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Preliminary Design of a Climate Controlled Environmental Test and Measurement

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***Abstract.* Climate chambers play an important role in the design and testing process. Several different chambers have been built over the years, specialising in different areas. It means there is a wide choice on the market and as a consequence, parameters necessary for us limit when choosing the ideal test chamber. Our instruments might be subjected to several environmental effects which require a lot of time and effort to be tested. An example is the Mars rover. NASA's Perseverance Mars rover was equipped with 2 pieces of Li-ion battery packs and the old solar charging was replaced by RTG (Radioisotope Thermoelectric Generator) thus a generator feeds the electricity consumers of the rover. Temperature on the surface of Mars varies from -150 C° to 20 C°. In addition, there are huge storms at regular interval lasting for month sometimes. These storms cause great difficulties because, on the one hand, the main power source on older types was the solar panels, and storms can cover them with Martian dust, limiting or eliminating their power supply. On the other hand, large sandstorms can completely cover the rover, and once the sandstorm is over, the Mars rover has to free itself from its trap. In addition, there were many other factors that engineers had to consider in the design. It is a well-known fact that we are not able to consider all the possible environmental conditions in design, and it is also known that some measurements may be inaccurate, so the prototypes produced have to be tested on the ground. The ground tests must ensure that the operating conditions on Mars are maintained. Special test chambers have been developed for this purpose. [1] The aim of the authors is to design and build a prototype of a climate chamber of their own design. An important component of the chamber is a measurement data acquisition system, which allows the collection of measured data and their preliminary processing.**

Keywords. measuring system, chamber, test, climate controlled environment, battery

I. INTRODUCTION

The most important factor for us in selecting the right battery for a given application is to determine the long-term low, high and sudden loss of battery performance due to large temperature changes. The primary and most important sizing design requirement for the test chamber we were designing was also the environmental parameters on which we wanted to test the devices. The test chamber was initially designed to test the discharge and charge temperature of Li-ion batteries code '18650' used in electric vehicles, but there are more than 3000-4000 of these batteries in a vehicle, weighing up to 400-500 kg. For example, in a Tesla Model 3, the largest battery pack with a net capacity of 75kWh is made up of 7104 of these small cells. These battery cells can only be tested in small quantities, but to test the total battery performance for a viable charge and discharge performance, a properly built electronic control unit would be required, and in addition, purchasing a battery set of this size would be quite expensive, not to mention the size and weight of the battery set. [2]

After the considerations above, we switched to the batteries of small UGV (Unmanned Ground Vehicle) and AGV (Automated Ground Vehicle) vehicles, as the batteries of these vehicles, given their size, can be conveniently placed inside the chamber and also require a smaller capacity system in terms of electronic power. We have also looked at the potential testing of UAV (Unmanned Aerial Vehicle) batteries, as, for example, in the case of a larger UAV, the temperature can cool drastically by up to 20°C - 30°C in a very short time due to rapid climb. These vehicles mainly use Li-ion and Li-Po batteries, whose assembled batteries are designed for low voltage (below 50V). These energy sources have a low energy density and therefore have a short range and short operating time due to current technology limitations. It is worth mentioning that there are also solar powered, electrically driven UAVs (e.g. NASA Helios, NSA Pathfinder, etc.) that continuously charge their batteries during flight. The test chamber must be able to model not only the environmental effects but also the load current that will model the battery load, as these vehicles consume electricity during use, ideally little, but in extreme cases, the battery may be subject to higher instantaneous loads. [3]

II. THERMAL INSULATION MATERIALS

Choosing the right insulation material is also a key element in the construction of a climate chamber. Since all the materials have thermal conductivity (which cannot be equal to zero), the have thermal resistance and therefore all the materials have thermal insulating property including thermal insulation plasters: [4] [5] [6] [17]

- poor thermal insulation materials (0.15 W/mK < λ),
- medium insulating materials (0.06 W/mK <λ<0.15 W/mK),
- good thermal insulation materials (λ < 0.06 W/mK).

When a structure with any heat transfer value is complemented with a material with good insulation properties, it is called the insulation of the structure. [4] [5] [6] Thermal insulation materials consist of a solid skeleton and air-filled pores, capillaries. Since stagnant air is a good insulator, its presence in the pores provides good thermal insulation [4] [5] [6] Thermal insulation significantly reduces the differential thermal movement of the layers of the structure and the resulting stresses caused by daily and annual thermal fluctuations. They prevent or eliminate the damaging effects of vapour on the layers of the structure, its internal surfaces and/or along thermal bridges and reduce the cost of running the building. [4] [5] [6] [17]

The main requirements for thermal insulation materials are as follows [4] [17]

- the most important is the low coefficient of thermal conductivity;
- physical and chemical stability over the temperature range in which the material is used;
- not be hygroscopic, preferably insensitive to moisture. Water in thermal insulation materials significantly reduces the thermal insulation performance;
- no corrosion between the insulation materials and the materials in contact with them;
- • thermal insulation materials must be inert to various rodents and fungi;
- • in specific applications, insulating materials must be load-bearing. This is the case, for example, of a step resistant thermal insulation layer under floor coverings.

A distinction is made between fibrous, porous and bulk thermal insulation materials. [4] [5] [6] Types of thermal insulators [4]:

- fibre thermal insulation;
- hollow thermal insulator;
- bulk material for thermal insulation;
- fibrous thermal insulation materials;
- rock wool products;
- glass wool products;
- cement-bonded wood-concrete thermal insulation boards;
- hollow thermal insulation materials;
- foam glass;
- polystyrene foam;
- polyurethane foam products;
- polyethylene foam products;
- cork thermal insulation products;
- perlite and perlite products;

For battery environmental testing, it is essential that the built-in chamber is adiabatic, i.e. that there is no heat transfer between the chamber and its surroundings. [4] [5] [6] An adiabatic change of state or adiabatic process is a change of state in which there is no heat transfer between the thermodynamic system and its environment. For ideal gases, which have no internal friction, an adiabatic change of state is also an isentropic change of state, i.e. the entropy of the system does not change during the process. The word is of Greek origin. Diabatos (διαβατός) means walkable. The first word in the word is fostos: impassable. [14]

III. TEST CHAMBER SIZING

Due to the easy and cost-effective construction of the test chamber, EPS insulation material was chosen which is available at any construction shop. [4] EPS (expanded polystyrene) is a thermoplastic, foamable rigid foam with a cellular structure made from polymerised styrene. It is foamed by means of a steam heat treatment with pentane in the base material. It is also self-extinguishing due to the flame retardant additive already mixed into the base material. During the production of the material, the pentane is burnt out by heat treatment, creating very small holes in the material providing satisfying thermal condition. [4] [16] The most important characteristic of expanded polystyrene foam is its very good thermal insulation properties, due to the air that is kept in the closed cells. The sealed air does not escape from the cells and the thermal insulation properties of the material do not decrease over time. [4] [16]

3.1. Heat transfer coefficient – heat loss

Heat loss is the phenomenon where two media at different temperatures (for example, the heated air space of a dwelling and the air outside) exchange heat. The thermal insulating properties of the material separating them (insulating material) affect the amount of heat that is transferred: the better the insulating properties, the less energy is lost from the higher temperature medium to the lower one, i.e. the lower the heat transfer coefficient, the less heat is lost. [7] [8] [9] [10]

The unit of heat loss is W/K. The surface area (m^2) is obtained by multiplying the heat transfer coefficient (U, formerly k) (W/m^2K) by the surface area. [7] [8] [9] [10] It shows how much heat energy is dissipated per square metre of insulating medium per unit time if there is a difference of one Kelvin between the temperature of the outside and the inside.

For example, if U=1W/m2K, this means that 1 J of heat is lost per second (to the colder medium, by definition) per square metre of insulating surface separating two media of different temperatures, if the difference in temperature between the two media is 1 K. [7][8] [9] [10]

The rate of heat loss is therefore directly proportional to the size of the insulating surface and the difference between the internal and external temperature. [7] [8] [9] [10]

3.2. One dimensional heat transfer

One-dimensional heat transfer is a characteristic of a homogeneous surface. It gets its name from the fact that the heat flux across the surface is unidirectional, perpendicular to the surface. It can be calculated using the following equation [7] [8] [9] [10]:

$$Q = q \times A\ [W] \tag{1}$$

where q is the heat flux and A is the surface area.

3.3. Heat flow

The heat flux is given by the following equation

$$q = U \times (t_i - t_e)[\frac{W}{m^2}] \tag{2}$$

where U is the heat transfer coefficient, ti is the internal temperature and te is the external temperature.

3.4. Heat transfer coefficient

The heat transfer coefficient is the rate of heat loss in the house at the difference between the internal and external ambient temperatures. If this number is lower, the heat loss from your home or garage and therefore the heating bill will be lower. In other words, the heat transmission coefficient shows how well a material, such as reinforced concrete walls, bricks or stone walls, insulates. [7] [8] [9] [10]

$$U = \frac{1}{\frac{1}{h_i}+\Sigma\frac{d}{\lambda}+\frac{1}{h_e}}\ [\frac{W}{m^2K}] \tag{3}$$

where hi and he are the internal and external heat transfer coefficients (previously denoted αi and αe), respectively; d is the thickness of the structural layer; λ is the thermal conductivity of the structural layer material; The heat flux is proportional to the temperature difference, the cross-section perpendicular to the direction of the heat flux, and a conduction coefficient. The latter is the coefficient of thermal conductivity, which expresses the heat flux per unit time through a material of unit thickness and unit surface area perpendicular to the flow, under the influence of a unit temperature difference. Its unit of measurement is J/s m K, i.e. W/mK, its usual symbol: a. [7] [8] [9] [10] [13] [14]

In the design and sizing process, the thermal conductivity of the materials must be taken into account, reflecting the effect of the installation and the way in which they are used. If such data are not available, the thermal conductivity of 'new from the factory' materials should be corrected on the basis of empirical relationships. [7] [8] [9] [10] [13] [14]

The correction is usually made by

$$\lambda_{korr} = \lambda_0 (1 + k) \tag{4}$$

is described by the equation. For passive houses, the U value should not exceed 0.15 W/m2K. When sizing the prototype measuring chamber, it is sufficient to go below the thermal transmittance of passive houses. The resulting energy loss is not expected to have any effect on the accuracy of the measurements, and it is possible to maintain the set temperature parameters with a small energy investment. The modifying correction factor in equation (4), depending on the installation method and the conditions of use, is 0.42 [7] [8] [9] [10] [11] [13] [14]

IV. TEST CHAMBER DEISGN

The chamber is made of EPS G 80 graphite façade insulation board with dimensions 30 cm x 50 cm x 100 cm. The sheets were fixed using TYTAN B3 low heat transfer coefficient hand adhesive with a low heat transfer coefficient similar to pur foam. External parameters of the chamber with closed door: 210 cm long, 130 cm high and 130 cm wide. Internal parameters of the chamber, also with closed door: 120 cm deep, 70 cm wide and 70 cm high. The control unit is located at the top of the chamber and the external water cooling section is located next to the chamber. First of all, I would like to show 3-dimensional pictures of the assembly plans and the implementation of the ventilation system. [12]

TABLE I. CHAMBER PARAMETERS

Dimensions of the chamber	
External parameters	210 cm x 130 cm x 130 cm
Internal parameters	120 cm x 70 cm x 70 cm
Dimensions of graphite insulating sheets	30 cm x 50 cm x 100 cm

EPS G80 graphite Styrofoam thermal conductivity: λ = 0.031 W/mK

$$\lambda_{korr} = \lambda_0 (1 + k) \tag{5}$$

$$\lambda_{korr} = 0{,}031(1 + 0{,}42) \tag{6}$$

$$\lambda_{korr} = 0{,}044\ W/mK \tag{7}$$

External heat transfer coefficient [13]:

$$h_e = 24\ W/m^2K \tag{8}$$

Internal heat transfer coefficient [13]:

$$h_i = 8\ W/m^2K \tag{9}$$

$$U = \frac{1}{\frac{1}{h_i}+\Sigma\frac{d}{\lambda}+\frac{1}{h_e}} \tag{10}$$

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$$U = \frac{1}{\frac{1}{8}+\frac{0,5}{0,044}+\frac{1}{24}} \quad (11)$$

$$U = 0,086\ W/m^2K \quad (12)$$

$$0,086\frac{W}{m^2K} < 0,15\ \frac{W}{m^2K} \quad (13)$$

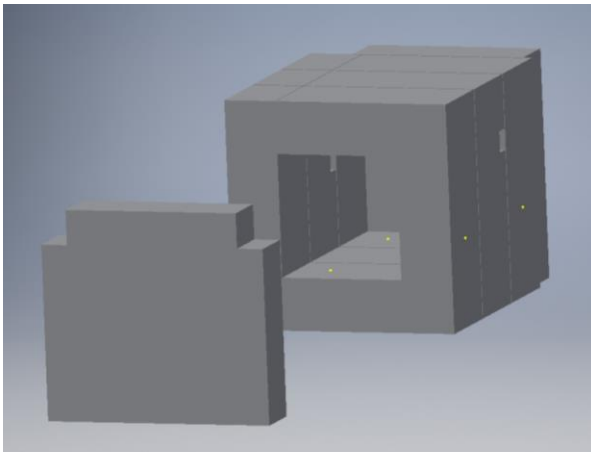

Fig. 1. Assembled chamber

Figure 1 shows the chamber with the door removed from the front, while Figure 2 shows the same 3D plans from the back.

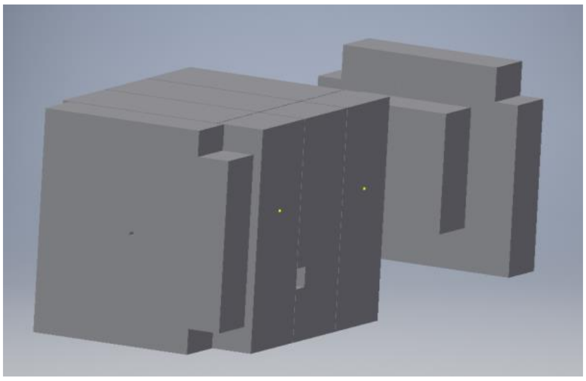

Fig. 2. Assembled chamber

An axonometric view is shown in Figure 3, where the ducts of the ventilation system and the location of the heat exchanger unit are clearly shown.

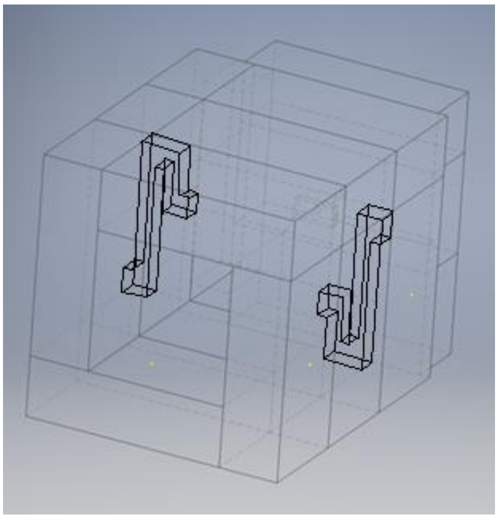

Fig. 3. Styrofoam placement, 3D view

The shape of the passage is such that it is taller than the inner airspace along its entire length, extending higher on one side and lower on the other. Warmed or cooled air is trapped in the passages. Warm air is light and rises, while cold air is heavier and stays down. In addition, the fans in the ducts, which are responsible for ventilation, only start when they are triggered from the controller. There are of course losses in both ducts as they are open, but these losses are kept to a minimum. Fans located in the inner plenum constantly mix the air in the chamber to prevent the temperature difference just mentioned from occurring between the bottom and top of the chamber.

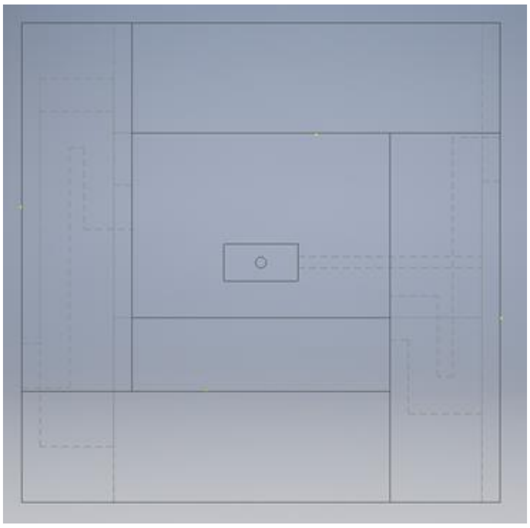

Fig. 4. Final ventilation system

Figure 4 shows the opposite view of the chamber, where the heat exchanger unit will be located on the inner surface of the rear wall. This is a square recess with dimensions of 20 cm wide, 10 cm high and 4 cm deep. From this cut-out, there are two holes in the back wall for the humidifier tubes, the silicon

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tubes of the water cooling unit and additional wiring. Some heat loss was expected in these holes, so I insulated them later, after installing all the necessary equipment. Control of climatic chambers is very critical point to simulate real environmental actions. [15]

V. THE ASSEMBLED TEST CHAMBER

Pictures in this chapter represent the final assembled test chamber, which has received some improvements during the measurements, for example; the chamber door has been insulated with glass wool, I have installed a fan on the internal heat exchanger, the chamber door can be clamped with a chip breaker to reduce heat losses.

Fig. 5. Climate chamber door with glued – on glass wool

To glue the glass wool, you have just seen, we used the same glue that was used to glue the Styrofoam slabs together, so the insulation is even thicker.

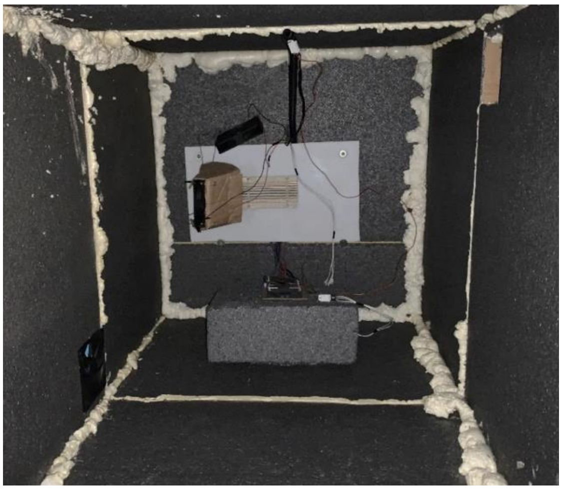

Fig. 6. Interior air space with battery holder installed

Figure 6 shows the inside of the chamber, with the ventilation openings in the position shown in the plans, the heat exchanger on the back wall, where it was necessary to install a fan initially and later a fan for faster and more efficient heat exchange (Figure 7).

Fig. 7. Chamber control, measurement and data acquisition system

Fig. 8. Final test chamber with chipboard clamp

The installation of the lashing straps (Figure 8) was necessary to ensure that the door would close properly. Since Styrofoam can collapse or break even with a small amount of force, the corners were reinforced by fitting cardboard plates so that the door could be tightened with greater force to achieve better thermal insulation. Further measurements were carried out using thermal imaging to verify that no heat loss was observed along the door.

Fig. 9. Advanced test chamber, side view

5.1. Thermal inspedtion of the test chamber

The heat loss of the chamber was checked using a Testo type thermal imager (Figures 10, 11, 12, 13). To interpret the images, it is worth noting that the lighter colours in the images indicate warm temperatures and the darker colours indicate cold temperatures.

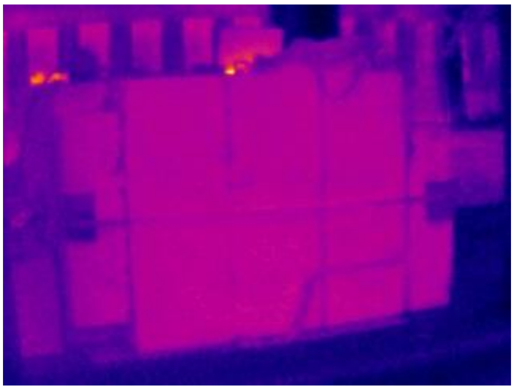

Fig. 10. Thermal imaging

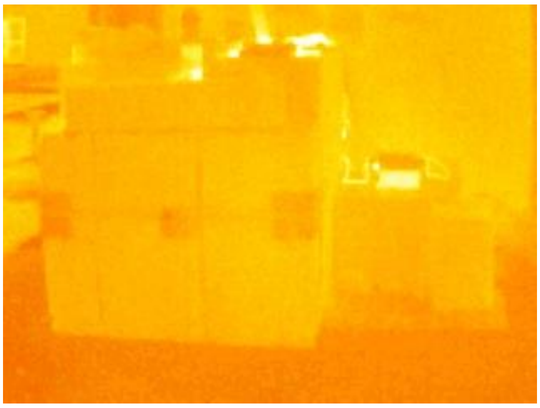

Fig. 11. Thermal imaging

In Figures 10 -11, it is clearly observed that the heat loss along the joints is very minimal and not noticeable. The critical point for us was the chamber door and the holes for the pipes and ducts. The chamber door is properly insulated, there was a slight heat loss along the top edge during heating, but this was corrected with glass wool.

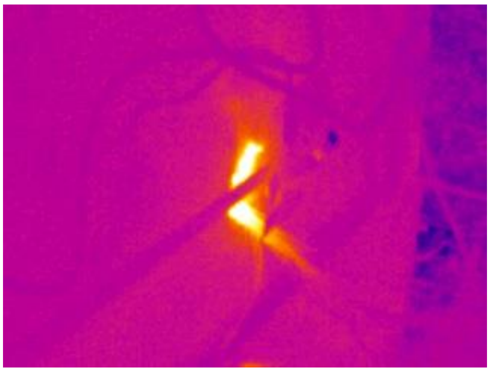

Fig. 12. Thermal imaging

There was a much higher loss along the holes, as shown in Figure 12, but again I was able to remedy this problem with glass wool. The insulation is shown in Figure 13.

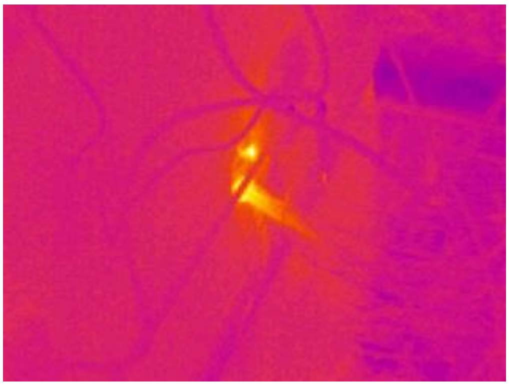

Fig. 13. Thermal imaging

VI. CONCLUSION

Our calculations have shown that maintaining static temperatures is not a major problem in practice, but if you want to measure dynamic temperature changes, you will need a more powerful heat exchanger or a completely new solution.

We would like to continue to work with Peltier elements, and therefore we cannot produce rapid temperature changes because of their low efficiency. To overcome this disadvantage, there is another solution: building a new chamber to be added to the existing one. The new chamber would have a separate airspace, connected to the existing chamber and separated by an automatic opening and closing door. The new chamber would also have a heat exchanger and controls like the existing one. The new air chamber would be located above the existing one in space, solving the problem of heat loss. As we know that the density of warm air is lower than that of cold air, the upper chamber would be used for heating and the lower chamber for cooling. The transfer from one air space to the other would be taken care of by a lifting device, either in the upper chamber or on top of it. The thermometers, the artificial load and the necessary electrical wiring for the batteries would be connected from the upper chamber. The battery pack would hang on special support wires. The design and construction of the door separating each chamber is more challenging, as a mechanism to close the door without a gap would have to be installed, and would be made of Styrofoam with a protective cover. Of course, the door and the lifting mechanism would be controlled by an Arduino, equipped with the necessary sensors to avoid malfunctions and accidents (end position sensor, weight sensor).

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