Heat loss and personal experience

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A question …

> Imagine you're in a bathroom that is air-conditioned to 25°C and about to take a shower. *What does Stefan's law tell us about how you feel and how does that match what you know from experience? To make estimates we need the emissivities of skin for radiation output to, and input from, the surroundings.*

Think of it this way. A furnace is heated to a bright orange glow at 1500 K. The door is opened for an instant and a brick is thrown in. When the brick has come to equilibrium at the *same temperature* as the walls of the furnace, everything inside is bright orange. Radiation input *to* the brick and output *from* the brick must now be the same because there are no further changes in temperature. Put simply: an object absorbs in the same way it emits, the emissivities are the same. A perfect black body absorber must be a perfect black body emitter.

Your net radiation output to the room is given by …

$$\Delta Q/\Delta t = \varepsilon\sigma A(T_1 - T_2)$$

…where ε is the emissivity of skin and σ is Stefan's constant. A is your effective surface area. T_1 is your skin temperature and T_2 is the temperature of the room.

Body area can be calculated. Mosteller's formula gives the area in square metres as ...

$$A = \sqrt{\frac{mh}{36}}$$

... where the mass m is in kg and the height h is in metres.

Your *effective* surface area for radiation is about 20% less because the body is not a sphere and surfaces facing each other or in contact do not radiate to the room. An average person has an effective radiation area of about 1.2 m^2. The emissivity of skin in the infrared as 0.98. Taking skin temperature as 35°C, a little lower than the core temperature (37°C).

$$\Delta Q/\Delta t = 1.2 \times 0.98 \times 5.67 \times 10^{-8}\,(308^4 - 298^4) = 74\text{ W}$$

Body heat is generated mostly in the liver, brain and heart and is about 120 Watts when sitting or standing still. Heat loss by convection cannot be easily calculated but can be measured and is found to be proportional also to $A(T_1 - T_2)$. Heat loss per second due to convection in this situation is similar to heat loss by radiation. If the body is dry, heat loss by evaporation will be smaller and can be neglected.

The estimates above show that in this situation we would expect heat loss per second to be a little higher than internal heat generation. If you were wet the rate of heat loss would be higher because of evaporation and you would feel cold sooner. If the room was at 23°C heat loss due to radiation would be ~90 W and you would also feel cold sooner.

Questions

1 Repeat the calculation for a bathroom temperature of 23°C. Can you confirm the estimates above from personal experience?

2 Imagine that you are dressed in a T-shirt and long pants. You are dry. Assume that heat loss due to radiation and convection are approximately the same.

a You are sitting in class. Estimate from your personal experience the temperature of the room that matches your heat loss per second with your heat generation (120 W).

b Use your answer to make a rough estimate of the percentage reduction in heat loss due to your clothing.

3 The average male when sleeping has a heat output of 75 W. When sitting in conversation or using a computer this rises to 100-120 W.

When doing mechanical work the body is about 25% efficient. Pedaling a generator or climbing stairs with a steady work output of 100 W raises waste heat production to 300 W. Fit athletes can exceed these limits by a factor of three or four for short periods of time.

The most demanding sustained power output of any sporting activity is manpowered flight in a one man pedal driven aircraft that requires 240 W of useful work for as long as the flight takes. It has been done but huge super-light aircraft are expensive and delicate, and once is enough for most “engines”.

a Imagine you are on exchange in a cold country and find yourself shivering in a classroom at a temperature of 12°C. In what ways could you attempt to become more comfortable?

Briefly explain the physics involved in each suggestion.

b Imagine you have a friend who has fallen into water at 4°C. Help is on the way but they must try to survive for five minutes before they can be pulled out.

Give advice … what should they do, and not do, and why?