Mechanical Design and Thermal Analysis of the MoreBac Experiment

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***Abstract*—Sending bacteria to space is a further step within the framework of transporting humans to distant locations in space. This can build a knowledge platform of how the bacteria behaves in the space environments, in order to be able to function in the long term as a LLS (long term life support system), i.e a mini ecology for the space station that handles waste (gas, liquid and solid) and transforms it into food, water and oxygen. By constructing a bacterial experiment (MoreBac) in a small satellite and thermally simulating it in space environment, it can aid future projects performed in similar but larger scales. To visualize the experiment in presentations, a CAD-model of the experiment will be designed and constructed in SIEMENS Solid Edge. The thermal analysis is made in Airbus SYSTEMA Thermica and will help show on the critical problem, which is to maintain suitable temperature conditions on the microfluidic chip inside the experiment. By performing the simulations, one can assure that the design is suitable and that the heat gradient is in required intervals for different components. The CAD-model was designed in a sandwich layout and consist of two printed circuit boards, one microfluidic chip and one reservoir. Not specified components of the experiment was not used in the CAD- model since they where still in early development. The thermal analysis of the experiment was studied in a steady state environment, with boundary conditions of 5°C in the cold case and 30°C in the hot case, which means that the time variable was not considered. Three configurations of heat dissipation were made; 16 nodes at the illumination board with 0,05 W each, 16 nodes at the detection board with 0,05 W each and finally 36 nodes on both PCBs together with 0,025 W each. In the hot case, the microfluidic chip reaches temperatures between $34,16^{\circ}$C and $42,15^{\circ}$C when 0,8 W is equally divided to both PCBs. In the cold case, the microfluidic chip reaches temperatures between $13,82^{\circ}$C and $22,32^{\circ}$C with the same heat distribution as the hot case.**

I. Introduction

THE human exploration of remote location in space means larger requirements on technical solutions to provide the crew with consumables. One solution may be to create a mini ecosystem that could work as a LLS (long term life support system). For example a system that handles waste and transforms it into oxygen and water, which means that the human must rely on micro-organisms transported from Earth [1]. In earlier experiments [2] there has been shown apparent results that bacteria growth in zero-gravity is greater than on Earths gravity conditions. Some years earlier, with similar hardware, an experiment also demonstrated a greater bacteria growth in spaceflight[3], which makes the subject interesting for further investigation.

The MoreBac experiment is based on the aforementioned experiments, and will be modeled in a more miniaturized measurement equipment module aboard the student satellite project MIST. The project is led by researcher Håkan Jönsson at Science for Life Laboratory, and aims to investigate, never before tested, freeze-dried micro-organisms ability to be transported, revived and stored in space environment. In a thermodynamic aspect, the MoreBac experiment is one of the most fragile modules aboard the MIST-satellite, due to the fact that microorganisms is extremely sensitive outside their habitable temperature. This carries out the opportunity to research how different thermodynamic factors from the nearby other experiments, but also from the space environment itself, affects this bacterial experiment.

Due to the space environment which the bacteria is exposed to in orbit, the radiation dose from neighboring celestial bodies should be a factor considered. According to Wayne L. Nicholson [4], the UV-radiation from the sun in our solar system is the most harmful radiation type to cells generally, because of the cell structures absorption characteristics. In this thesis this solar radiation factor is beyond the project aim, hence it will not be considered.

Before this thesis, the MoreBac project has made analyses of the aboard circuit boards and light detection equipment. To select a suitable design for the experiment, more research about the thermal environment has to be made.

II. Aim

The first aim of the thesis is to create a 3D CAD in the software SIEMENS Solid Edge. The 3D CAD will first and foremost be a tool to illustrate the experiment in presentations and to aid future MoreBac students who will be working with the experiment. The design and layout of the experiment will be based on discussions internally within the MIST project, and also within the MoreBac project team. The second aim of this thesis is to perform an unit level thermal analysis of the aforementioned created 3D model design. The model is desired to perform in a temperature interval from 5°C to 30°C, whereas the simulations will be performed in steady state at these end temperatures. By imposing a boundary temperature on the experiment and performing the unit level analysis, one can guarantee the predicted temperatures inside the experiment as long as the boundary temperatures do not exceed the specified temperatures, which will be needed to be guaranteed on a system level by the MIST subsystem team.

III. Boundaries

This thesis will not present a fully thermal analysis of the experiment, i.e when orbiting the earth, since that is completed by the thermal MIST team. Instead, an unit level analysis will be done, which means that only this experiment from the MIST satellite will be analyzed. The 3D CAD will not include components that are not specified.

IV. Introduction to Microfluidic Systems in Space

Microfluidic experiments investigating microorganisms in space is not a new phenomenon within the biological science. In 2006, NASA sent a triple CubeSat[1] configuration called Genesat-1 to space to investigate bacteria growth in microgravity [5]. As demonstrated in the project [5], the main components of the payload was a green LED lamp used to stimulate the micro-organisms placed in the microfludic chip, which can be seen in Figure 1 . On the other side of the fluidic-chip, a detector measured the amount of light passing through the biology and thereby measuring the density of the biology. The micro-organisms were also stimulated by a blue fluorescent LED and measured with same detector to investigate the metabolism of the culture.

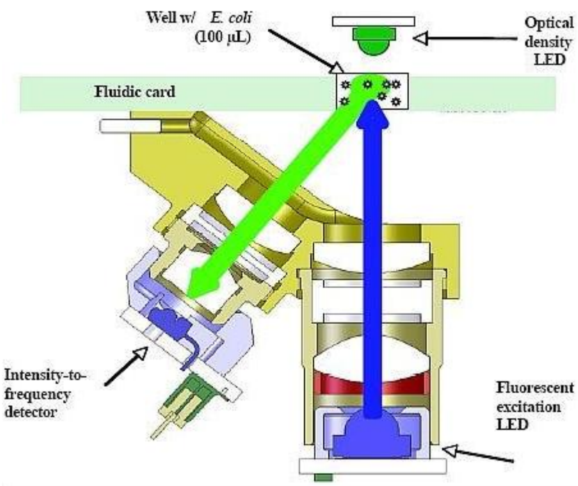

Figure 1. The Genesat-1 experiment with green LED for bacterial growth measurement and blue fluorescent LED for metabolism measurement. (see Kitts, et al.2006, their figure 5)

As a follow-up mission to Genesate-1, NASA sent the Pharmasat satellite to space in 2009 [6]. Unlike it's predecessor, the Pharmasat had a more similar setup as the planned MoreBac configuration, which can bee seen in Figure 2. The main components of Pharmasat consisted of an illumination board with LED light stimulating the micro-organisms, detection board with a light detector measuring the bacterial growth and a microfluidic chip with the investigated biological culture.
In comparison with these earlier experiments, the MoreBac experiment is almost five times smaller. This means challenges when it comes to lab setup and fitting required components. Since the MoreBac experiment is surrounded by heat dissipating payloads, there is also an additional complexity in thermal design compared to single experiment satellites.

V. MoreBac experiment lab setup

Until this thesis, the MoreBac CAD model only consisted of a solid box as a volumetric place holder, seen in Figure 3. The box was created to symbolical reserve a place for MoreBac and therefore defining the exact boundary dimensions in the CubeSat frame, with respect to other experiments. Based on simple principle sketches and prototypes, work was started on a more detailed model.

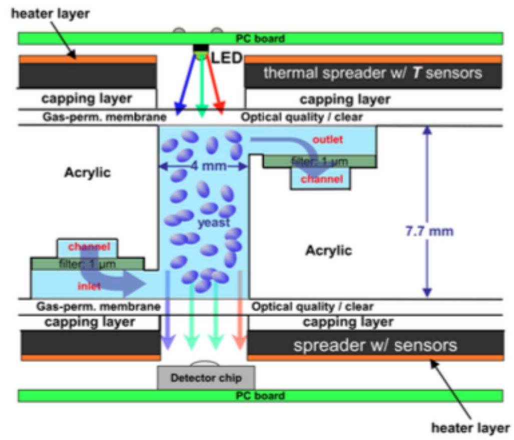

Figure 2. PharmaSat experiment with two green PCB boards and LED light stimulating the biology in the chamber(see Ricco,et al.2011, their figure 3).

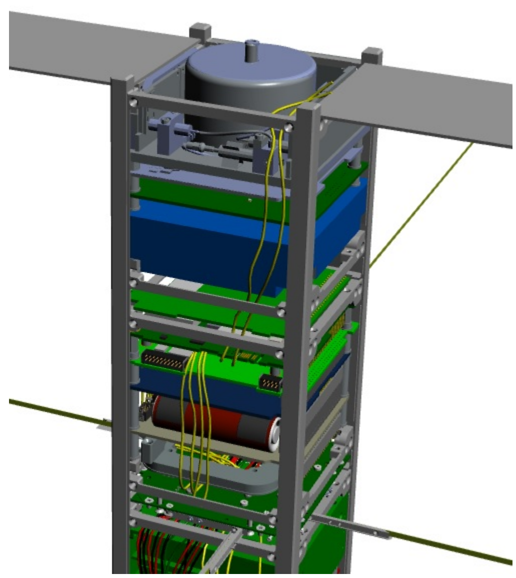

Figure 3. The blue box is the MoreBac experiment placed in the CubeSat.

Discussions with the project leader led to a design as a sandwich of PCBs (Printed Circuit Board), microfluidic chip, fluid reservoir, pump and valves, as seen in Figure 4and numbered in Table 1. The outer case of the experiment is mounted in the CubeSat in each of its corners. The internal parts of the experiment is constructed together with internal spacers, which means that the experiment can be assembled outside of the CubeSat.

[1]Small satellite structure, built by 100x100x111mm cubes

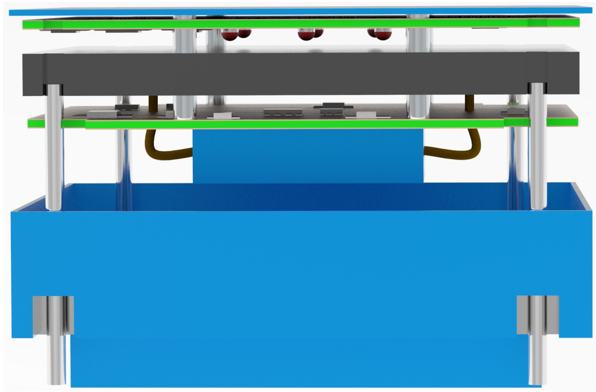

Figure 4. The experiments internal components, before attachment with the outer frame of the box

A. *Components of the CAD model*

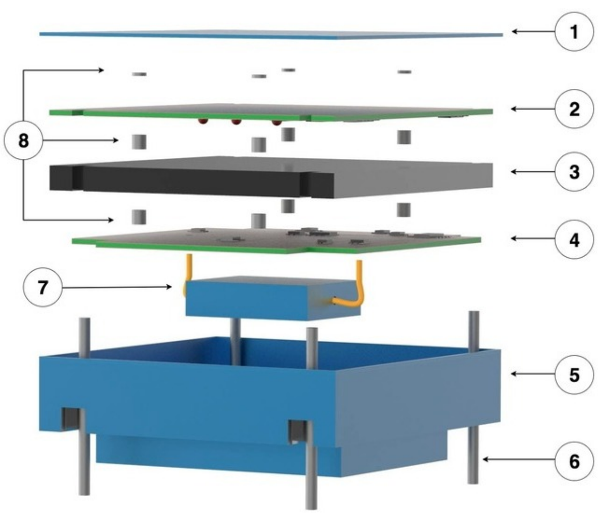

Figure 5. Exploded view of the experiment.

The LED light as seen in Figure 5 is placed at the illumination PCB on the top of the experiment, which are used to stimulate the bacterial growth. The PCBs is designed as a 94x94 mm standard circuit board from the dutch satellite supplier **Innovative Solutions In Space**, whereas the PCBs are 1.6 mm thick with two copper layers and an epoxy layer. The microfluidic chip is a simplified design of the real chip but will in reality contain a chamber with the investigated bacteria and channels to transport revival fluid. On the bottom PCB, as seen as number 4 in Figure 5, the light detection devices are attached. They measure the amount of light passing through the bacteria. Greater bacteria growth means less light is being let through to the detection board. Since the satellite is built by standard components from the supplier, the lower PCB has been adapted so that is fits inside the case and therefore not interfering with the cutouts of the outer frame.

In the bottom of the case, it is a reserved space for a liquid reservoir and automatic control equipment used to run the experiment. This part of the experiment is during early development and will therefore not be in the CAD.

Table I
TABLE OF EXPERIMENT COMPONENTS.

Object No.	Object Name	Description
1	Lid	Lid of the top frame
2	Illumination board	PCB with LED light, CPU
3	Microfluidic chip	Chamber with bacteria
4	Detection board	PCB with light detection sensors
5	Frame	A case used for thermal isolation
6	Rods	The rods in the CubeSat frame
7	Liquid reservoir	Contains microfluidic liquid
8	Spacers	Connects the PCB stack

VI. THERMAL ANALYSIS

Since the investigated bacteria is sensitive in a thermodynamic aspect, the thermal environment has to be simulated to assure the lifetime of the bacteria. The analysis will show the temperature of the microfluidic chip when other components dissipate heat, in a so called unit level analysis. The thermal MIST team will assure that the boundary temperature of the experiment will stay within a temperature range of 5°C - 30°C, when the CubeSat orbits the Earth. That is because the bacterial growth will not be optimal outside these boundaries. The unit level analysis is expected to be done by first assigning the boundary temperatures to the most extreme temperature cases, which is 5°C and 30°C. This will be done in combination of assigning the heat dissipation of the experiment, to different locations of the two PCB cards. If needed, for example if the internal components get to warm or to cold, the boundary temperatures will then be reassigned with new values inside the temperature range. Then the process is repeated until both the MIST system team and MoreBac sub system team is satisfied.
To let the software understand how the temperature is spreading, there are a number of input arguments required. The following chapter will briefly introduce thermal dynamic phenomenons that were used as inputs to the software and to calculate the temperature in each case respectively.

A. *Thermal Conduction*

Thermal conduction is defined as the energy transferred from less energetic molecules to a part with more energy due to colliding molecules [7]. Consider a wall with different temperature on each side of the wall.

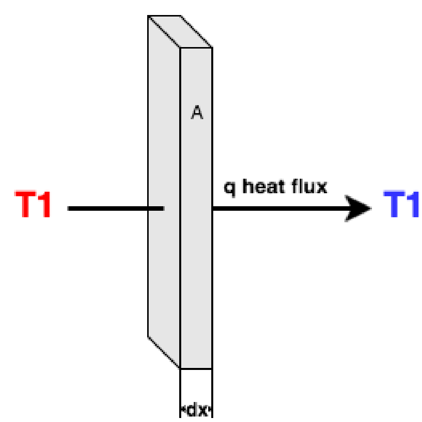

Figure 6. The heat flux is the rate of heat energy passing through a body.

Fourier's law describes the rate of heat through the material as

$$q = -KA\frac{dT}{dx} \qquad [\frac{W}{m^2}] \tag{1}$$

where the variables are defined as follows in table II.

Table II
TABLE OF VARIABLES AND THEIR DEFINITION IN FOURIER'S LAW.

Variable	*Definition*	Unit
K	the material conductivity	$[\frac{W}{mK}]$
A	cross section area	[m^2]
dT	the temperature difference	[K]
dx	wall thickness	[m]

B. Thermal radiation

Radiation is energy in the form of electromagnetic waves [7]. Thermal radiation is basically the energy emitted by bodies because of their temperature. All liquids, gases and solid emits, absorb or transmit radiation. The energy emitted from a surface can therefore be described as

$$\dot{Q}_{emit,max} = \sigma A_s T_s^4 \qquad [W] \tag{2}$$

where the variables are defined as follows in table III.

Table III
TABLE OF VARIABLES AND THEIR DEFINITION IN THE EQUATION FOR ENERGY EMITTED FROM A SURFACE

Variable	*Definition*	Unit
σ	Stefan-Boltzmann constant = 5.67E-8	$\frac{W}{m^2K^4}$
A$_s$	Surface area	[m^2]
T$_s$	Surface temperature	[K]

In the MoreBac experiment, the components has been defined as active or inactive in terms of radiation. An active surface means that it emits, absorb or transfer radiation. Solid components or components with no fully internal specification as the rods, microfluidic chip and liquid reservoir is defined as inactive on the inside. The outside surfaces and the rest of the experiment are active which means they are contributing to the exchange in radiation.

C. Convection

As mentioned before, heat transfer exists in the forms of conduction, radiation and also convection [7], whereas convection is heat transferred between a solid surface and a liquid or gas. In this thesis, the small liquid volume of the microfluidic system will not be considered to have stored heat or transferred heat by convection. In reality, heat transferred by convection occurs but in such small amount it can be disregarded in the analysis. Since the experiment is operating in vacuum, there is also no heat transferred by convection in the remaining parts of the whole model.

D. Specific heat capacity

Since the analysis is made in a steady state simulation, the heat capacity will not have any impact on the result. However, if a transient simulation is to be performed at a later stage, the heat capacity will become important. The specific heat capacity describes how much of energy that is required to change 1 kg of a material 1 Kelvin

$$C = \frac{q}{m\Delta T} \qquad [\frac{J}{kgK}] \tag{3}$$

where the variables are defined as follows in table IV.

Table IV
TABLE OF VARIABLES AND THEIR DEFINITION IN THE EQUATION FOR THE CONDUCTANCE OF EACH NODE

Variable	*Definition*	Unit
q	Energy	[J]
m	Mass	[kg]
ΔT	Temperature difference	[K]

Conductive couplings

In the thermal software, the model is divided into nodes. The conductive couplings are used to describe how the heat is spreading from one node to another. Here, the thermal path is defined as the distance between the center of the nodes as describes in Figure 7

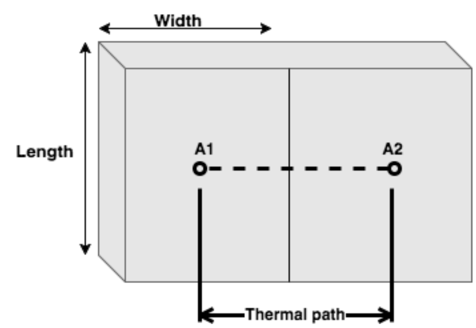

Figure 7. Two nodes and their conductive coupling

The conductance of the node is calculated by

$$GL_{A_i} = (\frac{KA_i}{dx}) \qquad [\frac{W}{K}] \tag{4}$$

where the variables are defined as follows in table V.

Table V
TABLE OF VARIABLES AND THEIR DEFINITION IN THE EQUATION FOR THE CONDUCTANCE OF EACH NODE

Variable	*Definition*	Unit
A_i	surface A_1 respectively A_2.	[m^2]
K	the material conductivity	$[\frac{W}{mK}]$
dx	Half the thermal path	[m]

The conductive coupling between the nodes can then be connected in serial according to

$$GL_{A_1 \rightarrow A_2} = \frac{1}{\frac{1}{GA_1} + \frac{1}{GA_2}} \qquad [\frac{W}{K}] \tag{5}$$

VII. Thermal Model

The thermal analysis were performed using the software Systema Thermica [7] developed by Airbus Defence and Space. The software allows the user to easily define thermal properties to import CAD models, with the aid of one geometrical model management, GMM, and one thermal mathematical management, TMM, and thus generating outputs in form of colour gradient scales for steady-state temperature cases.

A. Geometrical Model Management

In Thermica, the geometrical model of the experiment is imported from the CAD model and is then needed to be simplified and overwritten by hand with Thermicas own shape management. The reason of the latter is because the software uses built-in shape management to derive the nodes in the meshing, which also makes the user decide on how to reduce complexity of various shapes.

B. Thermal Mathematical Management

Together with the *Geometrical Model Management*, Thermica also requires an input with specified thermodynamic values of the nodes in the meshing. These node parameters are organized in an excel spreadsheet, which helps the user to calculate and add new nodes. The calculations are based on the values of the specific heat capacity, conductivity and the thermal path for each node, which is depending upon which kind of material the node consist of. In the excel spreadsheet, the user also have the possibility to define the conductive coupling between each node, which is based on how the node structure is chosen.

C. Meshing

Depending on how the different components are assigned to operate, the node structure will vary in quantity and size. A part of the internal objects classifies as parts with no internal heat dissipation, aside from interacting thermally with other objects. This applies, e.g to the *Upper Stack Rods* , where these parts are given a node structure with a minimum amount of nodes to ease the calculations in the software. For a difference, the *microfluidic chip* is purposed to be designed with internal bacterial chambers and thus requiring a more complex node structure, i.e more nodes per unit distance which helps analyze the thermal conduction and its path.

D. Meshing Parameters

For simplicity reasons, the geometrical nodes are restricted to two-dimensional *rectangles*, and for connective distances and rods, they are constructed as cylinders. To define the nodal network for the two dimensional rectangles, the software requires input data in form of meshing parameter **a** and **b** as shown in Figure 8.

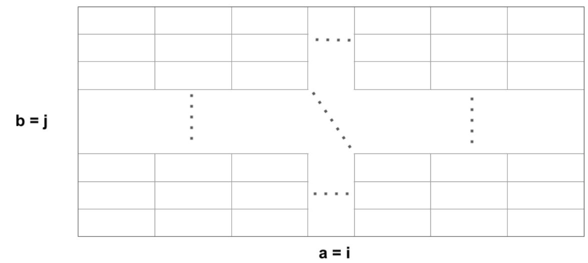

Figure 8. Definiton of meshing parameters

As previously mentioned, the *Upper Stack Rods* are assigned with a simple node structure since heat will only pass through this connection.

When designing the node structure for the *Top Frame* and *Bottom Frame*, the components active and inactive sides were taking into consideration. Although they are not desired to be equipped with heat dissipated components, the parts are plausible to be affected by thermal radiation. Thus the nodal network were needed to be constructed with individual distinctive nodes, so as the heat from the internal components could dissipate through the network in several paths. The nodal network can be seen in Appendix C, Figure 28.

E. Internal Components

The internal components are the objects closest to the dissipating sources, hence the nodal network is required to be in greater detail to get accurate results when simulating. The meshing parameters of the internal components are chosen in regards of level of interest. The *microfluidic chip* is the component which is in focus in the analysis, hence the nodal network consist of more nodes per unit distance. For difference, the *Liquid Reservoir* will contain liquid in the form of water, which makes the thermal affection on the component less interesting. The chosen parameters for the *PCB cards* and *microfluidic chip* can be seen in Figure 9.

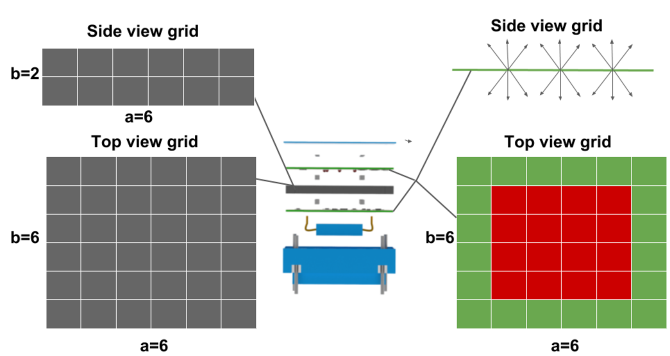

Figure 9. Meshing parameters for the internal components. The red nodes symbolize heat dissipating nodes. The arrow rays symbolize how the heat radiation uniformly radiate.

F. Heat dissipation of components

The MoreBac model is still in its early stage of construction, which has made the power consumption of specific components in the experiment yet to be defined. From earlier studies [8], it has though been made an approximation of the total power consumption from the model as approximately 0.8 W. In the simulations, the total power consumption is therefore equally distributed as heat dissipation from selected nodes on the upper and lower PCB card as shown in Figure 9.

VIII. Thermal Results

The following chapter is presenting the thermal results of the unit level analysis. The simulation was conducted in steady state with boundary temperatures of 5°C and 30°C and is presented in Figure 10-13. The figures graphically represents the temperatures at distinctive nodes in the model, when distributing heat due to electrical resistance at PCB nodes. With each figure, a corresponding temperature scale is presented and the temperature range in the colour scheme changes for each case. For example, a green colour could in one case symbolize a low temperature while in another case symbolize a warmer temperature. The resulting maximum and minimum temperatures for each component is concluded in Table VI-VII.

A. Thermal Analysis Results - Hot Case

Three configuration of heat distributions were simulated;

- 16 nodes at the illumination board with 0.05 W from each node
- 16 nodes at the detection board with 0.05 W from each node
- Finally 36 nodes in total, with 16 nodes on both PCB:s and with 0.025 W from each node.

These nodes represents the location of a possible CPU and its nearby components, where the largest heat dissipation is expected. The reason to test these 3 configurations, were to investigate how the heat distribution in the 3D CAD model affected the microfluidic chip in different possible scenarios.

Figure 10 shows the result when the heat dissipation is equally divided between the PCBs in the hot case. The illumination board is indicating lower temperatures than the detection board since the heat from illumination board is being lost to the CubeSat structure via the lid.

Table VI
Table of hot case temperatures, when illumination board and detection board dissipate equally divided effect of 0.4 W each.

heightCase.	Object Name	Min temp.	Max temp.
Hot	Illumination board	$28,78°C$	$29,04°C$
Hot	Detection board	$47,27°C$	$47,48°C$
Hot	Microfluidic chip	$34,16°C$	$42,15°C$
Hot	Frame	$28,17°C$	$28,20°C$
Hot	Rods	$30,00°C$	$30,00°C$
Hot	Microfluidic liquid reservoir	$47,24°C$	$47,24°C$

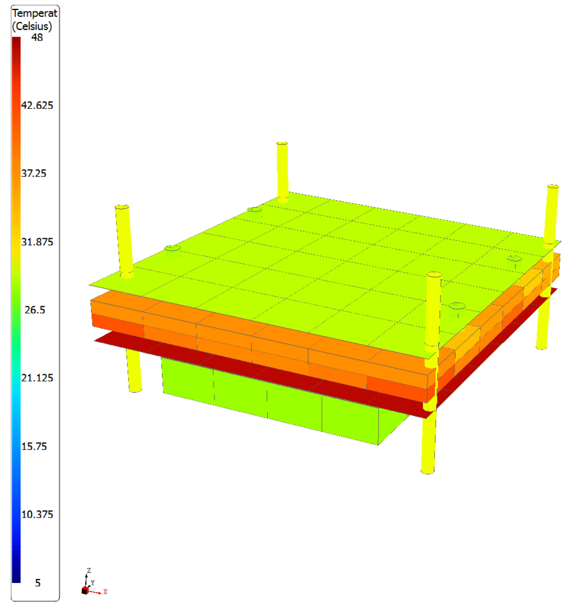

Figure 10. Temperature of the MoreBac model in steady state with boundary temperature 30°C. The illumination board and detection board dissipate equally divided effect of 0.4 W each.

Since the microfluidic chip contains the investigated bacteria, it is of great interest to study the heat distribution on the microfluidic chip. By hiding the illumination board, it is also possible to read the temperatures of the spacers which could have a great impact on the thermal paths.

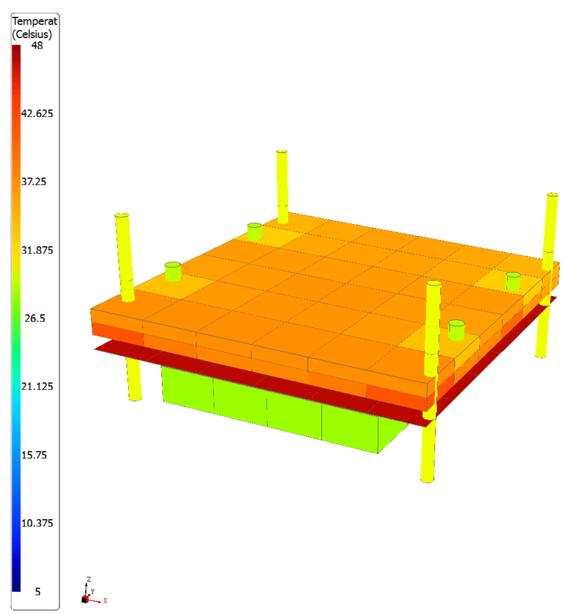

Figure 11. Temperature of the MoreBac model in steady state with boundary temperature 30°C. Shows the microfluidic chip, after hiding the illumination board. The illumination board and detection board dissipate equally divided effect of 0.4 W each.

Figure 11 shows the microfluidic chip when the illumination board is hidden. The microfluidic chip indicates a maximum temperature of $42,15°C$ and is mostly heated from the detection board via conduction through the spacers and via thermal radiation.

The results for the scenarios when the dissipation of heat is distributed on the PCBs separately are presented in Appendix A, figure 14 - 17. The results for the frame temperature, in the hot case, is presented in Appendix B, figure 22-24.

B. Thermal Analysis Results - Cold Case

The cold case simulates the experiment at the lower temperature limit of $5°C$ when the illumination board and the detection board dissipate equally divided effect of 0.4 W each, see Figure 12-13. In this case, the same nodes as the hot case are the ones dissipating the heat. The cold case results shows as follows, similar temperature distribution as the hot case.

Table VII
TABLE OF COLD CASE TEMPERATURES WHEN ILLUMINATION BOARD AND DETECTION BOARD DISSIPATE EQUALLY DIVIDED HEAT.

Case.	Object Name	Min temp.	Max temp.
Cold	Illumination board	$8,12°C$	$8,37°C$
Cold	Detection board	constant $27,76°C$	$27,98°C$
Cold	Microfluidic chip	$13,82°C$	$22,32°C$
Cold	Frame	$7,49°C$	$7,51°C$
Cold	Rods	$5°C$	$5,00°C$
Cold	Microfluidic liquid reservoir	$27,76°C$	$27,76°C$

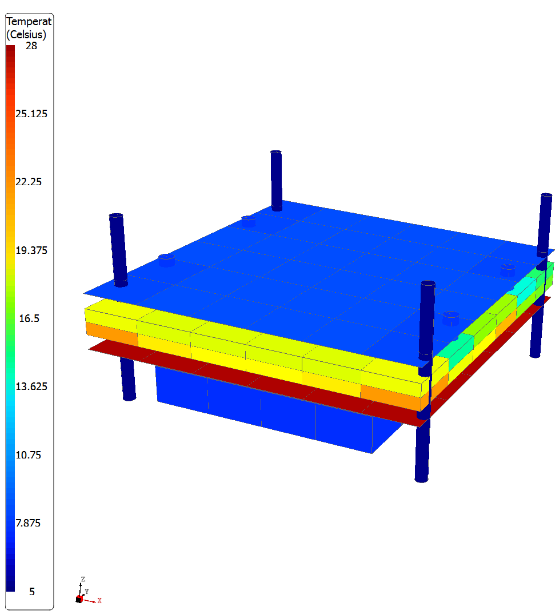

Figure 12. Temperature of the MoreBac model in steady state with boundary temperature $5°C$. Shows all internal components, with rods. The illumination board and detection board dissipate equally divided effect of 0.4 W each.

Figure 13 shows the microfluidic chip when the illumination board is hidden. The microfluidic chip indicates a maximum temperature of $22,32°C$.

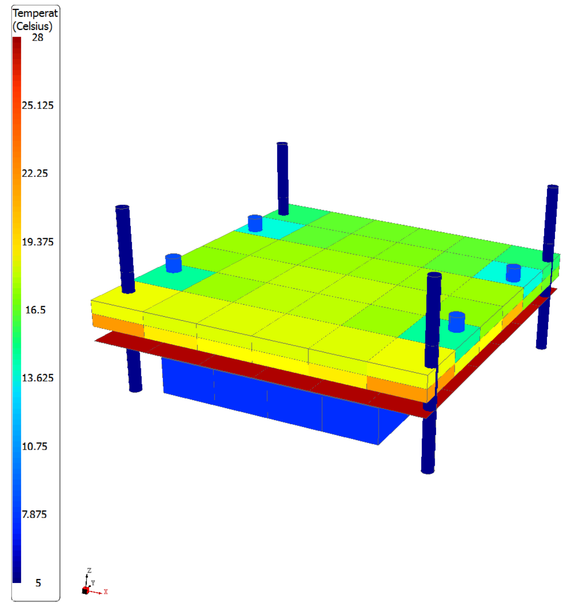

Figure 13. Temperature of the MoreBac model in steady state with boundary temperature $5°C$. Shows the microfluidic chip, after hiding the top PCB card. The illumination board and detection board dissipate equally divided effect of 0.4 W each.

The results for the scenarios when the dissipation of heat is distributed on the PCBs separately are presented in Appendix A, figure 18- 21. The result for the frame temperature, in the cold case, is presented in Appendix B, figure 25-27.

IX. Discussion

A. Mechanical

The MoreBac experiment is no larger than the size of a can of soda and with that comes many challenges. As mentioned earlier, NASA and ESA has sent similar experiment to space but in a relatively larger scale in comparison to the experiment in this thesis. Therefore, the biggest challenge with the MoreBac experiment is to fit the required components, and since many of the components are not yet specified, the CAD model in this project is a simplified model to aid further projects.

B. Conductivity

Both the Illumination- and detection layer are approximated of a single copper layer. In reality, the cards are based upon multiple layers of epoxy plastic and copper, which would generate a different conductivity in the thermal path of the cards. By doing this approximation it might generate an error in the resulting temperatures, but due to the small scale of the experiment it is not considered to have any major importance.

C. Heat Dissipation

A major uncertainty factor in the thermal analysis is the heat dissipation distribution of the circuit boards and the bacterial components. Not all component manufacturers specify the heat dissipation in their data sheets, and since the distribution of the heat sources was approximated it may cause unreliability in the results. A solution may be to measure the in and -out effect of the experiment, whereas the difference in effect will indicate how much effect, in the form of heat, that is lost to the surroundings.

D. Temperature results for the electronics

In the industry, the operating temperatures is based to about $60-80°C$ to $120°C$ which is set to extend the life span of the PCBs. In this thesis, the lower PCB in MoreBac experiment is reaching temperatures of around $60°C$, which is in no risk of overheating. The limitation is instead the microfluidic chip, and that it stays inside the required temperatures.

E. Thermal model

During this thesis there were a a problem to shape the thermal model, whereas Thermica interprets that some of the distances between components are closer than they actually are. Since heat through conduction needs to be pre-defined, only radiation could be affected. Due to the small size of the model, the radiation contribution is negligible.

F. Future Work

The designed model could be further elaborated with a more detailed overview of the internal components, to aid the input arguments in the thermal analysis. This could show how different components could affect the temperature flow in the model, and therefore aid the construction of the whole MIST model. A time dependent model would be interesting to investigate, since a steady state model assume a steady state heat dissipation which is not the most realistic case. A time dependent model can be implemented by using time variable temperatures in the boundary nodes which will indicate the temperature flow of the experiment in orbit.

X. Conclusion

A. Mechanical conclusions

The mechanical results in the CAD shows that the experiment is fully viable in this small scale, but currently have some design flaws. The following conclusions about the mechanical design were therefore made:

- The PCBs, the microfluidic chip and the microfluidic liquid reservoir are all connected and rigged to the lid of the box. Instead of attaching the internal components separately to the CubeSat framework, they will be mounted together with spacers inside the box. This layout makes it possible to assemble the experiment before attachment in the CubeSat, but it will also have thermal advantages which are presented in the thermal conclusion.
- Further cutouts of the bottom PCB card is needed, which is to fit the incoming fastening bolt applied from the MIST structure.

B. Thermal conclusions

- Since the lower PCB is not connected to the CubeSat structure, the heat will have to pass through the whole structure to the Cubesat structure connection in the lid. This layout causes the heat to rise through the microfluidic chip instead of spreading uniformly to the rest of the CubeSat structure. Since the illumination board has a shorter thermal path to the structure of the CubeSat, more heat is lost from the illumination board.
- It was observed that when the detection board dissipated the majority of the total effect, the microfluidic chip reached too high temperatures. Therefore it is recommended to put a larger proportion of heat dissipating components on the illumination board.
- The microfluidic liquid reservoir should be placed in the bottom of the experiment since the higher heat in the bottom minimizes the risk of freezing of the liquid.
- If a more even temperature distribution of the experiment is desired, thermal straps can be attached to the lower PCB to lead away the extensive heat through the CubeSat structure.
- If a heater is sought to be added to the experiment, it is recommended to be placed on the bottom of the experiment. This is since the connective distances on the top are thermally closer to the boundary node, which can drain the input heat faster than on the bottom.

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APPENDIX A

Table VIII
TABLE OF HOT CASE TEMPERATURES WHEN ONLY ILLUMINATION BOARD DISSIPATE HEAT.

Case.	Object Name	Min temp.	Max temp.
Hot	Illumination board	$28,87°$C	$29,35°$ C
Hot	Detection board	$28,75°$C	$28,75°$C
Hot	Microfluidic chip	$28,82°$C	$28,84°$C
Hot	Frame	$28,17°$C	$28,21°$C
Hot	Rods	$5,00°$C	$5,00°$C
Hot	Microfluidic liquid chamber	$28,75°$C	$28,75°$C

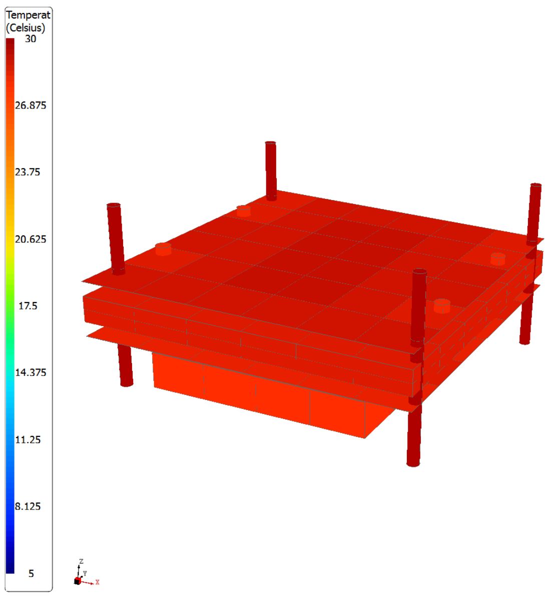

Figure 14. Temperature of the MoreBac model in steady state with boundary temperature 30°C. All internal components when the **i**llumination board dissipate 0.8 W.

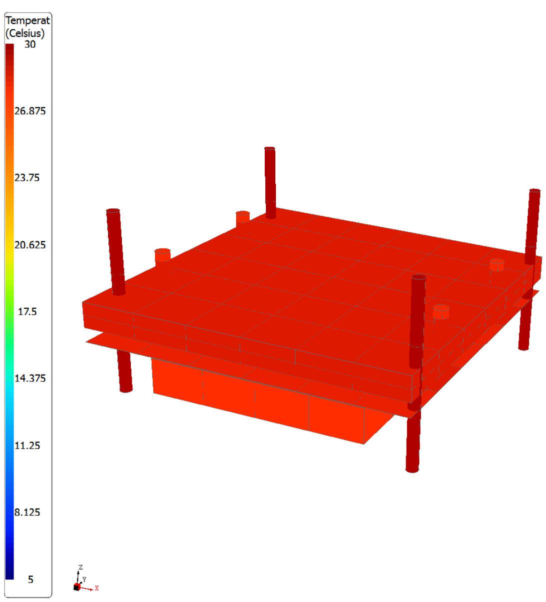

Figure 15. Temperature of the MoreBac model in steady state with boundary temperature 30°C. Shows the microfluidic chip when the **illumination board** dissipate 0.8 W.

Table IX
TABLE OF HOT CASE TEMPERATURES WHEN ONLY THE DETECTION BOARD DISSIPATE HEAT.

Case.	Object Name	Min temp.	Max temp
Hot	Illumination board	$28,68°$C	$28,72°$C
Hot	Detection board	$65,0°$C	$65,12°$C
Hot	Microfluidic chip	$40,75°$C	$54,79°$C
Hot	Frame	$28,16°$C	$28,20°$C
Hot	Rods	$30,00°$C	$30,00°$C
Hot	Microfluidic liquid chamber	constant $64,64°$C	$64,64°$C

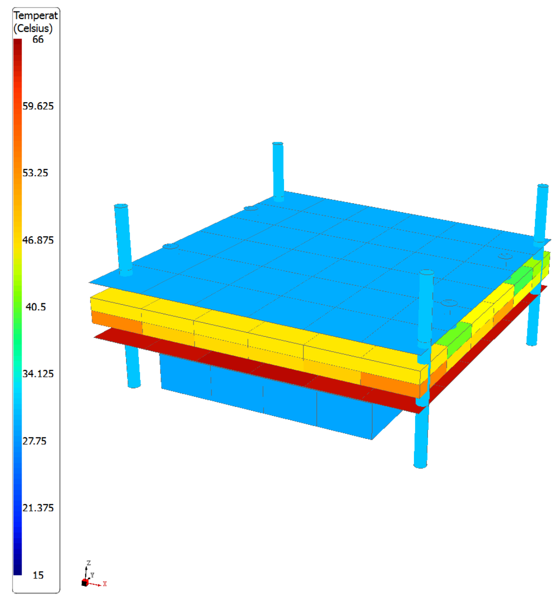

Figure 16. Temperature of the MoreBac model in steady state with boundary temperature 30°C. All internal components when the **detection board** dissipate 0.8 W.

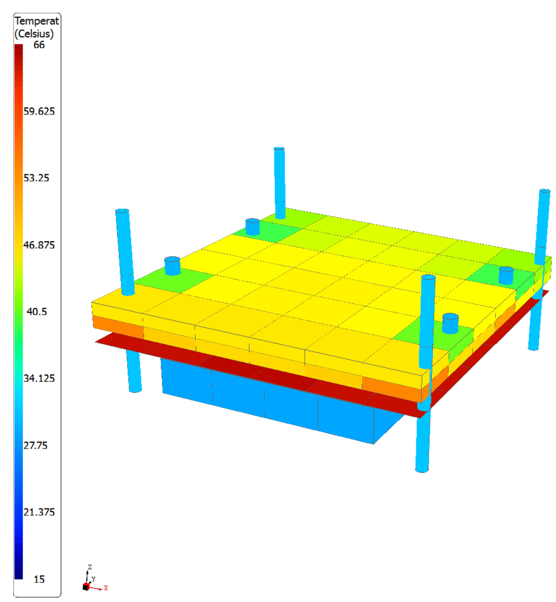

Figure 17. Temperature of the MoreBac model in steady state with boundary temperature 30°C . Shows the microfluidic chip when the **detection board** dissipate 0.8 W.

Table X
TABLE OF COLD CASE TEMPERATURES WHEN ONLY ILLUMINATION BOARD DISSIPATE HEAT.

Case.	Object Name	Min temp.	Max temp.
Cold	Illumination board	$8,19°C$	$8,67°C$
Cold	Detection board	$8,072°C$	$8,072°C$
Cold	Microfluidic chip	$8,14°C$	$8,17°C$
Cold	Frame	$7,50°C$	$7,53°C$
Cold	Rods	$5,00°C$	$5,00°C$
Cold	Microfluidic liquid chamber	$46,3°C$	$46,3°C$

Table XI
TABLE OF COLD CASE TEMPERATURES WHEN ONLY DETECTION BOARD DISSIPATE HEAT.

Case.	Object Name	Min temp.	Max temp.
Cold	Illumination board	$8,03°C$	$8,07°C$
Cold	Detection board	constant $46,33°C$	$46,77°C$
Cold	Microfluidic chip	$19,2°C$	$35,8°C$
Cold	Frame	$7,48°C$	$7,50°C$
Cold	Rods	$5,00°C$	$5,00°C$
Cold	Microfluidic liquid chamber	$46,3°C$	$46,3°C$

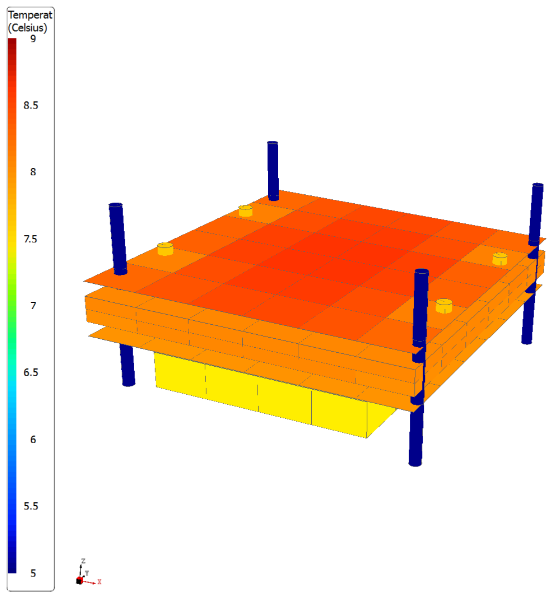

Figure 18. Temperature of the MoreBac model in steady state with boundary temperature 5°C. All internal components when the **illumination board** dissipate 0.8 W.

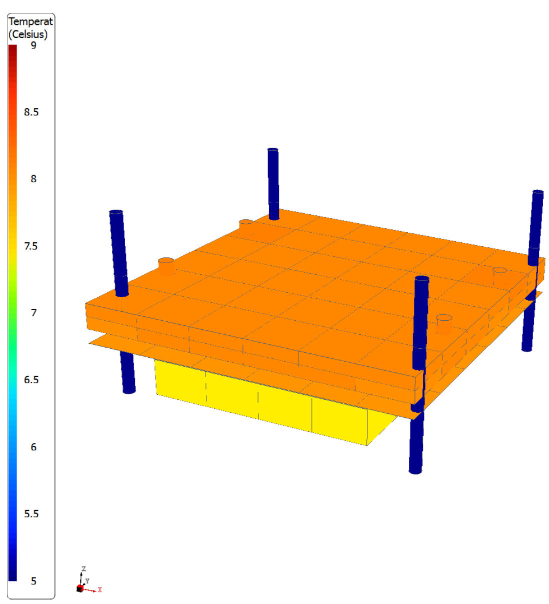

Figure 19. Temperature of the MoreBac model in steady state with boundary temperature 5°C. Shows the microfluidic chip when the **illumination board** dissipate 0.8 W.

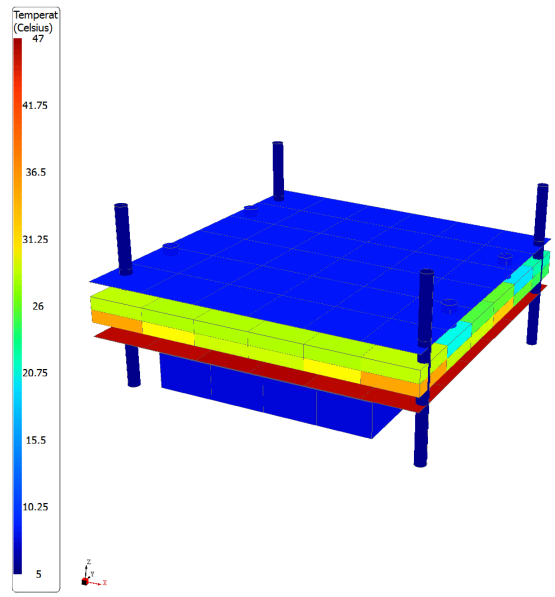

Figure 20. Temperature of the MoreBac model in steady state with boundary temperature 5°C. All internal components when the **detection board** dissipate 0.8 W.

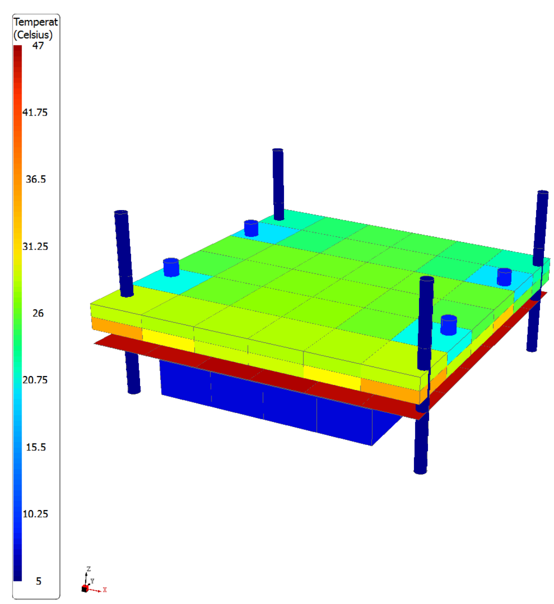

Figure 21. Temperature of the MoreBac model in steady state with boundary temperature 5°C. Shows the microfluidic chip when the **detection board** dissipate 0.8 W.

APPENDIX B

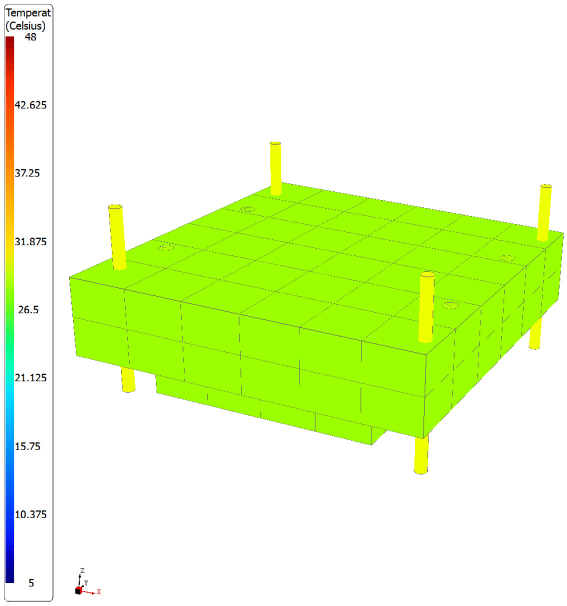

Figure 22. Temperature of the frame of the model in steady state with boundary temperature 30°C. The **illumination board** and **detection board** dissipate equally divided effect of 0.4 W each.

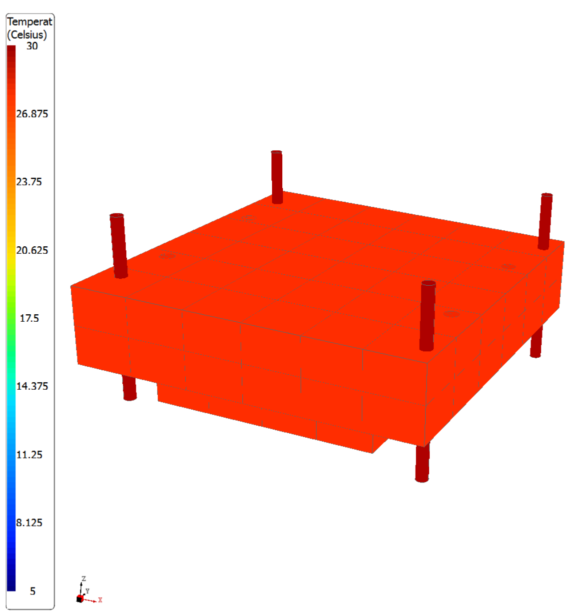

Figure 23. Temperature of the frame of the model in steady state with boundary temperature 30°C. The **illumination board** dissipate an effect of 0.8 W.

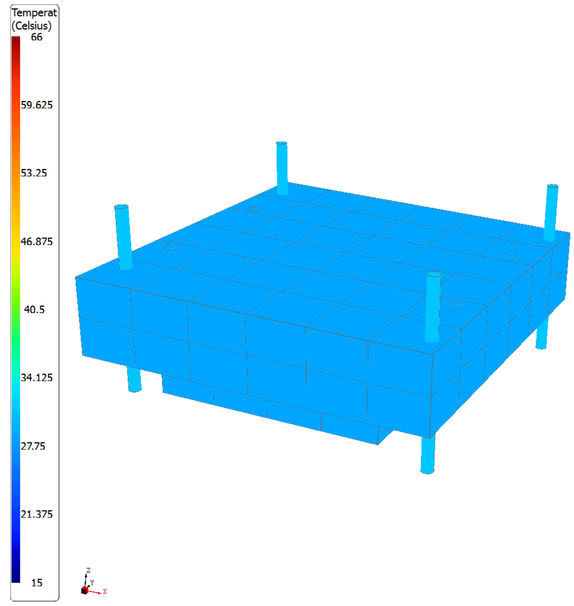

Figure 24. Temperature of the frame of the model in steady state with boundary temperature 30°C. The **detection board** dissipate an effect of 0.8 W.

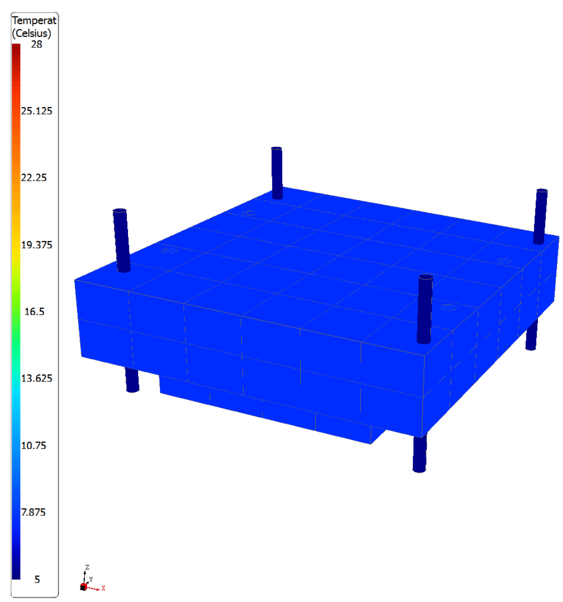

Figure 25. Temperature of the frame of the model in steady state with boundary temperature 5°C. The **illumination board** and **detection board** dissipate equally divided effect of 0.4 W each.

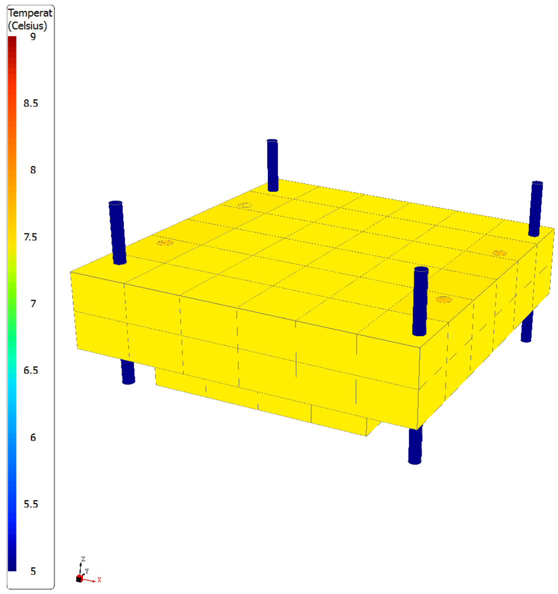

Figure 26. Temperature of the frame of the model in steady state with boundary temperature 5°C. The **illumination board** dissipates an effect of 0.8 W.

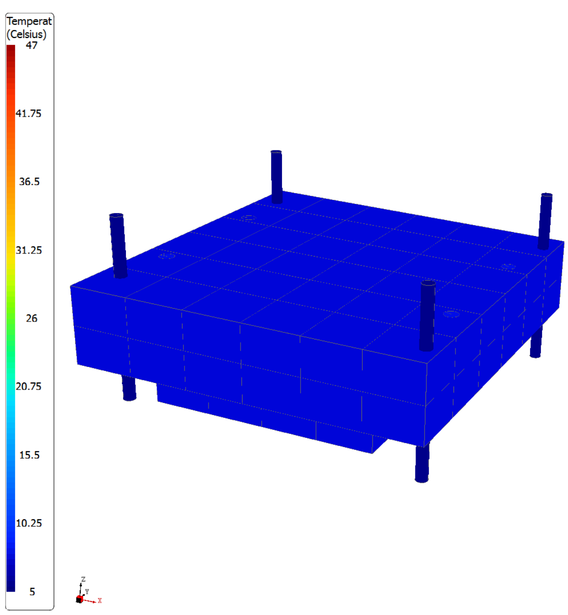

Figure 27. Temperature of the frame of the model in steady state with boundary temperature 5°C. The **detection board** dissipate an effect of 0.8 W.

APPENDIX C

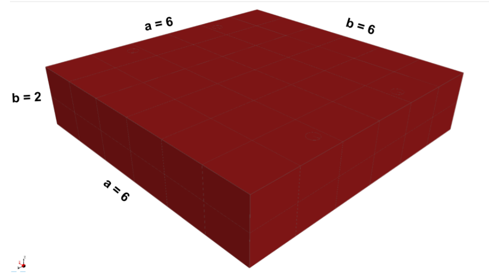

Figure 28. Meshing parameters building the nodal structure for the top frame