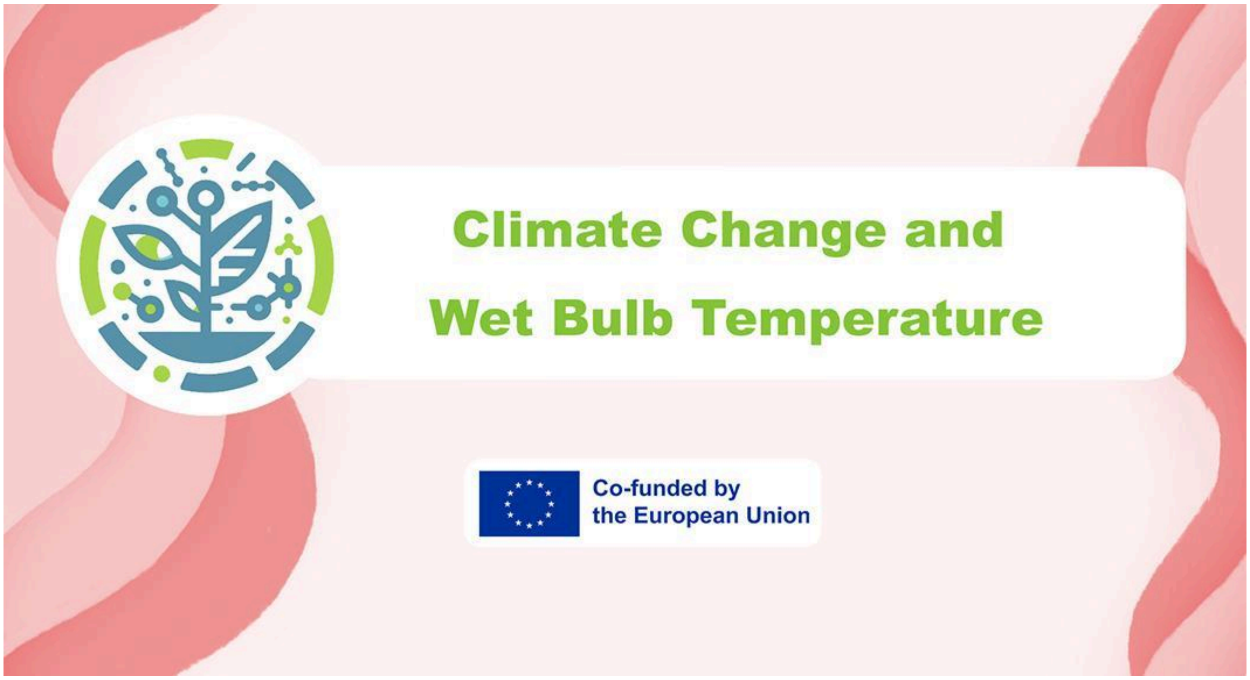

STEAM4Climate Worksheet

for students

Project: Climate Change and Wet Bulb Temperature

Creator: Thomas Joerg (Kepler-Gymnasium Pforzheim)

Contributors & Reviewers: Rene Alimisi Chrisanthi Papasarantou (Edumotiva-European Lab for Educational Technology), Dariusz Aksamit (University Warsaw)

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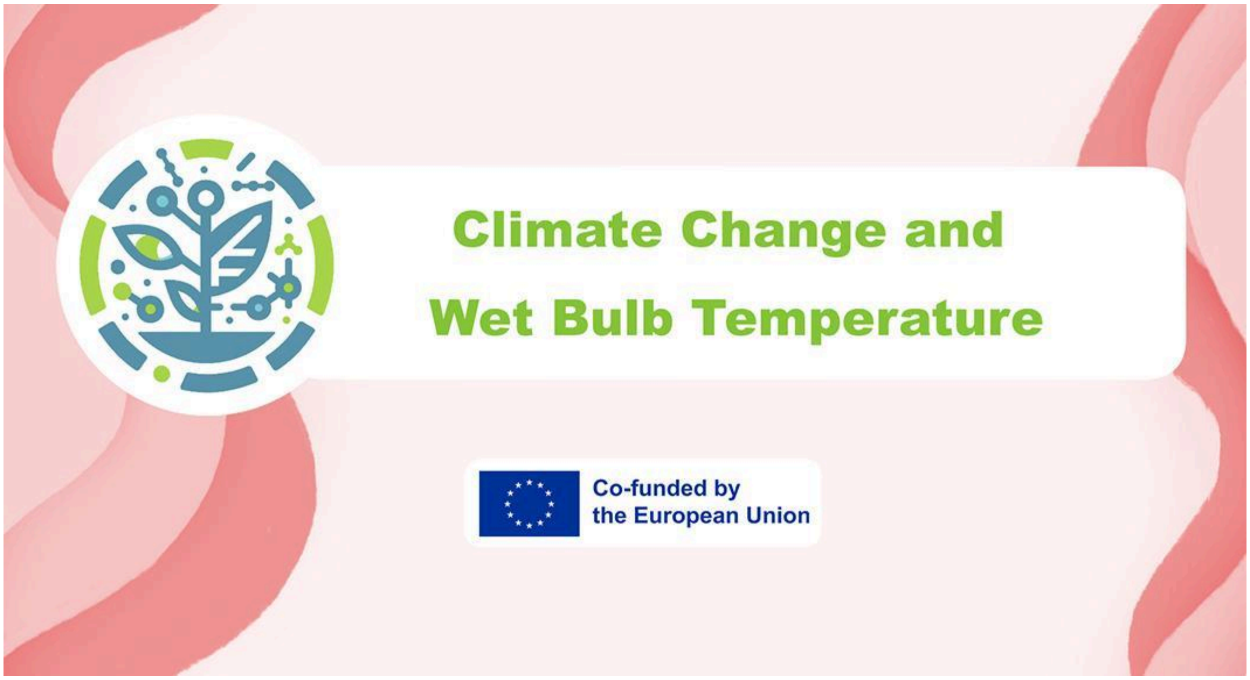

EU Project Consortium

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About This Booklet

Welcome to the STEAM4Climate Student Activity Worksheet on Climate Change and Wet Bulb Temperature, an educational resource designed to complement the STEAM4Climate Teacher's Guide Booklet one. Developed as part of the Erasmus+ STEAM4Climate project, the booklet introduces the concept of wet bulb temperature, its effect on the human body, and its relevance in our warming climate. Students will conduct hands-on experiments to explore how heat and humidity impact thermoregulation. To explore the full collection of student worksheets and related teacher guides, visit 🔗Steam4climate Website

It is designed to guide you through hands-on activities and experiments that explore the impacts of extreme heat and humidity. It includes step-by-step instructions, discussion prompts, and real-world case studies to help deepen your understanding of climate-related challenges.

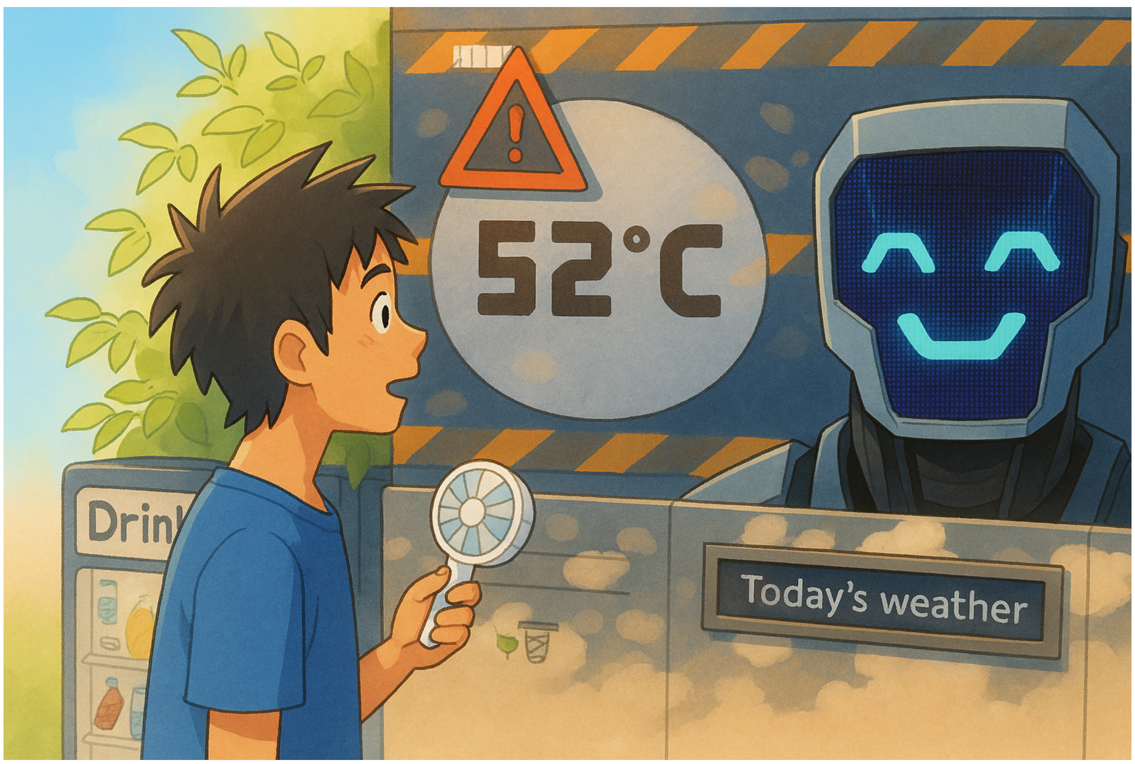
- Work through the activities in order to build on key concepts.
- Record your observations and reflections in a notepad.
- Engage in group discussions to explore solutions and share ideas.
- Use additional exploration prompts to expand your learning beyond the classroom.

By actively participating in these activities, you will develop problem-solving skills, scientific thinking, and an awareness of how climate change affects human health and the environment. Get ready to experiment, explore, and innovate!

🌡️ The Wet Bulb Temperature and Climate Change

This theme integrates physics and biology to explore the impact of the Wet Bulb Temperature effect on the human body's thermoregulation abilities. This is particularly relevant in the context of rising global temperatures and humidity, which can overwhelm the body's ability to cool itself through sweating.

Implementation Scenario



In the future, our earth will no longer look like it does now. The changes will probably mean that we will have to find our way around a 'new planet'.

To this end, students like you are getting together for a scientific project to understand these new environmental conditions and make them measurable. This is the only way to develop strategies for survival in this increasingly hostile reality.

When looking at current research results, one recognizes environmental conditions such as high ambient temperatures combined with high humidity levels. These environmental circumstances are constantly intensifying.

The task of this teaching unit is to first understand the effects of these changes, to measure them and, based on this, to develop strategies for dealing with them in the future.

Approaching the wet bulb temperature through experiments.

General Utensils: Pipettes, thermometers, isopropanol (or alternatives like ethanol or Benzinum medicinale), paper towels, small fans, cotton wool, Erlenmeyer flasks, and pierced stoppers.

Experiment 1: Evaporative cooling

- **Learning objective:** Understand evaporative cooling as a physical phenomenon and as a biological cooling strategy.

- **Utensils:** pipette, isopropanol (or ethanol, Benzinum medicinale).

- **Procedure:** A few drops of isopropanol are dripped onto the back of the hand, with the pipette.

- **Expected Result:** A strong cooling effect can be observed. (Often this attempt leads to astonishment among the students).

Playful Extension: Coolest hand

Divide the students into groups or pairs.
Each group will be given pipettes and small containers with different liquids such as water, ethanol, labeled clearly. The challenge will be to find out which liquid evaporates the fastest and has the strongest cooling effect.
Students will then rank the liquids from coolest to least cool.

Experiment 2: Evaporative Cooling Quantitative

Learning objective:
To record and measure evaporative cooling as a quantitatively detectable physical phenomenon.

Utensils:
pipette, paper towel, two thermometers, fixtures for the thermometers, isopropanol (possibly ethanol, petroleum medicinale, small fan).

Procedure:

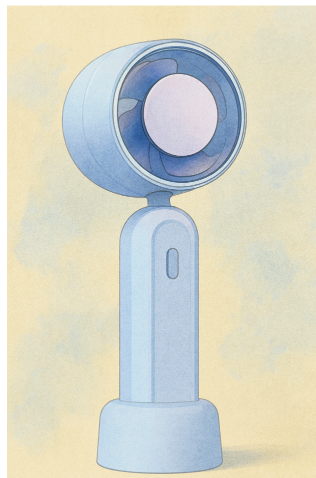
- Hang two thermometers up visibly as shown in the picture.
- Tie a paper towel around one of the two thermometers and secure it with wire to prevent it from slipping.

Then put a few drops of isopropanol on the cloth and observe the temperature differences and note the differences.

Thermal camera and cooling effect on skin:
https://www.youtube.com/watch?v=QJ44jUFsi2g

Expected result:

After about 2-3 minutes you can read: the cooling effect of the evaporative cooling of isopropanol is about 10°C temperature difference. A fan cools down faster, but not to a lower temperature.



Roll with wire and isopropanol
fan

Small USB-powered handheld

Playful Extension: Race to the coolest

Divide the students into small teams. Each team gets two thermometers, one paper towel, pipettes, and different liquids. One thermometer will be left "dry" as a control, while the second thermometer will be wrapped with a paper towel and secured with wire or an elastic band to prevent slipping. Assign each group a different liquid for their experiment (e.g., one group uses isopropanol, another group uses ethanol or water, and so on).

Steps:

Each group can use a pipette to apply a few drops of their assigned liquid to the paper towel wrapped around one thermometer. The other thermometer remains dry.

Start the stopwatch and record the initial temperature on both thermometers (dry and wet).

Monitor the temperatures for 5–10 minutes, noting how the wet thermometer temperature drops compared to the dry thermometer.

For the second round, turn on the small fan to blow air on the wet thermometer and repeat the measurements. Observe how the airflow affects the cooling rate.

Each team will track how much the temperature drops on their "wet" thermometer (with the paper towel) compared to the dry one.

Teams will also measure the difference in cooling with and without the fan. They'll record their results and share them with the class.

Gather the class and ask the teams to present their findings. Which liquid led to the biggest cooling effect? Did the fan make a difference, and how did it change the cooling rate? Why did some liquids cool better than others?

Experiment 3: Qualitative Wet Bulb Temperature

Learning objective:
The lowest possible cooling temperature also depends on whether the evaporating substance is already in the air. The more saturated the air with the cooling substance, the lower the cooling effect.

Tools and materials needed:
pipette, paper towel, two thermometers, attachment for a thermometer, Erlenmeyer flask, cotton wool, pierced stopper.

Procedure:

- Wrap both thermometers with a paper towel, as in experiment 2.

- Hang one of the two thermometers up as in experiment 2.

- Place the other thermometer in a prepared Erlenmeyer flask: The Erlenmeyer flask should contain cotton wool, which is dripped with the cooling substance. As a result, the air in the piston is saturated with the evaporative cooling substance.

- Read the Wet Bulb Temperature for both thermometers.

Result:

After about 2-3 minutes, it should be observed that the Wet Bulb Temperature has set again on the free thermometer. In the Erlenmeyer flask, on the other hand, there is virtually no cooling. In addition, the coolant does not evaporate; the cloth on the thermometer remains moist.

Conclusion:

The more cooling substances are already in the air, the worse it is for further substance to evaporate from the cloth. As a result, the cloth stays moist for longer. And where no substance can evaporate, there can be no cooling effect.

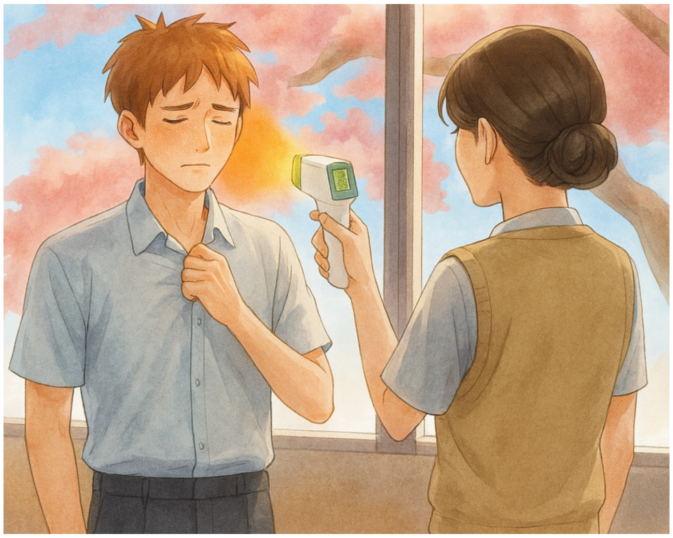
Application to human sweating,

This means that the higher the saturation of the air with humidity, the worse the cooling effect of sweating.

Playful Extension: More means more?

Different groups can work with different amounts of coolant in the Erlenmeyer flask. The results are then compared.

Experiment 4: body temperature at rest and during sports



Learning objective:
The human body dissipates the heat from metabolism and muscle work through the skin.

Materials needed:
Infrared thermometer or thermometer for the ear, possibly water sprayer

Procedure:

- Form groups of at least two students.
- One student in each group volunteers to have their temperature measured.
- Measure the student's temperature while they are sitting at rest (e.g., on the forehead).
  - Note: If using an infrared thermometer with a laser, switch off or tape over the laser for safety.
- Have the student engage in physical activity for 1–2 minutes, such as jumping rope, doing push-ups, or running up and down stairs.
- Immediately measure the student's temperature again after the activity is completed.

Expected Result:
At rest, the body surface temperature is in the low range, after physical activity it is significantly higher.

The body emits the waste heat via its body surface. In this way, a heat flow is created from the body into the environment (order of 50-100 watts, depending on the stress state of the body). In order to improve or accelerate the heat dissipation, the body begins to sweat

Experiment 5: What are you actually measuring with an infrared thermometer

In this experiment we will measure how much water vapor is contained in the entire vertical column of the atmosphere above us.

Water vapor is an important greenhouse gas and plays a key role in weather, cloud formation, and the Earth's energy balance.

Instead of using relative humidity, which only tells us about air moisture near the ground, we will estimate total atmospheric water vapor by measuring the temperature of the sky with an infrared pyrometer. When the air is moist, the instrument detects warmer radiation from lower layers of the atmosphere; when the air is dry, it sees colder radiation from higher altitudes. By taking several measurements toward the zenith on a clear day and calculating their average, we can later determine the total amount of water vapor using an online tool that processes our data.

- Make sure the sky near the zenith is completely cloud-free.
- Measure the air temperature using a regular outdoor thermometer.
- Point the pyrometer straight up at the zenith.
- Hold the measurement button for 5 seconds and estimate the average displayed temperature.

https://www.igf.fuw.edu.pl/~kmark/PolandAOD/PDF/ParaWodna.pdf

(Thanks to Darek Aksamit for the inspiration to this subject)

Introduction to the Wet Bulb Temperature of humans

Worksheet Body Temperature 1/3: Introductory Text

A person constantly generates heat through metabolic processes. The higher its activity, the more waste heat is generated. This waste heat must be emitted, otherwise the person will overheat and be damaged.

For heat to be transported away from the inside of the body, the surface temperature of the person must be lower than his core temperature. The core temperature is around 37°C.

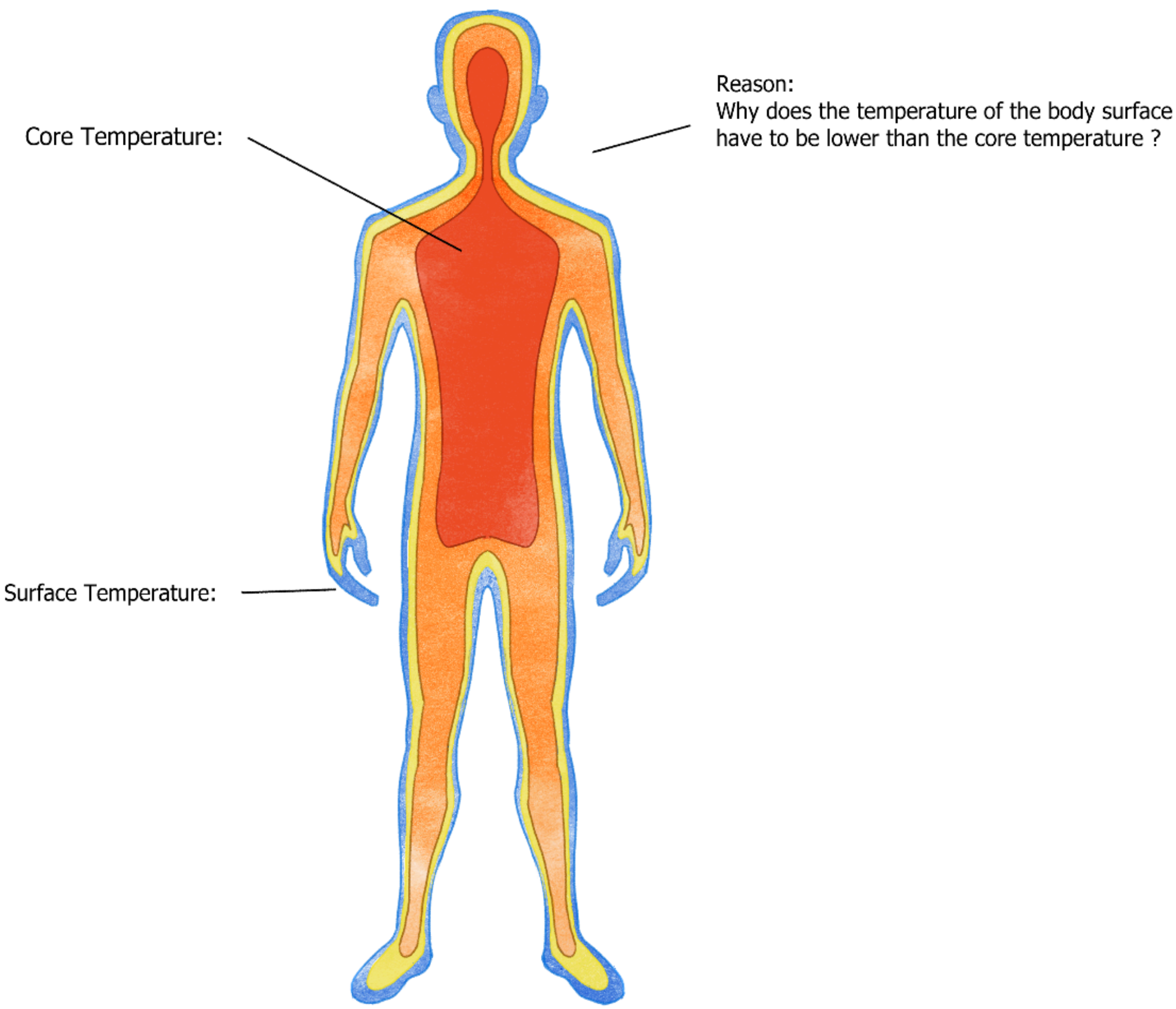
A person resting in the shade can tolerate a surface temperature of 35°C for a short time, then it becomes dangerous for humans. This maximum permissible surface temperature is lower, but researchers are not yet quite sure about that. A person who moves can tolerate a Wet Bulb Temperature of 31°C – i.e. someone who walks or works while sitting.

These guidelines apply to young, healthy people. Small children, elderly or people with pre-existing conditions can only tolerate lower Wet Bulb Temperatures. And they apply to people who drink enough fluids and wear appropriate clothing. If you drink too little, the body cannot dissipate enough heat through sweating.

Worksheet Body Temperature 2/3: Fill in the blanks

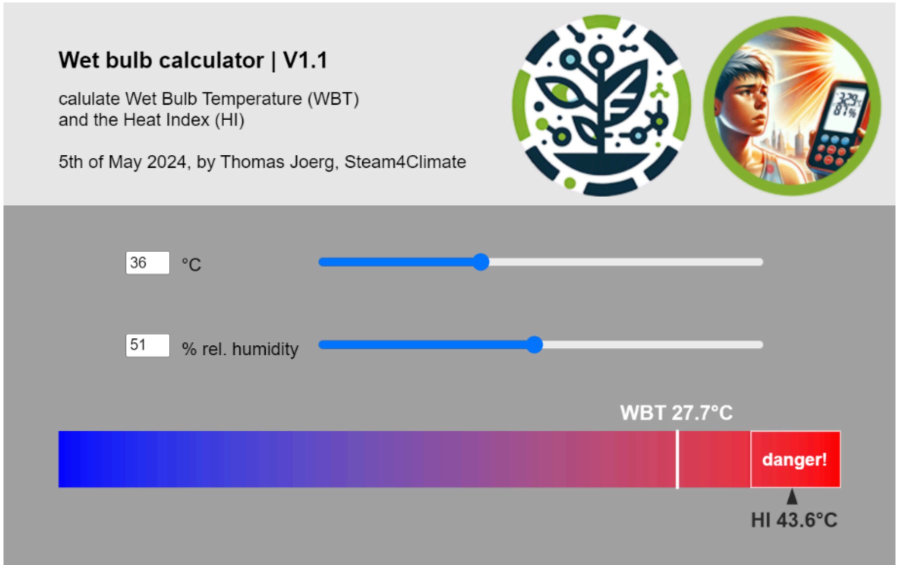
Summarize the introductory text and fill in the correct temperatures to the picture.

Describe and explain the values.



Worksheet Wet Bulb Temperature 3/3: Use the simulation

https://iludis.de/wetBulbTemp/index.html



Answer the following questions

How hot does it get in your summer? (In Germany, for example, it can get up to 42°C in summer, that's the record)	
At what relative humidity does it become dangerous? (or when does it become dangerous at the 42°C in Germany?)	
If it's 40°C outside, what is the maximum humidity you need to be able to go for a walk?	
Briefly explain the reasons why.	
In the jungles of Venezuela, the humidity is 65% at 1 p.m. at noon. At what temperature should you stop moving?	
Why are jungle regions generally much more at risk than desert regions in terms of Wet Bulb Temperatures?	

Table of Wet Bulb Temperatures for different humidity values.

On the following page you find a tables of values to determine the wet bulb temperature given local temperature and relative humidities.

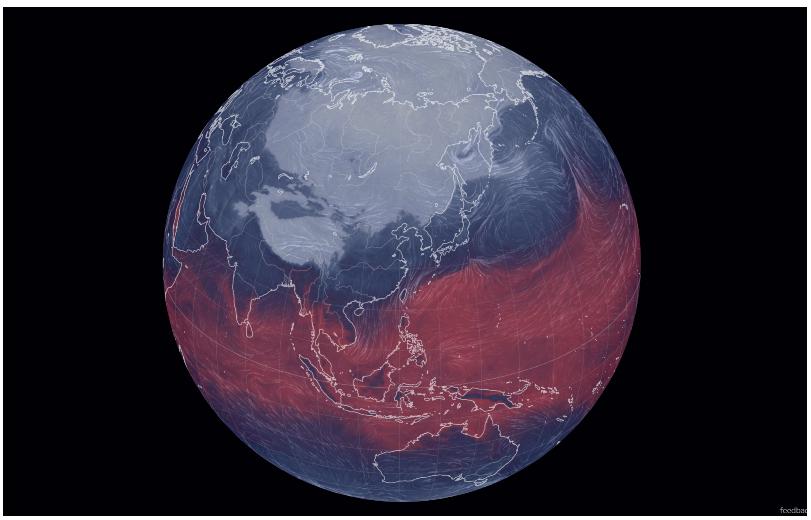
Example of how to read/use the table:

- If there is an air temperature of 40°C with a relative humidity of 50%, then evaporative cooling can be used to cool down to 30.9°C, but nothing more

- If there is an air temperature of 34°C with a relative humidity of 80%, then evaporative cooling can be used to cool down to 31.0°C, but not more.

Additional Excercise : Wet bulb temperature on our planet earth

https://earth.nullschool.net/#current/wind/surface/level/overlay=wet_bulb_temp/



	Relative humidity									
		10%	20%	30%	40%	50%	60%	70%	80%	90%
T (°C)	***0***	-4,6	-4,5	-4,3	-3,9	-3,5	-3,0	-2,4	-1,7	-0,9
	2	-3,5	-3,2	-2,8	-2,3	-1,8	-1,2	-0,5	0,2	1,0
	4	-2,3	-1,8	-1,3	-0,7	-0,1	0,6	1,4	2,2	3,0
	6	-1,1	-0,4	0,2	0,9	1,7	2,4	3,2	4,1	5,0
	8	0,0	0,9	1,8	2,6	3,4	4,2	5,1	6,0	6,9
	10	1,2	2,3	3,3	4,2	5,1	6,0	7,0	7,9	8,9
	12	2,3	3,6	4,8	5,8	6,8	7,8	8,8	9,8	10,9
	14	3,5	5,0	6,3	7,4	8,5	9,6	10,7	11,8	12,9
	16	4,6	6,4	7,8	9,1	10,3	11,4	12,6	13,7	14,8
	18	5,8	7,7	9,3	10,7	12,0	13,2	14,4	15,6	16,8
	20	7,0	9,1	10,8	12,3	13,7	15,0	16,3	17,5	18,8
	22	8,1	10,5	12,3	13,9	15,4	16,8	18,1	19,4	20,7
	24	9,3	11,8	13,8	15,6	17,1	18,6	20,0	21,4	22,7
	26	10,4	13,2	15,3	17,2	18,9	20,4	21,9	23,3	24,7
	28	11,6	14,5	16,9	18,8	20,6	22,2	23,7	25,2	26,6
	30	12,7	15,9	18,4	20,4	22,3	24,0	25,6	27,1	28,6
	32	13,9	17,3	19,9	22,1	24,0	25,8	27,5	29,0	30,6
	34	15,0	18,6	21,4	23,7	25,7	27,6	29,3	31,0	32,6
	36	16,2	20,0	22,9	25,3	27,5	29,4	31,2	32,9	34,5
	38	17,4	21,3	24,4	27,0	29,2	31,2	33,0	34,8	36,5
	40	18,5	22,7	25,9	28,6	30,9	33,0	34,9	36,7	38,5
	42	19,7	24,1	27,4	30,2	32,6	34,8	36,8	38,7	40,4
	44	20,8	25,4	28,9	31,8	34,3	36,6	38,6	40,6	42,4
	46	22,0	26,8	30,4	33,5	36,1	38,4	40,5	42,5	44,4
	48	23,1	28,1	32,0	35,1	37,8	40,2	42,4	44,4	46,3
	50	24,3	29,5	33,5	36,7	39,5	42,0	44,2	46,3	48,3
	52	25,4	30,9	35,0	38,3	41,2	43,8	46,1	48,3	50,3
	54	26,6	32,2	36,5	40,0	42,9	45,6	48,0	50,2	52,3
	56	27,7	33,6	38,0	41,6	44,6	47,4	49,8	52,1	54,2
	58	28,9	34,9	39,5	43,2	46,4	49,2	51,7	54,0	56,2
	60	30,0	36,3	41,0	44,8	48,1	51,0	53,5	55,9	58,2

Meeting the challenge: Dealing with wet bulb temperature

How can you protect yourself and your community from weather-related overheating?

- **Construct a weather station for the classroom:** Environmental conditions are to be recorded in real time and a warning is to be issued in the event of critical conditions.

Think about ways to prepare and protect the community by adapting and organizing for rising temperatures.

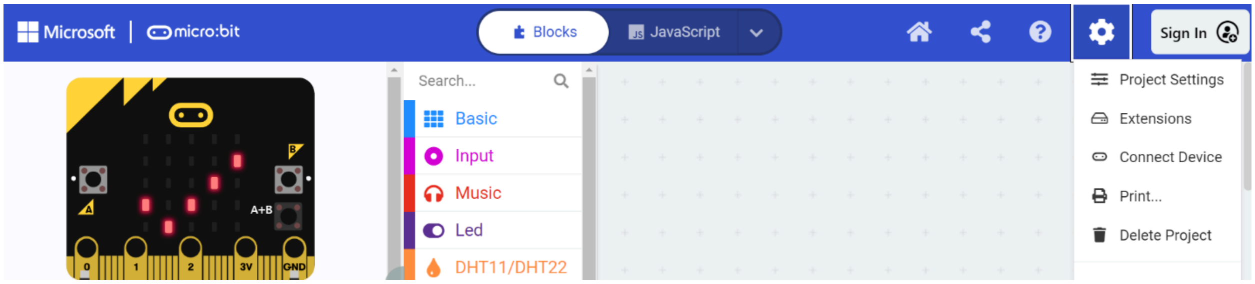
Variant 1 Microbit: DHT22 and Kitronik OLED

Learning objective:
Students should develop a warning device that measures wet bulb temperature constantly in the classroom.

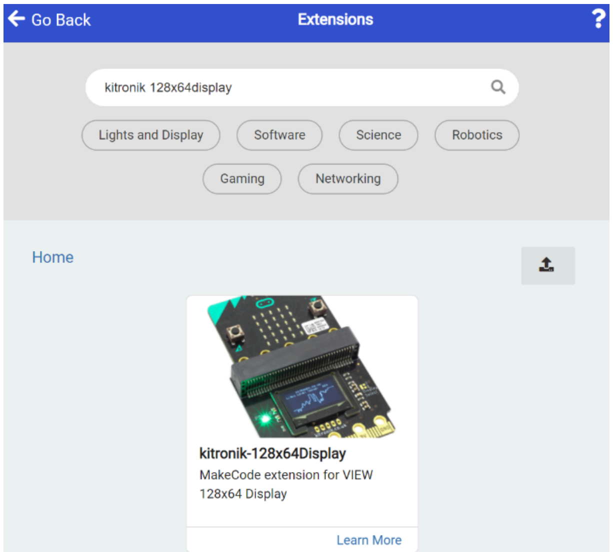
Utensils:
1. BBC Microbit.
2. Kitronik OLED Display for Microbit.
3. DHT22 Temperature and humidity sensor.
4. A computer with browser and internet connection.

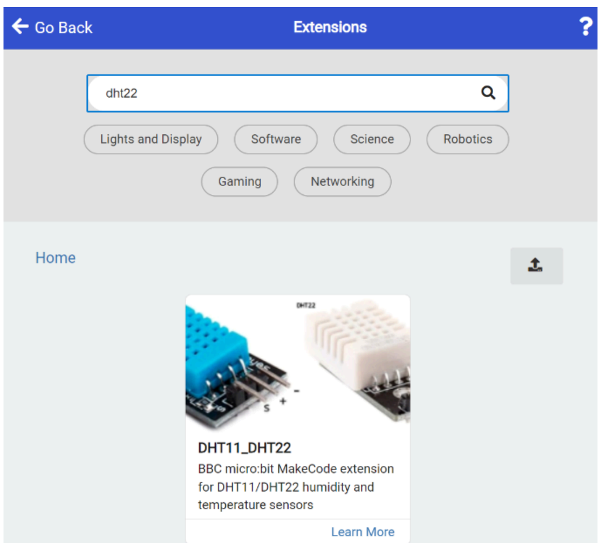
Necessary Extensions for Microbit:

To use the display and the sensor, you have to add the necessary software libraries as ready-made extensions already extensions:



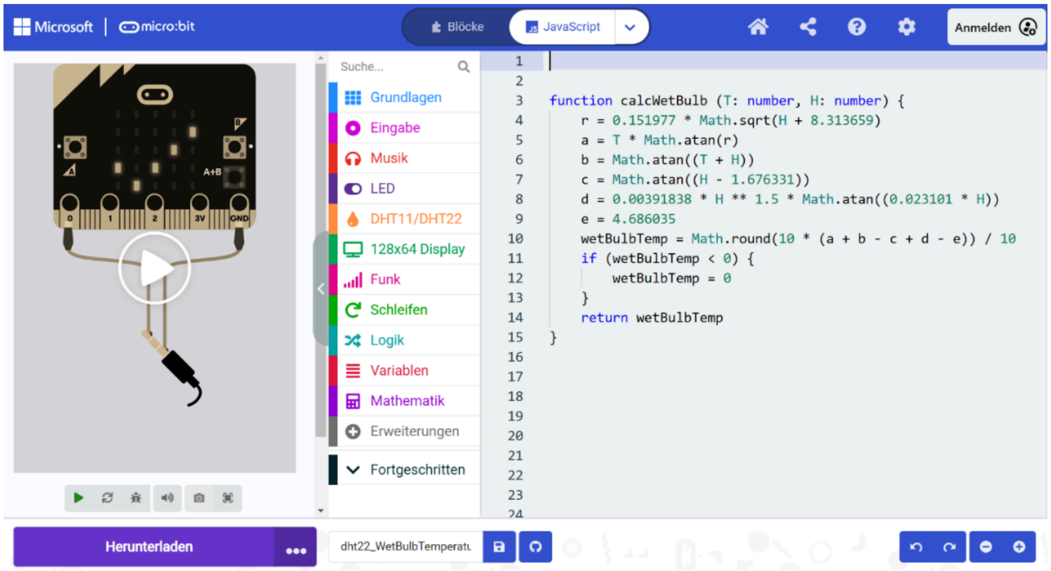
These two extensions have to be added:





Javascript Source code for calculating wet bulb temp.

Here a simple JavaScript function is provided, which can be copied and pasted into the JavaScript area of MakeCode:

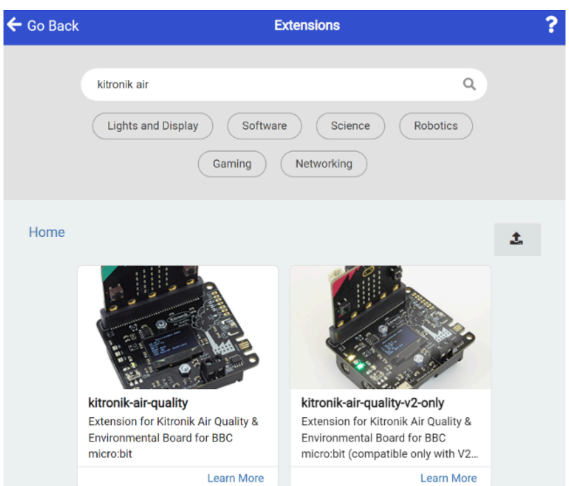



```
function calcWetBulb (T: number, H: number) {
    r = 0.151977 * Math.sqrt(H + 8.313659)
    a = T * Math.atan(r)
    b = Math.atan((T + H))
    c = Math.atan((H - 1.676331))
    d = 0.00391838 * H ** 1.5 * Math.atan((0.023101 * H))
    e = 4.686035
    wetBulbTemp = Math.round(10 * (a + b - c + d - e)) / 10
    if (wetBulbTemp < 0) {
        wetBulbTemp = 0
    }
    return wetBulbTemp
}
```

Alternative to Microbit: Kitronik Air quality board

Utensils:
1. BBC Microbit:
2. Kitronik Air quality board:
3. A computer with browser and internet connection

Necessary Extension for Microbit Makecode:



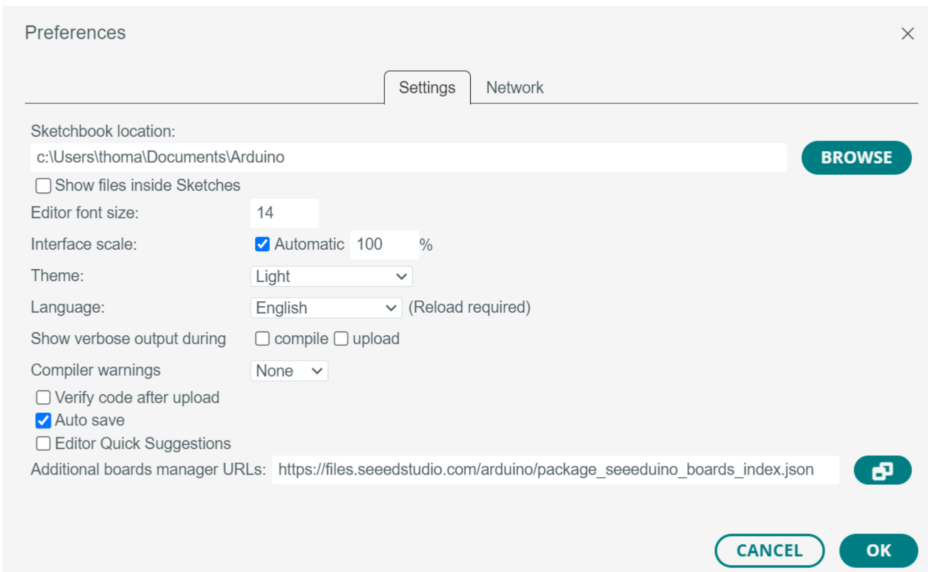
Variant 2 (Arduino): Seeed Grove WIO Terminal and SHT31

Utensils:
1. Seeed Grove WIO Terminal.
2. Seeed Grove SHT31.
3. A computer with browser and internet connection

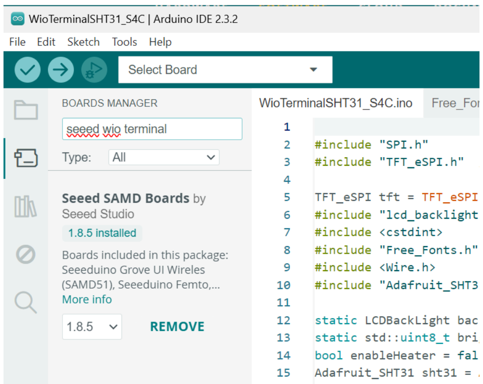
Installing Software, Boards and Libraries:
1. Download and install Arduino Software:
https://www.arduino.cc/en/software

2. In File > Preferences add "Additional boards manager URLs:"

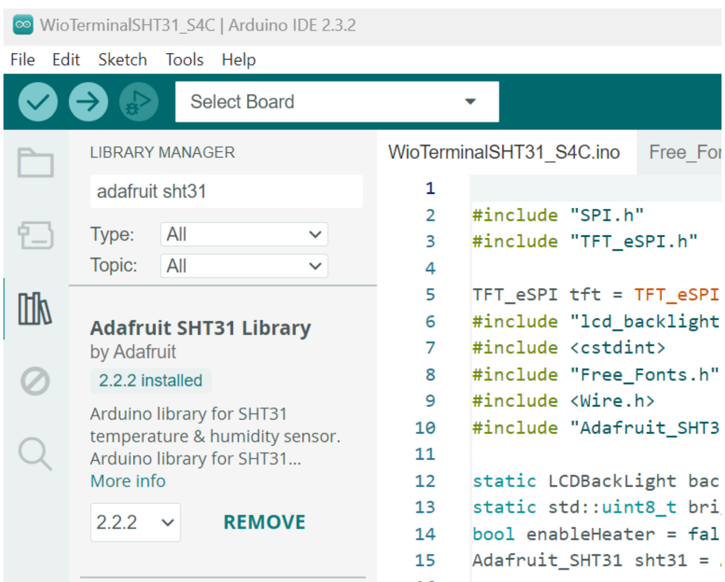
https://files.seeedstudio.com/arduino/package_seeeduino_boards_index.json



3. In the Board Manager menu add “***Seeed wio terminal***” as “***Seeed SAMD Boards***”



4. In the Library Manager menu add “***Adafruit sht31***” and install with all dependencies:



5. Inside your WIO terminal project folder add the following downloadable files:

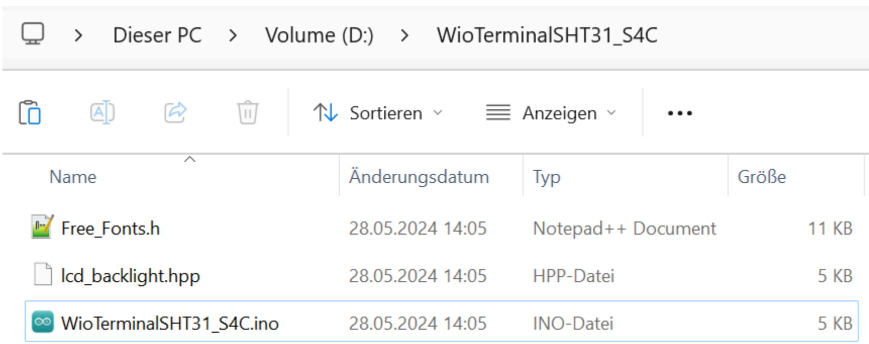
5a: LCD Backlight control:
https://github.com/ciniml/WioTerminal_BackLight/blob/master/lcd_backlight.hpp

5b: A Free Font library for the TFT-Display of the WIO-Terminal
https://github.com/Bodmer/TFT_eSPI/blob/master/examples/320%20x%20240/Free_Font_Demo/Free_Fonts.h

The European Commission's support to produce this publication does not constitute an endorsement of the contents, which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

6. It should look like this (in this example, the project is called

“***WioTerminalSHT31_S4C***”:



Example implementation: complete Arduino-C source Code:

```
//////////////////////////PART 1: Includes ////////////////////////
#include "SPI.h"
#include "TFT_eSPI.h"  // Hardware-specific library
TFT_eSPI tft = TFT_eSPI();  // Invoke custom library
#include "lcd_backlight.hpp"
#include <cstdint>
#include "Free_Fonts.h"
#include <Wire.h>
#include "Adafruit_SHT31.h"
static LCDBackLight backLight;
bool enableHeater = false;
Adafruit_SHT31 sht31 = Adafruit_SHT31();

//////////////////////////PART 2: SETUP ///////////////////
void setup() {
  Serial.begin(115200);
  tft.begin();
  tft.setRotation(3);
  tft.fillScreen(tft.color565(0, 0, 0));
  backLight.initialize();
  std::uint8_t maxBrightness = backLight.getMaxBrightness();
  backLight.setBrightness(maxBrightness);
  Wire.begin();
  if (!sht31.begin(0x44)) {   // Set to 0x45 for alternate i2c addr
    Serial.println("Couldn't find SHT31");
    while (1) delay(1);
  }
  Serial.print("Heater Enabled State: ");
  if (sht31.isHeaterEnabled())
    Serial.println("ENABLED");
```

```
  else
    Serial.println("DISABLED");
}

//////////////////////////PART 3: Mainloop /////////////////
void loop() {
  float t = sht31.readTemperature();
  float h = sht31.readHumidity();
  float wetBulb = calculateWetBulb(t, h);
  float heatInd = calculateHeatIndex(t, h);
  int offsety = 10;
  int offsetx = 130;
  int initx = 10;
  tft.fillRect(initx + offsetx, 13 + offsety, 160, 30, tft.color565(0, 0, 90));
  tft.fillRect(initx + offsetx, 53 + offsety, 160, 30, tft.color565(0, 0, 90));
  tft.fillRect(initx + offsetx, 93 + offsety, 160, 30, tft.color565(90, 0, 0));
  tft.fillRect(initx + offsetx, 133 + offsety, 160, 30, tft.color565(90, 0,
0));
  tft.setTextColor(TFT_WHITE);
  tft.setFreeFont(FF17);
  tft.drawString("Temperature: ", initx + 10, 20 + offsety);
  tft.drawString(String(t) + "  'C", initx + 10 + offsetx + 20, 20 + offsety);
  tft.drawString("Rel. Humidity: ", initx + 10, 60 + offsety);
  tft.drawString(String(h) + " %", initx + 10 + offsetx + 20, 60 + offsety);
  tft.drawString("Wet Bulb T.: ", initx + 10, 100 + offsety);
  tft.drawString(String(wetBulb) + "  'C", initx + 10 + 20 + offsetx, 100 +
offsety);
  tft.drawString("Heat Index: ", initx + 10, 140 + offsety);
  tft.drawString(String(heatInd) + "  'C", initx + 10 + 20 + offsetx, 140 +
offsety);
  for (int i = 0; i < 255; i++) {
    tft.drawLine(30 + i, 185, 30 + i, 220, tft.color565(i, 0, 255 - i));
  }
  int wetbulboffset = int(wetBulb * 7.3);
  tft.drawRect(30 + 226, 185, 29, 35, tft.color565(250, 140, 140));
  tft.drawLine(30 + wetbulboffset, 185, 30 + wetbulboffset, 220,
tft.color565(255, 255, 255));
  tft.setTextColor(tft.color565(240, 140, 140));
  tft.setFreeFont(FF19);
  tft.drawString("!", 265, 188);
  delay(50);
}

///////////////PART 4: Functions for calculating wet bulb and heat index
//////////
float calculateWetBulb(float Temp, float Hum) {
  float T = Temp;
  float H = Hum;
  float radicand = 0.151977 * sqrt(H + 8.313659);
  float term1 = T * atan(radicand);
  float term2 = atan(T + H);
  float term3 = atan(H - 1.676331);
  float term4 = 0.00391838 * pow(H, 1.5) * atan(0.023101 * H);
  float term5 = 4.686035;
```

```
  float wetBulbTemp = round(10 * (term1 + term2 - term3 + term4 - term5)) /
10.0;
  if (wetBulbTemp < 0) {
    wetBulbTemp = 0;
  }
  return wetBulbTemp;
}

float calculateHeatIndex(float Temp, float Hum) {
  float T = Temp;
  float H = Hum;
  float hitzeindex = 0;
  if (T >= 27) {
    hitzeindex = -8.78469 + 1.611394 * T + 2.338548 * H - 0.146116 * T * H -
0.0123081 * T * T - 0.0164248 * H * H + 0.002211732 * T * T * H + 0.0007256 * T
* H * H - 0.000003582 * T * T * H * H;
    hitzeindex = round(10 * hitzeindex) / 10.0;
  }
  return hitzeindex;
}
```

Social science approach: What do we learn from scenarios like this:

- More than 1300 people died during the haji in mecca due to heat stress (temperatures more than 50°C):

https://edition.cnn.com/2024/06/24/asia/indonesia-hajj-heatwave-burial-intl-hnk/index.html

- At least 40.000 cases of heat stroke during heat wave in india:

https://edition.cnn.com/2024/06/21/india/india-delhi-nighttime-heatwave-climate-intl-hnk/index.html

- Many died in heat wave in Athens during summer 2024:

https://edition.cnn.com/2024/06/12/climate/greece-shuts-acropolis-heat-climate-intl/index.html

How to prevent these scenarios and how to protect and prepare our community?

Discuss the topic in the classroom and develop possible solutions. in the best case, combine this with a direct possibility of implementation. Some examples for relevant questions could be:

1. *How can you protect your own classmates in the event of extremely high wet bulb temperatures? What rules of conduct should apply?*

2. *Is it necessary to adapt the school building - for example with water dispensers, warning signs, designated cooling zones and possibly prepared rooms?*

3. *If there are enough rooms available: should these rooms perhaps be opened to people who are not part of the school, such as passers-by etc.?*

Should help be offered to neighboring kindergartens or retirement homes, for example?