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Proposal for Universal Heat Exposure Unit

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# Overview

## Background

### Temperature, as a measure of heat exposure, is limited in many aspects. Firstly, it is a cross-sectional representation of ‘heat’ at a specific time-point, and so does not consider what we have been exposed to previously, and what we are going to be exposed to in the future. Secondly, it does not consider factors that modify the lived experience of heat, such as environmental factors like wind speed and humidity, or personal factors such as our body habitus, endogenous heat production and the clothes we wear.

### Multiple heat indices exist to quantify the exposure to cross-sectional temperature as experienced by individuals. These include the Wet Globe Bulb Temperaturehttps([[1]](https://www.weather.gov/car/WBGT#:~:text=Wet%20Bulb%20Globe%20Temperature%20(WBGT,cloud%20cover%20(solar%20radiation).)), Apparent Temperature[[2]](https://graphical.weather.gov/definitions/defineApparentT.html), and Universal Thermal Climate Index[[3]](http://www.utci.org/), among others[[4]](https://pubmed.ncbi.nlm.nih.gov/29290376/). These indices still only represent a cross-sectional temperature/heat exposure snapshot. One index was planned to be developed for use in dairy cattle to quantify the total heat exposure for a given period([[5]](https://portal.nifa.usda.gov/web/crisprojectpages/0230823-a-cumulative-temperature-heat-index-to-predict-the-effect-of-heat-stress-on-milk-yield-in-dairy-cattle.html)), to optimise milk production, however, this does not seem to have widespread uptake. One similar approach in humans was developed specifically for exercise-related heat *strain* [[6]](https://pubmed.ncbi.nlm.nih.gov/11482547/)). This approach does not look only at heat exposure but rather at heat strain and requires physiological inputs such as heart rate. It also lacks widespread utility and uptake.

## Aims:

### Develop a Universal Heat Exposure Unit to accurately quantify the degree of heat exposure over a given period, with a modifying factor allowing for different sensitivities to heat exposure.

### Allow for broad utility in quantifying heat exposure for observational and interventional studies, as well as for use in a personalised early warning system.

# Working Prototype

## Modelling daily temperature:

### where:

### T(t) represents the temperature(°C) at time t(hours)

### is the heat sensitivity factor, including sex, age, BMI, clothing, occupation, pregnancy status, etc. Otherwise, reverts to the average of 1 if not available.

### is the amplitude of the temperature variation.

### f is the frequency, which determines the length of the temperature cycle (24 hours in this case)

### φ is the phase shift, which determines the starting point of the temperature cycle. i.e. at 0, it equates to the temperature being T mean at midnight. Allows modelling heat exposure at a specific time(e.g from the three hours after Tmax, etc.)

### Tmean is the average temperature for a given day.

### All temperature variables could be substituted with existing heat indices, including humidity/wind speed etc.

## Modelling Cumulative Heat Exposure

### Option 1: Sum Area Under the Curve

#### Easily performed in python, takes inputs as above or actual hourly temperature data, and returns heat exposure units for a given day.

### Option 2: Indefinite Integral

### represents the cumulative heat exposure over time t(hours) in Heat Exposure Units(HEU) where 1 HEU = 1°C for 1 hour in units °C•hour

### is the heat sensitivity factor, to include sex, age, BMI, clothing, occupation, pregnancy status, etc. Otherwise, reverts to average of 1 if not available.

### is the amplitude of the temperature variation.

### f is the frequency, which determines the length of the temperature cycle (1 cycle/per 24 hours in this case)

### φ is the phase shift, which determines the starting point of the temperature cycle. i.e. at 0 it equates to the temperature being T mean at midnight. Allows for modelling heat exposure at a specific time(e.g from the three hours after Tmax, etc.)

### Tmean is the average temperature for a given day.

### All temperature variables could be substituted with existing heat indices, including humidity/wind speed etc.

### represents the constant of integration

#### Allows for modelling of predicted heat exposure.

# Use Cases

## Allows for more accurate quantification of cumulative long-term and short-term heat exposure in observational studies examining the effects of heat exposure on various short-term and long-term outcomes.

## Allows for the development of personalised heat early warning systems to predict heat exposure for any given time period in any given person adjusted for personal factors. Thresholds would likely vary over time, but would ideally be the same for all individuals, with the heat exposure equation adjusting for differences in individual sensitivity. This allows for easy and effective public health communication regarding heat waves, and increasing heat exposure.

## Broad application across disciplines with uses in occupational settings(e.g. miners, farm workers), public health research(observational and intervention studies), and agricultural fields(e.g. dairy cattle).

# Figures

## Current Temperature Metrics Used, (Heat Indices are just variations on these values)

## Area Under The Curve Visualisation

## Standard UTCI Static Exposure Thresholds

### Static Thresholds

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### Animated with typical temperature variation over two day period

## Logarithmic UTCI-based Cumulative Heat Exposure Thresholds

### Static Cumulative Heat Exposure Thresholds

### Animation of Cumulative Heat Exposure Thresholds over two days

### Dynamic Animation of Cumulative Heat Exposure Thresholds over previous t hours over two days