PERFORMANCE OF RETROFITTED AND NEW HIGH EFFICIENCY GAS EQUIPMENT: SOME RECENT GRI PROJECTS*

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ABSTRACT

GRI has been funding projects assessing the field and laboratory performance of developing and existing technologies related to residential space conditioning. These include research on performance of new equipment as well as existing equipment and retrofits.

This paper outlines the findings of some recent projects including:

- field tests of the Lennox pulse combustion furnace.
- an on-going field test of a heat pipe furnace developed by Thermo Electron.
- a field assessment of the effects of flue gas condensate from high efficiency gas equipment on a sanitary drain system.
- a detailed examination of the SHEIP data with additional measurements at specific sites.
- tests to determine the potential savings from retrofits of existing furnaces, including derating with and without excess air adjustment, vent restriction, electro-mechanical and thermal dampers, intermittent ignition devices, and stack heat reclaimers.

Empirical results of savings are presented, as well as computer simulation predictions.

1. INTRODUCTION

The Gas Research Institute (GRI) has been funding studies to determine the field performance of gas fired equipment in residential structures. These have included tests of conventional equipment retrofitted with energy conserving devices, as well as new high-efficiency equipment using advanced technologies. This paper describes some of the recent GRI projects, and reports on the energy savings from using the equipment tested.

The projects included in this report are: 1) the pulse combustion furnace field test performed by the American Gas Association Laboratories (AGAL) and Lennox Industries, 2) the heat-pipe furnace field test performed by Thermo Electron and Public Service Electric and Gas Company of New Jersey, 3) an analysis of the SHEIP data on derate and vent dampers by the Institute for Gas Technology (IGT), and 4) laboratory tests of the seasonal performance of gas space heating equipment, retrofits and advanced high-efficiency systems performed by AGAL. The final project, 5) was a project conducted by Battelle-Columbus Laboratories to determine the effects of flue gas condensate on sanitary drain systems, municipal sewage treatment plants and residential septic systems. Detailed reports describing the projects are listed in the references and can be ordered through the National Technical Information Service.

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2. PROJECTS

2.1 Pulse Combustion Furnace Field Test

The American Gas Association Laboratories (AGAL), sponsored by GRI, developed a pulse combustion warm air furnace for residential applications. The prototype design was field tested in the winter of 1979-1980 at ten locations in the United States and Canada, in cooperation with Lennox Industries (1),(2). The purpose of the field tests was to determine the operating efficiency of the pulse combustion units relative to the conventional furnaces, and determine any difficulties that could arise in applying the new technology.

The furnaces used the pulse combustion principle, which provided excellent heat transfer in the combustion chamber. The positive pressure in the combustion chamber forced the combustion gases through a secondary heat exchanger and facilitated direct venting. Polyvinylchloride pipe was used to introduce outside air and vent the combustion byproducts. Flapper valves introduced the air and gas into the combustion chamber, and allowed very low off cycle heat losses through the flue. An electric spark ignited the initial fuel/air mixture, after which the pulse combustion process was self-sustaining. In the secondary heat exchanger, the flue gases were cooled below their dew point, and condensation occurred.

The pulse combustion furnaces were installed in parallel with the conventional furnaces. Dampers were provided to isolate the non-operating furnace from the duct system and to close the conventional furnace vent system during pulse furnace operation. The furnaces were submetered for electricity and gas consumption, and were controlled by the central thermostat through a relay. A data acquisition system recorded temperature and other data in real time. The furnaces were operated for alternate one week periods - the so-called flip flop method, providing them with similar loads. The homeowners were instructed not to change the thermostat setting for the test duration, and provided AGAL weekly with qualitative assessments of operating characteristics.

Prior to installation, the furnaces were adjusted in the lab for a steady state efficiency of 95%. The test site locations are shown in Table 1, along with the approximate average yearly heating degree days for the site. The number of weeks of furnace operation for the pulse and conventional units are also shown. The gas savings from using the pulse furnaces relative to the conventional units are shown in Table 1 and Figure 1. The average savings were 28.3%, with a 3 to 1 variation in the savings in individual houses. If one assumes that the pulse combustion furnace had a 93% seasonal efficiency, the seasonal efficiency of the conventional equipment can be calculated. This has been done and the results are presented in Figure 2.

2.2 Heat Pipe Furnace Field Test

Thermo Electron, under sponsorship of GRI, has been developing a total heating system based on individual room temperature control (3),(4). The heart of the system is a high efficiency furnace which incorporates a heat-pipe heat exchanger, direct vent power burner with spark ignition and a fully modulating air and gas valve. The furnace can be modulated over a four-to-one turndown ratio. The forced warm air heating system uses individual room thermostats to control room diffusers. The furnace modulates both heat input and air flow to meet the room demands. Laboratory tests indicate that at a set input rate of 100k Btuh the furnace has a steady state efficiency of 86% and an annual fuel utilization efficiency (AFUE) rating of 83.4%.

An early non-modulating developmental prototype furnace was field tested in two sites during the winter of 1981-1982. These were tests of the furnace with a conventional single zone thermostat. One heat pipe furnace was tested in Hillsdale, N.J. with the cooperation of Public Service Electric and Gas Company of New Jersey. The site had also been used to test an early prototype pulse combustion furnace, and a derated Singer furnace during previous seasons. A constant thermostat setting was maintained at the site. The furnace was submetered and the outside temperature was measured on-site for the test duration.

The gas consumption was plotted against the average outside temperature for each of several time periods for the heating season. A least-squares linear regression was performed, yielding a performance curve for each furnace tested. The furnace efficiency is approximately proportional to the slope of the line. The results of the field test at the Hillsdale site are shown in Figure 3. If the pulse furnace is assumed to be 93% efficient, the derated singer furnace had a seasonal efficiency of 72%, and the heat pipe furnace 83%. This comparison of course, ignores errors introduced by the cross seasonal comparison technique which may or may not be significant.

2.3 Condensate Disposal Field Test

In order to achieve very high efficiencies, advanced heating systems will condense part of the water vapor contained in their flue gases. A field study was performed by Battelle-Columbus Laboratories to 1) characterize the normal house effluent and the condensate produced by an operating pulse combustion furnace, 2) measure the corrosion rates of common plumbing materials before and after addition of condensate, and to 3) assess the effect of condensate disposal on municipal sewage treatment systems and residential septic systems (5),(6).

The test site was a home located in Westerville, Ohio. A pulse combustion furnace heated the home and provided the condensate to a special test loop in the drainage system as in Figure 4. Chemical properties of the effluent stream were monitored before and after the addition of condensate. A data acquisition system collected data at the site. For the condensate stream, continuous measurements were made of electrical conductivity, pH, redox potential, temperature and volume. For the effluent with and without condensate, the pH, electrical conductivity, temperature and corrosion (using a corrosometer*) were continuously monitored. In addition, laboratory analyses of grab samples from all streams were performed, including tests for sulfer and nitrogen containing ions, metals, alkalinity, hardness, dissolved oxygen, acidity and CO_2 and CO_3.

The corrosometer tests were used to obtain daily variations in corrosion rate. Long term tests for corrosion were obtained from corrosion coupons of typical plumbing materials placed in the two effluent streams. The coupons were removed and weighed after one, two and four month exposure to the effluent and combined effluent streams.

On-line characterization of the effluent and combined effluent streams indicated that during high flow in the sanitary drain system, the dilution was sufficient to make the two streams virtually indistinguishable. Grab sample analyses also indicated that the two streams were very similar in composition and within the bounds of what is typically encountered. During periods of little effluent flow, the pH of the effluent approached that of the condenste which was 3.5 to 3.8. The effect of condensate addition on the pH of the combined effluent stream is shown in Figure 5, which shows the fraction of time that the effluent stream was below a given pH, for the effluent and combined effluent. Condensate addition increased the fraction of time that the pH was low.

The results of the corrosion coupon tests are shown in Table 2. The corrosion rates of steels typical in drainage systems are essentially the same for the two streams, and the corrosion rates of the two types of mortar coupons are acceptable. Although there was a downward shift in pH, the corrosion rate was unchanged by the addition of condensate.

The tests were conducted in an area with typical hardwater conditions. Under these circumstances, the addition of condensate did not adversely affect typical drain materials. Further, there was no indication that the addition of condensate would adversely effect the operation of municiple sewage treatment plants or residential septic systems. It is not clear whether these conclusions hold in areas of soft-water supplies or when the house is subjected to long periods of non-occupancy.

2.4 SHEIP Data on Derate and Vent Dampers

The gas industry's Space Heating Efficiency Improvement Program (SHEIP) provided much information on the operating characteristics of gas fired heating equipment in actual homes. In a follow-up study, IGT took the best of the SHEIP data and supplemented it with additional on-site measurements, to determine why identical retrofit measures provided very different levels of energy savings (7).

To maximize accuracy and reliability of the study, only those houses with data meeting the following requirements were included for further analysis:

- testing of the retrofit was done using the flip-flop technique,
- data was available for a minimum of seven distinct time periods,
- submetered heating gas consumption showed a minimum 0.975 correlation coefficient with the average outside temperature of each time period.

* Registered Tradename of Rohrback Instruments Ltd.

Figure 6 shows the energy savings in control houses determined by using the flip-flop method and using the cross-seasoned approach in two test areas. The flip-flop approach is superior because it eliminates the variation caused by extraneous conservation.

Houses with data meeting the above criteria were studied to determine the energy savings from full derating and installation of electro-mechanical vent dampers. The savings from full derate were predicted using the H-FLAME, SPACE-FI and NBS-DOE computer models. The results are shown in Table 3, along with the actual savings. The three programs predicted the savings for the furnaces/boilers with varied success, with large errors for a few houses.

The expected energy savings from electro-mechanical vent dampers were calculated using the three computer models and are listed in Table 4 along with the actual savings. The H-FLAME and SPACE-FI predictions were somewhat better than the NBS-DOE predictions because of their use of an energy distribution factor (D_E). This number describes the extent to which the saved furnace heat was able to interact with the central thermostat. A value of D_E=1 implies full interaction while D_E=0 implies no communication. The value of D_E in the test houses was estimated based on the position of the basement door (open/closed), and the presence of supply and return air registers in the furnace room.

2.5 Lab Tests of Efficiencies of Retrofit and New Devices

The American Gas Association Laboratories (AGAL) built a test chamber to accurately estimate the seasonal efficiency of heating appliances (8). The test chamber simulated operating conditions in a home, including cycling, draft hood and flue losses and the building load. The test procedure provided a measure of the cyclic utilization efficiency (CUE) for the appliances tested, with a repeatability within 1 percentage point. Various conservation retrofit measures were tested to determine their affect on seasonal performance, including fuel and air derate, vent restriction, electric and thermal vent dampers, intermittent ignition devices (IID's), a heat reclaimer and combinations of the above.

The tests were run under conditions simulating a 40°F and 0°F outside temperature. The retrofit actions showed different levels of savings for the two conditions. In five furnaces and two boilers, derate without flue baffling showed zero or negative savings in all derating levels up to 60% derate. Derate with vent restriction only showed small positive and negative savings. Vent restriction with no derate, however, showed savings because of the typically oversized vent system. Derate with flue restriction had savings of zero to eleven percent. Derate with vent and flue restriction had the largest savings - 2% to 19% depending upon the unit and the level of derate.

Electro-mechanical dampers showed 5 to 15% savings at 40°F outside temperature at full input rate, and 8 to 20% savings with a 20% derate. A thermal damper achieved a 3 to 8% savings at full input and less savings when applied to a derated furnace relative to the unmodified state.

Tests of IID's showed that during the heating season, no significant energy savings resulted from their use. IID's would save energy during the non-heating season or in milder climates than those simulated. A heat reclaimer device consisting of fins attached to th flue was tested and showed a one percent improvement in CUE. A second device had a fan powered flue gas-to-air heat exchanger and showed an 8% savings at full input, and 16% savings with 60% derate and flue and vent restriction at 40°F. Addition of an electric damper brought the total savings up to 21 to 24%.

Six advanced technology appliances were tested in the chamber: a power burner instantaneous hot water boiler, an induced draft forced air furnace, a pulse combustion furnace prototype, a pulse combustion boiler, an instantaneous boiler using natural draft, and an induced draft condensing furnace. Table 5 lists the furnaces and their CUE's, along with the average CUE of the conventional boilers and furnaces tested. The most efficient boiler and furnace, both using pulse combustion, provide a 26 and 29 percent savings over the conventional equipment (water heater losses are charged to the furnace).

3. CONCLUSION

The techniques and products tested can significantly improve the seasonal efficiency of gas-fired space heating equipment. New generations of equipment can be expected to provide substantial increases in efficiency over conventional equipment.

4. REFERENCES

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TABLE 1. TEST SITES FOR PULSE COMBUSTION FURNACE PROTOTYPE FIELD TEST. AVERAGE HEATING DEGREE DAYS, NUMBER OF WEEKS OF OPERATION OF PULSER AND CONVENTIONAL FURNACE, AND MEASURED SAVINGS FOR EACH SITE.

TEST SITE	AVERAGE HEATING DEGREE DAYS	WEEKS OF OPERATION		SAVINGS
		PULSE	CONVENTIONAL	
Cleveland, OH	6351	8	7	24.9%
Dallas, TX	2363	9	5	14.2
Washington, DC	4224	9	8	20.9
Omaha, Nebr.	6612	4	4	20.6
Minneapolis, MN	8882	8	9	42.6
Aurora, IL	6155	8	8	28.2
Maplewood, NJ	4860	9	3	29.9
Calgary, Canada	$\geq$ 9000	6	8	38.5
Salt Lake City, Utah	6052	9	8	20.0
San Francisco, CA	3015	7	7	43.4

TABLE 2. AVERAGE CORROSION RATES OF METAL AND MORTAR COUPONS[6]

Metal	Environment[c]	Corrosion Rate, 0.001 in/yr (mpy) One-Month Exposure	Two-M h Expos.	Four-Month Exposure
Copper	E	0.5	0.3	0.2
Copper	E+C	0.3	0.4	0.3
Steel	E	6.5	6.2	4.9
Steel	E+C	6.5	6.0	4.7
Gray C. Iron	E	10.1	7.8	5.8
Gray C. Iron	E+C	8.8	6.9	4.9
Ductile Iron	E	8.0	7.5	5.5
Ductile Iron	E+C	7.2	7.2	5.9
Solder[d]	E	0.9	0.8	1.0
Solder[d]	E+C	0.6	0.8	1.0
Copper + Solder[e]	E	0.5	0.5	0.2
Copper + Solder[e]	E+C	0.6	0.4	0.3
Lead	E	0.9	1.0	1.0
Lead	E+C	0.7	0.9	1.0

Mortar[b]	Environment[c]	Corrosion Rate, $g/cm^2/yr$ One-Month Exposure	Two-Month Exposure	Four-Month Exposure
Type 1	E+C	0.10	0.06	0.03
Type 5	E+C	0.10	0.05	0.02

(b) Type 1 is ordinary Portland cement

Type 5 is an acid resistant grade of Portland cement

(c) E = effluent

E+C = combined effluent and condensate

TABLE 3. COMPARISON OF H-FLAME, SPACE-FI, AND DOE PREDICTIONS FOR DERATED FURNACES AND BOILERS (7)

TEST SITE	SEASONAL REDUCTION	REDUCTION IN CONSUMPTION H-FLAME	SPACE-FI	DOE-NBS
Furnaces				
68/50	8.2	11.0	12.4	2.3
68/51	10.9	10.2	13.6	9.2
68/54	9.9	0.9	6.8	- 8.7
68/79	5.4	4.4	5.7	3.6
68/117	12.3	6.2	10.0	1.6
68/137*	10.8	14.4	8.3	3.7
68/139*	8.7	11.7	10.4	1.7
68/142*	0.0	9.5	8.7	0.3
Boilers				
68/36	7.3	- 0.1	4.0	-18.7
68/52	12.1	7.5	13.2	3.3
68/60*	9.7	17.8	10.0	3.9
68/94	18.9	6.0	10.7	1.6
68/95*	9.6	2.8	6.1	3.0
68/116	6.9	4.3	10.2	- 0.1

* Sites for which detailed data were obtained for input into models. All other sites default input values were used.

TABLE 4. ENERGY SAVINGS PROJECTIONS FOR HOMES EQUIPPED WITH AN E/M DAMPER ON A WARM-AIR FURNACE (7)

TEST SITE	ACTUAL SEASONAL REDUCTION IN CONSUMPTION	REDUCTION IN CONSUMPTION		
		SPACE-FI	H-FLAME	NBS-DOE
12/246*	14.3	20.1	20.6	8.2
12/193*	13.2	14.4	16.1	8.3
68/83	9.1	9.0	ND	ND
12/191	11.1	3.0	3.6	10.9
12/152	9.9	8.5	5.3	5.8
12/158	7.8	12.4	11.5	4.5
12/286	8.9	4.4	5.3	12.6
12/148	11.4	11.2	11.0	6.6
12/143	0.9	9.5	7.1	7.6
68/21*	1.0	11.5	8.4	9.0
12/200*	7.5	4.1	4.8	10.9
12/56*	4.8	2.2	2.9	12.2
12/282*	4.9	1.1	2.3	14.4
68/18*	4.0	5.8	6.1	16.8
12/203	2.9	2.8	5.4	5.1
12/266	6.4	4.9	6.6	4.0
12/109*	0.2	6.9	4.9	11.2
12/234	- 2.5	2.8	0.0	5.5

TABLE 5. COMPARISON OF CYCLIC UTILIZATION EFFICIENCY OF SIX ADVANCED TECHNOLOGY HEATING SYSTEMS AND CONVENTIONAL SYSTEMS AT FULL RATE REFERENCE

UNIT	CYCLIC UTILIZATION EFFICIENCY (CUE) at outside temperature of:	
	$0^{o}F$	$40^{o}F$
Average of conventional furnaces	60.1	68.5
Average of conventional boilers	62.9	69.6
Pulse Boiler 2	83.0	87.5
Power Burner Boil 4	73.8	77.8
Instantaneous Boil 5	61.0	70.5
Power Vent FAF 4	69.7	74.2
Pulse FAF 6	83.7	88.5
Power Vent Condensing FAF 8	72.3	79

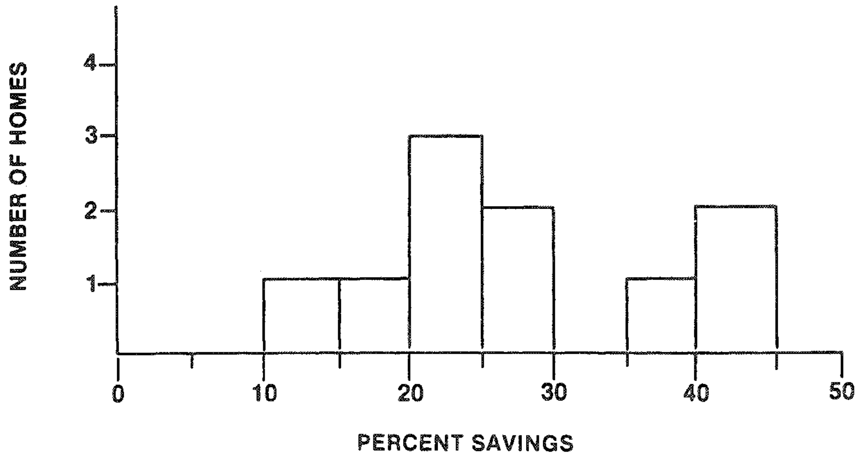

Figure 1. Percent savings from using pulse furnace as opposed to conventional furnace.

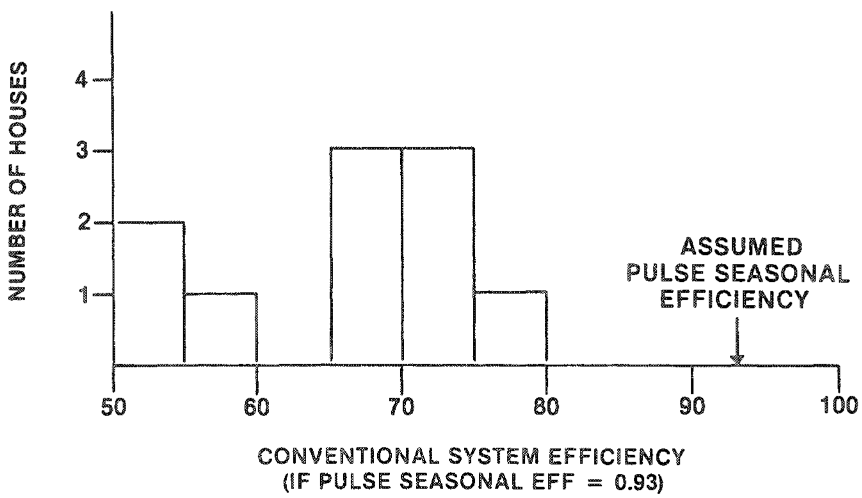

Figure 2. Conventional system efficiency if pulse combustion furnace is assumed to have a 93% seasonal efficiency (calculated from percent savings in field test N_c = .93 (1 - Savings).

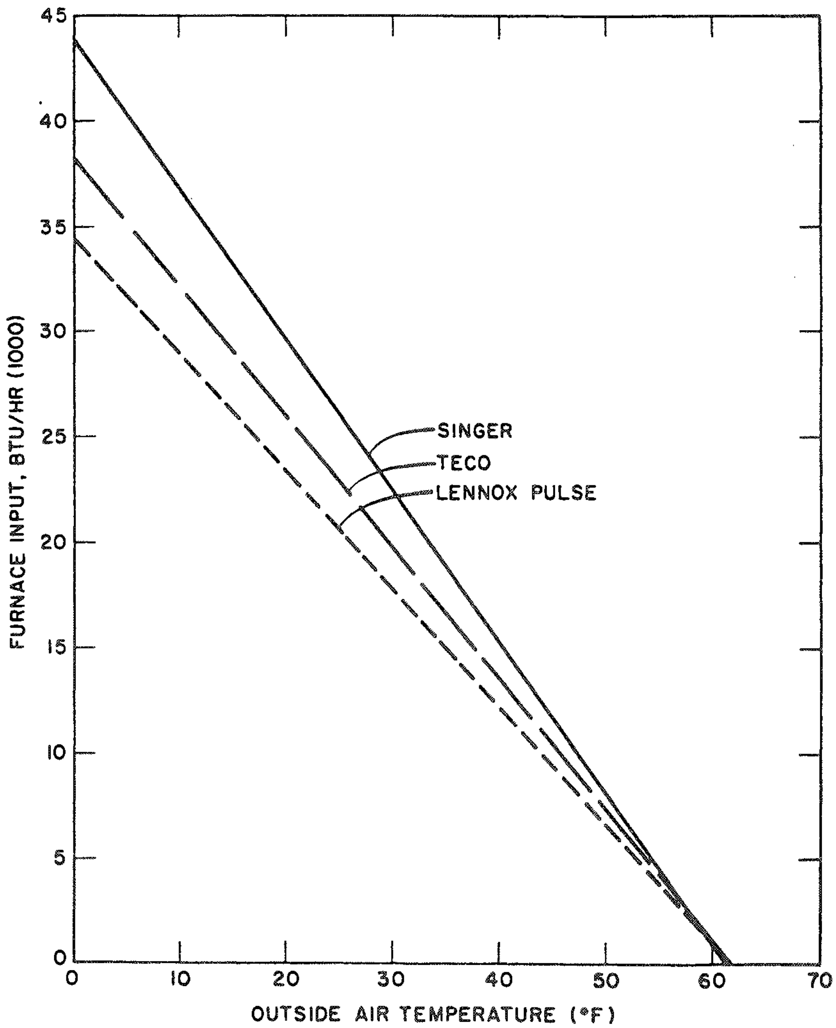

Figure 3. Gas consumption versus outside temperature for derated Singer, Lennox pulse combustion furnace prototype and thermo electron (TECO) heat-pipe furnace development prototypes[1].

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1 Special thanks to Mr. James Griffith of PSE&G Research Corp., New Jersey for this analysis.

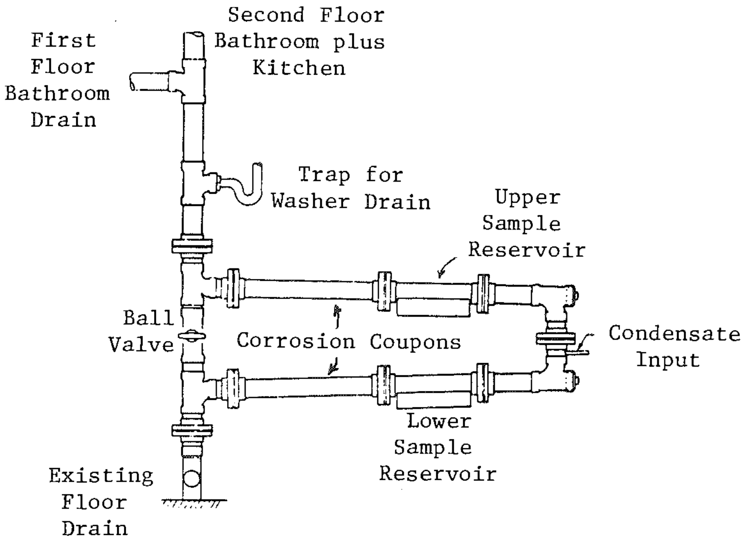

Figure 4. Artist drawing of sanitary drain flow diverter and test loop(6).

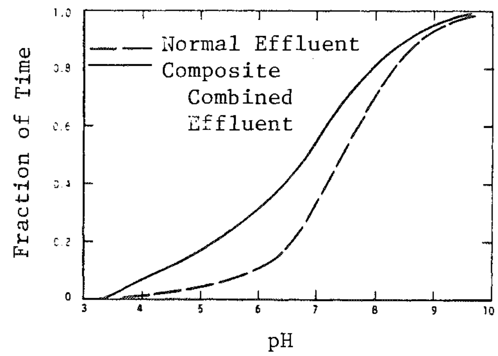

Figure 5. Fraction of time the pH of the effluent was less than indicated pH level (6).

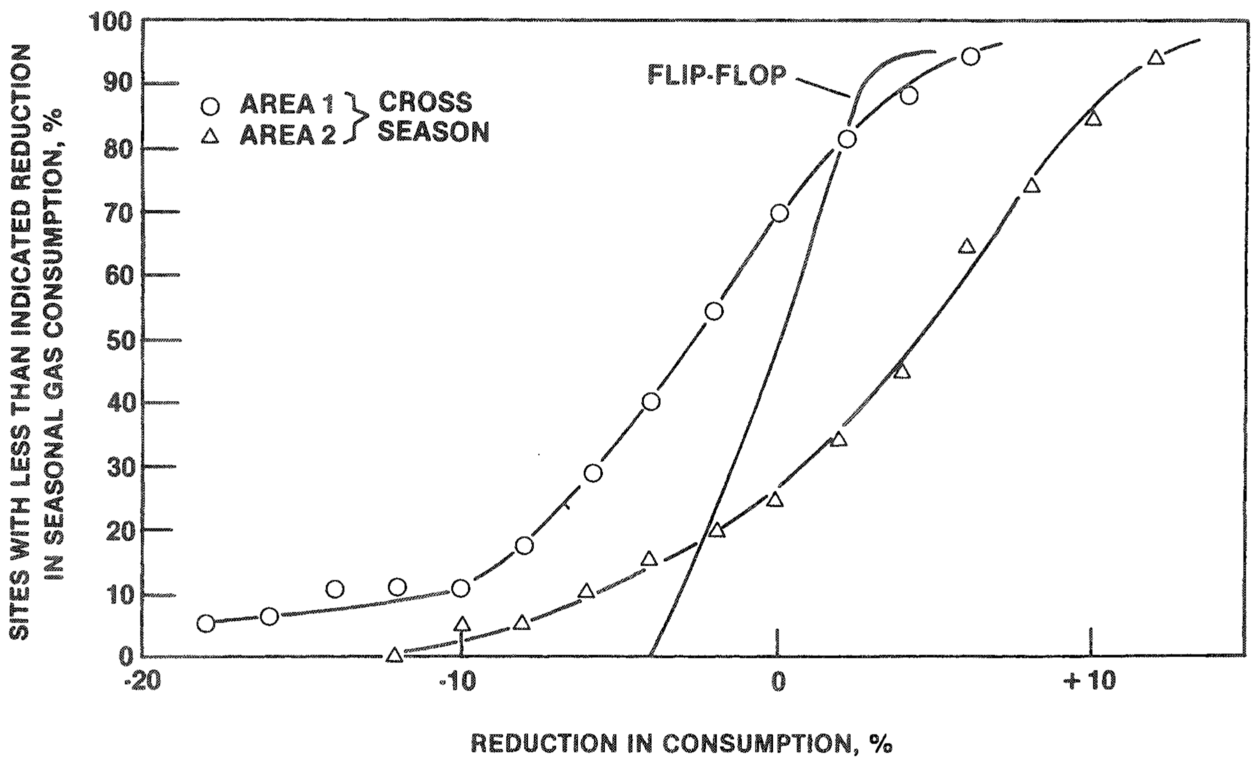

Figure 6. Cumulative distribution of "blank" sites monitored across two seasons with furnace submetering, and in one season using the flip-flop method.