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Development of sustainable renewable resource management tool for residential townships

Rijuta S. Bapat[1], Rahul V. Ralegaonkar[2], Vasant A. Mhaisalkar[3]

[1]AssociateProfessor, Dept. of Interior Design, L.A.D. college, Nagpur, Maharashtra, India.
[2,3]Professor, Dept. of Civil Engineering, V.N.I.T., Nagpur, Maharashtra, India.

Abstract - *Natural resources (clay, coal, water) are over exploited during building construction as well as over the life cycle. The majority of global energy use and proportion of carbon-dioxide emissions are associated with residential buildings. In order to conserve the natural resources present manuscript aims at developing Sustainable Renewable Resource Management (SRRM) tool. The tool aims at the integration of technically efficient and economically viable methods of material, water and energy conservation. It uses LCC analysis approach and is capable of computing sizes, costs as well as carbon emissions. The tool capabilities are elaborated with respect to a specific case study of a residential township of 200 tenements. Integration of material, water and energy conservation technologies for housing scheme shows prevention of 2929.19MT of carbon emissions, saving of 2581545.41 m^3 of water and 2019650.87 kWh of energy. The tool is useful for the stakeholders in decision making while integrating sustainable technologies in residential buildings. Sensitivity analysis and graphical presentation of results are the other benefits of SRRM tool.*

Key Words: Sustainable; renewable resource; technically efficient; economically viable; SRRM tool

1. INTRODUCTION

Owing to the economic drivers, urbanization is taking place at a rapid pace, having a dramatic effect on the increased demand for residences. In order to conserve the natural resources, native, renewable resources have to be evaluated, integrated and promoted for sustainable development.

The population of India is expected to stabilize around 1640 million by the year 2050 [1]. According to national surveys, nearly 100 billion bricks (which use 300 MT of topsoil) are needed every year in India, which produces 22% of the CO_2 emissions of the construction sector and requires about 27% of the energy used in building materials production [2]. Nearly 85% of the fly ash (FA) generated in India is 'disposed off' using the lean slurry disposal system which requires 810 parts of water for one part of fly ash [3]. In India, per capita surface water availability in 1991 and 2001 was 2309 m^3 and 1902 m^3, respectively, are projected to reduce to 1401m^3 and 1191m^3 by the years 2025 and 2050 respectively [4]. Depletion of groundwater due to over extraction for farming is going to create a severe water crisis by 2025 [5]. India suffers from the shortage of electricity, the overall power deficit has risen from 8.4% in 2006 to 11% in 2009. India's electricity production mainly depends on coal and natural gas. The current usage level of coal suggests that coal reserves may run out in 45 years [6]. In the year 2007, India's net CO_2 emissions were 1495.4 million tons out of which major portion (47%) was for electricity generation [7]. Use of renewable energy can help India to reduce carbon (CO_2) emissions and meet the energy demands as well.

1.1 AVAILABILITY OF RESOURCES

Availability of renewable resources shows that there is a great scope of practicing sustainable technologies in residential towering buildings of India for the conservation of natural resources like clay, water and energy. An industrial by-product, FA in India is expected to cross 225 million tonnes by the year 2017 [8]. India receives an annual precipitation of about 4000 km^3, including snowfall [9]. Greywater (GW) generated from hand washing and bathing is considered as the least contaminated type of GW contributes to around 50-60% of total greywater, represents the most profitable source in terms of its reliability, availability and raw water quality [10]. Solar power can be used in India as it has a high solar insolation, varies from 4-7 kWh/m^2 and has 1500-2000 sunshine hours per year [11]. Wind power density map of India shows the potential of wind energy in the states of Tamil Nadu, Maharashtra, Karnataka, Rajasthan, Gujarat, Andhra Pradesh, Madhya Pradesh, Kerala and West Bengal [12].

1.2 INTEGRATION OF SUSTAINABLE TECHNOLOGIES

Implementation of sustainable technologies in residential apartment buildings becomes convenient along with civil infrastructure, reducing the carbon footprint to a great extent. Many benefits associated with the combination of sustainable technologies encourage the use of integrated renewable resources in the form of hybrid systems. The costs of the sustainable technologies in residential apartment buildings if integrated get distributed among the tenements. Choice of sustainable technology will depend upon the natural and local availability of resources depending upon the location of residential apartment buildings, the practical feasibility considering the economics and availability of space for the sustainable technologies.

1.3 DEVELOPMENT OF SOFTWARE TOOL

In the present study technically efficient, economically viable, locally available sustainable technologies were identified for the conservation of natural resources in residential buildings through extensive literature and market/web survey. Life cycle cost (LCC) analysis approach was used for the integration of sustainable technologies. A methodology was developed to design a software tool for Sustainable, Renewable Resource Management (SRRM). The tool has capabilities of estimating the total saving of natural resources, carbon emission and financial savings during the lifetime of sustainable technologies. It generates abstract of results for the individual apartment buildings and the cluster of apartment buildings. The developed SRRM tool also facilitates the sensitivity analysis of the system parameters to evaluate the alternative costs of sustainable technologies.

2. METHODOLOGY

A detailed literature review and market survey was carried out to find out technically efficient, economically viable, commercially and locally available sustainable technology models along with their components suitable for residential buildings of India.

2.1 IDENTIFICATION OF SUSTAINABLE TECHNOLOGIES

For material conservation**, f**rom literature review it was revealed that among walling materials for residences, bricks using waste paper pulp, sugarcane baggase, FA, stabilized mud blocks, autoclaved aerated concrete (AAC) blocks, burnt clay bricks are the prominently available materials. Bricks manufactured using waste paper pulp, sugarcane baggase have the potential to reduce embodied energy and FA bricks, stabilized mud blocks, AAC blocks can reduce carbon emissions [13-15, 16, 17]. Jointing material, Portland pozzolana cement (PPC) is cheaper and has less carbon emissions compared to ordinary Portland cement [18, 19]. Hence FA bricks and PPC have the potential to reduce the use of natural materials, mainly clay, cementicious materials and carbon emissions in large quantities, without any compromise in strength and functionality was identified construction materials for walls [20].

For water conservation in residential buildings, methods of rainwater harvesting (RWH), greywater recycling (GWR) after proper treatment and use of LFDs were identified as water conservation techniques.

A rooftop RWH technique requiring least treatment for its on-site use consisting of impervious rooftop, a steel coarse mesh at the entry of rainwater pipes, a delivery system of Polyvinyl chloride rainwater pipes having ease in handling, light in weight, durable, resistant to chemical and electrochemical corrosion, resistant to microbial activity were found techno-efficient. Among various filters mentioned in literature and available in the market like Devas, Varun, Pop up and Rainy filter, Rainy filter was found efficient in various ways of removing suspended pollutants from rainwater, self cleaning, available in different capacities, having ease in connections with the delivery system and an underground tank, having a long life, requiring less maintenance, keeping the water cool was identified [21, 22, 24-25]. Easy and simple rooftop rainwater treatment of killing bacteria, a pump having less maintenance and operational cost and an overhead tank light in weight and durable was selected.

Wastewater collected from showers, baths, washbasins, having less pollutant load and disease-causing bacteria was identified for recycling after proper treatment. The purpose of on-site use of recycled water for toilet flushing, having the potential of saving one-third of the mains water in addition to reducing sewage generation creating less stress on a septic tank was identified [26].

Several greywater treatment (GWT) technologies have been developed since 1970 which are classified based on physical unit processes, chemical unit processes, physicochemical processes and biological unit processes. Treatment of grey water can range from simple coarse filtration to advanced biological treatment [27]. Gander M et al. (2000), Kader M (2013) stated that energy consumed using a membrane bioreactor; electro coagulation is 1.7 kWh/m^3 and 0.3 kWh/m^3 respectively. Kader M (2013) also mentioned that energy consumed using rotating biological contactor, submerged membrane bioreactor is 1.2kWh/m^3 and 3.6kWh/m^3 respectively. Kuntal A (2014) stated that the energy required for electro-coagulation is 0.3kWh/m^3 [28, 29]. Greywater treatment plant which was simple in installation, inexpensive, requiring less energy, conforming to the safe use, with National Environmental Research Institute's manual, for toilet flushing was selected.

Low flow toilet options are available in the market, which include vacuum or compressed air toilets, macerating toilets, ultra flush toilets (saving water 6.8 lit/flush), dual flush toilets (saving 16 lit/flush). Use of dual flush toilet having the maximum water saving capability, including separate water filled tanks selectively pivoted to deposit different quantities of water for flushing was chosen. Shower heads, faucets with aerators (saving 50% water) can be installed in residences for the conservation of water [30]. Considering economics, the amount of water saved local availability and ease of installation dual flush toilets of Parryware Company costing INR3999 and aerators costing INR225-INR510 were selected for residences. Use of expensive devices was avoided.

Alam M et al. (2012) stated that in order to improve the energy performance in residential dwellings, in countries, with remarkable solar irradiation resource as a key issue for sustainable urban development, the usage of solar water heaters (SWH) and solar lighting systems are inevitable [31].

SWHs are broadly classified as direct systems and indirect systems depending on the circulation of working fluids, SWHs are also grouped into passive circulation systems or active circulation systems. Passive systems like thermosyphon are identified for residences for its simplicity and ease of operation [32]. Type of collector for SWH depends upon the climate and quality of water to be heated [33].

Solar photovoltaic (SPV) systems can be used for the purpose of lighting in common areas of residential apartment buildings. Charabi Y (2011) concluded from the research study on solar resource assessment considering different photovoltaics (c-Si, a-Si, CdTe, CIGS, CPV) in Oman that crystalline photovoltaic technology (CPV) provides great potential in producing electricity [34]. As per market survey, monocrystalline PVs are costlier than polycrystalline PVs though more efficient. The cost of polycrystalline photovoltaic panels was around INR50 per Wp [35]. The cost of monocrystalline solar panels was found INR 60/Wp [36].

Performances of small wind turbines in Italy showed that horizontal axis wind turbines (HAWT) produce more energy than the vertical axis [37]. Most vertical axis wind turbines (VAWTs) have an average decreased efficiency from a common HAWTs, mainly because of the additional drag that they have as their blades rotate into the wind. Versions that reduce drag produce more energy, especially those that funnel wind into the collector area. It is less cost-effective [38]. Generally, average annual wind speed of at least 4.0- 4.5 m/s is needed for a small wind turbine to produce enough electricity [39]. SunChip Wind 1000,2000,3000,5000 Sikco Wind 1000, 2000, Windistar 400 are among the commercially available models of HAWTs in India.

2.2 DEVELOPMENT OF SUSTAINABLE, RENEWABLE RESOURCE MANAGEMENT (SRRM) TOOL

Sustainable Renewable Resource Management (SRRM) tool was designed and developed to integrate identified appropriate sustainable technologies for material, water and energy conservation to promote green and renewable energy options to be practiced for the cluster of residential apartment buildings. The design and development of the tool used for carving out interfaces of Sustainable Renewable Resource Management (SRRM) were in Power Builder from SAP technology. The database used for storing the data was also from SAP technology i.e. SQL Anywhere. Developed SRRM tool integrated modules of sustainable technologies of material conservation, water conservation and energy conservation. Each module of sustainable technologies has sub-modules. Overall flow diagram for SRRM tool was developed as shown in Figure 1, in order to decide the structure of the tool.

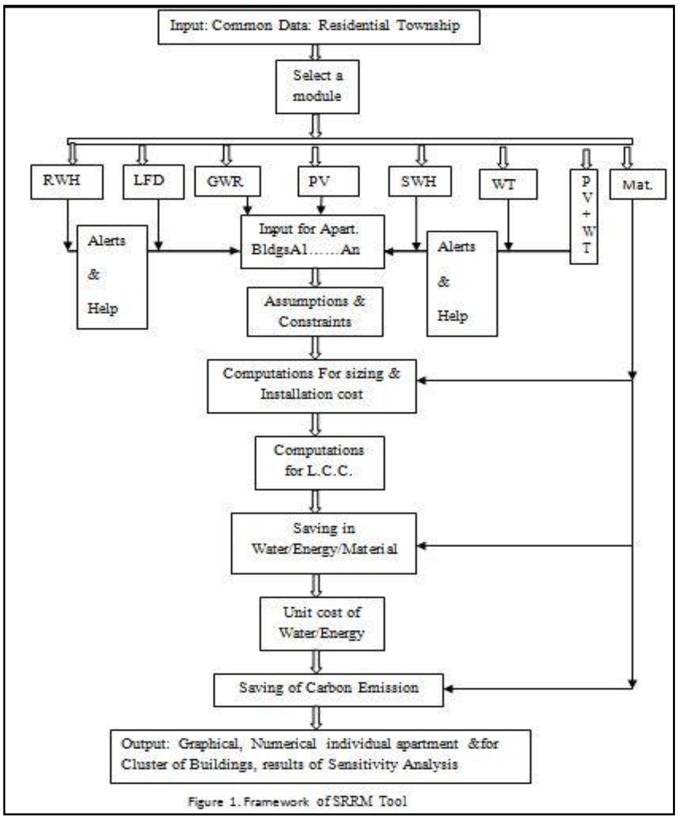

Fig- 1: Framework of SRRM Tool

2.3 SIZING AND LCC OF SUSTAINABLE TECHNOLOGIES

SRRM tool enables to design the sizes of sustainable technologies, generate the results for LCC, the unit cost of the natural resource and the quantity of natural resource saved.

Sizing parameters of the rooftop RWH system, run-off coefficient, diameter of pipe were identified [40]. The size of the underground tank and overhead tank depended on the rainwater saving parameter. Design method for units of the GWR system consisting of sedimentation tank up-flow, down-flow filters, wetland area and collection tank was followed as per NEERI's manual for GWR [5]. The number of tenements, toilets and wash basins decided the number of bib cocks, pillar cocks and health faucets.

Depending upon the heating water load the size of the solar water heating tank is decided. The ratio of cold water to the hot water mix was given by the following equation (1).

$$\frac{\text{Amount of cold water}}{\text{Amount of hot water}} = \frac{\text{Hot water temperature} - \text{Use water temperature}}{\text{Mean water temperature} - \text{Cold water temperature}} \quad (1)$$

The size of collector area was provided at the rate of 1 m^2 for obtaining 100 liters of hot water at 60 ^{0}c [41]. Sizing parameters of SPV include total electricity demand, confirming to Energy Conservation Building Code (ECBC) 2007 norms, array size depending upon solar insolation of the site of residential apartments and area of panels at the rate of 12 m^2 per kWp of array size. Required battery capacity (Ah) was calculated using equation (2).

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$$Ah = \frac{(Daily\ lighting\ demand * No.of\ back\ up\ days}{(voltage\ of\ battery * 0.65)} \quad (2)$$

Equation (3), based on Weibull distribution function was used to examine the performance of a wind turbine installed on a given site.

$$P_{e,ave} = P_{eR} * \left(\frac{e^{-\left(\frac{v_c}{c}\right)^k} - e^{-\left(\frac{v_r}{c}\right)^k}}{\left(\frac{v_r}{c}\right)^k - \left(\frac{v_c}{c}\right)^k} - e^{\left(\frac{v_f}{c}\right)^k} \right) \quad [3]$$

Where,

$P_{e,ave}$ and P_{eR} are the mean power output and rated power of a wind turbine.
v_c, v_r, v_f are the cut-in wind speed, rated wind speed and cut-off wind speed, respectively. k and c are Weibull distribution shape and scale parameters . The shape and scale factors were computed from equations (4) and (5) [42].

$$k = (\sigma / V_m)^{-1.086} \quad [4]$$

$$c = \frac{V_m k^{2.6674}}{0.184 + 0.816 k^{2.6674}} \quad [5]$$

Where,
'V_m' is the mean wind speed
'σ' is the standard deviation of wind speed.

Life cycle cost analysis (LCC) approach was identified to develop, design alternatives among the identified sustainable technologies. Following economic model (6) of the LCC was used [43].

LCC = I + Repl. – Res. + E + W + OM &R (6)

Where:
LCC = Present value of total life cycle cost
I = Present value investment costs
Repl = Present value of replacement costs
Res = Present value of residual cost
E = Present value of energy cost
W = Present value of water cost
OM & R = Present value of operation, maintenance & repair costs

LCC of RWH technique of water conservation consists of the capital cost of a rooftop RWH system, the operational cost of rooftop RWH system included the cost of chlorination and the cost of electricity required to pump the stored rainwater. Maintenance cost consists of labour cost for cleaning the terrace, maintenance of pump per annum (5 % of the total purchase price of the pump), cost of desludging of rainwater tank every three years. Replacement cost included replacement costs of strainers, filters, pumps and overhead tank.

Total costs of the GWR system during its life span consists of installation costs invested in GWR system components consisted of delivery pipe, chambers, gully traps, sedimentation tank, filters, collection tank, constructed wetland if required, pumps, pipes for circulation of treated greywater and overhead tanks [44]. The operation cost of the GWR treatment unit was calculated as the cost required for chlorination and cost of electricity required to pump the greywater at the rate of 30 liters per capita per day for toilet flushing. Maintenance cost of greywater reuse system consisted of maintenance of civil works (0.5% of the initial investment), Maintenance of the electromechanical equipment such as pump and electric work (3% of the initial investment). Labour cost was required for desludging equalization tank weekly, washing filter media every 10 days and cleaning of collection tank every 2 days [5, 45]. Replacement cost was for replacing filter media of up-flow, down-flow filter every year, replacing the pump for lifting treated reywater for recycling, replacing constructed wetland and the filter media of up-flow, down - flow filter [5, 44]. LCC of using LFDs consisted of installation cost which was considered as the difference in costs of conventional devices and LFDs. Maintenance cost of LFDs consisted of the cost of changing the aerators of faucets. The replacement cost of using LFDs consisted of the dual flush toilet, the cistern (4) and the bib cocks, pillar cocks, showerheads, and health faucets considering their lifespan.

LCC of thermosyphon SWH was calculated taking into account upfront cost, operating costs and maintenance costs (2 % of total installation cost) [46]. The total costs over the lifespan of SPV included the cost incurred on material purchase, transportation, handling and construction/installation of the energy component. It included costs of crystalline solar panels, batteries and inverter for storing energy and balance of system. The cost of the balance of the system was considered as 10% of the capital cost required for installing solar PVs [47, 48]. Replacement cost included replacement of the battery and inverter [49]. Residual cost of inverters was accounted [50]. In the modules of the wind turbine and hybrid energy (wind turbine + PV) also equation (6) was used [43]. The unit cost of natural resource was then calculated.

Carbon footprint during the operation period of each of the natural resource conservation techniques of material, water and energy conservation was calculated [51].

3. STRUCTURE OF SRRM TOOL

The SRRM tool interface was divided into two menu parts, 'Administration menu', and 'Activities menu'. The 'Administration menu' accommodated Module master, Rates master, Edit pump rate master, Formula master and light wattage master. 'Activity menu' allowed the user to create the new estimate, edit the estimate and to generate the results for the cluster of apartment buildings. 'Administration menu' captured the reference only data and configured the settings in order to influence the

'Activities menu' and 'Help menu'. It was created in the tool to make the user understand the structure and application of the tool.

Sample interfaces for Rates master and Formula master are shown in Figures 2 and 3. The developed interface for rates facilitated a user to add rates against tree-view elements.

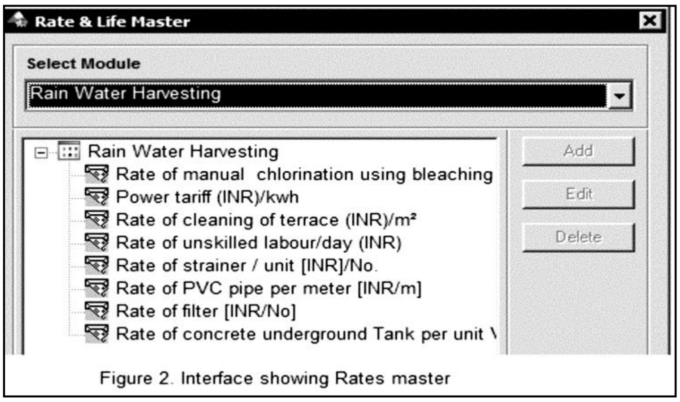


Fig- 2: Rate master

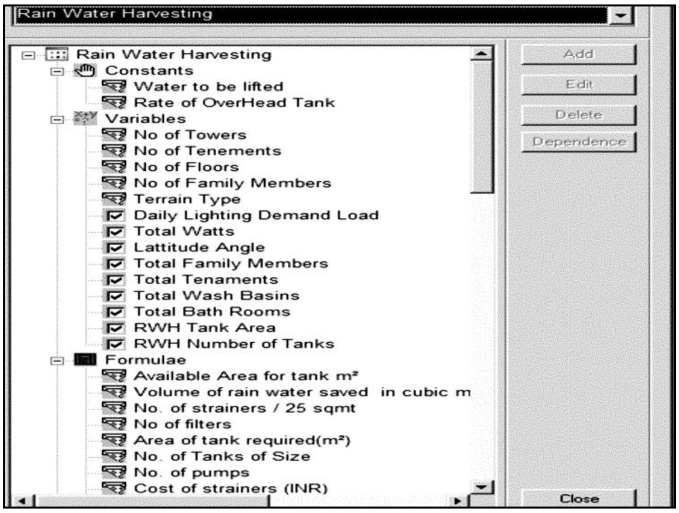


Fig- 3: Formula master

In a tree-like interface the elements were captured from 'Module master details' interface.

The components of a module configured as 'Computation', captured against the attribute 'Module type' was populated in this view. The 'Add' button becomes enabled when the cursor was on 'Constants', 'Variables' and 'Formulae'; the tree-elements. The interface of expression builder was created, which pop up when double clicked on the elements populated under the label 'Formulae' in a tree-view like interface of 'Formula master'. It comprised of 'Constants', 'Variables' and 'Formulae' to formulate the expression. The implementation of Formula Builder was carried out in two

parts front-end part and back-end part. The front-end was Power Builder a rapid application development tool from SAP and back-end was SQL Anywhere a database also from SAP. The front-end provided an easy to, understand user interface and back-end, which was invisible, housed the data, procedures and functions. The computation part of the expression was implemented at the database end in 'Functions' and 'Stored procedures'.

Activities menu allowed the activities like 'New estimate', 'Edit estimate' and 'Building cluster'. It also generated results for the cluster of buildings. The interfaces of input values and computed values were developed for each module separately.

The provision of generating results for each module was made in the computations windows using formulae captured against each module. SRRM also generated abstract of the results. Provision of what-if type of analysis was made in the interface of sensitivity analysis. Sensitive input parameters are required to be marked with 'Module master details' interface as sensitive. The SRRM tool was developed to generate graphical results of the economics of the sustainable technologies.

4. CASE STUDY

A case study of a housing scheme in Nagpur consists of a cluster of residential apartment buildings which is a (G+5) storied structure, and was selected for integration of identified sustainable technologies, for the conservation of construction material, water, and energy. Nagpur is located in the state of Maharashtra, India at the latitude of 21^0 06' N and the longitude $79^0$03' E, at an elevation of 310 m above MSL in the composite climate zone of India. Total plot area of the cluster is 9909.665 m^2. The plot has open spaces of 808.968 m^2 and 1011.064 m^2. There are buildings of type 'D' having 60 apartments (each having built-up area of 378.8 m^2), 'C' having 70 apartments (each having built-up area of 675.13 m^2), 'B' having 20 apartments (each having built-up area of 854.963m^2) and 'A' having 50 apartments (each having built-up area of 854.963m^2).

4.1 MODELING WITH SRRM TOOL

Figure 4 shows, the preliminary data interface of SRRM Tool, with the data for the 'D' type of apartment building of a case study. With a click on the button provided on this interface, lighting requirement to meet the standard illumination of 100 Lux in common areas of residential apartment buildings was given [52].

Total lighting demand was found 4150 Watt-hour considering lighting requirement for 10 hours. There was a choice of technologies from a module list as shown in Figure 5 to be implemented to the cluster of apartment buildings over the study area.

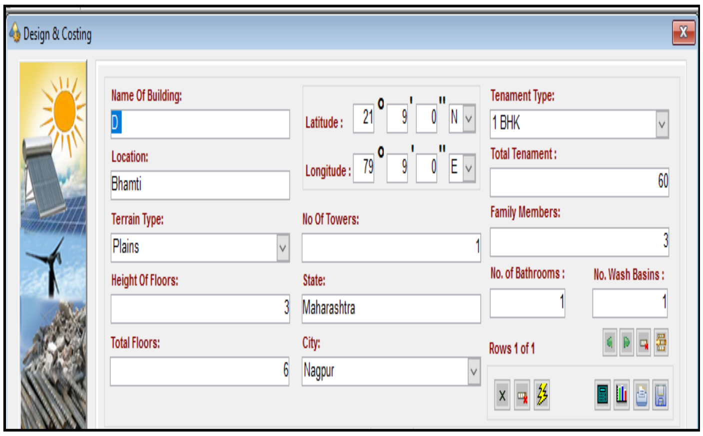


Fig- 4: Preliminary data interface of SRRM Tool

Rates of materials, labour and equipment were entered in Rates master for the base year 2015 for the selected modules. All the modules of material conservation and water conservation techniques were found feasible in this area in the city of Nagpur. Modules of energy conservation except for modules of use of the wind turbine and hybrid energy (solar PV + Wind turbine) were feasible, as the average annual wind speed at Nagpur was found 3.47m/s, less than the minimum wind speed of 4 m/sec, required for energy generation [53].

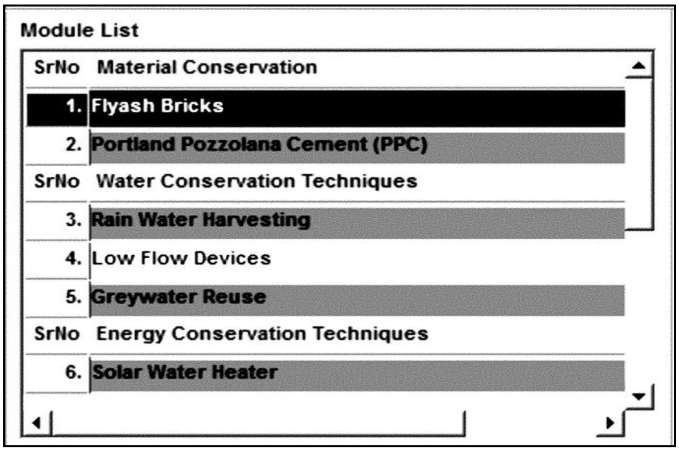


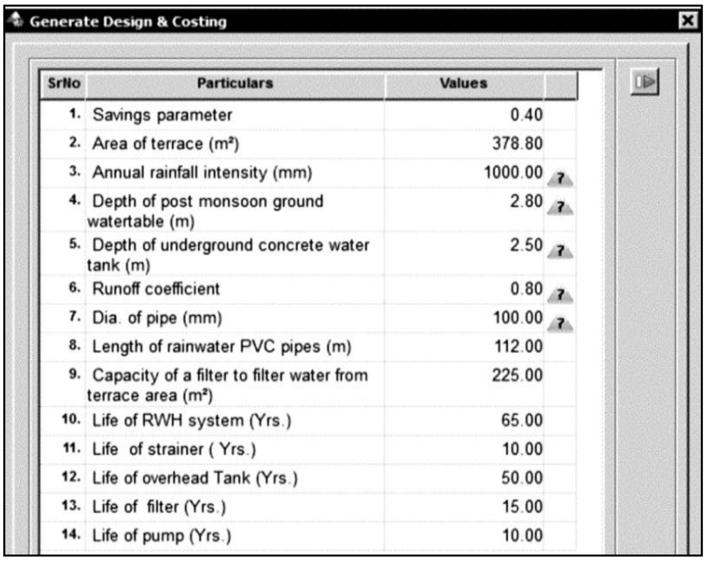
Fig- 5: Module list

For the module of fly ash bricks, input of total estimated quantity of the brickwork for building 'D' was given as 1985 m³. SRRM tool computed the total number of bricks of size 190 mm × 90 mm × 90 mm, total costs of FA bricks as INR44,29,031, saving in cost using FA bricks compared to burnt clay bricks as INR2, 60,531 and carbon emissions prevented using FA bricks as 500.22 MT. Input for the module of PPC was the number of cement bags of 50 kg, which generated the results of saving in cost using PPC as INR2, 29,170 and carbon emission as 110.77 MT.

For the module of RWH, the centrifugal pump was selected for the delivery head of 10 m, having discharge rate 720 liters/min, costing INR16, 400 for the lifting of rainwater, from 'Edit pump rate'. Snapshot in Figure 6 shows the input values required for the module of RWH.

The SRRM tool computes installation, maintenance, replacement costs, LCC, amount of water saved, unit cost of water saved and carbon emission as shown in Figures 7-9. In the module of the GWR, input values for 'D' type of apartment building were treatment parameter (0.6), project life (50), greywater generated per capita per day (45), the depth of the sedimentation tank (0.8), detention period (1.5 hours),

number of chambers (12), length of G.I. pipe of 40 mm diameter (156 m), length of UPVC pipe 150mm diameter (108m), the life of the pump , rates of material and labour for the base year 2015.


Generate Design & Costing

SrNo	Particulars	Values
1.	Savings parameter	0.40
2.	Area of terrace (m²)	378.80
3.	Annual rainfall intensity (mm)	1000.00
4.	Depth of post monsoon ground watertable (m)	2.80
5.	Depth of underground concrete water tank (m)	2.50
6.	Runoff coefficient	0.80
7.	Dia. of pipe (mm)	100.00
8.	Length of rainwater PVC pipes (m)	112.00
9.	Capacity of a filter to filter water from terrace area (m²)	225.00
10.	Life of RWH system (Yrs.)	65.00
11.	Life of strainer (Yrs.)	10.00
12.	Life of overhead Tank (Yrs.)	50.00
13.	Life of filter (Yrs.)	15.00
14.	Life of pump (Yrs.)	10.00

Fig- 6: Input values for RWH module

The computations consisted of sizes of sedimentation tank, filter chamber and costs required throughout the lifetime of the greywater treatment system. Carbon emission, the amount of water saved during the lifetime and hence the unit cost of water was also calculated. For the module of LFDs, input values required were the number of wash basins (1), toilets (1) per apartment and life of LFDs.

SrNo	Particulars	Computed Value
14.	Volume of rain water saved in cubic m.	121.22
15.	Area of tank required(m²)	48.49
16.	Available Area for tank m²	48.80
17.	No. of strainers / 25 sqmt	15.00
18.	No of filters	2.00
19.	No. of Tanks of Size	1.00
20.	No. of pumps	1.00
21.	Cost of strainers (INR)	2250.00
22.	Cost of pipes (INR)	14336.00
23.	Cost of Filters in (INR)	24500.00
24.	Cost of storage Tank in (INR)	223522.30
25.	Amount of Rainwater to be lifted (Lit)	2100.00
26.	Overhead Tank size (Lit)	2500.00
27.	Head of Pump Reqd.(m)	21.00
28.	Rate of Pump (INR)	16400.00
29.	Cost of pumps (INR)	16400.00
30.	Cost of selected overhead tank(INR)	16275.00
31.	Total Cost of Installations(INR)	297283.30
32.	Installation Cost of RWH/tenement (INR)	4955.00
33.	Life of RWH system (Yrs.)	65.00

Fig- 7: Computed values for RWH module 14-33

SrNo	Particulars	Computed Value
34.	Rate of manual chlorination using bleaching powder(INR)/kg	70.00
35.	Power tariff (INR)/kwh	7.12
36.	Rate of cleaning of terrace (INR)/m²	0.50
37.	Rate of unskilled labour/day (INR)	150.00
38.	Life of strainer (Yrs.)	10.00
39.	Life of overhead Tank (Yrs.)	50.00
40.	Life of filter (Yrs.)	15.00
41.	Life of pump (Yrs.)	10.00
42.	Amount of bleching powder reqd. (Kg)	0.36
43.	Cost of bleching powder per annum (INR)	25.20
44.	Cost of Chlorination during lifetime(INR)	11511.31
45.	Select a pump giving discharge Litre per minute	460.00
46.	HP of selected pump	3.00
47.	Wattage of pump (kw)	2.23
48.	Electricity reqd. to pump Rainwater (kWh / day)	0.17
49.	Electricity reqd. to pump Rainwater (kWh/month)	5.10
50.	Annual Cost of electricity for pumping water of Rainwater (INR)	435.74
51.	Cost of electricity for pumping rainwater to overhead tank during lifetime (INR)	2132384.00

Fig- 8: Computed values for RWH module 34-51

SRRM Computations generated results for the total installation, maintenance, replacement costs, LCC, the amount of water saved and the unit cost of water. Input parameters for the module of SWH module were the number of clear, sunny days (117), shadow-free area (378.8m²), average temperature of water in summer (30ºC) and winter (16º C), number of days of summer

SrNo	Particulars	Computed Value
52.	Total Operational cost(INR)	2143895.31
53.	Cost of replacing strainers (INR)	103029.10
54.	Cost of replacing filters (INR)	834594.07
55.	Cost of replacing pumps (INR)	750967.63
56.	Cost of replacing overhead tanks (INR)	16275.00
57.	Total replacement cost of overhead tanks during lifetime (INR)	554408.92
58.	Total replacement cost (INR)	2242999.72
59.	Cost of Cleaning of terrace/annum(INR)	189.40
60.	Cost of Cleaning of terrace in life time(INR)	926868.15
61.	No. of labourers reqd for desludging the tank	0.97
62.	Cost of desludging of tank per annum (INR)	145.50
63.	Cost of desludging of tank during the lifetime (INR)	236526.21
64.	Pumps maintenance (5% of Purchase price)per annum(INR)	820.00
65.	Pumps maintenance during lifetime(INR)	404999.96
66.	Total maintenance cost (INR)	1568394.32
67.	Life cycle cost (INR)	6252572.65
68.	Rainwater saved in (KL)	7879.04
69.	Unit cost of water (INR/m³)	793.57
70.	Carbon emission (MT)	1.35

Fig- 9: Computed values for RWH module 52-70

season (167), the number of days of the winter season (107), total length of G.I. pipe 50 mm diameter (207 m), project life (20 years), quality of water (hard) and subsidy provision (0%). The tool had provision of 'Help' to select ETC if the water is hard, FPC if the water is soft, FPC/ETC if the water is saline, ETC with PVC piping if the water is alkaline and FPC if there is hail storm. SRRM computed size of tank/tanks of SWH and collector. It provided LCC, the unit cost of electricity and the carbon emission saved.

Parameters required for sizing and costing of SPV were average annual solar radiation (5.2 kWh/m²), available rooftop area (348.8m²), daily lighting demand , a number of clear sunny days (98), life of the PV (25 years), battery (5 years), inverter (8 years), wattage of PV panel were input parameters, for the computations of array size, array load, required battery capacity, required wattage of inverter, area required for solar panels, the number of panels, installation, maintenance, replacement costs and residual cost of components, LCC, saving in energy, unit cost of energy, and carbon footprint.

Computations were generated in computed values windows individually for each module; sample of computations for RWH is presented in the snapshots in Figures 7-9, for 'D' type of building.

4.2 RESULTS

Figure 10 shows the abstract of results giving costs, carbon emissions of all the sustainable technologies integrated into 'D' type of apartment building.

The unit cost of energy saved using SPVs was found INR 11.16, preventing carbon emissions of 4.13 MT. The amount of energy saved during the lifespan of SWHs was 299541.81 kWh preventing considerable amount of carbon emission, 101.84MT. The LCCs of the GWR, use of LFDs and RWH were found as INR 1, 35, 05,055, INR 77, 47,355, INR 62, 52,572.5. The unit cost of water saved using techniques of the GWR, use of LFDs and RWH was found as INR 62.03/m^3, INR 32.76/m^3 and INR 833.36/m^3 respectively. The amount of carbon emission during the lifetime of techniques of GWR, RWH were found as 2.17 MT and 1.35 MT respectively.

Abstract of results for cluster of buildings, 'A', 'B', 'C' and 'D' type were also obtained as shown in Table 1.

SRRM tool generated graphical results for LCC of water and energy conservation techniques for individual building as well as for a cluster of apartment buildings. Figure 11 is the sample of pie diagram, a graphical view of the percentages of installation, operational, maintenance and replacement costs in the lifespan of RWH technique for a cluster of buildings 'A', 'B', 'C' and 'D'.

SRRM tool carried out a sensitivity analysis for water conservation and energy conservation techniques, keeping the rates as sensitive parameters. In the case study, it was found that the unit cost of SWH and dual flush toilet were the sensitive parameters of rates.

5. CONCLUSION

The developed SRRM tool is capable of designing the sizes, estimating the costs and carbon footprint of sustainable technologies used for conservation of natural resources. The tool was developed using LCC analysis approach which gave insight into the economics of the designed sustainable technologies throughout the lifetime. The tool is capable of calculating amount of water, energy savings and unit costs of water and energy. The user has a choice among modular technologies to select and integrate into residential apartment buildings. Sensitivity analysis of the tool enables to keep a tab on important rates affecting the unit cost of renewable resource. SRRM tool is useful for stakeholders to plan and take decisions for the integration of sustainable technologies into residential apartment buildings.

Print Preview

First | Prev | Next | Last | Print | SaveAs | Close

Name Of Building:	D			
Location	Total Floors	Height Of Floors	No Of Towers	Total Tenaments
Bhamti	6	3	1	60
Latitude & Longitude	Each Familiy Tenaments Members	Terrain Type	State	City
21° 9' 0" N 79° 9' 0" E	3	Plains	Maharashtra	Nagpur

		Conservation of Material		Energy		Water			
Sr No	Phd Module M Module Desc	Flyash Bricks	Portland Pozzolana Cement (PPC)	P.V.(Generating Electricity for lighting)	Solar Water Heater	Greywater Reuse	Low Flow Devices	Rain Water Harvesting	Total
1	Total Cost of Installations (INR)			181247	490697.59	331231.06	718140	297283.31	2018598.96
2	Total maintenance cost (INR)			173007.88	324507.63	8117848	1848105.13	1568394.38	12031863.02
3	Total Operational cost (INR)					1600212.75		2143895.25	3744108
4	Total Replacement Cost (INR)			769180.5		3455763.75	8770877	2242999.75	15238821
5	Life cycle cost (INR)			1101934.75	815205.25	13505055	7747355	6252572.5	29422122.5
6	Total Cost of Flyash Bricks[INR]	4429031							4429031
7	Cost of Pozzolana Cement (PPC)(INR		1986140						1986140
8	Amount of water saved (m^3)					217728	236520	7879.04	462127.04
9	Total Saving of Energy (kWh)			98701.2	299541.81				398243.01
10	Carbon emisssion prevented (MT)	500.22	110.77	4.13	101.84				716.96
11	Carbon emission (MT)					2.17	0	1.35	3.52
12	Unit cost of water (INR/m^3)					62.03	32.76	793.57	888.36
13	Unit cost of energy (INR/kWh)			11.16	2.72				0

Fig- 10: Abstract of results for 'D' type of building

Table – 1: Abstract of building cluster (A, B, C, D)

Sr. No.	Particulars	Conservation of material		Conservation of energy		Conservation of water			Grand total
		Fly ash bricks	PPC	P.V. Generating electricity	Solar water heater	Greywater	LFDs	RWH	
1.	Total cost of installation (INR)	---	---	584254	2416295.7	1642522.32	4227600	1670740.23	10541412.52
2.	Total maintenance cost (INR)	---	---	557694.98	1597942.66	44375825.5	10621293.63	8678557.38	65831314.15
3.	Total operational cost (INR)	----	---	----	---	8873868	----	7220151.13	16094019.13
4.	Total replacement cost (INR)	---	---	2557378.72		14976742.38	49260500	9625442.5	76420063.60
5.	Life cycle cost (INR)	---	---	3613325.07	4014238.75	69868957	42644664	27194890.5	147336075.32
6.	Total cost of fly ash bricks (INR)	13755656	---	----	---	----	---	----	13755656
7.	Cost of Portland pozzolana cement (INR)	-----	14368120	----	---	----	----	----	14368120
8.	Amount of water saved (m3)	-----	-----	----	----	1193472	1340280	47793.41	2581545.41
9.	Total saving of energy (kWh)	----	----	322077.60	1697573.27	----	----	----	2019650.87
10.	Carbon saving prevented (MT)	1553.58	801.3	13.58	577.17	-----	----	-----	2945.63
11.	Carbon emission (MT)	----	----	----	----	11.91	----	4.53	16.44
12.	Unit cost of water (INR/m³)	----	----	----	---	58.00	31.81	569.00	----
13.	Unit cost of energy (INR/kWh)	----	---	11.21	2.36	----	----	----	----

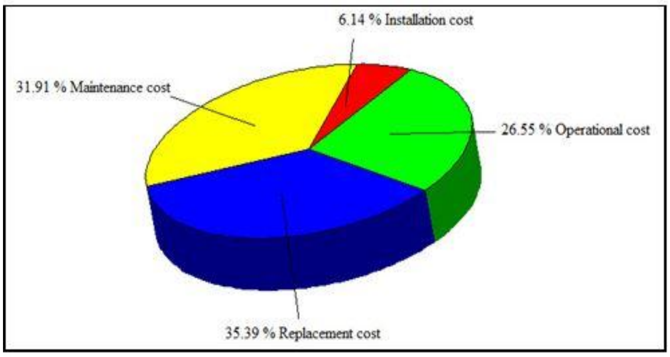


Fig-11: Pie diagram of LCC of RWH

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BIOGRAPHIES

Rijuta Bapat graduated in Civil Engineering in 1988. She is currently working as Associate Professor at L.A.D. College for Women, Nagpur, India. She earned Ph. D. in 2017 from Visweswaraya National Institute of Technology; Nagpur, India. Her main research fields are sustainable development and natural resources conservation. She is author of research papers in national and International journals. She is reviewer of research papers in international journals.

Rahul Ralegaonkar graduated in Civil Engineering in 1998.He earned Ph.D. from BITS, Pilani, India in 2005. He is presently Professor at Visweswaraya National Institute of Technology; Nagpur, India. He has to his credit D.S.T. sanctioned research projects. His main research areas are sustainability, energy conservation and natural resources conservation. He is author of more than 35 research papers in national and international journals. He is a reviewer for 3 international journals.

Vasant Mhaisalkar graduated in Civil Engineering in 1974. He earned Ph.D. in environmental engineering in 1987. He was scientist at National Environmental Engineering Research Institute, Nagpur, India for 15 years. Presently he is Professor at Visweswaraya National Institute of Technology; Nagpur, India. He has to his credit more than 85 research papers of national and international repute. He has many awards and honours to his credit. His main research areas are water supply and treatment, waste water engineering, environmental impact assessment, environment management and environmental engineering systems design.