A low technology approach to keeping a lunar settlement alive during a fortnight of lunar night

Building a moon settlement has been a dream from the early days of space exploration on. During the days of the Apollo Moon program it seemed to be the perfectly natural next step to space. Then the Moon turned out to be an airless, dead body, boiling hot during the day and freezing cold during the night.

At a fist glance it seems that settling regions on Earth which exhibit less extreme conditions, like for example Antarctica, or more distant celestial bodies like Mars could be done much easier than settling the Moon. But if we take a closer look, it turns out that it is exactly the extremeness of the Moon which allows for radically different approaches, impossible in the hostile but not yet hostile enough environment of the south pole or the red planet. The big advantages of the Moon are in fact cheaply available energy and a total lack of weather. No violent ice or dust storms that would damage buildings, blind windows and tear down mirror arrays, no drifting ice, no piling up of snow or sand, etc.

Cheap energy is supplied by the sun. On the Moon the sun shines about two times brighter than at the most sunny and cloudless regions on Earth, because there is no atmosphere to scatter and reflect part of the suns light away. Of course it does only shine for two weeks out of a moon day, followed by two weeks of moon night. This shortcoming is the main subject of this text.

No weather is a really big advantage when building is concerned. Of course it also helps that gravity on the Moon is only about one sixth of Earths gravity, but only in combination with a total weatherless climate this allows for large, lightweight installations of mirrors to collect sunlight.

But how to store energy for night time use? Theoretically there are plenty of ways to do it. It could be stored in batteries, as hydrogen and oxygen to be burned in fuel cells, etc. Even magnetic storage in large superconducting coils was proposed.

But consider this: bringing an astronaut to the Moon costs about its weight in gold. The same holds for any equipment or material brought from Earth. We may expect prices to drop, but flying stuff from Earth to the Moon will stay expensive. So ideally a moon settlement should live and grow completely self-contained and independent from Earth supplies. In other words: after the initial moon settling base is built, only resources available on the Moon should be used to build more moon settlements. And since the initial settlement should be as small as possible, the available technological base is limited.

Only the most crucial key technologies will be developed. That means while it is possible to use solar energy to convert moon dust into metal and oxygen, only one or two processes to do this can be implemented, because there will be only a small number of people to research, engineer and control these processes. Furthermore only a limited number of chemical elements are easily available from surface mining. Unless good locations of mines for lacking elements are found and developed on the Moon, the moon settlement has to live with a very limited set of materials and as a consequence must work on a lower level of technology. Building batteries or fuel cells needs some very special materials.

So a consistent set of low-tech solutions for all critical components of a lunar settlement have to be found, using only a minimum industrial base, i. e. using a minimal set of key industrial processes. We are used to associate space technology with the very finest and best earth with its billion people industrial base is able to produce. In contrast to that envisioning a lunar technology based on a few hundred people is a little like knowing all of todays science but having only a potter, a smith, and a glass-maker from the 18th century to build what is needed, i. e. craftsmen from the times when the first steam engines were invented.

Some space-advocates suggest to go to an even more extreme environment than the Moon and to settle in free space itself using resource brought from the Moon or from asteroids. This may very well turn out to be a good thing to do for a highly productive high technology society in space. But going for this goal immediately means to bring high technology to space in a single step, which would need an enormous effort. Compared to this the Moon seems to be an excellent stepping stone on which the time consuming process of developing and optimizing vacuum technologies like mining, refining, purifying, casting etc. can be done with respect to free and easily accessible sunlight energy. Also the Moon offers plenty of material to built upon and within, while being always close enough to Earth to allow to abort a mission or to return seriously sick or injured astronauts to Earth or to send help within a few days in case of an emergency.

Having plenty of material available on the moon allows to build solid and sturdy installations which last for many decades or even centuries without much maintenance needs, which is exactly what a labor-intensive low technology civilization needs. When the moon settlement becomes large enough to sustain a highly diversified high technology, the next steps of settling space will have become much easier and straightforward.

Electrical motors and generators are well possible to build for a low technology society, but only at much higher costs than what we are used to. Electrical motors are more complicated than steam engines and take more labor to build. So in the beginning of settling the Moon it might well be better to transfer energy in simpler forms like heat or pressurized gas directly to a motor or a heater instead of converting pressure to electricity first and then to convert it back to force and heat like we are used to do it on Earth. It might be worth noting here that energy transmission by pressurized air was and is still used in mines and places where sparks may cause explosions. As a beneficial side effect, this supports air ventilation.

Even though the need for electricity may be reduced, technology without electricity seems unlikely. On Earth most electricity is created with the intermediate step of mechanical energy. Converting solar energy to electrical energy can also be done by solar cells or by thermoelectric converters. Solar cells convert sunlight into electricity directly. But solar cells need semiconductors, which are well beyond the precision and purity capabilities of low technology, as I was told by several physicists working in semiconductor research. Furthermore solar cells do last only a few years when exposed to radiation of free space.

Thermoelectric converters based on the Seebeck effect convert heat into electricity directly. But even modern thermoelectric elements built from exotic materials have a much lower efficiency than solar cells. Those build with the few available metals available on the Moon may have some limited use, but whenever large quantities of electricity are needed, electrical generators are better suited. Avoiding conversion of solar energy to electricity for heating, lighting and motors whenever possible is probably the easiest way to go, but not always possible, especially when lighting is concerned.

So all solar energy conversion processes on the moon will use heat energy as an intermediate or even final step. Considering all of the above, the easiest, most useful and most flexible way to store energy for night-time appears to be by thermal energy storage. This principle is already successfully used on Earth. E. g. a night storage heater is heated up when cheap energy is available and gives away this thermal energy hours later when it is needed. An even more ancient application of this principle are stone ovens, which consist of a stone housing in which a fire is burnt for some time. Then the fire is removed and bread, pizza etc. is placed into the housing to bake. All the energy for baking is stored in the stones of the housing.

Of course an oven or a night storage heater which can store enough energy for heating and lighting several greenhouses and habitation buildings of a lunar settlement has to be much larger than a heater for a single room. Making it larger almost automatically reduces heat losses very much, so the problem of storing thermal energy for two weeks is solved easily.

Another everyday example of storing thermal energy is the thermos flask, which uses vacuum to avoid conductive thermal losses and metallic mirror-like surfaces to reduce losses by radiation. To point out the obvious: a metal suitable for mirrors is most certainly a key technology for lunar settlement and vacuum is available plentiful.

So my proposed low technology solution to store energy for the lunar night consists of a hole into which mirrors direct an intense flow of solar energy during lunar day. The hole is surrounded by a few meters of moon rocks, sintered moon dust or similar, which is covered by some thermal insulation. In its simplest form this thermal insulation could consist of about two meters of lunar sand. When night falls on the Moon the hole can be closed to reduce thermal losses due to heat radiation.

Pipes run through the rock surrounding this oven. Through these pipes some gas or liquid (e. g. water, steam, oxygen, or helium) will be pumped to extract the desired amount of thermal energy from the storage. In case thermal stress on the pipes causes leakage problems, rods of thermal conducting material could be used instead. Energy can be extracted day and night, so all machinery and installations using thermal energy can easily be designed to work all the time with mostly unchanging working conditions.

Some industrial processes, especially those that need very high temperatures (e. g. glass production) or very much energy (e. g. metal extraction from moon dust) may be difficult or simply not economical to be run from such a thermal storage oven. But two weeks should be long enough to start and end a production cycle. Furthermore there will be plenty of other, low energy tasks to do, which will keep the lunar settlers busy during the long night. And last but not least, they need and deserve some time for recreation and education.

Such an oven can easily supply heat to keep the settlement comfortably warm, for cooking and for some manufacturing processes. A more difficult task is to supply light for the settlers and–even more important–to supply enough light to keep the plants in the greenhouses alive. Generating low-tech electricity is labor intensive and building low technological but still reasonable efficient lamps isn't trivial either. Similarly to the direct, electricity-less transfer of force proposed above, direct use of sunlight for plant growing whenever possible simplifies technological demands very much. But what to do during the night? I know of no efficient method to store light directly and contemplations about efficiency of non-electrical lamps shall be skipped here.

Some simple plants like algae can be seeded, grown and harvested within two weeks. Furthermore it is worth noting that some plants can endure long times without light, e. g. when buried under snow for some weeks in winter. Some of them may be bred to be able to adapt to one winter per month. An the other hand side, many agricultural plants can easily stand two cloudy weeks, so they only need a few hours of comparatively dim light every 24 hours to stay healthy. So in the end the electrical needs of a low-tech settlement may be kept quite low.

Lets put some numbers into a simplified and somewhat random example to demonstrate the feasibility of the proposed simple thermal energy storage scheme. At first we need to estimate some thermal properties of moon rock and sand. It is said that moon rock is basically the same as Earth rock. Sand basically consists of grains of rock. Sand has a thermal conductivity of about 0.3 W/mK (Watts per meter and Kelvin) while rock has a much higher conductivity of about 2.9 W/mK. The difference is probably due to the gaps between grains of sand. Thermal conductivity of air is quite low, and within lunar vacuum conductivity of sand will be even lower. Thermal capacity of sand is 0.8 kJ/kgK (kilojoule per kilogram and kelvin). A typical density of rock is about 3 t/m^3 (3000 kilograms per cubic meter, i. e. 3 kg per liter, three times as heavy as water). Let's use rock which can be heated up at least to 1000 ℃, i. e. to 1300 K, which is considerably less than what the material used in night storage heaters can stand.

So let's say the oven has a hole of 8 m depth and 2 m width. That hole is surrounded by 4 m of rock, which in turn is surrounded by 2 m of sand. Then the volume of the hole is $1^2 \cdot \pi \cdot 8$ m^3 = 25 m^3. Volume of the energy storing rock around the hole is $(4+1)^2 \cdot \pi \cdot (8+4)$ m^3 - 25 m^3 = 920 m^3. This means it has a thermal storage capacity of 920 m^3 · 3000 kg/m^3 · 0.8 kJ/kgK · 1300 K = $2.9 \cdot 10^9$ kJ = 800000 kWh. To give a better idea of that amount, we might divide it by 14 days of night, which gives 2.4 Megawatts as an upper limit to the continuous power output during lunar night.

Knowing this we can get a better impression of the size of this power station by estimating the necessary area of mirror surface. Sunlight on the Moon delivers 1.4 kW/m^2. So an area of about 2.4 MW / 1.4 kW/m^2 = 1700 m^2 is necessary. As we see later about half of that energy will always stay in the oven, so half of this energy flow can already be used during the daytime, or be spared to compensate for losses due to sunlight arriving at a sharp angle and radiation losses through the opening of the oven. 1700 m^2 of mirror surface could be built as a single parabolic concentrator with 24 m radius. But probably it is easier to build, maintain, and control it as a farm of more mirrors of smaller size.

How much energy is lost due to imperfect insulation? Outer surface area of the oven insulation is about $(2+4+1) \cdot 2 \cdot \pi \cdot (8+4+2) + 2 \cdot (2+4+1)^2 \cdot \pi$ = 920 m^2. 2 m of sand at peak temperature of 1300K on the inside and about 300 K at the outside conduct 0.3W/mK · 1000K · 920m^2 / 2m = 140 kW. This uses the simplified form of Fourier's law, which assumes the insulating layer to be flat, which isn't exactly true. Surface area of the rock area around the oven hole is only $(4+1) \cdot 2 \cdot \pi \cdot (8+4) + 2 \cdot (4+1)^2 \cdot \pi$ = 530 m^2, so the effective heat loss will be considerably smaller. And while the oven becomes colder, the loss becomes smaller too. Basically this estimate tells us that even with a simple isolation scheme like this, i. e. putting some sand around the heat storage, thermal losses are already very small. Less than 6% of the thermal energy is lost during lunar night in this example.

How much of the remaining thermal energy is usable? It depends very much on how it is used. Let's consider conversion of thermal energy into mechanical energy here. This in turn depends on the temperature of the heat sink and the degree of efficiency of the machine doing the conversion. The efficiency is limited by physical laws to $1-T_0/T_1$, where T_1 is the temperature of the hot side of the machine and T_0 the temperature of the cold side. If we choose T_1 = 600K and T_0 = 300K (note that the Moon has a constant temperature of about 250 K or -20 ℃ a few meters below the surface) we can use the oven until it reaches a temperature of 600 K, i. e. we can use (1300-600)/1300 = 54% of the thermal energy. Note that most of the remaining 46% of residual thermal energy in the oven can be re-used for the next month. And we can convert these 54% at an efficiency of less than 1-300/600 = 50%, so ideally 27% are usable.

Note that it is well possible to use higher temperatures and correspondingly higher degrees of efficiency while high temperatures are available and theoretically it is also possible to radiate away the heat from the cold side into space and have T_0<10 K and hence we would be able to use almost all of the thermal energy at a quite good average efficiency, but this imposes some difficulties on engineering the machinery. For this example I assume that unchanging working conditions for generators and machinery are worth the trouble of making the thermal storage oven etc. correspondingly larger.

Thermoelectric power plants on Earth have a conversion efficiency of about 30%. The lunar installation will use a lower level of technology, which might reduce efficiency further. So let's say all in all 10% of the above 2.4 MW can be converted to electrical energy. This is still 240 kW of continuous electrical power supply, which is enough to power either 2000 to 20000 lamps for living quarters or to light some 500 lamps for greenhouses. So we may imagine the kind of power storage of this example to be used for small villages or farms. Building larger power stations with thermal night time storage for larger facilities will be even more efficient as soon as they become economically reasonable.

Concluding from the above, thermal power storage for lunar nights is feasible, simple, and efficient. It can be built with materials readily available on the Moon using only very simple processes of refinement. It is highly efficient due to the environment of the Moon and because storage is done before conversion to mechanical or electrical energy is performed. It is suitable to be applied both in a low technology scenario as well as in a high technology moon settling initiative and may even be considered for an initial moon base.