UNIVERSITY OF NAIROBI

SCHOOL OF COMPUTING AND INFORMATICS

CDT 599

RESEARCH PROJECT
USE REMOTE SENSORS TO COLLECT DATA CENTRE PERFORMANCE PARAMEMERS BASED ON SOA MODEL:

CASE STUDY OF AIRTEL-KE

BY:

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DECLARATION

I, Nderitu Anthony Githae declare that this research project is my work, which I've conducted between March`21 and Dec`21 and that, this work has not been presented in any other institution of higher learning for academic credit, or any public journal for publication.

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Signature   Date Wednesday, 08 December 2021

This research project has been conducted and findings submitted for examination with my approval as assigned university supervisor.

Dr. Andrew Kahonge

Signature   Date:
Wednesday, 08 December 2021

ABSTRACT

The main purpose/aim of this study is to understand the feastibility of implementing remote sensors coupled with micro-processors to collect Data centre traffic based on the Service oriented architecture model, in Kenya, as observed from the second largest public land mobile network (PLMN) operator in Kenya by customer base. Mobile carriers need to collect data centre health traffic on a periodic basis, mostly hourly, to be guaranteed about uptime of these centres, and this need to be done in a cost-efficient manner. Through the use of remote censors, temperature and humidity performance traffic is collected, aggregated and corelated at a central location, in a secure manner, using service oriented architectural models. This operational model is expected to cut operational costs to a great extent when compared with alternative manual models, or semi-automated ones and fully automated systems based on SNMP. As technology continues to improve, more radio access technologies are being rolled out putting strain to data centre managers, to ensure uptime at all times. This research aims to look into the feastibility assessment of implementing remote sensors coupled with micro-processor technology to collect data from Airtel data centres, in Kenya, to the benefit of all stakeholders, and particularly network customers. Implementation of this technology is expected to really improve the operational cost efficiency of data centres, KPI management and at the same time increase visibility in real-time across operator data centres and traffic aggregation hubs, located in the country.

KEY WORDS

Networks, Micro-processors, Sensors, Distributed systems, Telecommunication, Telco, Mobile Network Operators (MNO)

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ACRONYMS

ARPU	Average Revenue per Operator
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
BTS	Base Transceiver Station
CAPEX	Capital Expenditures
CCK	Communications Commission of Kenya
CAK	Communications Authority of Kenya
COMESA	Common Market for Eastern and Southern Africa
GB	Gigabyte
GNI	Gross National Income
HLR	Home Location Register
ICT	Information and Communication Technology
IMSI	International Mobile Subscriber Identity
ISP	Internet Service Provider
ITU	International Telecommunications Union
MB	Mobile Broadband
Mb	Megabyte
MNO	Mobile Network Operator
MSC	Mobile Switching Center
NMS	Network Management Station
OPEX	Operational Expenditures
PLMN	Public Land Mobile Networks
QoS	Quality of Service
RAN	Radio Access Network
RNC	Radio Network Controller
SAC	Subscriber Acquisition Cost
SIM	Subscriber Identity Module
SGSN	Serving GPRS Support Node
SMP	Significant Market Power
SMS	Short Messaging Service
UE	User Equipment
WHO	World Health Organization

CHAPTER ONE

1.1 Introduction

This chapter introduced the concepts around collection of remote data centres data in Kenya and the cost benefit analysis that such an implementation may present here in Kenya for the second largest mobile carrier in Kenya, by customer base. Particular emphasis will be paid to those data centres owned and operated by the second largest national carrier by customer base. The main reason of the study is to explore and understand the feasibility of designing and installing remote sensors coupled with micro-processors to collect Data centre traffic based on the Service oriented architecture model, in Kenya and specifically viewed from Airtel, the second largest mobile carrier in Kenya by customer subscription. Mobile carriers, across the world, generally need to collect data-centre health indicators on a periodic basis, mostly on an hourly basis, to be guaranteed about uptime of these centres and traffic aggregation hubs, and this needs to be done in a cost-effective manner. Through the use of remote sensors, temperature and humidity traffic will be collected and correlated at a central location using service oriented architectural models, using secure transportation to enhance operational efficiency and data security. It is the intention of this research to present an operational model that cuts costs to a great extent when compared with alternative manual models, semi-automated ones or those based on SNMP technology. As technology continues to improve, more radio access technologies are being rolled out putting strain to data centre managers to ensure uptime at all times. This research aims to look into the feasibility assessment of implementing remote sensors coupled with micro-processor technology to collect data from all the Airtel data centres in Kenya, to the benefit of all internal stakeholders, and business customers in general. Implementation of this technology is expected to really improve the operational cost efficiency of data centres KPI management and at the same time increase KPI visibility in real-time across the country.

1.2 Background of the Study

The aim of this study is to explore the feasibility of the service-oriented software models coupled with micro-sensors and micro-processors to collect data centre health parameters for one of the national mobile carriers in Kenya. More specifically, data centres in remote locations will benefit the most from this research. According to (Airtel-Kenya, 2021), Airtel Africa is a leading provider of telecommunications and mobile money services, with a operations in 14 African countries, mainly located in Eastern, Central and Western Africa; Airtel African vision is to provides a range of telecommunication products to its customer across the African continent and these include voice products, data offerings, mobile money transfer solutions, value added and roaming services; With its Headquarters in New Delhi, India, Bharti Airtel is ranked amongst the top 3 global mobile service providers, by subscriber base; Bharti Airtel had over 413 million customers, aggregated from all operations by the end of March 2018, and this trend has been growing steadily; Airtel Kenya launched operations in November 2010 after acquiring Zain-Kenya in Jun-2010. As at early 2021, there were about 21 data centres in Kenya that serve as both controller locations and points of traffic aggregation. These locations need guaranteed uptime and a lot of resources, both human and machine, have been deployed to guarantee service uptime. One of the challenges is the collection of sensor data from data centres to central management for reporting, on a real time basis, to assure management of quality of service. There are many sensors within these data centres like temperature sensors, humidity sensors, voltage and current sensors, security sensors, water flow/level sensors, etc. Many of these sensors are being managed in a semi-automated manner where KPI data is read manually and entered into a system that then reports this data on an hourly basis. Other sensors modules need to be plugged into a computing system to download readings. There has been attempts to deploy SNMP based tools to collect data over existing production nodes, but this has had challenges to a certain degree (running costs vs effectiveness). This is proving sub-optimal and better methods of collecting this data are required to keep service delivery optimal. It is envisaged that research on this topic will contribute to improved policy on collecting this KPI data, and possibly lead to wide-spread implementation of micro-sensors and micro-processors within the carrier`s data centres in Kenya. This may also be rolled out to other data centres across the region that may face similar challenges. In some countries, heat and humidity are major hurdles e.g. countries in the Sahara belt typically experience 40°C-50ºC environmental temperatures and cooling under these conditions needs even closer monitoring, to ensure that data centre hardware equipment is operated within the manufacturers recommended specifications. In addition, it is noteworthy that the limitations stated cut across many mobile network operator; this solution may easily be transposed to other large data centre operators in the country.

Recommended Parameters

According to (VERTIV, 2021), the majority of data centres aim for lower ambient temperatures, usually in compliance with ASHRAE`s recommended range of 18.0ºC and 26.89ºC (*variance is* *influenced by factors such as humidity and dew point*); This range is evidently below the CPU point of no return of around 35ºC. Again, cooling the server rooms below 18ºC may encourage formation of dew and condensation around motherboards and CPUs, leading to irreversible damage (VERTIV, 2021). Thus, it is important to think of data-centre temperature as a balancing act; allowing temperatures to drop without consideration for other environmental variables, namely humidity and dew point, will introduce undue risk to data centre equipment and furthermore, there is rarely justification for a cooling capacity that drops below 18ºC. Monitoring of temperature levels may be done through SNMP and compatible servers. However, this often means that vendors have to be willing to share this data, or even be paid to do this monitoring, a cost that mobile players will be keen to avoid. In addition, since there are many network elements within a data centre, it is often cheaper to deploy centrally managed sensors to monitor ambient parameters levels like temperature and humidity. Many sensors, like temperature sensor devices, measure ambient readings through changes to characteristics of electrical signals (pyrosales.com, 2021). These can either be Resistance Temperature detectors (RTD), Thermocouples, Thermistors, bi-metal thermometers or gas-filled/liquid filled thermometers. To put it simply, a temp-sensor senses the ambient temperature of any content that needs measurement, be it a solid object or a Liquid or a gas (pyrosales.com, 2021). Humidity Sensors, similarly measure changes in atmospheric water by translating these into electronically measurable aspects like voltage and current. A lot of work has gone into developing sensor technology for IoT applications and it is these sensors that this project targets to work with to develop a simple model that collects and reports this data for mobile operators.

1.3 Statement of the Research Problem

Site rental, site acquisition and installation form a large part of the CAPEX in infrastructure deployment and is an expensive affair (Eriksson, 2014). This is often accompanied by hub-sites that act as traffic aggregation centres. In addition, a number of data centres will be built, depending on the size of the network to house network controllers like BSCs, RNCs, MMEs and aggregation routers. With the high customer demands for high-capacity sites and fast throughput with relatively low latency, each site setup costs and additional improvement capital costs can be quite high to setup and all Mobile Network Operators (MNOs) carefully plan & dimension each site before deployment. Correspondingly, data centres are equally expensive to setup and efforts are expended to ensure that the whole infrastructure works as planned and in an optimum manner. To protect such investments, top management of these Public Land mobile Carriers (PLMN), needs regular and accurate installation health indicators to assure the owners of capital that their investments are secure. Often, regular reports are sent on an hourly and daily basis as part of that assurance. LTE sites are increasingly being rolled out in the country and as more and more users continue to buy and operate LTE capable handsets, this will mean more and more traffic being carried through data centres. These centres can then become a point of failure within the public land mobile carrier network. It is thus critical to ensure that data-centres continue to work as expected through positive and negative reinforcement of critical parameters like temperature voltages, humidity, voltage and connectivity. The fast adoption and implementation of mobile communication since the 1990s in Kenya, has creatively addressed people challenges, especially those in marginalized areas of the country. According to (Communication Authority of Kenya, 2020) Sept-2020 quarterly report, the uptake of ICT products has continued to grow in the third Quarter of 2020 financial year on account of mobile and internet usage. As at the end of the Sep`20 Quarter, the number of active mobile subscriptions or issued subscriber identity modules (SIM) Cards in the country were estimated at ~59.84 million translating to (SIM) mobile penetration of 125.8%.

INDICATORS	July-Sept 2020	Apr-Jun 2020	% Change
	Q1	Q4	Q1 to Q4
Mobile Subscriptions (Millions)	59.84	57.03	4.9
Fixed Line Subscriptions	17,650	19,100	-7.6
Fixed Wireless Subscriptions	992	998	-0.6
Fixed VoIP Subscriptions	47,038	49,064	-4.1
MOBILE MONEY TRANSFER SERVICES			
Number of Registered Mobile Money Agents	245,124	223,184	9.8
Number of Active Registered Mobile Money Subscriptions (Millions)	31.79	30.52	4.2
Value of C2B Transfers in Kshs. (Billions)	735.90	446.50	64.8
Value of B2C Transfers in Kshs. (Billions)	530.77	385.11	37.8
Value of B2B Transfers in Kshs. (Billions)	1,336.55	994.64	34.4
Value of G2C Transfers in Kshs (Billions)	7.49	-	-
Value of C2G Transfers in Kshs (Billions)	12.37	8.73	41.7
Volume of P2P Transfers (Millions)	713.96	559.04	27.7
Value of P2P Transfers in Kshs. (Billions)	896.50	722.55	24.1
Total value of Deposits in Kshs. (Billions)	888.11	634.03	40.1

Figure 1 Active mobile subscriptions in millions **source (CAK quarterly bulletin)

This clearly shows that mobile devices are an important tool of daily use for communication and ecommerce, since a number of people have more than a single sim-card in their phone for dual SIM handsets/phones or somewhere in their custody. Mobile broadband has become the most common source of an internet connection in most Sub-Saharan countries, including Kenya, since fixed line internet penetration is very low. Enabling even more penetration is important as it further enables inclusion of all citizens within mainstream financial products as well as improving communication reach to all. Ensuring uptime of aggregation sites and data centres then becomes a critical support function requiring both human resource capital and machine deployments to protect these vital assets. There are some challenges in implementing full cycle feedback control systems. Collecting parameter data is just the beginning. Often these sensors are looped back to negative and positive reinforcement equipment like fans and coolers to maintain optimum ambient parameters. However, where there is significant breakdown of ambient parameters e.g., cooling function within a data centre, additional human intervention will often be needed, and in a timely fashion, to protect data centre assets. The cost of collecting wrong data needs to be considered, when existing semi-automated methods are employed. In such semi-automated systems, annual operational costs will typically exceed Kshs 960,000 per data centre. In more automated scenarios, some commercially available products that employ network management protocols like, SNMP protocol as defined by IEFT, have annual license fees of around Kshs 163,800 for a single module, excluding costs of end user support, Taxes and AMC costs which can be prohibitive. It is possible for the same service to be offered for less than Kshs 10,000 per data centre location/site using commodity sensors, logic controllers, a desktop machine and a single centralized resource, thus savings large amounts of CAPEX and OPEX. This study will look at collection of data centre parameters and how this can be sent to top managers in real-time, so that if there is a failure in the automated systems, then human intervention can be taken in a timely fashion to arrest an otherwise run-away situation.

1.4 Significance of the Study

According to (ASHRAE-TC9.9, 2016), hardware failure rate increases with increase in temperature, that is, a higher operating temperature for a given hardware will precipitate a higher failure rate; a plot of server failure rate as a function of temperature is shown below, where IT equipment run on a continuous basis at 30°C or 86°F, will experience an x-factor of 1.4 or an increased 40% failure rate, than if the same equipment was run at 20°C or 68°F.

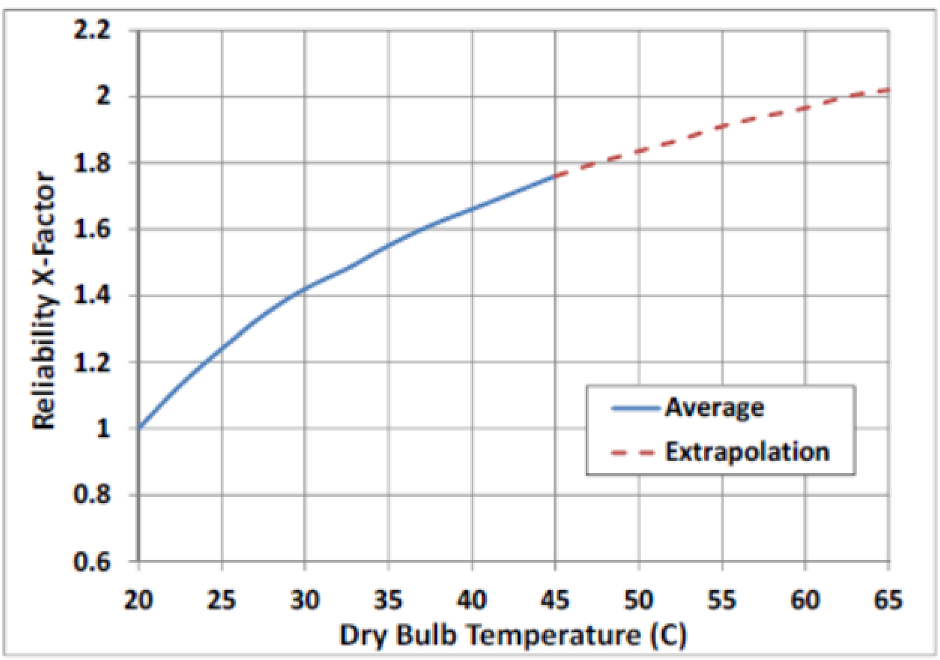


Figure 1.0 Failure rates vs Operational Temperature. Adopted from ASHRAE 2016 report.

The same is also true for humidity. Server equipment operated at high levels of relative humidity will fail faster due to corrosion than one operated within the recommended ASHRAE`s recommendations. It is then critically important to monitor in real time the environmental factors that affect data centres and hence indirectly affect the IT and power equipment installed therein. A Securely installed SOA based system can increase the levels of efficiency and reporting of these critical environmental factors within the data centres without increasing significantly the costs of operations. This forms the axis of this research paper.

1.5 Research Objectives

1.5.1 General objectives

The main purpose/aim of this study is to study and understand the efficiency improvement that can be achieved by automating datacentre parameter collection centrally through the use of a service-oriented architecture (SOA) based system to increase real-time visibility into the operation of data centres of the second largest mobile operator in Kenya. Current collections methods have proven sub-optimal and a real-time system that is cost effective is needed to improve visibility and management of these nodes, since they are critical to the operations of a mobile carrier. Temperature and humidity sensors will be explored in this study. However, there are many other sensors than can be investigated and automated in a similar manner and hence this study will somewhat be a POC that will lay the ground-work for further areas of improvement. These areas include data centre working voltage measurements, power outage sensors, Spectrum frequency in use per site sampling, power consumption measurements, real-time audits, security alarms, water level alarms, fluid flow sensors, connectivity alarms, etc. It is the intention of the study to quantify empirically the improvement of visibility and efficiency relative to the current method(s) in use, which will help better understand feastibility of this SOA based system and the best ways of its implementation country-wide. These objectives need to be viewed within the context that automated systems tend to be cheaper generally, than semi-automated ones that need employee interventions. The cost of collecting stale data needs to be factored in as well, in addition to costs of having no data all during any sampling period as policy dictates.

1.5.2 Specific objectives

This research study will be guided by the following specific objectives

1. What is the current level of efficiency in collecting and reporting datacentres temperature and humidity parameters to the management team?
2. What improvements can be achieved through the use of automated sensors, logic controllers and a SOA based system to report temperature and humidity data to management in real-time?

3. What is the cost trade off and is such a real-time system financially viable?

1.6 Research Questions

The fundamental purpose/aim of this project is to give insights into the following questions of research as outlined below:

i. What is the current level of efficiency in collecting and reporting datacentres temperature and humidity parameters, using the current semi-automated system that involves use of employees within the data centres?

ii. What technical improvements can be achieved through the use of automated sensors, logic controllers and a SOA based system to report temperature and humidity data to management in real-time? Can such a system be implemented in a simple manner with little re-training to current staff?

iii. Is such an automated system, that reports data in real-time, financially viable, relative to current systems?

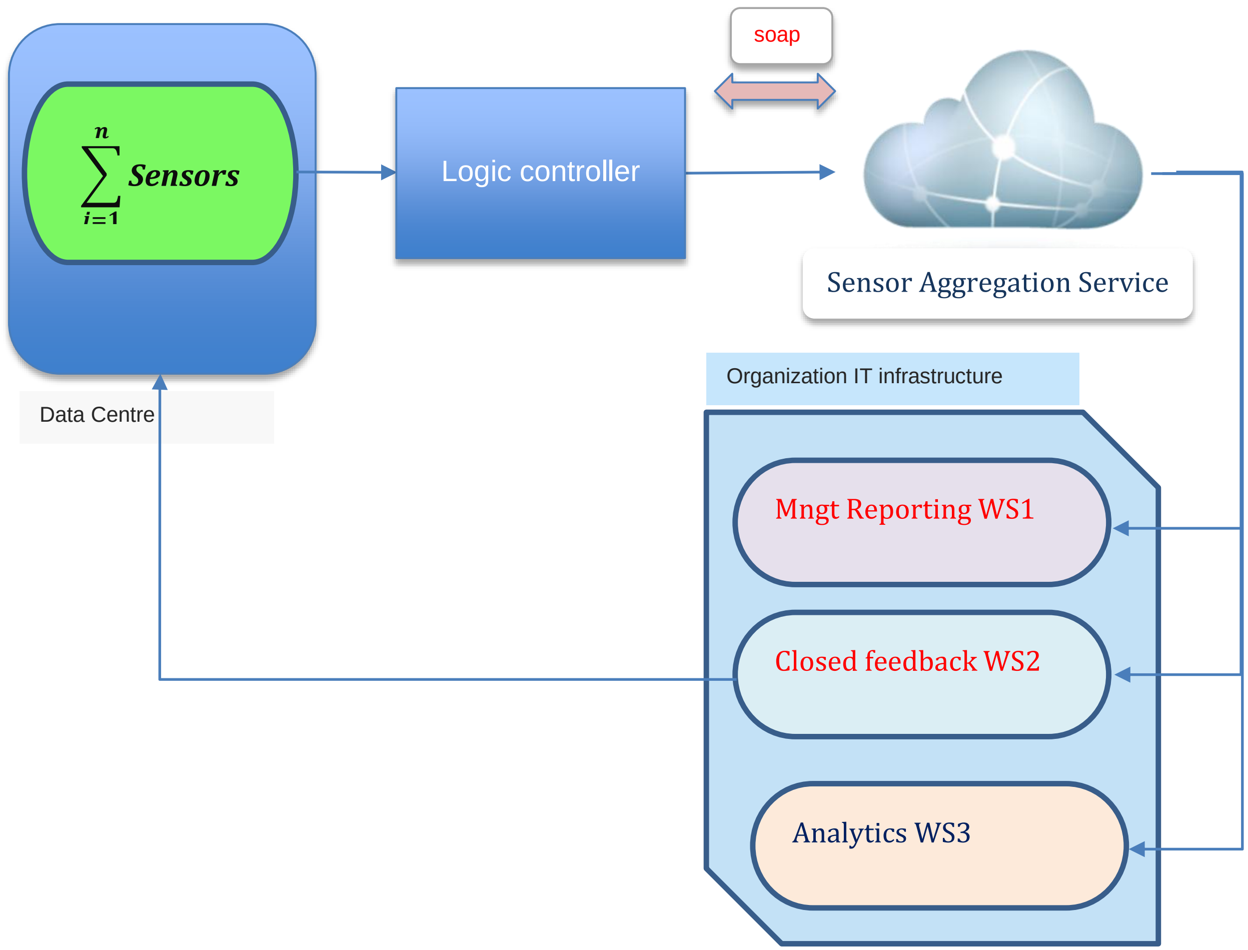
1.7 Theoretical Framework

A theoretical framework offers a set of theories that guide investigations into a given area of research. The application of a theory or extracts from the theory, can help offer explanations to observed events and indeed shed light on natural phenomena observed in real life. According to (SureshNeethirajan, 2020), a sensor is defined any a device, capable of measuring or detecting a chemical, physical characteristics and/or biological/mechanical properties of that substance or a combination of thereof; It then records and collects the data for interpretation by a human or a machine; Hardware based sensors are devices such as vision sensors or cameras, temperature based sensors, infrared thermal imaging sensors, accelerometer, Radio Frequency IDs (RFID) tags, pedometers, motion sensors, facial recognition machine, vision sensors and microphones (SureshNeethirajan, 2020). Most sensors are used, together with AI, to either find ways of optimizing performance, understand complex systems or recognise complex patterns, predict patterns. In the agricultural industry, sensors coupled with AI, has been shown to improve early detection of diseases in animals. In the health industry, sensors have been used to improve faster diagnoses of diseases. In the travel industry, sensors have improved passenger safety in Airports. The use of this technology is only limited by imagination.

1.8 Conceptual Framework

Conceptual framework analysis allows for an ordered way to theorize idea frameworks based on well-established theory methods (Jabareen, 2009). According to (Miles, A. M, Huberman, & Matthew, 1994), a conceptual framework provides descriptively or in an illustrative way, the fundamental items to be examined and their component factors, constructs or variables--and the presumed relationships among them; a framework can be elementally or detailed, theory-driven or common sensical, in descriptive form or causal (pg 32). This paper seeks to explore sensors and their application in the wider context of a mobile carrier network, to find areas to improve operational efficiency. In addition, financial viability will be an important consideration since mobile operators needs to see financial viability of any product they acquire as ARPU has been falling over time. Below is a diagram that shows the broad conceptual areas under consideration. The concept explores a closed loop system that controls data environmental parameters either directly or indirectly.

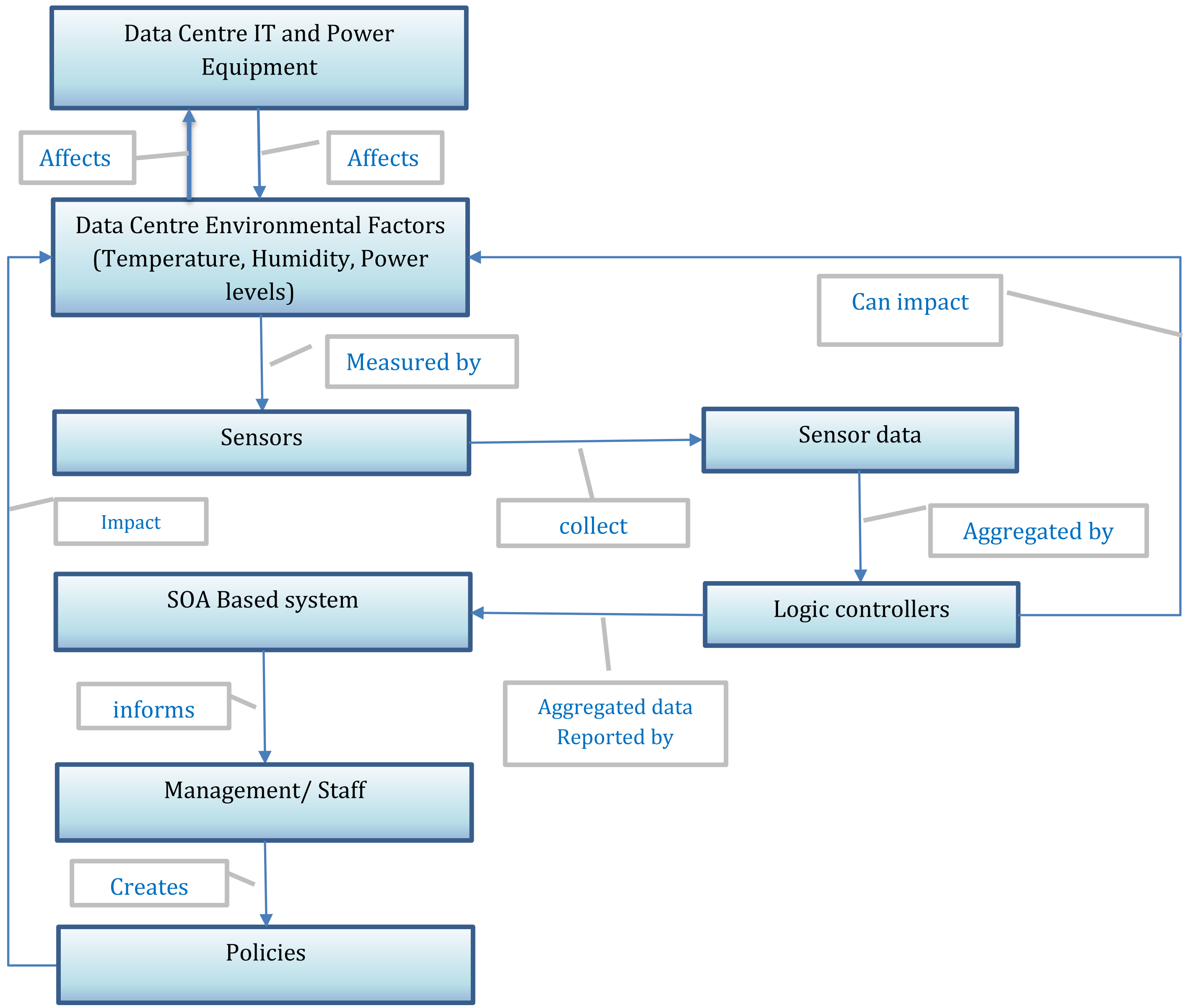
Sensor-SOA logical connection model



Multiple sensors being monitored and managed by a single controller through polling or interrupt techniques, for example, humidity, temperature, open door alarms, spectrum in use sensors, voltage sensors, surge sensors, water level sensors, diesel level sensors e.t.c.

a) The logic controller consumes the sensor aggregation service. Main methodology is soap messaging.
b) The programable logic controller(PLC) can connect and download network settings from the sensor service.
c) The sensor aggregation service in turn stores the received data in a database, and serves this information to any other service that wishes to use this data
d) Three SOAP services are shown here in, within the vendors network. However, there can be many more dependent services
e) This model allows for scalability of the system, as logic controllers, service instances can be added to serve many clients.
f) To allow for redundancy in a high availability system, sensor aggregation service instances can be added.

Conceptual model on SOA Based Sensor Model (Data centre sensors and management reporting)



1.9 Research Gap

In his research paper, (John Oyiego,2020) studied the effect of SCADA systems within the petroleum industry and his study was limited to the factors that influence the security of such systems and the vulnerability that such systems face in a live implementation and found out that it is important to protect communication to and from such systems as they are vulnerable to attack. In his research, he noted that SCADA systems tend to be heavy industrial specific and deploy heavy duty protocols like ControlNet, Modbus RTU, Modbus TCP, Device-Net and Fieldbus, all of which are too advanced for simple data centres or data aggregation centres, especially in a star-based topological network typically operated by mobile carriers. What are needed are light weight programmable logic controllers that are easy to deploy and cost effective, since many of these will be needed per data centre. These devices need to use already existing, widely deployed protocols like TCP and HTTP/HTTPS and physical connectivity links like ethernet, Bluetooth/(BLE) and WIFI to achieve their goals. In fact, some data centres will already contain some type of independent sensors and collection and corelation of this data, in a cost-effective way, is needed. The cost of collecting wrong data needs to be considered, when existing semi-automated methods are employed. Some commercially available products that employ SNMP protocol as defined by IEFT have annual license fees of around Kshs 163,800 for a single module, excluding costs of end user support, Tax and AMC costs. It is possible for the same service to be offered for less than Kshs 10,000 per data centre location/site using commodity sensors, logic controllers and a virtual machine, thus savings large amounts of CAPEX and OPEX. This is the opportunity that this research project seeks to investigate, unearth and offer insights upon.

1.10 Further Research

This research is only limited to the findings within the republic of Kenya, and explores sensor data collection only for one mobile carrier, whose case was studied. In addition, it only studies temperature and humidity sensors as these were the pain areas for the operator. However, many other parameters can be explored like power outage sensors, voltage surge sensors, voltage drop sensors, open door alarms, water level sensors, security sensors, fluid flow sensors, Diesel level sensors, solenoid valves state sensors etc. There will still be need to explore the issue of sharing sensor traffic across network sharing scenarios where vendors share active hardware like RAN or Core nodes, as envisaged by 3GPP, so that the full extent of benefits can be quantified. It will also be interesting to investigate the impact of sensor networks for countries in the desert belts like the Sahara or very cold countries like those near the arctics. This is still a development area and growth is to be expected as miniature components continue to be discovered and fabricated.

CHAPTER TWO

2.0 Literature Review

This chapter presents theories that are relevant to this study and qualitative and quantitative review of studies that have explored the subject of remote sensors and micro-processors that assist improve everyday life of engineer and users in general. While most of this technology has involves electronic and chemical engineers, its importance has permeated almost all spheres of specializations. This section seeks to investigate in a deeper way, the use of sensors especially in networking engineering and how this can be used to better improve mobile network management.

According to (Aminabhavi, 2021), Sensor based prescriptive technologies have become increasingly popular in recent years, in part, due to their tremendous importance in many disciplines e.g. environmental monitoring, health monitoring, water pollution, defence, air pollution in addition to many other industrial applications such as gas sensors; As such, a sensor is a versatile and highly interdisciplinary field, which needs fundamental knowledge of differentiated disciplines; The Author further postulates that huge opportunities are available for researchers, who work in this area of knowledge, to develop new bionano-engineered surfaces, designing of new goals for drug delivery/receptors/nano catalysts, and their integration to powerful signal transduction systems such as optical, electrochemical, micromechanical and/or piezoelectric. As technologies continue to evolve, new sensor technologies have been developed, with the end products being highly miniaturized and robust analytical sensors and accompanying embedded software tools that improve personalized health care and improve industrial applications.

In his research paper, (SureshNeethirajan, 2020) demonstrated that Modern technologies such as sensors, big data, ML and AI can constantly monitor animal health instead of humans enabling fewer farmers to keep for an increased number of animals, in turn lowering production costs. In a typical data centre scenario, importance factors relating to collection of data centre help include

i. Accuracy of data collected.
ii. Efficiency of collection.
iii. Cost per KPI, during each sampling period.
iv. Reliability: the capability to aggregate metrics given the same conditions.

These parameters are important and the next section looks at theories that relate to data centres and policies/guidelines that exist to control and guide network managers.

2.1 Review of Theories

The strategy of data centre temperature management has changed drastically with the introduction of new operating temperature guidelines by the American Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), as noted by (Vertiv Group, 2021). ASHRAE Technical Committee (TC), 2016, has been a good reference point on matters data centre design, especially after they published a paper whose recommendations have been used widely. According to (ASHRAE-TC9.9, 2016), altering data centre ambient data centre conditions are important both to IT equipment and also to power equipment, especially where the two types of equipment (*IT and power equipment*) share the same ambient-physical space and air streams; passive power equipment will generally have extended periods of economic use than information technology (IT) equipment. This committee defined earlier recommendations in 2015 and has become widely referenced.

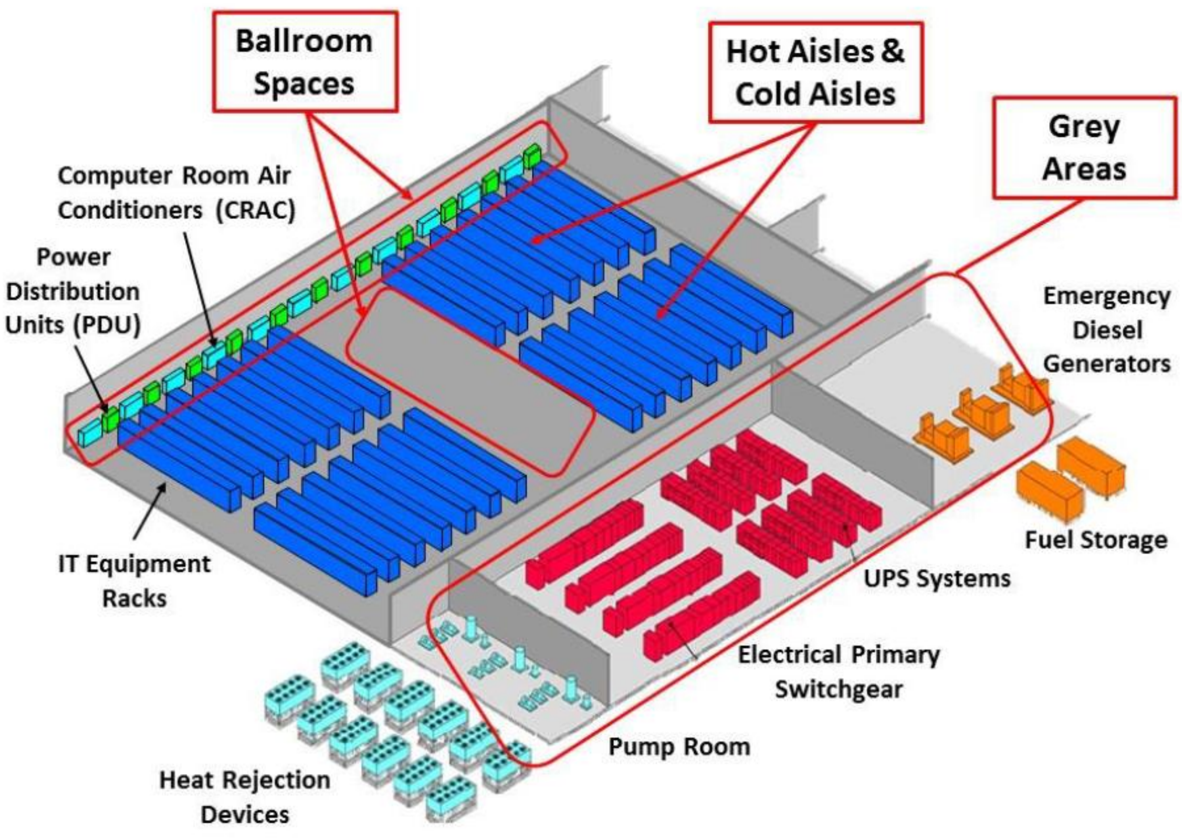


Fig 2. General classification of data centre spaces: ballroom, hot aisles, cold aisles, and grey areas; *Adopted from ASHRAE TC9.9 paper.

The ASHRAE 2016 edition, revised the operating temperature and humidity levels from the earlier published reports; The revised recommendations for rack level inlet temperature

range was adjusted from (18 °C to 27 °C) to (5 °C to 32 °C). Humidity level were also adjusted from (8% - 60%) to (8% to 80%). These increase in operating temperatures make higher load densities possible, within RACK cabinets containing several servers without swapping air conditioning systems or increasing additional investments in the existing infrastructure. It also enables big cuts in energy usage assuming the same load capacity (Vertiv Group, 2021). Large, Tier3, data centres use the ASHRAE 2016 typical installation design while smaller data centres vary the design a bit to only keep important power elements while keeping in phase with the main concepts. Telcos also vary the design a little but the overall concepts remain. It can also be seen from (ASHRAE-TC9.9, 2016), that the front face of the rack is where IT equipment takes in its cooling air while the coolest air temperatures in the data-centre are found in the cold aisle; Hot aisles are created by the gaps between two rows of back-to-back cabinets where the heated north bound server gases from both cabinets is funnelled into a common exit (ASHRAE-TC9.9, 2016). Sensors will generally be placed near where the hot gases leave the close system and also on the cold side. Taking measurement from these 2 sets of sensors will generally enforce -ve and +ve reinforcement of temperature within the data centre. In addition, humidity sensors are needed to ensure that the temperatures don’t fall too low in a humid environment to cause condensations within cabinets and ruin servers and other installed equipment. Below is the ASHRAE 2015 recommended temperature ranges and the various categories of equipment in consideration.

Class[a]	Equipment Environmental Specifications for Air Cooling						
	Product Operations[b,c]					Product Power Off[c,d]	
	Dry-Bulb Temperature[e,g] °C	Humidity Range, Non-Condensing[h,i,k,l]	Maximum Dew Point[k] °C	Maximum Elevation[e,j,m] m	Maximum Temperature Change[f] in an Hour (°C)	Dry-Bulb Temperature °C	Relative Humidity[k] %
Recommended (Suitable for all 4 classes)							
A1 to A4	18 to 27	-9°C DP to 15°C DP and 60% RH					
Allowable							
A1	15 to 32	-12°C DP & 8% RH to 17°C DP and 80% RH[k]	17	3050	5/20	5 to 45	8 to 80
A2	10 to 35	-12°C DP & 8% RH to 21°C DP and 80% RH[k]	21	3050	5/20	5 to 45	8 to 80
A3	5 to 40	-12°C DP & 8% RH to 24°C DP and 85% RH[k]	24	3050	5/20	5 to 45	8 to 80
A4	5 to 45	-12°C DP & 8% RH to 24°C DP and 90% RH[k]	24	3050	5/20	5 to 45	8 to 80
B	5 to 35	8% to 28°C DP and 80% RH[k]	28	3050	NA	5 to 45	8 to 80
C	5 to 40	8% to 28°C DP and 80% RH[k]	28	3050	NA	5 to 45	8 to 80

Figure 2 ASHRAE 2015 recommended data centre temperature ranges

ASHRAE has published recommended values of temperature as 18°C-27°C, or 64°F-81°F; changed from the 2011 published report classes that allowed a temperature range of 5°C to 45°C or 41°F to 113°F; Category A3 of 40°C or 104°F and category A4 of 45°C or 113°F classes were created to support new energy efficient technologies, and save on resources (ASHRAE-TC9.9, 2016). These temperature ranges allow use of greener cooling like Airside economization, waterside economization and refrigerant economization. Additional economies can be achieved by importing minimally filtered air from the outside environment into the data centre and performing little if any air-conditioning and humidity control in an attempt to minimize costing (ASHRAE-TC9.9, 2016). To master how much cooling to administer within the closed data centre environment, then data sensors are typically deployed to control the inputs and output parameters.

2.1.1 Temperature Sensors

Temperature sensors come in various forms and these include 1) Thermistors 2) Resistive Temperature Device (RTD) sensors 3) Thermocouples, 4) Integrated silicon linear sensors, 5) InfraRed Pyrometers 6) Thermopiles. According to (Yang, 2011), desired characteristics of all temperature sensors are a) high sensitivity, b) large temperature range c) Repeatability, d) Relationship between measured quantity and temperature (linear vs nonlinear), e) easy calibration and f) fast response. One needs to consider the fit between the measured items and the type of sensor selected as these sensors vary on the operating ranges and sensitivity; so one needs to consider the desired temperature range, tolerable error limits of the sensor instrument, the environmental factors at play during the measurement and the financial efficiency trade-off between cost and accuracy. For a thermistor, the voltage across the device decreases as the temperature increases. For a thermo-couple, the voltage increases as temperature increases for the same current. Resistive temperature devices also increase voltage as temperature increases for the same current level, but this soon starts decreasing. These are summarised below:

2.1.1.1 Thermocouples:

According to (Baker, 2002), thermocouples are fundamentally rugged, low cost sensors which are generally available in smaller packages than the other temperature sensors; Due to the material that these sensors are created from, any external pressure on them like bending, stretching or compression can alter then fundamental characteristics of these sensors; In addition, some corrosive matter can infiltrate the external protective shielding and cause a variations of protected materials thermal characteristics; However, it is possible to shield these sensors in protective caging like ceramic tubing. Metallic wells can also provide mechanical protection

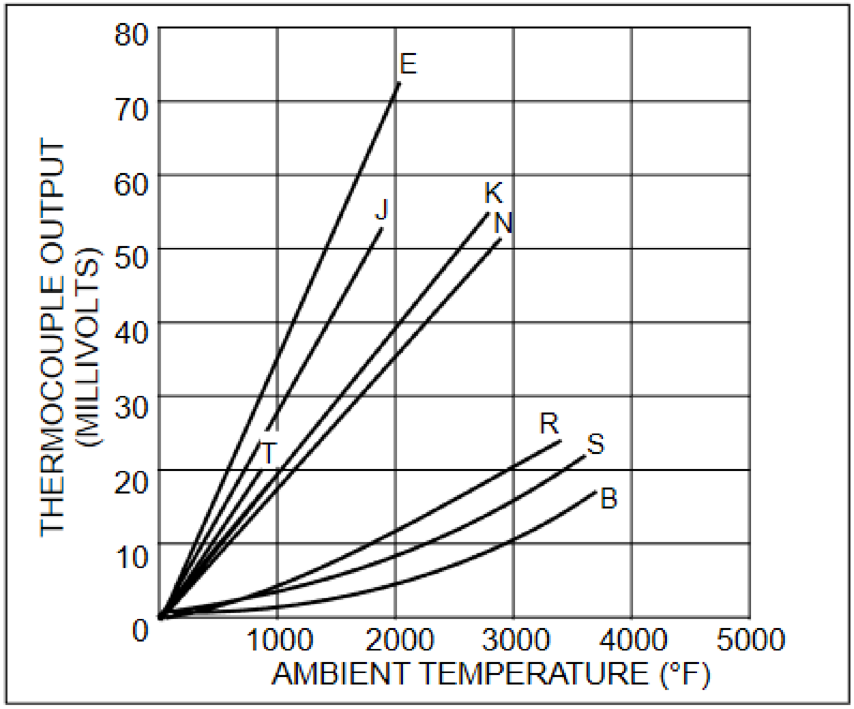


Figure 3 Thermocouples can be applied in scenarios that need a wide range of temperature sensing and this make them appropriate for many hostile environments (Baker, 2002).

Thermocouples are essentially non-linear when compared to Thermistors, Integrated silicon based sensors and RTDs; As a result, elaborate algorithms are needed within the processor portion of the circuit, for example, with type-K thermocouples, coefficients that can be used to normalize the output voltage for a temperature range of 0℃ to 1372̊ are shared below (Baker, 2002) and applied to the equation below:

$$V = C_0\mathrm{t} + C_1t^2 + C_2t^3 + \cdots$$

c_0	$-1.7600413686 \times 10^{-2}$
c_1	$3.8921204975 \times 10^{-2}$
c_2	$1.8558770032 \times 10^{-5}$
c_3	$-9.9457592874 \times 10^{-8}$
c_4	$3.1840945719 \times 10^{-10}$
c_5	$-5.6072844889 \times 10^{-13}$
c_6	$5.6075059059 \times 10^{-16}$
c_7	$-3.2020720003 \times 10^{-19}$
c_8	$9.7151147152 \times 10^{-23}$
c_9	$-1.2104721275 \times 10^{-26}$

Figure 4 k-type thermocouple coefficients for temperature ranges between 0-1372º ((Baker, 2002)).

The diverse/wide/extended temperature ranges of the sensor renders it ideal/appropriate for many sensing environments.

2.1.1.2 Resistance Temperature Detector (RTD):

The RTD (Resistance Temperature Detector) is fabricated from a conductive element, made from metals such as Nickel, Platinum or Copper, as these elements demonstrate a predictable change in resistance as temperature changes and have the fundamental physical property that allows for easy fabrication and calibration; In addition, the temperature coefficient of resistance of these elements is large enough to enable detectable changes with temperature (Baker, 2002). RTDs are absolute temperature sensing devices as opposed to operationally comparable temperature detection devices like thermocouples, which senses relative temperature. From the same author (Baker, 2002), the formulae in use for measurements between 0º-859˚C is

$$R_t = R_t(1 + At + Bt^2)$$

where

Rt is the change in resistance of the RTD at known temperature points,

t is the temperature being measured,

R0 is the magnitude of the RTD at 0℃,

A, B and C are calibration coefficients calculated from experimentation.

The RTD provides a way of mapping temperature into voltage electrical signals and hence easy way of recording temperature measurement, thus making it easier for use with a computerized systems (idc-online, 2021).

2.1.1.3 Thermistors

Thermistors are temperature dependent semiconductor resistors which are generally more accurate and operate reliably between -100ºC and 450°C, with appropriate packaging, thermistors have a continuous detection of resistance when compared to temperature (Baker, 2002). The higher sensitivity property of thermistors has rendered them ideal from an accuracy point of view.

2.1.1.4 Integrated Silicon Temperature Sensors

The integrated circuit temperature sensors offer alternatives methods to resolving temperature measurement problems related to sensitivity, most of which are associated with thermistors since, integrated circuit silicon temperature sensors include, user friendly out-put formats and ease of installation in the printed circuit board (PCB) assembly environment and can be easily implement on the same silicon as the sensor (Baker, 2002). This means then that a single printed circuit board can take the measurements and report to an external module with little margin for error.

2.1.1.5 Pyrometers

Pyrometers are contactless temperature sensors and they operate through detecting the amount of heat energy radiated, as opposed to the amount of heat conducted and convected to the sensor; there exists many varieties of pyrometers such as photoelectric pyrometers (idc-online, 2021). Since temperature is related to the emissivity of a body, there are some assumptions that are made regarding the emissivity of materials and this introduces some degree of unknowns and errors in the readings; Due to these errors, pyrometers are not often use commercially in the industry; Their main applications are in very high temperatures use cases, but they can be used at cooler settings as well; there are lots of industrial applications to pyrometers, for example, plant operations, but the disadvantage to pyrometers is that they are not very accurate as thermocouples or RTD sensors, as they fundamentally rely on quantifying colors of light (idc-online, 2021).

2.1.2 Humidity Sensors

According to (Corp, 2005), inside temperature ranges of -50°C to 150°C and at atmospheric pressures of less than 1000 kPa, water vapor practically behaves like an ideal gas. This water within the gas causes corrosion on the components that make IT components and damage them over time. It is important to ensure that this water (humidity) is controlled so that it is within the ASHRAE's recommended levels of humidity for a data centre. From the notes of (Tiwali, 2021), humidity is a general term and can be expressed quantitatively in different ways; Absolute Humidity is the mass of actual water vapour contained in defined cubic volume of air and by convention is normally expressed as weight(grams) per cubic volume (metre-cubed) of air; Air varies in its ability to hold water vapour, mainly dependent on its temperature; warm air has higher capacity to hold onto water vapour than cold air at the same temperature; For example, at a ambient temperature of around 10°C, one cubic metre of air will contain an estimated 11.4 grams of water vapour; Similar volume of air will contain an estimated 22.2 grams of water vapour when heated to 21°C (Tiwali, 2021). Thus, an increase in temperature of air increases its capacity to retain water vapour, whereas a reduction in temperature decreases it. The challenges with this absolute measurement of humidity is that changes in the ambient temperature or changes to the pressure of the air will cause a change in the volume of the air being measured and consequently the absolute humidity. Alternately, when compared with absolute humidity, Relative Humidity is then the more practical as a measure of atmospheric moisture since it is the ratio of the water vapour present in the measured volume of air compared to its capacity to hold water vapour at that temperature; To simplify readings and presentations, absolute humidity and the maximum moisture holding capacity of air at a particular temperature is always expressed in percentage form (Tiwali, 2021). As relative humidity is calculated from the air`s water vapour content and also its capacity to hold water vapour at a given temperature, its value can be altered on 2 main ways: (i) if water vapour is increased by evaporation, the relative humidity will augmented; (ii) A reduction in temperature (hence, reduction in holding capacity) will precipitate an increase in relative humidity (Tiwali, 2021). When the RH reaches 100%, then the air is said to be saturated as the air cannot hold more water at this temperature. The temperature at which saturation occurs in a given volume of air or water vapour begins to change into water is known as the dew point (Tiwali, 2021). This is a critical factor to check within data centres since this is the level at which water forms on the equipment and begins the process of corrosion. This is the data that humidity sensors seek to collect and report.

According to (Corp, 2005), the humidity sensor of the capacitive type, mainly comprises of a hygroscopic dielectric material that is installed between a binary set of electrodes which then forms a small capacitor; most capacitive sensors use a plastic or polymer as the dielectric material, with a conventional dielectric constant being from 2 to 15; with moisture absent in the sensor, the dielectric constant and the geometry of the sensor determine the value of capacitance; absorption of water vapor by the sensor results in an increase in sensor capacitance which at room temperature gets to a value of around 80. This then form the basis of humidity sensors and humidity measurement of capacitive sensors within data centres. By convention, relative humidity calculation is based on the ambient temperature and water vapor pressure and as such there is a relationship between relative humidity and the amount of water vapour present, within the sensor and hence the sensor capacitance; The characteristics forms the basic operation of a capacitive humidity instrument (Corp, 2005). An example of such an instrument is one from rotronic corporation as shown below

Figure 5 A image of a device that measures both ambient temperature and relative humidity **adopted from rotronic corp website (Corp, 2005).

2.1.3 Micro-controllers and Micro-processors

Microcontroller are small, light-weight and low-cost microcomputers, which are designed to perform specific tasks of embedded systems e.g., measuring temperature, humidity, voltages, receiving remote signals and displaying information and performing simple logic actions. They tend to be simple to replace and generally build with CMOS technology hence require less power to operate. These can be 8 bit controllers, 16 bit controllers or 32bit controllers. A microprocessor is an embedded electronic chip that serves as the control module of a micro-computer, and is normally encaged inside a tiny chip; it performs Arithmetic Logical Unit (ALU) operations and also communicates with the other peripheral devices connected with it, and is usually a single Integrated circuit in which several functions are combined (guru99, 2021). Examples of micro-processors are those in the intel family of micro-processors like Intel-8253, 8254, 8255 micro-controller chips. Microprocessors are usually composed of one Central Processing Units whereas Micro Controllers, also known as programmable logic controllers, contain Memory, CPU and input/output devices, all embedded into a single chip. There are a number of categories of Microprocessors, and these include: i) Complex Instruction Set Microprocessors, ii) The Application Specific Integrated Circuit, iii) Reduced Instruction Set Microprocessors and Digital Signal Multiprocessors (DSPs) (guru99, 2021). For simple tasks the Micro-controllers are desirable due to costs involved, but for more complex tasks, then the micro-processors are desirable. With the falling costs of micro-processors, then single-board processors are now available for less than $50, as witnessed on online platforms like Amazon and Jumia. These have now enabled their used in research, to collect a large array of data and compile for other systems to consume. Recently, there has been a move to used micro-processors like the Arduino Uno and the Raspberry Pi to aggregate sensor data, transmit and report. This project intents to use this model to collect sensor data and report it centrally to management.

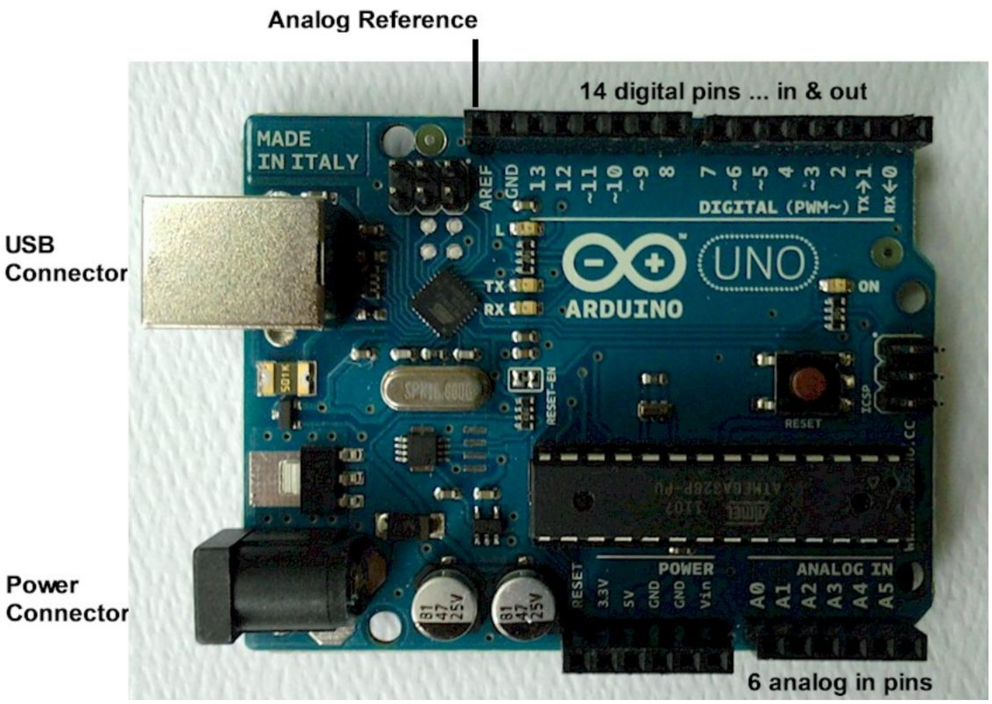


*Figure 6 An Arduino Uno micro-processor. * Adopted from (wikipedia, 2021)*

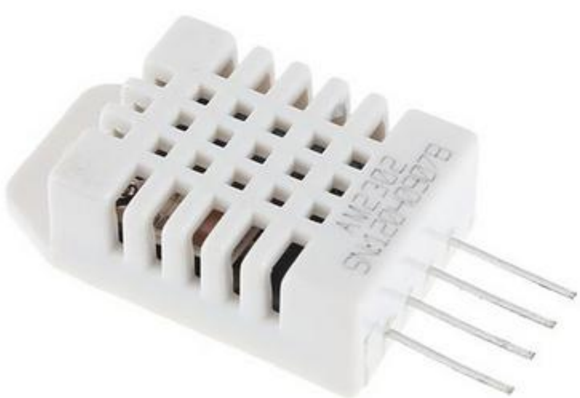


Figure 7 A Generic 3Pcs DHT22/AM2302 Digital Temperature Humidity Sensor ** from Geekcreit®, Jumia.

When these are combined with consumer grade sensors, then data can easily be aggregated and securely reported. By combining these fairly affordable technologies, then complex system of sensor data can be collected and analysed using SOA based application systems and powerful insights derived from the collected data, in a cost effective manner.

2.1.4 Simple Network Management Protocol (SNMP)

Simple Network Management Protocol (SNMP) is an application layer, standardized, internet protocol, that is used for collecting, aggregating and organizing information from managed SNMP capable devices and works on IP networks and features capabilities of sending information back to managed devices to somehow change their behaviour; SNMP was defined by the Internet Engineering Task Force (IETF) in the 1980s` to assist with the monitoring of complex multi-vendor networks (Peter Murray et. al, 2021). According to (H3C Technologies Co Ltd, 2021), SNMP is an application-layer protocol between an NMS and several agents; It defines the standardized management framework, the acceptable communication protocols, and the data protection and access mechanisms used in monitoring and managing devices in a network. Devices that natively support SNMP include hardware like cable modems, switches, routers, desktops, servers, printers, and others (Douglas et al, 2001). SNMP works through the use of poolers, traps, agents and managers. There are a number of message formats defined in the specification for operations like Get, GetNext, Set and Trap. SNMP uses port 161 for management operations and 162 for agent operations this allowing a device of act both as NMS or an agent (H3C Technologies Co Ltd, 2021). In conventional uses of SNMP, administrative computer(s), also refered to as SNMP managers are tasked with monitoring and/or managing a group of agents/devices within a suitable network; With each managed agent device, the agent system executes embedded software which then reports SNMP information to the manager (Wikipedia, 2021).

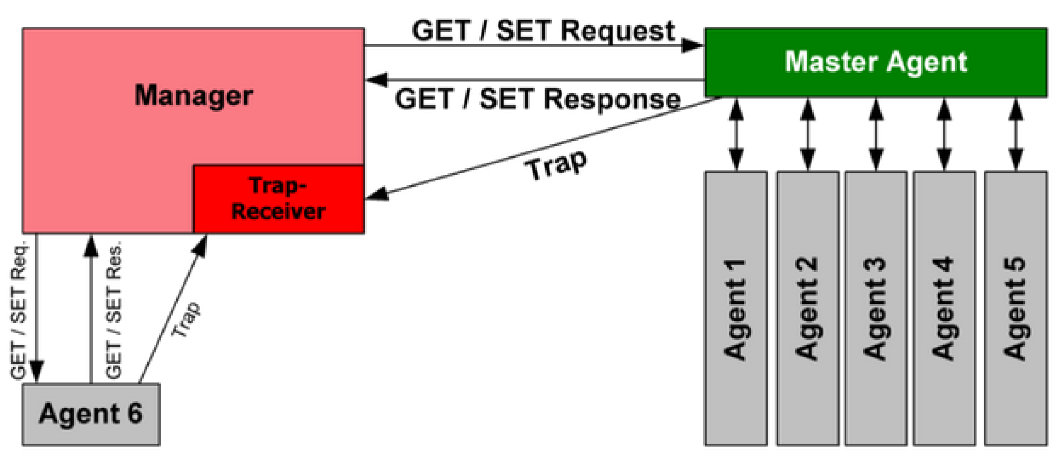


Figure 8 High level Schema that shows how SNMP works in practice ** Image adopted from Wikipidea

SNMP enabled IP network will largely contain 3 critical components (i) Managed SNMP devices (ii) The agent software which runs on the managed devices (iii) Network management station (NMS) software which runs on the SNMP manager (Wiki, 2021). Some of the commercially available products tend to be feature rich, sometimes expensive and occasionally over-dimensioned given the need that exists to collect some basic data centre parameters and key performance indicators. Even in the basic implementations of SNMP, the leaf node must understand SNMP and respond to polls/traps from the master agents. In certain implementation scenarios, there is need to get a model that is cost effective, that is able to serve use cases needing small users or installations, which need to monitor only basic parameters at a low cost. For example, Solar winds, an American software company, sells a product called [*Network Performance Monitor*] that uses SNMP to monitor nodes for a starting annual licence fee of Kshs163,800 (SolarWinds LLC, 2021). This product is part of a wider suite of products that use this management protocol. This is sometimes too much for small players. Use of microcontroller and commodity sensor devices can offer a real alternative to SNMP.

According to (H3C Technologies Co Ltd, 2021), SNMP includes three versions: SNMPv1, SNMPv2c, and SNMPv3; (i) SNMPv1 is the initial published edition of the SNMP protocol, that offered minimalistic network management functions, and the structure of Management Information (SMI) and MIB of SNMPv1 are simple and have a number of known security defects; (ii) SNMPv2c uses data strings, refered to in the industry as (community names) for authentication and these are compatible with SNMPv1; however, they supports higher number of SNMP operation types such as getbulk, more data types such as Counter32, and more error codes for managing exceptions during application runs; (iii) SNMPv3 as published, created avenues for user-based security models (USM), fundamentally engineered to integrity and privacy protect SNMP communication; You can configure privacy mechanisms and authentication to authenticate and encrypt SNMP packets for authenticity, integrity and confidentiality.

CHAPTER THREE: METHODOLOGY

3.0 Research Design and Methodology

This chapter identifies, describes, and justifies research objectives that will be adopted in this study. The chapter includes: research design, target population, description of research instruments, description of the data collection procedures, and description of data analysis procedures to be performed on the collected data. The design and creation research strategy focuses on developing new IT products (artefacts) and these may include constructs, models, methods and installations (Oates, 2006).

3.1 Research Design

The study proposes to adopt a design and creation research strategy and specifically instantiations approach method. Instantiations involves creation of working models, methods, ideas, genes or theories that can be implemented in a computer-based system (Oates, 2006). Data will be collected from one of the mobile carriers in Kenya in a case study, then built a data model to collect and report data. The case study analysis seeks to identify multiple, often inter-linked, factors that have an effect, or compares what was found in the case to theories from the literature in order to see whether one theory matches the case better than others (Oates, 2006). An instantiations research design, a subset of design and creations research strategy, is suitable for this research as it aims to explore the current observed situation of inefficiencies in data collection and aggregation, using IT tools readily available to vastly improve the efficiency. In addition, a number of sensors can work in unison to collect and report large quantities of data from many geographically diverse areas of the country so that useful insights can be derived from the collected data. According to (Oates, 2006), a researcher following the design and creation strategy could offer a construct, model, method or instantiation as a contribution to knowledge. Through this research paper, and after collecting and analysing the data, it is envisioned that this technology can be used in a simplistic manner to efficiently and economically collect and report a variety of sensor data within data centres. In-fact, this can be packaged as a product that can be offered to large companies that own many data centres like tower companies and mobile data carriers.

3.2 Target Case Study

The study proposes to use data from public land mobile network traffic players in Kenya. From the official government statistics (Communication Authority of Kenya, 2020), as at 31st March 2020, there were 55.2M mobile SIM cards in use in the country. The largest player in the market had 64.5% of the market while the second largest player had 26.6% of the market share; the thirst largest player had 5.8% market share while the fourth largest player had 3.1% of the market.

	Safaricom PLC	Airtel Networks Limited	Equitel	Telkom Kenya Limited	Mobile Pay Limited
Dec-19	64.8	25.9	3.1	6.2	0
Mar-20	64.5	26.6	3.1	5.8	0

Figure 9 Relative market share of mobile carriers in Kenya as at 31st March 2020 **source CAK report.

Operator Name /Indicator	*Mar-20*			*Dec-19*			*Quarterly Variation (%)*
	Pre-paid	**Post-paid**	**Total**	**Pre-paid**	**Post-paid**	**Total**	
Total Mobile Subscriptions	**50,912,628**	**4,294,000**	**55,206,628**	**53,266,480**	**1,289,017**	**54,555,497**	**1.2**
Safaricom PLC	34,590,154	1,017,148	**35,607,302**	34,161,953	1,173,154	**35,335,107**	0.8
Airtel Networks Limited	14,575,603	106,690	**14,682,293**	14,021,519	97,050	**14,118,569**	4.0
Telkom Kenya Limited	20,499	3,170,162	**3,190,661**	3,373,133	18,813	**3,391,946**	-5.9
Equitel	1,726,372	-	**1,726,372**	1,709,875	-	**1,709,875**	1.0
*Mobile Pay Limited**	-	-	-	-	-	-	-

Source: CA, Operators' Returns, * Mobile Pay Ltd data not available due to non-compliance by the operator

Figure 10 Mobile subscribers per mobile carrier **source CAK

This research intends to perform a case study on one of the mobile carriers in the Kenya. This is purely based on the ease of obtaining PLMN authorization to conduct this research. If access is granted from other PLMNs, then the same research can be easily done and results analysed. The target population will be the data centres of the second mobile carriers and the main hub sites that act the main data multiplexing locations, and this major points of failure. It is hoped that the insights offered during this examination will increase visibility into the efficiency of managing data centre parameters and areas of improvement if any. Since data centre policies are generally homogenous within the one company, and as not all centres can be accessed and analysed within the period of study, a stratified sample will be done and study done on these, as a representative sample.

3.3 Description of Research Instruments

The study proposes to use quantitative approaches to data collection and analysis. The data will not contain any customer identifiable data owing to the laws in force on customer privacy and applicable corporate policies. The research intends to use sensor data strategically located within data centres or aggregation hub(s). This data will be collected using sensors and micro-processors that are linked to the network either via ethernet (IEEE802.3) or wireless (IEEE802.11 b/g/n). Where these are not available or are proven unreliable, then data collection techniques via SDCARD will be employed. This is not expected to be a challenge though. Other collaborative data will be analysed, to support any observed trends, especially data collected and reported by the mobile network carrier. A research prototype is shown below in fig-11. Once the concept is proven, a more permanent design can be implemented via a PCB design and an appropriate enclosure.

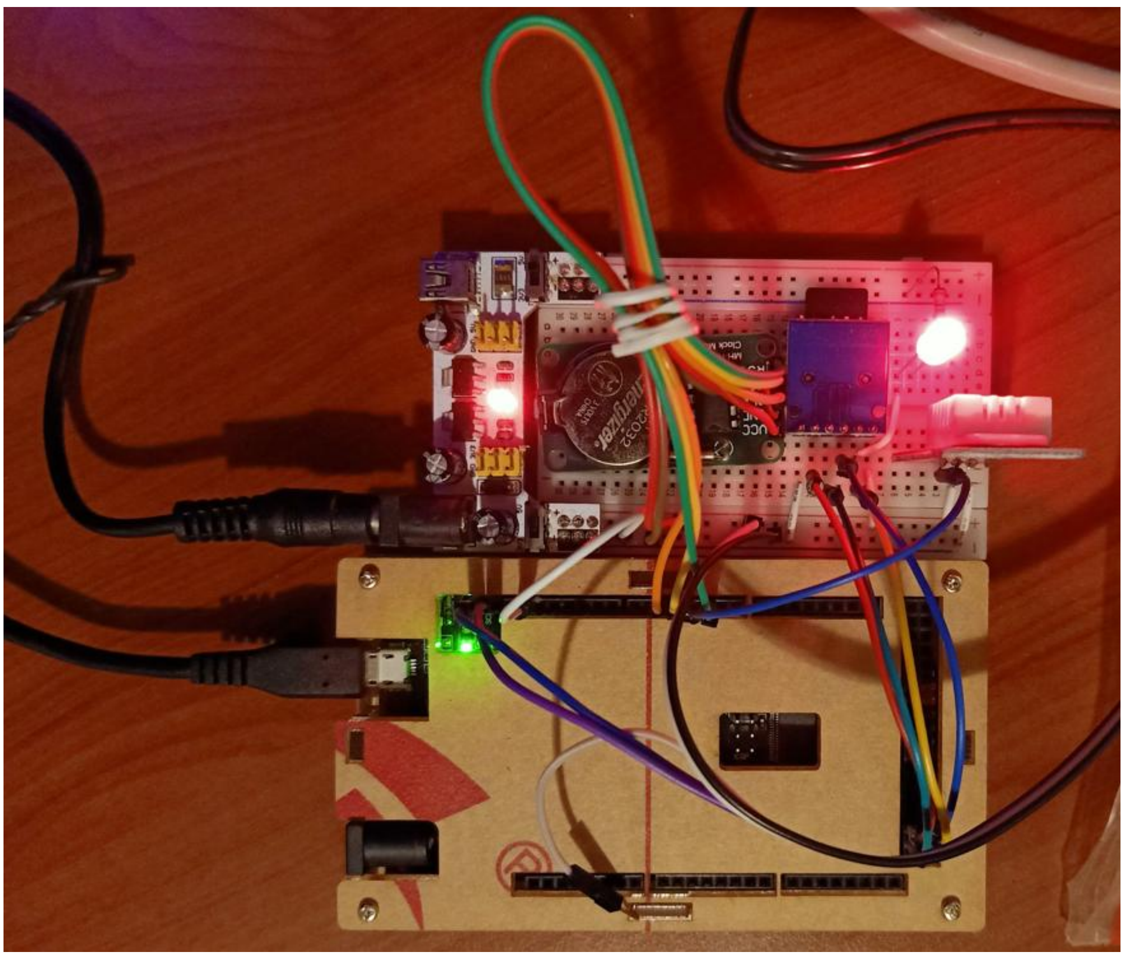


Figure 11 The prototyping ATmega Micro-controller, DHT22 Temp and Humidity sensor, the clocking module, SD card module and LCD module hook-up

Figure 12 the LCD display, showing the instantaneous temperature and humidity readings and also cumulative readings for the hour and day.

The system is setup so that to accumulate the counter data internally and calculate the averages through the micro-controller. This data is then output using an interrupt, via WIFI, to the server than reports this data. The main method of bitdata transfer is SOAP messaging carried over HTTP protocol. This data is also updated every minute to the LCD display, so as to serve as an easy verification method to the data being obtained from the server via WIFI. Wireshark was deployed over an unsecured http port to test the soap messaging and some output is shared below. Viewing of the message as transferred was only possible when data was passed over a http port. When SSL is employed (HTTPS), then the data is encrypted and not human readable as shown in Figure-13 and Figure-14 below.

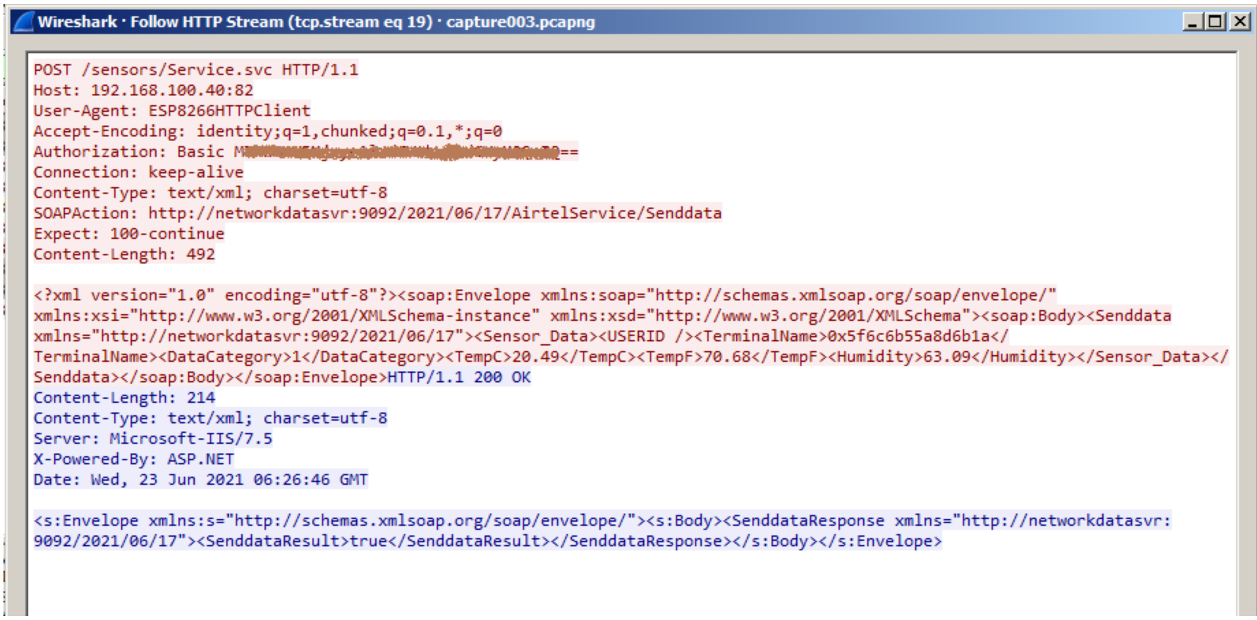


Figure 13 Soap message as captured using Wiresharp application during testing

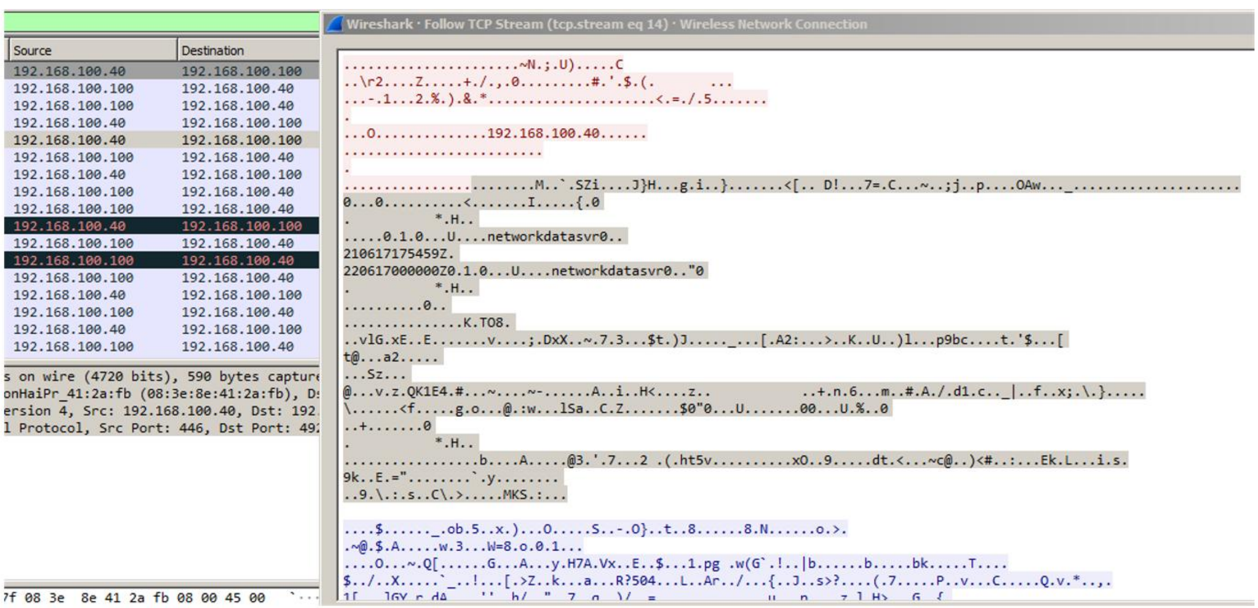


Figure 14 Encrypted HTTPS soap message as captured using Wireshark application during prototype testing

The prototype was validated using an independent temperature and humidity module and it was found to meet expectations.

3.4 Data Collection

The study proposes to collect sensor data from data centres owned by the second largest mobile data carrier with a view to improving the efficiency of operations while at the same time cutting costs. The first step of data collection will be seeking for an authorization letter from the university department to collect data from the service providers. Once this is received, authority will be sought from the service provider, before any data is analysed and published in this study. Additional, data in the public domain will be considered especially for calibration of collected statistics. The data will be corelated and any useful trends documented. The collected data will span a period of 1 months (Aug-2021). These dates are selected because the climatic conditions of data centres tend to be controlled all year round and this should be representative of the conditions therein. Collection over longer period would be desirable to ascertain any gaps in operational activities. It is possible that there are seasonal variations in observations. However, due to time constraints on the research resources, this has been reduced to Aug`21 time span.

3.5 Data Analysis

The study proposes to use temperature, humidity and current estimated costs as the main independent variables. Efficiency of data collection per unit time, hence OPEX savings, will be the dependent variable and this will be analysed and reported. OPEX savings are key in the mobile carrier business as the revenue per user have been falling over time. Hence any efficiency here will translate into profitability. The data will be analysed using a spreadsheet and where applicable using the statistical package SPSS. It is expected that the key metrics (KPIs) per data centre region will be presented and possibly used as an OPEX dip stick to measure improvement opportunities within these data centres. Since the data is quantitative, an web interface will be build to present this data in easy graphical format.

3.6 Validity

Validity refers to the extent to which constructs used in a study actually measure what they intended to measure (Blumberg et al., 2005). In order to determine the validity of the intended research instrument (case study), the author intends to use constructs from past studies that have established validity of statements. The researcher also anticipates the guidance of the university supervisor(s) in establishing the validity of the statements used in the research instrument. Sensors have been used for a long time to optimize the operations of machines and ease operations. These sensors when applied in the correct manner can greatly enhance efficiency. Each sensors errors margin will also be considered in the final aggregated result.

3.7 Description of data analysis procedures

The study will use two branches of statistical analysis describes in research methods: descriptive and inferential statistics. Descriptive statistics are a novel form of analysis where the aim is to summarize the large amounts of data into meaningful groups and categories that a reader would understand (laerd statistics, 2018); these include mean, frequency distribution, and standard deviation. On the other hand, the field of inferential statistics allows researchers to study samples and infer the characteristics of populations. The study proposes to use linear regression analysis and Pearson correlation analysis. Correlation measures the movement of variables together whilst regression analysis measures the direction and effect on independent variables on the dependent variable. The data will be presented in tables and figures and supported by interpretations.

3.7 Expected Contribution

The study intends to demonstrate that sensors when applied appropriately within a data centre and reported centrally can vastly improve the OPEX efficiency in management reporting and serve as a rapid switch to enhance correction of runaway conditions within data centres that would otherwise cause outages and revenue loss. This is especially so where other collections mechanisms like SNMP need to run in a multivendor environment and such vendors define contractual boundaries that either make it hard to transport this data efficiency or cause addition of costs of running these data centres since they need to be paid for the service rendered. In addition, there is need to always keep management well informed of conditions within data centres and aggregation hubs in a cost-efficient manner. Over time, this data can offer useful insights on data centre management. There are many many other areas of sensor data collection that can be aggregated and reported like voltage measurements, security triggers and reporting, Water level alarms, generator failure alarms, etc. The increamental costs of adding one more alarm is not much once the system is setup and operational. Descriptive and inferred statistics will be applied to deduce any trends. In addition, the impact this study will have on networking planning, especially with the falling ARPU across mobile carriers, will be a key contribution. It is hoped that the insights of this study will be useful in data centre operators within the country and also in other regions/countries with a similar sized populations and comparable data centre environmental metrics.

CHAPTER FOUR: TESTING AND RESULTS

4.0 Results

This chapter reports on the artefact testing activities, which sets the stage for expected output from the research study as outlined in chapter 3. Section 4.1 highlights the testing environment that was used to generates results. Section 4.2 shares preliminary findings of the artefact as tested and shares insights on the sampling period and reporting period. Section 4.3 Shares detailed results of the study.

4.1 Data Centre Environment

Testing of the prototype was done using actual data as collected from the sensors and reported to the aggregation service by the logic controller. The logic controller was programmed to collect 2 samples per minute hence about ~120 samples were collected and sent to the aggregation service every minute. These samples were logged into a database for analysis and presentation to other services that subscribe to the aggregation service.

4.2 Preliminary findings

The study, as outlined in the earlier chapter, used use 2 main independent variables for testing the developed artifact which are the data centre ambient temperature and the relative humidity, as part of the POC. Additionally, the data collected from the carriers` staff was used as an independent input so that the efficiency could be ascertained. Estimated cost of collection was also an input into the model, since the main objective is investigating that not only is collection of sensor data possible using SOA, but also that it cuts costs significantly. Data was collected over a 2-week period within the month of August`21. This period was selected since there is limited time scope within which the project needs to be closed. However, this can be collected over long periods of time to ascertain seasonal trends of temperature and humidity variations. The main goal was to proof the concept and test the prototype as opposed to getting data on seasonality of temperature and humidity. Some preliminary prototyping findings are shared in figure 15 below.

- The date field shows the date and time of the sample
- The terminal name shows a hexadecimal code of the prototyping logic controller. It is envisioned that there could be several terminals sending in data from remote locations at the same time.

- Data category field has 3 possible values; 1 denotes data aggregated and sent within a 60 second interval. 2 denotes data aggregated and sent within a 60-minute interval. 3 denotes data aggregated and sent within a 24-hour interval.
- TempC is the temperature of the data centre in Celsius.
- TempF is the temperature of the data centre in farenheight.
- Humidity is the relative humidity of the data centre.

Date	TerminalName	DataCategory	TempC	TempF	Humidity
2021-06-23 08:33:58.000	0x5f6c6b55a8d6b1a	1	20.4900000000	70.6800000000	62.4700000000
2021-06-23 08:32:58.000	0x5f6c6b55a8d6b1a	1	20.4900000000	70.5000000000	62.4600000000
2021-06-23 08:31:57.000	0x5f6c6b55a8d6b1a	1	20.4900000000	70.3200000000	62.4500000000
2021-06-23 08:30:58.000	0x5f6c6b55a8d6b1a	1	20.4900000000	70.3200000000	62.4500000000
2021-06-23 08:29:58.000	0x5f6c6b55a8d6b1a	1	20.4900000000	70.3200000000	62.4500000000
2021-06-23 08:28:58.000	0x5f6c6b55a8d6b1a	1	20.5000000000	70.3200000000	62.4500000000
2021-06-23 08:27:57.000	0x5f6c6b55a8d6b1a	1	20.5000000000	70.3200000000	62.4500000000
2021-06-23 08:26:58.000	0x5f6c6b55a8d6b1a	1	20.5000000000	70.5000000000	62.4500000000
2021-06-23 08:25:58.000	0x5f6c6b55a8d6b1a	1	20.5000000000	70.5000000000	62.4600000000
2021-06-23 08:24:58.000	0x5f6c6b55a8d6b1a	1	20.5000000000	70.3200000000	62.4700000000
2021-06-23 08:23:57.000	0x5f6c6b55a8d6b1a	1	20.5000000000	70.5000000000	62.4900000000
2021-06-23 08:22:58.000	0x5f6c6b55a8d6b1a	1	20.5000000000	70.5000000000	62.5000000000
2021-06-23 08:21:58.000	0x5f6c6b55a8d6b1a	1	20.5000000000	70.5000000000	62.5200000000
2021-06-23 08:20:58.000	0x5f6c6b55a8d6b1a	1	20.5000000000	70.5000000000	62.5400000000

Figure 15 Sample data as extracted from a prototype of the project.

Since this is a prototyping project, many other sensor data can be collected and reported in a similar manner, once the system is setup and running, e.g., data centre operating voltage, diesel generator fuel levels, security alarms, etc.

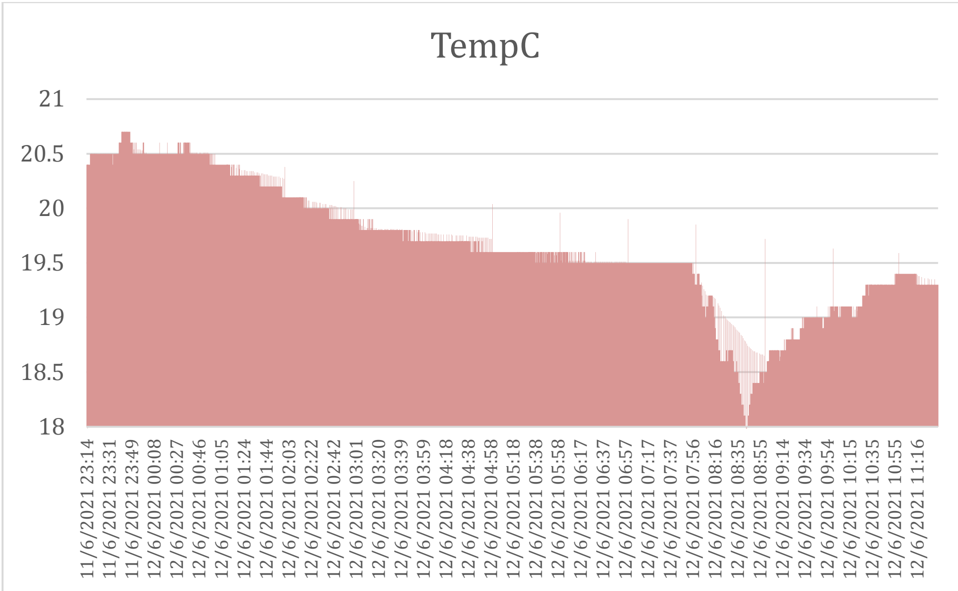


Figure 16 TempC data plotted during the prototype development period

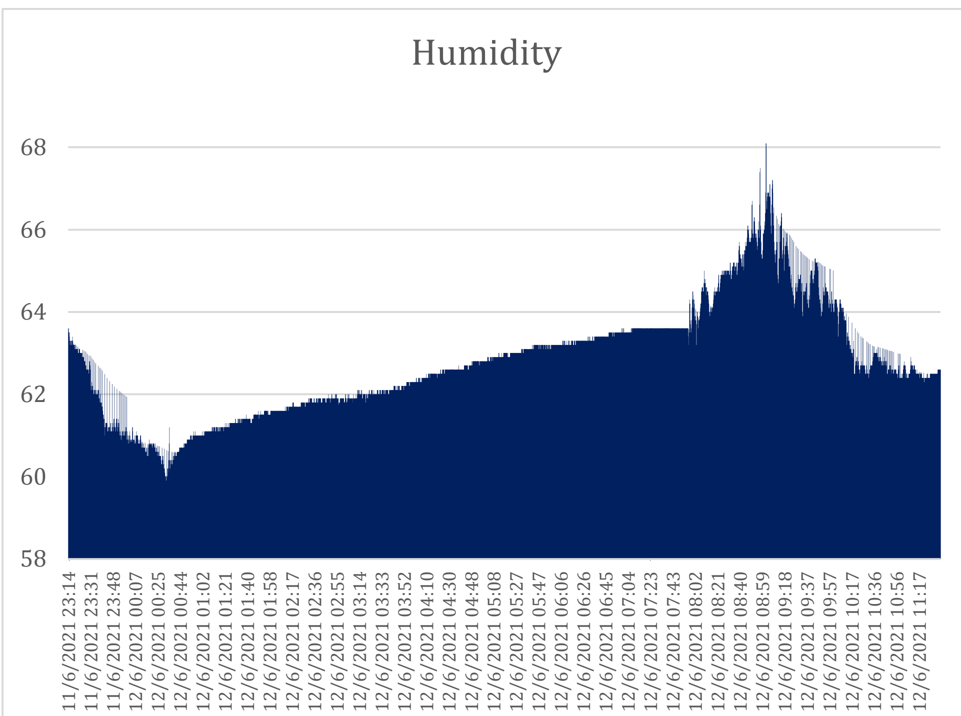


Figure 17 Humidity data plotted during the prototype development period.

The hourly standard deviation is shown below, which shown a tight range of temperature and humidity change

Row Labels	Average of TempC	StdDev of TempC	Average of Humidity	StdDev of Humidity
2021-6-11 23:00	20.52	0.45	61.98	1.58
2021-6-12 0:00	20.50	0.04	60.66	0.27
2021-6-12 1:00	20.27	0.09	61.29	0.17
2021-6-12 10:00	19.19	0.12	62.98	0.56
2021-6-12 11:00	19.34	0.05	62.50	0.11
2021-6-12 2:00	19.99	0.08	61.75	0.12
2021-6-12 3:00	19.78	0.05	62.03	0.13
2021-6-12 4:00	19.67	0.05	62.55	0.15
2021-6-12 5:00	19.57	0.05	63.00	0.12
2021-6-12 6:00	19.51	0.02	63.32	0.11
2021-6-12 7:00	19.49	0.04	63.59	0.10
2021-6-12 8:00	18.66	0.38	64.91	0.72
2021-6-12 9:00	18.85	0.16	65.03	0.85
Grand Total	**19.64363897**	**0.583164074**	**62.74329569**	**1.378257934**

4.3 Web-Service Testing

Since this study relies on the use if Webservices to accomplish its goals, it was found necessary to test all the services that were to be deployed, for aggregation and also for reporting/closed feedback. The SOAPUI tool was used to test the webservices as deployed, using various test cases. These test cases are briefly discussed below

4.3.1 Service Availability

It was necessary to test that the webservice, was up and running and ready to receive data from the logic controller. This was tested as shown below and a HTTP/1.1 200 OK result was returned which was the expected result.

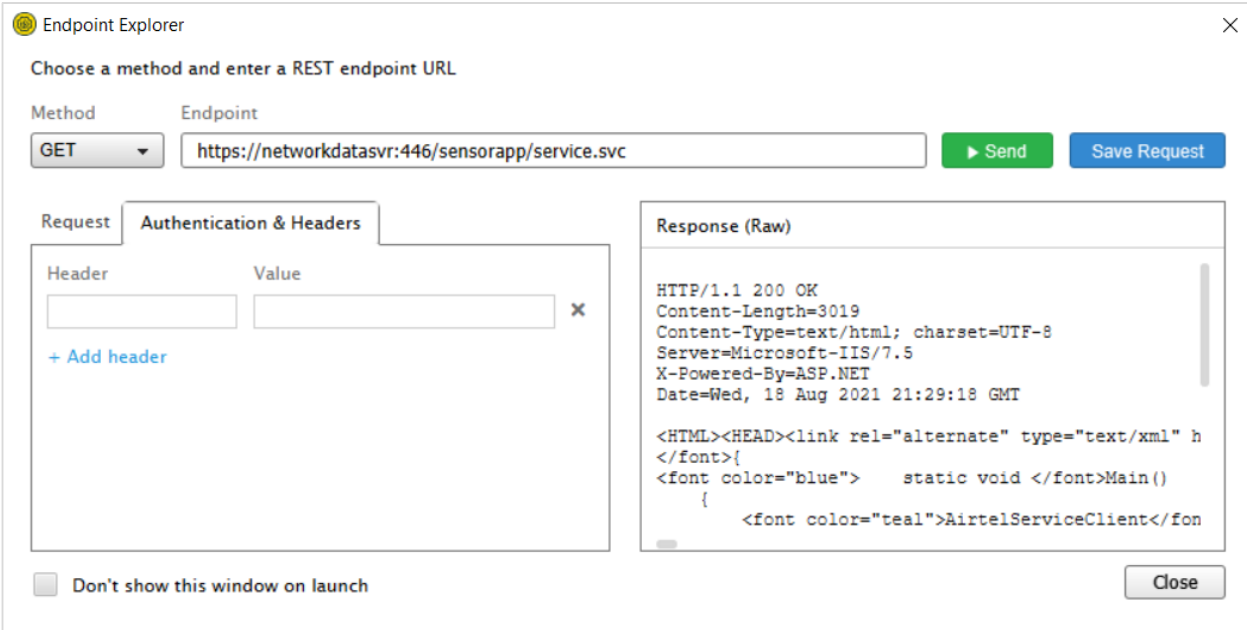


Figure 18 Service endpoint availability test

4.3.2 Service Methods

It was necessary to test that the webservice method responded as expected to logic controller

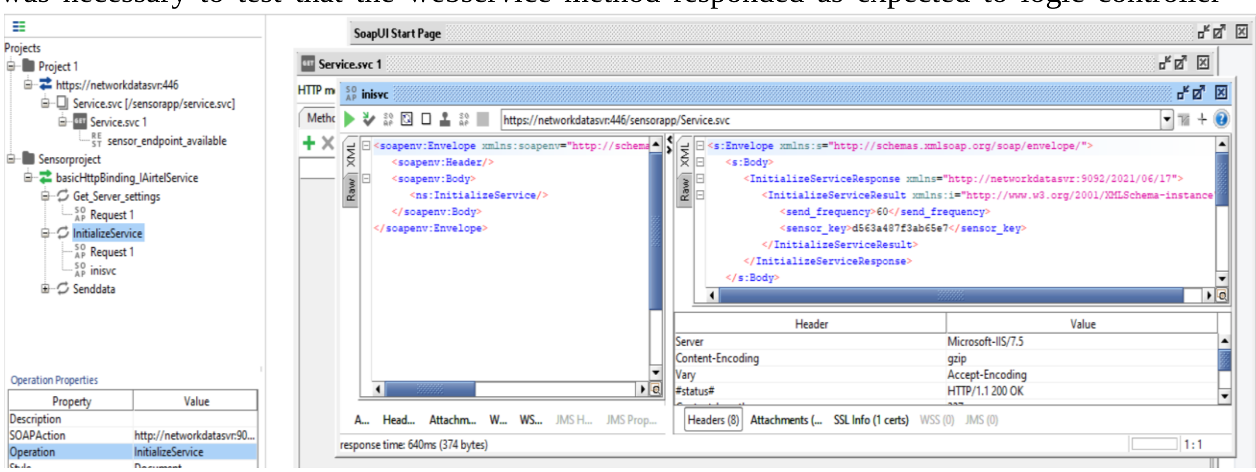


Figure 19 Initialization method tested successfully

requests. Since the logic controller has limited debugging features, this SOAPUI tool was used to test every method against a predefined expectation criterion. The results of the test are outlined below. The InitializeService method is used by the logic controller to get the update frequency from the server. This test was successful. The Senddata method was also tested successfully and this is used by the logic controller to send data securely to the aggregation service, see figure 20.

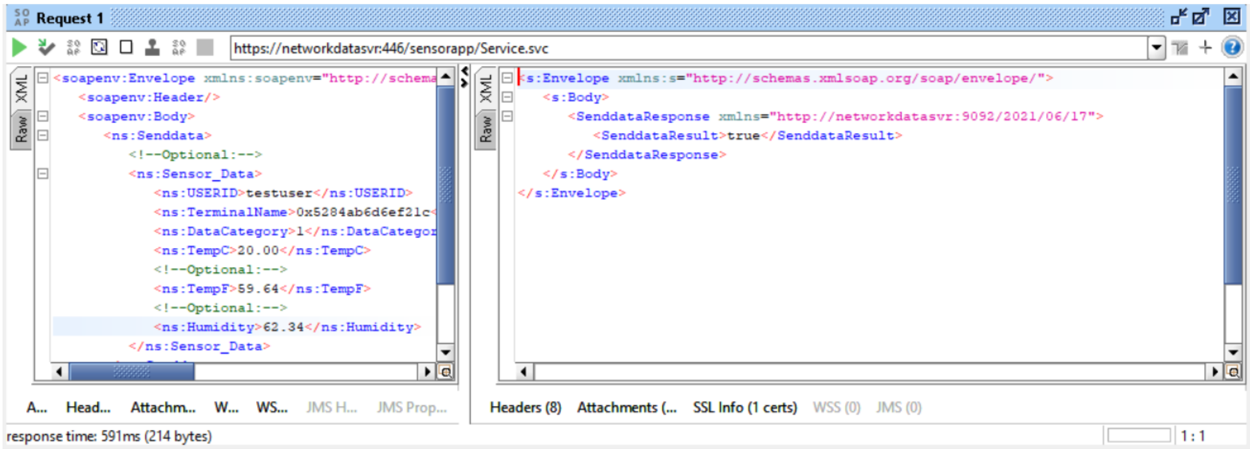


Figure 20 Senddata method was also tested successfully

4.3.3 Service Response time (TAT).

It was necessary to test that the webservice method responded within acceptable time as expected by the logic controller software. Since controller process many inputs from many sensors, it is important to ensure that the service response time is small enough so that sensors do not loose data. The results of the turnaround test (TAT) are outlined below.


Thu Aug 19 00:42:36 EAT 2021:DEBUG:Connection 0.0.0.0:4055<->172.23.74.100:446 closed
Thu Aug 19 00:48:18 EAT 2021:DEBUG:Attempt 1 to execute request
Thu Aug 19 00:48:18 EAT 2021:DEBUG:Sending request: POST /sensorapp/Service.svc HTTP/1.1
Thu Aug 19 00:48:19 EAT 2021:DEBUG:Receiving response: HTTP/1.1 200 OK
Thu Aug 19 00:48:19 EAT 2021:DEBUG:Connection can be kept alive indefinitely
Thu Aug 19 00:48:19 EAT 2021:INFO:Got response for [basicHttpBinding_IAirtelService.Senddata:Request 1] in 591ms (214 bytes)
Thu Aug 19 00:48:51 EAT 2021:DEBUG:Connection 0.0.0.0:4113<->172.23.74.100:446 closed
Thu Aug 19 00:53:05 EAT 2021:DEBUG:Attempt 1 to execute request
Thu Aug 19 00:53:05 EAT 2021:DEBUG:Sending request: GET /sensorapp/service.svc HTTP/1.1
Thu Aug 19 00:53:05 EAT 2021:DEBUG:Receiving response: HTTP/1.1 200 OK
Thu Aug 19 00:53:05 EAT 2021:DEBUG:Connection can be kept alive indefinitely
Thu Aug 19 00:53:36 EAT 2021:DEBUG:Connection 0.0.0.0:4163<->172.23.74.100:446 closed

Figure 21 Turnaround time for a data insertion transaction

From this, the turnaround time is about 691ms. Since around 115readings per hour are sent, then this turnaround time is acceptable for this sensor.

4.4 Detailed Findings

After seeking for permission to collect data from the university, on 18th August 2021, the developed artifact was taken to an actual data centre for testing. Permission was sought and granted to collect datacentre information from 2 geographically diverse data centres. For the purpose of this report, these data centre will be referred to as *PKS001 and VPK001,* since the operator was unwilling to have the researcher declare the full name of these data centre. The data centres that were used are tier-3 data centres. The artefact was deployed within one of the RACK cabinets, and powered using commercial redundant power. WIFI connectivity was provided using a WIFI router. The minute-by-minute data, as collected is at the appendix of this report. This was collected over a 7-day period for *PKS001* and over a 7-day period for *VPK001*. The findings are as detailed in the following subsections:

4.4.1a Detailed findings 1a (Observations)(PKS001)

In the PKS001 data centre, between *2021-08-20 14:35:16* and *2021-08-26 15:01:19*, a total of 16450 valid readings were recorded within a time span of 519963 seconds or 8666.05 minutes or 144.434 hours or 6.018 days. The average readings over this time were 113.893 readings/hour or ~113.9/hour. This compared well with the settings within the controller of sending 2 readings per minute or a max of 120 readings per hour. The small difference could be accounted for in delays within the controller and errors in wireless connectivity to the server, which normally happen intermittently and are not recoverable from. This represented a vast improvement from the one reading observed per hour and recorded on a datasheet (per hour) within the data centre. This improved granularity will help the data centre supervisor to deal with short lived spikes in the readings, as compared to the manually recorded /semi-automated readings.

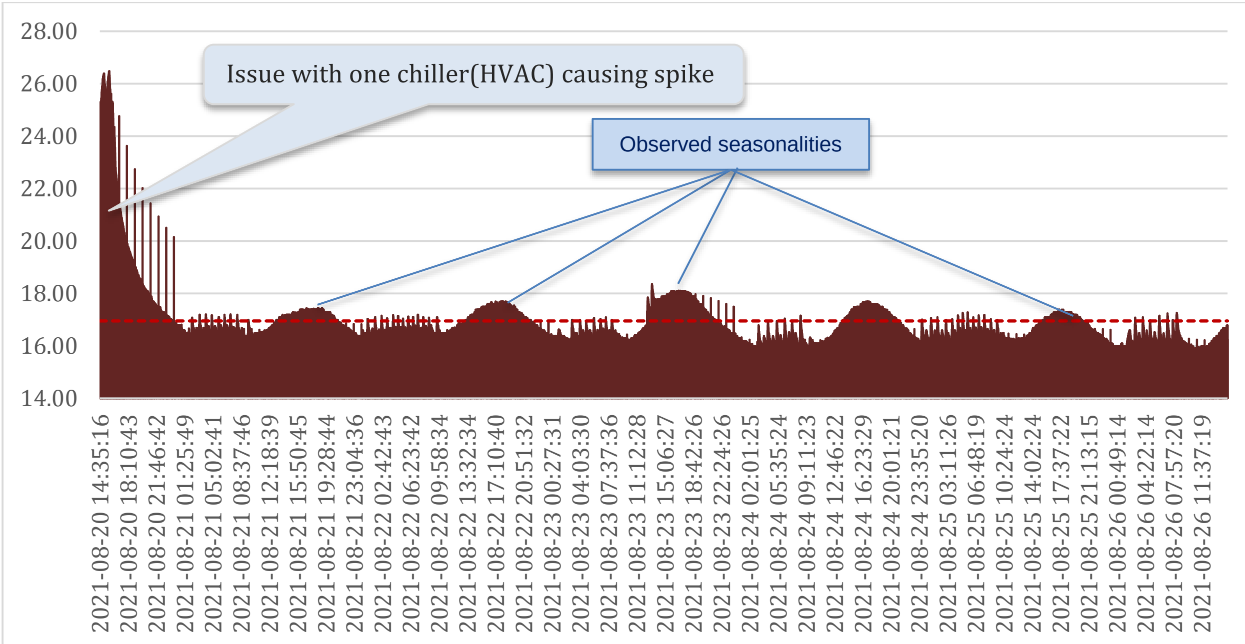


__Figure 22 Temperature readings as read from the sensor in VKS001 data centre__

From the graph it is clear that there was a period at the beginning of the sensor readings that the temperature was very high and this was accounted for by the fact one of the chillers within the centre has a power issue. When this was fixed, then the temperature dropped to normal levels of around 16.20ºC to 17.50ºC. The increased granularity provides a preview of how the temperature drops after managing a data centre incident, something not available with the current methodology.

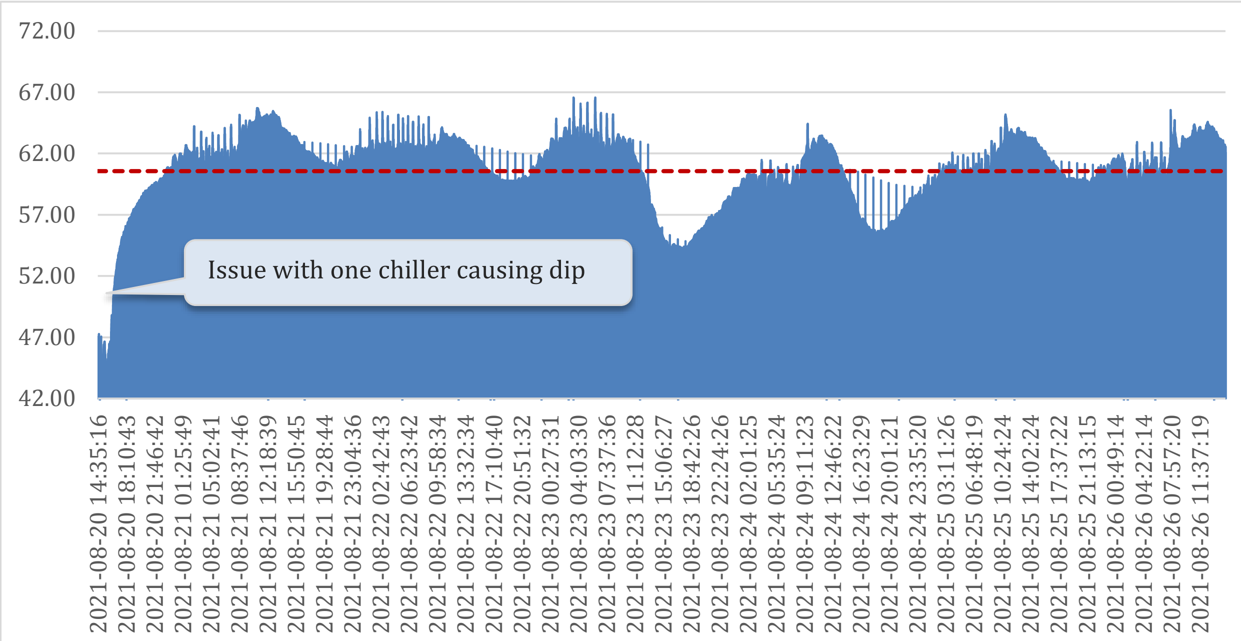


Figure 23 Humidity readings as read from the sensor in VKS001 data centre

From the graph it is clear that there was a period at the beginning of the sensor readings that the humidity dropped was low, around 44% RH, and this was accounted for by the fact one of the chillers within the centre had a power issue. When this was finally addressed around 2021-08-20 14:30 GMT+0300, the relative humidity rose to normal levels of around 60% to 65% RH, well within the (8% to 80% RH) recommended in the ASHRAE 2016 edition guidelines. The increased readings granularity provides a preview of how humidity rises after managing a data centre incident, something not available with the current methodology.

4.4.1b Detailed findings 1b (Observations)(VPK001)

In the VPK001 data centre, between *26/8/2021 05:06:11 PM* and *3/9/2021 04:32:42 PM*, a total of 12687 valid readings were recorded within a time span of 689191 seconds, 11486.517 minutes, 191.442 hours, 7.977 days. Some recording time was lost owning to a power problem at the data centre. This time was 3.354409722 days, or 80.50583333 hours or 4830.35 minutes or 289821 seconds, thus the net recording time was 399370 seconds or 6656.16667 minutes or 110.9361111 hours or 4.622337963 days. The average readings over this time were 114.363 readings/hour or ~114.4/hour. This compared well with the settings within the controller of sending 2 readings per minute or a max of 120 readings per hour. The small difference could be accounted for in delays within the controller and errors in wireless connectivity to the server, which was noted to happen intermittently and are not recoverable from, as shown in fig 25. This represented a vast improvement from the one reading observed per hour and recorded on a datasheet (per hour) within the data centre.

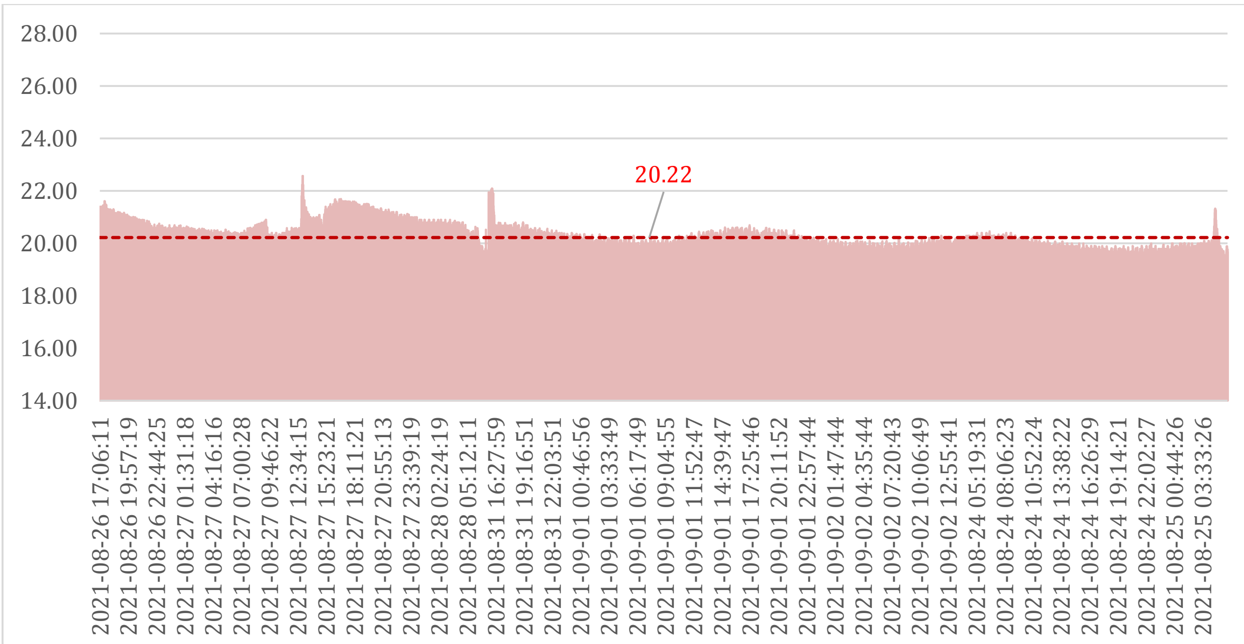


Figure 24 Temperature readings as read from the sensor in VKS001 data centre

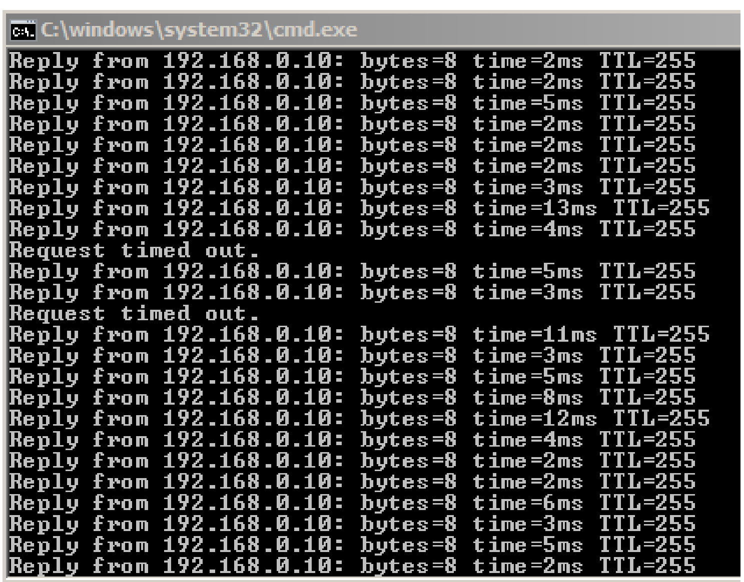


Figure 25 Images showing lost pings over the wireless interface to the sensor

From the graph it is clear that the readings are within a tight range with mean(λ) of 20.21 and standard deviation (σ) of 0.50, indicating that the chillers in the data are managing the environment well. The increased granularity provides a preview of how the temperature behaves within a data centre, with a reasonable costing per reading.

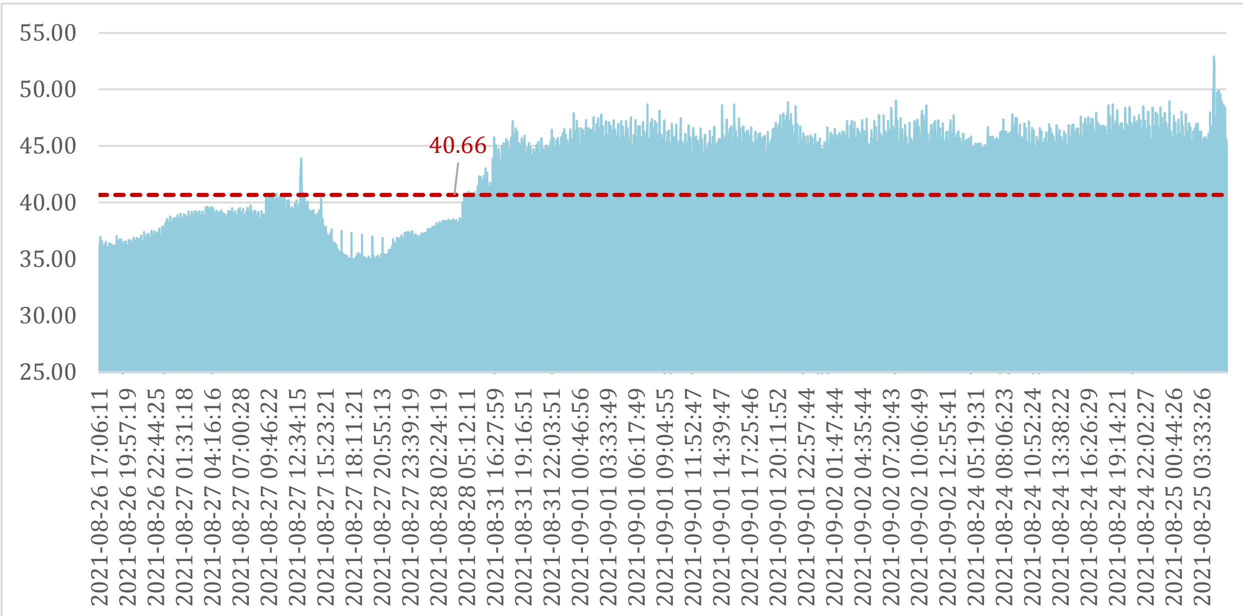


Figure 26 Humidity readings in the VPK001 data centre

From the graph it can be observed that the data centre humidity oscillates between 34% RH to around 50% RH. The mean(λ) is 40.66, with a standard deviation(σ) of 3.94, with no observed incident of HVAC outage. This observation was well within the (8% to 80% RH) recommended in the ASHRAE 2016 edition guidelines. The increased readings granularity provides a preview of how humidity rises and falls during normal data centre operations and can be used as a signature to identify abnormalities in the future.

4.4.2 Detailed findings 2 (Current solution)

In the PKS001 data centre, the data centre has a manually read sensor module pinned to the wall, but this needs to be plugged into the computer and read manually from time to time. A snippet of the sensor is shared in figure 22, as shown below, which shows 47.89 RH (relative humidity) in the image.

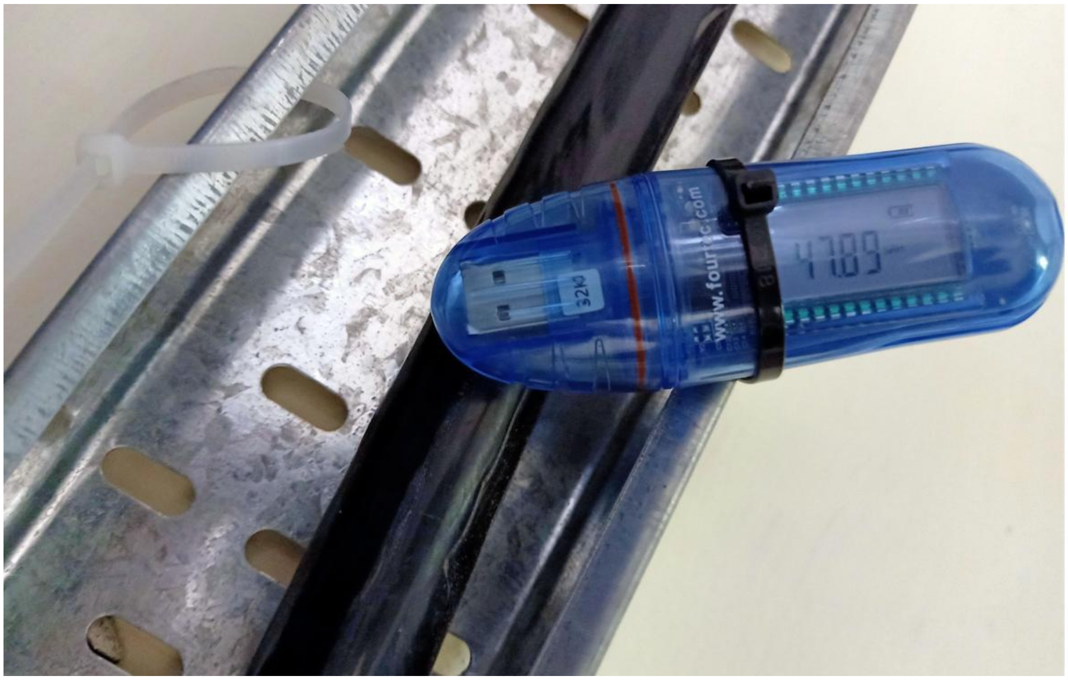


Figure 27 Manually installed and read sensor (Courtesy PKS001 Supervisor)

According to (fourtec, 2021), the offering of MicroLite USB data loggers constitute of six models deal with humidity, temperature, current and voltage measurements, offering a wide range solutions to industrial applications; They are lightweight, direct USB interface, accurate measurement devices that have up to 32K cyclic memory and feature an LCD display with an LED for alarm indication; According to the manufacturer (fourtec, 2021), they come with easy to replace batteries with up to 1.5-year life, in normal operating conditions and include a cradle for wall mounting, with a dust and water resistant casing depending on logger model. This device, which is in use currently doesn`t feature real-time connectivity to a server for real-time feedback. It was not immediately possible to get the cached readings therein, since we couldn’t dislodge the sensor off the wall easily and also get clearance to read the contents there-in. The efficiency of the installed system is only as good as can be manually read from time to time and hence the efficiency is somewhat not as good as that obtained from a SOA system, which took and reported more than ~113.7 – 114.4 readings per hour. The improved granularity is useful for a data centre as the supervisor can take action without necessarily physically taking readings from the sensor and taking action on them. From the sellers` website, it was clear that there are suitable products that could transmit wirelessly in real-time, but these were connected to a PC within the data centre and it was not immediately clear if this product could collect data over several data centres in real-time.

Figure 28 Image from fourtec website (fourtec, 2021), showing datanet wireless loggers and their specifications

In addition, the cost per unit was $~168 per unit, makes it costly for implementation in very many networking sites. (instrumentcompaniet, 2021) (https://www.instrumentcompaniet.no/files/Fourtec/ DataNet_Brochure.pdf). The solution offers data logging solution by leveraging the power of ZigBee wireless, 2.4 GHz telemetry protocol, supporting up to 65,000 units per network (instrumentcompaniet, 2021). The challenge here is the ability to scale given the pricing in sub-Saharan Africa. Additionally, the research noted displays pinned to the main entrance of the data centre as shown in the figure 26 below.

Figure 29 PSK001 data centre door LCD displays showing temp readings

From these LCD displays (data from sensors), hourly readings are taken and logged. Some summarised readings were taken and shared for comparison purposes by the PSK001 supervisor. Based on these hourly readings, a graph was plotted as shown below, in fig 27.

Hourly Tempearature logs														
1-Aug-2021	DAY	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	Max temp
		19	19	19	19	19	19	19	19	19	19	19	19	19
		51	51	51	51	51	51	51	51	51	51	51	51	51
	NIGHT	19:00	20:00	21:00	22:00	23:00	00:00	01:00	02:00	03:00	04:00	05:00	06:00	
		19	19	19	19	19	19	19	19	19	19	18	18	19
		51	51	51	51	51	51	51	51	51	51	51	51	51
2-Aug-2021	DAY	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	Max temp
		18	18	18	18	18	18	18	19	19	19	19	19	19
		51	51	51	51	52	52	51	51	51	50	50	50	52
	NIGHT	19:00	20:00	21:00	22:00	23:00	00:00	01:00	02:00	03:00	04:00	05:00	06:00	
		19	19	19	19	19	19	19	19	19	19	18	18	19
		51	51	51	51	51	51	51	51	51	51	51	51	51
3-Aug-2021	DAY	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	Max temp
		18	18	18	18	18	18	18	18	18	19	19	19	19
		51	51	51	52	52	52	52	52	52	52	52	52	52
	NIGHT	19:00	20:00	21:00	22:00	23:00	00:00	01:00	02:00	03:00	04:00	05:00	06:00	
		20	20	20	20	20	20	18	18	18	19	19	19	20
		52	52	52	52	52	52	52	52	52	53	52	52	53
4-Aug-2021	DAY	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	Max temp
		18	18	18	18	18	18	18	18	18	20	20	20	20
		52	52	52	52	53	53	53	54	54	54	53	53	54
	NIGHT	19:00	20:00	21:00	22:00	23:00	00:00	01:00	02:00	03:00	04:00	05:00	06:00	
		19	19	19	19	19	19	19	19	19	19	19	19	19
		52	52	52	52	52	52	52	52	52	54	52	52	54
		07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	Max temp

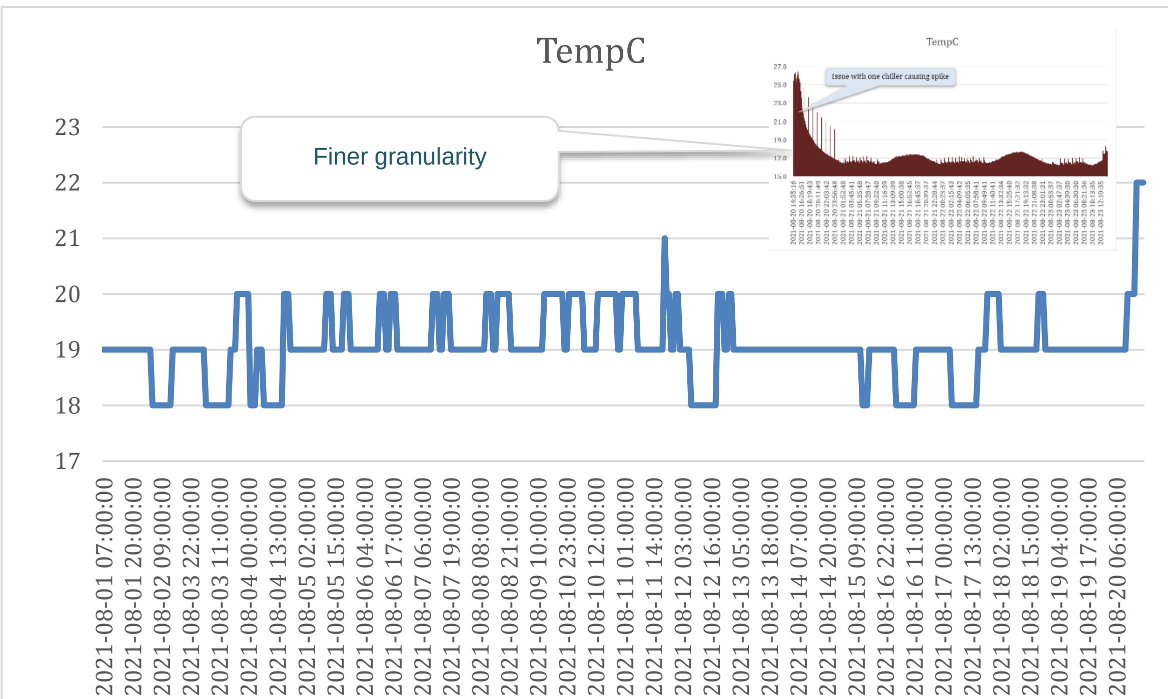


Figure 30 Hourly Readings and Chart showing recorded hourly TempC readings for pks001 data centre.

Based on these hourly readings, the sampled data represented a mean value of 19.07692308, with a std-deviation of 0.646570212. It can be seen from the chart, that the readings are not very granular and just provide a coarse indication of the data centre environmental parameters, as compared to figure 22, a snippet of which is reproduced in fig 30. This is despite the fact that this data spans 19 days, vis a vis the more granular data shared over just 2.96 days.

4.4.3 Detailed findings 3 (Costs)

In the PKS001 data centre, between *2021-08-20 14:35:16* and *2021-08-23 13:50:35*, a total of 8102 valid readings were recorded. The time span is 256519 seconds or 4275.316667 minutes or 71.25527778 hours or 2.968969907 days. The average readings over this time were 113.7038582/hour or ~113.7/hour. The estimated prototyping costing of the product was ~Ksh5.3k ($48). It is estimated that in a production setting this can be produced at a lower costing estimated to be around Ksh3k ($28), see fig 26 below. When you calculate the cost per reading, assuming a 5-year lifespan, 115 reading per hour, then the prototyping cost per reading comes to Kshs 0.00105/reading ($0.0000096/reading). The optimized production costing per reading come to Ksh 0.00060/reading ($0.00000546/reading).

1	0.00105~=(5300/(5*365*24*115))
2	0.00060~=(3026/(5*365*24*115))

This costing is further itemized below

Prototyping Costing

Prototyping costs

	Estimated Sensor Costing	Price	Qty	Kshs
1	Arduino Mega Controller	2500	1	2,500.00
2	Temperature and Humidity Sensor	600	1	600.00
3	SDCARD Module	248	1	248.00
4	Clock	276	1	276.00
5	LCD Display	650	1	650.00
6	Power Adapter	500	1	500.00
7	Breadboard and Cables	500	1	500.00
8			-	-
9			-	-
10			-	-
11			-	-
12			-	-
13			-	-
14			-	-
	Total-Day 1			**5,274.00**

Figure 31 Prototyping expenses

Production Costing

Estimated production costs

	Estimated Sensor Costing	Price	Qty	Kshs
1	ATMEGA8-16PU ATMEGA8 DIP	200	1	200.00
2	Temperature and Humidity Sensor	600	1	600.00
3	ESP-01 ESP8266 serial WIFI wireless module wireless transce	300	1	300.00
4	Clock	276	1	276.00
5	LCD Display	650	1	650.00
6	Power Adapter	500	1	500.00
7	PCB	300	1	300.00
8	Case	200	1	200.00
9			-	-
10			-	-
11			-	-
12			-	-
13			-	-
14			-	-
	Total-Costing			**3,026.00**

Figure 32 Estimated costing of a production level device to measure Humidity and Temp

A device with similar capabilities of Amazon website was costing around $176.99 or around Ksh 19.2k, see (Amazon, 2021). There is clearly a case for a customized solution using a small logic controller and a centralized SOA system to allow for scaling of the sensor model without exploding the costing of the overall solution. In addition, the estimated costing of the sampled operator, per data centre, is about 493k ($4930)

Current Costing

	Pipe Repair Expenses	Price	Qty	Kshs	
1	Data logging solution	16000	22	352,000.00	22 data centres being monitored
2	Door Display	3500	44	154,000.00	2 devices per centre
3	Staffing costs: Engineers	135000	66	8,910,000.00	assuming 8 hour shift, 1hr working on soln
4	Staffing costs: Casual/security	28500	44	1,254,000.00	assuming 12 hour shift, 1hr working on soln
5	Annual maintance	8000	22	176,000.00	once per data centre
6			-	-	
7			-	-	
8			-	-	
9			-	-	
10			-	-	
	Total-Day 1			**10,846,000.00**	est.costing

Average costings per module	Kshs
Expenses as tabulated	10,846,000
Number of data centres	22.00
Costing per module	**493,000.00**

Figure 33 Estimated current cost of temp and humidity monitoring solution

Using the proposed logic controller solution, the estimated costing per device is about Kshs 5.5k ($48), see fig 31. At this price, it is easier to scale and monitor not just the main data centres but also the traffic aggregation hubs and indeed all sites in the country.

Current Costing

	Pipe Repair Expenses	Price	Qty	Kshs	
1	Remote secure logger	3,026.00	132	399,432.00	assuming 6 modules per data centre, 22 centres
2	Paas Fees	15000	12	180,000.00	assumes 15k per month
3	Software Annual maintainance	200000	1	200,000.00	annual fee for main central software
4			-	-	
5			-	-	
6			-	-	
7			-	-	
8			-	-	
9			-	-	
10			-	-	
	Total-Day 1			**779,432.00**	est.costing

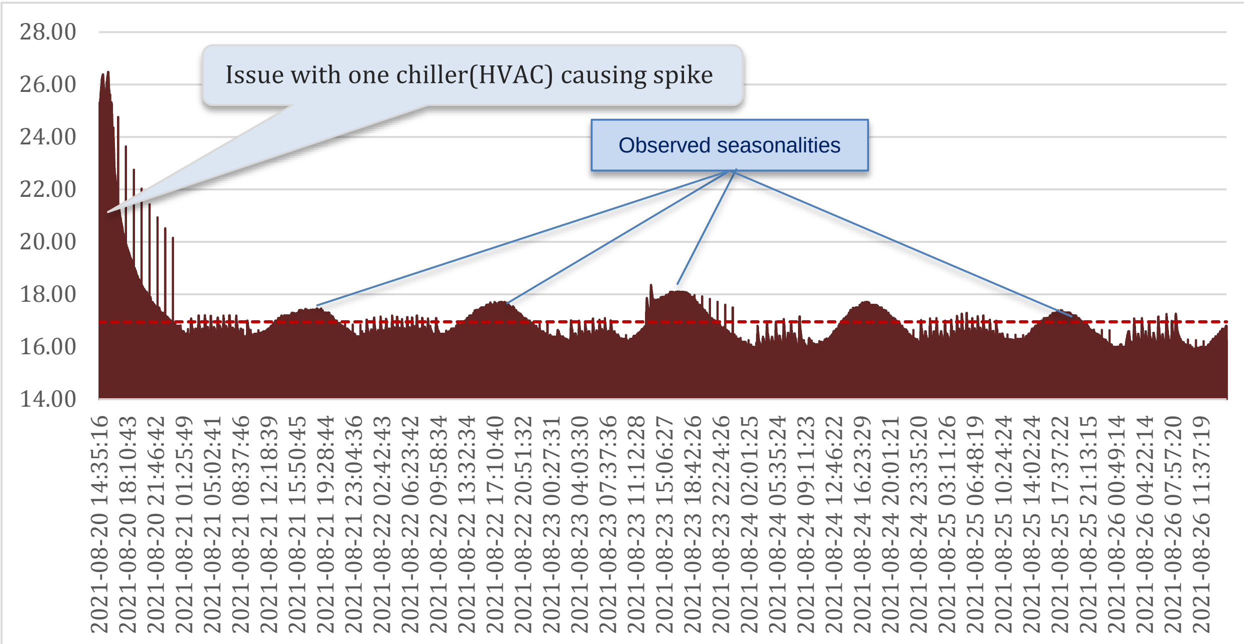
Average costings per module	Kshs
Expenses as tabulated	779,432.00
Number of developed modules	132.00
Costing per module	**5,904.79**

Figure 34 Estimated production cost of temp and humidity monitoring solution using logic controllers and SOA

In addition, increamental costs of adding another sensor service like adding a voltage sensor is not expected to fundamentally alter the costs of the final product since the largest component of the costing is fixed, and the sensor general cost is low. This clearly makes a case for using of these commodity sensors for industrial use in the telecommunication industry.

4.4.3 Detailed findings 4 (Seasonalities)

In the PKS001 data centre, between *2021-08-20 14:35:16* and *2021-08-26 15:01:19*, a total of 16450 valid readings were recorded within a time span of 519963 seconds or 8666.05 minutes or 144.434 hours or 6.018 days. This data clearly shows that there are seasonalities in the observed readings. Observed parameter trends seem to repeat at predefined intervals, in this case peaks in temperature are observed around 17:45HR, every day. These qualitative findings are useful since they may indicate to the supervisor when power savings can be done, since computing demands on the servers are lower. These qualitative findings are more useful, when reported in real time and over several data centres/aggregation hubs so that generalities can be derived.



These are the by-products of having a real time solution that reports to a remote SOA based system.

4.5 Statistical Analysis of Results

4.5.1 Introduction

Data was collected from a data centre over the course of 20 days to determine the effectiveness of data collection in data centres. A sensor was also developed that recorded temperature and humidity readings. The temperature and humidity readings are presented in this chapter using descriptive and inferential statistics. Results from thirteen days are presented in the analysis.

4.5.2 Data Centre Readings

Data from the centre was collected for 20 days. Data was collected 24 hours a day recording the temperature of the centres. The minimum and maximum temperatures recorded each day from the centre are shown in figure 35 and table 4.1.

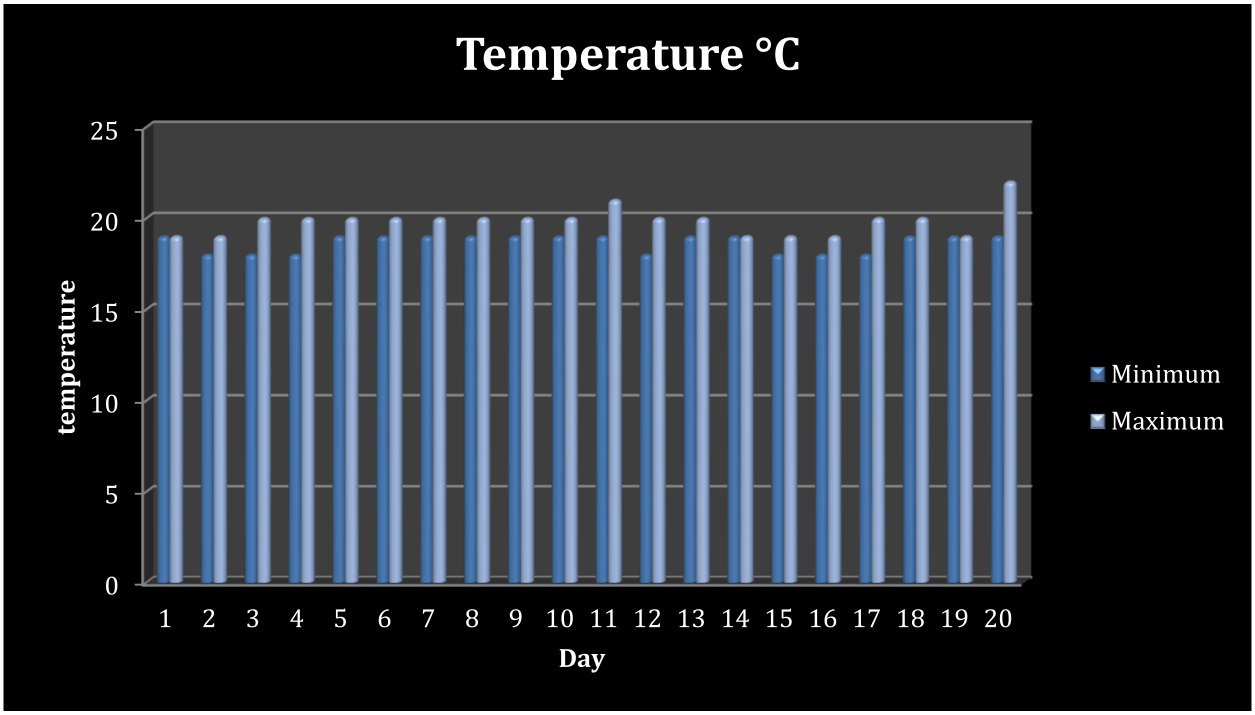


Figure 35: Minimum and maximum temperature readings from data centre

The minimum recorded temperature over the 20-day period was 18°C recorded on days 2, 3, 4, 12, 15, 16 and 17 while the highest recorded temperature was 22°C on day 20.

The number of readings per day as well as the average recorded temperature per day was also recorded as indicated in table 4.1.

Table 4.1 Temperature readings from data centre

Day	N	Readings per hour	Mean	Std. Deviation	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
Day 1	17	1	19.00	.000	19.00	19.00
Day 2	23	1	18.59	.503	18.37	18.81
Day 3	24	1	18.72	.737	18.42	19.02
Day 4	23	1	18.70	.822	18.34	19.05
Day 5	24	1	19.25	.442	19.06	19.44
Day 6	24	1	19.25	.442	19.06	19.44
Day 7	24	1	19.25	.442	19.06	19.44
Day 8	24	1	19.38	.495	19.17	19.58
Day 9	24	1	19.38	.495	19.17	19.58
Day 10	24	1	19.67	.482	19.46	19.87
Day 11	24	1	19.46	.588	19.21	19.71
Day 12	24	1	18.71	.806	18.37	19.05
Day 13	24	1	19.08	.282	18.96	19.20
Day 14	24	1	19.00	.000	19.00	19.00
Day 15	24	1	18.88	.338	18.73	19.02
Day 16	24	1	18.63	.495	18.41	18.83
Day 17	24	1	18.58	.654	18.31	18.86
Day 18	24	1	19.29	.464	19.10	19.49
Day 19	24	1	19.00	.000	19.00	19.00
Day 20	24	1	19.96	1.268	19.42	20.49
Total	471	1	19.09	.673	19.03	19.15

Temperature readings were summarised and reported once every hour for 24 hours. There were thus 24 temperature readings every day with the exception of days 1, 2 and 4 which had 17, 23 and 23 readings respectively. The lowest recorded mean temperature was 18.58°C [(18.31°C, 18.86°C) 95% CI] recorded on day 17 and the highest recorded mean temperature was 19.96°C [(19.42°C, 20.49°C) 95% CI] on day 20. There were no humidity readings recorded for the 20 day period.

4.5.3 Sensor Readings

The sensor recorded temperature and humidity for thirteen days. The readings were recorded concurrently for both temperature and humidity. The total numbers of readings per day and cumulatively as well as the average number of readings per hour and per minute are presented in table 4.2.

Table 4.2: Total Number of Readings

Day	N	Average readings per hour	Average readings per minute
Day 1	1077	113.36 (9.5 hours)	1.89
Day 2	2738	114.00	1.90
Day 3	2726	113.58	1.89
Day 4	2702	112.58	1.88
Day 5	2753	114.71	1.91
Day 6	2744	114.33	1.91
Day 7	2491	103.79	1.73
Day 8	2756	114.83	1.91
Day 9	836	114.05 (7 hours 20 mins)	1.90
Day 10	940	113.93 (8 hours 15 mins)	1.90
Day 11	2754	114.75	1.91
Day 12	2731	113.79	1.90
Day 13	1889	114.48 (16.5 hours)	1.91
Total	**29137**		
Average	**2241**		

The total number of readings for the thirteen days was 29,137. The number of averaged readings per day was 2,241. Days 1, 9, 10 and 13 had fewer readings than the average readings per day which could be attributed to power outages where the sensor was only able to record temperature and humidity for limited hours. The average number of readings per hour ranged from 112.58 to 114.75 with the exception of day 7 that had an average of 103.79 readings per hour. These observations were further divided into temperature and humidity readings.

4.5.4 Temperature Readings

The temperature readings recorded over the thirteen days are presented in figure 36 and table 4.3.

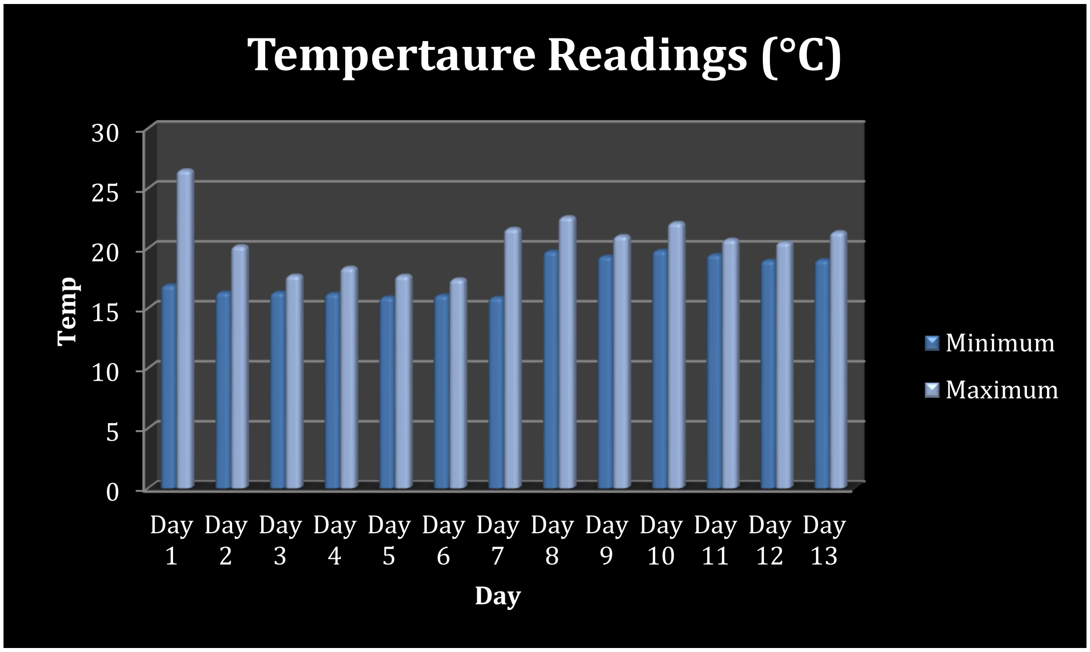


Figure 36: Temperature Readings

The lowest recorded temperature was recorded at 15.87ºC on day 7 while the highest recorded temperature at 26.49ºC was recorded on day 1. The mean temperature recorded per day is shown in table 4.3.

Table 4.3 Temperature Readings

Day	N	Mean	Std. Dev.	95% Confidence Interval	
				Lower Bound	Upper Bound
Day 1	1077	20.10	3.084	19.92	20.28
Day 2	2738	16.84	.3455	16.83	16.85
Day 3	2726	16.91	.4095	16.89	16.92
Day 4	2702	16.96	.6625	16.93	16.98
Day 5	2753	16.63	.5478	16.61	16.65
Day 6	2744	16.63	.3656	16.62	16.65
Day 7	2491	17.65	2.0984	17.57	17.73
Day 8	2756	20.68	.5283	20.66	20.70
Day 9	836	20.49	.4060	20.46	20.52
Day 10	940	20.46	.4300	20.43	20.48
Day 11	2754	20.09	.2256	20.08	20.09
Day 12	2731	19.91	.2021	19.91	19.92
Day 13	1889	19.73	.2443	19.72	19.74
Total	**29137**	**18.38**	**1.900**	**18.35**	**18.40**

The lowest average daily temperatures was 16.63ºC recorded on day 5 (16.63ºC [(16.61ºC, 16.65ºC) 95% CI]) and day 6 (16.63ºC [(16.62ºC, 16.65ºC) 95% CI]) while the highest recorded mean temperature was 2a0.68ºC [(20.66ºC, 20.70ºC) 95% CI] on day 8. Five days had mean temperatures recorded at the 16 degrees mark while five days had mean temperatures at 20 degrees.

Further analysis was conducted to determine if the sensor recorded when temperatures fell below 18ºC or rose above 26.89ºC. Results are presented in table 4.4.

Table 4.4 Temperature ranges

Temperature	Frequency	Percentage
15.87º-17.99º	15,369	**52.75%**
18.00º- 26.89º	13,768	**47.25%**
Above 26.89º	0	
Total	**29137**	**100%**

The majority of temperature readings (52.75%) were recorded below 18ºC while the remaining 47.25% were between 18ºC and 26.89ºC. None of the readings were above 26.89ºC.

4.5.5 Humidity Readings

The humidity readings recorded over the thirteen days are presented in figure 37 and table 4.5.

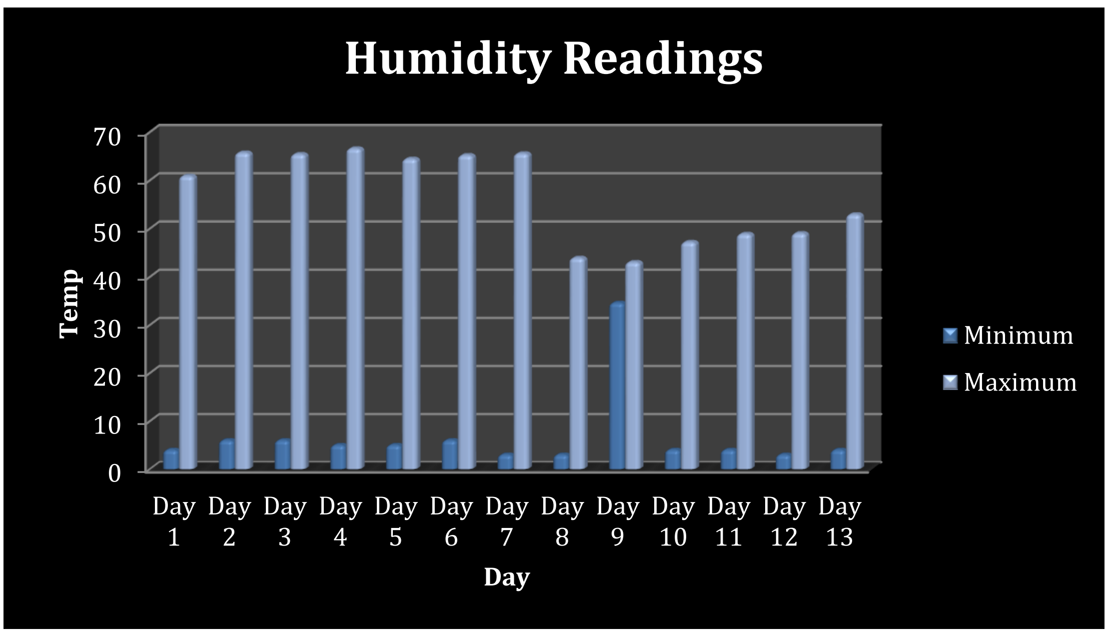


Figure 37: Humidity readings

The lowest recorded humidity value was 3g/m^3 recorded on days 7, 8 and 12. The highest recorded humidity value was 66.58 g/m^3 on day 4. The mean humidity values are presented in table 4.5.

Table 4.5 Humidity Readings

Day	N	Mean	Std. Dev.	95% Confidence Interval	
				Lower Bound	**Upper Bound**
Day 1	1077	55.21	5.6797	54.88	55.56
Day 2	2738	62.50	2.0753	62.42	62.57
Day 3	2726	61.71	2.7272	61.61	61.82
Day 4	2702	59.62	4.1624	59.46	59.77
Day 5	2753	59.21	2.8568	59.10	59.31
Day 6	2744	60.97	2.3655	60.88	61.06
Day 7	2491	53.59	12.6456	53.09	54.09
Day 8	2756	36.65	1.9007	36.58	36.71
Day 9	836	37.39	1.7426	37.28	37.51
Day 10	940	41.83	2.7773	41.65	42.00
Day 11	2754	42.93	2.6504	42.83	43.03
Day 12	2731	42.68	3.1358	42.56	42.79
Day 13	1889	43.37	2.5790	43.26	43.49
Total	**29137**	**51.89**	**10.5687**	**51.77**	**52.01**

The lowest mean humidity value recorded was 36.65 g/m^3 [(36.58 g/m^3, 36.71 g/m^3) 95% CI] on day 8 while the highest recorded mean humidity value was 62.50 g/m^3 [(62.42 g/m^3, 62.57 g/m^3) 95% CI] on day 2.

4.5.6 One Way ANOVA

One way ANOVA was conducted to determine if the values recorded for both temperature and humidity were significant. The results are presented in table 4.6.

Table 4.6 One way ANOVA

ANOVA						
		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Temperature	Between Groups	79448.831	12	6620.736	**7470.814**	**.000**
	Within Groups	25810.079	29124	.886		
	Total	105258.910	29136			
Humidity	Between Groups	2626422.722	12	218868.560	**10149.764**	**.000**
	Within Groups	628027.182	29124	21.564		
	Total	3254449.904	29136			

The F value for temperature readings for all the 13 days was 7470.814 (p=0.000) while the F value for humidity readings was 10149.764 (p=0.000). The values recorded for both temperature and humidity were significant indicating that the sensor device is viable in the recording of temperature and humidity.

4.5.7 Correlation Analysis

Pearson Correlation analysis was conducted between temperature and humidity to determine if there was a relationship between the two variables. Results are presented in table 4.7.

Table 4.7 Correlation

Correlations

		temperature	humidity
Temperature	Pearson Correlation	1	-.901**
	Sig. (2-tailed)		.000
	N	29137	29137
humidity	Pearson Correlation	-.901**	1
	Sig. (2-tailed)	.000	
	N	29137	29137

**. Correlation is significant at the 0.01 level (2-tailed).

Temperature and humidity were found to have a strong significant negative correlation of -0.901 (p=0.000). This is indicative that temperature and humidity have an inverse relationship thus; an increase in ambient temperature will result in a decrease in ambient humidity and vice versa.

4.5.8 Sequence Charts

Sequence charts were separately plotted to demonstrate the relationship between temperature and humidity. Intervals of 1,000 for all the 29,137 data points were used on the X axes and the Y axes had the temperature and humidity values respectively as shown in figures 38 and 39.

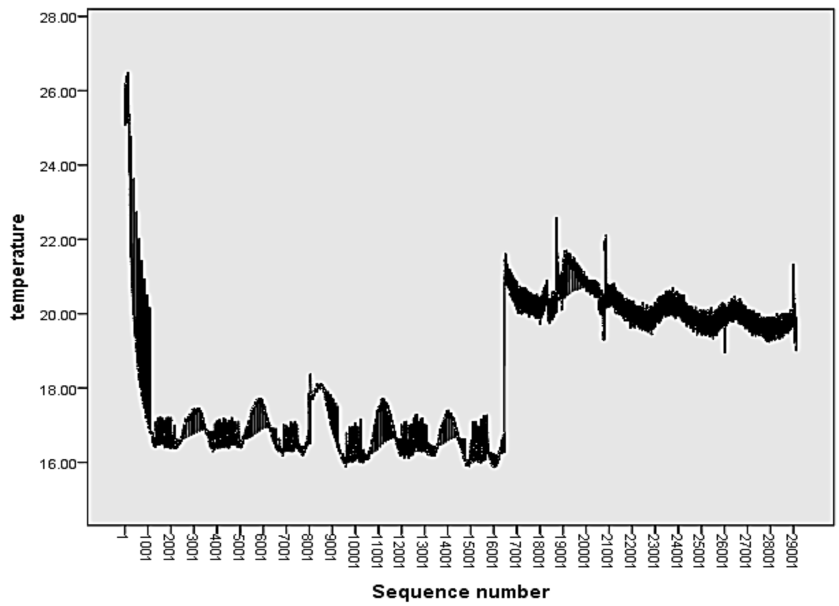


Figure 38: Temperature sequence plot

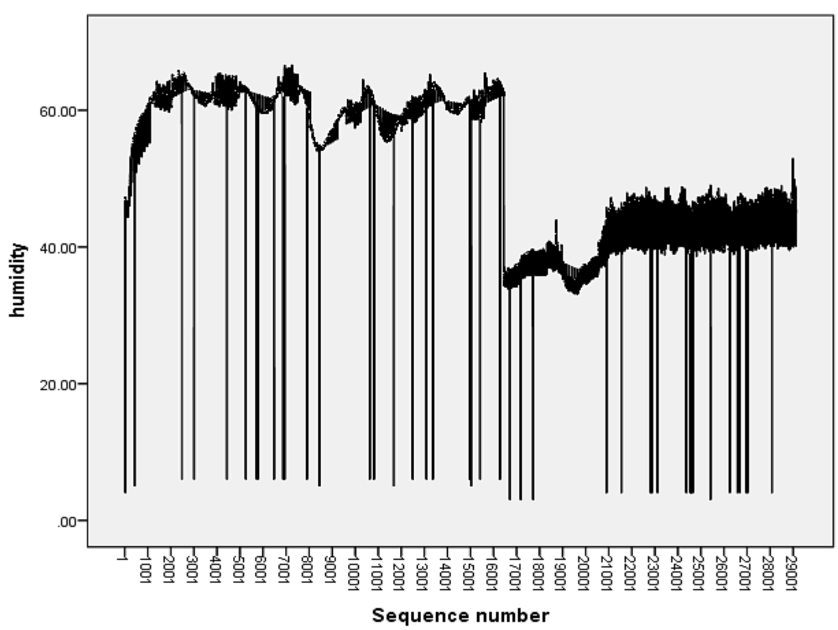


Figure 39: Humidity sequence plot

From the sequence plots, it is evident that when temperature was high, humidity was low. Lower temperatures resulted in more humidity. Temperature and Humidity were also plotted together as shown in figure 40.

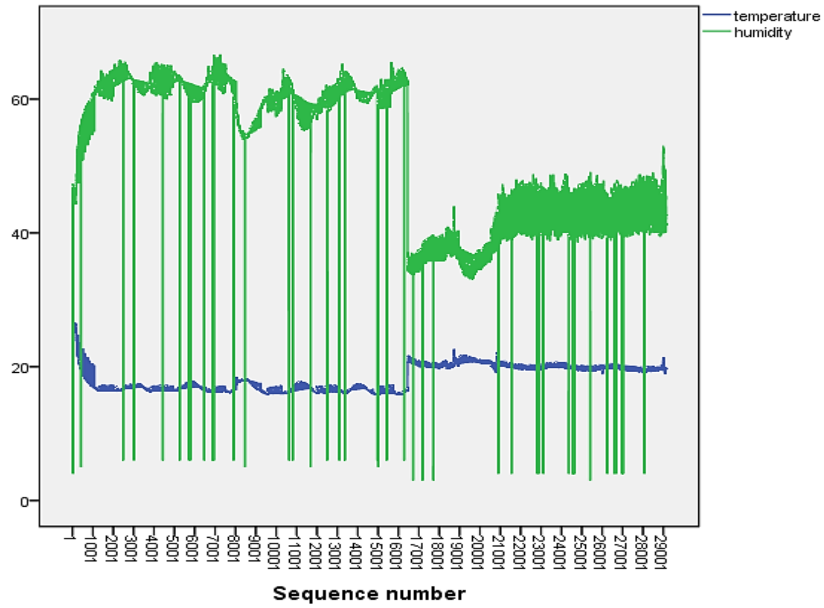


Figure 40: Temperature and Humidity sequence plot

The temperature and humidity sequence plot is a combination of the two previous sequence plots and it better shows the relationship between temperature and humidity. Whenever temperature (as shown in blue) is high the corresponding humidity value (as shown in green) tends to be much lower than when temperature is low.

4.5.9 Cost of the Sensor

The total cost of the sensor used was arrived at by adding up the costs of the constituent parts and the production costs. The constituent parts of the sensor included an SD card, a micro-controller, a bread board, and LCD display, a temperature and humidity sensor and jumper cables. The aggregated cost of the developed sensor module is shown in table 4.8.

Table 4.8 Sensor costs

Constituent part	Minimum cost (KES)	Maximum Cost (KES)	Actual cost (KES)
SD Card	200	200	200
Micro-controller	2,500	2,500	2,500
Bread board	200	200	200
LCD display	650	800	800
Temperature and humidity sensor	600	700	600
Jumper cables	500	625	500
Total	4,650	5,025	4,800

T-test, significance	
Minimum price (KES 9,087)	t=39.11, p=0.001
Maximum price (KES 29,495)	t=226.39, p=0.000

The cost of the sensor, based on the market prices, was around KES 5,000 which was below the cost of sensors normally KES 10,000 to KES 30,000. The minimum, maximum and actual costs of the sensor were subjected to a one sample test for both the minimum (KES 9,087) and maximum (KES 29,495) market price ranges. At the minimum market price of KES 9,087, there were cost savings of KES 4,087 which were significant (t=39.11, p=0.001). At the maximum market price, there were significant cost savings of KES 24, 695 (t=226.39, p=0.000).

Further, mass production of the sensors is estimated to be a fraction of current costs (KES 3,026) which will result in more cost savings if this model is adopted.

4.6 Discussion

The developed sensor was designed to take both temperature and humidity readings in a data centre environment. The sensor took readings from the environment at an average rate of 1.9 readings per minute. This translated to an average of 114 readings per hour. In contrast, the data collected from the data centre showed that temperature readings were recorded once per hour manually.

Additionally, the data centres did not collect any humidity readings which indicate a deficiency in data collection in the centres. The system currently in use is inefficient while compared to the developed sensor.

The lowest recorded temperature was 15.87°C while the highest recorded temperature was 26.49°C. The optimal temperatures in a data centre range from 18°C to 26.89°C. Temperatures below 16°C are not recommended for a data centre since they cause higher humidity levels that can lead to corrosive damage while temperatures beyond 26.89°C can lead to over-heating and subsequent damage. The sensor was able to detect temperatures over a wide range some of which were below the recommended 18°C. This could be very useful in a data centre when monitoring temperatures to determine when they are too low or high.

In contrast, the data centre readings indicated the lowest readings at 18°C and 22°C which while within the recommended range shows a lack of range in data collection. This could be due to the fact that data was manually collected in the data centre so the person/people recording the data missed when fluctuations in temperature occurred. It could also be wilful bias on the part of the person/people manually recording the data since they might want to indicate temperatures that are within an acceptable range. The sensor however picked up fluctuations by the minute and recorded fluctuations but when temperature is manually recorded then it is possible to miss such fluctuations.

Humidity values recorded by the sensor ranged from 3 g/m^3 to 66.58 g/m^3. There were no humidity readings from the data centre.

The temperature and humidity readings were found to have an inverse relationship where lower temperatures resulted in higher humidity readings and vice versa. This was similar to the already established inverse relationship between temperature and humidity by various researchers (Tiwali, 2021).

The readings recorded both on temperature and humidity are proof that the sensor is capable of accurately measuring them and at intervals of less than a minute and that the output is timely. The method of recording temperature in the data centres is currently ineffective as readings are taken once an hour. Important fluctuations and necessary adjustments can be missed.

The most important outcome of this research is that not only can the sensor prototype record many readings per hour, but the overall costing is relatively low and scalable in companies with tight margins and tight cost control.

CHAPTER FIVE: ANALYSIS OF RESULTS

5.0 INTRODUCTION

Chapter one introduced the subject matter and chapter 2 offered literature review plus insights into previous work in this area. Chapter3 detailed the protype/artifact that was to be developed to assist meet the goals of the research project. Chapter 4 has discussed at length the findings from the prototype developed and tested in a real data centre environment. This chapter identifies, describes, and sets the stage for expected output from the research study.

5.1 Research Objectives and Results

At the beginning of the project, the goals and objectives of the project were defined. These were to study and understand, the efficiency improvement that can be achieved by automating datacentre parameter collection centrally through the use of a service-oriented architecture (SOA) based system to increase real-time visibility into the operation of data centres of the second largest mobile operator in Kenya. More specifically

5.1.1 What is the current level of efficiency in collecting and reporting datacentres temperature and humidity parameters to the management team?
It has been demonstrated that the current level of efficiency is low and costly, with a average of a single reading taken per hour owing to cost implications mostly, when semi-autonomous systems are employed to collect and report data.

5.1.2 What improvements can be achieved through the use of automated sensors, logic controllers and a SOA based system to report temperature and humidity data to management in real-time?
With an automated solution, based on the SOA model, the levels of efficiency on data centre parameters data collection rises dramatically while keeping costing at bay. This hinges on the uses of cheap commodity sensors coupled with cloud-based service-oriented architecture (SOA) models, to allow for scalability, autonomy, usability and composability of the ultimate solution.

5.1.3 What is the cost trade off and is such a real-time system financially viable?
It has also been shown that through the use of use of commodity sensors, solutions can be found at

the right price-point for many use cases not only in telecommunications by in general manufacturing as well. Lastly, on the question of cost efficiency, it has been shown that up to 85%-90% savings can be derived through the use of these sensors and SOA based systems, especially where there are widespread applications by large consumers

5.2 Conclusion

In this research project, we have explored the use of sensor technology and logic controllers to collect data from remote data centres and aggregation hubs for the second largest operator in Kenya. Data centres for most corporates operate within well-defined standards and research findings in one corporate should offer useful insights to another corporate body operating within the same environmental constraints. We have presented useful data that the use of remote sensors can cuts costs dramatically while at the same time increase data collection efficiency of a data centre. The success of this methodology rides on 3 main factors 1) availability of reliable connectivity to the sensor location 2) reasonably good latency from the logic controller to the aggregation service endpoint. 3) good passive infrastructure like commercial power, to ensure that data is continuously collected and reported as expected.

The developed sensor was found to be effective at measuring both temperature and humidity in the environment. The sensor took an average of 2 readings every 63.15 seconds and an average of 114 readings per hour. The data centres on the other handed only recorded temperature and humidity once an hour. The data centres were thus found to be inefficient in their temperature and humidity recordings. There were attempt to get more efficient methods of data collection, but these were not effective in the eyes of the researcher. The sensor was able to measure temperature and humidity readings over a wider range than is currently available in data centres.

The cost of the sensor was KES ~5,000 which was KES 4,087 below the minimum market price based on the surveyed samples from the open market. The cost savings incurred by the developed sensor were statistically significant. Further, mass producing the sensor is expected to be done at a fraction of the prototyping cost, producing it at KES ~3,000.00.

The developed sensor was found to be more efficient in recoding temperature and humidity than the current method; from the analysed data, it was also noted that it was more cost effective. Given that more sensors can be hooked up to the model, the levels of cost efficiency can only increase for the solution.

5.3 Limitations

There are a number of limitations that were encountered in this project. First, the time from idea conceptualization, artefact fabrications and collection of remote data was fairly constrained and more can be done in this are to collect even more sensor data and hence increase the over use of the concept. Secondly, sensors are sensitive to power fluctuations and a lot of care is needed to handle them safely. Thirdly, the network carrier was unwilling to release data from many data centres which would have offered more insights into the variability of data centre environments and hence how remote sensors can be employed to varying degrees to assist resolve data collection problems. However, since data centre environments are fairly controlled environments, lack of such data is thought to be not very significant to the findings of this research project. In addition, the data centres considered were fairly large and considered representative. Fourthly, the data centre had a lot of electro-magnetic interference. The S/N (*signal to noise ratio*) was low and indicative of wireless interference, and this impacted getting some sensor readings. It may be necessary in a future project to design a solution that uses low frequency communication e.g., the more resilient 400kHz band radios or cabled ethernet solutions to improve data throughput. Firth, it was noted that leaving the door open for some periods of time affected temperature and humidity reading in one of the data centres. It may be necessary to add a door sensor and read the data together with that collected by the temperature and humidity sensors to gain more insights into how data centre running costs are impacted by the opening and closing of access doors, in live production environments.

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Exhibit 01

Actual data values used in the research are embedded herein

Sensor_Readings_20210904.xlsx

Sample snippet with actually used data is shown below.

idxno	Date	datestr	TerminalName	DataCategory	TempC	TempF	Humidity	USERID
113678	20/8/2021 14:35	2021-08-20 14:35:16	0x5f6c6b55a8d6b1a	1	25.30	25.30	46.74	GitEsp8266
113679	20/8/2021 14:35	2021-08-20 14:35:44	0x5f6c6b55a8d6b1a	1	25.25	78.96	46.79	GitEsp8266
113680	20/8/2021 14:35	2021-08-20 14:35:50	0x5f6c6b55a8d6b1a	1	25.25	78.96	46.79	GitEsp8266
113681	20/8/2021 14:36	2021-08-20 14:36:44	0x5f6c6b55a8d6b1a	1	25.20	78.96	46.88	GitEsp8266
113682	20/8/2021 14:36	2021-08-20 14:36:51	0x5f6c6b55a8d6b1a	1	25.20	78.96	46.88	GitEsp8266
113683	20/8/2021 14:37	2021-08-20 14:37:44	0x5f6c6b55a8d6b1a	1	25.19	78.78	46.93	GitEsp8266
113684	20/8/2021 14:37	2021-08-20 14:37:51	0x5f6c6b55a8d6b1a	1	25.19	78.78	46.93	GitEsp8266
113685	20/8/2021 14:38	2021-08-20 14:38:43	0x5f6c6b55a8d6b1a	1	25.11	78.78	47.04	GitEsp8266
113686	20/8/2021 14:38	2021-08-20 14:38:50	0x5f6c6b55a8d6b1a	1	25.11	78.78	47.04	GitEsp8266
113687	20/8/2021 14:39	2021-08-20 14:39:44	0x5f6c6b55a8d6b1a	1	25.10	78.78	47.07	GitEsp8266
113688	20/8/2021 14:39	2021-08-20 14:39:51	0x5f6c6b55a8d6b1a	1	25.10	78.78	47.07	GitEsp8266
113689	20/8/2021 14:40	2021-08-20 14:40:44	0x5f6c6b55a8d6b1a	1	25.08	78.60	47.00	GitEsp8266
113690	20/8/2021 14:40	2021-08-20 14:40:51	0x5f6c6b55a8d6b1a	1	25.08	78.60	47.02	GitEsp8266
113692	20/8/2021 14:41	2021-08-20 14:41:51	0x5f6c6b55a8d6b1a	1	25.08	78.78	47.26	GitEsp8266
113693	20/8/2021 14:42	2021-08-20 14:42:44	0x5f6c6b55a8d6b1a	1	25.18	78.96	47.27	GitEsp8266
113694	20/8/2021 14:42	2021-08-20 14:42:50	0x5f6c6b55a8d6b1a	1	25.18	78.96	47.27	GitEsp8266
113695	20/8/2021 14:43	2021-08-20 14:43:44	0x5f6c6b55a8d6b1a	1	25.29	79.14	47.01	GitEsp8266
113696	20/8/2021 14:43	2021-08-20 14:43:51	0x5f6c6b55a8d6b1a	1	25.29	79.14	47.01	GitEsp8266

Exhibit 02

P53/35030/2019

Estimated Prototyping costs

SD_CARD

Micro SD Storage Expansion Board Micro SD TF Card Memory Shield Module SPI For Arduino

KSh 200.00

Micro-Controller

MEGA2560 Mega+WiFi R3 ATmega2560+ESP8266 32M Memory USB-TTL CH340G Compatible Mega NodeMCU ESP8266

KSh 2,500.00

Bread Board

Breadboard 830 Point PCB Board MB-102 MB102

KSh 200.00

LCD Display

LCD2004+I2C 2004 20×4 2004A Blue/Green screen HD44780 Character LCD /w IIC/I2C Serial Interface Adapter Module For Arduino

KSh 650.00 – KSh 800.00

Bread Board
Bread Board
LCD Display
LCD Display

Temperature and Humidity Sensor

High Precision AM2302 DHT22 Digital Temperature & Humidity Sensor Module For arduino Uno R3

KSh 600.00 – KSh 700.00

Jumper Cables

100PCS 20CM Color Flexible Two Ends Tin-plated Breadboard Jumper Cable Wires

~~KSh 625.00~~ **KSh 500.00**

Proto-typing Total Costs = 4,800/- to 5,200/-

Expected production costs ~(2/3) of prototyping costs

Exhibit 03

P53/35030/2019

Estimated SNMP product costs based on conducted survey of comparable products.

Tripp lite UPS card ($271.19)

Tripp Lite UPS Web Management Accessory Card, Remote Monitoring, SNMP, HTML5, SSH, Telnet or Web Browser (WEBCARDLX)

24

$271.19

Ships to Kenya

X-410 Web Enabled sensor ($294.95)

X-410 Industrial Web-Enabled Ethernet Relays, Digital Inputs, and Temperature/Humidity Monitor

7

$294.95

Ships to Kenya

More Buying Choices

$270.95 (2 new offers)

CyberPower Enviro-Sensor ($99.95+shipping)

CyberPower ENVIROSENSOR Environmental Sensor, 12V, RJ45 Ethernet Port, 10FT Cable

36

$90.87

Ships to Kenya

In stock soon.

More Buying Choices

$89.99 (17 new offers)

Sensor Push G1 WIFI/Ethernet

SensorPush G1 WiFi/Ethernet Gateway. Receive Data/Alerts from Anywhere via Internet. No Monthly Fee. Unlimited History....

1,219

$99.95

Ships to Kenya

Temp-Cube Wifi & Humidity Sensor
Temp/Humidity Monitor

tempCube WiFi Temperature & Humidity Sensor | 2.4GHz Wireless Remote Temperature Monitor with USB-Powered Rechargeable Batter...

49

$159.00 ~~$199.00~~

Ships to Kenya

MarCELL Cellular

MarCELL Cellular Temperature/Humidity Monitor (Verizon)

465

$189.00 ~~$199.00~~

Ships to Kenya
In stock soon.

More Buying Choices
$124.95 (2 used & new offers)

Minimum Price = $90.87 + Shipping + Vat + Customs
Maximum Price = $294.95 + Shipping + Vat + Customs

USE REMOTE SENSORS TO COLLECT DATA CENTRE PERFORMANCE PARAMEMERS BASED ON SOA MODEL

ORIGINALITY REPORT

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