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Optimization of a Small Scale Thermal Energy Harvesting Device

BACHELOR'S THESIS

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DECLARATIONS

Declaration about the acceptability of the thesis

This thesis fulfills every formal and content requirements of the regulation of the Budapest University of Technology and Economics, moreover it fulfills the assignment of the final project. This thesis is suitable for a review and an open defence.

Budapest, 16.12.2021

Supervisor’s signature

Declaration about the independent work

I, Huang Kangjian (a4cbm5), hereby declare that the Thesis submitted for assessment and defence, exclusively contains the results of my own work assisted by my supervisor. Further to it, it is also stated that all other results taken from the technical literature or other sources are clearly identified and referred to according to copyright (footnotes/references are chapter and verse, and placed appropriately).

I accept that the scientific results presented in my Thesis can be utilised by the Department of the supervisor for further research or teaching purposes.

Budapest, 16.12.2021

Huang Kangjian

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I want to thank my supervisor, Dr. Josh Davidson for his patience. I had zero knowledge of my project at the beginning of the semester. Dr. Josh Davidson had guided me through the tough time, and then I had a closer experience with the knowledge behind the project, and he has expertise with the software that I used during the semester. Even when I was panicking initially, he would still patiently explain everything. This has been an honor to work with him.

I would also want to thank my friends around me, especially when you are studying abroad. English is our second language, and we did not speak any Hungarian when we just arrived in Budapest. We have known each other since the first semester of my bachelor's journey. They have always been supportive. I want to thank my friends, Hui Xiaobao, Luo Yifan, Li Qiaoyi, Li Zijian, Jiang Peng.

Parents are the reason why I came to Budapest, and I want to thank them for bringing me such an incredible journey.

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Abstract

In today's life, the public is starting to be aware of the importance of renewable energy. However, fossil energy still plays a massive role in global energy production. The use of natural gas, fuel, and coal to generate electricity is harmful to humans and contributes to air pollution and global warming. These days, the development of technology has really skyrocketed, the efficiency of devices has increased a lot during the past years. Some of the things that we could only dream of had become the facts. Hydropower, thermal power, wind power, tidal power, and many other resources that come from nature have become more and more grown methods to generate energy. Over the last decade, the size and the power consumption for wireless sensors have significantly decreased, which brings the topic to this report. This report investigates the method to provide a robust power supply for autonomous wireless sensor networks in the environment. This project will involve the optimization of a thermal energy harvesting device. The technologies discussed in this report are thermoelectric devices known as thermal generators. Simulations of thermal generators are going to be done in different situations.

Keywords: Renewable, technology, efficiency, size, power consumption.

1. Introduction:

After the industrial revolution, a lot of modern equipment was built. During the operation of the machine, thermal energy is produced as a by-product of every kind of generation or industrial process. For a power station, fuel has to be buried to spin the turbine, and that is how the mechanical energy is formed; after this, we need a generator to convert the mechanical energy to electrical energy. During the process, about two-third of energy is lost as heat. And this brings me the idea of how I could reuse this resource to do something useful.

Almost all the equipment is installed with sensors to track some important parameters. In recent years, the size and the power consumption of the sensor have decreased significantly, and a lot of them are still running with batteries. This puts a limitation on the lifetime of the sensor. Once the battery runs out, we must change the battery manually. It is time-consuming, and it could be costly. The first thing that comes to mind may be to increase the battery capacity so that we can extend the lifetime of the sensor, this might be the possible solution for some cases, but while increasing the capacity of the sensor, the volume of the sensor would increase as well. If the geometry of the sensor changes, it might no longer fit in the position that it was used for. Of course, there are people just wondering that why don't we connect cables to the sensor, so the energy supply would not be a problem anymore. In this case, the sensor would not be wireless, and the place we can put this wireless sensor would be limited according to the length of the cable, and if we have hundreds of sensors installed, it will not make sense to connect all the sensors with cable. As such, we need a reliable energy resource to avoid all these unnecessary costs.

If we can make a device that can absorb energy from its surroundings, and it would be a perfect solution. The sensor networks can achieve a lifetime for years. If we will have a device like this, it could reduce the cost dramatically as the energy harvesting device can continue providing the energy to the sensor. The lifetime of the sensor is theoretically limited by the reliability of its own.

The problem of the power supply must be solved in order to accomplish the goal of monitoring. The renewable power source would vary according to the time in general, for example, time of the day, time of the year. If we would have an equipment that runs at a relatively constant temperature which is higher or lower than ambient temperature, we can attach the thermoelectric generator to it. Some of the heat flow will be transferred into power, and we can use that amount of power to run the sensor. This concept was inspired by the papers that my supervisor has done[1] [2] [3].

This paper is about "Thermal energy harvesters scavenge energy from natural temperature gradients, to provide a robust power supply for autonomous wireless sensor networks in the environment. This project will involve optimization of a thermal energy harvesting device".

2. Applications

2.1 Electricity generation in extreme environments.

In order to achieve a huge temperature gradient, some extreme situations can be imagined. For example, if someone is living in a freezing area, like the north or south pole, if there is heat generated, we can use the thermoelectric device to generate power. If there is an extreme cold situation, the same method can be applied. The only problem will be if we are running the operation in a critical environment, the lifetime of the device would be a big question.

2.2 Solar,

When it comes to heat or temperature, the first thing that comes to my mind is the sun. one interesting fact is that the surface of the earth receives about 1kW per meter squared power from the sun, and this adds a lot of potentials if we are going to apply solar as one of our factors to build the thermoelectric generator. Imagine if we have the material under the sun, it would definitely absorb energy since the solar radiation would have an effect on it. The material would no doubt has a greater temperature than the ambient temperature. If we could apply the same method to the thermoelectric generator, we would have the heat resource for the hot side. The only thing remaining is decreasing the temperature on the cold side to achieve better power output.

2.3 Automobile

A thermoelectric generator is a relatively simple device. We need to find the heat resource to make it work. And Automobiles can be one of them, during the operation of the automobile, a lot of heat will be generated. If we can take advantage of it, we can install it around the engine or on the exhaust gas pipe, theoretically anywhere if there is heat generated. I have seen one paper that talks about the Automotive exhaust thermoelectric generators[11].

3. Theoretical background

The main theory behind the thermoelectric device is going to be invested. There are temperature differences exiting between two sides which would result in a heat flow from hot to cold in order to keep a thermal equilibrium. The heat flow can be used as one way to generate energy. This process follows the laws of thermodynamics; therefore, the efficiency is calculated by the ratio of the useful work, which is represented by the letter W, to the input heat, which is Q, which is constrained by the fundamental Carnot efficiency. The Carnot efficiency can be used for all the heat engines and generators, and we can calculate it by using the two terms, “hot temperature” and cold temperature as[4]:

$$\eta = \frac{W}{Q} = \frac{T_H - TC}{T_H} \tag{1}$$

From the efficiency formula, we can tell the efficiency would be extremely limited if the temperature difference between the hot side and the cold side is low. For example, if we have a heat source that is 303.15 Kelvin(30℃) and it is placed inside the room with the room temperature of 293.15 Kelvin(20℃), even in the ideal case, the temperature difference between them will be 10, which would result in 3.3% of the efficiency. In case you might be wondering, what if we can just increase the temperature difference? And yes, the task of this project will be optimization, and it serves one aim only. Expand the temperature difference. For example, we have a heat source that will be 373.15 Kelvin(100℃), and the environment will be the same 293.15 Kelvin(20℃). In theory, we would reach 26.8% of the Carnot efficiency. But all of these are based on the background of the ideal state. In reality, the efficiency that we can achieve can not be as high as the ideal case.

Since the efficiency of the device is low, a larger amount of heat is required in order to harvest enough energy for consumption. In theory, the heat transfer would be present in three ways: via conduction, convection, and radiation. Roundy et al. [5] made an analysis to determine the power that can be generated from temperature difference by assuming heat conduction through a material. He found that if the temperature gradient is small, the heat convection and heat radiation would have a really small impact compared to the heat conduction. Due to this reason, the formula of the heat flow is:

$$q = k \cdot \frac{\Delta T}{L} \tag{2}$$

Where q denotes heat, k denotes the material's thermal conductivity, ΔT denotes the temperature differential between the cold and hot sides, and L denotes the material's thickness.

We know the formula to compute the heat flow now the unit of the heat flow will be $[W\ /\ m^2]$. Therefore, we just need to multiply the heat flow with the area, and then multiply the value with Carnot efficiency, which is mentioned as equation 1. We can calculate the power output:

Power output =(heat flow)(cross-section area)(Carnot efficiency)

$$P_{out} = q \cdot A \cdot \eta = k \cdot A \cdot \frac{T_H - TC}{L} \frac{T_H - TC}{T_H} \tag{3}$$

Although one of the ways to absorb energy is to increase the temperature difference to hundreds of Kelvins, but in this case, we are going to use this device on hot water. There is no way that we can achieve that amount of gap for the temperature difference. We will put our focus on how we can get a suitable amount of energy to run the sensors by optimizing the system.

One more thing that is worth mentioning will be the ZT value. Figure-of-merit (ZT) is a dimensionless index. S is Seebeck coefficient, σ is the electric conductivity, λ is the thermal conductivity. The reason why this value is important is that this value will be the key factor in determining whether the thermoelectric material is the best one to be used. Suppose we are going to have a high value, then it means the material is suitable for thermoelectric purposes. For a very long time, this value has been kept around the value of 1. However, during the modern days, we have made progress within the laboratory, but the final goal will be reaching the value above 4.

$$ZT = \frac{\sigma S^2}{\lambda}\left(\frac{T_H - T_L}{2}\right) \tag{4}$$

4.Intruduciotn to softwares

4.1 Amesim

Figure1. picture of Amesim software

In this project, we will use Amesim to simulate. You might be wondering what Amesim is; amesim stands for “advanced modeling environment for simulations of engineering system.” Amesim was published in France by the company called “Imagine” in 1995. In 2007, it was bought by “LMS,” which stands for learning management system. Finally, Simcenter bought the "LMS International" with 680 million euros in 2012.

Simcenter Amesim is a software that performs the simulation; it can be used for modeling and analyzing the multi-domain system. We can build a model that contains many different physical fields and complete the simulation calculations. We can also do the analysis like plotting and so on.

Engineering designers can use the integrated set of Amesim application libraries to design a system. Experiments have rigorously tested and verified all these models from different physical fields. Amesim helps engineers to quickly reach their goal of modeling and simulation: analyzing and optimizing engineers' designs, thereby helping users reduce development costs and shorten development cycles.

There are many libraries in the software, which are signal, mechanical, hydraulic, and thermal, and many more other libraries to select. In this project, we will put more focus on the thermal library. It contains everything that we need in order to carry out this project.

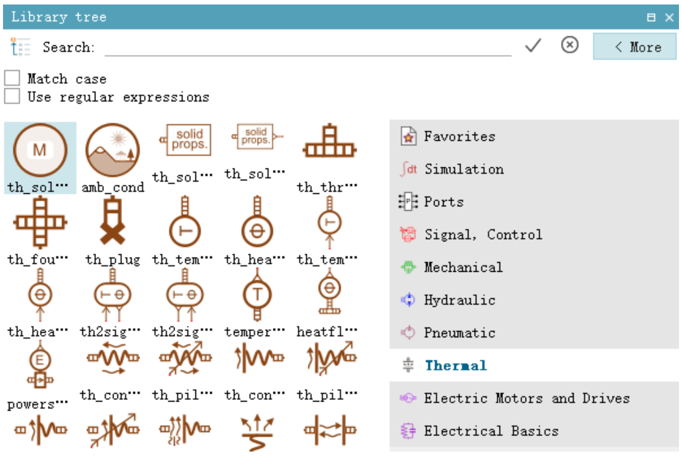


Figure2. picture of amesim's library tree

4.2 Inventor

When it comes to creating the model of the thermoelectric generator, I selected Inventor as the software to go. The reason why I choose Inventor is that I have experience with the software before. I have used Inventor for two of my classes, which are "introduction to CAD" and "machine Element." I will do a basic introduction for Inventor.

Inventor is one of the CAD software tools among all other software. The original author for Inventor is called Jacob Sain, and it is one of the software at Autodesk now. The initial release date was in 1999. It is operating at windows system.

Inventor is one of the design software in Autodesk. You might know the other famous design software in Autodesk as well, which is called AutoCAD. Both of them create 2D and 3D models. But Inventor has its own terminology and workflows. You may find it strange when you are switching from one to another. In the case of Inventor, parametric and features are the main idea of the software. We can use its own feature-based system to create a sketch, 3D parts, assemblies, and then drawings. We have to strict the dimensions and relationship between the parts to avoid the deformation of the object that you are creating. Product design, tool creation, mechanical design, and product simulation are all made easier using Autodesk Inventor. Users can use the software to create precise 3D models that can be used for simulation and visualization before building their products. Inventor has become more and more popular these days. When it comes to design, many companies rely on this platform.

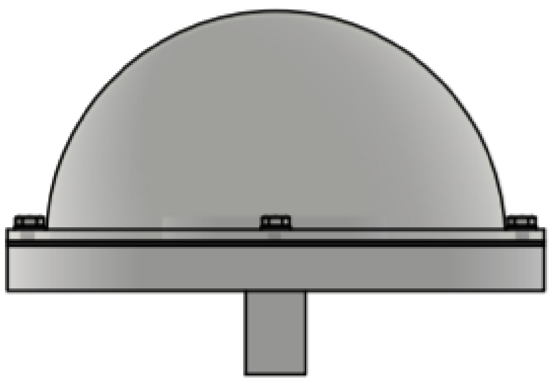
INVENTOR

Figure3. icon of inventor

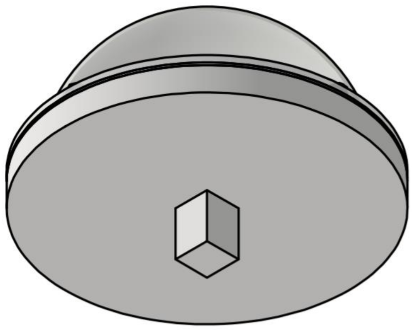
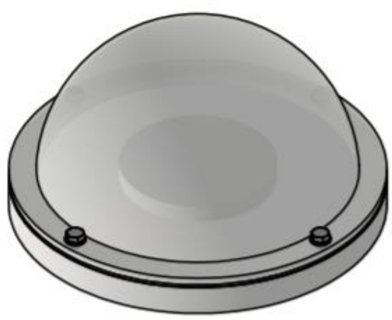
5. Modeling

5.1 Geometry of the model

In this section, I am going to build the model for simulation; before I get into the modeling, I would like to introduce the geometry of my project, and I think it would be easier to visualize the project in a general view.
Geometry overview:



(a)

(b) (c)

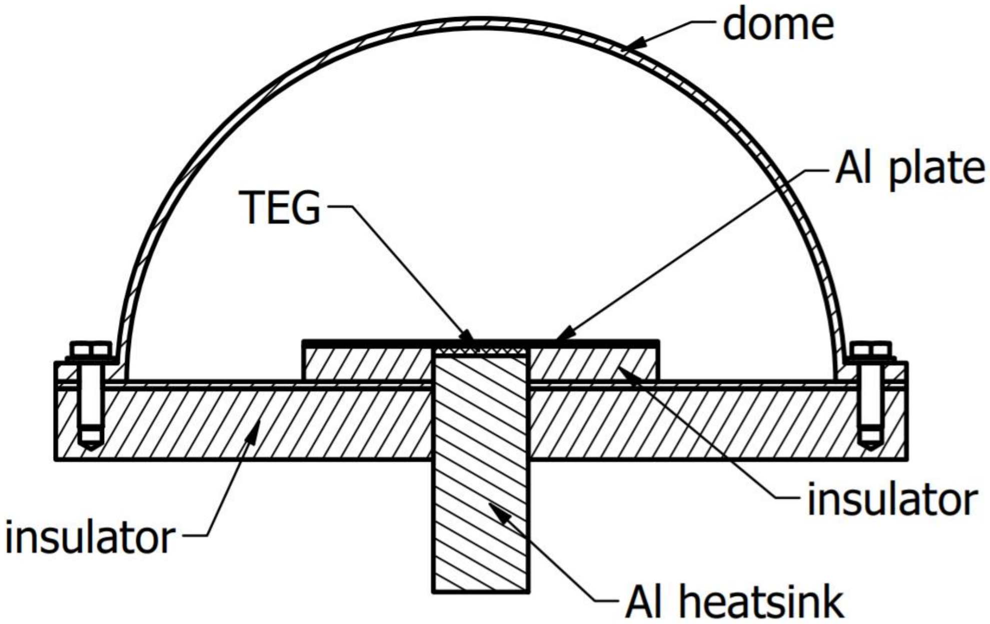


Figure4. Geometry overview of the system and (a),(b),(c) is the 3D versions of the model.

I created this model in Inventor, and I am going to have a brief introduction to my system. We have the heatsink, insulators, thermoelectric generator, aluminum plate, and we have the dome to cover the design. Once those components are assembled, we need a washer and bolt to fix the system as we can see in the picture. The geometry will be introduced as well. in the case of the heatsink, it is a cuboid, with a length of 100mm and a side of 40mm. For the TEG, it is a cuboid as well, with a length of 4mm and a side of 40mm. The next one will be the aluminum plate, it is a disk with a radius of 75mm, and its thickness will be 2mm. For the dome, it will be hemispheric with an inner radius of 300mm, and its thickness will be 4mm. For two insulators, they will have a radius of 75mm and 180mm, and a thickness of 15mm and 30. Also, there is a plate for locking the system in between two insulators, it will have a thickness of 3mm and a radius of 180mm.

5.2 Simulation steps:

There are four steps in general, which will be the sketch, submodel, parameter, and simulation. We are going to create them one by one in order to run the simulation. First of all, we are going to have a fully connected system, and then, we should determine the submodel of each component. The next step will be to fulfill the parameters of every component. After we finish all the necessary steps, we will be able to carry out the simulation. In our case, since there is not any phase change throughout the process, we are going to use the standard submodel for every single component.

There are multiple components that are involved in this simulation. First, after the industrial process, the heated wastewater (50°C) will have heat convection with the aluminum heatsink. And, of course, there will be heat transfer within the system since the thermal electric generator is installed on the aluminum heatsink. Because they are in touch with each other, so the phenomenon called heat conduction would occur. In order to have the heat flow within the thermal generator, I need to increase the temperature gradient between the top and bottom sides of the TE generator. In order to achieve the goal of increasing the temperature difference. I installed an aluminum plate on the thermal generator in order to decrease the temperature of the top part of the TE generator. And then, the aluminum plate would release the heat by the phenomenon of heat convection and heat radiation with air inside of the dome and the environment. The heat transfer would occur with the air inside the dome and dome. And finally, the dome will be in contact with the ambient air.

In order to do the simulation, all of the material above will have its own properties, so I will have to create the so-called “th_solid_data” for each component. Of course, all the thermal relationship has to be set to do a successful simulation. And here is what my sketch will be looked like:

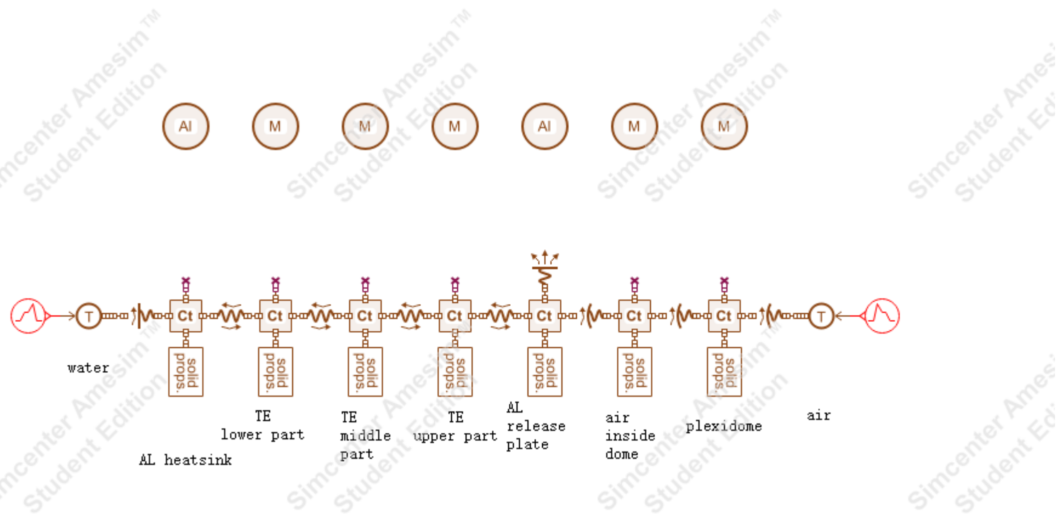


Figure5. sketch of amesim

As you may have realized already, I have divided the TE generator into three parts, which will be the mid part and two insulators part, which is called alumina ceramic. For the lower and upper TE part it has a thickness of 0.7mm. I think in this case, separating it into three different solids helps us to visualize the relationship between them, and most importantly, we can see what is going on within the TE generator, and this also helps us in increasing the accuracy of the model. If we are going to use the temperature gradient between the release plate and the heatsink, the measurement will not be accurate. Just like this, the sketch is done. The next step will be trying to input the properties of each element.

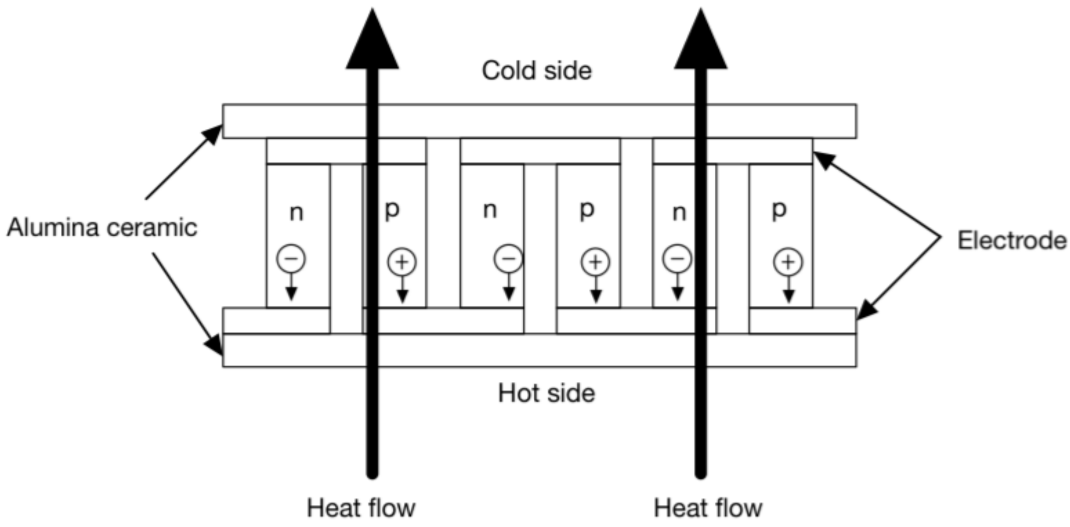


Figure6. sketch of thermoelectric

We can start with the wastewater: I assumed that the wastewater has a constant temperature of 50°C. Within the software, I need to use two components to simulate this simulation process. In the software, it is called a "piecewise linear" and a "th_temperature_converter." The piecewise linear is like a device for signal input, and the thermal temperature converter receives the signal, then it will have the temperature as output. As we can see below, we can set many different stages for signal input and duration time, but since we have assumed the temperature is constant, we only need one stage and the duration time till the system becomes equilibrium.

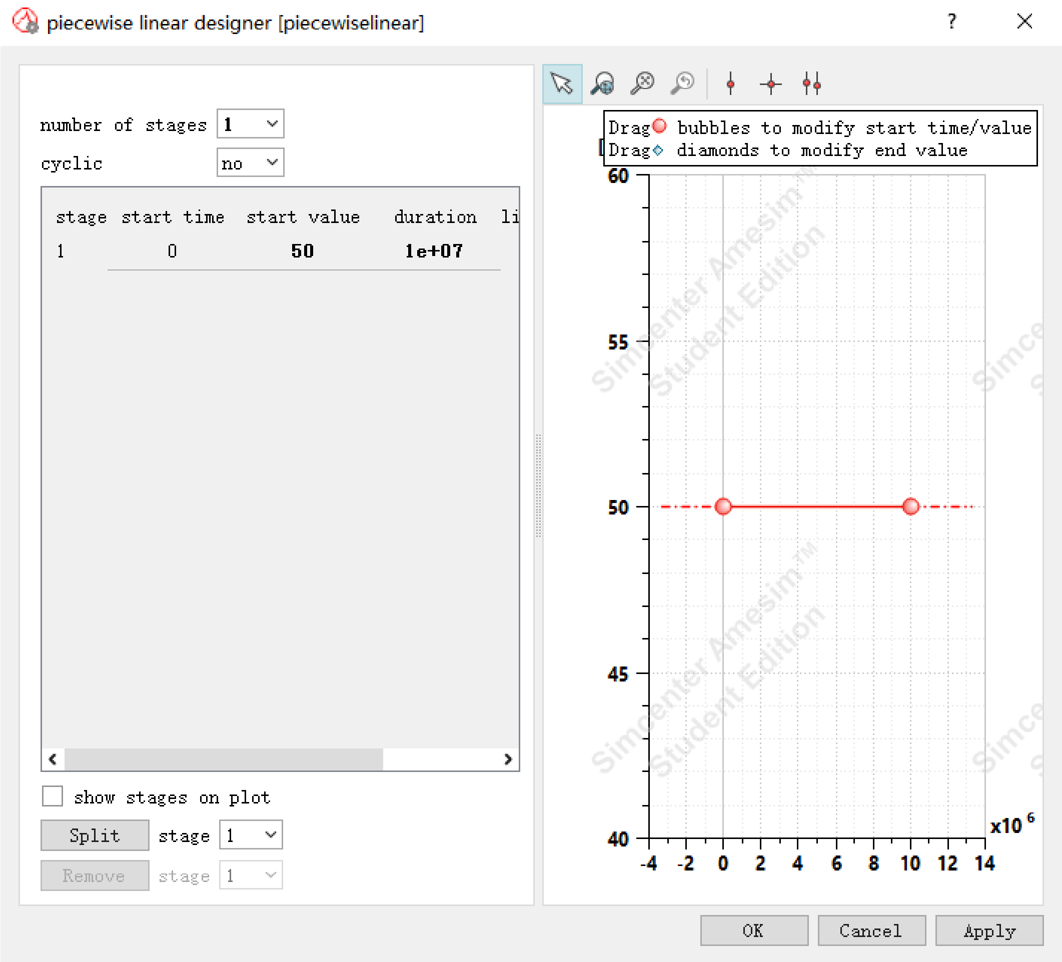


Figure7. data of input heat temperature

After setting the temperature of the water, the next step will be the heat convection between the water and the heat sink. In this case, we need a component called "th_convection2p." The 2p stands for two ports. We need to use the geometry of the heatsink and the water properties to fulfill the table. As for water properties, it is pretty straightforward. We can search on the internet, it was found on this website[6]. For the velocity of the fluid, it does not matter since we are looking for the stationary state.

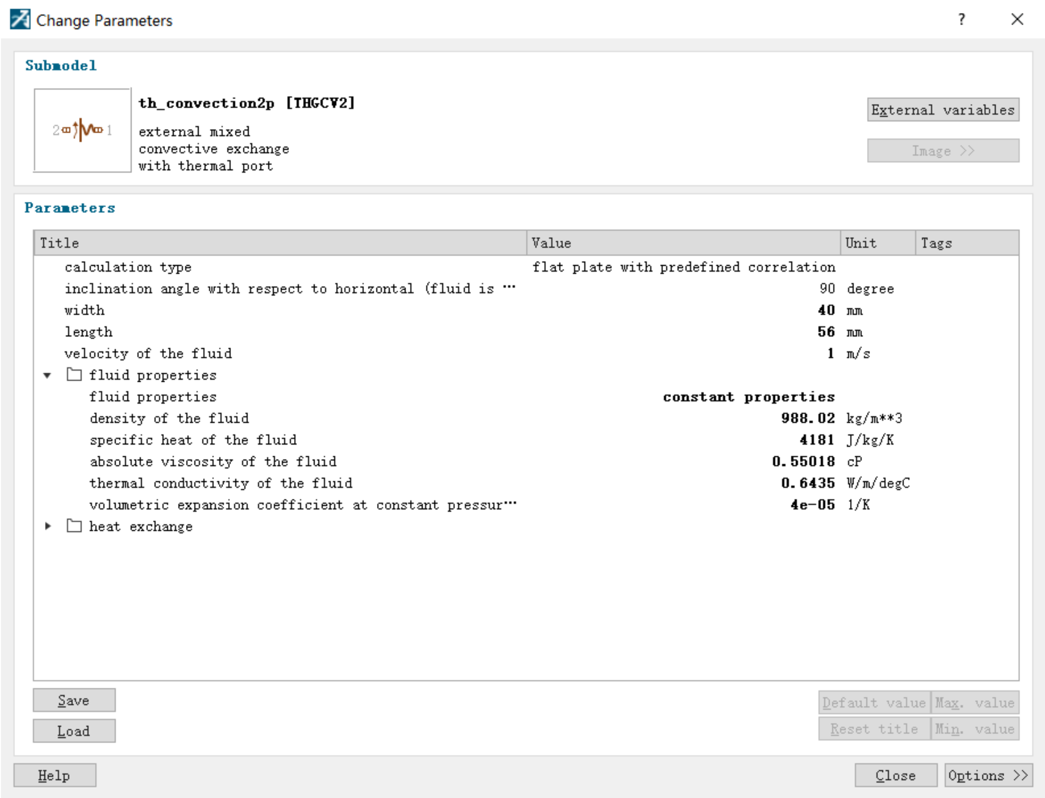


Figure8. convection properties between water and heatsink

The next step is to set the parameters of the aluminum heatsink. We also need two components to define the heatsink. One is called “th_solid_data” which will be presenting the material of the heatsink. The other one is called “th_c” which stands for the essential parameter of the heatsink. First, we need to identify the material of the solid. In this case, we just choose aluminum, and after that, the basic geometry of the heatsink should be defined, and it will be shown as follows:

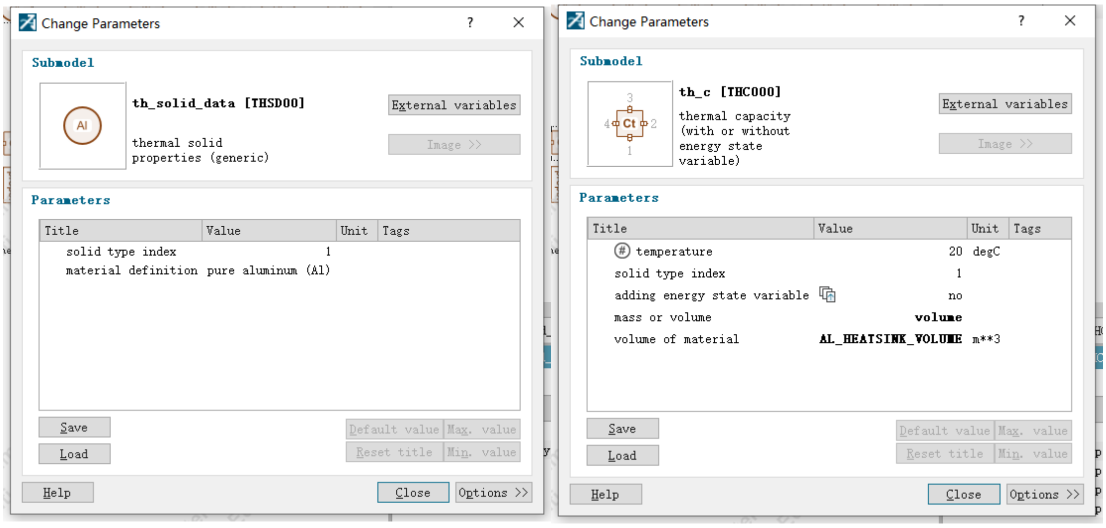


Figure9. material properties of the heatsink

Since the aluminum heatsink is in contact with the TE generator, heat conduction would occur; we should set the values for thermal conduction and select the fundamental quantities of TE. To do this, we need a component called “th_conduction” and in order to do this, we need to know the area of the contact surface and the thermal contact conductance. We do have a reference model, so the contact area is known, as for the thermal contact conductance, it will be set in standard value for now, but we will talk about it later in this project.

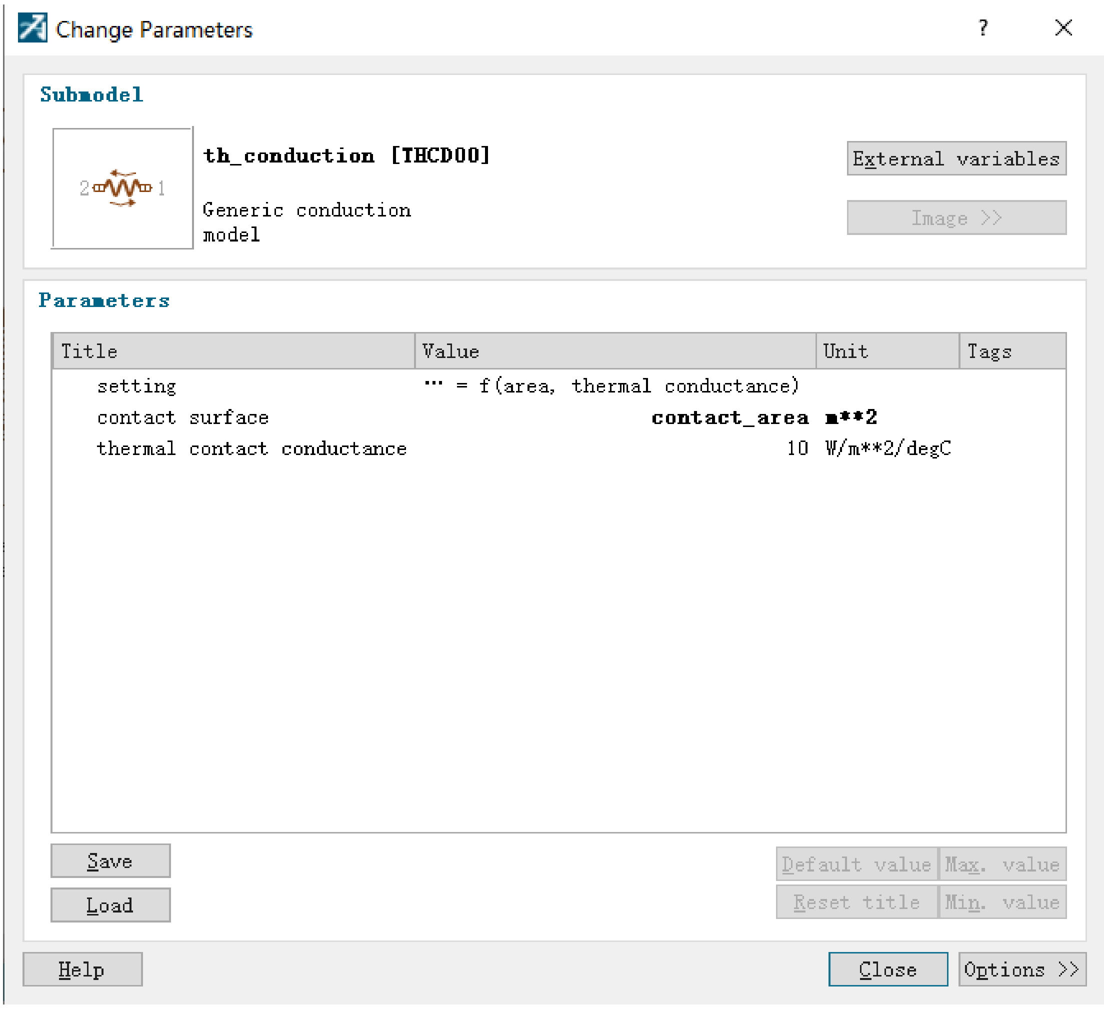


Figure10. thermal conduction properties between the heat sink and the lower TE

We need to set the parameter for TE. As we have mentioned above, the TE device is divided into three parts. We need two components to be able to compute the material quantities and fundamental geometry quantities. For the material quantities of the insulator, I have chosen the material that is called alumina ceramic, which is an excellent insulator. And the series code of it is “A-479”[9]. , we can find all of its property on its website.

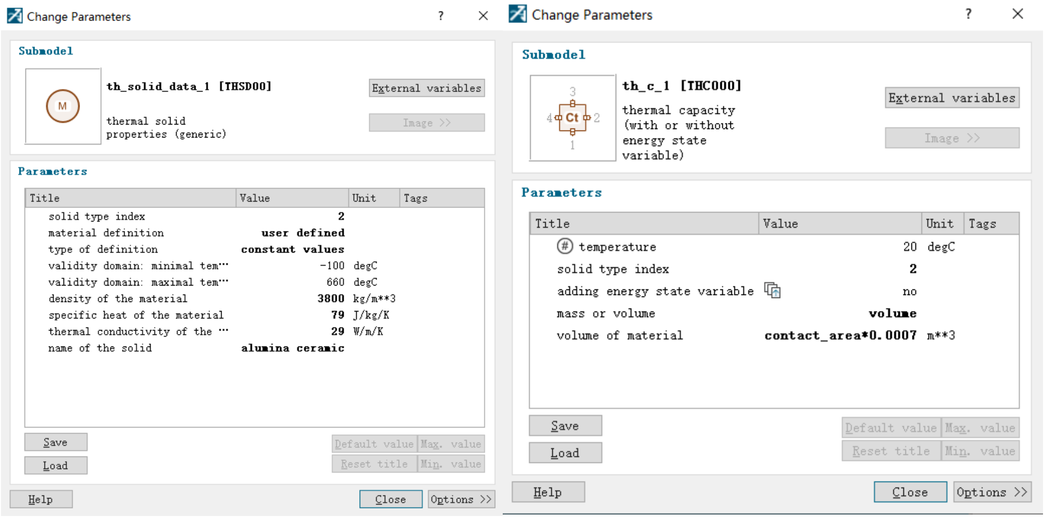


Figure11. material properties of the lower part of the TE

Of course, we need to set the parameter for the middle part of the TE. As we have mentioned above, we need two components to be able to compute the material quantities and fundamental geometry quantities. For the material quantities of the TE, we are using the semi-conducting material Bismuth Telluride, and it has a thermal conductivity of 1.20 W/(m·K). and all the other material parameters are given by my supervisor Dr.Josh Davidson[1][7].

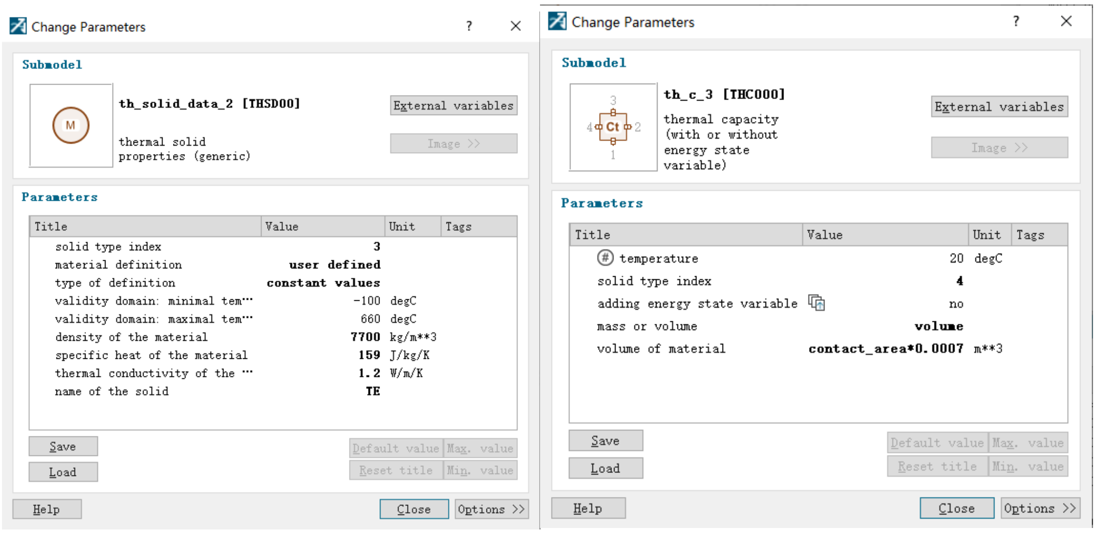


Figure12. material properties of the middle part of TE

For the parameters of the heat conduction of the upper part of the TE, it will be the same as the lower part of the TE, which is the alumina ceramic insulator. The area of the contact surface will be the same, and for the thermal contact conductance, it will still be the standard value.

The next step will be the heat conduction between the upper part of TE and the aluminum release plate, and just like the workflow we did above, we need to determine the contact surface and the thermal contact conductance.

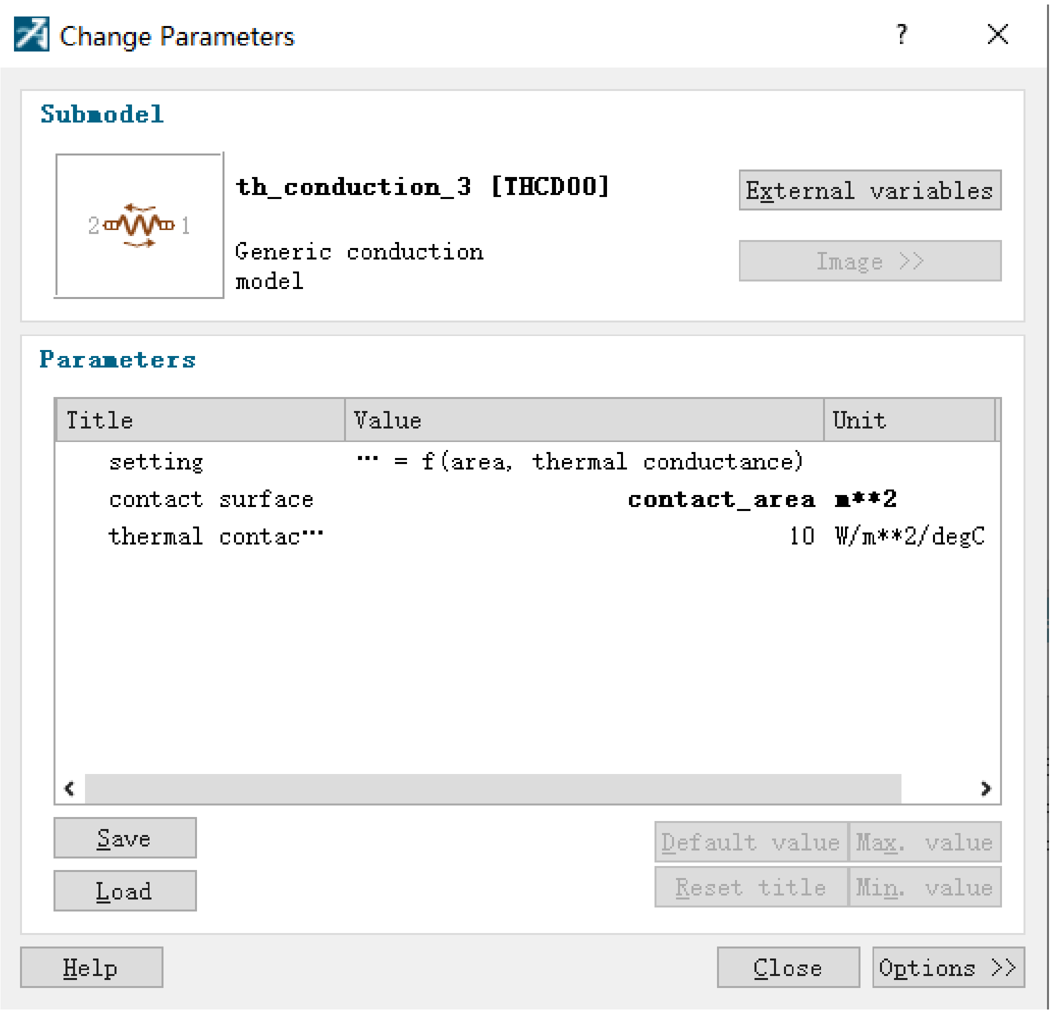


Figure13. thermal conduction properties between the upper TE and plate

The next step will be the material properties and the fundamental quantities of the aluminum release plate, but in this particular object, we do have one more component, which will be heat radiation. In the software, it is called “th_rad2”. I am going to show the properties of heat radiation first, and then I will show the properties of the material and the basic quantities.

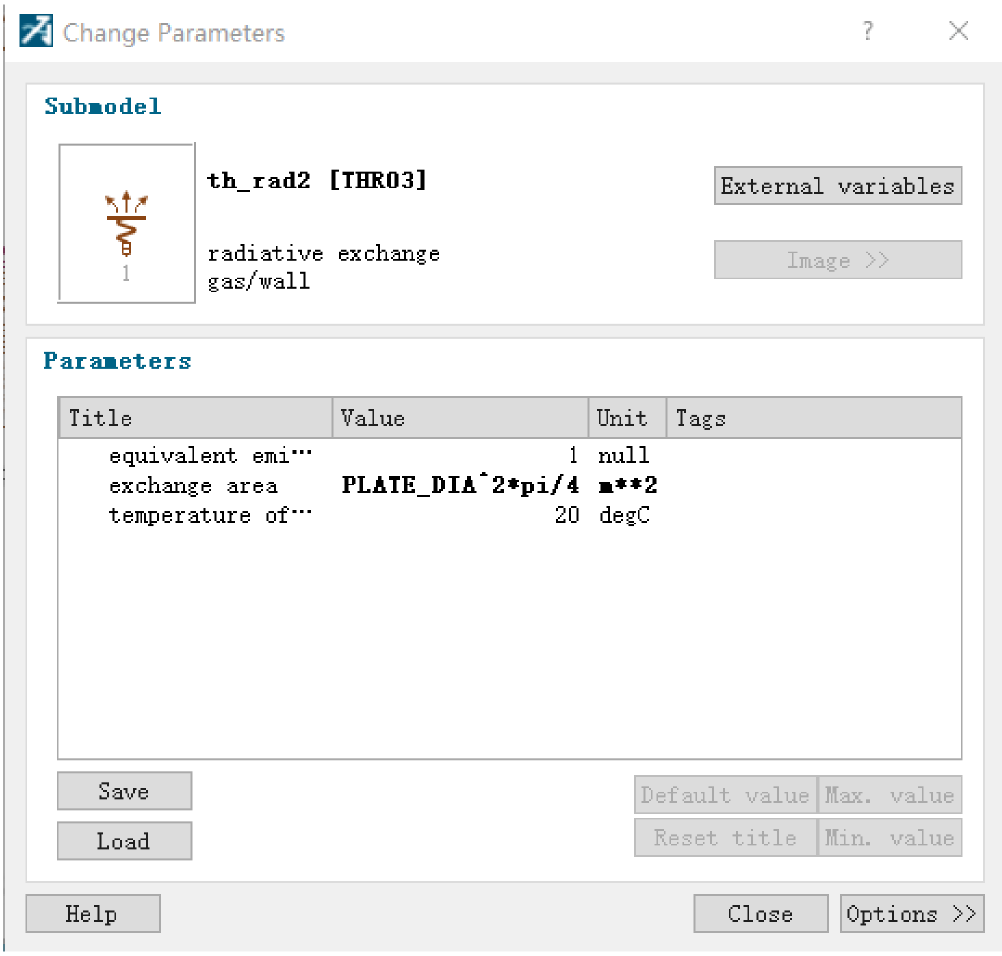


Figure14. thermal radiation properties of the aluminum plate

The properties of the aluminum release plate will be shown below.

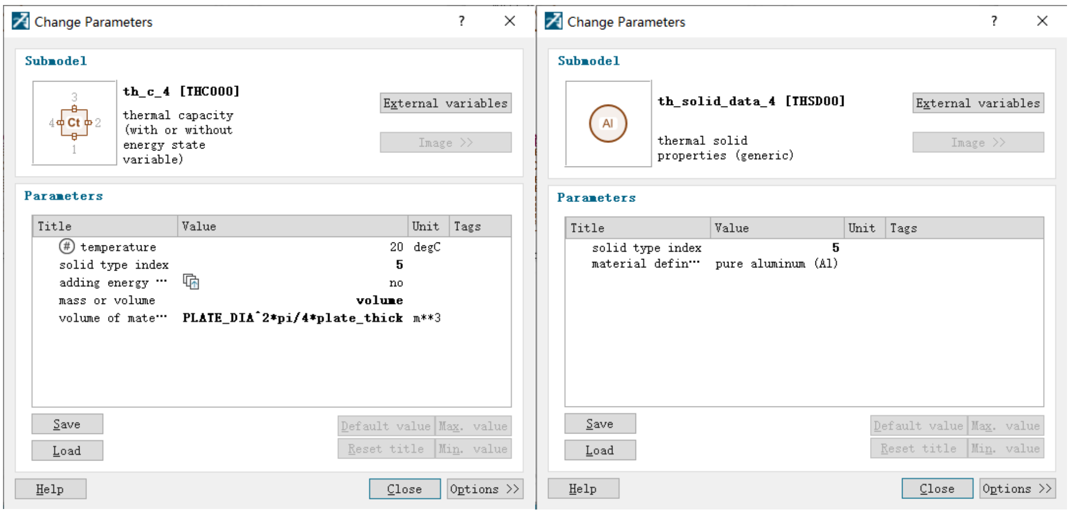


Figure15. properties of the aluminum release plate

The next step will be heat transfer between the air inside the dome and the aluminum release plate, since the air is a fluid. Heat convection will take place in this process. We are going to set the parameter for heat convention. The geometry is known, and since the dome covers the system, I would assume the velocity of the air to be zero.

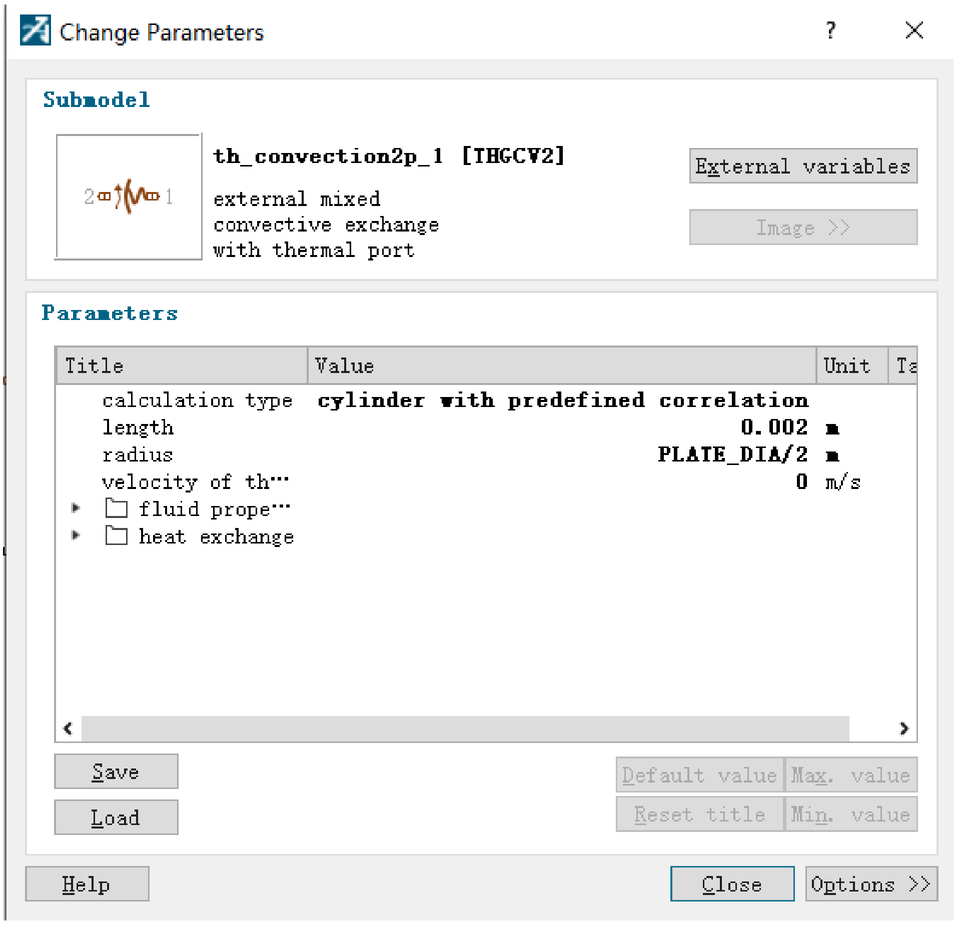


Figure16. heat convection properties between the aluminum release plate and the air

For the material quantities and the geometry of the material, we can find the thermal properties of the air using the internet. It is a related simple question since it is operating at room temperature. I would say the temperature of the air is 20 °C. The parameters of air can be found[8]. As for the geometry of the air, it will simply be the volume of the hemisphere by using the inner diameter of the dome.

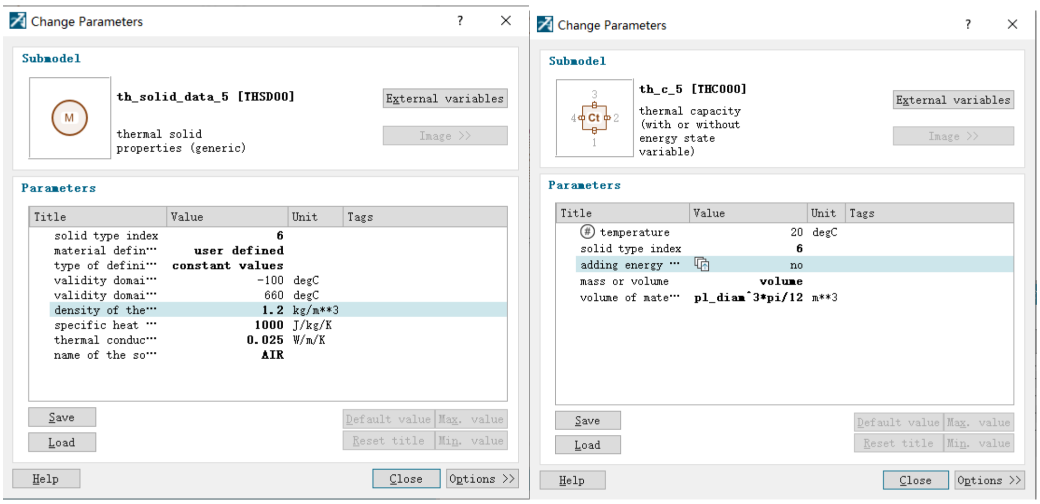


Figure17.properties is the air inside the dome

The next step will be the heat convection between the air inside the dome and the dome. We are going to show the parameter for heat convection as usual, and the velocity is zero again since we have assumed it to be zero in the previous case.

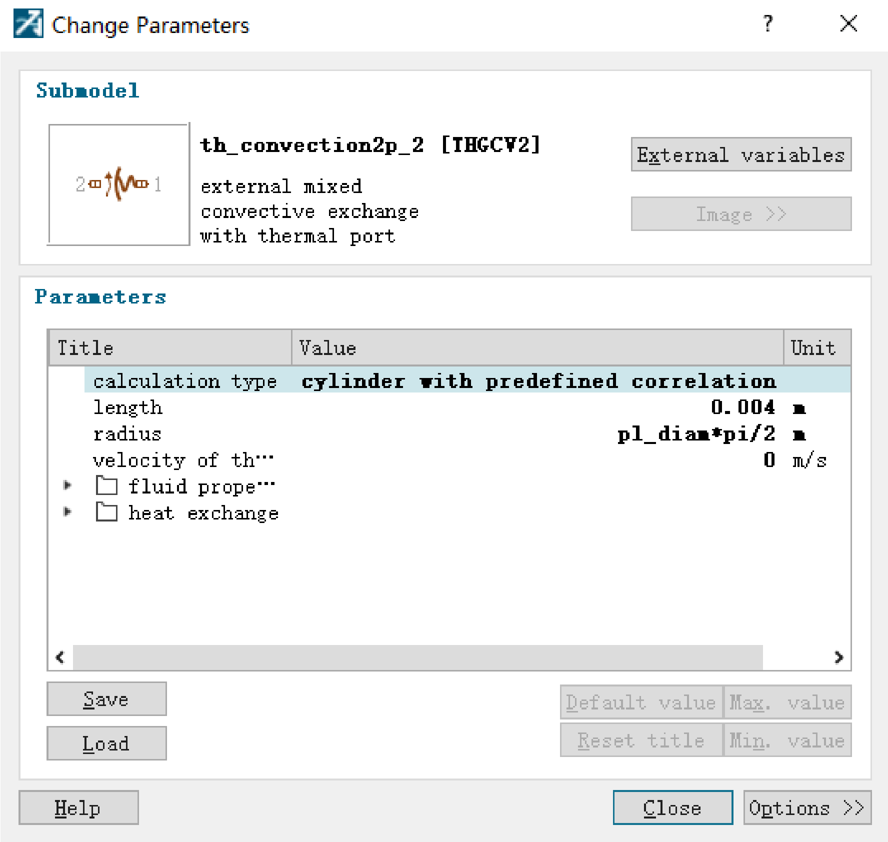


Figure18.heat convection properties between the air inside the dome and the dome

For the dome material, I will go for a Polycarbonate dome. The material properties can be found on the internet and for the volume using the outer radius minus the volume using the inner radius.

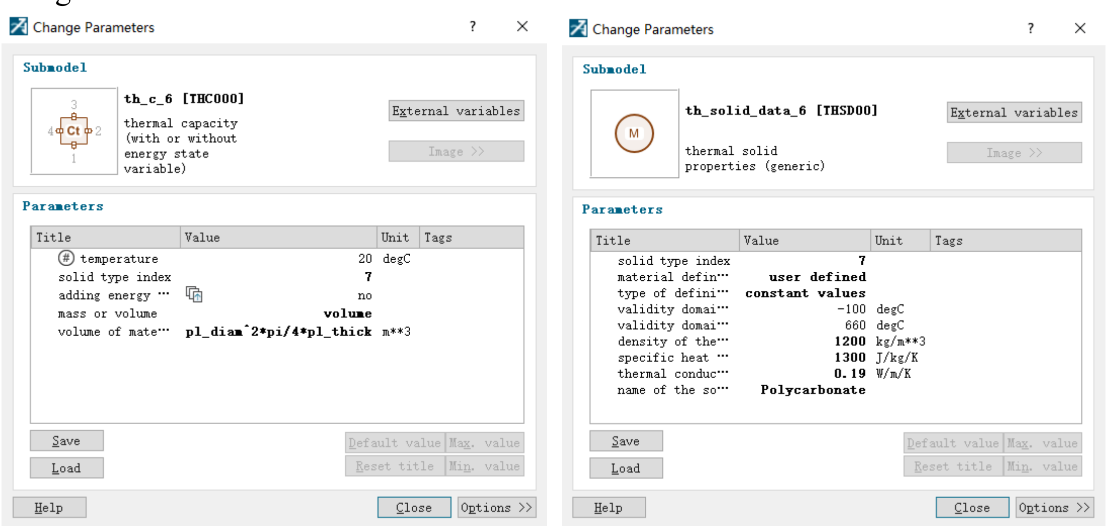


Figure19.material properties of the polycarbonate dome

Finally, the dome is going to have heat convection with the ambient air. Just like what we did, the parameter will be shown:

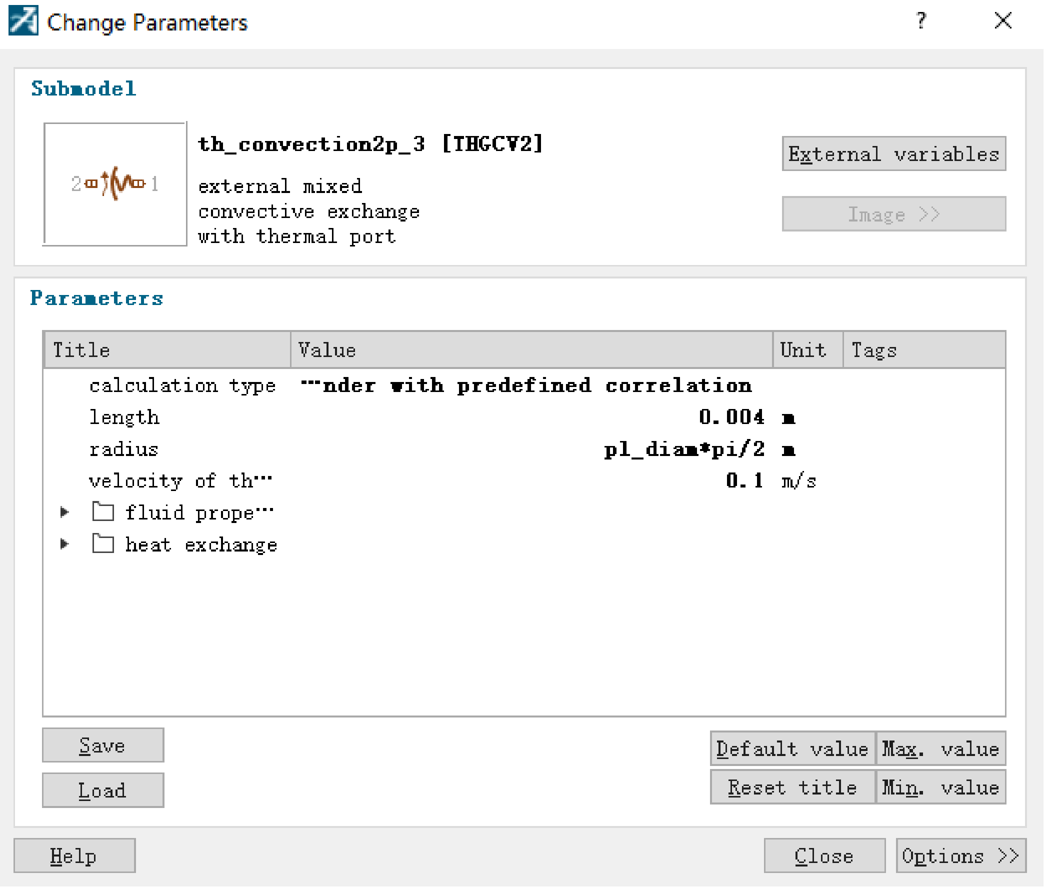


Figure20.heat convection properties between the dome and the ambient air

The last step will be setting the temperature value for the ambient air, and just like what we did to set the temperature of the water. I need a “piecewise linear” and a “th_temperature_converter” In order to compute the last process.

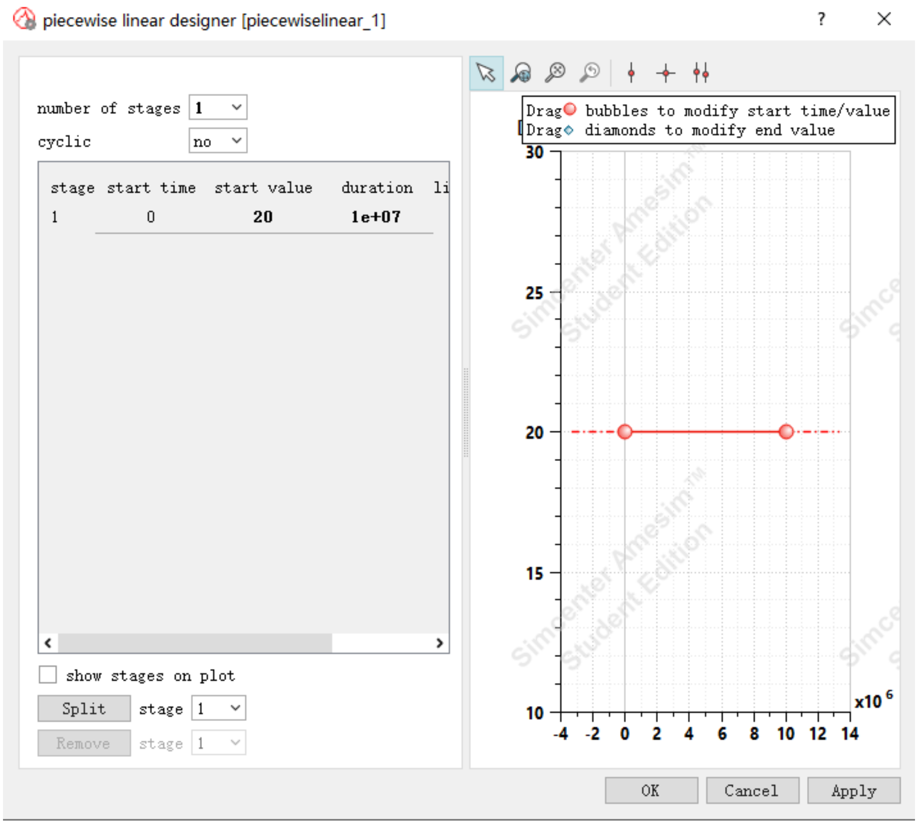


Figure21. ambient air temperature

Just in case you might be wondering, all the parameters that are shown with letters, this is because that I have stored all of the often used parameters in the column called Global parameters. All of them are stored with units as well.

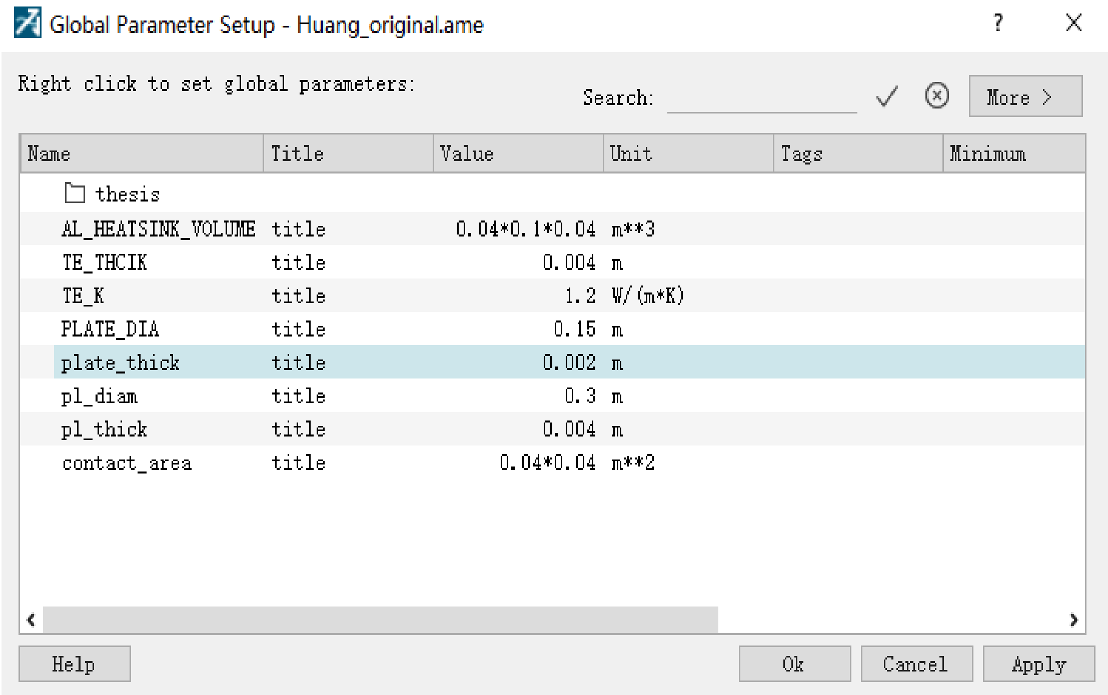


Figure22.global parameters

6. post-processing

6.1 Variation of the release plate

At this moment, we have the geometry of our TEG, and we have all the parameters set to the individual component. Since this project is about optimizing the TEG, we will try to select one or two parameters as variables. There are many different parameters within the system. We will start with examining the temperature output of each component and the power output of the TEG by setting the diameter of the aluminum release plate as our first variable. In our model, the diameter of the aluminum plate is 150mm. Since the contact surface has already been set, so the low area of the plate should be bigger than the contact surface area, which is $40 \times 40mm^2$.

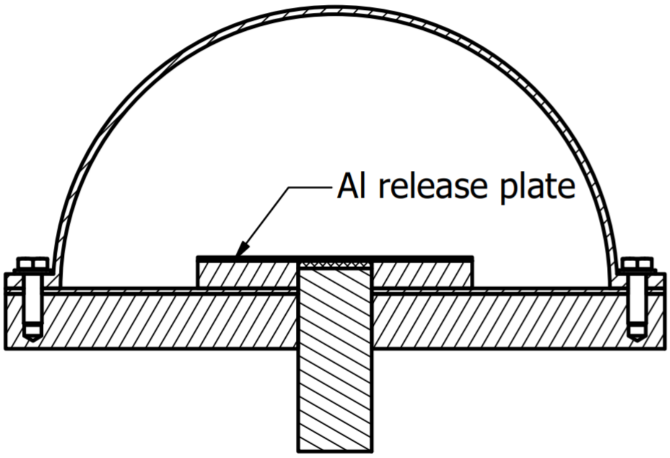


Figure23.sketch of the model

After a simple calculation, we can start with a diameter of 60mm. There is a function called "batch run" inside the Amesim software. We can run the simulation with one variable. Before using the "batch run," we need to set the parameters. Within a tab called "study manager," we can drag the variable to the column and click next. The picture will be shown below:

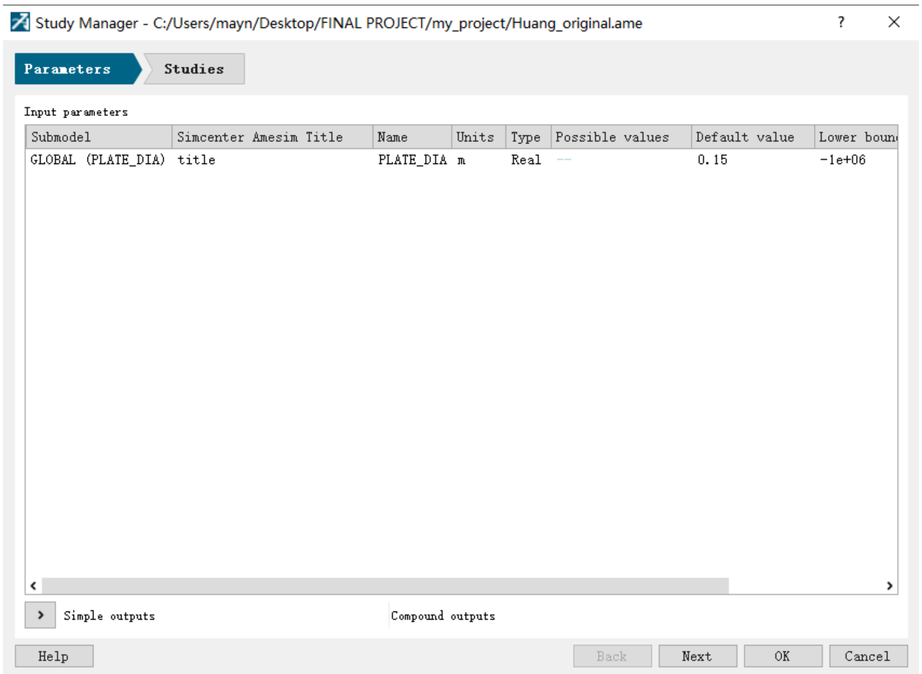


Figure24.study manager

And here we are at the table for setting the variable. In this project, my reference value will be 150mm. I put the step size to 10mm, as you can see in the picture below. My initial value will be 60mm, and my max value will be 290mm since the diameter of the inner dome will be 300mm. In this case, the simulation will repeat itself 24 times.

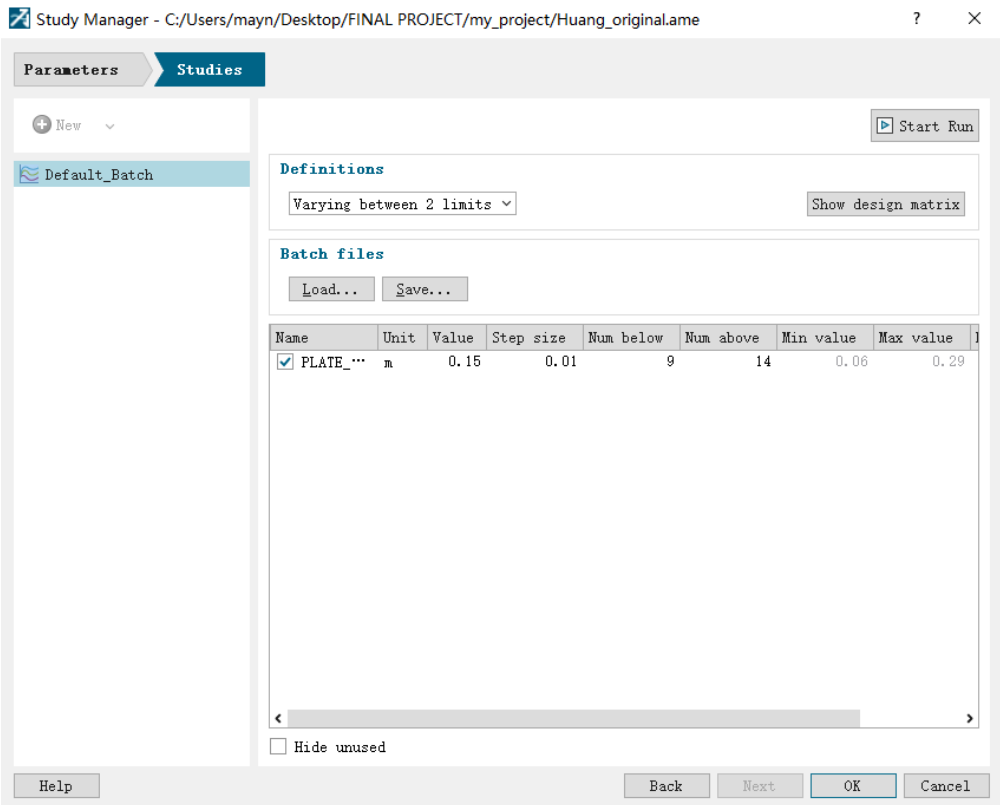


Figure25.step value and numbers of simulation

We have defined the batch parameter, and there are three more things to be set: the start time, final time, and the print interval. Once everything is filled, we will be able to run the simulations now.

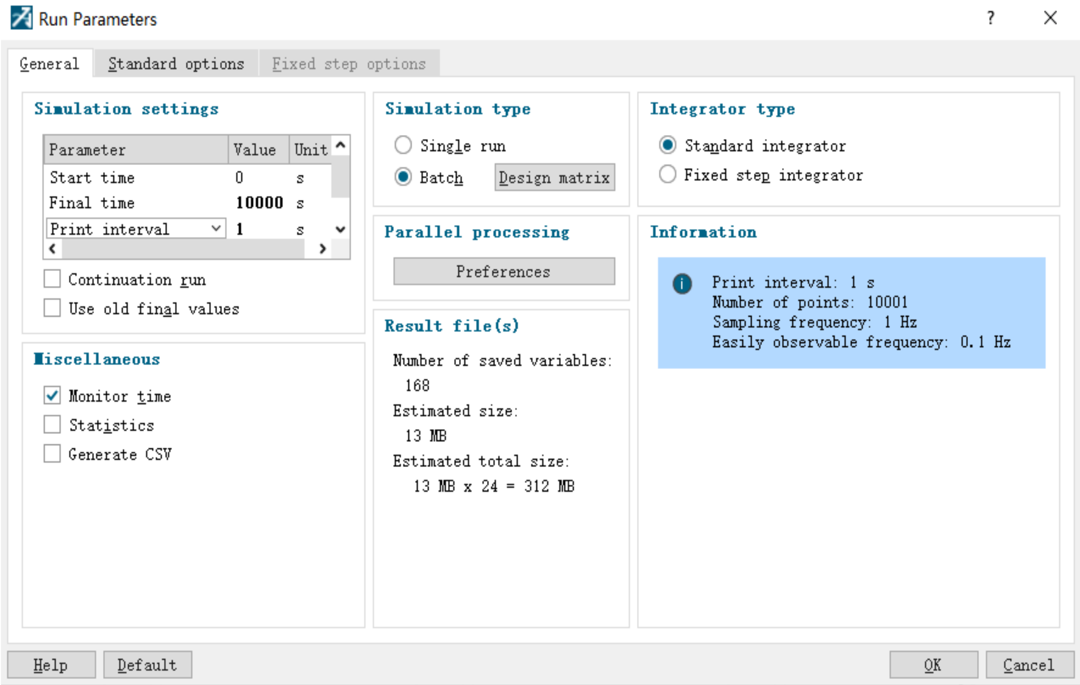


Figure26. simulation settings

We can check the simulation result of the aluminum plate first. We will see how the temperature would vary according to the change in the diameter of the aluminum plate. The simulation result will be shown below:

6.1.2 Results

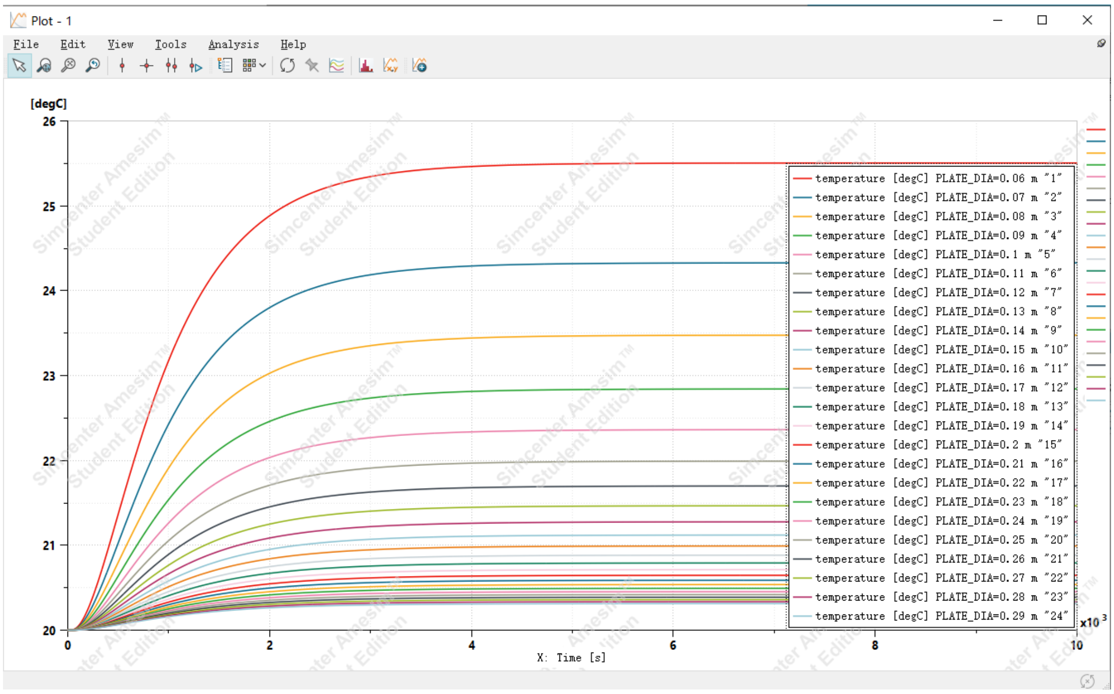


Figure27.temperature of the aluminum release plate

As we can see, once the temperature drops below 21℃, which is the line in orange and it represents the diameter of 160mm. We will see the temperature does not change much by then. Although the diameter will keep increasing to 290mm when we compare its temperature to the previous value, we would see only a 0.5℃ difference even we almost have two times the diameter.

The next step is that we are going to investigate the temperature between the lower and upper parts of the TEG, we are going to check the temperature difference between them, and then we can use the formula for power to compute the power output.

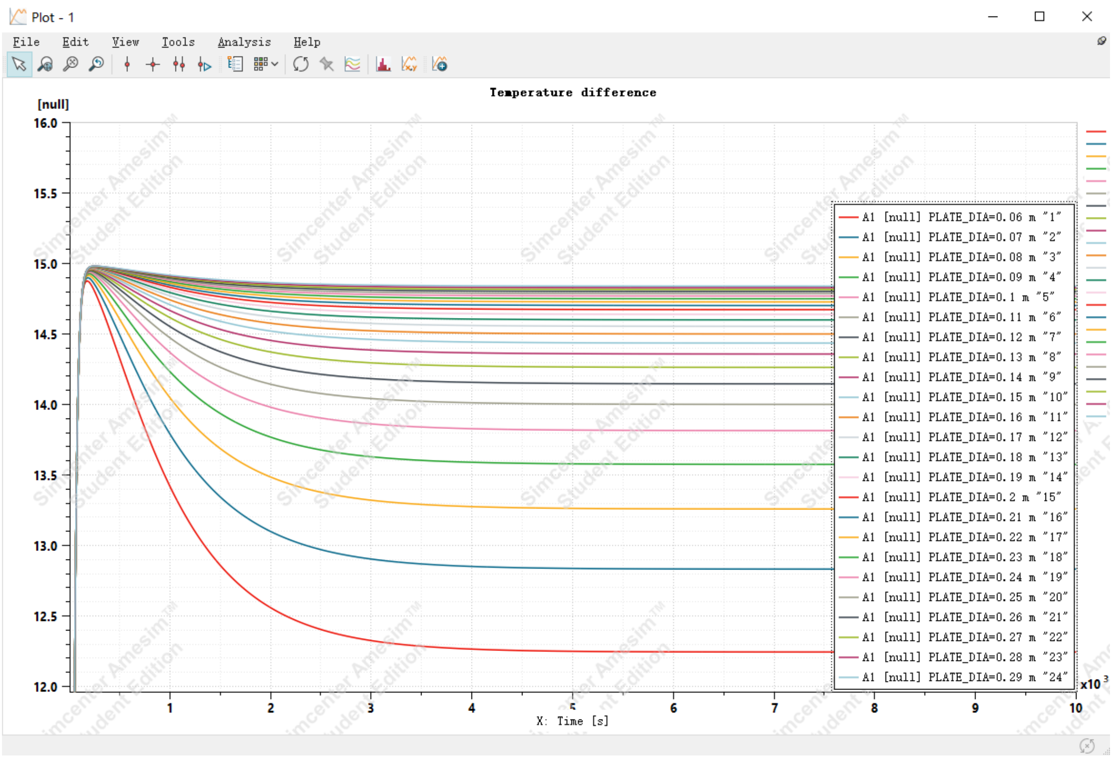


Figure28. the temperature difference between the upper and lower TE plate

From the graph, we can see that the temperature difference between the lower and upper parts of the TE is significant according to the diameter of the aluminum release plate. The larger the diameter, the greater the temperature gradient value we will have. But at some point in the graph, the effect of the diameter variable is decreasing. When the temperature difference reaches 14.5K(line no.11), we can see the diameter which represents this line will be 160mm. Even the simulation keeps operating till the diameter reaches 290mm, but it does not have that much effect on the temperature difference. We can see the temperature difference variation between two diameters will be around 0.3K even though the difference between two diameters is quite large.

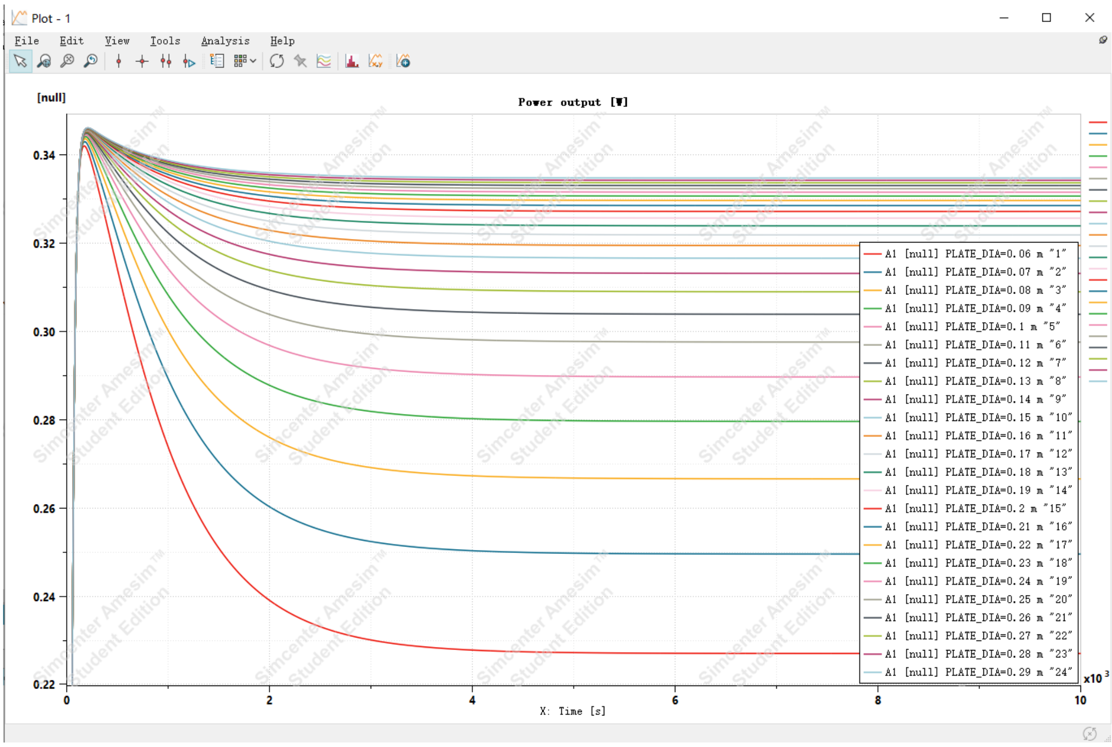


Figure29. the power output of the TE device

Just like what we have evaluated above, the diameter of the aluminum release plate does affect the temperature difference. And it will obviously affect the power output since the temperature difference is one of the quantities within the power equation. Like what we mentioned above, the output value would no longer change rapidly according to the variation of diameter. We will use two same diameters as a reference,160mm and 290mm. We can see that at 160mm (line 11), we will have around 0.32W as power out. In the case of 290mm (line 24), we will have 0.335 as the power output, which does not have that much of a difference.

Once we know the power output, we will be able to select a proper wireless sensor in order to complete the system. Saba Akbari[10] has written a paper about energy harvesting for wireless sensors. I will choose the sensor type: "SGS-21XX Semiconductor Sensor," and it is made by the company of "Delta, Russia" with a power consumption of 200 mW. Although we have a power output of 320mW in theory, in reality, we would only have lower power output.

6.2 Variation of input temperature

The second variation will be the temperature of the water. We will set the temperature as 40℃,50℃, and 60℃. The case in 50℃ is already mentioned in the previous section. Since the temperature has changed, the thermal properties of the water would change as well. And we can use the formula to compute power. We knew that the power output would not change significantly after the diameter reached 160mm. We would only simulate the situation until 160mm.

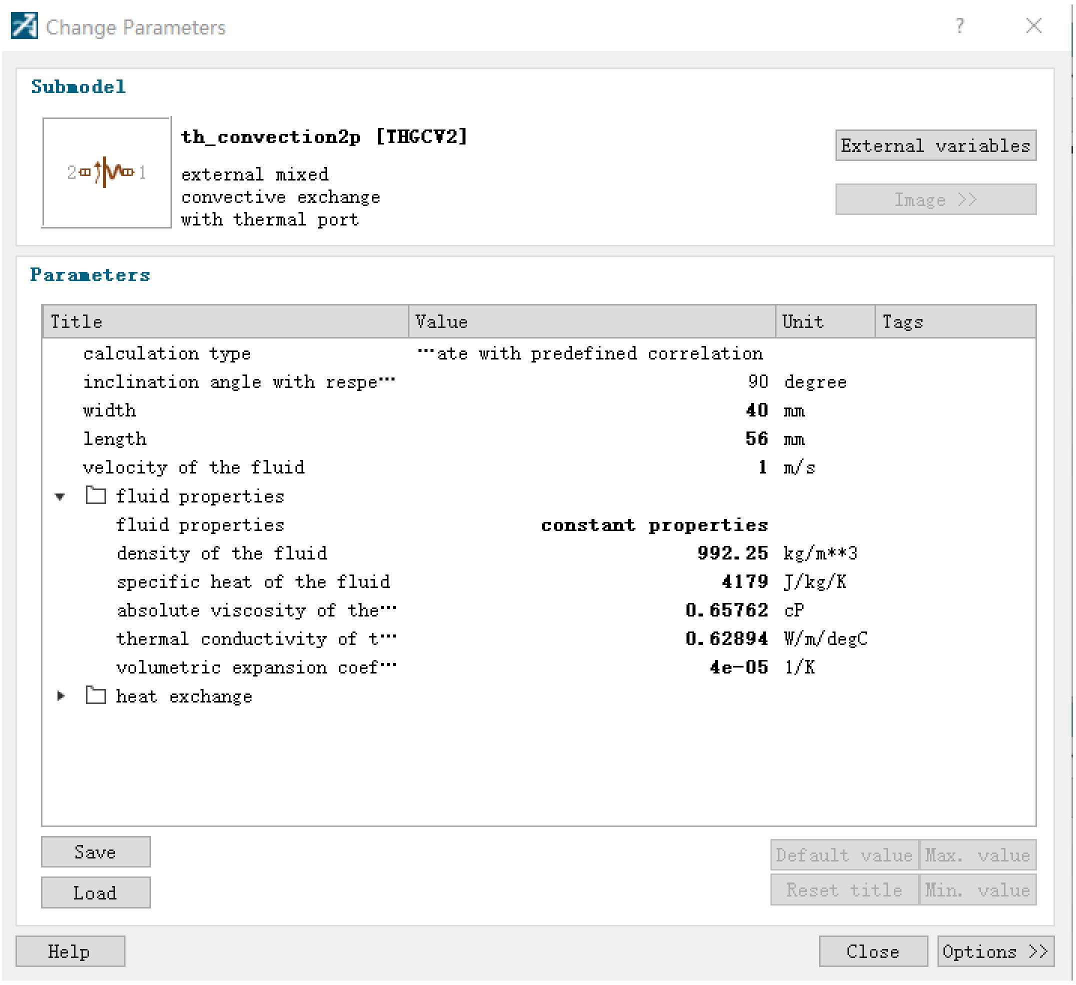


Figure30. thermal properties of water at 40℃

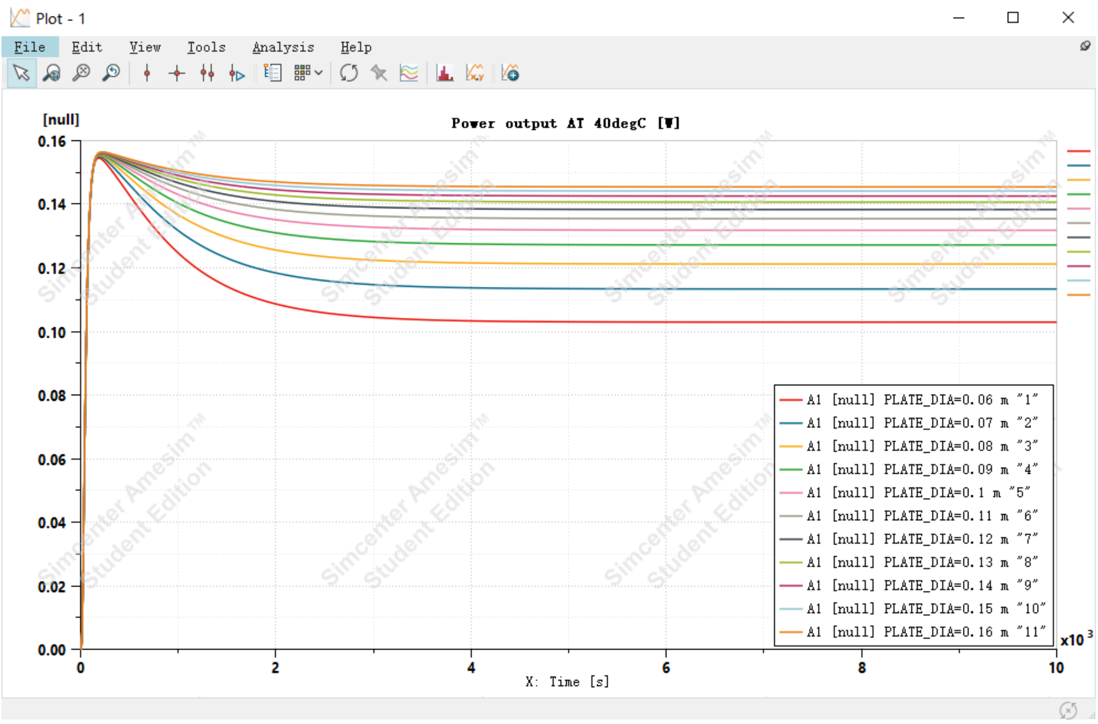


Figure31.power output when the temperature is 40℃

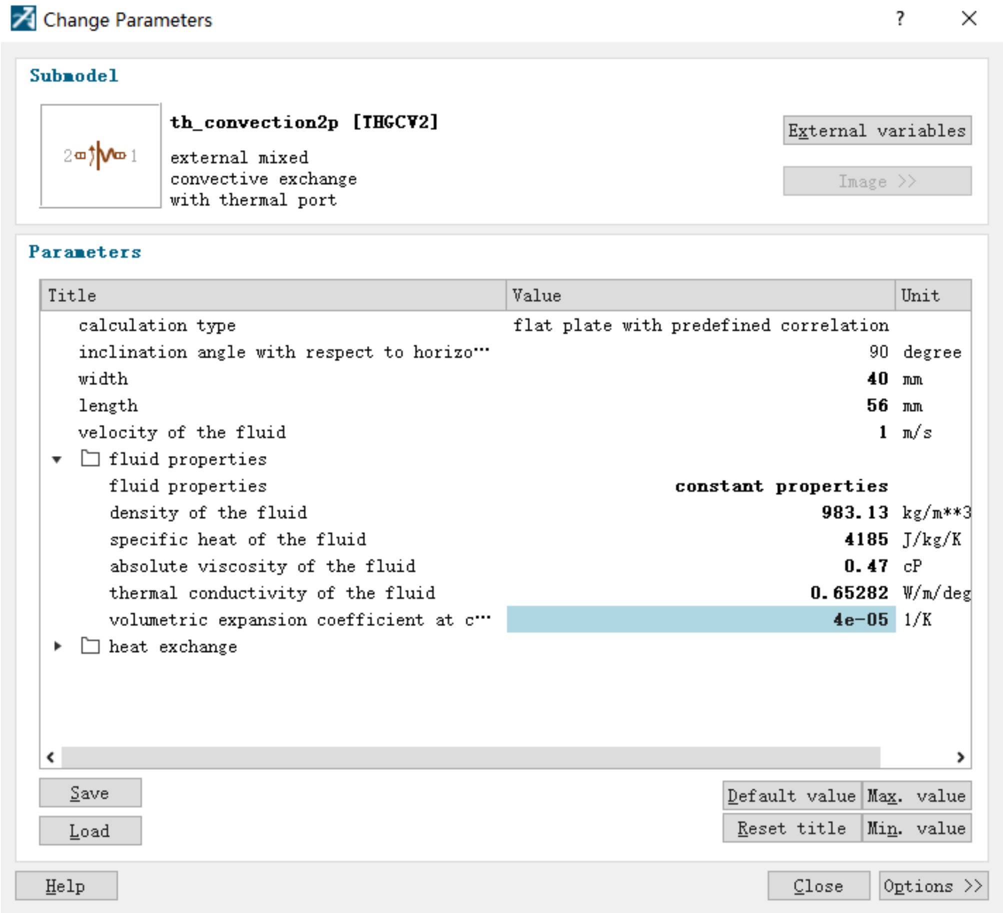


Figure32. thermal properties of water at 60℃

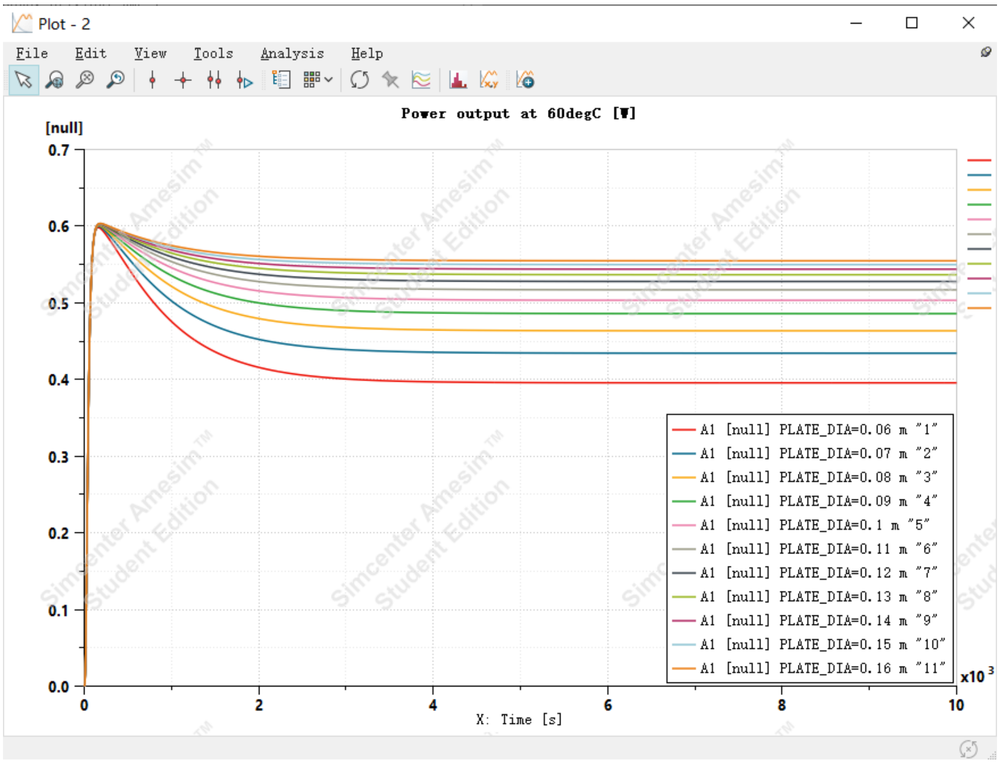


Figure34.power output when the temperature is 60℃

From the graph, we can see that even the gap between the temperature input was 10℃, but the value of the power output changed dramatically. It went from around 0.32mW at 50℃ to 0.14mW at 40℃. The power output is almost half the initial value. When the heat input reaches 60℃, the power output goes from 0.32mW to 0.55mW. It increases significantly.

6.3 Variation of thermal contact conductance

The third variation will be the thermal contact conductance. Thermal contact conductance is the quantity that indicates the thermal conductivity between two bodies that are in contact, the inverse property of the thermal contact conductance is called thermal contact resistance. There are many factors that can influence the contact conductance, which will be the contact pressure, interstitial material, surface roughness, surface deformation, and surface cleanliness between 2 bodies.

Like we have mentioned, the value of contact conductance can vary due to many factors. This is the reason why I want to find out how this property would affect the temperature of the material.

In order to reduce the number of contact conductance that I personally used in the system, I would like not to separate the TE device into three parts. I will consider the TE device as one component using the material property of Bismuth Telluride. In this case, I would only have contact conductance for the heatsink with the TE device and the TE device with the Al plate. Since both materials are in aluminum and they are both in contact with the same TE device, I would assume that they will have the same value for contact conductance.

In this case, I will need to reduce the component of the system and construct a relatively similar model to the one I used in the previous case. The geometries are the same as the reference. For the parameters, it would also remain the same besides the value for contact conductance.

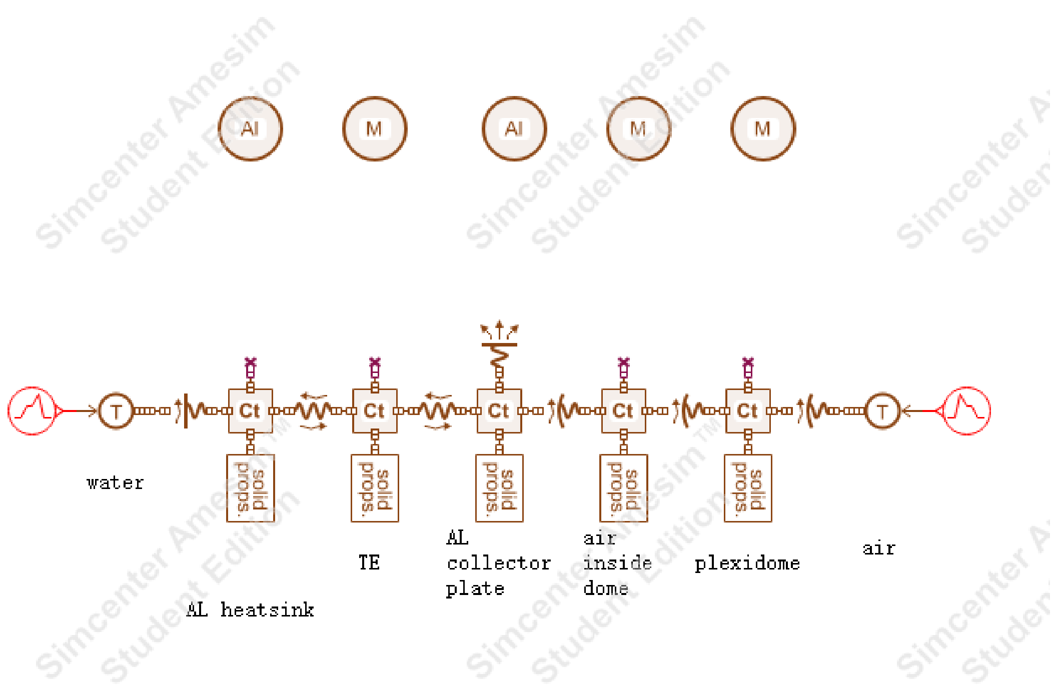


Figure35. amesim sketch when the TE device presents as one component

In this case, we are going to investigate how this particular value would change the temperature of the TE device in general. The value of the thermal contact conductance that we used is 10 $[W/m^2/\deg C]$, and I would like to simulate this value from 1-210 with the step value of 1. We can simulate this process using "batch run" again, and we can finish the settings from the menu called study manager. Once everything is completed, we will be able to carry out the simulation.

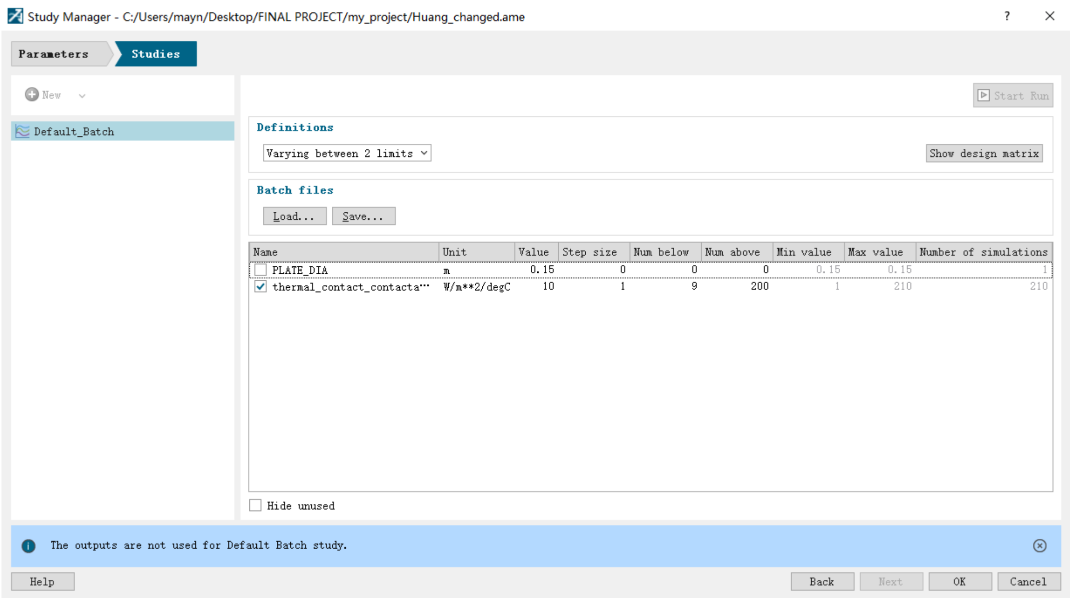


Figure36. step value and numbers of simulation

After the simulation is done, we will be able to compute the temperature value according to the changes in thermal contact conductance. The temperature will be shown below:

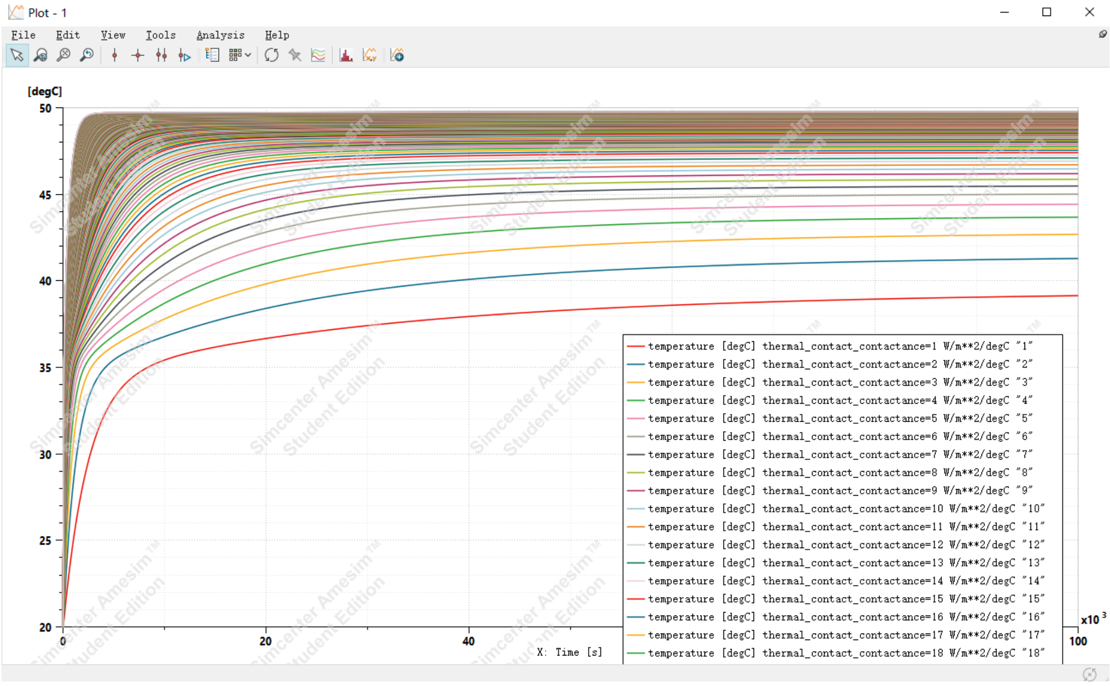


Figure37. the temperature of the TE device

From the graph, we can see that the thermal contact conductance does have a significant effect on the temperature. The temperature changed from around 37℃ to around 50℃. When we have a higher value of thermal contact conductance, we will receive a greater value of the temperature of the TE device. But we can see from the graph that when the temperature of the device reaches around 47 ℃, even the value of the thermal contact conductance keeps increasing, it does not show a significant value change in temperature.

7. Conclusion

This project is carried out under a highly ideal circumstance. We have managed to compute the power output of the TE device, but there were some assumptions about some of the quantities that were used during the operation. For example, I have set the water temperature and the ambient temperature to a constant number. In reality, it would not be as accurate as we have assumed. This would cause some errors compared to the real-life situation. Another critical factor will be the thermal contact conductance. Like what we have mentioned in the project, the value of the thermal contact conductance may have either a positive or negative effect on the system. We need to know the accurate value for this in order to compute a better simulation.

There are also many other ways to optimize the system. For example, we can have a greater heat input to make the hot side of the TE device even hotter, but we should find a way to cool down the other side of the TE device to make a more significant temperature gradient. We can also use different materials instead of the aluminum that I used in my system. We can use a different material for the thermal electric device as well. Once we find a material that has a better ZT value, this means that the system can achieve better results.

8. Reference

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