stacks, fitting shapes, and vent stack design) would result in further size definition of the various vent types addressed by the table 12 criteria. This would broaden the criteria and contribute to the development of a rigorous, generalized, mathematical model for reduced venting.

The current study has provided not only practical evidence in terms of acceptable trap-seal performance under tests simulating adverse service conditions, but also fundamental evidence of the excessive present design criteria as the reason for the good performance of the system under operating conditions. Present design criteria have been developed principally from continuous flow experimentation and the assumption of static relationships. It has been shown experimentally in this study that, based on 0.2 s peak values, the widely held assumption that a fluctuating suction of 1 in W.G. is roughly equivalent to 1 in trap-seal reduction is erroneous.

Data obtained using the new capability for dynamic measurement showed that trap seals were safe under dynamic peak (0.2 s) suctions of 1.5 in W.G. Tolerance to high momentary suction values is greater when the pressure is rapidly fluctuating. In addition, the high momentary (shorter than 1 s) suction values such as those reported here are believed representative of normally operating residential plumbing fixtures. Different criteria may prevail, however, for a load that produces "sustained" (over 1 s or longer) peak pressure levels. These criteria are under development as part of the general computational method, referred to in section 1.2.

In the current investigation, data have confirmed and expanded the earlier findings with regard to the reduced air demand in short stacks (versus air demand in tall stacks on which the estimates are traditionally based). It is believed, furthermore, that the additional benefits of reduced air demand at slight suctions e.g. 1.0 or 1.5 in W.G. (versus air demand at atmospheric pressure) and of reduced air demand in some elements of vent networks attributable to circulation (versus air demand assuming that the demands by multiple operating fixtures are uni-directional and additive) which contributed to the favorable performance of RSV in systems with short stacks, would contribute importantly to favorable performance of RSV in tall-stack (high-rise) systems. Delineation of these criteria under dynamic conditions is an essential part of the development of the general computational method.

Although eliminating the air circulation path through the building drain by submergence of the drain in the system tested did not compromise the performance of this system with the vent terminals open, it is recommended that in the utilization of RSV, the building drain (and building sewer) should be large enough that it would not completely fill with water under normal service conditions. It is believed that building drains and building sewers sized according to the codes would provide this capacity. Because of limited knowledge of the possible effects of submerged sewers on various designs of RSV systems, RSV is not recommended where frequent occurrence of sewer backwater is anticipated. The present investigation has indicated that the building drain is an important element of the air circulation path within a vent network system.

Field studies provide the opportunity, greatly needed, to document plumbing loads and performance in real systems. It is anticipated that, in the long-range program, field trials will be utilized. This could furnish a realistic basis for improved selection of test loads in the laboratory and of performance limits in design computations. For RSV field trails, these should incorporate measurements of street sewer pressure to determine if any criteria for this parameter will be needed should RSV become extensively utilized in one community. It has been assumed in this study that street sewer (pneumatic) pressures in residential communities are usually sufficiently close to atmospheric so as to preclude adverse effects on fixture traps in RSV systems.

The authors wish to acknowledge important contributions made by the following persons: John R. Schaefgen who helped with the instrumentation and laboratory work on the component stack and the programming needs of the tests; Daniel E. Rorrer who assisted in mapping out the utilization of the data acquisition system; DeForest Z. Rathbone for coordinating some of the test procedures in the townhouse tests to account for precision in terms of service conditions and construction parameters; Grover C. Sherlin who helped with the organization and mode of presentation of the data; and Jack E. Snell for his many helpful suggestions for clarity in the presentation and interpretation of complex technical ideas in the context of the performance approach. In addition, we wish to thank Donald F. Dickerson, a professional plumbing engineer, Dickerson/Gladstone/Associates, Van Nuys, California, for consultation contributing to the clarity of the presentation of the table 12 sizing criteria.

The present support, by the Directorate of Civil Engineering, Headquarters U.S. Air Force, of a field application of the laboratory findings to design has resulted in improved usefulness of the criteria reported. The performance data to be measured in this field study at Andrews Air Force Base, Maryland are to be the subject of a later report.

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Appendix A. Sizing Reduced-Size Vents, Procedure and Examples

A.1. General Approach

It is recommended that the piping schematic first be marked with applicable fixture unit ratings by fixture. The sizing sequence, using table 12, is:

STEP 1—Fixture vents
STEP 2—Confluent vents
STEP 3—Arterial vent

It is important to identify on the DWV piping schematic the various vent types given in table 12. A *fixture* vent is a vent pipe that provides the sole or primary ventilation for a trap or group of traps located at the base of the vent. A *confluent* vent is a vent pipe that serves two or more fixture vents. The fixture vents need not all join the confluent vent at a single point. That is, confluent vents should be sized on the basis of the fixture vents served, not on the basis of the branch vents that may connect directly to the confluent vent. For example, figure A.1 shows that Confluent Vent 2 serves Fixture Vents 1, 2, and 3 which do not all connect at the same point.

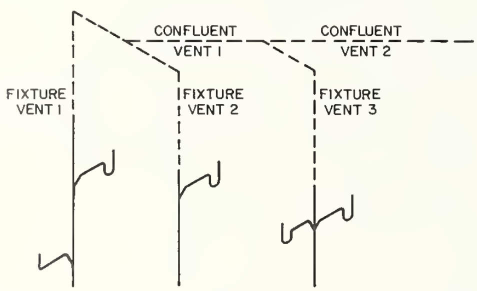


FIGURE A.1 *Schematic showing fixture and confluent vents.*

The *arterial vent* (applicable only to systems greater than one story) may be recognized as the main artery of the vent system serving other vents and as the most direct route for the relief of potential back pressure in the building drain.

A.2. Example of Use of Table 12 to Size RSV

Sample calculations of how the vents in the townhouse system were sized, step-by-step, are as follows:

STEP 1—Fixture vents. The appropriate fixture-unit loads for single fixtures were obtained from the National Standard Plumbing Code [2], for the fixtures in the townhouse system, as listed in footnote c of table 12. From this, the connected fixture-unit load by stack was determined as listed in table A.1 for the five stacks. From the geometry of the system however, W5 was considered to be vented equally through stacks 4 and 5. On this basis, the FU loads vented by these two stacks were recalculated as listed in table A.2.

TABLE A.1. *Connected fixture-unit load by stack*

Stack designation	Fixtures	Load
		FU
1	L1+W1+B1	7
2	L2+W2	5
3	S3	3
4	C4	3
5	L5+W5	5

TABLE A.2. *Estimated fixture-unit loads vented through stacks 4 and 5*

Stack designation	Fixtures	Load
		FU
4	C4+½W5	5
5	½W5+L5	3

The results of the determination of the FU loads for the five stacks are shown in figure A.2. Fixture-unit loads considered to be *vented* through each stack are shown, rather than the loads *connected.* The DWV vent piping is standard size to 6 in above the fixture flood-rim level.

To complete *STEP 1*, the early tentative criteria [5,7] (now incorporated in table 12) were utilized to size the fixture dry vents for stacks 1–5. This produced the sizes shown in table A.3.

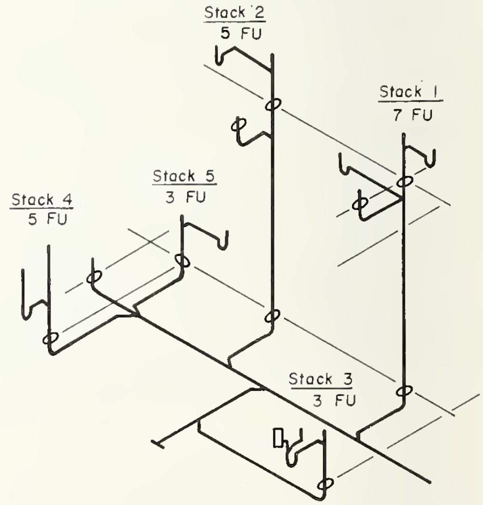


FIGURE A.2 *Schematic showing Fixture Unit loads vented through each stack.*

Table A.3 *Fixture dry vent sizes for townhouse system*

Stack designation	Selection Criteria			Normal pipe size
	Fixture vent type	Elevation of trap(s)	Load	
		ft	*FU*	*in*
1	Stack vent....	8 to 16.......	7	1½
2	Stack vent....	8 to 16.......	5	1¼
3	Individual....	Up to 8......	3	½
4	Common.....	Up to 8......	5	1
5	Common... .	Up to 8......	3	¾

STEP 2—Confluent vents. As an aid to the computation of sizes for confluent vents, figure A.3 was prepared showing, not only the sizes for the fixture dry vents, but also the unsized elements X, Y, and Z, (the vent header). The sizes for these elements were determined by computation using the square–root relationship given in table 12, and selecting the next larger pipe size from footnote g of table 12. The relationship is:

$$A_{CONFLUENT} = \sqrt{A_{LARGEST} \cdot \sum A_{SERVED}} \qquad \text{(A.1)}$$

where

$A_{CONFLUENT}$ = theoretical internal cross-sectional area required in the confluent vent

$A_{LARGEST}$ = actual internal cross-sectional area for the largest fixture vent served by the confluent vent

$\sum A_{SERVED}$ = sum of actual internal cross-sectional areas of all the fixture vents served by the confluent vent

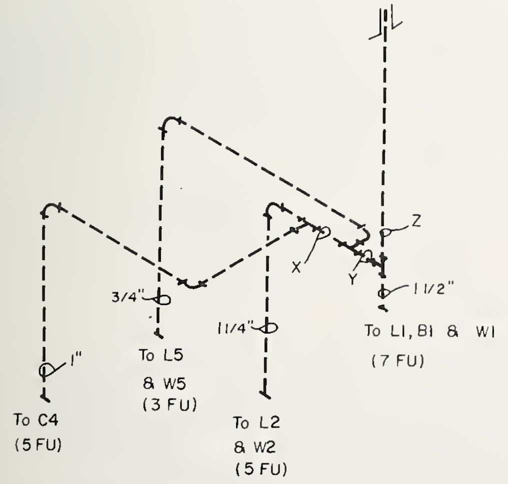


Figure A.3 *Schematic showing four fixture vents and three confluent vents (X, Y, and Z) for the townhouse system.*

Sizing confluent vents by eq (A.1) results in a one-pipe-size increase for all cases where two fixture vents (from ½ to 2 in) are served. Where three fixture vents (any combination of three of ½ to 2 in) are served, eq (A.1) produces eight exceptions to a one-pipe-size increase. These require a two-pipe-size increase over the largest fixture vent served and are listed as footnote f of table 12. For confluent vents serving four or more fixture vents, the confluent vent size should always be calculated by use of eq (A.1).

Confluent vent sizing of X, Y, and Z, the elements of the vent header of the townhouse system, is tabulated in table A.4. This completes *STEP 2.*

Table A.4 *Confluent vent sizes for townhouse system*

Confluent vent	Nominal sizes of fixture vents served	Nominal size confluent vent	
	in		*in*
X	1, 1¼..........	Increase one size........	1½
Y	1, 1¼, ¾.......	Increase two sizes....... (see table 12, f)	2
Z	1, 1¼, ¾, 1½....	Use eq (A.1) area and select nearest larger commercial size...... (See table 12, g)	2

STEP 3—Arterial vent. Utilization of these sizing criteria to provide a pressure relief route for the building drain may take precedence over the sizes calculated for this route in *STEP 1* or *STEP 2.* For the NBS experimental townhouse system, the arterial vent was chosen as Stack 1. The FU load on the system was 23 FU, and a flooded sewer was not made a condition, thereby making the arterial vent size, 1½ in. This size was already the size of Stack 1 by *STEP 1*; the vent terminal size was 2 in by *STEP 2.* Thus no size change was called for to meet the 1½ size determined in *STEP 3.*

When the final vent sizes are determined as just described, a DWV piping schematic should be marked to complete the procedure.

A.3 Construction Note

Familiarity with the RSV sizing procedures and the rationale behind them is needed when they are applied to the on-site as-built wet piping configuration. This can be particularly important because construction constraints and other field conditions may result in on-site changes in the planned wet system that would require significant modifications in the planned sizing of the reduced-size dry vents.

Beyond the systematic sizing of RSV, special details of their installation are covered in Appendix B which follows at the top of the next page.

Appendix B. Installation Recommendations for Reduced-Size Venting in 1–2 Story Drain-Waste-Vent Systems

In the utilization of reduced-size venting for split level and one- and two-branch interval slab-on-grade or basement houses, it is important that several simple rules be observed by designers and installers, that are not necessarily relevant to traditional DWV systems:

1. Reduced-sizes should not be installed below a point approximately 6 in above the flood rim of the fixtures served. Vents for single-bowl sinks with food-waste-disposal-units should not be reduced below the elevation corresponding to the shut-off head of the unit. These measures are necessary to minimize the fouling or clogging effects of intermittent deposits of particulate matter in reduced-size vents over a period of time in normal service.

2. Reduced sizes should be used for dry vents only. Thus, wet vents or reaches of vents designed as dry vents, but nevertheless likely to be intermittently submerged or subjected to wetting by aerosols or suds, should be designed to conventional sizes.

3. In areas where frost closure may occur, vent terminals should be sized to account for the effects of local weather as explained by Manas and Eaton [14] and Eaton and Wyly [15]. The use of vent piping that has low thermal conductivity, or the use of some other means for reducing or counteracting natural heat loss might be employed to reduce the likelihood of frost closure. Reduced-size vents should not run through unheated spaces where frost closure is likely.

4. Vent terminals serving reduced-size vents should be fitted with durable, corrosion-resistant enlarged caps of screen having open areas greater than the cross-sectional area of the vent terminal, so as to provide an allowance for clogging of the screen and to prevent entrance of leaves and insects into the vent system. Probably an open area 50 percent greater than the area of the terminal is adequate.

5. All vent piping should be positioned, supported, and continuously graded so that condensation or other moisture will drain by gravity to (a) a soil or waste pipe, or (b) to an acceptable location outside the structure, provided that this solution is not employed in frost-closure-prone areas without suitable protection against freezing.

6. Reduced-size vents should be made of material that does not contribute to substantial reduction in diameter from scale formation or other causes under ordinary conditions of use.

7. Use manufacturer's recommendations on fittings for making size changes, for the materials selected for the pipes, fittings and joint systems, and for installation procedures.

Appendix C. Units of Measure and SI Conversion Factors

The results of the investigation described herein are reported primarily in U.S. customary units, for two reasons: first, most of the instrumentation used was calibrated and graduated in U.S. customary units and, second, the results of this research are directed to those groups who ordinarily use these units.

However, in recognition of the increasing importance of international standards in foreign commerce and of international technical committee activity in plumbing technology, it is recommended that those who utilize the results of this work assume the responsibility for appropriate conversion to International Standard (SI) units, recognized by the USA in 1960 as a signatory to the General Conference of Weights and Measures which gave official status to the metric SI system of units. For this purpose, the following conversion factors are given applicable to the U.S. customary units used in this paper:

Force

1 pound-force (lbf) = 4.48 newtons (N)

Length

1 inch (in) = 0.0254* meter (m), or 25.4* millimeters (mm)

1 foot (ft) = 0.3048* meter (m), or 30.48* centimeters (cm)

Volume

1 gallon [U.S. liquid] (gal) = 3.785 liters = 3.785×10^{-3} meters^3 (m^3)

1 cup [U.S. dry] (c.) = 0.2753 liters

Volume/Time

1 gallon [U.S. liquid] per minute (gpm) = 6.309×10^{-2} liters per second

Pressure

1 newton per meter^2 (N/m^2) = 1* pascal (Pa)

1 psi = 1* (lbf/in^2) = 6895 pascal (Pa) = 6.895k Pa

1 inch water gage (in W.G.) [at 60 ° F] = 248.8 pascal (Pa)

Area

1 in^2 = $6.4516^* \times 10^{-4}$ meter^2 (m^2), or 6.5416* centimeter^2 (cm^2).

Prefix

k = times 1000

*By definition.

Conversion charts for units of air flow, and for pneumatic and hydraulic pressure used in this paper are given in figure C.1, opposite, as a convenience to readers who may wish to convert between units systems.

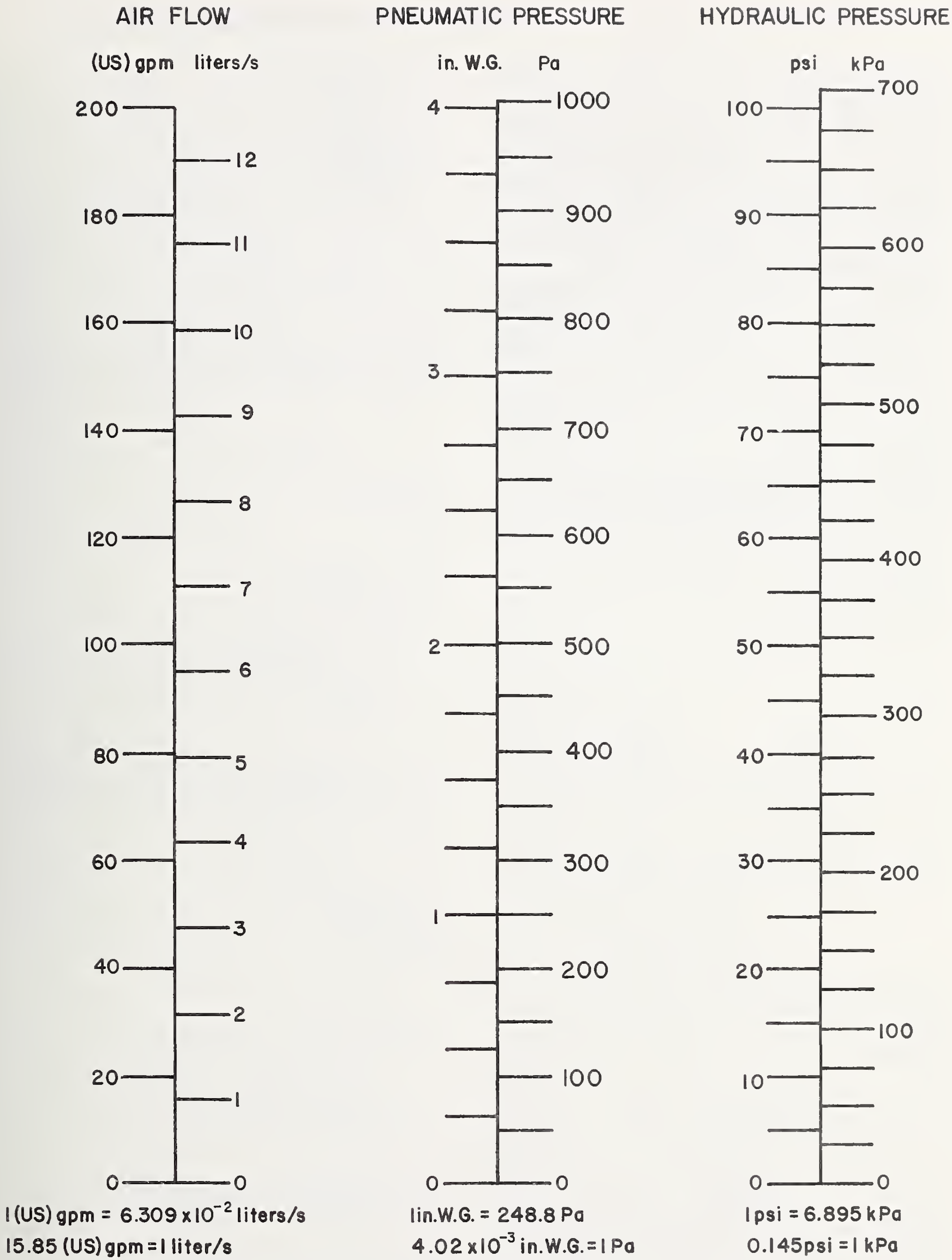


FIGURE C.1 *Conversion charts for air flow, pneumatic pressure and hydraulic pressure.*

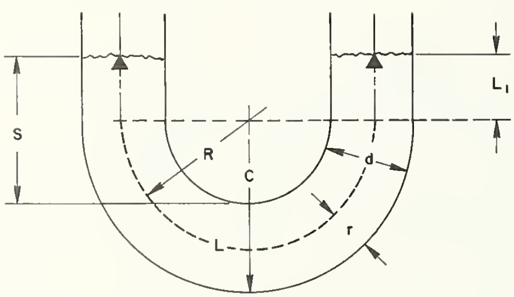
Appendix D. Determination of Time Increment for Data Averaging

To take advantage of the capability of the DAS for averaging rapidly changing phenomena, some rationale was needed to select an appropriate increment. As an aid to the selection of an appropriate value, it was decided to utilize the formula for computing the undamped natural frequency of oscillation of a liquid in a U-tube [16]. The phenomenon is similar to that in a plumbing fixture trap partially filled with water.

An averaging period of ¼ the natural frequency was then chosen, arbitrarily, on the basis that the trap seals could not readily respond to very short transients because of inertia. Selection of too large an averaging period, on the other hand, would result in misleadingly low values, much less than those of the shortest transients to which the trap seals could respond.

The same increment, 0.2 s, was used for all the experimental work. Considering the arbitrary choice of a ¼ cycle, it was convenient to keep the increment fixed to reduce variability in the data due to different averaging periods.

Calculations of ¼ the natural frequency for three sizes of trap follow:



ASSUMED TRAP GEOMETRY

FIGURE D.1 *Assumed trap geometry.*

FORMULAE

$$L_1=(S+d)-(R+r) \qquad \text{(C.1)}$$

$$L=\frac{2\pi R}{2}+2L_1 \qquad \text{(C.2)}$$

$$f=\frac{1}{2\pi}\sqrt{\frac{2g}{L}} \qquad \text{(C.3)}$$

where $g=386$ in/s^2; L=length of trap seal, in

$$t=1/f \qquad \text{(C.4)}$$

where f=natural "slosh" frequency, Hz; and t=time for one cycle, s.

CALCULATIONS

For $d=1½$ in

S (assumed) $=2$ in

R (assumed) $=(C-r)=2½-¾=1¾$ in

$$L_1=(2+1½)-(1¾+¾)=3½-2½=1 \text{ in} \qquad \text{(C.1)}$$

$$L=\frac{2\pi R}{2}+2L_1=5.498+2=7.498 \text{ in} \qquad \text{(C.2)}$$

$$f=\frac{1}{2\pi}\sqrt{\frac{2g}{L}}=0.159\sqrt{\frac{2\times 386}{7.498}}=1.613 \text{ Hz} \qquad \text{(C.3)}$$

$$t=\frac{1}{f}=\frac{1}{1.613}=0.620 \text{ s} \qquad \text{(C.4)}$$

$$\frac{t}{4}=0.155 \text{ s}$$

For $d=2$ in

S (assumed) $=2$ in

R (assumed) $=(C-r)=3-1=2$ in

$$L_1=(2+2)-(2+1)=4-3=1 \text{ in} \qquad \text{(C.1)}$$

$$L=\frac{2\pi R}{2}+2L_1=6.283+2=8.283 \text{ in} \qquad \text{(C.2)}$$

$$f=\frac{1}{2\pi}\sqrt{\frac{2g}{L}}=0.159\sqrt{\frac{2\times 386}{8.283}}=1.535 \text{ Hz} \qquad \text{(C.3)}$$

$$t=\frac{1}{f}=\frac{1}{1.535}=0.651 \text{ s} \qquad \text{(C.4)}$$

$$\frac{t}{4}=0.163 \text{ s}$$

For $d=3$ in

S (assumed) $=3$ in

R (assumed) $=(C\text{-}r)=4½-1½=3$ in

$$L_1=(3+3)-(3+1½)=6-4½=1½ \text{ in} \qquad \text{(C.1)}$$

$$L=\frac{2\pi R}{2}-2L_1=9.425+3=12.425 \qquad \text{(C.2)}$$

$$f=\frac{1}{2\pi}\sqrt{\frac{2g}{L}}=0.159\sqrt{\frac{2\times 386}{12.425}}=1.253 \qquad \text{(C.3)}$$

$$t=\frac{1}{f}=\frac{1}{1.253}=0.798 \text{ s} \qquad \text{(C.4)}$$

$$\frac{t}{4}=0.199 \text{ s}$$

Appendix E. Definitions, Acronyms, and Symbols

1. *Active trap*—Trap of a fixture discharged at the beginning of a run.
2. *Additives*—Materials added in some of the townhouse tests including paper diapers, bubble bath, and detergents; operation of the food-waste-disposal-unit in the sink.
3. *Averaging period*—Time period selected for measurement for which the computer data acquisition system will retain a single value representing an average value of the many values scanned for that period. The value selected, 0.2 s in this work, was input to the computer for each channel (for each transducer) before taking data. (In this case the averaging period used was the same for all the channels but this is not required by the data acquisition system.)
4. *B1*—Bathtub on stack 1.
5. *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.
6. *Branch*—Any part of the piping system other than a main, riser, or stack. (Usually branches are horizontal.)
7. *Branch interval*—Distance between two branches, usually about 10 feet, corresponding to the distance between stories in a building.
8. *Building* (verb)—In the context of this report, the word "building" refers to the process of design and installation.
9. *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 beginning 3 ft outside the building wall.
10. *Building sewer*—That part of the drainage system which extends from the end of the building drain and conveys its discharge to a public sewer, private sewer, individual sewage disposal system, or other point of disposal.
11. *C4*—Clothes washing machine on stack 4.
12. *CI*—Cast iron.
13. *Cleanout plug*—Screw plug in a fitting to facilitate entry of mechanical cleaning tools.
14. *Common vent*—A vent serving two fixtures.
15. *Component stack*—Simple one-stack system of this study (a partial DWV system).
16. *Confluent vent*—A vent pipe that serves two or more fixture vents.
17. *Crossflow*—The movement of waste water from the trap of an active fixture to the trap of an idle fixture.
18. *Cumulative dH*—Trap-seal reduction after four runs under identical conditions without refilling traps of fixtures between runs.
19. *DAS*—Data acquisition system.
20. *dH*—The amount of decrease in trap-seal depth from full-seal depth.
21. *dP*—Maximum value of vent pressure suction obtained during a run for a selected averaging period (0.2 s in this study).
22. *Drainage stack*—A soil or waste stack.
23. *Dry venting*—The arrangement of drainage piping such that only air passes through the vents.
24. *DWV*—Drain-waste-vent.
25. *Failure*—Trap-seal reduction of at least 1 in.
26. *Fixture-discharge load*—The hydraulic load of (from one to four) active fixtures discharged at the beginning of a run.
27. *Fixture vent*—Any single vent pipe that provides the sole or primary ventilation for a trap or a group of traps located in the proximity of the base of the vent.
28. *Flushometer valve*—A device which by external actuation discharges a predetermined quantity of water to a fixture for flushing purposes and which involves an internal automatic operating cycle energized by direct water pressure.
29. *FU*—Fixture unit. A number assigned to plumbing fixtures that is used as a measure of the probable peak demand on the water supply system or peak discharge into the drainage system.
30. *fwdu*—Food-waste-disposal-unit in one compartment of the double-compartment kitchen sink on stack 3.
31. *Idle trap*—Trap of a fixture not discharged during a run.
32. *Individual vent*—A pipe 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 (not part of a vent header).
33. *Induced siphonage*—Phenomenon of the reduction in trap-seals of idle fixtures caused by the discharge of active fixtures.
34. *L1*—Lavatory on stack 1.
35. *L2*—Lavatory on stack 2.
36. *L5*—Lavatory on stack 5.
37. *P trap*—Descriptive term for type of trap which resembles the letter P on its side and is found on waste fixtures such as lavatories and sinks (distinct from water closets which have integral traps).
38. *pascal*—SI unit of pressure measurement that equals 1 N/m^2 by definition, equals also 4.02×10^{-3} in W.G. (see Appendix C).
39. *Piezometer*—A device for the measurement of pressure in pipes consisting of a vertical transparent tube which is connected at its lower end to an orifice in the wall of the pipe (at 90 degrees and carefully finished at the inner edge of the hole) and is open to the atmosphere at its upper end. The height to which the fluid rises in the transparent tube is a measure of the head or pressure in the pipe.

40. *PRL*—Plumbing Research Laboratory.
41. *PVC*—Polyvinyl chloride.
42. Q_a—Maximum value of the air demand flow rate obtained during a run for a selected averaging period (0.2 s in this study).
43. *RSV*—Reduced-size vents.
44. *Run*—A complete hydraulic event, e.g., a water closet flush.
45. *S3*—Kitchen double-compartment sink on stack 3.
46. *Self-siphonage*—Phenomenon of reduction in trap seal in a fixture after discharge, caused solely by operation of that fixture.
47. *Service parameters*—Factors intended to simulate normal and severe in-service conditions: additives, closed vent terminals, flooded building drain.
48. *Short stack*—A drainage stack in which the maximum height of (water) fall does not exceed 20 ft measured with reference to the building drain or a vented horizontal offset at the base of the stack.
49. *Single-fixture flush test*—Flush of one water closet four times (4 runs) in the work on the component stack as distinct from a back-to-back flush test in which both water closets were flushed four times (4 runs).
50. *Single run dH*—Trap-seal reduction produced by a single run (in a series of four) under identical conditions, by filling the idle trap between runs.
51. *Soil stack*—A stack intended to convey sewage containing fecal matter to the building drain.
52. *Stack*—General term for any vertical line of soil, waste, vent, or inside conductor piping.
53. *Stack 1*—Soil stack serving a second-floor water closet, a bath, and a lavatory.
54. *Stack 2*—Soil stack serving second-floor water closet and a lavatory.
55. *Stack 3*—Waste stack serving first-floor 2-compartment sink with a food-waste-disposal-unit in one compartment.
56. *Stack 4*—Waste stack serving first-floor clothes washing machine.
57. *Stack 5*—Soil stack serving first-floor water closet and a lavatory.
58. *Stack vent*—The extension of a soil or waste stack above the highest horizontal drain connected to the stack.
59. *Submerged building drain*—A building drain in which a positive hydraulic head exists at the crown of the drain without the discharge of plumbing fixtures or appliances.
60. *Tall stack*—A drainage stack in which the maximum height of (water) fall is greater than 20 ft measured with reference to the building drain or a vented horizontal offset at the base of the stack.
61. *Test*—Four runs under identical conditions. Additives when used are used on the first and third runs of a test.
62. *Trap-seal reduction*—Same as *dH*.
63. *Trap-seal retention*—The amount of a trap-seal retained in relation to full-seal depth (commonly expressed as a percent).
64. *Trap weir*—The lowest point in the vertical cross-section of the horizontal waterway at the exit of the trap.
65. *Trapway*—Water passage way through a trap.
66. *Vent header*—A vent that joins together or serves two or more vents with the principal pipe being horizontal, see confluent vent.
67. *Vent stack*—A vertical vent pipe installed to provide circulation of air to and from the drainage system (usually the vertical main of a vent system in a multi-story design).
68. *W1*—Tank-type water closet on stack 1.
69. *W2*—Tank-type water closet on stack 2.
70. *W5*—Tank-type water closet on stack 5.
71. *W.G.*—water gage. A measure of pressure, with reference to atmospheric pressure, expressed in terms of equivalent height of water column (see Appendix C).
72. *Waste*—Liquid waste not including fecal matter.
73. *Waste stack*—A stack that conveys only waste.
74. *Wet venting*—The arrangement of the drainage piping such that the venting of some fixtures is provided by pipes that also serve intermittently as drains for other fixtures.

75. A Air flow demand sensing point.

76. D Depth measurement sensing point.

77. L Load cell.

78. P Pressure measurement sensing point.

79. W Water flow rate.

80. Z Trap ruler or piezometer location.

81.  Butterfly valve.

82.  Gate valve.

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report describes the experimental findings of tests on a full-scale two-story plumbing system with reduced-size vents under a range of operating conditions including tests with the vent terminals closed and the building drain submerged. Results indicate that dry vent piping in 1-2 story housing units can safely be smaller than presently allowed by design without jeopardizing the trap seals. On the basis of the current investigation and from earlier work on full-scale systems of substantially different geometry, criteria for sizing reduced-size vents are given for general application to conventional 1-2 story housing units. In addition to the practical evidence in terms of acceptable trap performance, the current study provided fundamental evidence of the excessive present design criteria. For the first time measurements were obtained which relate traditional design criteria (air flow and vent pressure) to presently recommended performance criteria (trap-seal retention) under dynamic conditions. These findings indicate that the vents can be sized on the basis of 1.5 in water gage (equals 372 pascals) suction in the vent rather than the 1.0 in W.G. (equals 248.8 Pa) presently specified in the plumbing codes. Also air demands measured were significantly less than assumed in current practice for short stacks and for systems with vent networks.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

DWV; performance testing; reduced-size vents; trap-seal retention; venting criteria; venting; vents, reduced-size

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