Heat Loss from the Human Body on Mars and Antarctica

Due to Mars's thin atmosphere providing very little thermal insulation, at the Martian equator where the daytime high is about 0ºC the surface temperature falls to around -80ºC just before dawn [1]. At higher latitudes the temperatures are even lower and near the Martian poles it drops to around -150 ºC in winter. The only place on Earth which has comparable temperatures is the interior of Antarctica during the long Antarctic winter.

In this article I consider the ways in which humans wearing protective cold weather clothing in Antarctica at -80ºC, and an insulated spacesuit on Mars at the same temperature lose heat to the environment and come to the interesting conclusion that it is easier to stay warm on Mars.

This article has all the equations for the different types of heat loss and is aimed at someone with an understanding of physics to high school level. For those readers who don't want to go into this level of detail. There is a simplified version on my Explaining Science blog available at:

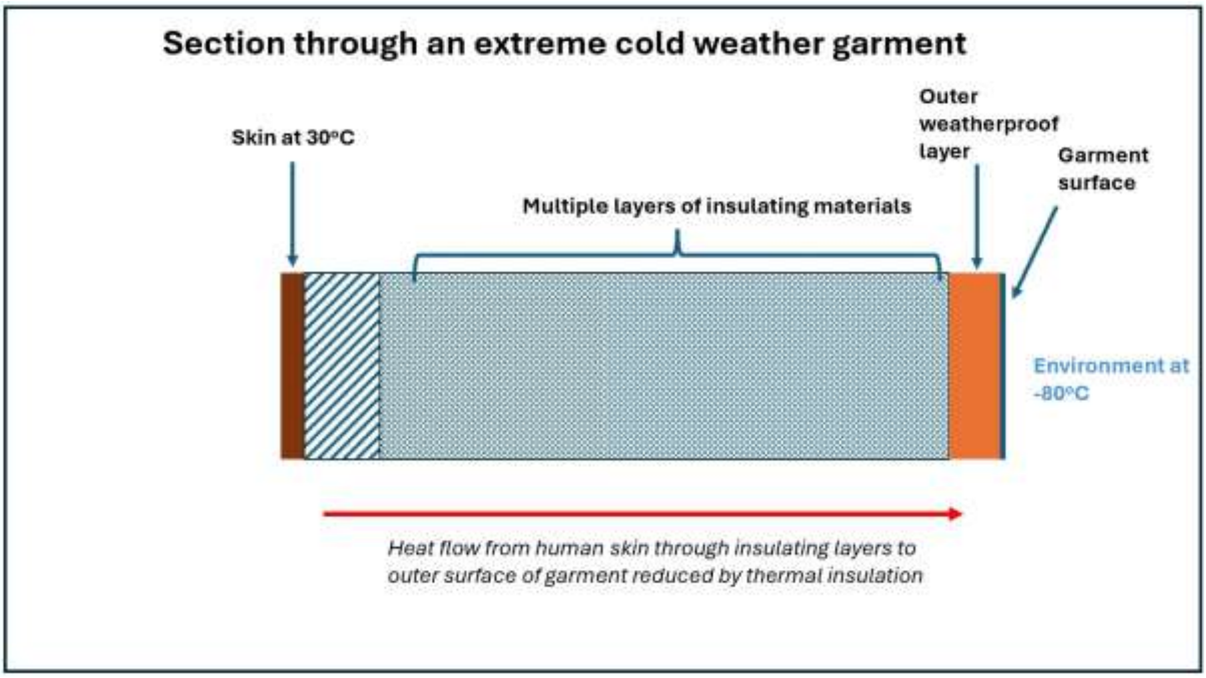
Heat Loss on Antarctica and Mars

1 Heat loss from the human body in Antarctica at -80°C

Let's first consider the case of a polar explorer on the surface of Antarctica at -80°C and then go on to look at an astronaut on Mars, highlighting the differences between the two environments and explaining why these cause a different rate of heat loss.

The importance of insulated clothing

The average human skin temperature is around 30°C. If our polar explorer were wearing thick specially designed ***multi-layer insulated polar garments,*** heat conduction from their skin through the layers of the garment to its outer surface exposed to the elements is minimised. As I'll explain later to reduce heat loss it is vital that the temperature of the surface of the garment is as close to the environment temperature as possible



Assumption

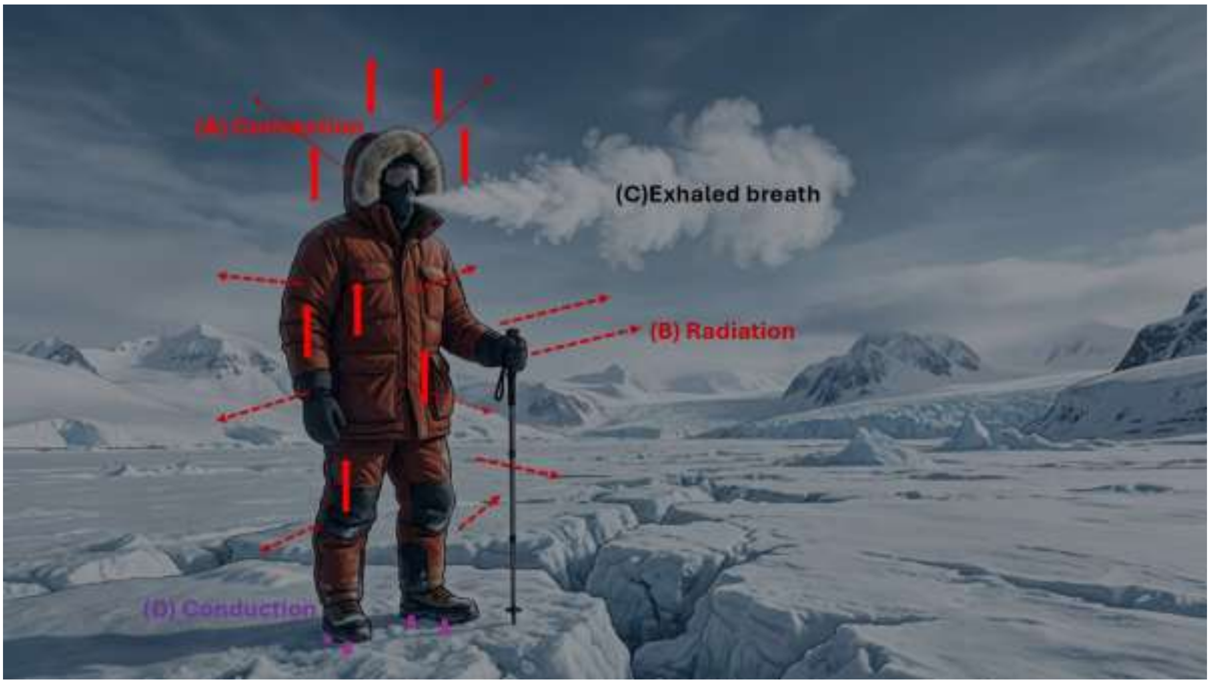
I will assume that the temperature of the surface of the clothing is only 10 degrees Celsius above the surroundings.

Mechanisms of heat loss

Heat is lost in four ways.

- Because the outer surface of the clothing at -70°C is warmer than the atmosphere (-80°C) heat is lost by convection to cool surrounding air.
- Heat is lost by radiation to the cooler surroundings.
- Extremely cold air is breathed in, and warm moist air is breathed out.

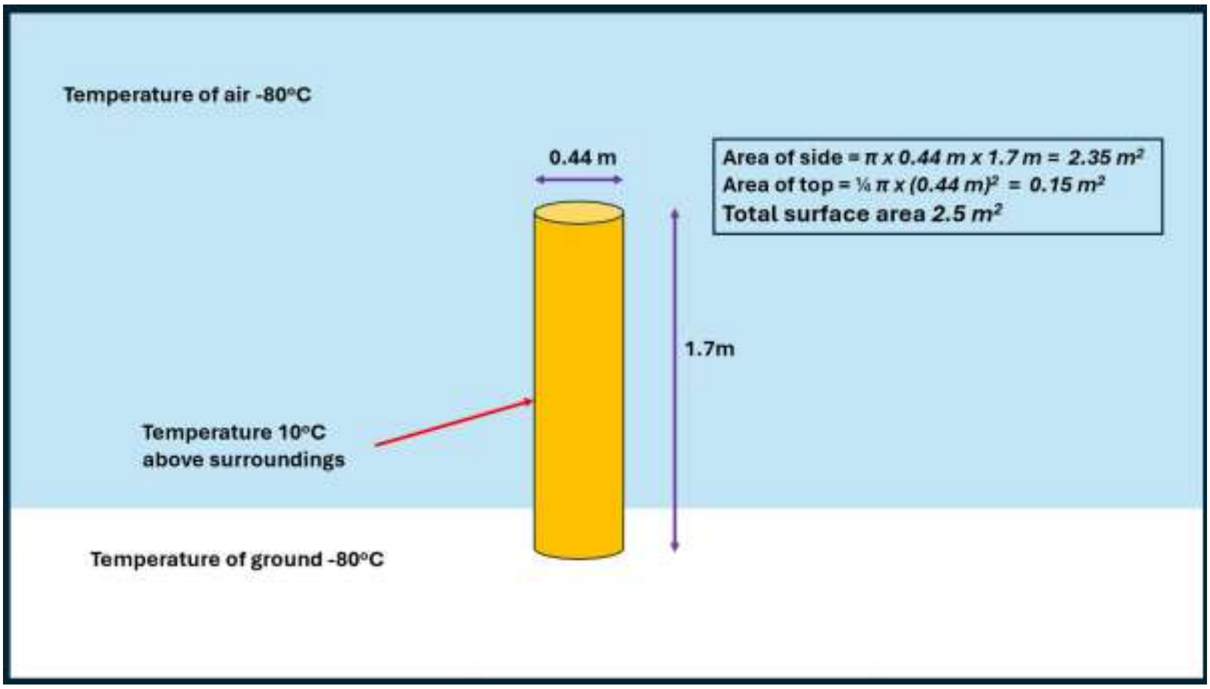
- Heat is lost by conduction through the soles of the polar explorer's boots, which are in direct contact with the frozen ground.



I will now estimate the rate of heat loss through these mechanisms.

1.1 Heat loss by Convection.

Of the four mechanisms, this causes the greatest rate of heat loss. The detailed calculation is complex. To simplify it and to get an approximate value I will assume the clothing's outer surface can be approximated by a cylinder of height 1.7 m and diameter 0.44 m. The surface area of the top of this cylinder is much smaller than its sides and its total surface area is 2.5 m^2.



Using this simplifying assumption the rate of heat loss by convection (Q_{conv}) is:

$$Q_{conv} \;=\; h\mathrm{A}\,(T_S - T_E) \qquad [1]$$

Where

- h is the convective heat transfer coefficient. For still air at 193 K (-80°C), where the natural buoyancy of the air warmed by the garment's outer surface is the only form of convection h = 4 W m^{-2} K^{-1}.

  Strictly speaking the value of the convective heat transfer coefficient differs between the top and the sides of the cylinder, because of the difference in the way air flows around the sides of the cylinder compared to its flat top. The top has a larger value of h, around 5 W m^{-2} K^{-1}. For simplicity, I will ignore this because the area of the top is relatively small.

- If a breeze were blowing, h would be much higher, around 20 W m^{-2} K^{-1}.
- A is the garment's outer surface area, 2.5 m^2.
- T_S is the temperature of the garment's outer surface, 203 K (-70°C).
- T_E is the temperature of the environment, 193 K (-80°C).

Putting these numbers into equation [1] gives:

Q_{conv} = 4 x 2.5 x (203 – 193) = **100 watts**

If a breeze were blowing, then the heat loss by convection is much higher.

Q_{conv} = 20 x 2.5 x (203 – 193) = **500 watts**

1.2 Heat loss by radiation.

All bodies which are warmer than their surroundings radiate heat. The heat loss by radiation (Q_{rad}) is given by the Stefan-Boltzmann law:

$$Q_{rad} = \sigma \epsilon A (T_S^4 - T_E^4) \quad [2]$$

Where

- σ is the Stefan-Boltzmann constant, 5.67 x10^{-8} W m^{-2} K^{-4}
- ϵ is the emissivity of the garment. At infrared wavelengths clothing is a good emitter. I will assume a value of 0.95.

and as before

- A is the garment's outer surface area, 2.5 m^2.
- T_S is the temperature of the garment's outer surface, 203 K (-70°C).
- T_E is the temperature of the environment, 193 K (-80°C).

Putting these numbers into equation [2] gives:

Q_{rad} = 5.67 x10^{-8} x 0.95 x 2.5 x (203^4 - 193^4) = **42 watts**

1.3 Heat loss by respiration.

The polar explorer breathes in air at 193 K (-80°C), at this temperature the vapour pressure of water is extremely low. Therefore, this inhaled air contains very little moisture. As it passes through the nasal passages and upper respiratory tract the air is warmed and moisture added. By the time it reaches the lungs it will be close to body temperature 310K (37°C). Exhaled air leaves the lungs at 310K, saturated with water vapour.

As it passes through the nasal passages, which are cooler than the lungs, the exhaled air cools slightly, and some water vapour condenses back into liquid water.

Assumption

I will assume the air exhaled from the explorer's nose into the Antarctic environment, is 100% saturated with water vapour and has a temperature of 300 K (27°C).

The human body loses heat by respiration in two ways.

- The cold air is warmed by the body and is exhaled at a much higher temperature.
- Energy (latent heat) is needed to convert liquid water from the linings of the lungs into water vapour. Some of this latent heat is released when condensation occurs as the air cools as it passes through the nasal passages.

1.3.1 Heat loss caused by warming air

If Q_{wma} *is* the rate of heat loss caused by warming the inhaled air and exhaling it at a higher temperature.

It is given by.

$$Q_{wma} \;=\; \dot{m}\,\mathrm{C}_p\;\Delta T \qquad\qquad [3]$$

Where

- $\dot{m}$ *is the* rate of mass transfer, i.e. the mass of air which is inhaled per second.
- C_p is the specific heat capacity of air at a constant pressure. This is the amount of energy it takes to raise the temperature of one kg of air by one degree. I will use a value of C_p =1004 J kg^{-1} K^{-1} . C_p varies with temperature, but this variation is small over the temperature range 193 K to 300 K
- ΔT is the temperature difference between inhaled and exhaled air. ΔT = (300 K – 193 K) = 107 K

Calculating the rate of mass transfer ($\dot{m}$)

Assumptions

- The average breathing rate for an adult is 6 litres per minute, which is equal to 0.0001 cubic metres per second.
- Density of air at -80°C is 1.83 kg m^{-3}

Using these assumptions gives us.

$\dot{m}$ = 0.0001 m^3 s^{-1} x 1.83 kg m^{-3} = 0.000183 kg s^{-1}

Putting these numbers into equation [3] give us:

Q_{wma} = 0.000183 x 1004 x 107 = **20 watts**

1.3.2 Heat needed to vaporise water

If Q_{evap} *is* the rate of heat loss caused by vaporising water,

then

$$Q_{evap} \;=\; \dot{m}\,L_V \qquad\qquad [4]$$

Where

$\dot{m}$ is the rate of evaporation of water in kg s^{-1}

L_v = 2.437 x10^6 J kg^{-1} is the specific latent heat of vaporisation of water at a temperature of 310 K. This is the energy needed to convert one kg of liquid water into water vapour.

Calculating the rate of evaporation of water ($\dot{m}$)

Calculating $\dot{m}$ *is a multistep process.* By using the **Ideal Gas Law** $(PV = nRT)$ and **Dalton's Law of Partial Pressures**, we determine how many moles of dry air inhaled per second, its new volume, and finally, the mass of water vapour that can occupy that new volume.

Step 1 calculate the number of moles of dry air n_{air}

We will use the following values.

- Volume of air inhaled per second (V_1) 1.0×10^{-4} m^3
- Initial Temperature (T_1) 193 K
- Initial Pressure (P_1)
  assume a standard pressure of 1 atm which is equal to 101 325 N m^{-2}
- Ideal Gas Constant (R): 8.314 J $mol^{-1}\ K^{-1}$

From the ideal gas law

$$n_{air} = \frac{P_1 V_1}{RT_1} \qquad [5]$$

Putting the values into equation [5] gives

n_{air} = 0.00631 moles

Step 2 determine the partial pressure of water vapour and air at 300 K.

Standard atmospheric pressure, in SI units, is 101 325 N m^{-2}. This is shared between the dry air and the added water vapour.

- **Saturation Vapour Pressure of Water (P_{water}):** At 27°C, the pressure exerted by water vapour is approximately 3566 N m^{-2}
- **Partial Pressure of Dry Air (P_{air}):** According to Dalton's Law of Partial Pressures, the remaining pressure belongs to the dry air:

$$P_{\text{air}} = P_{\text{total}} - P_{\text{water}} \quad [6]$$

Using the value for P_{total} of 101 325 N m^{-2} gives P_{air} = 97 759 N m^{-2}

Step 3 calculate the new volume of air (V_2)

Although some oxygen is converted to carbon dioxide, for each molecule of O_2 removed one molecule of CO_2 is added. Because the number of air molecules is unchanged, we can find the new volume (V_2) under the partial pressure P_{air} = 97 759 N m^{-2}.

Using the ideal gas law we get:

$$V_2 = \frac{n_{air} R T_2}{P_{air}} \qquad [7]$$

Putting the values into equation [7] gives

$V_2 = 1.611 \times 10^{-4}\ \mathrm{m}^3$

Step 4: Calculate the number of moles and finally the mass of water vapour.

Now that we know the final volume (V_2), we can find the number of moles of water vapor (n_{water}) that fill this space at its saturation vapour pressure, $3\ 566\ \mathrm{N\ m^{-2}}$. By once again using the ideal gas law we get

$$n_{water} = \frac{P_{water} V_2}{R T_2} \qquad [8]$$

Putting the values into equation [8] gives us:

$n_{water} = 2.302\mathrm{x}10^{-4}$ moles

1 mole of water weighs 0.0018 kg. Therefore, we have

$\dot{m}$, the rate of evaporation of water, is $4.15\mathrm{x}10^{-6}$ kg s^{-1}

Putting these numbers into equation [4] gives

$Q_{evap} = 4.15\mathrm{x}10^{-6} \times 2.437\mathrm{x}10^{6} =$ **10 watts**

Adding Q_{wma} and Q_{evap} together gives the total rate of heat loss due to respiration *(Q_{resp})* of **30 watts.**

1.3.3 Use of cold weather masks reduces to reduce heat loss

The human body has not evolved to breathe at temperatures as low as -80°C. Breathing air as cold as this will damage the upper respiratory tract and the sensitive tissues in the lining of the nose. If anyone attempted to breathe air at -80°C through their mouth it would cause frostbite to the lining of the mouth, the tongue and the throat.

Worst still, as the cold air hit the airways it would cause a ***cold shock***. The smooth muscles would go into spasm and tighten. It would feel like a severe asthma attack—the airways would constrict, making it difficult to draw another breath.

To prevent this happening, people who work in Antarctica during the winter use a cold-weather mask when they venture outdoors. The mask traps warmth and moisture in its material. When air is breathed in, it passes through warm, damp fabric, pre-heating and pre-humidifying it before it reaches the airways. By using a cold weather mask, the heat loss due to respiration is much smaller.

Assumption

I will assume the use of a cold weather mask reduces the rate of heat loss by respiration from the calculated value of **30 watts** down to **10 watts.**

1.4 Heat Loss by Conduction

The polar explorer's boots are in direct contact with the frozen ground. So, heat is lost by conduction from their feet through the soles of their boots. Of the four mechanisms of heat loss this is the smallest, provided the boots are thick and well insulated.

The heat loss by conduction (Q_{cond}) is given by.

$$Q_{cond} = K\, A_{boots} \frac{\Delta T}{t} \quad [9]$$

Where

- K is the thermal conductivity of the soles of the boots. For thick well-insulated boots worn by polar explorers. K is around 0.03 W m^{-1} K^{-1}
- A_{boots} is the area of the boots in contact with the ground. I will assume A_{boots} is 800 cm^2 (0.08 m^2)
- ΔT is the temperature difference between the soles of the feet and the ground. If we assume the temperature of the soles of the feet is 30°C (303 K) then ΔT = 110 K. *To get a more accurate estimate we should take into account that our polar explorer is wearing multiple layers of thick socks to insulate the feet and take ΔT to be the temperature difference between the outer sock layer and the ground, but we will ignore this in this simplified calculation.*
- t is the thickness of the soles of the boots. I will assume t = *0.04 m*

Putting these numbers into equation [9] gives the rate of heat loss by conduction (Q_{cond})

Q_{cond} = 0.03 x 0.08 x (110/0.04) = **7 watts**

1.5 Conclusion - Can our Polar Explorer stay warm?

The total rate of heat loss from a polar explorer (Q_{tot}) standing on the Antarctic ice at -80°C (Q_{tot}) is

$Q_{tot} = Q_{conv} + Q_{rad} + Q_{resp} + Q_{cond}$ *[10]*

Putting in the values we have calculated previously gives an estimated rate of heat loss of **159 watts.** An adult human generates about **100 watts** of heat when standing still which gives a heat deficit of **59 watts.** To keep warm, our polar explorer would shiver, raising their heat output to around **200 watts.**

If there was a breeze blowing, as discussed earlier, the rate of heat loss by convection jumps to **500 watts** and the total rate of heat loss increases to **559 watts.** So, if our explorer were standing still, they would have a heat deficit of **459 watts.** Their body temperature would fall, and they would be in danger of hypothermia. The body would switch to *survival mode* where short bursts of high intensity shivering could raise the heat output to around **500 watts.**

If our explorer was taking part in a vigorous activity, then the balance between heat lost and heat generated would be different. The volume of air inhaled would jump fivefold from around 6 litres per minute to 30 litres per minute. The heat lost by respiration (Q_{resp}) would also rise fivefold to 50 watts. Therefore, the total rate of heat loss (Q_{tot}) would be:

- **199 watts** if the air were still
- **599 watts** if a breeze were blowing

If we assume that the human body generates **500 watts** of heat when exercising vigorously, and our explorer is in still air without a breeze, there would be a **heat surplus of 301 watts** and in their well-insulated polar clothing they would be at risk of overheating in such an extremely cold environment!

1.6 Catastrophic heat loss if not wearing insulated clothing

If we re-run the calculation so that rather than wearing well-designed polar clothing, our explorer is foolishly wearing casual outdoor clothing, then the numbers look very different.

The clothing is what someone might wear when going for a walk in southern England in a January afternoon where a typical temperature is +8°C. It would provide a small degree of protection from the extreme cold, but it would not have the multiple layers of insulation to drastically reduce the flow of body heat escaping. As a result, the outer clothing surface would be far warmer.

If we assume the outer surface of the clothing is at a temperature of 0°C (273 K) and re-run our calculations, then we have the following.

Heat loss by convection

From equation [1]:

$$Q_{conv} = 4 \times 2.5 \times (273 - 193) = \mathbf{800\ watts}$$

If a breeze were blowing, then we have.

$$Q_{conv} = 20 \times 2.5 \times (273 - 193) = \mathbf{4000\ watts}$$

Heat loss by radiation

From equation [2]:

$$Q_{rad} = 5.67 \times 10^{-8} \times 0.95 \times 2.5 \times (273^4 - 193^4) = \mathbf{561\ Watts}$$

Heat loss by respiration

If we assume our foolish explorer is not wearing a cold weather mask, the rate of heat loss by respiration would be **30 watts.**

Heat loss by conduction

Rather than wearing specially designed polar boots, we will assume that our foolish explorer is wearing casual outdoor boots having rubber soles of thickness (t) 1 cm.

The thermal conductivity (K) of rubber is around 0.3 W m^{-1} K^{-1}

If we put these numbers into equation [9] we get

Q_{cond} = 0.3 x 0.08 x (110/0.01) = **264 watts**

The large amount of heat conducted through the thinner rubber soled boots would cause a massive rate of heat loss from our explorer's feet. It would be an extremely unpleasant experience and would lead to frostbite.

Total heat loss

From equation *[10]*

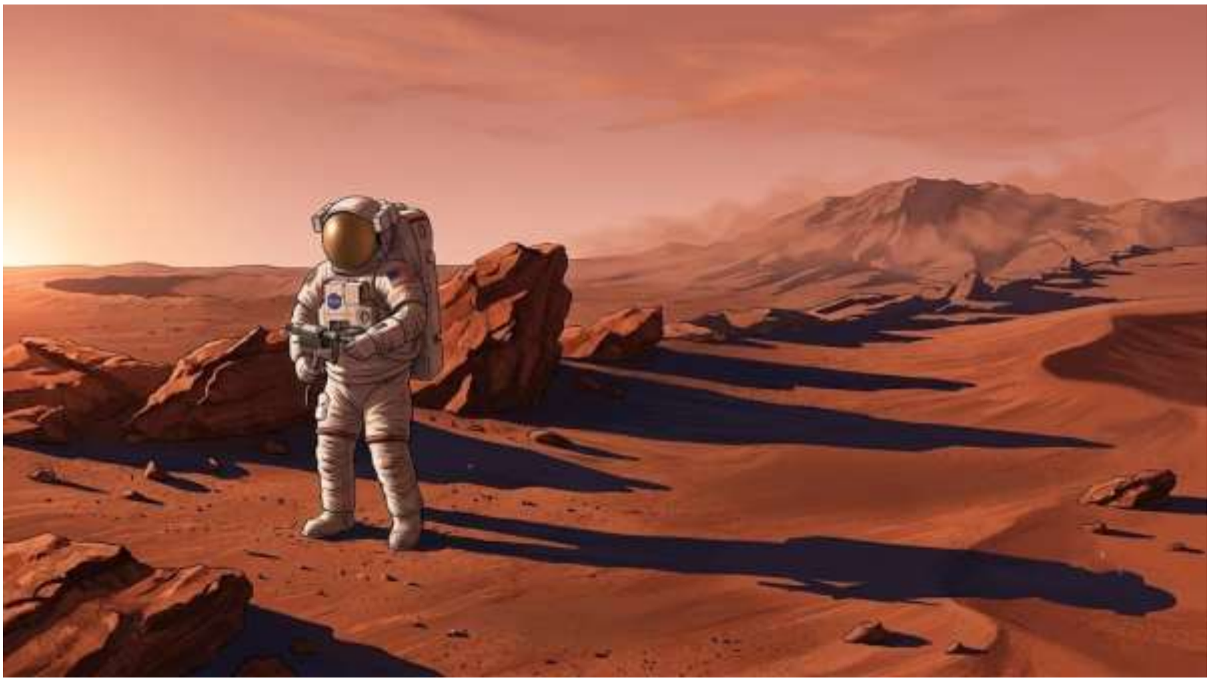
$$Q_{tot} = Q_{conv} + Q_{rad} + Q_{resp} + Q_{cond}$$

Putting in the values we have calculated previously gives an estimated rate of heat loss of **1655 watts** in still air and **4855 watts** if there were a breeze blowing**.** In either case there is a massive heat deficit, which the body could not make up by increasing its heat output by intense shivering or vigorous exercise.

The body temperature would rapidly fall and our foolish polar explorer without adequate protection would quickly succumb to death by hypothermia.

2 Heat loss from a human on Mars at -80°C

On Mars the much thinner atmosphere and the fact that there is no heat loss by respiration means it is easier to keep an astronaut warm in a very cold environment. The challenge, if anything, is keeping them cool.



Let's assume our Martian astronaut is wearing a well-designed, insulated spacesuit, which has multiple layers of thermal insulation to reduce heat loss. The insulation isn't quite as effective as the polar clothing worn by our Antarctic explorer and the temperature of the surface of the spacesuit from which heat is lost to the surroundings is -60 °C - twenty degrees warmer than the environment. If we look at the way the four mechanisms of heat loss work, the numbers are very different .

2.1 Heat loss by Convection.

If we assume again for simplicity that the spacesuit's outer surface can be approximated by a cylinder of surface area 2.5 m^2, then as before the heat loss by convection (Q_{conv}) is:

$$Q_{conv} = hA\,(T_S - T_E) \qquad [1]$$

Where

- h is the heat transfer coefficient. The thin Martian atmosphere means h is much smaller than it is on Earth. Measurements using data from the Phoenix lander [2] have estimated:
  - $h = 0.15$ if the Martian atmosphere is still
  - $h = 1$ if a 15 km/h breeze is blowing
- A is the surface area, 2.5 m^2.
- T_S is the temperature of the outer surface of the spacesuit, 213 K (-60°C).
- T_E is the temperature of the environment, 193 K (-80°C).

Putting these numbers into equation [1] gives:

Q_{conv} = **8 watts** for still air and Q_{conv} = **50 watts** if a 15 km/h breeze is blowing.

2.2 Heat loss by radiation

As before this is calculated by using

$$Q_{rad} = \sigma \epsilon A (T_S^4 - T_E^4) \quad [2]$$

Where

- σ = 5.67 x10^{-8} W m^{-2} K^{-4}
- ϵ =0.95
- A = 2.5 m^2.
- T_S = 213 K
- T_E = 193 K

This gives Q_{rad} = **90 watts.**

2.3 Heat loss by respiration.

It is very likely that the astronaut's spacesuit would be *a closed loop* system. The gases exhaled would have their carbon dioxide and water removed and be recycled to be breathed in again. There would be no venting of exhaled gases to the Martian atmosphere. In this case, the heat lost by respiration would be zero.

The spacesuits worn by the Apollo astronauts when they were walking on the surface of the Moon also had a closed loop system.

2.4 Heat loss by conduction.

Assuming the spacesuit boots had comparable properties to the polar explorer's boots the heat loss by convection would be unchanged at 7 watts.

2.5 Conclusions heat loss from an astronaut on Mars

2.5.1 Heat loss from the Martian surface at -80°C

The total heat loss from our Martian astronaut

$Q_{tot} = Q_{conv} + Q_{rad} + Q_{resp} + Q_{cond}$

Using the values we have calculated gives an estimated rate of heat loss of **105 watts.** If a breeze were blowing, this would rise to **147 watts.**

Astronauts on Mars would have a life support system in their spacesuits. This would consume around 50 watts of power - generating heat in the process. This heat needs to be added to the heat generated by the astronauts body. Therefore, the total rate of heat generation inside the astronaut's spacesuit would be:

- **150 watts** when standing still, which would approximately balance the rate of heat loss from the spacesuit.
- **550 watts** when exercising vigorously , which would provide a large heat surplus. To prevent the astronaut overheating, heat would need to be removed by a cooling mechanism built into their spacesuit.

So, the challenge when wearing a well-insulated spacesuit would be keeping cool. Confined inside their spacesuit the Martian astronauts would not be able to lose heat by sweating. There would need to be an adjustable cooling mechanism built in. Spacesuits worn by Apollo astronauts on the lunar surface and by astronauts on spacewalks have such a cooling system.

2.5.2 Heat loss from the Martian surface at -0°C

In the early afternoon, near the Martian equator, temperatures rise to around 0°C [1]. If we assume in this case the temperature of the outer surface of the spacesuit is just above the environment at 5°C (298K) and re-run the calculations, then we get the following.

Heat loss by convection

Putting these numbers into equation [1] gives:

$$Q_{conv} = 0.15 \times 2.5 \times (278 - 273) = \mathbf{1.9\ watts}$$

If a breeze were blowing, then we have the following.

$$Q_{conv} = 1 \times 2.5 \times (278 - 273) = \mathbf{12.5\ watts}$$

Heat loss by radiation

Putting these numbers into equation [2] gives:

$$Q_{rad} = 5.67 \times 10^{-8} \times 0.95 \times 2.5 \times (278^4 - 273^4) = \mathbf{56\ Watts}$$

Heat loss by respiration

As before, because the spacesuit is a closed loop system this would be zero.

Heat loss by conduction

From equation [9]

Q_{cond} = 0.03 x 0.08 x (30/0.04) = **1.8 watts**

Total Rate of Heat loss

If we add these four numbers together

$Q_{tot} = Q_{conv} + Q_{rad} + Q_{resp} + Q_{cond}$

It gives us a total rate of heat loss Q_{tot} from the astronaut's spacesuit of:

- **60 Watts** in a still atmosphere – giving an overall heat surplus of **90 watts** when the astronaut was standing still.
- If a breeze were blowing, this would rise to **76 watts** - giving an overall heat surplus **of 74 watts** when the astronaut was standing still.

In reality, the heat surplus would be larger than this. In addition to the heat generated by the astronaut's body and life support systems, there would be significant solar heating because the Sun would be at a high elevation in the Martian sky.

In both cases, still atmosphere and breeze, the astronaut would need to activate the cooling system in their spacesuit -even when standing still so their bodily heat generation is at a minimum and despite the outside temperature being zero degrees Celsius.

3 References

[1] Nasa.gov. (2013). *Steady Temperatures at Mars' Gale Crater - NASA Science*. [online] Available at: https://science.nasa.gov/resource/steady-temperatures-at-mars-gale-crater/. (Accessed 21 July 2026).

[2] Gendron, S., Wang, G., Jiang, X., Nikanpour, D., Davis, J.A., Lange, C.F. and Stéphane Lapensée (2010). Phoenix Mars Lander Mission: Thermal and CFD Modeling of the Meteorological Instrument based on Flight Data. Available at https://www.researchgate.net/publication/268574708_Phoenix_Mars_Lander_Mission_Thermal_and_CFD_Modeling_of_the_Meteorological_Instrument_based_on_Flight_Data

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