# WATER EFFICIENCY TECHNIQUES AND STRATEGIES FOR SUSTAINABLE USE OF WATER DURING CONSTRUCTION PHASE OF BUILDING PROJECTS

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## *ABSTRACT*

*A significant wastage and misuse of water in construction sites has been identified as a critical problem by previous researchers. However this aspect has not been well explored in the current literature. Therefore, this paper aims to explore the appropriate techniques and strategies to be adopted in construction sites for efficient water use. Moreover, the ways and means of sustainable use of water in construction projects is suggested. Various techniques and strategies of efficient water use were identified through a literature review and taken to the professionals involved in construction through a structured questionnaire survey to identify and rank their relevance to construction. Data was analysed through descriptive statistics and non-parametric tests using SPSS software. The findings of this study highlight the top five applicable water efficiency techniques to be: water audits, water leak detection and monitoring systems, pressure reduction valves, high pressure trigger operated spray gun hoses and sub-metering.The top five applicable strategies were: monitoring and supervision, implement environmental policies on natural resources, enhance water awareness among workers, assign responsibility and targets among the site staff and introduce water action plan at the beginning of the project.In addition, the paper discusses the professionals' views on practical implications of improving the uptake of water efficiency techniques and strategies. Cost was identified as the main barrier for implementing water efficiency practices in Sri Lanka.*

***Keywords:*** *Construction; Strategies; Techniques; Water efficiency.*

## 1. INTRODUCTION

"Development of new sustainable competencies and technologies will present fundamental challenges for virtually every industry in the recent decades (Hart, 1995: 1003)". There is a growing need for the construction sector to adopt principles of sustainability in their policies and day to day activities (Walton *et al*, 2005; Xing *et al.*, 2007). Henceforth, Architects, Surveyors, Engineers, Project managers and other professionals who are responsible for decisions are expected to use sustainable solutions throughout the different stages of a construction project (Xing *et al*, 2007). As the construction stage transfers the design into reality, it involves the utilization of variety of natural resources including water. Therefore, activities happening during the construction stage have a close association with environmental impacts including generation of waste and pollution (Shen *et al.*, 2007).

Baxter *et al.*, (2004) categorised impacts of a project into economic, environmental, natural resources consumption and social. Natural resources such as water, fossil fuel, and land are amongst the most important to consider in sustainability assessment (Xing *et al.*, 2007). Waidyasekara *et al*, (2013) compared eleven sustainability assessment tools and found only two, namely Building Research Establishment's Environmental Assessment Method (BREEAM) of UK and Green Rating for Integrated Habitat Assessment (GRIHA) of India, have included water efficiency during construction phase in their assessment criteria. Since construction is considered to be a water intensive industry, its inclusion in

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environmental assessment tools will be an effective way of controlling it. For instance, the simple step of effectively monitoring water use on site will deliver direct benefits to all concerned. It is a known factor that water resource are scarce and water efficiency and conservation are increasingly being discussed as a way of protecting this valuable natural resource. Construction industry is becoming very sensitive to the need to be more environmentally responsible and is seeking ways and means of conducting itself to minimize negative environmental impacts (Kibert, 1994). Nevertheless, the strategic forum for construction (SFfC) has identified that relatively little work has been carried out on water sustainability on construction sites as water use is generally considered to be a low priority by its stakeholders (Waylen *et al.,* 2011). Strategies for Sustainable Construction published in 2008 highlighted the issues of water use and included number of targets (Waylen, *et al.,* 2011). Waste and Resource Action Programme (WRAP) found water efficiency practices during construction can save £200,000 per year on water costs to a large scale contractor in UK (McNab, *et al.,* 2011).

In Sri Lanka, various sustainability techniques and management skills have been implemented in construction projects to achieve project goals. However, literature provide evidence that water efficient techniques and strategies are yet to become commonplace (Waidyasekara *et al,* 2014).

In order to identify the importance of water efficiency and the ways and means of implementing it during construction, more research is necessary in the Sri Lankan context. Therefore, this study aims to obtain views from professionals on water efficiency techniques, and strategies for sustainable use of water during construction. This study refer to sustainable use of water as optimum use of water resource (i.e reduce water wastage and inefficient activities/processes) with minimum damage to ecosystem in view of preserving it for future generations.

## 2. LITERATURE REVIEW

### *2.1. WATER MANAGEMENT, WATER EFFICIENCY AND WATER CONSERVATION*

Water is one of the most important resources related with human life and economic activities. Reducing water use both save money and preserve this invaluable natural resource. Recent environmental research has warned that water resources are under pressure and current levels of water abstraction are unsustainable in many countries. In the coming years the combined effects of climate change, increasing population growth and rapid industrial developments will put further pressure on water resources. Thus, water management, efficiency and conservation are essential elements in sustainability.

Optimum use of water covers both conservation and efficiency and includes planning, monitoring and controlling. Water resource management try to optimize the use of water and minimize the environmental impacts associated with its use (Biswas, 2008). As Brooks (2007) argues, water efficiency (WE) and water conservation (WC) are two different concepts although interchangeably used in the literature. Dexter (2011) describes that conservation demands to do less by sacrificing the needs whereas efficiency deals with doing more with less. Similarly, National Cleaner Production Centre (NCPC) of Sri Lanka (2012) observes that WE focuses on achieving the same result with the minimal amount of water usage while WC aim towards reducing the wastage of water.   Thus, water conservation relies on individuals to change their behaviour to achieve results; while water efficiency encourages using best available technology and innovative ideas to achieve long-term water sustainability without sacrificing the present needs (Dexter, 2011). In addition to the reduction in loss and waste, the concept of water efficiency is also supported by innovative ideas and modern technologies such as reuse, recycle, and alternative sources. Therefore, as stated by Dexter (2011) water efficiency is a smart investment for future, which is the most significant water management strategy instead of solitary water conservation. In addition, Cohen et al. (2009) described that management of water quality is also a part of water management. Department of energy of United States (2011) identified that managing available water resources and satisfying water demand (water quantity) are also basic principles of a good water management. Waste and Resource Action Programme (WRAP) identified four principles of water efficiency as: monitor and manage, reduce use, minimize water and replace potable water with grey or rainwater ( McNab *et al.,* 2011). According to the definition given by WRAP, water efficiency overlaps with some characteristics of water conservation. Thus, based on the existing literature, the authors identified key activities that fall under the water management with a filtering process as illustrated in Figure 1. These key activities are not fully independent as it could be seen closely linked each other to fulfil the objective of water management while it is being controlled by external factors such as behaviour, policies, rules and regulations, and cost for a better output. It is clear that water management is very broad and it covers many aspects. This study refers to water efficiency instead of water management as it aligns with the four principles identified by WRAP in addition to WE's general explanation.

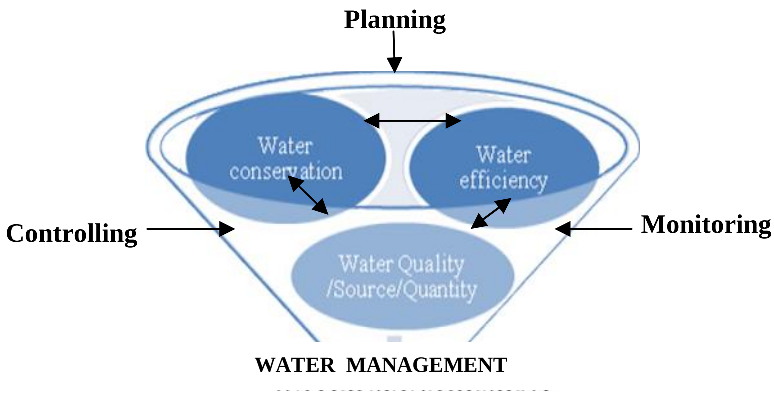


Figure 1: Key Activities of Water Management Process

### 2.2. *WATER EFFICIENCY TECHNIQUES, TECHNOLOGIES AND STRATEGIES*

Techniques and technologies are closely related but have different meanings. Aggazy (1998) explained techniques to mean a display of practical abilities that allow one to perform easily and efficiently in a given activity (be it purely material or bound to certain mental attitudes). Technology, on one hand, as being included in the domain of technique, while on the other, set off by specific traits (Aggazy, 1998). Technology is the application of scientific principles and people have different techniques of making use of the same technology. Bourg (2010) clearly stated that human factor is critical to obtaining the desired results from water conservation strategies. According to the United States General Services Administration (1999), successful water management consider both technical (installing efficient fixtures) and human (behaviour and expectations) aspects. Installing a retrofit device or replacing outdated technology or fixtures alone might not produce expected water savings unless user behaviour is improved.

Water management strategies are categorised into three areas as: reducing losses, reducing water quantity and reusing water. According to Department of Energy (DOE) of USA (2011) water efficiency implementation starts with understanding of water use facility and water use pattern and then developing a water management plan. As Cohen *et al.* (2009) highlighted, effective water management offers economic, environmental and social benefits also. Technologies and techniques will help achieve certain strategies to make efficient use of water in certain instances. Water efficiency tool allow the user to identify targets for water efficiency in building designs and to compare and specify certain water appliances (McNab, 2011).Water efficient plumbing fixtures, waterless urinals, low-flow and sensored sinks, taps and showers, dual flushing systems, water efficient dishwashers and washing machines, water efficient landscaping and irrigation systems, water recycling and reuse measures, gray water and process recycling are some technologies, and techniques commonly used to reduce water use in a building (Bourg, 2010; McNab,2011). Thus, it could be observed that certain overlaps exist with techniques, technologies and strategies. The study refers techniques instead of using terms of technologies and techniques.

### 2.3. *SUSTAINABLE CONSTRUCTION AND SUSTAINABLE USE OF WATER RESOURCE*

Previous studies have shown that construction industry and its activities have significant effects on the environment (Shen *et al.* 2007; Ding *et al.* 2004; Sjostrom and Bakens, 1999; Kibert, 1994). Construction activity makes extensive use of natural resources, energy, and water (Balio, 2003). Although various techniques and management skills have been used in construction projects to improve sustainable performance, these techniques seem not being effectively implemented due to the fragmentation and poor coordination among construction stakeholders (Shen *et al.*, 2007). Moreover, Shen et al (2007) identified lack of consistency and a holistic approach to help participants implement sustainable construction practice at various stages of a project. Theo (2003) emphasizes the importance of commitment of the management staff for its success. The first step in the process of establishing evaluation tools or techniques is to set forth the issues that are encompassed by sustainable construction. Kibert (1994) identified common issues in sustainable construction (SC) and categorized them into four main groups as shown in Table 1. This shows water use during construction as a sub- theme in sustainable construction. Table 2 illustrates key principles of SC.

Table 1: Issues of Sustainable Construction (SC)

| Main Issues | Sub-issues |
|---|---|
| **Resources** | Energy Consumption<br>**Water Use**<br>Land Use<br>Materials Selection |
| **Healthy environment** | Indoor Environmental Quality<br>Exterior Environmental Quality |
| **Design** | Building Design<br>Community Design |
| **Environmental effects** | **Construction Operations**<br>Life Cycle Operation<br>Deconstruction |

Source: Kibert (1994)

Table 2: Principles of SC

| Sustainable Construction Principles |
|---|
| **Minimize resource consumption (Conserve)** |
| **Maximize resources reuse (Reuse)** |
| **Use renewable or recyclable resources'** |
| **Protect the natural environment** |
| **Create a healthy, non-toxic environment** |
| **Pursue quality in creating the built environment** |

Source: Kibert (1994)

There is no motivation for conservation of air and water since they are not privately owned (Daly, 1993). In the past, the criteria for energy and water resources were not connected to one another, to materials selection, or to the other issues of sustainable construction (Kibert, 1994). Water was just considered to be another input in construction projects (Kibert, 1994). Kibert separated construction industry into two layers. Layer one consists of parties who has the most influence on the physical content and creation of the built environment: architects, engineers and builders. Layer two consists of sustainable construction which is just one component of creating an overall sustainable environment. As stated by Kibert (1994), construction industry must change its historical methods of operating with little or no regard for environmental impacts. It should embrace a new mode where environmental concerns should become a centerpiece of its efforts.

Water is as an integral part of the ecosystem, a natural resource and a social and economic good (Zbigniew and Kundzewicz, 1997; Gleick, 1998). Gleick et al. (1995 cited Gleick, 1998) offers a working definition of sustainable water use as "the use of water that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of the hydrological cycle or the ecological systems that depend on it". The current study refers sustainable use of water as optimum use of water resource (i.e reduce water wastage and inefficient activities/processes) with minimum damage to ecosystem and preserve it for future generation. Zbigniew and Kundzewicz (1997) explain that the availability of water in adequate quantity and quality is a necessary condition for sustainable development. In addition, knowledge and understanding of freshwater resources is also essential for sustainable development. A case study of the UK construction industry conducted by Jones et al. (2006) indicates that the consideration of corporate social responsibility (CSR) can also help to reduce costs by efficient water use.

### *2.4. CONSTRUCTION SECTOR FOCUSED WATER EFFICIENCY TECHNIQUES AND STRATEGIES*

The benefits of water efficiency are identified in construction industry. Water conservation techniques and strategies are often the most overlooked aspects of a whole –building design strategy (Bourg, 2010).Thus implementation of water saving initiatives within a building is increasingly becoming a priority and wide range of technologies and measures are employed to reduce the amount of water consumed by buildings. Even industries like agriculture and manufacturing are talking about water efficient techniques and technologies. Similarly, identifying water saving techniques to reduce water use in construction sector also can be beneficial. The Strategic Forum for Construction (SFfC) Water sub-group, Waste and Resource Action Programme (WRAP), and Construction Industry Research and Information Association (CIRIA) are the main research bodies conducting research on water use on construction sites. As stated by Waidyasekara et al (2012), there is a vacuum in the area of water management body of knowledge during the execution phase of a construction project in Sri Lanka.

A study conducted by SFfC of Waste and Resources Action Programme (WRAP) on water audits on construction sites in UK found that the largest barrier to improve water efficiency on site was the lack of quantitative information due to the use of unmetered stand pipes and faulty water meters. Thus they have suggested to utilize robust metering and monitoring systems on site to overcome this issue (McNab et al., 2011). Tam and Lee (2007) suggested that it is necessary to encourage and educate the staff on monitoring of water usage, water reusing and recycling systems, and the use of wastewater treatment during construction. Further WRAP identified key opportunities to reduce water use on site as (i) good housekeeping (ii) monitoring and targeting (iii) use abstracted water where available (iv) specifying water efficient taps, and fittings and (v) use water efficient plant and equipment (McNab, 2011). They showed that savings in the tune of ~90%, ~ 40% and ~30%, respectively for dust suppression, wheel washing and road sweeping by selecting efficient plant and equipment. Further, WRAP identified following water efficient techniques: pressure reduction valves, flow regulators/restrictors, use of aerated and spray tap/shower fittings which improve perceived user experience, and two-stage taps with water brakes, sub-metering, fix dripping taps and leaking taps, motion-sensor operated taps, grey / rainwater systems for reducing potable water consumption, auto shut-off of flow to toilet areas when unoccupied. Similarly the SFfC water group identified following water efficient techniques: water audit systems, leak detection systems, fit trigger guns to hoses, vacuum toilets, pressure reducing valves, closed looped water recycling, admixtures, water hierarchy which look at alternative sources for potable water, reduce, reuse, and recycle (Waylen et al., 2011). Water audit determines the amount of water loss from a distribution system due to leakage and other reasons such as theft, unauthorized or illegal withdrawals from the system and the cost of such losses to the utility. Water action plan seeks to address reducing water usage by encouraging and promoting water activity to obtain better information.

Further, SFfC water subgroup identified best practices for water efficiency by incorporating water efficient construction practices at pre-design and tender stage and incorporate water efficient construction sites into sustainability assessment systems (BREAM, LEED, GreenSL). SFfC group further mentioned that chemical additives are an option to assist in reducing the volume of water needed and waterless systems are other innovative options. It was identified high pressure low volume efficient spray pattern to reduce water use and closed loop systems (re-use of washout water from concrete batching plants). Fernando (2007) shows that applying 're-use' concept in the batching plant process, $2m^3$ per day can be re-used. This result derived through one case study conducted in Sri Lanka and the water used for cleaning the batching plant is subjected to filtering process and reuse for concrete production. The Australian Industry Group (2006) identified water efficient strategies as water saving action plan, high pressure cleaning, storm water reuse, filters, ensure that water efficiency methods induced in tender and contractual documents. Modern techniques such as curing compounds, sprinkler techniques, pre-cast construction methods, dry partitions work, pre- mixed concrete and pre-mixed mortar and more steel intensive construction recommend in order to reducing water volume in a site (Ramachandran, 2004). Further same author mentioned that workers participation, recognition, team belonging, management commitment and leadership, effective training impact on water efficiency at site level. As McNab et al., (2011) stated, creating a culture within the construction sector that changes staff's attitude and behaviour to accept ownership of water efficiency is fundamental to improving the use of water in an efficient manner.

As Savenije and Van der Zang (2002) suggest, water pricing is an important instrument to break the vicious circle of the 'free water dilemma'. Zbigniew and Kundzewicz (1997) and Horn (2012) emphasized the necessity of increasing water prices to appropriate levels in order for it to be taken seriously by the consumers. Environmental Management System (EMS) can provide a framework to achieve and to demonstrate a desired level of environmental performance (Tse, 2001, Wu, 2003). Baloi (2003) highlights, EMS enables companies to respond to environment challenges and legislative/regulatory requirements proactively. The establishment and implementation of ISO 14001, EMS requires a total commitment and cooperation of all parties involved in the supply chain (Chen and Wong, 2000). However, Tam and Le (2007) observed that construction organizations' poor response to EMS is attributed mainly to their lack of environmental consciousness. Mactavish and Greenhalgh (2013) show that through effective management of resources on site, 15-25% of reduction in water use could be achieved. However, the same authors highlighted that historically, cost has always been the language that captures the concentration of investors and clients and their project teams were required to respond. Perhaps in the future, metrics such as tonnes of carbon or litres of water saved will gain equal attention in cost evaluation.

## 3. RESEARCH METHODOLOGY

The aim of this research is to identify applicable water efficiency techniques and strategies for efficiency water usage during construction phase. Further, the paper will discuss limitations on uptake of water efficiency technique and strategies in the construction industry. Both quantitative and qualitative approaches were integrated to achieve the research aim. A questionnaire survey was undertaken in order to get a broad view on water efficiency methods that are relevant for the construction industry. It consisted of both closed and open ended questions. Although, some overlap could be seen with techniques and strategies, the study identified 17 techniques (TEchs) and 14 strategies (STrgs) popularly used in the construction industry based on the literature review.

Data were collected using an online survey method among professionals working for contractors and consultants such as Project Managers (PM), Civil Engineers (CE), Quantity Surveyors (QS) and Architects (ARCHT) who have more than ten years of experience. The sample consisted of 105 professionals, 54 belonging to contractors and 51 consultants. Figure 2 and 3 illustrates the experience of these respondents.

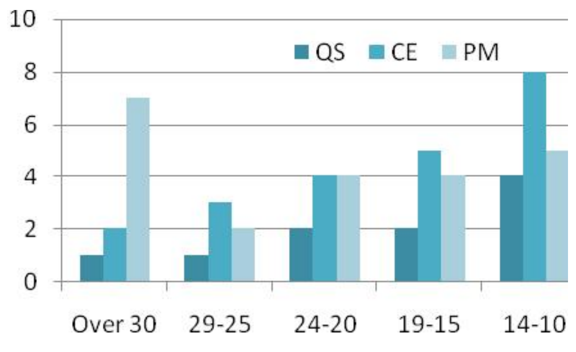


Figure 2: Experience of the Contractor Group

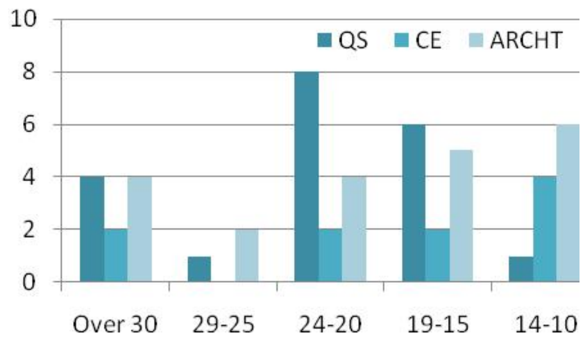


Figure 3: Experience of the Consultant Group

The statistical software of SPSS (Statistical Package for Social Science) version 22.0 was used during the data analysis. Cronbach alpha was used to check the internal consistency and the reliability of the data set. Descriptive statistics such as frequencies and percentages were used as while a non- parametric tests, namely, Mann Whitney and Kruskal- Wallis H were used to determine whether there is a significant difference between the average responses among these groups (between the contractor and consultant as well professional groups). The criterion for accepting or rejecting the hypothesis was set at .05. If the asymptotic significance level (p-value) is less than .05, the null hypothesis was rejected. Qualitative data that originated from open-ended questions of the questionnaire survey were also included in the discussion.

## 4. RESEARCH FINDINGS

### *4.1. FINDINGS OF THE QUESTIONNAIRE SURVEY*

Out of the 105 responses, over 27% of them had more than 25 years' experience while 23% between 20-24 years, 23.8% between 15-19 years and 25.7% between 10-14 years, respectively. Respondents were asked to give their views on why water efficiency practices were not considered by stakeholders during the construction phase. More than 88% of respondents believed that the main reason was 'low priority given for water efficiency management'. Lack of integration of water efficiency practices during i) pre-design and ii) construction stages were considered by more than 80% respondents. 78% respondents agreed 'Value of water is hidden to construction parties' and 'less awareness of new technologies' while 73% believe adoption of water efficiency TEchs and strategies will add cost to a contractor and 59% believe that it is an additional cost to a client.

Literature shows that many techniques can be used to achieve efficiency of water use during construction. The main purpose of the survey was to obtain the perception of the respondents on the applicability of above water efficiency techniques for the Sri Lankan construction industry. They were asked to rank their applicability on a Likert scale as shown in Table 3.

Table 3: Likert Scale for level of applicability

| Scale | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Level of applicability** | Very low | Low | Neutral | High | Very High |

### *4.2. WATER EFFICIENCY TECHNIQUES (TECHS) APPLICABLE FOR USE DURING CONSTRUCTION PHASE*

A total of seventeen (17) potential water efficiency TEchs have been included in the survey. As noted previously, prior to performing the analysis, Mann-Whitney U test was performed to determine whether there was a statistically significant difference between the average responses of the contractor and consultant group. The results show that there is a significant difference between the average response of TEch16 (water efficient taps) [Asymp.sig. (2-tailed)=.04]. Except that all the other TEchs have no significant difference between the groups. Therefore, Tech16 was analyzed separately and all other TEchs under one sample. When reporting ordinal data (non-parametric), median is considered to be more appropriate for the central tendency and equivalent parametric test focuses on mean of the data set. The study used a proportion of responses in each category, which is considered as being the most appropriate and more informative than the use of median. Table 4 summarized the survey results.

Table 4: Applicability on Water Efficiency TEchs

| Ref. | Techniques for Efficient Water use During Construction | Level of Applicability | | | | | TR | H &V.H |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | | |
| | | % | % | % | % | % | | % |
| **TEch1** | Admixtures /chemical additives | 7.6 | 12.4 | 3.8 | 51.4 | 24.8 | 105 | **76.19** |
| **TEch2** | Closed loop systems (waste of one product is used for another process) | 1.9 | 14.3 | 1.9 | 60.0 | 21.9 | 105 | **81.90** |
| **TEch3** | Curing agents | 9.5 | 4.8 | 3.8 | 39.0 | **42.9** | 105 | **81.90** |
| **TEch4** | Dust suppression vehicles -bowsers with sprinklers | 18.1 | 11.4 | 1.9 | 51.4 | 17.1 | 105 | 68.57 |
| **TEch5** | Efficient showers : Low-flow showerheads | 4.8 | 12.4 | 2.9 | 61.9 | 18.1 | 105 | **80.00** |
| **TEch6** | Fan misting systems for dust suppression | 22.9 | 12.4 | 16.2 | 31.4 | 17.1 | 105 | 48.50 |
| **TEch7** | High pressure trigger operated spray gun hoses for concrete cleaning & wheel washers | 4.8 | 2.9 | - | 48.6 | **43.8** | 105 | **92.38** |
| **TEch8** | Low flush cisterns/urinals/waterless urinals | 1.0 | 9.5 | 5.7 | 63.8 | 20.0 | 105 | **83.81** |
| **TEch9** | Pressure reducing valves | - | 1.0 | 6.7 | 65.7 | 26.7 | 105 | **92.38** |
| **TEch10** | Rainwater collection and reuse | 8.6 | 8.6 | 1.0 | 31.4 | **50.5** | 105 | **81.90** |
| **TEch11** | Sprinkler systems for curing concrete work | 1.9 | 14.3 | 9.5 | 61.0 | 13.3 | 105 | 74.29 |
| **TEch12** | Sub-metering systems | - | 6.7 | 1.9 | 53.3 | 38.1 | 105 | **91.43** |
| **TEch13** | Vacuum toilets | 22.9 | 24.8 | 7.6 | 37.1 | 7.6 | 105 | 44.70 |
| **TEch14** | Washing bay for wheel washers | 23.8 | 11.4 | 1.9 | 43.8 | 19.0 | 105 | 62.86 |
| **TEch15** | Water audit methods | 1.9 | - | - | 49.5 | **48.6** | 105 | **98.10** |
| **TEch17** | Water leak detection and monitoring systems | - | 1.9 | 1.0 | 38.1 | **59.0** | 105 | **97.14** |
| **1:Very Low 2: Low 3: Neutral 4: High 5: Very high TR: Total Respondent** | | | | | | | | |

**Note: H - High V.H – Very High**

The empirical data shows that 59% of respondents reported that water leak detection and monitoring systems (TEch16) to be the most applicable TEch followed by TEch10 (50.5%), TEch7 (43.8%) and TEch3 (42.9%), respectively. Furthermore, Table 5 summarises the percentages reported 'very high' and 'high' applicability TEchs by the respondents. Accordingly, almost ten (10) TEchs were reported by 80% respondents as applicability for the construction phase (the top five TEchs are highlighted in Table 5). These top water efficiency TEchs well matches with the literature review. Therefore, it is important to look at current extent of application of these water efficiency TEchs uses in construction sites in Sri Lanka.

Table 5: The Top Five Applicability Water Efficiency Techs for Construction Phase

| Ref. | TEchs | High% | V. high % | High% + V. high % |
|---|---|---|---|---|
| **TEch15** | Water audit | 49.5 | 48.6 | 98.1 |
| **TEch17** | Water leak detection and monitoring systems | 38.1 | 59.0 | 97.1 |
| **TEch9** | Pressure reducing valves | 65.7 | 26.7 | 92.4 |
| **TEch7** | High pressure trigger operated spray gun hoses for concrete cleaning and wheel washers | 48.6 | 43.8 | 92.4 |
| **TEch12** | Sub-metering systems | 53.3 | 38.1 | 91.4 |

**Note: V.high: Very high**

The highest percentages for 'very low' were for TEchs of 'Washing bay for wheel washers' (23.8%) , 'Fan misting systems for dust suppression' (22.9%) and 'Vacuum toilets' (22.9%). Although, literature shows that a typical vacuum system can reduce potable water consumption for toilets by 68% and it is highly efficient than the traditional methods, respondents were not very favourable for that option. 72.2% of contractor and 58.8% of consultant-based professionals reported 'high' or 'very high' for applicability of water efficiency taps (Tech16) to be relevant for construction. On the other hand, 17.6% participants from the consultancy group and 23.5% from contractors have given 'very low' for applicability of water efficiency taps (TEch16) respectively. The results seem to show that consultants are less favourable on TEch16 compared to the contractor group.

It is important to note that the results of Kruskal-Wallis H test showed that there were no significant differences of views between the professional groups: Project Managers, Civil engineers, Quantity Surveyors and Architects. The value of the asymptotic significance level (2 tailed) for all items were greater than .05. Accordingly, Null hypothesis (no variance between groups) was not rejected. Moreover, Cronbach's Alpha was 0.764. This shows high internal consistency and reliability within the measurement used for each variable.

### *4.3. STRATEGIES FOR LOW WATER USAGE DURING CONSTRUCTION PHASE*

Fourteen strategies were included in the questionnaire survey and respondents were asked to rank them on their applicability for water efficiency for construction on a likert scale as given in Table 3. As a first step Mann-Whitney non- parametric test was conducted to establish whether there are any differences between the responses of contractor and consultant group. It is important to note that the value of the asymptotic significance level (2 tailed) for all the strategies were greater than 0.05. This indicates that there was no significant difference between the groups. It was considered all participants to be a single sample and the results are summarized in Table 6. As shown in Table 6, 'Monitoring and supervision' (Strg14), 'Introduce water action plan initially' (Strg7), and 'Assign responsibility and targets among the site staff' (Strg1) were recognized as 'very high' strategies applicable by majority of respondents. The results summarize the combined percentage of 'Very high' and 'High' responses for applicability of each strategy. Figure 4 illustrates the applicability strategies reported by more than 80% of respondents.

Table 6: Strategies for Low Water Usage During Construction Phase

| **Ref.** | **Strategies for Low water usage during construction phase** | **Level of applicability** | | | | | **TR** | **H & VH** |
|---|---|---|---|---|---|---|---|---|
| | | **1 %** | **2 %** | **3 %** | **4 %** | **5 %** | | **%** |
| **STrg1** | Assign responsibility and targets among the site staff | - | - | 9.5 | 57.1 | **33.3** | 105 | **90.5** |
| **STrg2** | Develop a builder guidebook for builders and add steps to reduce water in construction | - | - | 10.5 | 62.9 | 26.7 | 105 | **89.5** |
| **STrg3** | Integration of pre-cast or prefabricated construction methods | 1.0 | 14.3 | 15.2 | 50.5 | 19.0 | 105 | 69.5 |
| **STrg4** | Integration of steel intensive construction methods | 1.9 | 19.0 | 21.9 | 46.7 | 10.5 | 105 | 57.1 |
| **STrg5** | Integration of dry wall partitions instead of brick and block walls | 1.0 | 15.2 | 20.0 | 41.9 | 21.9 | 105 | 63.8 |
| **STrg6** | Integration of pre-mixed concrete and pre-mixed mortar | 1.0 | 23.8 | 37.1 | 35.2 | 2.9 | 105 | 38.1 |
| **STrg7** | Introduce water action plan initially | - | 1.9 | 8.6 | 49.5 | **40.0** | 105 | **89.5** |
| **STrg8** | Implement environmental policies on natural resources (EMS/ Sustainability assessment systems) | - | 1.0 | 6.7 | 65.7 | 26.7 | 105 | **92.4** |
| **STrg9** | Integrate water efficient techniques during the pre-design and tender stage (rainwater/recycling) | - | 2.9 | 14.3 | 55.2 | 27.6 | 105 | **82.9** |
| **STrg10** | Introduce penalty system for unsustainable practices by site staff | 1.9 | 3.8 | 26.7 | 49.5 | 18.1 | 105 | 67.6 |
| **STrg11** | Increase of unit rate | 2.9 | 33.3 | 40.0 | 20.0 | 3.8 | 105 | 23.8 |
| **STrg12** | Implement licensed water abstraction system (Surface water/ tube well) | 6.7 | 9.5 | 63.8 | 20.0 | - | 105 | 20.0 |
| **STrg13** | Monitoring and Supervision | - | - | 4.8 | 55.2 | 40.0 | 105 | 95.2 |
| **STrg14** | Water awareness among workers (posters, meetings, Toolbox talking) | - | 1.9 | 6.7 | 58.1 | 33.3 | 105 | 91.4 |

**1:Very low 2: Low 3: Neutral 4: High 5: Very high TR: Total respondent**

It could be observed that a close relationship exist between water efficiency TEchs and STgs. For instance, Strg 8 (Implement environmental policies on natural resources) related with the importance of implementing TEch 2 (Closed loop systems) and TEch10 (Rainwater collection and re-use). Although literature based evidence show that the licensed abstraction is a common strategy practiced in other countries, majority of respondents reported as neutral position on this aspect (STrg12) with an average rating of 63.8%. On the other hand, increase of unit rate (STrg11) was considered by majority as not applicable. Among water efficient construction methods (STrg3, STrg4, STrg5, and STrg6), the use of pre-cast (STrg3) and dry partitions (STrg5) were favoured over steel construction and pre-mixed concrete/mortar by majority of respondents.

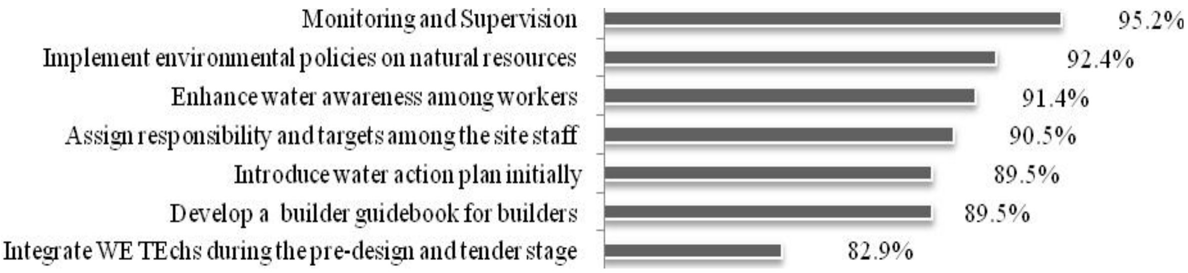


Figure 4: The Top Strategies Applicable for the Construction Phase in terms of Low Water Usage

The Kruskal-Wallis H test results show that except STrg 3 and STrg 5, there were no significant differences of views between the professional groups. Cronbach's Alpha was 0.662. This shows high internal consistency and reliability within the measurements used for each variable.

### *4.4. PERCEPTIONS ON UPTAKE OF WATER EFFICIENCY TECHNIQUES AND STRATEGIES*

Perceptions of the respondents conveyed through the open ended questions are reported below. Few respondents opined that water efficiency TEchs/STrgs should be initiated from an early design stage in order to maximise savings in the most cost-effective way. Cost was mentioned as the main barrier for implementing some of the Techniques and strategies during the construction phase. For example, the use of curing agents, admixtures, sprinkler systems, rainwater harvesting etc, would be hampered by the cost involved in these. One of the civil engineers shared his experience and observed that "*Water curing is more effective than membrane curing. Water curing delays the initiation of corrosion more than the membrane curing"*.

It is important to note that the existing literature give evidence to the effect that there is less consideration on environment during construction. However, many respondents highlighted the importance of implementing environmental policies to conserve natural resources, rainwater (or storm water) collection and storage during construction. In contrast, few respondents observed that space limitation on site and cost are barriers of rainwater collection. Increasing the price for water has been identified by some scholars as the best strategy to control water usage. However, the results show that majority of respondents are neutral with regard to water pricing (STrg11) in Sri Lanka. However, a project manager observed that "*treated water should not be provided free of charge under any circumstance. This leads to severe misuse"*. Many respondents believe that cost of water is the main reason for such less attention on water efficiency during the construction phase. An Architect mentioned that "*many Sri Lankans lack of knowledge on the value of water and conservation methods. It can be controlled by introducing water pricing strategies*. Another engineer stated that "*people are much obliged to conserve water if they have sound awareness about scarcity of drinking water"*. However, some quantity surveyors stated, "*water management is one of the neglected areas by the middle and top management of construction projects. Water quality test reports and approval for shallow tube wells should be included in tender documents"*. However, majority of respondents reported (63.8%) are neutral on 'implement licensed water abstraction system (Surface water/ tube well)' (STrg12). One of consultant quantity surveyors claimed that "*if water is expensive for construction then the use may get reduced but the cost of construction would increase. Then high cost may induce new technologies and innovation"*. Few respondents said it is practical to use pre-mixed concrete and mortar as a water efficiency strategy.

'Integration of water efficiency TEchs during the design and tender stage' (STrg9) is one of the highly applicable strategies reported by the respondents. The importance of this strategy further proved with comments made by few respondents during the survey. For instance, one comment was *to implement better water management system, it is very important to have awareness of users and its requirements should be included to condition of contract*. Other comments were, *the management is paying a less attention in the area of water usage during the pre -construction stage as well as during the construction stage at present in Sri Lanka; still there are no sustainable solutions for the water management at tender stage or any proposals or the innovations introduced by the consultants / or responsible parties whenever they are doing designs or the practice in construction; the requirements for water efficient practices need to be identified in Tender Document otherwise if the Contractors have to incur any additional cost to implement water efficient practices they will not allow for such costs when pricing tenders and take the risk of winning the tender and loosing during implementation. This should be resolved and implemented by an authorized government body or the relevant institutes which are engaged with construction industry as a compulsory requirement in the country.*

In general, majority of respondents reported that nature of project, scope of construction, location, water source, project team attitude and behaviour, cost, and other environmental and logistics mainly impact on water efficiency TEchs and STrgs. Although, approximately more than 90.5% respondents were agreed with STrg1, at present responsibility of individual is not established at site level as stated by few respondents. Few respondents shared their previous experience in terms of use of water efficiency TEchs during the construction phase.

***Case I*****:** *"The labour accommodations had long tanks filled with potable water for bathing and washing. Instead of that introduced showers and taps and as a result water bill came down by more than 70 %".*

***Case II:*** *An unskilled labourer was rewarded for proposing reduction of cistern capacity by introducing one litre water filled glass bottle inside the cistern."*

***Case III****: "The batching plant water run-off and the truck wash water were passed through sedimentation and settling a tank and a filtering process and this water was then re-used for curing work. Ultimately these practices changed the attitudes and wrong practices of the workers as well.*

## 5. CONCLUSIONS AND WAY FORWARD

This paper focused on applicability water efficiency techniques and strategies for sustainable use of water during the construction phase in Sri Lanka. The survey approach was used to fulfil the study aim with questionnaire survey conducted among professionals such as Project Managers, Civil Engineers, Quantity Surveyors and Architects who have more than ten years experience belonging to contractors and consultants. This study used descriptive statistics, and non-parametric tests to analyze the responses of questionnaire data using the statistical software of SPSS version 22.0. The results of Mann - Whitney U test ($p > 0.05$) showed that there is no significant difference of average responses of the two groups and the data were analyzed considering all participants as a single sample. The results show that the top five applicability water efficient TEchs as water auditing, water leak detection and monitoring systems, pressure reducing valves, high pressure trigger operated spray gun hoses and sub-metering. All these TEchs were accepted by more than 90% of the respondents. Vacuum toilets and fan misting dust suppression systems were not in favour for building construction sites. The top five applicability strategies were: monitoring and supervision, implement environmental policies on natural resources, enhance water awareness among workers, assign responsibility and targets among the site staff and introduce water action plan at the beginning. Majority of respondents do not agree with the increase of water price, and were neutral on implementing licensed water abstraction system in Sri Lanka. Main reasons for less consideration on water efficiency practices during construction phase were, namely, low priority given by the industry, and not integrating water efficiency techniques and strategies during the pre-design and construction stages as identified by the respondents.

It was found that initial planning and management of water and water efficiency techniques and strategies used on construction sites encourage minimal environment risks associated with construction activities. According to the empirical data, nature of project, scope of construction, location, water source, project team attitude and behaviour, and other environmental and logistics related to the project impact on use of water efficient techniques and strategies. In addition, cost was mentioned as the main barrier for implementing efficiency TEchs and STrgs during the construction phase although identified by the respondents as applicable. This study looked at a broader view on applicability of water efficiency techniques and strategies for construction industry by its professionals. It is important to look at the application of these water efficiency techniques and strategies in building construction sites in Sri Lanka. Therefore, the next step of the study is to use case study approach to explore the empirical data found from survey with real scenarios selecting few cases from ongoing building construction projects.

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