Wet Venting of Plumbing Fixtures

United States Department of Commerce

National Bureau of Standards

Building Materials and Structures Report BMS119

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Wet Venting of Plumbing Fixtures

by John L. French, Herbert N. Eaton, and Robert S. Wyly

Building Materials and Structures Report BMS119

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Foreword

This report on the wet venting of plumbing fixtures is the second of a series of three National Bureau of Standards reports giving the results of an investigation of the problems involved in the proper venting of single plumbing fixtures or a relatively small group of such fixtures, the first report being BMS118, Stack Venting of Plumbing Fixtures, published in January 1950. This investigation was sponsored by the Housing and Home Finance Agency as a part of the continued efforts of that Agency to secure rational and economical design of housing.

A fixture is said to be *wet vented* when its vent serves also to carry the discharge from fixtures connecting into the drainage system at a higher level. The use of wet venting reduces the number of individual vent pipes required by a plumbing drainage system as contrasted with the number required by the conventional back-vented system and hence reduces the cost of the venting system. This fact has led to an increasing tendency among code-writing authorities to permit the wet venting of plumbing fixtures under certain circumstances. One of the objects of this investigation was to determine under what circumstances it is legitimate to use this form of venting in order to afford a sound basis for code provisions relating to this matter.

Drainage pipes of various materials are referred to in this report as forming parts of one or more of the test systems constructed for use in the investigation. These materials were used merely because of their availability at the time when the systems were constructed, and the fact that they were so used should not be construed as constituting an approval or recommendation of those materials in preference to any other materials that might have been used.

The research forming the basis for this report was first undertaken for the National Housing Agency in connection with the Veterans Emergency Housing Program of that Agency and was continued and completed under the Housing Research Program of the Office of the Administrator, Housing and Home Finance Agency, as part of the research program of that Agency under its statutory authority.

E. U. Condon, *Director.*

Wet Venting of Plumbing Fixtures

John L. French, Herbert N. Eaton, and Robert S. Wyly

This report gives the results of laboratory tests of various wet-vented single and two-story plumbing drainage systems. A suggested test or design loading for such systems is developed, and a permissible trap-seal loss for the fixtures of wet-vented systems is proposed. Conclusions regarding the limits under which wet-vented fixtures located on the upper floor of a system will operate satisfactorily are given in a form sufficiently simple for inclusion in plumbing codes.

CONTENTS

I. Introduction

Plumbing fixtures ordinarily discharge into the building drainage system through traps located between the fixture and the fixture drain. The function of a fixture trap (see fig. 3) is to provide a water seal between the drainage system and the interior of the building in order that sewer gas in objectionable quantities will not flow from the drainage system into the building. The discharge of fixtures creates pressure fluctuations in the drainage system, which, if excessive, will reduce the water seals in the fixture traps and hence may render them unable to perform their function. In order to control the pressures in the drainage system so that the water seals of fixture traps will not be reduced excessively, vent pipes connecting various points in the drainage system with the atmosphere are ordinarily installed. The term *pressure* as used in this report refers to pressures either above or below atmospheric pressure.

The pressures in a drainage system that may affect the water seals of fixture traps adversely may be classified conveniently into two groups—pressures caused by the discharge of the fixtures connected to the fixture trap in question and pressures caused by the discharge of other fixtures in the system. The trap-seal losses caused by the first group are said to be due to self-siphonage, and, in order to control the trap-seal losses due to this cause, it is necessary to have the vent located relatively near the fixture trap. For this reason it is customary to provide some type of vent adequate for the protection of each fixture trap of a plumbing drainage system. However, in this connection the argument has been advanced that adequate protection of a fixture trap by a vent does not necessarily imply that each fixture trap requires a separate vent, and it has been suggested that various types of group venting, in which a single vent serves more than one fixture, provide adequate protection to fixture traps and provide an acceptable method of decreasing the cost of the plumbing system.

The venting of groups of fixtures by a single vent may take two basic forms. These are shown in figure 1. In the arrangement of figure 1, A, two fixtures connected at the same level to a vertical drain use the same vent. The vent in this case carries only air and is sometimes termed a *dual* or *common* vent. In figure 1, B, the upper fixture is vented in the conventional manner. Its vent carries only air and is the only type of vent permitted by many plumbing codes. However, the lower fixture in figure 1, B, does not have an individual vent that carries only air. Its vent is frequently termed a *wet vent* because it carries the discharge of the upper fixture, as well as whatever

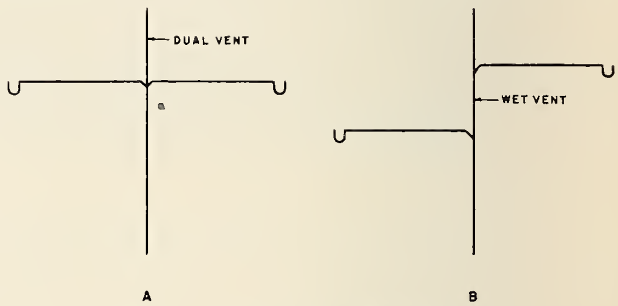

FIGURE 1. *Basic group-venting arrangements.*

air may travel along the pipe to relieve pressures at the lower fixture drain.

The use of wet vents has the general effect of reducing the number of individual vent pipes required by the plumbing drainage system as compared with the conventional back-vented system and for this reason results in a reduction in cost of the venting system. Because of the possible economies involved, there has been an increasing tendency among code-writing authorities to permit the wet venting of plumbing fixtures under certain circumstances. However, there has been no unanimity among these authorities as to the adequacy of wet venting, and many codes prohibit the use of wet vents altogether. For this reason the Uniform Plumbing Code Committee believed, in view of the economic advantages involved, that an experimental investigation of the merits of wet venting of plumbing fixtures was fully justified, and the Housing and Home Finance Agency sponsored such an investigation at the National Bureau of Standards. The purpose of this report is to present the results of that investigation.

II. Scope of Investigation

A great many variations in the basic wet-vented arrangement of figure 1, B, are possible. Some arrangements that are permitted by various plumbing codes are shown in figure 2. In this connection, it will be observed that the arrangement shown in figure 2, F, is of the type commonly referred to as a stack-vented installation. Current terminology in the plumbing industry loosely describes the group of fixtures in figure 2, F, as stack-vented, while in reality only the topmost fixture is stack-vented, and the three lower fixtures are wet-vented in the sense that the vent to the lower fixtures —in this case the stack —also carries waste from the upper fixtures. A report on stack venting has already been published [1][1], and hence it will not be considered further here.

[1] Figures in brackets refer to references at the end of this report.

The results of laboratory tests on installations containing the type of wet-venting shown in figures 2, A, 2, B, and 2, E, will be presented in this report.

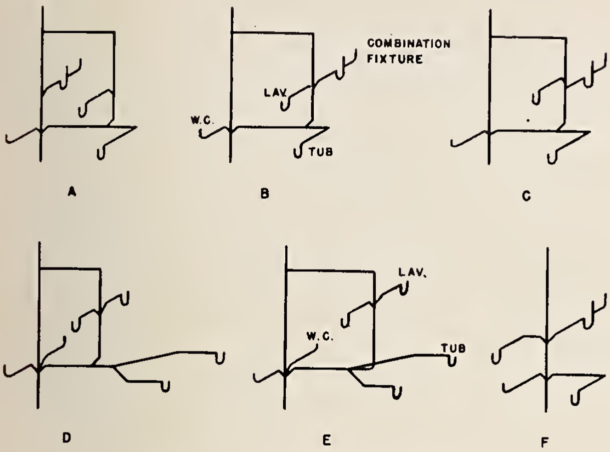

FIGURE 2. *Wet-venting arrangements.*

Since the function of the venting system is to prevent the occurrence of excessive seal losses in the fixture traps of the system, the efficiency of a venting system can be measured in terms of the trap-seal losses caused by the discharge of a particular group of fixtures. In this connection a trap-seal loss of 1 inch is sometimes [1, 2] considered the dividing line between satisfactory and unsatisfactory performance. Although this criterion of satisfactory trap performance, which has been based solely on personal judgment, is arbitrary and is undoubtedly overly conservative in all installations in which the stack, building drain, and venting systems are not loaded to capacity, it is nevertheless adequate for the purpose of this investigation and has been used throughout this report as the line of demarcation between satisfactory and unsatisfactory trap performance.

The specific problem of this investigation thus becomes one of determining the limitations on the lengths, slopes, and diameters of the drains in the installations of figures 2, A, 2, B, and 2, E, required to prevent the occurrence of trap-seal losses in excess of 1 inch, when a reasonable test loading consisting of the simultaneous discharge of a particular group of fixtures is applied to the system.

Although wet-vented fixtures may be used satisfactorily under certain conditions on all floors of a plumbing drainage system, the experimental investigation reported here was confined to wet-vented fixtures on the top floor of a building.

The terms *trap weir, trap-seal loss,* and *depth of trap seal* will be used frequently in this report, and their significance is shown in figure 3.

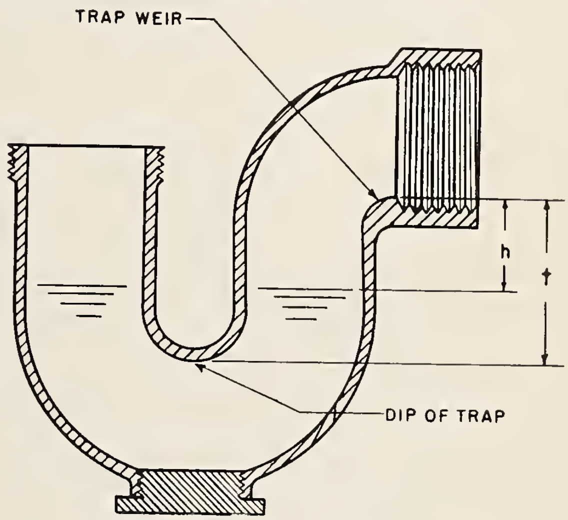

FIGURE 3. *Definition sketch of trap.*

h=trap-seal loss.
t=trap seal.

III. Previous Investigations of the Performance of Wet-Vented Fixtures

In 1924 Roy B. Hunter [2] reported in detail the results of tests with certain types of wet-vented systems. Tests with the fixture arrangement shown in figure 4, A, located on the first floor of a two-story system and with a 1¼-inch-diameter wet vent led Hunter to draw the conclusions (1) that each small waste connecting independently to the stack must be vented separately, (2) that considering the slight probability of all the fixtures of the group above discharging at the same time as the basin or bathtub in the lower group, the water closet may be left without a separate vent with comparative safety, and (3) that with heavier discharges from above than described the water closet should be separately vented.

Hunter's tests of the same arrangement on the top floor resulted in no seal losses in any of the fixture traps, and he concluded that the wet venting of a bathtub by the drain from a lavatory such as shown in figure 4, A, was also satisfactory on the top floor of a building.

Hunter also investigated the problem of wet venting on the upper floor as applied to two bathrooms back-to-back, with the vertical drain of the two lavatories serving as a wet vent for the two bathtubs. The test installation is illustrated in figure 4, B. Hunter's conclusion was that, for duplex installations of the type shown, the wet vent was not sufficient to prevent a material trap-seal reduction in one of the bath tub traps when the other bathtub was discharged and that a back vent to the two tubs as shown in figure 4, B, was required to prevent this from occurring. In this connection, it may be pointed out that,

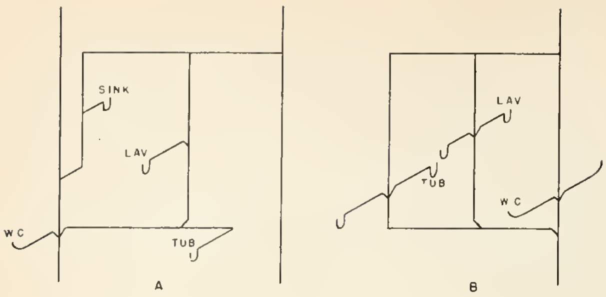

FIGURE 4. *Hunter's test system.*

since the observed trap-seal loss occurred when neither of the lavatories was discharged, the reduction in trap seal observed was not caused by any lack of efficiency of the wet vent from the lavatories. The specific test merely indicated that the discharge of one bathtub into an unvented vertical drain resulted in a reduction in pressure in the vertical drain sufficient to cause a substantial seal loss in any trap connected to the vertical section of the drain in question.

Hunter, in a later publication [3], although not reporting test data, indicates that the wet venting of bathroom fixtures back-to-back is satisfactory, provided the bathtub drains between the wet vent and the bathtub traps are laid on a uniform slope and otherwise comply with the restrictions necessary to prevent self-siphonage.

It will be observed that Hunter's test installation shown in figure 4, A, is for all practical purposes identical with figure 2, A. Experimental data on the other two test installations of this investigation, figures 2, B, and 2, E, have not been published heretofore, but wet-venting arrangements identical with either one or both of these installations have been described in at least two publications [3, 4] as representing safe practice.

IV. Nature of the Phenomena Involved in Wet Venting

The physical phenomena occurring in wet venting are complicated, and the tests of this project were not sufficiently extensive, and neither was it their primary purpose, to delineate clearly in detail the processes involved. Nevertheless, many of the tests were made with transparent plastic tubing and fittings, and a general qualitative, although by no means complete, description of the functioning of a wet vent was made possible thereby.

In the tests made with transparent tubing on the test installation shown in figure 2, B, it was observed that, if the flow through the wet vent was started before or at the end of the period of tub discharge, the tub drain remained substantially filled with water, and small quantities of air bubbled from the wet vent through the tub waste and formed a pocket in the drain at the trap, with the air-water interface forming, of course, a horizontal plane.

As discharge continued through the wet vent and air bubbles continued to move up the tub drain from the air pocket over the trap, a gradual lowering of the water surface occurred. At the end of the period of flow from the wet vent, a group of large air bubbles moved rapidly upstream toward the trap, immediately relieving the vacuum over the trap weir and allowing the water seal in the trap to return to equilibrium.

If, prior to the end of flow through the wet vent, sufficient air had been admitted to the tub drain to reduce the depth of water over the trap weir to a small value or to zero, a larger trap-seal loss was obtained than if only a small pocket of air formed and the depth of water over the trap weir was relatively large. This was due to the fact that, if the depth of water over the trap weir was relatively large at the time when flow through the wet vent ceased, the trap was refilled, at least in part, by flow from the tub drain into the tub trap, and only a small, if any, trap-seal reduction resulted. On the other hand, if the pocket of air was large enough so that the water level in the tub drain was at or below the tub-trap weir, there was not in general any flow of water from the drain into the trap, and large trap-seal losses would result under certain conditions.

In these tests, in which the tub was discharged while flow from the wet vent was occurring, the amount of the tub trap-seal loss thus depended upon the size of the air pocket in the tub drain and more specifically upon the height of the water surface in the tub drain with respect to the trap weir. The depth of water over the trap weir was observed to depend on a number of factors, some of them being relatively indefinite.

First, and as would be expected, the water surface in the tub drain could be made to remain above the trap weir with small or no resulting trap-seal losses by making the tub drain sufficiently short or by laying it on a sufficiently low slope. In addition, the amount of air that bubbled back into the tub drain was observed to be highly variable, depending on a number of factors, such as the rate and duration of the discharge through the wet vent, and the diameters of the wet vent and the horizontal branch. Figure 5 shows the marked effect on the trap-seal loss of the duration of flow through the wet vent. The data in the figure were obtained from tests made on the arrangement of figure 2, A, with the horizontal branch, tub drain, and wet vent made of 1½-inch-diameter pipe. The tub drain was 6 feet long and had a slope of ½ inch per foot.

In figure 5 the rapid increase of trap-seal losses with increase in the duration of flow through the

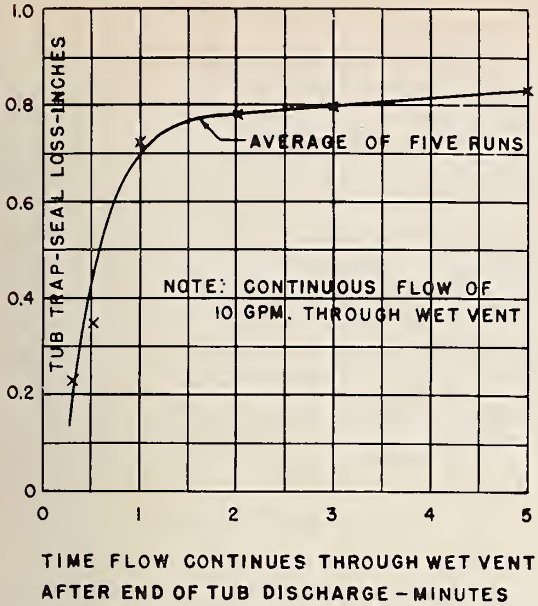

FIGURE 5. *Effect of duration of flow in wet vent on tub trap-seal losses.*

wet vent during the first minute of flow reflects the growth of the air pocket and the consequent lowering of the water surface in the tub drain with respect to the tub-trap weir and the smaller flow of water into the trap from the drain when flow through the wet vent ceases. The comparatively flat portion of the curve above a duration of approximately 1 minute reflects the fact that sufficient air had been admitted to the tub drain from the wet vent to lower the water surface in the drain to a level at or below the level of the trad weir, so that little or no refill of the trap from the drain was occurring.

The physical phenomena occurring when flow through the wet vent is taking place at the end of the period of discharge from the tub are further complicated by the fact that under certain circumstances air is drawn into the tub drain through the tub trap. This may occur either at the end of the period of flow from the tub or at the end of the flow from the wet vent. The flow of air through the tub trap at the end of the period of discharge of the tub appears to be principally due to the entrainment of air by the flowing water during the formation of the vortex which occurs in the tub when the depth of water over the outlet orifice has become sufficiently small, but it is also undoubtedly due partly at least to the inertia forces in the tub drain operating at the end of the period of tub flow and causing the water surface in the down leg of the trap to recede below the dip of the trap, with consequent flow of air through the tub trap and into the drain. The air drawn through the tub trap in this manner has the effect, of course, of increasing the size of the air pocket over the trap and hence of decreasing the depth of water over the trap weir. In this way it may cause increased trap-seal losses.

From the foregoing description of the process by which a wet-vented tub trap loses a portion of its seal when the tub and a fixture on the wet vent are discharged, it is apparent that the phenomenon consists of such a complex flow of air and water that no simple analysis of the complete problem is possible.

The trap of a wet-vented fixture may lose trap seal by the discharge of one or more fixtures on the wet vent alone, as well as when the wet-vented fixture is discharged in conjunction with flow in the wet vent. Indeed, for sufficiently short tub-drain lengths and sufficiently low drain slopes, and for small wet-vent diameters, trap-seal losses will be materially greater for certain fixture discharges through the wet vent when the tub is not discharged than when it is discharged.

Apparently trap-seal reduction of the tub trap, for loadings not including the discharge of the tub, is a process of entrainment or aspiration of air from the tub drain by water flowing through the wet vent, which in turn, of course, causes a partial vacuum to be formed in the tub drain with consequent loss of trap seal.

V. Tests on a Single-Story Wet-Vented System With Lavatory and Combination Fixture Connected to the Wet Vent

1. Description of the Test System

The system tested in this phase of the investigation is shown in figure 6. The 3-inch-diameter vertical stack was made of transparent methacrylate plastic tubing and fittings. Some of the plastic fittings used are shown in figure 7. The internal dimensions of these fittings were made identical, to within a small tolerance, with those of the corresponding soil-pipe fittings. The use of these fittings, together with transparent stack and drains, was indispensable in obtaining an insight into the complicated physical phenomena occurring in the wet-vented systems. Although many tests were made with the transparent traps, drains, and fittings, the large majority were made with the wet vent, fixture drains, and horizontal branch of conventional metal pipe and fittings.

The building sewer was made of 4-inch-diameter fibre conduit laid on a slope of ⅛ inch per foot and was connected to an 8-inch-diameter clay-tile street sewer. The rate of flow in the street sewer could be varied up to 300 gallons per minute.

The types of building-drain materials used in these tests, consisting of methacrylate tubing, fibre conduit, clay tile, and metal pipe, were selected only because of their availability to the laboratory, except in the case of the methacrylate

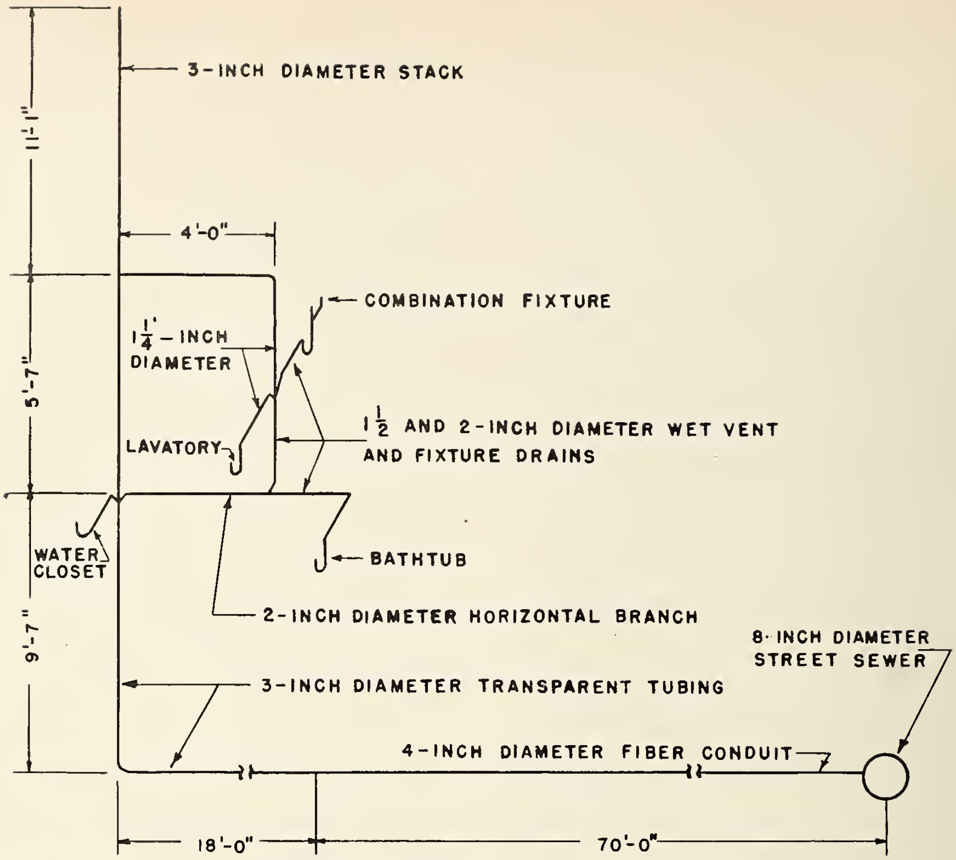

FIGURE 6. *Single-story wet-vented system.*

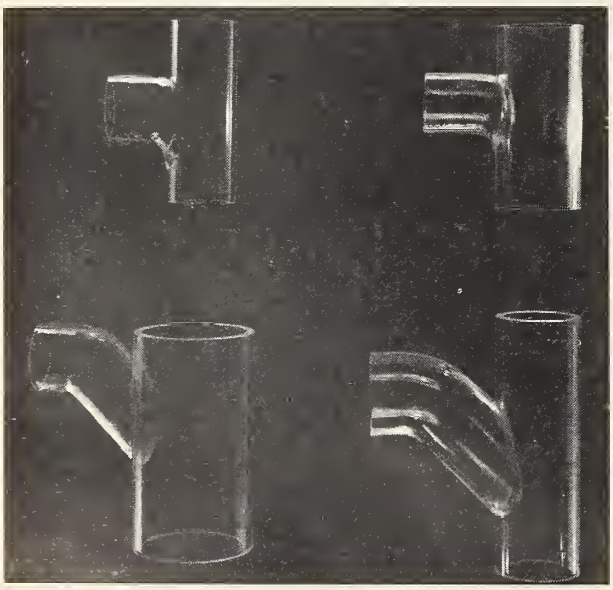

FIGURE 7. *Typical drainage fittings made of transparent plastic material.*

Upper left	1½-inch sanitary tee.
Upper right	1½- by 2-inch sanitary tee.
Lower left	1½- by 3-inch-long-turn T-Y.
Lower right	2-inch-long-turn T-Y.

tubing, which was selected because such tubing is transparent. The purpose of the tests reported here was not to investigate the possible application or the relative merits of any of these materials for use in the plumbing drainage system.

The fixtures were of current manufacture and were selected to give a loading on the test system that would be representative of those found on similar systems in service. The lavatory used was 20 by 24 inches in size with a 1¼-inch-diameter outlet orifice. The lavatory was connected to the wet vent by a 1¼-inch-diameter trap and drain.

The water closet on the test system was of the tank-supply, siphon-jet type, with a volume of discharge of 8 gallons. The bathtubs were of standard design, with both 1½- and 2-inch-diameter outlet orifices.

The combination fixture used on the system was the typical fixture with sink and laundry-tray compartments. The trap was located directly under the outlet orifice of the sink compartment. The tray compartment was 17½ inches wide by 18¼ inches long by 13 inches deep. The sink compartment was of the same dimensions except that the depth was 8 inches. The widths and lengths are for the top of the combination fixture. The bottom dimensions of both the sink and tray compartments were slightly smaller. The tray compartment was equipped with a metal drain plug with a cross-bar strainer and rubber stopper. The diameter of the tray outlet orifice was 1$^{19}/_{32}$ inches. The sink compartment was equipped with the removable basket-type strainer shown in figure 8.

The average rates of flow from the fixtures used in the investigation are shown in table 1. The rates of flow given are average rates obtained by measuring the volume of water in the fixture and then observing the time required for the fixture to empty. In the case of the combined rate of discharge from the sink and tray compartments of the combination fixture, the problem was slightly more complicated, inasmuch as the sink compartment empties more quickly than the tray compartment. In this case both compartments were filled with water, and the time required for the sink compartment to empty was noted. At the end of the period of discharge from the sink, the height of the water level in the tray compartment was observed. In this manner the total volume of water discharged from the combination fixture during the period of flow from the sink was obtained, and the average rate of flow was, of course, this volume divided by the time required for the sink compartment to empty.

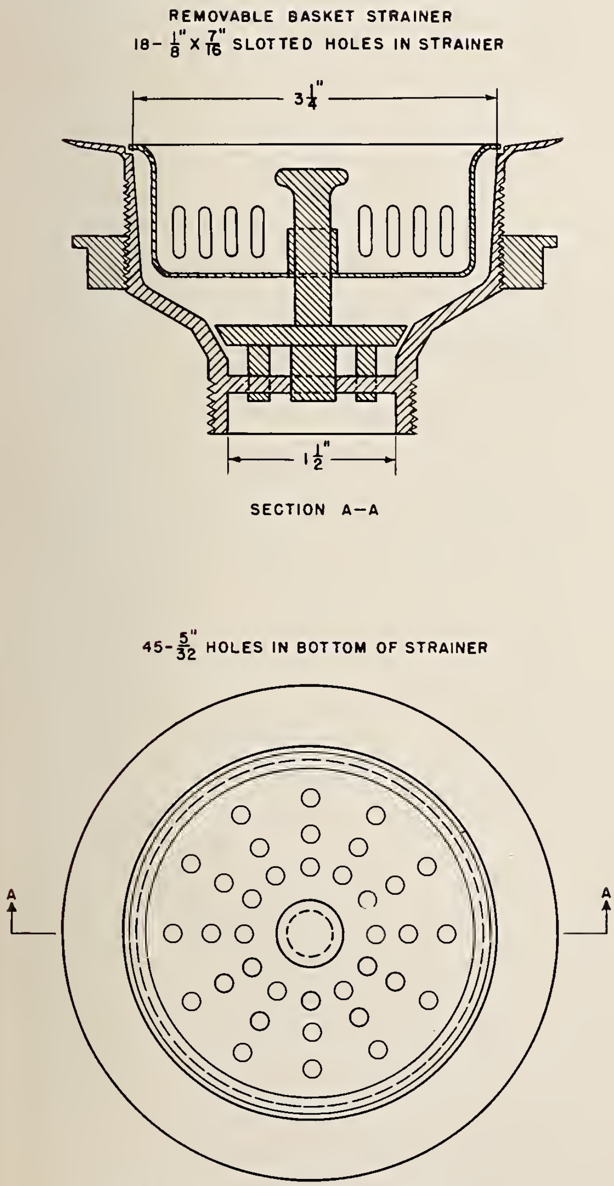

FIGURE 8. *Removable basket-type strainer.*

TABLE 1. *Average rates of flow of fixtures used in wet-venting tests*

Fixture	Special conditions	Average rate of flow: Plastic system. 1½-in. tub and sink wastes	Plastic system. 2-in. tub and sink wastes	Metal system. 1½-in. tub and sink wastes
		gpm	*gpm*	*gpm*
Tray		23.1	23.0	23.2
Sink	Grid strainer			25.2
	Basket strainer in			18.0
	Basket strainer removed	33.8	40.2	32.0
Lavatory	1¼-in. trap and waste.	10.6	10.3	10.6
Water closet		26.1	26.1	26.1
Bathtub		12.5	23.7	12.9
Sink and tray	Grid strainer			34.2
	Basket strainer in			31.1
	Basket strainer removed	37.1	43.8	35.0
Sink, tray, and lavatory.	Grid strainer			44.8
	Basket strainer in			41.7
	Basket strainer removed	47.7	54.1	45.6

The rates of flow from the sink and tray varied appreciably, depending on the length and slope of the fixture drain. The rates shown are for a drain 16 inches long on a ¼-inch-per-foot slope. The rate of discharge for the tub given in table 1 is for an initial depth of water of 6 inches.

2. Test Procedure

The tests were made by discharging certain of the fixtures connected to the system and then observing the trap-seal losses or other pertinent behavior of all the traps. For reasons to be presented shortly, the flow in the wet vent was obtained by two methods: first by filling the fixtures connected to the wet vent and then pulling their plugs, and second by allowing water to flow into the fixtures continuously from their faucets, with the fixture plugs removed. For convenience the first method of fixture discharge, in which the fixture was filled and the plug then removed, will be termed throughout the remainder of this report as *plug discharge*.

In the plug discharge of the lavatory, the fixture was filled to the overflow level. In the case of

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the sink and tray compartments, the fixtures were filled to a level approximately one inch below the rim. The tub was filled to a depth of six inches in those tests requiring the discharge of this fixture.

In the preliminary tests it was found, for those test loadings which included the discharge of the bathtub, that the maximum tub trap-seal losses were obtained when the fixtures on the wet vent were discharged from 3 to 5 seconds prior to the end of flow from the tub, and this sequence of fixture discharge was used in all subsequent tests.

3. Test Results

In the test system shown in figure 6 it will be noted that the watercloset is stack-vented and the lavatory and combination fixture are back-vented, and that these fixtures can be subject only to trap-seal losses attributable to self-siphonage effects or to the failure of the stack and back vents to perform their function properly. Only the bathtub trap of the system shown in figure 6 is wet-vented, and the tests applied to this system were designed to make apparent the conditions under which the wet vent protected the bathtub trap adequately from excessive seal losses.

It is convenient to divide the tests applied to the system into two groups—those in which the tub was discharged as well as other fixtures, and those in which the tub was not discharged. The test results of these two general test groups will be presented separately.

a. Tub Not Discharged

In tables 2 and 3 are given test data on the system shown in figure 6 for the discharge of various combinations of the fixtures on the wet vent. The data in table 2 were obtained from tests made with the cast brass trap shown in figure 9 on the bathtub, and table 3 includes similar data obtained with the tubing trap shown in figure 10. The tabulated trap-seal losses in these tables represent the losses observed in 10 consecutive test runs made under identical conditions.

It will be observed from these tables that in general, for the higher rates of flow, greater seal losses are produced in the tub trap when the lavatory and combination fixture are connected to the wet vent by a short-turn fitting than when this connection is made by means of a long-turn fitting. On the other hand, it will be observed also that in general, for the lower rates of flow, the reverse is true and that the difference in trap-seal losses obtained with the two fittings is not substantial. It is concluded, therefore, that, while the type of fitting connecting the fixtures to the wet vent apparently exerts some influence on the wet-venting phenomena, the effect is not marked and can be considered to have no practical importance.

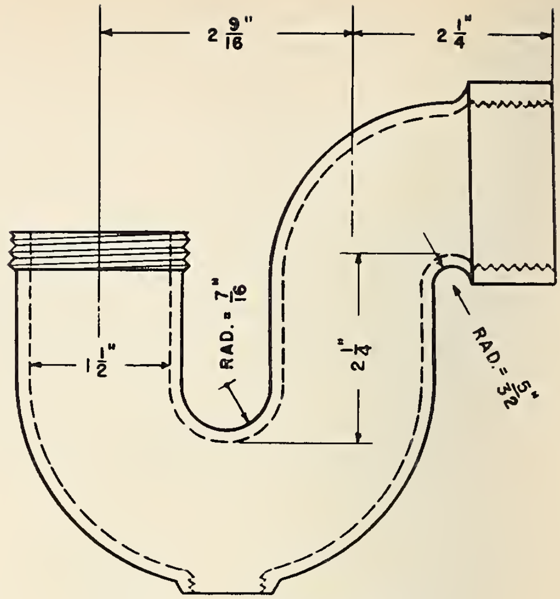

Figure 9. *1½-inch cast brass trap.*

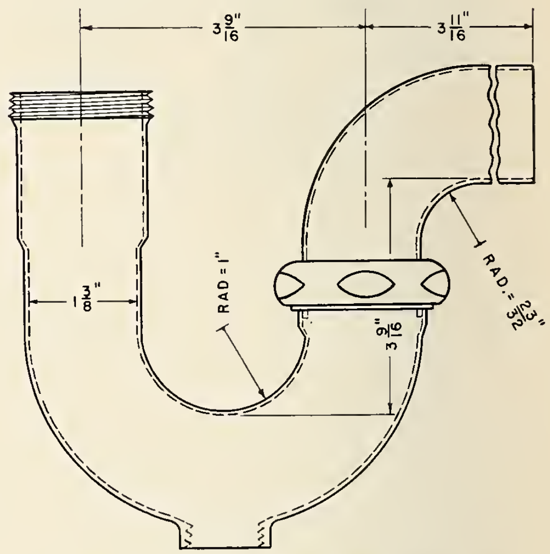

Figure 10. *1½-inch drawn brass tubing trap.*

At low rates of flow it is reasonable to expect that the wet vent will not be completely filled at any point and that consequently it will be able to perform its venting function fairly well when either type of drainage fitting is used. Probably the greater vertical component of the entrance velocity into the wet vent occurring with the use of a long-turn fitting will tend to create a greater aspirating effect when the flow enters the horizontal branch, thus possibly causing trap-seal losses to be slightly greater than if a short-turn fitting were used for low rates of flow. When the rate of flow into the wet vent is large, it appears that the use of a short-turn fitting results in more or less complete filling of

Table 2. *Tub trap-seal losses—cast trap—tub drain on ½-inch-per-foot slope—tub not discharged—plug discharge*

Fixtures discharged	Type of fitting connecting lavatory and combination fixture to wet vent	Rate of flow through wet vent	Wet vent diameter	Tub trap-seal loss					
				Tub drain 4 ft long		Tub drain 5 ft long		Tub drain 6 ft long	
				max	avg	max	avg	max	avg
		gpm	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*
Sink (basket strainer in normal position)	Long turn	18.0	1½	------	------	0.50	0.38	0.50	0.13
	do	18.0	2	------	------	------	------	0	0
	Short turn	18.0	1½	0.38	0.33	.38	.30	.25	.20
	do	18.0	2	------	------	0	0	0	0
Sink (basket strainer out)	Long turn	32.0	1½	------	------	.50	.50	.50	.35
	do	32.0	2	------	------	0	0	0	0
	Short turn	32.0	1½	.50	.45	.38	.35	.25	.23
	do	32.0	2	------	------	0	0	0	0
Sink, lavatory (basket strainer in normal position)	Long turn	28.6	1½	.38	.38	.38	.38	.50	.43
	do	28.6	2	------	------	------	------	0	0
	Short turn	28.6	1½	.63	.43	.50	.38	.38	.25
	do	28.6	2	------	------	0	0	0	0
Sink, lavatory (basket strainer out)	Long turn	42.6	1½	1.25	.82	1.00	.93	.75	.67
	do	42.6	2	------	------	0	0	.12	.02
	Short turn	42.6	1½	1.75	1.25	1.75	1.40	1.62	1.19
	do	42.6	2	------	------	0	0	.25	.08
Sink, tray, lavatory (basket strainer in normal position)	Long turn	41.7	1½	.88	.75	.75	.70	.75	.70
	do	41.7	2	------	------	------	------	0	0
	Short turn	41.7	1½	1.50	1.20	1.25	1.02	.75	.65
	do	41.7	2	------	------	0	0	.12	.02
Sink, tray, lavatory (basket strainer out)	Long turn	45.6	1½	1.88	1.52	1.12	1.05	1.00	.85
	do	45.6	2	------	------	0	0	.25	.15
	Short turn	45.6	1½	1.88	1.48	1.75	1.57	1.25	1.00
	do	45.6	2	------	------	.25	.12	.38	.32

Table 3. *Tub trap-seal losses—tubing trap—tub drain on ½-inch-per-foot slope—tub not discharged—plug discharge*

Fixtures discharged	Type of fitting connecting lavatory and combination fixture to wet vent	Rate of flow through wet vent	Wet vent diameter	Tub trap-seal loss					
				Tub drain 4 ft long		Tub drain 5 ft long		Tub drain 6 ft long	
				max	avg	max	avg	max	avg
		gpm	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*
Sink (basket strainer in normal position)	Long turn	18.0	1½	------	------	------	------	0.50	0.35
	do	18.0	2	------	------	------	------	0	0
	Short turn	18.0	1½	------	------	0.38	0.25	.12	.12
	do	18.0	2	------	------	------	------	0	0
Sink (basket strainer out)	Long turn	32.0	1½	------	------	------	------	.38	.23
	do	32.0	2	------	------	------	------	0	0
	Short turn	32.0	1½	------	------	.75	.43	.50	1.33
	do	32.0	2	------	------	------	------	0	0
Sink, lavatory (basket strainer in normal position)	Long turn	28.6	1½	0.38	0.33	------	------	.38	.28
	do	28.6	2	------	------	------	------	0	0
	Short turn	28.6	1½	.25	.22	.50	.38	.25	.17
	do	28.6	2	0	0	------	------	0	0
Sink, lavatory (basket strainer out)	Long turn	42.6	1½	1.00	.80	------	------	.88	.57
	do	42.6	2	------	------	------	------	0	0
	Short turn	42.6	1½	.88	.65	1.38	1.18	1.12	.85
	do	42.6	2	0	0	------	------	0	0
Sink, tray, lavatory (basket strainer in normal position)	Long turn	41.7	1½	.62	.46	------	------	.75	.57
	do	41.7	2	------	------	------	------	0	0
	Short turn	41.7	1½	------	------	1.25	1.05	1.00	.75
	do	41.7	2	------	------	------	------	0	0
Sink, tray, lavatory (basket strainer out)	Long turn	45.6	1½	1.00	.85	------	------	1.00	.78
	do	45.6	2	------	------	------	------	0	0
	Short turn	45.6	1½	------	------	1.38	1.31	1.12	1.00
	do	45.6	2	------	------	------	------	0	0

the wet vent at the entrance point, whereas this condition exists to a lesser extent when a long-turn fitting is used. Hence it might be expected that the wet vent would not function as effectively with the short-turn fitting during periods of high discharge, possibly resulting in slightly greater trap-seal losses in the wet-vented fixture trap when a short-turn fitting is used on the wet vent.

The slope of the bathtub drains on the test setups from which the data in tables 2 and 3 were obtained was ½ inch per foot. In table 4 the data for tub drains on a ¼-inch slope are compared with similar data for a ½-inch slope from table 3. It will be observed that the ½-inch slope yields in general slightly larger maximum trap-seal losses than does the ¼-inch slope and appreciably greater average trap-seal losses.

As is noted in table 4, the length of the tub drain used was 6 feet. For reasons to be discussed later, it would be expected that the difference between trap-seal losses for the ½-inch and ¼-inch slopes would increase as the length of

TABLE 4. *Effect of slope of bathtub drain[1] on the trap-seal losses of a wet-vented bathtub*

[plug discharge]

Fixtures discharged	Rate of discharge	Tub trap-seal losses			
		¼-inch slope		½-inch slope	
		max	avg	max	avg
	gpm	*in.*	*in.*	*in.*	*in.*
Sink and lavatory with basket strainer in normal position	28.6	0.38	0.22	0.25	0.17
Sink and lavatory with basket strainer out	42.6	1.00	.37	1.12	.85
Sink, tray, and lavatory with basket strainer in normal position	41.7	.88	.50	1.00	.75

[1] The length and diameter of the bathtub drain were 6 feet and 1½ inches' respectively. The diameter of the wet vent was 1½ inches. The bathtub trap used was the tubing trap shown in figure 10. The combination fixture drain and the lavatory drain were connected to the wet vent by means of a double short-turn drainage fitting.

drain is decreased and would decrease as the length of the drain is increased. It may be concluded from the data in table 4, nevertheless, that the trap-seal losses given in tables 2 and 3 will not be exceeded in general, for the lengths of drains tested, by those obtained with tub drain slopes of less than ½ inch per foot.

A close examination of the data in tables 2 and 3 will indicate (1) that the trap-seal losses for the tub drain 6 feet long are in general somewhat less than those for the drain 5 feet long, and (2) that the trap-seal losses for the 4-foot-long drain are substantially equal to those for the 5-foot-long drain, with a tendency for them to be slightly less. In figure 11 the maximum trap-seal losses for the drains 4 and 5 feet long, with the short-turn fitting, have been plotted. From this figure and the data in tables 2, 3, and 4, it is apparent that (1) tub trap-seal losses increase as the volume rate of flow through the wet vent is increased, (2) the tubing trap and the cast trap yield substantially the same trap-seal losses when the losses are appreciably under 1 inch, whereas the cast trap yields the greater seal losses when the losses are in the neighborhood of 1 inch or greater. In this connection it is obvious, of course, that the difference in behavior of the two traps is attributable to differences in the internal dimensions of the two traps (3) substantially greater trap-seal losses are produced by the 1½-inch-diameter wet vent than by the 2-inch diameter wet vent, (4) tub trap-seal losses do not increase indefinitely with increase in length of tub drain, but, on the contrary, appear to decrease after a length of 5 feet on a slope of ½ inch per foot is exceeded, and (5) the tub trap-seal losses shown in tables 2 and 3 will not be exceeded by those obtained with drains of the same length but on a slope of less than ½ inch per foot.

In view of conclusions 4 and 5, it is evident that the data in figure 11 will serve to indicate the maximum trap-seal losses to be expected from any installation having a tub drain 4 feet or more in length and laid on a slope of ½ inch per foot or less. As will be shown later, it would not be expected that a decrease in the length below 4 feet or an increase in slope above ½ inch per foot would in any way cause increased trap-seal losses over those indicated in tables 2 and 3 and figure 11.

It will be observed in tables 2 and 3 that the trap-seal losses for several possible combinations of fixture discharges have not been listed. In particular, the trap-seal losses for the discharge of the lavatory, tray, or water closet by themselves, or the discharge of the water closet in any combination with the other fixtures have not been listed.

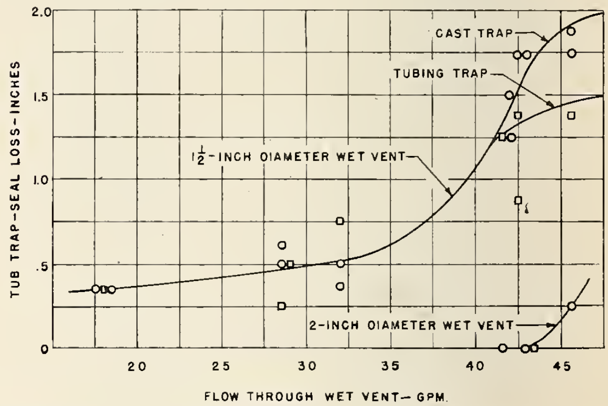

FIGURE 11. *Trap-seal losses of wet-vented bathtubs—tub not discharged.*

On none of the tests was a trap-seal loss caused by the discharge of the lavatory alone. Preliminary tests showed that the losses resulting from the discharge of the tray either alone or with the sink were not significantly different from the results obtained by the discharge of the sink, and the trap-seal losses from these fixture discharges may be approximated with sufficient accuracy from figure 11 by using the discharge rates in table 1.

Preliminary tests were also made to determine the effect on tub trap-seal losses of the discharge of the water closet in combination with other fixtures on the system. These data are given in table 5. It will be noted that, for the 2-inch-diameter wet vent, the simultaneous discharge of sink, tray, and lavatory gave practically the same trap-seal loss as occurred when the water closet was also discharged. It is apparent, therefore, that the test loading need not include the water closet when a 2-inch diameter wet vent is used.

In the case of the 1½-inch-diameter wet vent, however, it is obvious from table 5 that the discharge of the water closet causes increased trap-seal losses. It will be observed, nevertheless, that the tub trap-seal loss obtained with the discharge of the sink, tray, and water closet is less than that obtained with the discharge of the sink, tray, and lavatory, and hence it may be concluded that, for a given number of fixtures in the test loading, a greater trap-seal reduction is obtained when the fixtures of the test loading consist only of those on the wet vent rather than including the water closet.

TABLE 5. *Effect of adding water closet to test loading—tub not discharged*[1]

Fixtures discharged	Tub trap-seal reduction			
	1½-inch-diameter wet vent		2-inch-diameter wet vent	
	Maximum of 5 tests	Average of 5 tests	Maximum of 5 tests	Average of 5 tests
	in.	*in.*	*in.*	*in.*
Sink, lavatory	1.12	0.85	0.50	0.35
Sink, tray, lavatory	1.12	1.00	.62	.60
Sink, tray, water closet	.75	.60		
Sink, tray, lavatory, water closet	1.38	1.20	.62	.55

[1] In these tests the length, diameter, and slope of the bathtub drain were 6 feet, 1½ inches, and ½ inch per foot, respectively. The fitting connecting the lavatory and combination fixture drains to the wet vent was a double 1½-inch sanitary tee. The bathtub trap used was the tubing trap shown in figure 10. The basket-type strainer of the sink compartment of the combination fixture was removed.

For this reason, and since, as will be shown presently, a safe and conservative test or design loading consists of the discharge of any two, or at most three, of the five fixtures on the system, the great majority of the tests were made with the discharge of various combinations of the three fixtures on the wet vent and did not include the discharge of the water closet.

As has been stated previously, the foregoing test results are for loadings which do not include the discharge of the bathtub.

In the following section the results of tests in which the bathtub was among the fixtures discharged will be given.

b. Tub Discharged

In tables 6 and 7 are given experimental data for test loadings that included the discharge of the bathtub. The fixtures on the wet vent were discharged 3 to 5 seconds prior to the end of tub flow. The piping arrangement was as shown in figure 6.

It is apparent from tables 6 and 7 that trap-seal losses of the wet-vented tub, for the loading now under consideration, increase rapidly with an increase in the length of the tub drain.

The data in tables 6 and 7 are for a tub-drain slope of ½ inch per foot. Additional tests were made with a tub drain on a ¼-inch-per-foot slope and with a length of 6 feet. No trap-seal losses were obtained in these tests with any loading. In view of this fact and the data in tables 6 and 7 for a tub drain of similar length but on a ½-inch-per-foot slope it is apparent that the seal losses of a wet-vented tub trap increase rapidly with an increase in slope.

The precise manner in which the length and slope of a tub drain affect the wet venting processes is not known. However, as has been stated in section IV, it was observed in the tests with the transparent tub trap and drain that, immediately after the flow of water from the tub ceased, the tub drain was initially nearly full of water with only a small air pocket in the drain adjacent to the tub trap, and the air-water interface was, of course, horizontal. Under these circumstances it might be expected that the principal effect of the length and slope of the tub drain on the wet-venting process would be exerted through their effect on the vertical drop in the tub drain between the trap weir and the wet vent; i. e., on the product S_3l_3, where S_3 and l_3 are, respectively, the slope and length of the tub drain, which might be expected to be the controlling factor through which the slope and length of the bathtub drain influence the magnitude of the seal losses of a wet-vented bathtub.

In figure 12 tub trap-seal losses for a constant rate of flow of 15 gallons per minute through a

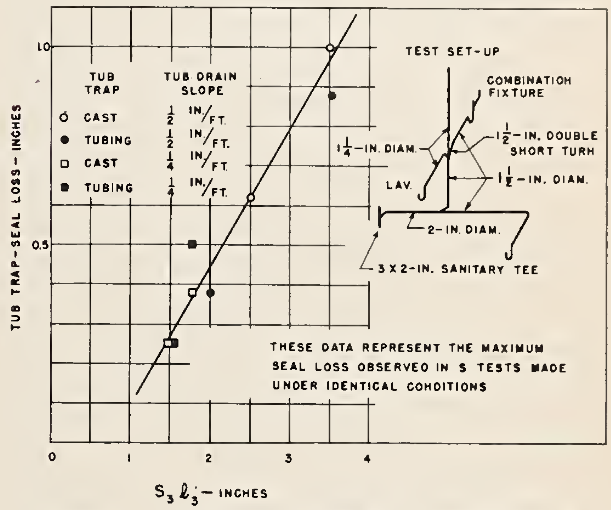

FIGURE 12. *Tub trap-seal losses for a constant flow of 15 gpm through the wet vent.*

1½-inch wet vent have been plotted against the factor S_3l_3. It will be observed, for the range of tub drain lengths and slopes tested, that approximately at least, the effect of tub drain length and slope can be considered to affect the trap-seal losses of a wet-vented tub only through their effect on the factor S_3l_3.

Data from tables 6 and 7 for the discharge of the bathtub and all the fixtures on the wet vent have been plotted against S_3l_3 in figure 13. Where the trap-seal loss was greater for one type of fitting connecting the lavatory and combination fixture drain to the wet vent than for the other, the larger trap-seal loss has been plotted. The data in figure 13 are for the basket type strainer in its normal position in the sink compartment of the combination fixture.

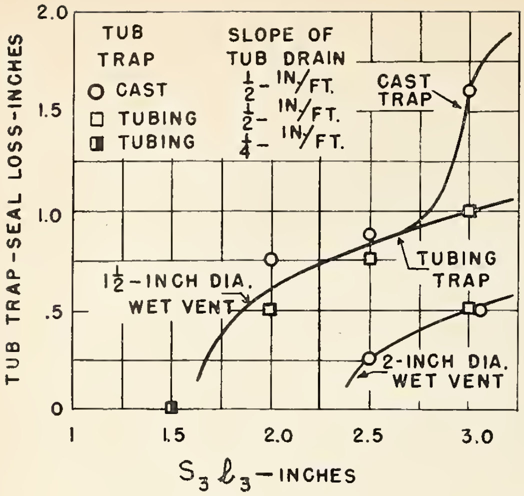

FIGURE 13. *Tub trap-seal losses for loading which includes the discharge of tub.*

TABLE 6. *Tub trap-seal losses—cast trap—tub drain on ½-inch-per-foot slope—tub discharged—maximum losses observed in 10 consecutive tests*

Fixtures discharged	Type of fitting connecting lavatory and combination fixture to wet vent	Rate of flow through wet vent	Wet-vent diameter	Tub trap-seal losses		
				Tub drain 4 feet long	Tub drain 5 feet long	Tub drain 6 feet long
		gpm	*in.*	*in.*	*in.*	*in.*
Sink (basket strainer in normal position).	Long turn	18.0	1½	------	0.62	1.00
	do	18.0	2	------	0	.50
	Short turn	18.0	1½	0.50	.50	.88
	do	18.0	2	------	0	.62
Sink (basket strainer out).	Long turn	32.0	1½	------	.50	1.38
	do	32.0	2	------	------	0
	Short turn	32.0	1½	.12	.25	1.25
	do	32.0	2	------	0	.25
Sink and lavatory (basket strainer in normal position).	Long turn	28.6	1½	------	.50	1.62
	do	28.6	2	------	------	.50
	Short turn	28.6	1½	.62	.12	1.62
	do	28.6	2	------	0	.50
Sink and lavatory (basket strainer out).	Long turn	42.6	1½	.50	.50	1.25
	do	42.6	2	------	0	.50
	Short turn	42.6	1½	.69	.62	1.00
	do	42.6	2	------	0	.38
Sink, tray, and lavatory (basket strainer in normal position).	Long turn	41.7	1½	.69	.88	1.62
	do	41.7	2	------	.25	0
	Short turn	41.7	1½	.75	.62	1.00
	do	41.7	2	------	.25	.50
Sink, tray, and lavatory (basket strainer out).	Long turn	45.6	1½	.88	.88	1.00
	do	45.6	2	------	0	.62
	Short turn	45.6	1½	1.0	.75	1.00
	do	45.6	2	------	.25	.62
Tub		0	1½	0	0	0

In table 8 are given data showing the effect of the addition of the water closet to the test loading when the bathtub is among the fixtures discharged. It is apparent that when the tub is discharged greater trap-seal losses are obtained for a test loading consisting of a given number of fixtures when all the fixtures discharged except the tub consist of those connected to the wet vent and do not include the water closet.

For the conditions under which they were obtained, the data presented in the two foregoing sections may be used to determine the adequacy of venting a bathtub trap through a wet vent carrying the discharge of a lavatory and combination fixture.

TABLE 7. *Tub trap-seal losses—tubing trap—tub drain on ½-inch-per-foot slope—tub discharged—maximum losses observed in 10 consecutive tests*

Fixtures discharged	Type of fitting connecting lavatory and combination fixture to wet vent	Rate of flow through wet vent	Wet-vent diameter	Tub trap-seal losses		
				Tub drain 4 feet long	Tub drain 5 feet long	Tub drain 6 feet long
		gpm	*in.*	*in.*	*in.*	*in.*
Sink (basket strainer in normal position).	Long turn	18.0	1½	------	------	0.75
	do	18.0	2	------	------	.25
	Short turn	18.0	1½	------	0.62	.25
	do	18.0	2	0	------	.25
Sink (basket strainer out).	Long turn	32.0	1½	------	------	.62
	do	32.0	2	------	------	.25
	Short turn	32.0	1½	------	.25	.50
	do	32.0	2	0	------	.25
Sink and lavatory (basket strainer in normal position).	Long turn	28.6	1½	.38	------	.75
	do	28.6	2	------	------	.25
	Short turn	28.6	1½	------	.62	.50
	do	28.6	2	0	------	.50
Sink and lavatory (basket strainer out).	Long turn	42.6	1½	.25	------	.50
	do	42.6	2	------	------	.25
	Short turn	42.6	1½	------	.38	1.00
	do	42.6	2	0	------	.50
Sink, tray, and lavatory (basket strainer in normal position).	Long turn	41.7	1½	.50	------	1.00
	do	41.7	2	------	------	.38
	Short turn	41.7	1½	.50	.75	.75
	do	41.7	2	0	------	.50
Sink, tray, and lavatory (basket strainer out).	Long turn	45.6	1½	.25	------	.88
	do	45.6	2	------	------	.38
	Short turn	45.6	1½	.25	.75	1.00
	do	45.6	1½	0	------	.50
Tub		0	1½	0	0	0

4. Interpretation of Test Results

In determining the adequacy of a drainage system with a particular type of venting system, it is necessary first to determine by experiment the trap-seal losses which occur in the system under various loading conditions. This has been done for a single-story, wet-vented system, and the results are shown in figures 11 and 13, and in tables 6 and 7.

It is also necessary to establish a criterion of satisfactory trap performance; that is, to establish a dividing line between trap-seal losses that may be considered satisfactory and those that may be considered sufficiently large to impair the ability of the trap to prevent the entrance into the dwelling of sewer gas in objectionable amounts.

TABLE 8. *Effect of adding water closet to test loading—tub discharged*

Fixtures discharged	Tub trap-seal reduction			
	1½-in.-diam. wet vent		2-in.-diam wet. vent	
	Maximum of 5 runs	Average of 5 runs	Maximum of 5 runs	Average of 5 runs
	in.	*in.*	*in.*	*in.*
Sink and lavatory	1.00	0.63	0.62	0.37
Sink, tray, and lavatory	1.00	.70	.75	.45
Sink, tray, and water closet	.75	.70	------	------
Sink, tray, lavatory, and water closet	1.50	1.20	.75	.30

In these tests the length, diameter, and slope of the bathtub drain were 6 feet, 1½ inches, and ½ inch per foot, respectively. The fitting connecting the lavatory and combination fixture drain to the wet vent was a double 1½-inch sanitary T. The bathtub trap used was the tubing trap of figure 10. The basket-type strainer of the sink compartment of the combination fixture was removed.

Finally, it is necessary to establish a criterion of what constitutes a reasonable test loading. That is, it is necessary to select a portion of those fixtures on the system, the use of which can be assumed to occur simultaneously with reasonable frequency, to serve as a guide in determining whether a trap-seal loss caused by the discharge of a particular group of fixtures is a sound basis for rejecting or accepting the wet venting of plumbing fixtures as a satisfactory method of venting.

To summarize, figures 11 and 13 and tables 6 and 7 present trap-seal losses of a wet-vented bathtub under certain conditions. In order to apply these data to the problem of determining if wet venting of plumbing fixtures is permissible, it is necessary to determine (1) what trap-seal losses are permissible, and (2) what combinations of fixture discharges are likely to occur simultaneously with reasonable frequency. The latter problem will be considered first.

a. Loads on the Drainage System From a Single Group of Bathroom Fixtures and a Combination Fixture

Unfortunately there are few or no data available on which to base a decision as to what combination or sequence of fixture discharges might be considered to constitute a reasonable design or test load for a single-family plumbing drainage system. It might be argued that the laboratory test loading for any single-family plumbing system should consist of either the simultaneous discharge of all the fixtures on the system or of that combination of fixture discharges which produces the most adverse results. As Hunter pointed out in BH13 [5, page 160] "For large installations the matter of coincident discharge constituting a maximum fair test might be determined from tables of probable coincident discharge . . . For small installations consisting of two or three bathroom units and other small fixtures the arbitrary method of selection . . . adopted by the plumbing committee is believed more applicable for the types of buildings under consideration." Here Hunter was referring to one and two-story single and double-family dwellings.

Of course, as he points out, the selection of a fair test loading is arbitrary. Nevertheless, by considering the probabilities of occurrences of various combinations of discharges of the fixtures in small dwellings, it would seem that a logical approach to the problem can be achieved. It should also be remembered that the different parts of the system will have different design loads associated with them. For example, the design load for the building drain will be different than the design load for a wet vent in the system.

The criterion of simultaneous discharge of all the fixtures as a means of establishing the design load would obviously lead to safe and conservative design of the drainage system. However, it is not sufficient that the plumbing drainage and venting systems be designed in such a manner that they will operate satisfactorily. It is essential that, at the same time, they be designed so as to avoid economic waste. It is a fundamental consideration that the over-all cost be kept to a minimum, consistent with satisfactory operation of the system.

Our immediate problem, in its broader aspect is, as the heading of this section indicates, to determine what constitutes a reasonable design load for the drainage system imposed by a single group of bathroom fixtures and a combination fixture. In its more restricted aspect it is to determine what should be taken as the design load associated with that part of the system which includes the wet vent. Once this design load has been established, then the diameter of the wet vent should be so chosen that no excessive reduction in trap seal will occur when this design load is imposed on the system. We shall consider the more restricted problem in what follows. The criterion of satisfactory performance will be the effect of the discharges of fixtures on the seal of this bathtub trap.

If we wish to use the probability of occurrence of various combinations of discharges as the criterion for determining the design load, it will be necessary to consider at some length the assumption that must be made—that the various fixtures are discharged completely at random. It is obvious that this assumption does not fit the facts perfectly. The kitchen sink would undoubtedly be used most frequently before and after meals. With regard to the bathtub, the common habits of families would indicate that this fixture would be used most frequently early in the morning and late in the evening. The laundry tray would probably be used most frequently during the middle of the morning or afternoon. One code [3] has recognized this fact of the probable use of the kitchen and laundry fixtures during periods of minimum use of the water closet, tub, and lavatory, and permits these fixtures to be neglected in sizing the soil drains of the system.

In like manner it is undoubtedly an error to consider that the water closet and the lavatory discharge independently at random in small systems, as in normal usage there is in general a definite sequence of use of these two fixtures.

The duration of the discharge from the water closet is short, being for most such fixtures between 8 and 16 seconds. In the usual sequence of use of the water closet and the lavatory by a single individual, it appears obvious that the flow from the water closet will have ceased before the lavatory has been filled, the hands washed, and the plug pulled, and hence the assumption of completely random discharge of the water closet and lavatory will yield probabilities of coincident discharge larger than what will actually occur in service and, therefore, will yield safe and conservative estimates of the relative frequencies with which these two fixtures will be in coincident discharge.

In the above discussion it has been assumed that the lavatory will be used by inserting the plug or otherwise closing the outlet orifice, filling the fixture, and discharging it by removing the plug from the outlet orifice. However, quite often the lavatory is used by merely drawing the water continuously from the tap without closing the outlet orifice. If the lavatory is used in this manner, the probability of coincident discharges with the water closet may possibly be increased, but, on the other hand, the rate of discharge from the lavatory will ordinarily be only a fraction of the 10 to 13 gallons per minute discharged when the fixture is filled and the plug removed, and its effect on the trap-seal losses of wet-vented fixtures will be negligible.

For the above reasons it would seem that a consideration of the probable frequency of occurrence of particular combinations of fixture discharges may prove fruitful, even though it is apparent that the fixtures in a single-family dwelling are not used completely at random.

In order to facilitate the discussion we assume that the fixtures on the single-story system in question do discharge at random, and we justify this somewhat questionable assumption on the grounds that the lack of randomness pointed out above is such that the error made is on the safe side. That is, the error made by assuming the fixtures to discharge completely at random will result in the computed probabilities of coincident discharge of a group of fixtures being higher than the actual probabilities, and hence the error made will be on the safe side, insofar as the problem of determining a reasonable test or design load is concerned.

We shall now compute the probabilities of occurrence of the various combinations of discharges which may occur, on the assumption that the discharge of each kind of fixture occurs on the average with the frequency indicated in table 9 and that each discharge has the duration specified.

TABLE 9. *Assumed conditions of use of fixtures*

Fixture	Interval between consecutive discharges, *T*, seconds	Duration of discharge, *t*, seconds	Probability, *t/T*	
Sink	300	15	15/300	0.0500
Tray	600	40	40/600	.0667
Lavatory	180	9	9/180	.0500
Bathtub	900	60	60/900	.0667
Water closet	300	9	9/300	.0300

The probabilities given in table 9 are those of finding the fixture in question discharging, without any regard to whether or not any of the other fixtures are also found discharging. Table 10 lists the probabilities of finding any particular fixture discharging and not discharging and will serve as the basis for computing the probabilities of finding various combinations of fixtures discharging, the latter probabilities being given in table 11.

TABLE 10. *Probabilities of finding individual fixtures discharging and not discharging*

Fixture	Probability of finding fixture discharging	Probability of not finding fixture discharging
Sink	0.0500	0.9500
Tray	.0667	.9333
Lavatory	.0500	.9500
Bathtub	.0667	.9333
Water closet	.0300	.9700

The following examples will illustrate the use of table 10 in computing the probabilities given in table 11.

(a) *Probability that only the sink will be found operating:*

Probability that the sink will be found operating	0.0500
Probability that the tray will be found not operating	.9333
Probability that the lavatory will be found not operating	.9500
Probability that the bathtub will be found not operating	.9333
Probability that the water closet will be found not operating	.9700

The desired probability is found by multiplying together the five probabilities in the list above and is 0.0401.

(b) *Probability that all five fixtures will be found operating:*

Probability that the sink will be found operating	0.0500
Probability that the tray will be found operating	.0667
Probability that the lavatory will be found operating	.0500
Probability that the bathtub will be found operating	.0667
Probability that the water closet will be found operating	.0300

Again the desired probability is obtained by multiplying together the five probabilities listed above and is 0.00000033. The values given in table 11 have been computed in the manner described above.

As indicated in table 9, it has been assumed in the computation of table 11 that the sink, tray, lavatory, water closet, and bathtub discharge at random once during a time interval of 5, 10, 3, 5, and 15 minutes, respectively, on the average. These average time intervals between consecutive uses of these fixtures correspond in general to those used by Hunter [3, 6] for public washrooms, which were based in part on limited field observations. The use here of Hunter's data on public washrooms for computing the probable loads on a single-family plumbing system is not intended to imply that the frequency of use of the fixtures in the two installations is the same. On the contrary, it is obvious from our general knowledge of family household habits that the frequency of use of the fixtures in a private dwelling is in general much less than for public washrooms.

TABLE 11. *Probability of finding the following combinations of fixtures in a single-story, wet-vented system discharging at any arbitrarily chosen instant of observation*

Fixtures discharging	Probability	
	Individual	Sum
None	0.7626	0.7626
Sink only [a]	.0401	
Tray only [a]	.0545	
Lavatory only [a]	.0401	
Bathtub only	.0545	
Water closet only	.0236	
Any one fixture		.2128
Sink and tray only [a]	.00287	
Sink and lavatory only [a]	.00211	
Sink and bathtub only	.00287	
Sink and water closet only	.00124	
Lavatory and tray only [a]	.00287	
Lavatory and water closet only	.00124	
Lavatory and bathtub only	.00287	
Water closet and tray only	.00168	
Water closet and tub only	.00168	
Tray and tub only	.00389	
Any two fixtures		.0232
Sink, tray, and lavatory only [a]	.000151	
Sink, tray, water closet only	.000089	
Sink, tray, tub only	.000205	
Sink, lavatory, water closet only	.000065	
Sink, lavatory, tub only	.000151	
Sink, water closet, tub only	.000089	
Tray, lavatory, tub only	.000205	
Tray, water closet, tub only	.000120	
Lavatory, water closet, tub only	.000089	
Any three fixtures		.001253
Sink, tray, lavatory, tub only	.0000108	
Sink, tray, lavatory, water closet only	.0000047	
Sink, tray, water closet, tub only	.0000063	
Sink, lavatory, water closet, tub only	.0000047	
Tray, lavatory, water closet, tub only	.0000063	
Any four fixtures		.0000328
All five fixtures		.00000033
		.9999

[a] Individual fixtures or combinations of fixtures on wet vent.

Hunter's data on public washrooms were used in computing the probabilities in table 11 merely because they serve adequately in the absence of similar data for the private home, to furnish an upper limit for determining the design or test loading for the wet-vented drainage system of a single-family dwelling, and it is recognized that a design load computed in this manner will be overly conservative.

The specific problem of this section of this report is to determine what constitutes a reasonable test or design load for the single-story, wet-vented drainage system. Approaching it from the point of view of the probability of occurrence of different combinations of discharges from the fixtures on the system, we note that table 11 shows the probability of the simultaneous discharge of all three fixtures on the wet vent to be about 1 in 6,600. Thus, under the conditions of use of fixtures assumed, the probability of all three fixtures on the wet vent discharging simultaneously is very remote, and it appears reasonable to take the discharge of only two of the fixtures on the wet vent as the design load.

Figure 14 shows the trap-seal losses (from tables 2, 3, 5, 6, and 7) for a 1½-inch wet vent and for various combinations of fixtures plotted against probability of occurrence.

Data are plotted for two cases: the first when the tub is not discharged, and the second when the tub is discharged. In no instance does the trap-seal loss of the bathtub exceed 1 inch when not more than two fixtures are discharged simultaneously. The corresponding probability is about 1/300. For any three fixtures discharging simultaneously the only cases in which the trap-seal loss exceeded 1 inch was when the cast trap was used and the tub was discharged. Here the trap-seal loss was about 1.6 inches, and the probability of occurrence is about 1/6700.

There is no corresponding plot given for the trap-seal losses when a 2-inch wet vent is used, but the trap-seal losses were all less than 1 inch when this diameter of wet vent was used. Even with the three fixtures on the wet vent and the tub discharged simultaneously, the trap-seal loss did not exceed 0.5 inch.

Our conclusion from the preceding discussion is that the design or test loading for a single-story wet-vented system, as far as the diameters of the wet vent and its associated drains are concerned, may be taken as the discharge of two of the fixtures on the system. Whichever pair of fixtures discharged gives the worst conditions should be taken as the test loading. This statement applies to a system having one water closet, one lavatory, one bathtub, one sink, and one tray.

The above conclusion regarding the use of the discharge of any two fixtures as a design load for the single-story, wet-vented system has been influenced by the fact that loads in excess of the one chosen do not result in any serious ill effects to the system. That is, trap seals are not completely broken and flooding of fixtures or blowing of traps does not occur. If such ill effects did occur for loads in excess of the design load selected above, it is possible that a proper consideration of the magnitude, frequency, and relative seriousness of these ill effects would have been a compelling basis for increasing the design load above that given in the preceding paragraph.

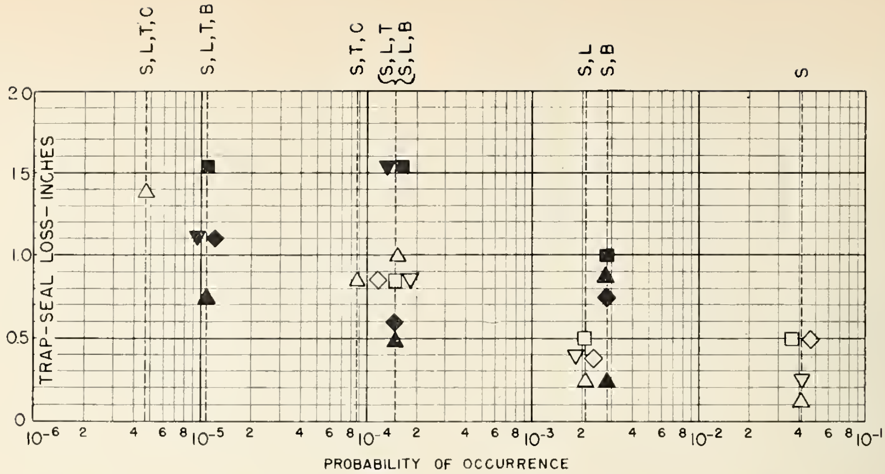

FIGURE 14. *Probability of occurrence of various simultaneous discharges.*

1½-inch wet vent. Drain 6 feet long on all tests. Slope ½ inch per foot.

Tub not discharged		
□	Long-turn fitting	Cast trap.
▽	Short-turn fitting	Do.
◇	Long-turn fitting	Tubing trap.
△	Short-turn fitting	Do.
Tub discharged		
■	Long-turn fitting	Cast trap.
▼	Short-turn fitting	Do.
◆	Long-turn fitting	Tubing trap.
▲	Short-turn fitting	Do.

S=sink, T=tray, L=lavatory, B=bathtub, C=water closet.

b. Permissible Trap-Seal Losses

For the purposes of this investigation it is sufficient to adopt the criterion of satisfactory trap operation first stated in "Recommended Minimum Requirements for Plumbing in Dwellings and Similar Buildings." [2], that, for traps having a 2-inch depth of seal, the seal loss shall not exceed 1 inch. In applying this criterion of satisfactory trap performance, we shall use the maximum trap-seal loss observed in 10 consecutive tests made under identical conditions.

c. Permissibility of Venting a Bathtub Trap With a Wet Vent to Which a Lavatory and a Combination Fixture are Connected

The application of the test loading and the permissible trap-seal loss discussed above to the data given in figures 11 and 13 and in tables 6 and 7 make it possible to draw certain conclusions regarding the permissibility of venting a bathtub trap with a wet vent to which a lavatory and a combination fixture are connected.

Consider first the case in which the tub is not one of the two fixtures making up the test loading. From table 1 we see that the maximum rate of flow from any two of the three fixtures (considering the sink and tray compartments of the combination fixture to be separate fixtures) is 35.8 gallons per minute, if we except the case of the basket strainer withdrawn (sink with grid strainer and lavatory with 1¼-inch trap and waste discharging). Reference to figure 11 will show that, for this rate of flow through the wet vent, trap-seal losses will be appreciably below the adopted permissible trap-seal losses for both the 1½-inch- and the 2-inch-diameter wet vents for the 4- and 5-foot-long tub drains tested. Inasmuch as the data in figure 11 and tables 2 and 3 indicate that trap-seal losses do not increase as the length of the drain increases, this suggests that the test loading under consideration may not impose any limitation on the maximum permissible length of the drain of a wet-vented tub.

The strict application of the adopted test loading and the permissible trap-seal loss to the determination of permissible lengths and slopes of the bathtub drain for a loading that includes the discharge of the bathtub is materially handicapped by the fact that such application, as can be seen from figure 13, would lead to severe extrapolation of the test results, with permissible lengths of tub drains far in excess of those actually tested.

For example, in the case of tub drains on a ¼-inch-per-foot slope, drains 6 feet long were the longest tested, while an application of the adopted trap-seal loss to the data in figure 13 would lead to a permissible drain length for a ¼-inch-per-foot slope of more than 11 feet for the 1½-inch wet vent and to something in excess of 11 feet for the 2-inch wet vent. Similar, though smaller, extrapolation would be necessary for tub drains on a ½-inch slope. Such extrapolation of limited test data of this nature is, of course, not warranted, and it is proposed that, until such time as more experimental data are available for tub drains on lower slopes, a permissible design value of $S_3l_3=1.5$ inches be adopted for the 1½-inch wet vent and a value of $S_3l_3=2.0$ inches be adopted for the 2-inch-diameter wet vent. In computing values of S_3l_3, S_3 should be expressed in inches per inch or feet per foot, and l_3 should be expressed in inches.

The permissible values of the factor proposed above lead to the simple and obvious design criterion for a wet-vented bathtub drain—that the value of S_3l_3/d_1, where d_1 is the diameter of the wet vent, shall not exceed unity. Figure 15 shows permissible lengths of tub drains, measured from

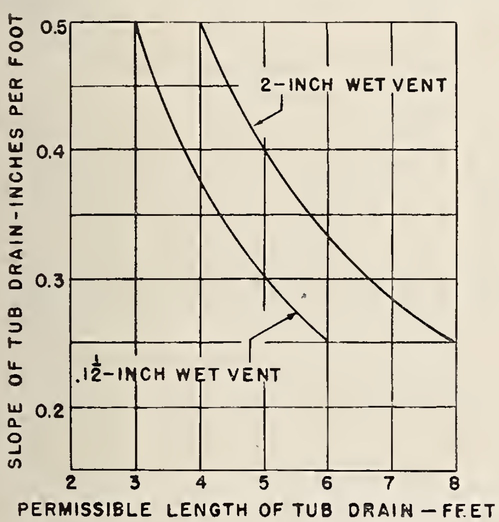

Figure 15. *Design data for wet-vented tub drains.*

the trap weir to the wet vent, for various slopes of the tub drain, computed from the criterion, $S_3l_3/d_1=1$.

In applying this general criterion it should be noted that S_3 should be expressed in inches per inch or feet per foot, not in inches per foot, as is the customary way of expressing drain slopes, and that l_3 and d_1 should be expressed in the same units—inches, feet, centimeters, etc.

It should also be noted, while we are discussing the effect of a test loading which includes the discharge of the tub together with only one fixture on the wet vent, that figure 13 shows the results of the discharge of all the fixtures on the wet vent in addition to the discharge of the tub. Figure 13 was used merely to illustrate the fact that even with a design load substantially in excess of the one adopted, extreme extrapolation of the test data is necessary to obtain a tub drain sufficiently long to result in trap-seal losses of 1 inch. Since the application of the design load adopted previously will cause smaller trap-seal losses, for a given slope and length of tub drain, than is shown by the data in figure 13, it is apparent that this procedure will result in the introduction of an appreciable safety factor into the conclusions.

The foregoing conclusions regarding the permissible lengths of wet-vented tub drains are based on tests of a system in which the diameter of the horizontal branch was 2 inches and the diameter of the tub drain was 1½ inches, and in which both a lavatory and a combination fixture drained into the wet vent through a double fitting. The wet-vented bathroom and kitchen fixtures were located on the topmost branch interval of the stack. The diameters of the combination fixture and lavatory drains were 1½ and 1¼ inches, respectively. In practice many of these dimensions vary, and other factors affect the efficiency of a wet-vented drainage system. These factors will be duscussed in section VI.

d. Summary

1. A loading consisting of the simultaneous discharge of the two fixtures on the system which cause the largest trap-seal losses has been adopted as the design or test loading of the system.
2. A trap-seal loss of one inch has been adopted as the limiting value for distinguishing between satisfactory and unsatisfactory performance.
3. The application of the design load and the permissible trap-seal loss given above indicate that both 1½- and 2-inch-diameter wet vents will be adequate for the system under consideration, provided that the value of the quantity, S_3l_3/d_1, does not exceed unity. S_3 and l_3 in this factor are, respectively, the slope and the length of the tub drain, and d_1 is the diameter of the wet vent, all expressed in consistent units, as described previously.

VI. Factors Affecting the Performance of Wet-Vented Systems

1. Length of Horizontal Branch

As indicated in figure 6, the drain connecting the wet vent and tub drain to the stack is commonly called a *horizontal branch*. For most of the test results presented so far, the horizontal branches were 4 feet in length. However, in practice this branch may be either shorter or longer than 4 feet, and it is desirable to determine the effect on the trap-seal losses previously reported of changing this length. Test results relating to this question are given in figure 16. These tests were not made on a complete system but were made with the test setup shown in the figure. The water was not introduced to the wet vent from conventional fixtures but through a valved connection to the city water supply. The length of horizontal branch was varied from 1.3 to 8.25 feet. As can be seen from the figure, tub trap-seal losses appear to be independent of the length of the horizontal branch.

A number of tests were also made to determine the effect of length of the horizontal branch on trap-seal reductions in the complete system shown in figure 6. These tests consisted in changing the length of the horizontal branch from 4 to 2 feet. In no case was there a significant difference noted.

Hence it may be concluded that the test data presented in this report are valid for any length of horizontal branch, at least within the range of lengths tested.

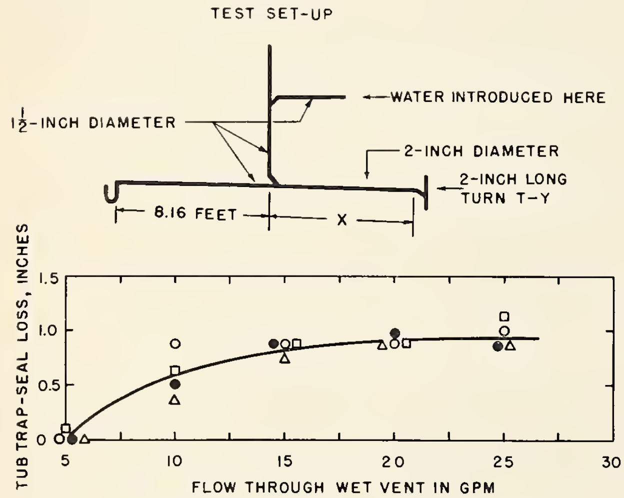

Figure 16. *Effect of length of horizontal branch on tub trap-seal reduction.*

Slope of tub waste was ½ inch per foot. Data shown represent the maximum of five tests under identical conditions. Cast-brass trap shown in figure 10 used on tub. Tub discharged in tests.

Symbol	Dimension x in feet
○	1.3
△	4.25
□	6.41
●	8.25

2. Slope of Horizontal Branch

Although the usual slope of the horizontal branch in a wet-vented system is ¼ inch per foot, it is occasionally necessary or desirable to increase this slope. For this reason the slope of the horizontal branch was varied in some of the tests. The results of these tests for several modifications of the test setup are given in figure 17, and it will

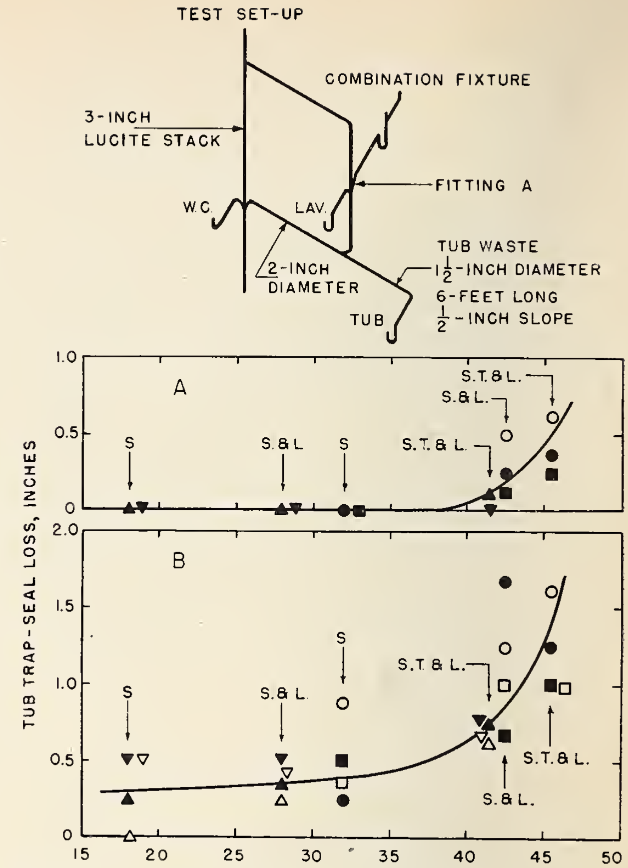

Figure 17. *Effect of slope of horizontal branch on tub trap-seal reduction.*

A. 2-inch wet vent. B. 1½-inch wet vent.
Plug discharge of fixtures. Metal pipe fittings were used on lavatory, sink, and tub wastes, wet vent, and 2-inch horizontal branch. Cast-brass trap shown in figure 10 used on tub. Tub not discharged. Above data represent the maximum seal reduction obtained in 10 tests made under identical conditions.

Slope of horizontal branch inch-per-foot		Fitting A	Position of basket type strainer
¼	½		
△	▲	Short-turn	In normal position in sink.
▽	▼	Long-turn	Do.
○	●	Short-turn	Pulled out of sink.
□	■	Long-turn	Do.

S=sink, T=tray, L=lavatory.

be observed that there is no consistent effect of variation of slope of the horizontal branch.

3. Diameter of Horizontal Branch

The experimental data so far presented in this investigation have been, for the most part, obtained with the system shown in figure 6 with a 2-inch-diameter horizontal branch. Tests were not made with this system using a 1½-inch horizontal branch because the general horizontal-branch loading tables of most codes do not permit a load on a 1½-inch horizontal branch approaching that shown in figure 6. However, tests to be described shortly were made with a 1½-inch horizontal branch on a single-story, wet-vented system in which only a lavatory discharged into the wet vent. As indicated in table 12, an 0.88-inch trap-seal loss was obtained when the tub and lavatory were discharged. Inasmuch as no trap-seal loss was obtained on the system shown in figure 6 with the same fixture discharge, it can be concluded that a decrease in the diameter of the horizontal branch from 2 inches to 1½ inches will cause increased trap-seal losses.

Table 12. *Trap-seal losses of wet-vented bathtub* [a]

[Only lavatory connected to wet vent]

Fixtures discharged	Tub trap-seal loss				Water closet trap-seal loss	
	Tub drain 7 ft long, ¼-inch slope		Tub drain 6 ft long, ½-inch slope			
	max	avg	max	avg	max	avg
	in.	*in.*	*in.*	*in.*	*in.*	*in.*
Lavatory, tub	0	0	0.88	0.48	0	0
Lavatory, water closet, tub	0	0	.88	.48	0	0
Lavatory, sink, tray, tub	0	0	.75	.08	.75	.62
Lavatory, sink, tray	.12	.11	.12	.09	.75	.64
Lavatory, sink, tray, water closet	.19	.13	.12	.12	0	0

[a] The cast trap shown in figure 9 was used on the tub.

Whether the increase in trap-seal losses would be sufficient in the case of the system shown in figure 6 to warrant the prohibition of 1½-inch-diameter horizontal branches is problematical. There are, however, no experimental data available at present justifying the use of 1½-inch horizontal branches on such a system.

4. Tub Drain Length and Slope

It has been concluded from the data in tables 2, 3, and 4 that, for the loadings that do not include the discharge of the tub, the data in figure 11 will serve to indicate the maximum trap-seal losses to be expected from installations with a tub drain 4 feet or more in length on a ½-inch-per-foot slope or less.

In this connection, it will be recalled that, on the tests with the transparent drains, a pool of water was observed in the tub drain under certain conditions, and when the pool was sufficiently long to extend back to the tub trap and to cover the trap weir to an appreciable depth, refill of the trap occurred when flow from the wet vent ceased, resulting in a smaller trap-seal loss than would have been the case had the drain been sufficiently long and on so steep a slope that the pool of water did not extend to the trap weir.

Since, when the test loading does not include the discharge of the tub, the length and slope of the tub drain can have no conceivable effect on the depth of water in the tub drain immediately upstream from the wet vent, it would be expected that, for sufficiently shorter drains than those tested or for sufficiently lower slopes, the trap-seal losses would be smaller than those shown in figure 11 or in tables 2 and 3. In this connection, it appears obvious that the direct cause of trap-seal losses in the particular tests under consideration must be the existence of a partial vacuum in the tub drain. If this vacuum is assumed not to decrease during the discharge of the fixtures on the wet vent, it is obvious that the air pocket in the tub drain must extend along the entire upper surface of the drain, and hence the maximum possible distance that the pool of water can extend back into the tub drain is d_3/S_3, where d_3 and S_3 are the diameter and slope of the tub drain, respectively.

If the above conception of the phenomenon is assumed to be correct, refill of the trap from the drain cannot occur when the length l_3 of the tub drain is greater than d_3/S_3; or, stated differently, when S_3l_3/d_3 is greater than unity and it would be expected that, for some value of S_3l_3/d_3 less than 1, trap-seal losses for loadings not including the discharge of the bathtub would be negligible for all rates of discharge down the wet vent.

If it be assumed, as has actually been observed, that the effect of trail discharge of the fixtures on the wet vent causes a decrease in the vacuum in the tub drain, near the end of the period of discharge, at least partial refill of the trap may occur for values of S_3l_3/d_3 greater than unity.

A careful examination of the data in tables 2 and 3 in the light of the above discussion will indicate that, while the data in these tables, with regard to the influence of the length of drain on trap-seal losses, are somewhat erratic and nonconclusive, there appears to be a definite tendency for the increases in trap-seal losses that are apparent as the tub-drain length is decreased from 6 to 5 feet to level off, and for the trap-seal losses to decrease as the drain is further shortened to 4 feet. Hence it is to be inferred that, for the 1½-inch-diameter tub drain on a ½ inch-per-foot slope, the effect of refill into the trap from the standing pool of water in the drain begins to make itself apparent when the length of drain is approximately 4 feet, and that any further appreciable decrease in length of tub drain will result in a decrease of trap-seal losses. Hence it would be expected that the data in figure 11 and tables 2 and 3 will not be exceeded as the length of the drain is decreased below 4 feet, and, therefore, that the data in tables 2 and 3 and figure 11 will not be exceeded by the trap-seal losses obtained with a tub drain of any length.

The above considerations of the effect of refill of the trap from the tub drain leave unexplained the decrease in the trap-seal losses listed in tables 2 and 3 for the drain 6 feet in length as compared with the 5-foot drain. In this connection it is believed that this decrease in trap-seal losses is connected with an effect which must exert an increasing influence on trap-seal losses as the tub drain is lengthened. The pressure reduction in the tub drain is created by the water flowing from the wet vent. For a given pressure reduction in the tub drain, the volume of air to be evacuated from a drain 6 feet long will be greater than for a drain 5 feet in length, and hence the time required for the pressure reduction in the tub drain to reach equilibrium will be longer for the 6-foot drain, assuming that the rate of evacuation is the same in the two cases. If the duration of the discharge through the wet vent is greater than the time required for the pressure reduction in the tub drain to reach equilibrium, this phenomenon will have no effect on the trap-seal losses as the drain is increased in length. However, for a given duration of flow in the wet vent, it is obvious that, as the drain length is increased, eventually a point will be reached at which the time required to evacuate sufficient air from the tub drain so that equilibrium exists will be greater than the duration of flow from the fixtures on the wet vent. When this point is reached, it would be expected that any further increase in tub drain length would cause decreased trap-seal losses. It is believed that the phenomenon described is the cause of the decrease in trap-seal losses observed for the drain 6 feet in length as compared to the 5-foot drain.

Inasmuch as the trap-seal losses for the 4- and 5-foot lengths of tub drain on a ½-in-per-foot slope are substantially equal, it has been concluded that, as the length of drain on a ½-inch slope is increased beyond approximately 4 feet, refill from the drain into the trap does not occur. Since the only possible effect, for the loading that does not include the discharge of the tub, of increasing the slope of the tub drain is to decrease trap refill, it follows that the trap-seal losses in tables 2 and 3 and figure 11 will not be exceeded when the slope of the tub drain is increased above ½ inch per foot.

In view of the above discussion regarding the effect of tub drain length and slope, it may be concluded, for the loading which does not include the discharge of the tub, that the trap-seal losses of tables 2 and 3 and figure 11 will not be exceeded with a tub drain of any length or slope.

In the case of loadings which include the discharge of the bathtub, it appears equally clear that the water surface in the tub drain will never be lower than would be the case for the loading which does not include the discharge of the tub, and hence it would be expected, as for the previous loading, that there exists some minimum value of S_3l_3/d_3 for which refill of the trap from the drain is such that all loadings, irrespective of whether the loading includes the discharge of the tub, will produce negligible trap-seal losses. It is interesting in this connection to note that Hunter [3] has proposed, in effect, that the slope, diameter, and length of the unvented portion of any fixture drain, whether wet, stack, or back-vented, be limited so that the value of S_3l_3/d_3 shall not exceed unity.

5. Trap Dimensions

There are two methods by which a tub trap-seal loss due to negative pressure in the fixture drain may occur. First, if the negative pressure, expressed in inches of water, in the tub drain created by the flow down the wet vent is less than the depth of trap seal; then, assuming that the tub drain is sufficiently long and on a sufficiently high slope to prevent refill of the trap from the drain, water will be drawn from the trap until equilibrium occurs. When the flow in the wet vent ceases, the seal reduction in the tub trap will be one-half the magnitude of the negative pressure head in the tub drain and is independent of the depth of the trap seal and of any other dimension of the trap, such as its diameter. However, if the flow down the wet vent is large enough to cause a pressure reduction in the tub drain greater than the depth of the tub trap seal, air will be bubbled from the atmosphere through the trap into the tub drain. This process pumps water out of the tub trap and into the drain and hence results in relatively large trap-seal losses.

Consequently it is apparent, for a given pressure reduction in the tub drain, that, if the depth of the tub trap seal is greater than the pressure reduction in the drain, a decrease in depth of trap seal will have no effect on the tub trap-seal losses until a point is reached at which the depth of trap seal is equal to the pressure reduction in the drain. Any further reduction in depth of trap seal will cause a rapid increase in trap-seal losses. Hence the effect of increasing the depth of tub trap seal from a value less than the pressure reduction in the drain to a value greater will be, in general, to decrease trap-seal losses substantially. And the effect of increasing the depth of tub trap seal, when it is at all times greater than the negative pressure in the tub drain, will be nil.

In the tests reported here, the depth of tub trap seal was 2 inches or more, and the adopted criterion of satisfactory performance was a trap-seal reduction of 1 inch. A trap-seal reduction of 1 inch corresponds to a negative pressure in the tub drain of 2 inches. Hence, the particular tests on which the conclusions as to the adequacy of wet venting have been based were made with loadings which produced negative pressures in the tub drain equal to or less than the depth of trap seal. It is apparent, therefore, that the conclusions expressed in this report for traps with depths of seal of 2 inches would not be changed by increasing the depth of trap seal.

From the discussion above on the effect of change in tub trap-seal depths on tub trap-seal losses, it is evident that a change in tub-trap diameter could have no effect on tub trap-seal losses, as long as these losses are less than 1 inch, which, as has been stated before, has been adopted in this report as the criterion of satisfactory trap performance. For this reason it is apparent that the conclusions expressed regarding wet venting apply with equal force to tub-trap diameters of any size.

For seal losses greater than approximately 1 inch in a trap with a depth of seal of 2 inches, air will be drawn through the trap, as noted previously, and, when this condition arises, the diameter of the tub trap undoubtedly has some effect on the amount of trap-seal reduction. This problem was not investigated, but it would be expected that a decrease in tub-trap diameter would cause greater trap-seal losses.

From the preceding discussion on the effect of changing the tub trap dimensions, it would be expected that, for trap-seal losses of approximately 1 inch or less, the cast and tubing traps shown in figures 9 and 10 would give the same results, whereas for the larger trap-seal losses, the cast trap, owing to its smaller depth of trap seal and its smaller diameter, would give the greater trap-seal losses. Figures 11, 12, and 13 show this to be the case.

6. Effect on the Trap-Seal Losses of a Wet-Vented Bathtub of Increasing the Diameters of the Lavatory and Combination Fixture Drains

Consider first the loading which does not include the discharge of the bathtub. The tub trap-seal loss, h, under the assumed conditions will depend only on the pressure, p, in the tub drain. This pressure, however, depends on a number of characteristics of the system—the length l_3, slope S_3, and diameter d_3 of the tub drain, the volume rate of flow Q through the wet vent, the pressure p_1 at the base of the wet vent, the diameter d_1 of the wet vent, and possibly the velocity v_1 at the base of the wet vent, and the diameter d_2, the slope S_2, and the length l_2 of the horizontal branch. In turn, p_1 and v_1 depend on certain additional characteristics of the system, such as the diameters d_4 and d_5 of the combination fixture drain and the lavatory drain, respectively, and the length l_1 of the wet vent. In addition they also depend on the acceleration of gravity. The roughness of the pipe walls will also have some slight effect, but this will not be important because the lengths involved are short.

Equation 1 is the formal expression of the statements made in the preceding paragraph. The pressures, p and p_1, and the velocity v_1 do not appear in the right member of the equation, since they depend, to a first approximation at least, only on quantities that are shown in the right member.

$$h=\phi(Q, d_1, d_2, d_4, d_5, l_1, l_2, l_3, S_2, S_3, g). \qquad (1)$$

This equation contains 12 physical or geometrical quantities that can be expressed in terms of two physical dimensions—length and time—and it follows from the theory of dimensional analysis that it can be rewritten in terms of $12-2=10$ dimensionless variables. The exact form of some of these variables is in part optional with us, and in these cases we use our physical intuition or our past experience to form the particular combinations that will be useful. We rewrite eq 1 as follows:

$$\frac{h}{d_1}=\phi\left[\frac{Q}{d_1^2\sqrt{gd_1}}, \frac{d_1}{d_2}, \frac{d_1}{d_4}, \frac{d_1}{d_5}, \frac{d_1}{l_1}, \frac{d_1}{l_2}, \frac{d_1}{l_3}, S_2, S_3\right]. \qquad (2)$$

We are concerned here only with the effect on the trap-seal losses of changes in d_4 and d_5. Aside from this, the geometrical characteristics of the system will remain constant, and hence we can eliminate from consideration the variables, d_1/d_2, d_1/l_1, d_1/l_2, d_1/l_3, S_2, and S_3. Equation 2 then simplifies to

$$h/d_1=\phi\left[\frac{Q}{d_1^2\sqrt{gd_1}}, \frac{d_1}{d_4}, \frac{d_1}{d_5}\right]. \qquad (3)$$

One further simplification can be made, owing to the fact that we do not need to consider d_4 and d_5 simultaneously, but only one at a time, depending on which fixture is producing the flow, Q. Hence we shall eliminate one of the two diameter ratios and arbitrarily refer to the one under consideration as d_4. Equation 3 then becomes

$$\frac{h}{d_1}=f\left[\frac{Q}{d_1^2\sqrt{gd_1}}, \frac{d_1}{d_4}\right], \qquad (4)$$

which is the final form of the equation we shall use to study the effect of changing the fixture drain diameter. This equation is identical with eq 3 of the earlier paper on stack venting [1].

In the paper referred to [1], it was shown that an increase in d_4, which amounts to decreasing the ratio d_1/d_4, has the effect of decreasing the trap-seal loss h, or the relative trap-seal loss h/d_1 of stack-vented fixtures. Since a change in d_1/d_4 can, for a given Q, affect the trap-seal losses only through the resulting effect on the velocities and pressures in the wet vent or stack, and since the basic phenomena governing the velocities and pressures in a vertical stack and in a wet vent are essentially the same, it would be expected that a decrease in d_1/d_4, as was the case with stack-vented fixtures, would cause, for a given value of $Q/d_1^2\sqrt{gd_1}$, a decrease in the trap-seal losses of wet-vented fixtures. However, the value of $Q/d_1^2\sqrt{gd_1}$ does not remain constant as d_4 is increased, owing to the fact that an increase in d_4 causes an increase in Q, the discharge of the fixtures connected to the wet vent; and the data shown in figure 11 indicate that an increase in Q will ordinarily be accompanied by an increase in h, the trap-seal loss of wet-vented fixtures. Therefore, in the absence of specific data on the effect of an increase in fixture drain diameters, it can only be concluded that, if such an increase in fixture drain diameters causes an increase in trap-seal losses, the increase will be due to an increase in the value of the term, $Q/d_1^2\sqrt{gd_1}$, and will not exceed those shown by the data in figure 11 by using the increased Q resulting from an increase in d_4 as the argument.

The data in figure 11 and table 2 for the cast trap have been replotted in figure 18, using the dimensionless variables developed above. It will be observed from table 2 that some of the data plotted in figures 11 and 18 are for flow from the combination fixture alone, while other data plotted from these figures are for flows from both the lavatory and combination fixture. It will be observed from both figures 11 and 18 that, for

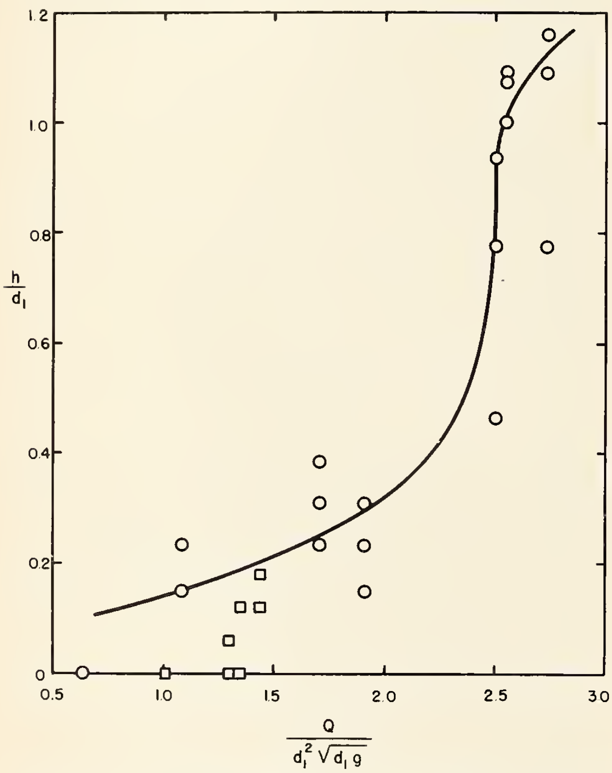

FIGURE 18. *Dimensionless plot of wet venting data for test loadings not including the bathtub.*

Symbol	Diameter of wet vent inches		$\frac{d_1}{d_2}$	$\frac{d_1}{d_4}$	$\frac{d_1}{d_5}$	$\frac{d_2}{d_3}$
	Nominal	Actual				
○	1½	1.61	0.78	1.00	1.16	1.29
□	2	2.07	1.00	1.50	1.29	1.29

the range of flows tested, there is little apparent difference in the test results between flows introduced through the 1¼-inch-diameter lavatory drain and the 1½-inch combination fixture drain. These limited experimental data on the effect of increasing the diameter of the fixture drains introducing water to the wet vent thus are in agreement with the conclusion expressed above that the trap-seal losses caused by increasing the diameter of the lavatory drain to 1½ inches or increasing the diameter of the combination fixture drain to 2 inches will not exceed those shown in figures 11 and 18 for the proper value of Q or $Q/d_1^2\sqrt{gd_1}$.

It will be observed in figure 18 that, for the range of variables tested, the data for the 2-inch-diameter wet vent approximate fairly closely the data for the 1½-inch wet vent. Inasmuch as the design or test loads developed in section V-4-a are such that no extrapolation of these data for either the 1½ or 2-inch-diameter wet vent is necessary, the curve in figure 18 may be safely used as a design curve for either 1¼- or 1½-inch-diameter lavatory drains or with 1½- or 2-inch-diameter sink or combination fixture drains. The use of a 1½-inch-diameter drain will increase the rate of discharge from the lavatory by approximately 3 gallons per minute. From table 1 the design loading proposed in section V-4-a becomes 38.8 gallons per minute (13.6+25.2) for a lavatory flow rate of 13.6 gallons per minute, which yields a value for $Q/d_1^2\sqrt{gd_1}$ of 2.32 for 1½-inch-diameter wet vent, and by reference to figure 18, it may be concluded that a value of h/d_1 of 0.5, or a trap-seal loss of 0.80 inch for a nominal 1½-inch wet vent, would not be exceeded. This trap-seal loss is less than the permissible value of 1 inch adopted in this report and hence is satisfactory.

In table 13 are given rates of discharge for a combination fixture with a drain 2 inches in diameter and 2 feet long on a slope of ¼ inch per foot. Assuming that the lavatory drain is 1½ inches in diameter and that consequently the lavatory has a rate of discharge of 13.6 gallons per minute, it is apparent from table 13 that the greatest discharge obtainable for any two fixtures on the wet vent is 41.2 gallons per minute, which yields a value of $Q/d_1^2\sqrt{gd_1}$ of 1.30 for a 2-inch-diameter wet vent.

TABLE 13. *Rates of discharge of combination fixture with drain 2 inches in diameter* [a]

Fixtures discharged	Rate of flow
	gpm
Sink—basket strainer	18.5
Sink—flat strainer	27.6
Tray	22.3
Sink and tray—basket strainer	30.3
Sink and tray—flat strainer	36.0

[a] The fixture drain was 2 feet in length and had a slope of ¼ inch per foot.

Reference to figure 18 shows that such a value of $Q/d_1^2\sqrt{gd_1}$ will yield a trap-seal loss substantially below 1 inch.

It may be concluded, therefore, that the increase in diameter of the lavatory drain to 1½ inches or the increase in the diameter of the combination fixture drain to 2 inches will not yield trap-seal losses in excess of the 1-inch seal loss adopted as the dividing line between satisfactory and unsatisfactory trap performance for these tests.

The above discussion of the effect of increasing the diameter of the lavatory or combination fixture drain has been confined to a test loading which does not include the discharge of the bathtub. It is obvious, however, that the inclusion of the discharge of the tub in the test loading would in no way alter the above conclusions.

The data in table 6 for the loading, including the discharge of the tub, have been replotted in figure 19, using the dimensionless variables developed above. The length of the tub drains used was 4 feet with the 1½-inch-diameter wet vent and 5 feet with the 2-inch-diameter wet vent. The corresponding values of S_3l_3/d_1 are 1.24 and 1.21, respectively, (S_3=½ inch per foot, and d_1=1.61 and 2.07 inches, respectively). Again, as the only possible effect of increasing d_4 and d_5 will be to increase the value of $Q/d_1^2\sqrt{gd_1}$ and to increase the pressure in the tub drain for a given value of $Q/d_1^2\sqrt{gd_1}$, it is concluded that the increase in h/d_1 because of an increase in d_4 and d_5 will be due to the resulting increase in the value of the term, $Q/d_1^2\sqrt{gd_1}$, and will not exceed the value of h/d_1 obtained from the data in figure 19 by using the increased value of $Q/d_1^2\sqrt{gd_1}$ as the argument.

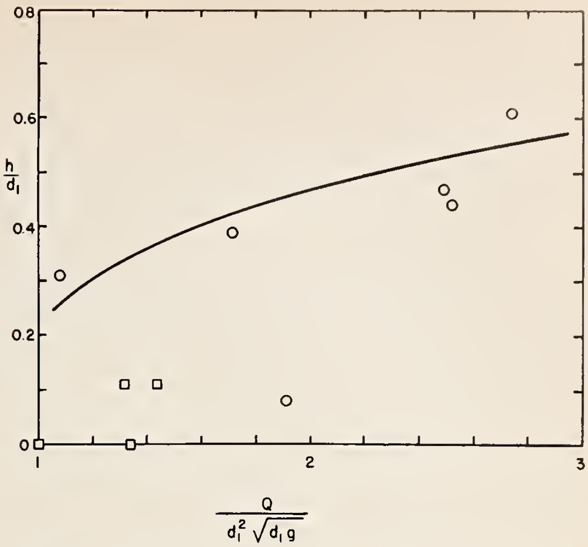

FIGURE 19. *Dimensionless plot of wet venting data for test loadings including the discharge of the bathtub.*

Symbol	Diameter of wet vent	$\frac{d_1}{d_2}$	$\frac{d_1}{d_4}$	$\frac{d_1}{d_5}$	$\frac{d_2}{d_3}$	$\frac{S_3l_3}{d_1}$
	Inches					
○	1½	0.78	1.00	1.16	1.29	1.24
□	2	1.00	1.50	1.29	1.29	1.21

The data in table 14 were obtained from a system with a 1½-inch-diameter wet vent, lavatory, and sink drain, and a 2-inch-diameter horizontal branch. The tub drain was 4 feet long and was on a slope of ½ inch per foot.

In obtaining the data given in table 14, only the diameter of the bathtub drain was increased. In figure 20 are shown similar data for another system in which both the bathtub and the combination fixture drain diameters were increased from

7. Diameter of Bathtub Drain

The great majority of the tests of this investigation were made with 1½-inch-diameter bathtub drains. However, as 2-inch-diameter tub drains are installed occasionally, a few of the tests were made with the larger diameter bathtub drain. The results of some of these tests are shown in table 14. It will be observed that the effect of increasing the diameter of the tub drain is to decrease the tub trap-seal losses.

TABLE 14. *Effect of tub drain diameter on trap-seal losses losses of a wet-vented bathtub*

Flow through wet-vent	Tub trap-seal loss	
	1½-inch-diameter tub drain	2-inch-diameter tub drain
Gpm	*In.*	*In.*
11.9	0.0	0.0
15.3	.38	.0
27.2	.38	.0

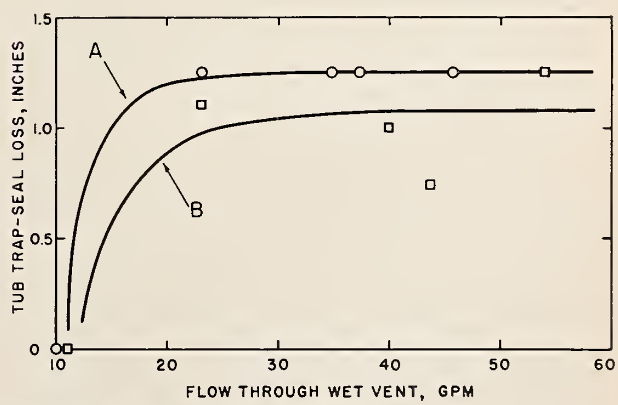

FIGURE 20. *Effect of tub and combination fixture drain diameters on trap-seal losses.*

A. 1½-inch-diameter drains on tub and combination fixture. B. 2-inch-diameter drains on tub and combination fixture.

1½ to 2 inches. It will again be observed that the increase in tub-drain-diameter decreases trap-seal losses.

Under these circumstances it is to be concluded that the data presented previously for 1½-inch bathtub drain diameters can be applied with at least equal safety to installations in which the diameter of the bathtub drain is 2 inches.

VII. Tests on a Single-Story Wet-Vented System With Only a Lavatory Connected to the Wet Vent

The test system for this series of tests is shown in figure 21. The stack and 18 feet of building drain were made of 3-inch-diameter transparent tubing. The remainder of the system was made of conventional pipe materials. The slope of the building drain was ⅛ inch per foot.

In table 15 are given tub and water-closet trap-seal losses for a tub drain 7 feet long laid on a ½-inch-per-foot slope. It will be noted from figure 21 that the water closet is stack-vented, so that in reality the bathroom group of fixtures is partially stack-vented and partially wet-vented. For this reason, water-closet trap-seal losses occur, and these have been listed in table 15. When the tub was among the fixtures discharged, the other fixtures making up the test loading were discharged in such a manner that their flow began 3 seconds prior to the end of the period of tub flow. In the case of the lavatory, the only fixture on the wet vent, the timing of its discharge with respect to the end of the tub discharge was found to influence greatly the amount of trap-seal loss obtained. For example, when the tub and lavatory discharges ended simultaneously, the average seal loss of 10 tests was 0.02 inch, whereas with the sequence of discharges noted above the average trap-seal loss was 0.48 inch.

It will be noted from table 15 that none of the trap-seal losses observed were in excess of the adopted permissible trap-seal loss, and that hence the wet-vented system in figure 21 may be considered to be adequately vented for the lengths and slopes of drains tested here—that is, for tub drain lengths and slopes up to a maximum length of 6 feet when laid on a ½-inch-per-foot slope, and up to a maximum length of 7 feet when laid on a ¼-inch slope.

Under these circumstances it is apparent that the conclusions derived from the tests made of the system shown in figure 6 may be applied with at least equal safety to the system being considered here, in which only the lavatory is connected to the wet vent, and the horizontal branch is 1½ inches in diameter.

The tests reported in table 15 were made with a house trap in the building drain. These tests were repeated without a house trap installed in the building drain, and in no case was there any appreciable or significant difference in the test results. It may be concluded, therefore, that any service condition, such as a house trap or a submerged house sewer, which causes an increase in the positive pressures in the stack will not cause a single-story wet-vented system to operate less satisfactorily.

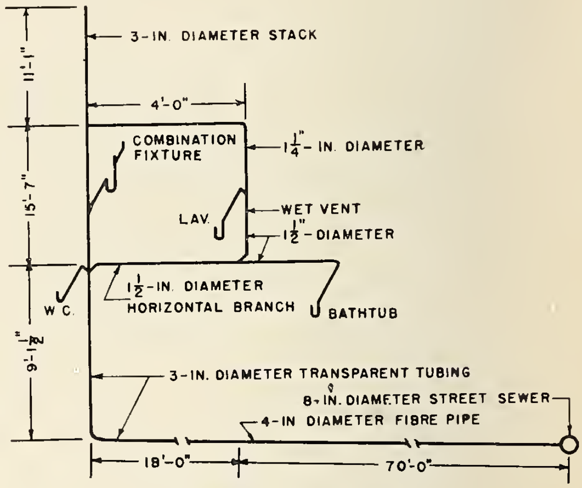

Figure 21. *Test system.*

Table 15. *Bathtub and water closet trap-seal losses for the wet-vented system shown in figure 21*

Fixtures discharged	Trap-seal losses [a]							
	Bathtub				Water closet			
	Tub drain 7 ft. long on ¼ in. per ft. slope		Tub drain 6 ft. long on ½ in. per ft. slope		Tub drain 7 ft. long on ¼ in. per ft. slope		Tub drain 6 ft. long on ½ in. per ft. slope	
	max	avg	max	avg	max	avg	max	avg
	in.	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*
Lavatory and tub	0	0	0.88	0.48	0	0	0	0
Lavatory, tub, and water closet	0	0	.88	.48	0	0	0	0
Lavatory, sink, tray and tub	0	0	.75	.08	.75	.62	.62	.57
Lavatory, sink, and tray	.12	.11	.12	.09	.75	.64	.62	.58
Lavatory, sink, tray, and water closet	.18	.13	.12	.12	0	0	0	0

[a] The data represent the maximum and average trap-seal losses observed in 5 consecutive tests made under identical conditions. The 1½-inch cast trap shown in figure 9 was used on the tub.

VIII. Tests on Two-Story, Duplex, Wet-Vented System

These tests were made on the system shown in figure 22. The greater part of the tests were made with all of the system except the building sewer made of transparent plastic tubing and fittings. As was the case with the other systems tested, the transparent fittings used were identical, within close tolerances, with conventional soil pipe fittings. The fixtures used in these tests were identical with those used on the other systems tested, and the data in table 1 for rates of flow from fixtures apply to this system as well as to the other two systems.

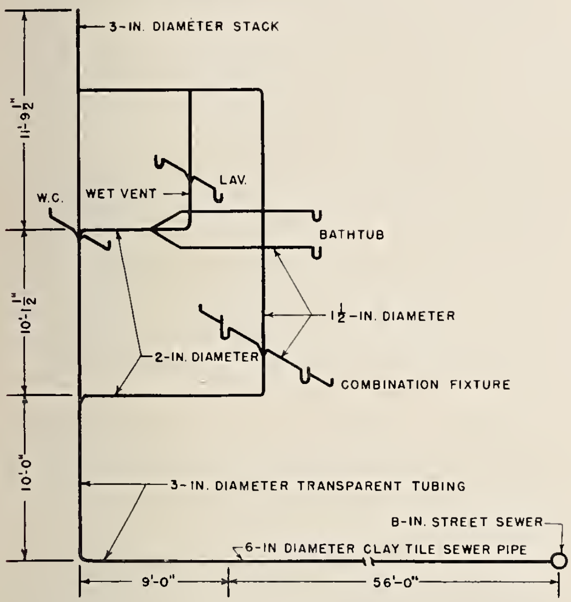

FIGURE 22. *Two-story, duplex, wet-vented system.*

In figure 23 are given tub trap-seal losses for this system for various lengths of tub drain. The data in figure 23 are all for tub drain slopes of ½ inch per foot. The lavatories were discharged so that the flow from the tubs and lavatories ended simultaneously. The two tubs and the two lavatories were discharged, since this loading was found to produce the greatest tub trap-seal losses. The data plotted in figure 23 represent the maximum trap-seal loss observed in 10 consecutive test runs made under identical conditions.

It is apparent from this figure that, for the plug discharge of the fixtures on this system, the trap-seal losses are independent of the length of the horizontal branch, as was the case with the other two systems tested. It will also be noted that the effect of the two different types of fittings used to connect the lavatory drains to the wet vent was negligible. Of particular interest in this figure is the fact that the trap-seal losses for the 1½- and 2-inch diameter wet vents were for all practical purposes identical. Since the rate of discharge of two lavatories approximates the rate of flow of a sink, it is evident from a comparison of these data with those of tables 5 and 6 that the volume rate of flow down the wet vent is not the only variable connected with flow conditions in the wet vent which affect the wet venting phenomena. The discharge of the lavatories was introduced to the wet vent through 1¼-inch-diameter drains, whereas the sink discharge was introduced through a 1½-inch-diameter drain. As has been stated previously, the velocity with which water is introduced to a vertical stack has an important effect on the trap-seal losses of stack-vented fixture traps below the point of water entrance, and it is to be inferred from this fact that the entrance velocity of the water introduced into a vertical stack or wet vent would have an important effect on the pressures in the stack or wet vent, and hence would affect the trap-seal losses of a wet-vented fixture.

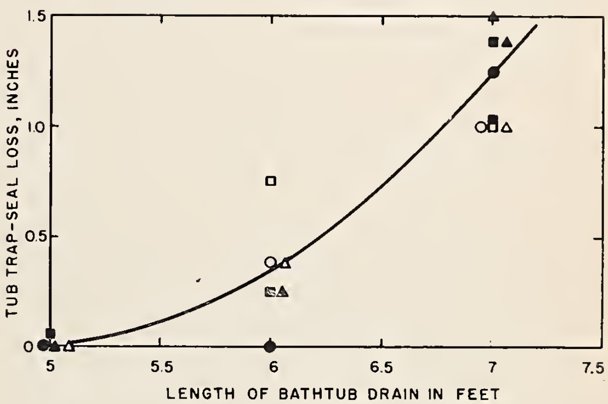

FIGURE 23. *Trap-seal losses of a two-story, duplex, wet-vented system.*

Both tubs and lavatories discharged

Symbol	Length of horizontal branch	Diameter of wet vent	Lavatory vent fitting
	ft.	*in.*	
●	2.58	1.5	Long-turn.
▲	2.58	1.5	Short-turn.
■	2.58	2.0	Do.
○	6.0	1.5	Long-turn.
△	6.0	1.5	Short-turn.
□	6.0	2.0	Do.

In addition, the duration of flow from the lavatories is approximately 10 seconds, while the duration of flow from a sink is approximately 15 seconds, and the data in figure 5 have shown that the duration of flow, under certain circumstances, materially affects the trap-seal losses of wet-vented fixtures. It is probable that these differences between lavatory and sink discharge into the wet vent account for the fact that the 2-inch-diameter wet vent yields smaller trap-seal losses than the

1½-inch wet vent for sink flow and the same loss for the discharge of two lavatories.

Test data for a constant rate of flow from the lavatories are given in figure 24, a condition which might occur when the lavatory is used by merely drawing water from the faucets. The data for flow rates of 6 gallons per minute were obtained by flow from one lavatory, whereas in the tests with a flow rate of 10.8 gallons per minute, 5.4 gallons per minute was flowing from each lavatory. These particular flow rates were chosen from the experimentally determined fact that a flow rate of approximately 5 gallons per minute is about the maximum that can be used in a lavatory in this manner without excessive and undesirable splashing.

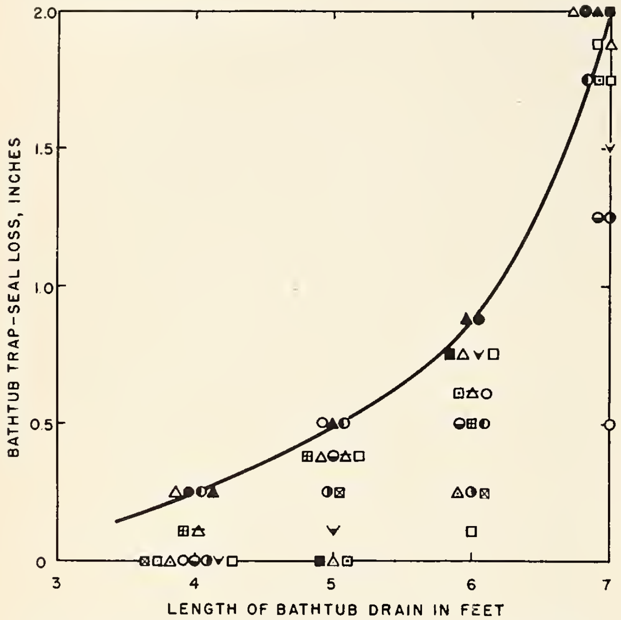

FIGURE 24. *Effect of length of bathtub drain*[a] *on wet venting of bathtub trap.*

Two-story duplex system. Continuous flow from lavatories.

Horizontal distance between wet vent and 3-inch stack: 2 ft. 7 in.	Horizontal distance between wet vent and 3-inch stack: 6 ft.	Diameter of wet vent	Lavatory vent fitting	Initial depth of water in bathtubs	Rate of flow from lavatory
		in.			*gpm*
○	●	1½	Long-turn *T–Y*	2¼ in. in one tub and 6 in. in other tub.	10.8
△	▲	1½	Short-turn *T*		
□	■	2	Short-turn *T*		
◐		1½	Long-turn *T–Y*	2¼ in. in one tub and 6 in. in other tub	6.0
⧋		1½	Short-turn *T*		
⊞		2	Short-turn *T*		
◒		1½	Long-turn *T–Y*	2¼ in. in each tub	6.0
◬		1½	Short-turn *T*		
⊠		2	Short-turn *T*		
◗		1½	Long-turn *T–Y*	2¼ in. in each tub.	10.8
⋎		1½	Short-turn *T*		
⊡		2	Short-turn *T*		

[a] Slope of bathtub drain, ½ inch per foot.

Preliminary tests with continuous flow from the lavatories showed that under certain conditions a greater reduction in trap seal was obtained when the tubs did not end their discharge at the same time. The most convenient method of regulating the length of time between the end of flow in one tub and the end of flow in the other was to fill the tubs to different depths and then pull the rubber stoppers simultaneously. It was found that a sufficiently long period between tub discharges was given by filling one tub to a depth of 2¼ inches and the other a depth of 6 inches. However, the maximum trap-seal loss does not always occur when the tub discharges end a minute or so apart. Therefore, tests were also made with both tubs filled to the same depth.

It was also determined in preliminary tests that the initial depth of water in the bathtubs had no effect on the amount of trap-seal loss, provided the initial depth was greater than a certain minimum.

The initial depths of water listed in figure 24, therefore, have no significance except to indicate that the discharge of the tubs either ended simultaneously or that they ended approximately one minute apart.

As has been stated, the data in figures 23 and 24 are for tub drain slopes of ½ inch per foot. Tests were also made with tub drains 7 feet long on a ¼-inch-per-foot slope. In no case, with the tub drain slope of ¼ inch were any trap-seal losses observed.

From the data in figures 23 and 24 it is evident that the adopted permissible trap-seal loss of 1 inch will not be exceeded on the two-story, duplex system provided the lengths of tub drains do not exceed 6 feet for a slope of ½ inch per foot and do not exceed 7 feet (the maximum length tested) for a slope of ¼ inch per foot.

It is clear that the conclusions regarding permissible lengths of wet-vented tub drains drawn from the test data obtained with the system shown in figure 6 may be applied with at least equal safety to wet-vented fixtures on the top floor of a two-story duplex system.

IX. Wet-Vented Fixtures on the Lower Floors of Multistory Buildings

All the venting tests made in connection with this project have been made either on a one-story installation or on the top floor of a two-story installation. There were no fixtures discharging into the stack on floors above the wet-vented fixtures being tested. For this reason the test results reported here apply directly only to the top floor of any structure, where the primary function of fixture vents is to prevent self-siphonage. In multistory stacks pressures and vacuum are of course created in the stack at the lower floor levels by the discharge of fixtures on the upper floors. In such cases the fixture vents will be required to relieve stack pressures and vacua, as well as to prevent self-siphonage.

Since the effect of using wet vents instead of back vents is to reduce the number of vents available on the lower floors for relieving stack pressures and vacuums, it is apparent that the indiscriminate substitution of a single wet vent to a group of fixtures for the purpose of replacing several back vents may lead to undesirable results on the lower floor, unless other means, such as the installation of a relief or yoke vent, are provided to control stack pressures and vacuums.

However, in this connection it may again be pointed out that Hunter [2] has shown that the wet-vented group of fixtures shown in figure 4, a, may be installed safely on the first floor of a two-story building in which a single bathroom group of fixtures, in addition to a kitchen sink or combination fixture, are located on the upper floor; and in a later publication [3] prepared in the form of a code by the Subcommittee on Plumbing, Central Housing Committee on Research, Design and Construction, to which Hunter was technical adviser, this type of installation, or that of figure 6, is permitted on the lower floor without a back-vent for the water closet, provided the fixtures on the upper floor do not exceed a single bathroom group and a kitchen sink or combination fixture.

X. Conclusions

From the test data presented it is concluded that the wet venting of one or two bathtub traps on the highset branch interval of systems such as those shown in figures 6, 21, and 22 is an adequate and satisfactory method of venting, provided:

1. The slope, S_3, and the length, l_3, of the tub drains and the diameter d_1 of the wet vent are such that the value of the quantity S_3l_3/d_1 does not exceed unity;

2. The diameter of the horizontal branch is not less than 1½ inches when one lavatory connects to the vent and not less than 2 inches when two lavatories, or a lavatory and a kitchen sink, or a lavatory and a combination fixture connect to the wet vent; and

3. The fixtures on the wet vent connect to this vent at the same level.

In connection with conclusion 1 above, it will be recalled that, in computing the values of S_3l_3/d_1, S_3 should be expressed in feet per foot or inches per inch and that l_3 and d_1 should be expressed in the same units of length.

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XI. References

[1] John L. French, Stack venting of plumbing fixtures NBS Building Materials and Structures Report BMS118 (1950).

[2] Recommended minimum requirements for plumbing in dwellings and similar buildings, NBS BH2 (1924).

[3] Plumbing manual, Report of the Subcommittee on Plumbing, Central Housing Committee on Research Design, and Construction, NBS Building Materials and Structures Report BMS66 (1940).

[4] Emergency plumbing standards for defense housing, Division of Defense Housing Coordination, Executive Office of the President, Office for Emergency Management (1942).

[5] Recommended minimum requirements for plumbing, NBS BH13, (1932).

[6] R. B. Hunter, Methods of estimating loads in plumbing systems, NBS Building Materials and Structures Report BMS65 (1940).

WASHINGTON, March 23, 1950.

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