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TIETO- JA SÄHKÖTEKNIIKAN TIEDEKUNTA
ELEKTRONIIKAN JA TIETOLIIKENNETEKNIIKAN TUTKINTO-OHJELMA

BACHELOR'S THESIS

Design of an electrical floor heating panel manufactured by transfer foil technology

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ABSTRACT

In this thesis, a heater-integrated floor material and its possibilities in the field of floor heating were examined. The heater was designed to be manufactured by transfer foil technology. LTSpice and COMSOL simulation tools were utilized to model power losses and heating power, and three different heater versions were designed with Altium designer, and their simulation results and other properties of the heaters were compared. The main goal of the work was to find out the possibility of making floor heating for large surface areas from these heating panels and it was found that it would be possible to make over 100m^2 surfaces with under 1 ºC tolerance for the desired heating temperature.

Key words: floor heating, underfloor heating, transfer foil technology.

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TIIVISTELMÄ

Tässä työssä tarkasteltiin siirtokalvotekniikalla valmistettavan lämmitysvastuksen integroimista lattiamateriaaliin ja sen mahdollisuuksia lattialämmityksen saralla. Työssä hyödynnettiin LTSpice- ja COMSOL-simulointityökaluja lämmitystehon ja tehohäviöiden mallinnukseen ja piirrettiin Altiumilla kolme eri lämmitinversiota ja vertailtiin niiden simulointituloksia sekä lämmittimien muita ominaisuuksia. Työn tärkeimpänä tavoitteena oli selvittää mahdollisuutta tehdä lämmityspaneeleista lattialämmitys suurille lattiapinta-aloille. Saatiin selville, että näillä lämmityspaneeleilla olisi mahdollista tehdä yli 100m^2 lattiapintoja alle yhden asteen toleranssilla halutulle lämpötilalle.

Avainsanat: lattialämmitys, siirtokalvotekniikka.

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FOREWORD

This thesis was carried out at VTT Technical Research Centre of Finland, Oulu site, following the experiments done in EMASS project.

I would like to thank Arttu Huttunen for the good guidance through all the phases of this thesis and Jussi Putaala for supervising the thesis. I would also like to thank my research team leader Teemu Alajoki for making this possible to carry out at VTT, and my project manager Terho Kololuoma for the same reason and for passing me this intriguing idea for further research.

Oulu, February 6, 2022

Vili-Jussi Mäkinen

LIST OF ABBREVIATIONS AND SYMBOLS

Al	Aluminium
Cu	Copper
HPL	High pressure laminate
HDF	High density fiberboard
PET	Polyethylene terephthalate
VTT	VTT Technical Research Centre of Finland Ltd
A	Surface area
D	Density
c_p	Heat capacity at constant pressure
I	Current
l	Length
P	Power
Q	Heat flow
R	Resistance
R_{Th}	Thermal resistance
T	Temperature
U	Voltage
κ	Thermal conductivity
ρ	Electrical resistivity
σ	Electrical conductivity

1 INTRODUCTION

The basis of this thesis was VTT's previous research on a new method of manufacturing electrical products, transfer foil technology. Among other applications, it was assessed to be suitable for manufacturing easy-to-install electrical floor heating panels. To bring this idea in practice, the first demos were made at VTT during summer of 2021. The demos showed some promise and therefore they were wanted to be further developed, which led to this thesis. In this thesis, the need for power is examined through simulations and calculations. Based on the result, a few different heaters are designed, and their properties are compared. The purpose of these studies is to establish an energy-efficient floor heating product for large floor surface areas.

1.1 Previous work

The starting point is to continue previous work that was made of industrial laminate flooring panels and heating patterns which were laminated in high pressure laminating process (HPL). The heating patterns were fabricated in a transfer foil process and the final structure of the patterns consisted of aluminium wiring and kraft paper substrate. Figure 1 shows the appearance of the laminated patterns.

Figure 1. 50 x 50 cm sample of ten high pressure laminated resistance patterns with resistance of 4.5 Ω each.

A single pattern had a resistance of 4.5 Ω, so coupling four patterns in series, the series resistance was 18 Ω. These four-pattern laminates were then glued together with an industrial laminate flooring panel with copper foil added to its tongue and grooves to enable electrical connectivity with surrounding flooring laminates. With these tongue and groove couplings, the surrounding panels were connected in parallel.

Figure 2 shows the realization of four four-pattern panels connected to each other and the copper foil pieces coming out of one panel which were used to measure its functionality. One piece was made twice the size of the other two pieces to demonstrate interlacing ability.

Figure 2. Connected panels.

The input voltage in the measurements was 24 volts which resulted in 1.3 A current per four-pattern heater. The power can be solved in equation (1).

$$P = UI \tag{1}$$

The power solved from equation (1) is therefore 31.2 watts. The measurement with a thermal imager showed that with this amount of power, the laminates heated up to over 40 ºC. Figure 3 shows the sequence of one-, two- and four-heater measurements.

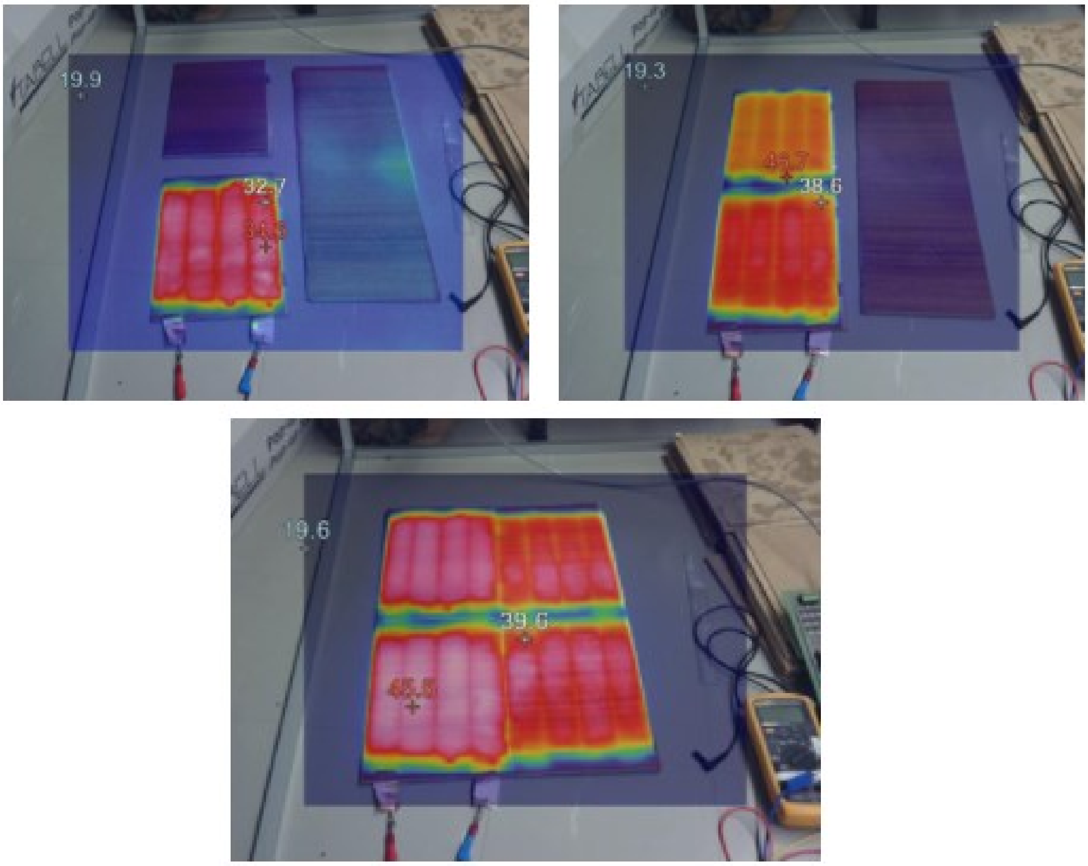


Figure 3. Thermal images of connected panels.

1.2 Aim of the thesis

The previous work showed some promise to this new kind of floor heating where the heating power does not necessarily need to heat the whole flooring structure, only the top of it. Therefore, this type of floor heating with the right design will decrease the amount of electrical power for heating and lower the operating costs. Ideally, other benefits would include both lower acquisition costs and easier installation of floor heating, especially for renovation projects because this type of floor heating panels can be installed directly on top of the old floor structure.

The aim of this thesis is to establish that this new design can be realized in larger surface areas. Also, the previous heating pattern was not compatible with industrial laminate flooring panels and because of that, both the heating pattern laminates, and the laminate flooring panels needed to be cut and the wiring was rather complicated to realize. The new design brings a solution to this as it is designed directly to an industrial laminate flooring panel.

2 THEORY

2.1 Transfer foil process

Transfer foil technology is used in electronics and similar technology, cold foil printing, is used in such areas as cosmetics packaging and decoration and it is a relatively low-cost production technology [1], [2]. The basic idea of transfer foil technology is that a certain pattern can be cut from one material and transferred to another material. A transfer foil process can be done in a converting machine that usually consists of a control system, die cutting machine and several rollers. Figure 4 shows the converting machine that is used to fabricate the heaters designed in this thesis.

Figure 4. Delta ModTech converting machine.

Depending on what is the wanted end product, the order of different steps during the transfer foil process can be swapped with each other. Figure 5 shows step by step one possible way to carry out a transfer foil process.

Composite material of a metal foil on a polyester film, aluminium/polyethylene terephthalate in this case, is adhered to a carrier material which keeps the structure together during the process. The Al/PET foil is then die cut to its designed shape. The remaining foil that has been cut is then removed and pulled to its own roller. This must be taken into account in the design because the waste has to be pulled in a continuous piece for the process to be working properly. After removing the waste, structural layers are adhered to the already cut material. In this case, the structural layer is kraft paper. Figure 6 shows a similar end product as the heater that is going to be designed in this thesis.

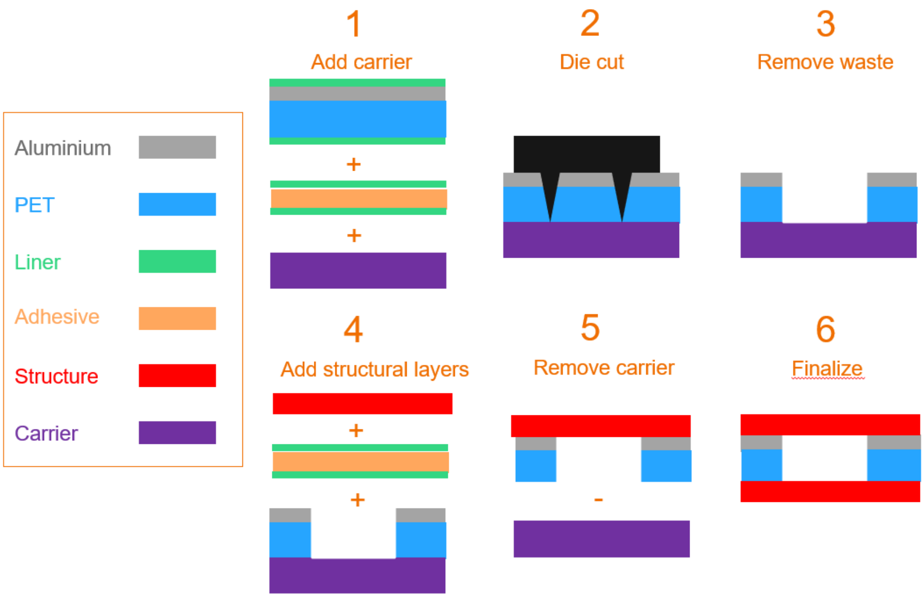


Figure 5. Transfer foil process step by step.

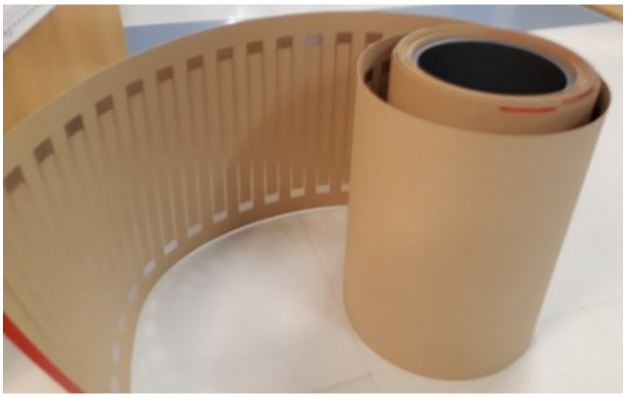


Figure 6. Aluminium heating pattern with kraft paper substrate.

2.2 Floor heating

In modern applications, floor heating, often expressed as underfloor heating, is implemented either using electrical or hydronical heating elements. Normally, these elements are installed below the floor structure and the installation often requires extra insulation and additional electrical or plumbing work.

There are three different types of heat transfer which are conduction, convection, and radiation. Floor heating is a radiant heating system, and all of these three different types are important for radiant heating system performance [3]. Radiant heating has a significant effect for operative temperature, which is different from ambient air temperature, meaning the temperature that person feels in a certain environment [4]. If floor is heated, the ambient temperature in the room is able to be lower, because the human feet are the primary sensory organs for temperature [5]. According to studies, radiant heating is more economical than air heating [6], [7]. When creating a similarly warm environment, secondary input energy is 34 % lower than air heating [8]. Floor heating therefore can be considered as an energy-efficient heating method.

The applications that are closest to this work are heating foils. They are also aimed to make structures as thin, and installation as simple, as possible. These foils' heating powers range at least from 65 W/m^2 to 140 W/m^2 [9], [10]. There also has been some patents with similar endeavours of bringing the heater inside the floors top structure [11].

2.3 Power losses

When designing electrical floor heating for large surface areas, the magnitude of feed line power losses should be considered.

From Ohm's law, equation (2),

$$\Delta U = RI \tag{2}$$

and equation (1), can be derived equation (3),

$$P = RI^2 \tag{3}$$

which is frequently used for calculating joule heating [12]. Power is measured in units of watts which can be expressed both A*V and J/s. Joules per second represent energy per time and in joule heating the energy signifies heat dissipating in a resistor. This heat flow through a resistance is analogous to current flowing through a resistance. In case of current flow, electric charge is transferred from one point to another by the movement of electrons and in case of heat flow heat is transferred from one point of a solid to another by the vibration of the molecules of the solid due to their increased energy [13]. Therefore, voltage difference in equation (2) is similar to temperature difference for the heat flow. Similar equation as Ohm's law can be derived for heat flow, equation (4),

$$\Delta T = QR_{Th} \tag{4}$$

where Q is heat flow, R_{Th} is thermal resistance and ΔT is temperature difference [14]. From this equation can be deduced that if heat flow decreases, also temperature difference will decrease. In floor heating design this means that feed line power losses result in less produced heat at the desired location.

Power losses can be reduced by optimizing resistances of wiring. Heaters in floor heating systems are often connected in parallel to retain voltage level high enough to cause enough power. Feed line wires however add series resistance, so when connecting heaters in parallel, every heater which is connected, decreases the total resistance of the whole coupling, and increases the resistance of the feed lines in relation to heater resistance. Relative difference between the heater resistance and feed line resistance is crucial regarding to power losses in the system and this basically means that resistance in the actual heater is desired but resistance in the connections of the heater is not desired. Every wire can be modeled as a resistor and resistance in a wire can be solved in equation (5),

$$R = \rho \frac{l}{A} \tag{5}$$

where ρ is resistivity, l is wire length and A is cross-sectional area [15].

The largest power loss in a floor area is presumably in the flooring panel which is furthest from the power supply. Placing the supplies evenly around the edges of the floor will minimize the distance to the furthest panel and therefore minimize the largest power loss, although this is not the most practical solution for supplying power to the heating system for floors with large surface area. Figure 7 shows the place of the panel with largest power loss depending on power supply placing. Figure 7 assumes that the resistance in the heater is symmetric to every direction.

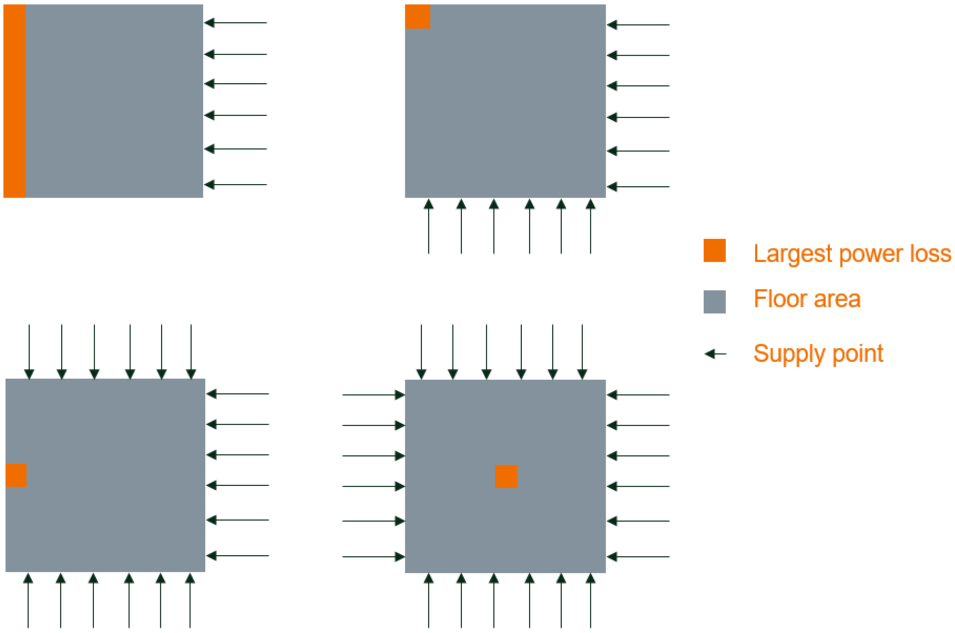


Figure 7. Place of the largest power loss.

3 RESULTS

3.1 Desired heater attributes and limitations

There were several limitations regarding the heater design and some desires for heater attributes were given by project team.

EU low voltage directive [16] sets a safety limit of 50 V for alternating current and 75 V for direct current for consumer usage of electrical equipment. The heater was wanted to be operative on lower voltages than the safety limits because it was wanted to be a consumer-installed product. Therefore, the heater was designed to operate below 48 V which is a common standard value for a low voltage power supply.

The input current was considered as a question of cost. Because of this, a maximum current of 6 A per supply point was desired. For an example, XP Power VES300 Series AC-DC power supply with output voltage of 48 V and output current of 6.25 A cost 100 euros as of December 2021.

Most laminate flooring manufacturers report the maximum heating temperature at 27 °C [10], [17], [18]. In addition to this, it was desired that the heater would heat up in under 2 minutes. Most importantly, the heater should also be efficient compared to other heating systems. Therefore, a limit of 65 W/m^2 power was set for the continuous heating power. For the under 2-minute heating rate, this power limit and the current limit could still be surpassed momentarily.

The previous work made with the converting machine at VTT was done successfully with copper and aluminum foil as the wiring material. Foil thicknesses varied from 9µm to 18µm. The narrowest wiring width and the narrowest clearance between traces that was considered possible to fabricate was 1mm. These proven practices were wanted to continue in this thesis and a wiring width and clearance of 1.25 mm was selected so that the heater could reliably be manufactured. Foil thickness of 9 µm was selected for aluminium and 10µm for copper because these were the thinnest possible that the foil supplier had.

High pressure laminating was not possible to make at VTT, so in the previous prototype phase the laminating was done by a partner company Surforma located in Portugal. The small scale HPL laminator at Surforma was able to press an area of 30x50 cm at a time. This limited the heater size significantly in this thesis. It is important to note that this does not limit similar work in the big picture, as a large laminate press is much more efficient in the later stages of manufacturing and thus the whole structure can be laminated at once.

Using an industrial laminate flooring panel was seen as the easiest way to realize the connections between the panels and to demonstrate its operability. Laminate flooring panels however have certain standard sizes, and this needed to be considered. When both laminate flooring standard sizes and HPL laminator abilities were considered, a panel of 1286x282 mm size was selected. This selection was supported by the fact that the surface area of the heater should be as large as laminate flooring sizes allow because more area means more length to the heater trace and therefore greater resistance is achieved. In longitudinal direction, the panel needed to be divided into three sections with each of them being a single heater. This made the heater size to 428.6x282 mm which fits to the HPL laminator.

It was wanted to study the maximum area of a functioning floor up to at least 100 m^2 and the final product should be functional in an area of at least 50 m^2.

3.2 Joule heating simulations

To define optimal power and resistance for the heater, a suitable way was to simulate the joule heating in the panel structure typical conditions. Simulations were executed with COMSOL Multiphysics simulation software with joule heating multiphysics which included heat transfer in solids and electric currents in layered shells. Figure 8 shows the used simulation model that had an 8mm thick laminate flooring panel on top of 20 cm thick concrete block and ambient air above the panel. The ambient air temperature was 20 ºC. In the close-up can be seen that the surface was divided in two parts, kraft paper and melamine layer.

Between the surface material and the flooring panel was a metal layer. COMSOL uses the finite element method to solve systems, which in a simplified way means that the system is divided into simpler finite elements and these elements form a mesh in the space dimension. The metal layer was computed as a thin layer which is a functionality in COMSOL to help the meshing when there are large differences in the thicknesses of the structures.

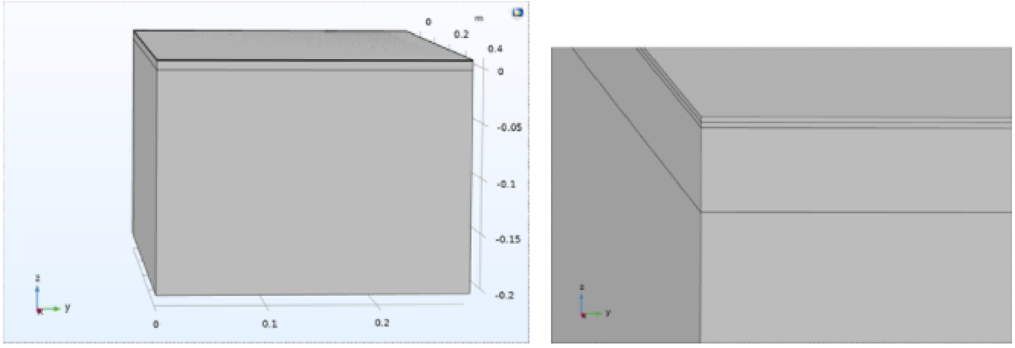


Figure 8. COMSOL Multiphysics simulation model.

3.2.1 Material parameters

To determine heat transfer in solids, material values of density, thermal conductivity and heat capacity at constant pressure was needed. For convective heat flux, the heat transfer coefficient of air, 10 W/(m^2*K) was used for this simulation [19]. To determine electric currents in layered shells, in addition to previous parameters, electrical conductivities were added. Table 1 contains these parameters.

Table 1. COMSOL material parameters

Material	**Density,** ***D*****, kg/m3**	**Thermal conductivity, *κ*,** ***W/(m*K)***	**Electrical conductivity, *σ*** ***S/m***	**Heat capacity at constant pressure, c$_p$** ***J/(kg*K)***
Al	2700	237	3.5×10^7	897
Cu	8940	401	5.96×10^7	390
HDF	800	0.14	Not needed	2100
HPL	1350	0.3	Not needed	1340
Concrete	2300	2	Not needed	1000

[20]-[28]

3.2.2 Simulation results

Considering the limitations of manufacturing, it was noticed in the simulations that to produce enough heat and keeping current low enough simultaneously, the resistance must be as large as the surface area allows for wiring length to be. The power was found to be between 6 watts to 10 watts for 23 ºC – 26 ºC temperatures. For a heater of 0.282x0.4286 m, 6 – 10 watts means a power per area value of 50 – 83 W/m^2 which means that the value falls below the set limit at lower temperatures. The highest resistance that fit the area was 86.2 Ω with aluminium and 49.2 Ω with copper.

There was no significant difference found between aluminium and copper heaters when both had the same resistance. This is assumably due to the small amount of metal compared to other materials in the structure.

Figure 9 shows a simulation result where 10 watts was supplied to 86 Ω heater which resulted in the desired 26 ºC temperature (299 K in the picture).

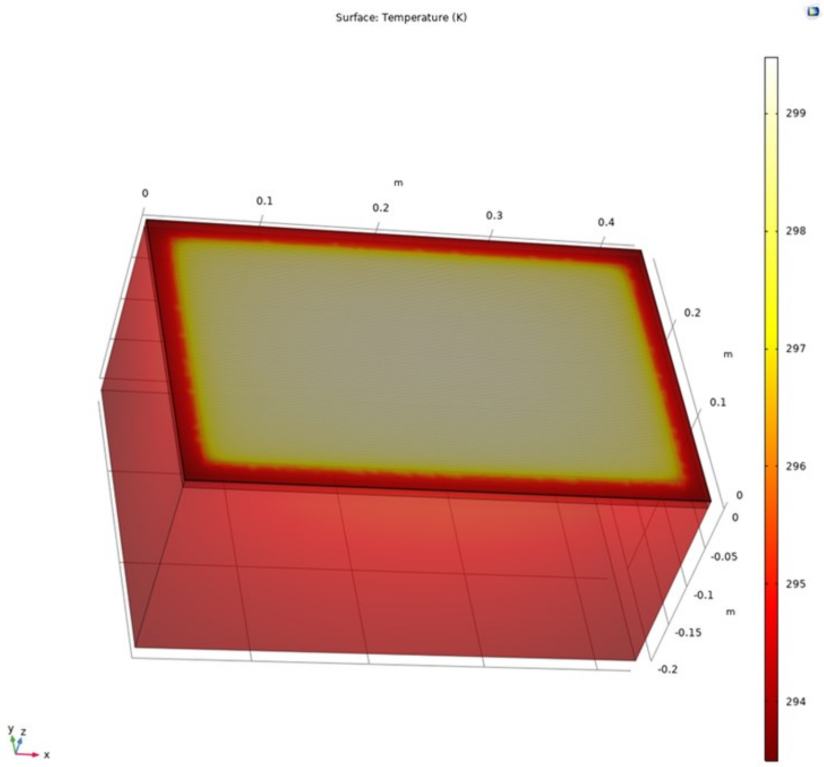


Figure 9. 10 watts supply to 86 Ω pattern.

Figure 10 shows a simulation result of 8 watts supply to 86 Ω heating pattern. This result compared to Figure 9 showed that supplying 80% of the power, the temperature drops more than a degree. This was later in the work used as a limit for large surface areas to not have any bigger power losses that would result in less than 80% efficiency.

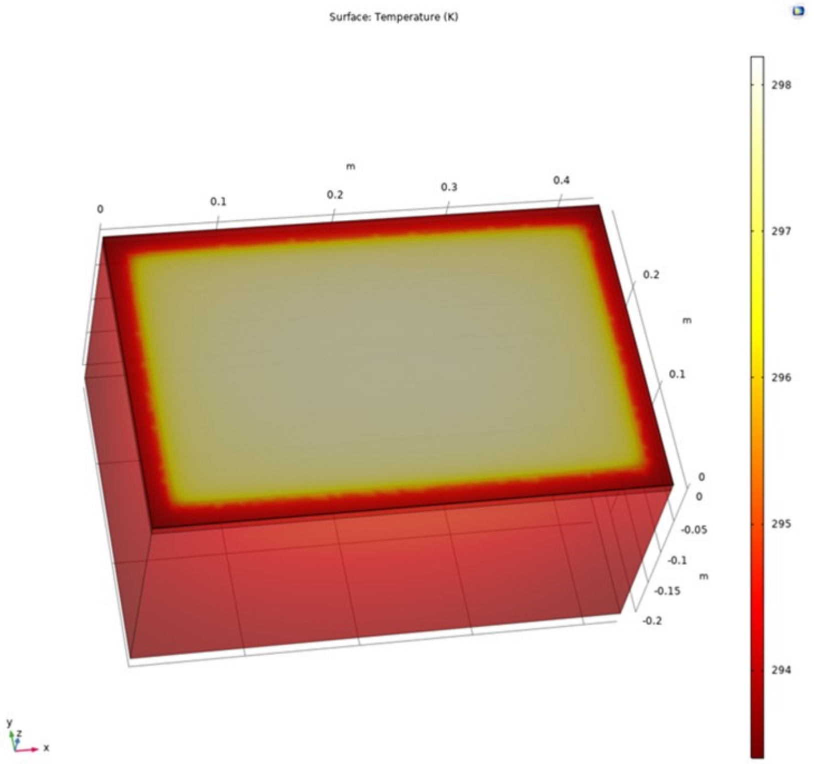


Figure 10. 8 watts supply to 86 Ω pattern.

To achieve heating as fast as possible, it was needed to supply more power. Figure 11 shows a result of 17 W supplied to the same 86 Ω heating pattern and the simulation resulted in 23 ºC in 120 seconds which narrowly fills the need of heating rate. For 86 Ω resistance and 17 W power can be deduced from equations (1) and (2) that it requires a 38 V voltage to achieve this heating rate and it is perfectly feasible with 48 V supply and it can be improved with more power.

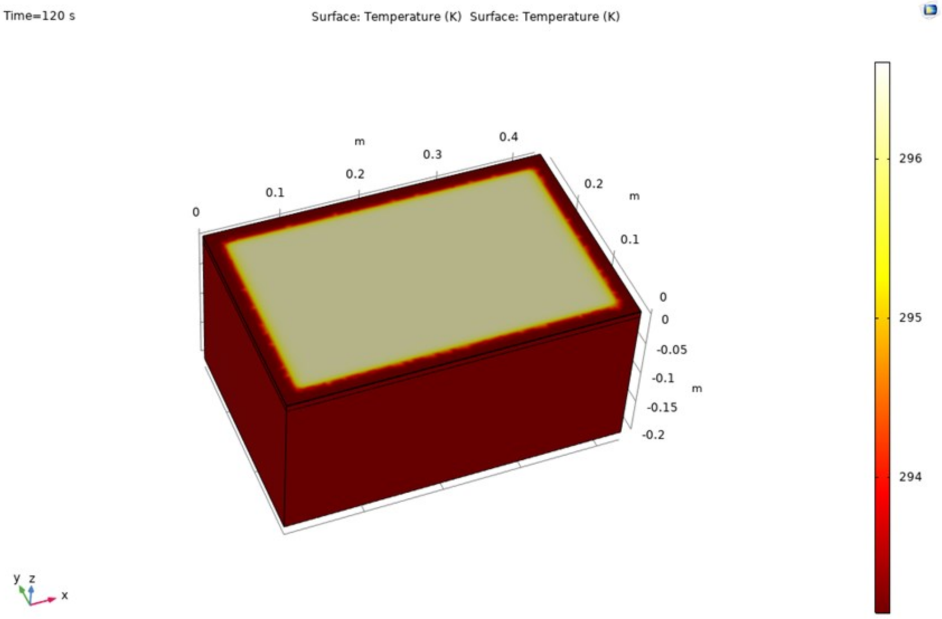


Figure 11. Time-dependent simulation.

3.3 Different versions and power loss simulations

There were several versions made of the heater. This was because it would be cheaper to manufacture a single layer heater than multilayer. However, multilayer was predicted to be more lossless.

Figure 12 and Figure 13 show the basic ideas of connections to both sides and to one side respectively. Light grey area represents the area of one heater circuit. In the middle of every heater circuit is the symbol R which in this case represents the actual heater. The circuits are designed so that the pattern is continuous.

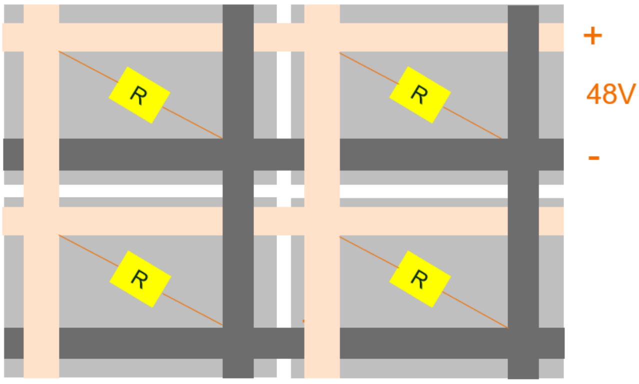


Figure 12. Basic idea of connections to both directions.

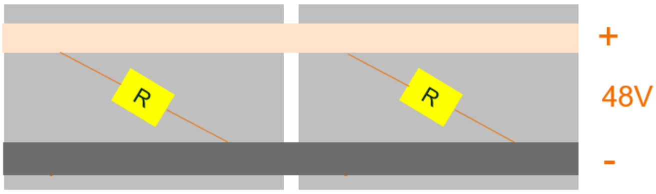


Figure 13. Basic idea of connections to one direction.

According to the results of COMSOL simulations, the length of the trace for the actual heater was needed to maximize in every version. The layouts of the heater circuits were designed with Altium designer.

3.3.1 First version

Figure 14 shows the first version of the heater. This version had only one layer and the placement of its pads was done so that the connections could be obtained on both the short and long sides. On the long side, pads were placed so that the heater could be interlaced in two different positions. This means that the pads were placed in the middle of ¼ and ¾ length of the long side. There was left some empty space because if it was filled with traces, there could be a chance that the waste could not be pulled in one piece in the transfer foil process.

Not all crossings could be circumvented, leading to the need to insulate the trace from the outer edge at two points. The two points are in the top right corner and bottom left corner in Figure 14. In this version it was known that the magnitudes of trace resistances could be challenging when fabricating the whole layout with the same trace thickness. Therefore, small resistances were considered as more important attribute than symmetry. This causes a situation that the place of the largest power loss does not behave the way as shown in Chapter 2.3. The coldest spot depends on the way the panels are mounted.

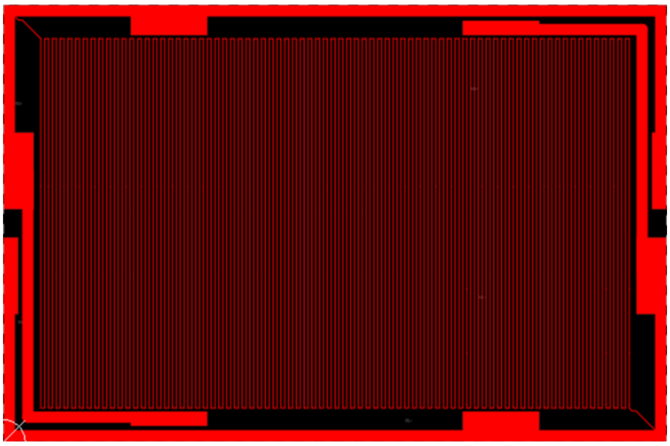


Figure 14. First version – single layer, connections in both directions.

Figure 15 shows an LTSpice simulation model of the first version with 9µm thick aluminium trace where every trace on the layout is modeled as a resistor. R_v represents the heater resistance and for an example, R_n represents the resistance of a trace starting from a corner and ending on a pad.

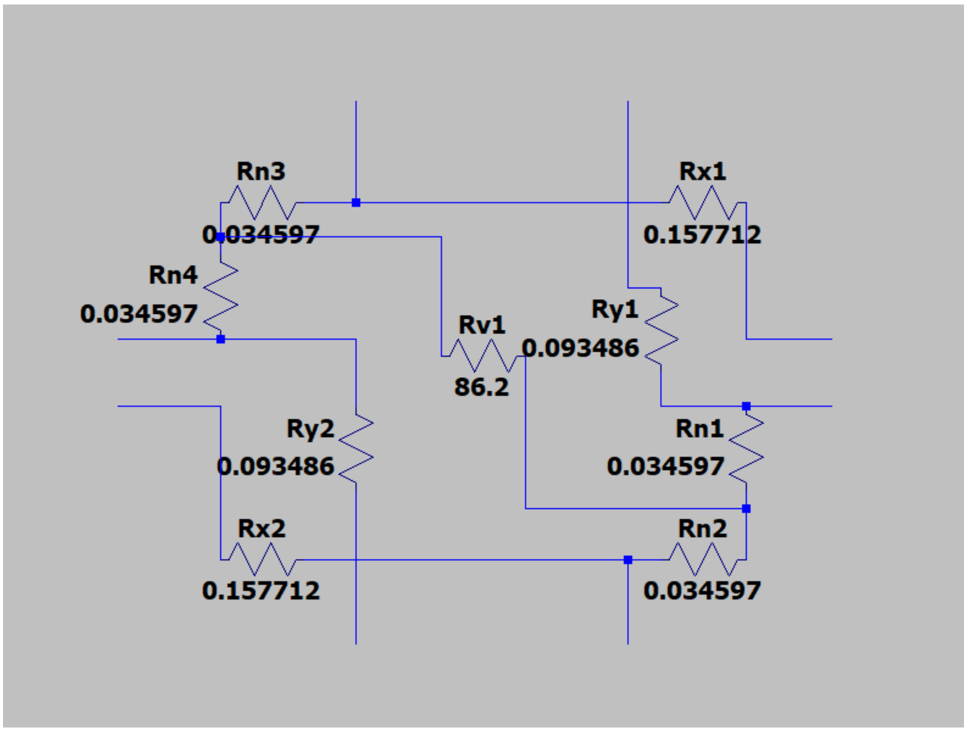


Figure 15. Simulation model for a single first version heater with 9 µm thick aluminium traces. (R_{v1} represents the heater resistance and the rest represent feed line resistances.)

In the simulations, the place of the largest power loss needed to be discovered and measure its voltage over the heater and the current flowing through the heater. These values were multiplied with each other to get the power value. This value was then compared to the value near a power supply and when the largest power loss was 80% compared to the power supplied to the heater near a supply, the floor was no longer enlarged. Figure 16 shows the simulation of the models showed in Figure 15. With these models, the 80% limit was reached with a 35 m^2 floor when the power supplies were evenly placed on the edges of the floor. In the right side of the figure can be seen the current measurement of the largest power loss and the smallest power loss. When all of the supplies were placed on the same side with this version, only 7 m^2 was achieved with over 80% of efficiency.

Figure 16. Simulation of 35 m^2 floor for the first version.

3.3.2 *Second version*

Figure 17 shows the second version of the heater. This version had three conductive layers. Between the layers, there must be an insulation layer so that the current does not get to flow from unwanted spots. Other than the heater layer, the two layers were designed to have two traces, both going from a pad to another and to do this as lossless as possible. These two layers are different to each other because they were wanted to symmetrical by their resistances, so the layer which had traces parallel to the long side also had wider traces to obtain the same resistance as the layer which had traces parallel to the short side. Traces of the two layers were selected to be 70µm thick copper because copper is less resistive than aluminium and the thickest foil that was available from the foil supplier was 70 µm. Also, going a lot thicker than this, the die cutting machine would not have been able to cut it.

The placement of this heater's pads was done so that the connections could be obtained on both the short and long sides. On the long side, pads were placed so that the heater could be interlaced in two different positions. This means that the pads were placed in the middle of ¼ and ¾ length of the long side. On the heater layer, there was left some empty space because if it was filled with traces, there could be a chance that the waste could not be pulled in one piece in the transfer foil process.

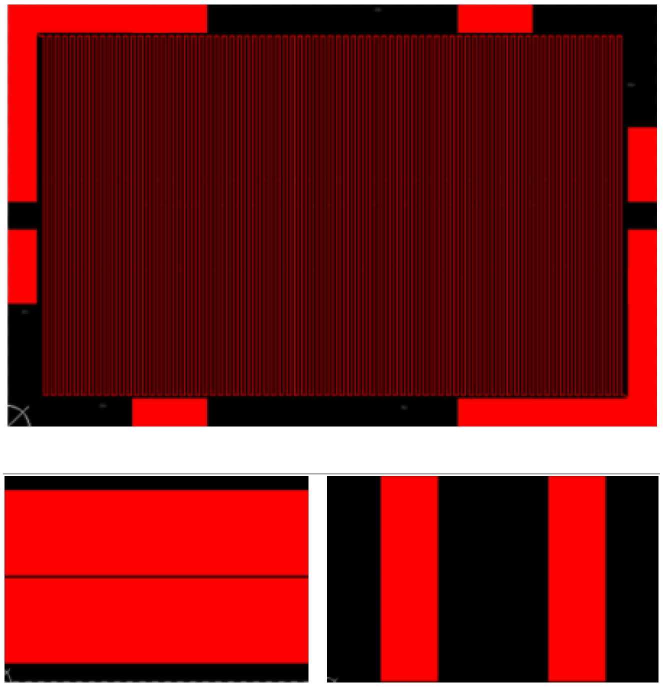


Figure 17. Second version – multilayer, connections in both directions.

The second version was modeled similarly to the first version although the coupling was different. This version had also symmetry and much smaller resistances in the traces. Figure 18 shows a LTSpice simulation model for the second version heater with 9 µm traces.

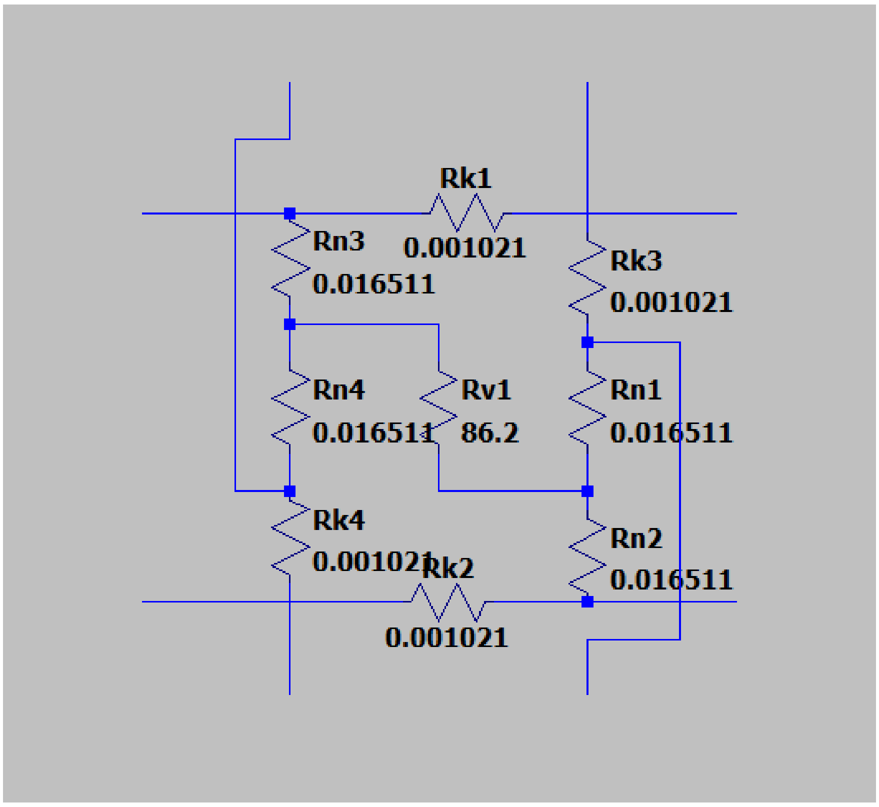
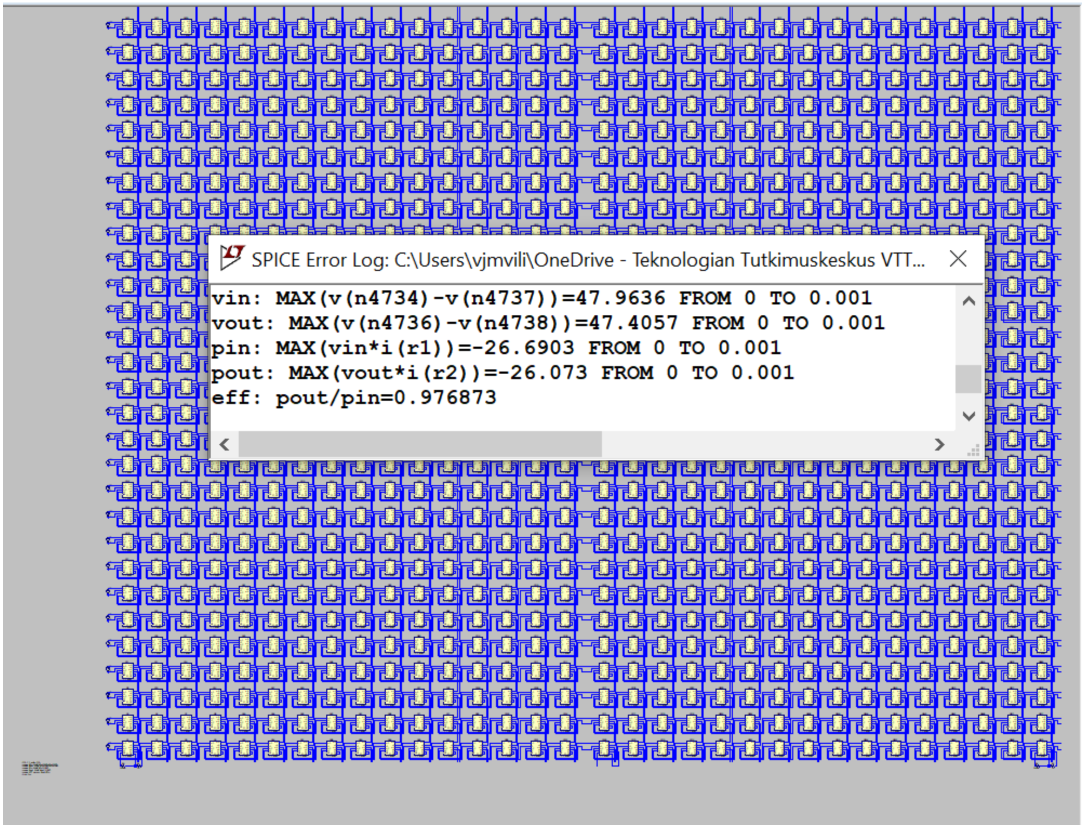


Figure 18. Simulation model for a single second version heater with 9 µm aluminium traces. (R_{v1} represents the heater resistance and the rest represent feed line resistances.)

Figure 19 shows the simulation of the second version where the heaters were included in subcircuits in order to ease the simulator's processing of large number of components. This particular simulation was executed so that the power supplies were all on the same side. In the middle of the figure can be seen the arithmetical operations of calculating the efficiency between the largest and the smallest power losses. This version showed promise as the efficiency was 97.7% with a 100m^2 surface area even when the supplies were not ideally placed.

The theory of the location of the maximum power loss described in Chapter 2.3 proved to be valid in the simulations with symmetrical trace resistances.



```
vin: MAX(v(n4734)-v(n4737))=47.9636 FROM 0 TO 0.001
vout: MAX(v(n4736)-v(n4738))=47.4057 FROM 0 TO 0.001
pin: MAX(vin*i(r1))=-26.6903 FROM 0 TO 0.001
pout: MAX(vout*i(r2))=-26.073 FROM 0 TO 0.001
eff: pout/pin=0.976873
```

Figure 19. Simulation of 100 m^2 floor for the second version.

3.3.3 Third version

Figure 20 shows the third version of the heater. This version had only one layer and connections only in one direction. This allowed more space to the wiring, and it resulted in more resistance per heater. With aluminium the resistance was 97.5 Ω and with copper 55.6 Ω. When not having pads on the long side, the width of the outer conductor could be minimized to make the cold spots thinner. This version was also simulated with a model having different thicknesses on the feed lines and heater traces.

Unlike the two previous versions, with this third version is possible to interlace the panels in unlimited ways because of not having to couple the long sides to each other. However, when installing, the row is not always started with a full panel rather a cut panel. This means that the connections from the end of the rows need to have a contact to the thinner part of the feed line which can cause problems.

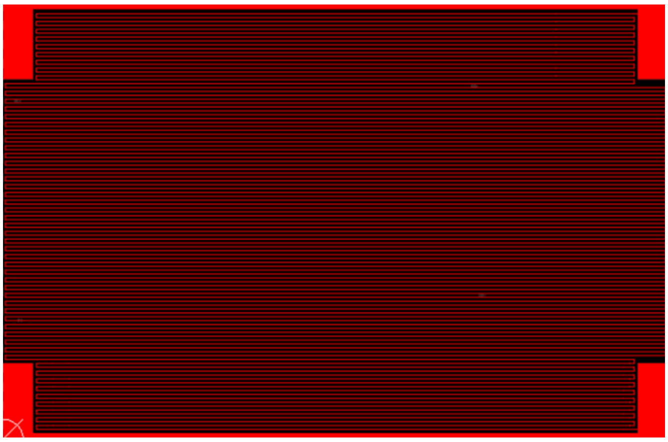


Figure 20. Third version – single layer, connections in one direction.

Figure 21 shows a LTSpice simulation model of the third version which was the simplest of the three. R_v stands for heater resistance and R_j stands for the resistance of a single trace and two pads. When connecting these third version panels, the trace resistances connect in series with the previous panels trace resistances.

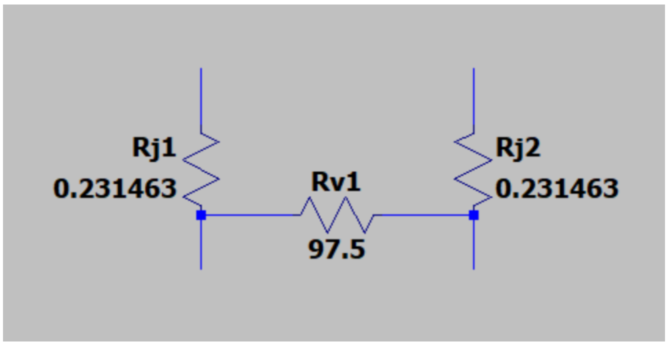


Figure 21. Simulation model for a single third version heater with 9 µm aluminium traces. R_{v1} represents the heater resistance and the rest represent feed line power losses.

There was no need to simulate the third version with a large surface area because every row behaves the same way. In Figure 22 can be seen a simulation of the third version where power was supplied from both ends of the row. On the right side of the figure is voltage and current measurements of the heaters from the middle and the end of the row. The set limit was reached with a 6 m long row of panels.

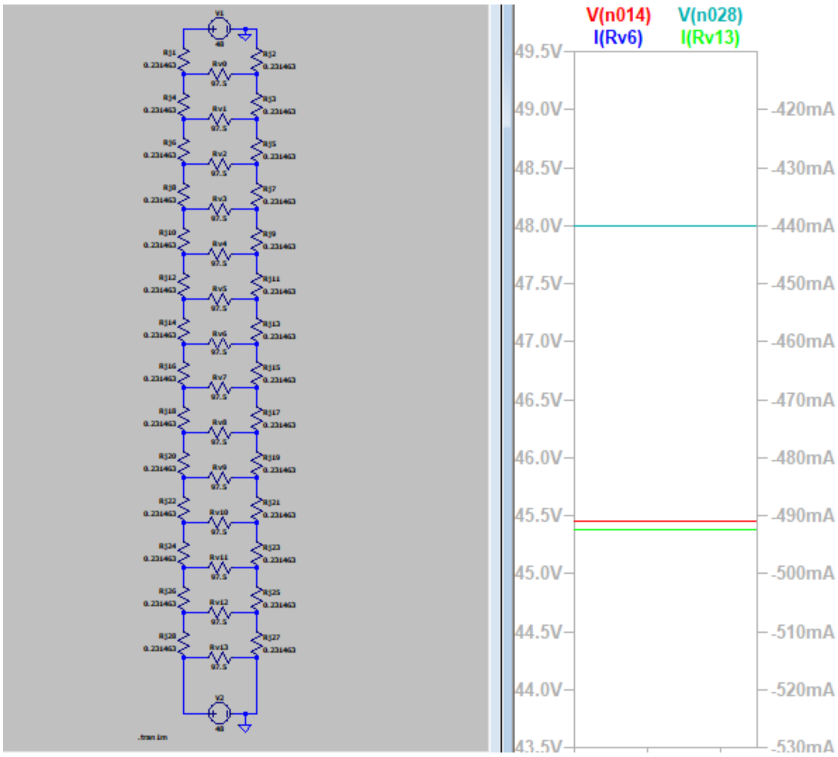


Figure 22. Simulation of 6 m long row for the third version.

3.4 Supply points

The number of points where the power was supplied was important to determine because it affects the easiness of panel installation. Number of supply points was determined by a maximum of 6 A current and 48 V voltage per supply, meaning 288 W power per supply, and under 2-minute warming attribute, meaning the ability to take 17 W per heater. The largest surface areas were achieved with evenly placed supply points which also reduced the number of supply points.

The third version was only able to have supply points in the ends of a row of panels which means that the largest surface area is achieved with placing the supply points in two opposite sides of the floor.

3.5 Comparison and discussion

Tables Table 2 and Table 3 show the power loss comparisons of different heater versions and they express the simulation results of maximum surface areas and calculation results of minimum number of power supply points at maximum surface area. With the third version is expressed maximum row length instead of surface area because every row needed to be coupled separately. It however gives a directional estimate of achievable surface area. The minimum number of supply points in the third version is always two because of the separate couplings. The nonexistent difference between maximum row lengths of the third version is presumably due to large tolerance because one heater circuit was over 40 cm long.

Table 2. Maximum surface area comparison for versions 1 and 2

Version	Material	Heater resistance	Max. surface area	Min. power supply points at max. surface area
1	Al 9 µm	86.2 Ω	35 m^2	17
1	Cu 10 µm	49.2 Ω	31 m^2	15
2	Al 9 µm + Cu 70 µm	86.2 Ω	Over 100 m^2	Over 49
2	Cu 10 µm + Cu 70 µm	49.2 Ω	Over 100 m^2	Over 49

Table 3. Maximum row length comparison for version 3

Version	Material	Heater resistance	Max. row length	Min. power supply points at max. row length
3	Al 9 µm	97.5 Ω	6 m	2
3	Cu 10 µm	55.6 Ω	6 m	2
3	Al 9 µm + Cu 70 µm	97.5 Ω	21.5 m	2
3	Cu 10 µm + Cu 70 µm	55.6 Ω	16.3 m	2

Based on the results, the use of aluminium was considered to be superior to using copper. This conclusion is also supported by the differences of the material costs.

The first version had very big power losses and it did not reach functionality for 50 m^2 surface area. The supply points needed to be on every side of the floor to achieve 35 m^2 so this version did not increase the ease of installation compared to the other versions. A panel made of these versions can be interlaced from five different spots.

The second version showed promise with achieving large surface areas with small power losses. 49 supply points for 100m^2 surface area means that for a square shaped floor the supply points needed to be placed to at least two sides of the floor. But for an example, a 6.7 m x 15 m rectangle shaped floor would be enough to place the supply points in only one side of the floor. The downside of the second version is that it is by far the most complex to realize and therefore raises the manufacturing costs. A panel made of these versions can also be interlaced from five different spots.

The third version had slightly better results than the first version considering the surface area and two-side supply lines. This version also had an ability superior to others that was unlimited interlacing ability which can come in handy when comparing a floor by its looks. To obtain large surface areas, the heater circuit’s feed lines and heater traces needed to be one or both of different material and different thickness. This raises the manufacturing complexity and price but not as much as the second version does.

Comparing these three versions it is easy to come to a conclusion that the second version is the most considerable for further implementation. Considering small power loss results in the second version, it could be modified so that pads on the edges would be narrower in order to minimize the cold spots.

This product could be improved by adapting a single circuit to a full laminate flooring panel. If selecting a version with two different materials, it could be possible to make the heater from a copper coated aluminium to help the bonding between two materials. It might also be appropriate to consider the possibility of connecting the panels to the mains current since the easiness of installation was not significantly improved at least in the case of supplying power.

With the second version this might help with the bundles of feed line wires because its functionality did not depend on the placement of the supply points.

Potential issues for this product that were not reckoned in this work would be the implementation of contacts between panels, water leakage to the contacts and point heating in an event of a fault, the last two being matters of electrical and fire safety, respectively.

If one of these versions will work in practice, the next step for the product development would be designing a layout with a size of a full laminate flooring panel or some else flooring material and to examine the possibilities of manufacturing on a larger scale.

4 SUMMARY

The aim of this thesis was to develop previous experiments with heater-integrated flooring panels further. The heaters were manufactured by transfer foil technology which is fairly unknown and new type of process for manufacturing electronics. The panels were wanted to be efficient and applicable for large surface areas.

Transfer foil process is explicated, and it is followed by the explanation of floor heating and heating power theories for basic understanding of what is needed to know to design the heaters. The challenges of the product were considered to be feed line power losses and different limitations in the manufacturing process.

The need of heating power for the panel was simulated with COMSOL Multiphysics simulation software in a situation where heat transfer, electrical currents, ambient air, and concrete base were all reckoned among other details. As a result, 6 - 10 W power was needed to heat the top structure to the desired temperature of 23 - 26 ºC and 17 W power was needed for the desired heating rate of 2 minutes. It was also noticed that 6 - 10 W power with 80% efficiency had a difference of 1 ºC on the top of the structure compared to 100% efficiency and this fact was reckoned in the power loss simulations later in the thesis. The simulated structure was able to reach the target temperature with 6 W per heater which corresponds to power per area of 50 W/m^2, which is less power when compared to typical solutions on the market [9], [10].

Three different versions of heaters were then designed with Altium and modeled with LTSpice to simulate power losses in large surface areas. When the power loss results and other heater attributes were compared, the first version turned out to be somewhat problematic, the second version showed promise with over 100m^2 surface heating ability and the third version was considered as a developable option if the manufacturing process allowed two different thicknesses or materials for the same conductive layer. In general, transfer foil technology manufactured electrical floor heating panel appear in this thesis as an executable product.

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