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Structurally - technological system of a house for the lunar surface

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Abstract

There is currently an increase in activity in missions to the lunar surface. Until 2030, as part of the Artemis program (USA), it is planned to land astronauts on the lunar surface. The next step in the exploration of the Moon logically follows the creation of a permanent inhabited station on its surface. The article solves the problem of creating a structural and technological system for a residential module for lunar conditions using lunar regolith as the main building and thermal insulation material. The proposed design solves the problem of providing comfortable temperature conditions and protection from micrometeorites and penetrating radiation.

Keywords: *ADDIE model; core literacy in biology; laboratory instruction*

Introduction

Currently, there is an increase in activity in missions to the lunar surface [1]. From 2020 to 2023, 5 successful flights of unmanned vehicles from China, India, the USA and South Korea to the Moon were carried out. Until 2030, as part of the Artemis program (USA), it is planned to land astronauts on the lunar surface [2]. The next step in the exploration of the Moon logically follows the creation of a permanent inhabited station on its surface.

If at the initial stage of exploration of the lunar surface by visiting short-term expeditions, a lightweight module delivered from Earth can be used as a shelter for astronauts, then when creating a long-term habitable dwelling on the Moon, it is necessary to ensure comfortable conditions inside the living module and maximum protection of the “lunauts” from external influences [1].

Proposed building designs on the Moon focus on maximizing the use of local resources. The design of the module must include the

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possibility of using local materials and is designed for minimal energy consumption during its operation. For this purpose, in [12-19, 29-30] the use of lunar soil (regolith) is proposed for the construction of a residential module.

The use of lunar surface materials to produce cement/concrete for in situ construction has been proposed previously [12, 28-30]. [29] proposed a 3D printing technology using cement for construction on the lunar surface. Binder production requires a significant amount of consumables (chemicals and water). In [30], a stone-like material is proposed, with phosphoric acid as a liquid binder. For this purpose, significant quantities of water and phosphoric acid would have to be delivered to the lunar surface.

In [17-18,31] the possibility of creating concrete or polymer material and building a building by using a 3D construction printer is considered.

In [13-16], the possibility of constructing a building on the Moon using a 3D printer, which ensures the sintering of regolith and the creation of a given structure, is considered.

When using the solutions proposed in [12-18] and [28-30], the problematic issues will be the impact of temperature changes during the day and night on building structures, the removal of excess heat during the day [19], the high labor intensity of creating building elements and construction, especially when using technologies with regolith sintering [1 3-16].

Using a printer, you can create only the load-bearing shell of a building; other impacts on the building structure and the microclimate of the residential area must be compensated by other means. The outer shell of the building, in addition to its load-bearing capacity, must solve problems associated with the noted features: protection from temperature changes, from vacuum, from radiation exposure. Technical and architectural solutions that allow construction on the satellite itself are no less important than delivery vehicles.

The article proposes an alternative solution: use frozen water-regolith mixture as a building material for the external supporting structure. In order to eliminate the possibility of melting and destruction of the supporting structure under the influence of solar radiation during a lunar day, it is proposed to place a pipeline inside the frozen wall to pump coolant, stabilizing the wall temperature at 240K, placing layers of insulation on the inside and outside that minimize heat flows. A construction technology has been proposed that provides for the creation of an insulation system simultaneously with freezing of external load-bearing walls.

Conditions on the Moon and requirements for the design of a lunar house

To date, the geography of the Moon, temperature conditions, flow and spectral characteristics of solar radiation on the surface of the satellite, and the properties of the lunar soil are largely known, which can become a good basis for constructing a habitable module on the surface of the planet [3, 4].

Table 1 presents basic data on conditions on the lunar surface [3,4].

Table 1 Basic data on conditions on the lunar surface [3].

Atmosphere pressure	10^{-10} m m Hg
Acceleration of gravity	1/6 g
Temperature conditions	± 150° C
: Stream micrometeorites :	
Primary	Speed 19.8 km/s, particle diameter 0.305 mm, density 0.498 g/cm ^{3}.
Secondary	Speed 0.198 km/s, particle diameter 2.388 mm, density 3.490 g/cm3.
Electromagnetic radiation	Intense infrared, ultraviolet and visible radiation

A day on one side of the Moon lasts about 13.5 days, and for the next 13.5 days it is immersed in darkness
Temperature conditions on the Moon [3] :

- When sunlight hits the Moon's surface, temperatures can reach 127°C.
- After sunset it can drop to minus 173 °C. Temperatures vary across the Moon's surface as it rotates both around the Earth and on its own axis.
- However, due to the tilt, there are places at the lunar poles that never see daylight. The *Diviner* instrument on NASA's *LRO probe* determined temperatures in the lunar south pole craters to be minus 238°C and minus 247°C in the north pole crater
- the temperature of rocks located at a depth of 1 m is constant and equal to −35 °C [20].

The daily radiation dose **on the Moon** , according to data from the Chang'e-4 station [21] , is 1369 microsieverts per day, which is approximately 1.9 times higher than the same figure on board the International Space Station (731 microsieverts per day) and approximately 200 times - on the surface of the Earth (6.8 microsieverts per day).

Conditions on the lunar surface set the basic requirements for a lunar home:

- Tightness;
- The strength of the external walls and the connection with the ground surface provide the ability to withstand air pressure inside, 0.1 MPa;
- The shape of the surface of the external walls is a hemisphere or half-cylinder, which will provide the minimum surface area for a given volume;
- Continuous structural system, including the floor, without joints or prefabricated elements, which will ensure maximum tightness;
- The degree of insulation (thermal resistance) of the external walls and floor sets the power requirements of the heat supply source, and the thermal insulation structure of the floor dictates the continuous thermal insulation system within the building envelope;
- The system of external enclosing structures together with thermal insulation should ensure protection of premises from overheating during the lunar day and hypothermia at night;
- The design of external walls should provide protection from radiation and protection of living space from micrometeorites;
- Instead of windows there are television screens with the possibility of all-round viewing and switching of

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television cameras from fixed points (or with the ability to move them);

- Transitional vestibule;
- The settlement can be imagined as a garland of domes or semi-cylinders, connected by star-shaped transition tunnels: from the center to the modules.

Regolith and its properties [7]

The main building material on the moon may be regolith. As a result of meteorite bombardment, which lasted throughout the entire geological history of the Moon, a cover of loose material - regolith - was formed on its surface, which consists of fragments, underlying crystalline rocks, fragments of minerals and secondary particles formed during the shock-explosive processing of matter - breccias, agglutinates and glass particles. The average thickness of the regolith, which covers the entire lunar surface, ranges from 4–5 m in the lunar maria to 10–15 m on the continents [7]. In terms of granulometric and morphological characteristics, lunar regolith has no direct analogues among natural terrestrial formations, which, as a rule, are more homogeneous.

Most lunar regolith samples are characterized by a bimodal particle size distribution [22–25]. For example, in the Sea of Crisis, lunar regolith is characterized by bimodality with maxima of about 1 mm and about 100 μm [26].

According to granulometric characteristics, a typical lunar regolith is a poorly sorted sandy-silty soil with an admixture of rubble and blocks. The median particle size (the average particle size dividing regolith samples into two fractions of equal weight) varies from 40 to 130 μm with an average value of 70 μm [27]. Thus, approximately half of a typical lunar regolith by weight consists of particles smaller than the resolution of the human eye. The average standard deviation of the coarse fraction is 2.5 μm , which corresponds to very poor sorting. The average standard deviation of the fine-grained fraction is only slightly less – 2.21 μm , which also corresponds to very poor sorting of the fraction [27].

The average measured density of regolith is 1500 kg/m 3 [7] and increases with depth.

Data on thermophysical parameters of regolith are presented in [8-11]. The generalized results of laboratory analysis of lunar soil samples delivered to Earth by the Luna 16, 20 spacecraft and the return modules of the Apollo 10-16 spacecraft, presented in [10], give for the average value of the thermal conductivity coefficient of the regolith the value $\lambda = 0.0019$ for a temperature of 293 K and 0.0016 for a temperature of 216K. The low value of the thermal conductivity coefficient of regolith gives grounds to conclude that there is an unlimited amount of material – insulation – on the planet.

The specific heat of regolith depends on temperature and is given in Table 1 for a wide range of temperatures.

Table 1 Dependence of the heat capacity of regolith on temperature [9,11]

No.	Temperature, T , K	Specific heat capacity, s , J/(kg*K)
1	100	275.7
2	150	433.9
3	250	672.4
4	300	758.1
5	350	848.9

Material for external walls.

The most promising material for the manufacture of external walls seems to be “regolithic-frozen concrete”. The name of the material follows from its composition: a frozen mixture of regolith and water. The key condition for creating the material is the presence of water on the Moon. In [38], after analyzing impact glass in samples of lunar rock collected by the Chinese rover in the Chang'e-5 mission, it was concluded that up to 297.6 billion tons of water could be stored in impact glass on the Moon. The presence of water in meteorite glass-impactite was discovered in samples brought to Earth in the Apollo missions. On the scale of the Moon, these are incredible reserves that promise to completely provide water for lunar bases up to the production of rocket fuel, and not just for human habitation.

Finding reserves of free water is a priority issue, an attempt to solve which was made during the unsuccessful launch of the Russian spacecraft Luna-25 and is being solved by the Indian spacecraft Chandrayaan-3, which landed near the South Pole [40].

Wet soils at subzero temperatures dramatically change their properties, since the ice formed when water freezes binds soil particles into a solid, high-strength monolith. Soil moisture affects not only the conditions for its freezing, but also its strength. In frozen soil with a moisture content not exceeding the full moisture capacity and quickly frozen, it is impossible to visually detect accumulations of ice-cement crystals. Such soil is a monolith with a continuous cryogenic structure [32].

A solution of regolith in water when frozen will have significant strength characteristics. To roughly assess the properties of a frozen water-regolith mixture, you can use test data on frozen soils [32] - [34].

Taking into account the research results in [41], the closest composition to regolith from the compositions presented in [32] can be considered sand, for which the compressive strength of frozen soil at a temperature of -30°C is 7 MPa and increases with decreasing temperature. Considering the low level of gravity on the Moon, such strength makes it possible to build buildings, even several stories high. The density of frozen soil is, depending on humidity, 1600 – 2000 kg/m3 [33].

In [32], the dependences of the tensile strength of frozen sandy soil on temperature for various humidity values are also presented, which is important to keep in mind in the absence of an atmosphere and a pressure inside the module equal to 0.1 MPa. At soil moisture of 19.5% and temperature

-30^{O}C the tensile strength of frozen soil will be 5 MPa and increases with decreasing temperature.

If, under Earth conditions, load-bearing structures are calculated from the condition of combating loads caused by gravity, then in conditions of low gravity and the absence of a dense air environment, significant forces on the enclosing structures will be created by atmospheric pressure inside the habitable module. If we consider a hemisphere as the shape of the outer shell of a building, then the stress arising in the shell due to air pressure is calculated using the formula [41]:

$$\sigma = \frac{p \cdot D}{4d}$$

Where D is the diameter of the hemisphere, m; p – internal pressure, Pa ; d – shell thickness.

For p = 0.1 mPa, D =12m and d =0.2m we obtain σ =1.5 mPa.

The properties of frozen sandy soil with a humidity of 19.3% satisfy the required condition with a margin.

The water content in the mixture should be sufficient to envelop the surface of regolith particles with a thin film and for particle sizes <25 μm in diameter [9] should be about 20% [34] by analogy with the preparation of cement paste. It is advisable to carry out construction from a water-regolith mixture using a 3D construction printer , which allows direct construction of buildings in automatic mode [35-37].

The heat capacity of frozen soil can be determined by the formula [41]:

$$C_m = \frac{0,2 + 0,5 * W}{1 + W}$$

Where W is relative humidity.

For W -0.2 we get C = 1.0475 kJ/(kg*K)

The problem with using a frozen water-regolith mixture as a building material is the heating and melting of the mixture during the lunar day. To prevent this phenomenon, technical solutions are needed that ensure a constant negative temperature of the array, regardless of external conditions.

Construction of external walls.
As stated earlier, the most appropriate shape for a building seems to be a domed hemispherical structure. External walls can be formed by layer-by-layer pouring of an aqueous solution of regolith by freezing the layers. To perform the work, you can use a 3D manipulator with an insulated heated hopper for liquid water-regolith mixture and a heated pipeline with a nozzle for delivering the mixture.

To prepare the water-regolith mixture, you need an electric mixer designed to work in lunar conditions.

The thickness of the walls and the method of interface with the lunar surface can be calculated according to the formulated requirements for strength, radiation protection and protection from micrometorites.

The following sequence of work is possible:

- During the lunar day, a water-regoliter mixture is prepared, which accumulates in an insulated container with the possibility of heating;
- A surface area is being prepared for installation of the residential module;
- In the area inside the boundaries of the module location, a hemispherical shell is inflated according to the shape of its internal volume:
- Construction work to form the module is carried out during the lunar night;
- The 3D printer distributes the regolith-water mixture layer by layer around the shell, leaving a free gap between the molded wall and the shell;
- The low temperature of the surface of the moon during the lunar night will ensure that the mixture freezes while the printer passes along the contour of the building and the cycle is repeated until the dome is completely erected;
- The gap between the wall and the inflatable shell is filled with dry regolith.

This technology will ensure the parallel execution of work on the construction of the supporting structure and the creation of a building insulation system.

Simultaneously with the construction and insulation of the module, a pipeline for the movement of coolant is laid in a spiral in the frozen mass. As a result, we get a modular building, a section of which along the maximum diameter is shown in Fig. 1.

To minimize the absorption of solar radiation, the surface of the dome and eliminate the sublimation of moisture from the frozen massif is advisable to cover with an additional layer of insulation and a reflective vapor-proof coating.

By pumping coolant through a pipeline in a frozen massif, it is possible to stabilize the heat removal from the premises at a constant level during the day and night time of the lunar day. One of the possible options for stabilizing the temperature of the coolant is pumping it through a heat exchanger at a depth of more than 1 m in the ground, where the temperature is stably at the level of 238 K [20].

The second possibility is related to the heat-storing properties of the frozen massif. In order to maintain the temperature of the array below a given threshold, during the lunar night, by pumping the coolant with the release of excess heat into the surrounding space, it must be cooled so that the arrival of solar energy during the lunar day does not increase its value above the established limit

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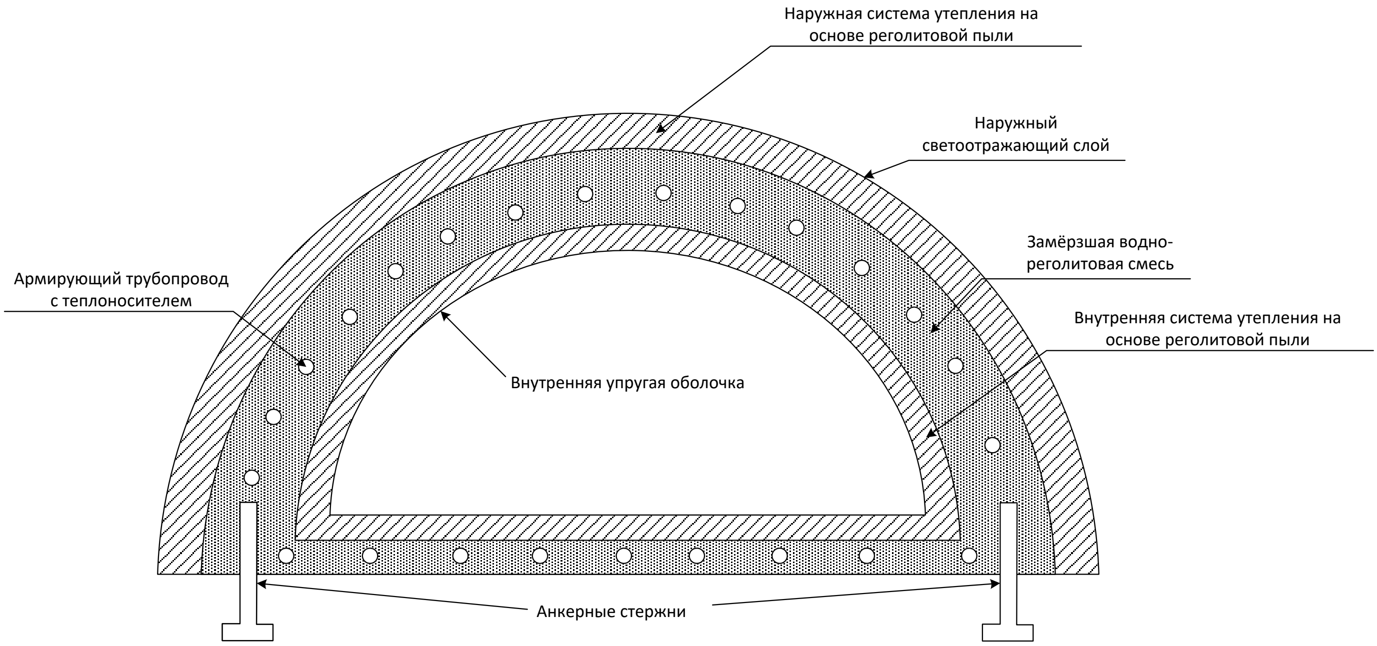

Figure 3 Sectional view of the building along its maximum diameter.

With the chosen design of external walls, the room insulation system is located inside the building. Under a pressure of 0.1 MPa, the inner shell will compact the regolith located between the shell and the frozen massif. The required value of the thermal resistance of the internal insulation system can be calculated from the heat balance equation under the formulated conditions for temperature values:

- inside the building, $T_0=22^{O}$ C ;
- vault of heaven -270.5^{O} C [43] ;
- coolant temperature in the pipeline -35^{O} C ;
- wall surface emissivity 0.05 ;

For the case of stabilizing the temperature of the frozen mixture at the level of $-35\ ^{0}$ C, we obtain the heat flow through the internal insulation system, without taking into account the additional thermal resistance of the wall air layer:

$$q = \frac{\Delta T}{R}$$

Where $\Delta T = 57K$; $R = \frac{d}{\lambda}$

d – thickness of the insulation layer, m;

λ – thermal conductivity coefficient of insulation, W/(m*K).

According to [10], the thermal conductivity coefficient of regolith is 0.0016 W/(m*K).

For example, let us consider the transmission heat loss of the interior of a dome-shaped building in the form of a hemisphere with a floor area of 100 m2 , uniformly insulated from the inside at a temperature of the load-bearing shell made of frozen water-regolith mixture $-35\ ^{0}$C. The area of the enclosing structures of the outer wall plus the floor is 300 ^{m2}. Table 1 presents the values of transmission heat losses for different thicknesses of the insulation layer of internal premises, considering the temperature of frozen regolith concrete equal to -35^{O} C.

Table 1 The values of transmission heat losses for different thicknesses of the insulation

d ,m	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
R, m^2*K/W	31, 3	62.50	93.75	125.00	156.25	187.50	218.75	250.00	281.25	312.50
q , W/ ^{m2}	1.82	0.91	0.61	0.46	0.36	0.30	0.26	0.23	0.20	0.18
Qin , $_{W}$	547, 2	273.60	182.40	136.80	109.44	91.20	78.17	68.40	60.80	54.72

We believe there are 4 people permanently present in the building. In this case, heat generation from the presence of people will be 400 W [42]. To this you can add energy for lighting and operation of personal equipment, say 200 W. For the expected conditions, an insulation thickness of more than 0.1 m is sufficient. The excess thermal energy that appears in the premises will be removed during air exchange. There are no heat losses from ventilation, therefore an additional air preparation system is required, which involves regenerating already used air, removing harmful impurities and excess heat, and also bringing its quality to the established values.

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As insulation, we assume regolith compacted by atmospheric pressure between the inner shell and the load-bearing wall of the building.

One of the problematic issues that requires a solution is the discharge of excess thermal energy during the lunar day.

Regardless of the design of the envelope, it is advisable to install a reflective coating to reduce the flow of solar radiation, for example, by covering the building with an aluminum-coated film. The heat balance equation for determining the temperature of the outer surface of the module can be written as:

$$(T - T_1)/R + \alpha * \sigma * T^4 - \alpha * Q_c = 0 (1)$$

Where T, K – temperature of the surface of the module wall;

$T_1 = 240$ K – average temperature of the load-bearing part of the wall. To simplify, we assume that the temperature of the wall mass is equal to the temperature of the coolant.

R, W/(m^2 * K) – thermal resistance of the layer through which the heat flow is calculated,

$\alpha = 0.05$ – degree of blackness of the outer surface with a reflective coating;

$\sigma = 5.67*10^{-08}$ W/(m^2 * K^4) – Stefan-Boltzmann constant,

$Q_c = 1360$ W/m^2 – solar radiation flux on the Moon.

From the heat balance equation (1) for stationary conditions, the temperature value T on the surface of the outer shell of the module is calculated, and the following values are determined from the temperature value:

- $q_1 = (T - T_1)/R$ – heat flow from the outer surface to the wall structure;
- $Q_1 = q_1 * S$ – thermal energy coming from solar energy through the shell. It is discharged outside using coolant circulating in a pipeline located in the shell, as shown in Fig. 1.
- $q_2 = \alpha * \sigma * T^4$ – radiative heat flow from the surface into space;
- $Q_2 = q_2 * S$ – thermal energy removed from the shell by radiation;
- $S = 200$ m^2 – area of the outer surface of the hemisphere.

Table 2 presents the calculation results. In the first line of the table, the calculation is performed for the case when the frozen mass is covered with a reflective film with a reflection coefficient of 0.95. In this case, about 5% of solar radiation passing through the reflective coating is directed into the array and must be removed outside with the help of a coolant.

Options 2-5 correspond to cases when the frozen massif is covered with a layer of insulation from regolith, and on top - with a reflective coating. A 5cm insulation layer reduces the value of thermal energy that needs to be removed from the array by more than an order of magnitude, and a 20cm insulation layer leaves only 240 W of energy entering the array. The 5th option corresponds to the case of the absence of a pipeline in the array. If there is no coolant, the surface of the dome will heat up to 393 K (120°C) during the lunar day and the dome will melt.

When calculating the amount of thermal energy removed by the coolant, it is necessary to take into account the additional thermal energy coming from the room, the values of which are given in Table 1. The first calculation option in Table 2 refers to the case of the absence of insulation above the surface of the frozen mass. Options 2 – 5 refer to cases where there are layers of insulation of varying thicknesses over a frozen load-bearing shell.

To remove excess heat from the load-bearing shell and maintain the temperature of the load-bearing shell at a level of 240 – 250 K, an ethylene glycol solution is pumped through the pipeline in the shell [39]. For a coolant temperature at the pipeline inlet of 240 K , and at the outlet - 250 K , the last column of Table 2 presents the values of the coolant velocity required to remove excess heat coming from the flow of solar energy and energy coming from the premises of the lunar module through the insulation layer equal to 20 cm. The table also shows the calculated temperature T of the outer surface of the shell. The calculation takes into account the presence of an insulation layer and a reflective film on the surface of the insulation layer.

Table 2 Results of thermal engineering calculations for the lunar day.

For coolant: $\rho = 1108$ kg/m^3, C = 3.04 kJ/(kg* K). $T_1 = 240$ K.

No. p/p	λ, W/(m* K)	d_1, m	q_1	q_2	$Q_1 = q_1 * S$	$Q_2 = q_2 * S + Q$	T	V, l/s
1	2	0.2	57.5	10.3	11500	2060	245.8	0.34
2	0.0016	0.05	4.7	63.3	940	12660	386.5	0.03
3	0.0016	0.1	2.4	65.6	480	13120	390	0.02
5	0.0016	0.15	1.8	66.2	360	13250	391	0.015
4	0.0016	0.2	1.2	66.9	240	13380	392	0.01

Table 3 shows the calculation results for the lunar night. In this case, the flux of solar radiation, $Q_c = 0$.

Table 3 Results of thermal engineering calculations for a lunar night

λ , W/(m* K)	0.0016	0.0016	0.0016	2	0.0016
d, m	0.2	0.1	0.05	0.2	0.15
T, K	132	150	168.5	239.8	152.3
T_1, K	240	240	240	240	295
q_2, W/m^2	0.86	1.44	2.29	9.25	1.53
$Q_2 = q_2 * S + Q$, W	172.14	287.04	457.07	1850.01	305.06
V, l/s	0.005	0.009	0.014	0.055	0.009

A comparison of the results of calculating the coolant velocity in Tables 2 and 3 shows that the calculation results for daytime are sufficient for the operation of the system during the lunar night.

The second option for maintaining a low temperature of the frozen load-bearing shell of buildings during the daytime is to use the thermal inertia of the shell. For this purpose, during the lunar night, using a pipeline with a coolant, it is necessary to lower the temperature of the supporting shell so much that the supply of thermal energy during the lunar day does not increase its value above the established limit, for example, 240K. Table 4 shows the results of thermal engineering calculations of the shell for various degrees of insulation over the frozen shell. It is assumed that the supply of thermal energy from the module premises corresponds to the case of internal insulation of 25 cm (see Table 1). The option of no insulation above the load -bearing shell is unacceptable due to the too large value of Δ T.

With the thickness of the frozen mass D = 0.34 m, its heat capacity will be equal to

C= 126 MJ/K.

The energy E entering the array during the lunar day is equal to:

$E = (Q_1 + Q_{in})*24*14.5*3.6//1000.$

It should be noted that during the lunar night, the temperature of the array must be lowered by the same number of degrees, that is, an amount of thermal energy must be removed equal to that received during the lunar day. This can be done by pumping coolant through a flat heat exchanger of the appropriate area S given in Table 4.

Taking into account radiation heat exchange with the vault of heaven, the heat exchanger area is equal to:

$S=(Q_1+Q_{in}) /(\alpha * \sigma * T^4)$,

Where $\alpha=0.9$.

Table 4 Increase in temperature of the massif during the lunar day

d_1 ,m	0	0.05	0.1	0.15	0.2
E, MJ	14543	1314,	737	587	437
ΔT , K	114.9	10.38	5.83	4.64	3.45
S, m^2		6.2	3.5	2.8	2.1

It should be noted that regolith, as a material for insulation, is found in abundance on the Moon, while other materials, except water, must be delivered from Earth.

With a thickness of the frozen soil wall of 34 cm, the area of contact with the surface of the lunar soil will be 12 m2 , a pressure of 0.1 MPa inside the living quarters will create a tensile force along the contact contour of the module wall with the lunar soil equal to 20 MN or the breaking stress in the wall will be 1. 66 MPa, which is less than the tensile strength values for frozen soil, for a humidity of 19.3% and exceeding 5 MPa for temperatures below -30^{O}C [32]. For a frozen regolith-water mixture, additional studies of thermal and physical properties in the operating temperature range are necessary.

The building envelope of the considered design will also provide protection from radiation. If we consider the properties of compacted regolith (frozen water-regolith mixture) by analogy with compacted soil, with a dome thickness of the frozen mixture of 34 cm plus a layer of regolith dust (insulation), the radiation inside the building will weaken by 128 times [10], i.e., daily The radiation dose will be 10 microsieverts, slightly exceeding the earthly level, which will ensure long-term stay of people in the Lunar Module without harm to their health.

Conclusion

When creating a long-term habitable dwelling on the Moon, it is necessary to ensure comfortable conditions inside the living module and maximum protection of the “lunauts” from external influences.

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Proposed building designs on the Moon focus on maximizing the use of local resources. The design of the module must include the possibility of using local materials and is designed for minimal energy consumption during its operation.

Conditions on the lunar surface, including temperature changes between day and night, solar radiation and ionizing radiation, made it possible to formulate the basic requirements for a lunar home.

The article proposes fundamental solutions to ensure the construction and operation of a residential module for the lunar surface:

- use frozen water-regolith mixture as a building material.
- A module wall design is proposed with a pipeline frozen inside for pumping coolant, stabilizing the wall temperature at 240K, which ensures stable operation of the residential module both during the lunar day and at night;
- construction technology using a construction 3D printer ;
- simultaneous construction of external load-bearing walls, laying a pipeline for coolant inside and creating an insulation system.

Thermal calculations were performed for the module surface temperature and the components of the heat balance during the day and night. The proposed design of the outer wall includes external and internal insulation using lunar regolith as insulation. Stabilization of the temperature of the frozen water-regolith mixture by a pipeline with coolant located inside the monolith will ensure a constant level of heat loss from the module during the lunar day. Discharge of thermal energy by a coolant is possible by pumping it through a heat exchanger in the ground at a depth of about 1 m, where the temperature is stable at 238K.

The proposed design also provides protection from radiation exposure, reducing radiation levels to earth levels.

The technical solutions proposed in the article for the construction of residential modules can be used on other planets with no atmosphere and similar temperature conditions.

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