Rainwater harvesting systems

are they a green solution to water shortages?

Concern over the sustainability of drinking water supplies for new developments has increased over the last decade. One of the 'green' solutions favoured by architects and designers is to specify rainwater harvesting systems to collect rainwater, store it and then use it for garden watering and toilet flushing, thereby decreasing the demand for potable water from the mains supply. Judith Thornton wonders if this is really the greenest solution ...

Rainwater harvesting (RWH) systems obviously require considerable infrastructure at the household level (a tank, pump, filters, controller and a modified plumbing system to prevent mains contamination). This infrastructure will have an environmental cost, and if we are interested in the environment as a whole, rather than simply water scarcity, these environmental costs need to be carefully assessed.

Studies of the environmental impacts of RWH systems in Switzerland[1] and Australia[2] have indicated that the environmental impacts of domestic scale systems are higher than that of a mains water supply, and have emphasised the importance of water efficient appliances as a way for reducing environmental impacts rather than RWH systems. Some suppliers of systems agree that these systems are not suited to small scale domestic installations, and are now focussing on larger scale systems precisely because of these infrastructure requirements and concern over their environmental impacts. The argument is logical; a larger scale system, such as for a school or an office building, still only requires one pump and one tank (albeit a considerably larger one), but since it collects from a larger roof area (e.g. 3000m^2, as opposed to 100m^2 for a domestic system), it is much more likely to result in water savings that justify the environmental costs of both the initial installation, and the subsequent energy in use. Or is it?

In order to shed some more light on this situation, I have undertaken some life cycle assessment (LCA) on commercial scale rainwater harvesting systems. The boxout (far right, next page) introduces the LCA method and considers its merits and drawbacks compared to other environmental assessment techniques.

LCA of a typical system

The system chosen for study was a generic one, based fairly closely on a real installation. Details of the system are given in Table 1 and Figures 1 and 2. The building chosen was a school with 600 pupils and 30 staff, with a total water use for toilet flushing of 10m^3/day. The roof area was 3100m^2, and the annual rainfall was 1 metre. Attenuation of peak storm water flows was required, which was achieved with a 34m^3 attenuation tank with an outlet throttled to a maximum outflow of 14 litres/second.

Element	Comments
Building details	School, 600 pupils, 30 staff. Water use for toilet flushing 10m^3/day occupied. Building in use 5 days a week, 40 weeks/year. Roof area collected from 3100m^2. Outside water use discounted as was less than 1% of total.
Rainfall data and harvesting assumptions	1000mm annually. Filter coefficient 0.8. Roof coefficient 0.8. (industry standard data)
Transport	Transport of components to site was included, with an assumption of 100km for all components except concrete (50km). Return journey (empty vehicle) was included.
Rainwater harvesting system details	
Tank	GRP, 1500kg, 27m^3, (Forbes), situated underground on a 6m by 3m reinforced concrete slab of 230mm depth. Backfilled with concrete.
Filters	2 underground vortex separators (EcoVat first flush vortex filter, ECVLF150, ECVLF300).
Pump	Submersible pump (Multigo). Control system (EcoVat)
Underground drainage	Pipes sized by Rational Method. 100mm, 150mm, 225mm, 300mm all clay. 375mm diameter in concrete.
Roof water goods	Gutters, downpipes uPVC (polypipe).
Storm water attenuation system	34m^3 stormcell (extruded polypropylene with 95% void ratio) from Hydro International, installed according to manufacturers instructions in excavated hole lined and covered with impermeable membrane. Including low flow pipe and vent pipe. Hydrobrake flow controller (stainless steel) in concrete chamber.
Mains water supply	Ecoinvent data (Europe) was used with additional energy consumption to mimic UK industry standard.

Table 1. Key assumptions, data sources and description of the system and its installation.

Figure 1. Elements considered in the LCA of the production and installation of a RWH system. Transport of all components was included but is omitted from the diagram for clarity.

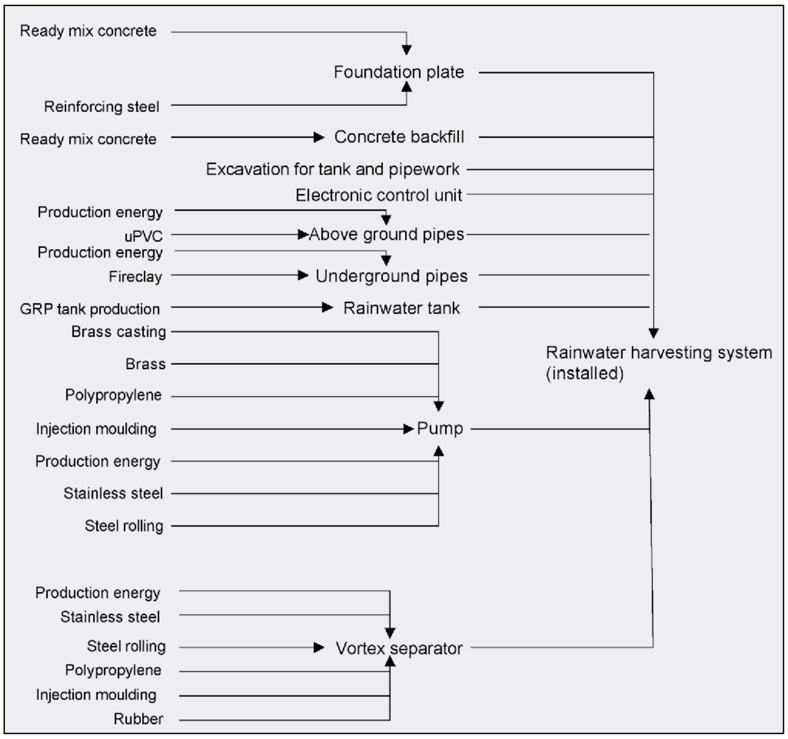


Figure 2. System boundaries in the study of the use of the RWH system for 1 year.

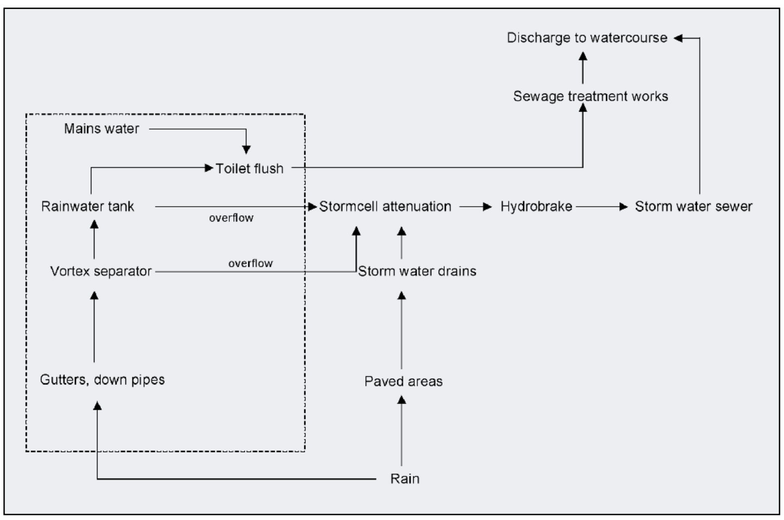
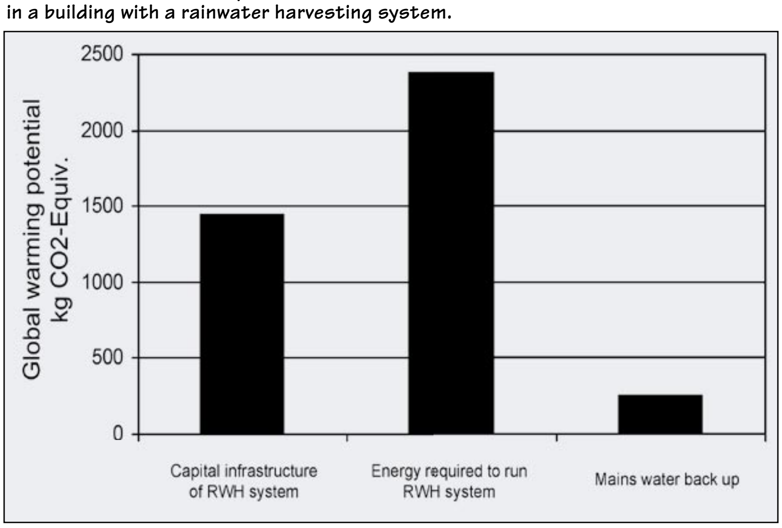


Figure 3. Global warming potential of water used for toilet flushing over one year in a building with a rainwater harvesting system.



Measuring environmental impact

Populist discussion on environmental impacts in recent years has tended to be dominated by ecological and carbon footprints. These are extremely useful as an educational tool, as data on a range of impacts is aggregated into a single unit of measurement and so will convey a simple message. However, expressing every type of impact in terms of kg of CO_2 emissions or hectares of bio-productive area results in controversial assumptions and simplifications, so the use of a footprint style methodology is inadvisable when conveying information to a professional or academic audience[3]. LCA data is usually presented in a less aggregated manner, but its complexity is often overwhelming unless a very specific situation is being addressed. On the plus side, LCA is internationally standardised (ISO 14040-14043).

The first stage of an LCA is to define the goal of the study and its scope. This includes defining the boundaries of the study, and the way in which data will be presented. The second stage is known as inventory analysis, and consists of modelling the system and calculating total inputs and outputs of raw materials and waste products in the system being studied. Impact assessment is the third stage. The inventory analysis is translated into impacts on the environment, such as climate change and ozone layer depletion, in a process known as characterisation, which are expressed in units relevant to the impact (e.g. kg phosphate equivalent for eutrophication potential, kg CO_2 equivalent for global warming potential). In some instances the results are then normalised and weighted (simplifying results for less technically minded audiences and producing something similar to an ecological footprint). The final stage of an LCA is the interpretation. This can include sensitivity analysis, independent review and reflection on data quality and uncertainty.

The input and output flows from the elements of the system, shown in Figures 1 and 2, were grouped into the major elements; production of the RWH system, energy to run the RWH system, and the impact of the mains water used.

LCA uses a system of 'impact categories,' that is types of environmental damage that we may be concerned with. For the sake of simplicity, this article just discusses the category of global warming potential[4] since this was the main focus of interest in the study, although we could equally well be concerned with other impacts. Figure 3 shows the impact of water used for toilet flushing over the course of a year in the generic building. As you can see, the major impact is the electricity used to run the RWH system, although the initial infrastructure installed (tank, pump, controller etc) contributes 36% of the total, despite being divided over a 30 year life span of the system.

The fact that the mains water back up is such a small part of the total impact in running the system should give you some indication of how badly a building with rainwater harvesting will compare to one without. This comparison is illustrated in Figure 4. Whilst only the data for global warming potential are presented here, data for other impact categories such as ozone depletion, eutrophication potential and eco-toxicity show similar trends; flushing toilets with rainwater is less environmentally friendly than using mains water[5].

Improving current practice

Despite the high environmental impact of a rainwater harvesting system relative to mains water, there will still be instances in which people choose to install them, especially when they are encouraged in assessment methodologies, such as BREEAM and the Code for Sustainable Homes. It is therefore up to the rainwater harvesting industry to take on board the major environmental impacts of their systems and reduce them where possible. Since the energy used in producing the tank is going to be a major part of the impact of the system, choice of tank material is critical. Table 2 shows the primary energy requirements for the production of the material that goes into a 5m^3 rainwater tank. As you can see, fibreglass has a far higher energy requirement in its manufacture than the alternative materials, yet it remains the most commonly specified type of rainwater tank in the UK. To make matters worse, the standard installation detail requires fibreglass tanks to be installed on a reinforced concrete pad and then backfilled with concrete. This requires more concrete than it would have done to build a concrete tank of a similar volume in the first place. Substituting a polyethylene tank, and investigating whether spoil from the site can be used instead of concrete backfill could reduce the impact of installing a RWH system by one third.

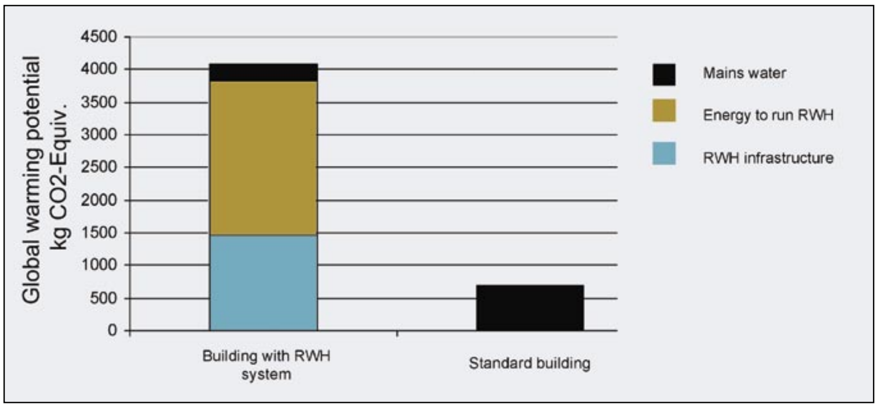


Figure 4. Global warming potential of the water used for toilet flushing over the course of one year in buildings with and without a RWH system.

Given that such a major part of the life cycle impact of a RWH system is in the capital infrastructure, the number of years the system lasts for will have a profound effect on the environmental impact. In practice, this will be related to eco-enthusiasm as well as technical/material issues. In the model described above, the tank was assumed to last 30 years, the filters 15 and the pump 10. Since the tank comprised 81% of the primary energy demand required to build the infrastructure (data not shown), we shouldn't be too concerned about replacing other elements, if a more efficient pump becomes available, or perhaps changing the display panel if it will rekindle interest in maintaining the system.

The energy cost for abstracting, purifying and delivering 1m^3 of mains water is estimated as 0.56kWh[6], although this varies between around 0.3kWh and 0.6kWh between regions, the difference being attributable largely to the amount of pumping required. Similarly, the energy use of a RWH system will vary massively according to pumping efficiency and the flow rates which the pump is operating at. Measured energy consumption data from a real rainwater installation showed a variation of between 0.23kWh/m^3 rainwater and 5.2kWh/m^3 depending on the flow rate required (an optimistic 0.4kWh/m^3 was used in the current study). Designing a system that pumps high flow rates for short periods of time (e.g. pumping to a header cistern rather than to point of use) would therefore massively improve pumping efficiency and so decrease the energy use of a RWH system. Even in a scenario where we increase the energy cost of mains water 5 fold (a crude way of mimicking an extreme water shortage scenario where mains water is supplied from a desalinated source), it is highly unlikely that RWH will become environmentally favourable.

Fitting your building into the hydrological cycle

Whilst currently installed RWH systems are environmentally disastrous, there may be scope for a more integrated approach with storm water drainage. Concerns about flooding reflected in Planning Policy Statement 25 (TAN 15 in Wales) dictate that new developments are having to limit their maximum rate of storm water run off, often to a level similar to that before the development took place. The use of SUDS has been slow to take off in England and Wales, consequently flood attenuation on new developments often consists of attenuation tanks with flow regulators on the outlets. RWH system installers have conventionally avoided using rainwater collected off the ground surface, rather than roofs, owing to its considerably higher pollutant load and consequent concerns about water quality and the need for treatment. However, since the main environmental impact of a RWH system is the tank, it makes sense for us to look again at the potential for reuse of water that has been stored for other purposes. It is unrealistic to expect use of harvested rainwater to allow any decrease in the size of attenuation tank needed for flood prevention; any potential water use within the building is tiny compared to the flow rates of water available during storm events (in the example above, the potential use of harvested rain water was 10m^3 per

Tank material	Tank weight (kg, for a 5m^3 tank)	Primary energy (MJ/kg)	Total primary energy required for tank materials (MJ)
Fibreglass	250	114	28500
Polypropylene	180	115	20700
Polyethylene (HD)	170	76	12920

Table 2. Comparison of the primary energy requirement for production of materials for a RWH tank. (data from Eco-profiles of the European plastics industry).

day, compared to a requirement to attenuate storm water run off to 14 litres/second - 120 times as much). However, developing attenuation systems to fulfil both purposes (so called 'retention and throttle' systems) could provide water reuse potential without adding significantly to the environmental costs of the flood prevention infrastructure.

Let there be light?

Risk averse engineers are now specifying ultraviolet treatment of harvested rainwater on many large scale RWH systems in addition to simple filtration. Whilst UV hasn't been incorporated into the current LCA study, it would obviously increase the environmental impact. A commercial system will generally use a 55W bulb (on 24 hours a day) as a minimum, and will also have an increased energy demand for pumping, as the UV is generally preceded by a fine filter (typically 5μm). But is this UV necessary? Studies of the microbiology of toilet bowls found 1 000 000 – 1 000 000 000, coliforms present in a toilet bowl flushed with mains water[7]. This mains water would have entered the building containing no coliforms, so regardless of how clean incoming water is, toilet bowls are far from a sterile environment and will 'seed' incoming water with bacteria. It's therefore rather implausible to suggest that UV disinfection of rainwater would make a toilet any safer, so it represents a completely pointless environmental impact.

Conclusions

The fact that rain water harvesting is environmentally worse than mains water supply is more to do with economies of scale than any specific fault with the technology itself; the argument is similar to that of domestic roof mounted wind turbines, compared to large scale machines with MW outputs. Much of modern day environmentalism has its roots in the self-sufficiency movement, and there are certainly instances where small is beautiful, but we must make sure that we prioritise efficient use of resources over some rose tinted view of what the answer might have been before large scale energy and water infrastructure arrived. Working out the environmental impacts of new 'green' solutions is an arduous task, but it is vital in order to prevent well meaning regulators and planners inadvertently making things worse by stimulating the uptake of environmentally damaging technologies.

Judith Thornton

Refs:

1. Crettaz et al,, 1999. Life Cycle Assessment of drinking water management and domestic use of rainwater. Aqua 48:3, p 73-83.

2. Hallman et al., 2003. Life Cycle Assessment and Life Cycle Costing of Water Tanks as a Supplement to Mains Water Supply. Melbourne, Centre for Design at RMIT.

3. Methods for measuring environmental impact are reviewed by Baumann & Cowell, 1998. An evaluative framework for conceptual and analytical approaches used in environmental management. Greener Management International 26, p 109-122.

4. Technical note for LCA geeks: CML2001, GWP 100 years was used, data for other impact categories available on request.

5. The results presented here are a summary of a more detailed LCA study, which will be submitted to an academic journal in 2008.

6. Data from Water UK Sustainability Indicators 2006/7

7. Gerba et al., 1975. Microbiological hazards of household toilets: Droplet production and the fate of residual organisms. Applied Microbiology. 30. 2, p229-237.

Insight

Michael Smith

Common sense should prevail

The Code for Sustainable Homes (CSH) was introduced by the government in 2006, and includes ratings from code level 1 to 6. These levels range from level 1 - equivalent to around a 10% decrease in emissions, compared to current UK Building Regulations and rated a BREEAM Ecohomes pass, through level 4 - a 45% decrease in emissions and equivalent to an Ecohomes rating of 'excellent', to level 6 - an 80% decrease compared to current regulations - a zero carbon home.

So what is the difference? Say we are a family of four wanting to buy an average sized new home and we want an ecohome at a higher level of the CSH, equivalent to a rating of 'excellent' or above. How much more, in emissions, can we expect to save by going for a home that is above level 4?

Savings and costs

It has been estimated that the thermal saving of a level 5 home, over level 4, amounts to about 50kWh/person/year. Assuming this energy is supplied from grid electricity (average 0.5 kg of emissions per kWh) the saving for each family member is around 25kg of CO_2. The average UK citizen has a footprint of 12 tonnes of CO_2, so the 5Kg saving represents 0.2% of a person's carbon emissions. The figures do not stand up much better when we look at heating; assuming that the heating in the level 4 home is provided by a gas condensing boiler (0.24kg CO_2 emissions per kWh) the additional saving in getting to level 5 amounts to 12kg of emissions per person, or 0.1% of the average person's carbon footprint.

If we also look into the additional cost in building fabric and assume it to be 5% or £1,250 per person on the average cost of building the home, the pay back period will be a minimum of 250 years. Of course, any increase in average winter temperatures will negate these savings altogether.

The CSH is about much more than energy saving and costs are associated with each aspect of it. While the code is not all about energy saving, this does illustrate the relatively small differences between level 4 and 5. Level 6, however, is an aspirational standard based on zero emissions for the dwelling and high performance across all of the associated environmental categories. Because the average person has become naturally wasteful, does this mean that level 6 will never be truly reached?

And on the other hand a rise from CSH level 1 to level 4 means cutting emissions by 44% of the current level. That is quite a feat and new housing is only just beginning to get near to this target.

Other options

How else might the family save 25kg of emissions per person from the energy supply? We could change our car for a less polluting model, erect an on site micro turbine, solar panels, or solar water heating. We could utilise ground source heating, biomass or CHP. Of course, all of these have their drawbacks. The change to a new car can be expensive – not to mention the embodied energy in production, as is installation of ground source heating, CHP and biomass. Microturbines have problems of their own, as well as expense; vibration, wear and the fact that they are of almost no benefit on some urban sites (as recent figures from an Encraft study show).

However there are cheaper alternatives that still save emissions; we could simply travel less in the transport we already have (10 miles a week in the average car), eat locally produced fruit and vegetables once or twice a week, turn our existing heating down, turn standby items off when not in use and use energy efficient bulbs.

Zero carbon

Emissions wise, the difference between level 4 and 5 is not great; however, the change to level 6 of the CSH is different. The government's zero carbon deadline is only eight years away, not long in the construction industry, but we can expect that code level 4 is where the industry will strive to be for the foreseeable future.

Should the standards really go any further? Should the industry really be spending millions on energy saving in new homes; spending that the consumer ultimately pays for? I think we need to begin using some basic rules regarding energy use first. Why price buyers out of the market with new standards and costly innovations when common sense and manually flicking a switch now and again can achieve the same result!