A study to assess alternative water sources for reducing energy consumption in a medical facility case study, Abu Dhabi

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Abstract

This paper presents the case for water and energy conservation in a desert type climate healthcare environment, which is based on the need for Abu Dhabi to decrease potable water and energy consumption to reduce environmental impact. The work documented in this paper is part of the first author’s Professional Doctorate change project in Sustainable Built Environment (D.SBE) at Cardiff Metropolitan University with a medical facility case study in the United Arab Emirates (UAE) in use since 2015. The project is investigating the impact of alternative water sources energy consumption versus public network seawater desalinated potable water for outdoor use. The context is a 364 beds hospital in Abu Dhabi with a 21,600m² building footprint area surrounded by a 36,310m² vegetated open space. The hospital includes a treated air cooling condensate water system suitable for use as irrigation water and water feature use. The condensate water has been tested in 2016 and 2017 to verify compliance for reuse. Whilst, the water test results demonstrate suitability for outdoor reuse in a healthcare setting, additional alternative water sources such as fire test pump water (450m³/year) have been tested in March 2017, which shows that a tertiary treatment system is needed for its reuse. It was also found that onsite alternative water sources are less energy intensive for irrigation (0.22kWh/m³) and water feature use (39.09kWh/m³) than offsite produced desalinated potable water (55.68kWh/m³ average). The next steps are to quantify the treated condensate water from the air cooling system for 12 months through the newly installed flow meters at the raw condensate water tanks to confirm the 2013 theoretical model and calculate yearly water energy consumption. To date (March 2017) 26 days of data have been recorded (February to March 2017) which align with the model by data extrapolation. This study will help understand how alternative water sources for outdoor use, impact on building systems energy consumption, greenhouse gas emission, operation and maintenance cost and the environment. This study may be beneficial to local competent authorities for making and adjusting standards for energy and water conservation strategies in healthcare settings.

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1. Introduction

The work documented in this paper is part of the first author’s Professional Doctorate change project in Abu Dhabi, at a newly built medical facility in use since April 2015. The medical facility is in Abu Dhabi capital city of the United Arab Emirates (UAE), a hot desert type climate [1, 2] and a Middle East Country laying between latitude 22° 29 N and 24° 53 N and longitude 56° 10 E and 51° 37 E [3]. The facility landscape is greater than its building footprint representing more than 50% of the site or a 36,310-square meter (m²) vegetated open space including decorative water features. The project is investigating energy to non-potable water consumption versus energy to public network desalinated potable water and how alternatives water sources can help reduce energy consumption for irrigation and water features water use. The water irrigation demand has been estimated at 386 cubic meter (m³) per day at peak by the landscape contractor, and 1,352m³/month for the combined water features capacity, which is discussed in this paper at Section three. The design of the 364 beds hospital includes an existing Air Handling Unit (AHU) Air Conditioning (A/C) condensate water treatment system, which is intended to treat condensate water from the air cooling system to a quality suitable for use as landscape irrigation and water features. The short fall in condensate water availability during the winter months in Abu Dhabi (December-February) is proposed to be met by soil improvement and by sourcing additional alternative water sources such as fire pump test water.

The aim of this D.SBE action research project designed, developed and implemented by the first author is to provide an account of water and energy conservation strategies for outdoor landscape for sites located in arid climates, such as the Emirates of Abu Dhabi (UAE). The anticipated outcome of this research project is to demonstrate how alternative water sources for outdoor use can help decrease potable water use and improve overall energy consumption and associated carbon emissions of a building, such as the medical facility. The strategy is to encourage the local authority to amend their water standard so that hospitals with irrigated outdoor space optimize their water need and increase the use of treated non-potable water use. Thus, impacts upon the environment, operation and maintenance cost and practices, greenhouse gas emissions, and building systems energy and water consumption can be minimized.

2. The Context of Water Energy Nexus in Abu Dhabi

The Middle East region including the UAE has the lowest fresh water resource endowment in the world. The water regional availability is as little as <100m³ per capita per year [4]. The UAE depends heavily on non-renewable groundwater and augments supplies by desalination of sea water to produce freshwater. The overall water need is supplied by groundwater supplemented by desalination and wastewater treatment plants [3]. 72% of the groundwater is used for agriculture, 29% of the desalinated water is used for commercial and residential need while wastewater accounts for 4% of the overall water demand [5]. Since rainfall is very small (<100mm/year) and the recharge of the groundwater is less than 4% per year, Abu Dhabi has no choice, but to supply municipal water from seawater desalination (ibid.). Water systems can save energy by reducing the amount of water that must be withdrawn, treated, and distributed [6] especially in place like Abu Dhabi where the technique of desalination is high energy intensive, such as Reverse Osmosis technologies that also has a very high cost (0.5-1 USD/m³) in comparison to conventional sources (0.05 USD/m³) [4]. To overcome this challenge and to align with the Abu Dhabi Vision 2030, the Regulation Supervision Bureau (RSB) released a plan in 2013 [7] “to ensure non-conventional generation, including renewable technologies, is developed and integrated in coming years” [7]. From 2020, fuel sources are intended to be diversified comprising of <58% Gas, >2% Renewable Energy, 20% Liquefied Gas and 20% Nuclear. Most of the Emirate’s water capacity production is powered by co-generation plants, with waste steam emanating from this process is used for thermal desalination. The desalination plant of the future will use a mix of reverse osmosis and standalone thermal, which will account for 20%+ in 2030 as opposed to 6%+ until 2017 and 10%+ in 2020 of the overall based production for financial and operational reasons. Co-generation thermal plant technology is planned to be utilized for 70%+ of the overall production of water desalination in compare to 94% (2017) and 84% in 2020 [ibid]. In comparison Reverse Osmosis energy consumption ranges from 1.6kWh/m³ to 3.0kWh/m³, stand-alone thermal 0.8kWh/m³ to 4.5kWh/m³ and 0.8kWh/m³ to 1.2kWh/m³ for co-generation technologies [8]. A Stand-alone system requires more heat than a combined cycle gas turbine coupled with thermal desalination [9]. The latter process requires less energy because it incorporates multiple stages or effects utilizing
thermal energy (heat) to vaporize water to be condensed to produce freshwater [10]. The concept of cogeneration takes the form of combined generation of power and water [9]. A conventional thermal desalination plant of combined cycle condensing turbine or Multi-Stage Flash (MSF) produces more heat than a Multi-Effect Distillation (MED) type technology: 130°C versus 80°C respectively (ibid.). The current configuration of Abu Dhabi desalination plant is of a MSF type and is said to be using 1.65kWh/m³ [8]. The Reverse Osmosis (RO) process uses pressure to force water through semi permeable membranes to remove essentially dissolved organic and organic constituents [11]. The amount of pressure needed is relative to the salinity of the water and therefore largely impacts upon energy consumption with associated carbon emissions [10]. For this reason, the RO technology is said to be used essentially on the East coast of the UAE where the ocean is less salty [7]. Moreover, desalination plants have been optimized since the last decade although the desalination process efficiency is still under investigation through pilot programs (ibid.), such as adsorption desalination system producing pure water with no need for fossil fuel [12]. Yet, in 2017 the process of desalination is still highly energy intensive [13, 4] hence, impacting on the environment. It takes 7.5m³ to 9m³ of seawater consumption for both MSF and MED ranges to generate 1m³ of distillate water [9]. Energy consumption and potential effects on the marine environment of brine disposal are the two largest aspects of environmental impact [14, 15, 16, 17, 18]. It was also found that desalination has a negative effect on airborne emissions [14, 16]. The greenhouse gas emissions arising from public electricity production and water desalination by Abu Dhabi plants totaled 30,840 Gg CO₂ eq. [19]. This challenges provide evidence that a holistic approach is needed to overcome the water challenge by balancing strategies to minimize use of finite resources such as water and potable water produced from desalination with its high-energy use and associated carbon emissions, and exploring and implementing water management and water reuse [14, 20]. Desalination alone cannot deliver the promise of improved water supply, which should remain the last resort and its application should only be considered after having carefully considered cheaper alternatives in terms of supply and demand management [16, 0, 21]. Wastewater treatment works in Abu Dhabi have been commissioned to replace and expand the capacity of the existing plants. 60% of the Abu Dhabi wastewater is planned to be returned to the sewer by 2030, to be recycled for reuse in applications such as irrigation [7]. This strategy forms part of the Abu Dhabi Government aiming at no longer permitting potable water to be utilized for irrigation purposes and so to alleviate stress on the existing water infrastructure [22]. As such it will be mandatory to use Treated Sewage Effluent (TSE) for irrigation [22]. Currently there is no TSE infrastructure near the medical facility location, and the timing for this to happen is presently unknown to the community [23, 24].

3. Case Study

3.1. Existing System Description

Figure one builds on Seguela et al’s case study [27, 28], which has been revised since to reflect on existing conditions for the year 2017. By adjusting the irrigation water demand with the Landscape Water Requirement (LWR) calculation from United States Environment Protection Agency [29] and by reusing the onsite Air Handling Unit (AHU) air conditioning (A/C) condensate water all year around, the project is aiming at saving 124,300m³ (equivalent to 50 Olympic swimming pools considering a 2,500m³ capacity) of desalinated potable water and subsequently saving 1,181 tCO₂ emissions based on EAD emission factor 2016 [30]. This water savings is based on the capacity of the existing AHU A/C condensate water to produce a theoretical 442m³ of water in average per day to satisfy an irrigation demand based on Urban Planning Council [31] irrigation rate from 154m³ in winter (December-February) up to 386m³ per day in summer (May-September) and 11m³ per day for water features (1,352m³ total capacity x 3 drains/year x 365 days excluding drains, refill, backwash and evaporation). For approximately 23% of the year (approximately 83 days each year) the irrigation demand will not be met by the treated AHU A/C condensate generated at the site when calculating the irrigation demand from UPC (2010) irrigation rate. The total estimated volume of potable water anticipated to be made up is approximately 13,079 m³ predominantly occurring from December to April of each year. However, similarly, the theoretical model for AHU A/C condensate water and water feature use (Figure 1) does not make allowances for precipitation and evaporation. As such the shortfall is an approximation that cannot be accurately determined in a theoretical model. This model is being verified by measuring water use and water produced by sub flow metering on the raw condensate water tanks line, starting from March 2017 onwards. The percentage (%) at Figure one indicates the quantities of A/C
condensate water used in 2016 against desalination water. Since condensate is formed from moisture in the air, it is relatively high-quality water. Therefore, it can be collected and used on-site within relatively little treatment [32, 33] subject to the implementation of a maintenance program [34]. The first flow meter reading at the raw condensate water tanks shows that from February 12th to March 9th 2017 (or 26 days), 4,950m³ was produced by the combined 167 AHUs and 40 Fan Coil Units (CFUs) at the site, which represents an average of 190m³/day average in the winter season. The theoretical model shown at per Figure one predicted 60m³/day in February and 230m³/day in March, which is in the range of the anticipated non-potable water generation when averaging these two months.

The facility management team maintains the functioning of the irrigation controller system to ensure optimum irrigation efficiency by ensuring the weather based central irrigation control management system operates as intended, with precise predefined water quantities based on the irrigation parameters entered by the landscape contractor based on ADM standard [35]. However, the ADM Standard has recently been adjusted and aligned to UPC [31] irrigation rate [23, 36], which is currently not available to the public. The combined condensate/water use exceeds the water needs in winter because the landscape contractor used the 2013 ADM standard for irrigation. If the US EPA irrigation rate [29] is proved to be feasible in the contextual climatic conditions that would mean the site is currently (March 2017) over watered by three times the actual requirement and thus a considerable waste of this finite resource. That also means condensate water would only be in deficit by 426m³/year in winter as shown at Figure one, blue line number eight when soil is not enhanced. If soil improvement proves to be effective and if the theoretical model is accurate the site may well be more than alternative water sources.

3.2. Existing Irrigation and water feature system: Energy and water demand

Irrigation is the primary water consumption worldwide [37]. In arid regions, where the mean annual precipitation (P) is substantially less than the characteristic potential evapotranspiration (ETo), appropriate selection of plants and efficient irrigation systems can conserve a great amount of urban irrigation water [37, 38]. In addition, wasting water in sectors such as agriculture and landscaping in arid regions, is further aggravating water scarcity and emphasizing the need for developing ways to improve irrigation efficiency (ibid.). In addition, and referring to Seguela et al [28], the landscape soil enhancement with a soil conditioner, which is being implemented now (March to May 2017) is anticipated to help soil water holding capacity to achieve a 40% to 50% water saving. Water and energy impacts on outdoor water pools are significant, particularly in arid climates [39]. In the absence of literature for assessing the environmental effect of large outdoor water features use in arid climates in terms of water, energy and Greenhouse Gas (GHG) emissions, swimming pools case studies and analysis were used. Pool energy and water consumption are like water features with the exception to the water heating factor in the winter season, which has been excluded in this paper. Transporting, collecting and using chemicals to treat water such as chlorine represents an environmental impact (ibid.). Energy is needed in all phases of the water cycle: water extraction and pumping, desalination, purification and distribution to end users [40]. In the case of the medical facility, and as shown at Figure one, 64%
of air handling unit condensate water was used in average in 2016. The site is hoping to be using 100% of the condensate water once outdoor valves flow have been verified, irrigation pump set point is confirmed and parameters of the irrigation controller are adjusted against US EPA [29] standard irrigation rates.

4. Methodology

4.1. A mixed method approach

The methodology of this D.SBE action research project has been designed, developed and is been implemented by the first author, which uses a mixed method. To analyze and evaluate the proposed change project, the medical facility has been used in both action research and case study research methodology. The mixed methods approach or methodology, which uses different methods of data collection is presumed to have considerable benefits since any method has distinct strengths and weaknesses [25, 26]. Yin [41] recommends the following four principles to maximize the benefits of accessing different sources of evidence: Use multiple sources of evidence by triangulating the data (Convergence of evidence) as part of the same study, but that can address different findings (Non-convergence of Evidence). Gill & Johnson [25] and O’Leary [42] note that multiple sources of primary and secondary data are used with both quantitative and qualitative methods to collect data to confirm triangulation: (One) Creating a case study database; (Two) Maintaining a chain of evidence by working back and forth on the model; (Three) Using data from electronic sources carefully. Action research is used to deductively test the water conservation strategy onsite; and this intervention undertaken becomes the case study - used to inductively reflect on this experimental approach. Firstly, the research looks at soil improvement coupled with onsite produced organic fertilizer in a desert environment and, secondly it investigates the collection and reuse of alternative water sources for landscape and water feature use including quantifying onsite generated air conditioning condensate water. It is essential that data collection methods are valid and free from any bias to be meaningful [26]. The water data has been collected since January 2016 and analyses via sub flow meters (flow meter one to four are illustrated in Figure two). The data is being captured via the Energy Management Control System (EMCS) and the weather based irrigation controller system (weather, water flow and valve wiring controlling, monitoring and reporting management system) daily. As illustrated at Figure two, part of this analysis is the development of a water balance against energy consumption model to operate this system, which comprises five elements, namely: (A) Condensate water production rate (Inflow) via sub metering; (B) Irrigation Water demand (Outflow) via deduction of water consumed; (C) Water feature water demand (Outflow) via sub metering; (D) Potable water (inflow) via sub metering; (E) Other alternative water sources (Inflow) via sub metering. The energy demand of the system is represented by the pumps (P) located at the inflow and the outflow points, see Figure Two.

4.2. Water Sampling

This section presents results of non-potable water tested, as undertaken by an independent certified Emirates Authority for Standardization and Methodology (ESMA) laboratory. Alternative water sources are evaluated against the maximum allowable concentration or characteristic of Restricted Substances as specified in Schedule A1 and A2 of the RSB for the Recycled Water and Biosolids Regulations 2010 [44]. The effluent test results are outlined at Table 1, below.

<table>
<thead>
<tr>
<th>Water types/location</th>
<th>BOD (mg/l)</th>
<th>pH</th>
<th>Turbidity (NTU)</th>
<th>TSS (mg/l)</th>
<th>TDS (mg/l)</th>
<th>Enterococci (CFU/100ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A- Raw air conditioning condensate water (Tank 1)</td>
<td>&lt;3</td>
<td>7.05</td>
<td>&lt;3</td>
<td>&lt;6</td>
<td>40</td>
<td>Non-detectable</td>
</tr>
<tr>
<td>A- Raw air conditioning condensate water (Tank 2)</td>
<td>&lt;3</td>
<td>6.80</td>
<td>&lt;3</td>
<td>&lt;6</td>
<td>30</td>
<td>Non-detectable</td>
</tr>
<tr>
<td>B- Treated air conditioning condensate water</td>
<td>&lt;3</td>
<td>7.62</td>
<td>&lt;3</td>
<td>&lt;6</td>
<td>56</td>
<td>Non-detectable</td>
</tr>
<tr>
<td>C- Water feature tank</td>
<td>&lt;3</td>
<td>7.90</td>
<td>&lt;3</td>
<td>&lt;6</td>
<td>76</td>
<td>Non-detectable</td>
</tr>
<tr>
<td>D- Fire Pump Test Water</td>
<td>19</td>
<td>8.05</td>
<td>24</td>
<td>38</td>
<td>98</td>
<td>Non-detectable</td>
</tr>
<tr>
<td>Desalinated domestic water at medical facility</td>
<td>&lt;3</td>
<td>7.70</td>
<td>&lt;3</td>
<td>&lt;6</td>
<td>78</td>
<td>Non-detectable</td>
</tr>
<tr>
<td>RSB recommended value for water recycling [44]</td>
<td>10</td>
<td>6-10</td>
<td>5</td>
<td>10</td>
<td>40</td>
<td>Not specified</td>
</tr>
</tbody>
</table>

Table 1: Results of the medical facility alternative water sources quality related to Figure 2 for sampling location.
Water quality tests were performed on six samples drawn from four different water sources in the medical facility to compare their quality to RSB recommended values \[44\] for each included as a reference. Whilst, not all parameters are shown, substances measured were sanitary, salinity, irrigation criteria for trace elements, heavy metals, and microbiology.

4.3. Energy savings calculations’ methodology

For each of the eight plant rooms serving the water features, one pump is used to recirculate the water and two pumps are used to operate the water treatment system. An additional four sets of pumps are also needed to convey the water to the water feature tanks or a total of 30 pumps to operate a combined 3,289sqm (1,587m³ capacity average per month) of decorative water features (Figure 2). The project in January 2017 installed new flow meters to account for water features consumption (Figure 2, M7), but a full year of data will only be available by March 2018. Hence, the following anticipated water feature water balance is calculated by totalizing water consumed from the combined main supply and condensate water in one year using equation (1) at Figure 3a \[39\]. Where \(W_i\) represents the water use in a month \(i\) calculated as the input required to maintain the water level between a minimum and a maximum level after adjustment for the total monthly addition of precipitation, evaporation, backflush and refill (ibid). \(Q_{\text{Prec}}\) (Figure 3b) is the water entering the water feature because of atmospheric precipitation where \(A_{\text{water feature}}\) represents the surface area of the water feature and \(I_{\text{Prec}}\) represents the average rainfall intensity and \(T_{\text{Prec}}\) represents the average precipitation time \[46\] and can be calculated using equation (4) at Figure 3b. In addition to precipitation, water is discharged from periodic backwash of the filtration system and is represented by \(Q_{\text{Wash}}\) as water loss \[39, 46\] and \(Q_{\text{Evap}}\) is the evaporation rate. Both parameters can be calculated using equation (2) and (3) Figure 3b \[47\].

Considering the existing pumps configuration at Figure two above, equation (5) at Figure 3b adapted from Forrest and Williams \[39\] is used to calculate electrical consumption within the treated water feature system all year around where \(P\) is the pump power (kW), \(H_{\text{op}}\) is the pumping hours per day in the open season and \(H_{\text{cl}}\) is the pumping hours in the closed season. \(S\) is the open season length in days \[39\]. Equation (5) Figure 3b was modified to reflect local conditions. The maintenance of the water features occurs year around and is drained once every quarter for cleaning and disinfection, which represents 18 days per year or 351 days total. Hence as specified in Figure 3a the Open Season is 365 days and the Closed Season is estimated at 351 days for accounting for maintenance and when the water features are drained. Peak power demand for the irrigation can be determined using formulae (6) Figure 3b where discharge is the peak scheme demand expressed in cubic meter per second (m³/s). It is assumed that the electric pumps work at an efficiency of 10% delivering 10 m³/h and 64 m³/h water to irrigate 36,310 m² of open vegetated landscape from different heads (m) to pump water ranging from 3m (lowest) to 25m (highest). The
maximum daily pumping is estimating at one hour for the trees and plants and 30 minutes for the grass area. The daily energy uses and the seasonal energy demand over the year to irrigate the overall landscape can be calculated using equation (7) and (8) Figure 3b respectively. Energy demand can be calculated from peak power demand calculation, using equation (9) Figure 3b where the volume of water (m³) represents the seasonal (yearly) scheme of water. The efficiency of the pumping plant provides the overall energy need [45].

<table>
<thead>
<tr>
<th>Physical characteristics</th>
<th>Water features</th>
<th>Irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined area (m²)</td>
<td>3,289</td>
<td>36,910</td>
</tr>
<tr>
<td>Combined volume (m³/month)</td>
<td>1,557</td>
<td>4,201</td>
</tr>
<tr>
<td>Pump (kW)</td>
<td>4-20</td>
<td>18.5</td>
</tr>
<tr>
<td>Pump flow rate (l/h)</td>
<td>10-10</td>
<td>10-10</td>
</tr>
<tr>
<td>Head (m)</td>
<td>2-25</td>
<td></td>
</tr>
</tbody>
</table>

**Operational parameters**

| Pump (hours/day)       | 10            |
| Backwash period per month | 4 n/a         |
| Backwash duration (mins) | 15 n/a        |
| Refill period (years)  | 0.5           |

**Environmental conditions**

<table>
<thead>
<tr>
<th>Season (length)</th>
<th>Rainfall (mm)</th>
<th>Evaporation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>385</td>
<td>72.4</td>
<td>3,204</td>
</tr>
</tbody>
</table>

\[
w^{2} = \sum_{i=1}^{n} w_{i}
\]

\[
Q_{group} = \frac{Evaporation \, rate \, (l/day) \times time \, (days \, per \, cycle \, period)}{Super \, surface \, area \, of \, water \, feature} \times \text{water \, feature \, surface \, area}
\]

\[
Q_{backwash} = \frac{Backwash \, rate \times backwash \, time \times \text{cycle \, per \, period}}{Super \, surface \, area \, of \, water \, feature}
\]

\[
Q_{peak便是} = \frac{Average \, irrigation \, demand \, during \, one \, cycle \times \text{water \, feature \, surface \, area}}{1,000 \times \text{pumping \, plant \, efficiency}}
\]

\[
E_{i} = P \times \left(\frac{\text{Discharge} \, (l/day)}{1,000} \times \text{Head} \, (m) \right)
\]

\[
\text{Overall \, seasonal \, energy \, demand} \, (kWh) = \frac{Q_{peak}}{\text{Crop \, duration \, (days \, per \, month)}} \times \text{pumping \, plant \, efficiency}
\]

\[
\text{Energy \, demand \, per \, day} = \frac{\text{Peak \, power \, demand} \times \text{Maximum \, daily \, pumping \, hours}}{1,000}
\]

Figure 3 (a) Water features and irrigation system main input summary; (b) Formulas used to determine energy use against water consumption [45] for (6) to (9); [39] for (1), (5); [46] for (4); [47] for (2), (3).

### 5. Results

As shown at Figure four, the energy consumed to irrigate the landscape comes to 29.96kWh/day average including all pumps serving the non-potable water treatment system (Figure 2). That is 0.22kWh/m³ considering the system will use over time 100% non-potable water as opposed to 64% to date (January-December 2016). That means when the system does not use 100% of its non-potable water capacity it consumes more energy to deliver high energy intensive desalinated potable water. This is even more evident with the water features water and energy consumption. For example, in January 2017, for 1,158m³ of water 52.53kWh/m³ energy is used whereas in August for 1,934m³ of water 34.44kWh/m³ energy is used. In comparison, a desalination plant in Abu Dhabi consumes between 1.65kWh/m³ to 4.2kWh/m³ energy an average of 3.57kWh/m³ [8], that is 16 times more than the onsite system. The water features use 1,925.40kWh energy average per day assuming quarterly maintenance, drain down and refill. Backwash assumes (Figure 3a; equation 3, Figure 3b) pumps run four times per month for 15 minutes each with only one pump operating at any given time plus average 15m³/h pumps operate four times per month for 15 minutes at each of the eight water feature rooms [48]. That is 39.09kWh/m³ average, which is 180 times more than the landscape irrigation energy demand. If the water feature would essentially use desalinated potable water, energy usage would increase by 8%. The least water used, the more energy consumed for the onsite system specifically for the water feature because the pumps are operational permanently and so the energy to water ratio increase in terms of kWh/m³. It is equivalent to leaving a window open at all time while a room is being air conditioned or heated. Energy is wasted including water because also the evaporation rate is 97% higher than precipitation. The latter may be controlled by the application of a transparent liquid cover to reduce water loss. Per Elam [47] this solution is yet to be proven in terms of cost and loss efficiency rate.

The actual air conditioning condensate water generated for the month of February is 183m³/day or 5,126m³/month considering extrapolation of data from February 12th to February 28th 2017 for a whole month, which is 33% more than the predicted model. If the month of March data is extrapolated from the 9 days' record (March 1st to 9th 2017) for also a whole month, the production of condensate water comes to 6,961m³ for this month or 224.55m³/day, which represents 3% less than the predicted model (Figure 4). In any case, the average between these two months demonstrates the theoretical model anticipated volumes are in the range of actual records. And non-potable water availability may even be higher in winter than predicted, i.e. month of February. To prove
this, 12 full months of record will need to be collected from March 9th 2017 to 11th February 2018 including records of outdoor temperature and humidity for each month. The results of the water testing have shown that all parameters for the condensate water are within the RSB limits and of similar quality than desalinated potable water. However, the fire sprinkler test water, which represents a volume of 450m³/year for potential reuse, are two to five times higher than the RSB limits. In the current configuration of the system of Figure two, an Ultra Violet (UV) irradiation and filtration treatment system is being installed, which is deemed suitable to regulate the sanitary and microbiology contaminants. This disinfectant treatment type system is effective towards inactivation of viruses, bacteria and trace organic contaminants [49].

Figure 4: 2017 Water energy demand results (calculations by main author, reviewed by MEP consultant)

6. Discussion

The paper has given an account of energy consumption for using alternative water sources for outdoor reuse versus seawater desalinated potable water use. Evidence is presented for the energy and cost savings a project can achieve by reusing AHU FCU A/C condensate water as opposed to potable water for irrigation and water feature use. However, this study is also showing that the use of non-potable water use for water feature is high energy intensive because of the large number of pump sets required to operate a 24/7 system year around, specifically in a hot desert type climate which has a very high evaporation rate with little rainfall. This said, using desalinated potable water would add up in terms of energy consumption because the process of desalination whether processed with co-generation or Reverse Osmosis is still today more energy intensive than an onsite system. The advantage of AHU FCU A/C condensate water is that it is gravity fed to the point of distribution and so energy is only needed to treat and convey the water to the point of consumption. Additionally, it was found that fire pump test water has the potential to be reused under the condition that a tertiary treatment system is used. Abu Dhabi water and energy strategy relevant to the study have been reviewed, which set out the importance of the water and energy nexus in the region. The local water supply is briefly presented, which identifies gap in terms of legislated sustainability options for sites not being connected to the TSE network. This brief review shows that the regulator has a large role to play in setting out directions for water and energy conservations to reduce greenhouse gas emissions, to protect the environment and the future of Abu Dhabi. The proposed methodology is the use of the medical facility as both a case study and an action research intervention. The latter is designed to test the facility onsite effluent generated by the AHU FCU A/C condensate water and the fire pump sprinkler test water (from the main test drain) on a short term to establish potable water, energy and greenhouse gas savings. This intervention has been measuring the impact of using onsite alternative water sources in a healthcare setting to alleviate the use of desalinated potable water in terms of energy consumption and greenhouse gas (GHG) emissions. Recommendations are for the adoption of a treated non-potable water reuse protocol by the health authority to help reduce healthcare water and energy consumption and GHG emissions born from desalinated water use for irrigation and water feature. The final steps are the monitoring and recording of AHU FCU A/C condensate water generation from March 2017 through to
February 2018 including the outside air temperature and humidity and the testing of Reverse Osmosis reject water quality against RSB limits to establish its potential for reuse.

7. Conclusions

The paper has discussed that the overall concept for the project and the methodology of this D.SBE action research project has been designed, developed and has been implemented by the first author. The paper has discussed the context to the water energy nexus in Abu Dhabi and it has been down that alternative water sources can greatly reduce not only seawater desalinated potable water but also energy consumption and GHG emissions. The case study presented is a medical facility in Abu Dhabi and the existing systems for recycling and reusing water have been discussed and illustrated. It has been shown that the reuse of onsite alternative water sources can substantially decrease the need for offsite desalinated water and thus decrease energy consumption specifically for irrigation water end use unlike water features, which is high energy intensive even for an onsite system. The more water use the best water energy ratio is achieved. This element points out the advantage of using onsite alternative water sources to minimize desalinated water and energy wastage. The methodology for several novel types of water reuse have also been discussed which include AHU FCU A/C condensate water and fire pump sprinkler test water and adequate treatment for reuse. The results from the water reuse and recycling have shown that desalinated water consumption can be reduced by 124,750m³ and energy use can also be minimized by 445Mwh/year. The next recommendations from this paper are to investigate water evaporation minimization techniques to decrease water and energy loss for outdoor water features use. The next steps to the research project are to quantify the overall year of AHU FCU A/C condensate water generation and to test Reverse Osmosis reject water to account for its potential for reuse. Finally, the results may be relevant to local authorities responsible for making and adjusting standards on water reuse and recycling for reducing energy consumption and greenhouse gas emissions overall for hospitals.

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References
