Wind chill equivalent temperature (WCET) Climatology and scenarios for Schiphol Airport

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Abstract

This report presents the background, climatology and scenarios of the windchill equivalent temperature (WCET) for Schiphol Airport. The WCET-information is recommended during cold winter events for working conditions outside. KNMI will start using a new method for the calculation of WCET in the winter 2009-2010, this method was established in 2000/2001 in Joint Action Group on Temperature Indices (JAG/TI).

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Chapter 1

Introduction

On a winter day with wind blowing in your face, the wind makes it feel colder due to extra loss of body heat. This colder feeling is called "windchill". The windchill equivalent temperate WCET (Dutch: "gevoelstemperatuur") indicates the equivalent temperature on a colder day without wind with the same loss of body heat. The difference between the (measured) actual air temperature and the (calculated) windchill equivalent temperature quantifies the influence of wind on heat loss. WCET is in cold winters sometimes mentioned by meteorological services in forecasts and warnings, as it helps to prevent cold injuries.

Wind chill equivalent temperatures are not observed for dead objects (like machines). Objects do not experience colder temperatures than air temperature, but wind can cool objects faster to the air temperature (and help to freeze water pipes faster). Calculations are based on the balance between heat loss and heat production of healthy adults ("average" height and weight). Individual differences can lead to different reactions during cold events. For instance taller persons, small children, older people and patients with heart-problems may be more susceptible to windchill than others.

WCET is calculated using air temperature and wind speed (temperature is indicated in this report in °C, WCET for clarity of presentation in degrees, wind in m/s). Although direct sun can raise WCET by 5-10 degrees, it is not accounted for due to local effects. Humidity plays a minor role as evaporation rates are small at low temperatures. Wet skin should be avoided as heat loss progresses with better conduction. The word "windchill" was used by Siple in 1939 (not published thesis). In 1945 he and Passel had two publications on this subject (Siple, 1945), (Siple en Passel, 1945). In the early seventies Robert Steadman developed another method (Steadman, 1971), revised in later years (Quale, 1998). From 1992 - now KNMI used the Steadman-1971 method for WCET-calculations (Zwart, 1992).

In April 2000 the Joint Action Group on Temperature Indices (JAG/TI) organised an "Internet Workshop on Windchill" in Toronto. Randall Osczevski and Maurice Bluestein (Osczevski en Bluestein, 2005) proposed a new method for computing windchill, which was broadly accepted and rapidly implemented in Canada and the United States in the winter of 2001-2002 (CWCP, 2009). This new method (named: JAG/TI-method) is used currently in the United States, United Kingdom, Canada and Iceland. KNMI implemented this new method in late 2009 as international use is expanding and national guidelines on health and labor during cold spells are based on the new method (Groen, 2009).

In chapter 2 and 3, three methods are presented (Passel, Steadman en JAG/TI). In chapter 4, climatology of WCET based on the JAG-TI-method and scenarios for 2050 are shown for Schiphol Airport and five main stations in the Netherlands. Suggestions for use of WCET are presented in the last chapter.

Chapter 2

Three methods for WCET-calculation

WCET can be calculated in various ways; three important methods are presented here. The description of the methods of Siple-Passel and Steadman are based on Floor (Floor, 1991) and Zwart (Zwart, 1992), and the JAG/TI-method based on material of Environment Canada (CWCP, 2009).

2.1 Siple en Passel

The oldest method for calculation of WCET is developed by the American researchers Paul Siple and Charles Passel from experiments in 1939 during the third polar expedition of admiral Byrd (Siple, 1945). Siple was a major, stationed in Antarctica and interested in the chilling effect on military staff on location. He studied the cooling speed of a cylinder with water of +10°C to the actual air temperature under different wind conditions.

The formula for the wind chill equivalent temperature G according to Siple and Passel is:

$$G(SP) = 33 + (T - 33) * (0,474 + 0,454 * W^{0,5} - 0,0454 * W) \tag{2.1}$$

where air temperature, T, is in °C at 1.50 meters, and windspeed, W, is in m/s at 10 meters.

Main objections to this method is the comparison of a cooling cylinder of warm water to a clothed person, who can also lose heat via breathing, evaporation and radiation, or gain warmth from the sun. Thus, the total cooling rate will differ from the cylinder-method.

Also, Siple and Passel did not account for humidity: evaporation rates are small at low temperatures. Because there is no direct sun at Antarctica during winter, also incoming radiation was neglected.

The method of Siple and Passel was used until the end of 2001 in the US and Canada, but it was increasingly criticised due to its low outcome of WCET. In 2001 the new method of JAG/TI became operational. The method of Siple and Passel is not used by KNMI but is mentioned in ISO 11079: "Ergonomics of the thermal environment – Determination and interpretation of cold stress when using required clothing insulation (IREQ) and local cooling effects".

2.2 Steadman

Robert G. Steadman made another approach in 1971 as he wanted a method for winter clothing calculations to protect against the cold, based on loss of heat due to cold and wind and production of heat by a clothed and walking adult (height 1.70 meters, skin area 1.7 m^2 and walking speed 4.7 km/hr, which translates to a warmth production of 188 W/m^2).

In his method heat loss is created by five factors: inhalation (exhalation) of cold (warm), evaporation on bare skin, heat loss from thin clothing on the hands and feet and heat loss from the other warmer clothed body parts. The last three factors have a relation with wind speed. The total sum of these five factors should be equal to 188 W/m^2. Steadman neglected (like Siple and Passel) humidity of surrounding air in cold events (but included this factor for heat stress at high temperatures (Steadman, 1984).

Steadman's method changed many times. Quale derived a direct formula for WCET based on the last changes of Steadman in 1997 (Quale, 1998):

$$G(S) = 1,41 - 1,162 * W + 0,98 * T + 0,0124 * W^2 + 0,0185 * W * T \quad (2.2)$$

where air temperature, T, is in °C at 1.50 meters, and windspeed, W, is in m/s at 10 meters.

The United Kingdom used Steadman-1984 between 1986 and 2002 (Dixons en Prayer, 1987) , and KNMI used Steadman-1971 since 1992 (Zwart, 1992).

2.3 JAG/TI

In April 2000 Environment Canada organised the Joint Action Group on Temperature Indices (JAG/TI), led by US National Weather Service and Meteorological Service of Canada. This first "Global International workshop on Windchill" was visited by more than 400 participants from 35 countries (JAG/TI, 2003). Almost all agreed on a new international standard for the calculation of "windchill equivalent temperature", as proposed by Randall Osczevski and Maurice Bluestein. Their elaborate model of heat transport through the body and skin, which accounts for lower transport as body temperature cools, was acknowledged by later medical research (Osczevski en Bluestein, 2005).

The formula of JAG/TI-2000 is:

$$G(J) = 13,12 + 0,6215 * T - 11,37 * (W * 3,6)^{0,16} + 0,3965 * T * (W * 3,6)^{0,16} \quad (2.3)$$

where air temperature, T, is in °C at 1.50 meters, and windspeed, W, is in m/s at 10 meters.

The formula is developed for a temperature range between -46 and +10°C and for windspeeds at 10 meters high between 1.3 and 49.0 m/s. The power function (0,16) translates the windspeed at 10 meters high to 1.50 meters high.

This method became operational in the US and Canada in the winter of 2001-2002, in later years in the UK and Iceland and KNMI is intending to implement it in the winter 2009-2010.

2.4 Sunshine

The JAG/TI-method is based on the loss of warmth by an average person walking at a speed of 4.8 km/hr, wearing winter clothing and with little or no sun. It should be noted that with direct radiation from the sun in late winter or early spring the wind chill equivalent temperature might be 5 to 10 degrees higher than calculated with the formula. As the influence is quite variable for human beings (like orientation of the body, changes from sun to shade) the method does not account for sunshine (CWCP, 2009).

Chapter 3

Table JAG/TI and comparison of three methods

3.1 Table method JAG/TI

JAG/TI:

$G(J) = 13,12 + 0,6215 * T - 11,37 * (W * 3,6)^{0,16} + 0,3965 * T * (W * 3,6)^{0,16}$

JAG/TI		+5 °C	0 °C	-5 °C	-10 °C	-15 °C	-20 °C	-25 °C	-30 °C
5 km/hr	1,4 m/s	*4*	*-2*	*-7*	*-13*	*-19*	*-24*	*-30*	*-36*
10 km/hr	2,8 m/s	*3*	*-3*	*-9*	*-15*	*-21*	*-27*	*-33*	*-39*
15 km/hr	4,2 m/s	*2*	*-4*	*-11*	*-17*	*-23*	*-29*	*-35*	*-41*
20 km/hr	5,6 m/s	*1*	*-5*	*-12*	*-18*	*-24*	*-30*	*-37*	*-43*
25 km/hr	7,0 m/s	*1*	*-6*	*-12*	*-19*	*-25*	*-32*	*-38*	*-44*
30 km/hr	8,3 m/s	*0*	*-6*	*-13*	*-20*	*-26*	*-33*	*-39*	*-46*
35 km/hr	9,7 m/s	*0*	*-7*	*-14*	*-20*	*-27*	*-33*	*-40*	*-47*
40 km/hr	11,1 m/s	*-1*	*-7*	*-14*	*-21*	*-27*	*-34*	*-41*	*-48*
45 km/hr	12,5 m/s	*-1*	*-8*	*-15*	*-21*	*-28*	*-35*	*-42*	*-48*
50 km/hr	13,9 m/s	*-1*	*-8*	*-15*	*-22*	*-29*	*-35*	*-42*	*-49*
55 km/hr	15,3 m/s	*-2*	*-8*	*-15*	*-22*	*-29*	*-36*	*-43*	*-50*
60 km/hr	16,7 m/s	*-2*	*-9*	*-16*	*-23*	*-30*	*-36*	*-43*	*-50*
65 km/hr	18,1 m/s	*-2*	*-9*	*-16*	*-23*	*-30*	*-37*	*-44*	*-51*
70 km/hr	19,5 m/s	*-2*	*-9*	*-16*	*-23*	*-30*	*-37*	*-44*	*-51*
75 km/hr	20,8 m/s	*-3*	*-10*	*-17*	*-24*	*-31*	*-38*	*-45*	*-52*
80 km/uhr	22,2 m/s	*-3*	*-10*	*-17*	*-24*	*-31*	*-38*	*-45*	*-52*

Table 1: WCET method JAG/TI

3.2 Comparison of Siple-Passel, Steadman and JAG/TI at -15°C

For illustration purposes, the three methods of calculating windchill equivalemt temperatures are illustrated using an air temperature of -15°C with increasing windspeed.

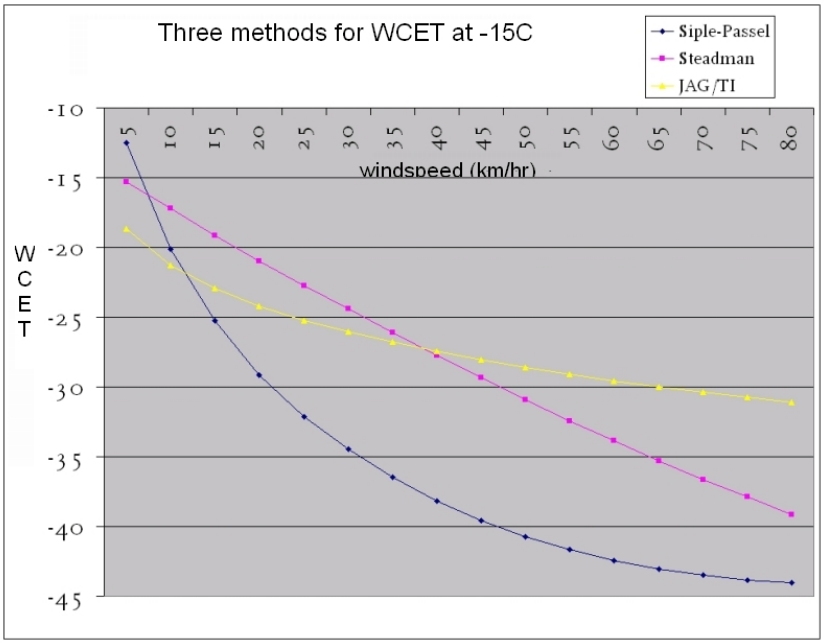

Figure 1: Comparison of the methods for calculating WCET of Siple-Passel, Steadman and JAG/TI at -15°C and increasing windspeed. Notice the cold WCET using the Siple-Passel method, and the lesser decrease of WCET at high windspeed using the JAG/TI method .

The methods of Steadman and JAG/TI give similar WCET with a windspeed of 40 km/hr, "JAG/TI" has lower WCET at lower windspeed and higher WCET with higher windspeed, "Steadman" shows a constant rate of cooling with increasing windspeed. "Siple-Passel", in use in the US and Canada until 2001, differs remarkably from "JAG/TI"" and "Steadman", thus illustrating the reasons for criticism of this method. KNMI prefers the JAG/TI-method for WCET because of the scientific basis of the method, the widespread international support and increasing use.

Chapter 4

Climatology and scenarios

4.1 Climatology WCET

KNMI publishes hourly wind- and temperature data (KNMI, uurgegevens), with these data WCET is calculated according to the JAG/TI-method. Figure 2 illustrates the number of days per year since 1971 with at least one hour below the chosen threshold for Schiphol airport.

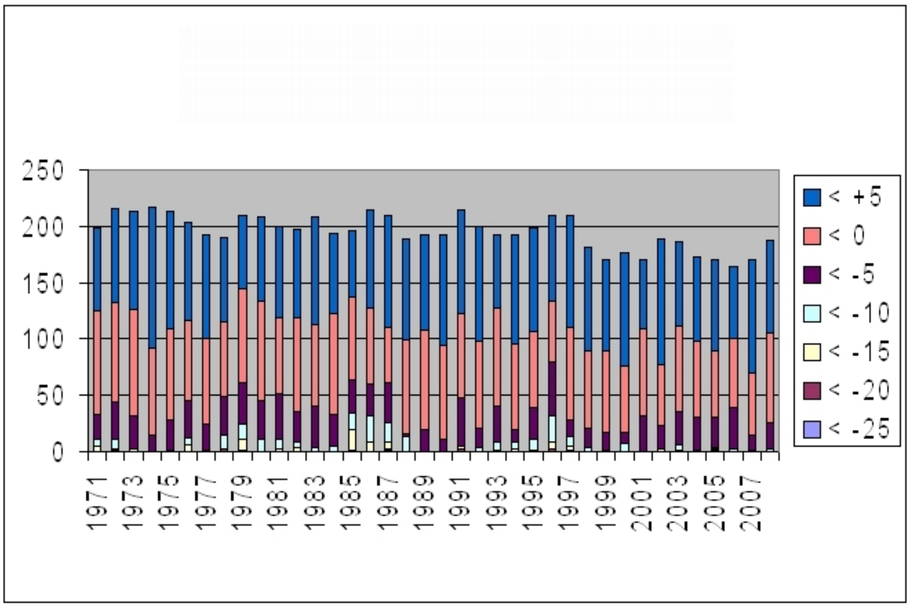

Figure 2: Number of days with WCET at least one hour below treshold for Schiphol Airport over the period 1971-2008.

The lowest WCET since 1961 at Schiphol Airport was -26.7 degrees at January 14th 1987.

For some other stations in the Netherlands since 1961 the minimum WCET was: Eelde and Twenthe -28 degrees and De Kooy, Leeuwarden, De Bilt -26 degrees on the same day; Flushing (Vlissingen) -23 degrees on January 18th 1963; Eindhoven -25 Maastricht -26 on December 31th 1978.

Table 2 illustrates the average number of days in the climatological period 1971-2000 with at least one hour where WCET is below a chosen threshold.

1971-2000	< -25	< -20	< -15	< -10	< -5	< 0	< +5
Schiphol	0.03	0.4	3	10	38	117	206
De Kooy	0.03	0.3	3	10	35	109	196
Eelde	0.03	0.7	4	14	47	137	217
De Bilt	0.03	0.3	3	9	31	102	190
Vlissingen	0.00	0.2	2	6	28	95	183
Beek	0.07	0.9	3	11	42	121	201

Table 2: Climatology of the average number of days per year with WCET at least one hour below threshold according to the JAG-TI method over the period 1971-2000.

The climatology in table 2 is for days with at least *one hour* with a certain WCET. For *a whole day* with a certain treshold of WCET the frequency is much lower, the number of days with *all day* WCET below zero degrees is on average 7 days, below -5 degrees about 1,7 days, below -10 degrees about 0,3 days.

4.2 Scenarios

In May 2006 KNMI published four climate scenarios for the Netherlands (KNMI'06 scenario's, 2006). In a supplement in 2009, the robustness of these scenarios for recent scientific developments was shown (Klein Tank en Lenderink, 2009).

The main message in the KNMI'06 climate scenarios is:

- temperatures will keep rising, mild winters and warmer summers will occur more often
- average winter precipitation and extreme precipitation amounts will increase
- intensity of extreme showers in summer increases, but number of rainy days will decrease
- changes in wind climate are small compared to natural variability
- sea level rises

4.3 Scenarios WCET

KNMI developed a transformation program for timeseries of (day-average) temperature on the KNMI-website (KNMI'06 tijdreekstransformatie, 2009). With the assumption that in winter changes in temperature per day (24 hours) are similar to the changes per hour, timeseries for (hour) temperature for 2050 are calculated. Combined with (not transformed) timeseries of wind, WCET-scenarios for 2050 are calculated.

Figure 3 illustrates the percentage decrease of the number of days with WCET below 0, -5, -10 and -15 degrees from the period 1990 to 2050. The largest decrease is under the W+ scenario (55%) the smallest decrease under the G scenario (25%). The different changes under the scenarios is due to the fact under the KNMI'06 climate scenarios extreme temperature increase faster than average temperature, leading to a faster decrease of colder WCET-days in a warmer scenario.

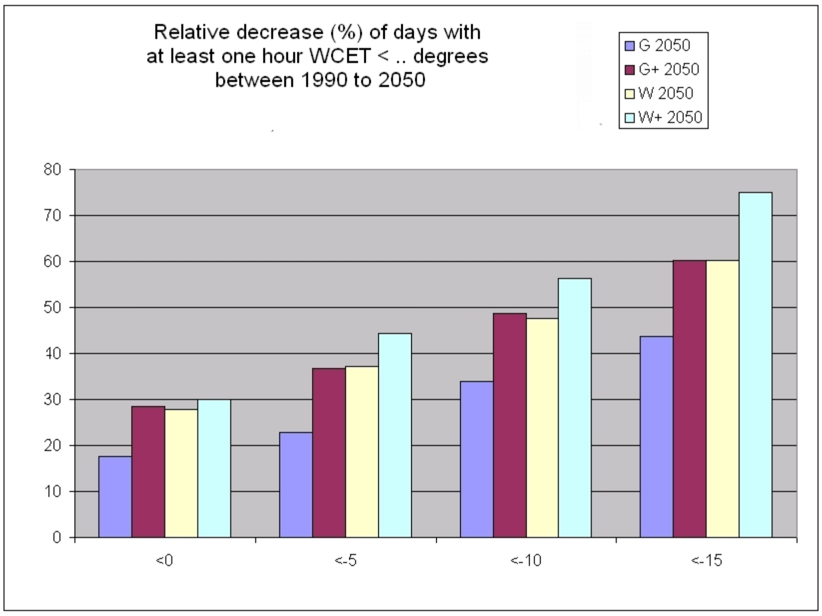

Figure 3: Average decrease of number of days per year of WCET below chosen threshold for Eelde, De Bilt, De Kooy, Vlissingen and Beek in scenarios G, G+, W and W+ over the period 1990-2050.

For Schiphol Airport, the changes from 1971-2000 towards 2050 in the scenarios G, G+, W en W+ show:

- the average number of days per year with at least one hour WCET below 0 degrees decreases from 117 to a range of 63 (W+) to 92 (G)
- days with at least one hour WCET below -5 decrease from 38 to 15 - 28 days per year

- days with at least one hour WCET below -10 from 10 to 4 - 8
- days with at least one hour WCET below -15 from 3 to 1 - 2
- days with at least one hour WCET below -20 from once per 2.5 years to once per 5 to 25 years
- days with at least one hour WCET below -25 will hardly occur any more.

Chapter 5

Inventory thresholds for advisory

In the Netherlands, severe winters are rare, and climate change indicates a further reduction of these events in this century. Despite this, we should stay aware of the risk of periods with low wind chill equivalent temperatures. In this chapter, advisory and thresholds for temperature (WCET) and duration are discussed.

Figure 4: The Chillings Facts, poster, Environment Canada. Source:http://www.msc.ec.gc.ca/education/windchill/

5.1 Advisory and tresholds in Canada

The Wind Chill Program of Environment Canada describes the dangers of low WCET on its website (CWCP, 2009).

Exposure to the cold can be hazardous, or even life-threatening. Your body's extremities, such as the ears, nose, fingers and toes, lose heat the fastest. Exposed skin may freeze, causing frostnip or frostbite. In extreme conditions or after prolonged exposure to the cold, the body core can also lose heat, resulting in hypothermia.

Cold Injuries can be catagorized in:

1. Frostnip

* a mild form of frostbite, where only the skin freezes
* skin appears yellowish or white, but feels soft to the touch
* painful tingling or burning sensation

What to do:

* do not rub or massage the area
* warm the area gradually – use body heat (a warm hand), or warm water, avoid direct heat which can burn the skin
* once the affected area is warm, do not re-expose it to the cold

2,. Frostbite

* a more severe condition, where both the skin and the underlying tissue (fat, muscle, bone) are frozen
* skin appears white and waxy, and is hard to the touch
* no sensation – the area is numb

What to do:

* frostbite can be serious, and can result in amputation. Get medical help.
* do not rub or massage the area
* do not warm the area until you can ensure it will stay warm
* warm the area gradually – use body heat, or warm water (40 to 42°C), avoid direct heat which can burn the skin

3. Hypothermia

* feeling cold over a prolonged period of time can cause a drop in body temperature (below the normal 37°C)

* shivering, confusion and loss of muscular control can occur
* can progress to a life-threatening condition where shivering stops, the person loses consciousness, and cardiac arrest may occur

What to do:

* get medical attention immediately
* lay the person down and avoid rough handling, particularly if the person is unconscious
* get the person indoors
* gently remove wet clothing
* warm the person gradually, using any available source of heat

Source:

Defence R&D Canada, Defence Research and Development Canada Toronto (DRDC Toronto, formerly the Defence and Civil Institute of Environmental Medicine) – the research agency of the Canadian Department of National Defence.

Wind Chill Hazards

Check the wind chill before you go outdoors in the winter, and make sure you are well prepared for the weather. Even moderate wind chill values can be dangerous if you are outside for long periods.

Note: The guidelines on frostbite in the table below apply to healthy adults.

Wind Chill Hazards and Risk of Frostbite

Wind Chill	Risk of frostbite	Health Concern	What to do
0 to -9	Low	- Slight increase in discomfort	- Dress warmly, with the outside temperature in mind.
-10 to -27	Low	- Uncomfortable - Risk of hypothermia if outside for long periods without adequate protection	- Dress in layers of warm clothing, with an outer layer that is wind-resistant. - Wear a hat, mittens and scarf. - Keep active.
-28 to -39	Increasing risk: exposed skin can freeze in 10 to 30 minutes	- Check face and extremities (fingers, toes, ears and nose) for numbness or whiteness - Risk of hypothermia if outside for long periods without adequate protection	- Dress in layers of warm clothing, with an outer layer that is wind-resistant. - Cover exposed skin: wear a hat, mittens and a scarf, neck tube or face mask. - Keep active.

-40 to -47	High risk: exposed skin can freeze in 5 to 10 minutes*	- Check face and extremities (fingers, toes, ears and nose) for numbness or whiteness (frostbite) - Risk of hypothermia if outside for long periods without adequate protection	- Dress in layers of warm clothing, with an outer layer that is wind-resistant. - Cover all exposed skin: wear a hat, mittens and a scarf, neck tube or face mask. - Keep active.
WARNING LEVEL** -48 to -54	High risk: exposed skin can freeze in 2 to 5 minutes*	- Check face and extremities frequently for numbness or whiteness (frostbite) - Serious risk of hypothermia if outside for long periods	- Be careful. Dress very warmly in layers of clothing, with an outer layer that is wind-resistant. - Cover all exposed skin: wear a hat, mittens and a scarf, neck tube or face mask. - Be ready to cut short or cancel outdoor activities. - Keep active.
-55 and colder	High risk: exposed skin can freeze in less than 2 minutes	DANGER! - Outdoor conditions are hazardous	- Stay indoors.

5.2 TNO research on dexterity

Manual performance during work in cold and windy climates is severely hampered by decreased dexterity, but valid dexterity decrease predictors based on climatic factors are scarce. Therefore, TNO investigated the decrease in finger- and hand dexterity and grip force for nine combinations of ambient temperature (–20, –10 and 0°C) and wind speeds (0.2, 4 and 8 $m \cdot s^2$), controlled in a climatic chamber. Extra insulation did affect cold sensation but not manual performance. The deterioration in manual performance appeared to be strongly dependent upon Wind Chill Equivalent Temperature (WCET) and the square root of exposure time (r=0.93 for group average) (Daanen, 2008).

The research shows a significant decrease of dexterity when fingertips become colder than 14 °C, formulated in the combination of WCET and exposure time as:

$$WCET * (exposuretime)^{0,48} = -113,07.$$

Thus, the maximum exposure time in order to prevent dexterity (ie., keep fingertips above 14°C) is, for various values of WCET:

- WCET of -10 degrees about 2.5 hours
- WCET of -20 degrees about 37 minutes
- WCET of -30 degrees about 16 minutes
- WCET of -40 degrees only 9 minutes
- WCET of -50 degrees at most 5 minutes.

5.3 GGD-advisory

Guidelines of GGD (RIVM) in 2009 indicate the effects of wintercold on health(Noorda, 2009), varying from mild impact when WCET is just below 0 degrees to strong impact when WCET is extremely low and body temperature cools to 35 degrees (hypothermia). Further development on guidelines for windchill is expected in future.

5.4 Suggestions for WCET advisory for Airport Schiphol

Indications for development of advisory for working outside in cold winter events on the basis of information fron Canada Environment, TNO-research and GGD-advisory could be:

- WCET between $\leqslant 0$ and $\geqslant -10$ degrees and exposure time for several hours, small impact.
- WCET $\leqslant -10$ degrees and exposure time for several hours, moderate impact.
- WCET $\leqslant -15$ degrees, exposure time $\geqslant 1$ hour, risk frostnip.
- WCET $\leqslant -20$ degrees, $\geqslant 0,5$ hour, risk frostnip and small risk frostbite.
- WCET $\leqslant -25$ degrees, <0,5 hour, increasing risk frostbite.
- WCET $\leqslant -30$ degrees, < 15 minutes, large risk frostbite.
- WCET $\leqslant -40$ degrees, in 5 to 10 minutes large risk frostbite.

Additional remarks:

- In sunny periods WCET could be $5 - 10$ degrees less cold
- Risk $< 5\%$ is indicated as “small” and $> 95\%$ as “large”.

In KNMI the windchill equivalent temperature will be mentioned in general forecasts when WCET drops below -

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