【*Technical Paper*】

FEASIBILITY STUDY ON COMFORTABLE SPACE ENVIRONMENT UNDER LOW GRAVITY

Katsuhiko SHIBATA [1], Tai NAKAMURA [2]

ABSTRACT

Today when even ordinary people could visit the International Space Station (ISS) as travellers, a new question is raised whether the current cabin environment of ISS set for professional astronauts such as temperature, humidity, air quality, and noise levels are really good for everyone. Above all, for the Asian people, whose habitus are different from Westerners, the comfortable environment and the air conditioning system that creates it must be different. In particular, when we travel to deep space or the lunar surface, the duration of stay extends no less than a few weeks. Consequently, the Crew Quarter (CQ), the relaxing and sleeping place, requires individually customized air-conditioning and noise suppression. Therefore, in this research, we investigated the desirable environmental conditions based on ASHRAE, ISO, and the standards of comfort in Japan by comparing and evaluating the ISS standards with them. In this paper, we propose an air conditioning method that realizes customization in temperature, humidity, and airflow in the CQ with low noise and proper diffusion of carbon dioxide from exhaled breath, using computational fluid dynamics (CFD) analysis.

1. INTRODUCTION

In Japan, JAXA holds a central role in implementing space development programs, and from the beginning of Japan's human space program, most of them were conducted in collaboration with NASA. In 2018, NASA issued a roadmap for Mars exploration in the 2030s as the new human space program after ISS (the International Space Station) [1]. Then, in 2019 Artemis program [2] was announced by NASA, which will begin with constructing a gateway in near lunar orbit in the 2020s to carry out lunar exploration based on the gateway. A Japanese private entity "ispace, Inc." [3] participates in the Artemis program providing a lunar explorer "HAKUTO-R" and Takasago Thermal Engineering Co., Ltd. has invested in this program taking on the challenge to electrolyze water on the lunar surface. On the other hand, the space travel business by private companies has become a reality and has already conducted several space flights. Through these activities, we recognized there are potential demands for ECLSS (Environment Control / Life Support System) in manned space missions to enable long travel in terms of the period and the distance and to embark the untrained tourists. Under such circumstances, the improvement of the environment quality of the cabin space from "endurance" to "comfort" by utilizing ECLSS functions. In particular, improving the CQ (Crew Quarter) environment in conformity with the request of the individual passenger is considerably important for long travel. In this research, we surveyed the literature on the environment quality standards of CQ, and investigated and examined a range of comfortable temperatures and humidity as well as the way to realize it.

This article is update of "73rd International Astronautical Congress (IAC), Paris, France, 18-22 September 2021."
1 R&D center, TTE Co., Ltd.
2 External Expert, Japan Aerospace Exploration Agency (JAXA)

2. STANDARDS OF THE INTERNATIONAL SPACE STATION

An environment standard with the requirements for the development was specified when JEM (the Japanese Experiment Module) of ISS (the International Space Station) was developed [4]. Since Japan has few experiences in human space programs, it followed NASA's environment standards almost as it is. Table 1 shows typical items related to air qualities extracted from the environment standards. This table listed the environment quality standards of JEM and NASA and the Japanese environment quality standards for building hygiene management on the ground as a reference. The validity of these criteria was verified based on literature such as NASA-STD-3000 [5] and related materials.

Table 1 Environment standards of relating to Air qualities.

Parameter	JEM Japanese Experiment Module	U.S ECLS	Building in Japan
Total pres. (kPa)	97.9〜102.7	97.9〜102.7	—
O_2 pres. (kPa)	19.51〜23.1	19.51〜23.1	—
CO_2 pres. (kPa)	Daily ave. 0.707, peak 1.01	Daily ave. 0.705, peak 1.01	1,000 ppm
Atmospheric temp. (°C)	18.3〜26.7	17.8〜26.7	17〜28
Dewpoint (°C)	4.4〜15.6	4.4〜15.6	—
Relative humi. (%)	25〜70	25〜70	40〜70
Particulate concentration	Daily ave. 3,530,000 part/m3 peak 70,600,000 part/m3	Daily ave. 0.05mg/m^3 (100,000 part/ft^3) peak 1.0mg/m^3 (2,000,000 part/ft^3)	0.15 mg/m^3
Intramodule circulation (m/s)	Daily ave. 0.067〜0.203 min. 0.035, max. 1.02	Daily ave. 0.051〜0.2 min. 0.036, max. 1.02	＜0.5 m/s
Noise	＜NC-50	—	—

2.1 CO_2 concentration standard

Dilution and removal of air contamination are a priority in non-ventilated spaces. In particular, as the amount of CO_2 produced by human exhaled breath is uncontrollable, appropriate control of CO_2 concentration is required. Since JEM's CO_2 concentration standard is based on a partial pressure marking, the concentration conversion at a total pressure of 1 atm is approximately 7,000 ppm. This is a considerably higher concentration than the hygiene control value on the ground. However, although CO_2 concentration is used as a substitute index for ventilation volume on earth, there is a difference in that JEM sets a standard value from the health hazard of single component gas. In the previous literature [6], [7], there is a description that the minimum concentration that affects health is 7,000 ppm, which is consistent with JEM's environment standards. Table 2 shows the permissible CO_2 concentrations on the ground of several countries [8]. In some cases, the upper limit is 5,000 ppm in the labour environment, but in the deskwork environment it is approximately 1,000 ppm, and as an index of CO_2 alone, it is 3,500 ppm.

In addition, Japanese ventilation standards set the required ventilation volume per person to 30 m^3/h. This requirement can reduce the CO_2 concentration in the habitable room to 1,000 ppm or less by dilution, but ventilation is not possible on the ISS. In addition, due to insufficient ECLSS performance, the current environment standard is 7,000 ppm, but further improvement is desirable in the future.

Fig. 1 shows the relationship between the CO_2 concentration and the dissatisfied rate [8]. The experiment in the figure is consistent with the increase in the concentration in CQ because it is the dissatisfied rate when the CO_2 concentration increases due to the bio-emissive substance. According to the results of Japanese experiments [9], a CO_2 concentration of about 1,000 ppm results in a 20 % dissatisfied rate. This experiment is the case when the CO2 concentration of the outside air is 370 ppm, and the concentration difference compared to the outside air is more significant than the absolute value. At the current standard of 7,000 ppm, the dissatisfied rate exceeds 70 %. Moreover, although there are some differences in sensation between Japanese and Westerners [10], [11], it seems that 3,000 to 3,500 ppm, which at least 50% of people do not feel uncomfortable, is appropriate.

Table 2 Permissible CO_2 concentrations of several country.

Country (Year)	Permissible CO_2 concentration	Target
Norway Ministry of Health and Welfare (1999)	Max 1,000 ppm ＊Indicator of indoor air pollution	Habitable room
Canada Ministry of Health (1995)	1,000 ppm ＊Indicator of ventilation	Office
Canada Ministry of Health (1987)	≦3,500 ppm ＊Acceptable long-term exposure range	Habitable room
Singapore Ministry of the Environment (1996)	1,000 ppm (8 hr average) ＊Indicator of ventilation	Office with air conditioning
China Hong Kong Special Administrative Region (2003)	Best quality ： 800 ppm (8hr average) Good quality：1,000 ppm (8hr average)	Building, enclosed space with ventilation andor air conditioning
China General Administration of Environmental Protection (2002)	1,000 ppm (24hr average)	Residence and office
South Korea Environment Department (2003)	1,000 ppm	Large-scale store, hospital building etc.
Taiwan Environmental Protection Agency (2012)	1,000 ppm (8 hr average)	―

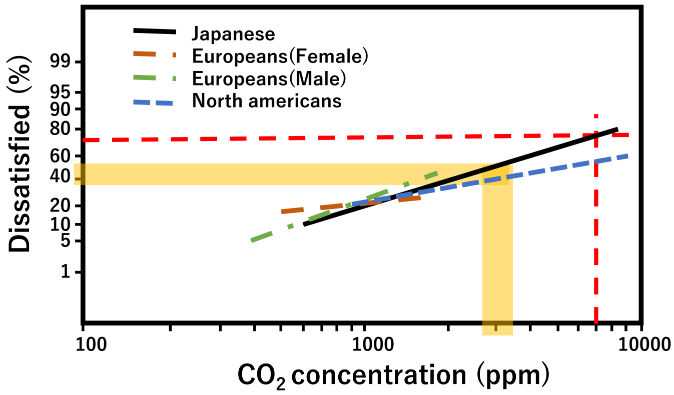


Fig. 1 CO_2 concentration and the dissatisfied rate.

2.2 Temperature and humidity standards

The heat sensation is a necessary item when a person judges comfortability. Temperature, humidity, airflow, and radiation are environment factors of human heat sensation. In addition, the human body elements such as the amount of clothes and the metabolic rate are also important factors. Hence, it can be determined by these factors in combination with the exposure time. Judging from the way of CQ utilization, the amount of clothes is presumed to be about 0.5 clo [Note 1], which is the same amount of summer clothing on earth, and the metabolic rate is about 1.0 met [Note 2], which is almost same level as a quiet state of the body. Assuming that the time of stay in CQ is about 8 hours including the sleep the lowest permissible temperature is 18 ℃, and the comfort zone is around 25 ℃ from the previous study shown in Fig. 2 [5]. This fact indicates that the current JEM temperature standard is set slightly lower.

For reference, Fig. 3 shows ASHARE Standard 55, which is well known as the thermal comfort range on the ground [12]. ASHRAE divides the temperature and humidity range into summer and winter based on the difference in the amount of clothes. In addition, the operative temperature, which is the average value of the air temperature, and the radiation temperature, are used as the temperature here. On the other hand, natural convection does not exist in the weightless space, but heat transfer by radiation still occurs. Therefore, it is considered more appropriate to use the operative temperature in the same way as on the ground to evaluate the heat sensation in CQ where the amount of clothes is half-sleeved and the metabolic rate is small.

Next, we consider the humidity standard. As for the heat sensation, the low humidity alleviates the heat even at a high air temperature. Fig. 4 shows the transition of ASHRAE's comfort zone [12]. With every standard revision, the relationship between temperature and humidity for comfort has become more detailed. Furthermore, in recent years, with the spread of PET bottled beverages, restrictions on the low humidity side have tended to be relaxed. As a result, if the temperature range is 23 ℃ to 26 ℃ and the humidity range is non-condensation, it is appropriate to consider it no problem.

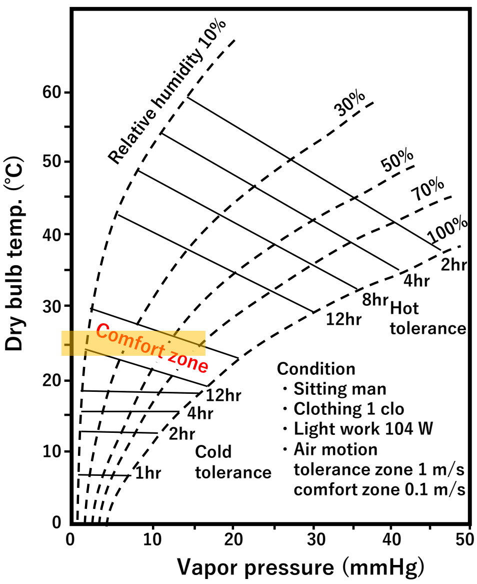


Fig. 2 Environmental requirements.

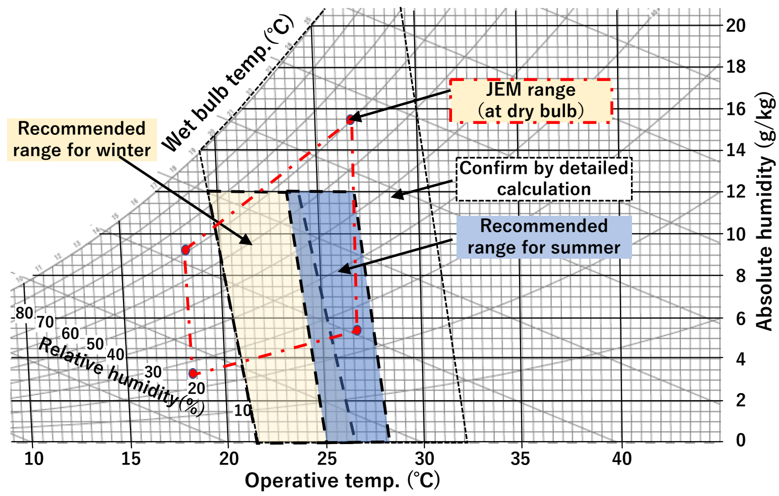


Fig. 3 ASHRAE standard 55.

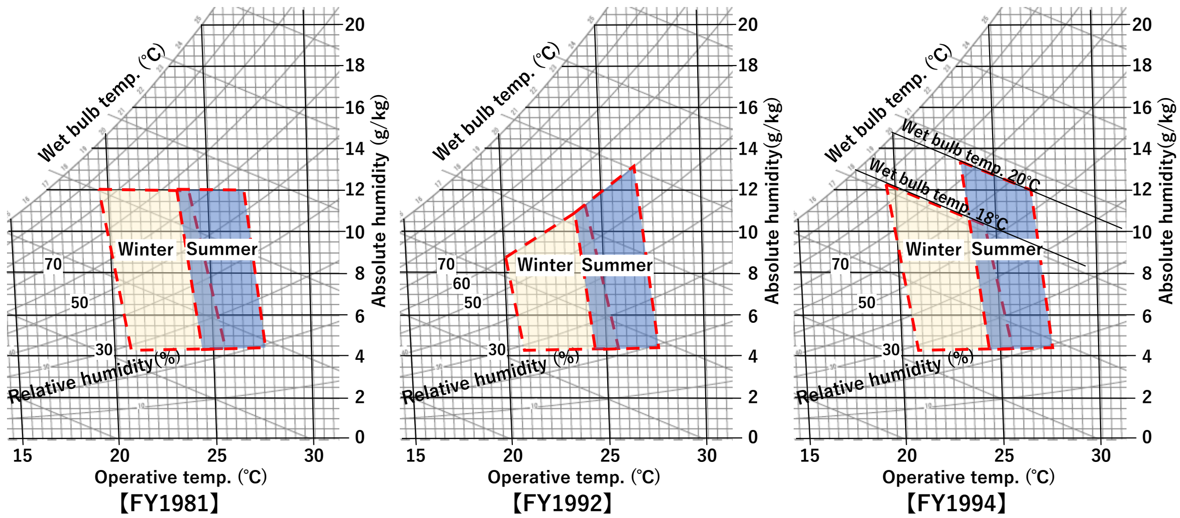


Fig. 4 Transition of ASHRAE's comfort zone.

2.3 Criteria for circulation air volume

For processing the internal heat load in ISS, we cannot count on radiational cooling because the inside walls of the experiment modules and common areas are equipped with various devices. Therefore, the heat load from human bodies and the lighting equipment is processed by the convective heat transfer with circulating air. On the other hand, since the CQ targeted here does not have a device on the wall that impedes heat transfer, we can also count on radiational cooling from the wall surface for heat load processing. It means the diffusion of CO_2 in the exhaled air rather than the heat load processing governs the amount of air supplied to the CQ. One of the previous research on CQ users [13] has examined the expiratory advection range from the analysis of the expiratory jet flow and CO_2 concentration. However, in this research, not only temperature distribution, the CO_2 concentration of exhaled air, and the subjects but the noise from the air supply and exhaust ports are equally concerned. And as far as we know, there is no such case as these factors have been comprehensively evaluated. Since CO_2 has a slower diffusion rate than air, it should be enough to exhaust the equal air to the breathing volume out of the zone between each breath to exhaust CO_2 from the respiratory zone. Generally, a human breathes 500 ml (≒8 cm×8 cm×8 cm) of air 12 to 20 times per minute. Based on this, if the airflow speed moves 8cm in 3 seconds, that is, if there is an airflow of 0.03 m/s or more one can breathe fresh air provided that the frequency of breaths is 20 times per minute, which is the worst case. Fig.5 shows the concept of the minimum air velocity. Also, regarding the upper limit of the airflow speed, we think 0.5 m/s or less is appropriate, which does not cause discomfort.

2.4 Noise standards

A quiet environment is necessary when resting or sleeping. The environment standards for noise based on the Environmental Basic Law of Japan are 50 dB or less at night in areas used for commercial and industrial purposes, and 45 dB or less at night in areas used for residential purposes. Therefore, NC-50, the requirement of JEM, seems acceptable. In the meantime, the noise data of the CQ during low airflow operation measured with the microphone installed at the head position at the pre-launch inspection of the CQ in Fig. 6 shows a higher noise level of 58 dB at 250 Hz. An environment in which such low-frequency noise is constantly generated interferes with a good night's sleep.

The noise source of the CQ is the air supply fan into the CQ. The drastic countermeasure is to make the air supply fan quieter, but there are other ways to do this by using the sound absorption effect of the CQ interior, such as sound absorption in the duct and the air outlet away from the head. In any case, noise reduction is closely related to the air conditioning system.

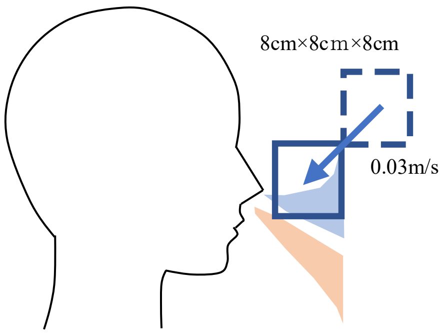


Fig. 5 Concept of the minimum air velocity.

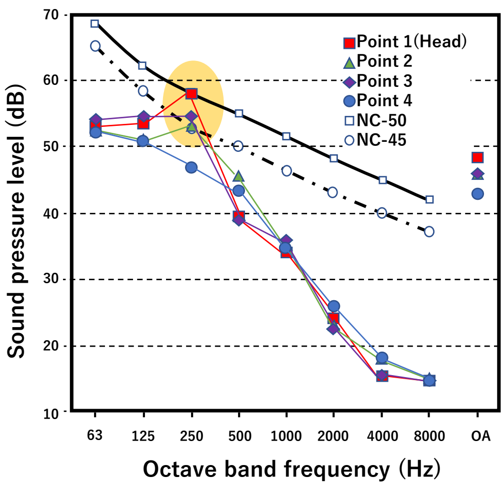


Fig. 6 CQ interior sound level measurements at low fan speed.

3. PROPOSAL OF COMFORTABLE ENVIRONMENT STANDARDS CONSIDERING UNSKILLED PASSENGERS

In this section we will review the environment standards of JEM again, which already have been shown as appropriate, assuming that unskilled people will advance into space hereafter, and then propose the comfortable environment standards as follows. Table 3 shows the current JEM standards and our new environmental standards that lay stress on comfort. As for the concept of the new standards, since the operating costs in space are significantly different from those on the ground, we prioritize comfort for the items that do not require significant improvements from the current ECLSS. At the same time, we tried to comply with the current standards considering the feasibility for the items such as processing devices that require increment of size and equipment that needs further replenishment. Moreover, as a new trial, here we focused on the sensation of the Japanese representing Asian people.

3.1 Standards for CO2 concentration, temperature, and humidity

Regarding the CO_2 concentration, the lower concentration is desirable to improve intellectual productivity [14] needless to say to prevent health damage by it. On the other hand, since CO_2 removal requires consumables such as adsorbents, it is not realistic to require too less concentration. Then, according to a policy we set in this study, the discomfort shall be less than 50%, and the CO_2 concentration in the inhalation zone of respiratory air shall be at 3,000 ppm as the upper limit.

As for temperature, since the amount of clothes is different, the working temperature, which is the average of the radiation temperature and the air temperature, was used as the standard. And we set the average temperature inside CQ at around 25 °C, which is the comfortable range in summer on the ground. In addition, the vertical temperature distribution near the person is kept within 3 °C [15] to reduce the discomfort caused by the temperature change. No lower limit is set for the humidity, which tends to be relaxed on the ground.

3.2 Criteria for circulation air volume and noise

As for the airflow speed that affects the circulation of air volume, the faster the velocity, the more discomfort we feel regardless of exposure time. Therefore, the airflow speed is better to set to the low range as much as possible. Then, the lowest limit of the velocity is determined by that the breathing air is replaced between each breath, and the upper limit is set at 0.5 m/s based on the air environment standard [16] for air conditioners in Japan.

For the sound environment, we recommend NC-45, which is equivalent to the level at night-time in residential areas in Japan, considerating a good night's sleep.

Table 3 Environment standards of current and new.

Parameter	Current JEM value	New CQ comfort value
CO_2 pres. (kPa)	Daily ave. 0.707(→7,000 ppm) peak 1.01	Breathing air peak 0.308 (→3,000 ppm)
Atmospheric temp. (°C)	18.3～26.7	Around 25 Vertical distribution ＜3°C
Relative humi. (%)	25～70	～70
Intramodule circulation (m/s)	Daily ave. 0.067～0.203 min. 0.035, max. 1.02	Around body Daily ave. 0.07～0.203 min. 0.03, max. 0.5
Noise	＜NC-50	＜NC-45

4. ENVIRONMENTAL ASSESSMENT OF CQ

Since the air sucked from the cabin space is supplied into the CQ, it is difficult to control its temperature, humidity, and CO2 concentration suitable for each CQ. Therefore, the location of the air supply/exhaust port, the shape of the air outlet, and the outlet velocity are the parameters for creating the environment inside the CQ. According to the open information, photos, papers, etc. [17], [18] about the ISS interior, the air outlet inside the CQ is at the top, and the jet flow is blown from the rectangular grill toward the head. Though the suction port is at the bottom, it is a unidirectional airflow system in which the blown jet flow reaches the suction port after stirring inside the CQ. One disadvantage of this method is that the noise reduction by distance is not feasible because the outlet is near the ears. In addition, since the blowing jet flow directly hits the human body, it is likely to cause discomfort due to exposure to the airflow and the

difference in the upper and lower temperature distributions. Furthermore, there is a risk of creating a dead space where the blown jet flow cannot reach and becomes stagnant.
To verify these concerns, we have performed the environmental analysis inside the CQ using computational fluid dynamics (CFD). The modelling and results of this analysis are specified below.

4.1 Analysis model

Fig.7 shows the analysis model of CQ. For the shape and dimensions of the analysis area, we referred to the previously published materials. Then we adopted the human body model standing at the center of CQ while resting and operating the PC and staying in a sleeping bag on the wall with only the head exposed during sleep. Table 4 shows the calculation conditions. In this table, we used the same turbulence model, radiational convergence calculation, convective heat transfer coefficient, and material and gas physical properties as on the ground. The only difference from the ground model is the gravitational acceleration in the x, y, and z directions, which is set to 0.0.

4.2 Analysis case

For the analysis case, we used the same unidirectional flow method of top blow-bottom intake following the current shape. To reduce the noise generation, we tested the following conditions: two cases for circulating air, such as the usual amount and a half amount, and two cases for processing the heat load in the break time and the sleep. Table 5 shows analysis cases.

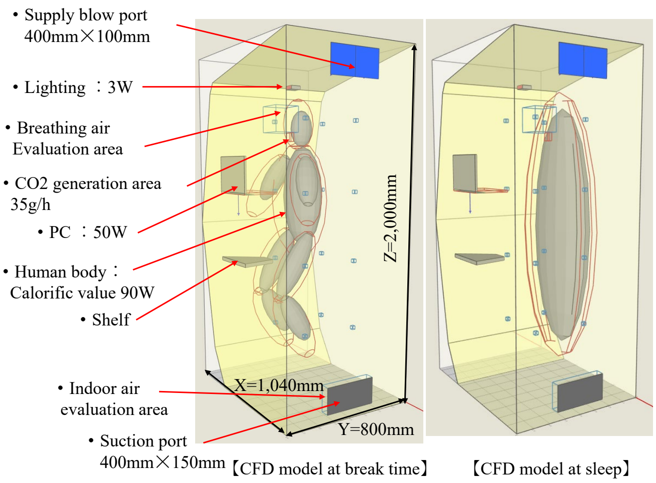


Fig. 7 Analysis model of CFD.

Table 4 Calculation condition.

Software	Flow Designer (Advanced Knowledge Laboratory Inc.)
Caliculation metho	Unsteady/steady
Turbulant model	High reynoise type κ-ε
Gravity setting	X,Y,X=0
Initial temp.	23 °C
Initial CO_2 coe.	2,000 ppm
Supply air	Temp. 23°C CO2 coe. 2,000 ppm
CO_2 genearation	35 g/h
Mesh	Rectangular mesh X,Y,Z=100×43×200

Table 5 Analysis cases.

Case	1-1	1-2	2-1	2-2
Human status	Break time		Sleep	
Heat load (W)	145		75	
Supply ari Flow speed (m/s)	0.5	0.25	0.5	0.25
Flow temp. (°C)	23			
CO_2 generation (kg/h)	35			

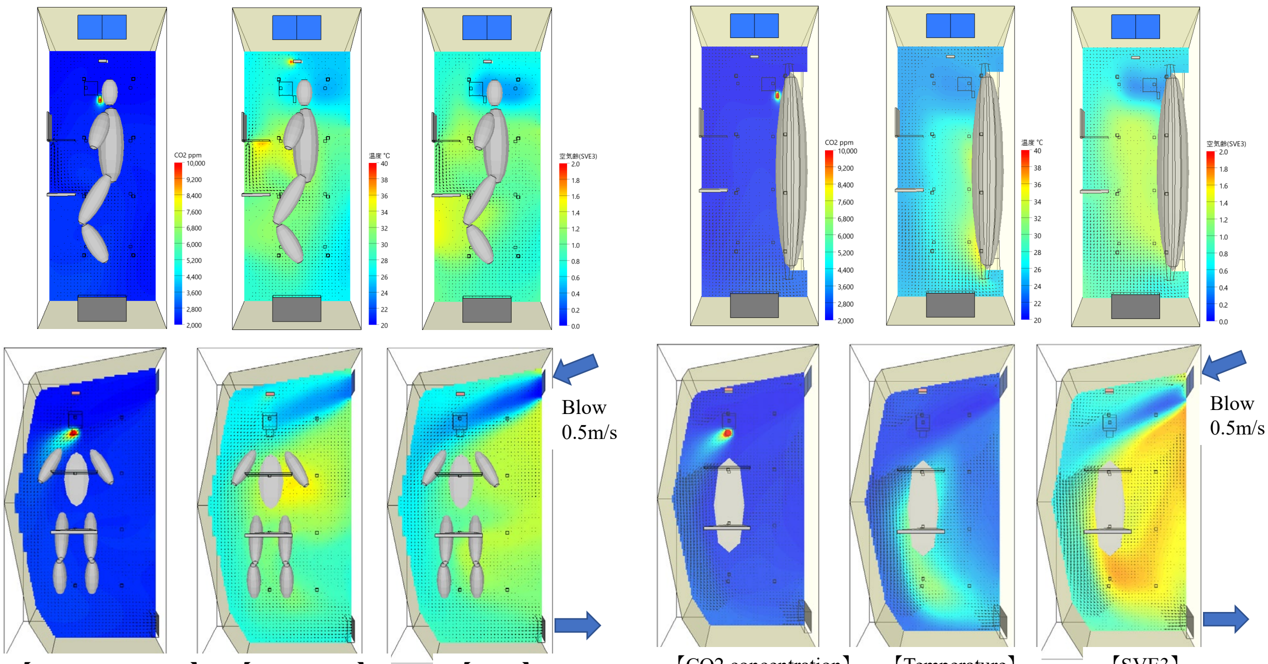
4.3 Analysis results

As an example of the analysis, temperature contours, CO_2 concentration contours, and ventilation efficiency SVE3 [Note 3] are superimposed on the airflow vectors of outlet velocity 0.5 m/s during rest in case 1-1 and outlet velocity 0.5 m/s during sleep in case 2-1. Fig.8 shows the results.
In case 1-1, although CO_2 in exhaled breath is blown away and the concentration is low, it is observed from this figure that the blown jet flow hits the human body directly, and the upper body is super-cooled. In addition, since the blown jet flow reaches the suction port from the bottom after it flows around the human body, local heating at the PC, and the increase of storage temperature and ventilation efficiency SVE3 are observed because the air in CQ is not well-stirred. Since this phenomenon is also observed in areas of CQ where the face is likely to come close, there is a danger of inhaling stale air.

And in cases 2-1, exhaled CO_2 is blown away and the concentration is low. Since the PC does not generate heat during sleep, heat spots do not occur. By staying in a sleeping bag, the respiratory zone and the environment around the human body are controlled and perceived to be comfortable. However, the distance of the head from the air outlet is less than 1 m, and the noise from the air outlet is heard directly without reduction.

Table 6 shows the maximum, average, and minimum values of CO_2 concentration, temperature, operative temperature, and wind speed at evaluation points around the respiratory zone and the human body in each analysis case. In breathing air zone, the comfort environment standards are mostly satisfied except for the sleeping state. In the environment around the human body, even in Cases 1-2 and 2-2 with the half volume of air supply, the CO_2 concentration almost satisfies the comfortable environment standard. However, the temperature is high except for Case2-1. Furthermore, the vertical temperature distribution obtained from the difference between the maximum and the minimum temperature widely exceeds 3 °C, and the heat sensation seems to be uncomfortable. Stirring the air in the CQ may be insufficient because the amount of CO_2 emissions from exhaled breath and the heat load are handled well by the difference in CO_2 concentration and temperature between the outlet and the inlet.

From the above results, we think it is necessary to improve the air conditioning system to improve stirring in the room while reducing noise during sleep by making the air volume changeable for both periods of rest and sleep.



【CO2 concentration】 【Temperature】 【SVE3】 【CO2 concentration】 【Temperature】 【SVE3】

(1) Case 1-1 **(2)** Case 2-1

Fig. 8 Example of analysis results.

Table 6 Analysis results of evaluation points.

		CASE	1-1	1-2	2-1	2-2
Breathing air zoon	CO2 (ppm)	Max	2,748	3,342	2,179	2,358
		Ave.	2,154	2,367	2,041	2,076
Around human body	CO2 (ppm)	Max	2,505	3,027	2,459	2,983
		Ave.	2,337	2,778	2,207	2,409
	Temp. (°C)	Max	33.9	40.4	32.5	42.9
		Ave.	29.7	35.0	26.5	30.3
		Min.	24.7	28.6	23.4	23.8
		⊿T(Max-Min)	9.2	11.8	9.1	19.1
	Operative temp. (°C)	Max	31.8	38.9	30.0	40.1
		Ave.	28.5	34.5	25.5	29.2
		Min.	24.5	30.2	22.4	24.5
	Intermodule circulation (m/s) (Upper half of CQ)	Max	0.22	0.13	0.22	0.11
		Ave.	0.11	0.07	0.09	0.05
		Min.	0.02	0.03	0.02	0.01
	Air age(SVE3) (Upper half of CQ)	Max	1.38	0.95	1.24	1.25
		Ave.	0.96	0.79	0.94	0.93
Suction air	CO2 (ppm)	Ave.	2,418	2,864	2,429	2,861
	Temp. (°C)	Ave.	28.1	33.5	26.4	30.1
	Intermodule circuration (m/s)	Ave.	0.33	0.17	0.35	0.17

5. CONCLUSION

Regarding the CQ environmental standards, we focused on CO_2 concentration, temperature and humidity, air velocity, and noise, which are closely related to air conditioning. After verifying the validity of conventional environmental standards aimed at sustaining life, we proposed comfortable environmental standards assuming unskilled people will advance to space. Furthermore, the environment in the current air conditioning system was examined by analysis using CFD. As a result, we confirmed that the CO_2 concentration could be controlled within the range of the comfortable environment standard during sleep when the heat load was low even if the air circulation was half volume. In the future, we plan to improve the air-conditioning system and study to lower the blower noise to satisfy the comfortable environment standards including the heat sensation.

Note 1: The unit of metabolic rate “met” is the metabolic rate of 58.2 W/m2 in the state of resting in a chair.
Note 2: The unit of clothing volume “clo” indicates the thermal insulation of clothing, and refers to the state of resting in a chair at a temperature of 21.2 °C, relative humidity of 50 %, and airflow of 0.1 m/s.
Note 3: Ventilation efficiency “SVE3” is the time it takes for the blowing air to reach.

REFERENCES

[1] Sogo Nakanoya, Naoki Sato: Study status of lunar orbit gateway, the Space Sciences and Technology Conference, No.62, OS05-3, 2018.10.
[2] https://www.cnn.co.jp/fringe/35136898.html (2022.8).
[3] https://www.tte net.com/topics/2020/pdf/20200820_1.pdf (2022.8).-
[4] JAXA JEM Development Project Team: Japanese Experiment Module "Kibo" Comprehensive Report - Main Volume (Volume 1), p.232, 2010.3.
[5] NASA-STD-3000, NATIONAL AERONATUTICS and SPACE ADMINISTRATION.
[6] Air Conditioning and Sanitary Engineers Society Standard, SHASE-S102-2011 Ventilation Standard and Commentary.
[7] Federal-Provincial Advisory Committee on Environmental and Occupational Health; Exposure Guidelines for Residential Indoor Air Quality, p.8, 1989.

[8] SHASE, Concept of Indoor Carbon Dioxide Design Standard Concentration for Calculating Required Ventilation Volume, 2021.5.
[9] Tsuyoshi Iwashita et al.: Fundamental study on evaluation of indoor air quality based on human sense of smell, Proceedings of Architectural Institute of Japan, No.410, pp.9-19, 1990.
[10] Berg-Munch, B., Clausen G., and Fanger, P.O., Ventilation Requirements for the Control of Body Odor in Spaces Occupied by Women, Environment International, Vol.12, pp.195-199, 1986.
[11] Cain, W.S., Leaderer, B.P., Isseroff, R., Bergland, L.G., Ventilation Requirements in Buildings-I :Control of Occupancy Odor and Tobacco Smoke Odor, Atmospheric Environment, Vol.17(6),pp.1183-1197, 1983.
[12] Bjarne W. Olsen: ASHRAE’s History With Thermal Comfort, ASHRAE Journal pp.32～39, 2020.11.
[13] Matei R Georgescu: Accumulation and spatial distribution of CO2 in the astronaut’s crew quarters on the International Space Station.
[14] Ministry of Health, Labor and Welfare in JAPAN: Act on Maintenance of Sanitation in Buildings.
[15] ISO7730: Moderate thermal environments, Determination of the PMV and PPD indices and specification of the conditions for thermal comfort, ISO, 2005
[16] Sue Fairburn:‘Sleeping With the Stars’ – The Design of a Personal Crew Quarter for the International Space Station, Kwantlen Polytechnic University, 2001.
[17] Susan M. Fairburn: Retrofitting the International Space Station, 2009.
[18] James L. Broyan , et.al.: International Space Station Crew Quarters Ventilation and Acoustic Design Implementation.

要　約

民間人による宇宙ステーション(ISS)での滞在が実現した現在、船内の温湿度や空気質、騒音などの環境に対して、従来の職業宇宙飛行士を対象とした基準で良いのか疑問である。また、欧米人に比べ体格が異なるアジア系人種にとって、好みの環境とそれを作り出す空調方式は異なるものである。特に、深宇宙や月面までを考えると滞在時間が週単位に及ぶことから、リラックスかつ就寝の場となる CQ（Crew Quarter）には、空調の個別性かつ静音な環境が求められる。そこで、ASHRAE、ISO、日本などで評価される快適性の基準を調査し、従来の環境基準と比較評価することで、推奨の環境条件を検討した。さらに、それらの条件を満足し、かつ静音な環境を提供し得る空調方式について例示し、数値流体力学(CFD)解析による CQ 内の温湿度、気流、呼気からの二酸化炭素の分布などについて検証した。