Design & Monitoring of Hybrid Living System for Onsite Wastewater Treatment & Recycling

Hemant Thakare

M.S. Building Design, Arizona State University, Tempe, AZ, USA

ABSTRACT: Living system is an emerging field, influencing the future of waste water treatment, environmental restoration, food production, fuel generation, and architecture. Healing of waste water using living technology can produce non-potable water for usage like irrigation, toilet flush, etc, and minimize potable water contamination. Systems like living machines evolved by Dr. John Todd can be designed to treat human solid waste on site, enabling up to 90% of the treated waste stream to be recycled. Especially at desert locations having water scarcity, there is a need to explore how to practice landscape principles coupled with water conservation. Different types of living / non-living systems are applied in different areas like sewage treatment, polluted water restoration, industrial waste treatment, agriculture, and architecture. Most of the working concepts and sciences are common in these systems. To take the maximum advantage of this fact, hybrid system can be designed, to achieve the specific design objective to achieve at particular site. Further, there must be quantifiable benefits that will provide useful data describing a positive life cycle of the system. Computers can be very precisely helpful in such system monitoring, improving the energy usage, and maximizing occupant comfort and health at the same time. Such monitoring tools will allow quantitative comparison of different system aspects, helpful for specific project needs like sewage treatment, building heating & cooling, etc.

Keywords: Onsite water conservation, Living systems

1. INTRODUCTION

It is not enough that green building is more efficient, sustainable or even more cost effective. A better understanding of the interaction of building systems with building elements, surrounding spaces, its energy performance, and monitoring is becoming important.

A Highly more energy efficient building design, using living systems is possible with technologies available in today's market. The designing of the living systems is basically maximizing the potential of the system under consideration, by accommodating its technical aspects in to existing site conditions and user specific needs.

This paper is focused on highly energy efficient water conservation, using hybrid living system. The focus is primarily on sewage treatment as well as indoor comfort at the same time. The information presented herewith is a collaboration of the interviews (student operators at Oberlin college Living Machine®), online case study (Wastewater Treatment Facility at Triangle School, Raleigh, NC), and field studies (1. Oberlin College, Oberlin, OH; and 2. El Monte Sagrado Resort, Taos, NM).

The idea behind this study is based on the assumption that high system performance with the help of simplified graphic output from an automated monitoring system, will help to schedule the regular maintenance, reduce operation problems, and thus increase the system lifespan. Automated living system will contribute towards the minimal operation & maintenance cost, energy consumption, and thus in minimizing environmental impacts.

2. BIOLOGICAL PRINCIPLES

Primary criterion for wastewater system design or selection of one design scheme over another is protection of the public health while preventing environmental degradation. Secondary criteria are cost and ease of operating and maintaining the system. The fate of all residuals resulting from the treatment and disposal system should be considered in the selection or design process. A properly designed, constructed, and maintained system performs reliably over a long period of time with little attention.

Biological principles for designing of living systems were developed by Dr. John Todd's "Ocean Arks International", after decades of trial and research. Some important principles are summarized below.

2.1 Mineral diversity

Living machines can simulate a rapid ecological history by having within them minerals from a diversity of strata and ages. The geological materials can be incorporated into the sub-ecosystems relatively quickly, for example- by being introduced as ultra fine powders -Igneous, sedimentary and metamorphic rocks, Minerals containing iron, colloids can be incorporated on a time scale measured in months, and can be solubilized over short time frames.

2.2 Nutrient reservoirs

Carbon/Nitrogen/Phosphorus ratios need to be regulated and maintained. Nutrient deficiencies are particularly common in biological systems. For the health of the system, waste streams can be blended (at controlled level) with other types of wastes on a periodic basis; or suitable fertilizers can be used to correct the imbalances. Organic and rock-based amendments for example are generally ideal for correcting those imbalances.

2.3 Steep gradients

Steep gradient means an abrupt or rapid change; used to increase the diversity of internal processes and the multiplicity of pathways within and between the sub-elements of the system. For example, a waste stream can benefit from passing through a series of stages that have different redox potentials, oxygen regimes, pH, temperature, humic and ligand or metal-related states. Sometimes a small percentage of the flow can be recycled back upstream to earlier subsystems. These gradients help develop the high process efficiencies predicted for living machines.

2.4 High exchange rates

Maximize the surface area of living material to which a waste stream is exposed. Develop large root surfaces for microbial growth; and provide aeration, to create upwelling that pass large volumes through the root mass and associated biological communities. The surface area of roots available to micro-organisms for example is several orders of magnitude greater than that of manufactured media surfaces.

In aquatic systems, high exchange rates over diverse biological surfaces can be achieved with ecological beds and/or geo-textile fabrics, which are sometimes fluidized. A wide variety of wet tolerant tree and emergent aquatic, semi-aquatic plants, small fish can cultured on the surfaces of the ecological fluidized beds. The media, whether plastic or of mineral origin, must have a specific gravity approaching one so that the medium will be buoyant or capable of being readily re-suspended, providing maximum potential for high chemical and biological exchange reactions.

2.5 Periodic and random pulsed exchanges

Pulsing is a critical design force and helps maintain diversity and robustness of the ways nature works. Creating a pulse, perhaps by controlling the water table, by using abnormal changes in the light regime, flow and supplemental aeration, or by introducing new plantings, to accelerate the self design can provide desired pulses in the process.

2.6 Cellular design and the structure of mesocosms.

Cellular mesocosms can have feedback loops and cross linkages between cells, which also enables system to expand or contract depending upon need. “Sub-ecosystems are coupled with other sub-ecosystems. This coupling should be maintained wherever possible and ecosystems should not be isolated from their surroundings.”

2.7 Minimum number of sub-ecosystems

A key issue in natural treatment system design is the “number of different kinds of sub-ecosystems” required to build a mesocosm, that is capable of sustaining itself over large life spans of several decades. House the subsystems in distinct cells separated in space and connected by flows. Basically three to four distinct types of ecological sub ecosystems need to be linked together that is able to self design and self repair.

2.8 Microbial communities

Microbial communities are the foundation of natural treatment systems like living machines. Bacteria are ubiquitous organisms (being everywhere at the same time), and have very specific nutritional and environmental requirements, according to their species. Nitrification & de-nitrification are very important biological processes in tertiary sewage treatment which are possible in the presence of appropriate bacteria in respective sub-ecosystems.

2.9 Solar-based photosynthetic foundations

Plant diversity enables living technologies for less energy consumption, and use of chemicals. Sophisticated engineered marsh systems use marsh plants for bacterial growth. Algae-based waste treatment systems can be as efficient as heterotrophic bacteria in the removal of organic matter from wastewater. Although algae and fungi have maintenance issues if used at greater extent in an artificial setup like computer monitored tank based living machine.

There is economic potential from the byproducts like compost from the pruning of the vegetation, mushrooms, medicinal plants, flowers, etc.

2.10 Animal diversity

All the organisms from every phylogenetic level are important contributor the functioning of living systems. These organisms are the regulators, control agents and internal designers of ecosystems. Many of animals in aquatic environments need solar energy, to develop a capability to remove particles of 0.1 to 50 µm.

Ecological fluidized beds in aquatic living systems needs sunlight as main source of energy. Snails and larva can play a dominant role in sludge reduction in EFB as well as constructed marsh. Pulmonate snails for example feed on the slime and sludge communities. Chironomid larvae for example attach themselves to the walls of the aerated tanks, often in great numbers, and can culture live foods for fish.

3. HYBRID SYSTEM

We may define onsite wastewater treatment and recycling system, designed for tertiary (advanced) treatment standards using biological principles along with the conventional systems, and further equipped with automated (computer) monitoring system; as a “hybrid living system”. What differentiates this system from conventional systems is the use of more evolved and diverse ecologies, to replicates nature, and a computer interface to monitor them. Thus "Hybrid living system = Conventional system + Biological principles + PLC (Programmable Logic Control)".

Modular living systems can grow as per the growing needs. Multi-step treatment process of hybrid living system, incorporating a monitored recirculation loop assures refined effluent.

4. AUTOMATED MONITORING SCHEME DEVELOPED BY LIVING DESIGN GROUP, LLC

PLC (Programmable Logic Control) system significantly alters the operation and performance level of living systems. Automated systems also has energy related implication, and will contribute towards the minimal operation and maintenance cost of the system, as well as entire building. Automated monitoring help in maximizing the system efficiency while maintaining the safety standards, and thus in minimizing environmental impacts. Automated monitoring helps to schedule the regular maintenance, and effective record keeping. Automated monitoring increases the system lifespan by reducing the operation problems. System can be developed for troubleshooting even from remote place.

4.1 "PLC" and "HMI"

PLC (programmable logic controller) is a computer system, acts as a brain of the system, and the HMI (human-machine interface) is a graphic interface of PLC with touch screen display. For monitoring purpose, such computer systems, and its graphic interface are consistently getting improved by practitioners like Living Design Group, LLC. A prototype of automated monitoring system for tidal wetland system, developed by 'Living Systems, Inc' is described below.

Integrated computer control system dynamics respond to climate, occupancy, and use patterns, minimizing energy usage. System can learn from past experience and adapt to future conditions. A decentralized network of micro-computers communicate with desktop PCs. Web-enabled interfaces reduce operations and maintenance attention and allow on-line reporting to regulatory agencies (living design group).

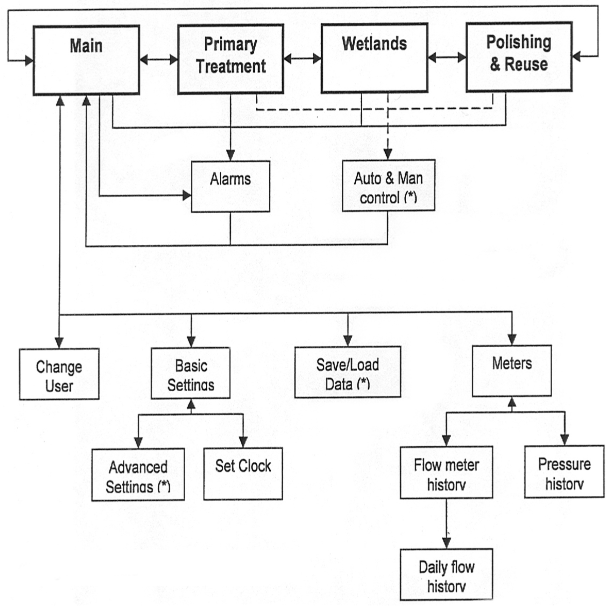
HMI can be operated in two different modes- guest and super-user (password-protected mode allowing greater control). Connection of HMI to the internet network for interface allows access from the remote office for monitoring, and trouble shooting.

4.2 Navigation

Figure-1 is a schematic showing the layout of the four principal pages (operational conditions) in the living system. These are Main, Primary Treatment, Tidal Wetlands, and Polishing and Re-use. Sub-pages allow additional functionality. Within each page there are a variety of icons that can be "tapped" with the stylus.

4.2.1 Main Page

The Main Page has five sub-pages as- change user, basic settings, save/load data, meters, and alarms; and has graphic depictions of the three treatment system subdivisions as- primary treatment, wetlands, and disinfection/reuse. If communications between the PLC and HMI fail, it is not system-critical since the PLC is liable to still be running.



(Source: Living Design Group, LLC, Taos-NM)

Figure 1: Navigation through pages in the HMI

4.2.2 Primary Treatment Page

This page covers the system components like equalization tank, settling tank, dosing pump basin. There are no user settings on this page — it is only for viewing. The level of equalization tank appears both in inches and as a gauge graphic. The makeup valve turns green when open, and for the motorized valve the direction of flow is shown with a green arrow.

4.2.3 Wetland Page

This Page covers all the wetland cells and their pumps. The pump conditions (on, off, or disabled) are highlighted in colour coding as green, grey, and red respectively. Each cell level appears both in inches and as graphic level expression. When the water is diverted to the different wetlands, the arrows will appear above respective cells, depicting the inflow of new wastewater. If logged in as SuperUser an additional button labelled "Auto/Man" shows up to open auto/man page (described in respective section).

4.2.4 Polishing and Reuse Page

This Page covers the polishing (final purification), the reuse holding tank and the pressure tanks for effluent water distribution at the user end. There are no user settings on this page – it is only for viewing or observation. Pump status is shown with similar colour coding as explained in wetland page section. The water level in the tank (measured with a pressure sensor) appears both in inches and as a graphic gauge. The UV lamp and ozone generator in ozone treatment unit are the two polishing components that require PLC control. The alarm icon may be tapped to open the alarms page.

4.2.5 Basic setting and Load and Save Data Page

The main page has basic settings page, and the load/save data icon. The user may change the basic operating parameters (determined by the control agency / Living Design Group, LLC). Data saving section relates to data logging, which is only accessible by Living Design Group over the internet.

4.2.6 Meters Page

From the main page, tapping the alarm's image icon opens the meters page, showing instantaneous readings from the flow meters and pressure sensors. It also displays volume totals calculated in the previous day (12:00am to 12:00am) for all the flow meters.

4.2.7 Auto / Man Page

The Auto/Man Page allows control over all pumps, valves, and disinfection components. This page is accessed from the primary treatment, wetlands, or disinfection/reuse page, and is only available when logged in as super-user.

4.2.8 History Pages

There are three history trend pages as- flow meter history, pressure history, and daily flow history. It displays instantaneous readings from the three flow meters, in gallons per minute. The pressure history displays instantaneous readings from the three pressure sensors. The daily flow history plots daily flow totals to dose and waste as well as total makeup water added in the primary pump basin.

5. ARCHITECTURAL INTEGRATION

Human exposure to the hazards bacteria and diseases spreading pathogens are major health issues, when living systems are designed for architectural integration. Integration of any passive strategies and /or other sustainable technologies with architecture should help with improved life standard and living environments at minimal cost. Designing of the living system infrastructure can achieve energy effective heating and cooling of the building, acoustic benefits, spiritual continuity with nature, natural lighting, and enhanced indoor environmental quality.

5.1 Indoor / outdoor system

Indoor, outdoor, or mix type of living systems have particular advantages and dis-advantages. Indoor and greenhouse based systems can be the best solution when the building have a small physical footprint to work with. Outdoor systems, with a mix of ponds and constructed wetlands, work best where one have land available, and interested in keeping the annual energy requirements to minimum.

5.2 Cost

US EPA -2001 concluded that systems like Living Machine®(s) are typically cost competitive with more conventional wastewater treatment systems at flow volumes up to 1,000,000 gpd, if they are located in a warm climate where a greenhouse is not necessary. However, if the climate cannot support the plants year-round and a greenhouse must be constructed, construction costs will increase. Addition of a greenhouse structure makes the Living-Machine® cost competitive with more conventional systems up to flow rates of around 600,000 gpd.

However, within last one decade, living technologies are improved towards greater sophistication; and cost efficiencies are competitive with conventional systems.

Economics of building design, construction, operation, maintenance, and property value can be manipulated at the conceptual design stage of the building, surrounding landscape, and integrated living system. Integration of interior/exterior spaces with living system can be articulated to blur the distinction between inside and outside and effectively establish the high standard of indoor environmental quality. Creative articulation can successfully increase in the cost of the property within permissible costs.

Cost effective integration of technologies like photovoltaic with the green house based living systems can be achieved, if PV panels are used as structural elements (eliminating the cost for extra materials).

5.3 Living Systems in Various Climates

Living systems can be designed to work almost anywhere from inside buildings to high latitudes, and all climates. If required, expected light levels can be supplied through artificial lighting to keep the temperatures above 10 degrees Celsius. The organisms within them have to be adapted to the climate the system is in. For example, if light levels are low, then low light adapted organisms will dominate.

Depending on the climate, and design details of the sub-ecosystems, living systems can be located (fully or partially) outdoors, in protective greenhouses, or under light shelter. For the green-house in the cold climate, ideally the roofing is recommended to be a high performance glazing system (high light transmission), with good thermal efficiency normally used for solar panels.

6. CONCLUSIONS

Tertiary sewage wastewater treatment is justified, since nutrient input is a significant environmental concern, and sewage is major nutrient sources.

Living systems for onsite sewage wastewater treatment and recycling is a proven technology; which can provide this tertiary treatment to sewage waste. However, the application of this relatively new concept is limited.

While the architectural integration of these systems is established up till considerable level, the extent to which the plants and animals contribute to the treatment process in current living system designs is still being verified.

Many biological concepts and principles for on-site wastewater treatments were experimented, developed, and are well defined. Further codification of those 'Biological Principles' is required, to be able to use them as design guidelines; and to be able to considered at the conceptual design stage itself.

The system should be able to produce high quality effluent. Typical BOD and TSS are around 10 mg/L with total nitrogen of less than 20 mg/L.

Aesthetically integrated living system increases usable floor space, improves market value of the property. It provides an opportunity for passive heating and cooling of the building and to improve indoor environmental quality.

Onsite wastewater treatment systems offer a viable means for controlling public health hazards, environmental degradation, and nuisances.

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