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The Negative Greenhouse Effect – Part I:

Experimental Studies with a Common Laboratory Set-Up

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Abstract

In two consecutive studies, the suitability of different experimental set-ups for detecting and measuring the emission of infrared-active gases is investigated, as this is of particular importance for understanding the atmospheric greenhouse effect.

The first part presents a horizontally arranged Styrofoam box, as described occasionally in the literature for such experiments. The gases are slightly heated by a heater at the bottom of the container, and the radiation—emitted by the infrared-active gases—is detected through an infrared-transparent window at the side. However, this arrangement is only suitable for demonstrating the positive or negative greenhouse effect with very strong greenhouse gases such as Freon. For weaker greenhouse gases like CO_2 or CH_4, the gas radiation can only be inadequately distinguished from the broadband background radiation of the container walls. In addition, the supplied heating power creates a circular air flow, which further complicates detection. Nevertheless, these investigations provide important clues for a significantly improved setup in the form of a vertical aluminum cylinder, which can be used to detect infrared emission under conditions such as those observed in the lower troposphere.

For a gas layer above a cooler surface, as this occurs during inversion weather conditions or can be observed in the Arctica and Antarctica during winter months, the radiation emitted by the surface and partially absorbed by the warmer gas layer is lower than the radiation emitted by the gas upward. This is known as negative greenhouse effect, which, despite the limited detection sensitivity, can be simulated for the first time in the laboratory with the presented set-up.

Keywords: Infrared-active gases; positive and negative greenhouse effect.

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1. Introduction

Infrared-active gases such as water vapor (WV) or carbon dioxide (CO_2), along with convection and evaporation, significantly determine the vertical energy transfer in the atmosphere. Whether these gases primarily contribute to warming or cooling depends largely on the sign of the vertical temperature gradient over the atmosphere. In the troposphere, the lowest layer of the atmosphere, the temperature on average drops by 6.5°C/km. In this case, the radiation emitted into space by the infrared(IR)-active gases is lower than the radiation absorbed by them from the Earth's surface. This is known as atmospheric Greenhouse Effect (GHE)[1]. The reduced radiation at the Top of the Atmosphere (TOA) thus leads to additional warming and an increase of the long-wave radiation emitted from the Earth's surface. This happens, until—together with the directly

[1] Although the terms greenhouse gases and greenhouse effect are somewhat misleading and should be replaced by designations like IR-active gases and atmospheric radiative effect (see also Koutsoyiannis & Tsakalias, 2025 [1]), here we still use the conventional terminology as established over 150 years.

absorbed solar radiation—an equilibrium is adjusted between the energy supply and removal at TOA.

However, in some parts of the troposphere, the temperature gradient can also be reversed, e.g., during inversion weather conditions or during the winter months in central parts of the Arctic and Antarctic. During these winter months, the surface of the poles can be colder than the troposphere, which is warmed by currents from the equator to higher latitudes, thus potentially reversing the GHE (see Schmithüsen et al., 2015 [2]). Then the radiation emitted by the warmer air is more intense than the thermal radiation coming from the Earth's surface and absorbed in the atmosphere.

However, one of the most common objections against the GHE–whether positive or negative–is that the IR-active molecules under the conditions of the lower atmosphere transfer the absorbed radiation energy almost completely to other air molecules, known as thermalization, and according to physical reasons suppress any gas emission.

The "thermalization" hypothesis was already refuted in a previous study by laboratory experiments (Harde & Schnell, 2022 [3]). Our actual experiments show, in agreement with theoretical considerations (Harde, 2013 [4]) that IR-active gases can also draw their radiation energy from the kinetic energy of the gas mixture, thereby lowering the temperature of the gas.

Such an effect can only be observed experimentally, if a heated gas container is in radiation exchange with a cooled radiation receiver, and the radiation emitted by the container walls is weaker than the gas radiation of the Greenhouse-Gases (GH-gases). This requires container walls made of polished metal, which have extremely low emission coefficients. Under this condition, addition of a GH-gas leads to an increase in IR radiation while simultaneously cooling the gas volume. This corresponds to conditions as found for a negative GHE. Such conditions can directly be replicated in the laboratory with a set-up as presented in Section 2 (for further details of an improved set-up see: Harde & Schnell, 2025, Part II [5], Subsection 4.4).

An unexpected air circulation in the set-up is discussed in Section 3, and despite some limitations in the sensitivity, we can demonstrate in Section 4 that GH-gases not only emit in higher altitudes but also under conditions similar to those in the lower troposphere, while deriving their radiation energy from the gas's kinetic energy. The decreasing gas temperature and altered distribution also lead to a slightly reduced wall temperature and thus cooling at constant heating power. The particular challenge, however, lies in detecting the increased radiation component of the molecular bands against the broad background radiation, which clearly predominates due to the large surface area of the container walls.

Our initial investigations using a horizontally positioned Styrofoam box were inspired by the experiments of Seim and Olsen in 2023 [6]. The authors used such a set-up to verify our previous experiments on the CO_2 GHE (Harde & Schnell, 2022 [3]). They found a slight *temperature increase* with increasing CO_2, but much smaller than expected. This could not be explained.

It is likely that these deficiencies are due to the nature of the experimental set-up, which introduce unnecessary complications such as multiple reflections and air currents. Therefore, the first part of our investigations presented here, primarily addresses the question, how far such a box is really suitable for demonstrating a positive or negative greenhouse effect.

In Part II, it is shown that with a vertical experimental setup—consisting of a cylinder with polished Aluminum walls—not only the negative GHE of the most important greenhouse gases water vapor (WD), CO_2 , methane (CH_4) and nitrous oxide (N_2O) can be reliably detected, but it is also experimentally confirmed that water vapor can attenuate the effect of the other gases by superposition and saturation on the spectral bands (see also Harde, 2014 [7]).

2. Experimental Set-Up

Based on the experimental set-up of Seim and Olsen [6], a horizontally arranged, rectangular-shaped Styrofoam box is used with the heating and temperature distribution in the box (Fig. 1).

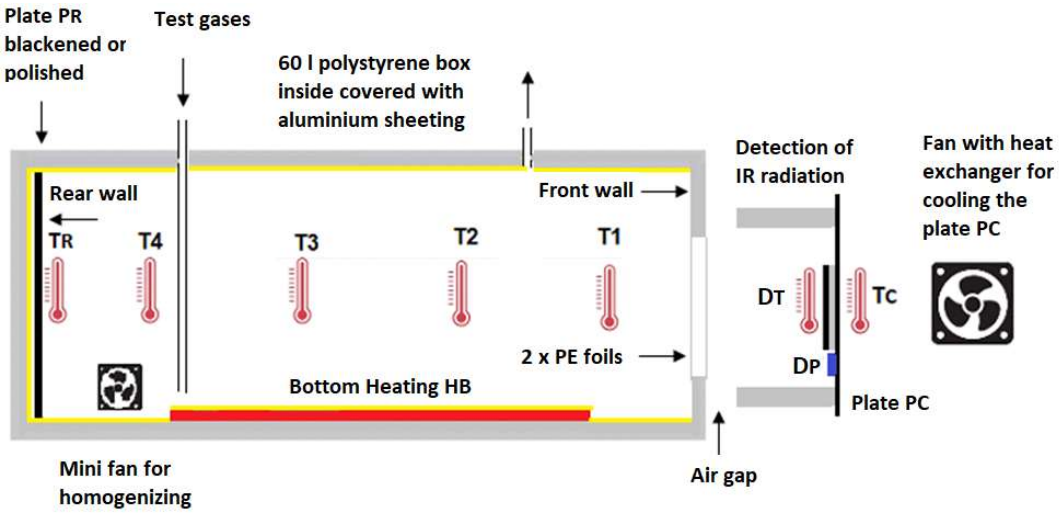

Fig. 1: Schematic experimental setup

The air inside the box is slowly heated to 36°C by a floor heating. Every 5 minutes, four temperature sensors T1 to T4 record the temperature profile inside the box and store the values in data loggers (see Appendix).

The infrared radiation emanating from the inner surfaces of the box is directed outwards through a large opening in the right-hand wall onto a cooled plate P_C at constant temperature T_C. The cooled plate P_C is an essential part of the experimental concept, because it creates an energy sink that enables a measurable energy flow by infrared radiation and/or heat conduction from the inside to the outside.

The opening is sealed inside and out with two thin Polyethylene (PE) foils that allow infrared radiation to pass through but retain the sample gases and virtually eliminate mechanical heat conduction to the outside.

If the box is filled with GH-gases, infrared radiation is generated by two sources: the radiation from the box's interior walls and the IR-active gases. GH-gases can only noticeably increase the emitted radiation intensity, if they generate a higher radiance on their absorption-emission bands than the inner walls. This requires the walls to have the lowest possible emissivity $\varepsilon << 1$. To ensure this, all interior surfaces of the box are covered with polished aluminum plates, so that these surfaces emit a significantly lower radiation intensity than a blackbody radiator.

The radiation passing through the opening is detected by two independent detector systems located on the cooled plate P_C (Fig. 2b). In the center of the plate is a blackened aluminum disc, separated from plate P_C by 8 mm thick Styrofoam insulation . The disc reacts to IR radiation with a temperature increase, which is measured by the temperature sensor D_T. In addition, four Peltier elements D_P are glued directly to the P_C plate. They generate a voltage in the mV range when there is a temperature difference between the top and bottom (Seebeck effect).

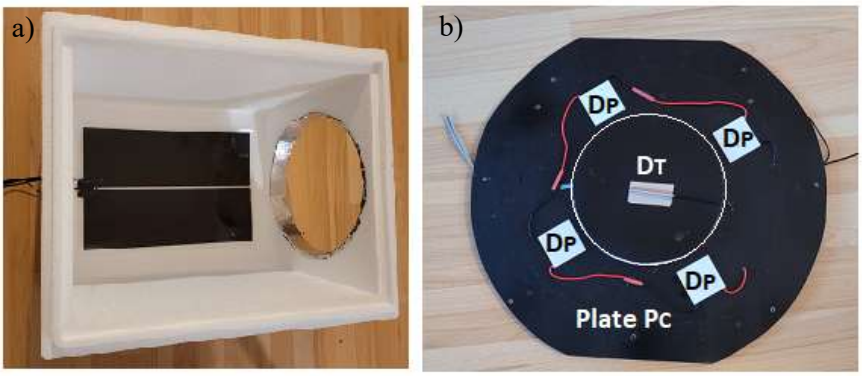

Fig. 2: a) Styrofoam box in its raw state (without lid and aluminum plates on the side walls) with heating foil H_B and radiation opening, b) detection of the IR radiation on the inside of the cooled plate P_C with the temperature sensor D_T and 4 Peltier elements D_P before its blackening.

A DC amplifier and data logger is recording and storing the data. In this set-up, the temperature and voltage changes are purely qualitative parameters of the radiation flux to the P_C plate and only represent trends for the investigations presented here. To derive the actual radiation intensities from these data, calibration is required, which is presented in Part II of this study [5].

The rear wall (left side) is covered with a polished or blackened aluminum plate P_R and its temperature T_R is recorded by a data logger. Since only this plate is aligned plane-parallel to the plate P_C, it can be used to demonstrate the radiation exchange with the cooled plate (see Section 3).

3. A Metastable Air Circulation

Without heating, all temperatures in the Styrofoam box are approximately 18°C, and the air is at rest. When the floor heating H_B is switched on, the air warms up, initially creating a surprising temperature distribution. The sensor T_1 has the highest temperature, and the rear wall P_R – polished or blackened – has the lowest temperature: $T_1 > T_2 > T_3 > T_4 > T_R$ (Fig. 3). This phenomenon cannot be explained by heat conduction. Then, for T_1 the exact opposite would be expected due to the large opening to the cooled sensors.

The unusual temperature gradient is an indication that the heat is mainly dissipated by IR radiation. Only the rear wall P_R in the box is aligned plane-parallel to the cooled plate P_C and thus can optimally exchange infrared radiation with the cooled plate P_C. As a result, the temperature T_R (green line) is up to 2°C lower than all other measuring points within the box, and the blackened rear wall is further 1.9°C colder than the polished rear wall (Fig. 3, Tab. 1).

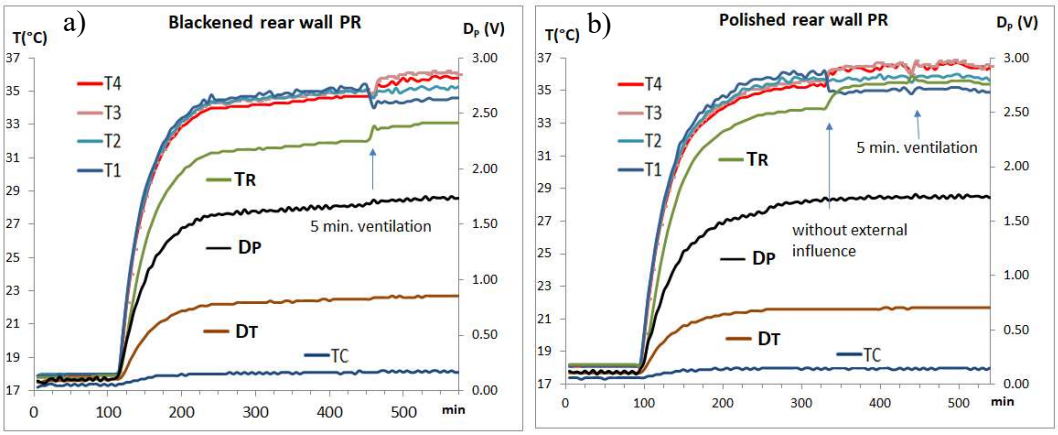

Fig. 3: Temperatures during heating of the Styrofoam box: a) Stop of the metastable air circulation by short-term ventilation at min 450, b) spontaneous stop of the air circulation without external intervention at min 330. Short-term ventilation in the stable state at min 450 has no effect on the temperature curve of the individual measuring points.

The colder rear wall P_R causes the adjacent air to flow downwards, creating counterclockwise air circulation in the box. The air passes the floor heating H_B and absorbs additional heat, which is transferred to T_1. Thus sensor T_1 (blue line) becomes the warmest point in the box (Fig. 3, Table 1). This phenomenon is a metastable air circulation that immediately stops when the internal fan is switched on for a short time. The fan then heats the rear wall, increasing its temperature T_R by up to 1.5°C and eliminating the downward flow as the driving force of the air circulation. A new and now stable temperature gradient $T_4 \sim T_3 > T_2 > T_1$ is formed, which corresponds to the expected heat flow from the warm box to the cold plate P_C. For the blackened back wall, the temperature T_R remains significantly below the air temperatures $T_1 - T_4$ (Fig. 3a), while the polished back wall is close to the air temperatures $T_1 - T_4$ (Fig. 3b).

With the polished back wall, from beginning the temperature T_R is higher than with the blackened wall, so that the abnormal air circulation can stop automatically after some time even without external influence (Fig. 3b).

Air circulation has no or only a negligible influence on the energy transport to the plate P_C, as can be seen from the sensors D_P and D_T (Fig. 3, Table 1). However, since air temperatures are an

important indicator of a negative GHE, a stable circulation and temperature distribution must be established before adding a GH-gas. Therefore, the mini-fan in the box is switched on for 5 minutes approximately 3 hours before adding a GH-gas to ensure that the stable condition is achieved (see Fig. 4, min 230). When stable circulation has already been established, the ventilation has no influence on the temperatures, as shown in Fig. 3b.

Table 1: Influence of air circulation on temperatures and energy transport, HB = 21 W.

Condition	T_C	T_R	T_4	T_3	T_2	T_1	D_T	D_P
the change	°C	°C	°C	°C	°C	°C	°C	V
				Polished back panel:				
Metastable	18.0	33.9	35.3	35.6	35.7	36.0	21.6	1.70
Stable	18.0	35.4	36.3	35.6	35.8	35.0	21.6	1.70
difference	0.0	1.5	1.0	0.0	0.1	-1.0	0.0	0.0
				Back wall blackened:				
Metastable	18.1	32.0	34.7	35.0	35.0	35.2	22.5	1.70
Stable	18.1	32.9	35.6	36.0	35.1	34.3	22.6	1.73
difference	0.0	0.9	0.9	1.0	0.1	-0.9	0.1	0.03

4. Evidence of Gas Radiation and the Negative Greenhouse Effect

Before starting an experiment as described in Section 2, the air in the Styrofoam box with the polished back wall is heated to 35 to 43 °C (heating power H_B between 21 and 28 W), and a stable condition is ensured by ventilation. After further 200 minutes, the greenhouse gas is poured in near the floor using a mini pump with a rate of about 1 l/min. Then the gas and air are homogenized for 5 minutes using the internal fan. The temperature changes measured 30 minutes before and after adding the GH-gas are used as averages of the recorded data (Table 2). As a control measurement, the IR-inactive noble gas argon is also examined to check whether mechanical heat conduction has an influence on the measurements. For the sake of simplicity, only data for the medium heating level H_B = 25 W are shown in Fig. 4 and Table 2.

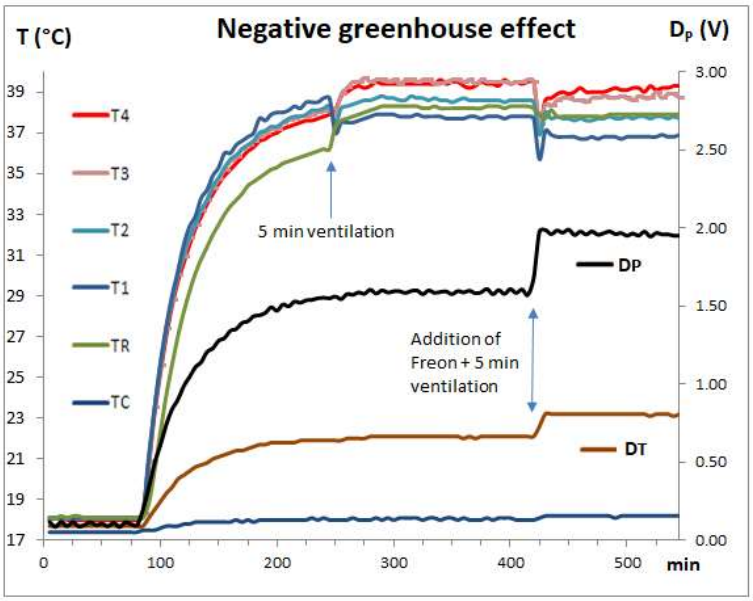

Fig. 4: Verification of the negative GHE with 2 vol.% Freon 134a, H_B = 25 W.

Table 2: Influence of sample gases on temperatures and IR radiation, H_B = 25 W

Gas Vol.-%	ΔT_C °C	ΔT_R °C	ΔT_4 °C	ΔT_3 °C	ΔT_2 °C	ΔT_1 °C	ΔD_T °C	ΔD_P V
Freon 2%	0.0	-0.5	-0.4	-0.9	-0.9	-1.0	1.1	0.38
N_2O 2 %	0.0	-0.1	-0.3	-0.2	-0.2	-0.2	0.2	0.06
CO_2 2 %	0.0	-0.1	-0.1	0.0	-0.1	-0.1	0.2	0.07
Argon 2%	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.00
Argon 5%	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.00

The addition of Freon 134a (1,1,1,2-tetrafluoroethane), a very strong greenhouse gas, leads to a significant increase in detectable radiation, which can be seen as increase of the measured values ΔD_T and ΔD_P. At the same time the air in the box cools down by up to 1.0°C.

This counter-reaction is the result of molecular collisions, which lead to a continuous repopulation of excited rotational-vibrational states of the Freon molecules (see, e.g.: Harde, 2013, Subsection 2.3 and 2.5 [4]). In this way the radiated energy due to spontaneous emission of the molecules occurs at the expense of the air's kinetic energy. Control measurements with Ar or He show no changes, so specific heat conduction can be ruled out for the measured temperature decrease.

The observed temperature drop over the box is a clear indication of a negative GHE, which can be demonstrated with this experimental set-up in a laboratory and under normal pressure conditions.

However, for other IR-active gases such as CO_2, CH_4 or N_2O, the described set-up only gives very weak or even no measurable radiation changes at the sensors or in the gas temperature. This shows, apparently, a simple Styrofoam box is not sufficiently suitable for detecting the GHE for these gases (Table 2).

Furthermore, these studies show that a blackened back wall is counterproductive for detecting the negative GHE. To this end, the Freon measurements were repeated with both a polished and a blackened back wall P_R at a heating H_B = 21 W (Table 3).

Table 3: Polished vs. blackened back panel, measured temperatures and radiation with respective changes when adding 2 vol.% Freon, H_B = 21 W

Adding Freon	T_R °C	T_C °C	T_4 °C	T_3 °C	T_2 °C	T_1 °C	D_T °C	D_P V
Polished back panel = Variant A								
Average	35.20	18.30	36.20	36.00	35.10	34.20	22.90	1.70
the change	-0.34	0.10	-0.36	-0.66	-0.79	-0.83	0.89	0.30
Back panel blackened = variant B								
Average	34.10	18.40	35.40	35.40	34.60	33.80	23.30	1.90
the change	1.04	0.10	-0.36	-0.74	-0.70	-0.77	0.30	0.12
Difference Var. B - A	1.38	0.00	0.00	-0.09	0.09	0.06	-0.59	-0.17

While the changes in air temperatures are almost identical, there are significant differences in the IR radiation (D_T and D_P). To understand this, one must examine the temperature changes ΔT_R of the various back panels. The polished panel (variant A) largely reflects the Freon radiation, preventing heat transfer and dissipating the heat output primarily through IR radiation to the P_C plate. The slight temperature decrease ΔT_R = -0.34 °C is caused by heat conduction to the cooler adjacent air layers.

In contrast, the blackened rear wall (variant B) absorbs the Freon radiation almost completely and thus experiences a significant temperature increase of $\Delta T_R = 1.04$ °C despite the cooled ambient air. As a result, part of the Freon radiation is converted into heat and partly disappears through the rear polystyrene wall to the room. This is lost as the IR radiation towards the P_C plate with the sensors D_T and D_P and results in a lower increase for variant B than variant A.

The experiment with the blackened back wall demonstrates, why proving the negative GHE is quite difficult and so far, has only been successful with the super GH-gas Freon. To detect the gas radiation of IR-active gases, the container and the GH-gases are both heating up. Even with polished walls and a small emission coefficient, due to the relatively large surface of a cuboid box it is difficult to distinguish the gas radiation from the background radiation of the container. Therefore, the set-up with a Styrofoam box is not sensitive enough to clearly detect the relatively weak IR radiation from CO_2 and nitrous oxide on this background. Especially a horizontal set-up with disruptive convection and multiple reflections is difficult to control.

In contrast, a cylindrical, vertically mounted radiation channel with polished Al-walls can be used, not only to measure the negative GHE of CO_2 and nitrous oxide, but also that of the weaker GH-gas methane (Harde & Schnell, 2025, Part II [5]).

5. Summary

In this contribution we demonstrate that IR-active gases are transferred to excited states through thermal excitation and convert the kinetic energy of their surrounding into infrared radiation by spontaneous emission. Due to inelastic collisions in the gas mixture, the lost radiation energy is continuously extracted from the thermal energy of the gas and observed as a temperature drop in the compartment. The hypothesis that collision processes of the gases in the lower troposphere prevent IR emission and that greenhouse gases cannot generate back-radiation is thus once again refuted.

However, with the presented set-up this effect could only clearly be demonstrated using the particularly potent greenhouse gas tetrafluoroethane (Freon 134a). Apparently, this limitation is caused by the set-up, consisting of a horizontally placed Styrofoam box, which is only partially suitable for radiation transfer. Multiple reflections of the infrared radiation from the parallel interior walls impede the radiation transfer to the cooled P_C plate and are overlaid by the wall radiation. Furthermore, the horizontal arrangement leads to complications due to the resulting air circulation. Part II of this study [5] shows that these problems can be overcome with a vertically arranged cylindrical radiation channel with polished Al-walls.

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Appendix

The laboratory is thermostatted at 18 °C ± 0.3 °C to prevent perturbations caused by fluctuating room temperatures.

To supply the H_B heating foil, the current from the socket is stabilized at 230 V via a digital voltage regulator. It is then rectified by another digital voltage regulator and adjusted to the desired heating output H_B using a percentage setting from 52 to 70%. The hole (diameter Ø = 28.5 cm) in the Styrofoam box is cut using an electric cutter. Commercially available aluminum plates are polished to a high gloss with polishing paste or blackened with "Matt Black" paint spray. Back panel = 36 x 32 cm, P_C plate Ø = 41 cm, IR detector plate Ø = 16.7 cm.

The housing for the IR detector is made of polystyrene wallpaper: length = 13 cm, outer diameter = 41 cm, inner diameter = 30 cm. The housing is connected to the front wall and the cooled P_C plate by four threaded rods, leaving a 2 cm air gap between the box and the housing.

The PE foils are glued to a wooden frame 37 x 33 cm and a hole with Ø = 29 cm and fixed to the front wall from both sides with silicone rubber.

Table A1: Distances of the temperature measuring points from the front wall of the box

Sensor	T_R	T_4	T_3	T_2	T_1	T_C	D_T	D_P
Distance (cm)	49	45	34	23	11.5	-20	-19.5	-19.5

Table A2: Compilation of materials used.

Device	Source
Styrofoam box = Thermobox 60 liters Internal dimensions: 49.0 x 37.0 x 33.0 cm External dimensions L/W/H: 57 x 45 x 41 cm	Amazon/Terra Exotica
Styrofoam plate for additional insulation of the lid 57 x 45 x 2 cm	hardware store
Heating foil 2x20 W NEKOSUKI reptile terrarium heating mats 42 x 28 cm	Amazon/Terra Exotica Terrarium
PE film , cling film 45 cm x 300 m	Amazon/Packaging Team
Thermocouple TEC1 12706 12V 6A 40x40mm	Amazon/ shenzhenshiyaoxingmaoyi
Digital voltage regulator 4000W AC 220V SCR	Amazon/ Luoyuuk
Digital voltage regulator KEMOT SER-2000	Amazon
Elitech Temperature Data Logger, RC-4	Amazon

Voltage data logger VOLTCRAFT VC-11015505 DL-250V	Conrad Electronic SE
DC 3-12V iHaospace AD620 DC Power Amplifier	Amazon/ iHaospace
Heat exchanger, ASHATA 120mm aluminum radiator	Amazon/Richer-R123
Fan Sunon 80 x 80 x 25mm	Amazon/ kessler -electronic
Mini fan 30 x 30 x 10mm	Amazon/CHEER CHAMP