

LUXPAK: Equipment and measurement problems

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1. The package

The Luxpak of the H.A.L.E project is a measurement package for several environmental parameters of the atmosphere: temperature, absolute air pressure, ozone mixing ratio and reflected light from the ground will be measured during the flight of the H.A.L.E stratospheric balloon..

The sensors are:

air temperature	PT100 sensor
absolute air pressure	SCX15AN from Sensor Technics (http://www.sensortechinics.com/)
ozone	Ecosensor A-21ZX (http://www.ecosensors.com/a21zx.html)
reflected light	ESR SI-diode sensor from Delta-T (http://www.delta-t.co.uk)

The PT100 and ESR sensors are driven by a purpose built electronic board ("Mootz-board"), developed and made by Jean Mootz.

Fig. 1 shows all these sensors and the Mootz-board

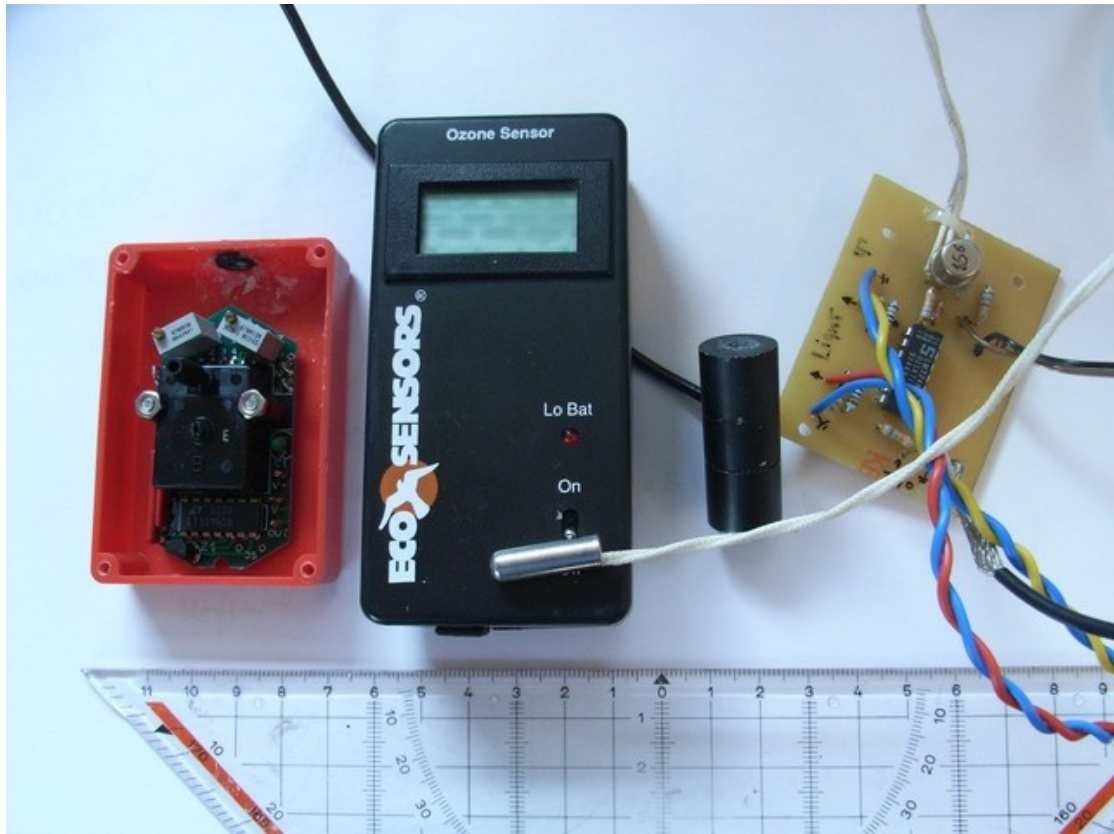


fig.1: The Luxpak sensors and the Mootz-board

2. The Mootz board

2.1. PT100

A PT100 sensor basically consists of a platinum wire whose resistance varies practically linearly with temperature. A PT100 sensor has a resistance of 100 Ohm at 0°C; the gradient is approx. 0.385 Ohm per °C. The sensor has to be driven by a constant current, so that the voltage drop at the connections is proportional to the temperature. We choose to use a constant current source delivering 1 mA.

Here are the schematics of the board built by Jean Mootz:

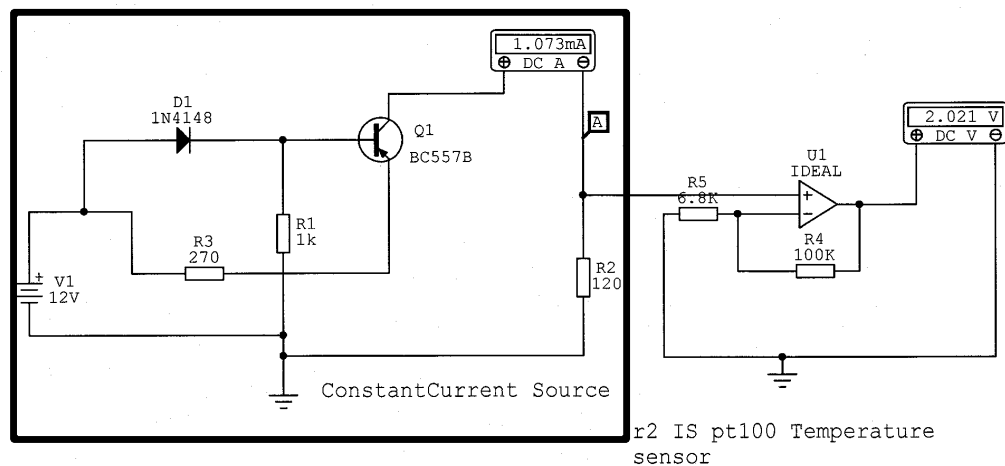


fig.2 Schematics of the Mootz-board

The left bordered portion is a very primitive constant current source, the right part holds the amplifier. A problem is that this circuit is not temperature stabilized, so that the influence of changing temperatures on the transistor give changing characteristics of PT100_Voltage versus Temperature, as can be seen from the following figure.

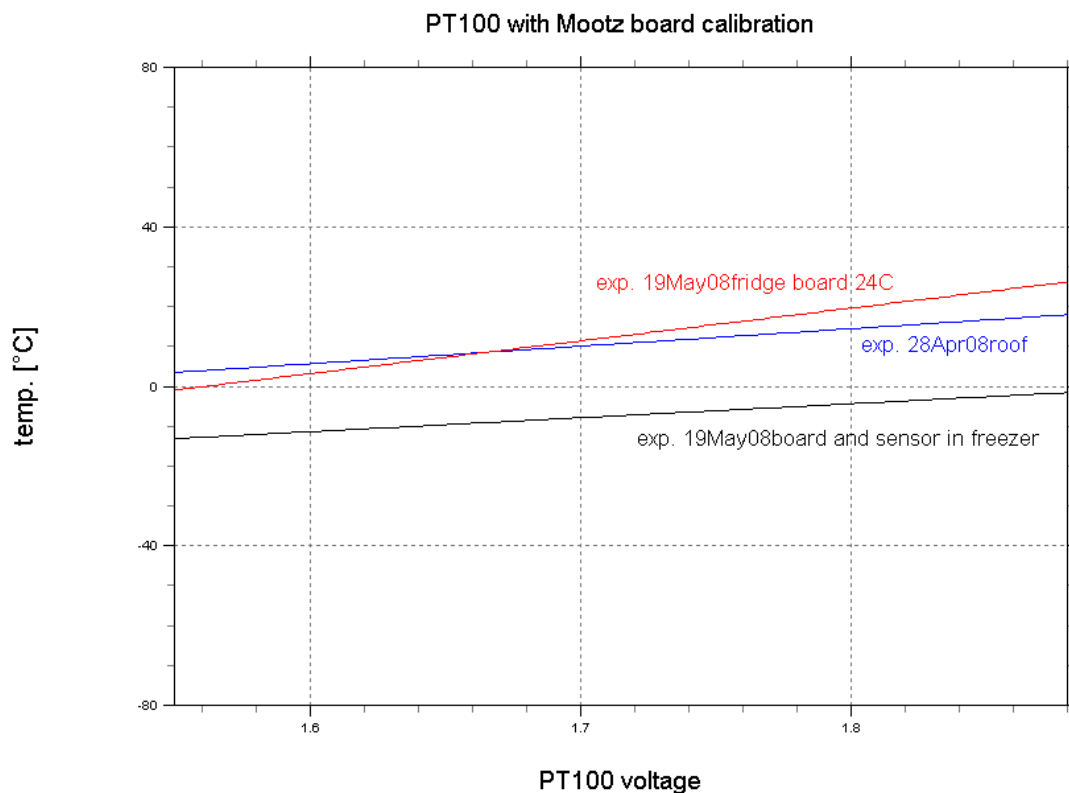


fig.3 Calibration lines of the PT100 sensor

The red and blue lines gives the output of the Mootz board if it is kept at ambient temperatures, the black line with the board kept in a freezer (at about -16°C).

As the temperature of the board will be monitored during the flight, the most appropriate calibration curve has to be used during data evaluation. The board is mounted backside to the RCX and will have it's own heating. With a bit of luck the temperature will be kept close to 20°C, so that the problem of temperature sensitivity may be a minor one.

2.2. The ESR light sensor

This is a Si-diode type sensor delivering a voltage proportional to the global irradiance (in Wm^{-2}) received. The sensor has a plastic diffuser and a relative flat response in the visible domain.



fig.4. ESR sensor (scale is centimeters)

To obtain a correct output voltage, the connections are shunted by a 400 Ohm metal-foil precision resistor: The sensor output is amplified by a standard OP on the Mootz board.

The main calibration was done on the roof of the meteorological station of the Lycée Classique in Diekirch, Luxembourg (<http://meteo.lcd.lu>), the reference being a precise Kipp&Zonen CM21 pyranometer.

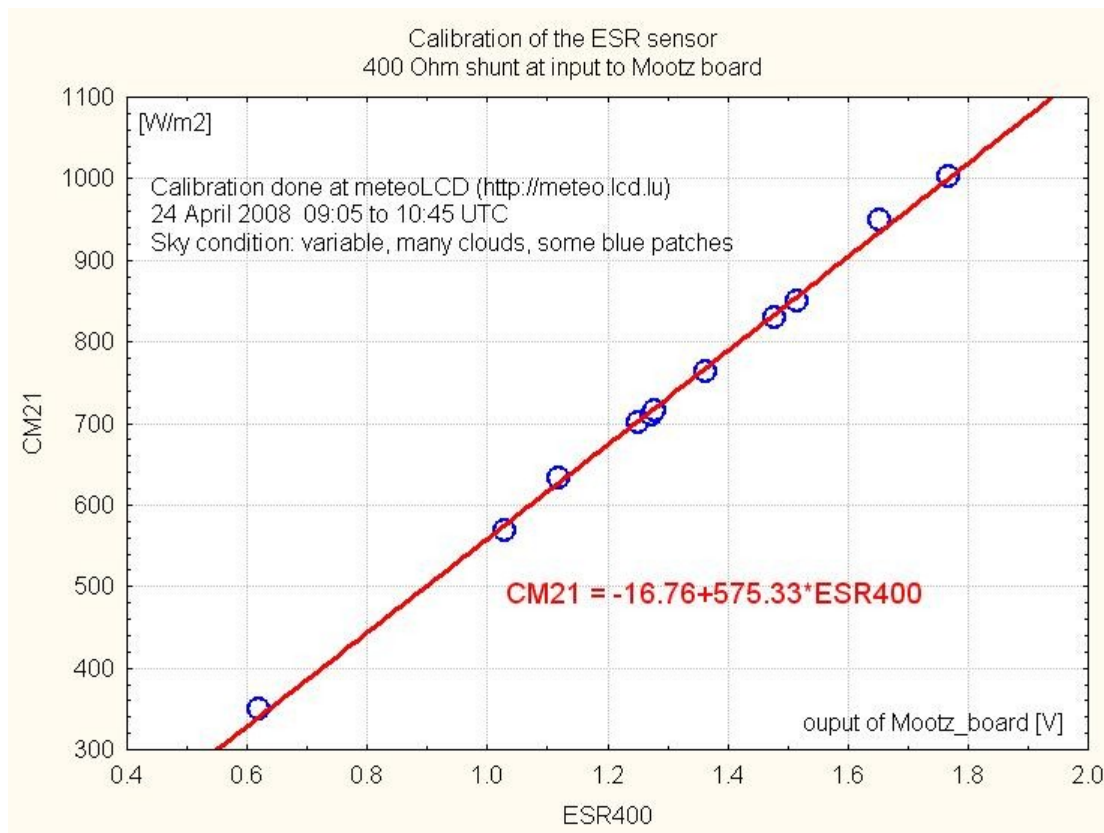


fig.5. Calibrating the ESR light sensor



fig. 6. Reference pyranometer

The linearity is excellent, as shown by the next figure. We could not detect a temperature sensitivity of the amplifier.



As the goodness of fit is practically the same for a simple multiplier, the global irradiance (direct and diffuse) in Wm^{-2} is obtained from the voltage output of the Mootz board by the relation:

$$\text{irradiance} = 563.1 \cdot \text{Voltage}$$

This assumes a horizontal sensor window; any inclination will lower the output, according to the cosine response. By retaining only maxima readings we can more or less ignore the influence of an unknown and changing tilt.

For a couple of reasons, the initial 12V power supply voltage to the Mootz board was reduced to 10.4 V. To find the new relationship between voltage and irradiance we made a quick check in the lab with a dimmable quartz lamp, using as a secondary reference an older CM5 Kipp & Zonen pyranometer with a response of 14.3 uV/Wm^{-2} . (obtained by comparison to the primary reference CM21). The new relation becomes:

$$\text{irradiance} = 636.3.1 \cdot \text{Voltage}$$

Thus the new multiplier is close to the previous one multiplied by $12/10.4$ as $563.1 \cdot 12/10.4 = 650$

photo!

3. Ozone sensor A-21ZX

This sensor is a small hand held device, build around a HMOS (Heated Metal Oxide) sensing element.

The manufacturers specification say that the air temperaure should be in the range 0-40°C, so this will clearly be a problem in the very cold higher atmosphere.

The sensor has no analog output, just a small LCD display. With some poking around, a suitable connection was found on the circuit board which gives a voltage varying with O3 concentration.

To find the calibration curve (voltage versus O3 concentration) a small air purifier (negative ion generator) was used as an ozone generator. This device readily gives O3 mixing ratios up to 10 ppm, covering the possible values found in the 20 to 30 km high layers of the stratosphere, as documented by fig. 4 (measurements done in Japan)

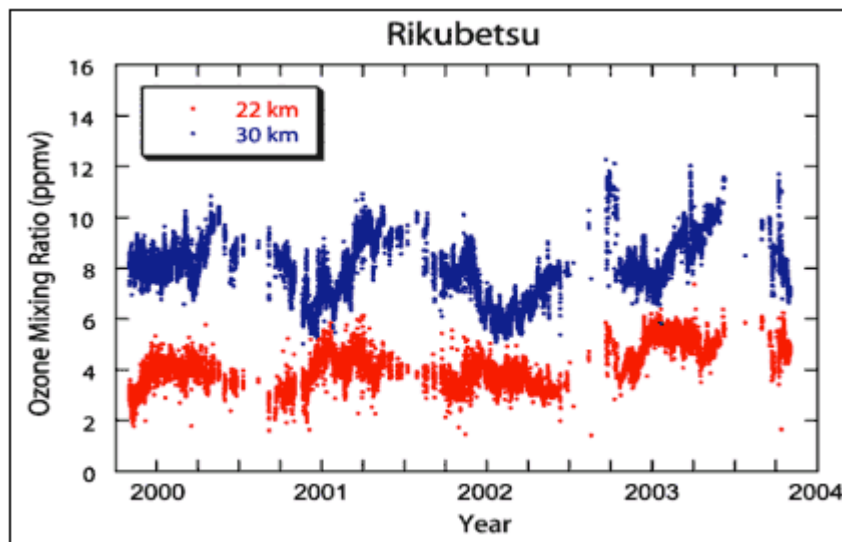
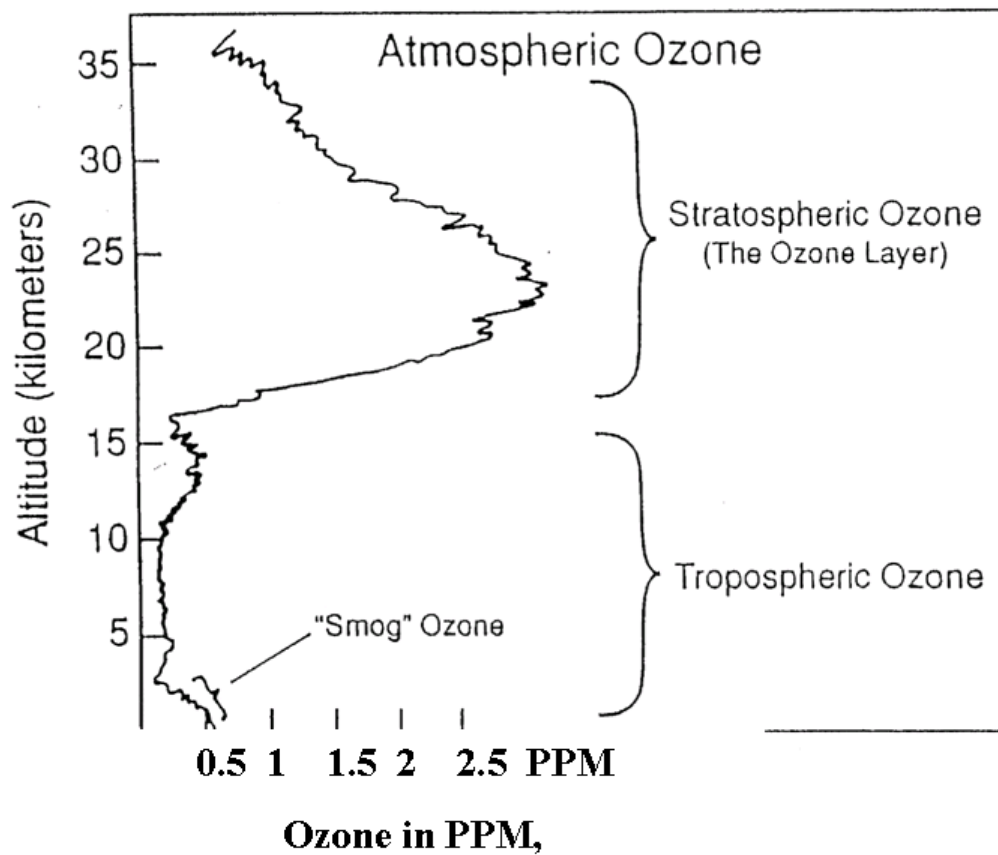


fig.4 from <http://db.cger.nies.go.jp/gem/moni-e/ozon/rikubetsu/riku02.html>

A typical complete profile (which varies with location and time) is here:
(<http://www.eoearth.org/image/Ozoneheight.gif>)



Parts per million. 1 ppm =1000 ppb

fig.5: Typical ozone mixing ration profile. The stratospheric peak may be much higher (<http://www.eoearth.org/image/Ozoneheight.gif>)

The relationship between output voltage and ozone mixing ratio is highly non linear, and can be best be given by a logarithmic relation:

$$\text{Mixing ratio [ppmv]} = 1.12 + 0.726 \cdot \log_{10}(\text{voltage})$$

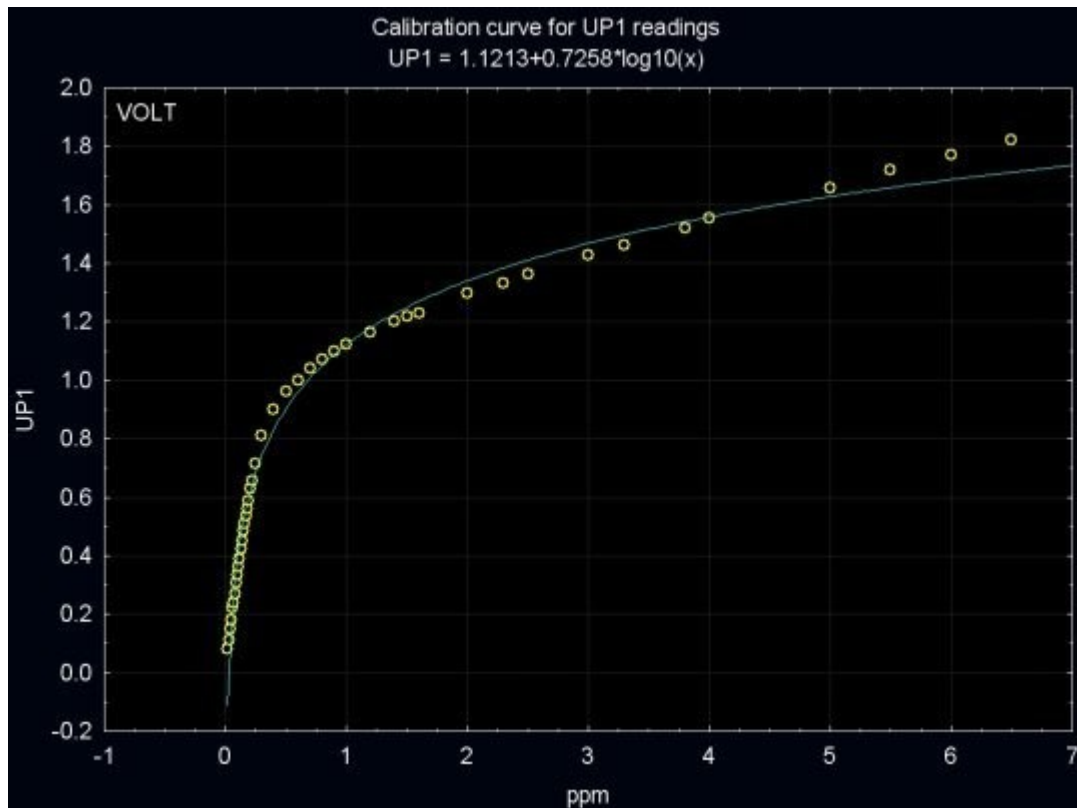


fig.6: Calibration curve of the ozone sensor

4. The absolute air pressure sensor

The SCX15AN pressure sensor from Sensor Technics (<http://www.sensortech.com/>) is a left-over sensor from a research project on cave climatology. This solid-state device is mounted on a small board containing the amplifier and zero/span potentiometers. The pressure operates from 0 to 1200 hPa, with an output of 0.5V for 0 hPa and 2V for 1200 hPa. The output is linear:

$$\text{pressure [hPa]} = 800 \cdot \text{voltage} - 400$$

As seen above, the power supply to the Mootz board was lowered to 10.4 V. A recalibration check of zero and reading gave:

0	hPa pressure:	0.500 V
991	hPa pressure:	1.659 V

Thus the relationship between pressure and voltage (in V) to be used is:

$$\text{pressure [hPa]} = 855 \cdot \text{voltage} - 427.5$$

5. Specific ozone sensor problems

5.1. Basic construction

The 2 main problems to be solved were:

- how to bring the outside air to the sensor.
- how to warm the very cold outside air.

When measuring ozone, one has to be careful to avoid all contact with rough surfaces, as O₃ is very easy to destroy by mechanical action. The air containing the ozone must flow in very smooth teflon tubes, and a pump should never be used in front of the sensor.

We decided to operate the sensor in a pump-less manner, using the vertical movement of the balloon to assure an air flow through the instrument; the ascensional velocity of the balloon will be approximate 5 m/s.

A teflon tube goes from the top to the bottom of the package and flows around the HMOS sensor of the instrument mounted in a case. To heat the air up to a minimum of 0°C, the teflon tube goes through 6 ceramic resistors, which are able to heat the tube up to 80°C (or even more). The RCX will monitor the temperature inside the heater as well as that inside the case holding the sensor.

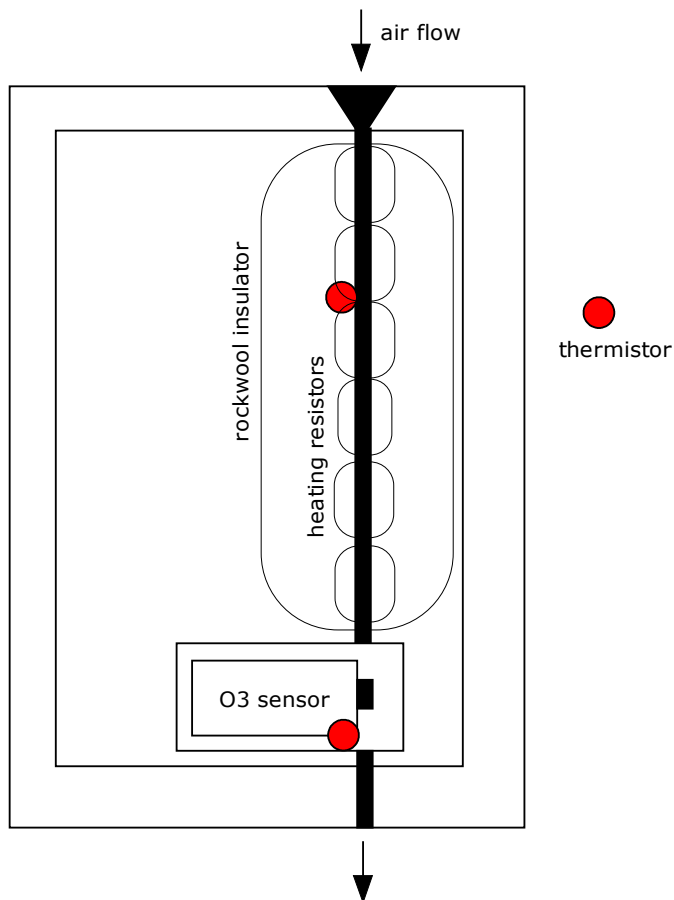


fig 7: schematics of the ozone flow and heating system

5.2. Thermal calculations

We made a lot of thermal calculations to get a feeling of the possible heating. The students of the 3BC physics class of Francis Massen participated in these calculations. Luckily they were studying heat and thermal insulation problems in April/May, so that they knew the basics.

We used the following formula from the book "Toute la Physique" (Dunod) by Horst Stöcker [ref. 1]

$$\Phi = \frac{2 * \pi * l}{\ln(\frac{d_o}{d_i})} * \lambda * (T_{out} - T_{in}) = c * L * (T_{in} - T_{atmosphere})$$

Here the left part corresponds to the thermal power Φ [Watt] delivered by a tube of outer/inner diameters d_o and d_i , thermal conductivity λ , outer wall temperature T_{out} and inner temperature T_{in} . The right part expresses the power needed to heat a mass flow L of air ($L = \text{air_density} * \text{velocity} * \text{tube_section}$) from $T_{atmosphere}$ to T_{in} . The unknown variable is T_{in} , the inner temperature of the air.

A typical calculation runs like this: (all units SI)

speed of airflow through heater	= 1 m/s
air density	= 1 kg/m ³
teflon thermal conductivity	= 0.25
bridging thermal resistance from teflon wall to air: α	= 20
outer diameter	= 6 mm
inner diameter	= 4 mm
length of the tube	= 20 cm

Here the part $\frac{\lambda}{\ln(\frac{d_o}{d_i})} = 0.62$ represents the inverse of the thermal resistance

of the teflon wall. So the thermal resistance is $\ln(6/4)/0.25 = 1.62$.

We have to add the $\alpha = 20$ bridging resistance for the heat flow from the wall to the inside air, total is now 21.62, and the conductance will become $1/21.62 = 0.046$ (instead of 0.62).

$$2 * \pi * l = 2 * \pi * 0.2 = 1.257$$

$$c * L = c * \rho * S * v = 1000 * 1 * 4 * \pi * 10^{-6} = 0.0126$$

$$T_{out} = \text{temperature of the tube} = 373\text{K} (100^\circ\text{C})$$

$$T_{atmosphere} = 223\text{K} (-50^\circ\text{C})$$

The Stöcker equation now is: $1.257 * 0.046 * (373 - T_{in}) = 0.0126 * (T_{in} - 223)$

which gives $T_{in} = 349 \text{ K} = 76 \text{ }^{\circ}\text{C}$

If we compute T_{in} as a function of α , ρ and v we have:

$$T_{in} = \frac{\frac{470}{1.6 + \alpha} + 2.81 * \rho * v}{0.0126 * \rho * v + \frac{1.26}{1.6 + \alpha}}$$

See the following plot:

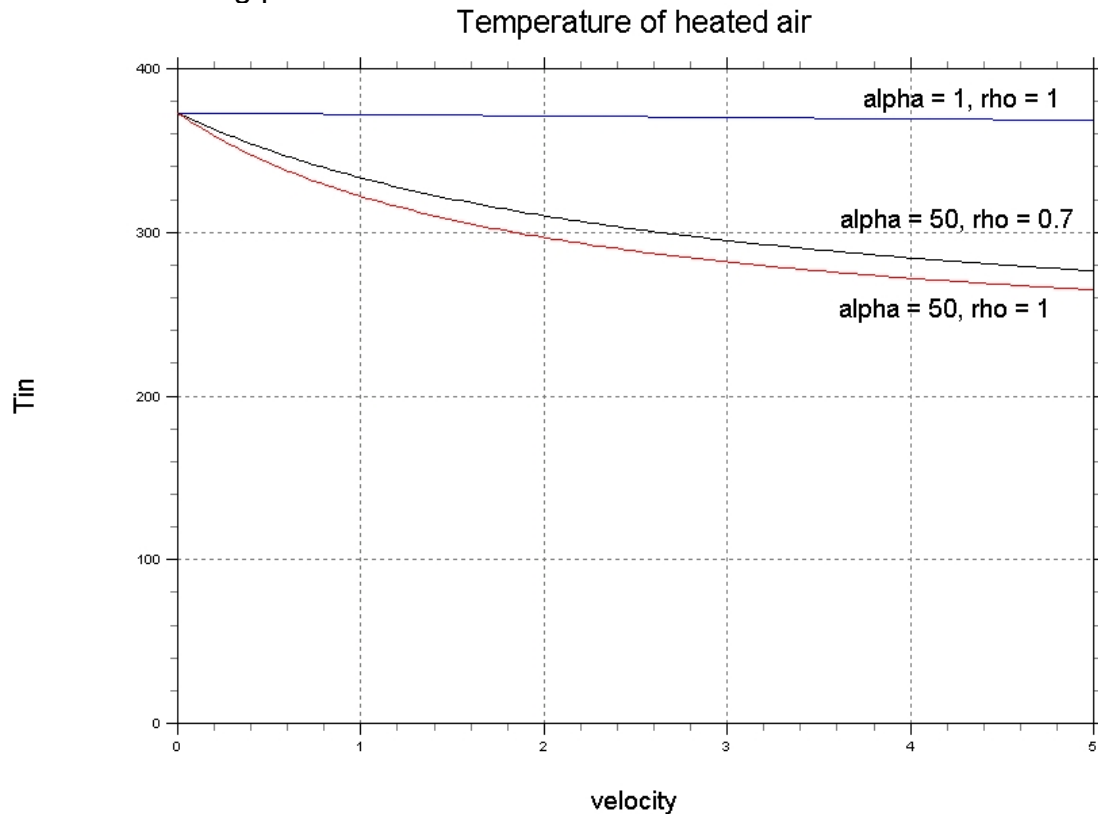


fig. 8: Temperature (in Kelvin) of heated air according to velocity
(cold air = -50°C)

As can be seen, the air density ρ (ρ) does only play a minor role if α is high. If this calculation is correct, we should not worry about the temperature of the air reaching the ozone sensor. It might even be prudent to lower the temperature of the heater below 100°C .

The extremely important parameter α can be expressed as a function of air velocity and tube diameter. For small velocities ($< 5\text{ m/s}$) Recknagel [ref. 2] gives the following expression:

$$\alpha = 4.4 * \frac{v_0^{0.75}}{d^{0.25}}$$

where v_0 is the velocity at STD ($v_0 = 273/T * v$), and d = diameter of tube.

In our situation $v_0 = 0.92 \cdot v$, so we will omit this small difference and take v as v_0 .

If α is replaced by this formula, the expression for T_{in} becomes:

$$T_{in} = \frac{373 + 3.61 \cdot \rho \cdot v + 39 \cdot \rho \cdot v^{1.75}}{1 + 0.0162 \cdot \rho \cdot v + 0.175 \rho \cdot v^{1.75}} \quad \text{with } T_{in} \text{ in Kelvin}$$

The next plot shows the difference between an assumed $\alpha = 50$ and this formula:

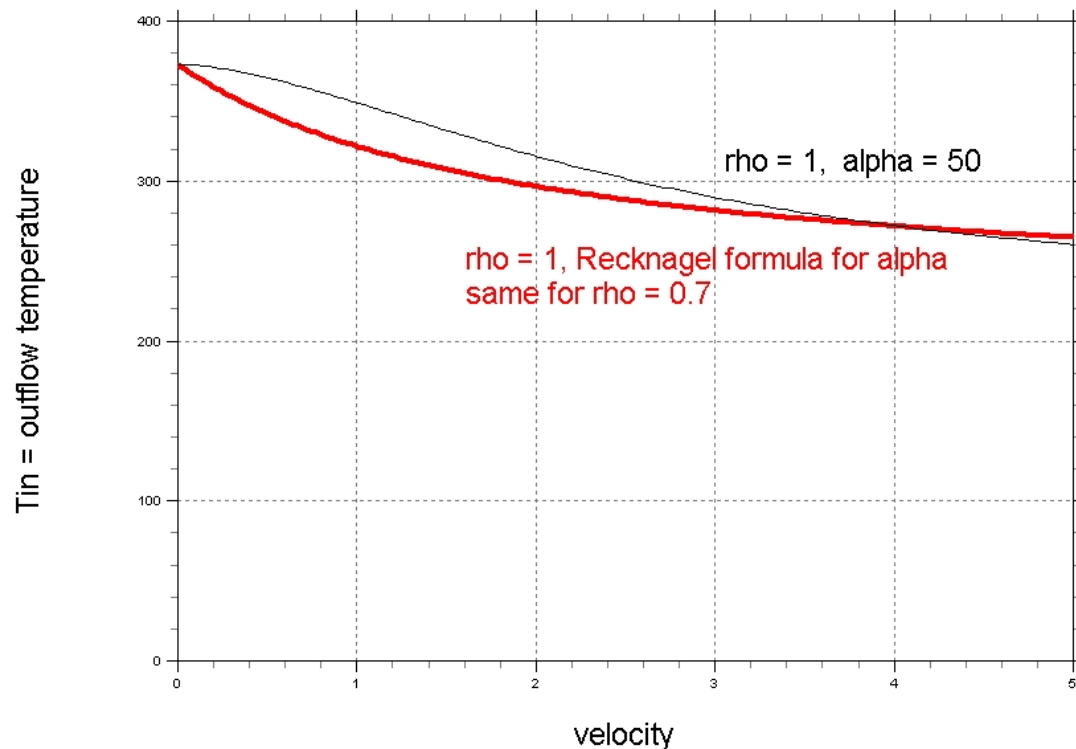


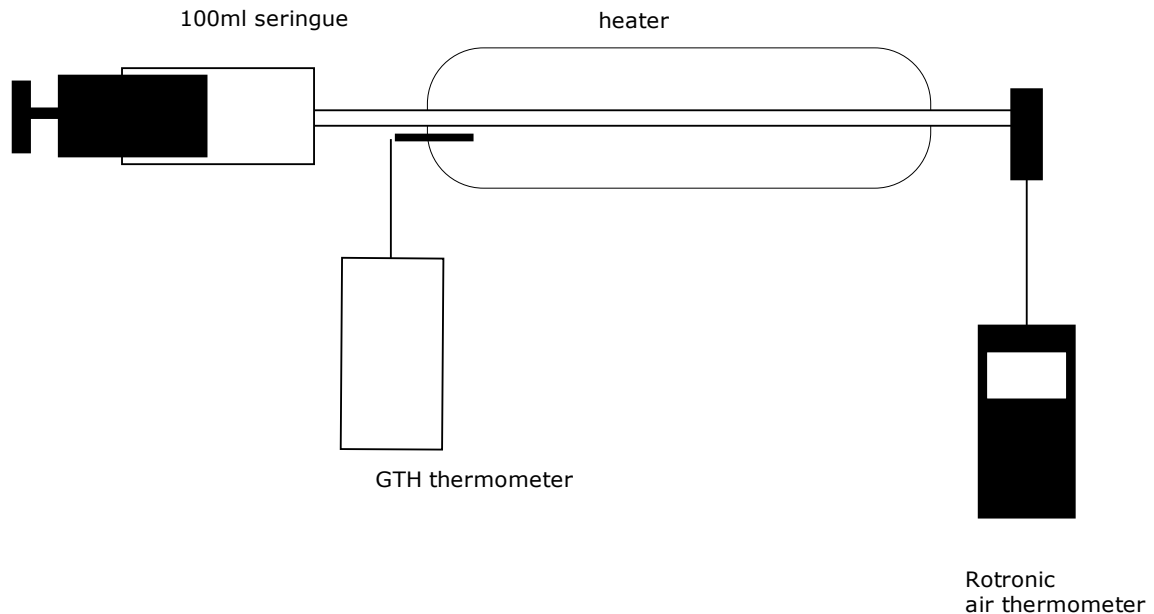
fig. 9: Using the Recknagel formula

The conclusion remains the same as previous: even for velocities up to 5 m/s, the air flowing out of the heater will not have temperatures below freezing point.

5.3. Experimentation

We built an experimental setup to verify these calculations.

A test bench was established in the following manner:



A main problem was to correctly measure the temperature of the small air flowing out of the tube. The electronic thermometers we had were too bulky to be heated up in a correct manner, so that the results of the experiments were unsatisfactory: our experiment showed only a small heating of a couple of degrees Celsius was possible, our calculations gave us reason to be optimistic!

5.4 The final setup

Finally we implemented the following measures:

- the air flow was restricted by an outlet tube of smaller inner diameter
- heater and air temperatures in the ozone enclosure will be measured and necessary regulations will be made by the RCX to avoid as well an overheating and to assure if possible a minimum temperature of 0°C.

The ozone sensor problems were difficult to solve, and there remains a real possibility that the sensor will not be working correctly throughout the whole flight.

6. Computing albedo from the ESR light sensor readings

The global albedo (Bond albedo) is the fraction of the direct and diffuse sun light reflected from the ground. It varies heavily with the structure of the ground: For desert sand, Ahrens [ref. 3] gives values from 0.15 to 0.45 (15% to 45%).

Usually the albedo is measured by a pyranometer:

- first a measure is made with the pyranometer pointing upwards (i.e. normal operation): Irradiance IR1
- then the pyranometer is rotated around a horizontal axis so that it points down: Irradiance IR2

The local albedo is the fraction $IR2/IR1$.



fig. 9: Albedo measurements in the Artic (<http://www.arcticice.org/albedo.htm>)

Remember that a pyranometer is influenced by all radiation, direct and diffuse, coming from the hemisphere above its dome (see fig. 6) and that its reading expresses total irradiant power on a horizontal plane, in Wm^{-2} .

There is a lot of discussions on how to measure albedo in a scientific manner, and a deluge of research papers insisting on one or another particular problem.

Pierre Holmuller from the CUEPE (Centre Universitaire d'étude des problèmes de l'énergie), University of Geneva, Switzerland, gives a very bold answer:

"If you measure albedo close to the ground, you get a local value; if you go higher, you get a global value" [ref.4] Well, this is exactly what we will do!

David Sailor and al [ref. 5] pour cold water on us: they recommend NOT to use silicon photovoltaic based sensors for measuring reflected radiation. These sensors usually are calibrated by looking upwards, and this calibration might not hold for reflected radiation whose spectral shape is not the same. Well, we **must** use our ESR silicon sensor, as a classical pyranometer would have been much too heavy. In their paper they also specify a relationship between the height H of the pyranometer and the diameter of the circular reflecting "effective" surface: **diameter = $8.7 \cdot H$**

This means that at an altitude of 20km, the surface of interest will be a disk of 174 km diameter (surface $\sim 23800 \text{ km}^2$), which represents a considerable area!

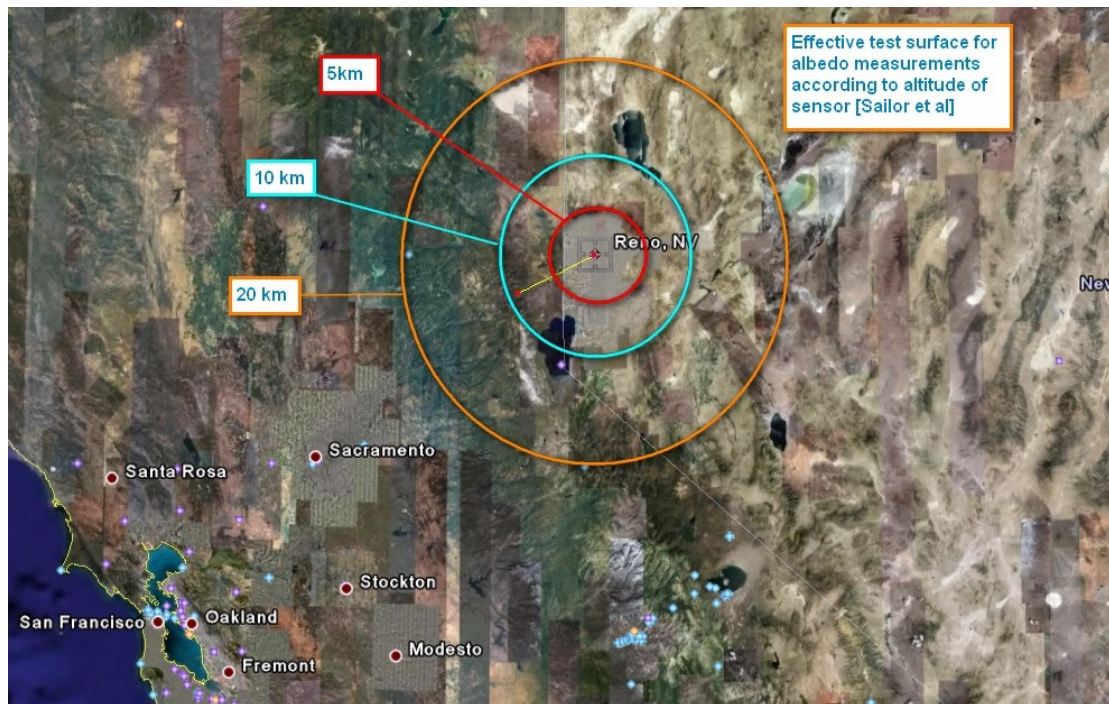


fig.10. Approximate "effective surface" according to altitude

Let us finish these musings by a very simple calculation, assuming a 100% transparent atmosphere without any diffusion.

If our sensor rises above ground, what does the output of the downlooking instrument really represent?

Simplifying assumptions:

1. the solar irradiance SIR measured at ground level remains constant during the time of the flight of the balloon.
2. the atmosphere is absolute transparent and does not absorb any light during the flight. There is no diffusion.
3. The surface of the sensor remains horizontal.

The raw readings of the light sensor is a voltage that is stored as a "Luxpak_raw".number in the memory. We know from our last calibrations that

$$\text{irradiance} = 1.1 * \text{Luxpak_raw}$$

So if we have an output of say 500, this means that the light emitting system (= desert ground) produces at the location of the sensor an irradiance of about 550 W/m^2 .

Only a portion of the direct and diffuse light reflected by the ground reaches the sensor: everything outside the cone of angle alpha is missed .

Let ALB be the local albedo (= Bond albedo), supposed constant.
 The total irradiant power emitted by the ground is $ALB \cdot S_{IR}$ [W/m²].
 This power is emitted through a solid angle of $2 \cdot \pi$
 Only a fraction of that emitted power is captured by the photodiode:

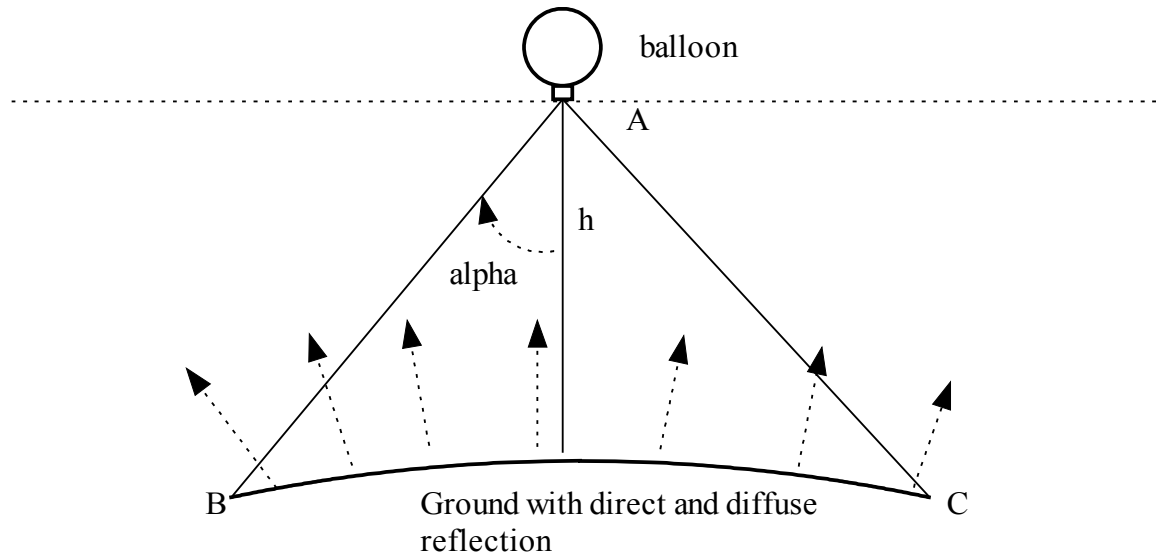


fig. 11: Field of view of the sensor

Alpha = $\pi/2$ represents the situation immediately after launch, and the readings at that moment allow to calculate the albedo. With the balloon at higher altitude, only the ground surface limited by a cone of half-angle alpha contribute to the light falling on the sensor. This will be less than if the sensor was located over an infinite wide horizontal plane. **To put us into the same situation, the irradiance measured at an altitude h should be multiplied by $(\pi/2)/\alpha$**

The next figure shows that $\sin(\alpha) = R/(R+h) \sim 1-h/R$ as $h \ll R$

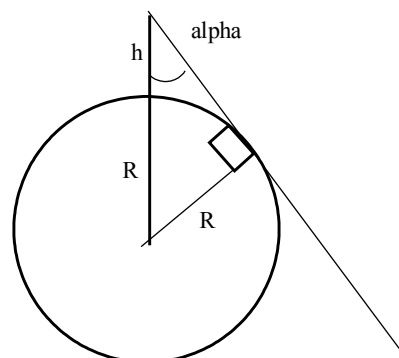


fig. 12: Definition of angle alpha

If the reading (in W/m²) of the sensor is RER , this should become $RER \cdot \pi / (2 \cdot \alpha)$ **and the local albedo would be:**

$$ALB... = \frac{RER * \pi}{2 * \alpha * SIR}$$

The multiplier $\pi/(2*\alpha)$ remains close to 1: 1.037 at 10km, 1.053 at 20km and 1.066 at an altitude of 30 km. It's useage probably is not mandatory, regarding the accuracy of the sensor which certainly does is not better than 5 percent.

As the sensor will not be horizontal during the flight, due to probale swinging movements, only the maxima readings during a certain time interval should be kept.

This concludes our study on the albedo problem. Probably Hollmuller's rule will be of some comfort!

7. Thermal insulation and heating problems

Keeping the interior of the Luxpak box above freezing point is a challenge: many unknowns, as the heating of the batteries, thermal leaking of the ozone heater etc. make a clear analysis hazardous.

The students of the LCD started by computing the cooling of the air in the box assuming a known thermal conductivity of the styropore (about 0.038) and a quasi instantaneous flow through the walls. The mass inside the box is density*volume, with the density diminishing with altitude (formula used is that of the adiabatic atmosphere). They rapidly saw, that even the thick 35mm styropore walls could not avoid a rapid cooling down.

The same observation was made with an empty box (except datalogger and thermometer) put into a freezer at -18°C and seeing that 0°C was reached in 30 minutes. Adding a bottle of 200g water (which would thermally represent about 800 to 1000g of a payload with specific heat $c = 1000$, changed the speed of the cooling down by half.

The lesson learned was that even an extremely good insulator can not avoid fast cooling if it contains only air, as the mass of that air is so tiny and does not need many Joules to cool down..

Fig. 12 shows the situation with the box and the bottle of water.

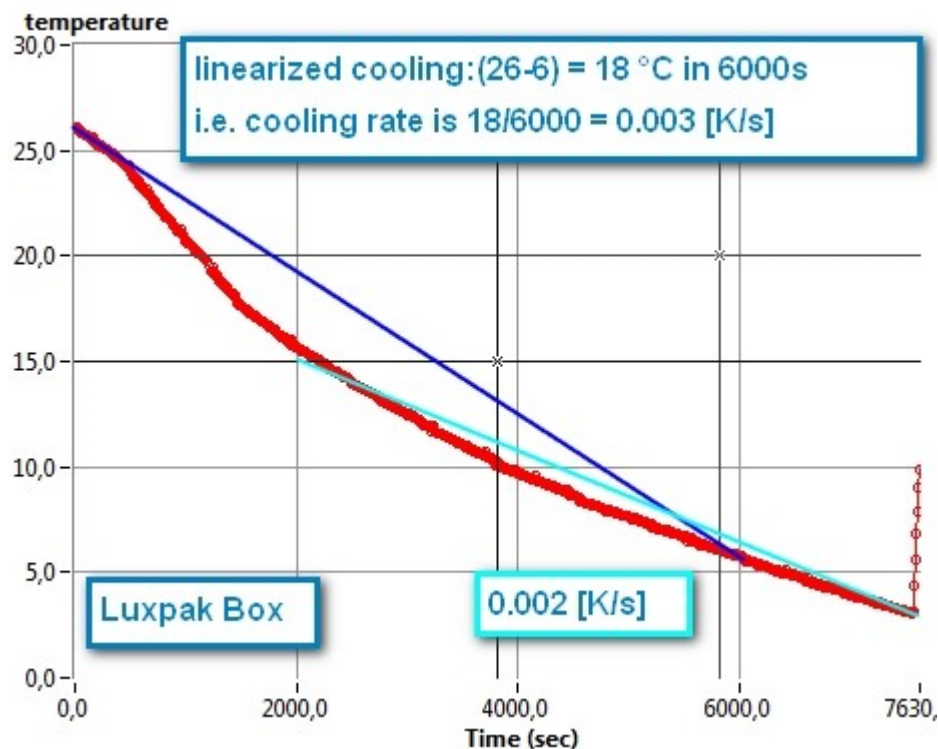


Fig 12: Cooling of box with water bottle put into a freezer at -18°C

More tests were made at the Konvikt. All point to the fact that probably it will be easy to assure non freezing conditions inside the box.

References:

1. Stöcker et al: Toute la Physique. Dunod, 1999.
2. Recknagel et al: Taschenbuch für Heizung und Klimatechnik. Oldenbourg.1992.
3. Ahrens: Meteorology Today. ISE, 8th edition. Thomson, Brooks/Cole
- 4.. Holtmüller, P. Measuring Albedo. Blog at <http://sel.me.wisc.edu>
5. Sailor, D. et al: Field measurement of albedo for limited test surfaces. Solar Energy, 80 (2006) 589-599.