Controlled Condensation in a Fixed Dome Camera Using Active Cooling

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Abstract

This thesis investigates the possibilities of preventing condensation from forming in the optical field of view in surveillance cameras with a dome through active cooling. The forming of condensation has been a challenge in these cameras, which can affect the quality of the image. By implementing different Peltier modules and varying their placement and power, this thesis has aimed to evaluate the ability of active cooling to prevent condensation from occurring in the optical field of view.

The methods include a combination of experimental tests, in both start-up cases and falling ambient temperature cases, and theoretical analysis to evaluate the effectiveness of different implementations. By comparing different sizes of Peltier modules and experimenting with different placements of them, the authors could assess their ability to decrease the amount of condensation formed and maintain optical clarity.

The results show that the use of active cooling is very effective in the falling ambient temperature case, and might be effective in the start-up case in domed surveillance cameras. Also, it shows that the active cooling should be placed far away from the optics for better results.

This study offers practical recommendations to improve the performance of surveillance cameras and also provides an understanding of the thermal and optical characteristics of such systems. Through the effective integration of active cooling, surveillance cameras with domes can, in some cases, perform high-quality surveillance in challenging environments.

Keywords: Condensation, active cooling, peltier module, dome camera, optical clarity.

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Edgar Portela and Jesper Johansson

Abbreviations

AH	Absolute Humidity
RH	Relative Humidity
DP	Dew Point
FoV	Field of View
PcP	Precondition phase
PM	Peltier Module
PoE	Power over Ethernet

Contents

Preface

During this thesis work, the two authors have equally contributed to the result, although some steps have been done separately to utilize the time in the best way possible. That said, both authors put equal effort and responsibility into the project.

Throughout this thesis work, both authors made significant and fair contributions to its outcome. While certain tasks may have been carried out independently to optimize time management, it is essential to emphasize that the combined effort and dedication put down by both authors remain equal. Each author has shown a committed and responsible approach to every aspect of the project, ensuring that the individual contributions complement and improve the overall quality and efficacy of this thesis project. By working together effectively and respecting each other's contributions, we created an encouraging and productive environment that enabled us to achieve our goals.

1. Introduction

In surveillance systems equipped with a dome around the camera lens, a common problem is condensation on the inside of the dome. Since a clear field of view (FoV) is crucial for a surveillance camera, this problem is something that has to be addressed effectively.

The terminology Dew Point (DP), Absolute Humidity (AH), and Relative Humidity (RH) will be discussed in detail in the background chapter but up until chapter 1.3, it is enough to know that DP is the temperature at which the air becomes saturated with water vapor while the AH is the amount of water vapor present in the air.

1.1 Project Description

In this project thesis, a method to remove the condensation on the inner side of the dome is investigated. The method relies a lot on the theory of psychrometry.

The general idea in this project is to create a “condensation trap” with the help of an active cooling element called Peltier Module (PM) to make the condensation happen elsewhere before it condenses on the dome’s inner side. This, in theory, would be achieved by creating a temperature on a surface, colder than that of the DP.

In later parts of the project, variations of this method are tested and investigated to see what performs better and what to avoid.

1.2 Occurrence of Condensation

For condensation to happen on the inside of the dome, certain criteria have to be met. Firstly, air with high humidity has to be trapped inside the camera and the temperature of the inner side of the dome is lower than the DP of the air, causing the water particles to condense on the inside surface of the dome. In practice, this translates into three scenarios:

Start-up case:

Condensation happens when the camera is turned on, resulting in an overall temperature increase inside the camera. The temperature increase affects internal materials such as plastic and they release moisture hence (Omnexus, 2024), the AH increases. However, the temperature of the inner side of the dome does not increase as fast or as much. This results in the dome's inner side slowly reaching the DP and condensation occurs.

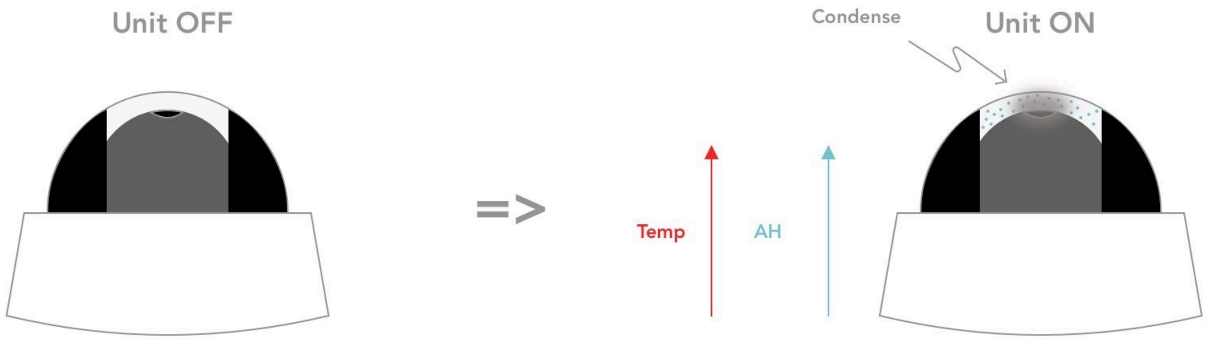


Figure 1: Demonstration of condensation in start-up case.

Fall of temperature:

When the camera is in operation and is balanced in a warm, humid environment but then experiences a rapid fall in ambient temperature, the dome's inner side temperature will also decrease with this fall. The temperature of the inner side of the dome will eventually reach the DP and condensation will occur.

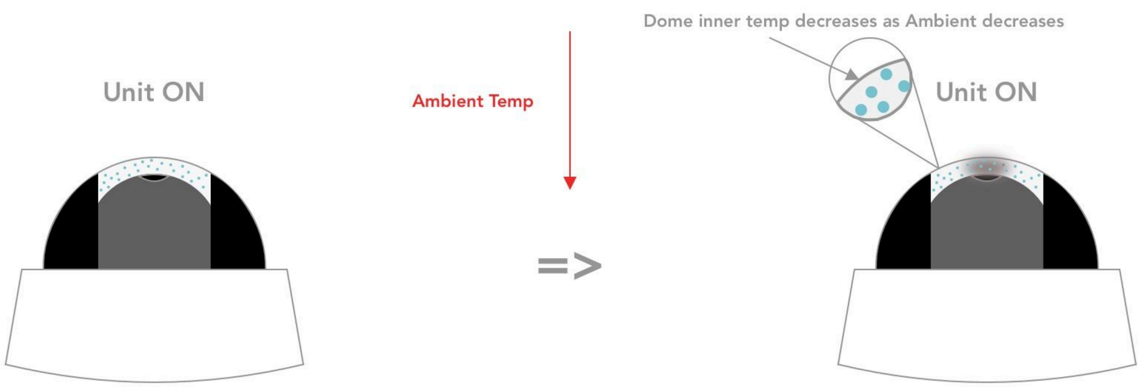


Figure 2: Demonstration of condensation in Fall of Temperature case.

Sunny, cold days:

Another situation, although not so usual for cameras used for this project, where condensation may occur, is on cold sunny days. This is because one side of the camera is exposed to the sun, while the other is not. This makes the materials on the side that are exposed to the sun evaporate the water that is trapped inside it, raising the AH in the camera. Because the other side of the camera is still very cold, the water vapor will condense on that side of the dome.

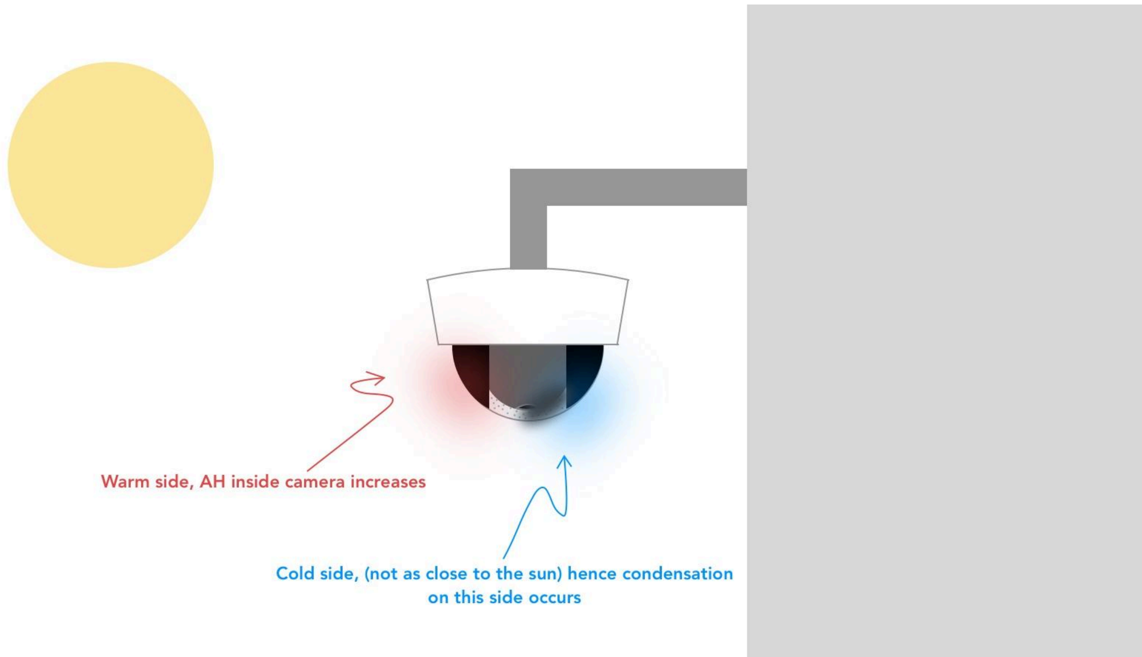


Figure 3: Demonstration of condensation during sunny/cold days.

1.3 Countermeasures

The three scenarios above are undesirable since they will render the camera ineffective in capturing clear images or footage.

A wide variety of countermeasures have been developed and studied. Most commonly a heater solution is used, to keep the surface of the dome hot enough for condensation not to form. Another solution that has been tried includes the use of a fan to make the air more homogenous, to reduce condensation. Solutions where dry bags are used today have shown to be very effective.

The earlier tried methods have been shown to help remove the condensation faster compared to a camera that has not been modified but the time it takes for the condensation to be removed is still an issue. In the case of dry bags, the bags will eventually become saturated making them useless in the long run.

1.4 Background

Psychrometry

Psychrometry is the science of humidity and its effect on the air and materials. Some important terms in this field are DP, RH, and AH.

The amount of water vapor the air can hold depends on its temperature, whereas the higher the temperature, the denser the air can be with water vapor. This creates an index called RH, calculated as (Technical Investigations Section, 1953, 3):

$$RH = \frac{P_w}{P_s} \tag{1}$$

where P_w is the current pressure of water vapor in the air, also known as AH, P_s is the pressure of water vapor in the air when saturated.

To put it in simpler terms, RH is a percentage that tells how much water vapor there is in the air relative to how much water vapor the air can hold as maximum.

Furthermore, the DP is the temperature at which the water vapor in the air starts to condense. When the RH reaches 100%, it means that the air is *saturated* with water vapor, in other words $P_w = P_S$. At this point, the air temperature is the same as the DP. The DP is calculated as equation 2, also known as the Magnus formula (G. Lawrence, 2004, 226):

$$T_{DP} = \frac{\lambda(ln(\frac{RH}{100})+(\frac{\beta*T_{Air}}{\lambda+T_{Air}}))}{\beta-ln(\frac{RH}{100})-(\frac{\beta*T_{Air}}{\lambda+T_{Air}})} \tag{2}$$

Where T_{air} is the temperature of the air, β = 17.62 and λ = 243.12 °C.

An example of when the temperature reaches the DP is when the grass is very moist in the morning. The soil retains moisture from the previous day, and when the sun rises the next day the soil is heated up and vaporizes the water that it contains, increasing the AH. When the air comes in contact with the cold grass, its temperature decreases until it reaches the DP and dew will form on the cold surface of the grass.

Air Saturation

Saturated air and unsaturated air are terms used when describing the different levels of water vapor in the air, in perspective to its maximum capacity at a given temperature.

The air is saturated when it contains as much water vapor as it can hold at a specific temperature. If more water vapor is added, the water vapor will condense and create fog or dew. If the temperature falls, the air will not be able to hold all the water, and the excess will condense.

If the air contains less water vapor than its maximum capacity at the given temperature, it is unsaturated. This means that there is room for more vapor to be added until the vapor starts to condense. If the AH of the air rises through evaporation or the addition of water, the air may be changed from unsaturated to saturated (University of Arizona, 2024).

Absorption of moisture in plastic materials

A commonly occurring material in cameras is plastics. Many plastics are hygroscopic, meaning they absorb moisture from their environment. The absorption of water is reversible by vaporizing the moisture that is trapped inside the plastic, also known as desorption.

Several of the cameras have heaters to heat cold surfaces and components. When the heater is turned on, the temperature of the surrounding components also increases; some of which are made of plastic. This temperature increase results in the desorption of the plastics, hence increasing the AH.

Conversion from RH to AH in Density Units

It was of interest to calculate the AH as a *density* given the temperature of the air and the RH at that temperature. The constants P_w, P_s are given in pressure units (kPa), this means that once the pressure of the water vapor in the air, P_w, has been calculated, a conversion has to be done as a last step, using the ideal gas law to determine the density of water molecules present in the air. The calculation is done in the following matter:

Rearranging formula 1 gives us:

$$P_w = RH \cdot P_s(T) \tag{3}$$

Here it is explicitly shown that P_s is temperature-dependent. To calculate P_w, P_s has to be calculated. This is done with the *Tetens formula* (Tetens, 1930, 298-299):

$$P_s(T) = 0.611 \cdot exp(\frac{bT}{c+T}) \quad (4)$$

Where b = 17.27 and c = 237.3. The constant b is dimensionless while c is given in degrees celsius.

Inserting the calculated value $P_s(T)$ and the given value of RH in (eq.3) gives us the value of P_w. Knowing the pressure of the water vapor in the air, P_w, one can now calculate the density of the air using the ideal gas law:

$$\rho_v = \frac{P_w \cdot M_w}{R \cdot T_a} \quad (5)$$

Where M_w is the molecular weight of water, (18.02g/mol), R is the universal gas constant, (8.31J/mol * K), and T_a is the temperature in Kelvin.

The calculated value ρ_v is the AH, given in density units. It is the mass of the gas per unit volume or in other words: it tells how much water there is per volume unit.

Peltier Effect

This thesis project used different PM:s to obtain cold temperatures. A PM works on the principle of the Peltier Effect invented by Jean-Charles-Athanase Peltier (Goldsmid, 2017, 1-2). The simple principle of the module is to transfer heat from one side of the component to the other. As a result, one side becomes hot and the other cold.

If current passes through two junctions either cooling or heating occurs. This junction is made with two different conducting materials, in the beginning, Peltier used copper and Bismuth. He noticed that when current passed from copper to the bismuth the temperature would increase. If the temperature passed from bismuth to copper the temperature decreased.

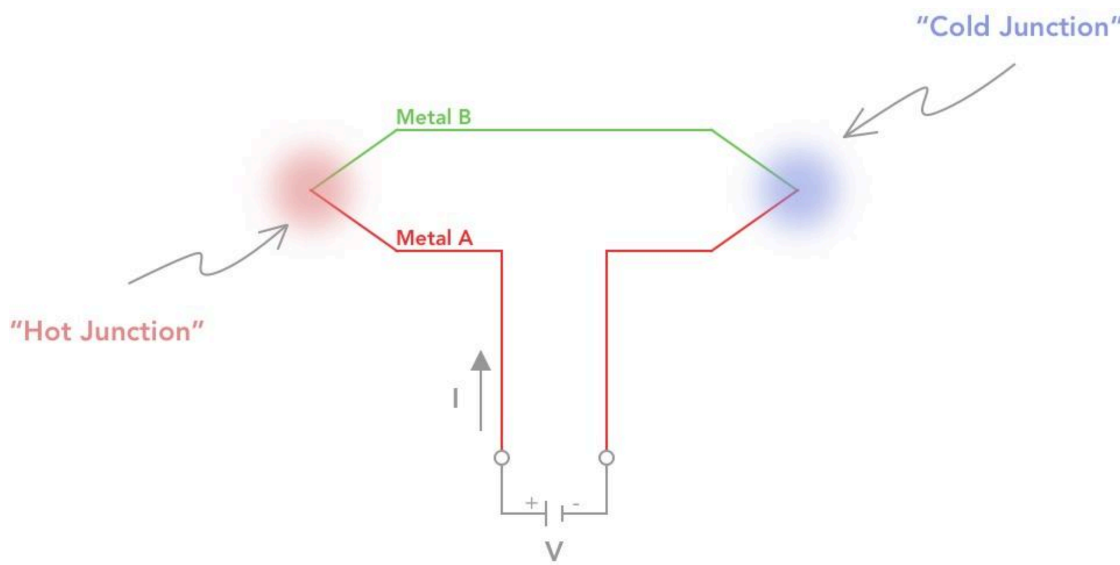


Figure 4: A demonstration of the Peltier effect.

Today, modern PM:s use semiconductors. Alternating legs of P-doped and N-doped semiconductors are arranged in a matrix (Rowe & Rowe, 1995, 497). On top and bottom of the array of semiconductors, insulators such as ceramic plates are placed. Current through these P-doped and N-doped materials results in the Peltier Effect.

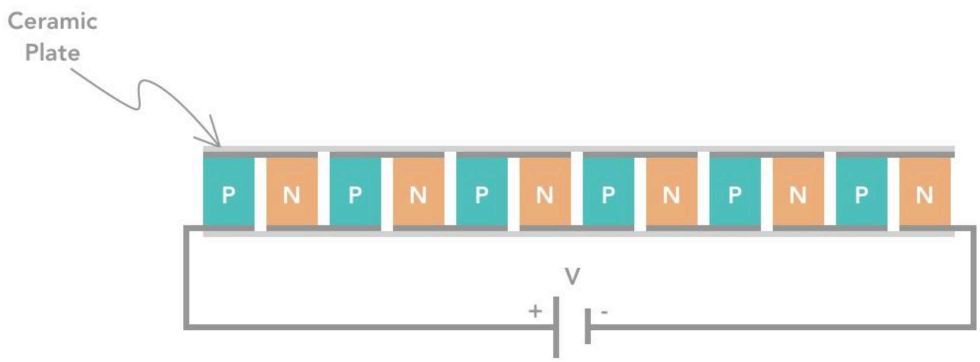


Figure 5: A modern Peltier Module.

1.5 Aims and Challenges

A challenge in this thesis project was to investigate whether or not a PM could be used to act as a condensation trap in fixed dome cameras to reduce the amount of condensation or fog in the FoV of the camera. It was therefore considered that proving this would be our main goal.

The other main goal that was set was to investigate how low power the PM could use while still being effective. This is an important aspect to investigate since many surveillance cameras use power over ethernet (PoE) which means a solution with low energy consumption is necessary. A side goal to this energy problem was to at some point create a control system that would regulate the power to the PM depending on the temperature and humidity inside and outside of the camera so that the PM wouldn't have to be turned on all the time. It was decided to remove this goal from the list because it was concluded that it would only be relevant to make a control system in the case of a fall in ambient temperature. Instead, the time that was left was investigated by doing more specific tests on the cameras.

2 Method

The following chapters describe the approach and methodology used for all of the different tests that were carried out. Before going through each test in detail there will be an illustration of how different test setups were made.

For all the tests, a consistent practice involves using a preconditioning phase (PcP) to allow the moisture to settle within the camera's materials.

2.1 Components

Following are all the components and materials used for the tests.

Camera

Taking the time and considering what camera to use for testing during this project was important. Different camera models were presented and it was discussed which one of these cameras would be a suitable candidate during the thesis project. A model was chosen as a candidate as this specific model had more volume to be utilized for the placement of the PM compared to other camera models. Since the cameras use PoE, the energy consumption is limited to about 20 W.

Sensors

Temperature and humidity of the air

For the temperature and humidity of the air, a digital sensor was used to measure the parameters of the air in the camera when the camera was undergoing a test. The choice of this sensor was due to its accuracy. This sensor was considered a great option with an accuracy of ±0.1 % RH, ±0.1 ℃ temperature. The sensor is manufactured by Sensirion, which also offers its software to analyze the data captured.

PT1000

PT1000 sensors are platinum-based temperature sensors. The sensors measured the temperature of different surfaces. Axis has provided a self-made logger and software to analyze the data (Peak Sensors, 2024).

The software for both the sensors can output the captured data into a file format that can be interpreted and analyzed with Excel.

Climate/Heating Chamber

During this project, Axis provided their climate chambers and heating chambers (CTS, 2024) to put the cameras under test. The purpose of the climate chambers is to test certain products and see if they meet certain conditions. In the case of this project, the climate chambers were used to form condensation inside the cameras. This was accomplished by changing different parameters inside the chamber such as temperature and RH.

The heating chamber can only regulate temperature, while the climate chamber can control the RH as well.

Peltier modules

Two different PMs have been used for the project, both are manufactured by CUI Devices. One of the PM has a bigger surface and requires a greater power. This PM will be referred to as "bigger PM". The other PM has a smaller surface and requires less power. This PM will be referred to as the "smaller PM".

2.2 Test in the heat chamber

Construction of test setup for tests in the heating chamber

For the upcoming tests, a setup had to be created. The camera model that was used can be divided into three parts as shown in the picture below:

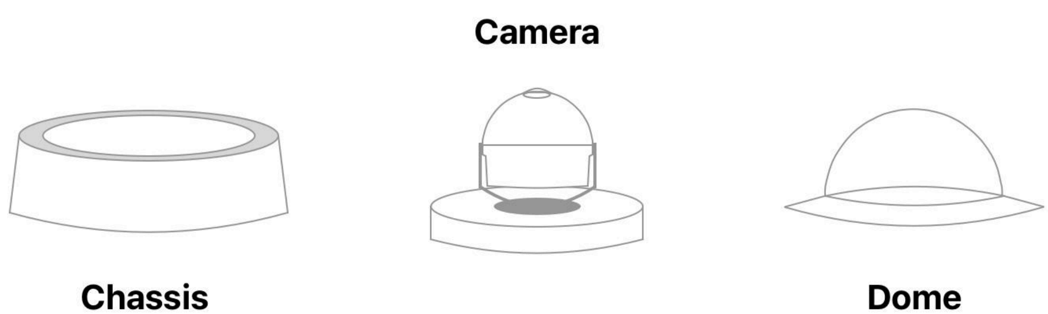


Figure 6: The chassis is to the left, the camera lens is in the middle and the dome is to the right.

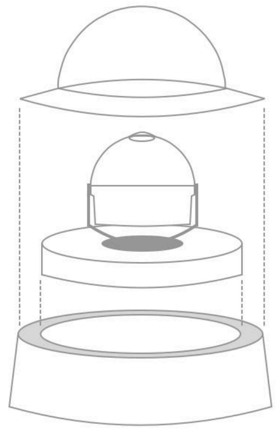


Figure 7: Exploded view on the different parts of camera

An optimal place for the PM to be put against would be a flat surface, preferably a surface made of metal so that the surface it is mounted against can drive out the heat from the warm side of the PM. Many places were flat but with little space for the PM to fit. It was decided that it should be put in the chassis of the camera as shown below:

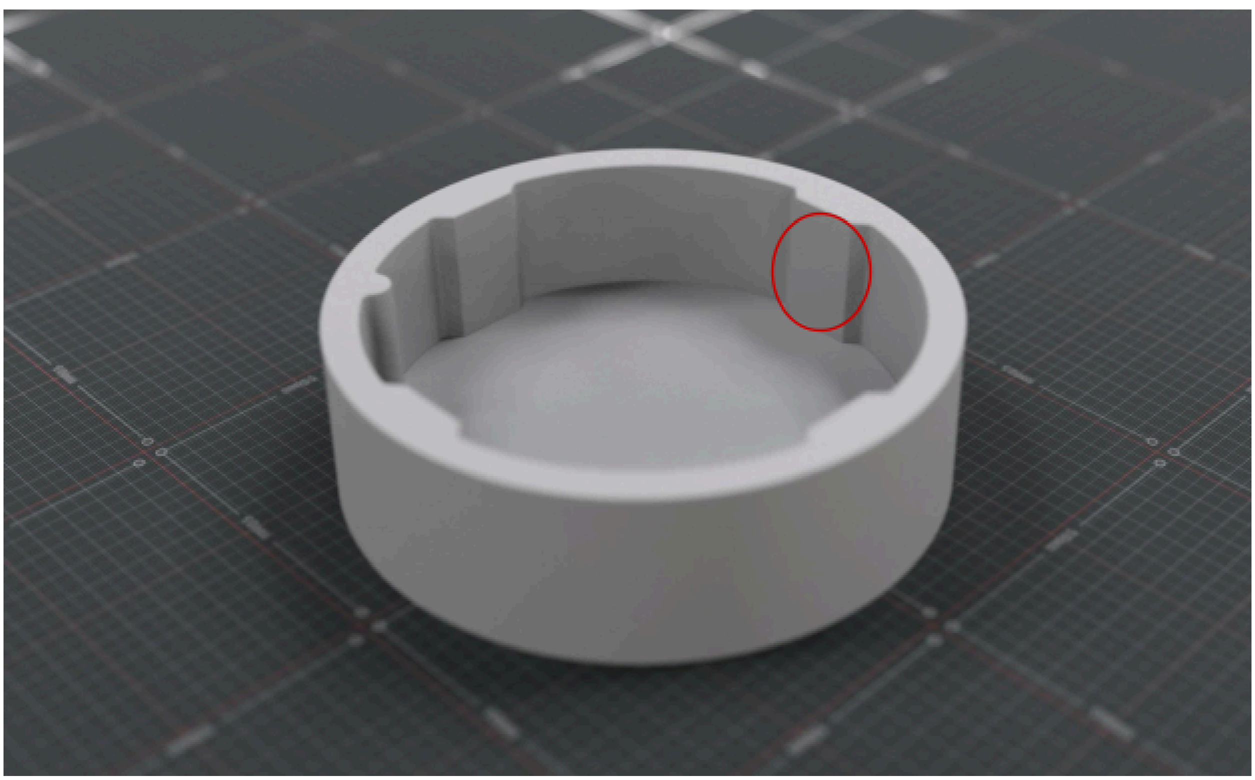


Figure 8: Surface for the PM to be mounted against.

The mounting of the PM was done with two gap pads, a zip tie, and a heat sink. The zip tie holds everything together like a belt. See figure 9.

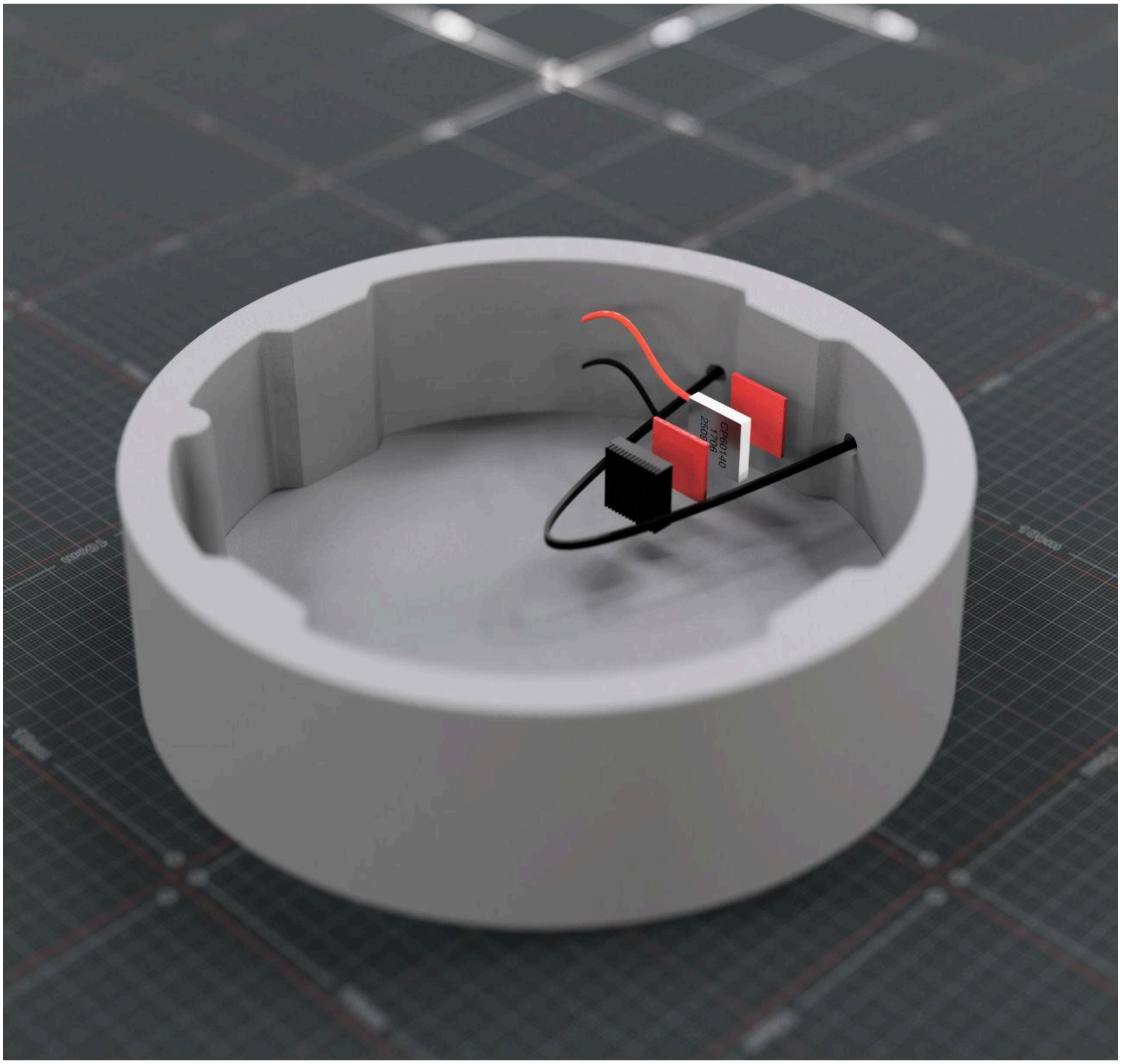
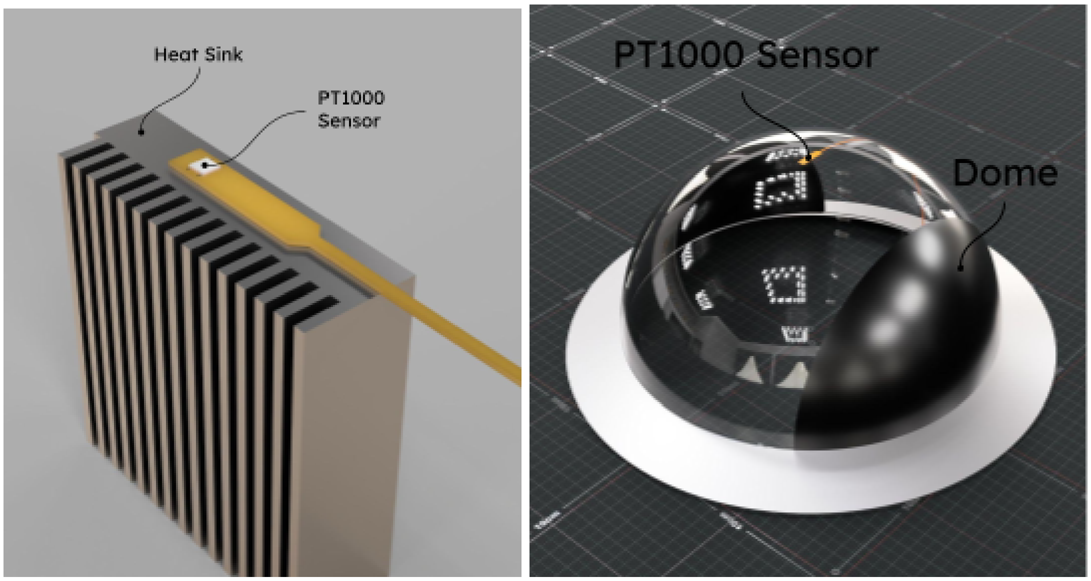


Figure 9: Mounting of PM with gap pads, heat-sink, and a zip-tie holding all the parts together on the inside of the chassis.

For these tests two PT1000 sensors were used; one on the inside of the dome and one on the heat sink. See figure 10 a) and b):



a) b)

Figure 10a) and b): Illustration of the sensor on the heatsink to the left and the right an illustration of the sensor on the inner side of the dome.

Initially, the tests were carried out in a heat chamber, with the ability to only regulate the temperature. This was mainly because of the easier access to the chamber. Two tests were carried out in this chamber.

Test 1

Since the idea is to let the condensation happen on the PM, the first test aimed to investigate if the PM could reach a lower temperature than that of the dome's inner side. The test was carried out in the following manner: the camera with the Peltier solution was inserted in the heating chamber with a closed dome. The temperature in the heating chamber was set to 0℃ for approximately one hour. After one hour had passed the PM was turned on.

Test 2

The second test aimed to determine whether it was possible to create condensation on the inner side of the dome in the heat chamber. Since the heat chamber did not have humidity regulation, a wet sponge was placed in the chamber, and when the temperature of the sponge rose, the water should have vaporized and humidity in the chamber should have risen. For this test, two additional SHT45 sensors were added, one in the ambient air in the chamber and one inside the camera. In this test, the temperature was set to 50 ℃ for 16 hours with the camera open. After 16 hours, the heating chamber was opened and the dome of the camera was closed. The heating chamber was then closed and the camera was left inside for four more hours to stabilize.

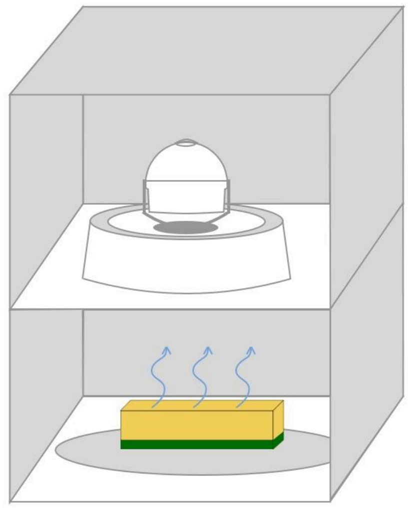


Figure 11: Illustration of the setup for test 2 in the heating chamber.

2.3 Test in the Climate Chamber

To make the tests more accurate, the next tests were carried out in a climate chamber with humidity control. All the tests henceforth use two cameras, one that has the same construction with the Peltier solution as in the test in the heating chamber and one that is a reference camera, to see if the PM makes any difference. The two cameras were mounted to a stand side by side, with the back facing the rear part of the climate chamber. This was done because at the rear part of the climate chamber is the air intake, giving the cameras equal conditions. A third camera was used to take pictures of the two cameras. See Figure 12:

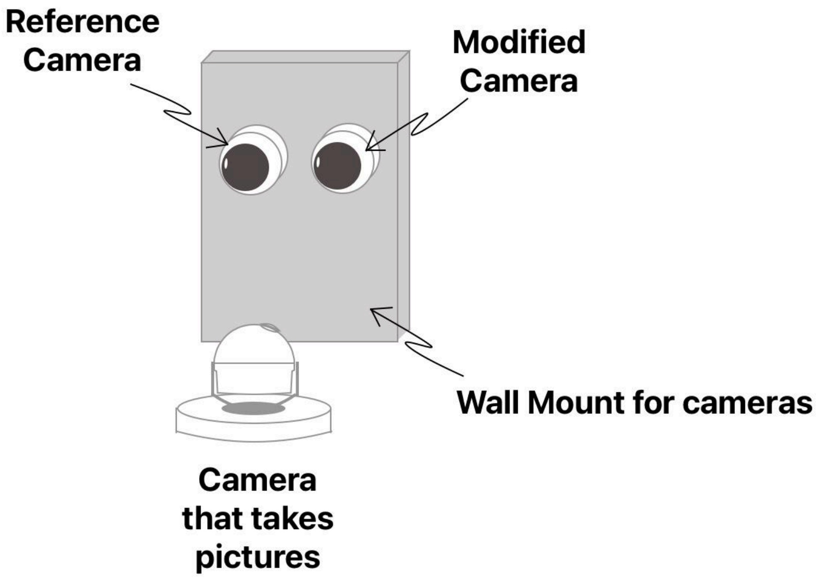


Figure 12: Picture of the setup for tests in the climate chamber.

For all the coming tests, the PcP involves first tightening the two lower screws of the dome halfway and placing a piece of a carton in the upper part, leaving the camera open so that the moisture can enter the cameras, whilst still being able to mount it rapidly. For 16 hours, the camera is left at 20 °C and 90% RH. The addition to this PcP in comparison to the one for the tests in the heat chamber is the humidity control.

After the 16-hour PcP, the climate chamber was opened to remove the carton pieces and to screw the dome tightly. This had to be done by two people at the same time to ensure that the cameras had more or less the same conditions when starting the test. After the cameras were closed the climate chamber was again shut and the cameras were stabilized for four more hours. After the four-hour stabilization period, the humidity control was disabled and the temperature in the climate chamber was set to 0 ℃ or 3 ℃, depending on the test.

2.3.1 Falling Ambient Temperature Tests

One occasion when condensation is formed is when the ambient temperature falls rapidly.

Since a fall in temperature is simulated in the climate chamber, the cameras were turned on before the PcP. After the PcP, some tests undergo a proactive phase where the PM is activated in advance to reduce the AH. The duration of this proactive phase will be specified before every test. After the PcP and the proactive phase, the chamber was set to 3 ℃, and humidity control was turned off.

Test	PM	P [W]	$t_{Proactive}$	Aim
1	Bigger PM	8.4	0 min	To evaluate whether or not any condensation will form in these conditions and if the PM could have any effect.
2	Bigger PM	8.4	20 min	Investigate if a proactive phase has an effect.
3	Bigger PM	2.8	20 min	Investigate if a decreased power could be applied.
4	Smaller PM	0.32	20 min	Evaluate the smaller Smaller PM.
5	Smaller PM	0.32	10 min	Investigate if a shorter proactive phase could be applied.

2.3.2 Start-up tests

Another situation where condensation forming on the dome occurs is when the camera is started up, and water vapor is released from the materials of the camera. After the PcP, the temperature was reduced to 0 ℃, while the humidity control was turned off. 4 hours later, the PM was turned on and after the proactive phase, the cameras were also turned on.

Test	PM	P [W]	$t_{Proactive}$[min]	Aim
1	Bigger PM	2.8	0	Evaluate the condensation forming in these conditions.
2	Smaller PM	0.32	10	Evaluate if a proactive phase affects.
3	Smaller PM	5	10	Evaluate an increased power.
4	Smaller PM	5	20	Evaluate a longer proactive phase.
5	Smaller PM	0.32	300	Significantly longer proactive phase, as well as decreased power.
6	Smaller PM	0.32	600	Evaluate a longer proactive phase.
7	Smaller PM	0.32	1 200	Evaluate a longer proactive phase.

2.3.3 Placement tests

Construction of test setup for placement tests

The upcoming tests were executed mainly to determine whether the placement of the PM affected the condensation forming. In contrast to the previously presented start-up tests, the PM was placed on the metal housing of the camera, close to the optics. See the figure 13:

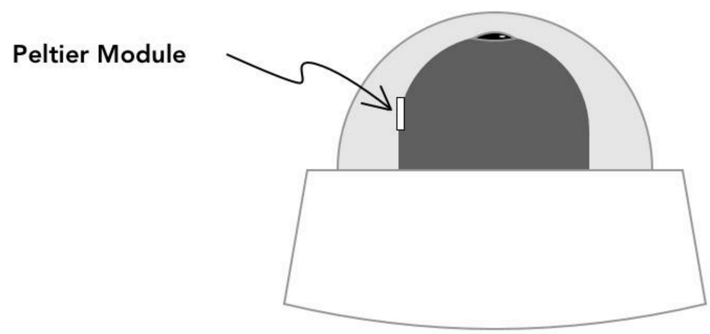


Figure 13: Picture of the construction for the placement tests.

There were two reasons for doing this test. The first one is that maybe the air inside the camera is not homogeneous, and therefore the water vapor in the air would have a shorter way to travel to reach the PM.

The second reason is to somehow utilize the warm side of the PM to heat the dome's inner side. Similar tests at Axis have been done before by placing heating cables close to the dome where the essential idea is the same; To heat the dome close to where condensation is a problem.

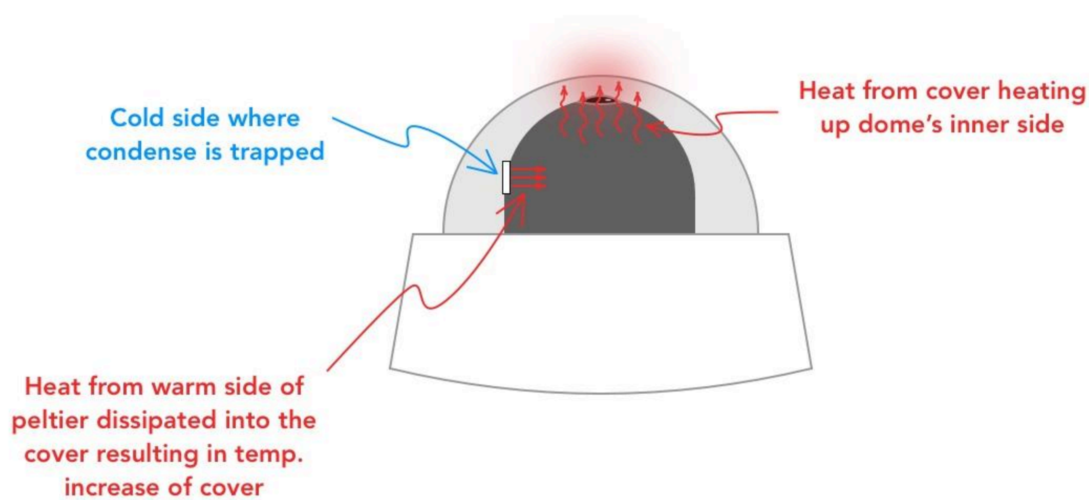


Figure 14: Demonstration of the idea with placement test

Test	PM	P [W]	$t_{Proactive}$	Aim
1	Bigger PM	2.8	0	Evaluate if the placement of the PM could affect the condensation forming.
2	Smaller PM	0.32	0	Evaluate a decreased power could affect.

3 Results and discussion

In this chapter, the results from the tests will be presented and analyzed. The results from all the tests are divided into different groups based on their purpose and circumstances.

Standard color coding (SCC) is described in the table.

Light blue	Ambient temperature in the climate chamber
Orange	Temperature of the cold side of the PM
Yellow	Temperature of the dome of the modified camera
Grey	The DP in the modified camera

If SCC is applied, it is also expected that the diagram is temperature [℃] on the y-axis and time [s] on the x-axis.

All images will contain the camera with the active cooling to the right and the reference camera to the left.

3.1 Test in the heat chamber

Test 1

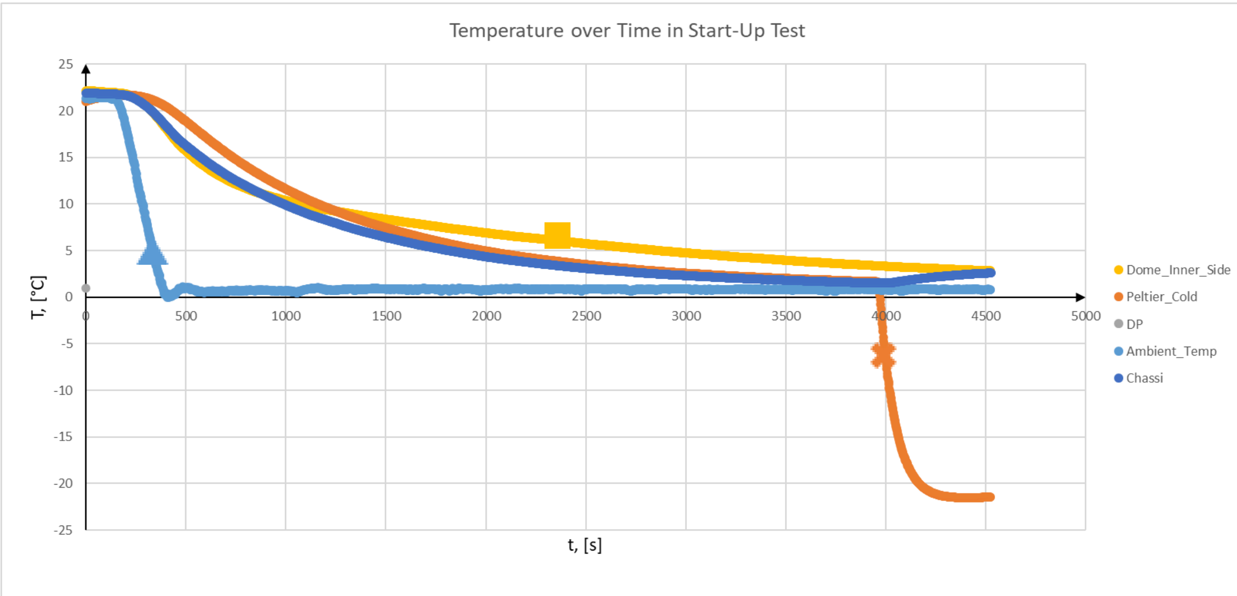


Figure 15: SCC is applied. In addition, the dark blue is the temperature of the chassis.

In the beginning, the temperature of the dome is slightly higher than that of the PM. Then, when the ambient temperature drops, the temperature of the PM drops lower than that of the dome. Finally, when the PM is activated, the temperature decreases significantly lower than that of the dome, and it is concluded that it is possible to have the PM colder than the dome.

No data will be presented from test 2. The only important conclusion was that it is not possible to create condensation in the heating chamber. It was observed that the RH always stayed at about 30% in the heating chamber's ambient air, which is not enough for condensation to happen in the cameras. It was therefore necessary to carry on with the tests in a climate chamber where the humidity could be controlled.

3.2 Test in the Climate Chamber

3.2.1 Falling Ambient Temperature Tests

Results from test 1

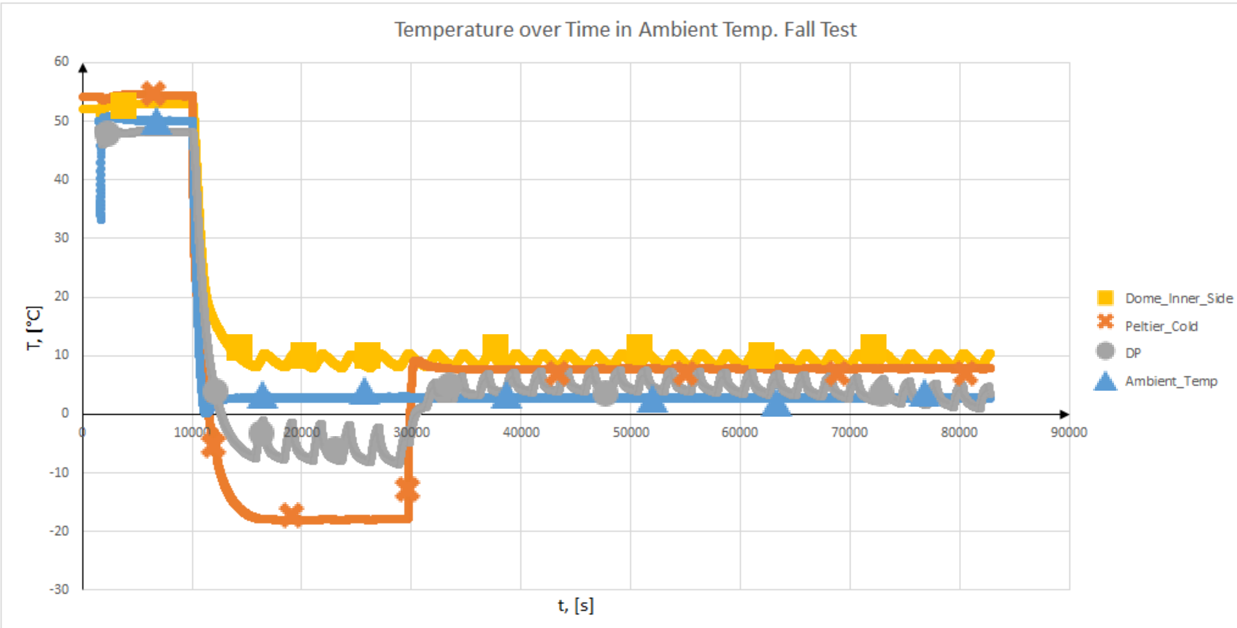


Figure 16: Data from test 1, SCC is applied. The peaks on the yellow (rhomb) and gray (cross) graph occur because of the built in heater system in the camera that turns on and off.

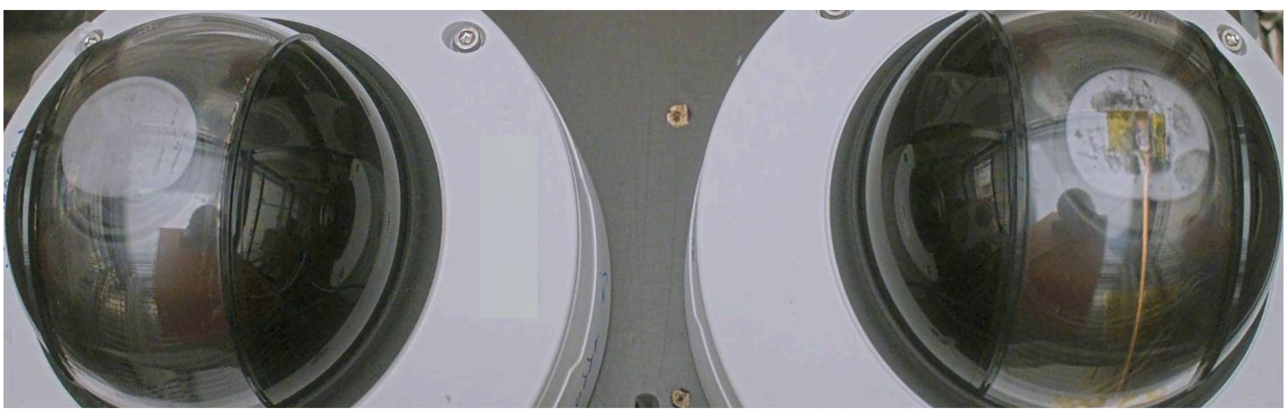


Figure 17: Image from test 1. Condensation can be seen in both cameras as light circles in the center of the dome.

Discussion test 1

During this test, a few observations were made regarding the preparations. One is that a piece of tape should be placed in the optical FoV of the reference camera as well, as this can affect the forming of condensation, giving the cameras equal conditions. It is also noted that fingerprints are present in the optical FoV of the modified camera, which also could affect the forming of condensation. Lastly, some mistakes were made regarding the cameras that were under test. In this test it was noted that the reference camera was a later version of the model, this camera had a later firmware. All of these notations will be adjusted for the upcoming tests.

Despite these flaws, the result shows that condensation can be formed in these conditions regardless if the active cooling is activated simultaneously with the fall of temperature or if no active cooling is used.

Results from test 2

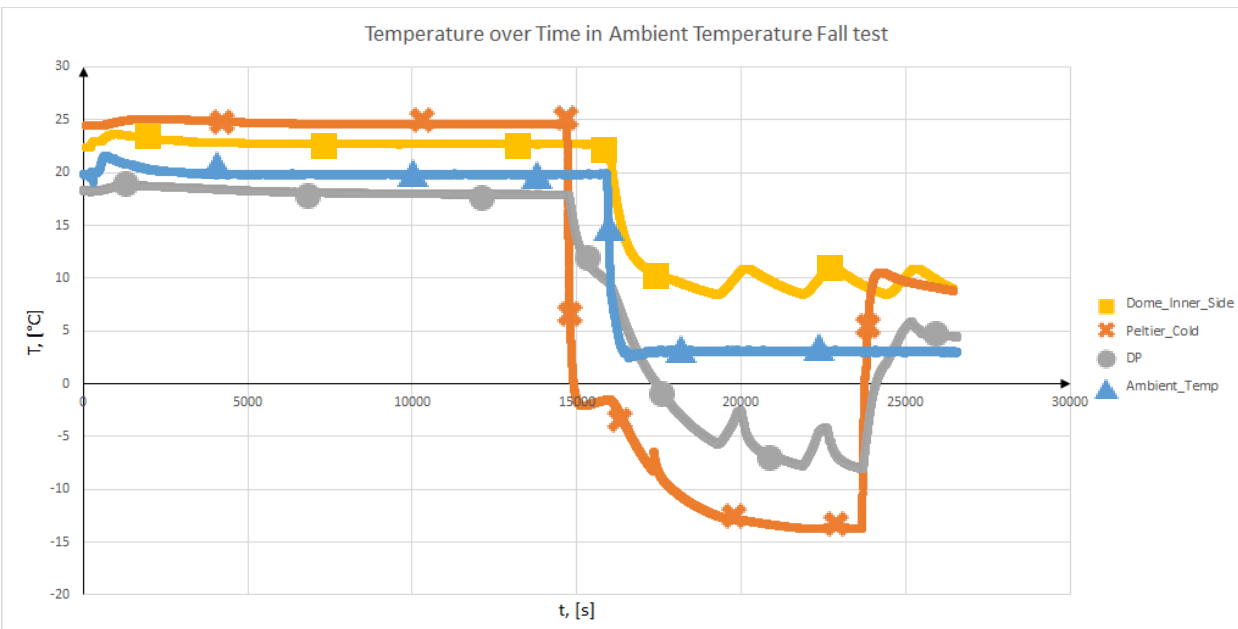


Figure 18: Data from test 2, SCC is applied.

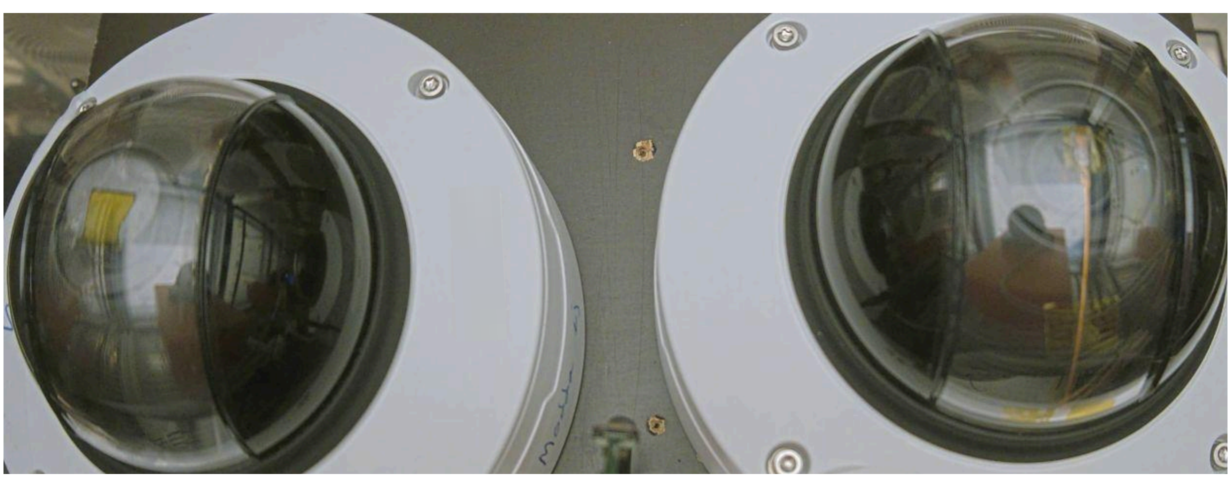


Figure 19: Image from test 2. Condensation can be seen only in the reference camera as a light circle

Discussion from test 2

In this test, no condensation was seen on the modified camera, while it is formed on the reference camera. The graph shows that T_DewPoint and T_Dome never intersect, also indicating that no condensation should form. One can also see that the temperature of the cold side of the PM experiences a steep fall a bit before the ambient temperature in the climate chamber. This is due to the proactive phase.

This is the first test that implies that the method of active cooling affects if used proactively, the condensation forming in the dome camera. With that being said, it is in terms of power unsustainable since it uses about 8,4W of the 20 W that is distributed to all the functions of the camera.

Results from test 3

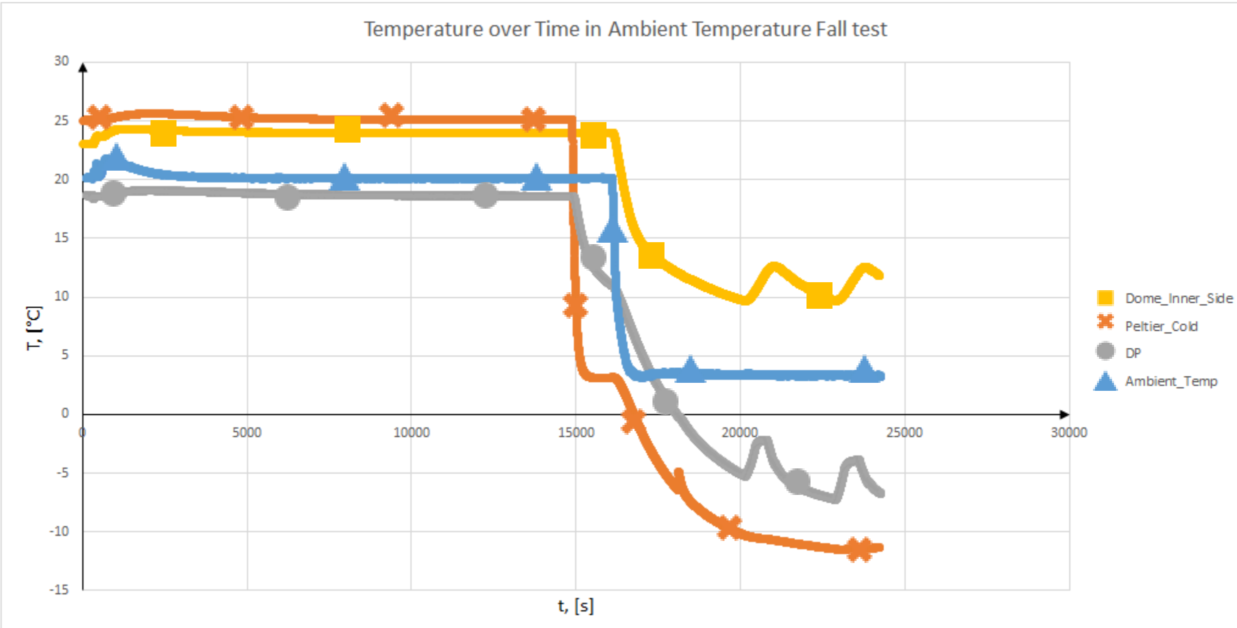


Figure 20: Data from test 3, SCC is applied.

Figure 21: Image from test 3. Condensation can be seen in the left camera as a light circle in the center of the dome, while in the modified camera no condensation is formed.

Discussion from test 3

No condensation formed on the camera with the PM, meaning that a smaller power could be applied. It is observable that less power is being used than that of test 2 because the temperature of the cold side of the PM does not fall as low as it does in test 2.

Results from test 4

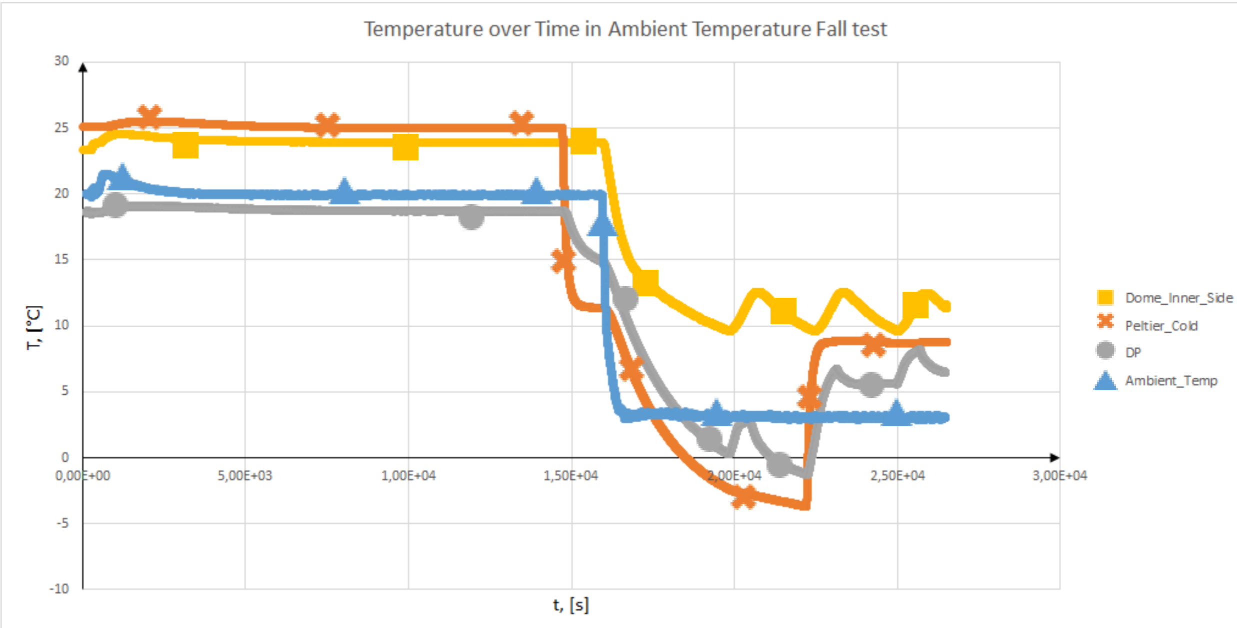


Figure 22: Data from test 4, SCC is applied.

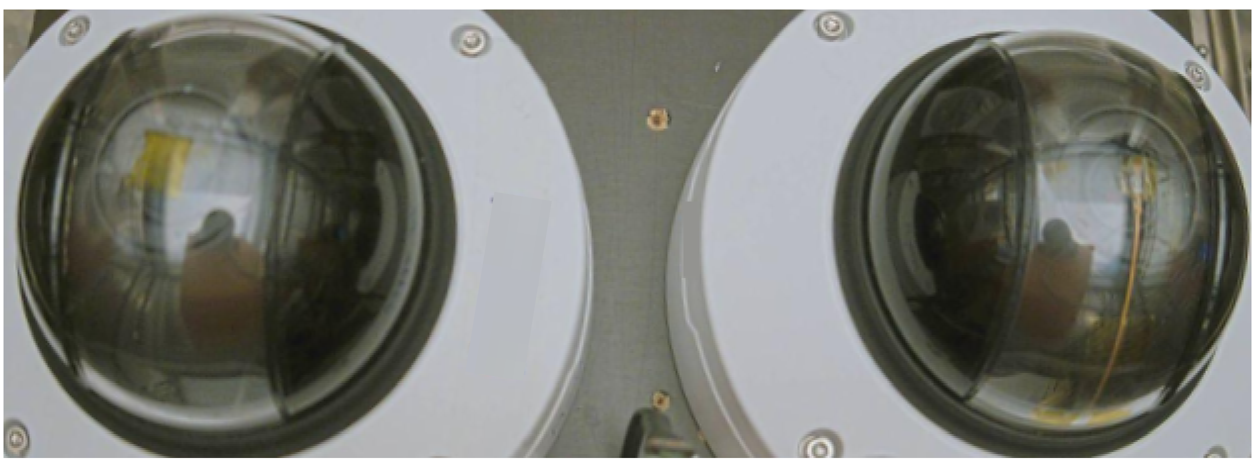


Figure 23: Image from test 4. Condensation can be seen in the left camera as a light circle in the center of the dome, while in the modified camera no condensation is formed.

Discussion test 4

No condensation formed on the modified camera, meaning that the C0P81030-M works as well. The decrease of power in comparison to test 3 is also visible in this test with the temperature of the cold side of the PM not falling as low as it does in test 2.

Results from test 5

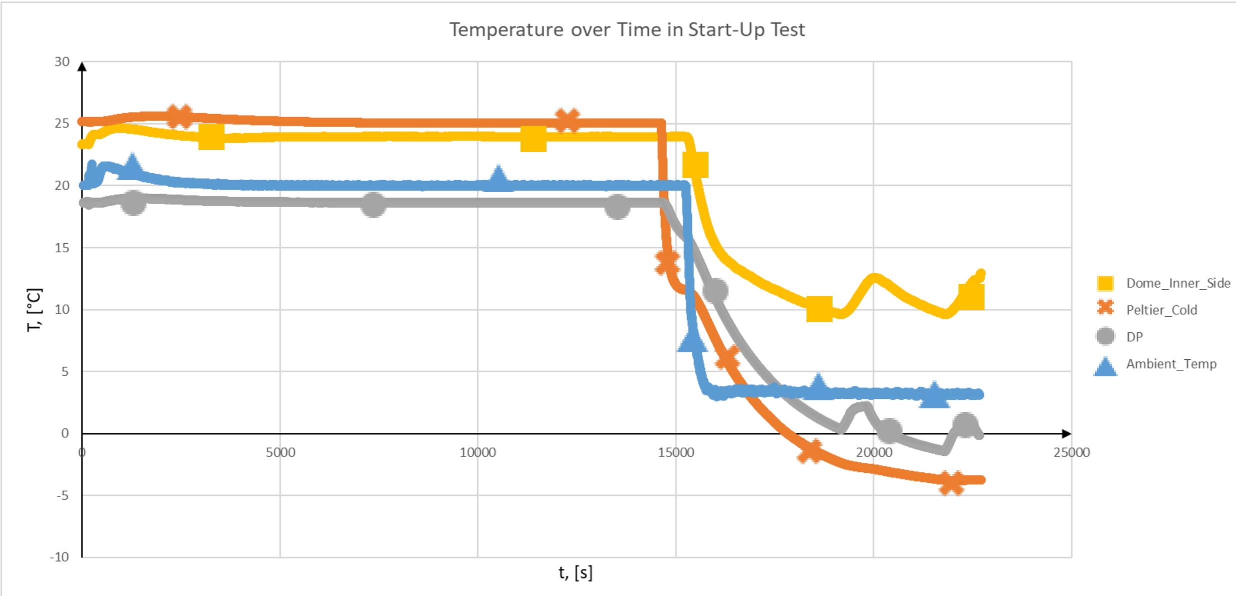


Figure 24 Data from test 5, SCC is applied.

Figure 25: Image from test 5. Condensation can be seen in the left camera as light circles in the center of the dome, while in the modified camera no condensation is formed.

Discussion from test 5

This test acts as the critical limit for a low power consumption and short proactive phase. Even though it is hard to see from the picture, a small amount of condensation is formed on the modified camera. Looking at the graph, it is visible that the proactive phase is even shorter compared to test 4.

The results from tests 2 to 4 proved to be effective since no condensation was detected in the modified camera while the reference experienced condensation in the optical FoV. For each test, either the time of the proactive phase or the power was reduced, until reaching 0.32 W, and 20 minutes for test 4. This is considered sustainable for various reasons. One is that the power is negligible in perspective to the total power of the product. Another is that creating an algorithm that can predict a rapid and significant fall in temperature should be manageable.

3.2.2 Startup tests

Results from test 1

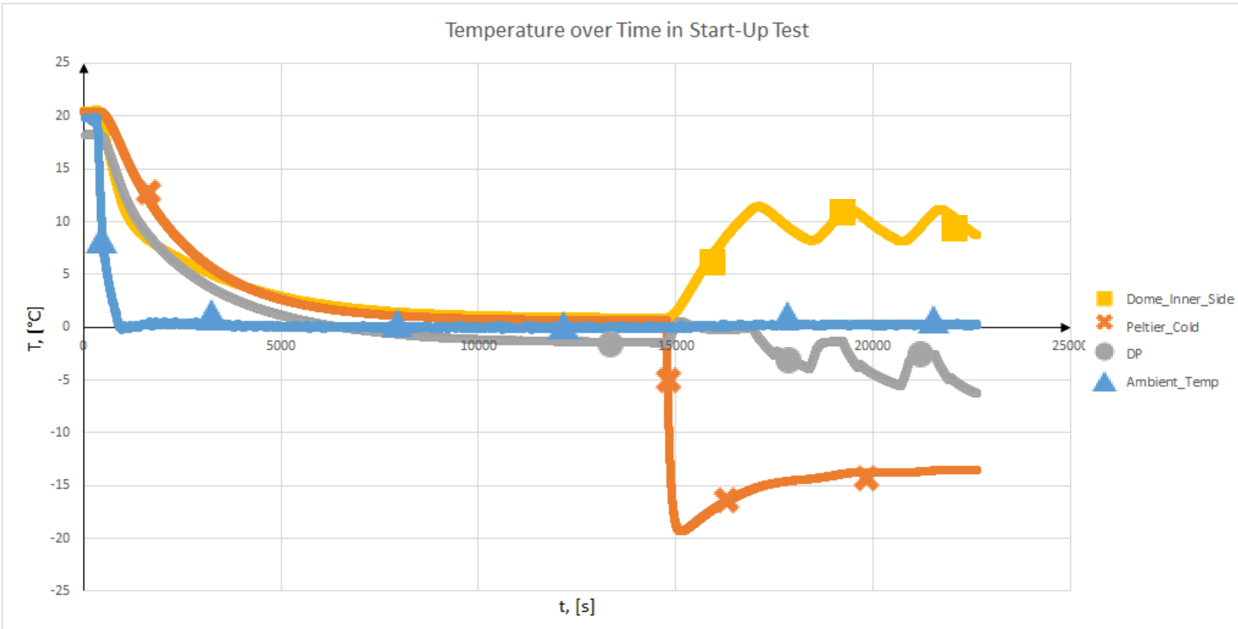


Figure 26: Data from test 1, SCC is applied.

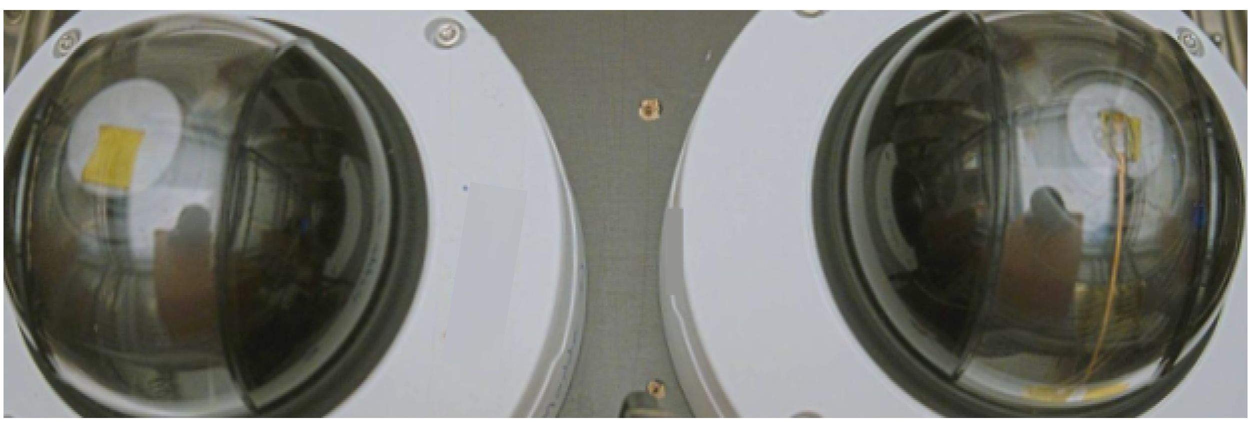


Figure 27: Image from test 1. Condensation can be seen in both cameras as light circles in the center of each dome.

Discussion from test 1

The first test showed condensation forming in the modified camera, as well as the reference. However, looking at the graph, it is evident that the temperature of the dome and the DP never intersect. This is contradictory to what was previously believed about the relation between DP, the temperature of the dome, and the forming of condensation. Regardless, it is concluded that these climate chamber conditions generate condensation.

Results from test 2

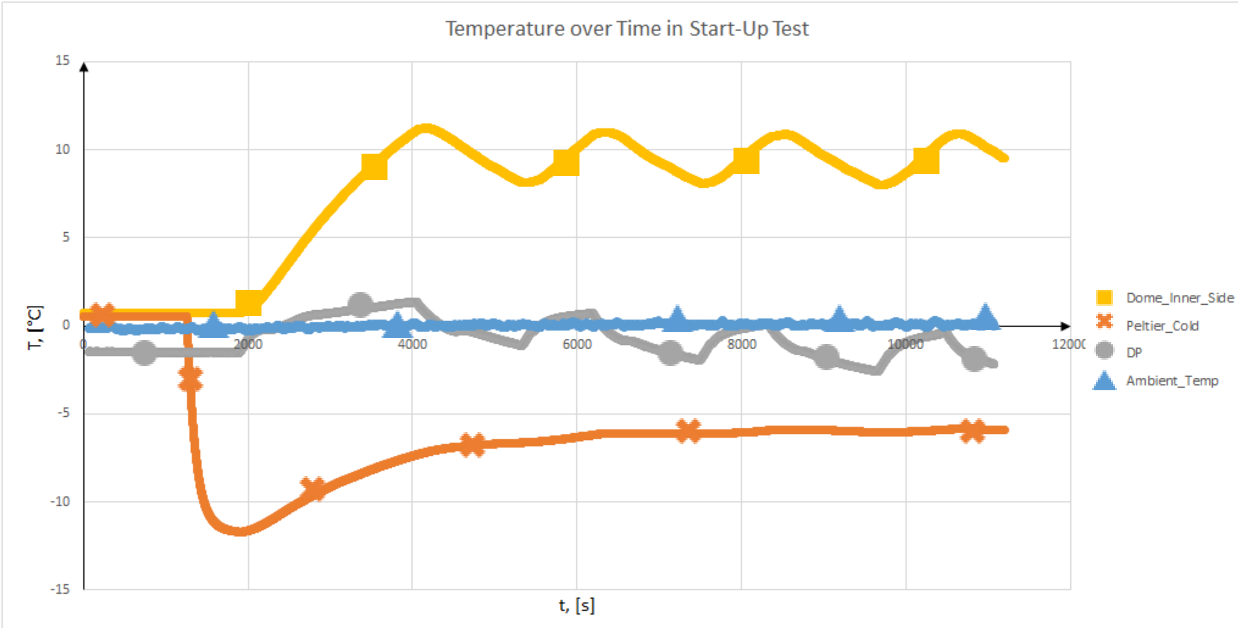


Figure 28: Data from test x, SCC is applied.

Figure 29: Image from test 2. Condensation can be seen in both cameras as light circles in the center of each dome.

Discussion from test 2

The image looks similar to that from test 1. From the graph, one can see the proactive phase by observing that the temperature of the cold side of the PM decreases before the temperature of the dome rises. The increase of temperature in the dome corresponds to the camera being turned on, as a lot of heat is produced. The conclusion is that the proactive phase was not big enough.

Results from test 3

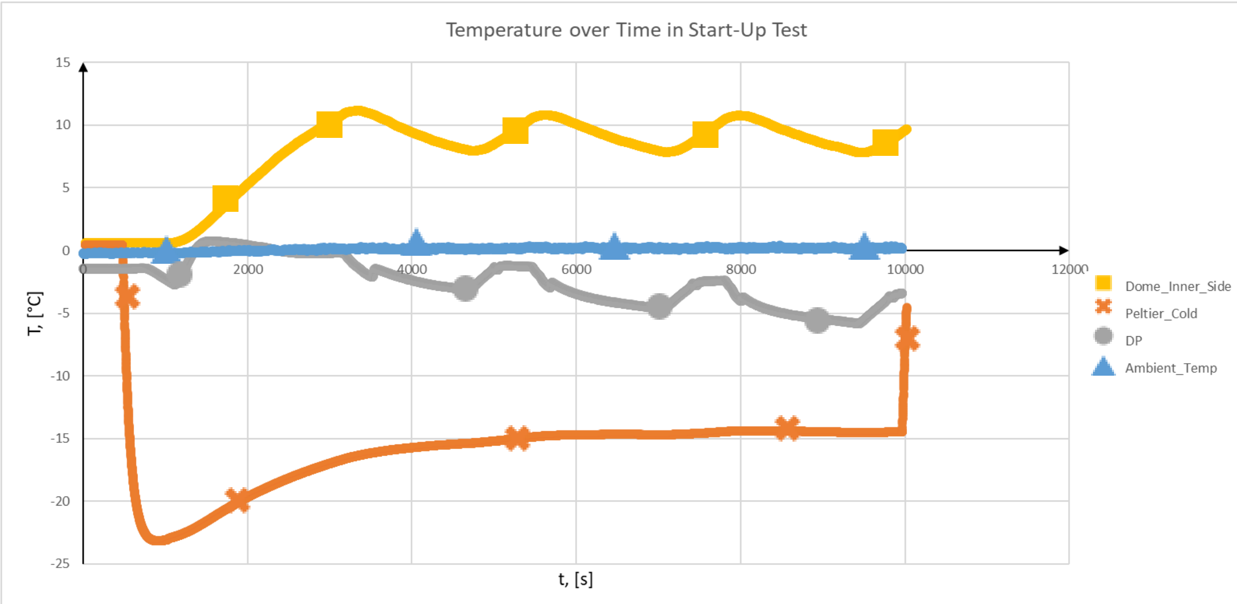


Figure 30: Data from test 3, SCC is applied.

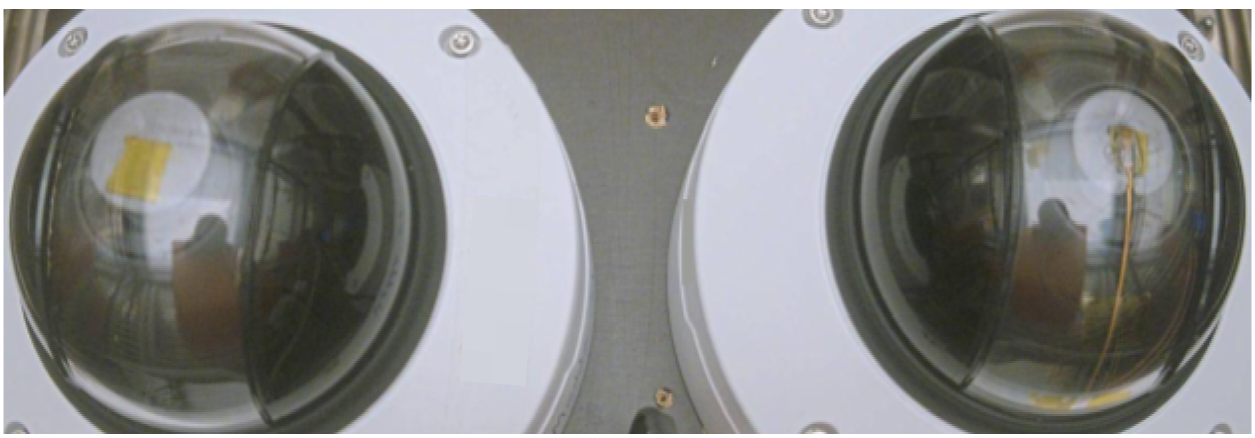
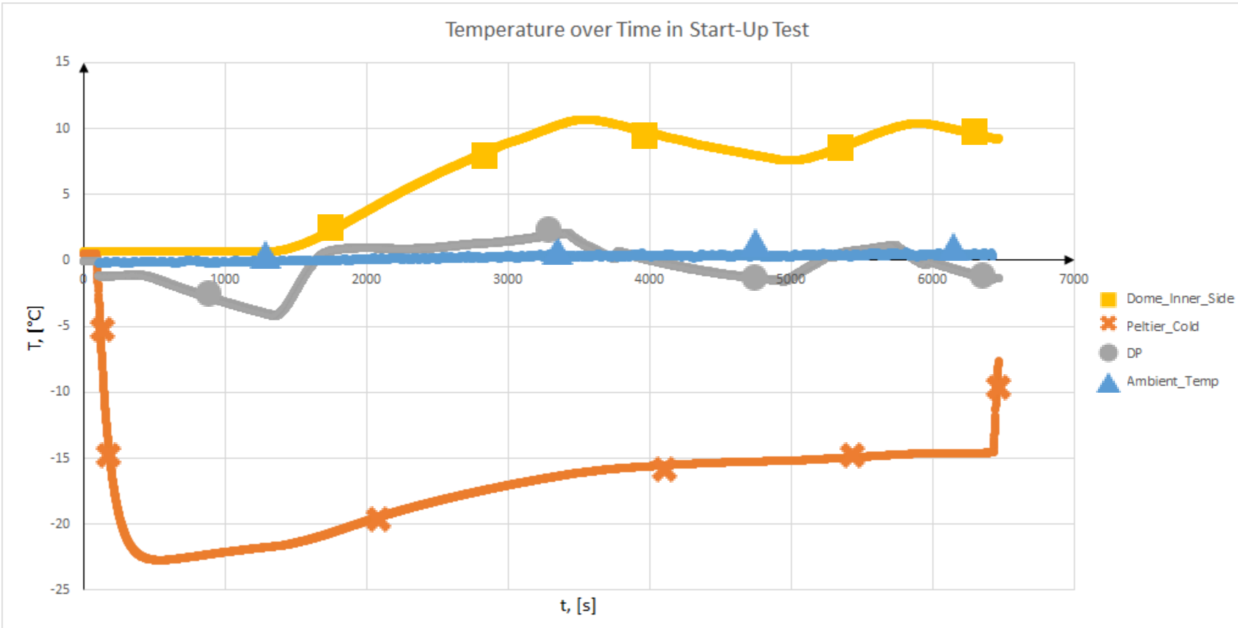


Figure 31: Image from test 3. Condensation can be seen in both cameras as light circles in the center of each dome.

Discussion from test 3

The image once again looks similar to that from the previous test. In the graph you can see a greater power consumption, resulting in a colder temperature of the PM than that from test 3. Since the modified camera is experiencing condensation, the conclusion is that a greater power was not a sufficient solution.

Results from test 4



AFigure 32: Data from test 4, SCC is applied.

Figure 33: Image from test 4. Condensation can be seen in both cameras as light circles in the center of each dome.

Discussion from test 4

Both cameras experience a similar amount of condensation. The graph is also similar to that of test 3, only that one can see the longer proactive phase from when the PM starts to decrease in temperature to when the temperature starts to increase. The longer proactive phase was not enough to prevent the formation of condensation.

Results from test 5

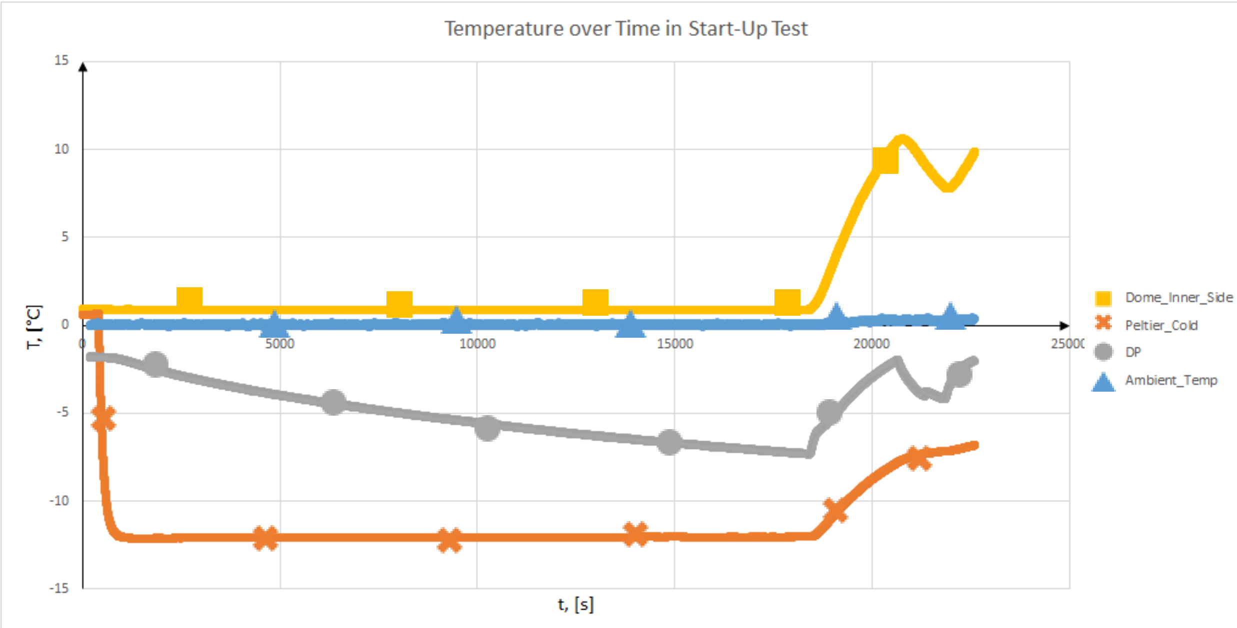


Figure 34: Data from test 5, SCC is applied.

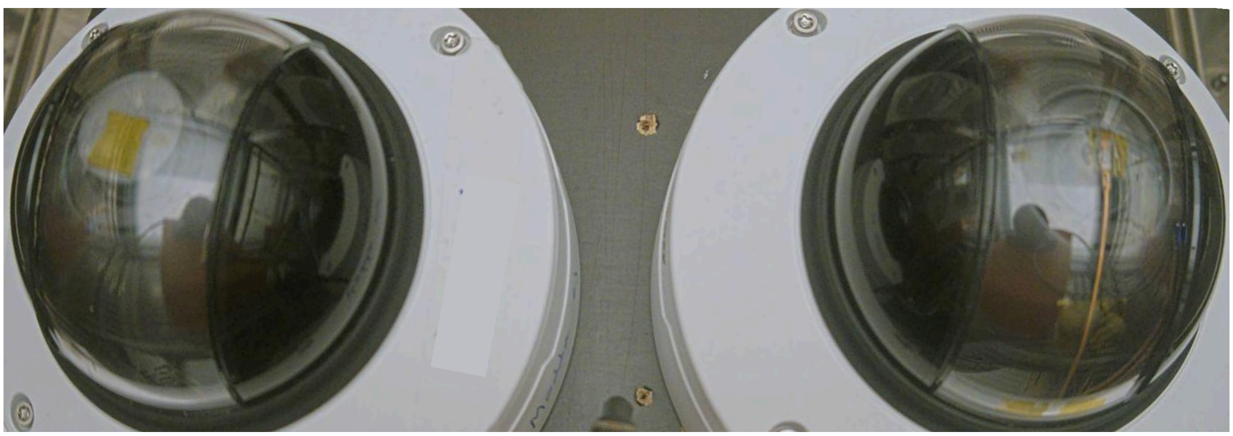


Figure 35: Image from test 5. Condensation can be seen in the left camera as light circles in the center of the dome. It is also possible to see a smaller, almost transparent circle in the center of the right camera.

Discussion from test 5

This was the first test with a significantly longer proactive phase, as can be seen in the graph. The visual results from the test prove that the method has been more effective than the previous test, as only a small amount of condensation can be seen on the dome.

However, as will be seen in the later tests with an even longer proactive phase, a step back will be taken as more condensation will form. This is contradictory and raises the idea that maybe the setup has been faulty. The most probable cause is that the camera with the PM has not been mounted properly and is not closed, causing the water vapor to escape.

Results from test 6

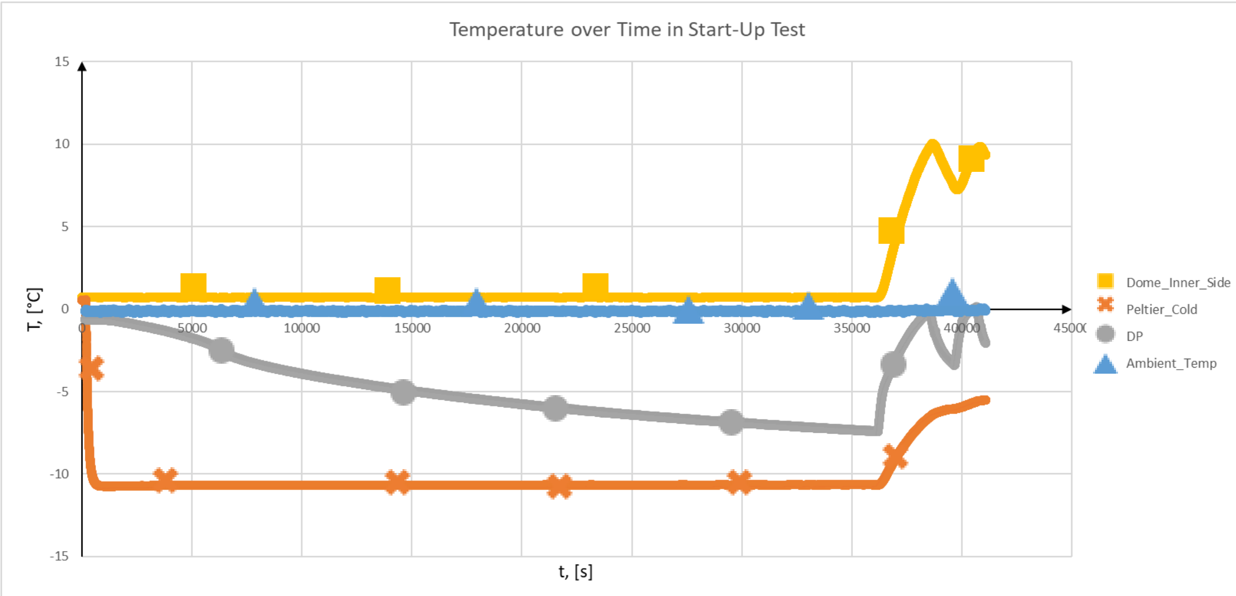


Figure 36: Data from test x, SCC is applied.

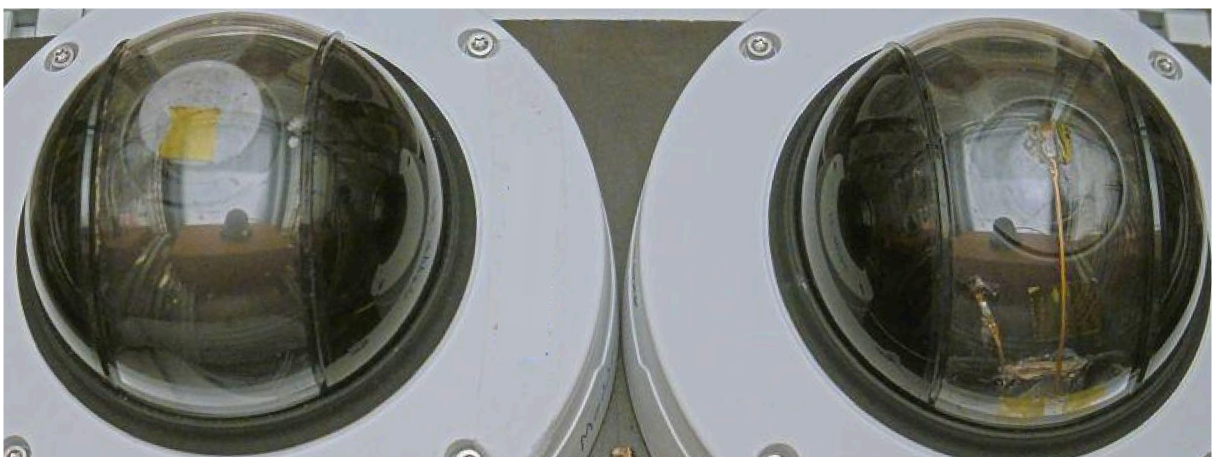


Figure 37: Image from test 6. Condensation can be seen in the left camera as a light circle in the center of the dome. A smaller, more transparent circle is visible in the center of the modified camera.

Discussion from test 6

Once again, the longer proactive phase can be seen in the graph as the gap between the decrease of the temperature of the cold side of the PM and the increase of the temperature of the dome is even longer. Looking at the image, the modified camera has experienced a bit of condensation, although less than the reference camera. A significantly longer proactive phase was not sufficient to prevent condensation from forming but had a positive impact.

Results from test 7

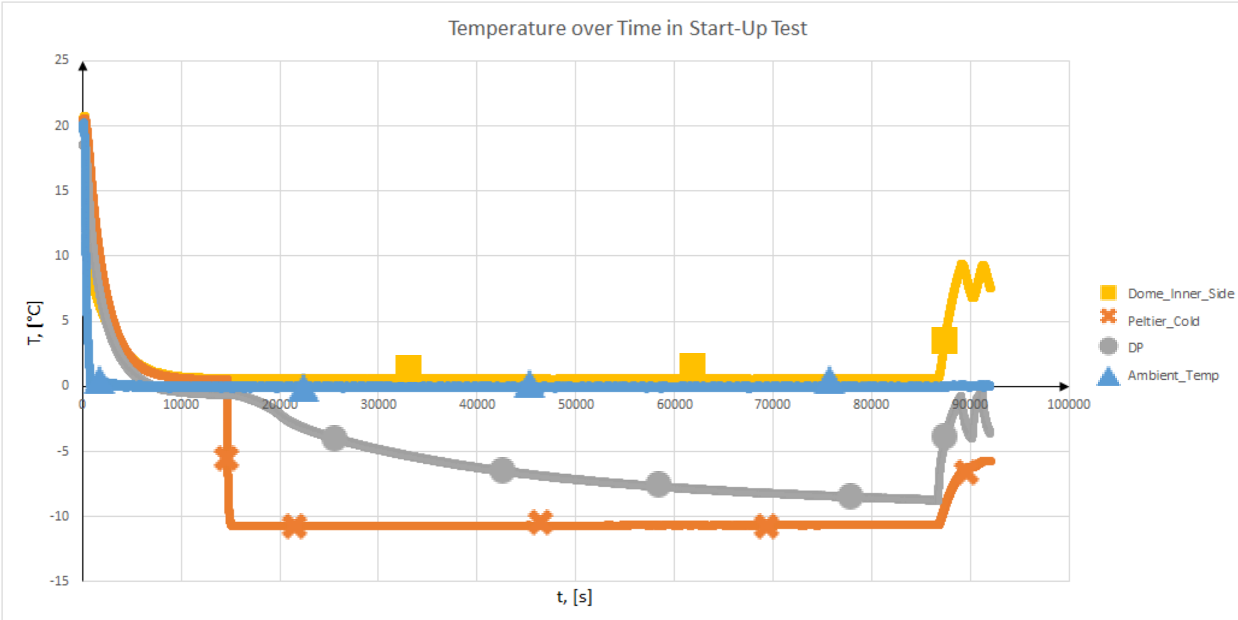


Figure 38: Data from test 7, SCC is applied.

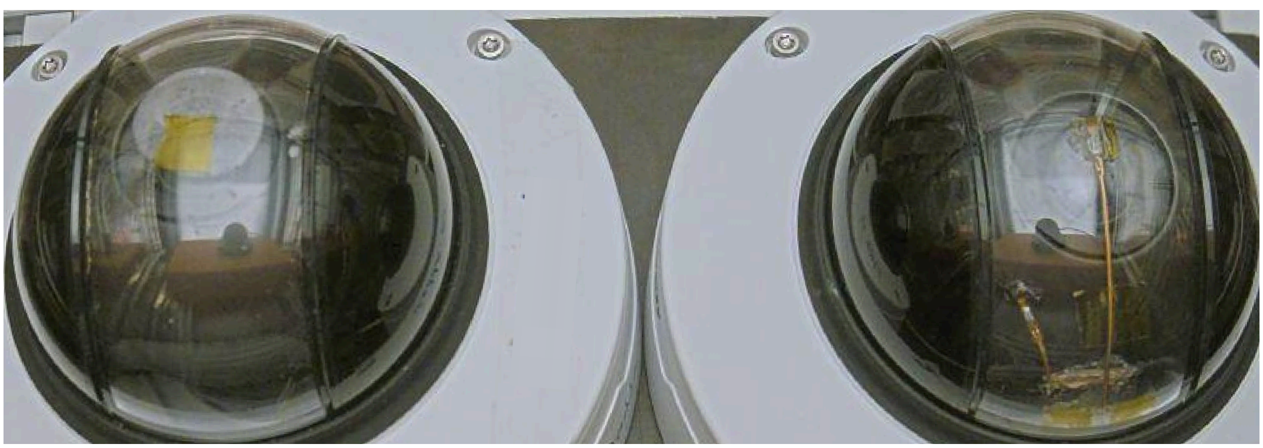


Figure 39: Image from test 7. Condensation can be seen in the left camera as a light circle in the center of the dome. A smaller, more transparent circle is visible in the center of the modified camera.

Discussion from test 7

Once again, the longer proactive phase is visible in the graph. From the image, it can be seen that a semi-transparent circle of condensation has formed on the modified camera, while the reference camera has a more large, opaque circle. This is of course proving the method to be relatively efficient but considering the conditions of a 20-hour proactive phase, a higher efficiency could have been hoped for.

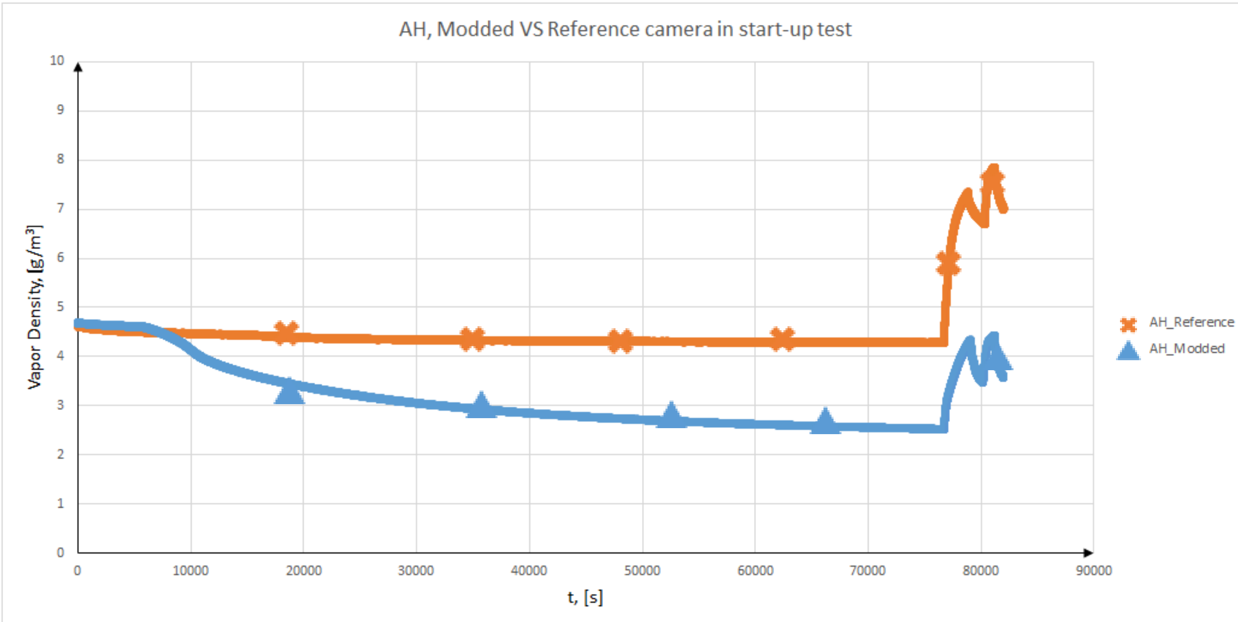


Figure 40: The diagram is AH [g/m^3] over time [s]. The blue graph is the AH for the modified camera, and the orange graph is the AH for the reference camera.

The AH graph shows that the active cooling had its biggest impact for the first 5 000 seconds and after that, it gradually decreased. From second 10 000 to second 15 000, the AH decreased from 4.6 to 4.2 g/m^3; during the remaining 67 000 seconds, it decreased to 2.5. This makes the first 5000 seconds 3 times more effective than the rest of the time.

A large amount of vapor is released when the camera starts. The AH for the reference camera increases from 4.1 to 7.0 g/m^3, just from water vapor released from the plastics of the camera. The spikes that can be seen after the big rise in AH suggest that condensation is occurring, either on the dome or on the inside of the camera. If this condensation had not occurred, the AH would have been even higher. This implies that a bigger part of the humidity that causes condensation is trapped in the plastics before the start-up of the camera and can not be trapped with active cooling. This could be an explanation for why the proactive start-up method has not been effective in reducing condensation.

3.2.3 Placement tests

Results from test 1

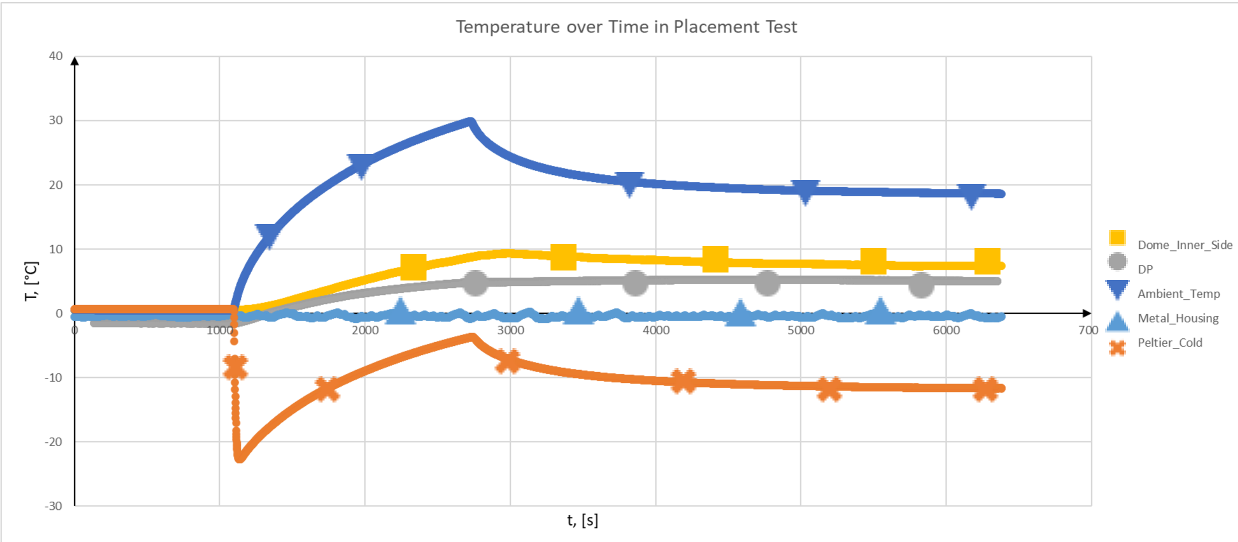
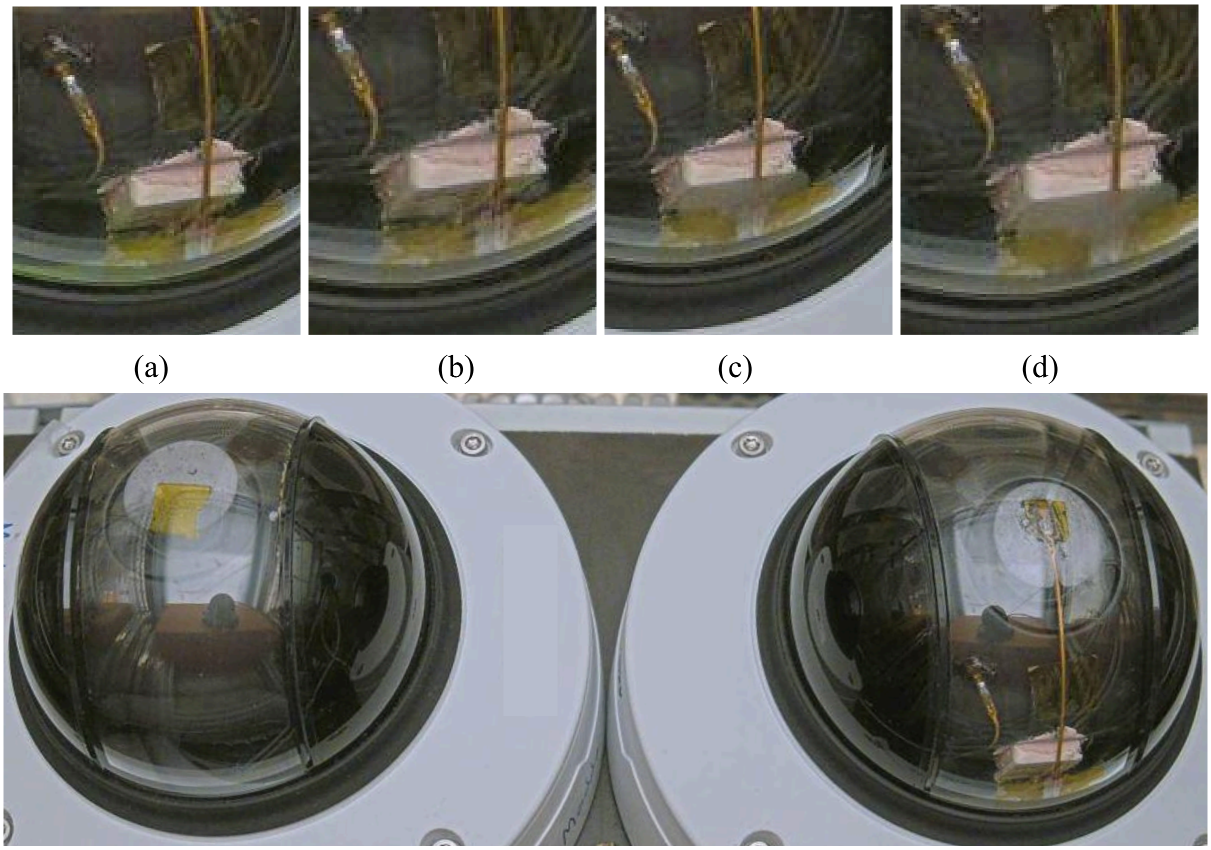


Figure 41: Data from test 1. SCC is applied. In addition, the dark blue graph (star) is the temperature of the camera ball.



(e)

Figure 42: (a) Image of the PM 0 minutes in. (b) Image of the PM 1 minute in. (c) Image of the PM 2 minutes in. (d) Image of the PM 3 minutes in. (e) Image of test 1. Condensation can be seen in both cameras as light circles in the center of the dome.

Discussion from test 1

In comparison to the tests where the PM is attached to the chassis when looking at the graph, it is apparent that the PM can not sustain the temperature on its cold side. This could be because the mass of the optical ball is not sufficient to withstand the heat from the warm side of the PM. This causes it to get hotter, which in turn backfires to the PM causing the cold side to rise in temperature as well.

The series of images shows that more and more condensation emerges close to the PM after its start-up. This indicates that rather than eliminating the humidity in the local area, it attracts more humidity. The last image is taken when most condensation is present in the dome, and the difference between the reference camera and the modified camera is not noticeable.

Results from test 2

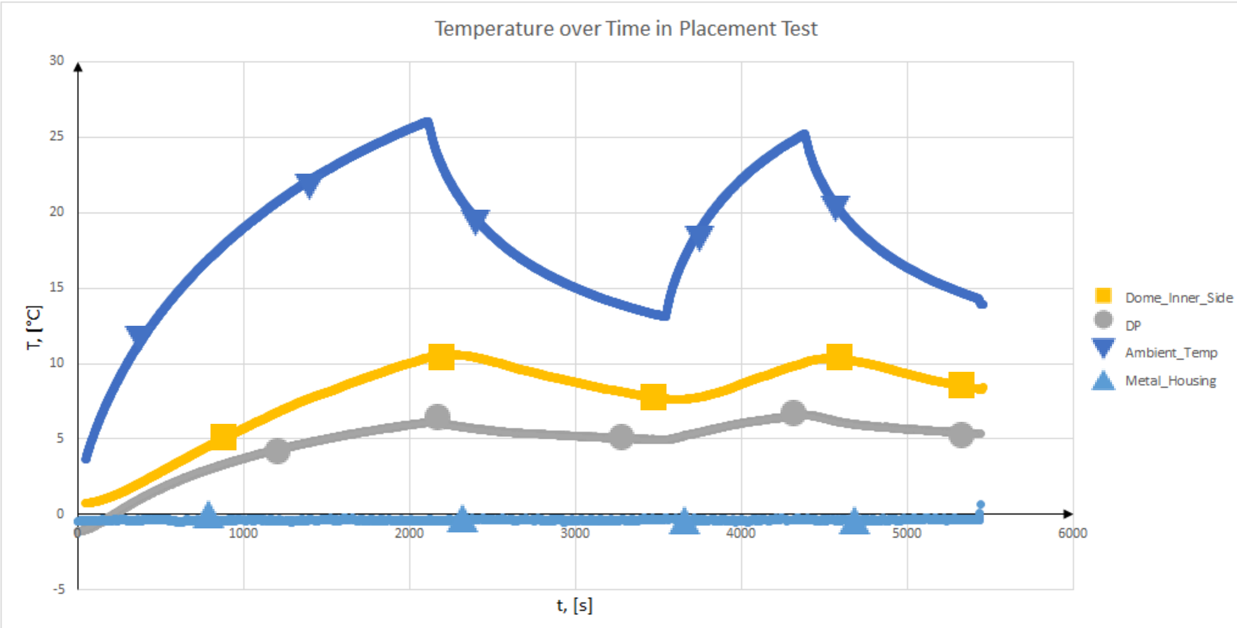


Figure 43: Data from test 2. SCC is applied. In addition, the dark blue graph (star) is the temperature of the camera ball.

Figure 44: Image from the test, 32 minutes in. Condensation can be seen in both cameras as light circles in front of the optical FoV.

4 Conclusions

In this chapter, the outcome of the tests will be presented in the form of tables. From this, conclusions will be drawn.

Outcomes from falling ambient temperature tests

These tests refer to the table in Chapter 2.3.1 and the results from Chapter 3.1.

Test	Outcome
1	Condensation could form in these conditions. No difference between the reference camera and the camera with the PM.
2	The proactive phase improved the camera with the PM visually. Also, it lowered the DP.
3	Lower power could be applied, and no condensation was detected visually.
4	The smaller PM worked as well, no condensation was detected visually.
5	Condensation could be detected in the camera with the PM, although less than that detected in the reference camera. This proactive phase was not long enough.

Outcomes from start-up tests.

These tests refer to the table in Chapter 2.3.2 and the results from Chapter 3.2.

Test	Outcome
1	Condensation could form in these conditions.
2	The proactive phase was not enough.
3	Greater power was not enough.
4	A longer proactive phase was not enough.
5	A significantly longer proactive phase had more effect, only a small amount of condensation was detected in the camera with the PM.
6	Even longer proactive showed more condensation forming, suggesting an error in the previous test. Even though condensation is detected in the camera with the PM, it is less compared to the reference camera.
7	An even longer proactive phase showed improvement, but condensation is still detected. Looking at the AH graphs, a conclusion as to why the proactive phase is not as effective in the start-up as the falling ambient temperature was made.

Outcomes from placement tests

These tests refer to the table in Chapter 2.3.3 and the results from Chapter 3.3.

Test	Outcome
1	At the end of the test, the cameras had the same amount of condensation. It could be seen that the minutes after the PM is turned on the condensation is forming close to the PM, suggesting that rather than eliminating condensation in the local area, it attracts more humidity.
2	Similar results to test 1.

Final conclusion

This project has given rise to various important conclusions. Primarily, in the case of a rapid ambient temperature fall, the method of using active cooling could be both effective and sustainable. In this case, the method would be ready to be implemented soon.

In the start-up case, the method is effective, although not sustainable time-wise. As of right now, the method needs a significantly big proactive phase, which could not be applied in a real-life scenario. This case needs more work!

Also, the placement of the active cooling plays a crucial part. It is shown in Chapter 3.2.3 that the PM should be placed far away from the area where its effect is intended. It is also shown that the PM needs to be mounted to a mass that can withstand the heat produced, otherwise the cold side will be hot as well.

All in all, the method of using active cooling to create a controlled condensation shows great potential, as it could be a power-effective method of preventing condensation on dome cameras.

5 Future Work

A central field that requires further research is the management of the water that has been trapped by the PM. Even though the method of using active cooling has been proven to be effective for extracting humidity from the air, there are still challenges when it comes to handling the collected water. An idea that was discussed was to create controlled vaporization by reversing the polarity of the PM so that the cold and warm sides switch places. This would result in evaporation of the collected water, increasing the AH in the camera again. This method might seem counterintuitive, however, if it can be done in a controlled manner it might work.

Also, more specific approaches need to be taken in the start-up case, for it to work sustainably. This could perhaps be made by having a colder surface area or maybe placing the cold area in a way that the air has to pass it, before reaching the dome. As this method shows a big potential, it would be interesting to see more research about it in the future.

6 References

CTS. (2024, May 7). *CTS-Temperature Test Chambers (Bench Top Version)*. CTS Umweltsimulation. Retrieved May 7, 2024, from https://www.cts.se/Portals/cts/MLData/Shop/Attachments/88/CTS_Temperature_Test_Chambers_Bench_Top_Version_eng.pdf

CTS-Temperature Test Chambers. (2024, May 7). CTS Umweltsimulation. Retrieved May 7, 2024, from https://www.cts.se/Portals/cts/MLData/Shop/Attachments/91/CTS_Temperature_Test_Chambers_eng.pdf

G. Lawrence, M. (2004). The Relationship between Relative Humidity and the Dewpoint Temperature in Moist Air: A Simple Conversion and Applications. Bulletin of the American Meteorological Society (BAMS), 86(2), 225. ttps://doi.org/10.1175/BAMS-86-2-225

Goldsmid, J. (2017). *The Physics of Thermoelectric Energy Conversion*. Morgan & Claypool Publishers.

Omnexus. (2024, May 7). *Water Absorption 24 Hour - (ASTM D570) Test of Plastics*. Omnexus. Retrieved May 7, 2024, from https://omnexus.specialchem.com/polymer-property/water-absorption-24-hours

Peak Sensors. (2024, May 7). *What Is A Pt1000 Sensor? [Complete Guide] – Peak Sensors*. Peak Sensors. Retrieved May 7, 2024, from https://peaksensors.com/what-is/what-is-a-pt1000-temperature-sensor/

Rowe, D. M., & Rowe, D.M. (Eds.). (1995). *CRC Handbook of Thermoelectrics*. CRC-Press.

Technical Investigations Section (Ed.). (1953). *Relative Humidity - Psychrometry Tables*. University of Michigan Libraries. https://books.google.se/books?id=R6zPAAAAMAAJ&printsec=frontcover&dq=relative+humidity&hl=en&newbks=1&newbks_redir=0&sa=X&redir_esc=y#v=onepage&q=relative%20humidity&f=false

Tetens, O. (1930). *Zeitschrift für Geophysik*. Gebrüder Borntraeger Verlagsbuchhandlung. http://resolver.sub.uni-goettingen.de/purl?PPN101433392X_0006

University of Arizona. (2024, May 7). *Saturation of air with water vapor*. Saturation of air with water vapor. Retrieved May 7, 2024, from http://www.atmo.arizona.edu/students/courselinks/fall16/atmo170a1s3/lecture_notes/humidity/saturation_figs/saturation.html