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Computing systems in a pseudo–marine operational environment: design and initial test results

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Abstract
Contemporary research recognizes the need to reduce the cooling costs of data centre systems. This is beneficial and also reduces the operational costs. The operational costs can be reduced by using water for cooling instead of relying on conventional cooling systems comprising air–conditioners, chillers and cooling towers. The cooling effect of water can be leveraged by siting the underwater data centre in a marine or pseudo–marine environment. A pseudo–marine environment is considered here since it overcomes the operational challenges associated with obtaining the regulatory permits required to access the marine environment. In addition, the discussion in the paper presents the design of a desktop computing system that uses water for cooling in a pseudo–marine environment. The performance test of the desktop computing system is conducted in Oyo, Oyo State Nigeria. This is done to examine the viability of designing and using mini–data centres sited in a pseudo–marine environment in Nigeria. The initial results indicate that a personal desktop computer in the role of the mini – data centre is able to support the execution of software installation without the use of conventional cooling i.e fans for a period exceeding 25 minutes. In this case, the cooling is realized using the emulated pseudo – marine environment.

Keywords *– Computing, Underwater locations, Cooling, Data Centres*

1. Introduction

Data centres play an important role in computing and hosting internet content. Cloud computing platforms comprise multiple aggregated and networked data centres. The operation of data centres in cloud computing platforms incurs high operational costs. These high costs arise due to the necessity of powering and cooling data centres. However, operational costs increase with the number of data centres. This has necessitated the design of solutions that can reduce data centre operational costs. Suitable solutions for reducing data centre cooling costs are siting data centres in naturally cold locations. Examples of such locations are countries with naturally cold climate, and non–terrestrial locations such as the ocean and the stratosphere.

The use of the ocean as a feasible location for hosting data centres has received consideration by organizations such as Microsoft (Cutler et al. 2017, Simon, 2018; [1, 2]). In addition, Google has also experimented with the use of an ocean barge as a data centre i.e. ocean data barge (Gough, 2015). The siting of data centres in the ocean or leveraging on the ocean's resources is only suitable for

locations with access to maritime resources. This implies that it challenging to deploy data centres leveraging on massive water cooling in locations without maritime resources.
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Nevertheless, it is important for data centres in such locations to benefit from the cooling capability of water arising from its high specific heat capacity. This is considered in this paper. The discussion in this paper focuses on describing a computing system that is intended for operation in a pseudo–marine environment. The computing system is realized via a single desktop computing system. In addition, the paper discusses the performance of the designed dis–aggregated computing system.

The discussion in this paper makes the following contributions:

1) First, the paper proposes the use of pseudo- marine environment for hosting servers i.e. computers to be used in future data centres. A pseudo–marine environment is one hosting an environment similar to the ocean's sub–surface. In this paper, the proposed pseudo–marine environment is capable of hosting multiple servers in the realization of a given data centre. In addition, the proposed pseudo – marine environment hosts a desktop computing system. In our consideration, the dis–aggregated computer is realized from the design of a personal desktop computer with components that are sourced from the Nigerian market. The research being presented discusses the factors that limit the realization of an ideally functioning dis–aggregated computing architecture in the context under consideration.

2) Second, the research presents the results obtained from performance tests with a focus on the cooling capability of the pseudo–marine environment. In the performance test, the pseudo–marine environment is realized in an emulated physical environment. An emulated physical environment is used due to the challenges posed by cost constraints. The cooling capability of water in the emulated physical environment is determined by the length of time i.e. duration for which the personal computer can function while solely relying on water for cooling. In addition, the success of installing software i.e. Windows Operating System and Microsoft Office on the computer is also considered in the description of the computer operation while being cooled with water in the emulated physical environment.

This research focuses on presenting the design and the performance test results for the proposed dis–aggregated computing architecture. The computer is sited in an emulated physical environment. The novelty of the research consists in it being the first to present the performance test for a dis–aggregated computing system in an emulated (marine) physical environment in cash constrained African (Nigerian) context. The performance test is conducted in Oyo Town, Oyo Nigeria. The choice of the location demonstrates the feasibility of using pseudo–marine environments to realize low-cost cooling computing platforms in Tropical Africa.

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[1]. R. Miller, 'Microsoft CEO Nadella: Underwater Data Centers Are the Future', Nov 2 2018, [Online] https://datacenterfrontier.com/microsoft-ceo-nadella-underwater-data-centers-are-the-future/, Accessed: August 12, 2020.

2. B. Cutler, S. Fowers, J. Kramer and E. Peterson, 'Want an Energy-Efficient Data Center? Build It Underwater: Microsoft wants to submerge data centers to keep them cool and to harvest energy from the sea', 21 Feb 2017, IEEE Spectrum, [Online] https://spectrum.ieee.org/computing/hardware/want-an-energyefficient-data-center-build-it-underwater, Accessed August 12 2020.

The rest of the paper is divided into six parts. Section 2 focuses on background work. Section 3 discusses computing system design. Section 4 describes the emulated marine environment. Section 5 presents details on system set – up and performance procedure. Section 6 is the conclusion.

2. Related Work

Krein (2017) examines the relations between building facilities housing the data centre and the power usage effectiveness (performance measure). Liquid immersion is recognized as a viable technological solution to enhance data centre performance usage effectiveness. In this regard, advanced hydro-fluorocarbon liquids[3] (Kawaguchi et al., 2017) and mineral oils (Shah et al., 2019) are reported to have been used. However, the use of these specialized fluids has high costs due to the high cost of fluid acquisition. Water is a suitable coolant since it has a high specific heat capacity. Moreover, water can be acquired for this purpose at low cost. In addition, water can be easily accessed without significant environmental degradation by siting data centres in the ocean.

Fujitsu has considered an approach where they totally remove fans thereby eliminating the role of fans in servers and computers [3]. The removal of fans in the servers is observed to enable noise–less operation for server farms. In addition, the removal of fans led to a reduction of the required floor space by 50%; with benefits also in the aspect of real estate acquisition for the establishment of server farm facilities. The cooling liquid used in this regard is a fluorocarbon fluid called Fluorinert. The inert liquid driven immersion does not rely on the availability of maritime resources[3]. Therefore, they can be used at locations without access to maritime resources i.e. oceans and rivers. However, this is at the expense of high cost.

Kawaguchi et al. (2017) addressed the challenge of reducing the energy consumption and improving the energy efficiency of data centers. The Fujitsu group is reported in Kawaguchi et al. (2017) to recognize that energy consumption in data centers is increasing with more subscription to cloud computing services. This is accompanied with increased CO_2 emissions. The main approach that has been recognized to be suitable is the conduct of measurements and tests in a building management system. A building management system displays operating conditions for air–conditioning facilities and server room temperature management systems. Deploying air conditioning technology and temperature sensors are suitable techniques for data centre management with the aim of improving energy efficiency. Though, the use of air–conditioning systems and temperature sensors can enhance data acquisition to improve data centre management; their use increases the power consumption in data centre facilities. This invariably exacerbates in the challenge of increasing data centre operational costs.
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In transitioning from air cooled systems to liquid cooling systems or immersion oil-based cooling systems for data centers, the reliability is an important performance parameter that should be considered. The impact of mineral oil data center cooling on data center reliability receives consideration in (Shah *et al.* 2019).

Shah *et al* (2019) recognize the suitability of using mineral oil-based cooling for server farm operation. It is recognized that submerging servers in dielectric mineral oil reduces energy consumption of server farms. The discussion in Shah *et al* (2019) recognizes that proprietary mineral oil cooling solutions have been designed and exist. However, it is recognized that mineral

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[3] J. Boyd, 'Fujitsu Liquid Immersion Not All Hot Air When It Comes to Cooling Data Centres', IEEE Spectrum, 18-May-2017, [Online] https://spectrum.ieee.org/tech-talk/computing/hardware/fujitsu-liquid-immersion-not-all-hot-air-when-it-comes-to-cooling-data centers, Accessed August 11, 2020.

oil has the potential of reacting with components of the computing system. Examples of such components are printed circuit boards in the computing payload and associated information technology equipment such as cables with important networking role. It is recognized that mineral oil can erode markings thereby making component identification challenging. This makes the conduct of maintenance and servicing difficult when the need arises. The visual results presented show that immersion in mineral oil results in the fading of component markings in comparisons to component labeling in an air–cooled server. From a mechanical perspective, components from servers immersed in oil results in a significant reduction in the Young's modulus of printed circuit board. The microstructure of capacitors used in oil immersed servers is also observed to experience significant degradation in comparison to those of capacitors in air–cooled servers.

Rispoli[4] acknowledge the increasing proliferation of liquid cooling technologies in data center systems. Two technologies i.e. direct to chip cooling and immersion cooling has been recognized. The study in Shah *et al* (2019) notes that direct to chip cooling has been adopted by a significant number of original equipment manufacturers. The identified challenges of direct to chip cooling are non–uniform heat dissipation, potential occurrence of vendor lock–in and risk of leak on critical components. Immersion cooling is noted to have reduced susceptibility to hardware failures, enhanced life span, reduction in capital and operating expenditures and reduced risk of vendor lock–in. However, it is recognized that direct to chip cooling relies on water as the main coolant[4], the best coolant for the immersion cooling technology has not been identified.

The use of immersion cooling has the benefits of reducing cooling costs, required operational power and data center facility associated real estate costs. Immersion cooling can be realized via inert liquids, mineral oil (Kawaguchi et al, 2017, Shah et al., 2019), and water (Krein, 2017). The use of these fluids for data center cooling poses different contextual challenges. However, the use of inert liquids and mineral oil has a high cost. The use of water overcomes the high costs associated with acquiring either inert liquids or mineral oil. However, the use of water in the considered manner is only feasible for regions with access to significant maritime resources.
[3]

This makes the use of regions with low access to water and maritime resources as potential data center sites challenging. Examples of regions in this category are Egypt (due to the renaissance dam conflict with Ethiopia), locations that are based in Africa's desert zones. Examples of locations in Africa's desert zones are Mali and Northern Nigeria. These locations do not have access to a marine environment in a manner similar to coastal African cities like Cape Town, Port Elizabeth and Lagos.

Nevertheless, it is important to site data centers in locations within Africa's desert zones to ensure that subscribers at these locations do not experience high content access latency. This challenge can be addressed by installing pseudo–marine environments at these locations. The usefulness and potential of pseudo–marine environments in realizing data center cooling as proposed here is yet to receive sufficient consideration in research. Pseudo–marine environments are marine–like systems that can be found in large aquaria, fish ponds and other controlled marine like artificial control systems. Aquarium systems have been observed to significantly benefit from technologies such as the internet of things (Lin *et al*. 2019). The use of aquarium in hosting computing systems

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[4]Danielle Rispoli, 'Immersion Cooling, High Performance Cooling for HPC', EuroHPC Summit Week 2019, 15/05/2019, [Online] https://events.prace-ri.eu/event/850/contributions/751/attachments/913/1580/15.05_15.30_Immersion_Cooling_High_Performance_Cooling_for_HPC_Rispoli_1.pdf, Accessed August 11, 2020.

has received consideration[5]. This discussion is from a hobbyist perspective and does not present performance test results.

The use of water has been recognized to be suitable for data centre cooling applications. In this application, it is implied that water is passed through a chiller that reduces water temperature (Sondur et al., 2018, Oltmanns et al., 2020 and Kohonen et al. 2020). The use of the chiller increases data centre energy consumption. This reduces data centre energy efficiency. A periodic operation of the chiller leads to the reduction of data centre energy consumption and leads to the use of warm water for data centre cooling (Jiang et al. 2019 and Meyer et al., 2013). The warm water arises due to the non – operation of the chiller at all data centre functional epochs. Another approach such as that presented in (Mytton, 2021) considers the use of smaller less power intensive chillers. The use of such chillers has the dual benefits of reducing acquisition and operational (power consumption) costs.

Another approach to realizing data centre cooling is via the use of liquid immersion cooling systems (Liu *et al.* 2021). Liu *et al.* (2021) identify two types of liquid cooling i.e. direct liquid cooling and indirect liquid cooling. The latter method i.e. indirect liquid cooling is described in (Liu *et al.* 2021) where the servers are submerged in a tank containing the dielectric liquid Novec 7100 from 3M. It is recognized by Liu *et al.* that the dielectric Novec 7100 is expensive. In this case, the process of heat transfer occurs from the data centre to the dielectric Novec 7100. The use of Novec 7100 though advantageous due to its high boiling point of $61^{O}C$ has the drawback of high cost.

Types of inert liquids that can be used for data centre cooling are the Fluorinert Electronic liquid and Novec Engineered Fluid[4]. These coolants are costlier than water. Nevertheless, the discussion in (Liu *et al.* 2021) demonstrates that the design of an engineered submerged environment hosting coolants is feasible for future data centre realization. The consideration of the use of coolants in cooling data centres has also received earlier attention in (Parida *et al.*, 2012). However, the procedure in (Parida *et al.*, 2012) describes results obtained for locations in the USA. In addition, it does not consider the context of a cash constrained developing tropical nation. This describes the case of a West African nation such as Nigeria.

[4]https://multimedia.3m.com/mws/media/1798606O/3m-immersion-cooling-brochure.pdf

3. Design of Low-Cost Computing System

The dis–aggregated computing system being proposed is realised using the conventional components of a desktop personal computer. These components are: (i) Motherboard hosting processors, (ii) Hard Disk Drives, (iii) Temperature Sensors, (iv) Aluminium Sub–casing, and (v) Plastic Casting. The motherboard hosts processors and other computing peripherals that enable data storage and algorithm execution. The hard disk executes the conventional function of providing a storage space for data and user defined programs. Temperature sensors are used to monitor the temperature of the environment in which the computer executes its functions.

The aluminium casing is used as an external component holder to support the positioning of computing components. It also ensures enhanced heat transfer from computing components to the surrounding environment due to Aluminum's high thermal conductivity. The plastic casing is used to store the coolant mixture of ice and water with the aim of insulating it from the heat arising in the external environment. This is because of poor thermal conductivity of plastic. These components are used to design an abstraction of a data centre that utilizes ice–water mixture as the main coolant. The use of an ice–water mixture is necessitated to model the sub–zero temperature of the ocean's sub– surface environment. The aim of the design is to realize a minimum function prototype of the abstraction of a data center while utilizing ice–water mixture as a coolant. This is done with the goal of realizing a type of the environment that can be found in existing work[4].

The realization of the abstraction of the computing entity makes use of two Aluminium casings. The first Aluminium casing hosts an array of hard disk drives. The second aluminium casing hosts the computer motherboard alongside the processors and supporting computing peripherals. Aluminium has a high thermal conductivity and radiates arising from the operation of the computing components to the environment. Nevertheless, it is important to ensure that the heat from the external environment does result in a rapid increase in the temperature of the ice–water mixture serving as the coolant. The setup limits the influence of external heat by placing each Aluminium casing in a plastic casing. The plastic casing is of larger dimensions than the Aluminium casing with sufficient volume to host the ice–water mixture and the Aluminium casing. There are two plastic casings with each casing hosting one Aluminium casing each. The displays on two important parameters are monitored for each plastic casing. The first display provides information on the operational temperature within each plastic casing. This is realized via the deployment of temperature sensors. The second display provides information on the time elapsed for the use of ice –water mixture composition as a coolant.

The implementation of an abstraction of the computing entity also serves as the realization of a minimum function prototype. The minimum function prototype is expected to support functionalities on the deployed hard drives. These functionalities are: (i) Hard Drive Formatting, (ii) Hard Drive Partitioning, (iii) Windows operating system installation, (iv) Linux operating system installation, (v) MATLAB software installation on Windows partition.

In the functioning of the minimum function prototype, it is intended that the ice-water i.e. coolant mixture will be changed seamlessly. This is necessary to ensure that the computer does not experience functional outage during the operation. Furthermore, the prototype is intended to be scalable and its full scale implementation should be able to support online video streaming and e-commerce applications. These are examples of applications requiring the use of data centres.

4. Emulated Physical (Marine) Environment

The marine environment should ideally be a location in the ocean's sub–surface environment. A suitable sub–optimal solution will be the launch of the abstracted computing entities into a large sized marine environment analog. However, these options have high costs that make their use for the realization of the proposed system infeasible in the research being described. The marine environment analog that is used here is designed within the limits of cost constraint and leverages on the easy availability of water and its derivatives i.e. ice. The emulated physical (marine) environment does not incorporate the feature of coolant circulation. This aspect is not incorporated for two reasons. The first is that the inclusion of coolant circulation feature requires the use of large-scale server farms comprising more computers than used in this study. This is cost–prohibitive. The second reason is that existing literature in [3–4] considers that single units of abstracted computing entities are housed in compartments with self-enclosed fluid coolants. In addition, existing work also demonstrates the feasibility of cooling from a hobbyist's perspective[6].
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[4] M. Szczys, 'Aquarium Computer', [Online], https://hackaday.com/tag/aquarium-computer/, June 10, 2019, Accessed August 11, 2020.

[6] M. Szczys, 'Aquarium Computer, [Online] https://hackaday.com/tag/aquarium-computer/,June10 2019, Accessed Aug 11, 2020

5. Description of Set Up and Performance Testing

The discussion in this section presents the experimental set up and the conduct of procedures enabling the performance testing. This section is divided into five parts. The first part presents considerations on the design for performance evaluation. The second part discusses the details associated with prototype design. The third part focuses on the procedural set–up and system design details. The fourth part describes the observed behaviour of the computing system i.e. the post set–up computing system behavior. The fifth aspect describes aspects related to scalability and system realization.

Existing work has significantly considered the use of inert liquids such as fluorinert and Novec. However, an attempt to mimic the ocean hosting an abundant of cold-water coolant in a terrestrial context is yet to be considered. The performance analysis has not considered using inert or dielectric fluids due to the high cost. Water is easier and less costly to obtain than inert or dielectric fluids. In addition, the performance procedure differs from existing work in focusing on a developing nation like Nigeria.

5.1 Considerations on the Design for Performance Evaluation

The performance evaluation aims to determine the ability of a computing system to enable data storage and algorithm execution while relying on maritime resources for cooling. The computing system is intended to be a dis–aggregated system. In a dis – aggregated system, computing components are not collocated within a single chassis. Instead, they are distributed and functionality is realized via local level bus inter–connections. In our consideration, a dis–aggregated system is one where components can be added to increase computing capacity without the need to execute a system shutdown procedure. However, this is challenging to realize.

The experiment aims to determine the functioning duration of the computing system without the use of conventional cooling components. This is done while algorithm execution is ongoing. The cooling environment is realized via a design ocean analog environment. This environment is realized via the use of water in ice state and liquid state. This cooling environment is used while removing the conventional onboard fan system that is initially installed and configured aboard the computing system. The computing system is realized by using components from a standard desktop personal computer.

The goal of the procedure is to determine the functioning duration of the proposed computing system for executing a given algorithm in a given environment state.

5.2 Prototype Design Details

The procedure intended to use a computing system with the capacity of a server, server farms or data centre. However, the realization of computing systems in these categories has a high cost which is beyond the reach of the research team. Hence, a computing system on a lower scale was designed considering the financial resources and the constraints being experienced by the research team. The computing system used in this case is a desktop computer with components enabling data storage and algorithm execution.

The prototype was designed using a lead cost strategy in which realization at the lowest possible cost was actually sought by the research team. This approach was considered without recourse to the use of computing components with a low reliability or known poor functionality level. In addition, this approach was considered due to the economic climate at the time.

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The research team that conducted the performance procedure had no funding support and used personal funds. In this regard, improvised components were used to realize expected functionality in the realization of the proposed components. The components that were used in realizing the computing system were all new. These components are: four hard drives, motherboard, cables, and two ATX form factor computer casings.

The conduct of the procedure also requires the use of additional components to prevent contact between the computing components and the cooling mixture. The cooling mixture models the underwater environment and is realized via an ice – water mixture. The ice–water mixture is intended to model the ocean environment and is an ocean analog. The components used in this regard are: Aluminium casing (two units) and polythene water proof material (two units) and two units of ice packs comprising multiple ice blocks. A pictorial view of an empty Aluminium casing, hard drives being placed in the Aluminium casing and Motherboard in the Aluminium casing are in Figure 1, Figure 2 and Figure 3, respectively.

In addition, recording devices such as thermometers and stop watch were also used for recording data. Thermometers are used to record the operating temperature of the computing system environment. The stop watch is used to record the functioning duration of the computing system. Furthermore, the performance evaluation procedure was also recorded using a video camera. The computing system components have been individually identified to enable the realization of low cost minimization without experiencing a vendor–lock in challenge. This also enables the realization of a heterogeneous desktop computing system.

Figure 1 – Aluminium casing used to host computing system components for enhanced heat transfer.

Figure 2 – Insertion and placement of hard disk array in the Aluminium casing.

Figure 3 – Motherboard being placed in Aluminium casing.

The placement of the motherboard showing the passage for the connecting cables is shown in Figure 4.

Figure 4 – Motherboard in Aluminium casing showing opening on casing side. The opening provides pathway and passage for connecting signal cable.

5.3 Procedural Set – Up and System Design

The computing system was initially assembled in a default configuration. The default configuration is one of a normal desktop computing system. This is done to ensure that all components are able to execute data storage and algorithm processing in the expected manner.

The original plan aimed at the design of a dis–aggregated computer system. In this conceptualization, the demonstration of the proof of concept/ prototype required the use of two power packs. In the initial system conceptualization, the first power pack unit was intended to drive the motherboard. The second power pack unit was intended to supply alternating current to the hard disk drive array. The hard disk drive array was enclosed within the aluminium casing in a separate computer casing (the casing is the standard ATX desktop casing form factor). The intended computing system set–up i.e. the disaggregated computing system is presented in Figure 5 and Figure 6. Figure 5 shows the hard disk drive arrays (4 hard drives) placed in the Aluminium casing within the ATX desktop computing system. The scenario in Figure 6 is one showing the intended design of the dis–aggregated system. The left casing in Figure 6 hosts the motherboard and hard disk drive array, respectively. In Figure 6, the power pack that supplies power each component is in the centre. The scenario in Figure 6 is intended to show the design of the intended computing system.

Figure 5 – Hard Disk Drives in Aluminium casing (with slanted lid) showing connecting cables to the motherboard in the next AT

Figure 6 – Two ATX form factor desktop casing with motherboard (left) and hard disk drive (right) and power pack (middle).

However, a dis–aggregated system configuration though desired is not technically realizable. This is because the power pack is not able to send simultaneous signals for switching between multiple motherboards (two multiple motherboards). This switching is essential for deploying the motherboards to be used in different roles while they are controlled by a single processor. The capacity here can be realized in a server with sophisticated capacity but challenging in a less sophisticated desktop computing system that is used here due to financial constraints.

The configuration of the computing system showing the placement of the Aluminium casing in the main chassis of the desktop computing system (with ATX desktop casing) is presented in Figure 7. Figure 7 shows ice blocks placed on the lid of the Aluminium casing. The Aluminium casing is housed within the ATX desktop casing. The case in Figure 7 is a scenario showing the layout of the components used in the procedure. The Aluminium casing in this case does not host any computing component.

A case showing the hard drives placed in the Aluminium casing in the within the ATX desktop casing is shown in Figure 8. There are four hard drives within the Aluminium casing that are connected via cables to a separate experimental set up (comprising ATX desktop casing and Aluminium casing hosting different components). The Aluminium casing has inlets on its side enabling the passage of cables to the separate and external experimental set up. An example of a separate experimental set–up to which the set–up in Figure 8 is connected in Figure 9. The set – up shown in Figure 9 hosts the motherboard (with on–board memory and processing capability) and is placed within a polythene water proof material. This is done to protect the motherboard from water which can lead to the occurrence of short–circuit.

The case in Figure 9 shows the placement of the onboard motherboard in the experimental procedure. In this case, the fan aboard the motherboard has been removed. In conducting the performance evaluation, the ice was added at the beginning and placed in the polythene water proof material. This was done before powering the components of the computer entity. Initially, the ice was solid with minimal liquid water dripping from the plastic. The temperature observed at this stage was very low as recorded by the digital thermometer device. This applied to components in both ATX form factor computer casings.

The motherboard in the Aluminium casing prior to being placed within the ATX desktop computing system casing is shown in Figure 10. The set up shown in Figure 10 is covered with main lid of the Aluminium casing and wrapped with the polythene to prevent water entry. Ice packs are placed on the top of the resulting experimental set–up. The resulting set–up is shown in Figure 11.

Figure 7 – Layout showing Aluminium Casing with overlaying ice block in ATX desktop computer casing.

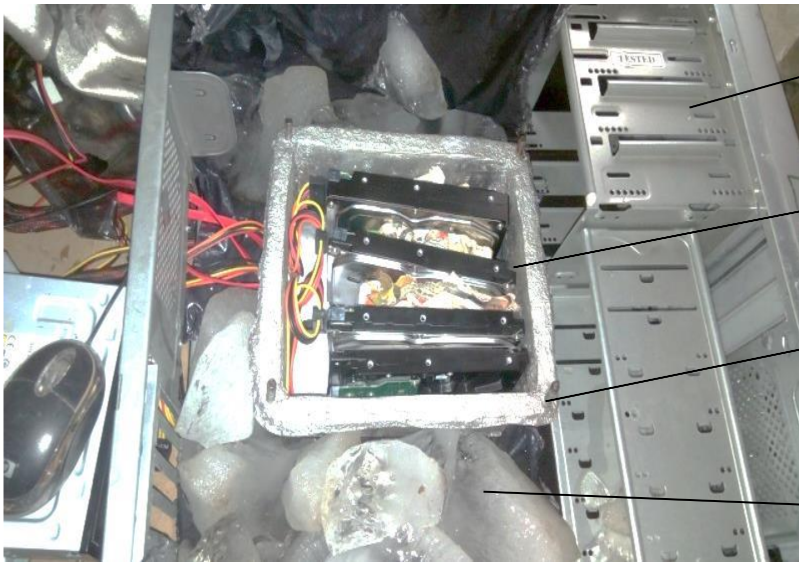

Figure 8 – Hard disk drives in Aluminium casing being cooled by ice blocks with connecting cables for signal transmission.

The effectiveness of the ice – water mixture is improved by increasing the exposed area i.e. the surface area of the ice. This is realized by crushing the ice and putting the crushed ice besides the aluminium casing hosted in the separate ATX computing casing. This is the case for the scenario presented in Figure 5. The ice was pre-loaded in the casing prior to powering all the components. This was done to avoid the occurrence of electric shock since some handling was necessary at this stage. It was observed that the hard disk drive array was non–functional after the provision of electrical power supply.

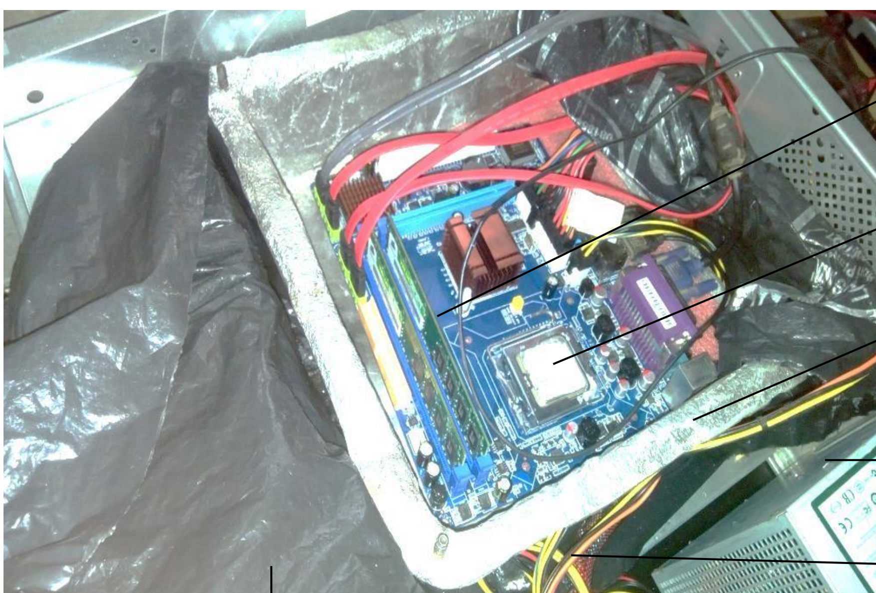

Figure 9 – Motherboard (with fans detached) showing connection to power pack housed in the Aluminium casing.

Figure 10 – Motherboard placed in aluminium casing being placed into the plastic plane and the ATX form factor casing.

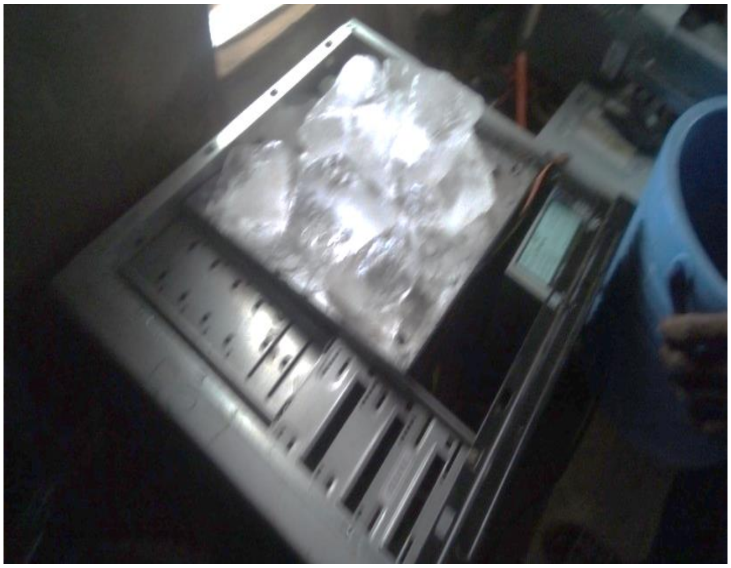

Figure 11 – Placement of additional ice blocks for cooling prior to commencement of performance tests and observations.

The observed challenge was addressed by powering the hard disk drive array using unutilized power connectors from the power pack unit providing the motherboard and processor with alternating current. However, this was a departure from the original design.

5.4 Post Set – Up Computing System Behavior

The completion of the experimental set–up is followed by the evaluation of the system performance. The behaviour of the components of the desktop computer system was also observed. The hard disk drive array was observed to become functional after implementing the change in the prototype design. Hence, it was concluded that the hard drive was designed to function in the presence of a switching mechanism i.e. function initiation trigger which was absent in the case of the initial conceptualization. In this case, the motherboard had a switching component (the port beside the main powering port). Hence, the hard disk was detected by the operating system.

Initially, four hard disk drives were intended to be used. However, we had to add an additional CD-ROM drive to achieve the installation of the Windows operating system. The CD-ROM drive derived its operational power from the powering unit supplying alternating current to the motherboard and the processor. The inclusion of the CD-ROM was also a change from the original design. This is because the power consumption of the CD-ROM exceeded that of the hard disk drive array.

The CD-ROM and the windows OS installation proceeded as intended. The installation procedure commenced after successful execution of hard disk drive formatting, selection and configuration. These processes were executed with the ice already loaded for the intended cooling of the computer system and with the motherboard onboard fan removed. The installation commenced smoothly until it was observed that the windows (with scrolling blue icon) awaiting final desktop display following installation was non–responsive. The screen later went blank after some time. This was not expected and we proceeded to troubleshoot the system.

Prior to this it was observed that the processor reached a peak temperature of $40.6^{O}C$ despite the presence of solid ice in the ATX casing. In response to the temperature build–up, we added more blocks of ice and the temperature measured was noted to decrease with the temperature sensor indicating a low temperature. It was observed that the installation proceeded smoothly after adding more ice. This drop in processor temperature was followed by another event. It was observed the installation process which was at the final stage was no longer responsive. This was observed due to faulty electronic circuit in the desktop computer's motherboard. The procedure of troubleshooting commenced and this could not be resolved during the procedure. Hence, the continuity in the conduct of the procedure was interrupted.

During the procedure, the total mass of ice used for the overall proof of concept was less than that calculated theoretically. In addition, the casing was exposed to the environment. This was necessary to ensure that environmental effects were considered to the fullest extent possible. A constraint that prevented the loading of significant ice for the cooling was the size of the ATX form factor casing. The casing could barely provide enough room to use 6kg of ice for cooling when we had determined that about 15kg of ice was theoretically required for cooling. Calculations show that 15kg of ice was required to provide cooling for the motherboard.

However, the use of roughly 5 kg of ice provided operations for *44mins 37 seconds*. Hence, it is recommended that a bigger casing with capacity to hold 15 kg of ice be used. However, it was challenging for us to obtain such a casing at this point due to capital and financial constraints. Secondly, it is recommended that the hard disk drive array be powered separately and not like used in the arrangement for the proof of concept. This is necessary to avoid increasing the load on the power pack that supplies the motherboard with electrical power. The experimental procedure that has been described was conducted on August 09, 2017 in Oyo Town, Oyo state between the hours of 08:10 am–09:48am. The minimum temperature and maximum temperature values are measured to be $2^{O}C$ and $37^{O}C$, respectively.

5.5 Aspects on Scalability and Realization of System Design

The proposed system design i.e. the non–disaggregated system whose performance is investigated via the conducted and described procedure is intended for data centre operators. Being intended for final use by data centre operators, additional design consideration is required. In realizing the achievement of a real-life deployment, the computing entity being used will be placed in an emulated underwater environment. The emulated underwater environment can be achieved via a large aquarium or aquaria system. The aquaria system in this case will have an underlying network enabling communications between data centres in different aquaria. Such a communications network is integral but its performance has not been tested here.

Instead of using a personal desktop computing system, a server or server farms will serve the role of the computing entity. In this case, the server's components are shielded from water by using a chassis that has good heat conduction property but dis–allowing water entry into each server interior. A real implementation will comprise a water ice mixture leading to the emergence of cold water which enters into a pipe and maintains a cold temperature environment. Servers are submerged in this cold temperature environment.

Therefore, the realization of the proposed system requires the provision of an underwater environment. This is realizable via a large aquaria or network of large aquaria systems. In addition, the aquarium or aquaria requires the supply of ice via an inlet of sufficiently high diameter to accommodate the ice packs. Furthermore, a steady supply of water and ice packs is required to ensure that the underwater environment consistently has a low temperature. This design option has been chosen to ensure that servers are maintained at a low temperature.

The duration of the test is less than an hour and falls short of the expected uptime for a server farm in a data centre. However, continuous supply and maintenance of the ice – water mixture environment enables the continuous functioning of a data centre or server farms realized using the proposed design.

6 Conclusion

The paper proposes the use of a pseudo–marine environment for the cooling of computing systems. The computing system is realized via a personal desktop computer system. In addition, the research designs a minimum function prototype of a dis-aggregated data center and presents preliminary performance test results. This is done while identifying design challenges and discussing the performance test results. The results presented in this research constitute an initial proof of concept for a desktop computer system in a Tropical African location. It also demonstrates the functional viability of using pseudo–marine based desktop computing system in Nigeria. Future work aims to investigate the functional viability for more computing systems, re–design the computing system with a new switching technique to support multi–scale dis–aggregated computing systems and explore larger sized pseudo–marine environments.

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