Factors Affecting HVAC System Maintenance - Abu Dhabi - UAE

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Abstract: **While HVAC maintenance is primarily a technical service, it is provided by people who work for other people, and is performed for people who own or occupy a building. A maintenance measure is only effective if technicians have the tools, skills and training to implement it properly. Heating, ventilating and air conditioning (HVAC) systems consume the largest portion of energy used in a building. Many building faults that occur during a project life cycle hugely contribute to energy loss, including: operational faults from improper installation, poor testing and commissioning, poor integration with building management systems, equipment degradation, sensor offset failures and control logic problems. They can be grouped into several categories, including: (1) control fault, (2) sensor offset, (3) equipment performance degradation, (4) fouling fault, (5) stuck fault, and others. The present study identified seven factors affected HVAC Maintenance performance that increased the energy consumption. These factors are: building design, temperature and humidity sensors, condition of HVAC Units, rules and regulations, engagement with stakeholders and allocation of budgets. Questionnaires were distributed to 150 participants: designers, facility managers and maintenance experts working in companies in Abu Dhabi. Exploratory data analysis using descriptive statistics was used to measure which of the above factors are more important and have significant effects on HVAC maintenance performance and increased the energy consumption. The results showed that the most important factors affecting HVAC system maintenance are: the HVAC system, the building design, and the engagement with stakeholders, in that order.**

Keywords: **HVAC Systems, HVAC Maintenance, Factors, Energy Consumption, Building Design.**

1. INTRODUCTION

The UAE's *per capita* energy consumption rating is the highest in the world. Upon becoming independent in 1971, the UAE started focusing extensively on economic development and urbanization projects, consequently quadrupling primary energy consumption from the 1980s until 2007 *as per* energy statistics (Kazim, A.M., 2007). HVAC electricity consumption constitutes the major component of energy use, typically around 40% of total building consumption and around 70% of a building's base electricity consumption (Lasath *et al.*, 2012; Noureldin *et al.*, 2016).

Many researchers have shown that the performance of existing residential and small-commercial heating ventilating and air-conditioning (HVAC) systems is far from optimal. In many cases, the systems were never installed correctly and have never operated optimally, resulting in lower efficiency than implied by the nameplate rating (Wireman, 2005).

In other cases, the performance has degraded over time, either because of faults or improper service, causing the equipment to malfunction or to perform poorly (Haniff, 2013). Measures such as duct sealing and repair, condenser and evaporator coil cleaning, refrigerant charging and air flow adjustments, economizer retro-commissioning and HVAC controls can potentially produce significant savings. Therefore this paper investigates seven factors: personal expertise, building design, temperature and humidity, HVAC units, rules and regulations, engagement with stakeholders and budget allocation. These factors can reduce the power consumption and improve maintenance operations and efficiency, as shown below.

2. PERSONAL EXPERTISE

Improving the performance of an HVAC system requires effectively trained professional technicians**.** Regardless of the maintenance programme, if the HVAC system is not frequently and appropriately maintained, it is of limited value. It was recommended that five HVAC maintenance staff and building operators should have suitable training. The training should comply with HVAC maintenance practices including the removal of HVAC filters and the management of work risks. Numerous HVAC maintenance staff and building operators have not had professional training for maintenance work (Hitchcock, 2006).

For the personal expertise factor, the study investigated many key sub-factors such as the personnel training and development, maintenance personnel evaluation, the effect of employing unskilled technicians, considering incentives for the personal growth of contractors and employing suitably trained staff to manage the HVAC systems (see Section 10.1).

3. BUILDING DESIGN

There are serious fundamentals in the design and construction procedures that can considerably impact upon maintenance e.g. performing periodic, recognized, well-ordered reviews throughout the pre-design and design stages of a project and allowing the managers from all divisions to contribute their expertise**.** Through evaluation meetings, the designers investigate the efficiency of documented needs and also integrate the ideas that may give the preferred results at lower costs (Lin, 2010).

Design engineers working on designs for new projects or the replacement of existing HVAC equipment need to take an active part in ensuring that new HVAC systems have intrinsic features that improve efficiency (Karg, 2000).

For the complexity of load calculation and equipment sizing, HVAC equipment suppliers provide facilities for HVAC' load calculation and equipment-sizing to their usual customers (contractors). The information that is given by the contractor to the HVAC supplier regarding the particulars of the building should be precise. Providing contractors with outline information/data and helping them to provide precise information may raise the precision of HVAC load calculations (Karg, 2000). Furthermore, poor installation is the common reason for the difficulty of accessing the HVAC system components.

Diverse HVAC system maintenance practices can result in considerable differences in building energy consumption. If an element of HVAC equipment is not properly maintained, its working performance will degrade. If sensors used for control purposes are not calibrated, not only could building energy usage be dramatically increased, but mechanical systems may not be able to ensure indoor thermal comfort (Wang, 2014).

HVAC maintenance practices should ensure that HVAC maintenance is part of a process that **provides** efficient, constant**;** operating facilities at all times (Wireman, 2005). Referring to Zhou, Wang & Ma (2009), maintenance procedures can be divided into three classes depending on the efforts made to develop them: Proactive Maintenance, Preventive Maintenance and Reactive Maintenance. The advantages and disadvantages for these maintenance classes are addressed in Table 1.

Table 1: Advantages and disadvantages of HVAC Maintenance Types (Sapp, 2010)

Maintenance Type	Advantages	Disadvantages
Proactive maintenance	- Improved parts working life - **Activates** pre-emptive remedial activities. - Reduces procedure downtime. - Reduces labour and parts costs. - Improved product value. - Enhances workers' and environmental safety. - Enhances workers' morale. - Power savings. - Approximate (8% - 12%) cost savings more than preventive maintenance plan.	- Improved savings in investigative equipment. - Improved savings in workers' training - Investments probably not willingly made by the organization.
Preventive maintenance	- Cost-efficient in numerous capital-intensive procedures. - Adaptability takes into account the change of maintenance periodicity. - Expanded segment life cycle. - Power saving. - Decrease equipment or procedure breakdown.	- Cataclysmic disappointments still prone to happen. - More workers needed. - Incorporates execution of unneeded maintenance. - Potential for accidental harm to parts in directing maintenance.

	- Assessed 12% to 18% more costly than reactive maintenance programmes.	
Reactive maintenance	- Lower cost. - Fewer staff.	-Increased cost because of impromptu downtime of equipment. - Expanded worker costs, particularly if extra time is required. - The cost required with repair or substitution of equipment. - Equipment or process harm from equipment malfunction. - Wasteful use of resources.

For the building design factor, the study investigated many key sub-factors such as the building design, the ability to access the HVAC system components, complex building designs and HVAC system accessibility, building aspects and effective maintenance practice, as shown in Section 10.2.

4. TEMPERATURE AND HUMIDITY

Some authors, like Liu (2001), have studied the Gulf region and discovered that temperatures increase up to 50 degrees in summer. These conditions are being blamed for system failures in other technological implementations.

The indoor thermal atmosphere is an imperative issue influencing the health of occupants and profitability of clients. When planning heating and cooling systems, the customary settled temperature set points are not appropriate in the Gulf, the indoor comfort temperature relies upon the outside air temperature and the business culture, for example, the nature of exercises, the dress of tenants, and so on. Specialists have been occupied with researching versatile temperature control to provide a reasonable, comfortable, *in situ* temperature. Sadly, these examinations can cause problems when considering energy saving (Djongyang, 2010).

This study has investigated many key sub-factors such as the temperatures and the HVAC system response and system maintenance schedules along with temperatures fluctuation and the HVAC system maintenance (see Section 10.3).

5. HVAC UNIT

For this factor, many key sub-factors were investigated, such as the dependent level of the HVAC system, the type of filters used, the maintenance faults that caused significant power consumption, the frequency of balancing the air system, the HVAC system's working schedule, the factors that dictate the number of HVAC units installed, the average time for HVAC system operation after maintenance, the tools needed to conduct regular maintenance, the maintenance frequency of the HVAC system and the installation of adequate energy and water metering for the HVAC system.

If the HVAC is integrated with the Building Management System, many benefits will be achieved such as the plausibility of individual room control, expanded staff profitability, viable checking and focusing of energy utilization, and enhanced plant dependability and life**.** Viable reaction to HVAC related protests, saving time and cost amid the maintenance **(**Roth, 2002).

The study investigated if the HVAC is operating separately or if it was integrated with the Building Management System (BMS) by measuring the dependent level of the HVAC system (sees Section 10.4).

As indicated by Waring (2008), filtration in HVAC is the most generally utilized strategy for protecting individuals and equipment from airborne particulate damage. To help in filter choice, several norms address HVAC filtration productivity including ASHRAE Standard 52.2: Technique for Testing General Ventilation Air-Cleaning Gadgets for Evacuation Effectiveness by Molecule Measure (ASHRAE 1999) and ASHRAE Standard 52.1: Gravimetric and Tidy Spot Methodology for Testing Air-Cleaning Gadgets Utilized as a part of General Ventilation for Expelling Particulate Issue. This study investigates the types of filters used in HVAC Systems (see Section10.4).

As indicated by Basarkar (2013), data on frequently-occurring HVAC issues is available. There is an accumulation of reports on fault discovery and findings from specialists worldwide. Valuable data was likewise found in the doctoral proposals of Siegel (2002), and additionally an ASHRAE Exploration Task, ASHRAE 1043-RP. These three investigations identified basic faults in auxiliary HVAC systems, fouling in heat exchangers and shortcomings with chillers individually. Table 2 records a portion of the frequently occurring faults distinguished by Basarkar's examination.

Table 2: List of Common HVAC Faults (Basarkar, 2013)

Components	Faults	Symptoms
Chiller	Contaminated condenser.	Diminished chiller effectiveness and expanded condenser outlet temperature.
Chiller	Refrigerant leakage.	Diminished condenser weight and compressor capacity, leading to wasteful cooling.
Heating/Cooling coil	Valve stuck open or blocked.	Unneeded concurrent heating or cooling can happen if a valve is stuck open. On the off chance that it is stuck shut, comfort declines because no heating or cooling is available when required.
Heating/Cooling coil	Contaminated coil.	Lessened UA diminishes coil limit. Builds pump control (made up for by lessened load).
Fan	Stuck at full/middle speed, neglects to react to control flag.	Higher power utilization if fan is stuck at speed higher than required. Decreased indoor air quality when it is stuck at brings down speed.
Mixing box	Stuck outside air damper.	Outdoor air damper can't regulate, bringing about power penalty when outside HVAC is dealing with the expectation of complimentary cooling or least outside air is requested for mechanical warming/cooling modes.
Mixing box	Releasing open air damper.	Result in power penalty when spillage rate is higher than the requested outside air flow current rate. The power effect could conceivably be noteworthy relying upon system type, economizer type and building area.
Temperature sensor	(SAT, RAT, OAT), Temperature sensor offset.	Open air damper, return air damper and warming/cooling valve poorly controlled, bringing about power penalty and thermal comfort issues.
Water distribution system	Obstruction inside the pipe.	Increment on the up and up weight drop causes higher energy utilization. Conceivable comfort issues because of inadequate water flow rate in the plant circuit.
Pump	Stuck at full/middle speed, neglects to react to control flag.	Higher power utilization if pump is stuck at speed more than required. Diminished indoor air quality when it is stuck at a lower speed.

This study investigates the maintenance faults that caused significant power consumption as shown in Section 10.4.

Balancing HVAC air and water system calls for an efficient approach. Viable testing and adjustment requires a connection between the mechanical exchanges to take part in the operation of the system to create powerful outcomes. Adjustments to be made according to requirements and plans. The proprietor's representative should witness or take an interest in the the retesting of a system or a zone inside the task subsequent to submitting the final report (Sugarman, 2015).

Un-balanced dampers decrease the air flow current to one line while multiplying the airflow stream to another. Finding the correct adjustment implies that each room gets the appropriate measure of treated air, making the rooms equally agreeable (Chen, 2016). Basic issues caused by an unequal HVAC Framework are summarised in Figure 1.

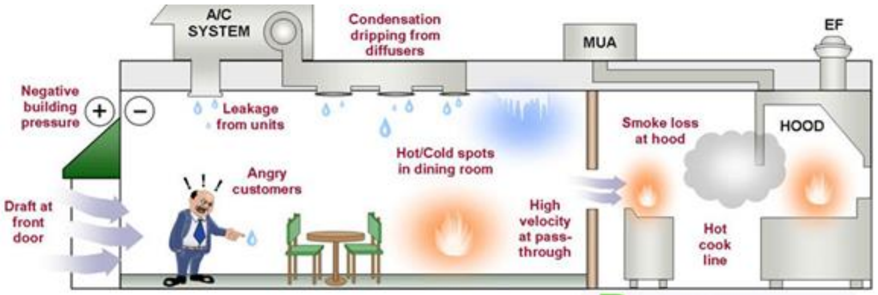

Figure 1: Common Problems Caused by an Unbalanced HVAC System (Sugarman, 2015).

This study investigates the frequency of balancing for an air system by measuring how often the air system is balanced in order to maintain the required rates of air flow and quality levels *as per* location needs, as shown in Section 10.4.

The ASHRAE HVAC Handbook (2001) lists eight of the most-widely recognized factors that influence the selection of an HVAC system, including the preferences of the building proprietor, the projected cost, the state of the building, the function of the building, any architectural restrictions, the life-cycle cost, the simplicity of operation and maintenance, and the development time-scale. This study investigates the factors that dictate the number of HVAC units in buildings in Abu Dhabi by measuring the proposed factors such as the number of floors for the building, operating hours, the type of system installed, the total capacity of the system and the quality of the air, as shown in Section 10.4.

Suppliers invest a great deal of time and cash testing their equipment to identify what the maintenance needs are (Suttell, 2006). As indicated by Nguyen (2014), neglect or postponement of maintenance activities at the ideal time may make problems worse and cause, for example, excessive damage, wear and flaws. At that point, extra maintenance works are essential to treat the issues. For example, maintenance staff may have distinguished an issue happening in an HVAC system, for example, a deficient chiller; however, they postpone the support and repair to suit the residents, which may further harm the chiller and lead to increased material and work costs and extra maintenance and repair works. This study investigates the average time for HVAC system operation after maintenance, as shown in Section 10.4.

Many tools are used to conduct regular maintenance including devices that recognize and **locate** sensor faults in normal AHUs with regular checking and control instrumentation (Xiao, 2006):

- A vacuum pump to ensure the coordinated segments with the light and brilliant packaging (Muller, 2008).
- An Advanced Thermo-Hygrometer: an accurate, battery-operated instrument for measuring temperature and dampness (Muller, 2008).
- An HVAC Meter/HVAC Analyser for Trying, Adjusting and Balancing (TAB).

These three devices can ensure legitimate operation of heating, ventilation, cooling (HVAC) and refrigeration (HVACR) systems (Higgins, 2002).

This study investigates maintenance tools to conduct regular maintenance such as diagnostic equipment, the manufacturer’s toolkit and a basic tool set, equipment accessibility and system location, as shown in Section10.4.

HVAC maintenance is the everyday exercises required to safeguard, hold or re-establish equipment and systems in first-rate condition or to a condition in which it can be successfully utilized for its intended purpose. Proactive maintenance incorporates preventive, predictive and reliability-centred maintenance. Preventive maintenance is a type of maintenance planned after a specified time (Lewis, 2010).This study investigates the maintenance frequency for HVAC systems in Abu Dhabi (see Section 10.4).

As indicated by the Estidama Pearl Rating framework, effortlessly available and obviously labelled water meters should be provided and equipped for observing the water utilization. Providing an arrangement of metering offices permits the energy consumption to be recorded and observed to allow future change and an understanding of the energy-use in buildings. One of the credit necessities for the Estidama Pearl Rating Framework is that effortlessly available and obviously named energy sub-meters ought to be provided which enable at least 90% of the evaluated yearly energy utilization to be checked, as outlined within the calculations and methodologies section (Abu Dhabi Urban Planning Council, 2010).

This study investigates the installation of adequate energy and water metering for the HVAC system (see Section 10.4).

6. RULES AND REGULATIONS

For this factor, many key sub-factors were investigated including accessing documents for the HVAC system, the mechanical codes affecting the HVAC maintenance protocol; the regulatory frameworks that cause maintenance challenges, the structure of maintenance operations and the kind of formal **standards** required **e.g.** sustainability policies, environmental & maintenance policies, maintenance strategy and sustainability benchmarks & HVAC KPIs.

Energy policies set the level of energy effectiveness required for the design of new constructions and building retrofitting. Energy regulations and policies should at least concentrate on the main power consumers for HVAC system services in buildings. They should also incorporate the quality of the building envelope since this has an important impact on HVAC use (Chua, 2007).

High-quality documentation is necessary for better maintenance. It is basic to keep up and refresh the essential documentation identified for a building and its services, from outline planning through to demolition. Ensuring full documentation is basic for various reasons, including health, safety and security; maintenance and operation; financially-related responsibility and for ensuring energy and water efficiencies (Mazzei, 2005).

This study investigates the access to documents for an HVAC system as shown in Section 10.5

Codes are for the most part obligatory to ensure that designers produce legal designs that give due regard to human health and safety. Country codes regarding auxiliary uprightness and energy saving have to be taken into account. Standards ensure predictable techniques for testing, indicate conformation to plan rules and benchmarks and prescribe standard practices (Wang, 2014). According to the Department of Municipal Affairs (2014), the Abu Dhabi International Mechanical Code (ADIMC) is a code that directs the design and installation of mechanical systems, apparatus, machine venting, ducts and ventilation systems, combustion air provisions, pressure driven systems and solar-energy systems.

As indicated by the Abu Dhabi Urban Planning Council (2010), the accompanying codes have been incorporated as a part of the outline and operation of air conditioning systems in Abu Dhabi:

- Abu Dhabi International Building Code (ADIBC), Edition 2013. Prepared by the Department of Municipal Affairs, Abu Dhabi.
- Abu Dhabi International Mechanical Code (ADIMC) Edition 2013. Prepared by the Department of Municipal Affairs, Abu Dhabi.
- Operation and Maintenance manual, substantially in agreement with ANSI/ASHRAE 62.2:2007.
- Ventilation Rate Procedure and indoor air quality are *as per* areas 4.2 and 4.3 of ASHRAE 62.1.2007.
- Mixed Mode Ventilation for the completely mechanically ventilated time of operation *as per* ASHRAE 55-2004 segment 5.3.

This study investigates how the developed mechanical code for HVACs is affecting HVAC maintenance protocols in Abu Dhabi, as shown in Section 10.5.

Referring to Pérez (2011), the enhancement of the prescriptive way for fulfilling the HVAC system part of the buildings energy regulations has to consider the 'list of effectiveness necessities'. Authoritarian organizations should accept more strict and homogenous necessities and must improve new documents and software specifications to develop code information, fulfilment and enforcement. A reliable HVAC performance method is also required to supplement the prescriptive method. In order to promise consistent, equal paths, the adoption of the self-reference method along with the utilisation of an imitation tool for power use evaluation seems the most appropriate option. Otherwise, building effectiveness would be unattainable and the rising trend in HVAC power use due to the global desire for thermal comfort will carry on for years to come.

This study investigates the regulatory frameworks that cause maintenance challenges as shown in Section 10.5.

According to Lin (2010), the maintenance process should incorporate maintenance information and knowledge into the project delivery procedure, as well as corporate-level and project-level actions as shown in Figure 2. This presents a technique for accessing maintenance information throughout the project delivery procedure. A maintenance procedure requires well-informed manufacturing professionals to recognize the correct questions at the right time. This study investigates the maintenance operations structure as shown in Section 10.5.

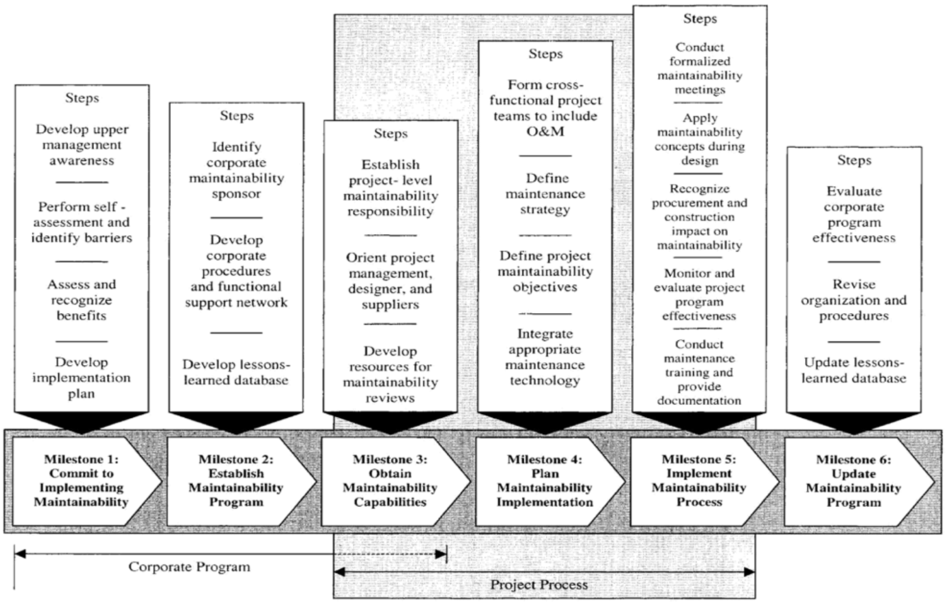

Figure 2: Phases of the Maintenance Procedure (Lin, 2010).

Occupants, their designer and contractor should look for approval from the aforementioned facility manager before handling any job that is associated with the building systems or might influence the performance of the HVAC systems (Lewis, 2010). Additional HVAC systems should incorporate the main building systems rather than counteract them. When fixing additional HVAC systems, their controls should be connected to avoid the occupant systems interfering with the central system. As an option, the main building services that **cover** this area should be detached, with the facilities manager's agreement (Krarti, 2016). This study investigates the kind of formal approval required (see Section 10.5).

The repair and maintenance of HVAC systems improves a building's conditions and, moreover, its quality and image, thereby providing noticeable energy cost savings (Martinaitis *et al*., 2004). In the UK, retrofitted thermal insurance ventilation controls and sunspaces for tall structures provide savings in heating costs in the region of 25% and 60% (Ding, 2008). In Italy, low energy housing adds to speculation assets of 26% to 35% in private structures' essential services (Blengini and Di Carlo, 2010). In Denmark, it is evaluated that the energy saving potential for space warming could achieve 80% inside the present private building stock until the energy usage is redesigned or rebuilt in around 2050 (Tommerup and Svendsen, 2006). This study investigates the sustainability policies for maintenance in Abu Dhabi, as shown in Section 10.5.

According to Wang (2000), the aim is to offer an HVAC&R system which is ecologically friendly, power efficient and practical, as follows:

- Effectively control indoor natural parameters, for the most part to keep temperature and humidity inside required cut-off points.
- Provide a satisfactory measure of outside ventilation air and an acceptable indoor air quality.
- Use energy efficient equipment and HVAC&R system.
- Minimize ozone exhaustion and the impact of unnatural weather changes.
- Select financially-effective parts and systems.
- Ensure legitimate maintenance, simple after hour access, and essential fire insurance and smoke control systems.

The regulations and strategies set by the building client provide procedures for setting up the application of a maintenance agreement and effectiveness measures (Chua, 2007).

This study investigates the environmental & maintenance policies to ensure that the environmental & maintenance policies are considered **by** the maintenance practices in Abu Dhabi, as shown in Section 10.5**.**

The significant targets for maintenance engineers are to execute a maintenance strategy which boosts the accessibility and effectiveness of the equipment; controls the rate of equipment deterioration; guarantees a safe and well-organised operation and limits the aggregate cost of the operation. This must be accomplished in an organized way that deals with the investigation of equipment malfunction and outlines an ideal strategy for inspection and maintenance (Khan, 2003). The study investigates maintenance strategies in order to develop one for Abu Dhabi (see Section 10.5).

According to Chua (2007), Key Performance Indicators (KPI) are a type of performance management. For an HVAC maintenance contract to deliver power and water savings, the organization of sustainable KPIs and benchmarks is significant for the following reasons:

- Using important rating tools, for example, NABERS power and water, is a dependable technique for comparing the situation in two or more buildings. This provides a way to compare potential power and water cost savings.
- The foundation of KPIs and benchmarks is basic for expressing the current execution of a building and for setting legally binding focuses for the maintenance contractor to either maintain or enhance the current performance. If valid KPIs are established and agreed as a contractual requirement, this would provide a sound reason for checking whether specialist maintenance organizations are really achieving power and water savings.
- For any charge-related motivations offered for repairing or improving power proficiency, it will be important to legally monitor and agree the KPIs against which the maintenance contractor worker's progress can be judged.

This study investigates the sustainability benchmarks & HVAC KPIs to ensure that they can be developed in Abu Dhabi (see Section 10.5).

7. ENGAGEMENT WITH STAKEHOLDERS

For this factor, many key sub-factors were investigated such as discussing the energy-saving opportunities with the maintenance contractor including monitoring HVAC KPIs, building performance targets and regular energy audits with third parties.

For HVAC maintenance to provide efficiencies and to accomplish target execution appraisals, it is fundamental that partners cooperate as a group to improve and understand the shared objective of accomplishing sustainability. Those occupied with the Green Maintenance process must have the fundamental background, knowledge and awareness of current innovations and the ability to execute an upgrade. It is basic to have the correct demeanour and enthusiasm to have any kind of effect (Chua, 2007).

This study investigates whether the existing construction contracts in Abu Dhabi are discussing the energy-saving opportunities with maintenance contractor (see Section 10.5).

As per Lewis (2010) observing HVAC KPIs, KPIs in an administration contract are contingent upon the fact that they are fundamental to successful HVAC maintenance. There is a broad assortment of usable performance measures to monitor KPIs including Critical Success Factors (CSFs), KPIs and Performance Measures (PMs).

This study investigates HVAC KPIs monitoring a building's performance targets to ensure that corrective actions, such as re-commissioning and fine tuning, are carried out where necessary (see Section 10.5).

As indicated by Suttell (2006), a standard audit should occur annually. Performing the audit identifies wasteful aspects on a daily or weekly basis. A power management system will activate alarms to warn of serious issues, these are then reported and recorded. Essential checks are made according to a preventive maintenance timetable to guarantee that any power investment funds are **effectively used** (observing power utilization of key segments, for example, chillers, AHUs, and so on; guaranteeing the correct operation of dampers, the state of filters, and ventilation rates; and so on). This study investigates regular energy audits by third parties to improve power consumption and HVAC maintenance, as shown in Section 10.5.

8. ALLOCATING A BUDGET TO ENABLE EFFICIENT MAINTENANCE

The four greatest cost savings regarding HVAC maintenance are as indicated by Krarti (2016), as follows:

- Adding variable speed drives to chillers, AHUS and Fans and other huge loads.
- Proper and precise estimation of fans.
- Adjusting controls (changing set focuses and day-by-day/occasional cycles) or updating them.
- Optimization of ventilation.

As indicated by Shah (2009), unique measures to limit maintenance costs include:

- Tenants and residents share in maintenance management activities;

- Introducing property O&M and principles, controls, including preparing for occupants and residents and compelling a suitable maintenance approach.

- Possessing balanced cost plans in each maintenance undertaking; proactive maintenance and repair for serious and on-time assignments in advance of problems occurring.

- Adapting preventive support.

- Ensuring that all residents pay the maintenance charge on time.

- Employing the lowest number of qualified and ideal staff needed to maintain satisfactory standards.

This study investigates the allocation of budgets to enable efficient HVAC maintenance in Abu Dhabi, as shown in Section 10.5.

9. METHODOLOGY

The study utilizes a field survey to evaluate the impact of the seven factors affecting the HVAC system maintenance mentioned above, namely: building design, temperature and humidity sensors, the HVAC unit, rules and regulations, engagement with stakeholders and the budget allocation.

Data were collected from 150 participants of varying nationalities. The majority, 126 (84%), were males, and 24 (16%) were females. The majority of respondents (28%) were aged between 41-45 years old, the second highest age group (20.7%) was between 46-50 years old, then 18.7% were between 36-40 years old, 13.3% were between 51-55 years old, 6% were between 56-60 years old and the other 2.0% were between 25-30 years old. Respondents' years of experience were measured, the result indicated that the majority (46%) had 16-20 years of experience, 31.3% had 11-15 years of experience. This proves the accuracy of respondents' answers.

Respondents were from different countries; the highest numbers of respondents were from Sudan (18.7%), next were from Egypt (17.3%), then from Syria (10.7%). Others were from countries like Saudi Arabia, Yemen, Oman, UAE, India, Iraq, Jordan, Pakistan and others (see Table 4.4). Table 4.5 and Figure 4.4 indicate that the majority of respondents (76.7%) were from Facility Management (FM). Table 4.6 indicates that the majority of respondents were working as Senior FM Engineers (27.3%), FM Managers (15.3%), Senior Mechanical Engineers (10.7), and FM Engineers (10%). The rest were also holding important positions in their organizations. To determine the sample size for the study, the following formula was used in the computerized sample-size calculator.

$$SS = \frac{Z^2 \times (p) \times (1-p)}{C^2}$$

Where:

SS	=	Sample Size
Z	=	Z value (e.g. 1.96 for 95% confidence level)
P	=	Percentage picking a choice, expressed as a decimal used for sample size needed)
c	=	Confidence interval, expressed as a decimal (e.g. 0.04 = ±4)

The population size for the study was 2,593 construction firms which represented the construction firms working in Abu Dhabi according to the Abu Dhabi commercial directory which includes all the construction firms registered with the Abu Dhabi Chamber of Commerce and Industry (ADCCI) (Abu Dhabi e-Government Gateway, 2013). The sample group size of 500 was determined from the population size of 2,593 for the construction firms in Abu Dhabi. The population for the questionnaire were selected randomly to give a sufficiently random and representative sample of the general population. This means that each respondent for the questionnaire was selected from each construction firm in Abu Dhabi.

The confidence interval of 3.94 was used and when 47% of the sample picks an answer we can be "sure" that if we had asked the question of the entire relevant population between 43% (47-4) and 51% (47+4) would have picked that answer. The confidence level is expressed as a percentage and represents how often the true percentage of the population who would pick an answer lies within the confidence interval. A 95% confidence level means that we can be 95% certain; the 99% confidence level means we can be 99% certain. Most researchers use the 95% confidence level. When determining the sample size needed for a given level of accuracy, the study used the worst-case percentage (50%) to determine a general level of accuracy for a sample. The parameter used is the sample statistical parameter which is an estimate, based on sample data, of the population parameter. The estimate of that percentage will be based on the data sample.

The computerized sample-size calculator determined the sample size of 500 needed for this study based on the total number of construction firms in Abu Dhabi, as discussed above. The questionnaire was distributed through the Survey Monkey to the 500 participants and responses were received from 150 participants.

Exploratory data analysis uses descriptive statistics, e.g. frequency/percentages and means/standard deviations, and graphical forms to analyse data. For the proposed objective, the target is to identify the factors affecting the power consumption in the HVAC system during maintenance. The measurements from the sample can be clustered into seven factors affecting the HVAC system maintenance.

10. DATA ANALYSIS AND RESULTS

ANOVA analysis was used to measure which of these factors are more important and have more effect on the power consumption. Multiple regression is used to predict the significance of power consumption based on the value of the above seven factors (Bagdonavicius, 2013).The following sections show the data analysis and result for each factor.

Data Analysis for Personal Expertise Factor:

For this factor, descriptive statistics were produced to measure the personnel training and development, maintenance personnel evaluation, the effect of employing unskilled technicians, considering incentives for personal growth of contractors and employing suitably trained staff to manage the HVAC system.

To measure the personnel training and development, descriptive statistics were conducted on survey question No.04. Table 4 indicated that 75% of respondents agreed that there is not enough training for the HVAC system maintenance personal. So, the maintenance for the HVAC system is poor in the UAE, and, as a result, the power consumption in the system is high.

Table 4: Personnel Training and Development

Q4. Are HVAC system maintenance personnel adequately trained in your view before being deployed in various stations across the nation to conduct their operations according to building environmental needs?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	37	24.7	24.7	24.7
	No	113	75.3	75.3	100.0
	Total	150	100.0	100.0	

To measure the evaluation of maintenance personnel, descriptive statistics were applied to question No.23. To optimize the HVAC system operation, we need to look into the maintenance personnel. This result indicates that 56% of the maintenance personnel are evaluated by “recording their performance levels”, as shown in Table 5.

Table 5: Maintenance Personnel Evaluation

Q23. How is maintenance personnel evaluated?				
	Frequency	Percent	Valid Percent	Cumulative Percent
Missing value	2	1.3	1.3	1.3
Recommendation from clients	27	18.0	18.0	19.3
Recorded performance levels	85	56.7	56.7	76.0
Rate of system failures in allocated zones	17	11.3	11.3	87.3
Rated technical expertise	12	8.0	8.0	95.3
Provided qualifications including professional evaluations	7	4.7	4.7	100.0
Total	150	100.0	100.0	

To measure the effect of employing unskilled technicians, a statistical analysis of the data from question No.27 was conducted. Table 6 indicates that 89.3% of respondents agreed that the unskilled technicians have a “Very Bad” effect on the maintenance of HVAC systems. Therefore, skilled technicians need to be available all the time for optimizing the operation of the HVAC systems.

Table 6: The Effect of Employing Unskilled Technicians

Q27. What do you think the effects on HVAC performance were when employing unskilled technicians to maintain the HVAC system?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Missing Value	1	.7	.7	.7
	Very bad	134	89.3	89.3	90.0
	Minor effect	9	6.0	6.0	96.0
	No effect	6	4.0	4.0	100.0
	Total	150	100.0	100.0	

To measure the consideration of the incentives for personal growth of contractors, descriptive statistics were conducted on question No.37. Table 7 indicates that the majority of respondents (70%) agreed that incentives are important for enhancing efficient operation and maintenance of HVAC systems.

Table 7: Consideration of the Incentives for Personal Growth of Contractors

Q32. Consider incentives to maintenance contractors for enhancing efficient operation and maintenance of HVAC systems					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Missing value	2	1.3	1.3	1.3
	Important	105	70.0	70.0	71.3
	Moderately important	35	23.3	23.3	94.7
	Slightly important	6	4.0	4.0	98.7
	Not important	2	1.3	1.3	100.0
	Total	150	100.0	100.0	

To measure the employment of suitably trained staff to manage an HVAC system, descriptive statistics were conducted on survey question No.4 (see Appendix A). The majority of respondents in Table 8 indicated that employing trained staff was either 'very important' or 'important' (46% and 46.7% respectively).

Table 8: Employ Suitably Trained Staff to Manage the HVAC System

Q4. Employ suitably trained staff to procure and manage HVAC maintenance & operation.					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Missing value	1	.7	.7	.7
	Very important	69	46.0	46.0	46.7
	Important	70	46.7	46.7	93.3
	Moderately important	5	3.3	3.3	96.7
	Slightly important	2	1.3	1.3	98.0
	Not important	3	2.0	2.0	100.0
	Total	150	100.0	100.0	

Data Analysis for the Building Design Factor:

For the building design factor, analysis was produced to measure the building design and the ability to access the HVAC system components. Factors involved include**: c**omplexity of building design, system accessibility, **construction** aspects and effective maintenance practice.

To measure the building design and the ability to access the HVAC system components, an analysis of data from question No.2 took place. Table 9 shows that 51.3% of respondents have difficulty accessing various HVAC system components within the structures of Abu Dhabi's building designs. Moreover, 82.7% of them believe that the more complex the building designs in Abu Dhabi are, the more difficult is the access to the HVAC system, which leads to additional challenges for system maintenance.

Table 9: Building Design and Ability to Access the HVAC System Components

Q2. Based on the building designs in Abu Dhabi, how can you rate your experience in accessing various HVAC system components within the structures?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very Easy	22	14.7	14.7	14.7
	Easy	51	34.0	34.0	48.7
	Difficult	77	51.3	51.3	100.0
	Total	150	100.0	100.0	

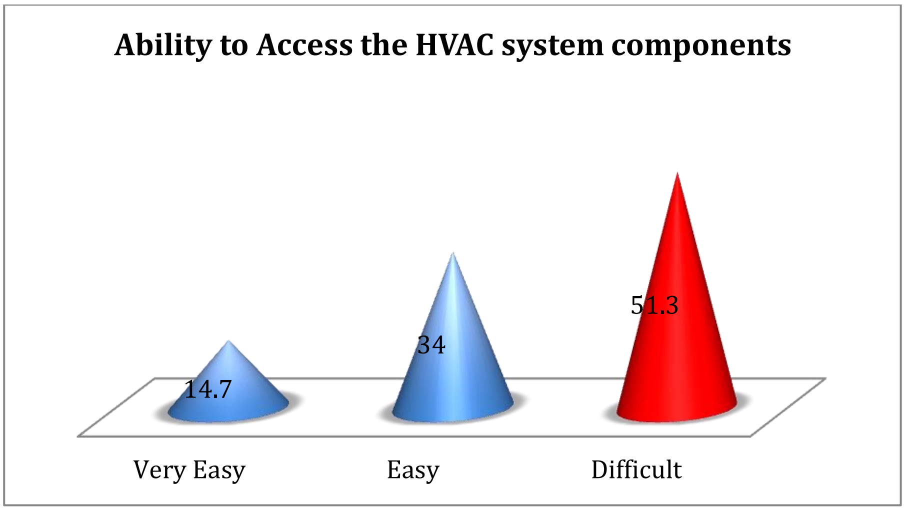

Figure 3: Ability to Access the HVAC System Components

To measure the complex building design and system accessibility, question No.3 was analysed. Table 10 indicates that 82.7% of the respondents agreed with the idea that complex building designs create additional challenges for system maintainers due to issues associated with accessibility.

Table 10: Complex Building Design and System Accessibility

Q3. Do you think that the increasingly complex building designs in Abu Dhabi are creating additional challenges for system maintainers due to issues associated with accessibility?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	124	82.7	82.7	82.7
	No	26	17.3	17.3	100.0
	Total	150	100.0	100.0	

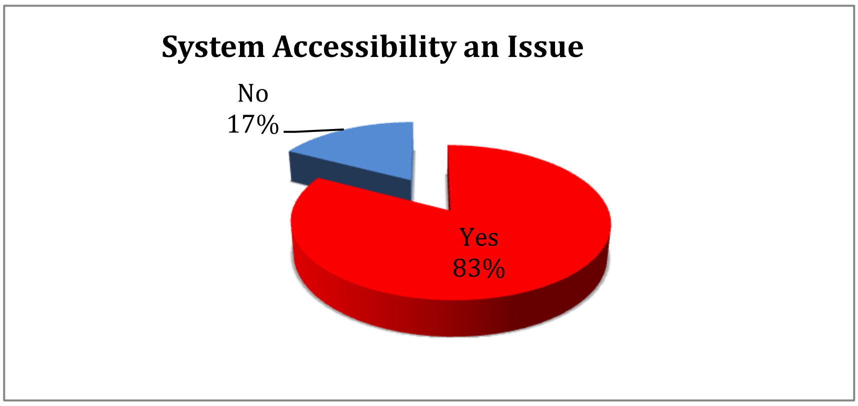

Figure 4: HVAC System Accessibility

To measure the problematic building aspects and effective maintenance practice, descriptive statistics from question No.16 were obtained. Based on respondents' answers in Table 11, 82% of them were agreed that problematic building aspects would influence the performance of effective maintenance practice. This is considered as another factor that could affect the HVAC maintenance.

Table 11: Problematic Building Aspects and Effective Maintenance Practice

Q16. Are there any problematic building aspects, such as electrical systems, plumbing design, and structural maintenance, which influence the performance of effective maintenance practices?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	123	82.0	82.0	82.0
	No	27	18.0	18.0	100.0
	Total	150	100.0	100.0	

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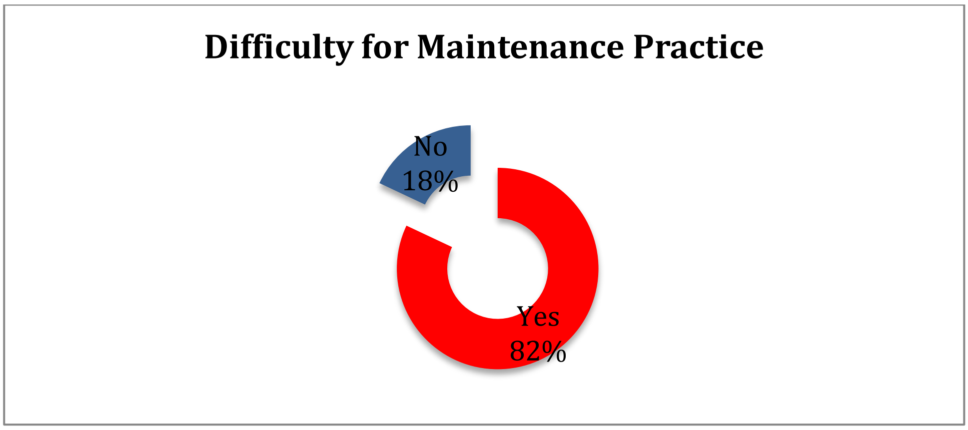

Figure 5: Difficulty for Maintenance Practice

Temperature and Humidity:

For this factor, descriptive statistics were produced to measure the following items: the temperatures and the HVAC system response, the temperatures and the HVAC system maintenance schedules, and temperature fluctuations and the HVAC system maintenance.

To measure the temperatures and the HVAC system response, an analysis of the data from question No.6 (see Table 12) indicates that a majority (52%) of respondents agreed that the HVAC system degrades faster while operating in high temperature conditions, while 28% of respondents had not noticed any changes to the operational capabilities of the HVAC system. However, only 18% indicated that the systems operate normally.

Table 12: The Temperatures and the HVAC System Response

Q6. Some authors, like Liu (2015), have studied the region and discovered that temperatures increase up to 50 degrees in summer and they are being blamed for system failures in other technological implementations. How does an HVAC system respond to this instance?					
		Frequency	Percent	Valid P.	Cumulative P.
1	They degrade faster while operating in these conditions.	78	52.0	52.0	52.0
2	The systems operate normally.	27	18.0	18.0	70.0
3	I have not noticed any changes to operational capabilities.	42	28.0	28.0	98.0
	1 & 2	1	.7	.7	98.7
	2 & 3	1	.7	.7	99.3
	All of the above	1	.7	.7	100.0
	Total	150	100.0	100.0	

To measure the temperatures and the HVAC system maintenance schedules, analysis of the data from question No.7 (Table 13) indicated that 39.3% of respondents indicated that high temperatures caused maintenance times to be shorter than the ones prescribed by the manufacturer, and 38% indicated that the maintenance schedule varies slightly from that of the manufacturer. However, 22% indicated that the times were longer.

Table 13: The Temperatures and the HVAC System Maintenance Schedules

Q7. Existence of high temperatures has been noted as among the challenges influencing maintenance procedures in Abu Dhabi.				
	Frequency	Percent	Valid Percent	Cumulative Percent
Caused maintenance times to be shorter than the ones prescribed by the manufacturer.	59	39.3	39.3	39.3
Caused the times to be longer.	33	22.0	22.0	61.3
The maintenance schedule varies slightly from the one from the manufacturer.	57	38.0	38.0	99.3
All of the above.	1	.7	.7	100.0
Total	150	100.0	100.0	

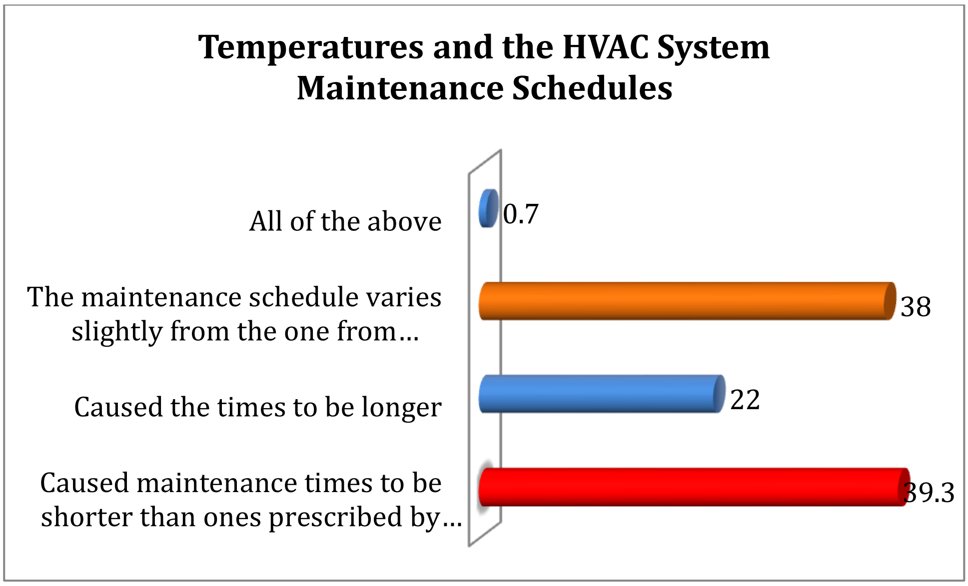

Figure 6: Temperatures and the HVAC System Maintenance Schedules

To measure temperature fluctuations and the HVAC system maintenance, descriptive statistics were applied to the responses to question No.8. Table 14 verifies another important factor that affects the HVAC system maintenance and power consumption, namely, temperature fluctuations. A majority of respondents - 43.3% and 48.7% respectively - agreed or strongly agreed that temperature fluctuations affect HVAC system maintenance.

Table 14: Temperature Fluctuations and the HVAC System Maintenance

Q8. Do you agree that temperature fluctuations affect HVAC system maintenance?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	I strongly agree	73	48.7	48.7	48.7
	I agree	65	43.3	43.3	92.0
	I disagree	8	5.3	5.3	97.3
	I strongly disagree	4	2.7	2.7	100.0
	Total	150	100.0	100.0	

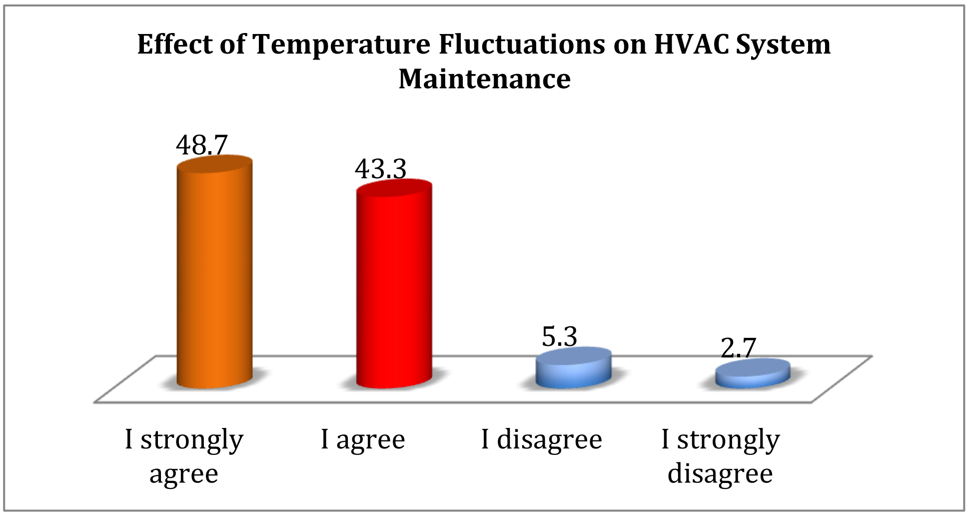

Figure 7: Effect of Temperature Fluctuations on HVAC System Maintenance

HVAC UNIT:

For this factor, analyses were produced to measure the following items: the dependent level of the HVAC system, the types of filters used in the HVAC system, the maintenance faults that caused significant power consumption, the frequency of balancing the air system, the HVAC system's working schedule, the factors that dictate the number of

HVAC units in a building, the time for which HVAC systems operate after maintenance, the tools to conduct a regular frequency of maintenance for the HVAC system and the installation of adequate energy and water metering for the HVAC system

To measure the dependent level of the HVAC system, descriptive statistics were used to analyse responses to question No.10. The HVAC system is not working as an independent entity as indicated by 62.7% of respondents in Table 15.

Table 15: The Dependent Level of the HVAC System

Q10. Are HVAC systems working as independent components?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	56	37.3	37.3	37.3
	No	94	62.7	62.7	100.0
	Total	150	100.0	100.0	

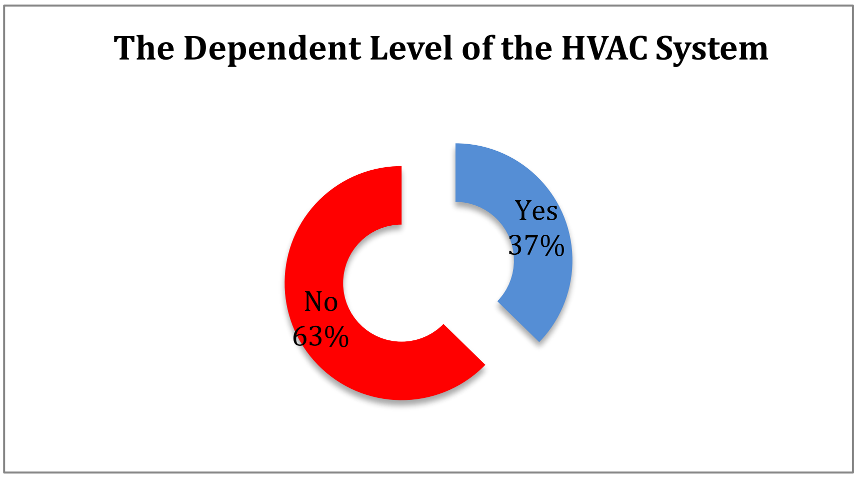

Figure 8: The Dependent Level of the HVAC System

To measure the kind of filters used in HVAC systems, descriptive statistics were conducted on question No.11. Table 16 shows that the type of filter is considered among the factors that influence the maintenance of HVAC systems. A majority (56%) agreed to use washable air filters. This might help to reduce the risks of the systems being damaged.

Table 16: Types of Filters used in HVAC Systems

Q11. Since the working environment is characterized by high temperature, humidity and contaminating particulates, what kind of filters are being used to resolve this challenge in order to maintain the recommended environmental conditions in buildings?					
		Frequency	Percent	Valid Pr.	Cumulative Pr.
	Missing value.	1	.7	.7	.7
1.	Fibreglass filters,	24	16.0	16.0	16.7
2.	Pleated and polyester filters,	7	4.7	4.7	21.3
3.	High efficiency particulate arresting filters,	17	11.3	11.3	32.7
4.	Washable filters for air,	84	56.0	56.0	88.7
	2 & 4	4	2.7	2.7	91.3
	3 & 4	11	7.3	7.3	98.7
	2 & 3	1	.7	.7	99.3
	1 & 4	1	.7	.7	100.0
	Total	150	100.0	100.0	

To measure the maintenance faults that caused significant power uptake, descriptive statistics were conducted on survey question No.12. Table 17 indicates that maintenance faults like dirty filters, dirty condensers, faulty thermostats and faulty sensors will cause significant power usage as indicated by 52.7% of the respondents. Therefore, minimizing all these faults will help to minimize energy consumption.

Table 17: The Maintenance Faults that Caused Significant Power Usage.

Q12. Which among the following maintenance faults are causing significant power usage?					
		Frequency	Percent	Valid Percent	Cumulative Percent
1.	Dirty filters.	31	20.7	20.7	20.7
2.	Dirty condensers.	5	3.3	3.3	24.0
3.	Faulty thermostats.	3	2.0	2.0	26.0
4.	Faulty Sensors.	5	3.3	3.3	29.3
5.	All of the above.	79	52.7	52.7	82.0
	1 & 4	10	6.7	6.7	88.7
	3 & 4	3	2.0	2.0	90.7
	1 & 3	7	4.7	4.7	95.3
	1 & 2	1	.7	.7	96.0
	1, 3 & 4	5	3.3	3.3	99.3
	2, 3 & 4	1	.7	.7	100.0
	Total	150	100.0	100.0	

To measure the frequency of balancing the air system, descriptive statistics were used to analyse the data from question No.13. To optimize the HVAC system operation, frequent balancing of the air system is required. According to Table 18, a majority of respondents indicated that the air system is balanced “once in a month” and/or “it takes longer than a month” (44.7% and 31.3% respectively). Therefore, this might be one of the factors affecting HVAC system maintenance.

Table 18: Frequency of Balancing the Air System

Q13. How often do you balance the air system in order to maintain the required rates of air flow and quality levels *as per* location needs?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Every week.	25	16.7	16.7	16.7
	Every fortnight.	11	7.3	7.3	24.0
	Once in a month.	67	44.7	44.7	68.7
	It takes longer than a month.	47	31.3	31.3	100.0
	Total.	150	100.0	100.0	

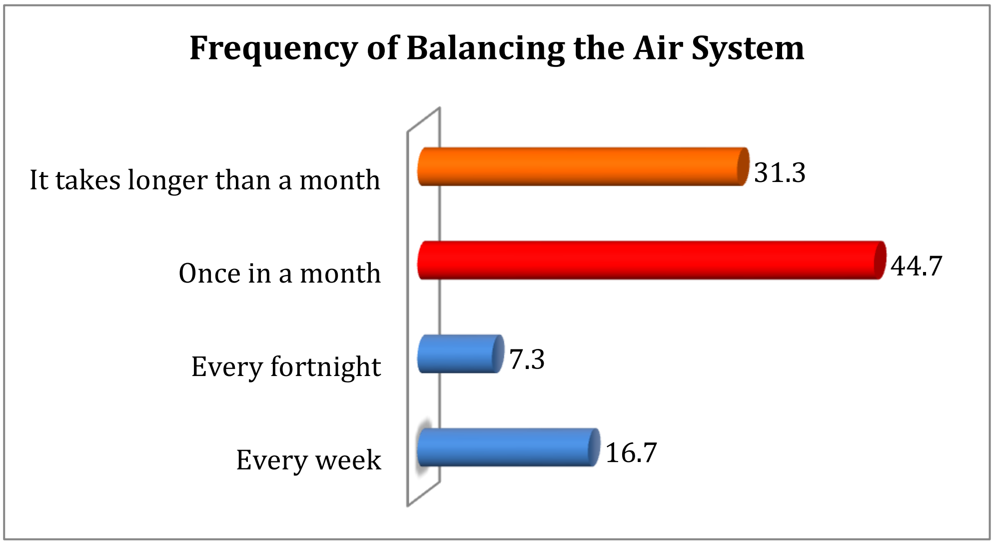

Figure 9: Frequency of Balancing the Air System

To measure the HVAC system working schedules, descriptive statistics were used to analyse the data from question No.14. The working schedule of the HVAC system is another issue that causes high-energy consumption and maintenance difficulties. Table 19 indicates that respondents agreed that the system required to work “at predefined times” (32%) and/or “they are automatically set to work according to situational conditions” (42%) in order to maintain the required operating environment in their respective installation locations.

Table 19: The HVAC System's Working Schedule

Q14. How long are HVAC systems required to work in order to maintain the required operating environment in their respective installation locations?				
	Frequency	Percent	Valid Percent	Cumulative Percent
Only during working hours.	28	18.7	18.7	18.7
Throughout the day even without occupancy.	11	7.3	7.3	26.0
At predefined times.	48	32.0	32.0	58.0
They are automatically set to work according to situational conditions.	63	42.0	42.0	100.0
Total.	150	100.0	100.0	

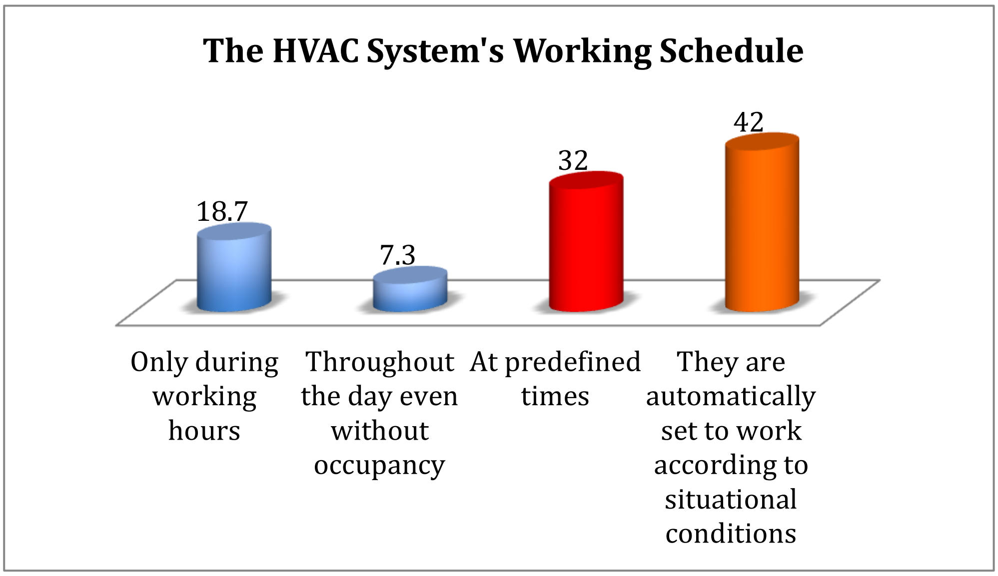

Figure 10: The HVAC System's Working Schedules

To measure the factors that dictate the number of HVAC units in a building, an analysis of the data from question No.15 was carried out. To optimize an HVAC system's operation, we need to look at the factors that dictate the number of HVAC units in buildings. The "total capacity of the system" was indicated by 66.7% of the respondents, see Table 20.

Table 20: Factors that Dictate the Number of HVAC Units in a Building.

Q15. What are the determining factors that dictate the number of HVAC units in buildings in Abu Dhabi?					
		Frequency	Percent	Valid Percent	Cumulative Percent
1.	Number of floors.	21	14.0	14.0	14.0
2.	Operating Hours.	6	4.0	4.0	18.0
3.	Type of the system installed.	13	8.7	8.7	26.7
4.	Total capacity of the system.	100	66.7	66.7	93.3
5.	Quality of the air.	0	.0	.0	93.3
	1 & 2	1	.7	.7	94.0
	3 & 4	2	1.3	1.3	95.3
	3, 4, & 5	1	.7	.7	96.0
	All of the above	6	4.0	4.0	100.0
	Total	150	100.0	100.0	

To measure the average time for HVAC system operation after maintenance, an analysis of the data from question No.22 was carried out. The average time for an HVAC system to operate after maintenance is a very important factor that influences the HVAC system maintenance and also helps to optimize the HVAC system operation. This research recorded hours, days, and weeks 30%, 36%, and 20% respectively to be the average time for HVAC system operation after maintenance, as shown in Table 21.

Table 21: Average Time for HVAC System Operation after Maintenance

Q22. If downtimes for equipment are cumulatively recorded, what is the average time for which HVAC systems are out of operation before restoration to normalcy?				
	Frequency	Percent	Valid Percent	Cumulative Percent
Missing value.	2	1.3	1.3	1.3
Hours.	45	30.0	30.0	31.3
Days.	54	36.0	36.0	67.3
Weeks.	30	20.0	20.0	87.3
Months.	4	2.7	2.7	90.0
Depends on the kind of breakdown.	15	10.0	10.0	100.0
Total	150	100.0	100.0	

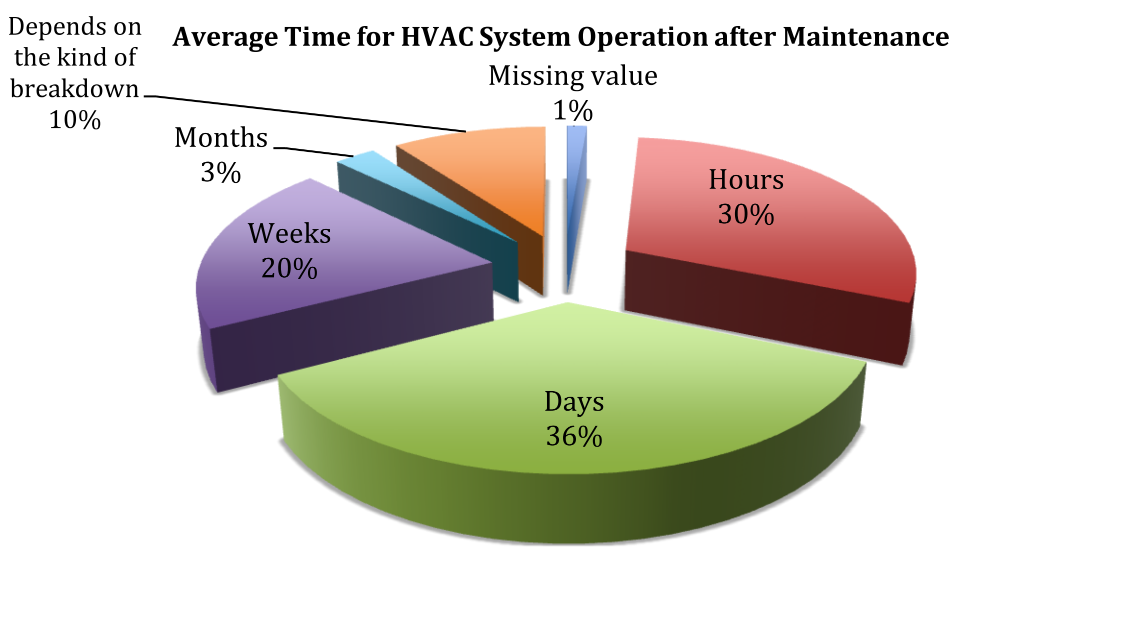

Figure 11: Average Time for HVAC System Operation after Maintenance

Analysis of the data from question No.25 shows that to maintain the HVAC system operation, the researcher needs to look into the tools used for regular maintenance. Respondents indicated that 45.3% of them use “Diagnostic equipment”, 29.3% use a “Basic tool set” and 19.3% use the “Toolkit from the manufacturer”, as shown in Table 22

Table 22: Tools to Conduct Regular Maintenance

Q25. What tools are provided to conduct regular maintenance?				
	Frequency	Percent	Valid Percent	Cumulative Percent
Missing Value.	1	.7	.7	.7
Diagnostic equipment.	68	45.3	45.3	46.0
Toolkit from the manufacturer.	29	19.3	19.3	65.3
Basic tool set.	44	29.3	29.3	94.7
Access to equipment depending on system location.	8	5.3	5.3	100.0
Total	150	100.0	100.0	

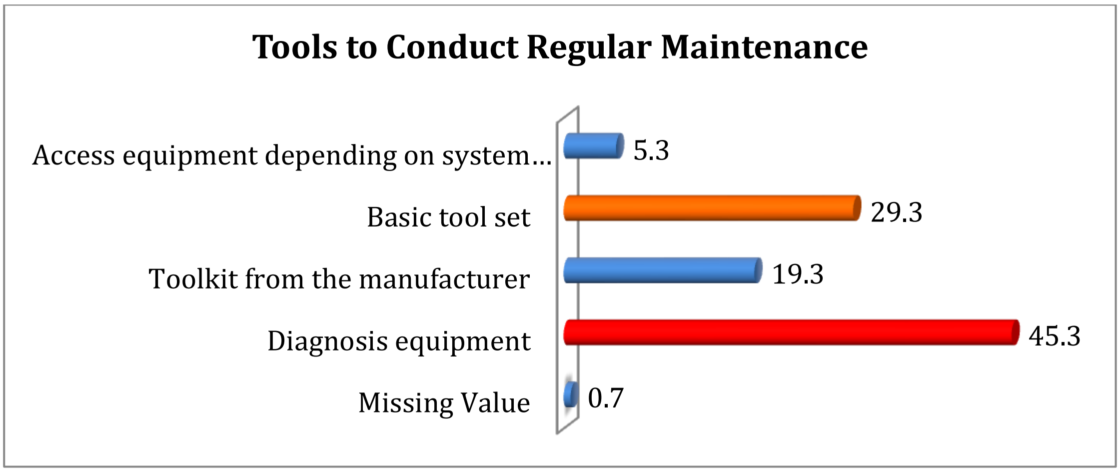

Figure 12: Tools to Conduct Regular Maintenance

To measure the maintenance frequency of an HVAC system, analysis of the data from question No.26 shows that frequent maintenance is required, and in the case of Abu Dhabi, the maintenance frequency of HVAC systems is *as per* the manufacturer's schedule as indicated by 72% of respondents (see Table 23).

Table 23: Maintenance Frequency of HVAC Systems

Q26. What is the maintenance frequency of HVAC systems in Abu Dhabi?				
	Frequency	Percent	Valid Percent	Cumulative Percent
Missing value.	2	1.3	1.3	1.3
As per manufacturer's schedule.	108	72.0	72.0	73.3
Often.	29	19.3	19.3	92.7
Always.	11	7.3	7.3	100.0
Total	150	100.0	100.0	

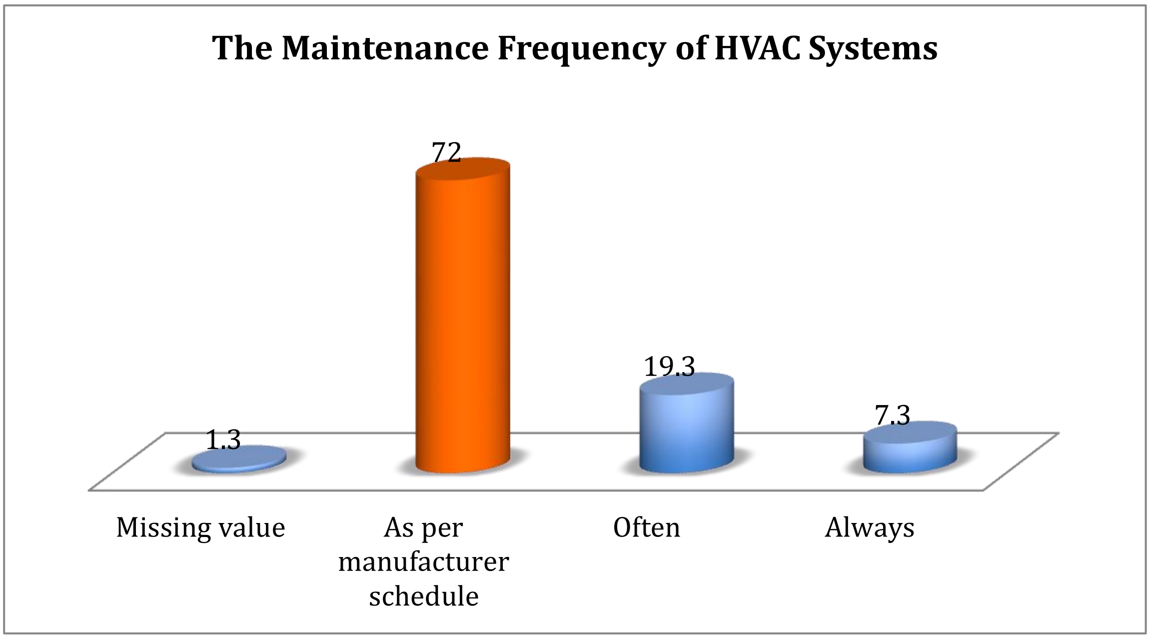

Figure 13: The Maintenance Frequency of an HVAC System

Based on the data from question No.33, the installation of adequate energy and water metering for the HVAC system was classified as 'important' or 'very important' - 32.0% and 58.0% respectively - for HVAC system maintenance (see Table 24).

Table 24: Installation of Adequate Energy and Water Metering for an HVAC System

Q33. Ensure adequate energy and water metering is installed					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Missing value.	2	1.3	1.3	1.3
	Very important.	87	58.0	58.0	59.3
	Important.	48	32.0	32.0	91.3
	Moderately important.	6	4.0	4.0	95.3
	Slightly important.	1	.7	.7	96.0
	Not important.	6	4.0	4.0	100.0
	Total	150	100.0	100.0	

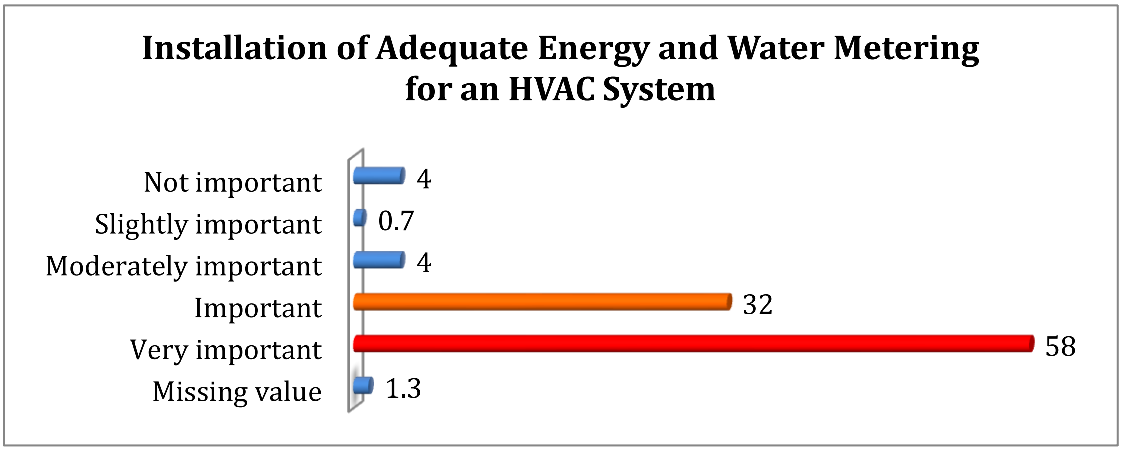

Figure 14: Installation of Adequate Energy and Water Metering for an HVAC System

Rules and Regulations:

For this factor, descriptive statistics were produced to measure the following items: accessing documents about the HVAC system, mechanical codes that affect the HVAC maintenance protocol, regulatory frameworks causing maintenance challenges, maintenance operations structure, the kind of formal approval required sustainability policies, environmental & maintenance policies, maintenance strategy and sustainability benchmarks & HVAC KPIs.

To measure access to the documents for an HVAC system, analysis of the data from question No.5 shows that the majority of respondents (40.7%) in Table 25 indicated that they are allowed to access the mechanical drawings when conducting maintenance procedures. In addition, 38% indicated that they are allowed to access prior maintenance records for a specific system whilst only 18% of respondents indicated that they are allowed to access the original system plans. Indeed, access to proper documentation will help maintenance personnel to carry out their tasks successfully.

Table 25: Accessing Documents for an HVAC System

Q5. As part of the maintenance personnel, what kind of documentation are you allowed to access when conducting maintenance procedures?				
	Frequency	Percent	Valid Percent	Cumulative Percent
Missing Value.	1	.7	.7	.7
Original System Plans.	27	18.0	18.0	18.7
Mechanical Drawings.	61	40.7	40.7	59.3
Prior Maintenance Records for a specific system.	57	38.0	38.0	97.3
None	4	2.7	2.7	100.0
Total	150	100.0	100.0	

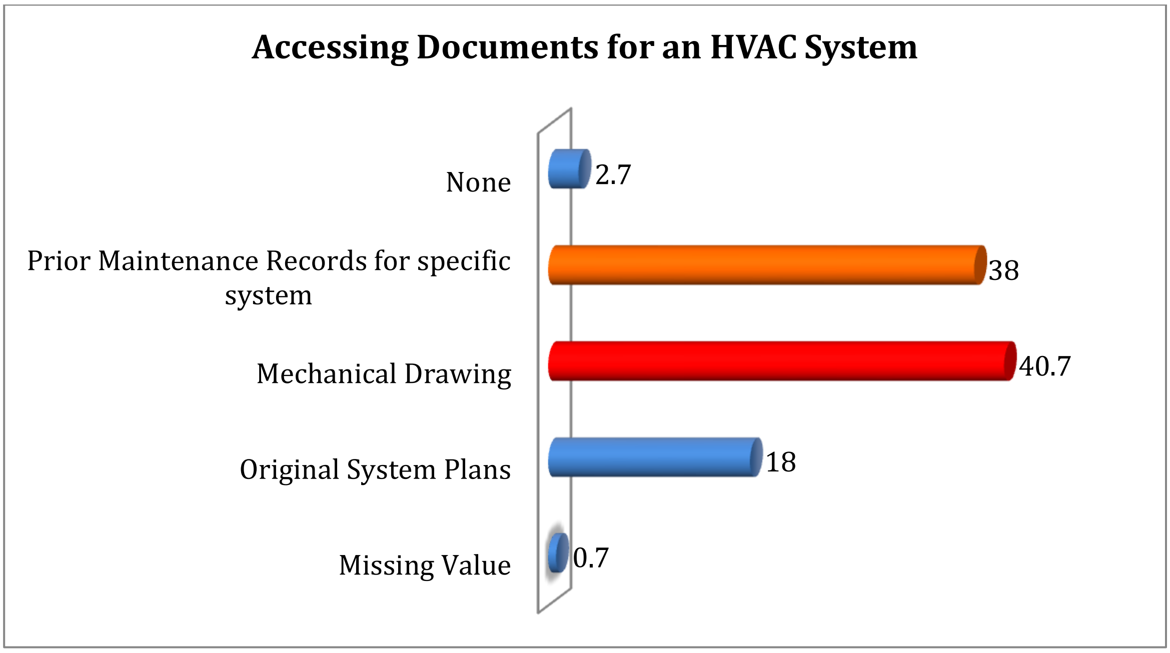

Figure 15: Accessing Documents for an HVAC System

To measure the mechanical code affecting the HVAC maintenance protocol, analysis of the data from question No.17 indicates that the "design of schedules" (28%) as well as the "maintenance procedures" (42%) are the main mechanical codes that affect the HVAC maintenance protocol.

Table 26: Mechanical Code Affecting the HVAC Maintenance Protocol

Q17. Abu Dhabi has developed a mechanical code that conforms to international standards with modifications that address specific local needs. From your perspective, select ways in which these codes are affecting HVAC maintenance protocols?

		Frequency	Percent	Valid Percent	Cumulative Percent
1.	Design of schedules.	42	28.0	28.0	28.0
2.	Installation of units with mechanical parts.	12	8.0	8.0	36.0
3.	Maintenance procedures.	63	42.0	42.0	78.0
4.	Alteration and inspections of mechanical systems.	21	14.0	14.0	92.0
	1 & 3	2	1.3	1.3	93.3
	1 & 4	1	.7	.7	94.0
	3 & 4	4	2.7	2.7	96.7
	1, 3 & 4	1	.7	.7	97.3
	2, 3 & 4	2	1.3	1.3	98.7
	All of the above.	2	1.3	1.3	100.0
	Total	150	100.0	100.0	

To measure the regulatory frameworks that cause maintenance challenges, analysis of the data from question No.18 indicates that 31.3% mention the "Maintenance of control systems to guarantee achievement of energy efficiency" as the main regulatory framework that increases the maintenance challenge. The other frameworks such as "compliance with air quality thresholds", "cleaning and inspection of HVAC equipment", "design of systems positions depending on control zones", "incorporation of minimum control features", "air exhausts dispersal and recovery system maintenance" and "implementation of duct work" are equally important in increasing the maintenance challenge.

Table 27: Regulatory Frameworks that Cause Maintenance Challenges

Q18. Which aspects of the current regulatory frameworks are increasing maintenance challenges when planning and executing maintenance protocols?					
		Frequency	Percent	Valid Percent	Cumulative Percent
1.	Compliance to air quality thresholds.	29	19.3	19.3	19.3
2.	Cleaning and inspection of HVAC equipment.	6	4.0	4.0	23.3
3.	Maintenance of control systems to guarantee achievement of energy efficiency.	47	31.3	31.3	54.7
4.	Design of systems positions depending on control zones.	2	1.3	1.3	56.0
5.	Incorporation of minimum control features.	24	16.0	16.0	72.0
	1 &2	2	1.3	1.3	73.3
	1 & 3	3	2.0	2.0	75.3
	1 & 5	3	2.0	2.0	77.3
	1 &7	1	.7	.7	78.0
	1 & 4	1	.7	.7	78.7
	3 & 4	1	.7	.7	79.3
	3 & 5	10	6.7	6.7	86.0
	1, 3 & 5	5	3.3	3.3	89.3
	1, 4 & 5	1	.7	.7	90.0
	3, 4 & 5	2	1.3	1.3	91.3
	2, 3 & 4	2	1.3	1.3	92.7
	1, 3 & 4	1	.7	.7	93.3
	1, 3 & 6	1	.7	.7	94.0
	1, 2 & 7	1	.7	.7	94.7
	2, 5, 6 & 7	1	.7	.7	95.3
	1, 2, 3 & 4	1	.7	.7	96.0
	1, 2, 5 & 6	1	.7	.7	96.7
	1, 3, 6 & 7	1	.7	.7	97.3
	1, 2, 4 & 7	1	.7	.7	98.0
	2, 3, 5 & 6	1	.7	.7	98.7
	1, 2, 3, 4 & 6	1	.7	.7	99.3
	1, 3, 4, 6 & 7	1	.7	.7	100.0
	Total	150	100.0	100.0	

Note: 6. Air exhausts dispersal and recovery system maintenance.

To measure the maintenance operation structure, the data from question No.20 was analysed. Based on Table 28, the operation structure is considered another factor that influences the maintenance of HVAC systems. Respondents in this research have indicated that maintenance operation structures are more “centralized” (25.3%), done in an “area specific” way (30.7%) and are operated by “multi-skilled personnel” (28%).

Table 28: Maintenance Operations Structure

Q20. How are maintenance operations structured?					
		Frequency	Percent	Valid Percent	Cumulative Percent
1.	Centralized.	38	25.3	25.3	25.3
2.	Area Specific	46	30.7	30.7	56.0
3.	Work teams.	12	8.0	8.0	64.0
4.	Multi-skilled personnel.	42	28.0	28.0	92.0
5.	Other.	2	1.3	1.3	93.3
	1 & 2	1	.7	.7	94.0
	3 & 4	4	2.7	2.7	96.7
	2 & 4	3	2.0	2.0	98.7
	1, 3 & 4	1	.7	.7	99.3
	1, 2, 3 & 4	1	.7	.7	100.0
	Total	150	100.0	100.0	

Question No.20 aimed to measure the kind of formal approval required. Based on the descriptive statistics in Table 29, 50% of respondents agreed, “Approvals from Maintenance Company and client are required before work is conducted” was most frequently required.

Table 29: Kind of Formal Approval Required

Q21. What kind of formal approvals are required before conducting maintenance work on HVAC systems?				
	Frequency	Percent	Valid Percent	Cumulative Percent
Missing Value.	4	2.7	2.7	2.7
Written approvals from the maintenance company.	27	18.0	18.0	20.7
Documented approval requesting maintenance from building management.	44	29.3	29.3	50.0
Approvals from Maintenance Company and client are required before work is conducted.	75	50.0	50.0	100.0
Total	150	100.0	100.0	

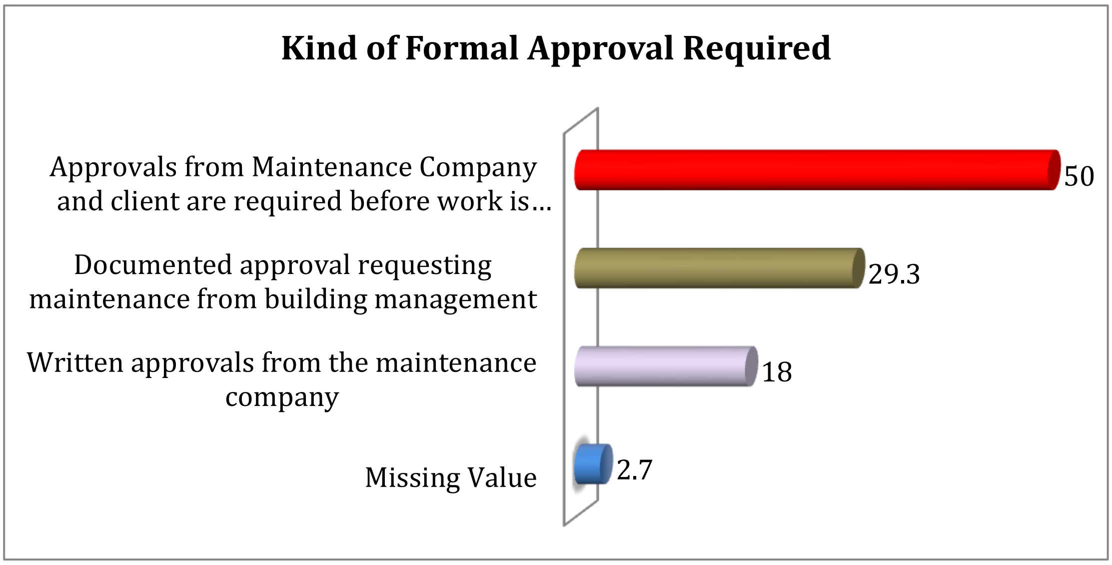

Figure 16: Kind of Formal Approval Required

Question No.28 aimed to measure the Sustainability Policies. Based on descriptive statistics in Table 30, 52% of respondents agreed that a sustainability policy is ‘important’ for HVAC system maintenance.

Table 30: Sustainability Policies

Q28. Set-up Sustainability policies					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Missing value.	2	1.3	1.3	1.3
	Very important.	33	22.0	22.0	23.3
	Important.	79	52.7	52.7	76.0
	Moderately important.	28	18.7	18.7	94.7
	Slightly important.	8	5.3	5.3	100.0
	Total	150	100.0	100.0	

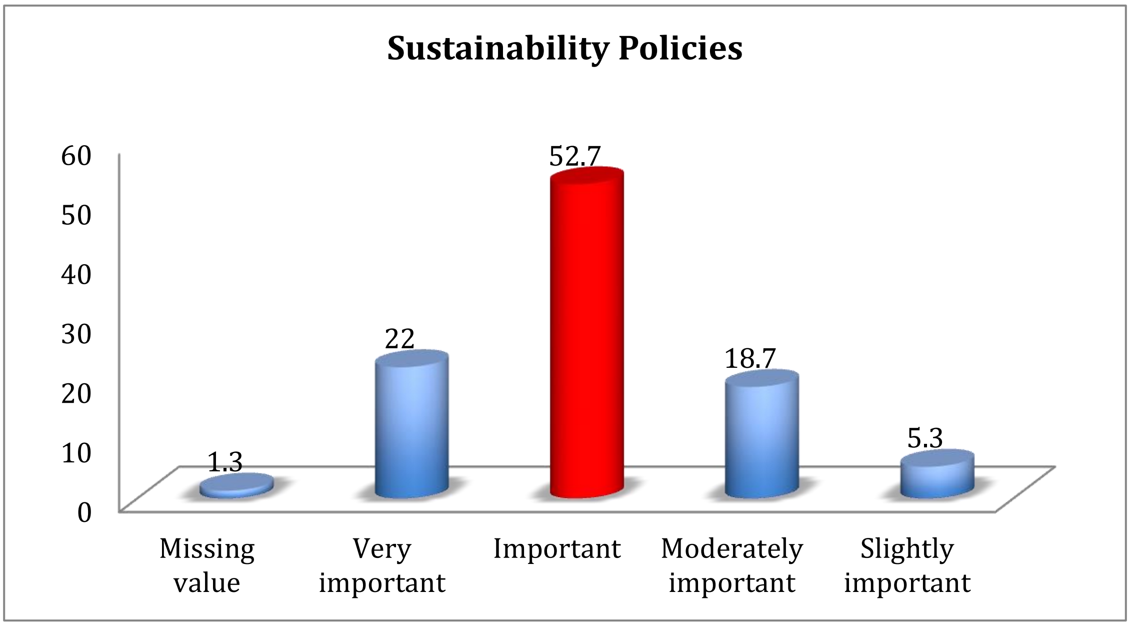

Figure 17: Sustainability Policies

Question No.29 aimed to measure the environmental & maintenance policies. Based on the descriptive statistics in Table 35, 51.3% of respondents agreed that environmental & maintenance policies are important for HVAC system maintenance.

Table 35: Environmental & Maintenance Policies

Q29. Ensure environmental & maintenance policies are in place, taking into account the aspirations of environmental polices					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Missing value.	3	2.0	2.0	2.0
	Very important.	44	29.3	29.3	31.3
	Important.	77	51.3	51.3	82.7
	Moderately important.	21	14.0	14.0	96.7
	Slightly important.	3	2.0	2.0	98.7
	Not important.	2	1.3	1.3	100.0
	Total	150	100.0	100.0	

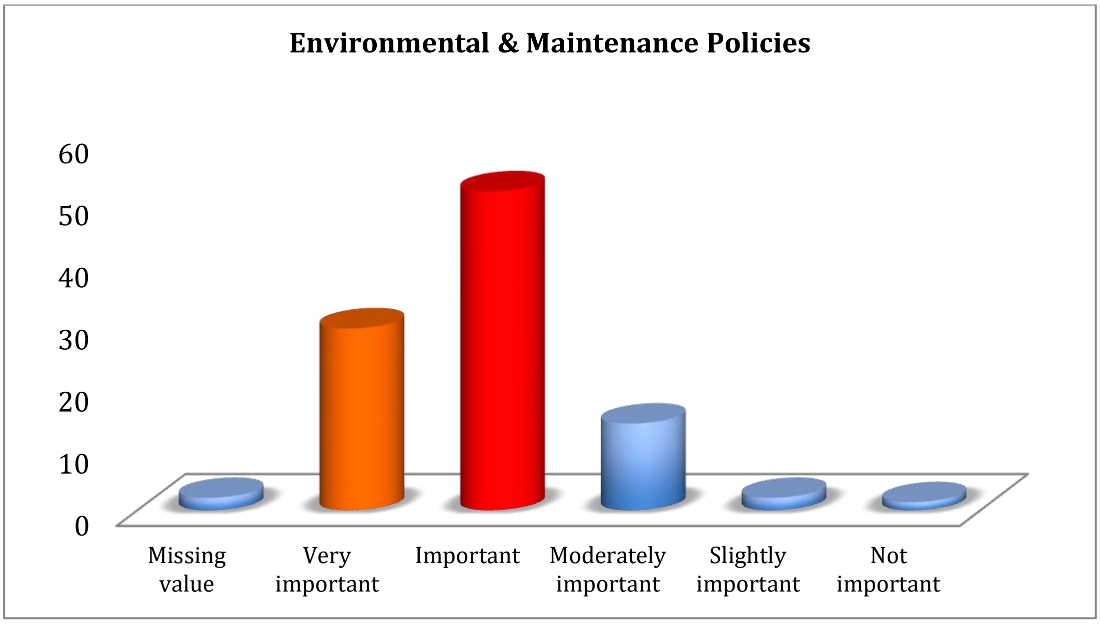

Figure 18: Environmental & Maintenance Policies

To measure the maintenance strategy, analysis of the data from question No.30 (Table 36) shows that 55.3% of respondents agreed that a maintenance strategy is 'very important' for HVAC system maintenance.

Table 36: Maintenance Strategy

Q30a. Ensure a **Maintenance strategy is developed**					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Missing value.	2	1.3	1.3	1.3
	Very important.	83	55.3	55.3	56.7
	Important.	6	4.0	4.0	60.7
	Moderately important.	55	36.7	36.7	97.3
	Slightly important.	4	2.7	2.7	100.0
	Total	150	100.0	100.0	

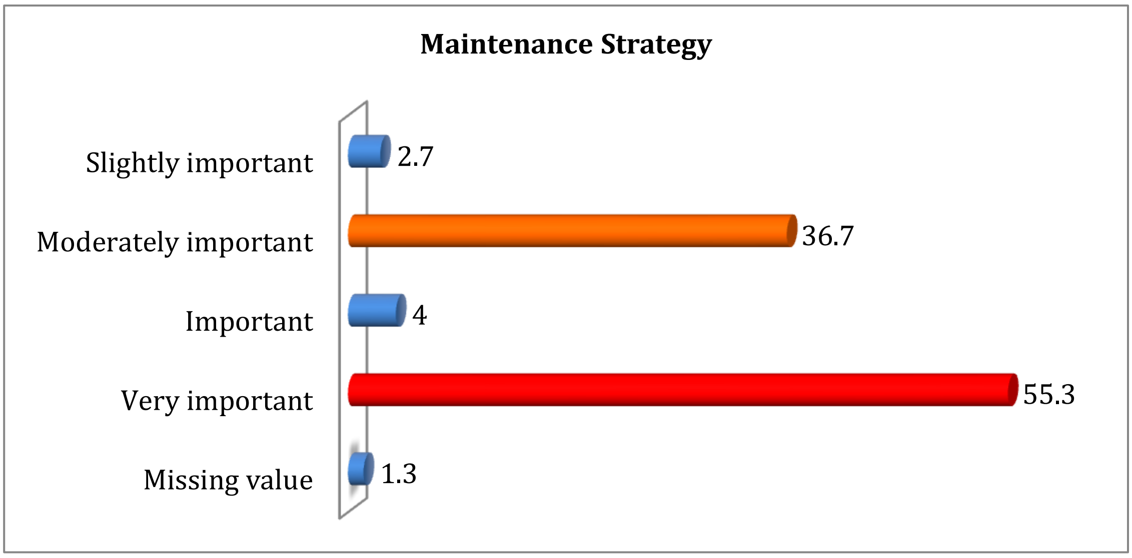

Figure 19: Maintenance Strategy

To measure the sustainability benchmarks & HVAC KPIs, analysis of the data from question No.31 (Table 37) shows that the majority of respondents agreed that sustainability benchmarks & HVAC KPIs are 'very important' or 'important' - 50.0% and 35.3% respectively - for HVAC system maintenance.

Table 37: Sustainability Benchmarks & HVAC KPIs

Q31. Ensure sustainability benchmarks & HVAC KPIs are developed.					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Missing value.	3	2.0	2.0	2.0
	Very important.	75	50.0	50.0	52.0
	Important.	53	35.3	35.3	87.3
	Moderately important.	12	8.0	8.0	95.3
	Slightly important.	5	3.3	3.3	98.7
	Not important.	2	1.3	1.3	100.0
	Total	150	100.0	100.0	

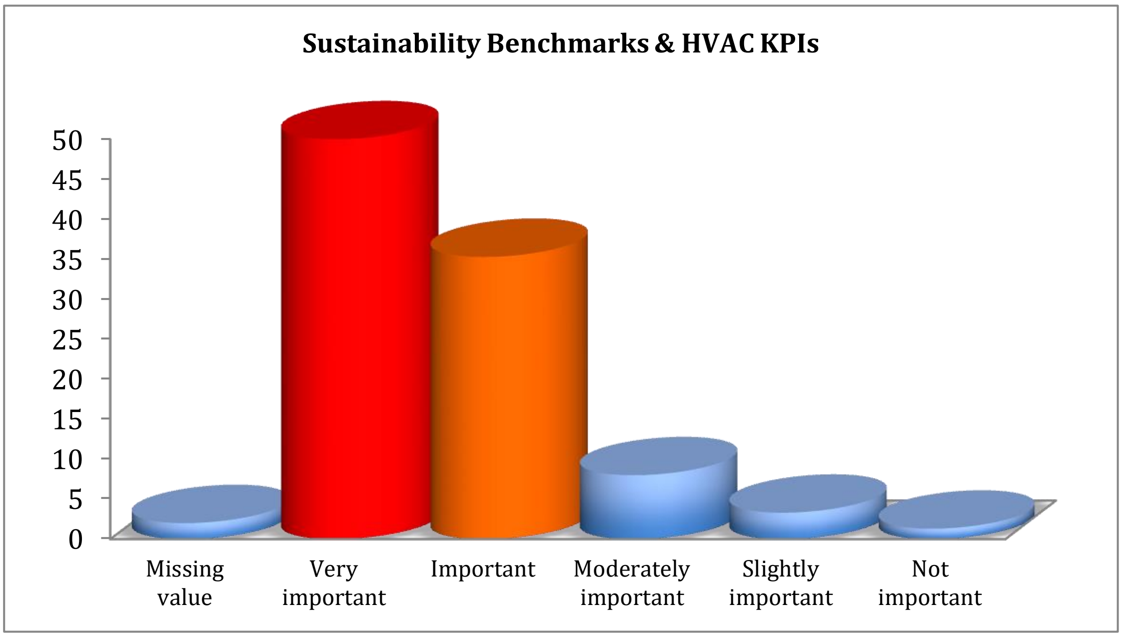

Figure 20: Sustainability Benchmarks & HVAC KPIs

Engagement with Stakeholders:

For this factor, descriptive statistics were produced to measure the following items: discussing the energy-saving opportunities with the maintenance contractor, monitoring HVAC KPIs and building performance targets and regular energy audits by third parties.

To measure the discussion of the energy-saving opportunities with maintenance contractors, analysis of the data from question No.34 (Table 38) indicates that a majority of respondents agreed that it is 'important' (52.7%) or 'very important' (32.0%) to discuss the energy-saving opportunities with a maintenance contractor to help optimize HVAC system maintenance.

Table 38: Discussing the Energy-Saving Opportunities with a Maintenance Contractor

Q34. Where an existing contract has a long tenure remaining, discuss and negotiate energy-saving opportunities with the maintenance contractor.					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Missing value.	1	.7	.7	.7
	Very important.	48	32.0	32.0	32.7
	Important.	79	52.7	52.7	85.3
	Moderately important.	15	10.0	10.0	95.3
	Slightly important.	6	4.0	4.0	99.3
	Not important.	1	.7	.7	100.0
	Total	150	100.0	100.0	

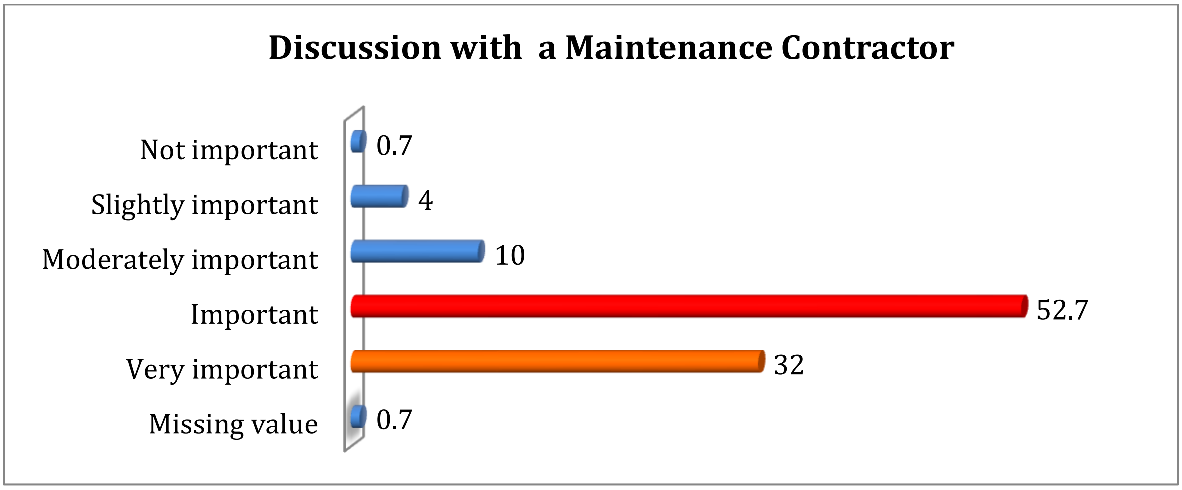

Figure 21: Discussion with a Maintenance Contractor

Question No.38 aimed to measure the monitoring of HVAC KPIs and building performance targets. Based on the descriptive statistics in Table 39, 56.0% of respondents agreed that monitoring HVAC KPIs and building performance targets is 'very important' for HVAC system maintenance. Another 36.0% agreed that they were 'important'.

Table 39: Monitoring HVAC KPIs and building performance targets.

Q38. Monitoring HVAC KPIs and building performance targets. Ensure corrective action such as re-commissioning and fine tuning are carried out where necessary					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Missing value.	1	.7	.7	.7
	Very important.	84	56.0	56.0	56.7
	Important.	54	36.0	36.0	92.7
	Moderately important.	8	5.3	5.3	98.0
	Slightly important.	2	1.3	1.3	99.3
	Not important.	1	.7	.7	100.0
	Total	150	100.0	100.0	

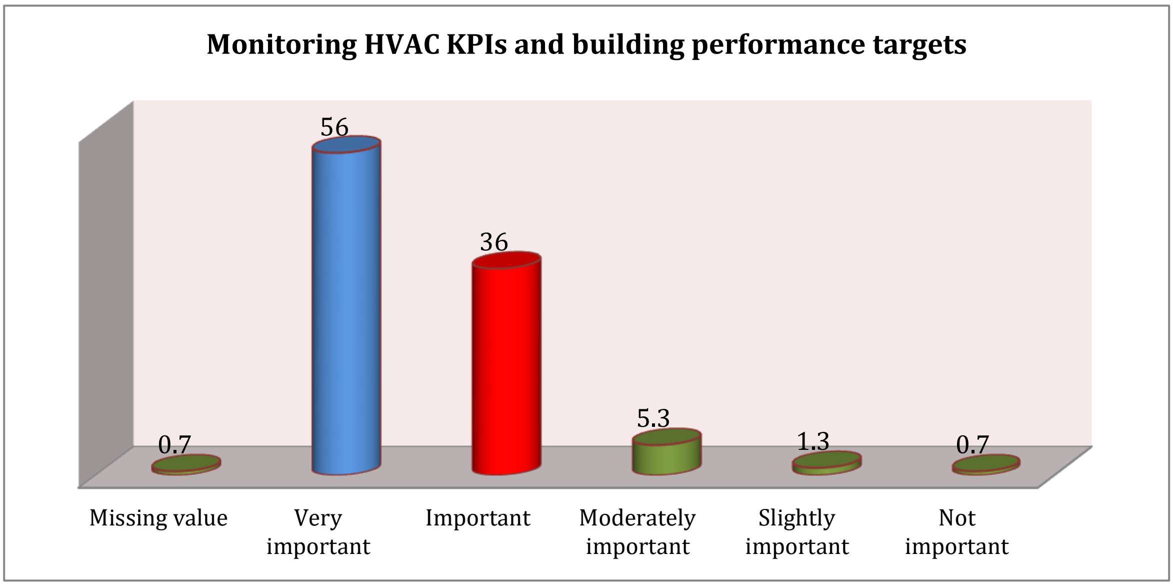

Figure 22: Monitoring HVAC KPIs and building performance targets

Question No.39 aimed to measure the regular energy audits by third parties. Based on the descriptive statistics in Table 40, almost all respondents were agreed on the importance of regular energy audits by third parties as indicated by 48.7% and 40.7% identifying them as 'very important' or 'important' respectively.

Table 40: Regular Energy Audits by Third Parties

Q39. Do you think carrying out regular Energy audits by third parties will improve power consumption and maintenance?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Missing value.	1	.7	.7	.7
	Very important.	73	48.7	48.7	49.3
	Important.	61	40.7	40.7	90.0
	Moderately important.	6	4.0	4.0	94.0
	Slightly important.	6	4.0	4.0	98.0
	Not important.	3	2.0	2.0	100.0
	Total	150	100.0	100.0	

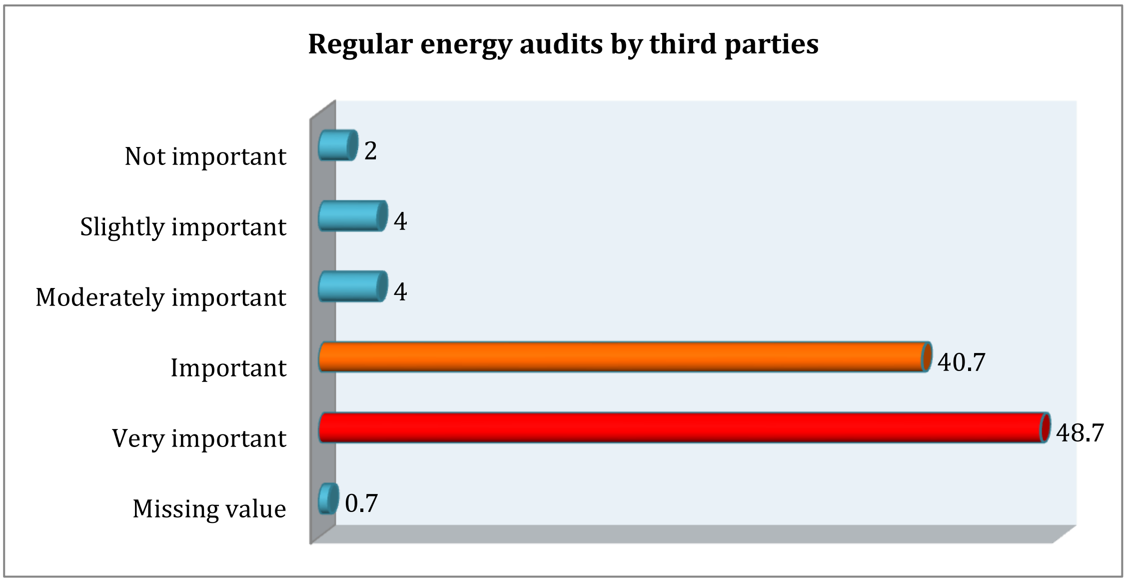

Figure 23: Regular energy audits by third parties

Allocation of a Budget:

To measure this factor, descriptive statistics were used to analyse the data from question No.35. Table 41 indicates that almost all agreed that it is 'important' (41.3%) or 'very important' (44.0%) to allocate a budget to secure efficient maintenance.

Table 41: Allocation of Budget

Q35. Do you think allocating a budget to enable efficient maintenance is important					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Missing value.	2	1.3	1.3	1.3
	Very important.	66	44.0	44.0	45.3
	Important.	62	41.3	41.3	86.7
	Moderately important.	12	8.0	8.0	94.7
	Slightly important.	5	3.3	3.3	98.0
	Not important.	3	2.0	2.0	100.0
	Total	150	100.0	100.0	

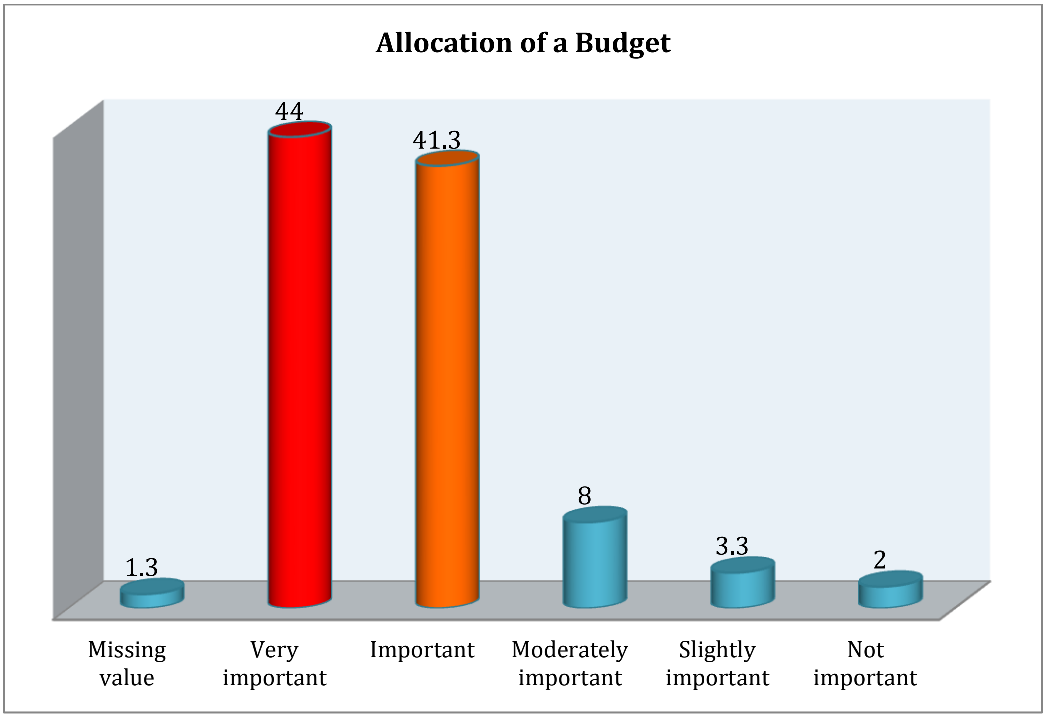

Figure 24: Allocation of a Budget

11. IMPORTANCE OF THE FACTORS AFFECTING THE POWER CONSUMPTION IN THE HVAC SYSTEM

To measure which of the above factors are more important and have more effect on the power consumption, multiple regression is used to predict the significance of power consumption (the dependent variable) based on the value of the above seven factors.

Table 42 indicated that the client's complaints 'very often', 'always' or 'sometimes' concern high bills for power consumption (32.7%, 32.7% and 30.7% respectively). These complaints could be due to the poor maintenance of the HVAC system, as shown in Table 42.

Table 42: Dependent Variable (Clients' Complaints on High Bills for Power Consumption)

Q9. How often do you receive complaints from clients regarding high bills for power consumption?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Very often	49	32.7	32.7	32.7
	Always	49	32.7	32.7	65.3
	Sometimes	46	30.7	30.7	96.0
	Rarely	3	2.0	2.0	98.0
	Never	3	2.0	2.0	100.0
	Total	150	100.0	100.0	

Table 43 indicates that the most significant **(a= 0.05)** predictors of high bills for power consumption are "HVAC unit" and "Building Design" with correlation coefficients of 0.328 & 0.325 respectively. Other relatively high correlation coefficients included: Rules & Regulation (0.288), Engagement with Stakeholder (0.256), and Personnel Expertise (0.193).

Table 43: Correlations

Correlations									
		How often do you receive	Personnel Expertise	Building Design	Temperature/Humidity	HVAC Unit	Rules & Regulation	Engagement with	Allocation of Budget
Pearson Correlation	**How often do you receive complaints from clients regarding high bills for power consumption?**	1.000	.193	.325	.164	.328	.288	.256	.079
	Personnel Expertise?	.193	1.000	.211	.125	.318	.213	.591	.567
	Building Design?	.325	.211	1.000	.353	.688	.396	.097	-.056
	Temperature/Humidity ?	.164	.125	.353	1.000	.381	.153	.143	.186
	HVAC Unit?	.328	.318	.688	.381	1.000	.594	.205	.069
	Rules & Regulations?	.288	.213	.396	.153	.594	1.000	.159	.022
	Engagement with Stakeholder?	.256	.591	.097	.143	.205	.159	1.000	.635
	Allocation of Budget?	.079	.567	-.056	.186	.069	.022	.635	1.000
Sig. (1-tailed)	**How often do you receive complaints from clients regarding high bills for power consumption?**	.	.009	.000	.022	.000	.000	.001	.168
	Personnel Expertise?	.009	.	.005	.064	.000	.004	.000	.000
	Building Design?	.000	.005	.	.000	.000	.000	.119	.247
	Temperature/Humidity ?	.022	.064	.000	.	.000	.031	.040	.011
	HVAC Unit	.000	.000	.000	.000	.	.000	.006	.201
	Rules & Regulations?	.000	.004	.000	.031	.000	.	.026	.394
	Engagement with Stakeholder?	.001	.000	.119	.040	.006	.026	.	.000
	Allocation of Budget?	.168	.000	.247	.011	.201	.394	.000	.
N	**How often do you receive complaints from clients regarding high bills for power consumption?**	150	150	150	150	150	150	150	150
	Personnel Expertise?	150	150	150	150	150	150	150	150
	Building Design?	150	150	150	150	150	150	150	150
	Temperature/Humidity ?	150	150	150	150	150	150	150	150
	HVAC Unit?	150	150	150	150	150	150	150	150
	Rules & Regulation?	150	150	150	150	150	150	150	150
	Engagement with Stakeholder?	150	150	150	150	150	150	150	150
	Allocation of Budget?	150	150	150	150	150	150	150	150

From Table 44, the multiple correlation coefficient R = 0.328a, 0.380b, 0.409c, and 0.396d indicates that there is a strong correlation between the complaints from clients regarding high bills for power consumption and the independent variables. In terms of variability in complaints from clients, by our fitted model, this amounts to a proportion of R2 = 0.107, 0.145, 0.167, and 0.157. Since, by definition, R2 will increase when further terms are added to the model, even if these do not explain variability in the population, the adjusted R2 is an attempt to provide an improved estimation of R2 in the population.

Table 44: Model Summary

Model Summary					
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	0.328[a]	0.107	0.101	.896	
2	0.380[b]	0.145	0.133	.880	
3	0.409[c]	0.167	0.150	.871	
4	0.396[d]	0.157	0.145	.874	2.112
a. Predictors: (Constant), HVAC Unit					
b. Predictors: (Constant), HVAC Unit, Engagement With Stakeholder					
c. Predictors: (Constant), HVAC Unit, Engagement With Stakeholder, Building Design					
d. Predictors: (Constant), Engagement With Stakeholder, Building Design					
e. Dependent Variable: How often do you receive complaints from clients regarding high bills for power consumption?					

From Table 45, the last column shows the goodness of fit of the model. The lower this number, the better the fit. Typically, if "Sig" is greater than 0.05, we conclude that our model could not fit the data. But, as shown in the above ANOVA table, the significance level is close to zero (lower than 0.05) suggesting that the regression is significant.

Table 45: ANOVA Analysis

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	14.296	1	14.296	17.818	.000[b]
	Residual	118.744	148	.802		
	Total	133.040	149			
2	Regression	19.241	2	9.620	12.427	.000[c]
	Residual	113.799	147	.774		
	Total	133.040	149			
3	Regression	22.209	3	7.403	9.752	.000[d]
	Residual	110.831	146	.759		
	Total	133.040	149			
4	Regression	20.822	2	10.411	13.638	.000[e]
	Residual	112.218	147	.763		
	Total	133.040	149			
a. Dependent Variable: How often do you receive complaints from clients regarding high bills for power consumption						
b. Predictors: (Constant), HVAC Unit						
c. Predictors: (Constant), HVAC Unit, Engagement With Stakeholder						
d. Predictors: (Constant), HVAC Unit, Engagement With Stakeholder, Building Design						
e. Predictors: (Constant), Engagement With Stakeholder, Building Design						

Looking into the Coefficients in Table 46, it is important to check the Standardized Coefficient (Beta values) and "Sig.' box in the model. Where the "Sig." value for an independent variable is less than 0.05; then we can assume that the estimate in column "B" can be asserted as true with a 95% level of confidence. Moreover, the Beta column concludes that the best predictor for a high bill for power consumption is the HVAC Unit (β= 0.328), followed by Building Design (β= 0.303), and Engagement with Stakeholder (β= 0.207).

Table 46: Coefficients

Coefficients						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.856	.299		2.863	.005
	HVAC Unit	.464	.110	.328	4.221	.000
2	(Constant)	.515	.323		1.592	.114
	HVAC Unit	.407	.110	.287	3.687	.000
	Engagement With Stakeholder	.291	.115	.197	2.527	.013
3	(Constant)	.202	.357		.567	.571
	HVAC Unit	.203	.150	.143	1.351	.179
	Engagement With Stakeholder	.305	.114	.207	2.671	.008
	Building Design	.384	.194	.206	1.977	.050
4	(Constant)	.300	.351		.857	.393
	Engagement With Stakeholder	.335	.112	.227	2.978	.003
	Building Design	.565	.142	.303	3.982	.000

Finally, the most important factor affecting HVAC system maintenance is the HVAC unit and the second most important factor is the building design and the third most important factor is the engagement with the stakeholder, as shown in Figure 25.

Figure 25: The Sequence of Factors Affecting HVAC System Maintenance

12. CONCLUSION

The qualitative data collected from the questionnaire were analysed by using descriptive analysis, as shown in this paper, and the quantitative data were analysed through ANOVA analysis. The key findings from the results analysis show that the most important factors affecting HVAC system maintenance are the HVAC unit and the second most important factor is the building design and the third most important factor is the engagement with the stakeholder. Therefore, to improve the HVAC maintenance performance and to reduce the energy consumption, the HVAC system should be integrated with the Building Management System to reduce the energy consumption. Changing air filters routinely will enhance maintenance and operation of AHUs, the diagnosis of maintenance faults will save significant power usage, balancing the air system in order to maintain the required rates of air flow and quality levels *as per* location needs and adhering to the specified maintenance frequency for HVAC systems will increase the HVAC system performance and reduce the energy consumption. Installation of adequate energy and water metering at the HVAC system will help to monitor the energy and water consumption.

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