



## Mission Space Lab Phase 4 Report

Team Name: Juno

Chosen theme: Life in Space

Organisation name: Institut d'Altafulla

Country: Spain

## Introduction

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When we began researching for an experiment idea we came across a picture of astronaut [Chris Hadfield on ISS playing guitar in shorts](#) which led us to wonder how hot it really feels on ISS (heat index).

It turns out apparent temperature is an important factor in demanding environments like on board ISS because it can decrease motor skills and mental performance thus making completing tasks and avoiding errors more difficult.

Our goal is to find out heat index from on-board temperature, pressure and humidity by means of psychrometric calculations.

For a known [humidity level on ISS of around 60%](#) we expect the heat index (HI) to be lower than [28°C](#) (actual temperature being  $\leq 27^{\circ}\text{C}$  or  $\leq 80^{\circ}\text{F}$ ) since higher values could pose a threat to crew safety and efficiency (Fig-4).

## Method

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Our code recorded CPU temperature and sensor-hat readings for temperature, humidity and pressure about every 10 seconds into a csv file. Meanwhile the LED matrix showed different patterns as feedback.

Due to CPU temperature, the sense-hat performs inaccurately (Fig-1) when attached just on top of RaspberryPi so back on Earth we needed to work out a way to tell how far apart AstroPi readings were from the actual values. We therefore took measurements with the [setup](#) shown in Fig-2 while the CPU was being stressed with the benchmark tool [sysbench](#) the usage of which can be seen in this [video](#).

In order to get reliable readings to compare sense-hat data with, we've tested a DHT22 sensor against a type K thermocouple (Fig-2) and data from the local weather station ([WS-Torredembarra](#)). From the data series gathered we concluded that the DHT22 sensor performs broadly within specifications (Fig-2).

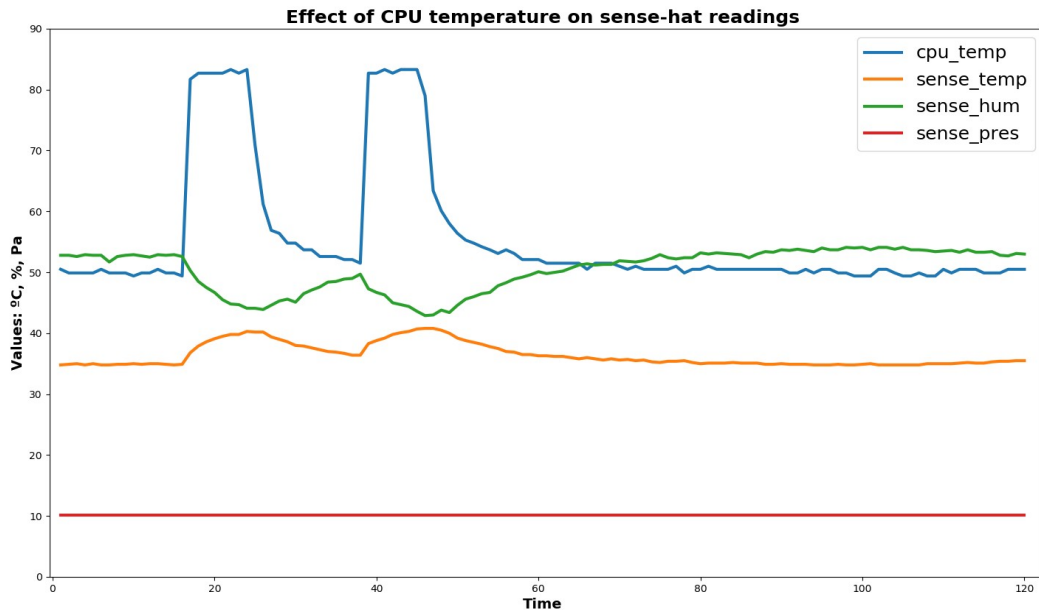
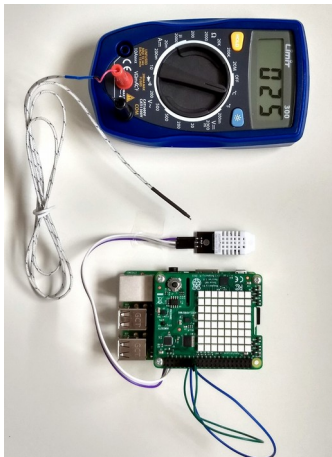


Fig-1: Stress testing CPU ([sysbench](#) tool) shows the influence of CPU temperature on sense-hat readings



Date	CEST	DHT22_Temp	DHT22_Hum	WS_Temp	WS_Hum
07/06/2021	09:00	20.0	87.1	19,4	76,0
07/06/2021	10:00	21.2	77.0	20,6	72,0
07/06/2021	11:00	21.8	72.7	21,6	62,0
07/06/2021	12:00	23.4	59.1	23,2	59,0
07/06/2021	13:00	23.1	60.3	23,8	58,0
07/06/2021	14:00	23.4	61.7	23,6	58,0
07/06/2021	15:00	23.9	66.2	24,4	58,0
07/06/2021	16:00	24.8	61.7	24,6	58,0
07/06/2021	18:00	23.7	79.4	23,3	74,0

Fig-2: [DHT22 calibration setup](#) on the RaspberryPi 3B from AstroPi kit and data from DHT22 and WS

Measuring simultaneously, sense-hat gets slightly below 8 degrees over and 15 points under DHT22 corresponding values for temperature and humidity (Fig-3).

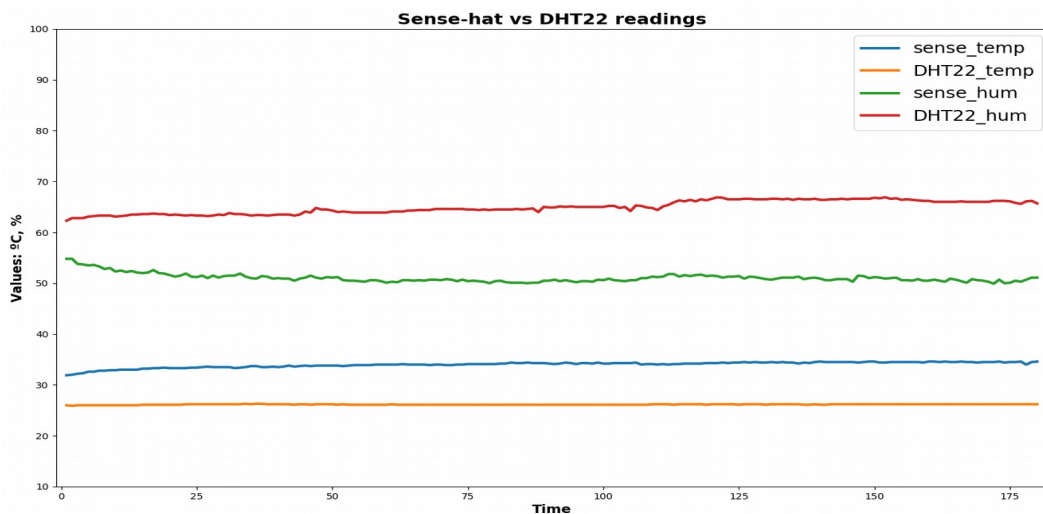


Fig-3: Sense-hat and DHT22 readings differ notably

Since AstroPis are model B+, whereas those in the kits are model 3B, subtracting or adding the aforementioned differences doesn't make much sense. Instead the CPU effect could be taken into account to calculate [correction factors](#) for both magnitudes. This is what the factor calculations look like

$$DHT\ 22\_temp = senseHat\_temp - \frac{(CPU\_temp - senseHat\_temp)}{temp\_factor} \rightarrow \text{which follows as}$$

$$\rightarrow temp\_factor = \frac{(CPU\_temp - senseHat\_temp)}{(senseHat\_Temp - DHT\ 22\_Temp)}$$

$$DHT\ 22\_hum = senseHat\_hum - \frac{(CPU\_temp - senseHat\_hum)}{hum\_factor} \rightarrow \text{which follows as}$$

$$\rightarrow hum\_factor = \frac{(CPU\_temp - senseHat\_hum)}{(senseHat\_hum - DHT\ 22\_hum)}$$

Finally, the factored T and H values are fed into a HI formula. For the sake of simplicity we've chosen the Australian [APPARENT TEMPERATURE](#) over [NOAA's HEAT INDEX](#) and [CANADIAN HUMIDEX](#).

$$AT = T_a + 0,33 \cdot \rho - 0,70 \cdot ws - 4,00$$

$$\rho = \frac{rh}{100} \cdot 6,105 \cdot e^{\frac{(17,27 \cdot T_a)}{(237,7 + T_a)}}$$

**AT** is the Apparent Temperature in °C

- **T<sub>a</sub>** is the Dry bulb Temperature in °C

- **ρ** is the water vapor pressure (hPa)

- **ws** is the wind speed (m/s)

- **rh** is the Relative Humidity (%)

## Results

From [AstroPi data](#) we've got [average CPU temperature, sense-hat temperature and humidity values](#) of

av. cpu\_temp: 34,94°C (!!!)<sup>1</sup>

av. sense\_temp: 30,65°C (!!!)

av. sense\_hum: 32,81°C (!!!)

From our testing series we've got [average temperature and humidity factors values](#)

av. temp\_factor: 1,92

av. hum\_factor: 0,22

We use this data to find factored temperature and humidity

$$Factored\_temp = sense\_temp - \frac{(cpu\_temp - sense\_temp)}{temp\_factor} = 30,65 - \frac{(34,94 - 30,65)}{1,92} = 28,41\ ^\circ\text{C}$$

$$Factored\_hum = sense\_hum - \frac{(cpu\_temp - sense\_hum)}{hum\_factor} = 32,81 - \frac{(34,94 - 32,81)}{0,22} = 23,15\ \%$$

1 Oddly enough, the CPU and sense-hat data we've got this year differ much from those of last year's edition. For instance, 2020 averages were 30,4°C, 26,26°C and 42,28% for CPU temperature, sense-hat temperature and sense-hat humidity, respectively.

Finally, from the factored values we find out apparent temperature either using the formulas or looking up the table (Fig-5). As for air speed we assumed a minimum of 0,5 m/s (forced air circulation).

$$\rho = \frac{23,15}{100} \cdot 6,105 \cdot e^{\frac{(17,27 \cdot 28,41)}{(237,7 + 28,41)}} = 8,9$$

$$AT = 28,41 + 0,33 \cdot 8,9 - 0,70 \cdot 0,5 - 4,00 = 26,99 \text{ }^{\circ}\text{C}$$

NOAA national weather service: heat index

Temperature Relative humidity	80 °F (27 °C)	82 °F (28 °C)	84 °F (29 °C)	86 °F (30 °C)	88 °F (31 °C)	90 °F (32 °C)	92 °F (33 °C)	94 °F (34 °C)	96 °F (36 °C)
40%	80 °F (27 °C)	81 °F (28 °C)	83 °F (29 °C)	85 °F (30 °C)	88 °F (31 °C)	91 °F (33 °C)	94 °F (34 °C)	97 °F (36 °C)	101 °F (38 °C)
45%	80 °F (27 °C)	82 °F (28 °C)	84 °F (29 °C)	87 °F (31 °C)	89 °F (32 °C)	93 °F (34 °C)	96 °F (36 °C)	100 °F (38 °C)	104 °F (40 °C)
50%	81 °F (27 °C)	83 °F (28 °C)	85 °F (29 °C)	88 °F (31 °C)	91 °F (33 °C)	95 °F (35 °C)	99 °F (37 °C)	103 °F (39 °C)	108 °F (42 °C)
55%	81 °F (27 °C)	84 °F (29 °C)	86 °F (30 °C)	89 °F (32 °C)	93 °F (34 °C)	97 °F (36 °C)	101 °F (38 °C)	106 °F (41 °C)	112 °F (44 °C)
60%	82 °F (28 °C)	84 °F (29 °C)	88 °F (31 °C)	91 °F (33 °C)	95 °F (35 °C)	100 °F (38 °C)	105 °F (41 °C)	110 °F (43 °C)	116 °F (47 °C)
65%	82 °F (28 °C)	85 °F (29 °C)	89 °F (32 °C)	93 °F (34 °C)	98 °F (37 °C)	103 °F (39 °C)	108 °F (42 °C)	114 °F (46 °C)	121 °F (49 °C)
70%	83 °F (28 °C)	86 °F (30 °C)	90 °F (32 °C)	95 °F (35 °C)	100 °F (38 °C)	105 °F (41 °C)	112 °F (44 °C)	119 °F (48 °C)	126 °F (52 °C)
75%	84 °F (29 °C)	88 °F (31 °C)	92 °F (33 °C)	97 °F (36 °C)	103 °F (39 °C)	109 °F (43 °C)	116 °F (47 °C)	124 °F (51 °C)	132 °F (56 °C)
80%	84 °F (29 °C)	89 °F (32 °C)	94 °F (35 °C)	100 °F (38 °C)	106 °F (41 °C)	113 °F (45 °C)	121 °F (49 °C)	129 °F (54 °C)	
85%	85 °F (29 °C)	90 °F (32 °C)	96 °F (36 °C)	102 °F (39 °C)	110 °F (43 °C)	117 °F (47 °C)	126 °F (52 °C)	135 °F (57 °C)	
90%	86 °F (30 °C)	91 °F (33 °C)	98 °F (37 °C)	105 °F (41 °C)	113 °F (45 °C)	122 °F (50 °C)	131 °F (55 °C)		
95%	86 °F (30 °C)	93 °F (34 °C)	100 °F (38 °C)	108 °F (42 °C)	117 °F (47 °C)	127 °F (53 °C)			
100%	87 °F (31 °C)	95 °F (35 °C)	103 °F (39 °C)	112 °F (44 °C)	121 °F (49 °C)	132 °F (56 °C)			

Key to colors:   Caution   Extreme caution   Danger   Extreme danger

Fig-4: Maximum value expected according to NOAA Heat Index and usual HR values

Apparent temperature (AT) from temperature and relative humidity - after Steadman 1994

Relative Humidity (%)	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
0	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
5	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
10	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
15	17	18	19	20	21	22	24	25	26	27	28	29	30	31	33	34	35	36	37
20	17	18	20	21	22	23	24	25	26	28	29	30	31	32	33	35	36	37	38
25	18	19	20	21	22	24	25	26	27	28	29	31	32	33	34	36	37	38	40
30	18	19	21	22	23	24	25	26	28	29	30	31	33	34	35	37	38	39	41
35	19	20	21	22	23	25	26	27	28	30	31	32	34	35	36	38	39	40	42
40	19	20	21	23	24	25	26	28	29	30	32	33	34	36	37	39	40	41	43
45	19	21	22	23	24	26	27	28	30	31	32	34	35	37	38	40	41	43	44
50	20	21	22	24	25	26	28	29	30	32	33	35	36	38	39	41	42	44	45
55	20	22	23	24	25	27	28	30	31	32	34	35	37	38	40	42	43	45	46
60	21	22	23	25	26	27	29	30	32	33	35	36	38	39	41	42	44	46	48
65	21	22	24	25	27	28	29	31	32	34	35	37	39	40	42	43	45	47	49
70	21	23	24	26	27	28	30	31	33	35	36	38	39	41	43	44	46	48	50
75	22	23	25	26	28	29	31	32	34	35	37	38	40	42	44	45	47	49	
80	22	24	25	27	28	30	31	33	34	36	38	39	41	43	45	46	48	50	
85	23	24	26	27	29	30	32	33	35	37	38	40	42	44	45	47	49		
90	23	25	26	28	29	31	32	34	36	37	39	41	43	45	46	48	50		
95	23	25	26	28	30	31	33	35	36	38	40	42	43	45	47	49			
100	24	25	27	29	30	32	33	35	37	39	41	42	44	46	48	50			

Fig-5: Calculated apparent temperature

## Conclusion

The results match our initial hypothesis in that apparent temperature is below 28°C (Fig-5) albeit not by that much. Despite this fact, we can't be quite confident about the accuracy of the final number because we don't know the flight case dissipation capabilities or the effect of space-hardening treatment on the sense-hat sensors and because we run the tests on a Raspberry Pi 3B from the Astro Pi kit whereas actual AstroPis are model B+.

On the other hand, the data from current experiment differ noticeably from those of last year's edition. So much so that after having double checked data we searched for clues in the [daily logs](#) as to what may have happened onboard ISS but, unfortunately, we couldn't find any.

Nevertheless, we've learnt a lot and now feel encouraged to do more extensive testing on sense-hat performance.

Finally, we would like to thank ESA and RaspberryPi for giving us such an amazing opportunity.

And also special thanks to Josep Palau for mentoring us through this challenge.

Project data and code can be found at:

<https://github.com/jpalau-edu/AstroPi2021/tree/main/Juno>