Mission Space Lab Phase 4 Report

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Chosen theme: Life in Space

Organisation name: Institut d'Altafulla

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Introduction

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 28ºC (actual temperature being ≤27ºC or ≤80F) since higher values could pose a threat to crew safety and efficiency (Fig-4, p. 4).

Method

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).

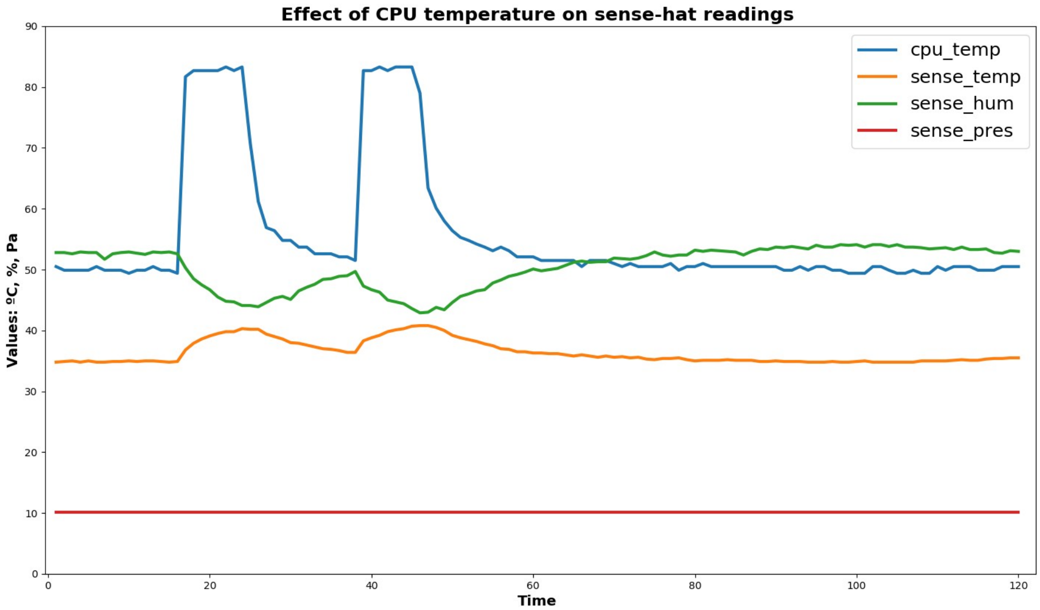
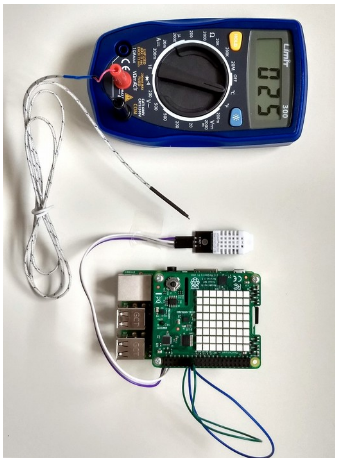


Fig-1: Stress testing CPU (*sysbench* tool) shows the influence of CPU temperature on sense-hat readings



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).

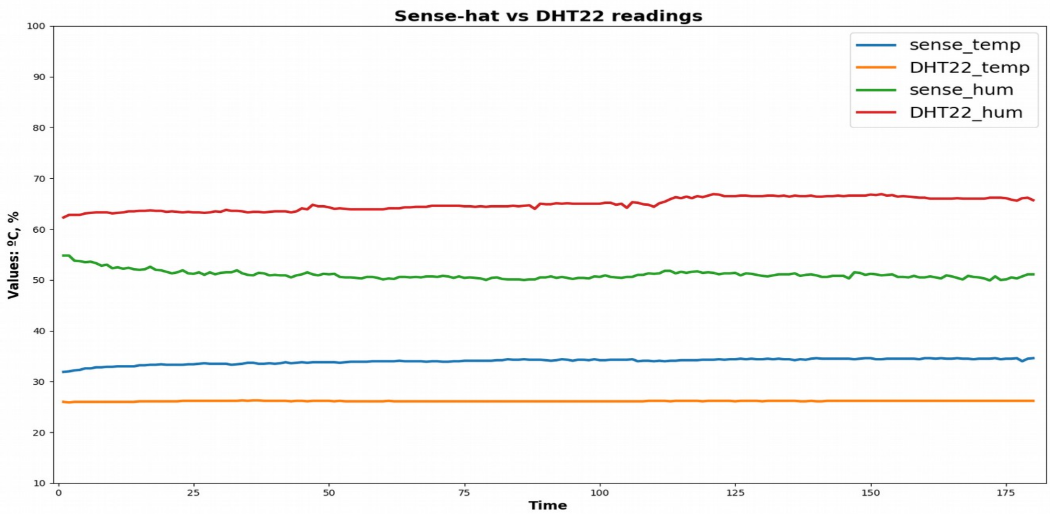


Fig-3: Sense-hat and DHT22 readings differ notably

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

$$DHT22\_temp = senseHat\_temp - \frac{(CPU\_temp - senseHat\_temp)}{\boldsymbol{temp\_factor}} \rightarrow \text{ which follows as}$$

$$\rightarrow \boldsymbol{temp\_factor} = \frac{(CPU\_temp - senseHat\_temp)}{(senseHat\_Temp - DHT22\_Temp)}$$

$$DHT22\_hum = senseHat\_hum - \frac{(CPU\_temp - senseHat\_hum)}{\boldsymbol{hum\_factor}} \rightarrow \text{ which follows as}$$

$$\rightarrow \boldsymbol{hum\_factor} = \frac{(CPU\_temp - senseHat\_hum)}{(senseHat\_hum - DHT22\_hum)}$$

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 ºC

- $\mathbf{T_a}$ is the Dry bulb Temperature in ºC
- **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: 34,94ºC

av. sense_temp: 30,65ºC

av. sense_hum: 32,81ºC

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

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

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

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).

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

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

NOAA national weather service: heat index

Relative humidity \ Temperature	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 (27 °C)	83 °F (28 °C)	85 °F (29 °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 (34 °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 (%) \ Temperature (°C)	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	28	29	30	31	32	33	34	35
10	17	18	19	20	21	22	23	24	25	26	27	28	29	31	32	33	34	35	36
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 28ºC (Fig-5). Despite this fact, we can’t be entirely confident about the accuracy of the final number because the method used doesn't come without its shortcomings.

First, we don't know the flight case dissipation capabilities or the effect of space-hardening treatment on the sense-hat sensors. And second, we run the tests on a Raspberry Pi 3B from the Astro Pi kit whereas actual AstroPIs are model B+.

All in all though, we could confirm that ISS crew work in conditions of thermal comfort since resulting AT is beyond "caution area" regarding thermal stress (Fig-5).

We've also noticed that sense-hat performs better outdoors and when mounted with a stacking header instead of simply attached on top of the raspberry.

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