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R.J. Osczevski

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Wind Chill:

Whole body vs. facial cooling

R. J. Osczevski

Defence and Civil Institute of Environmental Medicine

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Abstract

This report examines the question of whether wind chill should be calculated as an effect of exposed skin heat transfer or of whole body heat loss. Theory suggests that it is not possible to derive a useful index of wind chill based on heat transfer through normal outdoor winter clothing. A test is described that demonstrates that one proposed index, AT, which is based on a clothed, whole body model, does not consistently and uniquely correspond to levels of human sensation. That is, the same value of AT results from wind and temperature combination that produce different cold sensations. Refinements to the DCIEM Facial Cooling Model to include a variable internal thermal resistance, dependent on skin temperature, are described. This model of wind chill is based on cooling of the windward side of a cylinder. Any value of equivalent temperature calculated with this model corresponds to only a narrow range of thermal sensation.

Résumé

Le présent rapport examine la question de savoir si le refroidissement éolien devrait être calculé comme transfert de la chaleur d'une peau exposée ou comme perte de la chaleur du corps entier. La théorie laisse entendre qu'il est impossible de calculer un indice de refroidissement éolien en considérant le transfert de chaleur par les vêtements d'hiver ordinaires qu'on porte à l'extérieur. On décrit un test qui démontre qu'un indice proposé, l'AT, calculé d'après un modèle de corps entier vêtu, ne correspond pas toujours ni uniquement aux degrés des sensations humaines. Plus précisément, la même valeur AT est produite par une combinaison de vent et de température qui provoque différentes sensations de froid. On expose les améliorations apportées au modèle de refroidissement du visage, mis au point par l'IMED pour inclure une résistance interne à la chaleur, variable en fonction de la température cutanée, comme décrite. Ce modèle de refroidissement éolien est basé sur le refroidissement du côté vent d'un cylindre. Toute température équivalente calculée à l'aide de ce modèle correspond uniquement à une gamme étroite de sensations thermiques.

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Executive summary

Efforts to determine how much colder it feels when the wind blows began early in the 20th century and continue to the present day. The most widely used and the most successful ways of characterising cold, windy weather have been based on the wind chill index, developed by Paul Siple in Antarctica in 1941. Despite its success and wide acceptance by the public, Siple's wind chill index has been harshly criticised by experts over the years.

The experiments on which the wind chill index was based were designed simulate the cooling of unprotected skin. Recently, it has become possible to estimate heat loss in wind through clothing, with the assistance of mathematical models and computers. This has given rise to the notion that wind chill should be determined from a consideration of whole body heat loss. The most widely touted calculation of this kind expresses the effect of wind and temperature as an Apparent Temperature (Steadman, 1971, 1984)

This report examines the question of whether wind chill should be calculated as an effect of exposed skin heat transfer or of whole body heat loss. Also, it describes a test of the usefulness of any index of wind chill. This test is applied to Steadman's AT and a refined version of the DCIEM Facial Cooling Model. The latter has been refined to include a variable internal thermal resistances that depends on the skin temperature. This simple test demonstrates that one such index, AT, does not consistently and uniquely correspond to levels of human sensation, which it would have to, at least approximately, to be useful as an index of wind chill. Theory suggests that it is not possible to derive a useful index of wind chill based on heat transfer through normal outdoor winter clothing.

The facial cooling model suggests that the classic wind chill index works because combinations of wind and temperature that produce consistent values of the index also result in consistent skin temperatures on the exposed face. Facial skin temperature and overall thermal comfort seem to be intimately related. Wind erodes the boundary air layer adjacent to the skin and increases convective heat transfer. This reduces the temperature of exposed skin and creates the sensation that the air temperature is lower than the thermometer says it is.

The sensation of wind chill is largely an effect of exposed skin temperature. However, the temperature of the skin beneath clothing may play a role when the face is protected from the wind and the focus of discomfort awareness is transferred to the legs or some less well protected area.

Although calculations of total body heat transfer in cold weather are important in assessing the risk of hypothermia and in estimating survival times in cold conditions, they do not relate directly to the sensation of wind chill.

An index or an equivalent temperature derived from Siple's wind chill index, or from the DCIEM facial cooling model will pass this test. Either can be used as they are associated with narrow ranges of human thermal sensation in cold winds. However, some changes to the way wind speed is measured or used in the calculation of the wind chill index would be required.

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Further work is required to relate human sensation to wind chill values in non-sedentary conditions and to further clarify the relationship between skin temperature and skin thermal resistance, especially at skin temperatures at or below 0 °C. The facial cooling model might be further improved by relating wind speed to the local heat transfer from areas on the midline of the face, where cooling should be highest when facing the wind.

Sommaire

Depuis le début du 20^e siècle jusqu'à nos jours, on s'efforce de déterminer combien il fait plus froid quand il vente. Les moyens les plus efficaces et les plus utilisés pour caractériser un temps froid et venteux reposent sur l'indice de refroidissement éolien, mis au point dans l'Antarctique, en 1941, par Paul Siple. Malgré son succès et sa vaste acceptation par le public, le refroidissement éolien de Siple a été sévèrement critiqué au fil des ans par les experts.

Les expériences sur lesquelles repose le refroidissement éolien étaient conçues pour simuler le refroidissement de la peau exposée. Grâce à des modèles mathématiques et aux ordinateurs, on est arrivé, depuis peu, à évaluer la chaleur qu'on perd au vent à travers les vêtements. Cela a suscité la notion que le refroidissement éolien devrait être déterminé en considérant la perte de chaleur du corps entier. Le calcul le plus préconisé de ce genre exprime l'effet du vent et de la température en température apparente ou Apparent Temperature (AT) (Steadman, 1971, 1984)

Le présent rapport étudie la question de savoir si on devrait calculer le refroidissement éolien comme l'effet d'un transfert de chaleur de la peau exposée ou de la perte de chaleur subie par le corps entier. En outre, le rapport décrit un test de l'utilité de n'importe quel indice de refroidissement éolien. On a fait subir ce test à l'AT de Steadman et à une version améliorée du modèle de refroidissement du visage, mis au point par l'IMED. Ce modèle à été perfectionné pour y inclure une résistance thermique interne variant en fonction de la température de la peau. Ce simple test démontre qu'un de ces indices, l'AT, ne correspond pas toujours ni uniquement aux degrés de sensation humaine. Or, pour être un indice utile, il devrait y correspondre, au moins d'une manière approximative. La théorie laisse entendre qu'il est impossible de calculer un indice utile de refroidissement éolien en se basant sur le transfert de chaleur par des vêtements d'extérieur d'hiver courants.

Le modèle de refroidissement du visage sous-entend que l'indice classique de refroidissement éolien fonctionne car les combinaisons de température et de vent qui donnent des valeurs cohérentes de l'indice produisent également des températures cohérentes sur la peau exposée du visage. Il semble que la température de la peau du visage et le confort thermique global sont étroitement liés. Le vent ronge la couche atmosphérique qui borde la peau du visage et intensifie le transfert de chaleur par convection. Cela réduit la température de la peau exposée et fait sentir une température inférieure à celle qu'indique le thermomètre.

Le refroidissement éolien que l'on sent est en grande partie l'effet de la température de la peau exposée. Toutefois, la température de la peau couverte par les vêtements peut jouer un rôle lorsque le visage est protégé du vent et que la sensation d'inconfort se retrouve concentrée aux jambes ou à une région moins bien protégée.

S'il est important de calculer le transfert de la chaleur du corps entier par temps froid pour évaluer le risque d'hypothermie et estimer les temps de survie dans des conditions froides, les calculs ne sont pas liés directement à la sensation de refroidissement éolien.

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Un indice ou une température équivalente établi selon l'indice de refroidissement éolien de Siple ou selon le modèle de refroidissement du visage, de l'IMED, satisfera au présent test. L'un ou l'autre peut être utilisé étant donné qu'ils sont associés à des gammes étroites de sensation thermique humaine liée aux vents froids. Il serait nécessaire d'apporter quelques changements à la façon de mesurer la vitesse du vent ou d'utiliser celle-ci dans le calcul de l'indice de refroidissement éolien.

Des travaux plus poussés sont nécessaires pour faire le rapprochement entre la sensation humaine et les valeurs de refroidissement éolien dans des conditions variables et mieux préciser la relation entre la température de la peau et la résistance de celle-ci à la chaleur, surtout aux températures de la peau égales ou inférieures à 0° C. Le modèle de refroidissement du visage pourrait être amélioré encore en établissant le rapport entre la vitesse du vent et le transfert de chaleur locale qui se produit aux zones médianes du visage, où le refroidissement devrait être le plus intense lorsqu'elles sont exposées au vent.

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Introduction

Everyone knows that it feels colder when the wind blows. Efforts to quantify this effect began early in the 20th century and continue to the present day. The most widely used and successful ways of characterising cold, windy weather have been based on the wind chill index, developed by Paul Siple in Antarctica in 1941. Despite its success and wide acceptance by the public, Siple's wind chill index has been harshly criticised by experts over the years.

The experiments on which the wind chill index was based were designed to simulate the cooling of unprotected skin. Recently, it has become possible to estimate heat loss in wind through clothing, with the assistance of mathematical models and computers. This has given rise to the notion that wind chill should be determined from a consideration of whole body heat loss through some assumed clothing system. The most widely touted calculation of this kind expresses the effect of wind and temperature as an Apparent Temperature (AT) (Steadman, 1971, 1984)

We will examine the question of whether wind chill should be calculated as an effect of exposed skin heat transfer or of whole body heat loss. Also, we will describe a test of the usefulness of any index of wind chill and apply it to three proposed indices.

The boundary layer, convective cooling and wind chill

If you dive into water and come back out again, a thin layer of water will adhere to your skin. We live in an ocean of air. Like water, air can be said to "wet" the skin or any other object that is immersed in it. Air molecules adhere to the skin surface. Because air has some internal stickiness or viscosity, there is drag between the adhering air and the air molecules farther away from the skin. As a result, next to the skin or any surface there is a zone of relatively still air that may be a few millimetres thick. This is the boundary layer. The air in this layer is not as mobile as the air a centimetre or so away.

The boundary layer insulates your skin from the environment. If it did not exist, your skin surface would quickly cool to the temperature of the air, making it impossible to go outside in below freezing temperatures without getting frostbite.

If you blow on your arm, it can feel cool even though your breath is relatively warm because you have blown away the warm boundary layer air that was insulating the skin. If you do the same experiment in a hot sauna, instead of feeling cool, the spot you blow on can feel painfully hot because you have blown away the boundary layer of sauna air that had been cooled by the skin. This allows the heat of the sauna to reach the skin more easily.

In a perfect calm, if free convection could be suppressed, the boundary layer would be infinitely thick. This is approximately the case in an orbiting spacecraft, where micro-gravity minimises natural convection. The still air comprises the entire atmosphere of the spacecraft.

Fans must used to force the air to circulate. When the fans are on, the only still air that remains is the air in the immediate vicinity of some surface, like the skin.

On Earth, in normal gravity, natural convection limits the thickness of the boundary layer to a few millimetres, even if there is no wind. The stronger the wind, the thinner the boundary layer. Because the outer layers of still air are more easily blown away than the ones closer to the skin, a small increase in wind speed when it is nearly calm causes a much greater increase in heat loss rate than the same increase in wind speed when the wind is already strong.

Convective heat loss is really conduction through the boundary layer. The insulation of the boundary layer depends on its thickness. When there is wind, the thermal resistance of the boundary layer is smaller, the heat loss is higher and the temperature of the skin is closer to the air temperature.

Humans do not sense the temperature of the air. When we feel that it is cold outside, we are actually sensing the temperature of our skin. Because our skin temperature is lower when it is windy, we feel that it is colder when it is windy. That is wind chill.

Siple's wind chill index

The term "wind chill" was first used in Paul Siple's 1939 PhD dissertation on the adaptation of antarctic explorers to cold. He proposed a simple formula combining wind speed and temperature to give an index that he thought would be proportional to the severity of the weather. However, when he returned to Antarctica in 1940 and tried to use his index, he discovered that combinations of wind and low temperature that produced the same index value did not always produce the same degree of cold discomfort. As he couldn't find a simple mathematical way to combine wind and temperature, he decided to seek guidance from experiments.

Siple and Charles Passel set up a simple experiment on the roof of one of the expedition buildings, using left-over equipment from other scientific programs (Siple and Passel 1945). From the rate at which water in a small cylinder froze when hung outside the expedition building, they determined what they called "wind chill factors" for each experiment. These were overall heat transfer coefficients. They related their wind chill factors (WCF) to the wind speed (V) by a simple mathematical formula.

$$WCF = \sqrt{V \times 100} + 10.45 - V \qquad [1]$$

Siple's wind chill factors depended primarily on the thermal resistance of the boundary layer and the thermal resistance of the cylinder wall. A recent attempt to model their experiment (Danielsson 1996) concluded that the thermal resistance of the ice in the cylinder had only a small effect on the results.

Siple then added the effect of air temperature, T_a, in the "Wind Chill Index", K_0.

$$K_0 = WCF \times (33 - T_a) \qquad [2]$$

The "33" is an assumed mean skin temperature. This was an error. Because the experiment was designed to model heat transfer from the core to the environment, it should have been a core temperature of 37 °C.

The wind chill index characterises the combined effect of wind and cold temperatures in a three or four digit number that is proportional to how cold it feels. To test it, Siple compared it with previously published (Gold 1935) information on human thermal sensation and comfort in the cold . He also asked field parties to keep track of their cold discomfort and the weather conditions (Siple and Passel 1945). Further, in conjunction with the expedition medical officer, he asked members of the expedition to face cold winds for extended periods of time, sometimes until frostbite appeared on their faces (Frazier 1945). Siple found that any value of the wind chill index consistently produced approximately the same level of cold discomfort, regardless of how wind and temperature had been combined to create it. This convinced him that he had found a useful formula.

Over the years, many experts have strongly criticised the design of the wind chill experiment and the way the data were analysed (Molnar 1960; Steadman 1971; Kessler 1993; Brauner and Shacham 1995; Danielsson 1996; Bluestein 1998). One major criticism has been that the cylinder they used had a much smaller diameter than the average diameter of a human being, or human head. Also it seemed odd to assume that the skin temperature was a constant 33 °C when it might be freezing. Despite such criticisms, the fact remained that the wind chill index worked. One critic admitted:

> ....the index of "wind chill" has enjoyed a considerable, and deserved, popularity for it has been proved in the field that it does indeed provide an index corresponding quite well with experience in the cold, i.e. of the discomfort and tolerance of man in the cold (Burton and Edholm 1955).

DCIEM facial cooling model

This mathematical model of the cooling of a face in wind provides insight into why Siple's much criticised wind chill index works. The facial cooling model was based on the experiments with the face of a thermal manikin head in wind. This was combined with a model of how heat is transported from the body core to the skin.

In the original model (Osczevski 1995), the thermal resistance of the tissues of the face was assumed to be constant at the maximum value measured in physiological experiments (Osczevski 1994). A recent revision calculates the thermal resistance of the tissues of the face, R_{cheek}, as a function of the cheek skin temperature, T_{skin}, using an empirical equation derived from previously published data on the thermal resistance of the cheek in the cold (Osczevski 1994).

$$R_{cheek} = -0.000084 \cdot T_{skin}^2 + 0.00192 \cdot T_{skin} + 0.0565 \qquad [3]$$

This equation was derived from measurements of heat flux at skin temperatures between +1 °C and 37 °C. At skin temperatures below –5 °C, the thermal resistance is assumed to be constant at 0.045 m^2 °K/W, which is the value given by extrapolation of equation 3 to a skin temperature of –5 °C. The tissue thermal resistance given by this equation has a maximum value of 0.067 m^2K/W at a skin temperature of 11.4 °C.

The hazard of wind chill and much of the uncomfortable sensation, is due to the temperature of the skin on the most exposed part of the body. This is very often the face. The sensation of cold on the face can have a disproportionately large effect on the overall sensation of discomfort (Cabanac 1979; Nielsen 1987, Maidment 1994, Nadel 1973). In the worst case, a person will be facing the wind. Even when it is calm, he or she may be producing a relative wind by walking, skiing, or driving an open vehicle such as a snowmobile.

In Siple's tests, his subjects were adequately clothed with only their faces exposed. Their cold discomfort therefore had much more to do with facial cooling than with whole-body cooling. Although pedestrians are normally not as well protected from the cold as the polar explorers who validated the wind chill index, they have found the index to be useful in forecasting their discomfort. This suggests that even in normal conditions, wind chill is related largely to the cooling of faces.

The DCIEM model predicts that each value of the wind chill index will produce a narrow range of facial skin temperatures. Because facial skin temperature and thermal comfort are related, the wind chill index values are related to consistent levels of thermal discomfort. Thus the wind chill index works because any combination of wind and temperature that produces a particular value of the index also produces a consistent skin temperature on the exposed skin of the face.

Conditions perceived as "Cold" have been reported at wind chill index values of about 750 kcal/m^2h (870 W/m^2) (Siple and Passel 1945). The model says that winds and temperatures that produce this wind chill index will result in a skin temperature of 14 ± 0.7 °C. This agrees with observations that facial skin feels the sensation identified as "Cold" when its temperature reaches 15 °C (LeBlanc 1976; Osczevski 1994).

Also, conditions that combine to produce a wind chill index of 1400 kcal/m^2h (1625 W/m^2), which Siple identified as the limit at which frostbite sometimes occurs, produce facial skin temperatures in the revised model of –1.2 ±0.5 °C, which is about the freezing point of human skin (Keating 1960; Wilson 1973).

Wind affects the convective heat transfer from a face in much the same way as it does the heat transfer from a cylinder of the size of the one used by Siple and Passel (Osczevski 1995). Siple's cylinder was much smaller than the one that many of his critics might have preferred he'd used to model convection from a human in wind, however, because he made it so small, it was about the right size to approximate the heat transfer from a face looking upwind.

The windward side of a cylinder is a better choice for modelling wind chill than the whole cylinder. Wind not only has a greater cooling effect on cylinders of small diameter, but also on the upwind side of cylindrical objects (Achenbach 1975). Heat transfer from the upwind side of a head-sized cylinder is very similar to the heat transfer from a face in wind (Osczevski, 2000) and from Siple's cylinder.

A test of utility

Any index of the combined effect of cold and wind can only be said to work if it consistently has the same value in all sets of conditions that produce the same level of discomfort, hazard or sensation. Another way of stating this is to say that any value of a proposed index must be associated with one, and only one, level of discomfort. An index would not be very useful if any value could be associated with two or more different levels of hazard or sensation in cold and wind; we would not know which to expect.

An index that has been calculated from consideration of whole body heat loss is Steadman's (1971, 1984, 1994) AT. It is determined from the thickness of clothing that would be required to maintain thermal equilibrium at the prevailing wind speed and air temperature. Adequate clothing, with a wind resistant cover, is assumed. AT is the air temperature that would be required to maintain thermal balance, if the wind were to drop to zero velocity while wearing the same clothing as in the wind.

In Figure 1, the Steadman AT (Quayle and Steadman 1998) and the wind chill equivalent temperature, Teq, calculated from the revised facial cooling model, are presented for sets of wind and temperature that produce three different levels of sensation or hazard. Siple's wind chill equation was used to find the air temperature that must be combined with any wind speed to create the wind chill index associated with a particular sensation or level of hazard.

A valid index of human sensation in cold and wind should appear in Figure 1 as a horizontal line. The sensation of "Cold" has been associated with a wind chill index of 750 original wind chill units. At winds and air temperatures that produce this sensation, both AT and Teq are approximately the same – about 0 °C – and both are approximately constant over the range of wind speeds. AT can be calculated at lower air speeds than Teq, but below about 2 m/s (4.5 mph) AT begins to depart significantly from its nearly constant value at higher wind speeds.

In conditions that Siple associated with the risk of frostbite, Teq has a fairly constant value of –28 °C ± 2 °C (S. D.). However, AT has an approximately constant value only at wind speeds above about 5 m/s (10 mph). The failure of AT is even more obvious in conditions where frostbite would occur in one minute. AT fails the test at wind speeds below about 6 m/s (13 mph). In contrast, Teq remains relatively constant at –57 °C ± 1 °C over this range of wind speeds.

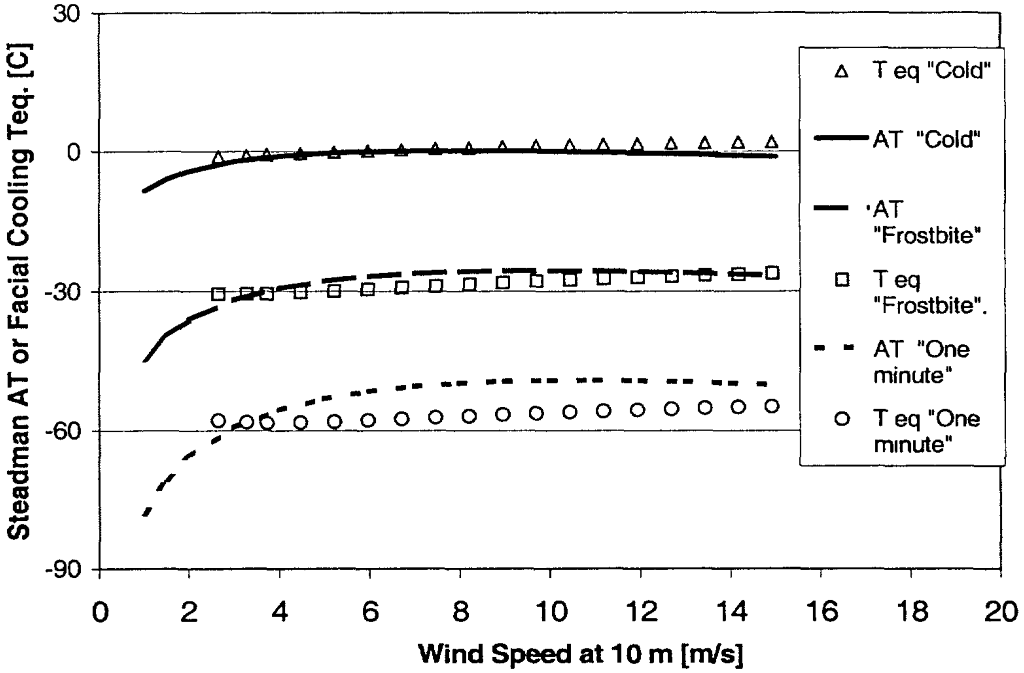

Figure 1. *A test of AT and Teq*

Discussion

Conditions that feel the same should always be described by the same number, whatever index is being used. This is true whether the sensation has been produced by high winds and a relatively warm temperature, or nearly calm winds and a much lower temperature. Elementary theoretical considerations suggest that an index based on clothed, whole body heat loss, such as AT, cannot pass this test in the cold.

On a windy day, at a temperature above freezing, a fleece track suit covered by a windproof nylon jacket and trousers might be adequate clothing. However, the same wind chill index can also be produced by a much lower temperature and almost no wind. Although a windproof nylon layer provides very good protection against heat loss when it is windy, it has very little protective value when it is almost calm.

Conditions that produce the same wind chill index feel about the same, as Siple and decades of general use have shown. The two situations should therefore feel the same. Teq would be almost the same for the two conditions and the exposed skin would be cooled to the same temperature. However at the lower air temperature with little wind, the individual would probably have to wear thicker clothing beneath his or her windproof layer to limit the heat loss to the same value. This means that the Apparent Temperature would be much lower.

Thus conditions that feel the same can have different Apparent Temperatures and conditions with the same Apparent Temperature can feel different.

Unless the index values form perfect horizontal lines in Figure 1, any y-axis value will be associated with more than one level of discomfort. For Teq, calculated from the revised facial cooling model, the lines are almost horizontal so that only a narrow range of sensation or hazard is associated with any value of Teq. If intermediate sensation lines had been plotted in Figure 1, it would be apparent that any value of AT can be associated with more than one level of discomfort or hazard. This is easier to see in the next example, in Figure 2.

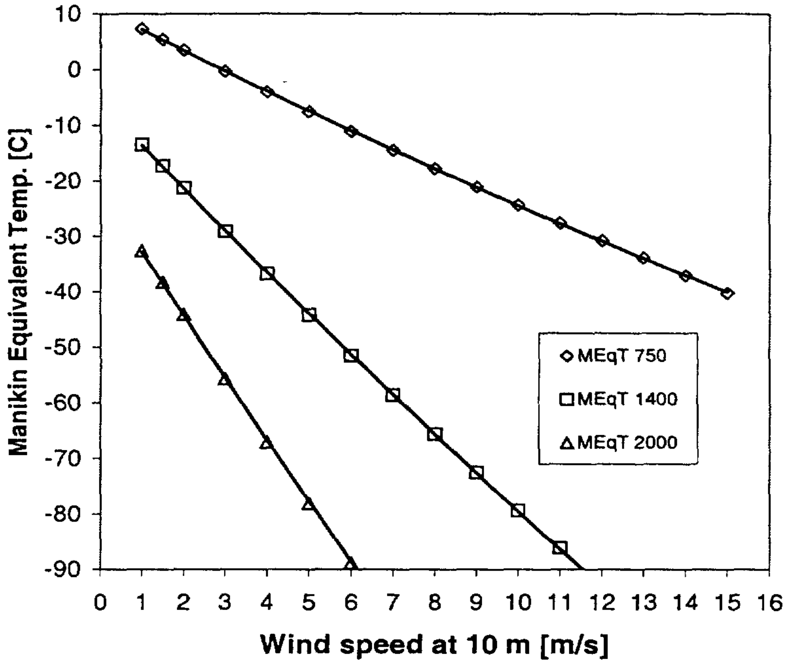

Figure 2. *Manikin wind chill equivalent temperatures do not form horizontal lines and constant values of the Wind Chill Index, and therefore do not correspond to constant levels of human sensation in cold winds.*

Equivalent temperatures derived from experiments with a heated manikin wearing average outdoor clothing (Wyon 1989) are presented in Fig. 2 for the same three discomfort or hazard levels. Wyon's manikin wind chill index clearly fails the test, for the lines of constant sensation are not even close to being horizontal. Each level of discomfort or hazard is represented by a wide range of values of the equivalent temperature on the y-axis. Conversely, each manikin equivalent temperature, MeqT, can describe many sensations. For example, a manikin equivalent temperature of –35 °C could be produced by the combinations of wind and temperature that produce wind chill index values of 750, 1400, or 2000. These combinations produce very different levels of sensation and hazard in human beings, but not in thermal manikins that maintain a constant skin temperature.

Conclusion

The facial cooling model suggests that the classic wind chill index works because combinations of wind and temperature that produce consistent values of the index also result in consistent skin temperatures on the exposed face. Facial skin temperature and overall thermal comfort seem to be intimately related. Wind erodes the boundary air layer adjacent to the skin and increases convective heat transfer. This reduces the temperature of exposed skin and creates the sensation that the air temperature is lower than the thermometer says it is.

The sensation of wind chill is largely an effect of exposed skin temperature. However, the temperature of the skin beneath clothing may play a role when the face is protected from the wind and the focus of discomfort awareness is transferred to the legs or some less well protected area.

Although calculations of total body heat transfer in cold weather are important in assessing the risk of hypothermia and in estimating survival times in cold conditions, they do not relate directly to the sensation of wind chill.

Theory suggests that it is not possible to derive a useful index of wind chill based on heat transfer through normal outdoor winter clothing. Such an index cannot consistently and uniquely correspond to levels of human sensation, which it would have to, at least approximately, to be useful.

An index or an equivalent temperature derived from Siple's wind chill index, or from the DCIEM facial cooling model will pass this test. Either can be used as they are associated with narrow ranges of human thermal sensation in cold winds. However, some changes to the way wind speed is measured or used in the calculation of the wind chill index would be required

Further work is required to relate human sensation to wind chill values in non-sedentary conditions and to further elucidate the relationship between skin temperature and skin thermal resistance, especially at skin temperatures at or below 0 °C. The facial cooling model might be further improved by relating wind speed to the local heat transfer from areas on the midline of the face, where cooling should be highest when facing the wind.

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14. ABSTRACT

(U) This report examines the question of whether windchill should be calculated as an effect of exposed skin heat transfer or of whole body heat loss. Theory suggests that it is not possible to derive a useful index of windchill based on heat transfer through normal outdoor winter clothing. A test is described that demonstrates that one proposed index, AT, which is based on a clothed, whole body model, does not consistently and uniquely correspond to levels of human sensation. That is, the same value of AT results from wind and temperature combination that produce different cold sensations. Refinements to the DCIEM Facial Cooling Model to include a variable internal thermal resistance, dependent on skin temperature, are described. This model of windchill is based on cooling of the windward side of a cylinder. Any equivalent temperature calculated with this model corresponds to only a narrow range of thermal sensation.

Le présent rapport examine la question de savoir si le refroidissement éolien devrait être calculé comme transfert de la chaleur d'une peau exposée ou comme perte de la chaleur du corps entier. La théorie laisse entendre qu'il est impossible de calculer un indice de refroidissement éolien en considérant le transfert de chaleur par les vêtements d'hiver ordinaires qu'on porte à l'extérieur. On décrit un test qui démontre qu'un indice proposé, l'AT, calculé d'après un modèle de corps entier vêtu, ne correspond pas toujours ni uniquement aux degrés des sensations humaines. Plus précisément, la même valeur AT est produite par une combinaison de vent et de température qui provoque différentes sensations de froid. On expose les améliorations apportées au modèle de refroidissement du visage, mis au point par l'IMED pour inclure une résistance interne à la chaleur, variable en fonction de la température cutanée, comme décrite. Ce modèle de refroidissement éolien est basé sur le refroidissement du côté vent d'un cylindre. Toute température équivalente calculée à l'aide de ce modèle correspond uniquement à une gamme étroite de sensations thermiques.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) Wind chill; cold weather; heat transfer; human physiology; face; convection; thermal boundary layer; winter

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