THE FREQUENCY OF TOTAL USE OF MANUAL AND AUTOMATIC LOW-CONSUMPTION FIXTURES IN THE LANGFORD ARCHITECTURE BUILDING AT TEXAS A&M UNIVERSITY

A Thesis

by

WOO SUNG CHUNG

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2005

Major Subject: Construction Management

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Approved by:

Chair of Committee,	Paul K. Woods
Committee Members,	Richard A. Burt
	F. Michael Speed
Head of Department,	James W. Craig

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ABSTRACT

The Frequency of Total Use of Manual and Automatic Low-Consumption Fixtures in the Langford Architecture Building at Texas A&M University. (August 2005)

Woo Sung Chung, B.En., Hongik University

Chair of Advisory Committee: Dr. Paul K. Woods

The Energy Policy Act of 1992 mandated that bathroom plumbing fixtures manufactured in the United States after January 1, 1994 meet standards for maximum water consumption. Manufacturers have developed low-consumption valves to meet these standards. The performance of low-consumption fixtures has become an important issue for facilities managers because the water saving by retrofitting low-consumption fixtures is significant.

The fixtures in the Langford Architecture Building A, Texas A&M University were used to conduct this study. An acoustic information retrieval system was utilized to collect the sound signals of each fixture and a speech recognition system was utilized to identify which fixture was in use.

The data from this study were analyzed to determine whether location of fixture and type of fixture—manual or automatic—caused a significant difference in frequency of use.

ACKNOWLEDGMENTS

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INTRODUCTION: THE PROBLEM AND ITS SETTING

Background

> The earth was not given to us by our parents. It was lent to us by our children. Kenyan Proverb

Water conservation is an important factor in environment issues, not only because saves valuable water but also decreases wastewater flow. The United States alone uses approximately 4.8 billion gallons of water every day to flush waste (Seo, 2003). One-third of water consumption that takes place in building is from toilets and urinals.

The Energy Policy Act of 1992 established water conservation standards for the manufacture of four types of plumbing fixtures:

- Water closets
- Kitchen and lavatory faucets
- Showerheads
- Urinals.

Prior to the passage of the Energy Policy Act, commercial toilets were required to use no more than 3.5 gallon per flush (gpf). The Energy Policy Act established Federal law mandating that residential toilets manufactured after January 1, 1994, use no more than 1.6 gpf.

This thesis follows the style of the *Journal of Construction Education.*

Commercial toilets manufactured after January 1, 1997, must use no more than 1.6 gpf and urinals must use no more than 1 gpf (U.S. General Accounting Office, 2000). See Table 1.

Since passage of the Act, low-consumption water closets have been developed to meet these standards and to satisfy consumers.

Table 1.

Water Efficiency Standards Established by the Energy Policy Act of 1992. Source: Energy Policy Act of 1992 (Seo, 2003)

Water Closets and Urinals	
Water-closet type	**Maximum flush rate for fixtures manufactured after January 1, 1994**
Urinals	1.0 gpf
Gravity tank-type toilets[1]	1.6 gpf
Flushometer tank toilets[2]	1.6 gpf
Electromechanical hydraulic toilets	1.6 gpf
Blowout toilets	3.5 gpf

[1]The maximum water use allowed for any gravity-tank type white two-piece toilet which bears an adhesive label conspicuous upon installation with the words "Commercial Use Only" manufactured after January 1, 1994 and before January 1, 1997, is 3.5 gallons per flush.

[2]The maximum water use allowed for flushometer valve toilets, other than blowout toilets, manufactured after January 1, 1997, is 1.6 gallons per flush.

Previous studies have shown that manual low-consumption water fixtures have a 7% greater frequency of use than manual water fixtures. This greater use might be explained by the lower volume of water used by the low-consumption toilets—1.6 gpf versus 3.5 gpf for the older models—necessitating multiple flushes to clear the bowl and to avoid clogging. “There have been anecdotal reports of problems with their functioning, including a need for multiple flushes to clear the bowl, and frequent clogging.” (Henderson and Woodard, 2000)

However considerable water saving was achieved by retrofitting with low-consumption water fixtures. The most recent development is the use of automatic sensors incorporated into the water fixtures to initiate the flush. These sensor-activated flush mechanisms have distinct advantages: hands-off operation, improved sanitation, and elimination of redundant manual operation. This comparative study on the performance of automatic low-consumption water fixtures and manual low-consumption water fixtures is intended to increase the knowledge base on these fixtures.

Statement of Problem

The purpose of this study is to compare the difference in the total frequency of use of the use of two types of low-consumption fixtures: the manual low-consumption fixture using the Royal II Flushometer and the automatic low-consumption automatic fixture using the G2 Optima Plus Flushometer, both products of the Sloan Valve Company. This research was conducted in restrooms of the Langford Architecture Building at Texas A&M University to assess whether there is difference in the total frequency of use between the two types of low-consumption fixtures.

Outline of the Study

This study took place in stages:

- Monitor the frequency of use of the automatic low-consumption fixtures using G2 Optima plus Flushometer via Acoustical Information Retrieval Systems (AIRS),
- Calculate the total frequency of use of the automatic low-consumption water fixtures, and
- Compare the total frequency of use of the low-consumption fixtures between the manual and the automatic low-consumption water fixtures.

Hypotheses

It is assumed that there is no difference in frequency of total use between the two fixtures: the manual low-consumption fixture and the automatic low-consumption fixture.

Valve Types

μ_{MMWC} = Population mean frequency of use of the manual men’s water closets

μ_{AMWC} = Population mean frequency of use of the automatic men’s water closets

μ_{MMU} = Population mean frequency of use of the manual men’s urinals

μ_{AMU} = Population mean frequency of use of the automatic men’s urinals

μ_{MWWC} = Population mean frequency of use of the manual women’s water closets

μ_{AWWC} = Population mean frequency of use of the automatic women’s water closets

Fixture Location

μ_{MWC1} = Population mean frequency of use of men’s water closet location 1

μ_{MWC2} = Population mean frequency of use of men's water closet location 2

μ_{MU1} = Population mean frequency of use of men's urinal location 1

μ_{MU2} = Population mean frequency of use of men's urinal location 2

μ_{MU3} = Population mean frequency of use of men's urinal location 3

μ_{WWC1} = Population mean frequency of use of women's water closet location 1

μ_{WWC2} = Population mean frequency of use of women's water closet location 2

μ_{WWC3} = Population mean frequency of use of women's water closet location 3

μ_{WWC4} = Population mean frequency of use of women's water closet location 4

Hypothesis One (Men's Water Closet)

To evaluate if there a significant difference in the average total frequency of use between the manual low-consumption and the automatic low-consumption men's water closets and between location1 and location 2.

Objective 1 – Valve Type

The Null Hypothesis

The average total frequency of use of men's water closets between the manual low-consumption and the automatic low-consumption water closets is same.

Ho: $\mu_{MMWC} = \mu_{AMWC}$

The Research Hypothesis

There is a significant difference in the average total frequency of use of in men's water closets between the manual and the automatic low-consumption fixtures.

Ha: $\mu_{MMWC} \neq \mu_{AMWC}$

Objective 2 – Fixture Location

The Null Hypothesis

The average total frequency of use of men's water closets between location 1 and location 2 is same.

Ho: $\mu_{MWC1} = \mu_{MWC2}$

The Research Hypothesis

There is a significant difference in the average total frequency of use in men's water closets between location 1 and location 2.

Ha: $\mu_{MWC1} \neq \mu_{MWC2}$

Hypothesis Two (Men's Urinals)

To evaluate if there is significant difference in the average total frequency of use of men's urinals between the manual low-consumption and the automatic low-consumption fixtures.

Objective 1 – Fixture Type

The Null Hypothesis

The average total frequency of use of men's urinals between the manual low-consumption and the automatic low-consumption urinals is same.

Ho: $\mu_{MMU} = \mu_{AMU}$

The Null Hypothesis

There is a significant difference in the average total frequency of use of in use in men's urinals between the manual low-consumption and the automatic low-consumption fixtures.

Ha: $\mu_{MMU} \neq \mu_{AMU}$

Objective 2 – Fixture Location

The Null Hypothesis

The average total frequency of use of men's urinals among location1, location 2, and location 3 is same.

Ho: $\mu_{MU1} = \mu_{MU2} = \mu_{MU3}$

The Research Hypothesis

There is a significant difference in the average total frequency of use of in men's urinals among location 1, location 2, and location 3.

Ha: $\mu_{MU1} \neq \mu_{MU2}$ or $\mu_{MU2} \neq \mu_{MU3}$ or $\mu_{MU1} \neq \mu_{MU3}$

Hypothesis Three (Women's Water Closet)

To evaluate if there is significant difference in the average total frequency of use of women's water closets between the manual low-consumption and the automatic low-consumption fixtures.

Objective 1 – Fixture Type

The Null Hypothesis

The average total frequency of use of women's water closets between the manual low-consumption and the automatic low-consumption urinals is same.

Ho: $\mu_{MWWC} = \mu_{AWWC}$

The Null Hypothesis

There is significant difference in the average total frequency of use of women's water closets between the manual and the automatic low-consumption fixtures.

Ha: $\mu_{MWWC} \neq \mu_{AWWC}$

Object 2 – Fixture Location

The Null Hypothesis

The average total frequency of use of women's water closets among location 1, location 2, location 3, and location 4 is same.

Ho: $\mu_{WWC1} = \mu_{WWC2} = \mu_{WWC3} = \mu_{WWC4}$

The Research Hypothesis

There is difference in the average total frequency of use of women's water closets among location 1, location 2, location 3, and location 4.

Ha: $\mu_{WWC1} \neq \mu_{WWC2}$ or $\mu_{WWC1} \neq \mu_{WWC3}$ or $\mu_{WWC1} \neq \mu_{WWC4}$ or $\mu_{WWC2} \neq \mu_{MWC3}$ or $\mu_{WWC2} \neq \mu_{WWC4}$ or $\mu_{WWC3} \neq \mu_{WWC4}$

Limitations

This research was conducted on the water closets and urinals in men and women's restrooms on all four floors in the Langford Architecture Building A at Texas A&M University. The men's first floor restroom was not used this study because of differences of its floor plan. The third floor women's restroom was also not considered because one of the water closets was not operational, affecting the frequency of use of other water closets.

Delimitation

Data sampling took place in only in one building, Langford Architecture Building A, due to equipment availability and building accessibility.

Definitions of Terms and Fixture Features

Early-close flapper toilet: A fixture in which the flapper closes before all the water escapes from the tank.

Fixture: the receptacles in plumbing or drainage systems, other than traps, intended to receive or discharge liquid or waste.

Flapper: The rubber or plastic part that closes the hole (flush valve) through which water flows from the tank to flush the bowl.

Flushometer valve: A device that discharges a predetermined quantity of water to fixtures for flushing purposes and is closed by direct water pressure.

Infrared sensor: A sensor that detects the presence human beings by their body heat.

Lobular sensing fields: fields that have a rounded projection that is part of a larger structure.

Low-consumption water closet: a toilet that uses no more than 1.6 gallons per flush; also referred to as a low-flow toilet.

Low-consumption urinal: a urinal that uses no more than 1.0 gallon per flush; also referred as low-flow urinal.

Valve: a mechanical device by which the flow of liquid, gas, or loose material in bulk may be started, stopped, or regulated by a movable part that opens, shuts, or partially obstructs one or more ports or passageways (Merriam-Webster Online Dictionary)

Toilet dam/flapper toilet: A fixture retains some water in the toilet tank behind the dam.

Abbreviations

AIRS: Acoustical Information Retrieval System

gpf: gallons per flush

Flushometer Features

Sloan, Royal II Model 111 Flushometer (manual low-consumption fixture). This flushometer (Figure 1) is designed to flush 1.6 gpf and operated by manual operation. The specifications are non-hold-open handle, fixed-metering bypass, no external volume adjustment to ensure water conservation, and flush accuracy controlled by CID™ Technology (Sloan Valve Company, 2003). The specification sheet is included in

Appendix A. Figure 2 shows the flushometer valve installed in a water closet and a urinal.

Figure 1. Low-consumption manual flushometer (Sloan Valve Company, 2003)

Figure 2. Manual low-consumption water closet and urinal (Hwang, 2003)

Sloan, G2 Optima plus Flushometer (automatic low-consumption fixture). This flushometer (Figure 3) is designed to use 1.6 gpf and is operated by automatic sensor. A battery-powered infrared sensor sets the flushing mechanism after the user is detected and completes the flush when the user steps away. Sloan G2 Optima plus Flushometer is activated via multilobular sensor detection to provide sanitary protection and automatic operation. The G2 Optima plus Flushometer includes an override button to allow a “courtesy flush” for the individuals’ comfort (Sloan Valve Company, 2003). The specification sheet is included in Appendix B. Figure 4 shows the flushometer valve installed in a water closet and a urinal.

Figure 3. Automatic low-consumption flushometer (Sloan Valve Company, 2003)

Figure 4. Automatic low-consumption water closet and urinal

Assumptions

1. Data collected for each fixture by the AIRS is assumed to be correct despite previous research showing that it is only 95% accurate.
2. Flow rate and gallons per flush of fixtures remains constant during the course of this study.

Importance of the Study

The basic benefit of this study is to show the how the frequencies of total use are altered by upgrading from low-consumption manual fixtures to automatic low-consumption automatic fixtures. Currently insufficient research has been conducted to show the acceptability of the automatic low-consumption water closets. This study can serve as a basis for additional research.

How This Research Will Benefit Facilities Managers

In addition, this research will help facilities managers better understand the features and benefits of automatic water fixtures. Allowing them to better decide as to whether or not the automatic low-consumption fixture is a good choice for them.

REVIEW OF THE RELATED LITERATURE

Study 1 – Functioning of Aging Low-Consumption Toilets in Tucson

Basic Information

Source: Water Resource Research Center, University of Arizona, Arizona

Author: Jim Henderson and Gary Woodard

Analysis period: Unknown

Location: Tucson, Arizona

Study objectives: Since 1.6-gpf low-consumption toilets became standard, there have been anecdotal reports of problems with their functioning, including a need for multiple flushes to clear the bowl and frequent clogging. The object of this research was to investigate the function of older low-consumption toilets.

Data

Data collection period: December 1999

Observational unit: Gallons per flush

Variables: The dependent variables of the research were the number of double flushes and the gallons per flush for each toilet type. The independent variables of the research were the five flush valve types: pressurized, early-close flapper, standard flapper, toilet dam/flapper, and tube and dam.

Population of interest: Toilets approximately 7 years old supplied through Tucson Water's low-consumption toilet rebate program.

Sample: The gallon per flush was measured for each toilet type.

Method

Data loggers were attached to the water meter on the water line going to each house, and four days of data at 10-second intervals were recorded. Data gathered from 170 homes were analyzed using specialized software for identifying toilet flushes. Toilet flushes were measured according to their peak flow, duration, and volume of flush, and compared to the expected inventory of toilets in the home. A follow-up survey confirmed the number and type of toilets in the household, then asked about toilet function problems, and elicited a rating of owner satisfaction with the functioning of these low-consumption toilets.

Findings

More than half (57.1%) of homes with approximately 7-year-old toilets had no detectable problem with their function. The average flush volume for all rebate toilets was 1.98 gallons per flush, or about 24% higher than the 1.6 gallons per flush they were designed to use. Double flushing occurred in 14.2 % of homes with rebated toilets, or 10.9 %of rebated toilets. At least 12% of households had recurring flapper leaks in their low-consumption rebate toilets.

Conclusions

The 20-year expected life of the low-consumption toilets would need to be adjusted downward to reflect the increase in average flush volume due to the deterioration of the functionality over time. However, the combined effect of flapper leaks and frequent double flushing was smaller than the increase in average flush volume.

Relevance to Current Study

This research demonstrated the performance of low-consumption fixtures and highlighted the problems—multiple flushes to clear the bowl and frequent clogging—as the low-consumption fixture aged. People were skeptical the performance of the low-consumption fixture when the low-consumption fixtures were introduced. However, this research concluded that the performance of most low-consumption fixtures was acceptable and it saved water.

Study 2 – Determination of Maximum Flow Rate in a Building Water-Supply System by Means of Acoustic Observation

Basic Information

Source: Dissertation, Doctor of Philosophy, Department of Architecture, College of Architecture, Texas A&M University, College Station, Texas

Author: Kenneth Barry Parker

Analysis period: Unknown

Location: Langford Architecture Building A, Texas A&M University, College Station, Texas

Study objectives: The objective of the research was to measure the maximum flow rate in a building's water supply system, which is determined by acoustic observation of fixture usage.

Data collection period: February 18, 2002 to February 24, 2002

Observational unit: Gallons per minutes in the water supply system

Variables: The dependent variable of the study was flow rate of water closets in a building's water supply system. The independent variables were the building's water supply system that includes the valve type, water closet or urinal, the position of the water supply control stop, the number of gallons discharged by the fixture, and the water pressure system.

Population of interest: Water closets and urinals in combined-use classroom/office buildings

Sample: Frequency of flush cycle was measured for each water closet.

Method

The frequency of flush cycles in water fixtures was measured using the fixed and portable acoustic monitoring systems. The monitoring system consisted of pickup devices, transmitters, cable, mixers, and computers to detect the flush of each water fixture and deliver the sound signal to the computers.

Cool Edit, a digital recording and sound editing program, and Microsoft Excel, an electronic spreadsheet application, were used to record the time and duration of flushes to measure the maximum flow rate in the building's water supply. Descriptive statistics were produced for the dependent variables. A histogram was produced for each of the independent variables and a visual analysis of the distribution of the data was carried out. A multi-regression model was used to explain the relationship between the dependent and independent variables.

Findings

For the women's water supply system, the flow rate 99% of the time was at or less than 41.72 gallons per minute. For the men's water supply systems, the flow rate 99% of the time was at or less than 72.06 gallons per minute.

Conclusions

The actual rate for the women's water supply system was more than half the 82 gallons per minute as expected by the Hunter method. The actual rate for the men's water supply system was close to 77 gallons per minute as expected by the Hunter method.

Relevance to Current Study

This research provided a methodology on how to measure the frequency of use of water closets. An acoustic observation method was used to detect the frequency of fixture use, and simultaneous events were successfully monitored over the course of the study. A sophisticated electronic monitoring system installed in Langford Architecture Building A was adjusted and upgraded for this study.

Study 3 – Predicting Annual Water Savings from Retrofitting Supply Valves in a University Classroom/Office Building by Means of Acoustic Observation

Basic Information

Source: Dissertation, Doctor of Philosophy, Department of Architecture, College of Architecture, Texas A&M University, College Station, Texas

Author: Hoonsik Seo

Study data: February 2002 to November 2002

Analysis period: Unknown

Location: Langford Architecture Building A, Texas A&M University, College Station, Texas

Study objectives: The objective of the research was to measure the water savings due to retrofitting water closets, urinals, and lavatories with low-consumption manual and automatic valves in an existing classroom/office building.

Data

Data collection period: February 2002 to November 2002

Observational unit: Gallons per flush for urinals and water closets; number of flushes for urinals and water closets; minutes per flush for lavatories

Variables: The dependent variables of this research were the flow rates for lavatories, urinals, and water closets; the frequency data for gallons per minutes for lavatories; and the flush of urinals and water closets. The independent variables of this research were four phases: as-is, tune-up, low-consumption manual, and low-consumption automatic and fixture types, lavatories, urinals, and water closets.

Population of interest: Water fixtures in the Architecture building A

Sample: gpf of water fixtures; Frequency of flush cycle of water fixtures

Method

From February 2002 to November 2002, the water consumption and frequency of use of each water fixture measured in four different phases: as-is, tune-up, low-consumption manual, and low-consumption automatic. Lavatory flow measurement and water closet and urinal measuring methods were used to measure the consumption of each lavatory, urinals, and water fixtures.

An Acoustic Information Retrieval System was used to measure the frequency of use of each water fixture. Microsoft Excel and Cool Edit were used to validate the frequency of use of each water fixtures. Statistical analysis was used to predict the annual water savings by retrofitting low-consumption supply valves.

Findings

The tune-up phase had the highest use, utilizing 23,763 gallons. Next was the as-is phase using 16,116 gallons (not including lavatories). Automatic valve consumption was 11,504 gallons. The best was the low-consumption manual with 8,715 gallons. The low-consumption manual water consumption was 40% less than the automatic valve phase when lavatories were not included and 32% less when they were.

Conclusions

The low-consumption manual valves offered excellent potential water savings over the original valves. The automatic valves used significantly more than water than the low-consumption manual valves.

Relevance to Current Study

This research measured the water consumption of each water fixtures in four phases and predicted the annual water consumption in each. This was one of the most comprehensive studies on the water saving on low-consumption fixtures. In particular, it measured the water saving of the manual low-consumption fixture, which is utilized in this study. Compared to the manual fixture under previous standards, the low-consumption fixture saved water, as it used less than 3.5 gpf. From this comparison, the performance of the automatic low-consumption fixture can be speculated upon.

Analysis of the Literature

The literature review addresses three concerns: the performance of low-consumption fixtures, the acoustical observation method, and the water saving of low-consumption fixtures. All three studies were conducted on low-consumption water fixtures and concluded that low-consumption water fixtures saved water and provided reliable service.

METHOD OF INVESTIGATION AND DATA ANALYSIS

The Research Methodology

Equipment Needed to Process the Research

Acoustic Information Retrieval System

The Acoustic Information Retrieval System was utilized to collect the frequency of use of each fixture. AIRS consists of sound collection devices and computer systems.

Sound Signal Collecting Devices

Sound collection devices consisted of acoustic sensor, transmitter, cable, and mixer. This system was installed during the course of a previous study but required a diagnostic to check to see whether or not the existing AIRS works.

Acoustic Sensor

The acoustic sensors are located directly under each fixture or near the plumbing pipe and capture the sounds created when fixtures are in use. Each fixture has a unique sound, and Cool Edit was used to identify the type of fixture from its acoustical signature. Figure 5 shows the acoustic sensor.

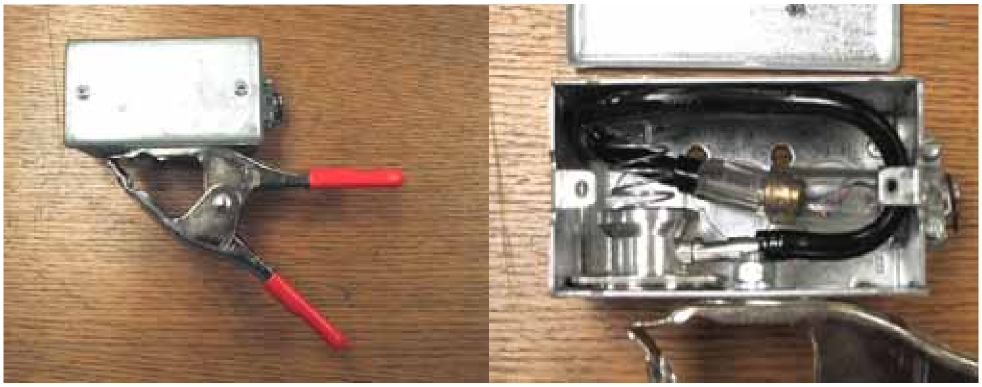


Figure 5. Acoustic sensor (Seo, 2003)

Transmitter

The transmitter is used to amplify the signal from the acoustic sensor, as the signal was insufficient for the long cable. Figure 6 shows the transmitter.

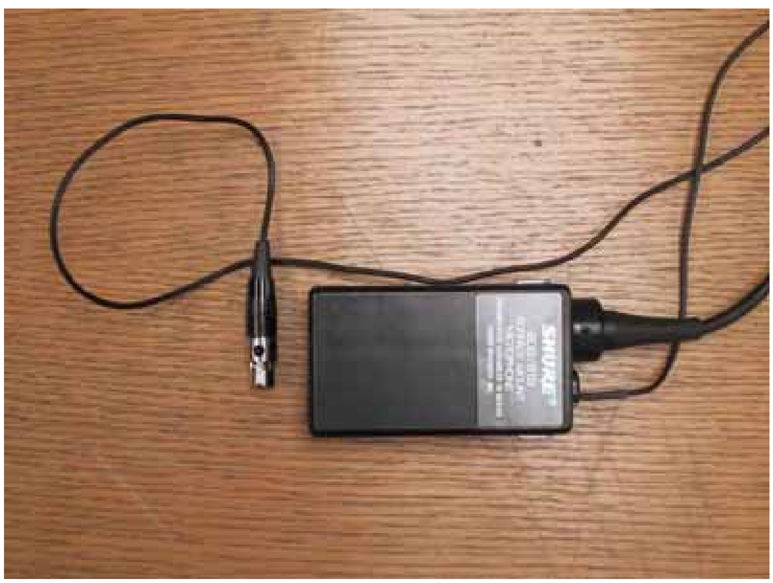


Figure 6. Transmitter (Seo, 2003)

Cable

The cable connects transmitter to sound mixer and is used to deliver the signal.

Sound Mixer

The sound mixer controls the level of sound, which is collected from the acoustic sensors. The output of the sound mixer is connected to the computer sound card and it is used to transfer the sound signals to the Cool Edit. Figure 7 shows the mixer.

Figure 7. Mixer (Seo, 2003)

Computer Systems

Hardware. Four computer systems were used to collect data and to run computer programs. They are equipped with sound cards, sound recording software, Cool Edit, and a CD recorder, utilized to record the entire raw signals. Figure 8 shows the computer systems.

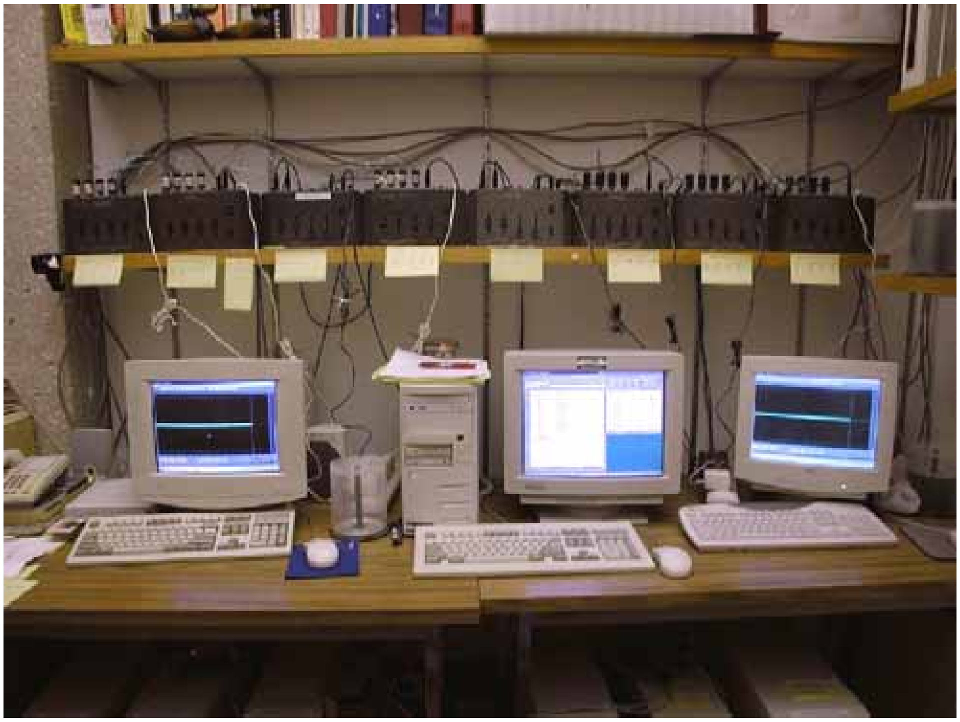


Figure 8. Computer systems (Seo, 2003)

Microsoft Excel. Microsoft Excel records what types of fixtures are activated and when the fixtures are in use.

Cool Edit. Cool Edit recognizes which fixtures are in use and transcribes the data to Microsoft Excel. Figure 9 shows a screen print from the Cool Edit program.

Figure 9. Cool Edit program

Monitoring system. The equipment and computer systems were connected to monitor and record the frequency of use of each fixture from each of the four floors and both restrooms. Figure 10 shows the men’s restroom monitoring system. Figure 11 shows the women’s restroom monitoring system.

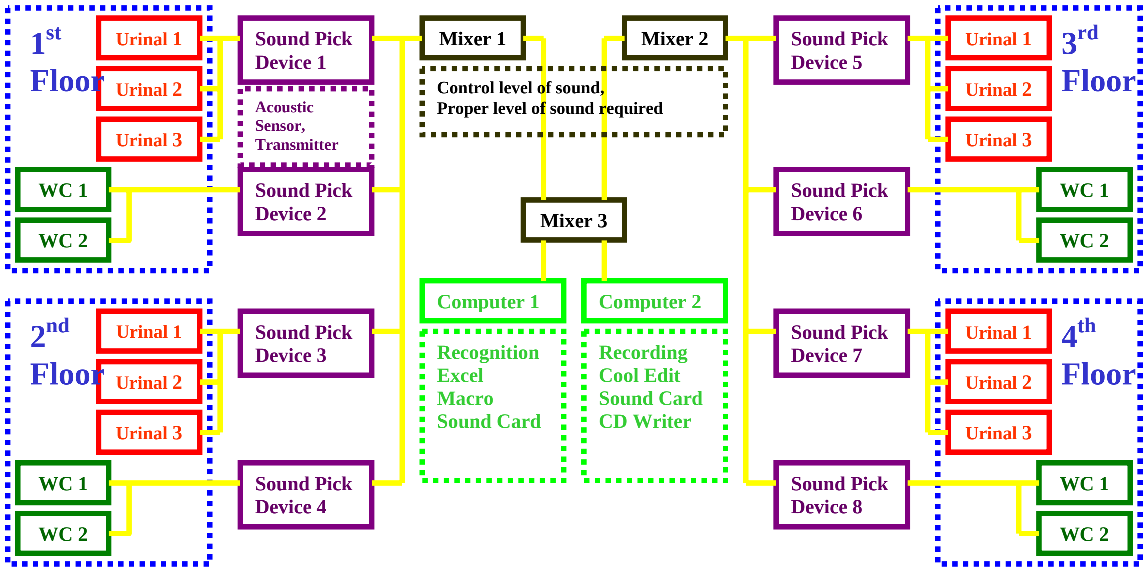


Figure 10. Monitoring system for men's restrooms

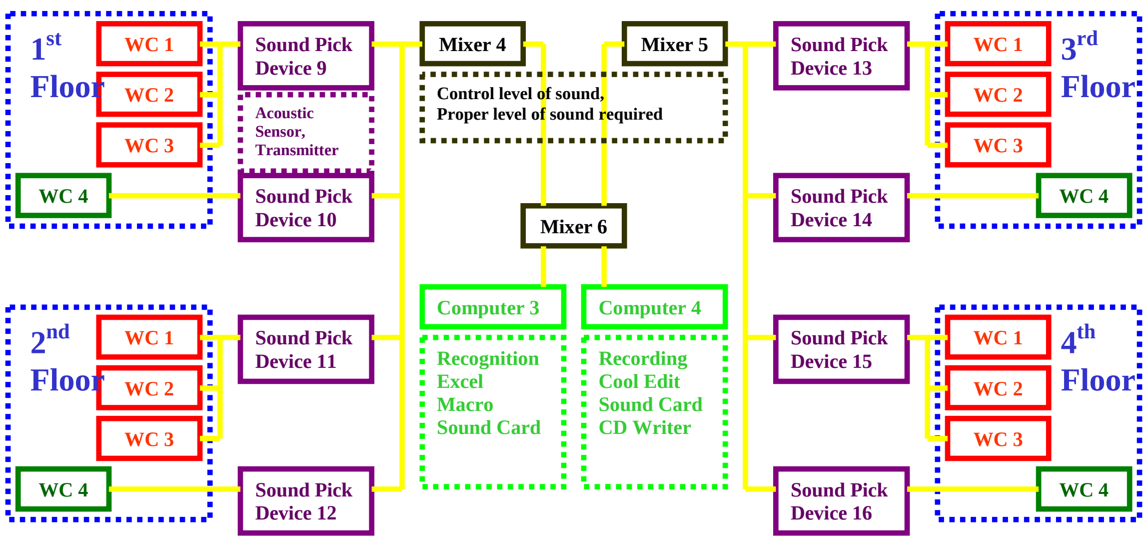


Figure 11. Monitoring system for women's restrooms

Files Needed to Collect Data

Digital Recording

A digital recording was made from 0:00 a.m. to 11:50 p.m. using Cool Edit and was saved on the CD-ROM. The files were then compared using the Excel log files to verify occurrences.

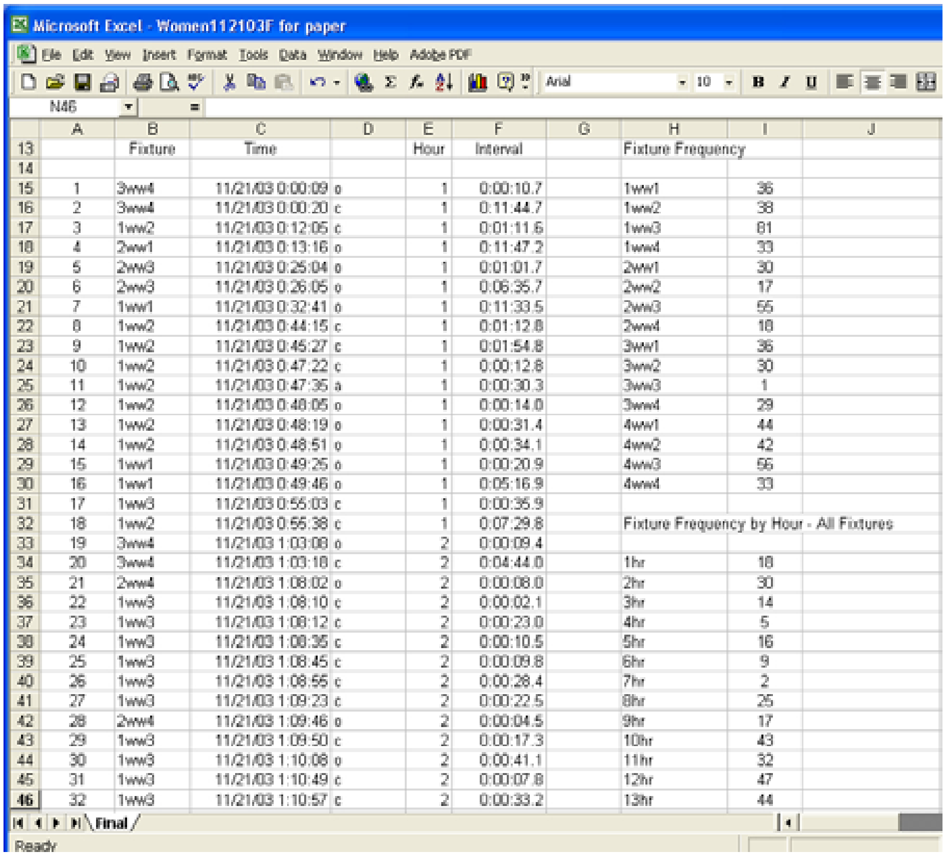
Excel Log Files

Excel log files were made in conjunction with the digital recording to CD-ROM. When the frequency of use was recorded, an Excel log file was automatically generated with the total frequency of use for each fixture, the total frequency and average frequency of use of all fixtures. Figure 12 shows the Excel log file.

Steps to Precede the Research

Equipment Setup

1. The fixtures were flushed 10 times to determine their operational status. The gallons per flush were also recorded to determine if they satisfied the EPA of 1992 standards.
2. If they didn’t meet the EPA of 1992 standards, the flow rate of each fixture is adjusted until it did s o.
3. The Control Stop is located to the right of the flushometer, and the flow rate is adjusted by turning it with clockwise or counterclockwise.



Microsoft Excel - Women112103F for paper

	A	B	C	D	E	F	G	H	I	J
13		Fixture	Time		Hour	Interval		Fixture Frequency		
14										
15	1	3ww4	11/21/03 0:00:09	o	1	0:00:10.7		1ww1	36	
16	2	3ww4	11/21/03 0:00:20	c	1	0:11:44.7		1ww2	38	
17	3	1ww2	11/21/03 0:12:05	c	1	0:01:11.6		1ww3	81	
18	4	2ww1	11/21/03 0:13:16	o	1	0:11:47.2		1ww4	33	
19	5	2ww3	11/21/03 0:25:04	o	1	0:01:01.7		2ww1	30	
20	6	2ww3	11/21/03 0:26:05	o	1	0:06:35.7		2ww2	17	
21	7	1ww1	11/21/03 0:32:41	o	1	0:11:33.5		2ww3	55	
22	8	1ww2	11/21/03 0:44:15	c	1	0:01:12.8		2ww4	18	
23	9	1ww2	11/21/03 0:45:27	c	1	0:01:54.8		3ww1	36	
24	10	1ww2	11/21/03 0:47:22	c	1	0:00:12.8		3ww2	30	
25	11	1ww2	11/21/03 0:47:35	a	1	0:00:30.3		3ww3	1	
26	12	1ww2	11/21/03 0:48:05	o	1	0:00:14.0		3ww4	29	
27	13	1ww2	11/21/03 0:48:19	o	1	0:00:31.4		4ww1	44	
28	14	1ww2	11/21/03 0:48:51	o	1	0:00:34.1		4ww2	42	
29	15	1ww1	11/21/03 0:49:25	o	1	0:00:20.9		4ww3	56	
30	16	1ww1	11/21/03 0:49:46	o	1	0:05:16.9		4ww4	33	
31	17	1ww3	11/21/03 0:55:03	c	1	0:00:35.9				
32	18	1ww2	11/21/03 0:55:38	c	1	0:07:29.8		Fixture Frequency by Hour - All Fixtures		
33	19	3ww4	11/21/03 1:03:08	o	2	0:00:09.4				
34	20	3ww4	11/21/03 1:03:18	c	2	0:04:44.0		1hr	18	
35	21	2ww4	11/21/03 1:08:02	o	2	0:00:08.0		2hr	30	
36	22	1ww3	11/21/03 1:08:10	c	2	0:00:02.1		3hr	14	
37	23	1ww3	11/21/03 1:08:12	c	2	0:00:23.0		4hr	5	
38	24	1ww3	11/21/03 1:08:35	c	2	0:00:10.5		5hr	16	
39	25	1ww3	11/21/03 1:08:45	c	2	0:00:09.8		6hr	9	
40	26	1ww3	11/21/03 1:08:55	c	2	0:00:28.4		7hr	2	
41	27	1ww3	11/21/03 1:09:23	c	2	0:00:22.5		8hr	25	
42	28	2ww4	11/21/03 1:09:46	o	2	0:00:04.5		9hr	17	
43	29	1ww3	11/21/03 1:09:50	c	2	0:00:17.3		10hr	43	
44	30	1ww3	11/21/03 1:10:08	o	2	0:00:41.1		11hr	32	
45	31	1ww3	11/21/03 1:10:49	c	2	0:00:07.8		12hr	47	
46	32	1ww3	11/21/03 1:10:57	c	2	0:00:33.2		13hr	44	

Final

Ready

Figure 12. Microsoft Excel log file

4. AIRS is checked to determine its status then activated to detect the sounds from the water fixtures and to verify which fixture was in use.
5. Computers and software, Cool Edit and Microsoft Excel are used to record sound signals and verify which fixture is working.

Count Frequency of Use

1. The sound signal from the fixture is recognized by a waveform recognition package, Cool Edit.

2. After recognition, the computer recorded each event of fixture usage into Microsoft Excel utilization of a custom macro.
3. The event log consists of fixture identification, the data and time of each use.
4. Using sound profiles from recording software, the event log fixture usage from the recognition system can be verified.
5. Simultaneous events can also be accurately detected.

Validate the Frequency of Use

1. Cool Edit can recognize which fixture is working because each fixture has unique waveform of sounds and deliver the information to Microsoft Excel.
2. The Cool Edit program, however, is not 100% accurate.
3. When the acoustical signatures of the fixtures are similar or in the event of an extraneous noise, Cool Edit would misidentify or skip events.
4. To prevent misidentified or skipped events, the recorded waveforms were compared with the Excel log files. Misidentified events were deleted while valid events are inserted.

Information on Building and Restroom

Langford Architecture Building A

Langford Architecture Building A is a four-floor building constructed in 1976. Reasons for choosing this building were ease in obtaining permission to install the AIRS monitoring system and the existence of retrofitted the low-consumption fixtures.

Restrooms

On each floor a men’s and a women’s restroom. Each woman’s restroom has four water closets, and the floor plan is same on each floor. Each men’s restroom has three urinals and two water closets, and the floor plan on the second, third, and fourth floor are the same, but the first floor plan is different.

Men’s Restroom

From the floor plan (Figure 13), it can be seen that the three urinals are located together but the characteristics of each are different: U1 is located in the farthest in, closest to the W2 water closets having the most space, U2 is in the middle of the urinals and little narrower than the others, U3 is nearest the entrance.

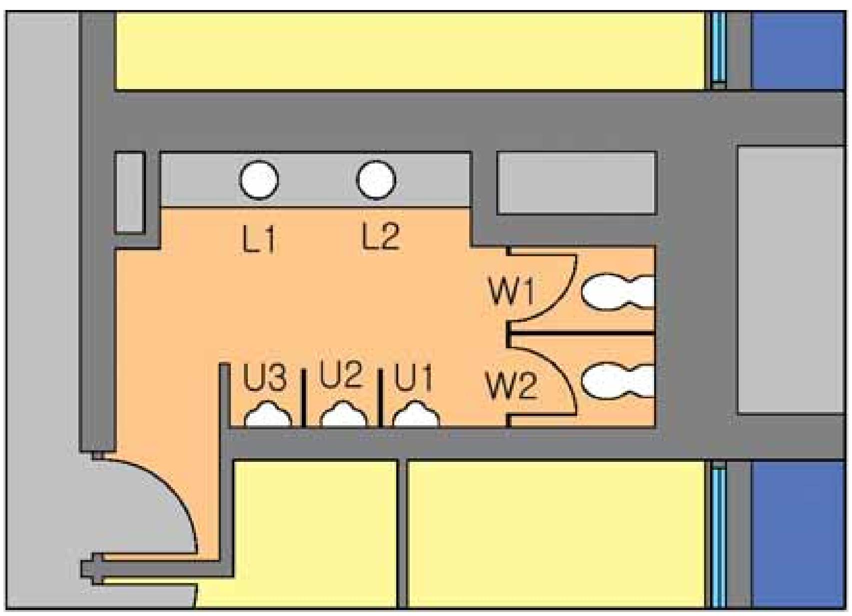


Figure 13. Second, third, and fourth floor men's restroom floor plan (Seo, 2003)

Women's Restroom

W3 has the most space of the water closets because it is designed for the disabled. W2 is the central water closet and W1 is the furthest inside. W4 is located alone. See Figure 14.

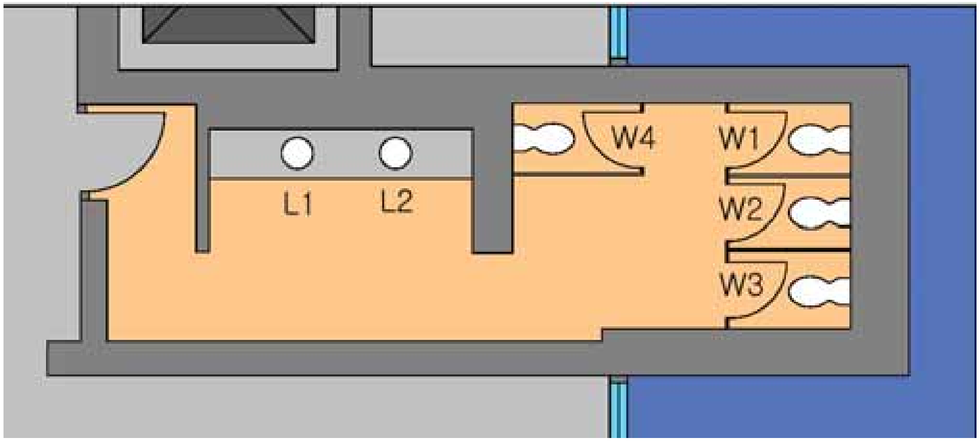


Figure 14. Women's restroom floor plan (Seo, 2003)

Fixture Designation

Each fixture has a four-part designation made up of two letters and two numbers. The first number indicates the floor, the second letter indicates either men or women, the third letter indicates either urinal or water closet, and the fourth number indicates the location of fixtures. Figure 15 shows the fixture designation system.

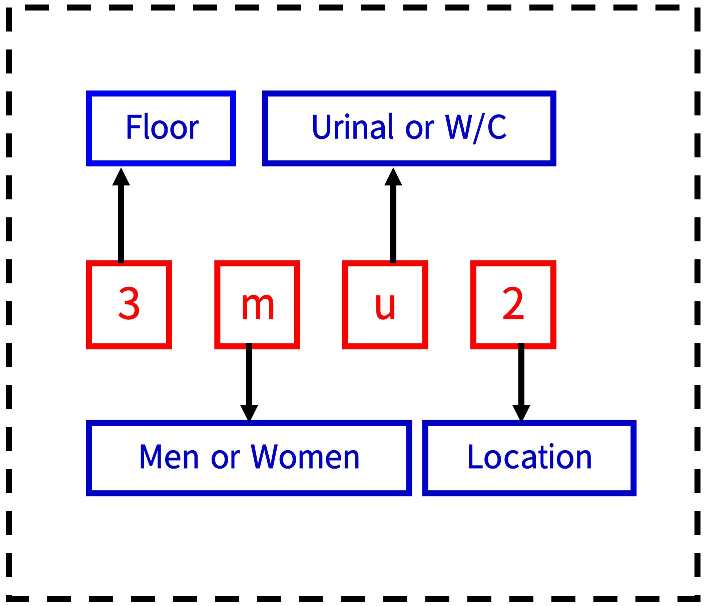


Figure 15. Fixture designation system diagram

Occupant Data

Occupants of Langford Building A include students registered at of College of Architecture, and staff and faculty with office and work space. Table 2 shows that the users of two water fixture types, the manual and the automatic are slightly different when the frequency of use was measured.

Table 2.

Occupancy of Langford Architecture Building (Fall 2002 vs. Fall 2003)

		Fall 2002	**Fall 2003**
Student	Women	611	574
	Men	1182	1209
	Total	1793	1783
Staff	Women	34	35
	Men	14	14
	Total	48	49
Faculty	Women	21	23
	Men	65	65
	Total	86	88
Total	Women	666	632
	Men	1261	1288
	Total	1927	1920

The frequency of use or the automatic fixtures is adjusted to remove the occupant differences.

Research Data General Information

Requirement

For this study, the frequency of use of the manual low-consumption water fixtures and the automatic low-consumption water fixtures was needed. The frequency data was generated by AIRS and recognized using Cool Edit and Microsoft Excel, giving information on the type of fixture and activating time.

The data was collected for the week, Monday to Sunday, 24 hours per day. However, only the data for Monday though Friday was utilized. The frequency of use during the weekend, Saturday and Sunday, was small in comparison, therefore posing problem to the normality of the data.

Collection Period

The frequency data for the manual low-consumption fixtures was collected in October 2002. The frequency of use for the automatic low-consumption fixtures was collected in November 2003. The acoustical signal and frequency data for the low-consumption manual and the original low-consumption automatic fixtures were collected during previous research (Woods et al. 2000; Parker, 2002; Seo, 2003; and Hwang, 2003).

Means to Collect Data

The Acoustic Information Retrieval System was used to collect the sound from each of fixture, then Cool Edit and Microsoft Excel were used convert the signals into frequency data. When the fixtures were in use, a unique sound was created and Cool Edit could then automatically determine which fixture was used based on the shape signals. Microsoft Excel was connected with Cool Edit to record the frequency of use for each fixture.

Condition of Data

The data has large variance because the nature of the research. The frequency of use of fixtures was affected by unscheduled and unexpected factors such as non-curriculum meetings and conferences, visitors, and design students working overnight to complete assignments. Therefore outliers may be deleted when it is required to have the normality of the data.

Analysis of Data

Statistical Analysis

Design Procedure**:** A fixed effect model design was used to analyze the data in the study.

Factors in the Experiment

Two factors are applied in the treatment structure: valve types and fixture locations. The two factors are independent and do not interact with each other. The manual and the automatic water fixture did not exist together, and there was no chance the valve types interacted with fixture locations.

Effect Model

The model is as follows:

$y_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij}$

where y_{ij} is the response variable frequency in use; μ is the mean of the response variable; α_i is the fixed effect of valve types (i = 1,2); β_j is the fixed effect of fixture locations (k = 1,2 or 1,2,3 or 1,2,3,4); ε_{ij} is the random effect caused by difference experimental units. This effect model was based on the normal condition and it was evaluated by using a residual analysis (Longnecker and Ott, 2001).

Analysis of Variance (ANOVA)

Test of Normality

The normality of the data is another base of ANOVA. If the data are not normal, either non-parametric method must be utilized to analyze the data or a more robust, approximately normal method must be used.

One-way ANOVA with Two Factors

The effect model has two factors: valve types and fixture locations. One-way ANOVA with two factors was utilized to reveal which factors affect the effect model. From the standardized residual, the normality of the data was tested, as ANOVA is based on the normality of the data.

Post Hoc Tests

Tukey HSD was utilized to make Multiple Comparisons and Homogeneous Subsets, when there were more than three data sets. Multiple Comparisons showed the 95% confidence intervals and Homogeneous Subsets groups the data sets into subsets.

RESULTS

Analysis

The data were analyzed to meet the research objectives and to answer the test hypotheses. The results of the data were analyzed to compare the frequency of use of each fixture type: the manual and the automatic low-consumption fixtures. Table 3 shows the frequency of use of the manual and the automatic low-consumption fixtures and Figure 16 shows the difference in frequency between the manual and the automatic low-consumption fixtures graphically.

Table 3.

Frequency of Use of Fixtures

	Total Frequency		**Average Frequency per Fixture**	
	Manual	**Automatic**	**Manual**	**Automatic**
Men's Water Closets	642	1037	21.40	34.57
Men's Urinals	1681	2017	37.36	44.82
Women's Water Closet	1712	2932	28.53	48.87

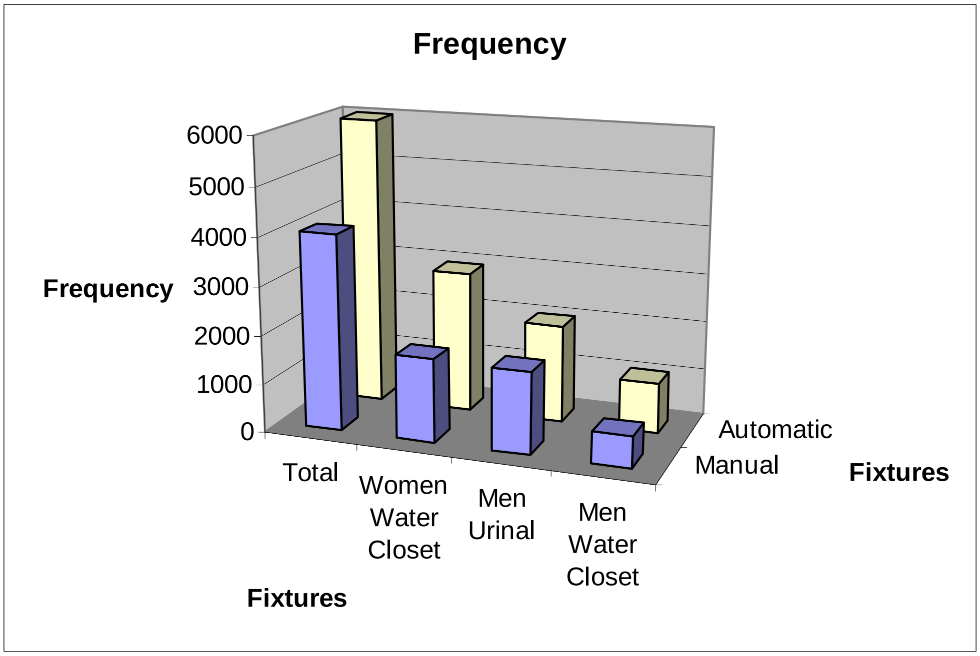


Figure 16. Chart for frequency of use of fixtures

Men's Water Closets

It is worth noting that the data does not include the frequency for the water fixtures on the first floor, due to differences in its floor plan. Figure 17 shows the frequency of use of men's water closets graphically. Figure 18 shows the scatter plots of the manual and the automatic men's water closet and it shows how far the data is scattered from the mean value.

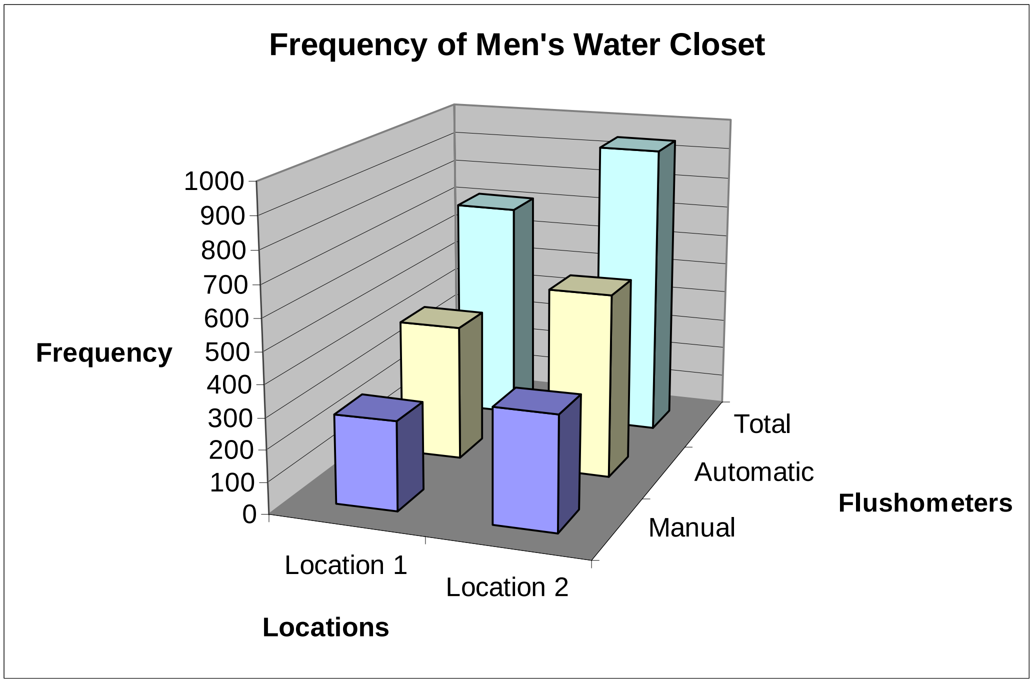


Figure 17. Frequency of use chart of men's water closets

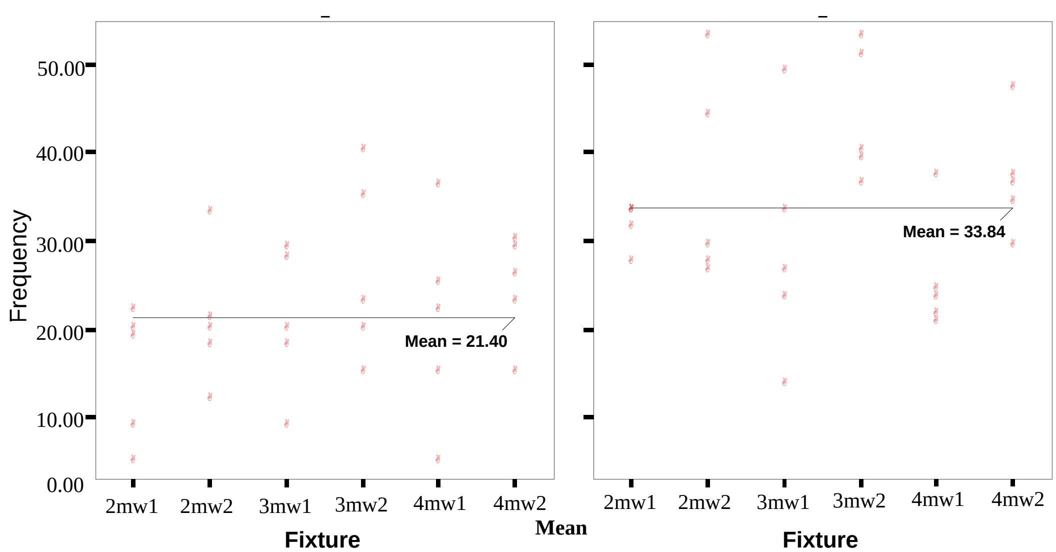


Figure 18. Scatter plot for men's water closets

Table 4 and Table 5 show the frequency of use of men's water closets from Monday through Friday with the total and average of the frequency.

Table 4.

Frequency of Use of the Manual Men's Water Closets

	Mon	**Tue**	**Wed**	**Thu**	**Fri**	**Total**	**Average**
2mw1	5	9	22	19	20	75	15.0
2mw2	33	18	12	20	21	104	20.8
3mw1	18	29	28	20	9	104	20.8
3mw2	40	35	23	15	20	133	26.6
4mw1	22	36	25	5	15	103	20.6
4mw2	23	26	30	15	29	123	24.6

Table 5.

*Frequency of Use of the Automatic Men's Water Closet*s

	Mon	**Tue**	**Wed**	**Thu**	**Fri**	**Total**	**Average**
2mw1	34	34	32	28	34	162	32.4
2mw2	27	54	30	45	28	184	36.8
3mw1	27	50	34	24	14	149	29.8
3mw2	41	54	37	40	52	224	44.8
4mw1	38	21	25	22	24	130	26.0
4mw2	48	38	37	35	30	188	37.6

Descriptive Statistics

From Table 6, a total of 30 frequency data were used for each valve type and fixture location. The mean frequency of the manual is 21.40 and the mean frequency of the automatic is 33.84. The automatic has greater frequency than the manual. The mean frequency of location 1 is 23.79 and the mean frequency of location 2 is 31.45. Location 2 has greater frequency than location 1.

Table 6.

Descriptive Statistics for Men's Water Closets

Valve type	**Fixture location**	**Mean**	**Std. Deviation**	**N**
1	1	18.8000	9.00159	15
	20	24.0000	8.05339	15
	Total	21.4000	8.79890	30
2	1	28.7826	8.42818	15
	2	38.8989	9.00670	15
	Total	33.8408	9.99607	30
Total	1	23.7913	9.95900	30
	2	31.4495	11.30841	30
	Total	27.6204	11.24798	60

Dependent variable: frequency of use

Test of Normality

To use the ANOVA, it is necessary to explore the standardized residual to determine whether the data is normal or not as the ANOVA is based on the normality of the data. The significant level is at 0.05, $\alpha=0.05$. Table 7 shows that the significance for the test for normality is greater than 0.05, therefore, the data is normal.

Table 7.

Test of Normality for Men's Water Closets

	Kolmogorov-Smirnov(a)			Shapiro-Wilk		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Standardized Residual for frequency	.069	60	.200	.977	60	.309

Table 8.

Analysis of Variance (ANOVA) Table for Men's Water Closets

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Corrected Model	3201.303(a)	2	1600.651	21.401	.000
Intercept	45773.135	1	45773.135	611.997	.000
Valve Type	2321.590	1	2321.590	31.040	.000
Fixture Location	879.713	1	879.713	11.762	.001
Error	4263.206	57	74.793		
Total	53237.643	60			
Corrected Total	7464.509	59			
Dependent Variable: frequency of use					

a R Squared = .429 (Adjusted R Squared = .409)

Univariate Analysis of Variance

Valve type and fixture location were the factors examined in this study. Table 9 shows what factors affect the frequency of use of the fixtures. The significance level is 0.05, α=0.05. Table 6 shows that the significance for the valve type is 0.000 and that the significant for fixture location is 0.001. Therefore, the valve types and the fixture locations affect the frequency of use of the fixtures. The adjusted R^2 value is 0.409 and is considered good given the nature of the data.

Men's Urinals

The data for frequency of use of the water fixtures on the first floor was excluded, due to differences in its floor plan. Figure 19 shows the frequency of use of men's urinals graphically. Figure 20 shows the scatter plots of the manual and the automatic men's urinal and it shows how far the data is scattered from the mean value.

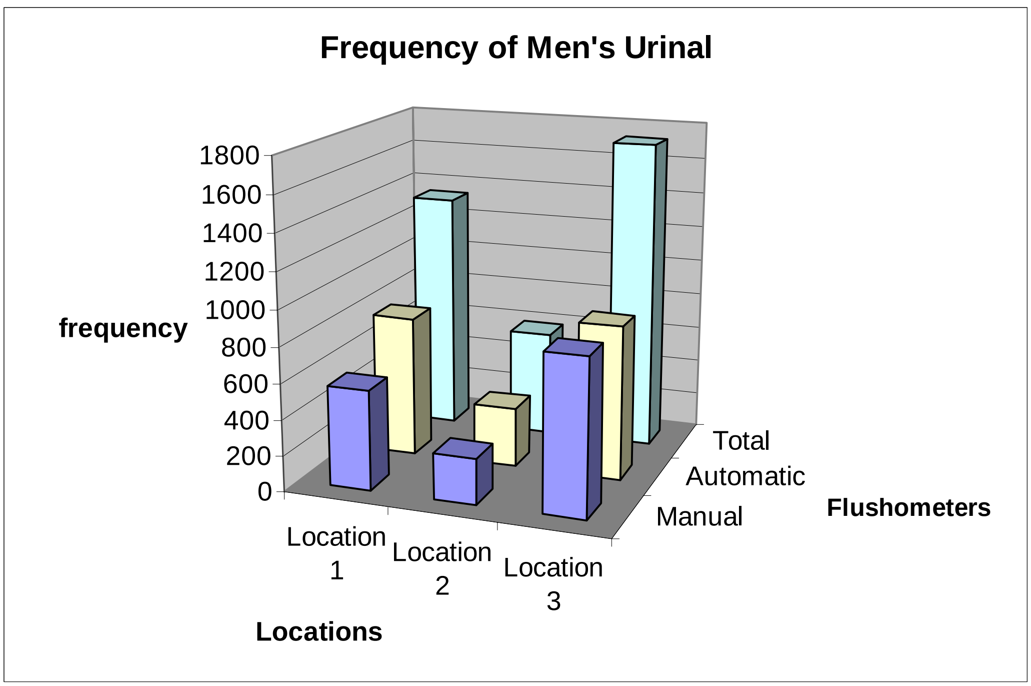


Figure 19. Frequency of use in flushes per day chart of men's urinals

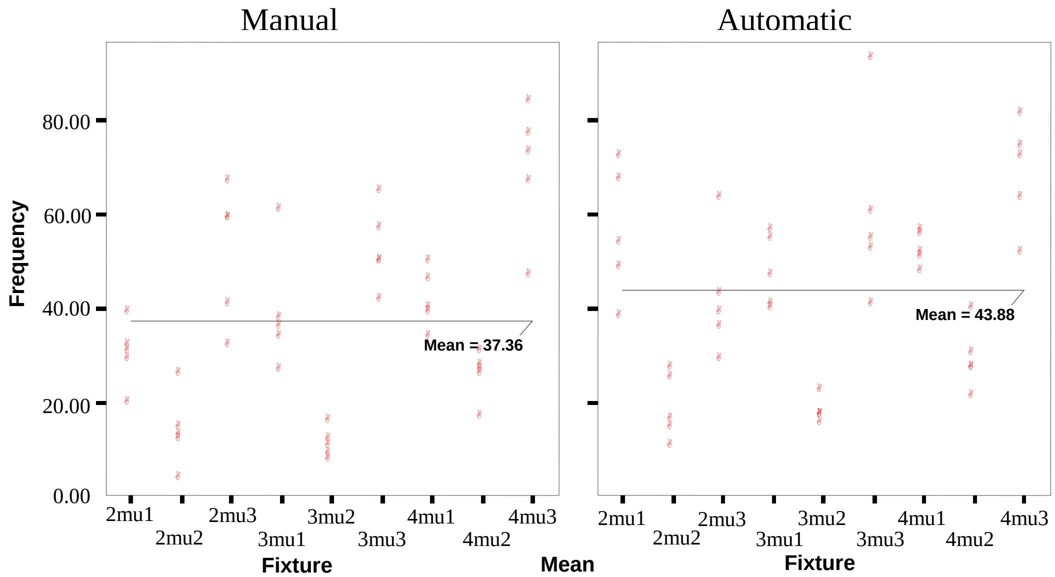


Figure 20. Scatter plot for men's urinals

Table 10 and Table 11 show the frequency of use of men's urinal from Monday through Friday with the total and average for the frequency.

Table 9.

Frequency of Use of the Manual Men's Urinals

	Mon	Tue	Wed	Thu	Fri	Total	Average
2mu1	32	31	39	20	29	151	30.2
2mu2	15	26	13	4	12	70	14.0
2mu3	59	67	59	32	41	258	51.6
3mu1	61	38	36	27	34	196	39.2
3mu2	16	8	12	9	11	56	11.2
3mu3	50	57	65	50	42	264	52.8
4mu1	50	46	40	34	39	209	41.8
4mu2	28	26	31	17	27	129	25.8
4mu3	73	84	77	47	67	348	69.6

Table 10.

Frequency of Use of the Automatic Men’s Urinals

	Mon	**Tue**	**Wed**	**Thu**	**Fri**	**Total**	**Average**
2mu1	50	74	69	55	39	287	57.4
2mu2	17	28	26	15	11	97	19.4
2mu3	65	37	40	44	30	216	43.2
3mu1	41	48	58	56	42	245	49.0
3mu2	18	16	23	18	18	93	18.6
3mu3	95	54	62	56	42	309	61.8
4mu1	57	58	53	52	49	269	53.8
4mu2	31	28	41	28	22	150	30.0
4mu3	76	74	83	65	53	351	70.2

Descriptive Statistics

Total 45 frequency data was used for each valve type and total 30 frequency data was used for fixture location. From Table 12, the mean frequency of the manual is 37.36 and the mean frequency of the automatic is 43.88. The automatic has greater frequency than the manual. The mean frequency of location 1 is 44.67, the mean frequency of location 2 is 19.60, and the mean frequency of location 3 is 57.59. Location 3 has the highest frequency.

Table 11.

Descriptive Statistics for Men's Urinals

Valve type	**Fixture location**	**Mean**	**Std. Deviation**	**N**
1	1	37.0667	9.91728	15
	2	17.0000	8.45154	15
	3	58.0000	14.50616	15
	Total	37.3556	20.18793	45
2	1	52.2786	9.38149	15
	2	22.1907	7.58029	15
	3	57.1736	17.99794	15
	Total	43.8810	19.84991	45
Total	1	44.6726	12.23988	30
	2	19.5953	8.31808	30
	3	57.5868	16.06676	30
	Total	40.6183	20.17541	90

Dependent Variable: Frequency of use

Test of Normality

To use ANOVA, it is necessary to explore the standardized residual to see whether or not the data is normal because ANOVA is based on the normality of the data. The significance level is 0.05, $\alpha=0.05$. Table 12 shows that the significance for the test of normality is greater than 0.05, therefore, the data is normal.

Table 12.

Test of Normality for Men's Urinals

	Kolmogorov-Smirnov(a)			Shapiro-Wilk		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Standardized Residual for frequency	.063	90	.200	. 989	90	. 691

Univariate Analysis of Variance

The valve type and fixture location were the factors examined. The table shows the factors affecting the frequency of use for the fixtures. The significant level is 0.05, $\alpha=0.05$. Table 13 shows that the significance for the o valve type is 0.013 and the significant for the fixture location is 0.000. Therefore, the valve types and the fixture locations affect the frequency of use of the fixtures. The adjusted R^2 value is 0.632 and is considered pretty good given the nature of the data.

Table 13.

Analysis of Variance (ANOVA) Table, Men's Urinals

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Corrected Model	23348.051(a)	3	7782.684	51.968	.000
Intercept	148485.842	1	148485.842	991.507	.000
Valve Type	958.069	1	958.069	6.397	.013
Fixture Location	22389.982	2	11194.991	74.754	.000
Error	12879.164	86	149.758		
Total	184713.056	90			
Corrected Total	36227.215	89			

Dependent Variable: frequency of use

a R Squared = .644 (Adjusted R Squared = .632)

Post Hoc Tests

From Table 14, it is evident that the 95% confidence intervals for location 1, 2, and 3 do not overlap with each other.

Table 14.

Multiple Comparisons for Men's Urinal Fixture Location

Dependent Variable: frequency of use

(I) Location	(J) Location	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	25.0773	3.15972	.000	17.5415	32.6131
	3	-12.9142	3.15972	.000	-20.4500	-5.3784
2	1	-25.0773	3.15972	.000	-32.6131	-17.5415
	3	-37.9915	3.15972	.000	-45.5273	-30.4557
3	1	12.9142	3.15972	.000	5.3784	20.4500
	2	37.9915	3.15972	.000	30.4557	45.5273

Women's Water Closets

The frequency of use for the water fixtures on the third floor were excluded due to one of the water closets being out of order, affecting the frequency of use other water closets. Therefore the fixture location factor doesn't work properly for the third floor. Figure 21 shows the frequency of women's water closet graphically. Figure 22 shows the scatter plots of the manual and the automatic women's water closet and it shows how far the data is scattered from the mean value.

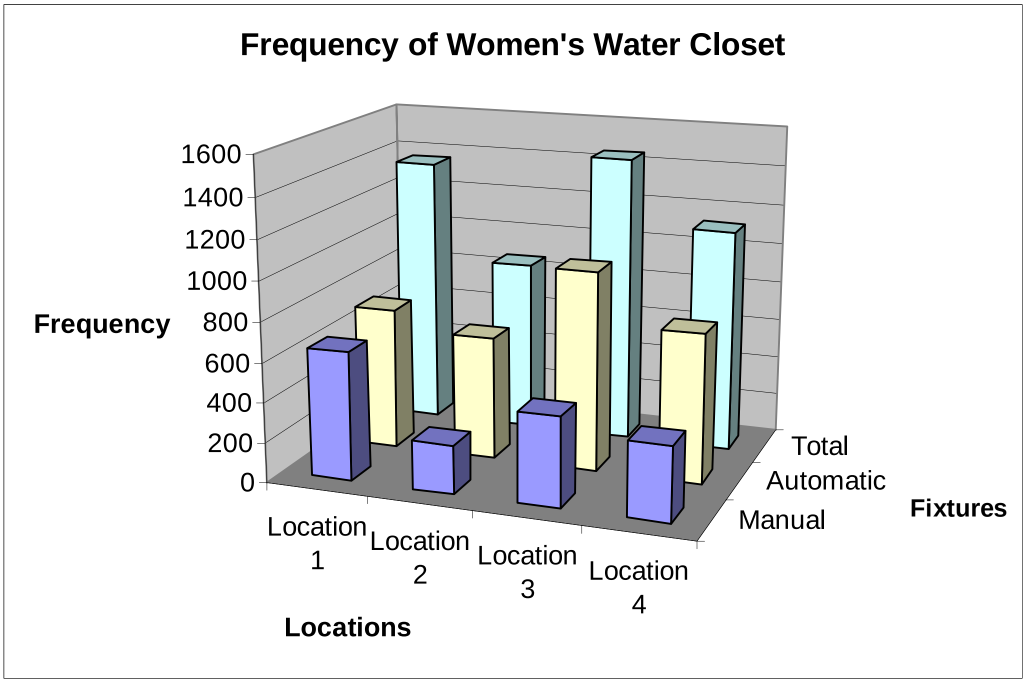


Figure 21. Frequency of use chart of women's water closets

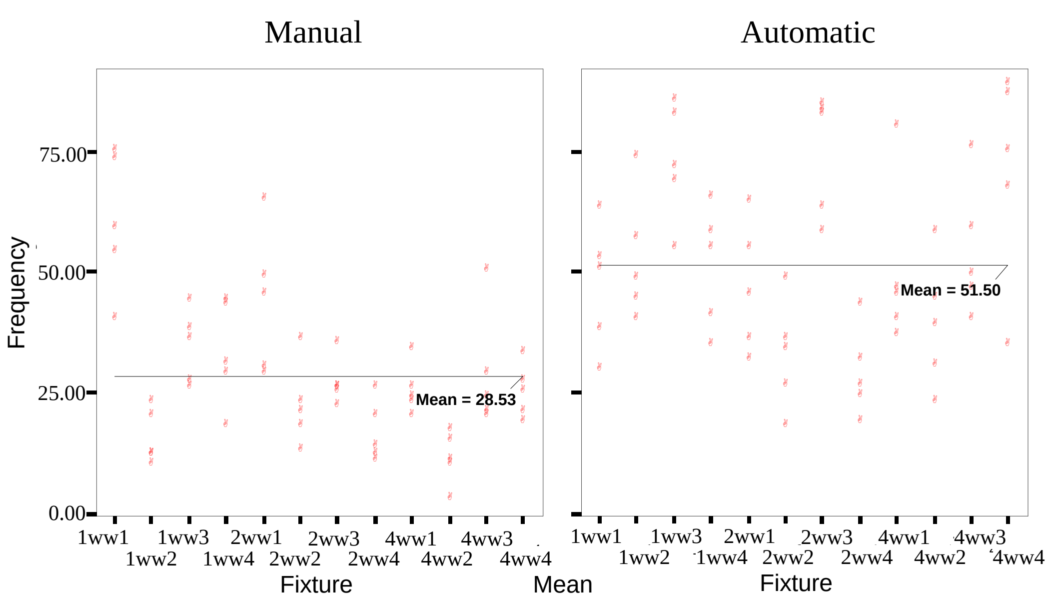


Figure 22. Scatter plot for frequency of use of women's water closets

Table 15 and Table 16 show the frequency of use for women’s water closet from Monday through Friday, with total and average use.

Table 15.

Frequency of Use of the Manual Women’s Water Closets

	Mon	**Tue**	**Wed**	**Thu**	**Fri**	**Total**	**Average**
1ww1	59	75	73	54	40	301	60.2
1ww2	12	23	20	12	10	77	15.4
1ww3	27	44	36	38	26	171	34.2
1ww4	44	43	29	18	31	165	33.0
2ww1	45	49	65	30	29	218	43.6
2ww2	21	36	23	13	18	111	22.2
2ww3	25	26	35	22	26	134	26.8
2ww4	20	26	14	12	11	83	16.6
4ww1	24	23	34	26	20	127	25.4
4ww2	17	11	15	3	10	56	11.2
4ww3	50	29	21	20	24	144	28.8
4ww4	27	19	25	33	21	125	25.0

Table 16.

Frequency of Use of the Automatic Women’s Water Closets

	Mon	**Tue**	**Wed**	**Thu**	**Fri**	**Total**	**Average**
1ww1	60	48	28	50	36	222	44.4
1ww2	46	54	42	70	38	250	50.0
1ww3	68	78	65	52	81	344	68.8
1ww4	52	39	55	62	33	241	48.2
2ww1	52	61	43	34	30	220	44.0
2ww2	34	32	46	25	17	154	30.8
2ww3	80	60	79	78	55	352	70.4
2ww4	30	23	41	25	18	137	27.4
4ww1	76	43	35	38	44	236	47.2
4ww2	55	37	22	29	42	185	37.0
4ww3	47	72	38	44	56	257	51.4
4ww4	71	64	84	82	33	334	66.8

Descriptive Statistics

A total of 60 frequency data was collected for each valve type and a total of 30 frequency data was collected for fixture location. From Table17, the mean frequency of the manual is 28.53 and the mean frequency of the automatic is 51.50. The automatic has greater frequency than the manual. The mean frequency of location 1 is 45.35, the mean frequency of location 2 is 28.82, the mean frequency of location 3 is 48.44, and the mean frequency of location 4 is 37.44. Location 3 has the highest frequency of use.

Table 17.

Descriptive Statistics for Women's Water Closets

Valve	**Location**	**Mean**	**Std. Deviation**	**N**
1	1	43.0667	18.62973	15
	2	16.2667	7.79621	15
	3	29.9333	8.80314	15
	4	24.8667	10.06313	15
	Total	28.5333	15.33188	60
2	1	47.6318	13.79288	15
	2	41.3792	14.64780	15
	3	66.9514	15.19220	15
	4	50.0204	22.62207	15
	Total	51.4957	19.06191	60
Total	1	45.3492	16.27209	30
	2	28.8229	17.20520	30
	3	48.4424	22.43283	30
	4	37.4435	21.43769	30
	Total	40.0145	20.72733	120

Dependent variable: frequency of use

Test of Normality

To use ANOVA, it is necessary to explore the standardized residual to see whether or not the data is normal because ANOVA is based on the normality of the data. From Table 18, the significance is smaller than 0.017; therefore, the data is not normal.

Table 18.

Tests of Normality for Women's Water Closets Without Outliers

	Kolmogorov-Smirnov(a)			**Shapiro-Wilk**		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Standardized Residual for frequency	.091	120	.017	.963	120	.002

Figure 23, the box plot shows that there are four outliers. Removal of these outliers normalizes the data allowing the use of normal methods rather than non-parametric methods.

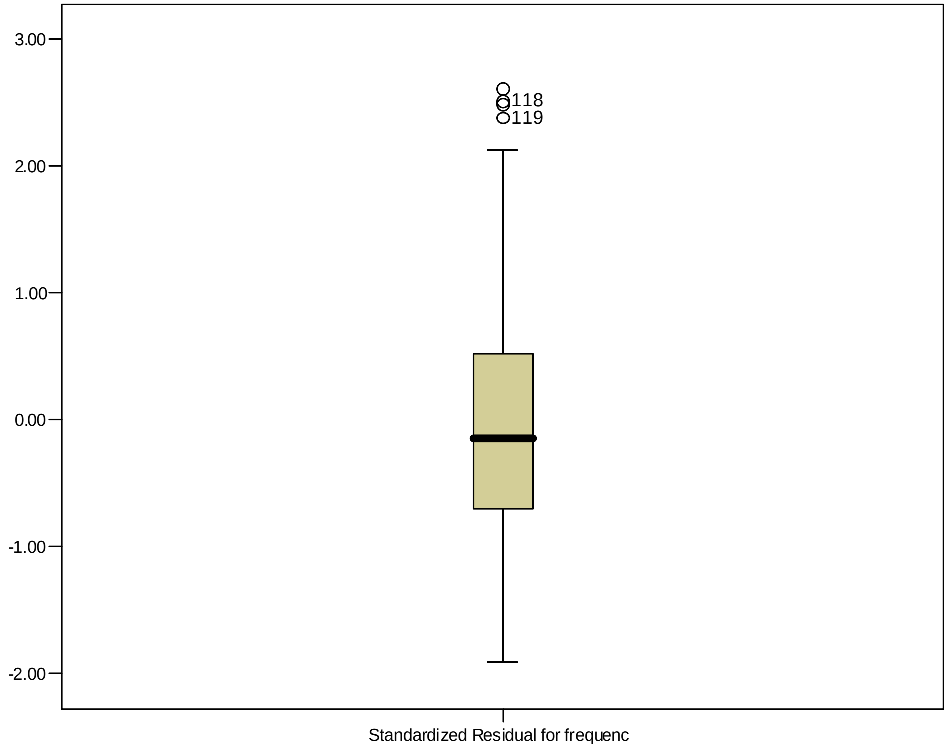


Figure 23. Box plot for women's water closets

The Robust Methods

The three outliers were removed to make the data normal and run Univariate Analysis of Variance to see whether or not the data was normal. Table 19 shows that the significance value is 0.061 and it is slightly greater than 0.05, therefore, the data is normal.

Table 19.

Tests of Normality for Women's Water Closets Without Outliers

	Kolmogorov-Smirnov(a)			**Shapiro-Wilk**		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Standardized Residual for frequency	.080	117	.061	.974	117	.022

Univariate Analysis of Variance

The valve type and fixture location were the factors examined here. The table shows the factors affecting the frequency for the fixtures. The significance level is 0.05, α=0.05. Table 20 shows that the significance of valve type is 0.000 and that the significant for fixture location is 0.000. Therefore, valve types and fixture locations affect the frequency of the fixtures. The adjusted R^2 value is 0.480 and is considered pretty good given the nature of the data.

Table 20.

Analysis of Variance (ANOVA) Table for Women's Water Closets

Dependent Variable: frequency

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Corrected Model	23070.271(a)	4	5767.568	27.755	.000
Intercept	177368.272	1	177368.272	853.535	.000
valve	16450.794	1	16450.794	79.165	.000
location	6359.881	3	2119.960	10.202	.000
Error	23274.098	112	207.804		
Total	224474.758	117			
Corrected Total	46344.369	116			

a R Squared = .498 (Adjusted R Squared = .480)

Post Hoc Tests

From Table 21, it is evident that the 95% confidence intervals for location 4 overlap with location 2 and location 1, location 1 overlap with location 4 and location 3, location 2 overlap with location 4, and location 3 overlap location 1.

Table 21.

Multiple Comparisons for Women's Water Closet Fixture Locations

(I) Location	(J) Location	Mean Difference (I-J)	Std. Error	Sig.	95%Confidence Interval	
					Lower Bound	Upper Bound
1	2	14.4798	3.78793	.001	4.6008	24.3588
	3	-5.1397	3.78793	.529	-15.0187	4.7394
	4	7.6204	3.81933	.196	-2.3405	17.5813
2	1	-14.4798	3.78793	.001	-24.3588	-4.6008
	3	-19.6194	3.72205	.000	-29.3266	-9.9123
	4	-6.8593	3.75400	.266	-16.6499	2.9312
3	1	5.1397	3.78793	.529	-4.7394	15.0187
	2	19.6194	3.72205	.000	9.9123	29.3266
	4	12.7601	3.75400	.005	2.9696	22.5506
4	1	-7.6204	3.81933	.196	-17.5813	2.3405
	2	6.8593	3.75400	.266	-2.9312	16.6499
	3	-12.7601	3.75400	.005	-22.5506	-2.9696

CONCLUSIONS

From these results, it can be concluded that the frequency of men's water closet between the manual and the automatic low-consumption fixtures is different, the frequency of men's urinal between the manual and the automatic low-consumption fixtures is not different, and the frequency of women's water closet between the manual and the automatic low-consumption fixture is different.

Men's Water Closets

Object 1 – Valve Type

Both types of men's water closets use the low-consumption valves, following the Energy Policy Act of 1992 standards. Theoretically, they should have the same average frequency of use under similar circumstances. This wasn't found to be the case. There was a significant difference between the manual and the automatic; the automatic had a higher frequency than the manual low-consumption fixture. Which we can see from Table 22, as the significance of 0.000 is much less than the significance level, α, of 0.05.

Table 22.

ANOVA Table for Men's Water Closets
Dependent Variable: frequency

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3201.303(a)	2	1600.651	21.401	.000
Intercept	45773.135	1	45773.135	611.997	.000
Valve Type	2321.590	1	2321.590	31.040	.000
Fixture Location	879.713	1	879.713	11.762	.001
Error	4263.206	57	74.793		
Total	53237.643	60			
Corrected Total	7464.509	59			

Object 2 – Fixture Location

There are two locations for men's water closets. Theoretically, they should have the same average frequency of use under similar circumstances. This wasn't found to be the case. There was a significant difference between location 1 and location 2, location 2 had a higher frequency than location 1. Which we can see from Table 26, as the significance of 0.001 is much less than the significance level, α, of 0.05.

Men's Urinals

Object 1 – Valve Type

Both types of men's urinals use the low-consumption valves, following the *Energy Policy Act of 1992* standards. Theoretically, they should have the same average frequency of use under similar circumstances. This wasn't found to be the case. There was a significant difference between the manual and the automatic; the automatic had a higher frequency than the manual low-consumption fixture. Which we can see from Table 23, as the significance of 0.013 is much less than the significance level, α, of 0.05.

Table 23.

ANOVA Table for Men's Urinals
Dependent Variable: frequency

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	23348.051(a)	3	7782.684	51.968	.000
Intercept	148485.842	1	148485.842	991.507	.000
valve	958.069	1	958.069	6.397	.013
location	22389.982	2	11194.991	74.754	.000
Error	12879.164	86	149.758		
Total	184713.056	90			
Corrected Total	36227.215	89			

Object 2 – Fixture Location

There are three locations for men's urinals. Theoretically, they should have the same average frequency of use under similar circumstances. This wasn't found to be the case. From Table 24, the significance of 0.000 is much less than the significance level, α, of 0.05. There was a significant difference among location 1, location 2, and location 3. Location 3 had a higher frequency, location 2 was the next, and location 2 had the lowest frequency. From Table 24, each location was in different subsets. Location 3 has the highest frequency, and location 1 is with location 2 having the lowest frequency. Location 3 is right next to the entrance and is more spacious than others. Location 2 has no distinct advantage.

Table 24.

Homogeneous Subsets for Women's Water Closet Fixture Locations

Location	N	Subset 1	Subset 2	Subset 3
2	30	19.5953		
1	30		44.6726	
3	30			57.5868
Sig.		1.000	1.000	1.000

Women's Water Closets

Object 1 – Valve Type

Both types of women's water closets use the low-consumption valves, following the *Energy Policy Act of 1992* standards. Theoretically, they should have the same average frequency of use under similar circumstances. This wasn't found to be the case. There was a significant difference between the manual and the automatic; the automatic had a higher frequency than the manual low-consumption fixture. Which we can see from Table 25, as the significance of 0.000 is much less than the significance level, α, of 0.05.

Table 25.

ANOVA Table for Women's Water Closets

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	23070.271(a)	4	5767.568	27.755	.000
Intercept	177368.272	1	177368.272	853.535	.000
valve	16450.794	1	16450.794	79.165	.000
location	6359.881	3	2119.960	10.202	.000
Error	23274.098	112	207.804		
Total	224474.758	117			
Corrected Total	46344.369	116			

Object 2 – Fixture Location

There are four locations for women's water closets. Theoretically, they should have the same average frequency of use under similar circumstances. This wasn't found to be the case. From Table 26, the significance of 0.000 is much less than the significance level, α, of 0.05. There was a difference among location 1, location 2, location 3 and location 4. From Table 30, there were three groups: location 2 and location 4 were in group 1: location 4 and location 1 were in group 2: location 1 and location 3 were in group 3. Group 3 had higher frequency than other groups. Overall location 3 has the highest average frequency and it is more spacious than others.

Table 26.

Homogeneous Subsets for Women's Water Closet Fixture Locations

	N	**Subset**		
Location		**1**	**2**	**3**
2	30	28.8229		
4	29	35.6823	35.6823	
1	28		43.3027	43.3027
3	30			48.4424
Sig.		.270	.187	.525

Discussion

The manual low-consumption water fixtures have a lower frequency than the automatic low-consumption water fixtures. From Lertbannaphong's study of the *Automatic flush valve performance (gallons per flush) measured from fixtures in a mixed-use classroom/office (2005)*, the gpf of the manual and the automatic water fixtures is known to be the same. We expected the frequency of the manual and the automatic water fixtures to be the same because both fixture types use same number of gallons of water. However there are differences on men’s and women’s water closets.

A possible explanation for these differences is that they have different types of valves, the manual and the automatic. The operation of the manual water fixtures is totally dependent on the user. While operation of the automatic water fixtures is dependent on a combination of the user and the automatic sensor. The users’ behavior in regard to the manual and the automatic water fixture could be an answer as to why there are differences in the frequency of the manual and the automatic water fixtures.

Despite fixtures follow the EPA of 1992 Standards and use the same valve type, there are differences in frequency in use in relation to fixture locations. Most case, there are higher frequency in use for fixtures having more spacious and an easy access. The reasons are due to psychological factors. People are likely to use enclosed and cornered spaces rather than open and non privacy spaces. For men’s urinal, the urinal located right next to the entrance has the highest frequency because of convenience.

Recommendations for Further Study

The effect model used demonstrated a relationship between frequency of use and location. This relationship should bear further investigations, as it could prove invaluable in predicting usage patterns. From Henderson and Woodard’s 2000 study, *Functioning of aging low-consumption toilets in Tucson*, we know that there is a history of complaints that the discharge would often require multiple flushes. We suspect there might be differences between the manual and the automatic water closets in this regard, as the discharge of waste depends not only on gallons per flush but also on flow pattern. Although manufacturers claim that their water fixtures have the same mechanical structures, each fixture possess unique acoustical signature which implies that each has a unique flow pattern. We suspect that this unique flow pattern plays a major role in the frequency of use.

The simplest improvement that can be made upon this study would be the improvement of the AIRS. From Figures 10 and 11, we can see two fundamental issues. The data for many of the water closets and urinals were detected using a single acoustical pickup and that multiple restrooms were funneled to a single mixer and recognition system. Using an AIRS for each water closet and urinal would dramatically improve the recognition of events, as there would not be incidents of overlapped events in the recognition process. This would also improve the recognition of multiple flushes. Also it would improve the discrimination of location of events.

EXPECTED BENEFITS

Beneficiaries

This research shows that the greatest water conservation can be achieved by upgrading to the new low-consumption water valves. The scope of this research was limited to Langford Architecture Building A and the automatic water valves in its restrooms; however, it could become the basis for larger and much more comprehensive study for water conservation. A much larger study would be able to capitalize on the successes and while avoiding the pitfalls of this pilot study.

Facility Management

The obvious benefactors of this study are facilities managers. Facility managers are always forced to decide when equipment should be retrofitted or how much money they can save by retrofitting new equipment. This research shows the performance of low-consumption fixtures and how much water can be saved by retrofitting to the new automatic water valves, giving managers an estimate of their potential savings.

REFERENCES

Energy Policy Act of 1992, Public law 102-486, 106 Stat. 2776, 102d Congress. Oct 24, 1992.

Henderson, J., & Woodard, G. (2000). *Functioning of aging low-consumption toilets in Tucson*. University of Arizona, Arizona.

Hwang, B. (2003). *The cost-effectiveness of retrofitting sanitary fixtures in restroom of a university building*. Unpublished thesis, Texas A&M University.

Lertbannaphong, S. (2005). *Automatic flush valve performance (gallon per flush) measured from fixtures in a mixed-use classroom/office*. Unpublished thesis, Texas A&M University.

Longnecker, M., Ott, R.L. (2001).*An Introduction to Statistical Methods and Data Analysis*, Fifth Edition. Pacific Grove, CA: Duxbury Thomson Learning, Inc.

Parker, K. B. (2002). *Determination of maximum flow rate in a building water-supply by means of acoustic observation*. Unpublished doctoral dissertation, Texas A&M University.

Reyes, M. D. (2004). *High volume flush vs. low-flush water closets and solid waste transport distance: a comparative study*. Unpublished thesis, Texas A&M University.

Seo, H. (2003). *Predicting annual water savings from retrofitting supply valves in a university classroom/office building by means of acoustic observation*. Unpublished doctoral dissertation, Texas A&M University.

Sloan Valve Company Products. *Royal II 110/111*, Retrieved Jan 31, 2005, [WWW document] URL: http://www.sloanvalve.com/specsheets/Royal_II_110_Rev0.pdf.

Sloan Valve Company (2002). *Sloan optima systems Optima plus Royal Model 111*, Sloan Valve Company, Franklin Park, IL

Sloan Valve Company (2003). *Sloan optima systems G2 Optima plus Model 8110/8111*, Sloan Valve Company, Franklin Park, IL

United States General Accounting Office. (2000). *Water Infrastructure: Water-Efficient Plumbing Fixtures Reduce Water Consumption and Wastewater Flows*. Washington, DC.

Woods, P., Bryant, J., Parker, K., Shea, K., & Seo, H. (2000). *An acoustic pattern recognition, retrieval and storage system*. Proceedings of the 36th Associated Schools of Construction Annual Conference.

APPENDIX A

Manual Low-Consumption Fixture Flushometer

Royal II® Model Flushometer 110/111

▶ **Description**
Exposed Water Closet Flushometer for floor mounted or wall hung top spud bowls.

▶ **Flush Cycle**
☐ Model 110 Water Saver (3.5 gpf/13.2 Lpf)
☐ Model 111 Low Consumption (1.6 gpf/6.0 Lpf)

▶ **Specifications**
Quiet, Exposed, Diaphragm Type, Chrome Plated Closet Flushometer with the following features:

- PERMEX™ Synthetic Rubber Diaphragm with Dual Filtered Fixed Bypass
- ADA Compliant Metal Oscillating Non-Hold-Open Handle with Triple Seal Handle Packing
- Aesthetically contoured Cover, Handle Socket and Flanges
- 1" I.P.S. Screwdriver Bak-Chek™ Angle Stop
- Free Spinning Vandal Resistant Stop Cap
- Adjustable Tailpiece
- High Back Pressure Vacuum Breaker Flush Connection with One-piece Bottom Hex Coupling Nut
- Spud Coupling and Flange for 1½" Top Spud
- Sweat Solder Adapter with Cover Tube and Cast Set Screw Wall Flange
- High Copper, Low Zinc Brass Castings for Dezincification Resistance
- Non-Hold-Open Handle, Fixed Metering Bypass and No External Volume Adjustment to Ensure Water Conservation
- Flush Accuracy Controlled by CID™ Technology
- Diaphragm, Handle Packing, Stop Seat and Vacuum Breaker to be molded from PERMEX™ Rubber Compound for Chloramine Resistance

Valve Body, Cover, Tailpiece and Control Stop shall be in conformance with ASTM Alloy Classification for Semi-Red Brass. Valve shall be in compliance to the applicable sections of ASSE 1037, ANSI/ASME 112.19.6, and Military Specification V-29193.

▶ **Special Finishes**
☐ PB Polished Brass (PVD Finish)
☐ GP Gold Plate (PVD Finish)
☐ BN Brushed Nickel (PVD Finish)
☐ SF Satin Chrome

See Accessories Section of the Sloan catalog for details on these and other Flushometer variations.

® Certified   Listed by I.A.P.M.O.

This space for Architect/Engineer approval

Job Name ______________ Date ______________
Model Specified ______________ Quantity ______________
Variations Specified ______________
Customer/Wholesaler ______________
Contractor ______________
Architect ______________

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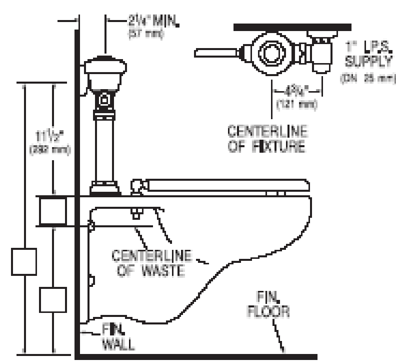

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Royal II 110 S.S. — Rev. 0 (02/03)

APPENDIX B

Automatic Low-Consumption Fixture Flushometer

SLOAN®
OPTIMA SYSTEMS
Battery Powered Flushometers

G2 OPTIMA *plus*®

Model **8110/8111**

Description
Exposed, Battery Powered, Sensor Operated G2® Model Water Closet Flushometer for floor mounted or wall hung top spud bowls.

Flush Cycle
☐ Model 8111 Low Consumption (1.6 gpf/6.0 Lpf)
☐ Model 8110 Water Saver (3.5 gpf/13.2 Lpf)

Specifications
Quiet, Exposed, Diaphragm Type, Chrome Plated Closet Flushometer for either left or right hand supply with the following features:
- PERMEX™ Synthetic Rubber Diaphragm with Dual Filtered Fixed Bypass
- Flex Tube Diaphragm designed for improved life and reduced maintenance
- ADA Compliant OPTIMA *Plus*® Battery Powered Infrared Sensor for automatic "No Hands" operation
- Infrared Sensor with Multiple-focused, Lobular Sensing Fields for high and low target detection
- Isolated Latching Solenoid Operator, isolates magnetic components from water contact
- Engineered Metal Cover with replaceable Lens Window
- User friendly three (3) second Flush Delay
- Courtesy Flush™ Override Button
- Four (4) Size AA Batteries factory installed
- "Low Battery" Flashing LED
- Infrared Sensor Range Adjustment Screw
- Initial Set-up Range Indicator Light (first 10 minutes)
- 1" I.P.S. Screwdriver Bak-Chek™ Angle Stop
- Free Spinning, Vandal Resistant Stop Cap
- Adjustable Tailpiece
- High Back Pressure Vacuum Breaker Flush Connection with One-piece Bottom Hex Coupling Nut
- Spud Coupling and Flange for 1½" Top Spud
- Sweat Solder Adapter with Cover Tube and Cast Set Screw Wall Flange
- High Copper, Low Zinc Brass Castings for Dezincification Resistance
- Fixed Metering Bypass and No External Volume Adjustment to Ensure Water Conservation
- Flush Accuracy Controlled by CID™ Technology
- Diaphragm, Stop Seat and Vacuum Breaker to be molded from PERMEX™ Rubber Compound for Chloramine resistance

Valve Body, Tailpiece and Control Stop shall be in conformance with ASTM Alloy Classification for Semi-Red Brass. Valve shall be in compliance with the applicable sections of ASSE 1037, ANSI/ASME A112.19.6 and Military Specification V-29193. Installation conforms to ADA requirements.

Special Finishes
☐ PB Polished Brass (PVD Finish)
☐ GP Gold Plate (PVD Finish)
☐ BN Brushed Nickel (PVD Finish)
☐ SF Satin Chrome

See Accessories Section and OPTIMA Accessories Section of the Sloan catalog for details on these and other OPTIMA *Plus*® Flushometer variations.

ADA Compliant

Automatic
Sloan G2 Optima *Plus*® Flushometers activate via multi-lobular sensor detection to provide the ultimate in sanitary protection and automatic operation. A battery powered infrared sensor sets the flushing mechanism after the user is detected and completes the flush when the user steps away.

Functional & Hygienic
Touchless, sensor operation eliminates the need for user contact to help control the spread of infectious diseases. The G2 Optima *Plus* Flushometer is provided with an Override Button to allow a "courtesy flush" for individual user comfort.

Economical
Sloan installed batteries speed installation and provide years of metered flushing to control the use of water and energy. Batteries can be changed without turning off the water. The patented Isolated Operator ensures reliability by isolating the solenoid components from the water.

Warranty
5 year (limited)

UL® Listed   CSA® Certified

This space for Architect/Engineer approval

Job Name ______________________ Date ________

Model Specified ______________________ Quantity ________

Variations Specified ______________________

Customer/Wholesaler ______________________

Contractor ______________________

Architect ______________________

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