Living On the Moon with LED Technologies

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About Yujileds

Yujileds is an innovative LED manufacturer focusing on developing high-performance LED products for different and specific applications. The industrial structure of both phosphor and LED gives us a unique view to develop our spectrum recipes. Compared to the general LED manufacturers, we have comprehensive information in evaluating the feasibility for both technical and commercial aspects. LED spectrum technology is not only about the quality of white LEDs, but also for different applications which have specialized requirements in lighting.

Yuji is one of the few companies that provide the service of designing or customizing a specific spectrum for clients, our confidence comes from the years of accumulation in focusing on the spectrum technologies and the control of LED phosphor and LED die supply-chain with thousands of successful cases in the past years. Innovating LED technologies and giving them commercial values are our eternal driving forces.

Abstract

The LUNARK habitat mission, designed and constructed by the Danish space architects Sebastian and Karl-Johan, aims to simulate the moon's real living environment. The habitat is tested over two months in Northern Greenland, where it behaves mostly like the south pole of the moon, including the extreme temperature, “the peak of eternal light”, the vast white landscape and remoteness. The mission will provide the data analysis for the next human landing on the moon, probably in 2024 according to NASA's current schedule. The last time is Apollo 17, fifty years ago.

Illumination in the habitat does not only mean the creation of a lighting environment in the enclosed space, but also a living condition that has to consider the circadian rhythm, emotional feeling and biological responses. There is on-longer any natural light here than on earth, everything depends on artificial lighting which almost provides all of the basics of visual and non-visual activities, people will not realize the challenge until they are personally on the scene. LED, undoubtedly, is the ideal option for this illumination considering its mature development in both technical and commercialized ways, especially its “digital” feature with flexible size and tunability.

Yujileds, the researcher, developer and manufacturer of professional LED, participates as the light source partner with their latest full-spectrum and multichromatic LED prototypes which are designed specifically for this mission of the circadian rhythm aspect; Louis Poulsen, the professional lighting fixtures founded in 1874, participates as the lighting fixture partner and the tuning sequence developer. This article introduces the basic theories of the circadian rhythm with the LED spectral performance and the engineering of the luminaire with relevant designing principles. With the experiment data, it also indicates how can we utilize LED technologies for such ultimate tasks and what results we obtain from this mission.

Introduction

“When we go to the moon, we must thrive, not just survive.”[1]

We rarely ask the question of “how will the sunlight change tomorrow?” because, since the birth of human civilization, the sun – the fixed star shines every day steadily, people have already get used to what it is from many generations ago. Objectively, the “Air Mass (AM)”, which is the ratio of the mass of atmosphere in the actual observer-sun path to the mass that would exist if the observer were at sea level[2], describes relevant definitions including the standard solar spectra. The AM 1.5 standard spectrum[3] stretches across from the deep ultra-violet to the infrared wavelengths, and the visible light spectrum, which is typically recognized between 380nm-700nm[4], only covers partly, however, the visible light spectrum affects human circadian rhythm and behaviors mostly, therefore, this range is what we always care, and the AM 1.5 standard spectrum also indicates an important reference that homogeneous spectral power distribution is ideal for artificial lighting to imitate.

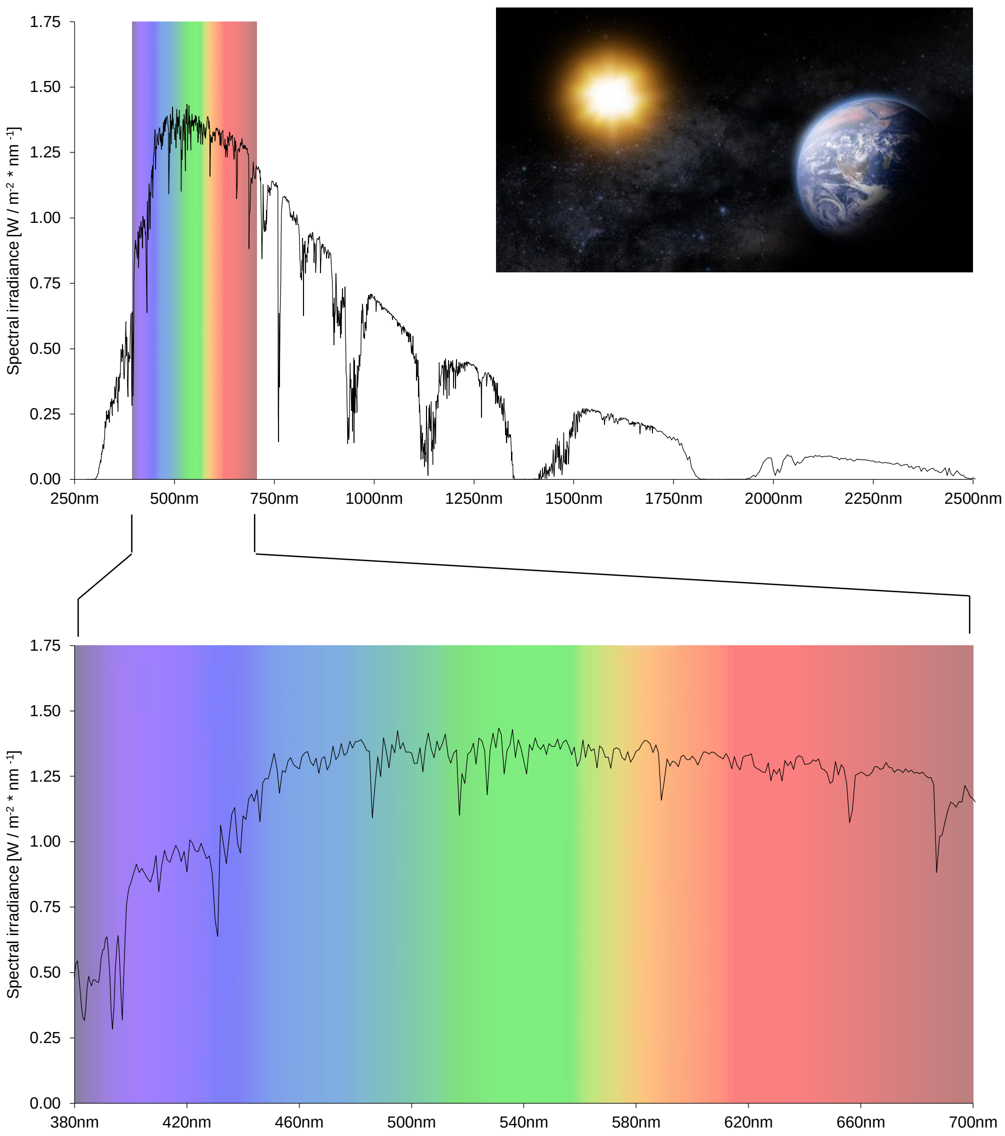


Figure 1. AM 1.5 standard spectrum (direct + circumsolar) in the range of 250nm-2500nm and 380nm-700nm.

The first moon landing for humans happens in 1969, and it is difficult to trace what light sources are assembled in the space capsule but not LED, since it is still far away from practical use at that time. Even today, astronauts can only rely on artificial lights for their daily activities and the lighting quality determines if they could accomplish the missions. The LUNARK habitat mission is not only for the short-term tasks but focused on studying how people thrive on the moon, not just survive. Thus, lighting has to be considered as for all human's full-time activities on the earth, it is difficult to imagine the importance and challenge of lighting quality until we think in this way.

In daily life, we rely on lighting, natural or artificial, for working, studying, entertainment, even for relaxing and treating. The light is not just for illuminating something to "see", in all activities, it also provides the correct feelings and emotions to do things appropriately. Lighting also affects health both biologically and psychologically, in this case, the illumination principles in different scenes would be quite distinct and should be flexible enough to tune at any time.

Illumination principles in different scenes

Scenes	Illumination principles
Work and study	Productive, exciting, concentrative, tireless, legible.
Relax and entertainment	Low-exciting, comfortable environment, legible.
Pre-asleep	Sufficient to reduce the excitement, promote the secretion of melatonin.
Emotional regulation	Regulate mental feelings by different lighting recipes accordingly.

Table 2. Illumination principles in different scenes.

The primary scenes in one day can be concluded in Table 2 that apparently most activities cannot be done without lighting.

Work and study

This scene is the most important part since it is the process of creating productive forces thus it needs alertness and concentration, the secretion of melatonin should be suppressed as far as possible to avoid tiredness. In addition, the lighting should be friendly to the eyes with good color rendition and correct chromatics to create a favorable environment for reading, operating, drawing and measuring.

Relax and entertainment

Relaxation happens during work and studies it requires a gradual switch from “exciting” to “peaceful”, in this scene the lighting would generate more melatonin to help with relaxing. For entertainment, the scene requires more than white light illumination, tunable colors are necessary for creating specific environments and here the white light is not the key lighting but the dynamic and colorful light plays the primary role.

Pre-asleep

The melatonin will be secreted sufficiently for this scene where the blue light should be reduced as far as possible. White light is no longer necessary, instead, the light should be able to create a warm and comfortable environment adding to sleep without creating any excitement.

Emotional regulation

It has proved that color has the ability to influence a variety of human behaviors, such as object recognition, the identification of facial expressions, and the ability to categorize stimuli as positive or negative[5]. When astronauts are kept in confined space for a long time, the health of emotion and psychology is necessary to be cared for and regulated accordingly.

Why LED lighting?

LED is unprecedentedly flexible in both spectral engineering and product modality. In Figure 3 there are the available spectral options for both semiconductor and phosphor-converted LED – covering almost all of the visual wavelengths with different FWHMs (Full Width at Half Maxima), by matching with each other, the spectrum can be designed in full-tuning possibility. Furthermore, thanks to the illumination theory, LEDs can be made to compact sizes and can be driven individually with relevant programs, this is significant for limited space especially for the habitat where every inch is expensive.

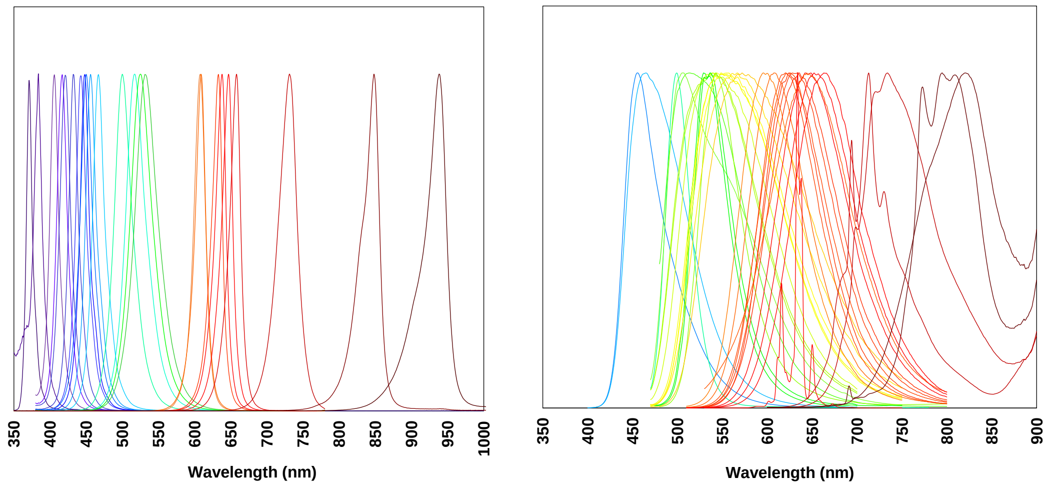
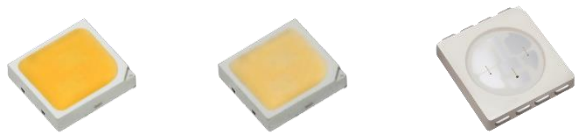


Figure 3. Available spectra for semiconductor and phosphor-converted LED.

LED light source



Natural light spectrum LED for key lighting

White light is the primary composition for all lighting scenarios, thus it plays a vital role in mimicking the natural light in the enclosed habitat. The selection of LED sources is based on homogeneous spectral power distribution and should cover as broad a visual wavelength as possible without missing obvious energy or creating spiculate peaks to avoid distortion comparing to the sunlight.

Meanwhile, two different color temperature LED should be selected to formulate stable and consecutive spectra during the tuning, therefore, the typical warm white of 2700K and daylight white of 6500K are chosen to be the white light bases (Figure 4).

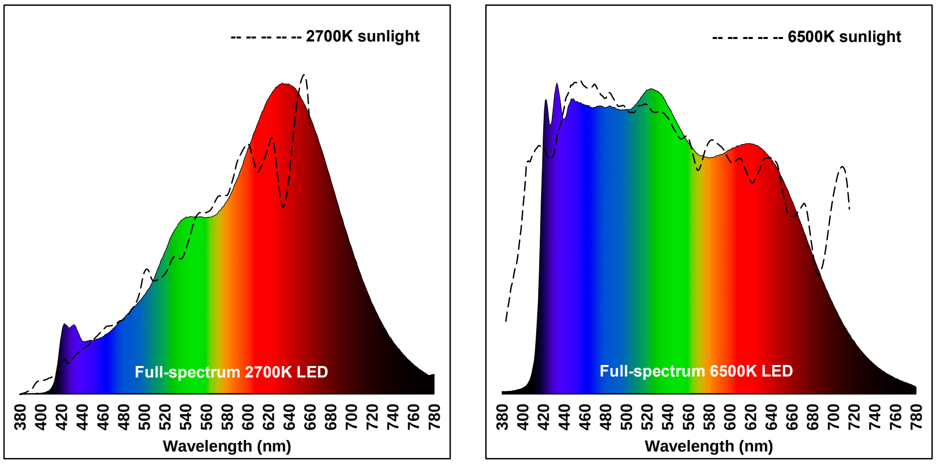


Figure 4. 2700K and 6500K natural light spectrum LED for white light bases.

Monochromatic LED for specific hues and spectral integration

Generally the monochromatic LED does not work individually but always cooperates to be added to the white light LEDs for creating different scenes. The monochromatic LED achieves saturated blue, green and red that cover most of the CIE 1931 diagram (Figure 5) which stands for human's visual range. Therefore, with the combination of full-spectrum white light and monochromatic LEDs, these LED light sources are capable enough to represent most of the colors and white lights.

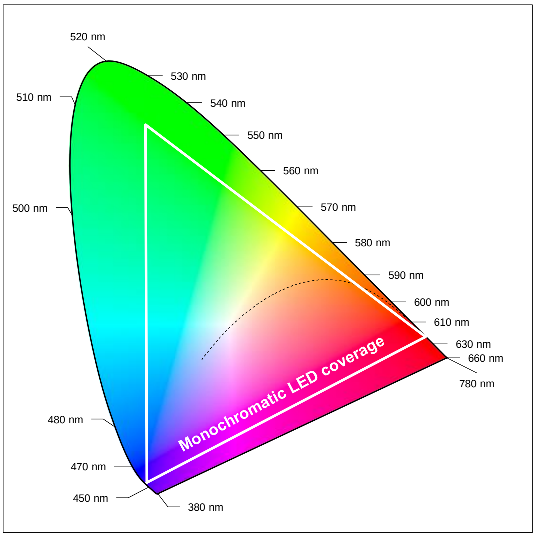
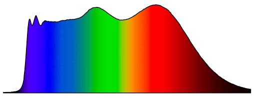
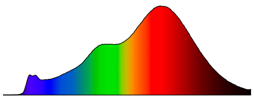
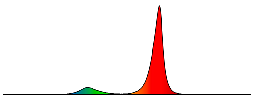
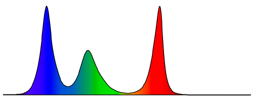


Figure 5. Monochromatic gamut in CIE 1931 diagram.

Spectral recipes for different scenes

Scene	Spectrum	CCT	M/P ratio	CRI	Visual color
Work and study		5000K	0.933	95	
Relax and entertainment		2700K	0.522	98	
Pre-asleep		-	0.263	-	
Emotional regulation		-	-	-	

The bactericidal effect from the UVA wavelength

Environmental cleanliness is extremely important especially with the global impact of Covid-19. The sterilizing device becomes necessary and the ambient lighting can help with this. The full-spectrum LED contains 400-420nm wavelength radiance which has been proved to be effective for killing the virus, germicidal properties of violet-blue visible light (380–500 nm), especially within the range of 405 to 450 nm have been shown as an alternative to UVC irradiation in human occupied whole-room disinfection scenarios where it has shown reduction of bacteria and surgical site infections. Although 405 nm or closely related wavelengths have been shown to be less germicidal than UVC, its inactivation potential has been assessed in pathogenic bacteria such as Listeria spp. and Clostridium spp. , and in fungal species such as Saccharomyces spp. and Candida spp. It is thought that the underlying mechanism of blue-light mediated inactivation is associated with absorption of light via photosensitizers such as porphyrins which results in the release of reactive oxygen species (ROS). [6]

LED luminaire

The lighting fixture

The panels used in the LUNARK mission are made to three different sizes and two large panels, 410mm by 1250mm over the working desks. At the top of the hab, there is triangle-shaped panel and in each of the pods.

The construction of the panels is the same for the rectangular and triangular panels. The LEDs are made to flexible strips then on a 3mm aluminum backplate. This served the purpose of being a heat sink that could dissipate the heat of a large number of LEDs.

The 40x40 aluminum V-slots are mounted on the sides of the backplate, these are ideal for fastening the backplate and the plexiglass dissipator. The plexiglass used is 3mm thick, 3.570 kg/m², blank white with color code WH14, and has a 47% light transmission. (Figure 6)

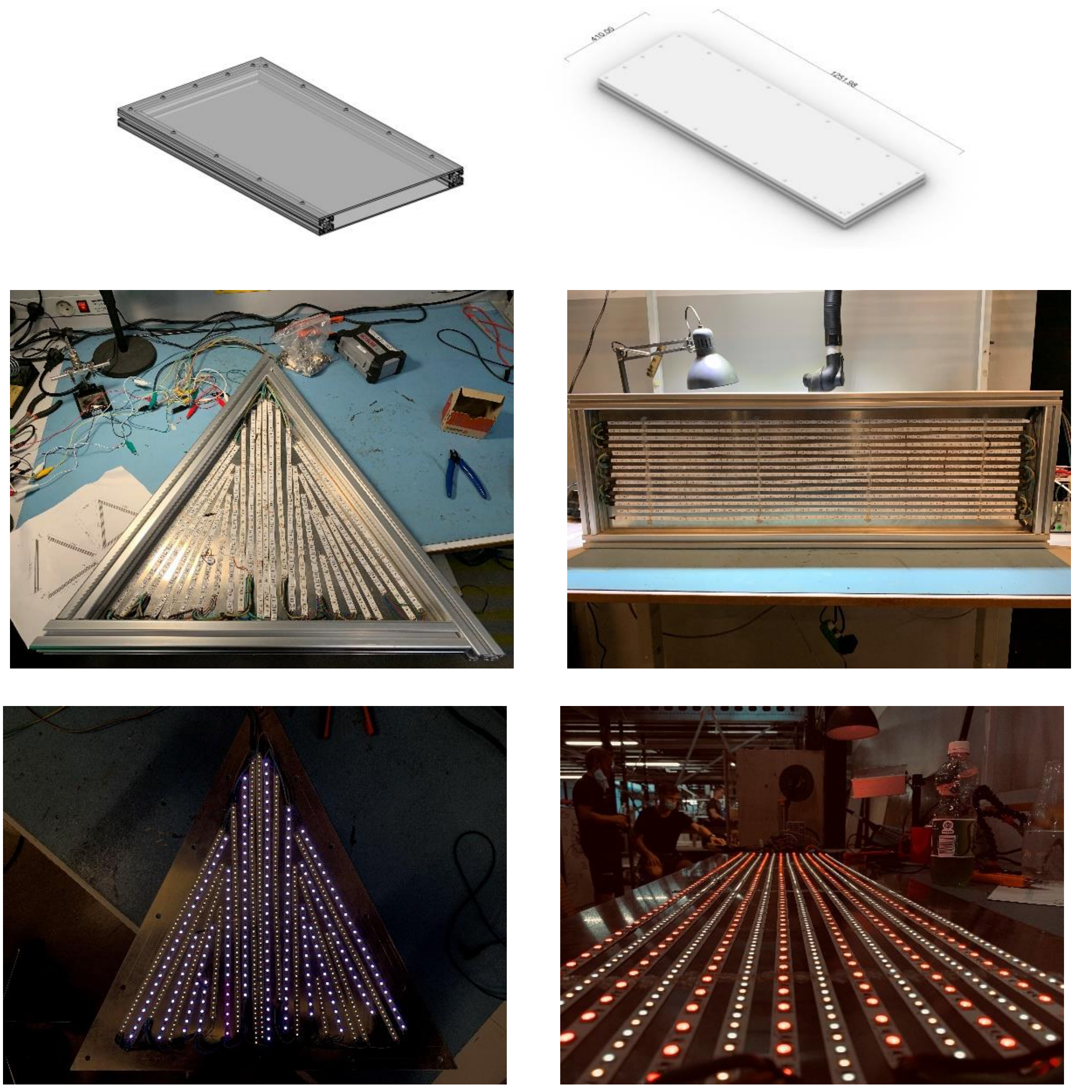


Figure 6. The lighting fixture with LED strips.

LED strip

Inside the rectangular panel, the room for LEDs is 15.4m. Since the V-slots were 40mm wide, they blocked 80mm of the total length of the backplate and due to the LED strips coming in 10cm cuts, the engineers have to have a length divisible by 10, thus it is ended up with 110cm strips in 7 rows, but both the RGB and WW (2700K) / CW (6500K) strips give a total length of 110*7*2 = 1540 cm.

Controller

The LED strips are controlled by a microcontroller, more specifically an ESP32. The ESP32 is a WiFi-enabled MCU, meaning the panel can be placed anywhere and it could wirelessly receive data from the main computer in LUNARK, aptly named ODIN. The ESP32 is running 3.3V - -5V and therefore could not control the LEDs running on 24v directly. Therefore the engineers use IRF520 MOSFETs between the ESP32 and the LED strip, enabling to quickly switch on / off, emulating PWM and thus the intensity of the light.

ODIN creates a WiFi hotspot to which all of the “Ravens (Figure 7)” (ESP32’s) could connect to. ODIN hosts an MQTT server, which is exposed to all connected devices. MQTT is a lightweight data transfer protocol, often used in IoT devices.

The MCU would request the current time and date from the main computer and used this to decide which type of circadian sequence it should play. These circadian sequences are hardcoded, developed by Louis Poulsen.

Circadian

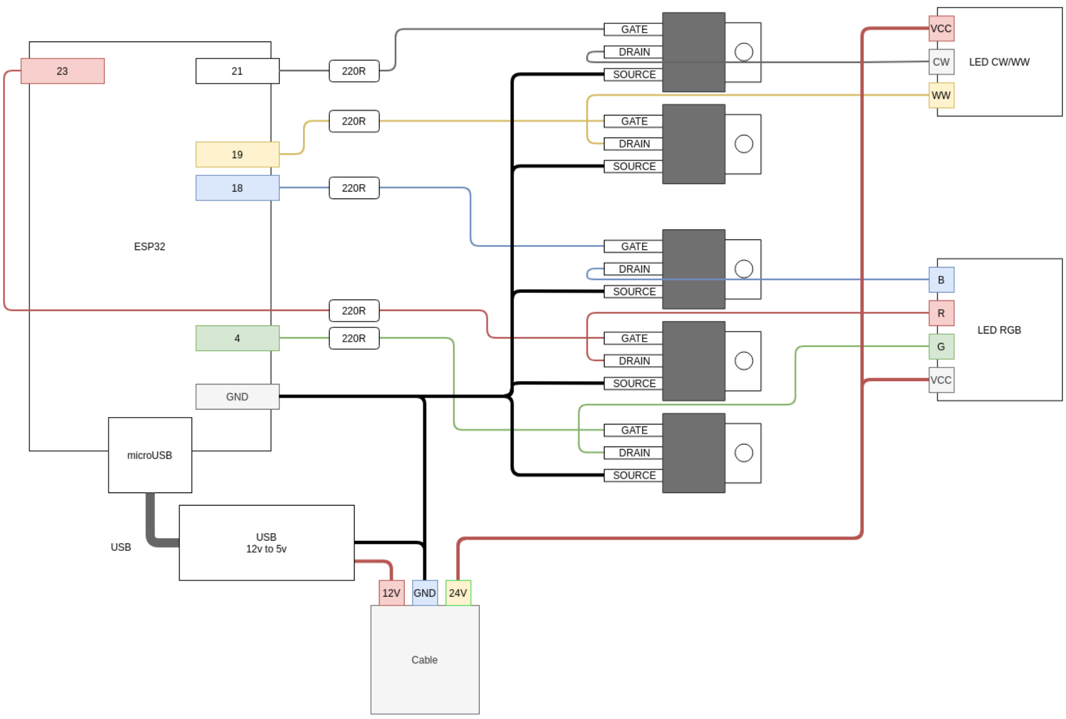


Figure 7. The wiring diagram of circadian “Raven”.

Future panels

If the panels are to be standalone, we need a different interface, since we cannot sell an ODIN with the panel. Therefore the engineers create a web UI (Figure 8) that can be accessed if connecting the ESP32 to the WiFi.

The ESP32 wakes up and checks if it has a remembered WiFi connection, if it does it tries to connect, if there is no remembered WiFi or it cannot connect to it, it opens up the configuration portal. This creates a WiFi hotspot. Navigating to 192.168.4.1 and in there inputting WiFi SSID (name) and password. The ESP32 reboots and connects to the now remembered WiFi. When connecting to the same WiFi and navigating to the address, presenting the below UI. Users can create a custom color by tuning RGB and CW / WW or using the built-in features. The “Auto Circadian” feature will start playing a defined sequence, using the current time of day.

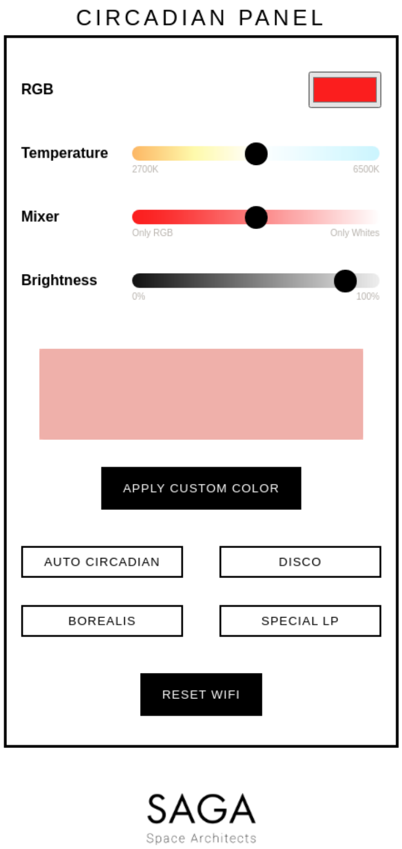


Figure 8. The web UI for circadian wiring diagram of circadian “Raven”.

Observation and study

To observe and analyze the team members' behavior and health during the mission, psychologists and scientists of Anders Kjærgaard, Gloria R. Leon and Konstantin Chterev measured their living and working status over the 60-day in the lunar analog habitat and the study indicated the circadian lighting system was a highly important component of the habitat; self-reports by teammates indicated that the lighting system facilitated regular sleep/wake schedules, cognitive activation, comfort, and time orientation. The configuration of the workspace regarding the placement of individual desks, the ability to flip them up against the wall, multifunctional and collapsible furniture, storage space to avoid clutter, and the occasional use of the airlock for work and privacy facilitated task performance and mitigated interpersonal conflicts. Both team members' use of isolated areas of the habitat for privacy facilitated the diffusion of tension and thus served as a means of coping with stress. The interior materials, color scheme, and the designed comfort of the sleep pods promoted relaxation and made the habitat feel more like an Earth home. The comfortable sleep pods also facilitated individual privacy as needed. [7]

Lighting in the habitat contributes important effectiveness but of course not the only one. The study concluded that A highly important comfort and sleep feature was the installation of a circadian light system with daily variation, high color rendering, and simulated sunsets and sunrises. According to TM #2's (Team member #2) self-report, these features promoted a healthy sleep-wake cycle, a sense of time, something to look at, and made the habitat feel natural: "It felt like we had large amounts of diffused sunlight flooding into the habitat, which in ways hard to define made it really pleasant to be there. The mornings especially were nice." TM #1 (Team member #1) stated that another comforting aspect was "the contrast between the interior and the exterior of the habitat. From the outside, the habitat shell is black with jagged edges and almost looks intimidating; the inside is the exact opposite - light colors, soft materials, and rounded edges."

Summarizing the effectiveness in the table below shows the lighting functions.

ITEM	TEAM MEMBER #1 (%+)	TEAM MEMBER #2 (%+)
Problems with gear and equipment[+]	12.5	62.5
Feeling of camaraderie/closeness with teammate	87.5	100
Concern about the well-being of my teammate	37.5	38
Enjoyment of the Arctic environment	87.5	87.5

Concern about how effectively my teammate and I are working together	25.0	62.5
Feeling down/low or stressed because my teammate is feeling that way	12.5	12.5
Tension or argument with my teammate	25	37.5
Satisfaction in making good progress today	100	100
Satisfaction that equipment is working properly	87.5	87.5
Satisfaction that I am able to cope with the challenges	87.5	87.5
Concerns about the effectiveness or safety of decisions I made today	0	0
Fear of being injured	37.5	25.0
Worried about family, friends	25.0	25.0
Worried about encountering bad weather	25.0	37.5
Loneliness, homesickness	0	62.5
Lack of privacy, time for myself	25.0	62.5
Personal Hygiene (wanting to be cleaner)	12.5	0
Muscle or joint ache	25.0	12.5
Headache	25.0	0
Other physical problems	12.5	0

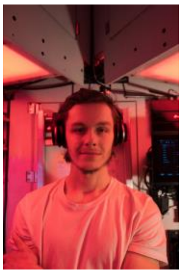
[+]Mean % of rating periods in which a particular item was endorsed.

Summary

With the rapid development of LED technology and the understanding of the biological effectiveness of lighting, it is not difficult to find the illumination principle of LED is more and more suitable to achieve different and specific lighting purposes, and it is also not difficult to believe the LED technology mentioned in this article is feasible to be applied in a real space capsule predictably. The latest LED development does not only offer a lighting environment but provides the thrive condition rather than just survival, we are confident to see that LED could illuminate the future.

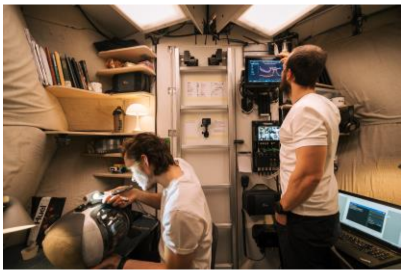
Album









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[1] https://saga.dk/projects/lunark

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[3] ASTM International, *ASTM G173-03(2020), Standard Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37° Tilted Surface*, 2020.

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[5] Tina M. Sutton & Jeanette Altarriba. (2015). *Color associations to emotion and emotion-laden words: A collection of norms for stimulus construction and selection.* Psychonomic Society, Inc.

[6] Raveen Rathnasinghe, Sonia Jangra, Lisa Miorin, Michael Schotsaert, Clifford Yahnke & Adolfo García-Sastre, *The virucidal effects of 405 nm visible light on SARS-CoV-2 and influenza A virus,* Scientific Reports (Sci Rep), 2021.

[7] Anders Kjærgaard, Gloria R. Leon, Konstantin Chterev, *Team Effectiveness and Person-Environment Adaptation in an Analog Lunar Habitat*, Aerospace Medical Association, 2022.