Arctic ice thickening to preserve polar ice caps

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ABSTRACT

As global temperatures continue to rise and arctic ice continues to melt due to the changing albedo, a solution must be formed to prevent the complete destruction of the arctic ice shelf. This project explores the viability of deploying a wind-powered water pump during the arctic winter to pump water onto the surface of the ice and form a thicker layer. Prior work was improved upon and research was conducted into what materials, design choices and communication methods would be optimal for use on the arctic ice. Simulations and physical experiments were also conducted to approximate the flow of water and the area covered by the pump. A full list of recommended materials and designs was created, and experiments showed the pump would likely cover an area of 27.5m with water before the water froze, leading to a carbon offset of 206.7 carbon tonnes and a regular income of £206-413 per use to the operator of the pump.

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STATEMENT OF ORIGINALITY & RELEASE

The work presented in this dissertation is entirely from the studies of the students listed, except where otherwise stated. Where derivations are presented and the origin of the work is either wholly or in part from other sources, then full reference is given to the original author. This work has not been presented previously for any degree, nor is it at present under consideration by any other degree awarding body.

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INTRODUCTION

A. MOTIVATION & RATIONALE

Global warming and the ensuing climate change that occurs with it has quickly become one of the largest world problems, with droughts, heat waves and hurricanes being just a few of the adverse weather conditions that have seen a dramatic increase over the last 50 years [1]. There is strong evidence indicating that humans are a substantial factor, if not the main cause of global warming.

One of the largest areas affected by global warming is the arctic, with predictions stating that it will be ice free by the middle of this century [2]. This has a large knock-on effect, as the loss of the ice will cause the sea levels to rise, as well as releasing methane and other greenhouses gasses back into the atmosphere that are currently trapped [3]. These greenhouse gases reflect the solar radiation bouncing off the earth back towards it, therefore heating the planet further. The ice in the arctic helps to counter this by reflecting the solar radiation back into the atmosphere, thus lowering the amount of radiation absorbed. This natural reflection is known as the albedo effect.

The snow, ice, and sea water in the arctic circle have vastly different albedo numbers, which are 0.9 (90%), 0.5 (50%) & 0.06 (6%) [4] respectively, providing a percentage-based reflection rating. As the arctic ice decreases, a large decrease in albedo affect will be seen. If more ice can therefore be created or at least preserved then the amount of solar radiation reflected will stop decreasing, allowing more time for future work to find a way to reverse global warming. This project investigates the thickening of arctic ice to stop the thinning and eventual loss of the polar ice caps.

B. AIMS AND OBJECTIVES

The aim of this project is to model and simulate an arctic ready, wind powered pumping system for the transport of sea water from below the sea ice. With aims to distribute it on the surface, therefore thickening and preserving the area for upwards of 4 years and helping to reduce the effect of global warming. An investigation into the sensors, networking capabilities and pump / power requirements are necessary to make a full-scale model.

1) Design a pumping system that can survive in the unique arctic climate.
2) Model the design to provide a framework for any future construction of the device.
3) Simulate the design to provide an estimate on the working functionality and amount of formed ice within a set time frame.
4) Enable further research into similar designs by documenting the experiments and research performed during the project.

LITERATURE REVIEW

Due to the importance of rising sea levels and melting of the arctic ice to humanity, much research has been conducted into the subject. Most of this research concerns analysis of melting speeds, as opposed to ways to prevent the ice from melting. In this section, several pieces of literature will be examined and reviewed, and their importance to this project will be analysed.

One of the key pieces of data for this project is the rate at which the arctic is disappearing, and the change in albedo over time. One paper that discusses this topic is the work of Vesa Laine et al. [5], which concerns the albedo of the arctic ice during melting and refreezing periods between 2003 and 2011. The researchers used a passive microwave radiometer to get an accurate result when measuring the albedo, with graphs and colour maps plotted for both seasons of each year. The research showed that there was an overall decrease in sea ice albedo over the course of the monitored period, but it also demonstrated that there was considerable variance on the sea ice albedo even between parts of the same season. This is important to the research, as it shows that the effects of strengthening the sea ice and increasing the albedo may not have much of a short-term effect, but over the long term it can help to prevent the overall decrease of albedo in the arctic region.

While little research has been made into increasing albedo, there have been a few novel approaches from non-arctic climates. The work of X. Fan et al [6] in China is one such approach, and details the use of agricultural plastic film to increase the albedo of structures and large areas of dry ground. The researchers observed the increase of buildings covered in agricultural film in recent decades, they set out to examine the effect of such coverings on the albedo of the area. To examine this, the team set up a 2m x 2m area of grassland that would be measured using an albedometer; one experiment done with bare soil, one with grassland and one with a covering of "0.12-mm-thick polythene that is widely used in Chinese farmland". The surface was measured in 5-minute intervals, alternating between the film and the bare ground, and was conducted for four days in October 2005 and for six days in the summer of 2007 (July-September). The research showed that over the observable period, the average albedo of the area increased by 16.6% when the plastic film was present, a clear increase over the albedo of the bare ground. This research helps to demonstrate that albedo can be increased artificially, and is often done accidentally as with the use of plastic sheets on buildings in China. It also helps to demonstrate how steps can be taken to increase albedo even outside of the arctic.

One project that has already been conducted that is similar to this proposed project is the work of Steven Desch et al. [7] who proposed a larger scale wind-powered pumping system, which could add an extra meter to the thickness of the arctic ice sheet during a single winter. The project proposes the use of one large pumping system situated at the centre of the arctic, powered by 1300 GW of wind turbines. This pumping system would pump water for 700km, or potentially use 100 million separate pumping units and smaller turbines attached to buoys. Such an endeavour would be a monumental task requiring the cooperation of dozens of countries and billions of pounds in spending, and thus is out of the scope of this smaller and more individually focused project. Steven Desch estimates that the cost of such a project would reach $50 billion per year for 10% of the arctic, or 500 billion per year for the entire arctic. While this concept would increase global CO_2 output by 0.5% due to the amount of steel produced, that amount would be easily offset by the benefit provided to the arctic. More research needs to be conducted into how this project and those like it can be applied on a larger scale.

One area where this project may well be useful is in the rail industry in regions with railways built over permafrost. Methods do already exist for preserving the permafrost, but are different to this project's concept of replenishing it. For example, the work of Guoyu Li et al [8] outlines a method involving a layer of crushed stones and a shading board to protect the permafrost in warmer regions. The report states that coarse stones in permafrost areas act as "thermal semi-conductor[s]" and help to keep the ground cold enough to prevent the melting of the permafrost. Since most of the permafrost melting occurred along the sloped embankments, the researchers expounded on this idea and covered the rock layer with a heat reflecting board, thereby keeping the temperature even lower even in harsh sunlight. The report concluded that the ideal system would include rocks of larger size and thickness and plenty of shading boards on the embankments. The addition of this project's device to their design could allow for water to be sprayed between the rocks to form a single uniform surface. This may be beneficial and could help to improve the thermal properties of the design.

The decreasing albedo of the arctic circle does not just affect its human inhabitants, but also its native wildlife. The work of Harry Stern and Kristin Laidre [9] looks at the effect of sea ice loss on the habitat of polar bears. The research points to the fact that polar bears "depend on sea ice as a platform for traveling, hunting, and breeding" and that "polar bear phenology – the cycle of biological events – is linked to the timing of sea-ice retreat in spring and advance in fall". This means that the amount of time the sea ice remains before retreating is vital to the survival of the polar bear population, and a decrease in this time could lead to struggles to find food and a mate. The research examined the dates at which the sea ice began to retreat and advance each year between 1979 and 2014, accounting for local variations in different parts of the arctic where different sub colonies of polar bears reside. The research found that there was a decrease in ice covered days of 7 to 19 days per decade over the monitored period, showing that polar bear habitat is being slowly eroded by the melting ice and rising global temperatures. This has a serious effect on the survival of polar bears and their ability to succeed as a species. It is hoped that this project will cause an increase in the arctic albedo, which can help to slow down this decreasing number of ice covered days, providing help to the polar bear population.

One alternative use for the generation of new ice is for ice roads, particularly using floating ice on rivers and lakes. The work of D.M. Masterson [10] discusses the use of such roads in northern Canada and Alaska. It particularly mentions its uses for offshore oil drilling, where an ice road is constructed to transport the oil and remove the need for transport via boats and helicopters. This same method has been used to support large structures such as drilling rigs "weighing up to 1200 tonnes" with an ice sheet as thin as 6 meters. The researcher notes that ice floating above water acts as an elastic foundation when pressure is applied to it, "whereby the ice directly under the load is deflected downward". The paper notes that to create particularly strong ice, any snow on the surface must be removed first, as a frozen snow-ice mixture is not as strong as pure ice and would weaken the integrity of the ice layer. The paper also recommends the use of "low head, high volume" pumps to pump water from beneath the ice onto the surface, a recommendation which may come in handy for this project. It also recommends allowing water from the pump to flow freely, creating a tapered cross section of road to prevent cracking and create a smooth transition.

BACKGROUND

I. POWER GENERATION

For the project to be a success a continual power source was required. Conventional forms such as petrol/diesel generators have numerous problems that make them unsuitable for use in arctic conditions. Firstly, they are too bulky to be moved around alongside the pumping system. They require daily refills which is undesirable as the device could be upwards of 50 miles away from the nearest person. Arctic blizzards would also make traveling too dangerous for up to months at a time [11]. Diesel run generators also run the risk of having their fuel freeze which occurs at -8.1^{o}C [12], much higher than the -34^{o}C average winter temperature that it would have been exposed to. For these problems to be overcome, alternative ways to generate power were explored. Preference was given to renewable and green sources of energy due to the environmental focus of the project. (A) Solar, (B) wind, (C) tidal, (D) nuclear and (E) Seebeck generators were all examined to find their relevant advantages and disadvantages so that a decision could be made on which one to use.

A. SOLAR POWER

Solar panels have become much more prevalent throughout the world as individuals and companies alike take steps in becoming more environmentally friendly. Solar panels are made from an array of photovoltaic cells, each of which converts the energy contained within photons to electricity. This photovoltaic effect was first documented in 1839 by Edmond Becquerel [13]. He showed that a voltage was produced when an electrode absorbed light whilst it was immersed in an electrolyte solution. A simple photovoltaic cell consists of 4 parts, an anti-reflective coating to allow for maximum photon absorption and two contacts sandwiching a photovoltaic (treated semi-conductor) material. The cell generates electricity when an incoming photon is absorbed by an electron within the semi-conductor layer. When this occurs, the electron moves to a higher energy state (closer towards the top contact) and is said to be excited. This creates a difference in energy ΔE, between the excited electron next to the top contact and the others that haven't absorbed a photon and remain within the semiconductor layer. This energy difference between the two contacts produces a potential difference thus a voltage is produced.

Initially solar panels were considered, as thanks to a lack of moving parts they couldn't be easily broken by the high arctic winds, so long as they were properly secured to a frame. The panel style structures allow for them to be easily stored on top or next to each other, allowing for the size of the overall system to be much smaller, thus eliminating one of the problems of conventional petrol/diesel generators. There's also the 'smartflower', which enables sun tracking and automatic storage if condition limits are exceeded allowing for self-preservation, an idea crucial to anything that's required to work within the extreme weathers associated with an arctic climate [14]. Another advantage to solar panels is that they work better in cold conditions as the electrons that are not excited will populate lower energy states than in hotter conditions. The potential difference that occurs between the top and lower contact is larger thus a higher voltage can be produced for the same intensity of light.

However, solar panels don't produce large amounts of energy unless they are assembled into an array which takes up a large amount of space when assembled, meaning that the supporting structure would be heavy. The power that was required for the system to function at the rate calculated needed a minimum of 1Kwh for the prototype and 10Kwh for the full-scale design. The 67m^2 area required for a 10Kw solar array and £15,000 price tag made their use financially unfeasible [15]. The pumping system is designed to work during the winter months so that the temperatures are cold enough to freeze the sea water being added, which provided an inherent flaw in using solar panels. During the winter months, areas within the arctic circle experience 24 hours of darkness every day for months at a time due to the tilt of the earth, meaning that device usage during the summer months (which is the intended use of the machine) would be impossible [16].

B. WIND POWER

Wind has been used as a valuable and reliable source of energy for thousands of years, ever since man put sails onto boats as early as 5000BC [17]. Since then the use of this renewable source of energy has increased, with onshore & offshore wind farms becoming a common sight.

Wind turbines work by converting the naturally occurring kinetic energy in the air to electricity by using a propeller system connected to a manual generator. The angle that the propellers are mounted at causes the lineal kinetic energy to induce a horizontal force to the blades, creating a spinning motion. The spin of the blades is fed through a prop shaft into a manual generator, thus creating electricity.

To decide if wind power was a viable source of power it was necessary to see the amount of power that one can produce under arctic conditions. To calculate this both the amount of wind energy present and the efficiency of the wind turbine must be examined. The amount of wind energy in any section of air is dictated by "three key factors, the volume of the air, the speed of the air and the density of the air". The kinetic energy contained by a set mass with a given velocity is [18].

$$E_k = \frac{1}{2}mv^2$$

Where the mass (m) is the density of the air (p) and the volume of the air (v) i.e.

$$m = pv$$

Hence the energy within the wind can be easily calculated by the merging of the two formulas to provide the following.

$$Ewind = \frac{1}{2}pv^3$$

The amount of this power that can be captured and used by a wind turbine is determined by the area the propellers occupy (A), as well as the Betz limit, which is a defining limit that stops any wind turbine from achieving a wind to power efficiency of greater than 59.3%. This is because as the kinetic energy is transferred to the turbine, the wind loses that energy and therefore slows down. This in turn causes the air to spread as the amount of incoming air must be equal to that exiting. The slower output air creates a barrier just behind the turbine which disperses the incoming wind, creating a current of wider and slower moving air directly in front of the turbine thus capping the maximum flow rate through the propellers, shown in figure 1. However, ignoring this effect, the theoretical maximum power of an ideal wind turbine is defined as [18]:

$$Pmax = \frac{pAv^3}{2}$$

Hence, the maximum power output of a Betz limited wind turbine is:

$$Pmax = 0.593\left(\frac{pAv^3}{2}\right)$$

During an average winter, wind speed tends to stay in the range of v = 7 to 12m/s (assuming 10m/s), meaning the maximum power output of a turbine with a 1m blade length at sea level air pressure (1.29kg/m^3) is [18] [19]:

$$0.593\left(\frac{1.29(\pi 1^2)10^3}{2}\right) = 1201W$$

Average wind turbines have a blade length much larger than 1meter. Eventually it was decided to go for a vertical axis wind turbine, which allows for wind collection in all directions. They are also much more compact and easier to transport, but do however take a hit on the efficiency.

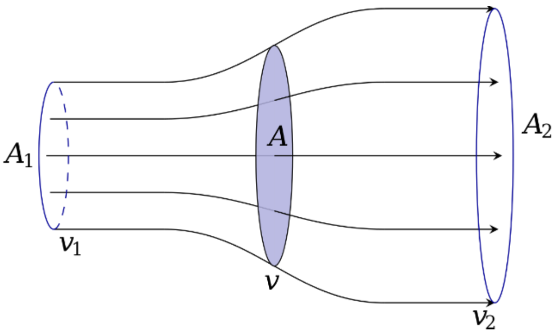

Figure 1: Illustrating the Betz limit of a wind with incoming area A1and velocity V1 being dispersed to the larger area A2 and slower speed V2 [19].

C. TIDAL POWER

As the arctic ice covers a large expanse of ocean, it is possible to harness the tides under the ice to power the device. Tidal waves are fairly constant, and thus an area with high tidal energy at any given moment can be assumed to have high tidal energy all year round.

Tidal energy relies on the movement of oceanic tides to turn sets of turbines (usually axial). These tides are generated due to forces acting between the moon and the earth, with the moon attracting water towards it and forming bulges of water. When the earth rotates, these bulges move and water is displaced, causing tides. As the earth and moon are both constant presences, tidal energy is reliable and cannot be depleted [20].

There are several different tidal power generator designs, but the main two are tidal barrages and tidal turbines. A tidal barrage is formed by creating a dam across an inlet with high tidal activity. When the tide comes in, water is allowed through the inlet gates and into the dam. Then, when the tide has gone out and there is a height difference between the sea water and the inlet water, the barrage releases the surplus inlet water through the turbines, causing them to spin and generate electricity [21]. This design is not viable for this project, as the barrage would have limited areas of use and would cause serious damage to the ice upon installation. It is also not portable as required by the design.

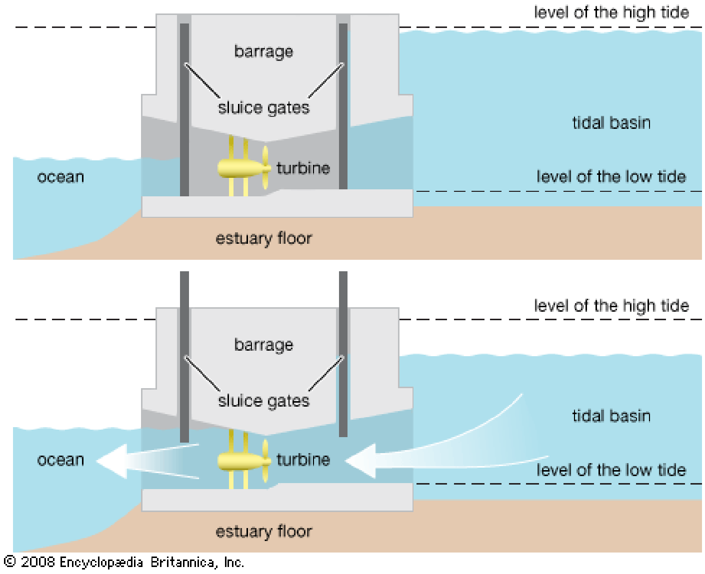

Figure 2: Diagram of tidal barrage operation [22]

Tidal turbines are a far more portable and small-scale approach to tidal power. They operate in a similar way to conventional wind turbines, with the flow of water pushing a rotating turbine to generate electricity. They are most often attached to the sea bed, but one could potentially be fashioned to hang from a thick ice sheet. As with wind turbines there are two types: vertical axis and horizontal axis. A vertical axis turbine generates electricity by having a turbine rotate perpendicular to the water flow, whereas a horizontal axis turbine rotates horizontal in relation to the sea-bed, in an orientation that allows the flow of water to spin the turbines (similar to an old-fashioned windmill) [21].

Viability

Tidal energy is still a fairly new technology, and there is much room for improvement. While large scale tidal barrages such as the La Rance Station in France have been shown to produce up to 240MW of energy [23], smaller scale devices are far less efficient. To calculate the viability of such a power source, we would use the equation:

$$P = \frac{1}{2} Cp * \rho * A * V^3$$

Where P is the power output, Cp is the turbine coefficient of performance, ρ is the water density, A is the sweep area of the turbine, and V is the velocity of the flowing water [24].

If we assume a Cp of 40%, a standard water density of 1023.6 kg/m³ [25], a sweep area of 1 metre (any larger and the logistical problems of drilling through the ice would be too cumbersome to continue) and a desired power output of 10kW, this shows that to fully power the device, it must be placed in water flowing at 3.66 m/s, or 13.2 km/h. In comparison, fast flowing straits such as the Fury and Hecla Strait near Igloolik have recorded flow velocity of 0.15 m/s [25]. Therefore, as tidal speeds are not sufficiently high, and larger turbines could not be installed without serious damage to the ice, the use of tidal power is not viable for this project.

D. Nuclear Generator

Nuclear Reactors work using the principles of nuclear fission, which is the splitting of larger atoms into multiple smaller ones. This process occurs in two types of reactions, namely nuclear bombardment or spontaneous fission [26]. The two most commonly used isotopes for nuclear fuel in these processes are uranium-235 and plutonium-239. [27]

In a nuclear power plant, the heat generated from the nuclear reactor is transferred to a steam generator. The steam is then fed through to a turbine which is hooked up to a generator. As the steam rotates the turbine, the generator uses the axial energy to produce electricity. The steam then condenses back into water which is then fed back into the steam generator to be used again. [28]

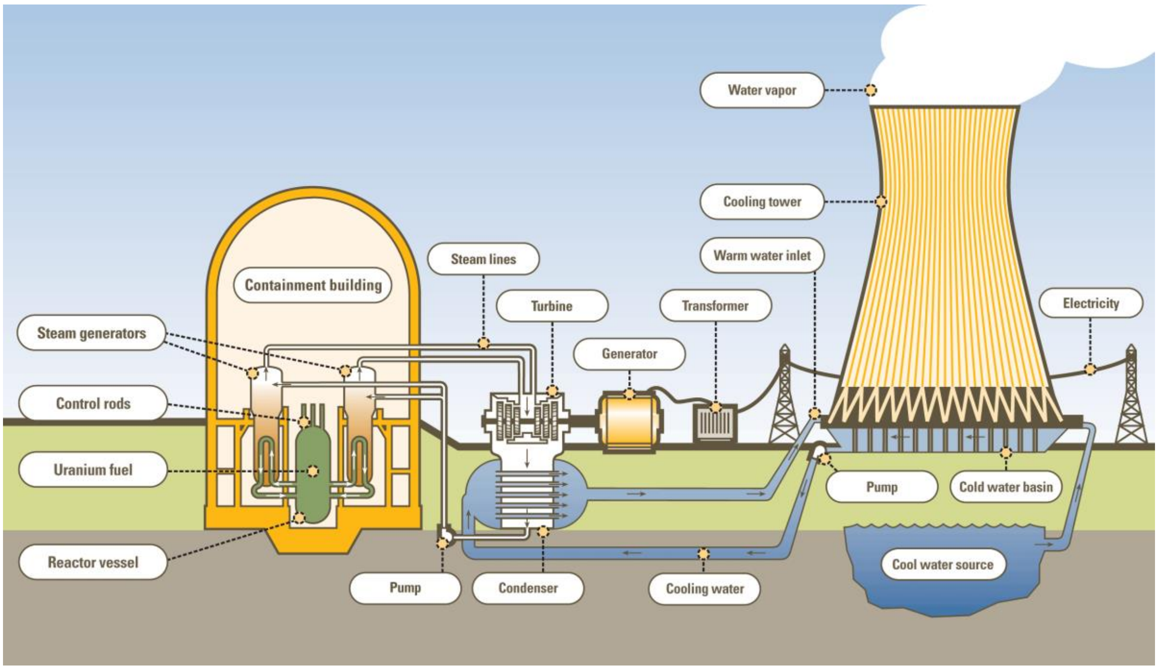

Figure 3: The main features of a Nuclear Power Plant [29]

Nuclear fission was discovered by physicists Lise Meitner and Otto Hahn, and chemist Friedrich Wilhelm Strassmann in 1939. [30] In their discovery, they examined a uranium-235 absorbing a neutron into its nucleus. It then broke down into "two roughly equal parts with mass numbers lying between 72 and 162 with neutrons also being emitted." [30] Through this fission, some mass was lost and converted into energy due to mass-energy equivalence ($E = mc^2$, where E is the energy, m is the mass and c is the velocity of light) [30].

Application of Nuclear Reactors

Nuclear reactors are used to power various transport vessels such as submarines, icebreakers and aircraft carriers [31]. It is "suitable for these vessels as they need to be at sea for long periods of times without refuelling" [31] but still require a lot of power.

Advantages of Nuclear Reactors

It has a much higher efficiency in terms of fuel to power ratio than any other energy source (e.g. fossil fuels).

Nuclear power plants only emit clean water vapour into the environment through their cooling towers; very little greenhouses gasses are released when generating nuclear energy. CO_2 is produced during the mining of the uranium as well as the construction of the power plant, but the amount produced in comparison to coal is about 50 times less [32]. The nuclear waste produced after fission is "handled properly and disposed of geologically without affecting the environment in any way." [32]

Nuclear power plants can be left running continuously for 1-2 years and last in operation without regular maintenance for up to 40-60 years, resulting in "fewer brownouts and power interruptions". As it is independent of the weather, nuclear energy is much more stable than other renewable forms. [33] [34]

Disadvantages of Nuclear Reactors

Potential meltdowns will release harmful amounts of radiation into the environment [34], causing the arctic ice to melt even faster. Maintenance of a nuclear reactor requires in depth knowledge of the subject and would not be possible to be performed by the Inuit. Even without a meltdown occurring the heat generated by even a small reactor would still be great enough to increase the localised temperature, it is also unlikely to be in the same compartment of the pump and electronics. Another main issue is that there is little to no support for nuclear waste disposal in the arctic.

Conclusion

A nuclear reactor would not be a viable source of energy to use in the project as it is very expensive. It requires a lot to maintain and disposing of nuclear waste is incredibly difficult due to the location. The time and money need to train the Inuit would also be redundant due to the initial costs of the reactor. The heat from the reactor would also cause problems to the ice and if the possibility of a meltdown occurs, it will melt the icecaps further which is against the aim of the project.

E. THERMOELECTRIC GENERATOR

Thermoelectric generators use the Seebeck effect to generate electricity. The Seebeck effect is the direct conversion of heat into electricity and was discovered in 1821 and named after its discoverer Thomas Johann Seebeck [35]. Using a closed loop formed by two different metals, he observed that a compass needle would be deflected when a difference in temperature was created at the metal interfaces. Seebeck initially believed that the magnetism was induced due to the change in temperature, however it was an electrical current that was being induced that created the magnetic field around the wire which consequently deflecting the compass needle [36].

By definition, the Seebeck effect occurs when two dissimilar electrical conductors or semiconductors (e.g. Iron and copper) produce a potential difference (ΔV), when the junctions between the two are maintained at different temperatures (ΔT) [37] [38]. The two dissimilar metals when coupled form two junctions which together are known as a thermocouple [38]. When heat is applied to one side of the conductors or semiconductors, the heated electrons flow toward the cooler side, [39] this is demonstrated in Figure 4. The Seebeck effect can be mathematically expressed as: [37].

$$\Delta V = \alpha s \Delta \mathrm{T}$$

Where α_s is the Seebeck coefficient of the material being measured, which is represented in Volts per Kelvin (V/K) [37]. The Seebeck effect is reversible as when the hot and cold junctions are interchanged, the direction of current also reverses [38].

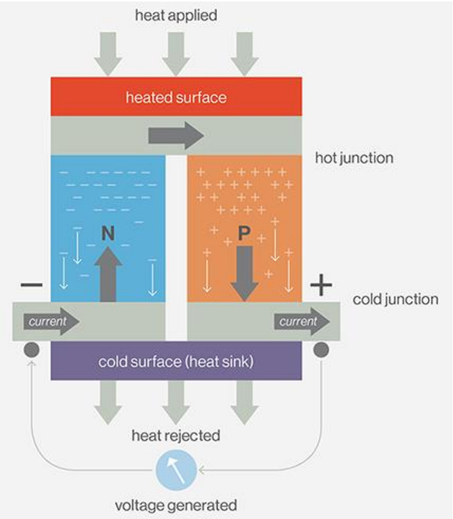

Figure 4: Simple circuit diagram demonstrating the Seebeck effect on a thermocouple [40]

<u>Applications of Seebeck-effect Devices</u>

As mentioned previously, thermoelectric generators also use the Seebeck effect and are used in a massive variety of utilities. They are usually used to convert wasteful heat into more electrical power; they've been used in power plants, microprocessors and automobiles to improve the fuel efficiency of the system or processes [41]. Most recently they've been developed in stove fans, [42] lighting, [43] fans, and in several appliances such as guard alarm systems [44].

Advantages of Seebeck-effect Devices

Seebeck based devices are all environmentally friendly as they don't require any sources of energy that may harm the environment to operate. They can use a reliable source of heat energy to function and are mostly used to convert wasted thermal energy into electricity. Finally, the devices are very scalable, as they can be applied to any size of heat source from a water heater to a manufacturer's equipment [44].

Disadvantages of Seebeck-effect Devices

Problems with Seebeck-effect devices include that the devices require a relatively constant heat source to function. Certain Seebeck devices also have a very high output resistance, low voltage output and very low energy efficiencies; thermoelectric generators typically have efficiencies of around 5-8%. The technology is very limited to applications and the progression of how it's developing is very slow, so efficiencies is unlikely to improve for a while [44].

Conclusion

The main reason that the thermoelectric generator isn't being considered for the arctic conditions is because there isn't a big enough heat difference to produce the amount of energy needed to power the pump. However, there is a possibility that the heat difference may be enough to power the circuit separately, but this will need to be investigated in the future.

II. PUMPS

The main component to the project was the pump. It had to conform to many critical parameters else the reliability and usefulness of the project would have become uncertain. Nearly all these parameters arose due to the arctic weather conditions the pump was required to operate within. This includes high winds, subfreezing temperatures and the potential debris and pollutants within the seawater being pumped. The other parameters are related to the power and positioning of the pump. Firstly, it had to be electric so that it was compatible with the chosen power source. It was decided early on that preference would be given to a pump that didn't need to be submerged, such that the hole being drilled would remain as small as possible. Thus, decreasing the chance of water leaking back through it. All other characteristics were individual to each pump and detailed the operation of each one; the (A) capacity, (B) head (discharge, suction & total), (C) efficiency and the (D) power usage, all of which are usually displayed within the pumps characteristics curve.

A. CAPACITY

The capacity of a pump is the amount of fluid that it can discharge within a given period, this value is usually given in gallons or litres per hour but can be in meters cubed per hour. Capacity is made up from "two components, the discharge rate and the discharge pressure" [45]. This characteristic is usually noted on a pumps data sheet as a maximum capacity which allowed an easy comparison between the different pumps. Due to the project needing the most amount of water volume, pressure could, for the most part, be ignored as the water travels through an intake pipe which was 3 meters in length and pumps with very high capacity are designed to flow through entire water distribution systems / pond filtration systems.

B. HEAD

Discharge head, Hd is the height of which a pump can output water vertically, and was of no importance for this project, as the water was discharged horizontally from the pump. Suction head Hs is the vertical lift of output water caused by the height of the input water [46]. For example, a pump working at the bottom of a full water tank, will have a greater discharge head than the same tank when its half full. This is due to the downward pressure that's pushing the water into the pump. The height of the output water is partially caused by the suction head which is dependent on the water supply available. Manufacturers list the total head, Ht = Hd – Hs, instead of each individual type, which provides the head added by the pump alone.

In this project the water is being pumped up from below the ice (positive value for Hs) and is then being distributed at the height of the pump. Because of this only the suction head must be counteracted by the total head hence, a bare minimum head of 3 meters had to be accounted for.

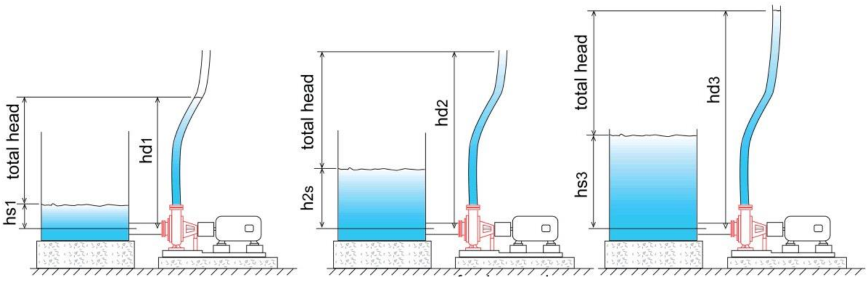

Figure 5: Shows the 3 different types of head, and the effect of suction head on the displacement head [47].

C. Efficiency

The efficiency of a pump "is defined as the ratio of water horsepower output from the pump to the shaft horsepower input for the pump". In layman's terms the efficiency of a pump is the horse power of the output water in relationship to the energy in horsepower provided by the driving mechanism, which in the case of this project, is an electric motor. The efficiency can be estimated using the total head and pump flow rate.

Water horsepower formula:

$$WHP = \frac{HtQ}{3960}$$

Where Ht is the total head and Q is the flow rate (gallons per minute). "Pump input horsepower is the speed and torque of the motor shaft input to the pump". Using these the efficiency can be found by:

$$\eta = \frac{hp(water)}{hp(pump)}$$

"which is defined as the ratio of water horsepower output from the pump to the shaft horsepower input for the pump" [48].

D. Power Usage

Power usage was a major factor in the final decision of which pump to use, as there is only so much power that can be generated by a wind turbine. If the power requirements of the pump needed the wind turbine to be running at its maximum capability, then the pump may not have provided any more water than that of a lower wattage pump, just because it wasn't able to run for as long. The pump, although the largest consumer of energy in the project, is not the only one, so leeway power had to be left over for the other electronics to function correctly.

III. ARCTIC CULTURES

The arctic circle has long been a very harsh and inhospitable environment, with intermittent periods of permanent twilight and permanent day. However, this has not stopped cultures from settling in these areas, with evidence of human settlements spanning back over 12,000 years [49]. Living in such a harsh environment has led to some interesting cultural features in these groups, and consideration must be made towards the culture, traditions and religion of peoples in this region. For the purposes of this project, emphasis will be placed on the largest North American and European arctic cultures, namely the Inuit and Sami respectively.

A. INUIT CULTURE

The Inuit people consist of a group of cultures that have inhabited areas of Northern Canada, Alaska and Greenland for over 1000 years. They make up a population of over 150,000 people, with the largest percentage residing in Northern Canada [50]. While the term "Inuit" is a catch-all for these similar cultural groups, they are in fact all distinct peoples with their own languages such as Inuinnaqtun, Inuktitut and Inuvialuktun [51].

Traditionally the Inuit have been a hunter-gatherer society, with the cold tundra of the arctic being unsuitable for any form of large scale agriculture. To an extent, this has not changed in recent times. Inuit still get most of their dietary needs from fishing and hunting, with fat and protein making up a large percentage of their diet [52]. This diet has become supplemented by traditional western food in more recent decades, with food being imported to Inuit territories, often at a steep price.

Hunting has also been made easier with the introduction of snowmobiles and modern weaponry, and the ever-present demand for animal skins and hides has turned hunting into a business for some Inuit. As large vehicles are not very common in Inuit areas, it is important to ensure that the device designed in this project can be hauled on a snowmobile or similar small motorized vehicle. This will allow the operator to deploy the device while out hunting or during their regular day.

The Inuit's careful balance with the nature around them is something that must be respected in this project. As such, the device must cause as little adverse effects to the environment as possible, meaning use of renewable energy sources, and must do minimal damage to the ice when deploying. In doing so, proper respect would be given to the Inuit people, and their native lands can be better protected in the years to come.

B. SAMI CULTURE

The Sami are an indigenous group native to northern Scandinavia and some parts of northern Russia, with their own languages and very distinct culture. In the past they have faced discrimination from their respective governments, and as such are often wary of outsiders [53]. As such, much consideration must be given towards their culture to gain their trust.

One of the main traditional careers in Sami culture is herding reindeer, with the career being protected in some countries as being exclusive to Sami people [54]. Most Sami, however, work in regular jobs and have assimilated into the rest of

Scandinavian culture, and as such their diets and accommodation would be the same as most Western people. The main aspects of Sami culture are their clothing, arts and music. Sami traditional clothing is known as a Gakti [55], and is worn by the Sami when working as well as in traditional ceremonies. As such, the distance they are willing to travel in such garments to deploy the device must be considered.

To operate the project's device in Sami controlled areas, it would be important to get the approval of the Sami government. Each country inhabited by Sami people has a Sami parliament, a political group that advocate for the Sami people and their culture [56]. Gaining their approval for the deployment of these devices by Sami people would help bolster the reputation of the Siku Project and would ensure that any work is being done in accordance with Sami law and traditions. As the Sami parliaments advocate for self-determination for their people, providing them with business and a reliable source of income would prove beneficial to their cause.

As with the Inuit, it is important that the device does not adversely affect the Sami way of life, and as such the effects of the device upon the surrounding environment must be taken into consideration, as well as the ease of use for whoever is operating the device.

IV. Arctic Climate

A proper understanding of the arctic climate will be vital for the project as this allows for the operation to run efficiently. To begin with, the final product must be operational under low temperatures and the varying wind speed present every day. Therefore, an understanding of the arctic climate is a must to run the device smoothly and efficiently.

A. Arctic Temperatures

One thing to note is the condition of the arctic ice. Over the years, arctic temperatures have been rapidly increasing, having increased by 2.3^{O}C since the 70s [57]. It has been predicted that by the middle of this century the arctic will likely have a three-month, ice-free period during summer, with this expected to increase to 5 months by the end of the century [58]. This increase in temperature has already caused some dramatic changes. Greenland has experienced 61 hours of above freezing temperatures this year alone, triple the number of hours compared to any previous years. This has often been described as "crazy" or "weird" [59]. The change in temperature within the arctic is increasing, according to data from March 2018 which has shown that air temperatures were 2 to 4 degrees Celsius higher than average in regions near Greenland and Alaska. In contrast to that, regions in the eastern arctic such as Scandinavia and Siberia show temperature of 4 to 7 degrees lower than average. This means that there is a global variation in arctic temperature depending if it closer to the east or western continent, as shown in figure 6 [60].

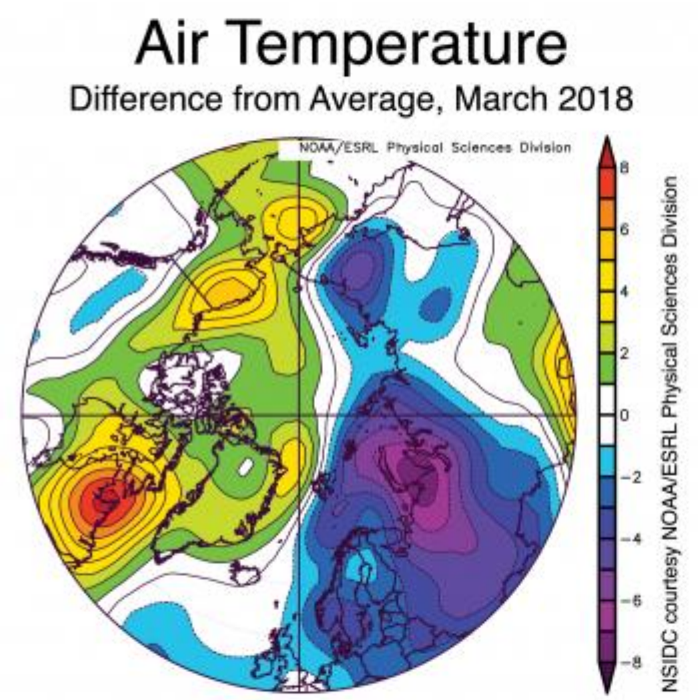

Figure 6: Average air temperature in the arctic; Yellow and red indicates higher than average temp; blue and purple indicate lower that average temp *[60]*.

As a result, the extent of arctic sea ice has decreased to 14.3million square kilometres, which was recorded as the second lowest in the 1979 to 2018 satellite record. This was 1.13million below the average 1981 to 2010 records which can be seen below [60]. This shows the change in fluctuating temperatures, and if this is allowed to continue at the same rate then there will be no arctic ice to preserve by 2050.

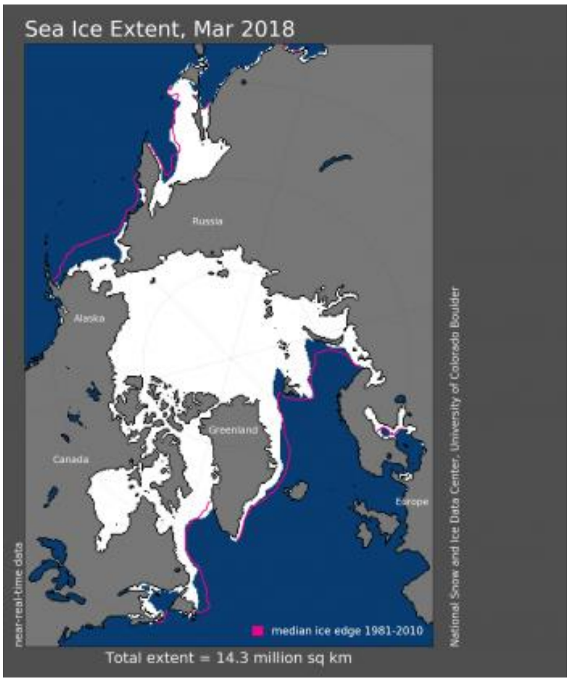

Figure 7: Arctic Sea Ice extent March 2018. Magenta lines show 1981 to 2010 average extent *[60]*.

B. ARCTIC WIND

Another aspect that needed to be understood is the wind speeds of the arctic, since this will be the main source of energy for the device and therefore the amount of wind available in the arctic will decide its function. According to a study the arctic has an average wind speed of about 6.4m/s shown in figure 8. This speed can produce 5.2kW of power if a wind turbine with 6m diameter blades intercepts it [61]. This is more than enough to power the pump and accompanying electronics.

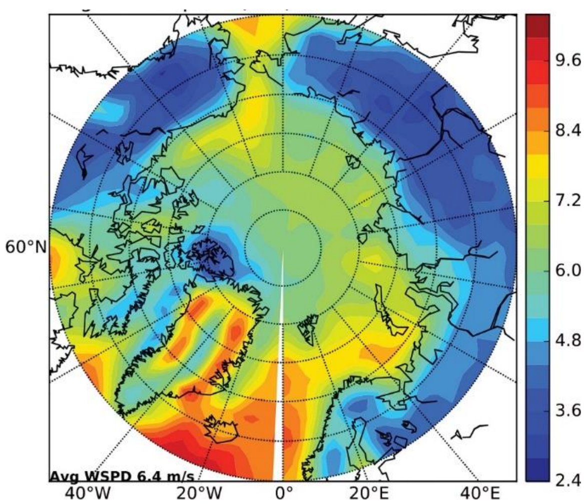

Figure 8: average wind speed in m/s *[61]*.

This is typically a light wind, however strong gales that reach hurricane strength can occur, some of which can last for several days. This wind speed in winter spreads snow much further, this can pose a problem for the wind turbine that will be planted along with the device, as the snow can seize operation if wind strengths are too high [62]. Upon further research, the Meteoblue climate agency based in Canada has produced data of wind speeds, with an accumulated 30 years of hourly weather model and simulations, giving a good indication of the typical climate patterns and conditions in the Arctic Archipelago, as shown in figure 9.

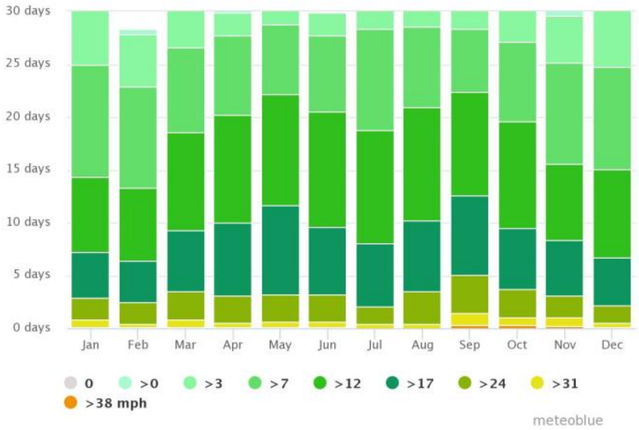

Figure 9: Wind speed chart of Arctic Archipelago *[63]*

This wind speed chart along with the wind rose can provide much-needed information to indicate the direction the wind blows, which means placement of the device can be in favour of the wind to pump water at a heightened distance. The wind rose for the Arctic Archipelago is shown in figure 10 [64].

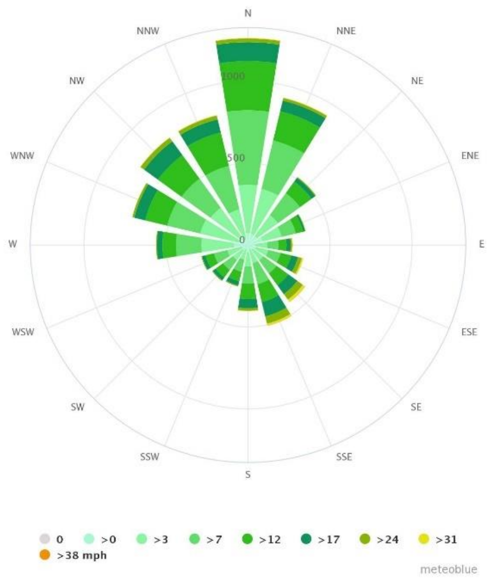

Figure 10: Wind rose, N indicates North *[62]*

V. Climate Change

Climate change is one of the largest problems to face humanity in the last 100 years. With the global temperature slowly increasing to record levels, scientists have worked tirelessly to figure out the cause. This increase in temperature is likely to have serious effects on the environment, human population and the fate of many arctic species. Many of these effects are already visible today.

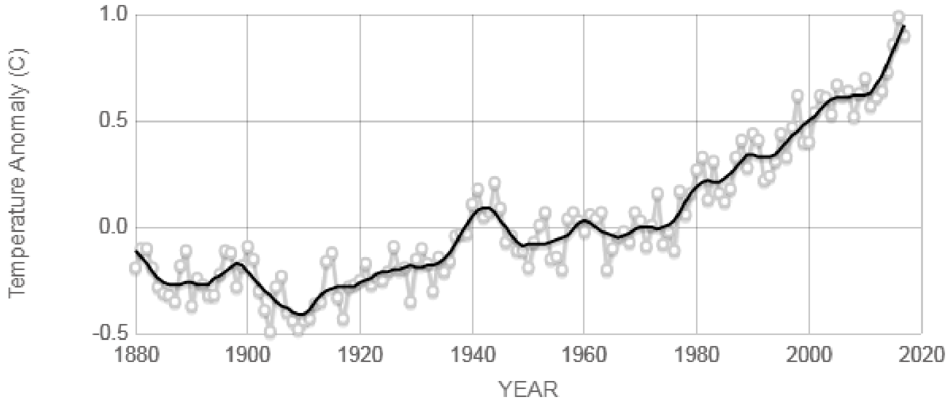

Figure 11: Global temperature increase over time *[65]*

This rise in temperature has been blamed for the decrease in the size of the polar ice caps, and therefore the decrease in polar albedo. It is responsible for the adverse changes in weather observed across the planet (namely wet areas getting wetter, and dry areas getting drier [66]). While the planet does go through cycles of high temperatures as well as ice ages [67], the current rise in global temperature does not conform to that model.

The prevailing theory behind the rising global temperature is that the change in atmospheric composition, namely the increase of CO_2 that's arisen since the dawn of the industrial era, is responsible for this increase. The issue with the increase of CO_2 and other greenhouse gases is that they reflect some heat that radiates from the earth back onto its surface. Therefore, damaging the heat equilibrium and leading to a lower net loss of heat from the planet [68]. This increase in greenhouse gases is likely due to human activity, with industries, manufacturing, transport and other large generators of greenhouse gases causing serious damage to the atmosphere. In the last few decades, several large governments have put policies into place to counteract this increase, such as encouraging the move to renewable energy, electric cars, and the introduction of the carbon tax.

Global warming has had particularly large effects on the arctic, with the increasing global temperature leading to a decrease in the size of the polar ice caps each year, with the polar ice edge decreasing considerably in the past few decades. Studies have shown that this decrease in the size of the ice caps has led to global polar albedo decreasing from 0.52 to 0.48 between 1979 and 2011 [69]. This has led to a change that "is equivalent to 25% of the direct forcing from CO_2 during the past 30 years". It is likely that this albedo change will continue to grow exponentially unless serious measures are taken to counteract global warming. This could potentially lead to the complete destruction of the arctic ice sheet, along with any disasters caused by the corresponding increase in sea levels.

VI. THE ALBEDO EFFECT

The temperature of the planet is regulated mostly by the sun's rays, which travel from the surface of the sun and into our atmosphere, eventually being absorbed by the earth. Since not all surfaces on earth fully absorb heat, some of these rays are reflected back out of the atmosphere by surfaces with a high albedo (highly reflective). One of the main sources of reflection on earth is the ice caps surrounding the poles, as ice (especially snow-covered ice) has a very high albedo, with some forms reflecting 80 to 90% of radiation that hits its surface [70].

As global temperatures rise, arctic ice begins to melt quicker in the summer, causing cracked and weak ice to form. This causes large chunks of ice or glaciers to break free of the arctic ice sheet. When floating freely, the higher temperature water causes them to melt and eventually disappear, thus reducing the size of the arctic ice sheet and in turn decreasing the overall albedo effect. Adding an extra protective layer along this weak ice should help to prevent cracking and thus result in a higher albedo effect [71] as the ice is preserved.

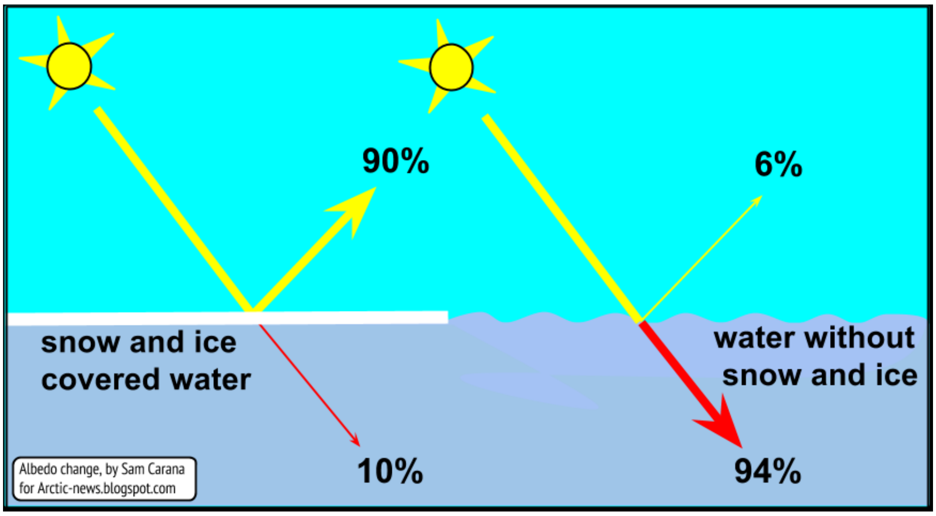

Figure 12: Diagram of differing albedo in snow-covered ice and water *[72]*.

This project focuses on multi-year ice, as this is the kind that is most at risk from global warming and provides the highest average albedo as it is there all year-round. First-year ice, on the other hand, tends to melt and reform with each summer melt cycle, and thus only reflect the sun's rays for a portion of the year [73]. Helping to provide a protective layer to multi-year ice will have a longstanding effect on the arctic by improving the ice's longevity and potentially stopping large glaciers from breaking free, assuming the device is deployed in specific locations.

A. CO2 NEGATION

As the arctic ice reflects energy away from the planet and reduces global temperature, it can be assumed that it acts in opposition to the warming effect of more CO2 in the atmosphere. A recent study showed that 1 tonne of CO2 would increase global temperature by 0.0000000000015 degrees Celsius [74]. If we take this value combined with the estimated total atmospheric weight of 5140 trillion tonnes [75] and the air's specific heat capacity of 1.006 kJ/kgC, we get a power of 7756 watts per tonne of CO2. Assuming every square meter of earth is hit by 1120 watts of solar energy

[76], and assuming an average year-round ice albedo of 0.6 [70], we can calculate that the warming effect of 1 tonne of CO_2 is negated by 11.5 m^2 of sea ice. To put this number into perspective, the average car produces 5.23 tonnes of CO_2 per year [77]. If the device produces an ice sheet 100m^2 in size (this being on the lower predicted estimate) then it will offset over 75 tonnes of CO_2, the equivalent of the yearly emissions of almost 15 cars. Along with this environmental benefit it is also financial beneficial to the operator, who can sell carbon credits to make a living (see Carbon Credits section).

VII. CARBON CREDITS

As defined by the Collins English Dictionary, a carbon credit is “an allowance that certain companies have, permitting them to burn a certain amount of fossil fuels” [78]. Carbon credits can refer to any number of schemes designed by various bodies. Essentially, companies pay a set amount per tonne of carbon or carbon equivalent to offset their carbon emissions. That money then gets split between the company running the carbon credits program and the individual projects that are directly offsetting carbon emissions.

The mechanism for buying and selling carbon credits was made formal in the Kyoto Protocol, an international environmental treaty signed by 192 countries in 1992 [79]. This helped to create an international competitive market and spawn countless environmental projects. According to the California Carbon Dashboard, as of January 22nd 2018 the price of carbon credits stands at $15.28 [80], roughly £11 at current exchange rates. Of this amount, the individual projects would receive a percentage, with the money being used to continue funding the projects.

It is the hope of this project that the carbon credit program could be used as an incentive for arctic locals to participate in the operation of the device. A native person could potentially take the device with them during their regular day and set it up in predetermined locations. In exchange for this, they would be given a share of the money accrued through the carbon credits program. This money could potentially improve their standard of living or replace their current income source entirely, creating much-needed jobs in an area with very little widespread industry.

Assuming that each device operator receiver £1-2 per carbon ton offset, and assuming the device covers a 100m^2 patch of ice, using our carbon-to-ice ratio from previous sections we can arrive at an income of roughly £75-150 per use of the device. This estimate is on the lower end of the potential area covered but demonstrates that a significant income can be made from the device, especially if multiple devices are used at once. This sum of money could provide a stable income for someone living in the arctic circle, which is particularly important given the high cost of imported goods and modern amenities.

VIII. ARCTIC COMMUNICATION

As the arctic is one of the least populated and most inhospitable environments on earth, long range communication poses a serious issue, particularly if the device is placed in a remote area far from any settlement. Mobile networks are practically non-existent, and any form of WIFI communication is a pipe dream. This means that if an error occurs in the device (i.e. ice stops the flow of water, wind turbine stops operating etc) then it would have no way of communicating with its operator to relay these issues, possibly setting back freezing goals by many days. Luckily, there are a few solutions that could allow for communication to occur.

A. SATELLITE COMMUNICATION

Satellite communication concerns the use of satellites orbiting the planet to pass messages from one device to another. A message is sent from one device to an orbiting satellite, which locates the intended recipient and passes the message on either directly, or through a satellite gateway if the recipient is not using satellite communications [81]. It is often used for communication in areas with low population and in emergency situations on mountains or in the wilderness.

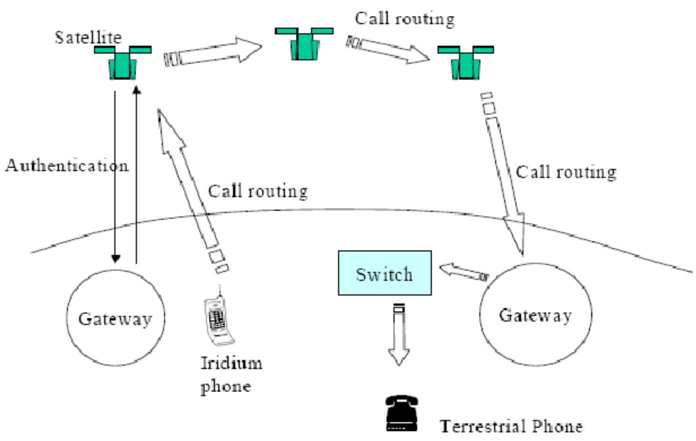

Figure 13: Diagram of satellite phone network *[82]*

While satellite communication is not as widespread in the arctic as it is in the rest of the world, (mainly due to the curvature of the earth making many satellite systems inaccessible), there are a few commercial entities that provide satellite communication in the area. One of these is Gonets, a Russian satellite system operating worldwide satellites, including some at high latitudes that would be ideal for Arctic use. The company provides a satellite messaging service that works in conjunction with mobile networks to send messages to and from phones [83]. This would allow the device to send an automated text to its operator when something is not working as intended.

There are many benefits to using such a system. For example, the system would be able to reliably send messages at any time due to the constant presence of satellites in the sky, and the low use of bandwidth and very occasional use of the system would mean that a satellite data plan could be acquired for an affordable price, or potentially for free if a deal could be worked out with the satellite companies.

B. MESH NETWORKS

A mesh network is a network of interconnected devices within relatively close proximity of one another. Each device can send/receive messages, allowing them to also pass on messages from other nearby nodes. A mesh network can involve every node connected to every other node (full mesh network), or some nodes connected to others in a loose web of connections (partial mesh network) [84].

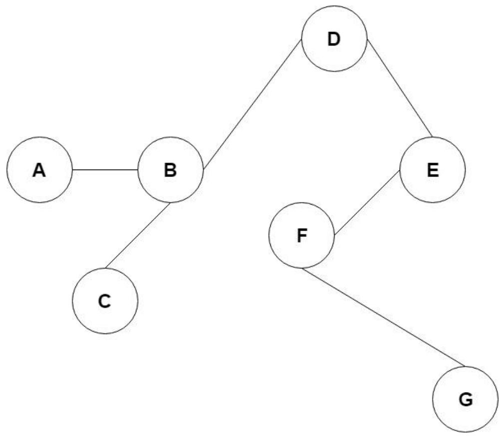

Figure 14: Example of a partial mesh network

In figure 14, if node A wished to send a message to node E, it would pass that message along to node B, who would forward it to node D and then node D would finally forward it to node E. Such a system would allow messages to be sent to and from devices quickly and over a far greater distance than the range of a single device.

An example of a pre-existing network of this kind is the Sinuni Mesh Network, which is a network of sensor devices in Northern Canada that are designed to monitor environmental conditions in the area [85]. Each node is powered by wind or solar energy, and contains a rechargeable battery to allow for the communication system to operate even in times of low wind or no sun. As the system is open source, it would be possible to integrate the pumping system into the network, allowing it to send messages via the network of nodes. Further information on this system could not be obtained, as the organization behind the network has declined to respond to emails.

Though there are many benefits to using a mesh network, there are also issues, particularly with this project. Firstly, as the device would have to be moved rather frequently, it would have to reconnect to the mesh network each time and update its location in the system. Secondly, any new additions to the network would mean that the device would need to be sent a new network map, or else remain outdated. As such, it is recommended that a satellite system be used for communication in this project, as opposed to a mesh network.

IX. COMSOL MULTIPHYSICS

COMSOL is an environment simulation program designed to mimic real world physical phenomenon as closely as possible, be that in an engineering or scientific context. COMSOL utilises a Multiphysics system which includes models of interest, for example: laminar/turbulent flow, heat transfers (solid and liquid), electromagnetics, etc [86]. Figure 15 shows the user interface, in which the parameters, boundaries, materials and conditions can be altered and accessed.

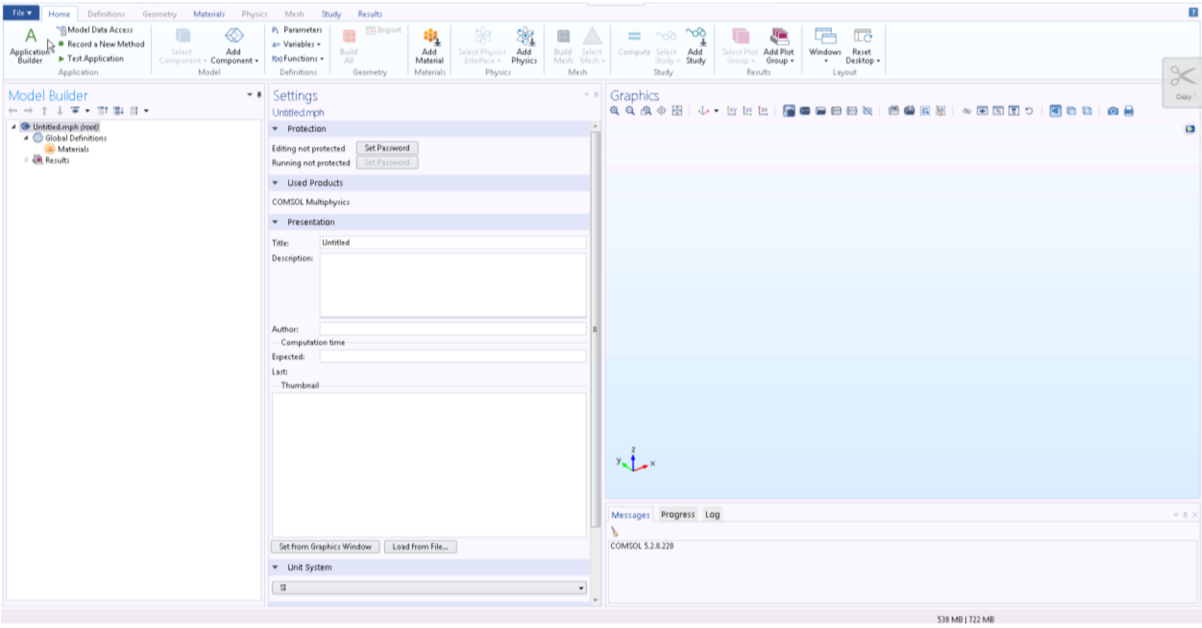

Figure 15: COMSOL User Interface

A typical COMSOL simulation follows a set series of steps. Firstly, a model must be created, either in a 2D or 3D plane. Then, the physics required for the desired simulation must be decided and selected, and a geometry must be designed or imported for the physics to act upon. Once the material is decided, the boundaries and parameters must be inputted. These can include inlets for water, starting voltages/capacitance for electrical circuits, etc. This helps to set up the conditions required for an accurate simulation. Once this is done, a mesh must be created and a study can be made, where COMSOL simulates specific parts of your model and outputs your desired data. This data can be plotted in graphs, colour maps, and a variety of other methods for data representation.

For this project COMSOL was used to simulate how long the water would travel before it reaches its freezing point. This will require the fluid flow physics and more specifically, laminar flow. For this simulation to work, certain specific parameters were needed such as the start temperature of the water, temperature of the ice and inlets/outlets to show where the input and output of the turbulent flow are in the model.

X. WATER FLOW SENSORS

Another part of the sensing equipment was a set of water flow sensors. These devices help to determine the flow rate of water being pumped out and can also be used as an indicator if there are problems with the pump, such as a low flow rate which would indicate a build-up of ice, or higher flow rate due to an anomaly in the power source (surges).

By nature, seawater is corrosive [87], which narrows down the types of flow meters that could be used. With the specific design of the pump and pipes in mind there are two ways of dealing with this problem. The first is to use an ultrasonic flowmeter. This type of flowmeter uses sound waves to determine the velocity of the fluid within the pipe. When a flow is detected, the frequency of the reflected waves changes in accordance to the Doppler effect. As the velocity increases, so does the rate of the shift. This device can be positioned from the opposite sides of the pipe shown in figure 16 below. The processed signal from the wave determines the flow rate. The benefits of using these devices is that they are accurate, don’t obstruct flow and handle the low temperatures common to the arctic environment. However, they also have disadvantages, for example the high sensitivity tends to cause it to detect stray process vibrations along with high cost. On the occurrence that there is build up on the pipe (internal or external) the diameter of the pipe will change, causing the clamp-on units to provide a lower accuracy [88].

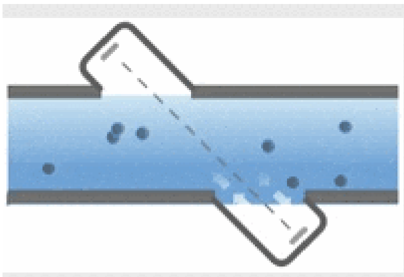

Figure 16: Ultrasonic Flowmeter *[88]*

The second option would be to use a pressure-based flow meter such as a differential pressure flowmeter. This utilises Bernoulli’s equation, and introduces a constriction on the pipe, creating a pressure drop between the upstream and downstream of the device. Therefore, the higher the flow, the higher the pressure drop is as shown in figure 17, and so the difference between the pressure upstream and downstream can be calculated thus determining the flow rate [88] [89]. The advantage of using this is that it is low cost, versatile, and can be used with any liquid. However, it has its own downsides, such as the poor range due to non-linear differential pressure, and the accuracy can deteriorate due to wear and clogging [88] [89].

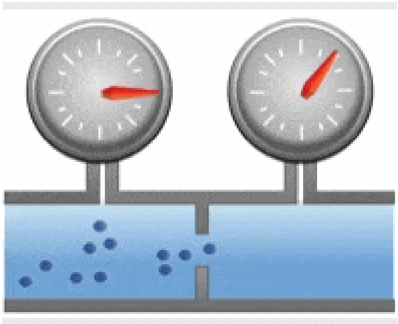

Figure 17: Differential flowmeter *[88]*

Due to the low cost and versatility of the differential flow meter it is by far the best choice to go for the prototype, however in the future once the product is ready for manufacture an ultrasonic flow meter would be a better option due to its higher accuracy, and ability to withstand the arctic conditions better than the differential flowmeter.

XI. WIND SENSORS

In agreement with the last year's project, there is a need to measure the wind speed since it will be powering the equipment, due to its place as the most viable option in powering the pumps and other accompanying systems. This means that the measurement of wind speed will be vital as it can relay information to the communication system notifying the Inuit about the status of the equipment. It can also be used to determine if the equipment is operating at peak performance. The use of an anemometer will be needed for wind speed measurements, which has similar functions to a wind turbine where a blade turbine spins at a speed proportional to the wind speed, enabling the actual wind speed to be calculated.

The use of a sonic anemometer was proposed as it proves to be practical for the scenario of two Inuit moving equipment monthly, since it lacks the presence of moving mechanical parts as shown in figure 18 below [90].

Figure 18: Sonic anemometer *[91]*

Sonic anemometers work by measuring the three-dimensional wind speed. This means that by measuring the time taken for a pulse of a sound to travel between two transducers, the speed of the wind between them can be determined. The time taken is dependent on the distance between the transducers, speed of sound and the air speed along the axis of the transducers, resulting in the equation:

$$T = \frac{L}{(c + v)}$$

Where T = time, L = distance between transducers, c = speed of sound, v = air speed along the transducer axis.

The speed of sound is dependent on temperature, pressure and travelling medium differences such as snow or ice. To obtain air speed along the transducers, each must act as transmitter and receiver alternately so that the pulse travels in both directions the velocity of air is calculated as follows:

$$v = \frac{0.5L}{\frac{1}{t1} - \frac{1}{t2}}$$

And the speed of sound can be estimated as [91]:

$$c = \frac{0.5L}{\frac{1}{t1} + \frac{1}{t2}}$$

Arranging the three transducer pairs on the three different axis provides a three-dimensional wind speed, but also provides the direction and angle.

The reason for choosing a sonic anemometer is mainly due to its lack of moving parts, but it can also provide a heating element allowing it to operate in arctic conditions which prevents riming. Riming occurs when there are high humidity levels at freezing temperatures. This means that ice particles can build up on the transducers blocking the sonic wave from reaching its counterpart. This interferes with the measurement and can create inaccuracies in the outputted value [92].

XII. MICROCONTROLLER SYSTEM

The software envisioned for the project was a messaging system which would contact the Inuit if any problems with the device were detected. Temperature sensors would be placed in the box containing the circuit and on the pipes themselves. If the temperature at these points drops below a certain degree, a message would be sent to the owner to inform and detail the problem. This could be due to the pump motor burning out or water freezing within the pipes. However, using just a temperature sensor to monitor the pipes could provide a false problem in the system. To alleviate this the temperature sensor would be used in conjunction with a flow rate sensor to monitor for blockages. Messages would also be sent out if the device power was low and wind speed was still high, indicating that the turbine itself was broken or any of the sensors seemed faulty. Finally, a message would be sent to indicate that the pumping was finished, and that the system was ready to be moved to a new location. Other than keeping the system in check, other temperature sensors and anemometers will be used to collect data from the local environment. This can be used to monitor any improvement or deterioration of the arctic and can be utilised by research centres to develop further improvements to the project. To develop the program a microcontroller system was required.

A. RASPBERRY PI

The Raspberry Pi is a credit-card-sized, single-board computer which was originally developed to encourage children and adults to learn how to program [93] [94]. However, many well skilled programmers were attracted to its potential as a pocket-sized, general-purpose computer as it could run multiples programs and tasks with ease, allowing it to be integrated with complex projects such as robotics and various other applications [94] [95]. Several models of the Pi have been developed since it was first created back in 2009, and since then it has been used for a variety projects [96]. The Raspberry Pi can run numerous operating systems including Ubuntu Core, Windows 10, IoT Core and Raspbian (the company's own OS) which is based around Linux [94]. Some of the main programming languages that the Raspberry promotes include Python, Scratch (for education) and C/C++ [94].

B. ARDUINO

An Arduino is a microcontroller motherboard, a simple computer which runs one program at a time repeatedly [95]. It was developed by the Arduino Company, which fabricates the microcontrollers and kits required to build a variety of projects [97]. A range of microprocessors and controllers are available, and every board is equipped with an arrangement of digital and analogue I/O pins for sensing components, breadboards or other circuitry. [97] Most boards feature serial communication interfaces such as USB (Universal Serial Bus) ports, which are mainly used to upload the created programs [97]. Arduinos use their own language that is a dialect merging features of C and C++. However, it is also provided with an IDE (integrated development environment) written in java to support C and C++ making it easier to use [97].

C. DIFFERENCE BETWEEN THE RASPBERRY PI AND ARDUINO

The main advantage of the Arduino over the Raspberry Pi is that the Arduino is more simplistic. Analogue sensors, motors and other components are much easier to implement using an Arduino. On the other hand, the Raspberry Pi requires adding additional libraries and software, such that it can interact with the circuitry, and requires a good understanding of Linux. The Arduino is also more robust as it is a “plug and play” device, meaning that the uploaded code will start immediately when the device is turned on. It can also be powered down at any point without any potential corruption of files, whereas the Raspberry Pi runs on an operating system that requires a shut down before power can be removed. Otherwise the operating system and running files could become corrupt and damage the Pi [98].

The main advantage of the Raspberry Pi is that it’s more powerful and able to run multiple tasks at once, allowing for more complicated projects. The Raspberry Pi also runs faster than the Arduino, with a CPU clock speed ranging from 700MHz, up to 1.4GHz in their latest model [94]. In comparison most Arduino models have clock speeds of 16MHz [99]. Furthermore, the Raspberry Pi models have networking capabilities including Bluetooth, wireless and Ethernet ports allowing access to networks directly, while the Arduino requires external hardware and software configurations to run on a network [98]. Finally, the Arduino requires a very good knowledge of programming languages and electronics to get started. The Pi, on the other hand, requires a small understanding of electronics but doesn’t require an immediate knowledge of coding, allowing people to develop the skills needed over time [98]. For these reasons the Raspberry Pi was the chosen system to design the code, mainly due to its networking capabilities and ability to perform multiple tasks.

D. RASPBERRY PI MODEL

The Raspberry Pi Zero W was the chosen model. This was because it has Bluetooth and WLAN (wireless local area network) features enabling laptops, keyboards and mice to access the Raspberry Pi from outside of the pump housing. Ensuring that reprogramming won’t damage the device. For a price of £12.82 (with pre-soldered components), it is a cheap and effective component for the project [99] [100].

XIII. MATERIALS

One of the main project objectives was the “Arctification” of the device, a word created to describe the creation of a device that can resist the extreme climate found in the arctic. To achieve this goal, it was necessary to research which materials to use for each of the various parts of the end project. This includes, (A) the pump housing, (B) inlet/outlet pipes and (C) insulation. The main deciding factor for each material detailed in this section is its ability to survive, extremely low temperatures (less than -40^{O}C), high winds (upwards of 30 m/s) and corrosion due to sea water. Thought was also given towards the practicality in terms of cost for each of the materials, as the project must eventually be funded by carbon credits. With initial funding relying upon the purchasing of the device by the local Inuit population.

A. PUMP HOUSING

The pump housing was modelled as a large rectangular box with holes for the inlet/outlet pipes, mounting holes for the wind turbine and wires that came from it. This structure is the underlying frame that all the other parts are connected to, and because of this the pump housing’s main material requirement is its tensile strength. A close second is the weight, such that two Inuit would be able to pick it up and move it to the different locations. Due to the properties required by the project, it was decided that an investigation into different types of metals was needed. This investigation started with aluminium and its alloys, later followed by stainless steel and the different grades available.

Ai. ALUMINIUM

Aluminium in its natural form meets a lot of the specification. With a density of 2.7g/cm^3 [101] and tensile strength of 90 MPa [102] it has a high strength to weight ratio, and it also does not become brittle in low temperatures. A naturally forming oxide layer provides it with a self-repairing corrosion resistant layer, [101] giving aluminium a marine service life that can be measured in decades [103]. Furthermore, these properties can be improved by mixing it with other elements to form an alloy. The extent of which these properties are improved is dependent upon the element being incorporated and the percentage amount used. The corrosion resistant layer can be improved on its own via anodising or by simply painting it. The following provides two aluminium alloys and the material improvements they offer.

I. 5XXX SERIES

- Uses magnesium as the alloying agent
- Used in products in direct contact to marine environments
- Has a moderate tensile strength ranging from 140 – 280 MPa at 1 to 2.5% magnesium
- Tensile strength can be further increased to 280 – 380 MPa at 3 to 6% magnesium [104]

II. 6XXX SERIES

- Uses a combination of magnesium & silicon (magnesium silicide) as the alloying agent
- Generally used for architectural extrusions and in car components
- Good weldability and corrosion resistant
- Moderate to high tensile strength of 150 – 380 MPa [104]

Aii. Stainless Steel

The second material consideration for the pump housing was stainless steel, an iron alloy that contains a minimum of 10.5% chromium [105]. The most notable properties of stainless steel are its strong corrosion resistance and high tensile strength of 560 to 755 MPa (depending upon grade) [106]. The corrosion resistance is due to the chromium as it acts similarly to aluminium in that it forms a thin oxide layer, which can self-repair upon contact with air as the oxide layer is reformed. The corrosion resistance that stainless steel can provide is dependent upon the grade, which defines the steel by its composition, and the series which defines a steel by its crystalline structure. Two different series were examined, namely the 200 and 300 series, both of which are austenitic steels meaning they have face-centred cubic crystalline structures [107]. The 200 series has a lower corrosion resistance and formability than that of the 300 series but is harder and stronger [107]. It should be noted that the corrosion resistance & tensile strength of the 300 series stainless steel was higher than that of aluminium. The downsides to using stainless steel over aluminium is that it is considerably more expensive than aluminium (per sheet) and is also 3 times heavier than aluminium.

However, it was decided that stainless steel should be used, more specifically the 316 marine grade due to its superior corrosion resistance and far greater tensile strength, when compared to aluminium, also it can survive extremely low temperatures. The added strength was required as the pump housing is the main hub that all the other parts of the project physically rely upon. If the housing became damaged in anyway it could lead to a catastrophic failure of the entire structure.

B. Inlet/outlet Pipes

Like the pump housing, the inlet pipe requires a high tensile strength and high corrosion resistance to salt water. Due to the corkscrew design on the inlet pipe it also requires a high sheering force such that it wouldn’t tear when being screwed into the ice. As the inlet pipe will be physically in the water it was necessary to ensure that it will not affect the water surrounding it. The outlet pipe’s main requirements were to be corrosion resistant and be capable of surviving the extreme temperature and wind speeds mentioned previously. Due to the possibility of corroding material being deposited by the pipe into the ocean, other materials were explored to see if any were more appropriate than 316-grade stainless steel previously investigated. The use of polyvinylidene fluoride (PVDF) was explored for the inlet/outlet pipes. This was investigated due to the accessibility and vastly reduced cost in comparison to metal as well as the characteristically high corrosion resistance that plastics are known for.

The intrinsic characteristics of plastics mean that PVDF meets many of the specified material parameters required for the overall project. It is lightweight, non-toxic & highly corrosion resistant [108]. These inherent values allow PVDF to be used as an outlet pipe as the design stops the possibility for ice to form a blockage as the water drains out. However, with a tensile strength of 7,800 Pa [109] it is the weakest of all the materials examined in this paper by an order of magnitude. It is because of this that it is not a suitable material for the inlet pipe as it would have to be screwed into the ice, causing a large sheering force that would likely splinter and crack the plastic. The need of a corkscrew structure on the inlet pipe also makes plastic less desirable as it cannot be welded onto.

The sheering force experienced by the instillation of the inlet is not applicable to the outlet pipe. Due to this PVDF is a good choice for the outlet as the weight and cost of the system would be decreased. PVDF is chosen as unlike other plastics it will become brittle in sub-zero temperatures, whereas others are susceptible to stress cracking [110]. The inlet pipe was chosen to once again be 316 grade stainless steel for the reasons previously given, as well as its ability to be welded onto (for the corkscrew). Using the same material also stops any potential metal on metal corrosion that could occur at the pipe to housing interface.

C. INSULATION

The internal structure within the pump housing needed to be protected from the extreme temperatures so that the internal pipes did not freeze, which would completely stop the system and potentially burn out the pump motor. The incorporated components such as the Raspberry Pi and pump will be heated via electrical pads. These aim to keep the internal components well above the freezing temperature of sea water. However, this will not be possible if there is no insulation within the housing as any provided heat will quickly escape via conduction through the metal housing.

a. POLYSTYRENE

Polystyrene has properties that make it ideal for the insulation of the pump housing. It is waterproof and capable of withstanding extremely cold conditions [111], and it would also act as a form of sound proofing, reducing the noise pollution given off keeping the impact on local wildlife down to a minimum. Also, as it is a form of plastic, it will take upwards of 1 million years to naturally degrade [112]. The main downside to the use of polystyrene is that it can cause a reaction with PVC, which is a common material used in the coating of electrical wires. This reaction would, given time cause the wire to soften and erode making the cable brittle, eventually cracking which would expose the live wire forming a potential fire risk. To solve this an interfacing material could be applied to the wire, this would slightly increase the manufacturing cost of the system [113] but eliminate the fire risk.

b. POLYURETHANE

Polyurethane is a common household insulator, and is lightweight and durable with a high thermal resistance, allowing for the internal temperature of the pump to be maintained. Generally, it can with stand a temperature range of -30°C to +90°C, although there are specialist versions that can withstand a range of -180^{O}C to 200^{O}C (when placed under asphalt) [114]. It also provides adequate sound proofing similarly to polystyrene. The main issue with polyurethane is that to be certain of it withstanding the arctic conditions, the specialist version of the material will be required, which will incur additional cost and still would not insure the temperature range when inside of the pump housing, and not under asphalt.

It was decided that due to the lower cost and easily rectifiable problems, polystyrene was to be used. Another driving factor for this decision was that polyurethane can degrade when exposed to ultraviolet radiation [115], an effect that is unlikely to be noticed due to the intended use. But is an additional downside to the use of the material.

DESIGN AND METHODOLOGY

I. EQUIPMENT AND PARTS

In this section, the equipment and tools used in the project will explored, and their purpose expanded upon.

A. FREEZER

To simulate arctic experiments, a freezer was required that could reach suitably low temperatures. As part of this project, an Iceboat Industries chest freezer was provided. The freezer measured 130cm x 65cm, and was 85cm deep. When the freezer's temperature was set to its minimum, it could reach a temperature of -28.5^{O}C, a temperature comparable to that of the arctic during the winter. The temperature was variable via a dial on the front of the freezer, and the internal temperature was measured using a laser thermometer.

Figure 19: Photograph of chest freezer

B. RASPBERRY PI

For this project, a Raspberry Pi Zero W was purchased. This would connect to all the sensors used in the design and would relay specific information, from the product to the operator via satellite communication or mobile messaging. The Raspberry Pi Zero W model was chosen due to its small form factor, relatively high processing power and the capability to connect to wireless networks without the use of an adapter.

C. BURETTE

To simulate a controlled flow for the freezer experiments, a burette was required. The school of chemistry at Bangor University provided a JayTec 50ml burette, with a measurement scale accurate to 0.1ml. The burette features a tap which controlled the flow rate of the fluid within, allowing for experiments of different flow rates to be conducted. When the burette tap was fully open, the water drained out at a flow rate equivalent to 5.34 litres per hour.

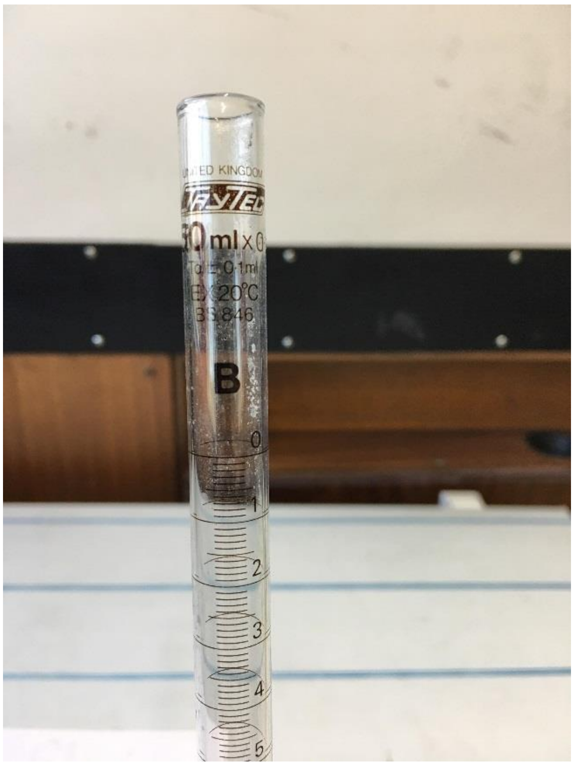

Figure 20: Photograph of top of JayTec 50ml burette

D. BOTTLES

To both transport sea water from Bangor Pier and move it from one container to another, sizeable bottles were required. Two litre soda bottles were used in this case, as the size and shape made for easy transportation and the size of the bottle opening was consistent, allowing for the flow rate to be calculated. Each bottle was emptied of its contents and thoroughly rinsed with clean water before being used to transport the sea water, ensuring that no contaminants were present.

E. SEA WATER

To accurately conduct experiments involving freeze times etc, water of the same salinity as that present in the arctic ocean would be required. For the experiments conducted in this project, sea water was collected from Bangor Pier to form the ice layer inside the freezer, and to fill bottles for use in experiments. It is assumed that this water is typical sea water, with salinity equal to the ocean wide average of 35 parts per thousand [116]. Water was collected from deeper areas of the pier and at high tide, to ensure that the number of contaminants from the sea bed were kept to a minimum.

II. Sea Water Experiments

A. Food Colouring Experiment

The purpose of this experiment was to test the behaviour of water when frozen in layers at different volumes: 5cm^3, 10cm^3 & 15cm^3. The experiment was conducted to determine if water from a second layer would flow similarly to the already frozen water from the first layer, the effect of building up layers over time, and to also know the time taken for the different volumes to freeze. Knowing this information would inform a decision on whether it would be more efficient to spray water out continuously, or to stagger the spraying to form multiple layers. The experiment will also be used to calculate the depth that the different volumes of water freeze at, this can be used to indicate the number of layers that would be required to form the project's 20cm goal. From this, the time between moving the pump to the next location could also be calculated.

Method

Several beakers of sea water were prepared at room temperature, and each was mixed with food colouring to give it a distinct colour, allowing for each layer to be visually distinct and identifiable. The layers, from bottom to top, were coloured with blue, red, yellow, and green food colouring respectively to ensure that each layer was a distinct enough colour compared to the layer below. For each layer, a burette was filled with 30cm^3 of coloured water to create three separate layering experiments, using 5, 10 and 15cm^3 of water respectively. The burette was positioned close to the surface of the ice sheet within the freezer, and water was let out onto the ice surface in the correct volume. Each layer and each separate volume was timed to calculate the average freezing time, determining whether the water had frozen both visually and with a digital thermometer. Once the layer was completely frozen, the steps were then repeated, with the burette positioned above the same spot on the ice. Thus, creating another layer on top with the different colour. Photographs were taken between each layer to provide visual evidence of the water flow, and the distribution of the first layers outlined so that the area spread could be estimated using a centimetre grid.

B. Car Park Experiment

While the food colouring experiment provided a good idea of the waters freezing patterns on a small scale and with staggered pumping. An experiment was required to identify the effects of pumping water for longer periods of time and on a larger scale. For this reason, the car park experiment was conducted. The purpose of this experiment was to provide a general idea of the pattern of water flow over a large area, and on a semi-rough surface like that of arctic ice.

Method

First, four two-litre bottles were filled with tap water to be poured onto the tarmac. Tap water is used as the difference in flow characteristics between sea water and tap water would be negligible with such a small amount of water. The two litre bottles were chosen due to the uniform size of the bottle openings, allowing for a consistent flow rate between the bottles.

These filled bottles were then taken to the car park behind the Dean Street university building in preparation for the experiment. This area is selected due to its relatively even surface with few slopes or dips, and the rough tarmac allowed for a better reproduction of the sea ice.

The four bottles were prepared, and two people assigned two each. A third person set a timer for one minute (to represent the freezing time of water in arctic temperatures). Upon activating the timer, the first bottle was turned completely upside down, allowing the water to flow freely from it onto the tarmac from a height of 30cm (to simulate the drop of the water from the pump nozzle to the ice). When this bottle was close to being empty, the second person brought their bottle close to the same spot as the first and tipped it upside down upon the emptying of the first bottle. This process was repeated until the time reached one minute, at which point the pouring ceased. The size of the water puddle created was then measured with a tape measure to determine the maximum distance travelled in each direction.

III. COMSOL SIMULATIONS

A. SIMULATION I – FREEZING TIME OF WATER ON ICE

To accurately calculate the distance that the water could flow across the arctic ice before freezing, a calculation must first be made to determine how quickly standing water would freeze on top of a layer of ice. To find this information, a COMSOL model was simulated to generate theoretical data. When this information was found, it was possible to use the freezing times in combination with the distance the water would travel in that time to determine the final ice sheet radius for the device. This experiment aimed to determine the freezing times of a thin layer of water on an ice surface at different temperatures.

Method

First, a 2D COMSOL project was created, and the required physics engines selected. In this case, heat transfer in fluids was chosen, as this allowed for heat to be exchanged between the air/ice and the layer of water above it. Next, a geometry was formed. The geometry formed was a 2m x 16m block of ice, with a 2cm deep pool of water sitting atop its surface, as shown in figure 21.

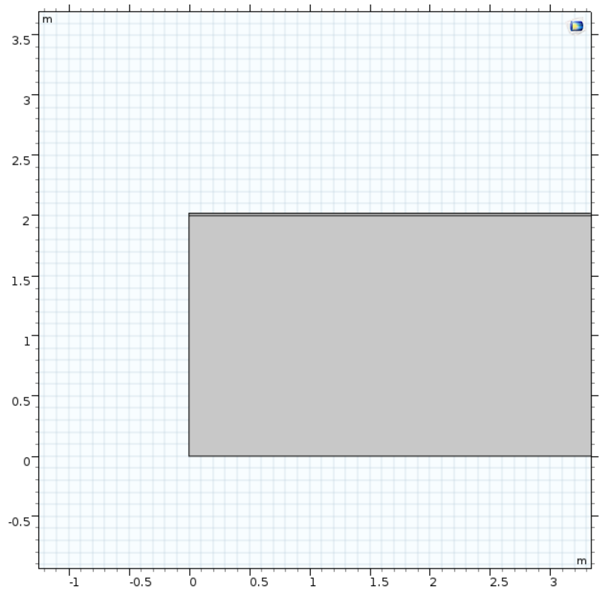

Figure 21: Partial diagram of COMSOL model

Once the geometry is completed, materials are chosen. In this case, two custom materials had to be created. For the ice block, a solid material was formed with a density of 920.8 kg/m^3, heat capacity of 1818 J/(kg.K) (constant pressure), the ratio of specific heat set to 1, and a thermal conductivity of 2.63 W/(m.K). This material was applied to the 2m x 16m ice block.

For the layer of water above the ice, a custom material was made to mimic sea water with an average salinity of 35g/kg. To model this, the material was given a density of 1028.1 kg/m^3, heat capacity of 3985 J/(kg.K) (constant pressure), the ratio of specific heats was set to 1.0004, and a thermal conductivity of 0.563 W/(m.K).

Once the geometry was built and the materials chosen, the desired physics were applied to the model. The water layer is given an initial temperature value of 285.15 degrees Kelvin, as the COMSOL model did not incorporate the higher temperature of the water inflow which in other experiments stopped the water from freezing. Heat flux was set up along the top of the water layer to simulate cold air meeting the water's surface. The external temperature was set to 233.15K, though this value was changed via auxiliary sweep during the study section. The ice was given an initial temperature value of 233.15K as well, though this will again change with an auxiliary sweep.

Once the physics were set, a mesh was created and set to use a normal element size, as this simulation is simple enough that Mesh fineness does not come into play. Finally, a study was created to set exactly what must be measured and done. A time dependent study was selected, with a time range of 0-600 seconds with a 1 second step time. An auxiliary sweep was then set up, allowing for the simulation to be repeated with air/ice temperatures of 273.15, 263.15, 253.15, 243.15, 233.15 and 223.15 Kelvins.

When the study finished computing, the results were then plotted using a line graph. This was made to display the average water temperature against time for all the values used in the auxiliary sweep. This data was then interpreted and commented upon, and the time taken for the water to reach freezing point (-1.8C in the case of water of this salinity) is extrapolated for each individual ice/air temperature.

B. SIMULATION II – FLOW DISTANCE OF WATER FROM PUMP

The second COMSOL simulation was used to find out the distance the water reached within the estimated time provided by the dye experiment and the first COMSOL simulation.

To simplify the second experiment, the distance was found using laminar flow directly from the pump using its flow rate within the allotted time of 60 seconds. To begin, a second 2D COMSOL project was made with the laminar flow and particle tracking physics for the distributed water as well as the movement of the water. This was followed by another geometry model containing a rectangular block, 2cm x 1000m which set the maximum possible distance for the water to travel. This acted as a pool of water flowing across the ice originating from the pipe. This was modelled as a slice of the total puddle and was used to determine a total theoretical radius.

Figure 22: Partial diagram for the 2nd COMSOL model

Once the geometry was set, the laminar flow physics was implemented using an inlet on one end of the pipe and an outlet at the other end to represent the water flow. The inlet was set to a laminar inflow condition, with the velocity set to the flow rate of the pump at 40,000 litres per hour which is 0.01111m^3/s, whilst the outlet was set to be a pressure condition which let the water flow freely. Following this a particle tracking for fluid flow physics was implemented. This was done to demonstrate the water movement which provided the maximum possible distance that the water could travel within the allotted time. This also had an inlet and outlet for the particles to travel to and from with the addition of a drag force to simulate resistance (friction and water tension). The materials and parameters used for this were the same from the previous experiment.

After the materials and physics were chosen and geometry built, the study was set up. To observe laminar flow a stationary study was chosen to show that velocity was present, and a time dependent study was used for the particle tracking to check the movement of the water within a time range of 0 to 200 seconds (with a 1 second time step). This was used to measure the distance travelled at the different times set from the previous experiment. Finally, a mesh was created for the whole geometry and set to be a normal element size. Once the program had finished computing and simulating the results were then interpreted.

IV. Pumping System Design

The designing and modelling of the pumping system was a crucial part of the project. It was necessary to obtain the different ratios between the different components to ensure the success of any building that may have occurred later in the project. The preliminary designs were first hand drawn and later modelled in 123D design, and the final design was then later made in Blender using both community provided models as well as the group's own. The first two designs are here to show the thinking and refinement of the overall system. The wind turbine was left out of designs 1 & 2 with the assumption that they would be placed away from the pump. However, in the final design it was decided that with no way of securing a cable between the two sections without it either becoming frozen over or requiring the drilling of extra holes for power pylons, the wind turbine would instead be mounted atop the pump housing as shown in figure 25. Each design features a box that contains a pump, Raspberry Pi, necessary insulation and sensors with their accompanying wires. In early designs this box was made to be small, with the understanding that it would be scaled to accommodate the size of the internal components.

A. Design 1

The first theoretical design used an above water centrifugal pump to draw the water from beneath the ice without the need for a large hole. The water was then to be propelled against a metal, corrosion resistant shield. This shield was designed to be in the shape of a parabolic curve, which theoretically allows the vertical jet of sea water to be evenly deflected; creating a 360^{o} spread around the delivery pipe. This was desired so that the pump would not have to be rotated to cover the other sides that would otherwise be missed. To secure the structure in the high arctic winds the inlet pipe to the pump was designed to have a corkscrew around it. This feature means that once a hole has been predrilled the entire structure could be screwed into place using a large hex bolt fitting at the pipe / pump interface. The corkscrew provided a few major benefits, when the water freezes around the pump, the pipe would still be easily unscrewed, secondly the screw creates a water tight seal against the ice stopping the pumped water from flowing back through the hole. Figure 23 shows the first design with the parabolic shield and corkscrew pipe.

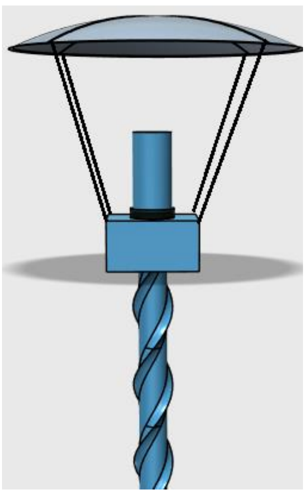

Figure 23: Initial design concept with corkscrew inlet pipe and parabolic shield

This design had the benefits of a theoretically even distribution of water across the ice. However, there were two major problems that stopped this design from being chosen for the final model. Firstly, the shield support structure would have to be thin so that the water didn't get trapped by it which would cause the structure to, in time, freeze over. It also had to be strong enough so that the lift generated by the wind passing underneath the shield didn't break them. Such a breakage would cause a catastrophic failure as the water would land directly on top of the pump freezing it entirely. This freezing is the second reason why this design was not chosen, as even with the shield the water would most likely fall back to the pump rather than being deflected outwards.

B. DESIGN 2

The second design took certain design aspects from the first. The above water centrifugal pump and the corkscrew pipe with accompanying driving hex bolt were again incorporated for the same reasons as previously mentioned. However, in this design the parabolic shield was removed and instead the pump outlet was placed on a bearing and the pipe made to be off centre, so that the outflow pressure would cause it to slowly rotate. This alteration would still provide the 360^o coverage of the previous design, whilst simultaneously lowering the possibility of the structure freezing over as the water is projected horizontally instead of vertically. This design extended the corkscrew pipe so that 30cm of the pipe could be left sticking out above the ice, keeping the rest of the structure dry from the distributed water. This added section also allowed the height of which the pump is above the ice to be variable, which would be dependent upon the surface of the existing ice. The outlet pipe of the pump was angled to provide some extra throw distance to the sea water. Figure 24 shows the basic components of the second design.

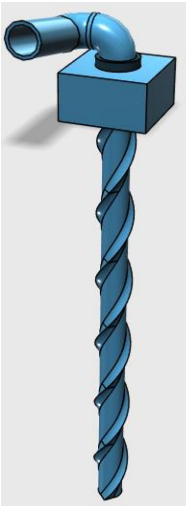

Figure 24: The extended corkscrew pipe with off centre horizontal pipe and bearing (shown in black)

This design had the benefit of still providing the 360^o distribution of the water in a simple and more compacted form. This benefits the Inuit who would have the job of moving and installing project at the different locations, as the size and weight of the system is vastly decreased due to the absence of the parabolic shield. However, even with the improvements certain problems could still be foreseen, such as the freezing of the device. This time the bearing used to allow the outlet pipe to spin was of concern. If ice was to form on the bearing itself, then the outputted water would be monodirectional. The design also required the use of output pressure to drive the pipes rotational spin, which would cause a pressure drop which in turn reduces the distance of propulsion. It also seemed unlikely that the pump would provide the amount of pressure required to spin the outlet pipe at a speed fast enough to stop the distributed water freezing before the next volume was added. If the outlet couldn't spin fast enough then the maximum distance the water would travel would be exponentially decreased. Using the improvements made in this second design the final design was modelled in Blender instead of 123D design.

C. Final Design

The final design removed the rotational pump outlet of the second, and instead had a static outlet directly from the pump as shown in figure 25. This static pipe was also angled downward as it was realised that any water left over would pool within the pump and freeze if angled the same as the secondary design. Once again, the corkscrew inlet pipe was extended to provide a variable elevation off the ice again making it variable to fit the need of the situation. The design shown in figure 25 is equipped with a single outlet. However, the outflow pipe can be divided into 2 or 4, to provide an outlet on each of the sides of the pump housing. With 4 outlets the pressure would be vastly decreased as with design 2, but the flow would be continuous, allowing for the constant addition of the warmer water to help stop the freezing process. The use of a single outlet ensures a much greater flow rate in a single direction.

Additionally, the pump housing was elevated using spikes for extra support, and the corkscrew pipe was removed due to the high cost but should be incorporated in the built project due to the reasons mentioned in design 1. In this design, the placement of the Raspberry Pi was finalised and can be seen on the nearside of the baseplate. The wind turbine was fixed on top of the pump housing, which was made possible by the extra support of the spikes. The polystyrene insulation was left out for clarity on the precise positioning of each individual component all of which can be seen in figure 25.

Figure 25: The final design of the pumping system along with wind turbine and internal component placement.

V. Raspberry Pi Code

A. Temperature Sensing Code

The first few lines of code import the GPIO (General-Purpose Inputs and Outputs) and Bluetooth module into the Raspberry Pi. The GPIO pins are then initialised using the "GPIO.setmode(GPIO.BCM)" code, which sets them up ready to use. A reset button was created so that in the event of an error, the Raspberry Pi can be restarted. An LED was also setup in conjunction with the sensing apparatus to indicate a problem should one arise.

When the thermo sensor detects an internal temperature lower than the freezing point of sea water, the code sends a message out through the mesh network until it reaches the client socket. In the case of our project the client socket will be the Inuit's phone or other Bluetooth device.

After the client socket has been made the operator must then manually input the phones wireless address into the Raspberry Pi code by using port 3. This allows the Raspberry Pi to know the address of which to send the necessary information.

Whilst the device is active, the program accesses the data collected by the temperature sensor and prints it to a file within the Raspberry Pi. If at any point this temperature is lower than the freezing point of sea water ($-2^{O}C$) then a message will be sent to the client socket saying, "Temperature too low" and the LED will turn on. This could later be used in conjunction with a flow rate sensor to detect ice blockages. Upon resetting the Raspberry Pi (once the issue is fixed) the program will stop and disconnect the client socket, which will be re-established once it has started back up.

A problem with the latest version of the Raspberry Pi being used was that it is too recent of a model to interface with the thermo-sensor. To solve this issue either a newer thermo-sensor or an older Raspberry Pi would need to be purchased, so that the kernel still contains the necessary functionality required for that specific sensor. The code shown in figure 26 will need to be converted into python (.py) for it to function on the Raspberry Pi.

```
import RPi.GPIO as GPIO                      #Import Statement; Note: This will need to be installed first "sudo apt-get install python-rpi.gpio"
from bluetooth import *                      #Import the bluetooth module; Note: Install: see Adafruit Tutorial Install Bluez

GPIO.setmode(GPIO.BCM)                       #Initialize the GPIO pins
GPIO.setup(17, GPIO.IN)                      #This number is the button GPIO pin, used to stop the program when run
GPIO.setup(18, GPIO.OUT)                     #LED pin if used, otherwise comment out
client_socket=BluetoothSocket( RFCOMM )      #Create the client socket

GPIO.output(18, GPIO.LOW)                    #Make the LED pin off for now
client_socket.connect(("xx:xx:xx:xx:xx:xx",3)) #Manually connect to the phone's MAC Address on port 3

while True:
        if GPIO.input(17):                   #If the button is pressed, stop the program
                print "Finished"
                client_socket.close()        #Close the socket
                break

while GPIO.input(17):                        #While button is held, do nothing
        pass

while True:
        tfile = open("/sys/bus/w1/devices/w1_bus_master1/serial_num/w1_slave")
        text = tfile.read()                  #Open the Thermosensor pin; Note: the serial number can be found:
        tfile.close()                        #sudo modprobe w1-gpio
        temp_data = text.split()[-1]         #sudo modprobe w1-therm
        temp = float(temp_data[2:])          #cd /sys/bus/w1/devices/
        temp = temp / 1000                   #ls <- This lists the contents of the file; the long string of numbers is the serial code
        print temp                           #Note: w1_slave is a file where the output of the thermosensor is put
        if (temp < -2.50):
                client_socket.send("Temperature too low!")
                GPIO.output(18, GPIO.HIGH)   #If temperature is lower than -2.5 Celsius, LED goes high
        if GPIO.input(17):
                print "Finished"
                client_socket.close()        #Close the socket
                break
```

Figure 26: Txt file of the temperature sensing code for the Raspberry Pi

B. Explanation of the Button Code

A secondary button was added to replace the temperature sensor due to the problems previously mentioned. Figure 27 shows the new GPIO for this button. When pressed this will send the message of "Temperature too low" to the client socket and the LED will turn on. As previously the code shown was converted to python (.py) so that it may run on the raspberry pi.

```
import RPi.GPIO as GPIO                      #Import Statement; Note: This will need to be installed first "sudo apt-get install python-rpi.gpio"
from bluetooth import *                      #Import the bluetooth module; Note: Install: see Adafruit Tutorial Install Bluez

GPIO.setmode(GPIO.BCM)                       #Initialize the GPIO pins
GPIO.setup(17, GPIO.IN)                      #This number is the button GPIO pin, used to stop the program when run
GPIO.setup(4, GPIO.IN)
GPIO.setup(18, GPIO.OUT)                     #LED pin if used, otherwise comment out
client_socket=BluetoothSocket( RFCOMM )      #Create the client socket

GPIO.output(18, GPIO.LOW)                    #Make the LED pin off for now
client_socket.connect(("xx:xx:xx:xx:xx:xx",3)) #Manually connect to the phone's MAC Address on port 3

while True:
        if GPIO.input(17):                   #If the button is pressed, stop the program
                print "Finished"
                client_socket.close()        #Close the socket
                break

while GPIO.input(17):                        #While button is held, do nothing
        pass

while True:
        if (GPIO.input(4)):
                client_socket.send("Temperature too low!")
                GPIO.output(18, GPIO.HIGH)   #If temperature is higher than -2.5 Celsius, LED goes high & string sent to phone
        if GPIO.input(17):
                print "Finished"
                client_socket.close()        #Close the socket
                break
```

Figure 27: Txt file of the button code replacing the temperature sensor for the Raspberry Pi.

RESULTS

I. FREEZER EXPERIMENTS

A. FOOD COLOURING EXPERIMENT

Figure 28: Photograph of frozen layers for 5cm^2 food colouring experiment

Figure 29: Photograph of frozen layers for 10cm^2 food colouring experiment

Figure 30: Photograph of frozen layers for 15cm^2 food colouring experiment

From the layers created, it is evident that each layer begins to fill in areas that the first layer did not, thereby increasing the total area covered. It was observed that while each layer does create a build-up of thickness over the first layer, it also spreads out to new areas and fills in uneven gaps created by the previous layer. It was also assumed that this phenomenon would lead to the layers eventually building a circular shape, as they spread out more and fill in more gaps.

Notice also the heavily saturated spots in the centre of each set of layers. This is an indentation in the ice, likely caused by the force of the burette water hitting the ice surface, combined with its much higher temperature. This effect is unlikely to be present in the arctic as the water would be pumped outwards instead of directly down at the ice surface, and the temperature would also be much closer to that of the ice.

The depth of each volume was calculated by dividing the volume (cm^3) by the area spread (cm^2). The results shown in table 1 are a rough estimate, due to the nature of the method used. As can be seen after a certain volume, depth of the ice formed is at a constant 0.12cm.

Volume (cm^3)	Area spread (cm^2)	Calculated depth (cm)
5	55	0.09
10	84	0.12
15	130	0.12

Table 1: Calculated depth from traced ice formation from varying volumes of water.

II. COMSOL SIMULATIONS

A. SIMULATION I

The temperature of the water over time for the six different air temperatures was plotted using a 1d plot group, as is shown in figure 31.

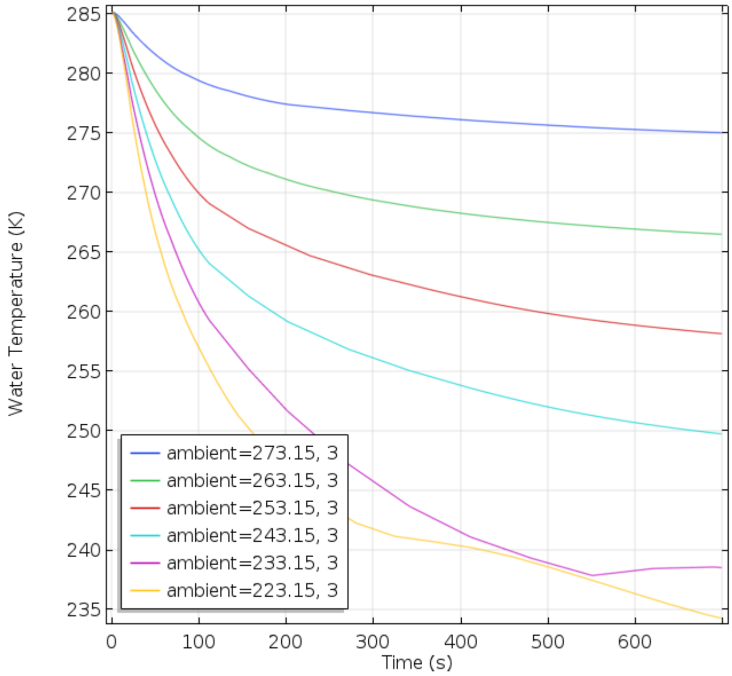

Figure 31: Change in water temperature over time at different ambient (air/ice) temperatures

A faster drop in water temperature was observed as the environmental temperature decreased. Notice also the slight upwards trend of the 223.15K (purple) line towards the 500 second mark. This is likely due to software error, as it does not conform to known theories of heat transfer in fluids.

From this graph, the time taken to reach 271.35K (the freezing temperature of sea water) is determined and plotted in a table and graph:

Air/Ice Temperature (Celsius)	Time to reach -1.8^{O}C (seconds)
0	n/a
-10	190.6
-20	84.5
-30	57
-40	43.9
-50	35.5

Table 2: Table of Environmental temperatures and the corresponding freeze time of the water

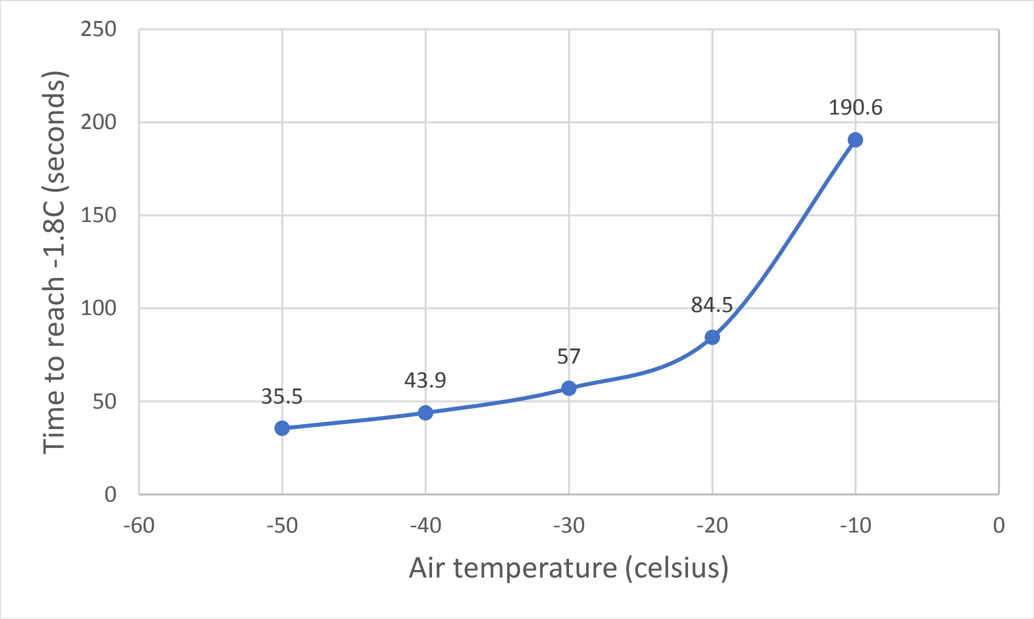

Figure 32: Graph of freeze time against environmental temperature

Notice the clear exponential rise in freeze time as the environmental temperature increases, and notice that the freeze time is not available for 0ºC, as the environmental temperature is higher than the freezing temperature of the sea water.

B. Simulation II

The first computation shown will be the stationary study of laminar flow to provide water movement, shown in figure 33.

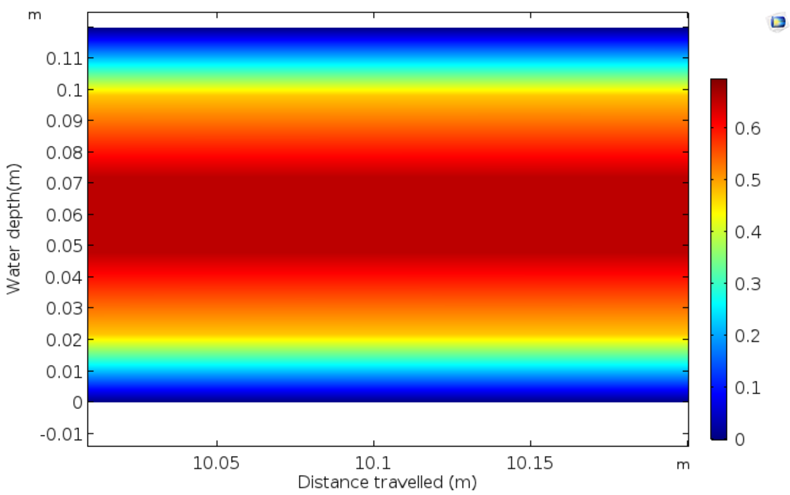

Figure 33: Stationary Study Laminar Flow

This figure shows a high velocity at the centre, with the maximum flow of 0.7m/s and minimum flow of 0.05m/s. The red zone is responsible for most of the water movement, and at the top it shows that it seems still, as if the red zone acts as current flow.

The second simulation is to show the particle tracking of the fluid flow. Previously a simulation was done on different temperatures to show at what times the water will reach -1.8^{O}C (freezing point of sea water), and these times will be used to measure the maximum and minimum radius that the water can travel as shown in table 3 below, along with the diagram for each particle tracking at maximum time of 200s

Temperature	Max Radius Distance (m)
0	0
-50	13.8
-40	16.9
-30	22
-20	33
-10	75.4

Table 3: Times for each freeze time and the maximum distance / radius that it can be achieved

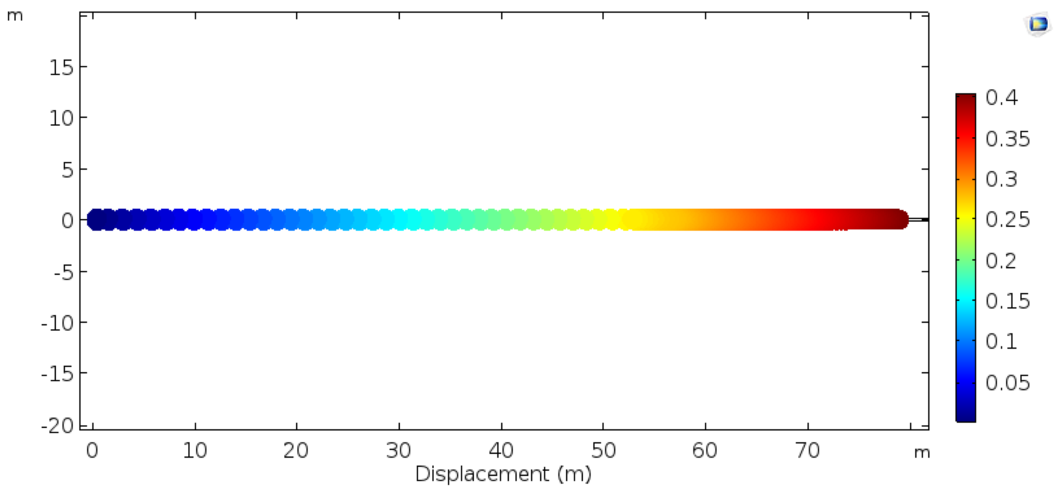

Figure 34: The particle tracking trajectory showing the first layer of ice from 0m (at the pump) to 80m

This shows that for each temperature, the water will travel at a constant velocity. With a trend that showed the water spreading over a larger distance when the water is of higher temperature. This means that in arctic temperatures around -20^{O}C to -30^{O}C that the maximum radius the water can spread is around 27.5m.

III. Car Park Experiment

Two iterations of this experiment were conducted, with the second being done due to the failure of the first. Shown below is a photograph of the results of the first attempt:

Figure 35: Photographs of first carpark experiment attempt, showing drainage towards wall

Figure 36: Photographs of first carpark experiment attempt, showing drainage towards water drain

Figure 37: Photograph of first car park experiment, showing initial water pouring area

Note the drainage towards the edge of the car park, near the walls and the drain, resulting in a smaller central water circle, as the water formed a puddle in the centre which then overflowed into small drainage ditches.

Due to this issue, the experiment was conducted again in a different part of the car park, further away from any drainage systems and on a flatter surface. This experiment provided more typical results, providing a semicircle shaped pool of water which was measured with a measuring tape:

Figure 38: Photograph of second attempt measurement

Figure 39: Photograph of second attempt measurement lengthways

Figure 40: Photograph of second attempt measurement diagonally

The measurements taken can be seen in the above photographs, with the measured lengths being 192cm, 189cm and 180cm. Thus, if the pool of water is approximated to be a circle with diameter of 185cm, it is possible to use the equation

$$A = \frac{\pi d^2}{4}$$

to provide a total area covered of 2.688m^2.

DISCUSSION

From the experiments conducted in this project, a few interesting points came to fruition. One of the main points that supports the viability of the project is the food colouring experiment, specifically the tendency of the layers to fill in areas that the previous layers had missed. This adds viability to the concept of pumping out water in stages, as each stage would bring the frozen area closer to a circular shape. It also provided the information that the distance the water spreads appeared to be directly proportional to the volume of water distributed, as the thickness appears to remain uniform around 0.12cm. This showed that there is potential for the system to be scaled up almost infinitely, as a higher power pump would not result in diminished gains. Such scaling up may be useful for future endeavours, particularly for replenishing ice in frozen lakes or permafrost regions, where access to the power grid can provide enough power for considerably larger pumps. More research should however, be conducted with the layering experiments, where a larger ice sheet should be available to layer with larger volumes of water and larger flow distances. This could likely take place in an ice skating rink or potentially in the arctic itself, should a working prototype be created.

With regards to the car park experiment, much knowledge was gained regarding the flow of water over a rough surface. The roughness of the car park led to a lot of randomness in how the water dispersed on the surface, and continuous flowing water did not produce a perfect circular shape, but instead moulded to the contours of the surface. This is important to note due to the rough surface of arctic sea ice, which is filled with edges and frozen waves that would prevent a perfect puddle of water from forming. This lends credence to the idea that a simulation such as the one in COMSOL could never fully describe the water flow in the arctic, but can merely approximate the extent of the pumping. The first failed attempt at the experiment also demonstrates that the presence of a slope or gradient to the surface can lead to water flowing considerably further from the water source, pooling up at the bottom of the slope. While in some ways this is beneficial due to the lowered risk of water freezing near the outlet pipe, it can pose a risk if the device is deployed near a crevasse or close to the edge of an ice shelf, as the water may flow off and provide no freezing benefits. This is something that must be taken into consideration when choosing where to deploy the device.

The COMSOL simulations themselves provided one of the biggest pieces of concrete data in this project, by outlining an average freeze time and typical distance travelled for water flowing from a 40000 LPH pump. The freeze times were an essential part of determining the viability of the project, because if the water froze too quickly, a tall block of water would form around the pump and eventually block it, resulting in the project failing. The freeze time provided by the simulation (roughly a minute for average arctic winter temperatures) was high enough that the water would be able to travel a considerable distance from the pump. The exact distance that it would travel was determined in the second COMSOL simulation, where it was discovered that a maximum distance of 27.5m would be travelled (under normal arctic conditions. This means that, if the distance travelled is comparable to the radius of a circle, the total area covered would be equivalent to 2375m^2.

While this represents a miniscule percentage of the total arctic ice extent, this amount of ice does produce a visible effect on counteracting carbon emissions. Combining this figure with the carbon emission calculations from earlier in the project, it can be estimated that one use of the system would produce enough ice to offset 206.7 tonnes of CO_2, or the equivalent of the annual emissions of over 41 cars. Translated into carbon credits, this gives the operator a regular income of £206-413 per use of the device, providing a stable income in a region of the world where regular work is difficult to come by. This demonstrates that the device not only offsets a considerable amount of carbon emissions, but also provides enough of a monetary incentive for arctic natives to deploy the device.

The experiments conducted in this project, along with the background research conducted and designs reviewed, has provided a clear outline and list of recommendations for the eventual construction of an arctic ice pump.

CONCLUSION

One of the largest areas affected by global warming is the Arctic. With climate change causing a rapid increase in global temperature, the ice caps have begun to shrink at such a fast rate that the global politics is unlikely to make the necessary changes in time. As the ice caps shrink, greenhouses gasses trapped within them are released into the atmosphere. The albedo effect of the area in general will decrease exponentially, as the reflectiveness of sea water is much lower than that of the ice. This shrinking therefore causes a 'cannon' effect as the ice caps become a contributing factor to global warming. This is ignoring the inevitable loss of habitat and wildlife as sea levels rise. It was decided that a global charity effort to buy time for the political stage to catch up was required, as it has been predicted that there will be no ice sheets in the summer by the year 2050. Consequently, this research was performed to investigate the feasibility of a wind powered, pumping system to thicken the arctic ice in those regions currently disappearing, as a form of edge strengthening onto the main ice shelf reducing the chance of pieces breaking off. Within this investigation, it was crucial that a design was created that can survive the arctic environment. With models and simulations available to provide a framework for future work that can provide an estimate on the devices functionality.

It was through the dye experiment that a rough calculation for the depth of ice was found at different volumes of water as well as the way in which the water filled the "gaps" that the previous ice layers missed due to the non-uniform way in which the water naturally spreads. Due to this finding, it was deduced that given enough layers there would be the correct depth for most of the theoretical circular area especially when the volume of water is dramatically increased. The results saw a darker area of colour where the flow from the burette melted the ice on the point of contact. This was likely due to the large temperature difference that arose from the use of room temperature sea water and is unlikely to occur using arctic sea water. However, this effect will need to be examine when a prototype model is built. It was also noted that the freeze times between volumes poured was fairly constant, likely due to uniform thickness of the water (0.12cm at volumes $10cm^3$+), and that freezing only occurred once pouring had finished. From this it was calculated that using a 40KLPH pump would give a potential hourly area of $17860m^2$ which provides a radius of 103m.

Using COMSOL Multiphysics the time taken for the water to freeze and the distance of which the water could spread in that time was found. This simulation allowed arctic testing without the need for a prototype, at varying air and ice temperatures using the data for depth found from the dye experiments. It was found that the lower these temperatures where the faster the ice freezes. However, a combination of the two simulations is required to simulate whether there is a maximum distance at which the water freezes regardless if pumping is still occurring or if the added warmer water is sufficient indefinitely. The flow rate of a pump using a laminar flow approximation, whilst under no slip boundary conditions, was also found. This was used alongside particle trajectories to find a theoretical maximum radius under arctic temperatures (-20 ^{O}C to – 30^{O}C) of 70 meters. It should be noted that this value is 33 meters less than the calculated maximum.

The car park experiment was found to be inaccurate due to the uneven and sloping surface that the water was distributed onto. It does however provide the insight that the water will fill in a crevice within the surface. This meant that the first few layers are likely to not travel as far in uneven ice shelves as the volume is used to fill in areas of increased depth. This would result in more layers to achieve the same overall thickness than the calculated minimum.

A Raspberry Pi was coded to simulate the sensing and networking capabilities of the pumping system. This will be a necessary component as the Inuit population uses a mesh network to communicate over long distances with each node in the network transmitting any received signals to boost its range. This is a requirement for the pump to be allowed onto the network, which is needed such that the Inuit can be messaged when necessary in the event of a breakdown or if it’s time for the system to be relocated. This section of the project requires future research to make this operational due to incompatibility problems between the new version of the Raspberry Pi being used and the thermo-sensor.

Finally, the feasibility of the device to generate money and be able to return a profit that is required for further investing was explored. It was calculated that per use of the pumping system the carbon emission offset caused is equivalent to 165 tonnes of carbon dioxide. In terms of carbon credits this would provide an income of £206 - $413 for every use, this was vital to the projects success as it provided incentive for the Inuit to purchase the product to begin with. This would provide the Inuit an arctic winter income of $2678 - $5369 for moving the device once every 3 weeks. Whether this value is enough to persuade the local population to initially buy the product would have to be surveyed.

FUTURE WORKS

Due to time constraints there is still more work needed for the device to become a reality. To start off, a prototype of this system needs to be built so that true to life experiments can be performed by sending it to the Arctic. This would provide real world data on the water spread and the freeze time, which could then be compared to the small-scale experiments to see if the simulations performed match the results gathered. This could then be used to refine the simulations more to reality, allowing for better modelling in the future. The Arctic would also provide a good opportunity to do some stress test on the prototype, to see if the materials suggested for the device would survive arctic conditions. A survey into the Inuit people will be ideal to provide feedback on how to improve the device, thus making it more suitable to the environment and Inuit. It will also answer whether the hiring of the local Inuit would be a viable relocation method for the pump.

To further improve the theoretical background, an improvement on the COMSOL simulation is needed. As there were some simulations that were left unfinished, for example the simulation of arctic conditions to determine the water distribution and freeze times. Once this simulation is corrected it will provide a reasonable idea on the expected results for the large-scale tests. More specifically this simulation requires the input of heat energy through the inlet pipe in order to remove the approximated initial value of the water.

Another improvement would be on the networking system, which will be used by the device to communicate to the Inuit. The messages sent about the device’s maintenance will play a major role in the projects future success, since the device will be left for upwards of 1 month at a time. If there are any emergencies then the communication network must be fast and accurate, to allow for maximum response time.

Finally, an improvement on the sensor networks would be ideal as this will go in tandem with the stress test of the device, to see if the current sensor system will hold its own in the Arctic environment. It will also help determine if there is any room for improving its power efficiency or make a system that could maintain itself.

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