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REVIEW

The immersion cooling technology: Current and future development in energy saving

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Abstract The world's energy consumption shows an increasing trend. Unfortunately, it is still dominated by the use of fossil energy. This condition results in concerns that an energy crisis will occur due to running out of non-renewable energy and an environmental crisis of global warming. One of the technology sectors that consumes a lot of energy is computer servers and data centers. This technology sector is growing rapidly due to the increasingly complex computing and larger data. One of the main causes of inefficiency in this technology is a decrease in performance due to an increase in temperature. Therefore, effective and efficient technology is needed to overcome the increasing operating temperature of computer servers and data centers. One of the most prominent cooling technologies to solve this problem is immersion colling. This method has developed in various types with their respective advantages and disadvantages according to application needs. Therefore, review literature is needed to comprehensively discuss the development of immersion cooling technology from the past until now and projected developments in the future. In more detail, this paper comprehensively compiles the latest findings of immersion cooling technology which includes an overview of the cooling system, history, implementation, construction type, and advantages.

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Contents

1. Introduction

Almost all countries are currently highly reliant on energy in their growth processes, resulting in an increase in global demand. According to British Petroleum primary energy consumption climbed by around 5% in 2019, the quickest rate of growth since 2013 [1]. Among the various types of fuels used in daily life, natural gas, saw the greatest rise in energy consumption, followed by petroleum and coal. Renewable energy still does not account for a sizable fraction of the energy mix, despite its importance and widespread use. In 2020, renewable energy amounted for around 10% of global final energy consumption [2]. This percentage, however, is likely to rise in the future as countries lessen their reliance on fossil fuels. Meanwhile, petroleum consumption as a fossil energy source and primary fuel for the world reached around 34.2 percent of global energy consumption in 2017 [1].

Numerous significant events and discoveries worldwide have sped the transition from fossil to renewable energy sources. These factors include growing concern on energy security and climate change, political and social pressures to rein in greenhouse gas emissions, rising and fluctuating oil costs, and a heavy reliance on foreign energy supplies [3]. Therefore, until 2035, the global energy industry's development will be primarily focused on meeting the worldwide demand for energy resources to support economic growth and population increase, as well as strengthening resistance to climate change [4]. Furthermore, dynamic changes are occurring in power systems, as indicated by the development in renewable energy.

Numerous developing countries have decided to increase their investment in renewable energy in order to reduce the significant reliance on fossil fuels. Global investment in clean energy has increased from 18% to 42% since 2004. China, Brazil, and India are the world's first, fifth, and eighth largest investors in renewable energy, accounting for 37% of worldwide clean energy investment [2]. The distributed energy business and digitization are critical stages toward fossil fuel abolition. To ensure the uninterrupted operation of future decarbonizing power systems, a quantum leap in technology development is necessary.

One of the organizations with huge energy consumption is a data center, this is a room or building that houses IT (Information technology) equipment, electrical systems, HVAC (Heating, Ventilation, and Air Conditioning) systems, and other related infrastructure, as well as providing critical services that ensure the equipment is kept secure and reliable [5,6]. Between 2000 and 2005, the amount of electricity consumed by data centers worldwide doubled, then rose by around 56% between 2005 and 2010. According to recent energy figures, the data center business accounts for 1.3 percent of global and 2% of US electricity usage. Indeed, the United States consumes between 25% and 35% of global data center electricity consumption [7]. According to a congressional report from the Environmental Protection Agency (EPA), data centers consumed 1.5 percent of America's electricity in 2006 [8,9]. The continued expansion has exacerbated the energy consumption problem. The cooling and electrical systems consume the majority of energy. Around 52% of electricity consumed in a data center is by IT equipment, 38% by cooling systems, and 10% by other equipment [10]. The majority of energy supplied to information technology equipment is turned to heat. Data centers have a high sensible heat load but a low latent heat load, necessitating constant cooling. Computers of the first generation were based on electron tubes and used a water-cooling system [11]. Air cooling systems were later developed to take the role of liquid cooling due to their reliability and feasibility in comparison to liquids. From a digital standpoint, the constant growth of electronic products causes the heat density of information technology equipment to rapidly increase [12], necessitating the development of liquid cooling systems. Liquid cooling technology improves the efficiency of data centers and enables heat to be reused [13,14]. It is possible to provide electricity to a large capacity chiller using an immersion cooling system in particular [15].

As stated previously, this paper analyzes the most promising cooling system, immersion-colling, for reducing power use and increasing energy efficiency. Since the first discovery of immersion cooling in the 19th century for usage in transformers until now, it has been developed rapidly for various applications in the latest technology. Initially, the method of immersion cooling with mineral oil only focuses on maintaining electronic components' temperature to prevent overheating [16]. However, current immersion cooling functions to save energy. Therefore, the latest findings need to be presented in a comprehensive literacy that can be easily understood by laypeople to practitioners and researchers with a higher level of understanding. To ensure simple literature for the laypeople, this paper begins with an introduction to cooling systems in general, followed by their history, applications, and types. Furthermore, the latest findings on immersion cooling concerning its energy saving benefits, are reported for the advanced literature.

2. General cooling system

Over the last decade, technological advancements have resulted in mass manufacture of electronic devices, increasing energy consumption during the manufacturing process and subsequent use of the devices. A nanotechnology approach has also been presented, which reduces the size and cost of the devices but has significant issues in terms of thermal management due to the high-power density, which results in increased heat output. Meanwhile, increased heat generation in the device typically results in decreased productivity and eventual failure.

It has been noted that increasing the temperature above 75 °C has the potential to exponentially increase the rate of failure [17]. As a result of the desire to shrink the size of electronic gadgets and boost their productivity, cooling systems have become critical. Numerous solutions have been developed in recent decades as a result of conventional methods' failure to meet the ongoing demand for these devices, with several of them outlined below.

2.1. Water-cooling system

The water-cooling system's role in an automobile, which is to circulate water between the heat source and the cooling radiator, is equally applicable to computer device and data center. In these systems, coolant is directed to the CPU, which generates the majority of the heat, while the remaining components are cooled by air. For example, in a personal computer, the components that generate the most heat are the central processing unit (CPU) and graphics processing unit (GPU), as demonstrated by the significant heat generated throughout each process. It is critical to highlight that the rapid advancements in technology and communication have increased the growth of data centers and energy consumption globally over the last few years [18]. As a result, it is necessary to place a greater emphasis on data center cooling systems, which have been claimed to consume more than half of energy via heating, ventilation, and air conditioning operations [19,20]. Additionally, it has been observed that the increasing power density of microprocessors is resulting in a large increase in data center mechanical cooling requirements [21,22].

Water cooling is a promising cooling technology that has been the primary choice for many data centers when it comes to lowering the temperature of the processor and other components such as graphics cards [23]. This is considered required because the speed of processors used in recent years has increased fast, resulting in an increase in the amount of heat generated. Water is used to cool these devices because it absorbs heat approximately 30 times faster than air [23], allowing the processor to function at a higher speed and with less noise. Due to the possibility of substituting other liquid substances for water, this water-cooling system is occasionally referred to as a liquid cooling system. Its primary advantage is that it has a larger heat transfer capacity per unit, allowing for a smaller temperature differential between the Central Processing Unit (CPU) and the cooler [6]. Additionally, it has a greater input temperature, which reduces the requirement for active heat rejection equipment and enables the reuse of generated heat [24]. Additionally, the method is efficient and may be applied on high-density servers [25], such as the one shown in the following image.

According to Fig. 1, the water-cooling system consists of two liquid loops: (i) an inner loop with a cooler that transports heat from the server to the heat exchanger; and (ii) an outer loop with inside water that facilitates heat transfer from the heat exchanger to the outdoor water-cooling tower via evaporation. It is critical to know that data centers often employ cold water temperatures of 7 °C to 10 °C to cool servers [10]. Additionally, the chiller typically keeps extracting heat from the water after the tower has taken some of it. This system is capable of cooling hundreds or even thousands of computers while consuming 22% less energy than the average air-cooling system [26]. Additionally, it enables the use of coolers with significantly superior thermophysical qualities to air, resulting in a significant improvement in thermal resistance and a decrease in energy usage in data centers via greater cooling temperatures and reduced airflow rates [27]. Additionally, water cooling can be administered directly or indirectly [28], as detailed in detail in the following subsections.

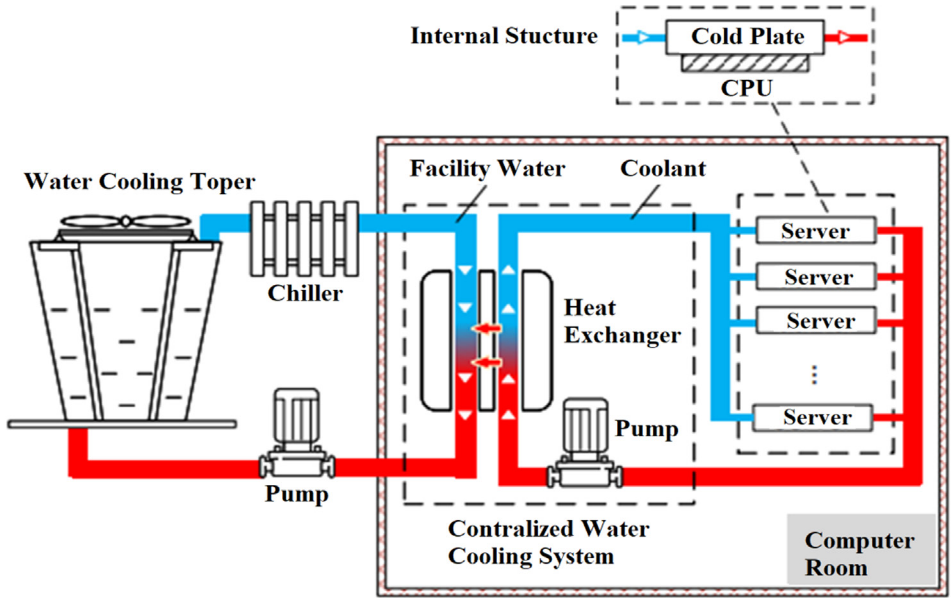

Fig. 1 Water cooling design in the data center [25].

2.1.1. Indirect water-cooling

Indirect water cooling is the technique of eliminating heat from a source without direct contact with the water. It entails substituting an evaporator or a water-cooled heat sink for the traditional air-cooled heat sink [29]. Additionally, the classic indirect liquid-cooled system is typically equipped with a cooling plate and water blocking mechanisms. Meanwhile, recent research in this field has tended to focus on microchannel heat sinks and their increased efficiency as a result of their superior heat transfer properties as compared to traditional indirect water-cooling systems [30,31].

Fig. 2 shows the coolant distribution unit (CDU) supplies the cold water closely controlled from the external source to the internal closed-loop cooling installed in the electronic device [33]. The cooling water is routed to racks, servers, and chips inside the device depending on the mechanism. Meanwhile, the installation of a closed water-cooling system in the data center requires adapting it to the layout of the facility and server. It was also reported that the fluidic connection usually limits the easy hot-swap access to server equipment which is normally present in air-cooled servers but this problem fixed using the fluidic quick-disconnect connector [34].

2.1.2. Direct water-cooling system

Direct water cooling differs from indirect water cooling in that the coolant comes into direct contact with electronic components [35]. Fig. 3 shows the difference between direct and indirect water cooling systems in a solar power plant application operated with a supercritical CO_2 cycle [36]. The adaptability of the coolant is one of the primary advantages of this technology, since no closed enclosures or pipes are required to guide and sustain fluid flow to the server. Due to latent heat transfer, this system comprises a phase-change phenomena that results in a uniform temperature profile on the surface of the heat source [37]. Due to the absence of a hermetically sealed enclosure, it also runs at atmospheric pressure, which results in a low-maintenance heat exchange process [33]. However, further precautions must be taken to avoid fluid loss and degassing of the air and moisture infiltration system [38,39].

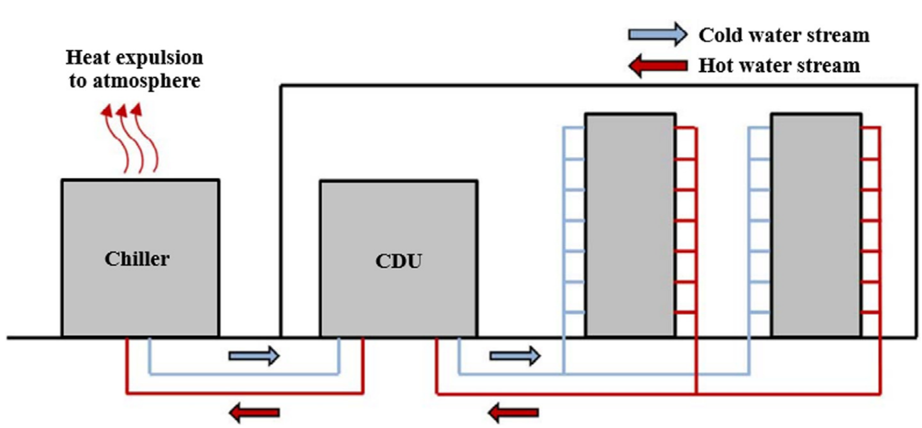

Fig. 2 Typical schematic diagram of indirect water cooling system [32].

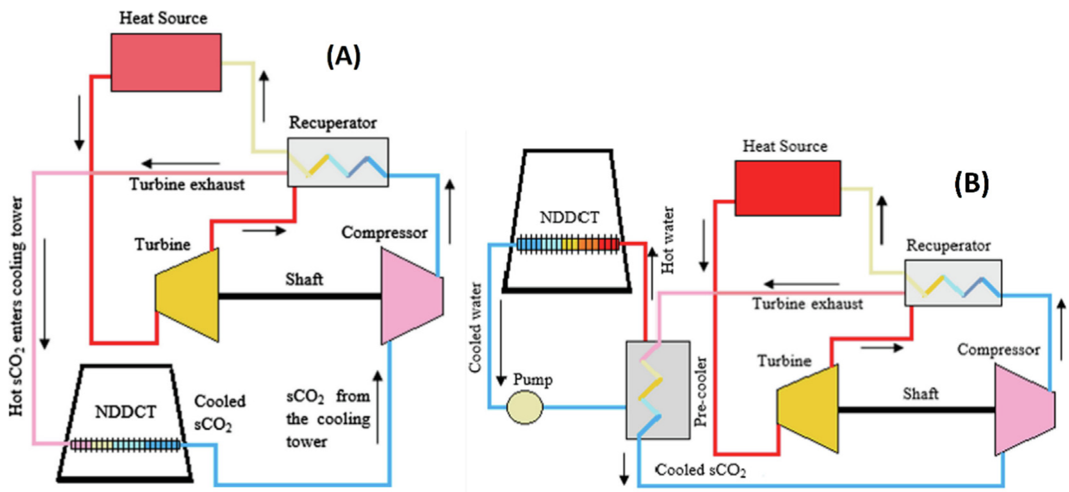

Fig. 3 Direct (A) indirect (B) water-cooling system [36].

2.2. Air-cooling system

Air-cooling is a heat-removing method that works by expanding the surface area and increasing airflow over an object through the addition of cooling fins to the surface and using a fan [40]. It is usually applied to vehicles [41], laptop computers [42], electronic [43], computer room [44,45]. The process of an air-cooled motorcycle engine involves forced convection to release heat into the [46,47]. This occurs through the absorption of the surrounding air by the fan into the fins provided on the outer surface of the engine cylinder block which then transfers the heat from the surface into the air [48]. Meanwhile, the principle of air-cooling in computers involves the absorption of heat from the CPU and keeping it away from the hardware. The heat is transferred from the CPU's Integrated Heat Spreader (HIS) through a thermal paste to a conductive base plate usually made of copper or aluminum, and later to the heat pipes installed in the electronic cooling system [48]. These heat pipes usually transmit energy in the form of heat to the thin metal fins that form the heat sink attached to the CPU package to increase its surface area for heat dissipation [49]. It is important to note that that heat sinks with heat pipes can offer up to a 20% increase in thermal performance when compared to aluminum or copper [50] but they are more expensive than the normal active heat sinks [51]. Moreover, the warm air passed into the heat sink is designed to be dissipated by the fan installed in the system [52] and an increase in the fan speed is expected to create a greater air flow rate through the heated fin surface, thereby, increasing the heat dissipation rate. This increase, however, causes unwanted vibration as well as an increase in noise level and power consumption [53]. Fig. 4 shows cooling the computer room by utilizing air circulation [54]. Utilizing external air circulation for cooling the computer room saves 56.1% compared to using air conditioners [44].

The effectiveness of air-cooling varies depending on several factors such as the configuration [55], airflow ratio [56,57], room arrangement [57,58], heat exchanger selected [59] and energy management [60]. Moreover, larger air conditioners usually dissipate heat better but there is not enough room for bulky cooling solutions, especially in PCs of smaller sizes. It is important to note that the difference between the application of air and liquid cooling systems in computers is that the air coolers designed using fans and heat sinks are relatively cheaper [50].

3. General description of immersion-cooling method

The advanced technology of immersion cooling method involves the reduction of heat component using a dielectric liq-

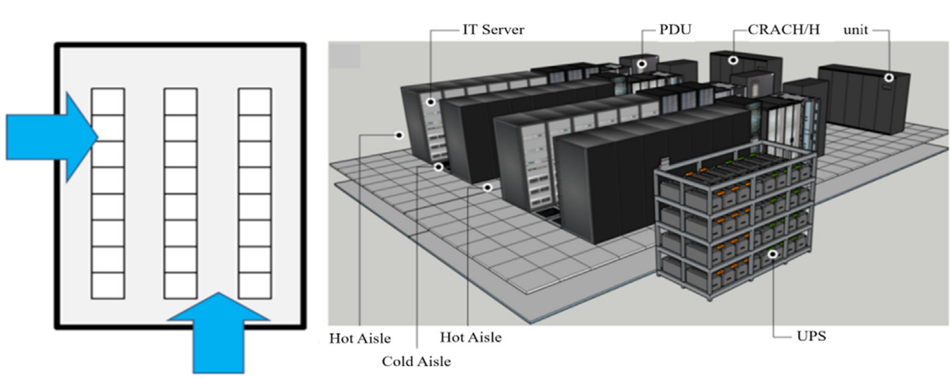

Fig. 4 Air-cooling system in Data Center [54].

uid [61] which absorbs the heat source by convection and release to the environment through either a single-phase or two-phase system [6]. Some of its advantages include a high heat transfer coefficient, stable hydrodynamic flow, and the ability to directly cool hot components using liquid [62]. Examples of dielectric materials that are popularly used today are mineral oil (MO) and virgin coconut oil (VCO) [63]. This cooling method is generally used in electronic devices such as computer servers [64-67], data centers [68-70], solar PVs [71-74], batteries [75-79], and power transformers [80-83].

Immersion-cooling has the ability to cool the entire surface in comparison with indirect cooling and this improves the temperature uniformity by reducing the local heating effect on the positive and negative electrodes [84]. It is possible to ensure high efficiency by using a cooling medium with high thermal conductivity, low viscosity, and high heat capacity [84]. Some problems are, however, associated with this system and these include electric short circuits and electrochemical corrosion. Therefore, the main consideration in the selection of dielectric material is the ability to avoid an electric short circuit [85,86] as well as safety and health concerns, non-toxic ability, good chemical stability, and non-flammability. The other potential cooling media are deionized water [87], silicon-based oil [62], and mineral oil [62].

4. Immersion-cooling history

The discovery of the immersion system was initiated in the 19th and 20th centuries based on the discovery of electromagnetic induction by Sir Michael Faraday on August 29, 1831 and Joseph Henry. The device invented by Faraday et al. is a primitive transformer because it can only open and close direct current since there was no alternating current at the time. Moreover, C. J. Page manufactured an auto-transformer in Washington, D. C in 1836 while the first closed-core transformer was built on September 16, 1884 under the supervision of M. Dery, O.Blathy and K. Zipernovsky at the GANZ Plant in Budapest. This means the immersion of electrical systems, especially transformers, in a dielectric fluid for thermal management was used before 1887 [88].

The first explicit mention of the use of oil as a coolant and insulator was recorded in 1899 in a patent filed for a Constant Current Transformer by Richard Fleming of Lynn, Massachusetts [89]. Meanwhile, the first-ever research which specifically used liquid dielectrics to cool "computers" was conducted in 1966 by Oktay Sevgin of IBM [90] while Richard C. Chu and John H. Seely working for IBM patented an "immersion cooling system for modularly packaged components" in 1968 [91]. Subsequently, Seymour R. Cray Jr., the founder of Cray Research, LLC. also patented "Immersion-cooled high-density electronic assembly" [92]. Cooling microelectronic components with liquids began to attract serious attention in the mid-1980s, when IBM, Honeywell, Sperry-Univac, Control Data, and Hitachi all introduced indirectly water-cooled mainframe computers [93]. Moreover, Cray T90 was released using a liquid-to-liquid heat exchanger and a one- or two-phase immersion coolant for heat removal in 1995 [94]. Meanwhile, the presence of CMOS in the CPU was also reported to have led to significant energy savings which quickly reduces the cooling constraints of high-pressure control (HPC) systems. The immersion systems started gaining attention again in the second decade due to the increased thermal properties of chips.

Research on immersion systems is observed to be growing in the 21st century as indicated by the establishment of Hardcore Computer Inc. in 2006 based on the concept of a closed-chassis-style PC for gaming [95]. In 2009, Green Revolution Cooling rebooted the concept of open bath immersion cooling by bringing commercial bath immersion systems to the HPC (High-Performance Computing) industry [96]. In 2010, Midas Green Technologies established the world's first commercial immersion cooling data center while the Iceotope launched the first commercial rack-style closed chassis-based technology, specifically designed for data center deployments in 2011 [96,97]. In 2016, Asperitas created the first pumpless natural convection circulating with a high-density open-bath immersion system in one phase [98]. This was the year cryptocurrencies began to rise and served as the main and significant driving force behind the immersion system due to the high TCO (Total Cost of Ownership) gains which are highly valued in crypto-mining. The period allowed many immersion technologies to gain important experience and improvement as well as the existence of a large volume of start-ups in the immersion cooling domain in the year 2017. Most of them are related to cryptocurrencies and this further increased the power and cooling challenges in the data center industry [99]. Moreover, Open Compute Project officially embraced the new project under the Rack & Power as part of ACS (Advanced Cooling Solutions) in 2018 while the first documented industry standard for immersion systems was presented at the OCP (Open Compute Project) summit in San Jose in 2019. Midas Green Technologies designed and built the first immersive Data Center in the same year [100].

5. Immersion cooling implementation

5.1. Solar photovoltaic

Cooling of concentrated photovoltaic cells is very important as with other electronic devices. This is due to the need to manage the heat generated from the cell properly in order to avoid reducing its efficiency [101-103]. Therefore, a reliable heat dissipation system is required to ensure the efficient performance of photovoltaic cells [104]. One of the solutions considered suitable by some experts is the placement of empty cells directly in the fluid [105] and this led early studies to focus on the expected electrical and optical effects of liquids on cells. Over time, the research advances with new revelations regarding PV cell cooling such as the possibility of using shallow liquid layers to surround the cells to capture light [106]. It is also important to note that cell fluid immersion does not end with surface wetting and optical advantages but also allows the direct immersion of a concentrated photovoltaic cell in a liquid [107]. Moreover, the absence of a contact wall between the cell and the liquid indicates the possibilities of effective cooling for the cell [107]. Fig. 5 shows the solar panel immersion cooling by utilizing lake water cooling [108].

The energy produced in solar PV devices normally reduces as the temperature increases [109-112]. The photon energy radiates more optimally on a sunny, cloudless, and non-polluting day [113] but also increases the surface temperature of the PV [112]. Therefore, cooling is needed to main-

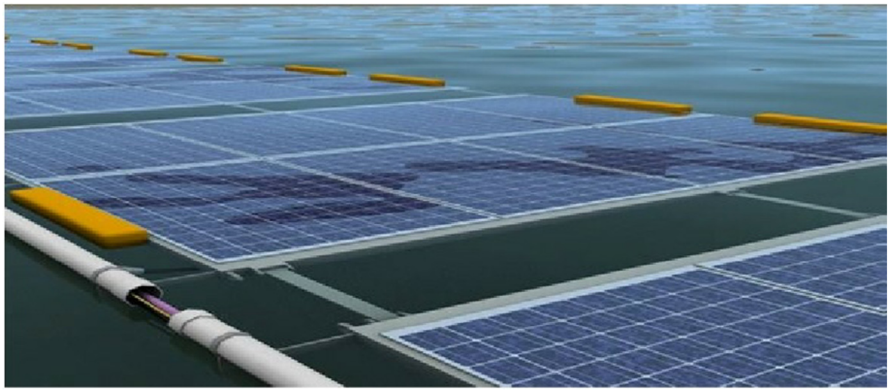

Fig. 5 Illustration Solar Photovoltaic Cooling [108].

tain optimal energy efficiency as indicated by the increase in the performance of a solar PV cooled by up to 47% in Peng et al. [114].

Cooling of the photovoltaic cells has also been reported to be important because of the energy efficiency dilemma [115-117]. It is, however, important to note that they can be cooled using both water and air immersion. Moreover, direct immersion is preferable for the process of cooling concentrated photovoltaic cells compared to other mechanisms [118]. It is also possible to increase the efficiency of the photovoltaic module using a water-cooling system but this mechanism is not ideal for cloudy days [119,120].

5.2. Data center

The computing speed of the data center computers and servers reduces when there is an increase in temperature [121,122], thereby, leading to the consumption of more energy under the same workload [123]. Data center with conventional cooling consumes the most energy, reaching 38%[6]. However, immersion cooling was tested on a 2 kW power converter operating at 97.2% efficiency in deionized water [62]. An uncontrolled increase in temperature can also damage these components but immersion-cooling technology was observed to have succeeded in increasing energy efficiency [97,124,125]. The use of VCO dielectric liquid or mineral oil has proven to be a data center energy saving and does not cause damage to its components [63]. Fig. 6 is an immersion cooling scheme in a data center.

5.3. Cryptocurrency mining

Bitcoin is a peer-to-peer payment system and cryptographic currency introduced as open-source software in 2009 [109-112,126]. It allows a user to attach a free client or wallet to the computer to send and receive payments using a Bitcoin address. The participants are known as miners and are charged with the responsibility of verifying transactions into blocks and broadcasting them to the public blockchain using a proof-of-work concept with a secure hashing algorithm (SHA) [127-130]. There are fees associated with verifying transactions with two features such as the capital to verify the cost and power consumption of the hardware used. It is important to note that the consumption of more power for 'hashing' usually leads to more profit for the miners in the form of big prizes. The miners were first using conventional CPUs to perform SHA but GPU

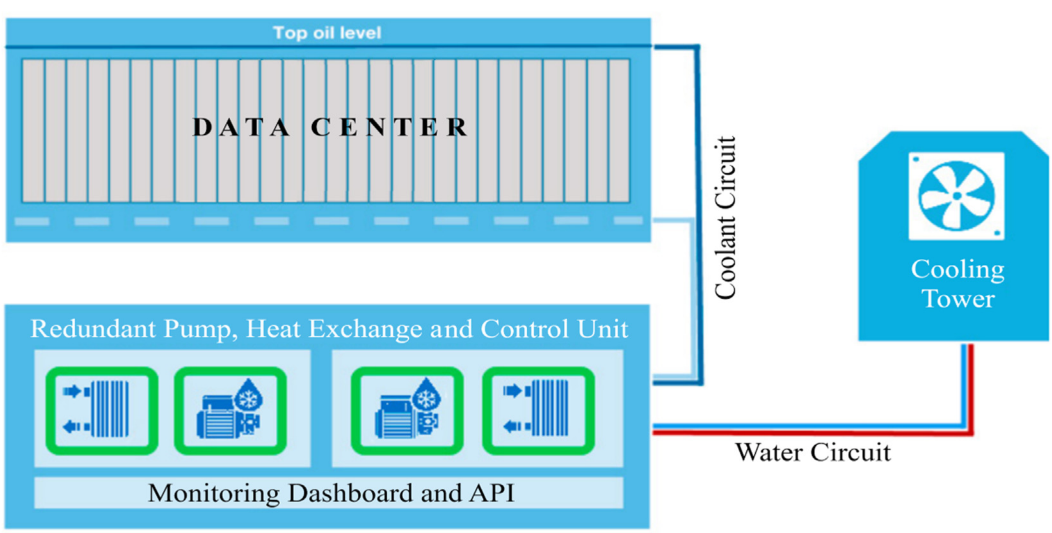

Fig. 6 Data Center [96].

(graphics processing unit) was found to be more cost-efficient, thereby, resulting in excess gain [131,132]. Therefore, the gamers realize that they have a "money-making machine" as Bitcoin grows in popularity and started competing to create the most efficient mining hardware. The rapidly growing power densities of mining clusters coupled with their short life cycles make the deployment of conventional air-cooled data centers a challenge [133].

The 2-phase immersion is observed by many as a viable technology to meet the power density and energy efficiency needs of the high-performance computing market. For example, a power density 100 times higher than a typical air-cooled server has been cooled using a superior method with higher efficiency than direct water cooling [134]. Moreover, the 2-phase immersion cooling was implemented in the IT industry by avoiding the risk despite numerous demonstrations in many countries but the new technical approach has simplified its implementation process [33]. Therefore, the passive 2-phase immersion cooling cycle is shown in Fig. 7.

5.4. Electric car battery cooling system

Battery performance decreases when used at temperatures greater than 45 °C [135] due to the reduction of the porosity and pore connectivity at high temperatures which subsequently leads to a decrease in the uniformity of the battery current [136]. However, a very cold operating temperature also has the ability to cause a significant decrease in battery performance [137] as indicated by the findings of Lindgren and Lund that the charging capacity of a battery can reduce by an average of 15% when charged at 10 °C [138]. This means it is important to manage the battery towards ensuring it is maintained at an optimal operating temperature of 20 °C [138] and Dubey, Pulugundla, and Srouji found immersion cooling to be better for this purpose compared to Cold-Plate Based Cooling [78]. Immersion cooling was also observed to have the ability to cool the entire cell surface and improve temperature uniformity by reducing the local heating effect on the positive and negative electrodes compared to indirect cooling [84]. Fig. 8 is a dielectric liquid immersion cooling technology for thermal management of Li-ion batteries [75].

5.5. Power transformers

Additional harmonic losses in power transformers increase the temperature of the components, thereby, reducing their service life [139]. The main heat sources in transformers are the windings and magnetic cores with the larger part of the energy lost to the surroundings as heat during the transformer operation [140]. This problem can be overcome using thermal energy management in the form of immersion cooling which has been reported to be better than the traditional air-cooling technology [141]. The combination of cooling using immersion and fin heat exchanger in power transformers is shown in Fig. 9.

6. Immersion cooling construction type

6.1. Single-phase

A single-phase immersion cooling, shown in Fig. 10, is generally a circulating cooling system without any phase-phenomena [32]. The electronic components are immersed in a dielectric cooler while a server is installed vertically in the thermally conductive dielectric liquid cooling bath [62]. The heat is transferred through direct contact with the server components, cooled through a heat exchanger in the coolant distribution unit (CDU), and finally discharged to the ambient through the cool-

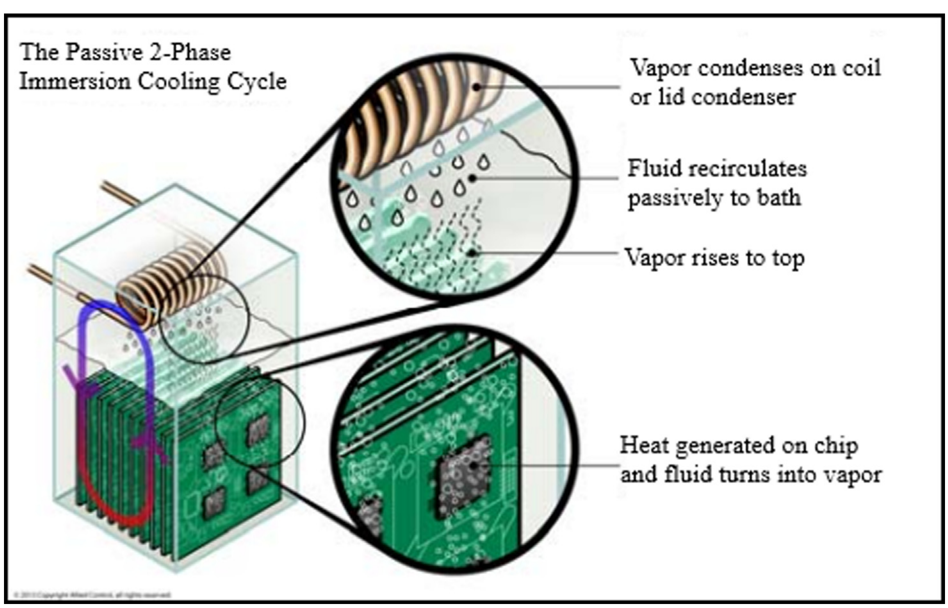

Fig. 7 Passive 2 phase immersion cooling cycle [133].

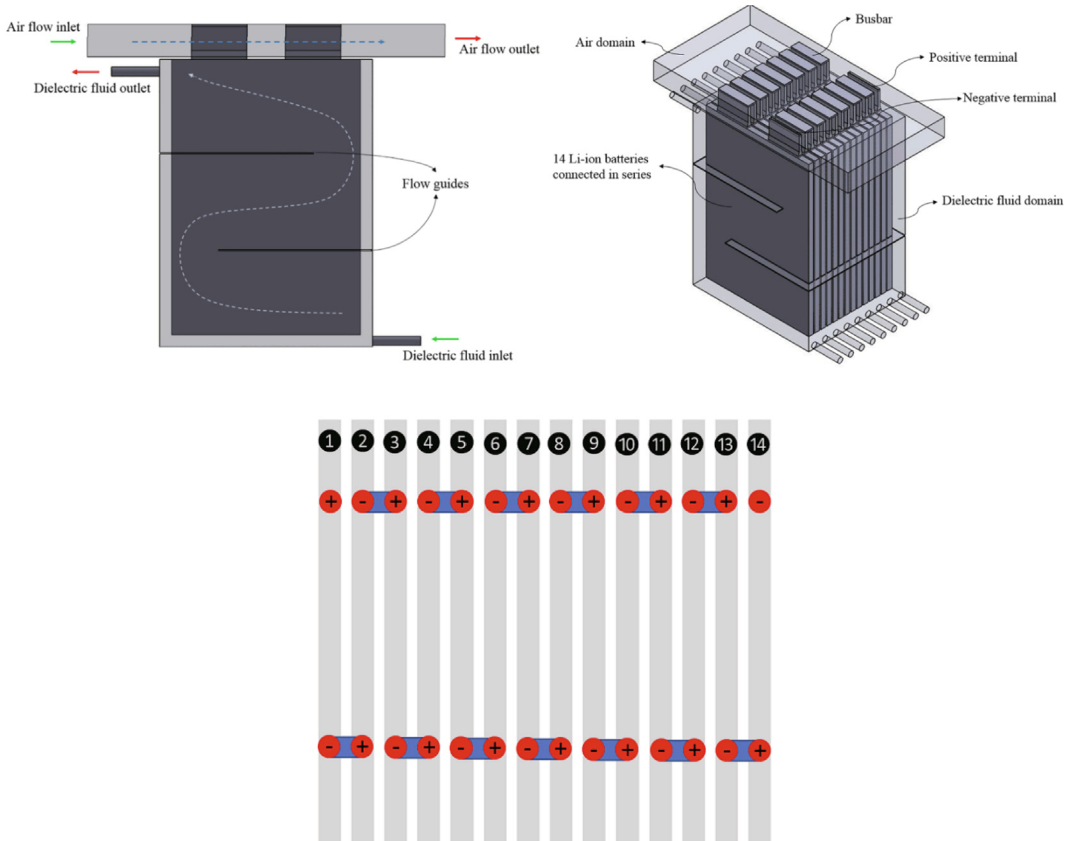

Fig. 8 Electric car battery cooling system [75].

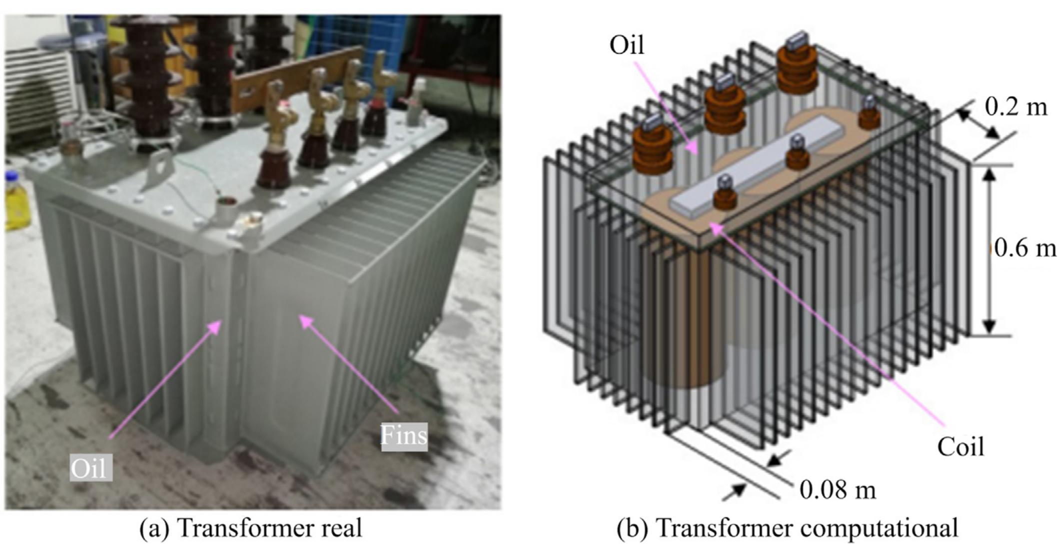

Fig. 9 Power transformers [142].

ing tower [133]. It is important to note that the coolant does not boil in this as opposed to the two phases where the coolant boils and produces steam. Single-phase immersion cooling can lower the temperature of computer components by up to 13 °C compared to conventional air cooling [63].

6.2. Two-phase

The passive two-phase cooling, shown in Fig. 11, is a liquid-cooled approach which also involves immersing electronic components in a phase-changeable liquid placed in a closed box

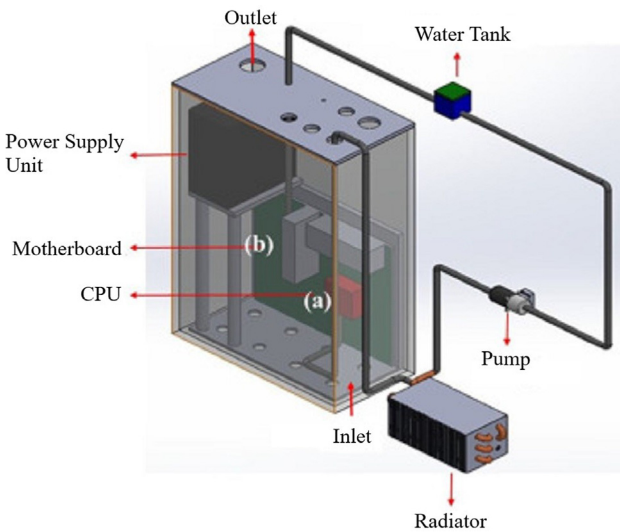

Fig. 10 Single Phase for CPU [143].

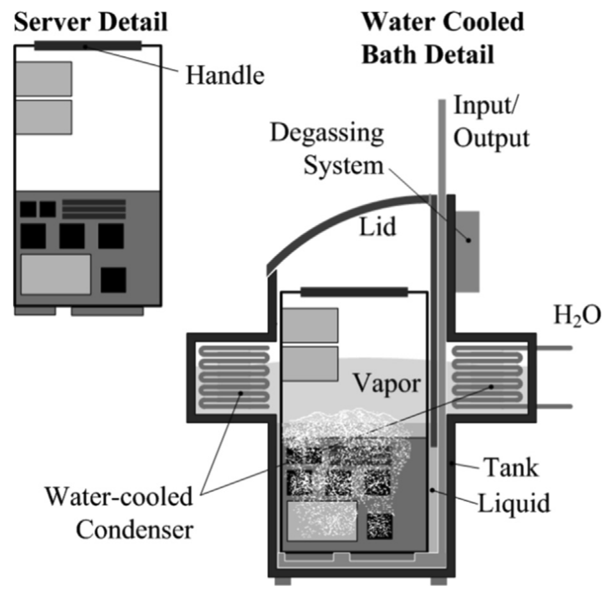

Fig. 12 Water-cooled open bath immersion concept [33].

[100] or in a specially designed liquid bath [144]. This involves a heat transfer process when the surface temperature of the electronic component exceeds the vaporization temperature of the liquid which allows the surrounding liquid to get boiled and become steam, thereby, causing a change in phase [145]. This vapor later rises and condenses further through a water-based condenser applied above the bath. Finally, the heat is absorbed and removed by the coolant and the steam drips back into the liquid bath to be recycled through the system [146]. Vapor bubbles are formed due to the release of heat in the form of evaporation as a result of the temperature of the electronic components being higher than the boiling point of the dielectric liquid [100]. Pond boiling is heat transfer by evaporation of the coolant around the surface and is often applied to cooling of high performance computing systems and nuclear reactor [147].

6.3. Open bath

Open bath immersion cooling, shown in Fig. 12, refers to the liquid-air interface which involves immersing an electronic device in the dielectric liquid placed in the tank in an open state [33]. This system can be fully sealed, but it is always opened from above to service the IT equipment. Open bath immersion cooling works at atmospheric pressure [149] thus, there is no risk of explosion due to high pressure. The system is open so that maintenance of this type of immersion cooling is also easier because it can replace components without opening the pressure valve. However, because this open system also results in the risk of getting dirty quickly due to dust and shrinkage of the dielectric fluid due to evaporation.

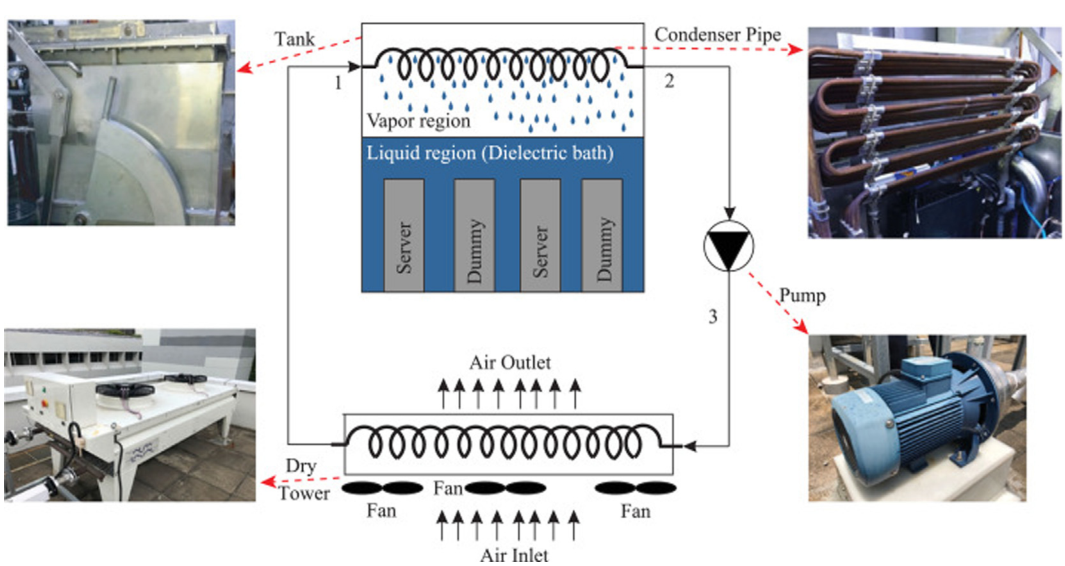

Fig. 11 Two-phase liquid immersion data center cooling system [148].

7. Advantages using immersion cooling as energy saving

Efficient energy utilization is one of the great advantages of liquid immersion cooling technology used in electronics. This is associated with the absence of connectors, valves, and fans observed to be causing large power consumption and inefficiency in the orthodox cooling mechanisms in this system due to the completeness of its technological design [150].

Other advantages of immersion cooling related to energy saving are described in the following sub-chapters:

7.1. Less cost

Immersion cooling is economical due to the fact that there is no need for fans (for certain types of immersion cooling) and the heat is well regulated. Moreover, traditional cooling techniques require a lot of space and contribute to the total cost of ownership. Meanwhile, the liquid immersion cooling technology is denser in terms of server density and this means two of the system can be installed in a place occupied by just one traditional system. The heat captured by the dielectric immersion liquid directly allows less efficient room air conditioning systems to be turned down or even shut down [151].

The use of immersion cooling in the data center does not need to add a chiller and without adding a raised floor so that it saves energy and construction costs [152]. In addition, two-phase immersion cooling for data centers in testing in hot and high humidity areas in Singapore has proven reliable, thus saving cost and space [153]. Therefore, compared to an air-cooled DC system in a data center, immersion cooling on a fixed capital investment is cheaper [68]. For batteries thermal management, immersion cooling is much cheaper and easier to use [154]. Furthermore, immersion cooling for water desalination systems is cheaper based on the price per liter as shown in Table 1 [155].

Table 1 Comparison of freshwater cost among different desalination systems [155].

Type	Productivity (Liter/dissipation heat)	Cost Per Liter ($(USD)/Liter)
Operating pressure 40 kPa, water immersion cooling	10.7	0.012
Operating pressure 40 kPa, natural air cooling	7.2	0.015
Conventional type	3.9	0.035
Vacuum fan, nanoparticles	9	0.035
Water cooling from top surface	27.1	0.013

7.2. Less infrastructure

Traditional cooling methods also require proper arrangements of the infrastructure and equipment as well as the addition of other related features [156], thereby, leading to the utilization of a higher quantity of power [157]. Meanwhile, a liquid immersion cooling system is simple and does not require complex infrastructure to function properly, thereby, leading to lower power consumption and overall operational cost of installation. Infrastructure room with immersion cooling technology 1/3 smaller than traditional Computer Room Air Conditioners [158]. As shown in Fig. 13, the comparison of immersion cooling to traditional Computer Room Air Conditioners, apart from a smaller room, the components are simpler because they do not have to add air conditioner. Therefore, the use of immersion cooling reduces energy consumption for air conditioners and even eliminates it.

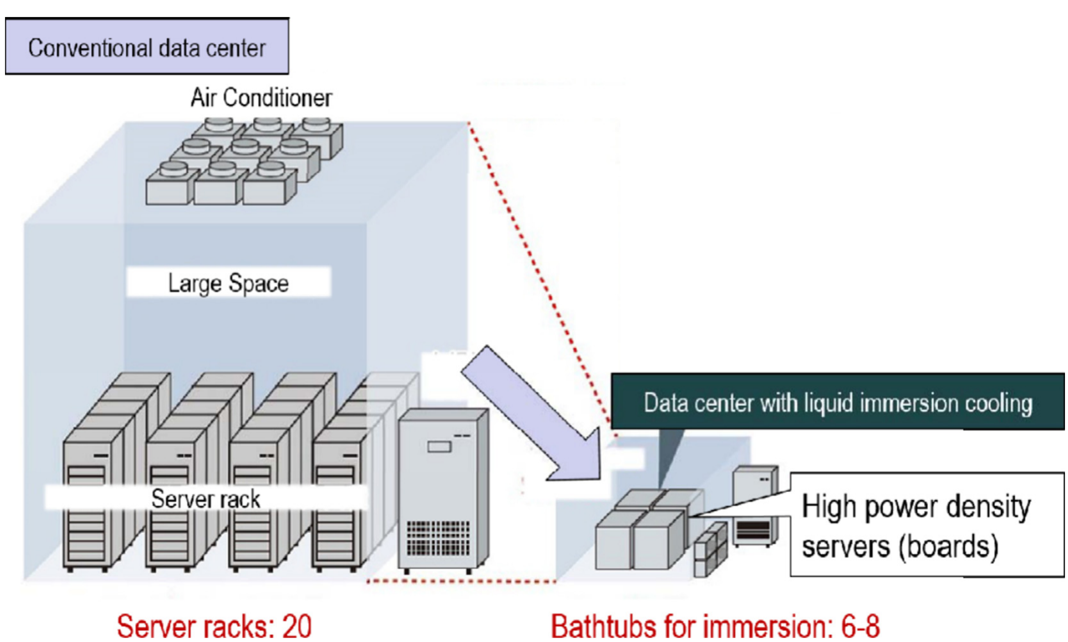

Fig. 13 Comparison of data center's space of Computer Room Air Conditioners to immersion technology [159].

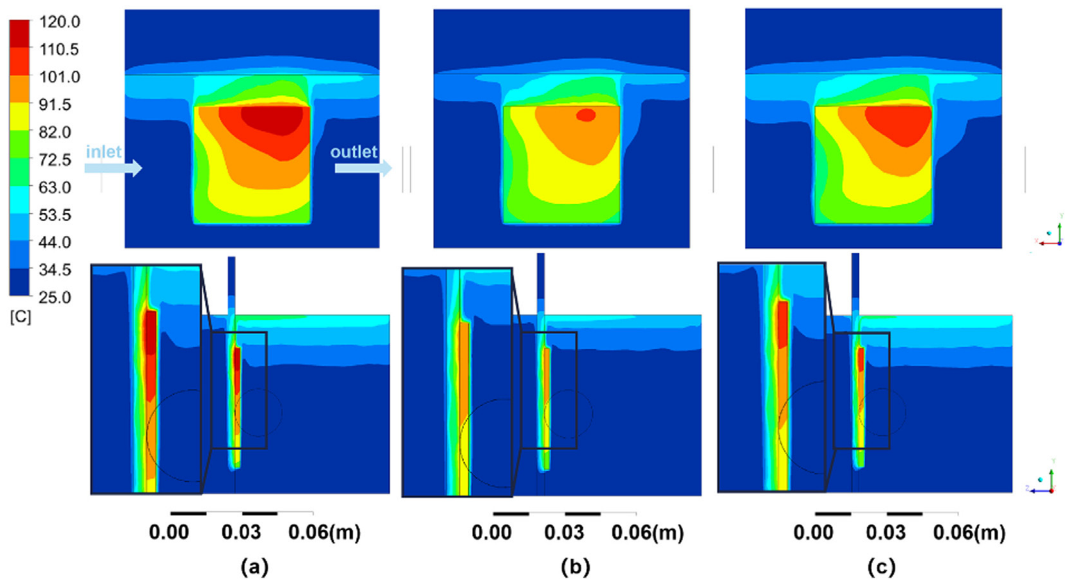

Fig. 14 Immersion cooling temperature contour with (a) base mineral oil, (b) 0.3 vol% and (c) 3.7 vol% nanofluids in 250 Reynolds number [158].

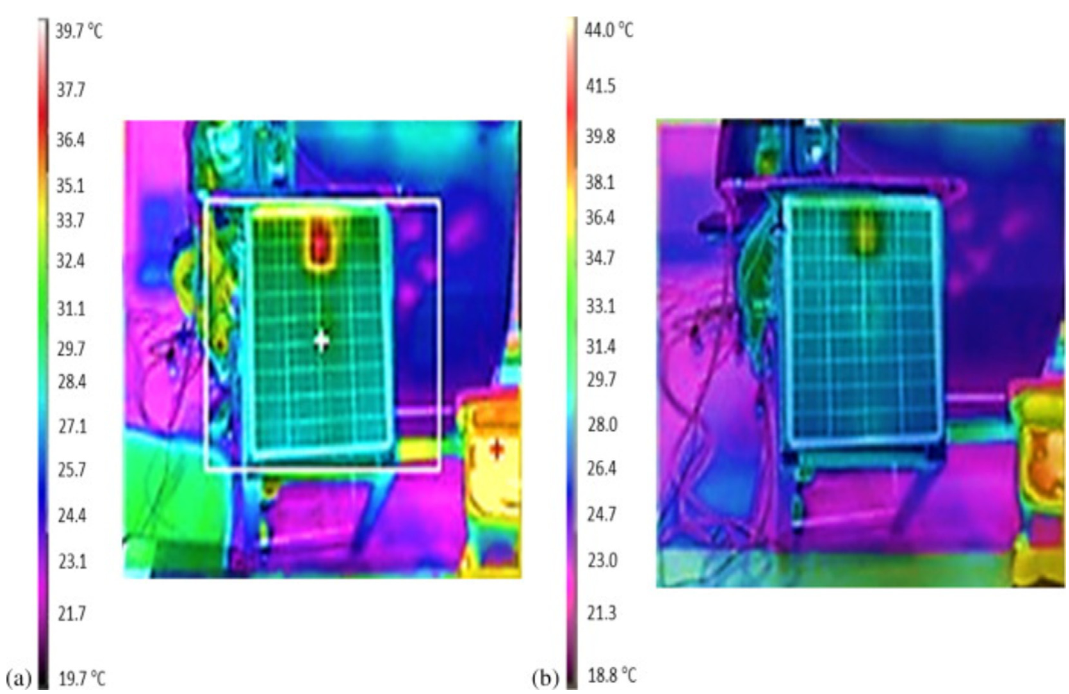

Fig. 15 Comparison between the 2-dimensional temperature distributions across solar photovoltaic panels actively cooled by heat pipes immersed in ethylene glycol (a) and in regular water (b) [173].

7.3. Easy installation and maintenance

Installation of this system is greatly simplified due to the density of its servers and its maintenance is also relatively easy due to the use of harmless and non-flammable liquid as the coolant [160]. Moreover, the problem of fire is also solved in some types by ensuring a non-combustible installation process in the intrinsic design [161]. Meanwhile, the maintenance and installation of the traditional methods are not easy due to their design and installation requirements. The most significant advantage of an open pool immersion cooling system is the absence of server-grade piping, fluid connectors and closed shells, which makes this scheme applicable to more environments and less maintenance of server components [69]. Easy installation and maintenance results in maintained reliability to ensure no spikes in energy consumption due to the difficulty of installation and maintenance.

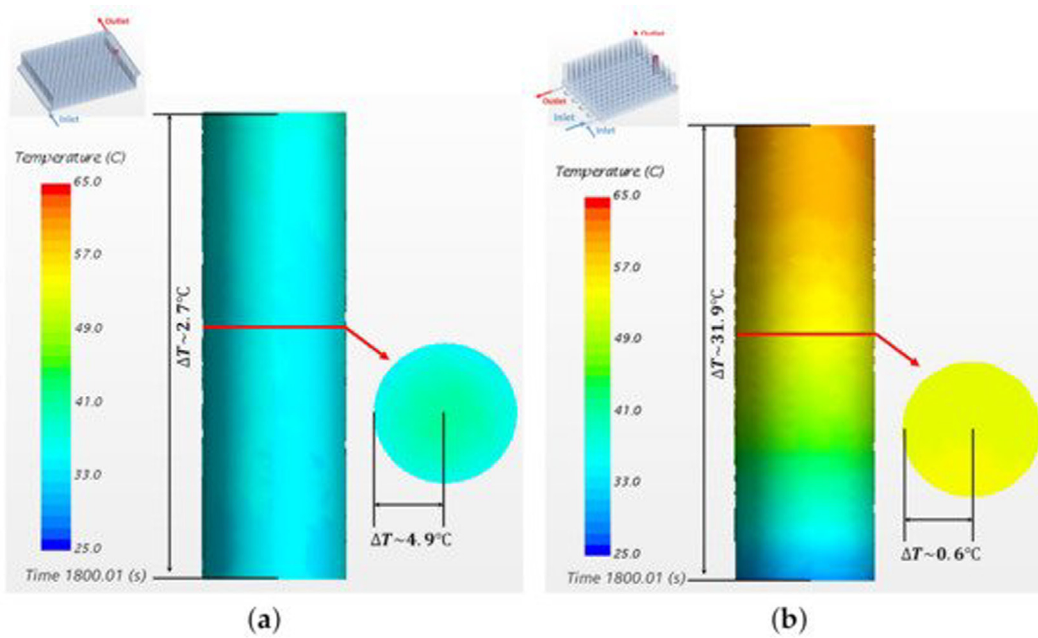

Fig. 16 Contours of temperature in (°C) on the outer surface of one Li-ion cell within the module for, (a) immersion cooling, and (b) cold-plate-cooling [78].

7.4. Environmentally friendly

Environmentally friendly technology is very important to pay attention to ensure environmental safety and user safety. With environmentally friendly technology, it will not incur additional costs and energy so that the technology can be used. As an example, noisy technologies are necessary to add other technologies to reduce the noise. Likewise, technology that produces emissions requires additional technology to capture these emissions to keep them safe.

The liquid immersion technology produces very low noise and is considered more environmentally friendly [162]. It is better than the traditional cooling technology which creates a lot of noise due to the overall installation materials and other features in its infrastructure [163] and consumes 40% of more power than the immersion cooling system [164]. It is also important to note that the liquid immersion cooling technology has efficient power usage and an excellent thermal management system [162,165]. Furthermore, immersion cooling does not require refrigerants such as hydrofluorocarbons (HFC), R22, and R113 which damage the ozone layer and strengthen the greenhouse effect which makes the earth warmer [166-168]. Although currently several freons have been developed which are more environmentally friendly, they have not been able to eliminate the overall impact of the damage on the environment [169]. Dielectric liquid for immersion cooling using Novec 649 [168,170] and mineral oil [150], proven to have a low and non-burning effect on global warming.

7.5. Stable and uniform temperature

Immersion cooling has stable [171] and uniform temperature characteristics [172]. This property is important to ensure that heat is properly distributed and released to the environment to prevent overheating. Overheating of electronic components results in decreased performance, increased energy consumption, decreased efficiency, and permanent damage.

Fig. 14 shows that the use of dielectric nanofluids with a concentration of 0.3 vol% has a lower temperature contour difference than mineral oil and other nanofluid concentrations. [158]. As for the application of immersion cooling solar PV, a uniform temperature is obtained without hotspots and an optimal temperature drop as shown in Fig. 15 [173]. Likewise for the thermal management system on the battery that the immersion cooling maintains a more uniform temperature as shown in Fig. 16 [76,78,174-176].

8. Conclusion

Almost all the countries in the world are currently highly dependent on the energy sector for development and this is increasing the world's energy needs. The fuel observed to be mostly consumed globally is natural gas followed by petroleum and coal. This is associated with several important events and developments discovered to have accelerated the transition from fossil to renewable energy sources. Therefore, this research provides an overview of immersion cooling technology by describing the history of its different cooling mechanisms and explaining the current technology in practice. The findings showed that the immersion system was discovered in the 19th and 20th centuries and experienced rapid development in 2019 with the design and construction of an immersive data center for the first time. The technology involves the reduction of heat using a liquid dielectric by convection and releases it to the environment through either a single-phase or two-phase system.

The immersion cooling technology has been applied to photovoltaic cells, data servers, crypto-mining, electric car battery and power transformers. This is due to the fact that the photovoltaic cells need a cooling system to maintain optimal energy efficiency in order to increase solar PV performance. Moreover, the rapid development of computing from data center computers and servers requires this technology to improve its efficiency while the 2-phase immersion systems are perceived as a viable technology to fulfill the power density and energy efficiency of the high-performance computing market in crypto-mining processes. In electric car batteries, immersion cooling has the ability to cool the entire cell surface and improve temperature uniformity by reducing the local heating effect on the positive and negative electrodes compared to indirect cooling. Furthermore, the thermal energy management using the system was also found to have the ability to overcome the problem of losing most energy to the environment as heat during transformer operation.

Immersion cooling technology was concluded to be feasible and superior to traditional techniques as a cooling method to save energy which is supported by several advantages:

1) Low cost because it doesn't require to use air conditioner [151,152], elevate the building [152] and proven to be cheaper in fixed capital investment data center [68], batteries thermal management [154], and water desalination [155].
2) The infrastructure is 1/3 smaller than Computer Room Air Conditioners [158] means more energy efficient for the building construction and maintenance.
3) Easy installation and maintenance because it uses non-hazardous and non-flammable liquids [160], simpler construction design [161] and easier maintenance [161], then reliability is maintained to ensure there is no spike in energy consumption due to the difficulty of installation and maintenance.
4) Environmentally friendly due to low noise [162] and low greenhouse gas emissions [150,168,170] then it doesn't need additional energy to activate the silencer and emission catcher.
5) Stable [171] and uniform temperature [172] to ensure that there is no decrease in performance and spikes in energy consumption.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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