Design And Operation Of A Residential Rainwater System For Potable Water And Fire Protection Perspectives Of Designer, Builder And Owner

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ABSTRACT

This paper discusses a rainwater system designed to meet total annual potable and fire protection water use in a large residence during a 10-month drought. The rooftop catchment and underground storage system was developed and built in conjunction with a major residential remodel. It is integrated into a sustainable residential architectural design incorporating photovoltaic power, solar water heating and the catchment itself. The first section of this paper describes the project from the perspective of the design engineer, the second, from the viewpoint of the general contractor, and the third outlines the owner's experience during the first two years of operation and maintenance.

OVERALL SYSTEM DESCRIPTION

Rainwater is collected from a 6,000 square foot standing seam coated metal roof through a network of interconnected coated metal gutters and downspouts. Storage is in a 40,000 gallon underground cistern comprised of two 20,000 gallon fiberglass tanks connected in tandem. The tanks meet NSF 61 standards for potable water. The collected water is filtered in a filter/roof washer vault before entering the cistern.

The stored water is delivered to independent branches at the building by a variable speed, pressure-controlled pump mounted in the outlet tank. The potable water branch passes through cartridge filters and an ultraviolet disinfection module before entering the hot and cold domestic water system. A UV monitor is connected to the system to provide system shutdown in the event of inadequate disinfection/inactivation. To prevent stagnation during lengthy storage a portion of the stored rainwater is continuously re-circulated through the filter/UV disinfection system and returned to the tanks.

The fire protection branch supplies the fire sprinkler network separately and is not further filtered. A street level, gravity-fed, fire hydrant fed directly from the cistern provides a supply accessible to the local fire department. Water quantity stored is monitored so as to reserve a minimum of 5,000 gallons to meet local fire protection supply requirements.

In order to reduce contamination of the potable water by leaching from piping (rainwater is slightly acidic) exposed piping in the mechanical room is constructed of stainless steel, and cold water interior piping is of PEX. The copper tubing of the solar water heating collectors is in contact only with the hot water supply. (Landscape irrigation water is provided by a nearby well of marginal quality.)

The large photovoltaic array, although grid connected, also has battery backup. The water system and other essential circuits can be powered by the PV system independently of grid power.

SYSTEM DESIGN PARAMETERS

a) Provide sufficient water to meet fire protection and potable water needs during a drought year. (10 months maximum without significant rainfall)-
b) Be consistent with the architectural concept for the residence-
c) Include no structures aboveground blocking the ocean view of Monterey Bay-
d) Assume 24 inches of low ph (acidic) wintertime rainfall during an average year-
e) Domestic water flow rate-10 GPM for potable water
f) Fire protection flow rate-26 GPM (two sprinkler heads operating simultaneously)-
g) Underground water storage structure to support the weight of light truck (4000lb)-
h) Domestic water to meet California Health Service Drinking Water standards-
i) System components to meet NSF standards for contact with potable water-
j) Low maintenance-
k) Monitor cistern level to maintain a minimum, of 5,000 gallons for the exterior street-level fire hydrant and residential fire sprinkler system-
l) Storage tanks to be stable (non-floating) during severe rainfall-
m) Provide for continued water system operation during electric grid outage-
n) Assume that household can reduce potable water use to <80 gallons per day if quantity stored drops below 15,000 gallons-
o) Collection system should be able to handle brief heavy rain >2” pr hour).

DESIGN ENGINEER’S COMMENTS

An aspect of the system requiring special attention was the need to accommodate a maximum flow rate for the potable water supply (10 GPM) which is quite different from that specified for the fire sprinkler system (26 GPM) by the local Fire Marshal. A variable speed pump control was chosen which can meet the maximum flow rate demand for the sprinklers and also operate at lower speed during normal conditions with domestic demand only.

Rapid flow rate changes, such as closing of valves or increasing flow abruptly, can loosen collected particles from cartridge filters or damage seals during transient pressure spikes (i.e.. water hammer). The pump control in addition to reducing speed and thus flow upon low demand also slowly ramps up pump speed upon demand. This rate increase is low enough to avoid water hammer. On the other hand, in order to avoid pressure spikes upon sudden shutdown or drop in water flow, a 4-gallon bladder-type expansion tank was installed to briefly maintain flow allowing slower pressure drop. This expansion tank also serves to reduce pump start/stop cycling during very low flows - such as water re-circulated from the tanks through the filter/UV module.

Future designs should plan for safe access to wash roofing and clean gutters. The present roof is extremely slippery and cannot be easily reached from the eaves.

A more troublesome issue, which was not solved satisfactorily, is the need to flush to waste a large amount of the initial rainwater flow after a dry period - so as to adequately clean the roof catchment before water is directed to storage.

During the design phase it was assumed that directing the first 0.05” of rainfall (≈200 gallons for the Chengson system) to waste after a period of dry weather would clean the roof sufficiently well. In the Monterey Bay environment this was found to be much too small a quantity.

A roof washer should flush initial flow to waste, then direct clean flow to storage. An automatic washer should remain shut during continued rainfall, but re-set itself in a reasonable period after rainfall stops - to be ready to clean the roof again during the next rain. It was realized early on that a limitation of most types would be that the self-draining feature might be susceptible to clogging, Since a roof washer (if there is no controlled dump feature) must necessarily drain slowly in order to remain closed when collecting rain a constricted drain aperture can easily be plugged by dust and pollen.

A number of commercially available roof washers were considered. The model chosen was a smart valve rainwater diverter vertical valve from the manufacturer FloTrue International. It was modified for easy insertion and removal from the roof washer vault waste. It can be adjusted for the original design wash quantity as planned. However, large amounts of dust and pollen accumulate quickly between rainfall events overwhelming the filters and plugging the roof washer drain aperture. The Owner has found it best to not collect rainwater in the cistern until after a substantial heavy rain has cleaned the roof.

A future system can be designed that accomplishes substantial roof washing prior to rainwater storage. An automatic dump system linked to a rain gauge can be calibrated for local conditions. Another option (possibly too expensive for small systems, would be to utilize a turbidity meter to monitor and control the roof washer valve -- collecting only when the flow is sufficiently clear.

The level monitor and control circuits can be simplified and integrated with commercially available units.

Poured-in-place concrete cisterns were designed - both cylindrical and rectangular. Seismic and cistern roof load considerations dominated. Although the price estimates were comparable, fiberglass tanks were selected to expedite the construction schedule.

An essential feature of this kind of system with interacting components is installation of sufficient sensors and gauges to clearly display operation performance. A monitor/shutdown control for the UV disinfection system is especially important.

BUILDER’S VIEWS-

This project presented some aspects unusual for residential construction in that it was designed to be an alternative home - largely independent of conventional utilities. This led to considerable complexity of valves and controls. Combined with the especially high water quality system requested by the Owners, this made for some demanding tasks. As with any unfamiliar construction there was a learning curve requiring extra supervision to coordinate the complexities of the rainwater plumbing system, the photovoltaic power supply, and solar water heating -- together with managing the construction of an architecturally unique and attractive building.

A builder usually takes it for granted that construction components and materials are already approved for residential use. For the Chengson residence, however, it was necessary to insure that all materials which can come in contact with the drinking water system were NSF approved for that use. Caulking and roof coating in some areas could not be the usual roofing products. Although not inherently much more expensive materials were needed - extra supervision was required to insure that tradesman did not automatically use conventional products.

Since the Engineer and Owner were concerned about the possibility of very high quality rainwater being somewhat acidic, to prevent leaching they specified that the potable water could only be in contact with stainless steel or PEX piping

The internal PEX water distribution system presented few problems other than the necessity for special fittings at the ends -- which required a tool provided by the manufacturer.

On the other hand, the stainless steel plumbing, mainly in the Filter Room, proved quite difficult to install leak free. The engineer had specified threaded stainless steel pipe and fittings. It took a surprising amount of effort for the plumbing contractor and engineer to find a combination of thread-sealing compound and installation strategy which would prevent weeping at the pipe joints. The conclusion was that it would have been cheaper to have used either SS tubing with compression fittings or welded-socket fittings as are used in milk processing plants.

A final difficulty was the usual one of developing adequate as-built plans and operation instruction manuals. The owner, Dave Chengson, was very involved with the technical details of the alternative energy and water supply systems so this was not as much of a problem as it could be with a less engineering-oriented owner.

As other alternative utility/energy homes are built -- the systems, and their construction and operation, will doubtless become much more routine -- and, it is to be fervently hoped, simplified!

OWNER'S EXPERIENCE WITH SYSTEM OPERATION AND MAINTENANCE

Some lessons learned:

Maintaining a clean roof washer vault has been a challenge. Since the roof washer vault is below ground level, it has to be cleaned almost every rainy day since bugs and earthworms can enter the roof washer vault. A gasket material to bug proof the roof washer door is being sought. Since the vault must be entered frequently a redesign of the lid hinge mechanism is necessary.

A contributing factor to the high maintenance requirements of the roof washer is the large amount of pollen deposited on the roof and then is washed down into the roof washer. Pollen mixed with water can easily clog the FloTrue rainwater diverter ball valve mechanism and overwhelm the mechanical filters.

It was found through trial and error that manually operating the collection valve when the roof is washed yields cleaner water and is less burden on the mechanical filters. Collecting water only during very heavy rainstorms rather than automatically with the roof washer valves yields much cleaner water.

The roof washer has overflow mechanisms to spill excessive water into alternate chambers. This overflow mechanism has been a source of bugs to contaminate the water. Somehow a bird has entered through these overflow mechanism holes and defecated in the roof washer. The fix was to insert styrofoam plugs into the holes.

Cleaning the roof gutters in some areas of the residence is a difficult and dangerous proposition. Moreover the unpainted metal roof (Galvalume Plus) has a sacrificial anode coating to prevent corrosion. Corrosion experts recommend not walking on the roof in order to maximize the metal roof coating life. The tradeoff is how often to clean the gutters versus the potential danger and the reduction of the lifetime of the roof surface. Recently it has been decided not to clean the gutters and instead rely on major rainfall to clean the gutters and roof.

The pump motor turns on and off frequently (once every few minutes) while the rainwater is being recirculated. It is difficult to reliably throttle the recirculation flow rate. This may be improved by adjusting the bladder pressure in the expansion tank or installing a larger capacity expansion tank. The new bladder pressure adjustment is 70% of the nominal water pressure. For a 40psi nominal water pressure, the bladder pressure should be 28psi.

The ultraviolet light monitor attracts dirt -- apparently from static charge. The glass port to the UV tube must be cleaned periodically with a Q-tip.

An electrical voltage surge occurred resulting in a small fire between the wall receptacle GFI and the male GFI plug for the ultraviolet filter. This has been solved by installing a surge protector for the power for the ultraviolet filter.

Neighbors have complained about the brightness and reflectivity of the metal roof. This is a consideration for roof design orientation and geometry - for large solar arrays as well.

The electrical power dissipation for the pump and the UV light is approximately 6kwhr/day for a 4gallon per minute flow. The electrical power dissipation breakdown is 4.3kwhr/day for the pump, and 1.7kwhr per day for the UV light.

There are several small nearly flat areas on the roof that were inadvertently roofed with conventional tar and gravel. Since the tar can readily leach harmful hydrocarbons into the drinking water supply all such areas were coated with a silicone-based paint.

Discussion of the inconveniences and errors listed above may help other potential rainwater system users and installers avoid some pitfalls. On the whole, however, the satisfaction and security obtained by an independent supply and use of the sustainable resource, rain, for our home far outweighs the difficulties.

SELECTED COMPONENT LIST

Roofing: Standing seam, coated "Galvalume Plus"

Tanks: Xerxes-DARCO 10D-20K-FRP)- Structural-UL1316/Potable Water NSF 61

Tank Connections: DARCO SS Bellows

Tank Connections: 4" FERCO Flexible Couplings - Seismic and settling protection
Pump: Grundfos SQE 15C-160NE Redi-flow- 1-1/2 HP
Pump Shroud (Required for open tank mounting): SQ/SQE Flow Sleeve
Variable Speed Pump Control: Grundfos "Smart Flo"
Vault Level Float Switches: Fluid Products SPST- CSL 3001 SS
Cistern Inlet Filters (Cartridge only): US Filter Model CP5-20
Roof Washer: FloTrue Rainwater Diverter valve 4" Vertical
Level Sensor Transducer: WIKA LS-10 - 0-150" W.C.
Level Monitor: Red Lion Analog Panel Meter - #PAXP000
Level Alarm Relay: Red Lion Dual Setpoint - #PAXCDS10
UV Purifier: Atlantic Sanitron 50SB (20 GPM)
UV Monitor: Atlantic Guardian
Polishing Filters: US Filter Big Blue Filter Housing
Filter Cartridges: US Filter P series
Expansion Tank: Amtrol Therm-X-Trol Model ST-12

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Rainwater Cistern (two 20,000 gallon cylindrical tanks) being backfilled with pea gravel to prevent empty tanks from floating during ground water saturation

Roofwasher/filter vault. From top left to bottom right, flotrue rainwater diverter valves (2), overflow, leave basket, inlet filters (3), access ladder

Filtration/pump control room. From left to right, inlet strainer and water flow meter, expansion tank (above), pressure transducer and pump control unit, cartridge filter, ultraviolet disinfection lamp with ultraviolet light monitor, 2nd cartridge filter, connection to domestic water distribution. Stainless steel square control box. Recirculation connection back to underground cistern.