

Pico Hydro Power Generation from Grey water in High Rise Buildings: Feasibility and Economic Analysis

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ABSTRACT: Energy consumption in developed as well as developing countries is high, especially in residential and commercial building sectors. The main consumers of energy in a Metropolitan city are the skyscrapers or the high rise building towers. Many researchers have been working on various technologies exploring the possibilities of non conventional methods to reduce the energy consumption in these buildings. The aim of this project work is to find out the feasibility to extract power from grey water and to economically identify the resultant savings achieved by incorporating the system in the building. It is proposed to use a micro/pico hydro turbine installed at the ground floor of the building utilizing the grey water from all floors above the refugee level. Scaled prototype of the system has been developed and tested. The paper also focuses on the Grey water treatment and the concept of a refugee floor; how the integration of the proposed system would help in improving fire safety measures of the building. The proposed design of the gravity energized waste water system in high rise buildings for generation of hydro electricity is being checked for its feasibility in Indian markets especially building construction groups. The Cost-Benefit analysis of the proposed system for possible commercialization of this technology is also carried out.

KEYWORDS: Grey water, high rise buildings, refuge floor, pico hydro.

I. INTRODUCTION

As we undergo a transition from the individualistic ground level concept of housing to the high rise or multi-storeyed style of community living with the urban backdrop, the stress we are applying on the ecosystem is humungous. The focus of the work is primarily upon the high rise buildings which are the principal consumers of energy whatever form it may be in a fast growing town or a cosmopolitan city, i.e about 60 to 70% of the energy needed in a thickly populated town would be for high rise buildings as well as they will be the major stake holders in the overall waste generated in the city both as municipal solid waste or sewage liquid waste. According to central water authority, Govt. of India a person uses 171 L of water per day of which in turn is generated as grey water and expelled to our environment. We are trying to extract energy from grey water coming out of these high rise apartments using Micro/Pico after collection and preliminary treatment of the grey water in a storage tank [1].

The grey water/Sullage in high rise buildings is considered for checking the need of the treatment system at the refugee level. The treated water/sullage is taken to the grey water tank and from which it flows to the hydro turbine producing power. The chemical test is conducted upon the treated water to identify the chemical constituents and to understand its effects on the Turbine and piping system. The feasibility of the proposed system is also checked for various scenarios considering aspects such as space constraint, setup costs and effective value or savings obtained in the electricity bill by integration of the proposed system in the building. Considering the real case scenario we develop a scaled prototype and test it under a certain head. The cost benefit analysis is also done to prove that this proposed system can be commercialised and system is feasible for Indian cities.

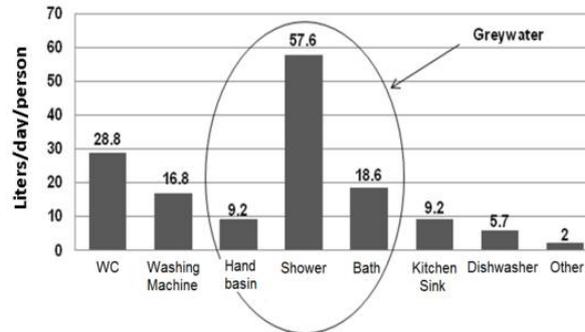


Fig. 1. Graph showing grey water generating sources in an apartment

A. ENERGY SCENARIO OF INDIA: SIGNIFICANCE OF PICO/MICRO HYDRO TURBINES

India has a large shortage of power. In December 2011, over 300 million Indian citizens had no access to electricity. Over one third of India's rural population lacks electricity, as did 6% of the urban population. Of those who did have access to electricity in India, the supply was intermittent and unreliable. In 2010, blackouts and power shedding interrupted irrigation and manufacturing across the country. During the year 2010-11, demand for electricity in India far outstripped availability, both in terms of base load energy and peak availability. Base load requirement was 861,591 (MU) against availability of 788,355 MU, an 8.5% deficit. During peak loads, the demand was for 122 GW against the available 110 GW, a 9.8% shortfall.

Hydropower is an eco-friendly clean power generation method. India is endowed with economically exploitable and viable hydro potential assessed to be about 84,000 MW at 60% load factor. In addition, 6780 MW in terms of installed capacity from Small, Mini and Micro hydel schemes have been assessed. Taking into account the current scenario, extensive research is going on in micro hydel projects. The study is designed to determine the practicality of the potential hydropower generation from the reuse of wastewater in high-rise buildings that can be used insitu. A structure is automatically listed as a high-rise when it has a minimum of 12 floors, whether or not the height is known. Pico hydro is a term used for hydroelectric power generation close to 5 kW. Even smaller turbines of 200W-300W may power a single home in a developing country with a drop of only 1 m. Pico-hydro setups typically are run-of-stream, meaning that dams are not used, but rather pipes divert some of the flow, drop this down a gradient, and through the turbine before being exhausted back to the stream.

B. SCOPE OF A PICO HYDRO SYSTEM IN A HIGH RISE BUILDING: THE INDIAN PERSPECTIVE

Pico hydroelectric power generation can be used in high-rise buildings that utilizes the potential head of water being used that drops down through a piping into the turbine rotating its wheel [10]. This turbine is then coupled to a generator. According to the estimated water consumption, about 76% (figure 1) of wastewater can be utilized for the production of hydroelectricity after some preliminary purification processes [8]. This purified water, which is also free from solid particles, can be directly fed to the turbine. On an average in urban environment water consumption by an individual is between 150 and 200L [2]. Over the years, many high-rise buildings have come up in India. More than 2200 high-rise buildings are already constructed in Mumbai Metropolitan Region (MMR) and there are more than 118 skyscrapers in the same city. In addition to these, more than one thousand mid-rises buildings exist already in the city of Mumbai. Kolkata is also emerging as India's next skyscraper city with 600 existing high-rises and many more under construction [9]. Hyderabad and Bangalore are also having many skyscrapers under construction and could well match up with a city like Mumbai in the near future in terms of the number of high-rise buildings. High-rises are also becoming common in Chennai in recent times after the removal of height restrictions on constructions in the relatively active seismic zone. More than 250 high-rise buildings have been constructed in Kochi.

II. AIM AND METHODOLOGY

The aim of this paper is to propose a commercially viable system to harness energy from used grey water flowing from different floors of a high raised building (figure 2). In high-rise buildings, an enormous amount of water

is consumed on a daily basis. The water after consumption is normally discharged directly into the drainage system. In certain cities, rules have been formulated to create wastewater collection and recycling plant for high-rise building, which have sufficient space falling from some height carries potential head and thus stored energy. This work aims at harnessing this energy from grey water. After collecting requisite volume of water, it is made to flow through the pipe over the turbine blades, thus rotating the turbine shaft. This shaft is then coupled to a generator converting the mechanical power to electrical power. This electrical power can then be directly used or stored in the batteries for later usage [6].

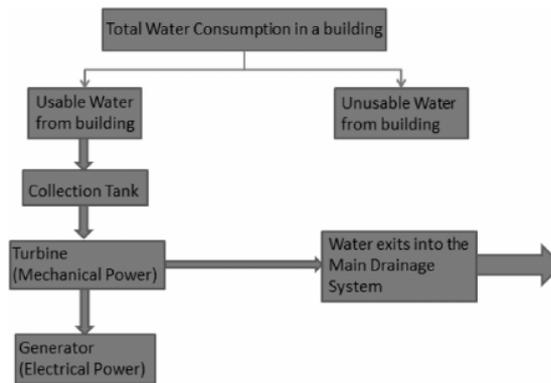


Fig. 2. Process of Extracting Energy from Grey Water

A detailed calculation of the theoretical model of the system along with the study of grey water treatment system to be installed at the desired level, chemical test of the grey water to understand its effects on the turbine-piping system. A scaled prototype of the system was also developed and tested. The detailed economic analysis of the system was done using NPV method to commercially justify the project.

III. RELATED WORK

The steps involved in the development of the proposed system (figure 3). To solve the optimization problem for the system, a methodology was developed. The problem is considered in several steps starting from:

- 1) Design of Grey water treatment system at the desired level (Refugee floor).
- 2) Chemical test of the treated Grey water/Sullage to identify its constituents and effects on the piping system.
- 3) A water collection tank of height X, radius R; is placed at a height (H-X) from the base. Water after being used is discharged into the conduit pipes. This system of conduits discharges the water collected from all the floors above the level of the collection tank (i.e. above height H) into the collection tank after preliminary treatment at refuge level.
- 4) The collection tank uses a water level sensor. After the required volume of water is collected in the tank, sensor actuates a valve at the bottom of the pipe connected to the tank.
- 5) The valve opens up allowing the collected water to flow down. A hydro turbine is attached to the base of the pipe. Water having an initial head h strikes the turbine blades thus rotating the turbine shaft.
- 6) Selection of turbine depends on the head and volume flow rate of water and availability. A Pelton wheel turbine is selected in this case because of low flow and reasonable water head. However, other turbine designs can also be explored based upon use.
- 7) The turbine is further coupled to an AC generator via a gearbox. Use of a gearbox is justified to achieve the desired RPM for the generator to obtain a steady output frequency. This generated electric power can either be directly used or stored as charge in the batteries for later use.

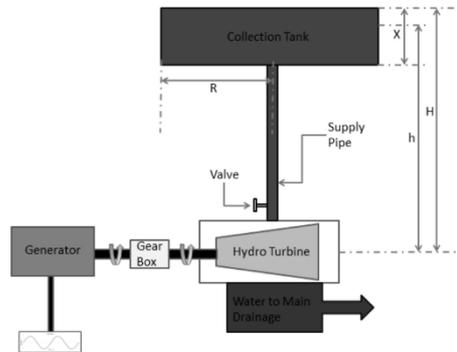


Fig. 3. Schematic Diagram of the Proposed system

The theoretical model of the proposed system and its calculations for Pelton turbine are included in Appendix 1. The Schematic diagram of the proposed system is shown in figure 3.

IV. DESIGN OF GREY WATER TREATMENT SYSTEM

This process will be possible only after the grey water/sullage undergoes certain preliminary treatment process before it passes out to the turbine if not it will cause clogging of the piping system and in worst case scenario it may cause corrosion to the Pico turbines [5]. There might be initial screeners at the outlets of washbasins, Sinks and bath tubs. Nowadays the Sullage and Sewage treatment systems are really dynamic and highly efficient such that they undergo Aerobic and Anaerobic digestion followed by Ultra filtration and the treated water can be pumped back to be used in flushes of toilets.

For the proposed system a part of the sullage treatment system is to be taken to the desired level in the high rise building. Figure 4 shows the Grey water treatment system to be integrated into the High rise building completely following the rules of State Pollution Control Board.[4]

Stages of Grey water treatment

The preliminary section of the Sullage treatment system installed underground is to be taken to the desired level. The main purpose of this treatment system is to avoid the presence of larger suspended solids that would create clogging of the system.

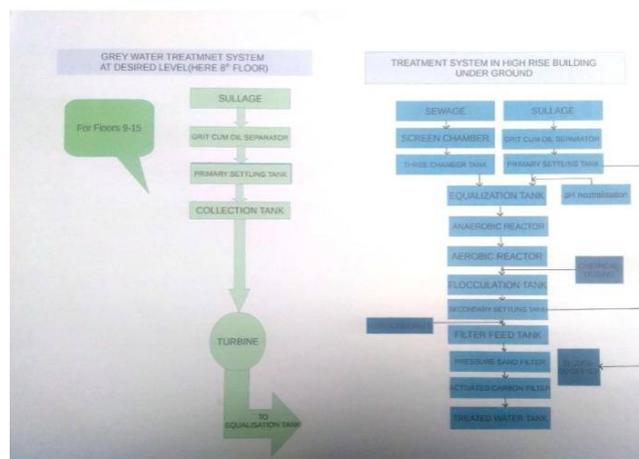


Fig. 3. Grey water treatment system

a) Screening

The sewage is passed via a screen chamber to three chamber tank. The process enables removal coarse particles from the stream that may clog pipes and cause operational disruptions in downstream unit processes.

b) Grit cum Oil Separator

The waste water from the kitchens and bath rooms will be routed through the Grit cum Oil separator chamber. In this chamber a series of baffles (figure 5) are provided which enable the settlement of grit particles at the bottom and the separation of the oil in the stream at the top. The final oil and grit free stream is directed to a primary settling tank. Here, the large particles are collected in the hopper bottom provided.



Fig. 4. Baffles within the Primary Settling tank

c) Collection Tank

The water coming out of the primary settling tank is taken to a collection tank which holds the treated water until a set point after which a sensor actuated valve beneath the collection tank operates allowing flow of water to the turbine.

Chemical Test on treated water

The treated water coming out of the primary settling tank is tested for the various concerned parameters (Table 1) like:

- pH
- Total Suspended Solids
- BOD(Biological oxygen demand)
- COD(Chemical Oxygen demand)
- Oil and Grease

TABLE 1
Chemical Test Results of the Treated Grey water

Parameters	Test Method	Result	KPSCB Limit
pH	IS 3025(P)11-1983	6.80	6.5-8.5
Total Suspended Solids, mg/l	IS 3025(P)15-1984	BDL	100
Oil and Grease, mg/l	IS 3025(P)39-1991	BDL	10
BOD, mg/l	IS 3025(P)44-1993	2.28	30
COD, mg/l	IS 3025(P)58-2006	15.80	260

It should be noted that there is no need of any power/ electricity at the treatment system located at the height of the building as well as there are no chemical agents added to the system, thus this makes the systems initial cost low as well does not alter the nature of the sullage and keep it within Pollution Control Board limits [7].

V. EXPERIMENTAL ANALYSIS

The scaled prototype of the proposed system was developed using a Pico Hydro turbine rated at 10W and 12V which was tested at an experimental head of 3.5m. The system had three successive tanks:

- Grit cum Oil separating Tank
- Primary Settling Tank
- Collection Tank

TABLE 2
Operating Characteristics (under 3.5m head) of Pico Hydro turbine

VOLTAGE	LOAD CURRENT	POWER
10.94V	35mA	0.389W
10.82V	31.7mA	0.342W
10.65V	28.8mA	0.306W
10.59V	16.9mA	0.178W
10.54V	11.1mA	0.1169W

The Grey water would flow from the sources to the tank with baffles where its grit and oil is removed followed by the passage through the primary settling and filtration tank filled with pebbles and charcoal (figure 6). Each of the three tanks have 20 litres volume which would operate continuously until the final tank i.e the collection tank is filled to the set level which is 20 litres here. On reaching the set limit the control valve at the bottom of the tank will open causing the flow of water from the tank to the Pico Turbine Generator. This prototype would continuously operate for 70 seconds producing power output i.e for 20 litres. The Voltage and Current was measured (Table 2) from no load to full load condition, load was given by using a 500ohm potentiometer. The V-I characteristic (figure 8) and the P-I characteristic (figure 9) of the Pico Hydro turbine was also plotted. The output in the case of a real building is detailed in appendix 1

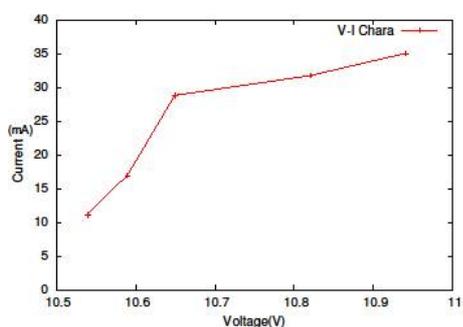


Figure 8: V-I characteristic

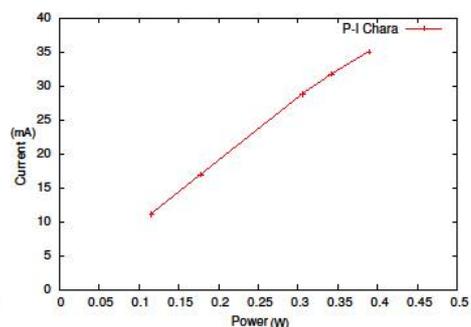


Figure 9: P-I characteristic

VI. ECONOMIC ANALYSIS OF THE PROPOSED SYSTEM

This paper proposes the concept of integrating a pico hydro turbine to a building and extract energy from the grey water flowing through the building itself. As already mentioned in the design part we need three tanks at desired level of the building for treating and holding the grey water before it is released to the turbine, thus we need space at a certain level of the High rise building to house these tanks and also there will be setup costs for tanks and piping system. The major

economics involved here is the value of 1 unit of electricity produced from the system which determines the payback period as well as overall economic feasibility of the system proposed.

A. SPACE CONSTRAINT: THE CONCEPT OF REFUGE FLOOR

As mentioned earlier the space constraint is a key factor which determines the initial cost of the project. We need to house three tanks which will need an area of 100 sqft. But if we look at it from the perspective that this area is to be taken out from the apartment living space then it will cost around 4000-5000 rupees per square feet. Here comes the concept of Refuge Area or Janitors floor. One needs to know what a refuge area is [11]. In a layman's language, it is a safety area provided in a high rise building. As the name suggests, it is an area specifically demarked in any commercial or residential building where people can take shelter in case of an emergency. At times, the rescue forces failed to fight emergencies related to fire with a number of cases in the past. Not only do the fire-fighting personnel had a hard time reaching the central location of the fire in case of a high floor, it also put lives of residents especially children and elderly at grave risk.

With an increase in the number of cases of misuse of refuge areas, the Government redrafted the basic guidelines for refuge areas in accordance with the modified Development Control Rules known as DCR introducing stringent provisions for fire-fighting and curb misuse of these areas by developers by manipulating and misusing certain portions of their towers. The State Urban Development Department issued the notification that in case the height of the building in more than 30 meters, the first refuge area must be located at 24-meter mark or the 1st habitable floor which is higher. After the first refuge area, every 7th subsequent floor must have the same refuge area in the building. As per the prevalent rule, the refuge area is restricted to a maximum of 4% of the habitable floor area it serves. The calculation of the refuge area is considered free of FSI (Floor space Index). If however the refuge area exceeds the limit of 4%, then the refuge area so exceeded will be calculated under FSI which is the ratio of permissible built-up area compared to the total size of the plot.

Thus the concept of grey water storage tank is integrated in the refuge area which is occupying about its 25% space but it provides the added advantage of 15,000 to 20,000 litres of treated water at the refuge floor which could be used to curb fire under emergencies.

B. SETUP COSTS: COST OF TURBINE, TANK MASONRY AND PIPING SYSTEM

The system needs three tanks of which collection tank is around 15,000 to 20,000 litres capacity, Pico turbine and Generator (battery if needed) and piping costs. There is no need of electric power and chemical agents in the system. Thus on whole it will cost around 1,30,000 to 1,50,000 rupees.

C. GREY WATER ELECTRICITY: RESULTANT SAVINGS

The savings obtained by the installation of the proposed system is to be looked from the perspective of cost of 1 unit of electricity consumed in the building. In Kerala these high rise buildings comes under the LT-1A tariff block and the key point to be noted here is that there are two types of Consumer billing in a high rise building:

- Individual apartments : consumption less than 500 units.
- Entire high rise building : consumption more than 500 units.

Tod tariff shall be applicable to LT-IV Industrial consumers having connected load of and above 20 kW and to LT-I domestic consumers (3 Phase) having monthly consumption above 500 units (Table 4). CT meter is provided when connected load is more than 20 kW. CT meters have a multiplication factor, thus readings obtained should be multiplied by the multiplication factor to get consumption. Power supplies to common facilities such as water supply, common lighting, lifts, etc. in multi-storied buildings mainly for domestic occupation shall be under the domestic tariff if the connected load other than domestic is less than 5% of the total load.

TABLE 3

METRO	POWER PROVIDER	TARIFF
Mumbai(MMR)	Reliance Infrastructure Ltd	10.80-12.85
Chennai	Reliance Infrastructure Ltd	10.40-12.60
Delhi	Tata Power Co	10.30-12.20
Kolkata	Mahavitaran	10.55-12.85
Kochi	KSEB	7.50-9.0

Thus always the consumption for High rise building unit (common bill) would be higher than 500 units so the tariff of all Indian cities where power is delivered by private sector companies for consumption of 500 or more units is shown in Table 3.

TABLE 4

ToD Tariff for Domestic Consumers(KSEB):% of the ruling tariff(7.50 rupees/unit)

Charges/Month	Normal Period	Peak Period	Of Peak Period
Time of day	(6 hrs to 18 hrs)	(18 hrs to 22 hrs)	(22 to 06 hrs)
above 500 Units	100% of ruling tariff	120% of ruling tariff	90% of ruling tariff

Thus for various Indian cities payback period also varies. For Mumbai Metropolitan Region (MMR) the payback period would be less than 8 years whereas in Kerala under current tariff scenario it would be nearly 20 years so for different places the payback period also varies (Fig 10). Detailed calculation using the Net present Value Method [3] is given in Appendix 2.

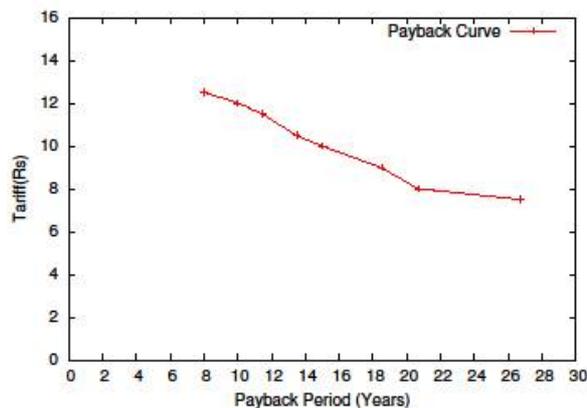


Fig 10: Payback Curve

VII. CONCLUSION

A method of harnessing the energy from Grey water flowing through the high rise buildings utilising its head was presented. The paper focused on the various aspects such as grey water treatment system at the desired level or refuge floor, various steps involved in treatment as well as chemical test on treated grey water to identify its effects on the system. A scaled prototype of the system was developed and its operating characteristics were analysed. A cost benefit economic analysis of the proposed system was also carried out to arrive at the payback period.

This clean method of tapping renewable hydel energy from high rise building in such an energy scarce situation can be commercialised in various Indian cities and would be the technology of the future times.

VIII. APPENDIX 1

Theoretical Model of the proposed system

- Effective Head of water(h) = $\{V \times (H - x)/2 + v \times (x/2)\} / (V + v)$
- Time for emptying the grey water storage tank(t) = $t = A \times (\sqrt{2} \times \frac{x}{g}) / a \times c$
- Discharge(Q) = V/t
- Turbine Output Power = $P_t = \rho \times Q \times g \times h \times 10^{-3}$

A Pelton turbine is selected for the system. The Pelton wheel is a water impulse turbine. Our selection is Pelton turbine because we have low volume flow rate and reasonably high head. Moreover, it is easily available in Indian markets and the manufacturing costs are low. Thus for the scaled prototype with a tank capacity of 20 litres we get the discharge as 0.00028m³/s, operating time of 70 seconds, effective head of 3.24m and power output of 7.5watts. All of above mentioned values are of the scaled prototype operating under 3.5m head.

Model of the system installed in a 15-floor building

The system with a collection tank of height 1.5m and radius 1.2m, thus a volume of 6.78m³/s. Similarly volume of pipe through which the grey water is falling is 0.07125m³/s and the effective head of falling water is 23.01m(8 floors). The discharge is 0.0084m³/s producing power output of 1.42kW. For a building which has 150 occupants from 8th to 15th floor (27.28m) the total usable water would be such that it will make the turbine operate four times a day. Thus on an average we would get between 5.5 to 6 units of electricity from the proposed system in one day.

IX. APPENDIX 2

Economic Analysis: NPV method to calculate payback period

The system has an initial cost of around 1,50,000. The annual operating cost is 1000 rupees. Salvage value or scrap value at the end of project life (taken as 40 years because the Mean time between failures for a Hydraulic turbine is always high) is 4000 rupees. Thus calculating the payback using NPV method bringing all future costs to present we get a payback of around 8 years, i.e producing 6 units per day and 2160 units per year we get back the investment in 8 years if one unit has an effective value of 12.50 Rupees.

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