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This is a published version of a paper published in *Prehospital and disaster medicine : the official journal of the National Association of EMS Physicians and the World Association for Emergency and Disaster Medicine in association with the Acute Care Foundation*.

Citation for the published paper:

Henriksson, O., Lundgren, J., Kuklane, K., Holmér, I., Björnstig, U. (2009)

"Protection against cold in prehospital care - thermal insulation properties of blankets and rescue bags in different wind conditions."

*Prehospital and disaster medicine : the official journal of the National Association of EMS Physicians and the World Association for Emergency and Disaster Medicine in association with the Acute Care Foundation*, 24(5): 408-415

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# Protection Against Cold in Prehospital Care—Thermal Insulation Properties of Blankets and Rescue Bags in Different Wind Conditions

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*Funding/Support:* Supported by the National Board of Health and Welfare, Sweden

**Keywords:** body temperature regulation; cold; emergency medical services; hypothermia; thermal insulation; thermal manikin; wind

## Abbreviations:

None.

Received: 08 December 2008

Accepted: 03 January 2009

Web publication: 05 October 2009

## Abstract

**Introduction:** In a cold, wet, or windy environment, cold exposure can be considerable for an injured or ill person. The subsequent autonomous stress response initially will increase circulatory and respiratory demands, and as body core temperature declines, the patient's condition might deteriorate. Therefore, the application of adequate insulation to reduce cold exposure and prevent body core cooling is an important part of prehospital primary care, but recommendations for what should be used in the field mostly depend on tradition and experience, not on scientific evidence.

**Objective:** The objective of this study was to evaluate the thermal insulation properties in different wind conditions of 12 different blankets and rescue bags commonly used by prehospital rescue and ambulance services.

**Methods:** The thermal manikin and the selected insulation ensembles were setup inside a climatic chamber in accordance to the modified European Standard for assessing requirements of sleeping bags. Fans were adjusted to provide low (< 0.5 m/s), moderate (2–3 m/s) and high (8–9 m/s) wind conditions. During steady state thermal transfer, the total resultant insulation value,  $I_{tr}$  ( $m^2 \text{ } ^\circ\text{C}/\text{Wclo}$ ; where  $^\circ\text{C}$  = degrees Celcius, and  $\text{W}$  = watts), was calculated from ambient air temperature ( $^\circ\text{C}$ ), manikin surface temperature ( $^\circ\text{C}$ ), and heat flux ( $\text{W}/\text{m}^2$ ).

**Results:** In the low wind condition, thermal insulation of the evaluated ensembles correlated to thickness of the ensembles, ranging from 2.0 to 6.0 clo (1 clo =  $0.155 \text{ } m^2 \text{ } ^\circ\text{C}/\text{W}$ ), except for the reflective metallic foil blankets that had higher values than expected. In moderate and high wind conditions, thermal insulation was best preserved for ensembles that were windproof and resistant to the compressive effect of the wind, with insulation reductions down to about 60–80% of the original insulation capacity, whereas wind permeable and/or lighter materials were reduced down to about 30–50% of original insulation capacity.

**Conclusions:** The evaluated insulation ensembles might all be used for prehospital protection against cold, either as single blankets or in multiple layer combinations, depending on ambient temperatures. However, with extended outdoor, on-scene durations, such as during prolonged extrications or in multiple casualty situations, the results of this study emphasize the importance of using a windproof and compression resistant outer ensemble to maintain adequate insulation capacity.

Henriksson O, Lundgren JP, Kuklane K, Holmér I, Bjornstig U: Protection against cold in prehospital care—Thermal insulation properties of blankets and rescue bags in different wind conditions. *Prehosp Disaster Med* 2009;24(5):408–415.

## Introduction

In a cold, wet, or windy environment, an injured or ill person often is exposed to considerable cold stress.<sup>1–3</sup> Heat loss occurs primarily due to warming of the surrounding air layer (convection), which is greatly increased by wind or movements. To a smaller extent, heat also is lost through radiation to cold

objects in the surroundings or clear sky, and by respiratory heat loss from the airways. Sweating and evaporative heat loss from the skin often is minimal in cold environments, but could be considerable in case of wet clothing or skin due to immersion or previous physical activity. In addition, if the injured or ill person is lying on the ground or is in direct contact with a cold surface, conductive heat loss will be significant.<sup>4,5</sup>

To counteract body cooling, the initial autonomous stress response involves peripheral vasoconstriction to minimize heat loss and involuntary muscle contractions (shivering) to raise endogenous heat production. This initial stress response can be limited due to exhaustion, central or peripheral nervous system injuries, medications, or the influence of drugs and alcohol. As body core temperature declines, the level of consciousness decreases, blood coagulation is disturbed, dysrhythmias occurs and the heart becomes more susceptible to ventricular fibrillation.<sup>1,2,6,7</sup> Hypothermia, defined as body core temperature below 35°C, is associated with worse outcomes in trauma patients.<sup>8</sup> This cold-induced stress response also will render great thermal discomfort, which might increase the experience of pain and anxiety, even in patients who are normothermic.<sup>9,10</sup>

Thus, reducing cold exposure, and thereby, avoiding further heat loss is an important and integrated part of prehospital primary care. Initial measures must be taken to move the patient into shelter, remove wet clothing if possible, insulate the patient from the ground, and contain endogenous heat production within adequate wind- and waterproof insulation ensembles. In addition, depending on the victim's physiological status, available resources, and expected evacuation duration, the application of external heat also should be considered to aid in protection from further cooling.<sup>1,2,11-16</sup>

The thermal properties of insulation ensembles determining their effect on body heat exchange are thermal insulation ( $I_{tr}$ ) and evaporative resistance. Thermal insulation of a material is defined as the resistance to heat transfer by radiation, convection, and conduction measured in m<sup>2</sup>C/W (where °C = degrees Celsius, W = watt) or clo units (1 clo = 0.155 m<sup>2</sup>C/W). Evaporative resistance, measured in Pa m<sup>2</sup>/W (Pa = pascal), is defined as the resistance to heat transfer by evaporation and vapor transfer through the material. However, at low activity levels in a cold environment, sweating is minimal, and therefore, if the patient and the surrounding insulation material is kept dry, heat exchange will be determined almost entirely by thermal insulation.<sup>5</sup>

Thermal insulation capacity of an ensemble depends mostly on its ability to retain air. Therefore, thermal insulation almost directly is proportional to the thickness of the ensemble (about 1.3–1.5 clo/cm). Additionally, form, fit, and coverage of the body also affects thermal insulation. External factors that could affect thermal insulation include moisture and wind.<sup>2,5</sup> Wetting of textiles reduces its ability to retain air; thereby, reducing thermal insulation.<sup>17-19</sup> Wind reduces thermal insulation due to loss of the still outer air layer surrounding the ensemble, the compressing effect of the wind, and the air permeability of the fabric. For every ensemble, thermal insulation is reduced exponentially

with increased wind speed, the relative reduction being larger at lower air velocities, but the greatness of the reduction is determined by the characteristics of the ensemble.<sup>5,20,21</sup>

Heat flow through an ensemble is three dimensional, passing through combinations of layers of textiles and retained air. Therefore, when determining the thermal insulation of an ensemble, the entire ensemble must be evaluated by using standardized, full-size, thermal manikins in climatic chambers.<sup>5,22-26</sup> Results from manikin measurements have shown good reproducibility and also agreement with wear trials.<sup>27,28</sup>

In the prehospital setting, many different materials and products are used for insulating patients against the cold. Some studies have been conducted to evaluate and compare materials and products,<sup>29-33</sup> but, recommendations for what should be used in the field mostly depend on tradition and experience, not on scientific evidence. Considering today's demands on evidence-based medicine and to contribute to prehospital guidelines on protection against cold, a thermal manikin was used to evaluate thermal insulation properties of different blankets and rescue bags commonly used in prehospital rescue and ambulance services in different wind conditions.

## Methods

### *Design and Settings*

The study was performed in January 2007 at the Thermal Environment Laboratory at Lund University, Sweden. Insulation ensembles were collected and sorted into two groups depending on their primary area of use. The *high insulation group* (Table 1) includes blankets and rescue bags used by mountain search and rescue teams and armed forces medical field units for prolonged prehospital care and evacuation in cold environments. The *low insulation group* (Table 2) includes different types of lighter blankets in use in urban ambulance and rescue services. The latter can be applied as either single blankets or in multiple layers depending on ambient temperature, number of casualties, and available resources. For comparative reasons the use of one single layer of these materials, representing a "worst case scenario" was evaluated.

The climatic chamber (3.2 x 2.4 x 2.4 m) and the thermal manikin TORE<sup>34</sup> were setup in accordance to the modified European Standard for assessing requirements of sleeping bags.<sup>23</sup> A rigid wooden board (194 x 60 x 1.6 cm) was positioned in the middle of the climatic chamber and supported about 90 cm above the ground to allow air circulation. To replicate a prehospital rescue scenario, the thermal manikin was placed in a supine position on an ordinary plastic spine board (Baxstrap, 180 x 39 x 2.5 cm, Laerdal Medical AS, Norway) instead of a using the prescribed sleeping mattress on top of the wooden board.

The thermal manikin has the size and shape of an ordinary male person with a height of 171 cm and 1.8 m<sup>2</sup> body surface area.<sup>26</sup> The manikin is divided into 17 segments representing specific body parts, with independent internal electrical heating and surface temperature sensors enabling area weighted heat flux recordings. Surface temperature was set to 34.0 ± 0.1°C and after calibration, the thermal manikin

Ensemble	Description	Manufacturer	Dimensions* (cm)	Thickness† (mm)	Weight (g)	Thermal Resistance†† (m <sup>2</sup> K/W)	Windproof
Armed Forces Rescue Blanket	Nylon outer and inner (dark green) with synthetic filling	Swedish Armed Forces Surplus	260 x 205	34	2,440	1.7 ±0.1	Yes
Five woollen blankets	Five felted wool blankets (grey)	Swedish Rescue Forces Surplus	190 x 135	30	10,340	1.3 ±0.1	No
Five Woollen Blankets with Plastic Cover	As above, but with additional outer plastic cover (300 x 250 cm)	Swedish Rescue Forces Surplus	190 x 135	30	11,290	1.3 ±0.1	Yes
RC42® Rescue Bag	Nylon outer (red) with synthetic filling and cotton inner (green)	Help&Rescue AB, Sweden	220 x 140	25	5,940	1.4 ±0.1	Yes

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**Table 1**—Characteristics of insulation ensembles selected for the high insulation group

\*Unfolded dimension of the ensemble except for the five woollen blankets which refers to the size of each blanket

†Average non-compressed thickness of the multilayer ensemble, measured on top of the manikin torso

††Thermal resistance, Rct (m<sup>2</sup> K/W), of a single layer of the material measured with a heated hotplate<sup>37</sup>

Ensemble	Description	Manufacturer	Dimensions* (cm)	Thickness† (mm)	Weight (g)	Thermal Resistance†† (m <sup>2</sup> K/W)	Windproof
RC20® Rescue Blanket	Nylon outer (red) with synthetic filling and cotton (green) inner	Help&Rescue AB, Sweden	220 x 140	6.8	1,910	1.4 ±0.1	Yes
Fly High® Rescue Blanket	As above but with a hood and an outer margin elastic cord	Help&Rescue AB, Sweden	275 x 125	6.8	2,320	1.4 ±0.1	Yes
Rescue Services Woollen Blanket	100% felted wool (grey)	Swedish Rescue Forces Surplus	190 x 135	5.5	2,070	1.3 ±0.1	No
Ambulance Services Polyester Blanket	100% woven polyester (yellow)	FM Trading AB, Sweden	200 x 135	4.3	1,180	1.1 ±1.1	No
Bubblewrap Blanket	Single layer of bubbles within laminated PE film on both sides	Sealed Air Ltd, England	300 x 150	3.5	230	0.7 ±0.0	Yes
Mediwrap Metallic Foil Blanket	Metallic laminated plastic foil (green) with inner textile lining (white)	Mediwrap Ltd, UK	200 x 120	1.0	200	0.7 ±0.1	Yes
Akla Metallic Foil Blanket	Dual surface (gold/silver) metallic laminated plastic foil	Akla AB, Sweden	200 x 150	0.01	60	0.7 ±0.0	Yes
Plastic Blanket	Plastic sheet from two 125 L bin bags (grey) sealed together	Papyrus AB, Sweden	200 x 150	0.03	120	0.5 ±0.0	Yes

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**Table 2**—Characteristics of insulation ensembles selected for the low insulation group

\*Unfolded dimension of the single blankets

†Non-compressed thickness of the single-layer ensemble, measured on top of the manikin torso

††Thermal resistance, Rct (m<sup>2</sup> K/W), of a single layer of the material measured with a heated hotplate<sup>37</sup>

was dressed in a modified standard clothing ensemble consisting of a light, two-piece thermal underwear and knee long socks with the addition of thermal gloves and a balaclava.<sup>25</sup>

The climatic chamber was set to 0°C for the high insulation group, 15°C for the low insulation group, and 25°C for the control condition with no additional insulation, in order to achieve heat flux values between 20 W/m<sup>2</sup> to 120 W/m<sup>2</sup>, thereby minimizing the measurement error. Ambient air temperature sensors (PT 100 ±0.03°C, Pico Technology Ltd, UK) were positioned in level with the supine manikin, adjacent to the ankles, the mid-trunk, and the head.

To provide wind conditions, three fans (VWB500, Indola, Holland) with 50 cm wing diameter and independently adjustable revolutions were set-up next to each other, in level with and facing the left side of the thermal manikin. Based on known wind speed effects on cold protective clothing insulation values,<sup>5,20,21</sup> three different wind conditions were selected; low (air velocity <0.5 m/s), moderate (air velocity 2–3 m/s) and high (air velocity 8–9 m/s). The low wind condition, for which the fans were shut off, was represented by intrinsic air flow in the climatic chamber and measured with a directionally independent wind speed sensor (SWA01, ±0.02 m/s, Swema AB, Sweden) in level with and adjacent to the thorax and knees of the manikin. Moderate and high wind conditions were provided by adjusting the fan revolution to the desired air velocities and measured using a rotating vane anemometer for linear air flow (AV2, ±0.02 m/s, TSI Instruments Ltd., UK), also positioned in level with and adjacent to the thorax and knees of the supine manikin.

#### *Protocol and Monitoring*

Prior to and in-between the trials, insulation materials were kept dry and at the determined temperature in an adjacent climatic chamber. Each trial then began with the insulation ensemble being applied to the thermal manikin in a standardized procedure.

In the high insulation group, the Armed Forces rescue blanket was folded around the manikin as a mummy-shaped, hooded sleeping bag with the overlapping sections on top of the manikin secured with two straps, one around the chest and the other around the upper legs. The five woolen blankets were applied in accordance to the guidelines of the Swedish Mountain Search and Rescue Organization, tightly folding the blankets in several layers around the manikin as a mummy-shaped, hooded sleeping bag and secured with straps as above. Then this condition was iterated with the addition of a plastic cover folded around the set of blankets for the evaluation of a wind-proof exterior. The RC42® rescue bag, designed as a rectangular, multilayer, hooded sleeping bag, was applied according to the manufacturer's prescriptions.

The different types of blankets in the low insulation group were applied on top of the manikin from the neck down and thereafter, tightly folded under and in-between the manikin and the spine board. Exceptions were made for The Fly High® rescue blanket, which is designed as a full length blanket with a circular opening for the face and an elastic band all around its outer margins, and therefore,

according to the manufacturer's prescriptions, secured under the spine board instead of under the manikin. The bubble wrap blanket, being larger than the other blankets, was applied in accordance to standard procedures of the Norwegian Air Ambulance Services (personal communication with Haakon Nordseth, HEMS crew, Norwegian Air Ambulance), tightly folding the bubble wrap around the manikin as a mummy-shaped, hooded sleeping bag and the over-lapping sections along the upper side of the manikin secured with adhesive tape. All materials were secured with two straps, one around the chest and the other around the upper legs.

After the application of the insulation ensemble, fans were either kept turned off for low wind conditions or adjusted to the desired air velocities for moderate and high wind conditions. Manikin surface temperature, heat flux, and ambient air temperature then was continuously recorded for about 60–90 minutes until steady state thermal transfer had been established and was persistent for 20 minutes. All trials were carried out and repeated in a randomized order so that all insulation ensembles, as well as a control condition with no additional insulation, were evaluated twice for each wind condition, resulting in a total of 78 scheduled trials.

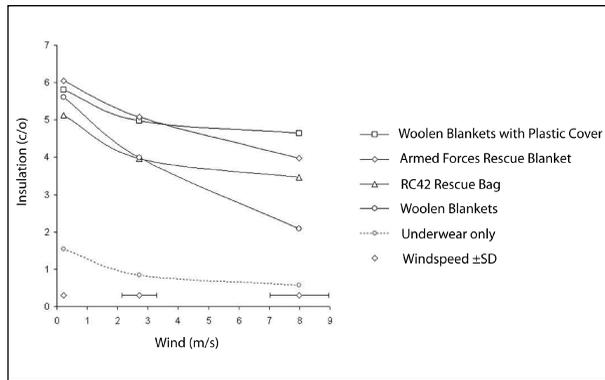
#### *Data Processing*

The average air velocity during the last three minutes of each trial was analyzed and the trial redone if average values were <2.0 m/s and >3.0 m/s in the moderate wind condition or >7.0 m/s or greater than 9.0 m/s in the high wind condition; or the turbulence (standard deviation/average air velocity) after each set of trials exceeded 25%. Results are reported as mean values ± one standard deviations (SD).

Total resultant insulation value, or *I*<sub>tr</sub> (m<sup>2</sup> °C/W), was calculated (parallel method) from heat flux (W/m<sup>2</sup>), the gradient between ambient air temperature (°C), and manikin surface temperature (°C) during the last 10 minutes of steady state thermal transfer.<sup>26</sup> After each set of repeated trials, the variation co-efficient (standard deviation/average *I*<sub>tr</sub>) was analyzed and the trials redone for values exceeding 10%.<sup>27</sup> Results were converted to clounits (1 clo = 0.155 m<sup>2</sup> °C/W) and reported as mean ±SD.

#### **Results**

After initial trials and protocol adjustments, a total of 84 trials were conducted, of which two trials were redone due to exceeded wind speed limits and another four trials were redone due to exceeded insulation variation co-efficient limit. The average wind speed for all trials was 0.2 ±0.0 m/s with 10% turbulence in the low wind condition, 2.7 ±0.6 m/s with 21% turbulence in the moderate condition, and 8.0 ±1.0 m/s with 12% turbulence in the high wind condition. The average insulation variation coefficient was 3.1 ±2.5 % for the accepted set of repeated trials. In the control condition with the thermal manikin dressed in the standardized clothing, but without any additional insulation, the total resultant insulation value (*I*<sub>tr</sub>) was 1.5 ±0.0 clo in low, 0.8 ±0.0 in moderate, and 0.6 ±0.0, in high wind conditions, respectively. The insulation capacity of the clothing is embedded in the total insulation values of the evaluated ensembles.



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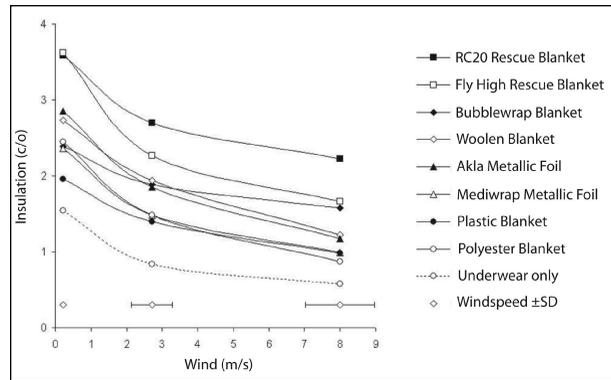
**Figure 1**—Thermal insulation (clo) for insulation ensembles in the high insulation group at low, moderate, and high wind conditions

#### High Insulation Group

In the low wind condition, the Armed Forces rescue blanket ( $6.0 \pm 0.2$  clo) had the highest insulation value, followed by the five woolen blankets with additional plastic cover ( $5.8 \pm 0.3$  clo), the five woolen blankets without the plastic cover ( $5.6 \pm 0.3$  clo), and the RC42® rescue bag ( $5.1 \pm 0.2$  clo) (Figure 1). When wind speed was increased to the moderate wind condition, insulation values for the Armed Forces rescue blanket ( $5.1 \pm 0.1$  clo) and the five woolen blankets with plastic cover ( $5.0 \pm 0.0$  clo) were both reduced to about 85% of their initial insulation capacity, while the five woolen blankets without the plastic cover ( $4.0 \pm 0.3$  clo) and the RC42® rescue bag ( $4.0 \pm 0.1$  clo) were reduced to about 75% of their initial insulation capacity. In the high wind condition, the insulation value of the five woolen blankets with additional plastic cover was reduced to about 80% ( $4.6 \pm 0.0$  clo) of initial insulation capacity, whereas the Armed Forces rescue blanket ( $4.0 \pm 0.1$  clo) and the RC42® rescue bag ( $3.5 \pm 0.0$  clo) were reduced to about 65% of their original insulation capacity, and the insulation value of the five woolen blankets without plastic cover ( $2.1 \pm 0.1$  clo) was reduced to about 40% of initial insulation capacity.

#### Low Insulation Group

In the low wind condition, the rescue blankets RC20® ( $3.6 \pm 0.1$  clo) and Fly High® ( $3.6 \pm 0.2$  clo) had the highest insulation values, whereas the plastic blanket ( $2.0 \pm 0.1$  clo) had the lowest (Figure 2). In between, the Akla metallic foil blanket ( $2.9 \pm 0.1$  clo) had about the same insulation as the woolen blanket ( $2.7 \pm 0.1$  clo), while the bubble wrap ( $2.4 \pm 0.1$  clo), Mediwrap metallic foil ( $2.4 \pm 0.0$  clo) and polyester ( $2.4 \pm 0.1$  clo) blankets all had equal and somewhat lower insulation values. When wind speed was increased to the moderate wind condition, the insulation value of the bubble wrap ( $1.9 \pm 0.0$  clo) was reduced to about 80% of initial insulation capacity, the RC20® rescue blanket ( $2.7 \pm 0.1$  clo) to about 75%, the woolen blanket ( $1.9 \pm 0.0$ ), and the plastic blanket ( $1.4 \pm 0.1$  clo) to about 70%, and the Fly High® rescue blanket ( $2.3 \pm 0.2$  clo), the Akla metallic foil ( $1.9 \pm 0.0$  clo), the Mediwrap metallic foil ( $1.5 \pm 0.1$  clo), and the polyester blanket ( $1.5 \pm 0.0$  clo) all were reduced to about 60–65% of their initial insulation capacity. Also in



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**Figure 2**—Thermal insulation (clo) for insulation ensembles in the low insulation group at low, moderate, and high wind conditions

the high wind condition, the bubble wrap ( $1.6 \pm 0.0$  clo) presented the least reduction, to about 65% of initial insulation capacity, and the RC20® rescue blanket ( $2.2 \pm 0.1$  clo) to about 60% of initial insulation capacity, whereas the polyester blanket ( $0.9 \pm 0.0$  clo) presented the greatest insulation reduction, down to about 35% of its original insulation capacity. In between, the Fly High® rescue blanket ( $1.7 \pm 0.2$  clo), the woolen blanket ( $1.2 \pm 0.0$  clo), the Akla metallic foil ( $1.2 \pm 0.0$  clo), the Mediwrap metallic foil ( $1.0 \pm 0.0$  clo), and the plastic blanket ( $1.0 \pm 0.0$  clo) all were reduced to about 45–50% of initial insulation capacity.

## Discussion

### Overview

In the low wind condition, thermal insulation values of the evaluated ensembles in both the high and the low insulation group were in the same relative order as measured thickness of the ensembles, except for the Akla and Mediwrap metallic foil blankets that had insulation values as high as the thicker woolen and polyester blankets, respectively. In moderate and high wind conditions, thermal insulation values in the high insulation group were best preserved for the five woolen blankets with plastic cover and reduced the most for the five woolen blankets without plastic cover, whereas in the low insulation group thermal insulation values were best preserved for the bubble wrap and RC20® rescue blanket and reduced the most for the polyester blanket.

### Possible Mechanisms for Results

In the low wind condition, thermal insulation values correlated to the thickness of the evaluated ensembles. This coincides with general knowledge that thermal insulation is dependant on its ability to retain air. The thicker the ensemble, the more air is retained within the ensemble and the higher the insulation value.<sup>2,5</sup> The higher than expected values for the Akla and the Mediwrap metallic foil blankets are most likely due to their reflective properties. The impact of this reflective effect is known to be dependent on the temperature gradients between the outer surface of the worn clothing and surrounding cold surfaces or clear sky, and also, on the proportion heat lost by radiation in relation

to convection, conduction, and evaporation.<sup>5</sup> In lower wind conditions, the proportion of heat lost by radiation is larger than in higher wind conditions, where convection is more pronounced. This likely explains the greater difference in insulation value between the Akla metallic foil blanket and the similar, but non-reflective, plastic blanket in the low wind condition than in the moderate and high wind conditions.

Wind is known to reduce the thermal insulation value of an ensemble due to loss of the still outer air layer surrounding the ensemble, the compressing effect of the wind on the ensemble, and the air permeability of the fabric.<sup>5</sup> In the moderate wind condition, insulation ensembles in the high insulation group all presented about the same relative reduction in thermal insulation. This similar initial reduction mostly depended upon the loss of the outer air layer surrounding the ensembles. In the low insulation group, relative insulation reduction in the moderate wind condition was more divergent, which seemingly was due to the compressing effect of the wind and the air permeability of the fabric having a greater impact in these lighter ensembles, in addition to the loss of the outer air layer. In the high wind condition, the diversity in insulation reduction was increased in both groups, as the differences between the ensembles in resistance to the compressing effect of the wind and the air permeability of the fabrics were more pronounced.

The compressing effect of the wind can be exemplified by comparing the Armed Forces rescue bag, which is light and porous, and thereby, relatively easily compressed, to the five woolen blankets with plastic cover, which are heavier and not that easily compressed. Even though both ensembles are wind proof, in moderate and high wind conditions, the thermal insulation value of the Armed Forces rescue bag was reduced more than was the thermal insulation value of the five woolen blankets with plastic cover. In the low insulation group, the Fly High<sup>®</sup> rescue blanket was secured under the spine board, instead of under the manikin, giving it a loose fit, which increased the impact of the compressing effect of the wind and rendered a greater reduction in thermal insulation in moderate and high wind conditions as compared to the RC20<sup>®</sup> rescue blanket, which is made out of the same windproof fabric as the Fly High<sup>®</sup>, but fits much tighter to the patient. In the same way as the RC20<sup>®</sup> rescue blanket, the windproof and tight fitting bubble wrap blanket also presented a high resistance to the compressive effect of the wind.

The effect of air permeability can be exemplified by comparing the five woolen blankets with and without the plastic outer cover. Although similar in resistance to the compressing effect of the wind, with increasing wind speed, the air permeable woolen blankets presented a much greater reduction in thermal insulation than the woolen blankets with an additional windproof outer cover. Also in the low insulation group, thermal insulation of the woolen and polyester blankets was greatly reduced due to their high air permeability.

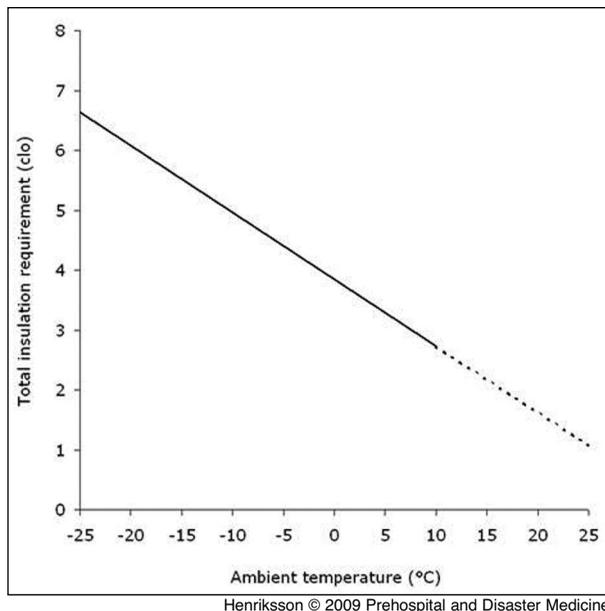
#### *Practical Implications*

At many outdoor related incidents, cold exposure can be considerable for an injured or ill person. Heat loss often is aggravated due to exhaustion, light or torn clothing, major bleeding, entrapment, or the administration of cold intra-

venous fluids or sedative drugs.<sup>3,35</sup> If heat loss exceeds possible endogenous heat production, body core temperature will decline and the patient's condition might deteriorate.<sup>1,2,6,8</sup> In addition to immediate care for imminent life-threatening conditions, early application of adequate insulation to reduce cold exposure, maintain heat balance, and prevent body core cooling therefore is an important concern for the prehospital care provider.<sup>2,12,14</sup> Insulation required (IREQ) to maintain heat balance for a determined level of activity at various ambient weather conditions can be calculated using a standardized heat balance model (Figure 3).<sup>36</sup>

According to the IREQ model for a non-shivering, awake person at rest (70 W/m<sup>2</sup>), all of the evaluated ensembles in the high insulation group provide required insulation to maintain thermoneutrality in calm environments down to about -10 to -20°C. In moderate and high wind conditions, the woolen blankets with plastic cover, the Armed Forces rescue blanket, and the RC42<sup>®</sup> rescue bag all provide required insulation for thermo-neutrality down to about 0 to -10°C. Five woolen blankets without an external plastic cover only provide required insulation down to about +15°C. Thus, for prehospital field care in a cold environment, the evaluated ensembles in the high insulation group are likely to provide sufficient insulation for most rescue scenarios. However, for protracted evacuations in windy conditions, where the ability to create a shelter is limited or delayed, the addition of a windproof outer cover to the five woolen blankets is of utmost importance to maintain insulation capability.

Used as single blankets, the evaluated ensembles in the low insulation group provide required insulation to maintain thermo-neutrality in calm environments down to temperatures ranging from about +5°C for the thick RC20<sup>®</sup> and Fly High<sup>®</sup> rescue blankets, +10°C for the Akla metallic foil and woolen blankets, to about +15°C for the polyester, bubble wrap, and Mediwrap metallic foil blankets, and about +20°C for the thin plastic blanket. However, in most ambulance and rescue services, each unit carries more than one blanket. Thus, for the common urban prehospital scenario where the exposure for wind or severe cold is limited, the evaluated ensembles in the low insulation group all are likely to provide sufficient insulation, either as single blankets or in multiple layer combinations depending on the ambient temperature. In moderate and high wind conditions, thermal insulation capacity is best preserved by using the RC20<sup>®</sup> rescue blanket and the bubble wrap blanket, providing required insulation for thermoneutrality down to about +10 to +15°C the Fly High<sup>®</sup> rescue blanket and +15°C to +20°C respectively, whereas thermal insulation capacity for the Akla and Mediwrap metallic foil blankets, the plastic blanket, and the woolen and polyester blankets is reduced down to about +20°C to +25°C. Thus, with extended outdoor, on-scene durations, such as during protracted extrications or in multiple-casualty situations, the results of this study emphasize the importance of using a windproof and compression resistant outer layer, such as the bubble wrap or the RC20<sup>®</sup> rescue blanket, to maintain adequate insulation capacity. Similarly, In accordance with the results in the high insulation group, thermal insulation



**Figure 3**—Total insulation required (clo) for maintaining thermoneutrality depending on ambient temperature at an average metabolic heat production ( $70 \text{ W/m}^2$ ) of an awake person at rest (modified for values  $>10^\circ\text{C}$ ).<sup>36</sup>

of the air permeable woolen or polyester blankets might be extensively improved by the addition of a simple windproof outer cover, such as a plastic sheet. Being lightweight and packable, the reflective metallic foil blankets are promising for low wind conditions; but as the reflective effect is reduced with increased convective heat loss, in cold and windy outdoor conditions, they might best serve as windproof outer covers.

### Limitations and Further Research

The design of this study enabled the evaluation of thermal insulation as resistance to heat loss at various wind conditions. Trials were conducted with the thermal manikin dressed in dry clothing and insulation material kept dry. However, if the patient is wet or the insulation material is exposed to rain or snow, evaporative resistance as well as water permeability and insulation reduction due to moisture also would need to be considered. In addition to manikin studies at different conditions, human wear trials are essential to verify and determine what impact these different insulation values would have on human thermoregulation and body core temperature. When assessing and selecting the most appropriate insulation material for a specific prehospital unit, other practical characteristics, such as ease in handling and transportation, durability, microbiological barrier capabilities, and economical aspects also must be considered.

### Conclusions

At low wind conditions, thermal insulation correlates to thickness of the ensemble. At higher wind conditions, insulation capability is best preserved for ensembles that are windproof and resistant to the compressive effect of the wind. Taking these basic insulation characteristics into account, all of the evaluated insulation ensembles might be used for prehospital protection against cold, either as single blankets or in multiple layer combinations, to achieve required insulation for various ambient temperatures. However, with extended outdoor, on-scene durations, such as during prolonged extrications or in multiple-casualty situations, the results of this study emphasize the importance of using a windproof and compression resistant outer layer to maintain adequate insulation capacity.

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