Article

Windtech – A sensory device for 'cold' sensation measurements

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Abstract: Windtech device is a novel tool for measuring the sensation of the 'cold'. Cold poses numerous challenges for industrial operations, human survival, and living convenience. The impact of the cold is not possible to be quantified just based on temperatures; however other factors such as wind speed, humidity, irradiance have to be taken into consideration. Efforts have been made to develop combined indices such as wind chill temperature (WCT), AccuWeather RealFeel®, and others. The presented article discusses these along with the industrial standards that emphasize on the quantification of the 'cold'. The following article introduces the Windtech device and its operating principle involving 'heated temperature', where the 'heated temperature' is affected by environmental parameters including ambient temperature, humidity, wind velocity, and irradiance. The discussed Windtech device is calibrated for operation according to the ISO 11079:2007 standard.

Keywords: Cold Sensation; Heat Loss; Cold Related Risks; Real Feel Temperature

1. Introduction

Most of the industries located in extremely cold climates face numerous challenges regarding operation conditions, human survival, and living convenience. The challenges can be named as lack of infrastructure, storms, blizzards, low humidity, icing, polar lows, low temperature, icing, wind chill, fog, sea temperature, polar night, and polar day [1, 2]. The average temperature in the Arctic is around -20 Celsius degrees according to meteorological data related to the years 1958-2018 [3]. The low temperature in the Arctic causes issues for the marine industry, offshore oil, and gas platform and increases ice formation in the polar and sub-polar regions [4]. Severe weather poses several risks for organizations and businesses; therefore, there exists a need for an advanced warning system that gives accurate predictions on weather conditions at specific locations [5]. The issues in cold regions involve both humans and equipment that are primarily general cooling and local cooling (e.g., face, feet and hands). In addition, exposure to extreme environmental conditions affects cognitive thinking and performance. What is of particular interest is how human performance is affected and how this may have an effect on the safety, quality, and production at the site [6, 7]. The sensation of 'cold' increases by the heat loss from the body [8]. The cold exposure and humidity over time can result in several health issues and injuries, including skin problems, cold burns, chill blains, trench foot, fingertip fissures, frostnip fissures, frostnip, frostbite, hypothermia, and cold-induced bronchoconstriction. These damages are briefly described in Table 1 [9-11]. Severe weather poses several risks for organizations and businesses; therefore, there exists a need for an advanced warning system that gives accurate predictions on weather conditions at specific locations.

Table 1 - Cold related injuries [9, 10]

Health problem	Symptoms
Skin problems	Sunburn: The ultraviolet radiation (UVB) from the sun can cause redness and tenderness to oedema, blistering and fever. Windburn: Windburn provokes dry skin and can be prevented by utilizing covers.
Cold burn	Cold burn is the instant, superficial freezing of tissue when touching a freezing cold object or tool.
Chill blains	Chill blains is an inflammatory condition due to exposure to cold and moisture. The hands and feet begin to swell, itch and become painful. These symptoms may develop some hours after exposure to cold exposure has stopped and may remain for several days.
Trench foot	Trench foot is due to constant exposure to cold without freezing, combined with constant humidity or immersion in water which causes inflammation, redness, itching, severe pain, numbness, and eventually blistering and tissue death.
Fingertip fissures	Usually, in dry conditions, deep, intractable, and painful fissuring can occur when exposed to cold for a long period.
Frostnip	Frostnip is the freezing of the skin and outer tissue, mostly in the face and fingers. The earliest symptoms are stinging, pricking pain and skin whitening.
Frostbite	Frostbite is the freezing of deeper and superficial tissue. It mostly affects the fingers, toes, nose, cheeks, and ears. It can cause damage to tissues to different extents: 1st degree: freezing without peeling and blistering of the skin; however, the skin changes color. 2nd degree: freezing in addition to blistering and peeling of the skin, with pain and violet skin color. 3rd degree: freezing with blackening and death of skin tissues, and in some cases deeper tissues. Pain gives way to numbness.
Cold-induced Bronchoconstriction	Cold exposure may trigger bronchoconstriction and asthma-like signs, usually in low humidity.
Hypothermia	Hypothermia is defined as the chilling of the body's core temperature below 35˚C, while it can occur in mild, moderate, and severe levels.

2. Wind Chill Temperature (WCT)

During the winter, usually high wind velocity is combined with low dry-bulb temperature, which results to a severity expressed by wind chill factor as a standard meteorological term. Wind chill factor, or in other words, wind chill temperature (WCT) states that how air temperature with no wind affects heat loss rate from bare human skin compared to a condition with a combination of wind and dry-bulb present [12, 13]. Wind chill effect can also be simply defined as the human feeling of discomfort and exposure to danger by considering several factors, including ambient temperature, wind velocity, humidity, and irradiance [14-16]. The wind chill effect increases heat loss by removing a thin layer of generated heat in the body; therefore, cold-related injuries such as frostbite, tissue freezing, and hypothermia can occur. On the contrary, if the heat is not removed appropriately, then hyperthermia, heatstroke, or fever can happen [17-19]. Humans have always been looking for a reliable approach to determine the environmental effect on the sensation of cooling. Several experimental methods and various formulas are developed to determine this effect [20]. The wind chill factor introduced by each method has inconsistencies and deficiencies due to irresistible data collection errors and implementation of the data with heat transfer principles [21, 22]. One of the earliest models for wind chill index was based on experiments on a water-filled plastic container exposed to the cold wind in Antarctica [23, 24]. In this method, the time taken for the water to freeze was recorded for a variety of temperatures and wind velocities. The data was used for heat transfer coefficient calculation, as shown in Equation (1),

$$h_{wc} = 10.45 + 10V^{0.5} - V, \quad (1)$$

where $h_{wc}(kCal/m^2h°C)$ is the heat transfer coefficient and $V\ (m/s)$ is wind velocity. Thereafter, wind chill index (WCI) can be calculated by implementing Equation (2),

$$WCI = h_{wc}(33 - T_{air}), \quad (2)$$

where $WCI(kCal/m^2h)$ is an arbitrary wind chill index, $T_{air}(°C)$ is the temperature of the surroundings, and it is assumed that the skin temperature is $33°C$. This model was too crude and had several inconsistencies; therefore, it was modified later, considering different modes of heat transfer and various parts of the body [13, 25]. In this model, heat transfer coefficients were separately calculated for head and face as shown in Equations (3) and (4),

$$h_{head} = 11.5V^{0.68}, \quad (3)$$

$$h_{face} = 14.4V^{0.61}, \quad (4)$$

where $h_{head}\left(\frac{W}{m^2°C}\right)$ is the head heat transfer coefficient, $h_{face}\left(\frac{W}{m^2°C}\right)$ is the facial heat transfer coefficient, and $V(m/s)$ is the wind velocity. In addition, the radiative and convective factors of the heat loss are considered [13] using Equations (5) and (6),

$$h_r = 4\varepsilon\sigma\overline{T}^3, \quad (5)$$

where $h_r\left(\frac{W}{m^2K}\right)$ is the radiative heat transfer coefficient, ε is the emissivity (estimated to be about 0.04 [26]), σ is the Stefan-Boltzmann constant and $\overline{T}(K)$ is the mean air temperature.

$$h_c = 8.7V^{0.6}, \quad (6)$$

where $h_c\left(\frac{W}{m^2K}\right)$ is the convective heat transfer coefficient.

The WCI model for facial cooling in this model is based on heat flow per unit area as shown in Equation 7,

$$Q = \frac{37 - T_{cheek}}{R_{cheek}}, \quad (7)$$

where $Q\ (W/m^2)$ is the heat flow per unit area, $T_{cheek}(°C)$ is the cheek skin temperature, $R_{cheek}\left(\frac{m^2K}{W}\right)$ is the thermal resistance of skin, and the body's core temperature is assumed to be $37°C$. The new WCI for the facial cooling can now be calculated having the value of Q by Equation (8),

$$WCI = 4.2Q - f(T_{air}), \quad (8)$$

where $WCI\left(\frac{kCal}{m^2h}\right)$ is the wind chill index (WCI), and $f(T_{air})$ is a function based on the temperature of the surroundings. Later this method was adjusted by Equation (9) which is the most common and accepted method for Wind Chill Temperature calculation [17],

$$WCT = 13.2 + 0.6215T_{air} - 11.37V_s^{0.16} + 0.3965T_{air}V_s^{0.16}, \quad (9)$$

where $WCT\ (°C)$ is wind chill temperature (WCT), $T_{air}(°C)$ is the temperature of the surrounding air and $V_s(km/h)$ is the wind speed. The wind chill chart plotted using Equation (9) is shown in Table 2 [27].

The wind chill index is based on heat transfer rules, and principles and equations are derived implementing those with collected environmental parameters data including air/ambient temperature, atmospheric/air pressure [28]. These parameters in addition to humidity, irradiance and wind velocity are the environmental parameters that affect how humans feel cold [9, 29].

Table 2. Wind Chill Temperature (WCT/°C) Chart [27].

Wind Speed (km/h)	Air Temperature (°C)												
Calm	**10**	**5**	**0**	**-5**	**-10**	**-15**	**-20**	**-25**	**-30**	**-35**	**-40**	**-45**	**-50**
10	9	3	-3	9	-15	-21	-27	-33	-39	-45	-51	-57	-63
15	8	2	-4	-11	-17	-23	-29	-35	-41	-48	-54	-60	-66
20	7	1	-5	-12	-18	-24	-31	-37	-43	-49	-56	-62	-68
25	7	1	-6	-12	-19	-25	-32	-38	-45	-51	-57	-64	-70
30	7	0	-7	-13	-19	-26	-33	-39	-46	-52	-59	-65	-72
35	6	0	-7	-14	-20	-27	-33	-40	-47	-53	-60	-66	-73
40	6	-1	-7	-14	-21	-27	-34	-41	-48	-54	-61	-68	-74
45	6	-1	-8	-15	-21	-28	-35	-42	-48	-55	-62	-69	-75
50	6	-1	-8	-15	-22	-29	-35	-42	-49	-56	-63	-70	-76
55	5	-2	-9	-15	-22	-29	-36	-43	-50	-57	-63	-70	-77
60	5	-2	-9	-16	-23	-30	-37	-43	-50	-57	-64	-71	-78
70	5	-2	-9	-16	-23	-30	-37	-44	-51	-59	-66	-73	-80
80	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81

[1] Blue shaded region represents WCT associated with frostbite in 30 minutes or less.

3. AccuWeather RealFeel® Temperature

The AccuWeather's exclusive RealFeel® temperature is a novel index created to give a unique indication of how humans feel about weather conditions. This measurement considers at least two weather-related parameters selected from a group, including wind velocity, solar intensity, water dew point parameter, atmospheric pressure parameter, and precipitation parameter, to provide a value representative of how cold or warm it feels outdoors on an accordingly dressed person [30, 31]. The index also takes into account people's perception of the 'cold'. The wind is a main contributing factor on the feeling of the 'cold'; however, humidity can have a considerable effect on certain regions [32]. Other indices of human comfort, such as wind chill index or heat index, report a value-based only upon two factors of temperature and wind speed or humidity; thus, they are not accurate [31]. Protective measurements through clothing and insulating can control and regulate the heat loss from humans or equipment [8]. Table 3 gives an indication of how the AccuWeather's RealFeel® temperature can be implemented based on recommendations [33].

Table 3. The AccuWeather RealFeel® temperature guide [33]

Temperature Range (°C)	Category	Recommendations
+10 to +4	Chilly	Jacket or Sweater.
+3 to -3	Cold	Coats, hats, gloves or scarf.
-4 to -12	Very cold	Caution recommended. Older adults, infants, people with medical conditions can get frostbite or hypothermia.
-13 to -23	Quite cold	Caution recommended. Frostbite can happen to exposed body parts with no cover in 15 minutes, Hypothermia is likely.
-24 to -31	Bitterly cold	Caution advised. Frostbite and hypothermia are likely
-32 to -41	Dangerously cold	Significant caution recommended. Frostbite to exposed skin within 2 minutes hypothermia likely without proper clothing. Outdoor activity avoided or limited.
-42 to -56	Very dangerously cold	Great caution advised. Frostbite to exposed skin within 1 minute. Hypothermia likely without proper protective clothing. Outdoor activity is very dangerous and life threatening. Can be conducted with proper coverage and limitations.

-57 to -67	Extremely dangerous cold	Extreme caution is recommended Frostbite to exposed skin in 30 seconds. Hypothermia likely. Outdoor activity is only allowed in absolutely necessary situations and should limited to few minutes
-68 to -84	Extraordinarily dangerous cold	Extraordinary caution is advised. Frostbite danger within 20 seconds. Hypothermia likely. Outdoor activity is extraordinary dangerous. Staying in heated areas recommended.

4. Industrial Standards

When the risk is referred to, it can involve numerous areas such as hazards related to a terroristic attack, concerns about complex technologies, stock market fluctuations, natural disasters, extreme sports dangers, or many other areas [34]. There is no specific definition for risk; however, it can be fundamentally defined as the probability of occurrence of accident times its consequence and uncertainties [35].

The human body's response to cold temperatures can increase the overall risk associated with these activities as situational awareness and decision-making abilities are decreased as exposure is amplified. Therefore, it is a requirement within high-risk industries for the safety of operators working in a cold environment to be monitored to ensure safe operations and to minimize the risk of injury in remote and vulnerable areas.

Risk analysis methods are tools used to uncover risk in various situations or operations [36]. After the risk analysis, a risk assessment is performed where the results of the analysis are evaluated. The risk assessment is done by assessing the probability or severity, and consequences of unwanted events or hazards. During the risk assessment, preventive measures can be implemented to minimize the risk by either lowering consequences or the likelihood of an unwanted event occurring [37]. Following standards are implemented for risk management strategy suggestion including:

4.1. ISO 11079 Determination and interpretation of cold stress when using required clothing insulation (IREQ) and local cooling effects:

International Organization for Standardization (ISO) 11079 provides methods and strategies for assessing the thermal stress associated with exposure to the cold environment. Cold stress is evaluated regarding both general cooling of the body and local cooling, such as extremities and face. The wind chill is defined as convective cooling. The standard claims that local cooling of the body part including hands, feet and head may produce discomfort, and may lead to physical injury. In addition, the environment's coldness is determined by weather and climate, and protective measures mostly include adjustment of clothing or exposure control [38].

4.2. ISO 15743 Cold Workplaces – Risk Assessment and Management:

ISO 15743 presents models and methods to manage and assess cold risk in workplaces, strategies to perform a cold risk assessment and health assessment in the workplace. The standard states that due to the negative effect of quality and safety, a risk assessment and management strategy is necessary for work in cold climates.

Cold risk assessment is a method to identify cold-related problems and consists of three stages [39]:

- Stage one (observation) identifies cold-related hazards at work
- Stage two (analysis) aims at quantifying, analyzing and estimating the cold-related effects from stage 1
- Stage three (expertise) aims at quantifying, analyzing and estimating cold risks

4.3. ISO 17776 Guidelines on Tools and Techniques for Hazard Identification and Risk Assessment:

The standard addresses principal tools and techniques which are used for identifying and assessing hazards associated with offshore oil and gas activities. Furthermore, it provides guidance on these tools and techniques can assist in developing strategies to both prevent hazardous events and to control and mitigate any events that can arise [40].

- Barrier is a measure which reduces the probability of realizing a hazard's potential for harm and which reduces its consequence.
- Tolerable risk is the risk which is accepted in a given context based on the current values of society.

The standard provides a risk-reduction measures hierarchy, from most to least efficient respectively:

- Prevention
- Detection
- Control
- Mitigation
- Emergency response

4.4. NORSOK S-002 Working Environment:

NORSOK S-002 describes requirements for the working environment for offshore installations. The purpose of the standard is to ensure the design of the facility promotes the quality of the working environment during the operational phase. The requirements cover analyses and issues in the design phase, along with project development for the working environment. The standard addresses heat loss as WCI. Based on this standard indication of the level of environmental exposure on individuals is useful in numerous situations. [41].

Appropriate actions and recommendations can be proposed for safer existing operation conditions such as: de-icing or anti-icing operations, appropriate clothing suggestions, work limitations, other HSE relevant actions.

5. Windtech Device

Windtech device provides a mean to measure environmental exposure [42]. The device is equipped with a novel sensor that measures cumulative response to the various environmental parameters, e.g., temperature, wind, humidity, irradiance, etc. It is designed to be wearable, henceforth it is an indicative of the environmental exposure level of an individual wearing the device. In essence, the device measures the heat flow and can be correlated to the heat loss experienced by the individuals, through exposed parts such as the face or hands. Since the device is in the proximity of the individual, it is capable of providing a more accurate indication of an individual's exposure than regional metrological data [43]. This allows the potential exposure risk to an individual to be more accurately assessed. The device can also be installed on the equipment or buildings to gather environmental parameters at specific locations. The information collected by the device is extremely useful for the health and safety of personnel and equipment exposed to the cold climate conditions and can be used to prevent cold-related injuries on humans working in harshly cold climates [44]. The CAD drawing of the device is shown in Figure 1. The real-life photo of the 3D printed prototyped model of the device is shown in Figure 2.

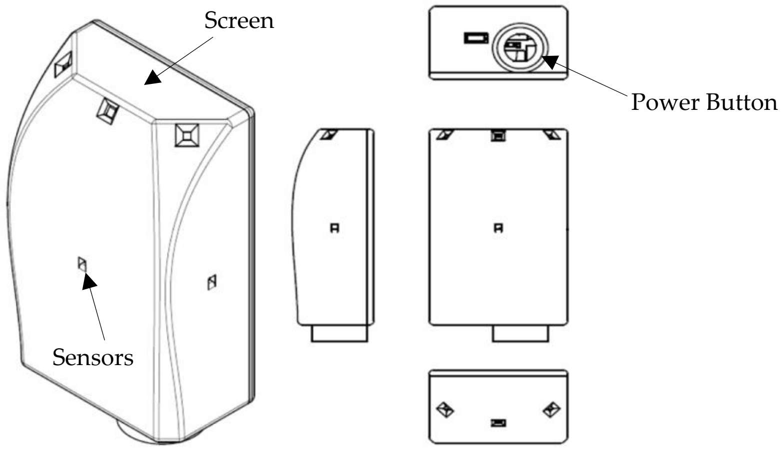

Figure 1. CAD drawing of the Windtech device prototype

Figure 2. 3D printed Windtech device prototype model.

6. Windtech Device Working Principle

The device is mainly comprised of a heater, a power supply, an exposed surface to an external environment, a temperature sensor arranged to sense a temperature at a region that is thermally coupled with the heater and with the exposed surface. Power is supplied to the heater from the power supply, therefore, emitting heat energy from the heater to the external environment from the exposed surface. Signals received from the temperature sensors are representative of the ambient temperature (T_a) at a desired location. The temperatures are further processed to determine a value representative of heat flow through the exposed surface, referred to as 'heated temperature' (T_h).

Figure 2 shows the graph for how the temperature of the exposed surface of the device, including the heating element and temperature sensor, change over one cycle of data logging. When the heating element activates, the temperature rises from an initial value of T_a representative of the ambient temperature to a stable value of T_h referred to as 'heated temperature'. Afterward the heater turns off and the temperature drops to the ambient value, and the cycle repeats.

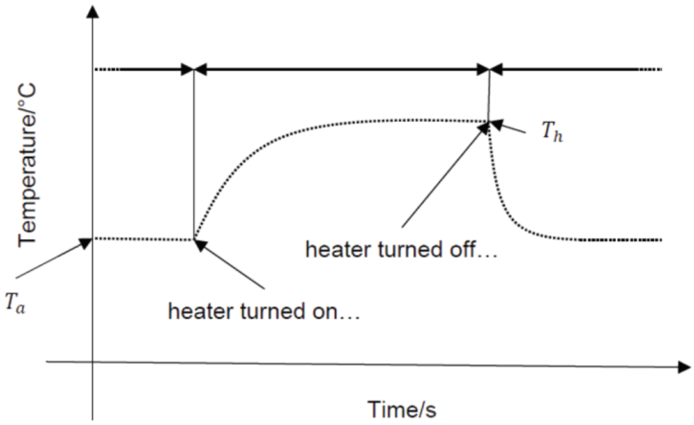

Figure 3. Graph of temperature against time for a cycle of heating [42]

The 'heated temperature' curve behaves according to Newton's law of cooling, where a heat transfer between a fluid and a solid surface occurs due to a temperature gradient. The Newton's law of cooling is expressed mathematically by Equation (10),

$$\dot{q} = hA(T_h - T_a), \tag{10}$$

where $\dot{q}\left(\frac{W}{m^2}\right)$ is the convective heat flux, T_h is the 'heated temperature' ($°C$) and T_a is the ambient temperature ($°C$), $A\ (m^2)$ is the surface area and the proportionality constant $h\left(\frac{W}{m^2K}\right)$ is termed the convection heat transfer coefficient [45, 46]. The temperature at any given time can be calculated explicitly using lumped-capacitance method as shown in Equation (11),

$$\frac{T-T_h}{T_a-T_h} = exp\left[-\left(\frac{hA}{\rho Vc}\right)t\right], \tag{11}$$

where $T(°C)$ is the temperature, $\rho(kg/m^3)$ is the fluid density, $V(m^3)$ is the volume of the solid surface, $c\left(\frac{J}{kg\ K}\right)$ is the specific heat capacity, and $t(s)$ is the time.

The device is a battery-powered item. The battery life experiences severe loss in temperature below $0°C$ [47-49]. Therefore, managing battery life by optimizing the period that the heater is working is of importance. The heater timer is adjustable by certain commands through controllers installed within the device. A data logger gathers the values collected by sensors and received through signals.

Figure 4 shows the device's internal components, including power source, voltage regulator, heating element, temperature sensor, and a controller. The voltage regulator is comprised with an electronic power switch or a controller for heating element on/off functions. The dotted lines show the paths for the transmission of electrical power between components while solid arrows indicate data and control signal paths. The heating element is exposed to ambient condition in addition, by transferring electrical power, the temperature of the heating element rise. The temperature sensor is also exposed to ambient conditions and the heating element. The response of the temperature sensor being exposed to the heating element and ambient condition is further sent to the controller to obtain the output.

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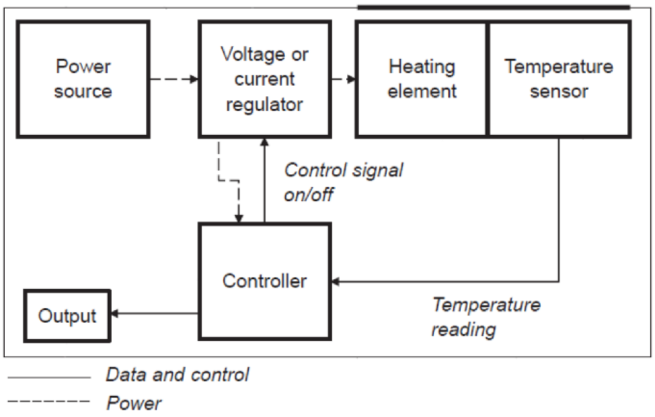
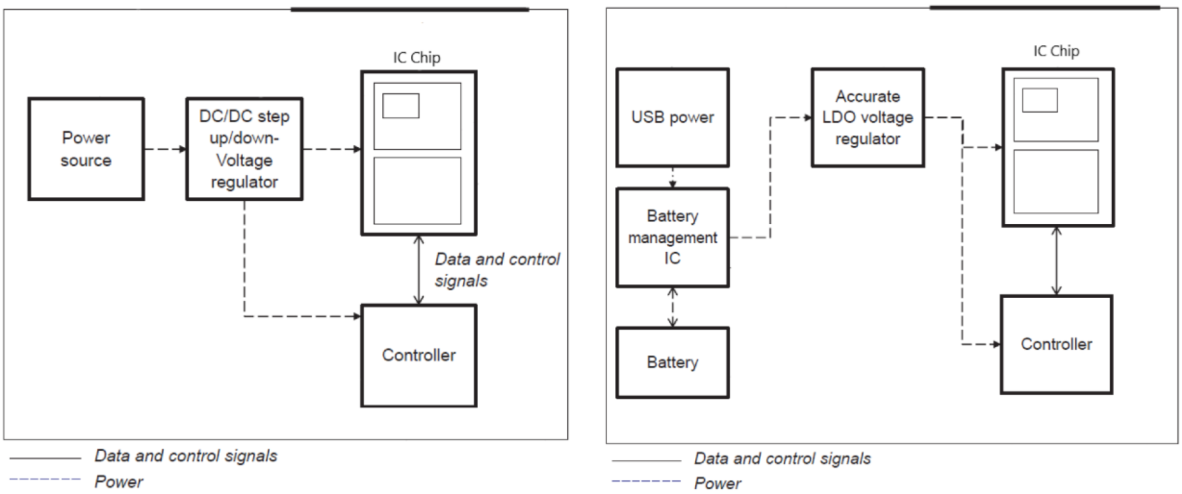


Figure 4. Schematic view of the device internal parts [42]

Figure 5 shows the schematics for the device alternatives. Figure 5(a) shows an alternative of the device broadly similar to the device shown in Figure 4. In this schematic, the heating element is part of an integrated circuit (IC) chip. The device contains a power source, a DC/DC step-up-down converter, an integrated circuit chip and a controller. The power source provides power to IC chip via voltage regulator. The IC chip comprises a heating element and a temperature sensor. The heating element comprises a power control circuit that can turn the heating element on and off with related commands. The temperature sensor is arranged to send the received signal from the exposed surface to the controller.



(a) (b)

Figure 5. Schematics of the device alternatives [42].

Figure 5 (b) shows another alternative of the device in which the heating element is again part of an integrated circuit chip in addition to the battery management integrated circuit chip. The device has a housing for a USB power source, a rechargeable lithium-ion or lithium-polymer battery, a battery management integrated circuit chip, an LDO (low drop-out) voltage regulator chip, an integrated circuit chip comprising a heating element and a temperature sensor, and a controller. The rechargeable battery is arranged to provide electrical power to the integrated circuit and to the controller via the battery management chip and the LDO voltage regulator. The battery can receive electrical power from the USB power supply through a battery management integrated circuit. Therefore, the device can be charged by connecting it to a USB port. The battery management integrated circuit chip monitors the state of the battery and provides step-up output voltage functionality. The LDO voltage regulator chip regulates the supply of electrical power to the integrated circuit and the controller to supply the electrical power at a constant voltage.

Figure 6 shows the flowchart for a heating cycle. In the first step the ambient temperature T_a is measured by the electrical temperature sensor, and the value is stored in the memory of the controller. In the second step, the power is supplied to the heater resulting in temperature rise and heat exchange with the exposed surface and temperature sensor; after stabilization, the 'heated temperature' T_h is measured. The temperature T_h of the exposed surface is affected by environmental parameters, including humidity, ambient temperature, irradiance, and wind velocity. In the next step T_r a value representative of heat flow is calculated from measured values of T_a and T_h. The ambient temperature and 'heated temperature' values are compared with calibration data obtained through empirical testing in controlled environments in order to determine the appropriate value of T_r. In the final step of the cycle, the heater switches off, and the cycle repeats.

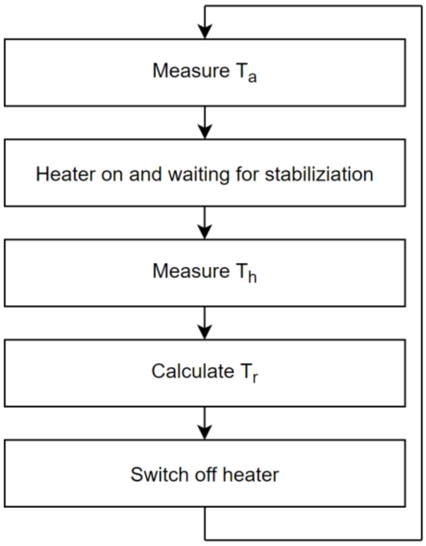


Figure 6. The device working cycle flowchart [42]

7. Windtech Device Calibration and Operation

The temperature sensors installed in the device are factory calibrated. The T_r value is the function of heated temperature T_h and ambient temperature T_a. For calibration, the device has been put through controlled conditions in the laboratory with different conditions regarding ambient temperature, irradiance, wind velocity, and humidity. The obtained data is calibrated and compared against other indications of representative temperatures such as wind chill temperature (WCT) chart [27, 30]. The values of T_r are used to determine a risk classification between zero and four that is based on the classifications provided in ISO 11079:2007 standard [38]. Table 4 shows the probability of injury such as frostbite for people being exposed to colds according to each risk classification based on T_h and T_r values. The recommended limitation for operation is suggested to be carried out by the wearer of the device. The Table 4 is also provided with exemplary values which may vary according to heater timer and design specifications of the device.

Table 4. Risk classifications based on ISO 11079:2007 standard [38,42].

Risk Classification	T_h/°C	T_r/°C	Risk	Recommended Limits for Work
0	45 or warmer	-9 or warmer	Low risk, <5% frostbite chance for most people	Normal work; emergency work. Planned maintenance
1	27 to 44	-10 to -24	Low risk, <5% frostbite chance for most people, Uncomfortable coldness	Normal work, (reduced work periods); emergency work
2	16 to 26	-25 to -34	Moderate risk, increasing risk of frostbite for most people in 10-30 minutes, severe cold	Normal work (reduced work periods); emergency work
3	5 to 15	-35 to -59	High risk, risk of frostbite for most people in 2-10 minutes, bitterly cold	Emergency work only
4	4≤	-60≤	Extreme risk, risk of frostbite for most people in 2 minutes or less, extremely cold	No work outside

8. Conclusion

Following conclusions can be drawn from the presented study,

1. Due to several risks regarding cold climate for organizations and humans, there exists a need for an advanced warning system that gives accurate weather predictions on specific locations.
2. Prolonged exposure to cold affects humans both motorically and cognitively.
3. Health injuries including skin problems, cold burn, chill blains, trench foot, fingertip fissures, frostnip, frostbite, cold-induced bronchoconstriction, hypothermia can occur due to cold.
4. Indications of human feeling on low temperatures have been developed, such as wind chill index (WCI) and AccuWeather RealFeel®.
5. Risk management strategies are suggested based on industrial standards.
6. The Windtech device makes it possible to gather environmental parameters data at specific locations.
7. The Windtech device gives a novel indication of cold sensation.
8. For calibration purposes, the device has been tested in different controlled conditions through experiments.
9. Based on direct measurement via Windtech device and calibrated data against other indices of cold and industrial standard ISO 11079:2007, risk management strategies are proposed.

9. Patents

The presented study has resulted in the following patent,

Hassan Khawaja, Daniel Swart, Ståle Antonsen via Windtech AS. UK Patent Application GB2588580 - Measuring environmental exposure. Intellectual Property Office, UK, Filing Date: 11th October 2019, Publication Date: 05th May 2021. Available from: https://www.ipo.gov.uk/p-ipsum/Case/PublicationNumber/GB2588580

Author Contributions: Conceptualization, H.K. and D.S.; methodology, H.K., D.S. and S.A.; software, S.A.; validation, A.L., H.K. and D.S.; formal analysis, A.L., H.K. D.S and S. A; writing—original draft preparation, A.L., H.K., S.A.; writing—review and editing, A.L., H.K.; supervision, H.K.; project administration, H.K.; funding acquisition, H.K, A.L.

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