A Study of Water Evaporation in Urinal Traps

A Report to Falcon Waterfree Technologies

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SUMMARY

In view to the increasing importance of water conservation in recent years, manufacturers have introduced very low flush urinals that derive from conventional water-supplied urinals but release small amount of water, i.e., 1/8 gallon (pint) instead of 1 gallon.

The downscaling of water-supplied urinals with the intent of promoting water conservation has however encountered a point of diminishing return in the vicinity of one-pint. This study challenges the notion that very low-flush urinals are enhanced one-gallon urinals, based on a reliable and economical technology. Indeed it shows that reducing urinal trap sizes renders trap seals more vulnerable to water evaporation.

First, the study examines the International Plumbing Code for sections relevant to design constraints for urinals, e.g., minimum requirements for trap diameter and depth of trap seal. It surveys very low-flush urinals and flush valves available from seven manufacturers. Second, the study reviews theories for water evaporation, and develops a practical correlation for the purpose of investigating water evaporation in urinals. Third, based on the examination of a particular very low-flush urinal, the study develops an experimental procedure for measuring water evaporation in urinal traps. The evaporation rates measured over a two-week period are found to be in agreement with evaporation rates published in the literature. Finally, the study interprets experimental results using a physical model for water evaporation in urinal traps. The model, which has for variables - depth of trap seal, relative humidity and ambient temperature, is useful to determine the circumstances associated with failure of urinal trap seals due to evaporation.

The findings of this study are applicable to all types of water-supplied urinals, ranging from one-gallon urinals to very low-flush urinals (1/8 gallon). From a practical point of view, the downscaling of urinal traps has reached a point of diminishing return due to plumbing code requirements. Beyond this breakpoint, clogging of traps due to debris and failure of trap seals may occur. The study concludes the reduction in depths of trap seal has adverse effects. Without appropriate but potentially costly countermeasures such as sophisticated flush valves, very low-flush urinals are likely to fail more frequently than larger water-supplied urinals because of shallow depths of trap seals.

1 INTRODUCTION

As water conservation has become more important in recent years, manufacturers have responded by introducing very low-flush urinals that derive from conventional water-supplied urinals without significantly innovative technical features. They simply release smaller amount of water, i.e., 1/8 gallon (pint) instead of 1 gallon. The main challenge they face is to release less water while remaining functional and meeting hygienic requirements comparable to those of one-gallon urinals.

From the general perspective of engineering design, technologies cannot be downscaled without making compromises and losing a few benefits. For instance, downscaling the size of conventional combustion engines reduces gas consumption, which adversely decreases engine power. From a practical point of view, engines cannot get too small or would not be powerful enough to propel cars. At some point, there is a breakpoint, also called a point of diminishing return, beyond which any technology cannot be downscaled further or simply fails to deliver. Breakpoints can be overcome however by innovations, e.g., with fuel injection in the case of combustion engines.

Like in any other technologies, the downscaling of water-supplied urinals to accommodate smaller and smaller water flows is bound to encounter breakpoints. There must be a minimum amount of water beyond which water-supplied urinals fail to deliver. At the present, very low-flush urinals are perceived to enhance traditional one-gallon urinals and to be based on a reliable and economical technology. There is a need for investigating the effects of downscaling water-supplied urinals, especially one of their critical features – trap seals.

2 OBJECTIVE OF STUDY AND REPORT ORGANIZATION

The objective of the study is to investigate the mechanics of water-supplied urinal traps and to examine effects related to the reduction in amount of water flush. The main tasks of the study were:

- Identify sections of plumbing codes relevant to urinal traps and their geometry.
- Design, perform and analyze experiments that simulate under controlled laboratory conditions the performance of urinal traps.
- Make recommendations for assessing performances of very low-flush urinals.

Following the introduction (Section 1) and definition of objectives (Section 2), Section 3 reviews relevant sections of the International Plumbing Code, surveys very low-flush urinals and associated flush valves, and examines the constrained optimization of urinal trap geometries. Section 4 reviews the theory of water evaporation, develops a novel correlation, and gathers evaporation rates measured from past studies. Section 5 examines a particular very low-flush urinal, and describes experimental procedure and results for water evaporation. Section 6 presents a physical model for water evaporation in urinal traps, and illustrates how the model determines the circumstances under which trap seals breakdown due to evaporation. Section 7 discusses findings and Section 8 draws conclusions.

3 REVIEW OF PLUMBING CODE AND EXISTING URINALS

3.1 International Plumbing Code and urinal technologies

The International Plumbing Code (IPC, 2012) contains several sections that have definitions, specifications and annotations relevant to urinals, i.e.,

- Section 202 – General Definition: Depth of trap seal (Page 2-13); Trap and trap seal (Page 2-27).
- Section 419.1 – Urinals: Approval (Page 4-63)
- Section 709.1 – Drainage fixture units for fixtures and groups (Page 7-41)
- Section 709.1 – Drainage fixture units for fixtures and groups (Page 7-41)
- Section 901.2 – Trap seal protection (Page 9-2)
- Section 1002.4 – Trap seals (Page 10-4)

Section 419.1 of IPC (2012) distinguishes two major types of urinals (1) water-supplied urinals including stall, blowout, siphon jet, and wash down, and (2) waterless urinals. All urinals - waterless or water-supplied - are connected to sewage pipes through a trap that act as seals and prevents sewer odors from entering buildings. Most manufacturers now design wall-hung wash-out urinals with an integral trap.

Figures 1 and 2 shows an example of a water-supplied urinal, which falls into the category of very low-flush urinal, i.e., which conserves water by releasing smaller amount of water (one pint) than its predecessors (one gallon or more).

All types of water-supplied urinals have a U-shaped trap the outlet of which connects to building drainage pipes. Because of its shape, the trap retains a small amount of water after being used, which creates a seal and prevents sewer gases from passing from the drainage pipes back into the buildings. When the water evaporates in the trap below the clip level (Figure 5) then noxious odors are allowed to escape.

Figure 1. Example of water-supplied very low-flush urinal (Zurn – Model Z5798.205.00).

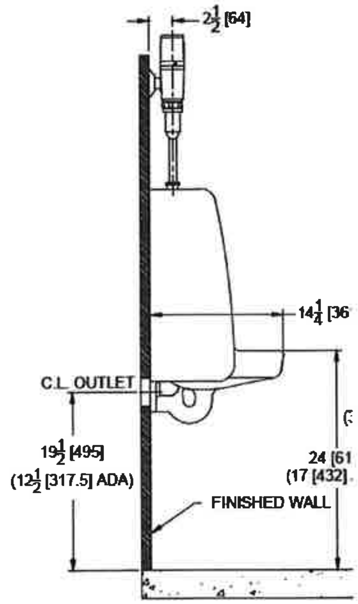

Figure 2. Cross section of urinal in Figure 1 showing U-shaped trap close to the outlet (Zurn – Model Z5798.205.00).

Figures 3 and 4 show an example of waterless urinals and their cartridges, which perform similar functions as traps in water-supplied urinals. Compared to water-supplied urinals, waterless urinals use a more advanced technology for traps. As shown in Figure 4, traps have more sophisticated geometries and are filled, not with water, but with an especially designed liquid/sealant that is lighter than urine and evaporates much slower than water. As illustrated in Figure 3, a few manufacturers have designed traps as removable cartridges that are replaced after a certain number of usages.

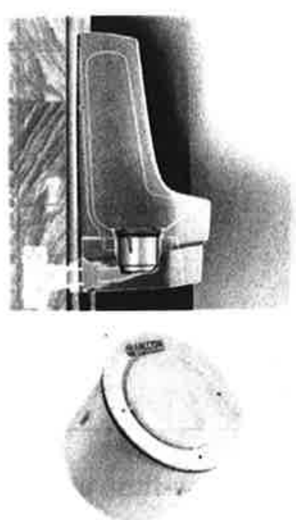

Figure 3. Waterless urinal (Photo courtesy of Falcon Waterfree Technologies).

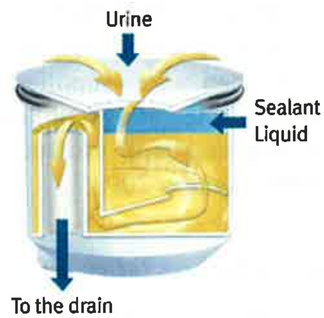

Figure 4. Waterless urinal cartridge (Photo courtesy of Falcon Waterfree Technologies).

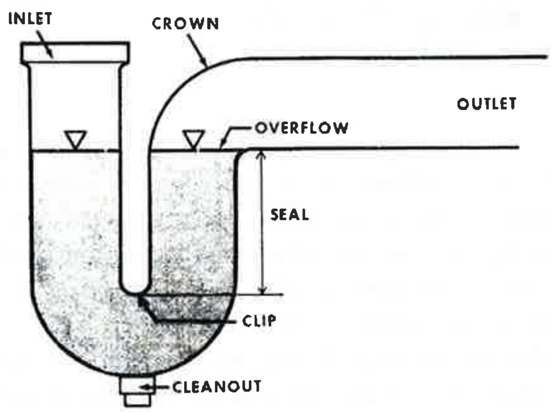

Figure 5. Schematic representation of a water trap used in water-supplied urinals (http://en.wikipedia.org/wiki/Trap_(plumbing)).

As shown in Figure 6, Section 202 of IPC (2012) defines a *trap* as "a fitting or device that provide a liquid seal to prevent the emission of sewer gases without materially affecting the flow of sewage or waste water through the trap." It defines *trap seal* as "the vertical distance between the weir and the top of the dip of the trap," and *depth of trap seal* as "the depth of liquid that would have to be removed from a full trap before air could pass through the trap."

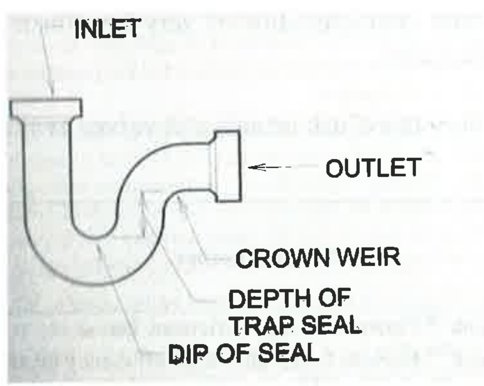

Figure 6. Depth of trap seal (IPC, 2012).

As shown in Table 1, Section 709.1 of IPC (2012) defines for different kinds of urinals the relative load weight to be used to determine the size of drainage pipes. Waterless urinals have smaller load factors than water-supplied urinals, which should have a trap size consistent with the fixture outlet size but should not be less than 1 ¼ inches (32 mm). As stated in Section 709.1, the trap seal depth is determined using a procedure defined in ASME A112.19.2 (ASME, 2008). Section 709.2

Table 1. Drainage fixture units for fixtures (after IPC, 2012).

Fixture Type	Drainage Fixture Unit Value Load Factors
Urinal	4
Urinal, 1 gallon per flush or less	2
Urinal, non-water supplied	½

Section 1002.4 of IPC (2012) states that "each fixture trap shall have a liquid seal of not less than 2 inches (51 mm) and not more than 4 inches (102 mm). When a trap seal is subject to loss by evaporation, a trap sealer primer valve shall be installed. Trap seal primer valves shall connect to the trap at a point above the level of the trap seal." This section notes "*traps that do not periodically receive waste discharge will eventually lose their seal as a result of evaporation. The rate of trap seal evaporation is somewhat dependent on the location of the trap. For example, water in fixture traps in environments with high ambient temperatures or high-volume air movement will evaporate rapidly.*"

Section 901.2 of IPC (2012) stipulates that the plumbing system shall be provided with a system of vent piping that permits the admission or emission of air so that the seal of any fixture trap shall not be subjected to a pneumatic pressure differential of more than 1 inch of water column (249 Pa). The combined requirements on vent piping and depth of trap seal ensure that trap seals do not fail due to pressure differentials across the inlet and outlets of urinal traps.

3.2 Survey of very low-flush urinals and flush valves

Table 2 surveys the main characteristics of very low-flush urinals and associated flush valves of seven manufacturers.

Table 2. Examples of very low-flush urinals and valves available from seven manufacturers.

Manufacturer	**Model Number**	**Flush volume (gpf)**	**Urinal**	**Valve**
American Standard	Washbrook™ Flowise 0.5 high efficiency urinal	0.5	✓	✓
	Washbrook™ Flowise 0.125 ultra high efficiency urinal	0.125	✓	✓
	Selectronic™ Innsbrook™ 0.5 gallon per flush urinal	0.5		✓
	Selectronic™ FloWise™ sensor operated concealed flush valve	0.125		✓

Manufacturer	Model Number	Flush volume (gpf)	Urinal	Valve
Caroma	Cube Ultra 0.13 gpf (0.5 lpf) electronic activation urinal suite	0.13	✓	✓
Kohler	Bardon™ 1/8th GPF high efficiency urinal (HEU) K-4904-ET	0.125	✓	
	Exposed Flushometer K-10949	0.125		✓
	Exposed Flushometer K-10668	0.125		✓
Mansfield	412 Brevity	0.125	✓	
Sloan	SU-1000-0.125	0.125	✓	
	SU-1000-0.25	0.25	✓	
	SU-1000-0.5	0.5	✓	
	SU-1010-0.125	0.125	✓	
	SU-1010-0.25	0.25	✓	
	SU-1010-0.5	0.5	✓	
	SU-1200-0.125	0.125	✓	
	SU-1200-0.25	0.25	✓	
	SU-1200-0.5	0.5	✓	
	SU-1210-0.125	0.125	✓	
	SU-1210-0.25	0.25	✓	
	SU-1210-0.5	0.5	✓	
	WEUS-1000.1301-0.13	0.13		✓
	WEUS-1000.1301-0.13-S	0.13		✓
Austral Heu	3601	0.5	✓	
Ada	3621	0.5	✓	
Zurn	Z6003AV-ULF	0.125		✓
	ZEG6003AV	0.125		✓
	ZEMS6003AV-ULF-IS	0.125		✓
	ZERS6003AV-ULF-CPM	0.125		✓
	ZEG6003EV	0.125		✓
	Z5792.205.00	0.125	✓	✓
	Z5708.205.00	0.125	✓	✓
	Z5799	0.125	✓	✓
	Z5798.205.00	0.125	✓	✓
	Z5758.205.00	0.125	✓	✓
	Z5738.205.00	0.125	✓	✓

3.3 Constrained optimization for size of urinal traps

Urinal trap sizes can be downscaled efficiently using a geometrical optimization approach with multiple constraints. As shown in Figure 5, the volume V of water contained in urinal traps can be idealized as being made of a half-tore and two vertical cylindrical branches. V is equal to the volume of two cylinders and one half-tore:

$$V = 2\pi R^2 h + \pi^2 R^2 (R+s) \quad (1)$$

Where h is the cylinder height, s is the tore internal radius and R is the radius of the tore and cylinder cross-section (Figure 7). Introducing the depth of trap seal D_s (Figure 6), V becomes:

$$V = 2\pi R^2 (D_s - s) + \pi^2 R^2 (R+s) \quad (2)$$

According to IPC (2012), R cannot be smaller than 5/8 inch (1.59 cm), which corresponds to an internal diameter of 1¼ inch, and D_s cannot be smaller than 2 inch (5.08 cm). When R = 5/8 inch, the depth of trap seal D_s for a given volume V and tore radius s can be expressed as follows:

$$D_s = \frac{V}{2\pi R^2} + s - \frac{\pi}{2}(R + s) \tag{3}$$

In addition, V must be smaller than the volume of water needed to replace the urine residing in traps, i.e., V has to be less than one pint in the case of one-pint urinals. Figure 7 shows the possible combination of s and D_s when V is constrained to be equal to 0.5, 0.4, or 0.3 pint and s is larger than 2 cm for the trap to have a sufficient smooth curvature. As shown in Figure 7, V cannot be smaller than 0.3 pint because of the minimum depth of seal trap (i.e., 5.1 cm) required by IPC (2012). Assuming that the volume of flushed water must be twice as large as the trap volume, one pint is about the smallest possible flush volume for water-supplied urinals.

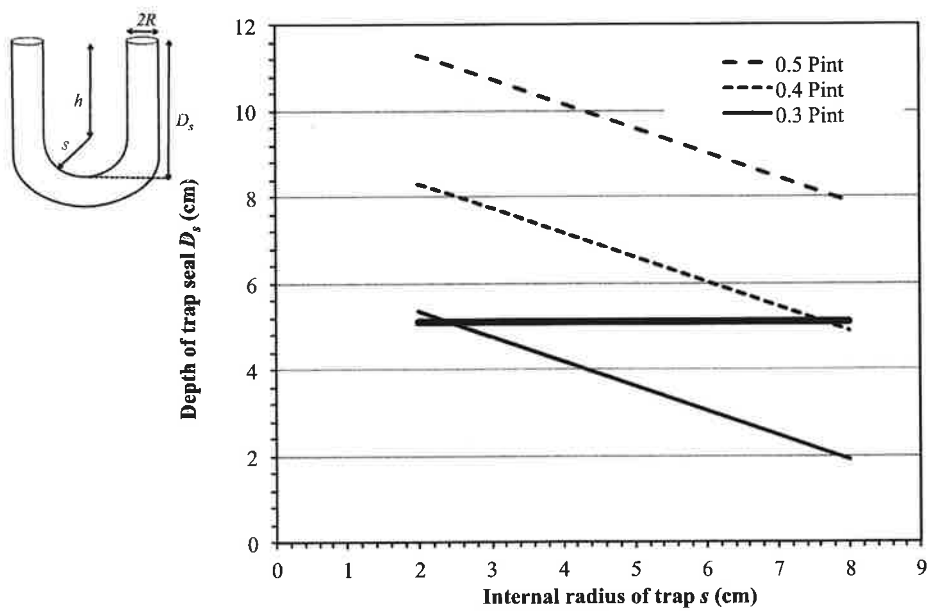

Figure 7. Possible combinations for internal tore radius s and depth of trap seal D_s in the case of urinal traps constrained by a volume V = 0.3, 0.4, or 0.5 pint and a minimum radius R = 5/8 inch.

4 PHYSICAL MODELING OF WATER EVAPORATION IN URINALS

As IPC (2012) noted, "traps that do not periodically receive waste discharge will eventually loose their seal due to water evaporation." To our knowledge, the evaporation of water has not been thoroughly investigated in the traps of water-supplied urinals. The following section reviews the existing theoretical framework, develops a novel physical model and identifies the main factors to account for in subsequent laboratory experiments.

4.1 Rate of evaporation of water

The McGraw-Hill Encyclopedia of Science and Technology (2007) defines evaporation as "the process by which a liquid is converted into a vapor. In the liquid phase, the substance is held together by intermolecular forces. As the temperature is raised, the molecules move more vigorously, and in increasingly high proportion have sufficient energy to escape from their neighbors. Evaporation is therefore slow at low temperatures but faster at higher temperatures. In an open vessel, the molecules escape from the vicinity of the liquid, and there is a net migration from the liquid to the atmosphere. In a closed vessel, net evaporation continues until the number of molecules in the vapor has risen to the stage at which the rate of return from the vapor to the liquid is equal to the rate of evaporation. At this stage there is a dynamic equilibrium between the liquid and its vapor, with evaporation and its reverse, condensation, occurring at the same rate. The pressure of the vapor in the closed vessel is called the vapor pressure of the substance; its value depends on the temperature. Boiling occurs in an open vessel (but not in a closed vessel) when the vapor pressure is equal to the ambient pressure."

The rate of evaporations depends on several factors including the vapor pressure at the water surface and the air above, the incident solar radiation, the atmospheric pressure, the water quality, the air and water temperatures, and the size of the water body.

The present study, which pertains to conditions commonly found in bathrooms, neglects the effects of advection, i.e., assumes that the air speed above the water surface, which may result from air circulation, ventilation and/or air conditioning, remains small enough to cause negligible effects.

Within the assumptions listed above, the rate of evaporation E can be modeled using Dalton (1802) as proportional to the difference between the saturation vapor pressure p_w at the water temperature and the actual vapor pressure in the air p_a:

$$E = \beta\,(p_w - p_a) \qquad (4)$$

Where β is a constant to be calibrated from experiments. E is a rate of mass evaporation per unit area, and is usually expressed in terms of kg/m^2/hour. The rate of evaporation increases with water temperature, but decrease with pressure. It is convenient to introduce the relative humidity R_H as follows:

$$R_H = p_a/p_w \qquad (5)$$

R_H varies from 0 for very dry atmosphere to 1 for very humid atmosphere. R_H is commonly expressed in percent and can be readily measured with barometric devices. Combining Equations 4 and 5, one obtains:

$$E = \beta\, p_w\,(1 - R_H) \qquad (6)$$

According to Buck (1981), within the range of temperatures (10 - 50°C) relevant to the present study, the saturation water pressure of water p_w (in Pascal, i.e. P_a) can be empirically fitted in term of temperature T in degree Celsius as follows:

$$p_w = e^{6.416 + 17.3\,T/(238+T)} \qquad (7)$$

It is convenient to relate the rate of mass evaporation E to E' the rate of vertical change in water surface level:

$$E = E'\rho_w \quad (8)$$

Where ρ_w is the water mass per unit volume, which can be assumed constant to $1 g/cm^3$ independently from temperature T. Corresponding to β, the constant β' is introduced:

$$\beta = \beta'\rho_w \quad (9)$$

The physical units for E and β are $kg/m^2/hour$ and $kg/m^2/hour/Pa$, respectively, whereas those for E' and β' are cm/day and cm/day/Pa, respectively.

Figure 8 shows the variation of saturated vapor pressure p_w as a function of temperature T which corresponds to Equation 7. Equation 7 fits well the experimental data points (e.g., Bridgeman and Aldrich, 1964).

Corresponding to Equation 6, Figure 9 shows the variation of rate of mass evaporation E as a function of temperature T for various values of relative humidity R_H ranging from 0% to 90%. The coefficient β is reported in Table 6 and will be determined from experiments described in a later section. Based on Equation 6, there is no evaporation $E = 0$ when $R_H = 100\%$. The evaporation rate E is the largest when $R_H = 0\%$.

Figure 10 shows the variation of the lowering rate of water surface level E' which corresponds to E (Figure 9) through Equation 8. E' and E varies similarly as they are proportional to each other.

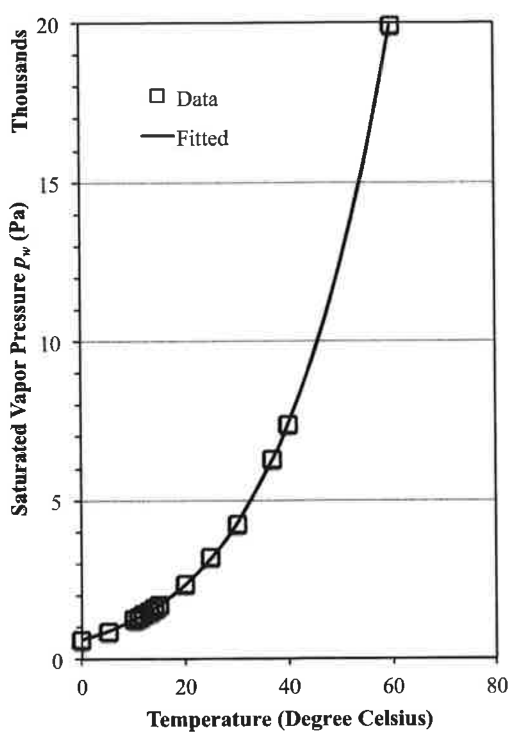

Figure 8. Variation of water saturation pressure (Pa) versus temperature (Degree Celsius). Data points after Bridgeman and Aldrich (1964) and fitted curve after Buck (1981).

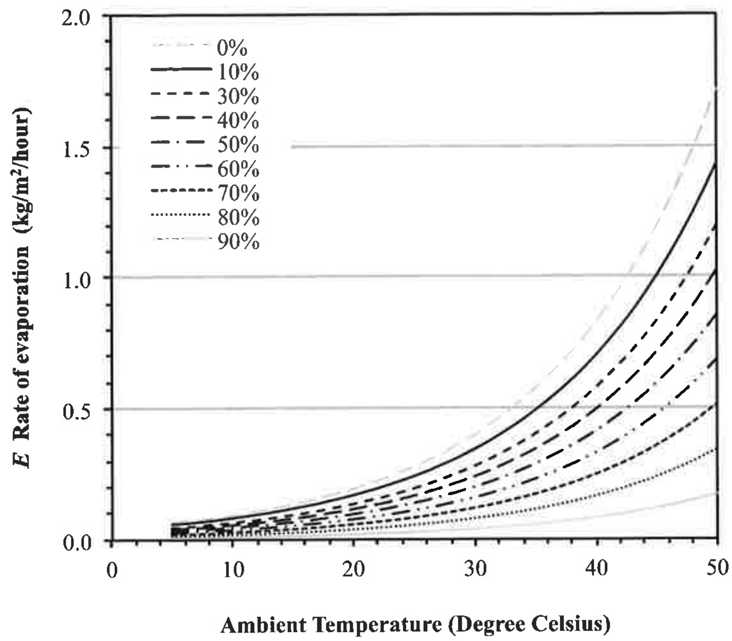

Figure 9. Variation of rate of mass evaporation E as a function of ambient temperature (Degree Celsius) for various relative humidity R_H = 0%-90% as predicted by Equation 6.

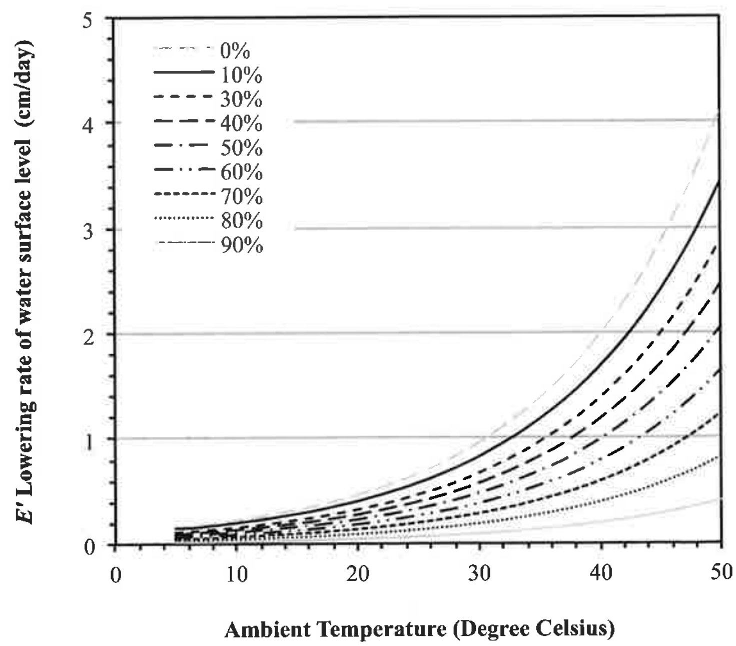

Figure 10. Variation of lowering rate of water surface level E' as a function of ambient temperature (Degree Celsius) for various relative humidity R_H =0%-90% as predicted by Equations 6 and 8.

4.2 Review of literature on evaporation

Many equations have been proposed to estimate the rate of evaporation of free surface waters, e.g., Biasin and Krummer (1974), Boelter et al (1946), Box(1876), Himus and Hinchley (1924), Leven (1969), Meyer (1942), Ferguson (1951), Sartori (2000), Shah (2008), and Tanny et al. (2008)

Table 3 lists five correlations that have been proposed to estimate the rate of evaporation from water pools (Shah, 2008). As shown in Figure 11, these five correlations are similar for small values of p_w-p_a (i.e., at low temperatures) but diverge for large values of p_w-p_a (i.e., at high temperatures). Box (1876) and Himus and Hinchley (1924) give similar results as Equation 6, which will be calibrated as explained in a later section. Figure 12 shows the lowering rates of the water surface level E' that corresponds to those predicted in Figure 11. As expected these two figures display similar correlations as E and E' are proportional to each other.
Figure 12. Comparison of empirical correlations for lowering rate of water surface level.

Table 4 lists a few measured values for rate of evaporation for different pool areas, water temperature, air temperature, air humidity R_H, and pressure differential p_w-p_a.

Table 3. Various empirical correlations for water pools (E in kg/m^2/hour and p_w-p_a in P$_a$).

Authors	Correlation
Boelter et al (1946)	$E = 0.0000162\ (p_w\text{-}p_a)^{1.22}$
Biasin and Krumme (1974)	$E = -0.059 + 0.000079\ (p_w\text{-}p_a)$
Box (1876)	$E = 0.0000778\ (p_w\text{-}p_a)$
Himus and Hinchley (1924)	$E = 0.0000258\ (p_w\text{-}p_a)^{1.2}$
Leven (1969)	$E = 0.00000162\ (p_w\text{-}p_a)^{1.3}$

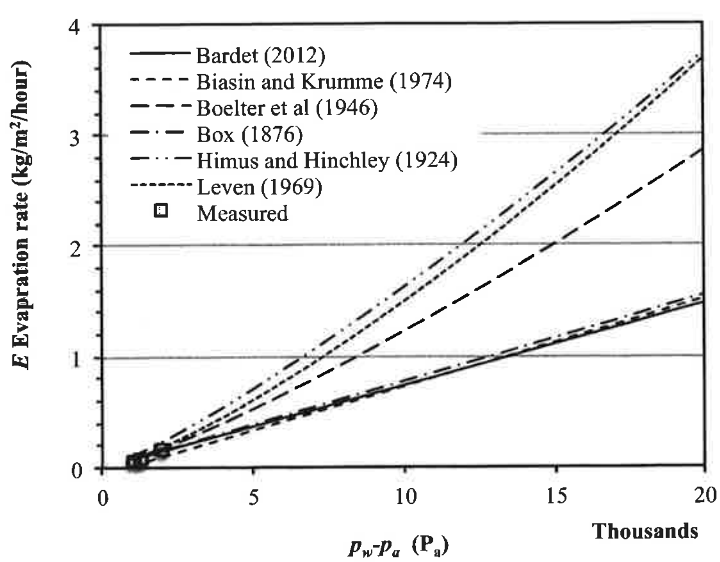

Figure 11. Comparison of empirical correlations for evaporation rates (see Table 3).

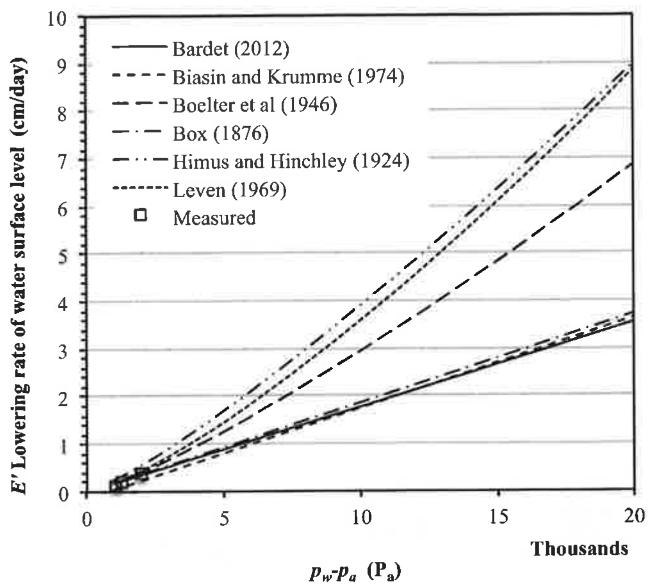

Figure 12. Comparison of empirical correlations for lowering rate of water surface level.

Table 4. Summary of measured data for evaporation rate (after Shah, 2008).

Authors	Pool area (m^2)	Water Temperature (°C)	Air Temperature (°C)	Air Humidity (%)	p_w-p_a (P$_a$)	E Evaporation rate (kg/m^2/hour)
Bohlen (1972)	32	25	27	60	1029	0.052
Boelter et al (1946)	0.073	24	18.7	64	1272	0.082
Tang et al (1993)	1.13	25	20	50	2001	0.168

5 MEASUREMENT OF EVAPORATION RATE IN URINALS

5.1 Examination of a particular very low-flush urinal

Figure 13 shows the very low-flush urinal examined during this study. This particular urinal, which is manufactured by Zurn, is equipped with a sensor-operated valve that delivers 1/8 gallon (one pint) flush. Its specifications can be found in Appendix.

Figure 14 shows a close view of the inlet orifice, the diameter of which was measured to be 1 ¼ inch. , The trap area slightly increases with depth. This orifice is covered by a metal screen (not shown in Figure) that aims at preventing the orifice from getting clogged by debris.

Figure 15 shows the rear view of the urinal shown in Figure 13. The round hole in the middle is the trap outlet orifice, and is connected to the sewage line. The two oblong holes shown in the picture are used to mount the urinal on bathroom walls.

Figure 16 shows the built-in trap of the urinal shown in Figure 13. The depth of the trap seal can be measured as described in AMSE (2008). Table 5 lists various values that were measured for this particular urinal.

Table 5. Main characteristics of Zurn – Model Z5798.205.00.

Description	Value	Unit
Diameter trap orifice	2.86	cm
Depth of trap seal	5.72	cm
Total volume of trap	239	cm^3
Volume of water in trap between crown weir and dip of seal (Figure 6)	137	cm^3

Figure 13. Front view of urinal (Zurn – Model Z5798.205.00) used in present study.

Figure 14. Closeup view of urinal in Figure 13 showing circular inlet orifice of trap.

Figure 15. Rear view of urinal in Figure 13.

Figure 16. Bottom view of urinal in Figure 13 showing urinal trap.

5.2 Experimental Procedure

In the first phase, the original experimental procedure consisted of flushing one pint of water in the urinal (Figure 13) and measuring the variation of water level in the trap over time. This experimental procedure was time consuming and yielded data at a very slow pace. It was also limited to a particular type of urinal and was difficult to generalize to other urinals.

In the second phase, an improved experimental procedure was conceived. It consisted of using ten ceramic cylindrical containers of various diameters for simulating urinal traps (

Table 6). The containers were partially filled with water, and their variations in weight were measured frequently over two weeks. Temperature and relative humidity were also recorded each time the containers were weighted.

5.3 Experimental Results

Figures 17-19 show the experimental results. Figure 17 shows the raw measurements, i.e., the variations in weight of the ten containers filled with water over a period of two weeks. The ten containers are labeled Sample 1 to 10. As expected from the existing theories on evaporation, losses in container weight depend on container diameters. The larger the container area, the larger the weight loss due to evaporation.

Figure 18 shows the variations in weight of evaporated water as a function of elapsed time, which corresponds to the weight losses shown in Figure 17. The evaporated mass at a given time t is the difference between the container weight at time $t > 0$ and $t = 0$. The data points are clustered along four curves depending on the four different container diameters.

Corresponding to Figure 18, Figure 19 shows the increases in weight of evaporated water per unit area as a function of elapsed time. The data points are fitted using a straight line.

Table 6 gives the average slope of the straight line fitted through the data points (Figure 19). This average slope is equal to E and E'. As shown in

Table 6, the corresponding values of coefficients β and β' were calculated based on an average ambient temperature equal to 22°C and a relative humidity equal to 65%.

Table 6. Diameters and areas of samples, average relative humidity and temperature during tests, and averages of measured evaporation rates.

	Diameter (inch)	Diameter (cm)	Area (cm^2)
Sample 1	1.1875	3.02	7.15
Sample 2	1.1875	3.02	7.15
Sample 3	1.1875	3.02	7.15
Sample 4	1.1875	3.02	7.15
Sample 5	2.75	6.99	38.32
Sample 6	2.75	6.99	38.32
Sample 7	3.25	8.26	53.52
Sample 8	3.25	8.26	53.52
Sample 9	4.25	10.80	91.52
Sample 10	4.25	10.80	91.52

$E =$	0.0069	g/cm^2/hour
$E =$	0.0686	kg/m^2/hour
$\beta =$	0.000074	kg/m^2/hour/Pa
$E' =$	0.165	cm/day
$\beta' =$	0.00018	cm/day/Pa
$R_H =$	65%	
$p_w =$	2643	Pa
$T =$	22	°C

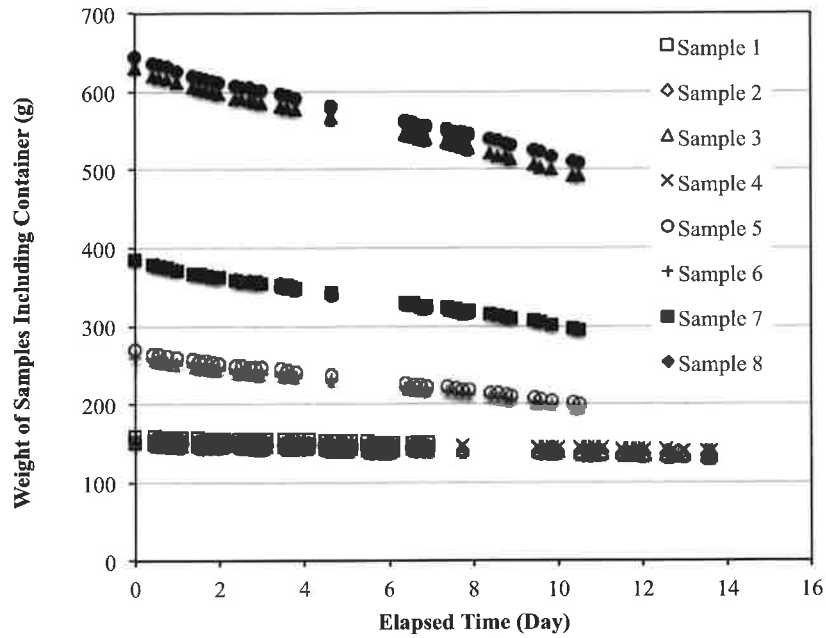

Figure 17. Measured variation of sample weights over two weeks due to water evaporation in ten samples of various diameters.

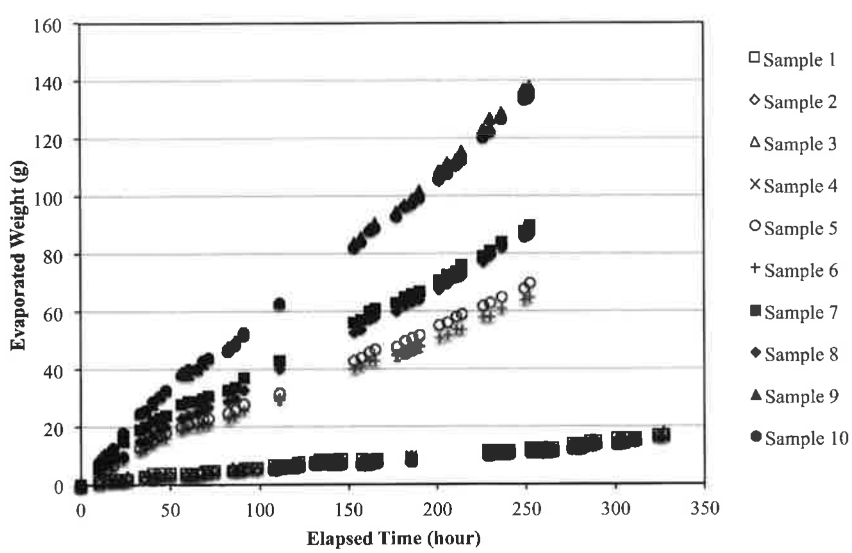

Figure 18. Measured variation of weights of evaporated water for ten different samples.

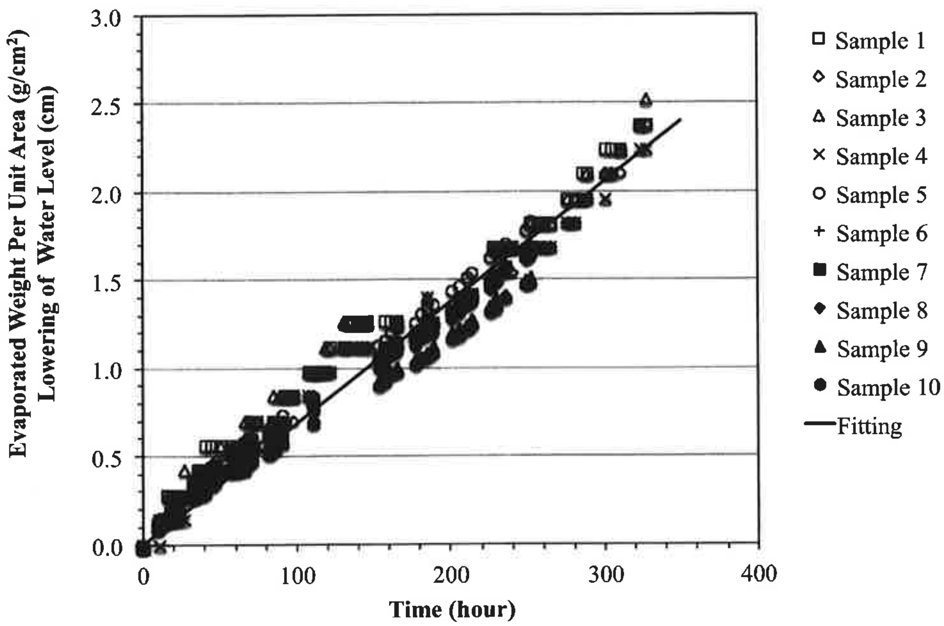

Figure 19. Measured and fitted time-variation of weight of evaporated water per unit area, i.e., lowering of water level, for ten different samples.

6 PHYSICAL MODEL FOR WATER EVAPORATION IN URINAL TRAPS

A physical model can be assembled to estimate the time t_e required for the water seal of a particular urinal trap to evaporate completely based on the trap geometry and the atmospheric conditions surrounding the urinal. The model characterizes the trap geometry using variables D_s and V_e:

- D_s, The depth trap seal (Figure 6)
- V_e, Volume of water in trap between crown weir and dip of seal (Figure 6)

And evaporation and atmospheric conditions using variables/parameters β, T and R_H:

- T, Temperature (water and air temperatures are assumed to be identical)
- R_H, Relative humidity of surrounding air
- β, Constant of evaporation rate determined from laboratory experiments

Assuming that water evaporates evenly across the two free surfaces facing the inlet and outlet, V_e is related to t_e, E and D_s through the following relation:

$$V_e = \frac{E}{\rho_w}\frac{V_e}{D_s}t_e = E'\frac{V_e}{D_s}t_e \qquad (12)$$

Where the ratio V_e/D_s represents the average cross-sectional area of the trap between the crown weir and the dip of seal, and accounts for the presence of two branches in the U-shaped trap. Using Equation 7, t_e can be expressed as follows:

$$t_e = \frac{D_s\rho_w}{E} = \frac{D_s}{E'} = \frac{D_s}{\beta'(1-R_H)e^{6.416+17.3T/(238+T)}} \qquad (13)$$

Equation 13 has three variables and one constant - D_s is the depth of trap seal, R_H is the relative humidity, T is the ambient temperature, and β' is the constant characterizing the physical phenomenon of water evaporation. It is useful to remark that t_e depends on the ratio $D_s/(1-R_H)$, which is hereafter referred to as the effective depth of trap seal. The larger the relative humidity, the larger the effective depth of trap seal. Evaporation effects become negligible when the relative humidity gets closer to 100%. Table 7 summarizes the physical units, values, and range for the values of these variables/constants.

Table 7. Values of constants and ranges of values for variables used in present study.

Constant	Description	Value	Unit
β	Constant of evaporation (mass)	0.0000741	$kg/m^2/hour/Pa$
β'	Constant of evaporation (level)	0.000178	cm/day/Pa
ρ_w	Unit mass of water	1	g/cm^3

Variable	Description	Range of Values	Unit
D_s	Depth of trap seal	2.54 - 10.16	cm
T	Ambient temperature	10 - 50	°C
R_H	Relative humidity	10% - 90%	-
$D_s/(1-R_H)$	Ratio for determing t_e	2.82 - 101.60	cm

Based on Equation13 and Table 7, Figure 20 shows the computed effects of ambient temperature T on the failure time t_e for four different depths of trap seal, i.e., $D_s = 1$, 1.5, 2 and 4 inch. In this graph, the relative humidity R_H is constant and equal to 50%. As shown in Figure 20, seals with shallow depths of trap seal may fail after only a few days when temperature exceeds 40°C.

Figure 21 illustrates how the time to trap seal failure t_e varies with ambient temperature for four different values of effective depth of trap seal $D_s/(1-R_H)$. Compared to Figure 20, Figure 21 applies to many more sizes of urinal traps and values of relative humidity. It implies that an increase in relative humidity R_H slows down evaporation and increases the time necessary for breakdown of trap seals.

Figure 22 shows the effects of ambient temperature and relative humidity on the failure of a trap seal that has a depth of trap seal $D_s = 5.72$ cm (2 ¼ inch). This graph applies to the particular urinal examined in Figures 13-16. The trap seal will fail after about five days for high ambient temperatures and low relative humidity.

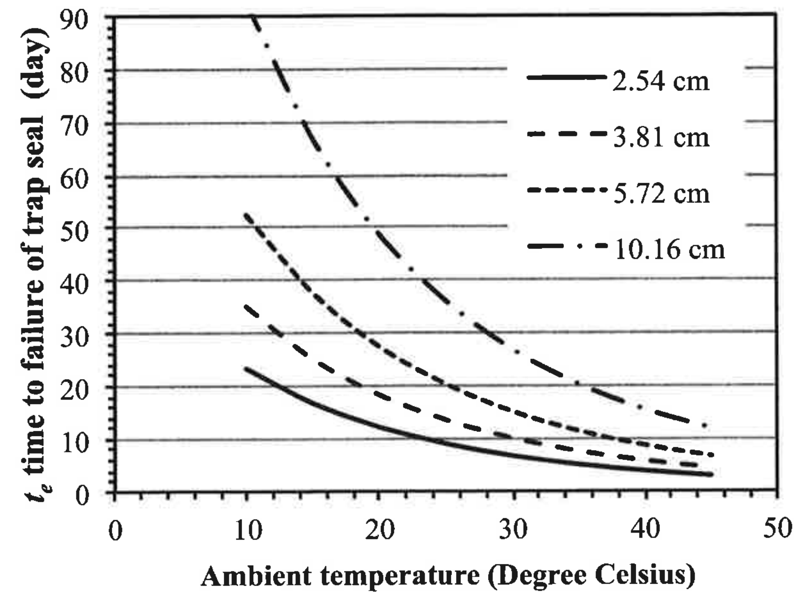

Figure 20. Effect of ambient temperature on time t_e corresponding to failure of trap seal for four different depths of trap seal (1, 1.5, 2, 4 inch) at constant relative humidity R_H= 50%.

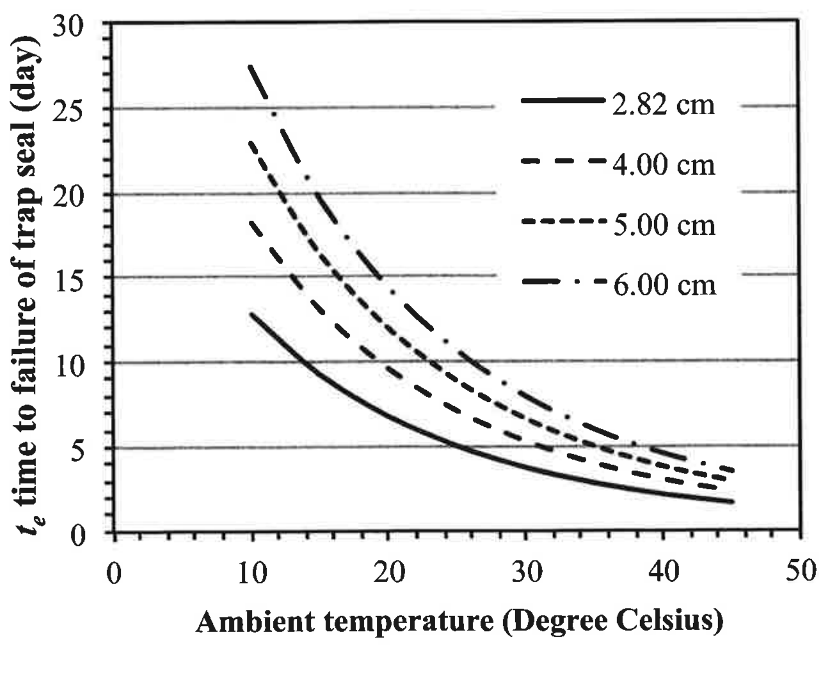

Figure 21. Effect of ambient temperature on time t_e corresponding to trap seal failure for four values of initial effective depth of trap seal $D_s/(1-R_H)$.

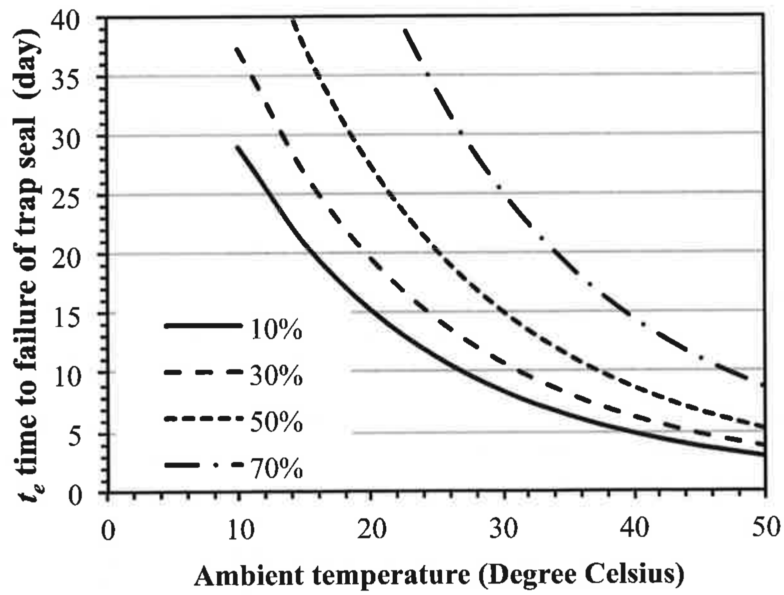

Figure 22. Effect of ambient temperature on time t_e corresponding to the failure of a trap seal having a initial depth of trap seal D_s=5. 72 cm (2 ¼ inch) for 10%, 30%, 50%, and 70% relative humidity.

7 DISCUSSION

7.1 Assumptions

Based on a literature review on water evaporation, the present study proposes a physical model for understanding the effects of evaporation on water-supplied urinal traps. The physical model is useful to determine the time it takes for trap seals of various sizes to fail due to water evaporation under a practical range of ambient temperatures and relative humidity. The physical model is however based on assumptions that define its domain of applicability.

(1) The air circulation around urinals is assumed to be small enough not to influence the rate of evaporation. This assumption may not apply for well-vented bathrooms that harbors significant air drafts. In well-vented cases, the present physical model underestimates the actual rate of evaporation, which implies that trap seals could fail sooner than presently predicted.

(2) The temperature is assumed to be identical in water, urinal ceramic body, and surrounding atmosphere. This assumption is justified for extended periods of time that lead to stable thermal equilibriums, but may not apply to shorter periods of time that display transient differences in water, ceramic, and air temperatures.

(3) In defining the minimum size for water-supplied urinals by constrained optimization, the trap geometry of water-supplied urinals is assumed made of a half tore and two

cylinders. More sophisticated trap geometries may be conceived to stretch a little the one-pint limit.

(4) The time to failure of a trap seal is determined using a physical model that assumes constant ambient temperature and relative humidity. The same model can be used to perform more detailed calculations that account for variations of ambient temperature and relative humidity.

7.2 Implications of study for very low-flush urinals

The findings of this study apply to all types of water-supplied urinals, including one-gallon urinals to very low-flush urinals (1/8 gallon). Its findings are especially useful to understand the effects of water evaporation on seals of very low-flush urinals.

Very low-flush urinals are designed with smaller traps than one-gallon water-supplied urinals. Trap sizes and amount of water release can be downscaled provided that enough water is flushed to replace the urine residing in the traps. In addition, trap diameters and depths of trap seals must comply with plumbing codes. IPC (2012) stipulates that trap diameters cannot be smaller than 1 ¼ inch and that depths of trap seal cannot be smaller than 2 inch. Constrained by plumbing codes, water-supplied urinals have reached a lower bound; they have met a breakpoint beyond which they may get clogged by debris and/or lose trap seals. The reduction in depths of trap seal has adverse consequences related to the loss of trap seals due to evaporation. The trap seals of very low-flush urinals are likely to fail more frequently than traditional urinals because of shallow depths of trap seals.

Manufacturers of very low flow urinals, e.g., American Standards, have recognized these shortcomings and have equipped urinal flush valves with a timer that releases periodically water and replenishes the trap water that may have evaporated. This approach addresses the problem of trap seal breakdown due to evaporation but comes with compromises. Consumers should be aware that flush valves for very-low flush urinals are sophisticated and more expensive to purchase and maintain than regular valves.

8 CONCLUSION

In view to the increasing importance of water conservation in recent years, manufacturers have responded by introducing very low-flush urinals that derive from conventional water-supplied urinals but release smaller amount of water, i.e., 1/8 gallon (pint) instead of one gallon.

The downscaling of water-supplied urinals with the intent of promoting water conservation has encountered a point of diminishing return in the vicinity of one-pint flush. This study challenges the notion that very low-flush urinals are enhanced one-gallon urinals, based on a reliable and economical technology. It shows that the reduction in urinal trap sizes render urinals more vulnerable to a breakdown of water seals due to water evaporation.

The study examined sections of the International Plumbing Code that are relevant to urinals, and outlined design constraints such minimum requirements for trap diameter and depth of trap seal. It also surveyed very low flow urinals and flush valves that are available from seven manufacturers. The study reviewed the theories that have been proposed for water evaporation in the literature, and developed a novel correlation for the purpose of investigating evaporation in urinals. Based on an in-depth examination of a particular very low-flush urinal, the study developed an experimental procedure to measure water evaporation in urinal traps. The measured rates of water evaporation were found to agree with those published in the literature. The study interpreted the experimental results using a physical model for water evaporation in urinal traps, which has three variables: depth of trap seal, relative humidity and ambient temperature. This model is useful to determine the circumstances for which urinal trap seals breakdown due to evaporation.

The findings of this study are applicable to all types of water-supplied urinals, ranging from one-gallon urinals to very low-flush urinals (1/8 gallon). From a practical point of view, the downscaling of urinal traps has reached a point of diminishing return due to plumbing code constraints. They have met a breakpoint beyond which traps can get clogged by debris and trap seals may fail due to evaporation. The reduction in depth of trap seal has adverse consequences from the point of view of evaporation. In other words, the trap seals of very low-flush urinals are likely to fail more frequently than traditional urinals because of shallow depths of trap seals.

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10 APPENDIX

Z5798.205.00

"The Pint®" 1/8 gpf, EcoVantage®, Ultra Low Consumption, Battery Powered Urinal System

TAG ____________

Z5798.205.00 Series

Z5798.205.00 Series

- Zurn One ultra low consumption urinal system designed for optimal performance between Zurn fixture and Zurn flush valve to save water while exceeding industry performance standards
- 1/8 gallons per flush [0.5 Liters per flush]
- Vitreous china
- High efficiency washout flushing action
- Over 88% water savings over standard 1.0 gpf [4.0 Lpf] system
- Pressure compensating internal flow regulator
- Manual override flush activator button
- Oversized footprint to make retrofit easy
- 3/4" top spud
- 2" I.P.S. outlet flange and rubber gasket with integral trap
- 14" extended rim for handicap compliance when installed at proper height
- Vandal resistant outlet strainer included
- Shipping Weight: 65 lbs.

ENGINEERING SPECIFICATION:

☐ **Z5798.205.00 EcoVantage® Battery Powered High Efficiency Urinal (HEU)** - System comes complete with sensor operated, battery powered, exposed ZEG6003EV high efficiency flushometer valve and vitreous china urinal. The system is designed to perform to industry standards with as little as 1/8th gallon per flush. Valve is operated by an infrared convergence-type proximity sensor with smart technology, powered by 4 "AA" batteries, furnished with vandal resistant chrome plated metal housing, chloramine resistant internal seals, and reversible cover. Valve features a manual override flush activator button, an internal flow regulator to maintain constant flow rates independent of line pressures and an in-line filter to protect the valve from debris within the water. Complete with high pressure vacuum breaker, one piece hex coupling nut, adjustable tailpiece, spud coupling and flange for top spud connection. Control stop has internal siphon-guard protection, vandal resistant stop cap, sweat solder kit, and a cast wall flange with set screw. Vitreous china urinal is supplied with retrofit bracket, 3/4" top spud, 2" outlet connection, vandal resistant outlet strainer and universal retrofit hanger bracket.

GreenSpec® LISTED

These dimensions and specifications are subject to change without notice.

Fixture dimensions meet ANSI/ASME standards A112.19.2 and CAN/CSA B45 requirements.

Meets the American Disabilities Guidelines and ANSI A117.1 requirements when urinal is installed 17" [432 mm] from finished floor.

This space is for Architectural/engineering Approval

ZURN INDUSTRIES, LLC. ♦ COMMERCIAL BRASS OPERATION ♦ 5900 ELWIN BUCHANAN DRIVE ♦ SANFORD NC 27330
Phone: 1-800-997-3876 ♦ Fax: 919-775-3541 ♦ World Wide Web: www.zurn.com
In Canada: ZURN INDUSTRIES LIMITED ♦ 3544 Nashua Drive ♦ Mississauga, Ontario L4V1L2 ♦ Phone: 905-405-8272 Fax: 905-405-1292

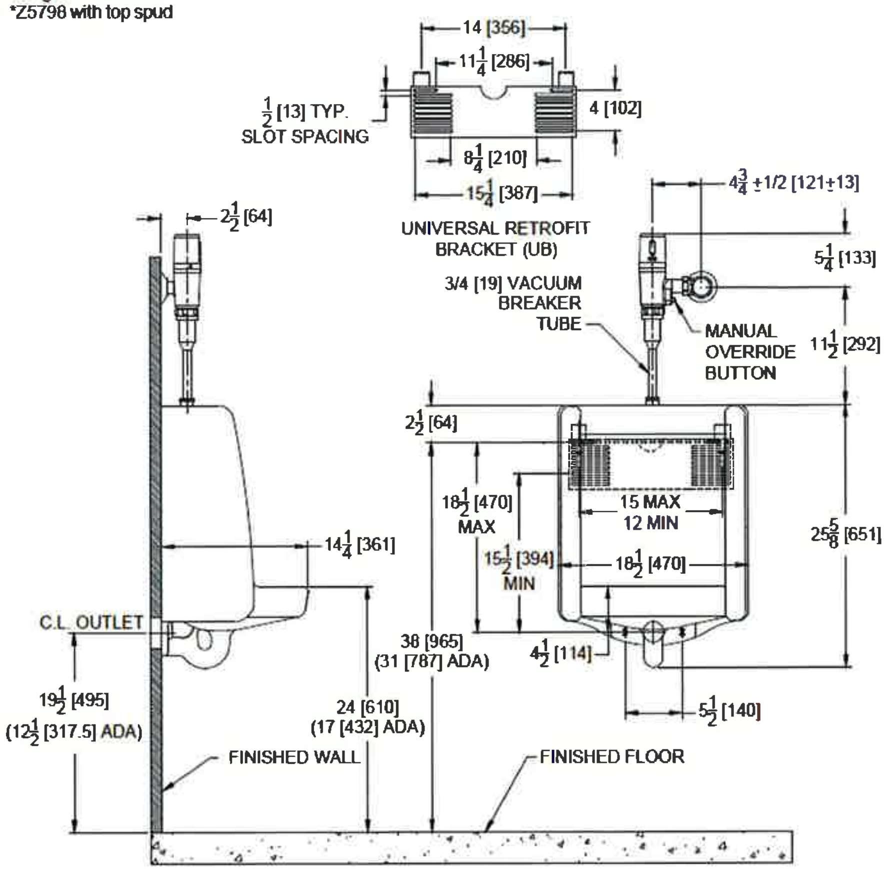
REV. B DWG. NO. 83741 DATE: 8/11/09 C.N. NO. 110050 PRODUCT NO. Z5798.205.00

Z5798.205.00

"The Pint®" 1/8 gpf, EcoVantage®, Ultra Low Consumption, Battery Powered Urinal System Rough-In

TAG ______________

Rough-in dimensions for Z5798.205.00 Series
*Z5798 with top spud



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