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Harvested Rainwater Volume Estimation Using TANGKI NAHRIM Software: Calculation of the Optimum Tank Size in Terms of Water Security

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ABSTRACT

Water is fundamental to our quality of life, to economic growth and to environment. Rainwater is one of the primary sources of all usable water in the planet. Rainwater harvesting (RWH) is an ancient practice of capturing rain runoff from roofs and other surfaces and storing it for later purposes. A variety of issues, such as: i) Urban growth, ii) Limited water supplies, iii) Ageing stormwater infrastructure and iv) Environmental sustainability, have prompted a renewed interest in this practice, which has become common in the developed countries such as Germany, Japan, and Australia and in developing countries such as India and Malaysia. In this study, we use Tangki NAHRIM software to calculate the captured rainwater volume, optimum rainwater tank size; quantify the impact of rainwater demand, captured rainwater volume, and tanks in managing institutional water demand at IUKL Campus in Selangor – Malaysia. This project achieves several goals such as: i) Promote environmental awareness through actively participating in storm water management, ii) Utilizing rainwater collected from building's roof as a catchment area which deliver relatively clean water source, iii) Reduce reliance and consequently the pressure on municipal water resource and iv) Avoiding the use of relatively expensive water source for toilet flushing within non-potable category application.

INTRODUCTION

Rainwater harvesting (RWH) systems are used for thousands of years, especially in the areas where water supplies are limited by climate or infrastructure (Amin & Alazba 2011). RWH system is foreseen as a solution to several problems and is being promoted almost in every country as a sustainable mean. The real benefits of RWH exceed the domain of the needs of water for domestic or agricultural purposes. They also include water management, flood control, and aquifers' replenishment to name a few.

For thousands of years, RWH was integrated into ancient cultures all over the world, like the Anti Atlas region in Morocco, the Mayan Civilizations in Central America, and the isolated Pacific Island of Fiji (Gould and Nissen-Peterson, 1999). Developing an effective stormwater management system is imperative to help preventing the detrimental results from the increase of flooding. RWH is shown to unravel these flooding-related stormwater problems as well as provide a resource for water-stressed regions (Coombes and Kuczera, 2001a; Fewkes and Warm, 2000; Ragab *et al.*, 2003). It is estimated that over 100 million people in the world currently utilize RWH (Heggen, 2000). One of the notable strategies that is adopted by Malaysia is the "integrated stormwater management and green buildings: stormwater management and road tunnels (SMART)" (The United Nations World Water Development Report 2015). The UN report stresses on the needs and the challenges that require multi-sectorial, inclusive and comprehensive strategies, like "water-energy-food" planning (Connor, R., 2015).

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Considering the situational facts that rainwater is one of the purest forms of natural water that nature provides us delivered right on roof tops. Nevertheless, without proper water management this valuable and pure gift usually is wasted through its run off into storm water drains. Eventually ends up causing flood and soil erosion on its way to the rivers, aquifers and sea.

At present, Malaysia is blessed with abundant rainfalls and it primarily depends on rainwater falling over the country where it is collected into large reservoirs and as ground water (Sehgal, 2005). The countryside areas in South and South-East Asian countries are well known for their practice of rainwater harvesting and can be dated back to about the ninth or tenth century to the small-scale collection of rainwater from roofs and simple brush dam constructions. The average precipitation (Salmah, Z., *et al* 1999), estimated around 3,000 mm a year.

This paper presents a study about investigate the feasibility of implementing RWH system within IUKL Campus to promote the awareness and importance of water resources and to improve the management of sustainable water resources through the utilisation of rainwater in Malaysia. In this paper, we address the following problems:

1. IUKL Campus has a lot of buildings with large roof areas and contributes to a lot of stormwater.
2. Using high-quality water class for potable use and wasted for toilet flushing uses.
3. Paying potable water tariff which is normally high cost relatively for the toilet flushing purposes.

The objective of this research is to use harvested rainwater properly by calculating the optimum tank size of water security using TANGKI NAHRIM software.

MATERIALS AND METHODS

The methodology that is adopted to determine the potential RWH use for the study site is indicated in the flow chart in figure 1.

The area under investigation is infrastructure university Kuala Lumpur (IUKL), Tow study sites are selected among the IUKL camp blocks 5 and 9. A quantitative analysis is conducted to estimate the potential captured volume of rainwater for each selected building using Tanki NAHRIM software base on precipitation historical data 15 years and total water demand for non potable uses is calculated using the actual monthly water consumption for each building under study based on the meter reading, comparison of rainwater volume versus water demand to estimate rainwater storage tank.

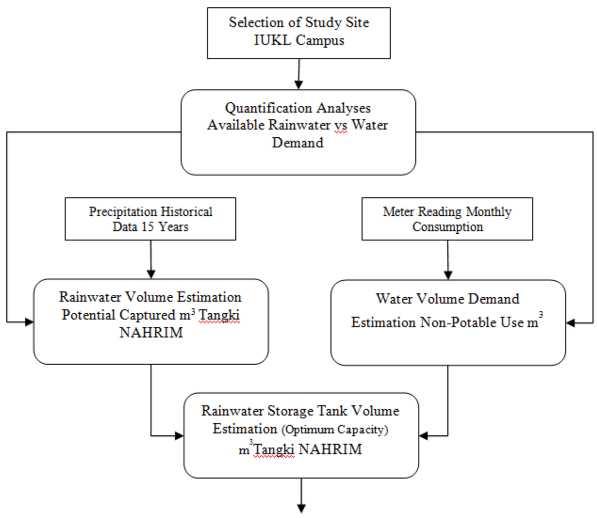

Fig. 1: conceptual framework for assessing RWH installation at the IUKL campus site.

Study Area

The area under investigation is the main Infrastructure University Kuala Lumpur IUKL campus whichare located in Bangi, within Selangor state, Malaysia. The building blocks number 5 and number 9 are part of the Main IUKL Campus, (Figure 2) with roof areas of 926 m^2 and 1382 m^2, respectively.

The implementation of the project started by studying and inspecting all of the available buildings within the campus site. It is decided to start with two blocks within IUKL campus site. These buildings were Block 5 and Block 9.

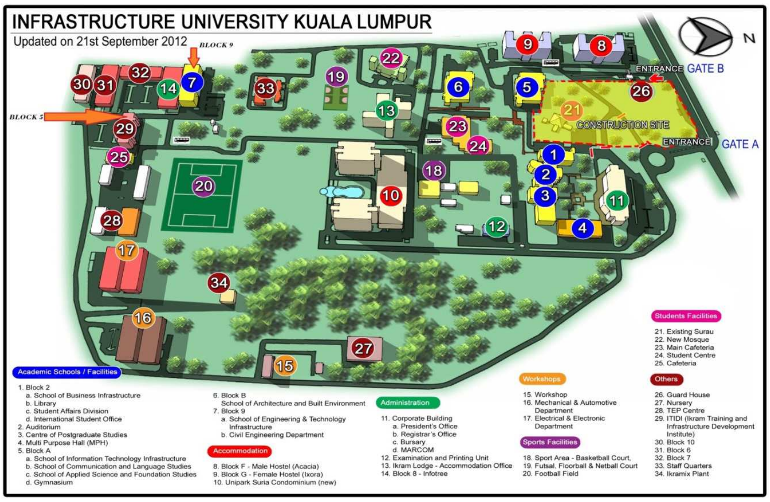

Fig. 2: IUKL Campus Site: Buildings Layout and Functions.

Rainwater Quantity Analysis:

Rainwater quantification considers collecting the necessary data, starting from the selected site, buildings functionality, and particular data pertinent to the addressed research topic. Alos, previous precipitation daily records, in order to estimate the potentially captured volume of rainwater; water usage profile for each selected building, to estimate water demand; and comparison of rainwater volume versus water demand, to estimate rainwater storage tank volume.

Rainwater Volume Estimation:

The quantity of rainwater volume analysis significantly depends on the quality of the weather input data. For purposes of this research, data was obtained from the Malaysian Meteorological Department (MMD) of the Ministry of Science, Technology, and Innovation (MOSTI). As most suitable for this research, PORM BANGI Weather Station was selected, as it is a part of the National Weather Station network, which is located 500 meters to the south of the IUKL Campus border.

For the purpose of this research, daily precipitation data for the period 2000-2014 was used. The focus of the analysis was on monthly mean values, in order to define annual precipitation regime, along with maximal daily values, in order to define extreme values.

Water Volume Demand Estimation:

Records of water usage data were obtained from the Administration Office at IUKL University. 2014 average water volume pumped from the municipal water station for the two selected building blocks 5 and 9, within the university campus, was 3561 m^3 and 7552 m^3 per year, respectively of disinfected potable water per year. With an estimated population of over 300 and 800 persons attending the building during working hours at block 5 and 9, respectively, the average water consumption equates to 45 and 42 liters/person/day, respectively.

IUKL University is in many ways like a small town, meaning that there are different types of buildings with different design codes for water usage. Furthermore, water demand varies with the type of building, and therefore buildings in the IUKL were sectorally categorizedto determine the amount of water used for flushing toilets.

Even though water usage data was provided for each building on the IUKL, the percentage of used water for potable and non-potable sources is not measured separately at IUKL University campus site. Therefore, the proportion of used water for non-potable uses was estimated to be 37% for office building (Block 5) (WaterSense at Office Buildings 2012) and 45% for

institutional building (Block 9) (WaterSense at Educational Facilities 2012),based on previous research (AWWARF, 1999; PI, 2003).

Rainwater Storage Tank Volume Estimation (Rainwater versus Demand):

For the purpose of the research, this analysis considers: water balance determination for Block 5 and Block 9 buildings using monthly rainfall data; and harvested rainwater storage sizing using annual and monthly demand assessment in Tangki NAHRIM software.

Monthly Water Balance for Block 5 and Block 9 Buildings:

To calculate the RWH potential supply, it is necessary to determine a water balance for both selected blocks 5 and 9. Firstly, the monthly rainwater supply is calculated using the monthly rainfall data for IUKL university campus, Selangor State-Malaysia. Blocks 5 and 9's total roof area in square meters (m^2), and the following equation (Mohammed, T. A., et. al., 2007):

$$RainwaterPotentialSupply = Precipitation * Kroof * \mathrm{A} \quad (1)$$

Where, $Kroof$ = 0.9 because the first 10% of rainwater typically is lost to initial abstractions such as transpiration, evaporation, and surface wetting (Malaysian EF). The toilet water usage demand for the selected buildings (Blocks 5 and 9) is calculated by assuming that each of the "design building occupants" would flush a toilet three times a day at 6 liters per flush. By collecting and utilizing 1209 m^3 and 2737 m^3 of the rainwater that runs off the (Blocks 5 and 9) buildings, between 37% and 45% of the potable water used for flushing toilets could be conserved, for Blocks 5 and 9, respectively.

Harvested Rainwater Storage Sizing:

There is a standardized approach to define the size of rainwater harvesting storage, which takes into consideration the estimated precipitation volume that is bearing the timing of water consumption/demand. In fact, the software has been developed by the National Hydraulic Research Institute of Malaysia (NAHRIM), and it has been called Tangki NAHRIM. The approach that is used in this research considers at the beginning an annual assessment and downscaling in time to a weekly water balance to clarify the precipitation water demand discrepancies at different temporal storage capacities. Additionally, the multi-temporal analysis is intended to focus on the need for a weekly water balance approach to analyz and design RWH systems for use at IUKL campus.

To conduct the technical analyses; precipitation data records for Bangi and the annual water consumption data for IUKL were obtained. The monthly water consumption data were summed to the annual level. Then the use of water for non-potable purposes were calculated based on the function of the buildings under study. Two criteria based on the European standards were adopted from the literature. Finally, the area of the rooftops for the two selected buildings were used to develop the daily water balance study.

The daily precipitation data were summed to the annual level (by calendar year)and multiplied by the area of each of the selected building for study (1382 m^2 and 926 m^2) to determine the annual precipitation volume that is associated with these selected buildings. Annual comparison of the precipitation volume and annual water use volume (based on the year 2014 meter records) was performed as an initial assessment of the required amount of water that could be potentially available and supplied by captured rainwater specific to these buildings. Building function estimated the number of occupants, holidays, summer and semester breaks were all taken into consideration in calculating the water use. This rate is based on the Malaysian guideline of water resources recommended consumption for sanitation purposes.

Tangki NAHRIM Software Package:

The main objective of developing this software, named Tangki NAHRIM, by the National Hydraulic Research Institute of Malaysia (NAHRIM) was to serve as a guide to estimate the best size for rainwater tank. However, the development of this software led to additional favorable features and capabilities.

Based on historical precipitation data, the dimension of the catchment area and the required/expected water demand for a hypothetical tank size, the software can calculate the amount of captured rainwater, total rainwater volume delivered reliability of the system, utilization coefficient of rainwater, storage efficiency, and the status where the tank is empty as a percentage time. Moreover, the software can provide an estimation of monthly water availability as a reliability indicator. The domain of application of the software can be expanded by adding additional station to the code and/or precipitation data to explore the various areas according to the user interest and availability of data for a certain location.

The basic idea of Tangki NAHRIM is the water balance between potential availability and probable consumption:

$$I - O = \frac{dS}{dt} \quad (2)$$

Where S is a volume of rainwater stored in the tank, $I$is the inflow rate to the storage tank, and O is the outflow rate from the storage tank. The water balance accounts for inflows to and outflows from the storage system to compute the daily change in the stored amount of harvested rainwater. The inflow volume is based on calculating the amount of precipitation that can be captured, where the runoff volume in (m^3) based on the daily precipitation amount in (mm), the runoff coefficient, and the catchment area in (m^2). The rooftop runoff coefficient can range depending on the material of the roof cover and slope. A typically assumed value of 0.9 was used to represent rooftops surface based on the engineering practice.

The volume of outflow is estimated to be the daily water demand. The total water demand is calculated using the actual water monthly consumption for each building under study based on the meter records for the year 2014. Then the average daily water use amount was calculated by taking into consideration, the non-potable portion of water use in toilet flushing, the number of holidays, summer breaks, semester break, and the weekend days.

Moreover, Tangki NAHRIM software is designed to study the impacts of tank size change on the technical feasibility of RWH in IUKL. The explicit representation of the daily water demand in Bangi area permits those variables to be modified to represent future conditions and then to use Tangki NAHRIM to determine the performance (percent of water demand provided by captured precipitation) based on the modified tank size.

RWH System Performance measure:

From the acquired data of the software, the user can conclude three performance measures ('reliability', 'satisfaction' and 'efficiency') associated with each selected tank size. These measures can be interpreted as per the need of the RWH user and defined as;

1) A high 'reliability' means that the RWH user will not need to fetch extra water from another source for most of the year.
2) A high 'satisfaction' means that most of the RWH's water can come from its RWH tank.
3) A high 'efficiency' means that most of the roof run-off is being used, little is being wasted by overflowing the tank andwhich imply that the performance is 'roof limited'.

RESULTS AND DISCUSSION

All of the figures and graphs that represent the analysis results depict the fact that rainwater catchment that is used for some type of indoor water use reduces the institutional building’s effect directly on water supply and indirectly on the stormwater system.

This research work presents arguments for the use of rainwater catchment as a proactive way to mitigate numerous impacts of the built environment. The benefits that are related to rainwater catchment will hopefully outweigh the costs associated with such practices.

The adopted software package ‘Tangki NAHRIM’ shows many interactions related to water use and storage tank size. One of the most surprising results of the study was the toilet scenario, with a 25 m^3 storage tank for the water use scenario in block 5. The 25 m^3 storage tank was large enough to work successfully for this scenario, diverting all of the stormwater being discharged from block 5. If rainwater is used to flush toilets alone, the 25 m^3 storage tank will work for the entire year. Similarly, Block 9 with 75m^3storage tank can divert the stormwater being discharged from Block 9 in a year, considering roof area and population for this block 9.

For this study of Blocks 5 and 9, this equates to diverting 3946 $m^3$of stormwater per year from only 2308 m^2 of roof areas of Block 5 and Block 9, thereby saving 3946 $m^3$from being withdrawn from the watershed (based on an average diverting 1209 m^3 for Block 5 and 2737 m^3 for Block 9 per year).

Site Data Calculations:

To evaluate the effectiveness of installing rainwater harvesting system, the study must involve at first, the site precipitation profile, roof characteristics, water demands, and finally the water demand for the intended purpose or use, as in our case, toilet flushing and general cleaning. The selected buildings for this research where chosen to be Blocks 5 and 9.

Site Data and Results for Block 5:

Block 5 is an office building with 300 occupants approximately, the roof area is 926 m^2, and the material of the roof qualify it for 0.9 as runoff coefficient. Using this basic information for the site, water demand from the meter reading for the year 2014 and the precipitation data of the area, with the building function in mind. For the rainwater yield, Tangki NAHRIM software is used to estimate the potential rainwater that can be captured annually and calculated on an average bases taken for the past 15 years precipitation data (from the year 2000 to the year 2014). From the water demand of the building during the year 2014 and the function of the building (Office building), the toilet flushing percentage was taken to be 37% of the total water used. The tank size was chosen to provide one week (5 working days) of water supply sourced from rainwater, which is, according to the demand, is chosen to be 25m^3.

Figure 3 shows Block 5: simulation input data for Tangi NAHRIM software

Figure 4 shows Block5 Tanki NAHRIM simulation result**.** While Figure 5 illustrates the monthly reliability and tank status when tank size 25m^3

Site Data and Results for Block 9:

Block 9 is an institutional building with 800 occupants approximately, the roof area is 1382 m^2, and the material of the roof qualify it for 0.9 as runoff coefficient. Using this basic information for the site, water demand from the meter reading for the year 2014 and the precipitation data of the area, with the building function in mind. The water demand Tangki NAHRIM software was used to calculate the potential rainwater that can be captured annually calculated on an average bases taking in consideration the past 6 years precipitation data (from the year 2009 to the year 2014) which reflects the age of the building. From the water demand of the building during the year 2014 and the function of the building (institutional building), the toilet flushing percentage was taken to be 45% of the total water used. The tank size was chosen to provide one week (5 working days) of water supply sourced from rainwater, which is according to the demand was chosen to be 75 m^3.

Figure 6 shows Block 9 simulation input data for Tangi NAHRIM program

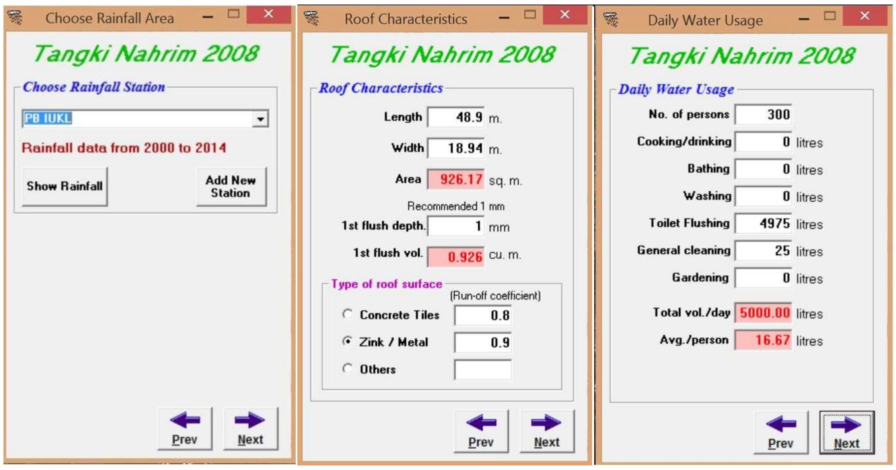

Fig. 3: Input data for Tanki NAHRIM software are rooftop dimensions for area calculation, first flush depth, Type of roof surface, No. of persons as water consumer, Daily required water for toilet flushing and general cleaning, and tank size (25m^3).

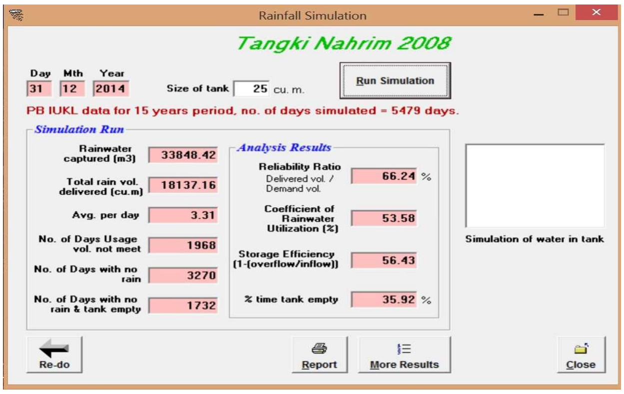

Fig. 4: Tanki NAHRIM output data, reports the total captured rainwater based on the roof dimension and the precipitation data, total delivered rainwater based on the rainwater data profile and selected tank size, average daily availability, reliability ratio, rainwater utilization percentage, and storage efficiency based on selected tank size.

Figure 7 shows Block 9 simulation result of Tangi NAHRIM program. While Figure 8 illustrates the monthly reliability and tank status when tank size 75m^3

Table 1 shows the results of basic parameters of Block 5 and 9.

The outcomes of the research was to proof that technology play a major role to mitigate the risk of water shortage by applying the RWH system which is alighned with previous study (Che-Ani A.I, et. al., 2009). The calculation of this work was based on the proportion of used water for non-potable uses was estimated to be 37% for office building (Block 5) (WaterSense at Office Buildings 2012) and 45% for institutional building (Block 9) (WaterSense at Educational Facilities 2012), based on previous research (AWWARF, 1999; PI, 2003). As of the result shows the high percentage can cover the demand for toilet flush and general cleaning in the selected buildings; Block 5 and Block 9, respectively by obtaining 93% and 81% of the nonpotable water and sufficient to reduce flooding as confirmed in Shaaban A.J., (2009), and will participate in green technology (Choo Lan, 2007), in addition to prevent enter the drainage system and avoid the blockage (A. J. Shaaban, H. et. Al. 2007) .

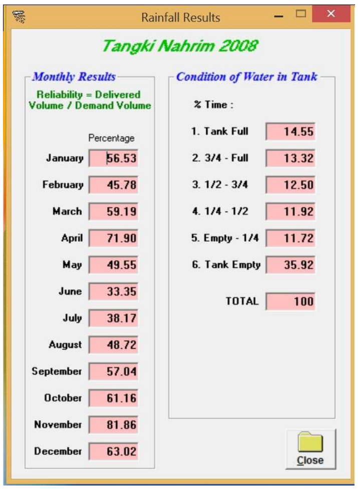

Fig. 5: Monthly reliability and tank status when tank size 25m^3.

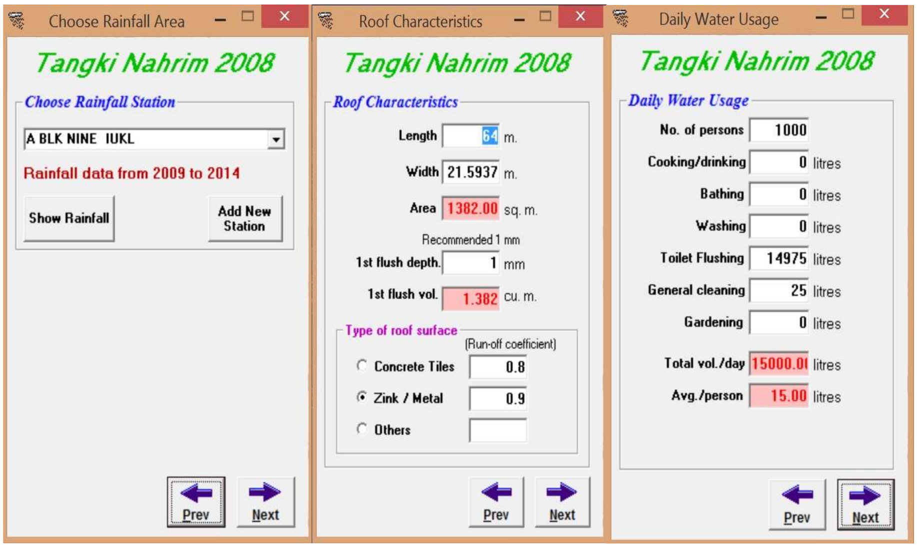

Fig. 6: Input data for Tanki NAHRIM software are rooftop dimensions for area calculation, first flush depth, Type of roof surface, No. of persons as water consumer, Daily required water for toilet flushing and general cleaning, and tank size (75m^3).

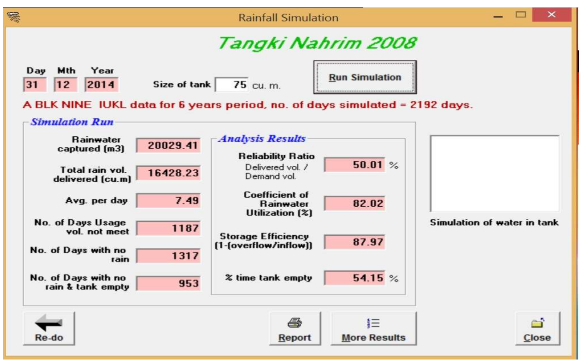

Fig. 7: Tanki NAHRIM output data, reports the total captured rainwater based on the roof dimension and the precipitation data, total delivered rainwater based on the rainwater data profile and selected tank size, average daily availability, reliability ratio, rainwater utilization percentage, and storage efficiency based on selected tank size.

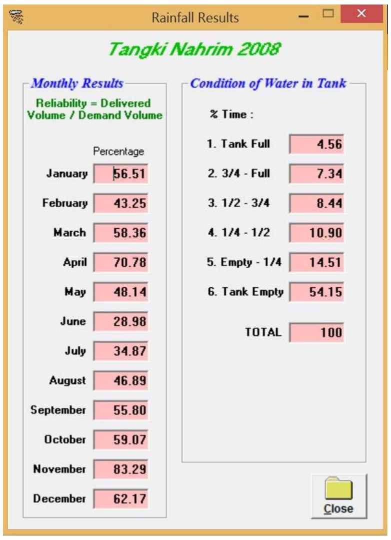

Fig. 8: Monthly reliability and tank status when tank size 75m^3.

Table 1: Basic parameters of selected buildings as study sites Blocks 5 and 9.

No	Parameters	Block 5	Block 9
1	Building Type / Function	Office	Educational
2	Water Demand Criteria for Toilet Flush % of the Total Water Consumption BFP BFP = Building Function Percentage	37%	45%
3	Roof Area (m^2)	926	1382
4	Roof Type	Metal - Coated	Metal – Coated
5	Runoff Coefficient	0.9	0.9
6	Number of Years for Simulation	15	6
7	Number of Days for Simulation	5479	2192
8	Water Consumption/Demand: (Source: Meter Reading) Annual Water Consumption (m^3) Av. Monthly Water Consumption (m^3) Av. Daily Water Consumption (m^3)	3561 297 9.76	7552 594 20.7
9	Number of Working Days (NWD) Days	261	226
10	Effective Daily Water Demand (m^3): Annual Water Demand (m^3)/ NWD	13.65	33.42
11	Daily Water Demand/Toilet Flush m^3 = EDWD x BFP m^3	5	15
12	Estimated Daily Rainwater (m^3): Estimated Delivered Rainwater (m^3) / Number of Simulation days	$\frac{18137}{5479} = 3.31$	$\frac{16429}{2192} = 7.5$
13	Effective Available Daily Rainwater (m^3): Annual Water Demand (m^3)/ NWD	$\left[3.31\ x \frac{365}{261}\right] = 4.63$	$\left[7.5\ x \frac{365}{226}\right] = 12.11$
14	Estimated Demand Percentage	%93	%81
15	Estimated Annual Saving of Water (m^3)	≈ 1209	≈ 2737

Conclusion:

Demand on water resources is expected to increase dramatically in the near future due to the population growth and expansion of urbanization, industrialization and irrigated agriculture. Adopting the concept of sustainability and conservation of water resources can help to cope with the global water shortage.

With these result, it was clearly established that rainwater utilization contributes to the economic viability of implementing the RWH system. Successful implementation of rainwater harvesting system at IUKL Campus is a significant contribution to future rainwater harvesting system development. More important, it will also support the development of a sustainable approach to any building in Malaysia. Universities, governmental research entities, and government agencies are playing an important role to promote the practice of installing RWH system and offering incentives for fees of concerned authorities.

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