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Power, Jonathan; Barker, Anne; Mahar, Melvin

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Evaluation of Canadian Armed Forces cold weather clothing with supplemental Indigenous clothing

Report No.: NRC-OCRE-2022-TR-013

Prepared for: Wendy Sullivan-Kwantes
Operational Health and Performance Section, Toronto Research Center
Defence Research and Development Canada
E-mail:Wendy.Sullivan-Kwantes@ecn.forces.gc.ca

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Author(s): Jonathan Power, Ph.D.
Melvin Mahar, E.E.T.
Anne Barker, P.Eng.

Ocean, Coastal, and River Engineering Research Centre

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Revision History

Document Version	Name	Affiliation	Date of Changes	Comments
1.0	Jon Power	NRC-OCRE	28 March 2022	Draft report
1.1	Jon Power	NRC-OCRE	7 April 2022	Client comments incorporated
1.2	Jon Power	NRC-OCRE	20 April 2022	Additional comments incorporated
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1.4	Jon Power	NRC-OCRE	10 July 2022	Correction to Table 5a

Executive Summary

Canadian Armed Forces personnel routinely operate in the harsh environments of the Northern Arctic, where they are exposed to freezing temperatures that could possibly result in injury or death. Canadian Armed Forces personnel often wear specialized clothing with high thermal insulation to help protect them against extremely low temperatures that can occur during the winter months. Improving the methods of protecting personnel in the Arctic would help to increase their safety and improve their performance.

Canada's Northern residents have lived and operated in the Arctic for hundreds of years, and have developed clothing to help protect them from these harsh environments. Defence Research Development Canada has requested that the National Research Council of Canada assist in investigating how the addition of Indigenous-made garments can change the amount of thermal insulation in typical clothing ensembles worn by Canadian Armed Forces personnel.

Clothing ensembles that are worn by different branches of the Canadian military, along with a variety of Indigenous-made garments, were tested using a thermal manikin. The standardized total insulation value for each ensemble was calculated, along with the clo values for the hand, foot, head, and neck garments.

Ensembles that incorporated Indigenous-made garments had higher standardized total insulation values compared to the base ones that did not use them. Indigenous -made hand garments had a higher clo value compared to those used in the base ensembles. When using Indigenous-made head and neck garments, ensembles had a slightly higher amount of thermal insulation compared to those that did not use them. There were negligible differences between the Indigenous made socks compared to those used in the base ensembles.

While it may not be feasible to replace larger garments such as parkas for general military use, the inclusion of smaller Indigenous-made garments such as mittens or neck warmers may offer increased protection for personnel in the harsh environments of the Canadian Arctic.

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1. Introduction

Canadian Armed Forces (CAF) personnel routinely operate in the harsh environments of the Northern Arctic, where they are exposed to freezing temperatures that could possibly result in injury or death. CAF personnel often wear specialized clothing with high thermal insulation to help protect them against extreme low temperatures that can occur during the winter months. Improving the methods of protecting personnel in the Arctic would help to increase their safety and improve their performance.

Canada's Northern residents have lived and operated in the Arctic for hundreds of years, and have developed clothing to help protect them from these harsh environments. Defence Research Development Canada has requested that the National Research Council of Canada's Ocean Coastal and River Engineering research center assist in investigating how the addition of Indigenous-made garments can change the amount of thermal insulation in typical clothing ensembles worn by CAF personnel.

The objectives of this work are to:

- Establish baseline thermal insulation of Royal Canadian Navy (RCN) issued cold weather clothing and Army cold weather equipment.
- Evaluate the thermal protection of Indigenous made cold weather garments.
- Investigate how the thermal properties of Indigenous clothing and its ability to protect the wearer according to its construction and purpose can provide guidance for design and construction of harsh weather clothing.

2. Materials and Procedure

2.1. Thermal Manikin (NEMO)

All tests were conducted using a 23-zone submersible thermal manikin, NEMO (Figure 1). Each of the 23 independently heated zones contain a heater and two precision thermistors for measuring skin temperature. While NEMO is capable of being submerged, all tests for this project were conducted in the air.

2.2. Thermal Measurements Lab (TML)

All tests were conducted in NRC-OCRE's thermal measurements lab (TML). The TML is a temperature controlled facility that is capable of maintaining an air temperature (T_a) over a range of 4°C to 30°C, which is monitored by a pair of thermistors located on the North side of the room. For all tests, NEMO was suspended from an overhead crane located in the TML (Figure 1).

Figure 1: Thermal manikin, NEMO, in NRC-OCRE's TML.

2.3. Clothing Ensembles

Pictures of the individual garments are provided in Appendix A. The different clothing ensembles tested are given in Tables 1-6. Pictures of the different ensembles on NEMO are provided in Appendix B. Ensemble 1A was representative of what would be worn by personnel in the Army, while ensemble 1B was representative of what would be worn by personnel in the RCN. Both ensemble 1A and 1B were considered the "base" ensembles, with subsequent ones replacing certain garments with Indigenous made clothing.

Table 1: Army -Clothing ensemble 1A garments.

Garment	Description
Underwear Top	Lightweight thermal undershirt, polyester, long sleeve, mock turtleneck w/ zipper, olive green. NSN: 8415-21-914-5151
Underwear Bottom	Lightweight thermal drawers, polyester, long legs, unisex, olive green. NSN: 8415-21-914-5157
Fleece Jacket	Fleece sweat shirt, combat type, long sleeves, reinforcement patches, CADPAT, ICE. NSN: 8415-21-920-8580
Fleece Pants	Fleece sweat pants, combat type, reinforcement patches, CADPAT, ICE. NSN: 8415-21-920-8554
Cold Weather Parka	Parka, combat, CADPAT, TW Integrated Clothing Ensemble (ICE). NSN: 8415-21-921-6904
Bib Pants	Overalls, cold weather, CADPAT, TW ICE, bib top. NSN: 8415-21-921-6950
Mukluks	Mukluks, extreme cold weather, high rise, nylon upper, rubber sole, white. NSN: 8430-21-104-6919
Mukluks Boot Liner	Mukluk liners, extreme cold weather, wool, white, NSN: 8430-21-104-6919
Mukluk Mesh Insole	Ventilated felt insoles with white nylon bias binding. NSN: 8335-21-104-7163
Mukluk Felt Insole	Non-ventilated wool felt insoles. NSN: 8335-21-520-5257
Wool Socks	Socks system, cold weather, CF, under knee design, wool, nylon, and lycra. Grey. NSN: 8440-21-920-3706
Liner Socks	Issued black liner socks
Arctic Mittens	Mitten Shells, extreme cold weather, gauntlet type. NSN: 8415-21-510-5951; and Mitten Inserts, cold weather. NSN: 8415-21-510-5961
Liner Glove[1]	Non-issued cotton liner gloves
Neck Gaiter	Lightweight thermal neck gaiter, poly/nylon/spandex, Canadian average green. NSN: 8440-21-921-0905
Green Toque	Toque, pull-on style, double-layer, polyester shell with fleece lining, Canadian average green. NSN: 8415-20-008-7687

[1] A commercially available liner glove purchased from a local hardware store was used as the existing ones were soiled.

Table 2: RCN- Clothing ensemble 1B garments.

Garment	Description
Underwear Top	Lightweight undershirt. NSN: 8415-20-004-7959
Underwear Bottom	Lightweight thermal drawers. NSN: 8415-20-004-7965
Coveralls	Naval board part coveralls. NSN: 8405-20-000-7318
Floater Jacket	Floater jacket. NSN: 4220-20-010-7469
Floater Jacket Liner	Floater jacket thermal liner. NSN: 4220-20-010-7477.
Overalls – Buoyancy Aid	Overalls – buoyancy aid. NSN: 8415-21-920-2560
Navy Safety Boots	Safety boots – cold wet weather. NSN: 8430-20-005-6368.
Liner Socks	Lightweight black liner socks NSN: SC 8440-21-920-7434
Cold Weather Socks	DND cold weather socks NSN: SC 8440-21-920-3705
Balaclava	Balaclava. NSN: 8415-20-007-4030
Cold Weather Gloves	Cold wet weather gloves. NSN: 8415-20-008-4022
Green Toque	Toque, 100% polyester. NSN: 8415-20-008-7687.

Table 3: Army-Clothing ensemble 2A garments.

Garment	Description
Underwear Top	Lightweight thermal undershirt, polyester, long sleeve, mock turtleneck w/ zipper, olive green. NSN: 8415-21-914-5151
Underwear Bottom	Lightweight thermal drawers, polyester, long legs, unisex, olive green. NSN: 8415-21-914-5157
Fleece Jacket	Fleece sweat shirt, combat type, long sleeves, reinforcement patches, CADPAT, ICE. NSN: 8415-21-920-8580
Fleece Pants	Fleece sweat pants, combat type, reinforcement patches, CADPAT, ICE. NSN: 8415-21-920-8554
Cold Weather Parka	Parka, combat, CADPAT, TW Integrated Clothing Ensemble (ICE). NSN: 8415-21-921-6904
Bib Pants	Overalls, cold weather, CADPAT, TW ICE, bib top. NSN: 8415-21-921-6950
Mukluks	Mukluks, extreme cold weather, high rise, nylon upper, rubber sole, white. NSN: 8430-21-104-6919
Mukluks Boot Liner	Mukluk liners, extreme cold weather, wool, white, NSN: 8430-21-104-6919
Mukluk Mesh Insole	Ventilated felt insoles with white nylon bias binding. NSN: 8335-21-104-7163
Mukluk Felt Insole	Non-ventilated wool felt insoles. NSN: 8335-21-520-5257
Underwear Top	Lightweight thermal undershirt, polyester, long sleeve, mock turtleneck w/ zipper, olive green. NSN: 8415-21-914-5151
Homespun Wool Socks	Socks made from homespun wool
Neck Warmer (Beaver)	Neck warmer made with sheared beaver fur
Long Hunting Mittens (Sealskin and Fur)	Mittens made with sealskin

Table 4: RCN-Clothing ensemble 2B garments.

Garment	Description
Underwear Top	Lightweight undershirt. NSN: 8415-20-004-7959
Underwear Bottom	Lightweight thermal drawers. NSN: 8415-20-004-7965
Coveralls	Naval board part coveralls. NSN: 8405-20-000-7318
Floater Jacket	Floater jacket. NSN: 4220-20-010-7469
Floater Jacket Liner	Floater jacket thermal liner. NSN: 4220-20-010-7477
Overalls – Buoyancy Aid	Overalls – buoyancy aid. NSN: 8415-21-920-2560
Navy Safety Boots	Safety boots – cold wet weather. NSN: 8430-20-005-6368.
Liner Socks	Lightweight black liner socks
Homespun Wool Socks	Socks made from homespun wool
Trapper Hat (Beaver)	Trapper style hat made with beaver fur
Neck Warmer (Beaver)	Neck warmer made with sheared beaver fur
Long Hunting Mittens (Sealskin and Fur)	Mittens made with sealskin
Balaclava	Balaclava, NSN: 8415-20-007-4030

Table 5: Army-Clothing ensemble 3A garments.

Garment	Description
Underwear Top	Lightweight thermal undershirt, polyester, long sleeve, mock turtleneck w/ zipper, olive green. NSN: 8415-21-914-5151
Underwear Bottom	Lightweight thermal drawers, polyester, long legs, unisex, olive green. NSN: 8415-21-914-5157
Fleece Jacket	Fleece sweat shirt, combat type, long sleeves, reinforcement patches, CADPAT, ICE. NSN: 8415-21-920-8580
Fleece Pants	Fleece sweat pants, combat type, reinforcement patches, CADPAT, ICE. NSN: 8415-21-920-8554
Siliapik Parka	Pull over parka made from siliapik
Bib Pants	Overalls, cold weather, CADPAT, TW ICE, bib top. NSN: 8415-21-921-6950
Mukluks	Mukluks, extreme cold weather, high rise, nylon upper, rubber sole, white. NSN: 8430-21-104-6919
Mukluks Boot Liner	Mukluk liners, extreme cold weather, wool, white, NSN: 8430-21-104-6919
Mukluk Mesh Insole	Ventilated felt insoles with white nylon bias binding. NSN: 8335-21-104-7163
Mukluk Felt Insole	Non-ventilated wool felt insoles. NSN: 8335-21-520-5257
Homespun Wool Socks	Socks made from homespun wool
Trapper Hat (Beaver)	Trapper style hat made with beaver fur
Neck Warmer (Beaver)	Neck warmer made with sheared beaver fur
Long Hunting Mittens (Sealskin and Fur)	Mittens made with sealskin
Liner Glove	Cotton liner gloves

Table 6: Army-Clothing ensemble 4A garments.

Garment	Description
Underwear Top	Lightweight thermal undershirt, polyester, long sleeve, mock turtleneck w/ zipper, olive green. NSN: 8415-21-914-5151
Underwear Bottom	Lightweight thermal drawers, polyester, long legs, unisex, olive green. NSN: 8415-21-914-5157
Fleece Jacket	Fleece sweat shirt, combat type, long sleeves, reinforcement patches, CADPAT, ICE. NSN: 8415-21-920-8580
Fleece Pants	Fleece sweat pants, combat type, reinforcement patches, CADPAT, ICE. NSN: 8415-21-920-8554
Cold Weather Parka	Parka, combat, CADPAT, TW Integrated Clothing Ensemble (ICE). NSN: 8415-21-921-6904
Bib Pants	Overalls, cold weather, CADPAT, TW ICE, bib top. NSN: 8415-21-921-6950
Mukluks	Mukluks, extreme cold weather, high rise, nylon upper, rubber sole, white. NSN: 8430-21-104-6919
Mukluks Boot Liner	Mukluk liners, extreme cold weather, wool, white, NSN: 8430-21-104-6919
Mukluk Mesh Insole	Ventilated felt insoles with white nylon bias binding. NSN: 8335-21-104-7163
Mukluk Felt Insole	Non-ventilated wool felt insoles. NSN: 8335-21-520-5257
Homespun Wool Socks	Socks made from homespun wool
Trapper Hat (Beaver)	Trapper style hat made with beaver fur
Neck Warmer (Beaver)	Neck warmer made with sheared beaver fur
Mittens (Beaver)	Mittens made with beaver fur
Liner Glove	Cotton liner glove

2.4. Procedure

All clothing ensembles were tested according to ASTM F1291-16 (ASTM, 2016) and ASTM F2732-16 (ASTM, 2016b) with the following deviations:

- NEMO was not calibrated using a calibration ensemble as described in ASTM F1291-16 (ASTM, 2016). A custom procedure (Mak et al., 2010) was used that verifies NEMO's power output by immersing it in a known volume of water. Additionally, NEMO was calibrated through a procedure compliant with ISO/IEC 17025 and ANSI/NCSL Z540.1.
- NEMO was programmed to maintain a mean skin temperature (T_{sk}) of 40°C instead of 35°C. This was done to increase the thermal gradient between NEMO and the ambient air temperature of the TML, which was set to 4°C; the lowest stable temperature it can maintain. Previous work by the NRC with high insulation clothing found that a T_{sk} of 35°C resulted in a thermal gradient that only required the heaters in NEMO to operate with minimal, if any, power. Having the heaters in NEMO operate with little to no power can make it difficult to get an accurate measurement of the thermal insulation provided by an ensemble. By increasing T_{sk} to 40°C, the thermal gradient is increased,

requiring more power from the heaters in NEMO, allowing for more accurate measurements of thermal insulation of clothing ensembles with high insulation.

- Only two tests of each ensemble were performed, instead of three specified by ASTM F1291-16 (ASTM, 2016).

NEMO was suspended off the ground for each test by two hooks underneath its axilla (armpits) (Figure 1).

T_a was set to 4°C in the TML for all tests.

A stationary Honewell Advanced QuietSet fan (model #: HSP600SC) generated wind at approximately 0.4 $m \cdot s^{-1}$ at the chest of NEMO (Figure 1). The wind velocity was measured using an anemometer integrated into NEMO's data acquisition system.

All garments were hung on a coat rack in the TML for at least 12 hours prior to testing to allow them to acclimatize with the atmosphere in the facility.

Once NEMO was dressed in the various garments to create the specified ensemble, it was programmed to raise its T_{sk} to 40°C and maintain for the duration of the test. Once NEMO reached a thermal steady state, a minimum of 30 minutes of data was collected. ASTM F1291-16 (ASTM, 2016) defines steady state as less than 3% variation in T_{sk} and power output of the thermal manikin. The last 30 minutes of steady state date was averaged to calculate thermal resistance.

After the test was completed, NEMO was undressed and allowed to cool down to the point where its skin temperature was near equal to room temperature. NEMO was then redressed in the same ensemble and the test repeated.

In addition to the ensembles, a single nude test was performed in which NEMO was suspended by the hooks while wearing no clothing garments. This test was performed to measure the thermal insulation of the air layer around NEMO.

2.5. Calculations

2.5.1. Thermal Resistance

NEMO's onboard software (ThermDac) automatically calculates total thermal resistance using the parallel method (parallel thermal resistance) for each zone during the tests using the following equations specified in its operator's manual (Thermetrics, 2007):

$$R_{ct} = \frac{T_{skin} - T_{amb}}{\left(Q/A\right)} \qquad \text{Equation 1}$$

Where:

R_{ct} = Zone thermal resistance ($m^2 \cdot °C \cdot W^{-1}$)

T_{skin} = Zone average temperature (°C)

T_{amb} = Ambient temperature (°C)

Q/A = Area weighted heat flux (W·m^{-2})

After the zone thermal resistance was calculated, parallel thermal resistance was calculated using the following equation:

$$R_{wtd}(parallel) = \frac{1}{\sum \frac{A_i}{(A_{tot} \cdot R_{ct})}}$$ Equation 2

Where:

$R_{wtd}(parallel)$ = parallel thermal resistance (m^2·°C·W^{-1})

A_i = Zone surface area (m^2)

A_{tot} = Total surface area (m^2)

2.5.2. Parallel clo value

Parallel thermal resistance values were converted to clo[2] units using the following equation (Thermetrics, 2007):

$$R_{clo} = R_{wtd}(parallel) \cdot 6.45$$ Equation 3

Where:

R_{clo} = Parallel clo value

The parallel clo values from each of the three tests were averaged to get the mean value for each clothing ensemble.

2.5.3. Intrinsic Thermal Resistance

As per ASTM F2732-16 (ASTM, 2016b), the intrinsic thermal resistance of each clothing ensemble was calculated using the following equation:

$$I_{cl} = I_t - \left(I_a / f_{cl}\right)$$ Equation 4

[2] One clo is equal to the amount of insulation needed to keep a seated person comfortable in air at a temperature of 21°C, 50% or less relative humidity, with an air velocity of 0.1 m·s^{-1} (Golden and Tipton, 2002).

Where:

I_{cl} = intrinsic thermal resistance (insulation) of the clothing (clo)

I_t = total thermal resistance (insulation) of the clothing and surface air layer around the manikin (clo), which is equal to R_{clo} calculated using Equation 3.

I_a= thermal resistance (insulation) of the air layer on the surface of the nude manikin (clo)

f_{cl} = clothing area factor (dimensionless). A value of 1.25 was used for Configuration 1; a value of 1.35 was used for Configuration 2 (ASTM, 2016b).

2.5.4. Standardized Total Thermal Resistance

Standardized total thermal resistance (insulation) was calculated using the following equation as defined by ASTM F2732-16 (ASTM, 2016b):

$$I_{t.s} = I_{cl} - \left({}^{I_{a.s}}/_{f_{cl}}\right) \qquad \text{Equation 5}$$

Where:

$I_{t.s}$ = standardized total thermal resistance (insulation) of the clothing and surface air layer around the manikin (clo)

$I_{a.s}$ = standardized thermal resistance (insulation) of the air layer on the surface area of the nude manikin which has a value of 0.5 clo.

2.5.5. Temperature Rating Calculations

The following equations, as specified by ASTM F2732-16, were used to calculate estimated temperature ratings for ensembles that cover a substantial amount of body surface area such as jackets, coats, and insulated pants (ASTM, 2016b). As the base layer worn in each ensemble was different than what is specified in ASTM F2732-16 (ASTM, 2016b), the temperature ratings reported are not “ASTM Temperature Ratings”, but are estimated values that would allow a person to remain in a thermoneutral condition for a given metabolic rate and T_a.

The temperature ratings of head wear, footwear, and hand wear cannot be determined using the methods described in ASTM F2732-16.

$$TR2 = \left((-23.78 \cdot It,s + 89.93) - 32\right) \cdot \frac{5}{9} \qquad \text{Equation 6}$$

$$TR4 = \left((-48.61 \cdot It,s + 86.70) - 32\right) \cdot \frac{5}{9} \qquad \text{Equation 7}$$

Where:

TR2 = temperature rating (°C) for a low level of physical activity, which is equal to a metabolic equivalent of 2 (2 MET). A low level of physical activity is equivalent to a person walking very slowly (ASTM, 2016b).

TR4 = temperature rating (°C) for a moderate level of physical activity, which is equal to a metabolic equivalent of 4 (4 MET). A moderate level of physical activity is equivalent to a person walking very fast (ASTM, 2016b).

2.5.6. Manikin Segment Heat Output Calculation

The heat output (W) for the four different zones of NEMO covered by the different head and neck warmer garments were calculated by multiplying the area weighted heat flux ($W \cdot m^{-2}$) by the surface area (SA; m^2) of each zone. The four zones and their specific surface area values (Thermetrics, 2007) are:

- Face: 0.03601 m^2
- Head: 0.10965 m^2
- Chest: 0.10033 m^2
- Shoulders: 0.10369 m^2

$$Q = {}^{Q}/_{A} \cdot SA \qquad \text{Equation 8}$$

Where:

Q = Zone heat output (W)

${}^{Q}/_{A}$ = Zone area weighted heat flux ($W \cdot m^{-2}$)

SA = Manikin zone SA (m^2)

3. Results

3.1. Standardized Total Insulation Value and Temperature Rating

Table 7 provides the mean standardized total insulation value (STIV; clo), TR2 (°C), and TR4 (°C) values for each of the ensembles. Figure 2 provides the TR 2 (°C) and TR4 (°C) for each ensemble.

Table 7: STIV (clo), TR2 (°C), and TR4 (°C) values for each ensemble.

Ensemble	STIV (clo)	TR2 (°C)	TR4 (°C)
1A	3.693	-15.9	-67.9
1B	3.214	-10.3	-56.4
2A	3.815	-18.3	-72.6
2B	3.436	-13.3	-62.4
3A	3.746	-17.4	-70.8
4A	3.928	-19.8	-75.7

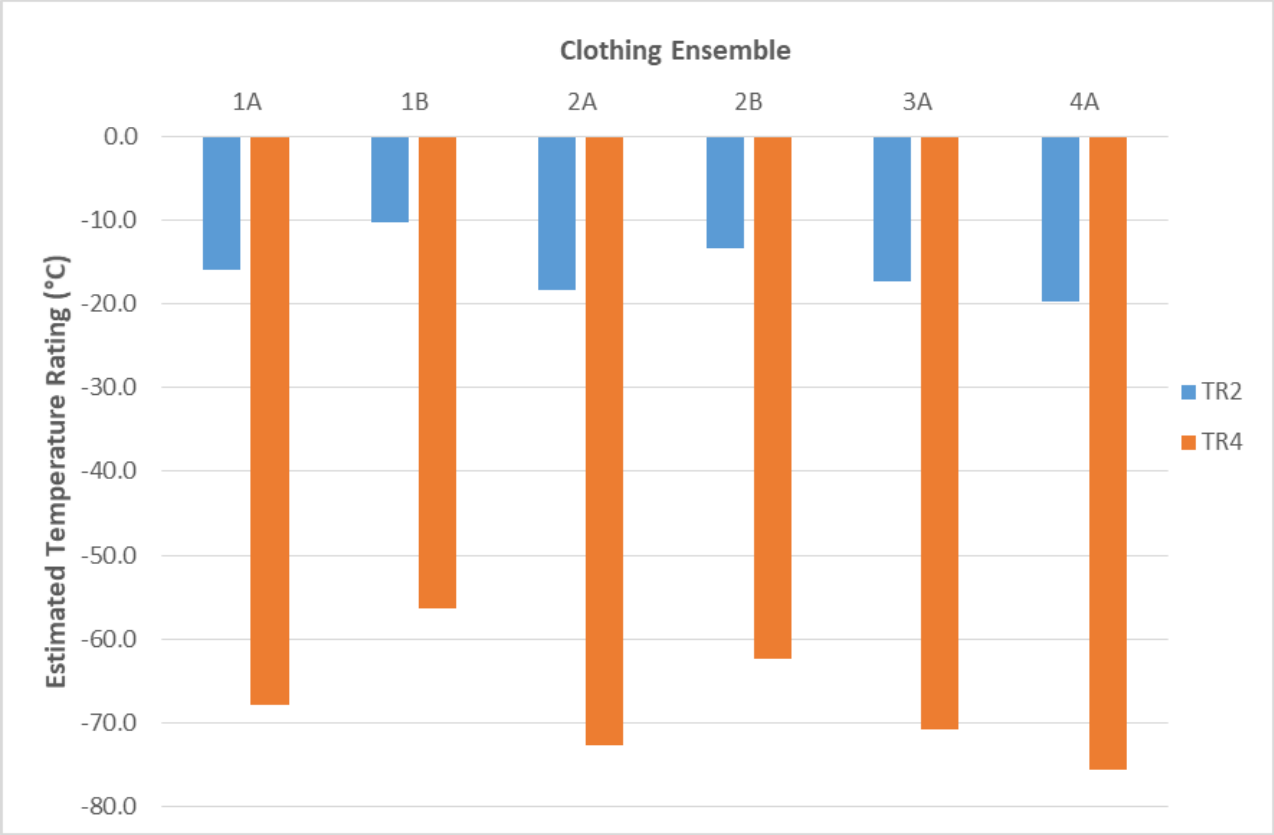

Figure 2: Estimated TR2 (°C) and TR4 (°C) for each clothing ensemble.

3.2. Hand Garments

Table 8 and Figure 3 provide the clo values (clo) for the different hand garments tested.

Table 8: Right, left, and mean clo values (clo) for the various hand garments tested.

Hand Garment	Ensemble Tested In	Zone Mean Clo Value (clo)		
		Right Hand	Left Hand	Mean
Arctic Mitten With Liner Glove	1A	1.715	1.736	1.726
Cold Weather Black Sea Gloves	1B	1.425	1.642	1.533
Sealskin and Fur Long Hunting Mittens	2A	1.988	2.041	2.014
Sealskin and Fur Long Hunting Mittens	2B	2.015	2.181	2.098
Sealskin and Fur Long Hunting Mittens	3A	2.081	2.160	2.120
Beaver Mittens	4A	2.632	2.790	2.711

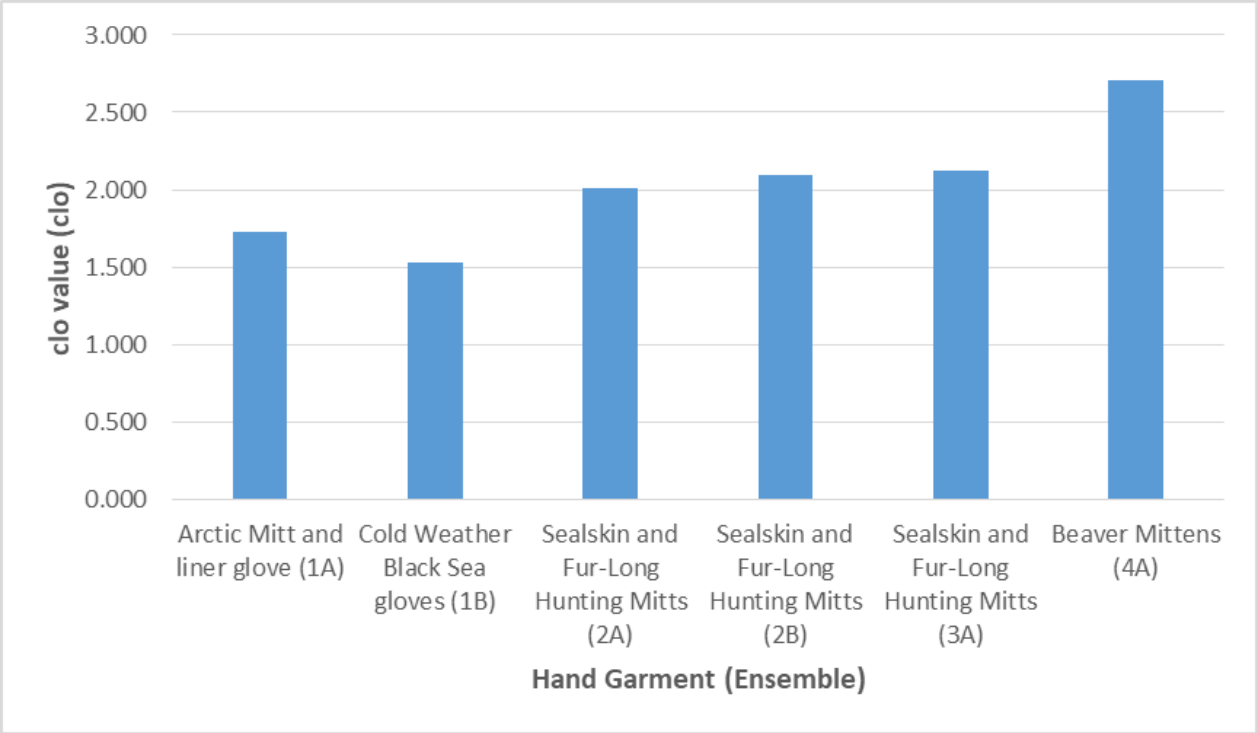

Figure 3: Mean clo value (clo) for the various hand garments (and associated clothing ensemble) tested.

3.3. Foot Garments

Table 9 and Figure 4 provide the clo values for the various foot garments tested.

Table 9: Right and left clo values (clo) for the different foot garments tested (Mukluk system includes the mukluks, mukluk liners, felt and mesh insoles).

Foot Garments	Ensemble Tested In	Zone Mean clo Value (clo)		
		Right Foot	Left Foot	Mean
Army grey wool socks, black socks, mukluk system.	1A	2.240	2.277	2.259
Army black liner socks, cold weather socks, navy safety boots	1B	1.986	1.907	1.947
White homespun wool socks, mukluk system	2A	2.257	2.269	2.263
Black liner socks, white homespun wool socks, navy safety boots	2B	1.956	1.914	1.935
White homespun wool socks, mukluk system	3A	2.224	2.228	2.226
White homespun wool socks, mukluk system	4A	2.234	2.226	2.230

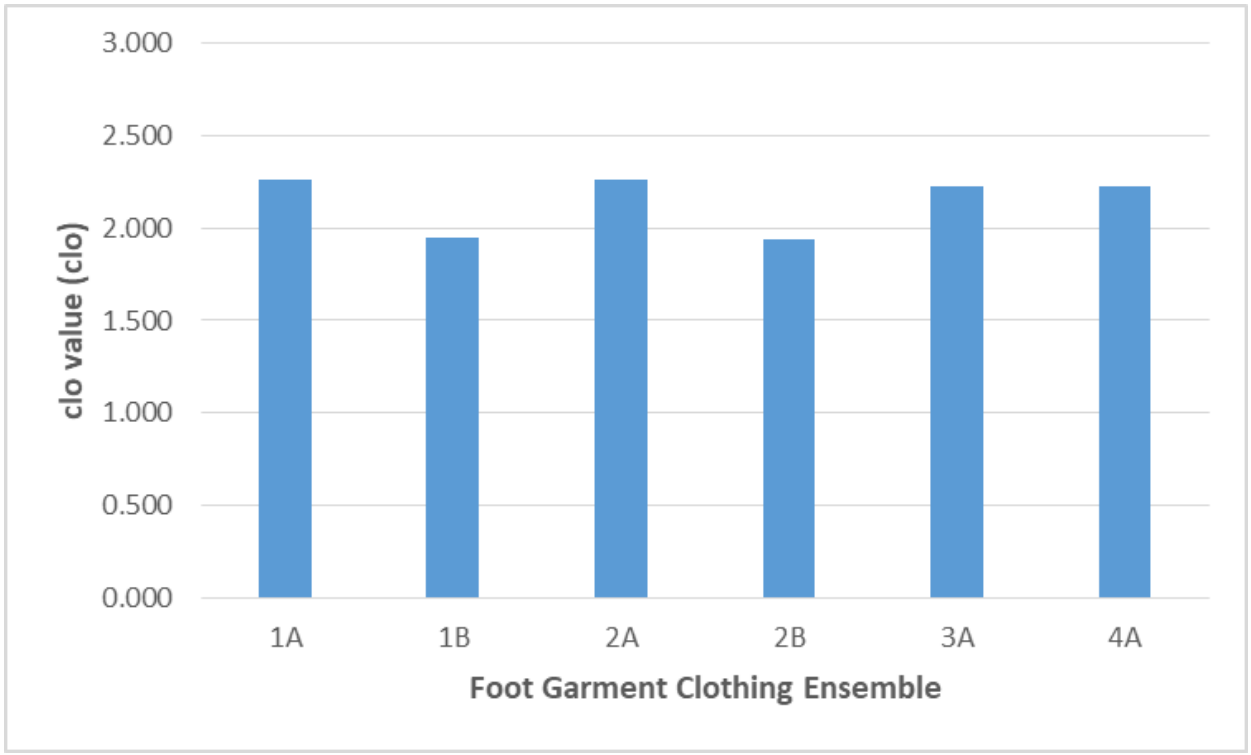

Figure 4: Mean clo value (clo) for the various foot garments tested.

3.4. Head and Neck Garments

Table 10 and Figure 5 provide the clo values of the face, head, chest, and shoulders zones of NEMO for the various head and neck warmer garments tested.

Table 10: Face, head, chest, and shoulders clo values (clo) for the various head and neck warmer garments tested.

Garments	Ensemble Tested In	Zone Mean Clo Value (clo)			
		Face	Head	Chest	Shoulders
Neck Gaiter and Green Toque	1A	0.736	2.788	4.700	5.34
Balaclava and Green Toque	1B	0.758	2.722	5.671	5.419
Trapper Hat – Beaver, and Neck Warmer – Beaver	2A	0.848	3.074	4.967	5.564
Balaclava, Trapper Hat - Beaver, and Neck Warmer- Beaver	2B	1.005	2.999	5.880	5.569
Trapper Hat – Beaver, and Neck Warmer – Beaver	3A	1.317	2.825	5.085	4.746
Trapper Hat – Beaver, and Neck Warmer - Beaver	4A	0.908	3.024	4.999	5.560

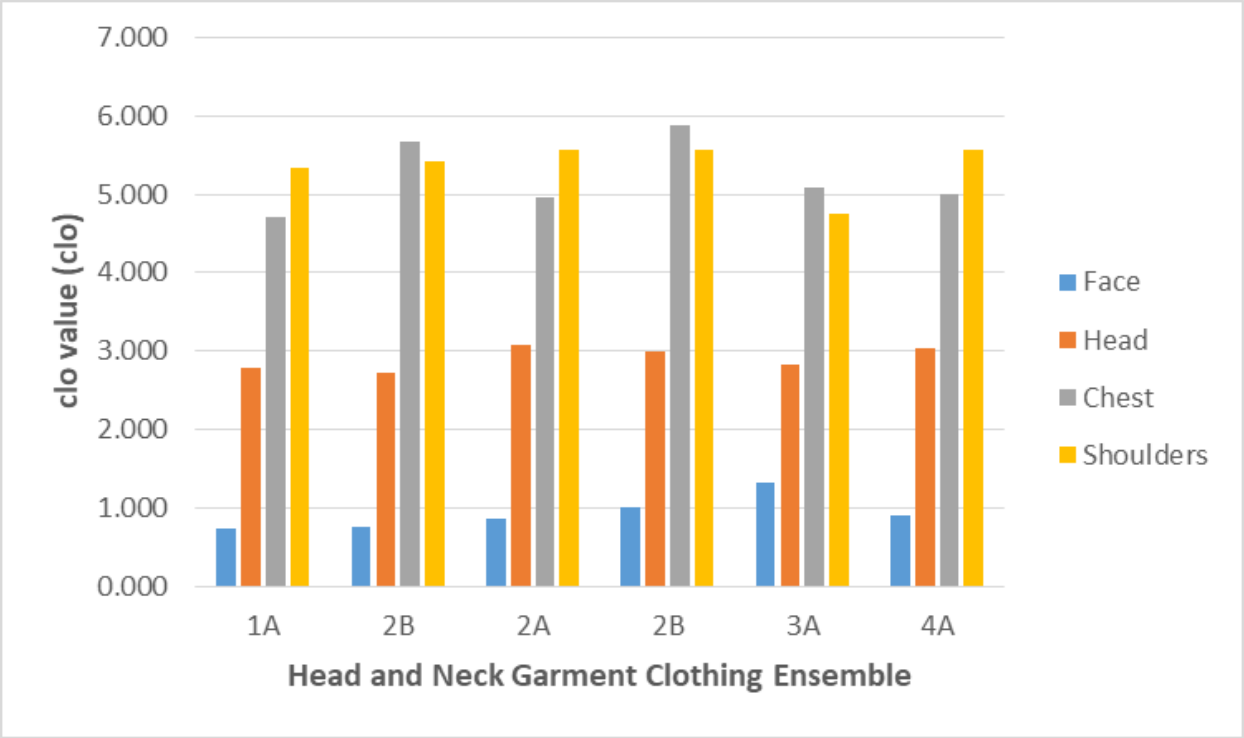

Figure 5: Mean clo values (clo) for the various head and neck garments in the ensembles they were tested in, for the zones that they covered on NEMO.

As the head and neck warmer garments cover more than one zone on NEMO, and are affected by other garments on NEMO at the time, such as a coat or parka, information is also provided on the individual and total heat output (W) for the four different zones of NEMO covered by these garments. This gives the actual amount of heat required by each zone to maintain the set skin temperature, allowing the different zones covered by the garments to be summed. A lower amount of heat output (W) to maintain the set skin temperature indicated the garments covering these zones have a higher level of insulation. Table 11 provides the heat output (W) from each of the four zones of NEMO for the various head and neck warmer garments.

Table 11: Face, head, chest, and shoulders heat output (W) for the various head and neck warmer garments.

Garments	Ensemble Tested In	Zone Heat Output (W)				
		Face	Head	Chest	Shoulders	Total
Neck Gaiter and Green Toque	1A	11.3	9.1	4.9	4.5	29.8
Balaclava and Green Toque	1B	11.0	9.2	4.1	4.4	28.7
Trapper Hat – Beaver, and Neck Warmer - Beaver	2A	9.8	8.2	4.6	4.3	26.9
Balaclava, Trapper Hat – Beaver, and Neck Warmer – Beaver	2B	8.2	8.4	3.9	4.3	24.8
Trapper Hat – Beaver, Neck Warmer – Beaver, and Silapak Parka	3A	6.3	8.9	4.5	5.0	24.7
Trapper Hat – Beaver, and Neck Warmer - Beaver	4A	9.1	8.4	4.6	4.3	26.4

4. Discussion

4.1. Standardized Total Insulation Value and Temperature Rating

For the Army ensembles, the addition of Indigenous garments resulted in a higher STIV compared to the standard clothing. Ensemble 1A consisted of all standard clothing and had the lowest STIV for the Army configuration (3.693 clo) (Table 7). Ensemble 3A had a slightly higher STIV of 3.746 clo, with ensemble 2A having the next highest STIV of 3.815 clo. The highest clo value for the Army ensembles was measured in ensemble 4A which had a STIV of 3.928 clo (Table 7). The increase in STIV when moving from ensemble 1A to 2A and 3A were small (3.3% and 1.4% respectively), but a higher increase was observed when moving to 4A (6.3%). The associated higher STIV with the ensembles incorporating Indigenous garments had lower TR as expected (Figure 2). For the RCN ensembles, there was a similar increase in STIV with the addition of Indigenous garments with ensemble 1B having a STIV of 3.214 clo, and ensemble 2B having a value of 3.436 clo.

While these increases in STIV values may be small (< 10%), it is interesting to note that, with the exception of ensemble 3A, the Indigenous garments that replaced the standard ones covered small areas of NEMO (e.g. hands, feet, head). Even those these areas only contribute a small amount to the overall STIV, the addition of Indigenous garments did increase the values regardless. In ensemble 3A, the standard parka was replaced with the Siliapik parka, which resulted in it having a lower STIV compared to 2A (3A: 3.746 clo; 2A: 3.815 clo), but it was less than a 2% change. This would suggest that the Siliapik parka provides a near equivalent level of insulation as the standard parka.

4.2. Hand Garments

For both the Army and RCN ensembles, the Indigenous hand garments had higher clo values compared to the standard ones (Table 8). Of all the hand garments tested, the cold weather black sea gloves had the lowest mean clo value of 1.533 clo. The hand garments that had the next highest clo value were the Arctic mittens with the liner glove with 1.726 clo, with the long hunting mittens - Sealskin and fur having the next highest with a mean clo value of ~ 2.078 clo (Table 8). The Beaver Mittens had the highest clo value of all the hand garments tested, with a clo value of 2.711 clo which was significantly higher than all the others.

Based on the previous work by Fallahi et al. (2017), the cold weather black sea gloves would provide a level of thermal insulation (1.533 clo) that would protect the wearer against frostbite in -30°C air for ~ 120 minutes. In similar conditions, the Arctic mittens with the liner glove would provide a level of thermal insulation (1.726 clo) that would offer protection for ~180 minutes, but only just so as the minimum value is 1.637 clo (Fallahi et al., 2017). Both Indigenous made garments exceed this minimum value, particularly the Beaver mittens which exceed it by ~1.100 clo. The high clo value of the Beaver mittens would ensure that the wearer has more than enough thermal insulation to protect their hands from frostbite at -30°C for at least 180 minutes.

4.3. Foot Garments

Two different outer foot garments were tested in this test program: the mukluk system (ensembles 1A, 2A, 3A, and 4A) and the navy safety boots (ensembles 1B and 2B). The army grey wool socks, black socks, and mukluk system in ensemble 1A had a mean clo value of 2.259 clo (Table 9). When the Army grey wool socks were replaced with the white homespun wool socks (ensembles 2A, 3A, and 4A), the mean clo value (~ 2.240 clo) was nearly equal (Table 9). However, the ensembles that used the white homespun wool socks did not use the black socks. While the black socks most likely only provided a small amount of thermal insulation due to their lightweight nature, it is interesting to note that the single white homespun wool socks provided a level of thermal insulation near equivalent to two garments.

When the navy safety boots were tested with the black liner socks and the cold weather socks (ensemble 1B), the mean clo value was 1.947 clo (Table 9). When the cold weather socks were replaced with the white homespun wool socks (ensemble 2B) the mean clo value was 1.935 clo. Changing the cold weather socks with the white homespun wool socks did not result in a significant change in the measured clo value, suggesting that the two garments offer a near equivalent level of thermal insulation.

4.4. Head and Neck Garments

Due to the fact that a singular head or neck garment can cover more than one zone on NEMO (e.g. a neck warmer can cover the head, chest, and shoulders zone), it can be difficult to determine the amount of thermal protection it provides by simply looking the clo value from a specific zone (Table 10). Instead, it is more beneficial to determine the total amount of heat required by NEMO across all the zones of interest to maintain the set T_{sk}. The less heat required by NEMO to maintain the set T_{sk}, the more thermal insulation should be present across the zones of interest.

The base Army ensemble (1A) required the greatest amount of heat (29.8 W) across the four zones (face, head, chest, and shoulders) compared to the other ensembles. When the neck gaiter and green toque were replaced with the trapper hat – Beaver and neck warmer – Beaver (ensembles 2A and 4A), NEMO required slightly less heat (26.9 W and 26.4 W) compared to ensemble 1A (Table 11). When the Silapak parka was used with the trapper hat – Beaver, and neck warmer – Beaver (ensemble 3A), NEMO again required slightly less heat (24.7 W).

The base RCN ensemble (1B) required slightly less heat (28.7 W) to maintain the set T_{sk} compared to the base Army ensemble (Table 11). When the green toque was replaced with the trapper hat – beaver, and the neck warmer – Beaver was added to the ensemble (2B) the heat required by NEMO dropped to 24.8 W (Table 11); a ~14% decrease compared to the base RCN ensemble.

For the head and neck garments, the NEMO generally required less heat to maintain the set T_{sk} in the ensembles that used Indigenous made items (2A, 2B, 3A, and 4A) compared to the base ensembles (1A and 1B). While the majority of differences in heat output between the ensembles were small, they still suggest that the use of Indigenous made head and neck garments would provide more thermal insulation compared to the standard ones in the base Army and RCN ensembles.

5. Conclusions

For the majority of the tests, Indigenous made garments provided a higher level of thermal insulation compared to those that were part of the base ensembles. The base Army and RCN ensembles (1A and 1B, respectively) had the lowest STIV out of all the ensembles tests, which resulted in the higher estimated temperature ratings (Table 7). When Indigenous made garments were swapped into the ensembles, it resulted in slightly higher STIV, which translated into lower estimated temperature ratings. Both the Indigenous made sealskin and fur long hunting mittens, and Beaver mittens had clo values higher that then garments included in the base Army and RCN ensembles (Table 8), with the latter in particular being significantly higher. Generally, the Indigenous made head and neck garments did provide a higher level of thermal insulation compared to those in the base ensemble, though the differences were small between certain ensembles (Table 11).

The only tests where Indigenous made items did not provide a higher level of thermal insulation than those in the base ensembles were with the foot garments. The Indigenous made homespun wool socks provided a level of thermal protection near equivalent to the Army grey wool socks and black liner socks (ensemble 1A) and the cold weather socks (ensemble 1B). Even though they did not provide more thermal insulation than the Army grey wool socks and black liner socks, the homespun wool socks were only a single garment compared to the two that were used in the other ensemble.

The addition of Indigenous made garments did increase the thermal protection of the various ensembles compared to their base configurations. While it may not be practicable, or operationally feasible, to replace larger garments like the cold weather parka with Indigenous garments such as the Siliapik parka; replacing smaller garments for hands and neck may be feasible while still offering improvements. For example: the beaver mittens had a significantly higher clo value compared to all other garments measured, ensuring more than enough thermal insulation to protect against frostbite at -30°C. While the beaver neck warmer did not increase thermal insulation as dramatically as the mittens, they were still an improvement compared to the garments that made up the base ensembles. While the improvements to thermal insulation were small, it may be easier to include and cost effective to add garments such as the beaver mittens or beaver neck warmer compared to switching in or adding larger garments.

While it may not be necessary to replace all existing garments used by the CAF with Indigenous made garments, improvements in thermal insulation can be gained by strategically swapping out certain ones. The results from these tests show that significant improvements can be gained in hand protection by using the beaver mittens, while smaller ones were achieved by using a beaver neck warmer. Therefore, if Indigenous made garments are to be included in ensembles used CAF, consideration should be given to smaller items that can still offer significant increases in thermal insulation, especially for personnel who operate frequently in the Arctic or are at a higher risk for a cold weather injury. Future work could examine the incorporation of an additional variety of garments not tested in this study to measure how thermal insulation may change. Along with these additional garments, future testing could also incorporate wetting of the garments to simulate wearing them in cold and wet conditions which is another operationally challenging environment that many personnel in the CAF are required to operate in to see if these items can affect performance, and if some garments are more resistant to this effect than others.

6. References

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Appendix A: Individual Clothing Garments

Figure 6: Cold weather parka (ID: D1).

Figure 7: Fleece jacket (ID: D2).

Figure 8: Fleece pants (ID: D3).

Figure 9: Underwear top (ID: D4).

Figure 10: Underwear bottoms (ID: D5).

Figure 11: Arctic mittens (ID: D6).

Figure 12: Neck gaiter (ID: D8).

Figure 13: Toque (ID: D9).

Figure 14: Wool socks (ID: D10).

Figure 15: Liner socks (ID: D11).

Figure 16: Mukluks (ID: D12).

Figure 17: Mukluk boot liner (ID: D13).

Figure 18: Mukluk felt and mesh insole (ID: D15 and D14).

Figure 19: Bib pants (ID: D29).

Figure 20: Coveralls (ID: D16).

Figure 21: Underwear top – Navy (ID: D17).

Figure 22: Underwear bottom – Navy (ID: D18).

Figure 23: Navy safety boots (ID: D21).

Figure 24: Cold weather socks (ID: D22).

Figure 25: Cold weather gloves (ID: D23).

Figure 26: Balaclava (ID: D24).

Figure 27: Floater jacket (ID: D26).

Figure 28: Floater jacket liner (ID: D27).

Figure 29: Overalls – buoyancy aid (ID: D28).

Figure 30: Liner Glove (ID: 12).

Figure 31: Trapper hat – Beaver (ID: 21).

Figure 32: Parka –Siliapik (ID: 35).

Figure 33: Homespun wool socks (ID: 33).

Figure 34: Neck warmer – Beaver (ID: 22).

Figure 35: Mittens – Beaver (ID: 28).

Figure 36: Long hunting mittens - Sealskin and fur (ID: 36).

Appendix B: Clothing Ensembles

Figure 37: NEMO dressed in clothing ensemble 1A.

Figure 38: NEMO dressed in clothing ensemble 1B.

Figure 39: NEMO dressed in clothing ensemble 2A.

Figure 40: NEMO dressed in clothing ensemble 2B.

Figure 41: NEMO dressed in clothing ensemble 3A.

Figure 42: NEMO dressed in clothing ensemble 4A.