Atsic°

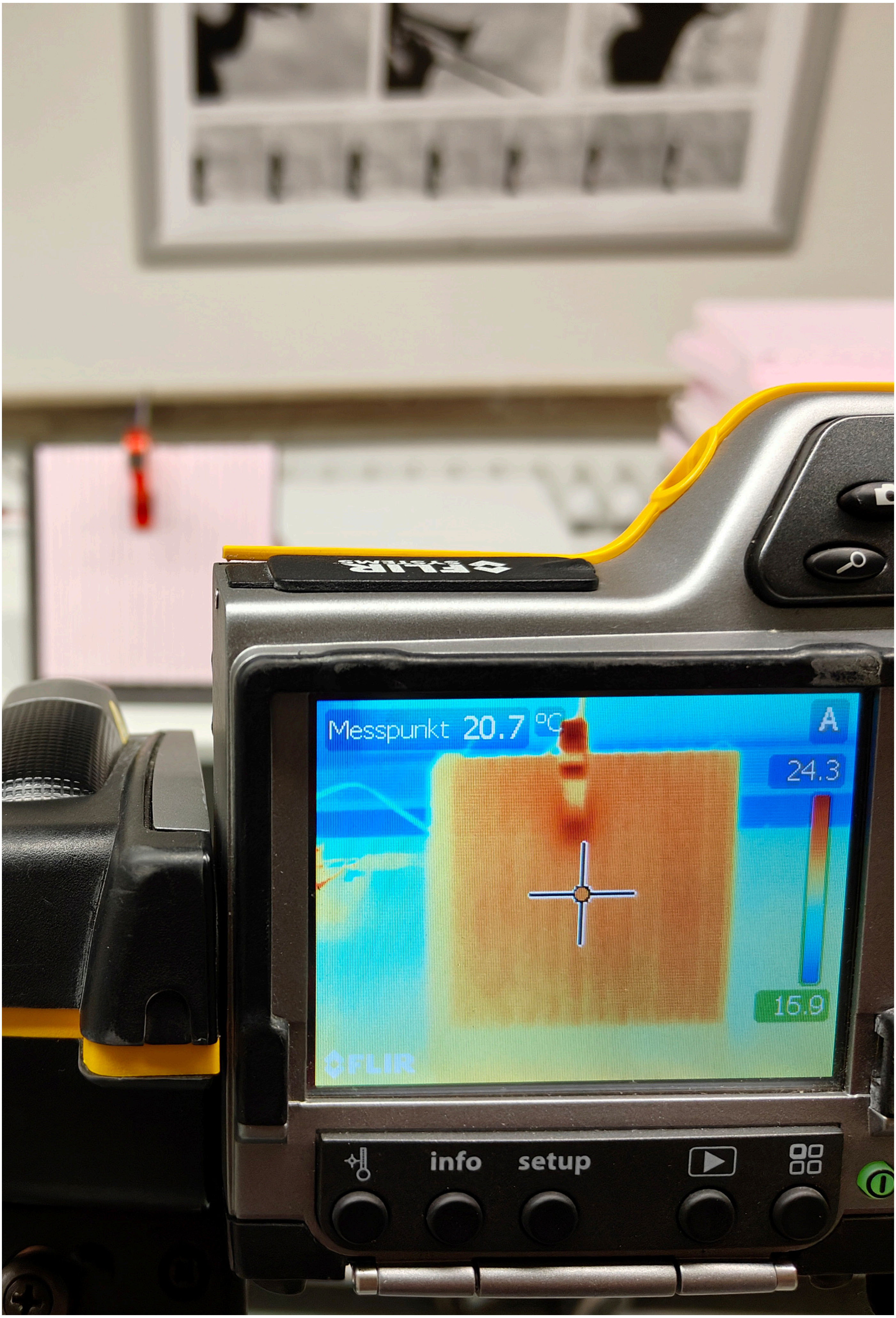
Adjustable thermodynamic Simulation Clothing

Bauhaus-Universität Weimar
Aaron Leonard Merten, Niels Cremer, Tom Kemter
Freis Fachmodul in Zusammenarbeit mit der Fakultät Bauingeneuerswesen
Betreut durch: Dr.-Ing. Hayder Alsaad, Mario Schneeweiß, Dipl.-Des.Timm Burkhard

mares

Bauhaus-Universität Weimar
Faculty of Civil Engineering

Bauhaus-Universität Weimar
Faculty of Art and Design


Messpunkt 20.7 °C
A
24.3
15.9
info
setup

Introduction

Thermal manikins are highly complex and precise instruments used in various industries where simulating the emitted warmth, radiation and even particles (to an extent) of the human body are of relevance and where the risk of inherent human inaccuracies need to be avoided. In essence, the manikin is an electrically heated dummy with a surface area and skin colour similar to that of a human being, which heats up and emits this heat (infra red radiation) with a high degree of homogeneity, much like the human body itself.

For the controlled climate chamber at the Bauhaus University, one such Manikin was purchased. It is capable of individually heating over 30 different patches on its body to simulate thermal scenarios where locally increased blood flow is seen in humans. It can also be hooked up to a machine which lets it breathe pre heated and moisturized air through its nostrils. Needless to say it comes with highly accurate temperature measurement and a program to control all the operations of the dummy. Equally unsurprisingly, the price of such a manikin comes to about 110.000 Euros. This means that for many institutions, including ours, the price is simply too high to afford more than one manikin, leaving the options for experimentation relatively narrow when it comes to situations where more than one human are to be simulated.

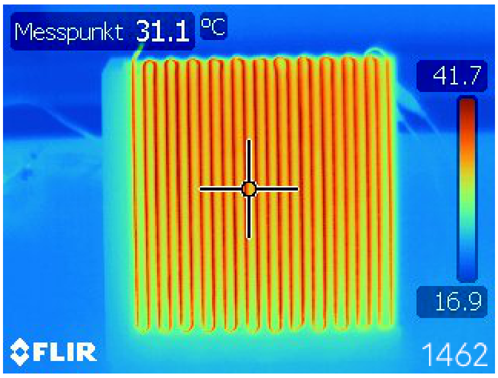
The goal was therefore clear. We were tasked with making a viable low cost alternative to a high end thermal manikin, preferably a system adaptable to a commonly available styrofoam dummy, possibly even an article of clothing which could be put on the dummy. This was the initial goal- as well as the reason for the name "ATSiC°" which stands for adjustable thermodynamic simulation clothing.

The target was that the dummy should be able to reach and maintain a highly homogenous temperature of 34 degrees Celsius. Adjustability would be a beneficial feature, allowing for further applications of the finished product. The skin should be smooth and mostly free of folds, an unbroken, uniformly heated, skin coloured surface if you will.

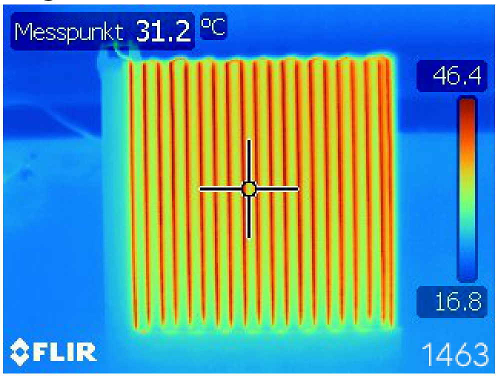
Reference Blocks

Before starting, we needed to have a scientific reference with which to compare the upcoming results. We would use these blocks to test what the thermal imaging camera sees without any cover material being present. For this purpose, we made 4 reference blocks with winding densities of 4, 6, 8 and 10 mm. Again, these did not yet have a top layer so that we could better compare which winding density was most suitable in the subsequent tests. The reference tests already made it quite clear what the core constraints of the project were going to be; the denser we wrap the wire, the more homogenous the result, as expected. However, the higher wrap density also greatly limited the current flow at 30V, making it impossible to reach above a temperature of about 27 degrees celsius. The time it took to wrap each block aslo came into play. When also considering the amount of time it took to wrap each sample, it became quite clear that the only real option would be something around 8-10mm for the wire wrap density. The results from this first row of experiments is visible below.

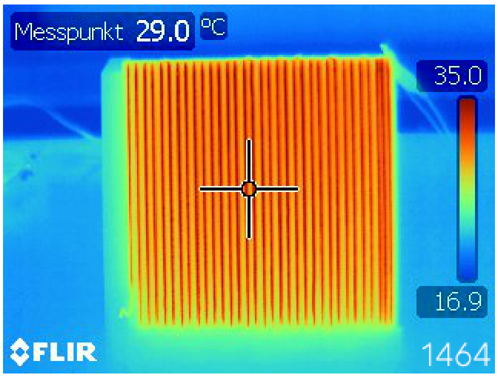
8mm wire wrap density
32.2V
0.2 A



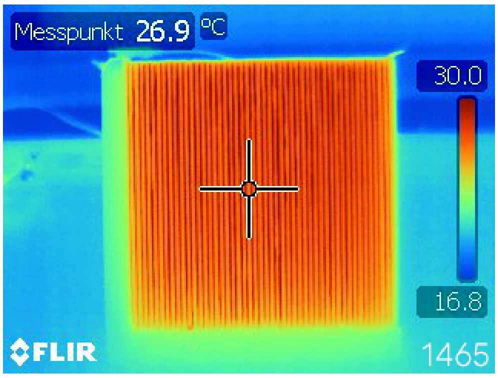
10mm wire wrap density
32.2V
0.23 A



6mm wire wrap density
taken at 29.0 degrees (current limited, could not go higher)
32.2 V
0.14A

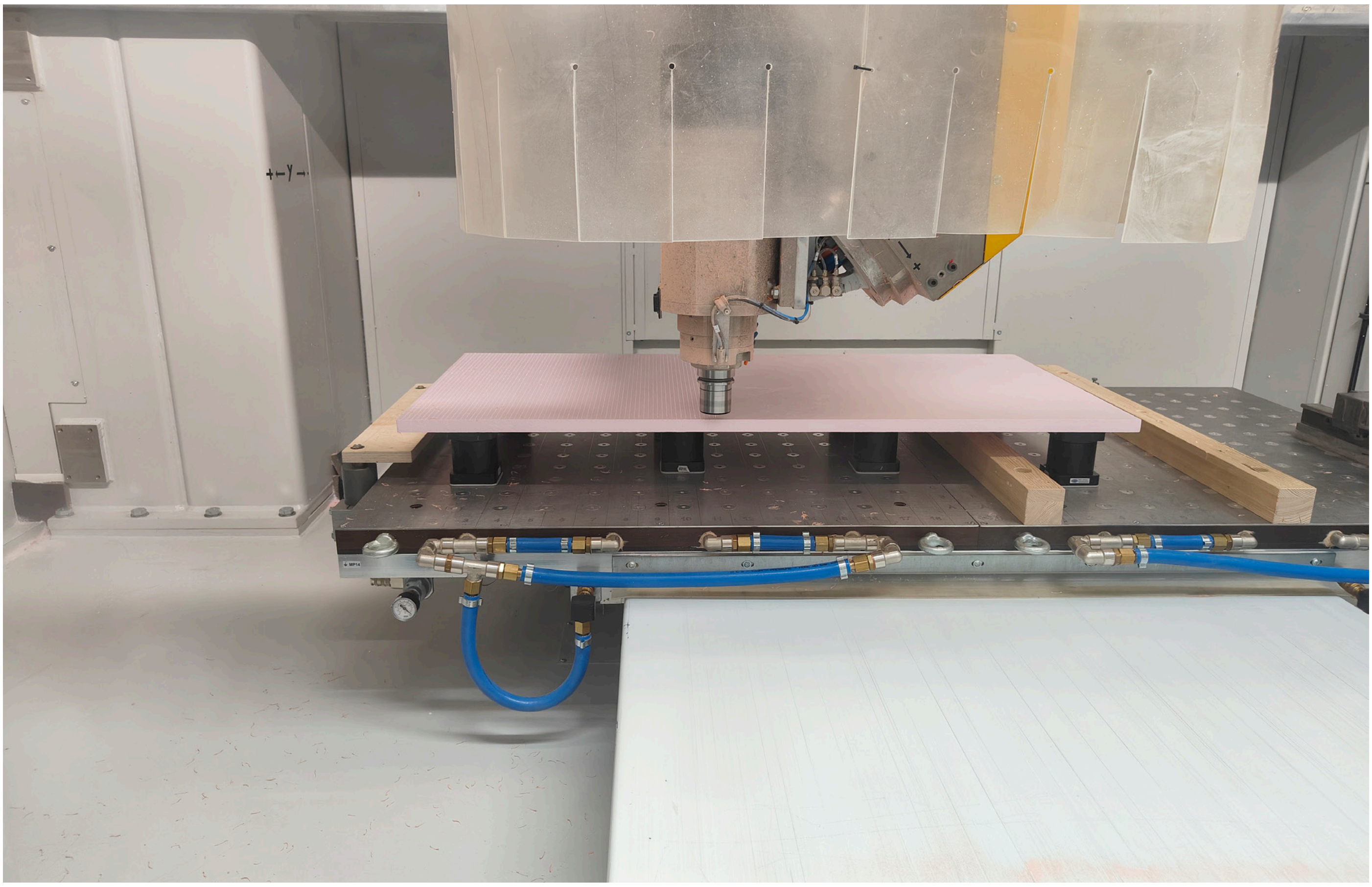


4mm wire wrap density
taken at 27.0 degrees (current limited, could not go higher)
32.2 V
0.10 A



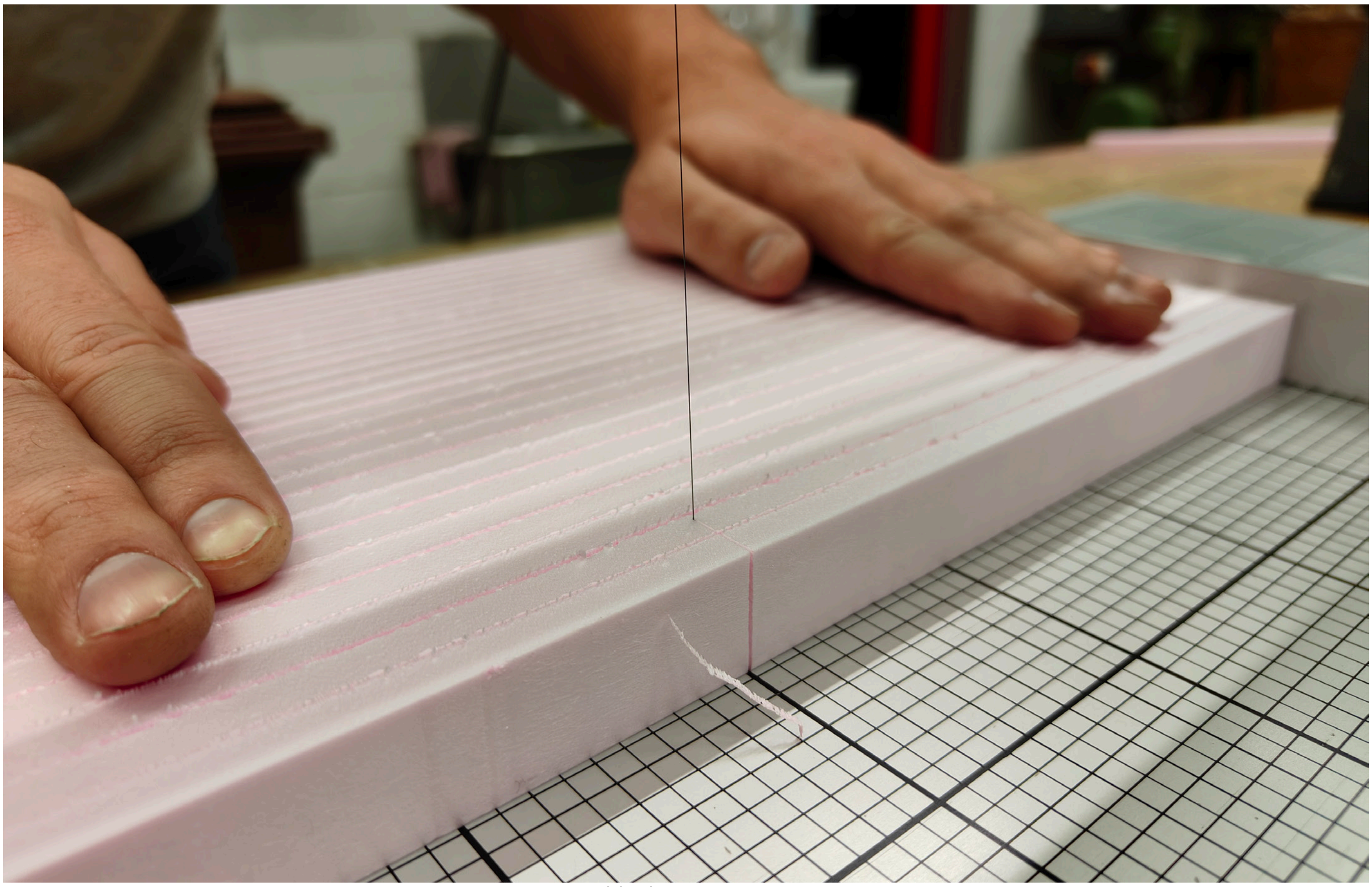
Material tests

The next step was to test various cover materials with a fixed wire wrap density. The experiment was set up using blocks of 20*20*2cm pink high density styrofoam, into which we CNC routed 0.8mm slots exactly 8mm and 10mm apart, into which we later pressed the PFA-insulated type K heating wire. The reason we tested 8mm and 10mm was that in the study by Schön and Kolka[1], a wire wrap width of 4mm was used for the final piece. We wanted to purposefully make our materials to be tested 'fail', by wrapping with double that distance in the hopes that we would be able to observe the width of the individual heat-affected zones and thereby determine the best amongst the materials. As it turned out, some of the materials we tested were so good at homogeneously emitting the heat outward, that even the 8mm wrap proved too dense. The best amongst all the materials we tested was neoprene. Luckily for us, we had chosen this material specifically as it already exists in the form of a skin-tight, nearly fold-free suit in various thicknesses, all of which were necessities in making our thermal suit. Or so we thought...



CNC routing 0.8mm wide slots
at 8, 10mm width apart

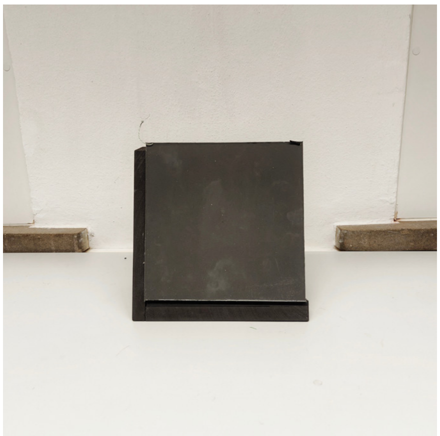
1 Studienarbeit: „Raumklimatische Messungen mit einem thermischen Manikin – Entwicklung & Aufbau eines Prototyps" von Kai Philip Schön, Christoph Kolka


*Cutting blocks into 200*200mm*

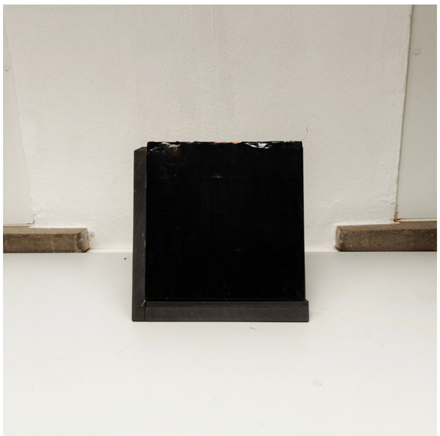

Pressing in the type K resistance wire

Materials

We therefore decided to start a test series to determine which material would best suit becoming... well... a suit. The idea was to only test materials that we could viably wrap or stick around the manikin to hopefully create a removable boundary layer, infused with the heating elements, which would homogeneously heat and emit the radiation. The materials we decided to test were the ones shown below. Steel wool, spraying rubber, polymer plaster, silicone-aluminium powder and neoprene, some variations with copper tape underneath as a better heat conductor.



Silicone rubber + aluminium powder



Spray rubber

Gypsum + copper tape

Plain gypsum

Copper tape

Steel wool

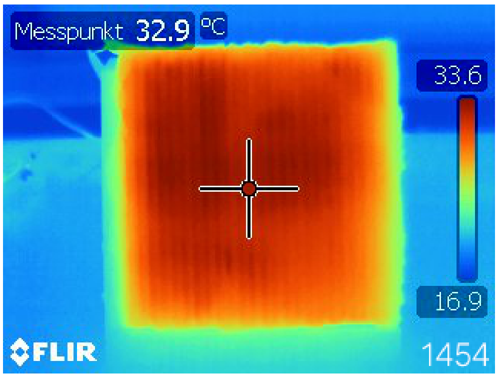
Neoprene 3mm

Neoprene 5mm

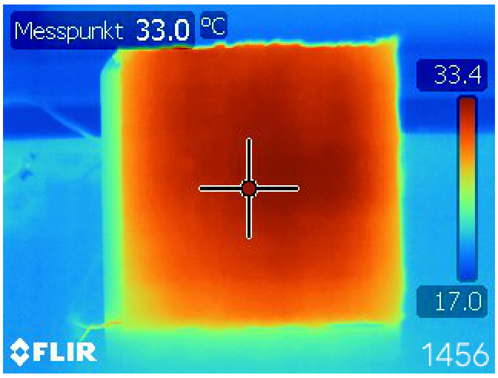
Neoprene 8mm

Test results with 8mm wire spacing (wrap density)

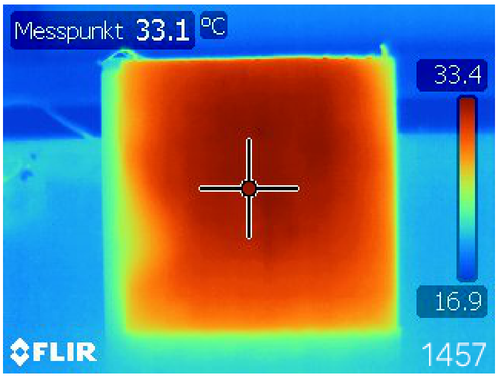
8mm+ gypsum plaster plain
32.2 V
0.20 A



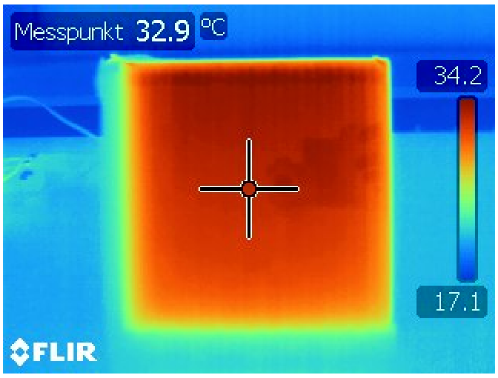
8mm+ gypsum plaster with copper foil
32.2 V
0.20 A



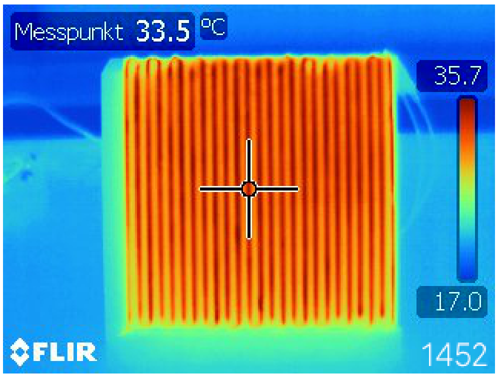
8mm + Copper with 3mm neoprene
32.2 V
0.20 A



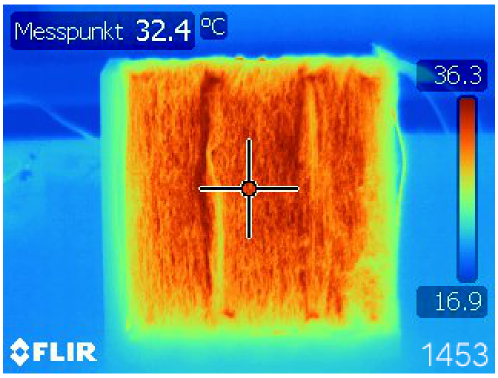
8mm+silicone with Al powder
32.2 V
0.20 A



8mm+Spray rubber
32.2 V
0.19 A

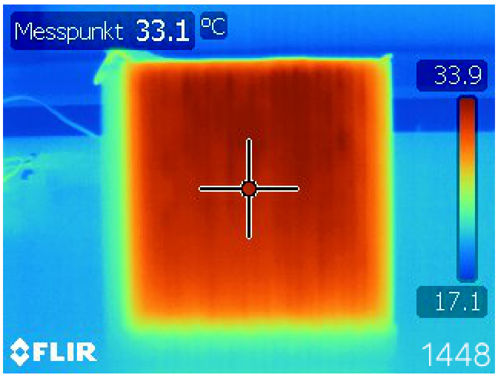


8mm + Steel wool
32.2 V
0.19 A

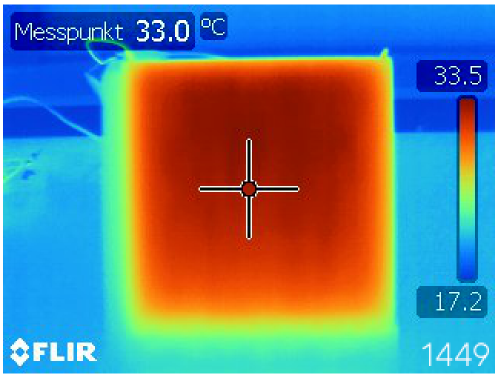


Test results with 8mm wire spacing (wrap density)

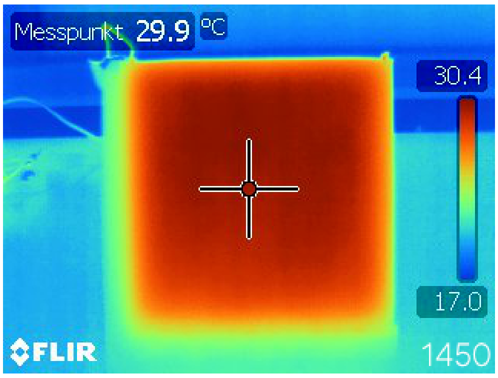
8mm +neoprene 3mm
32.2 V
0.20 A



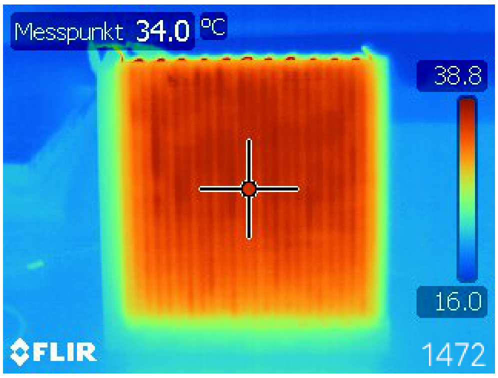
8mm+Neoprene 5mm
32.2 V
0.20 A



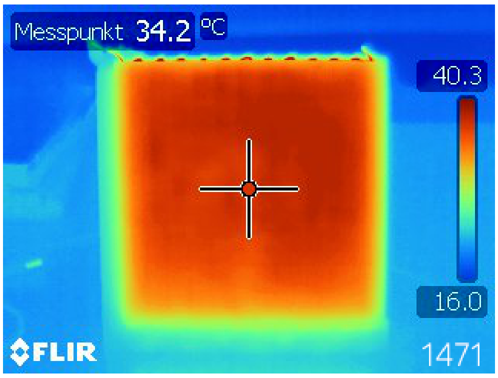
8mm + Neoprene 8mm
32.2 V
0.20 A



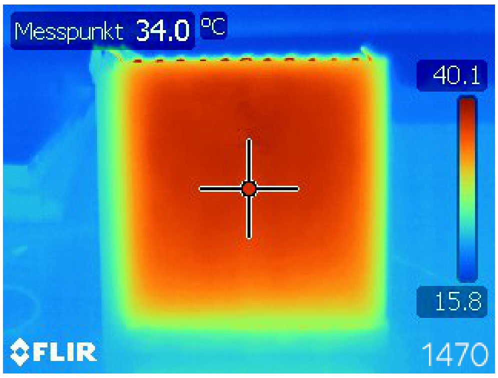
8mm + 3mm neoprene painted
32.2 V
0.20 A



8mm + 5mm neoprene painted
32.2 V
0.20 A

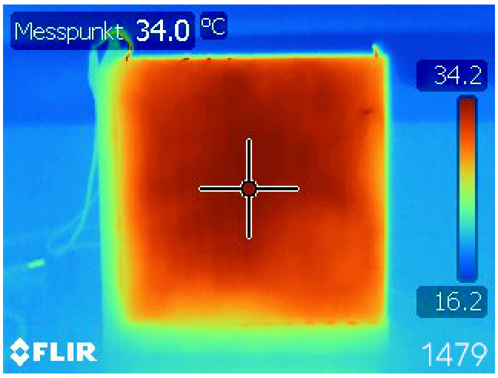


8mm + 8mm neoprene painted
32.2 V
0.19 A

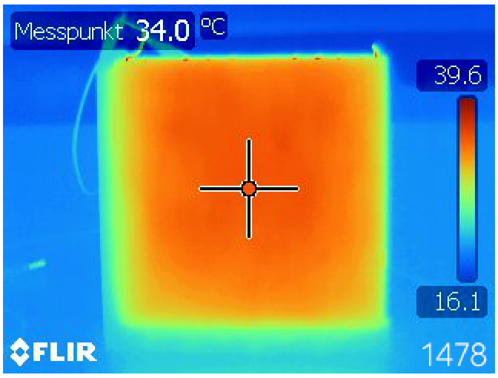


Test results with 8mm wire spacing (wrap density)

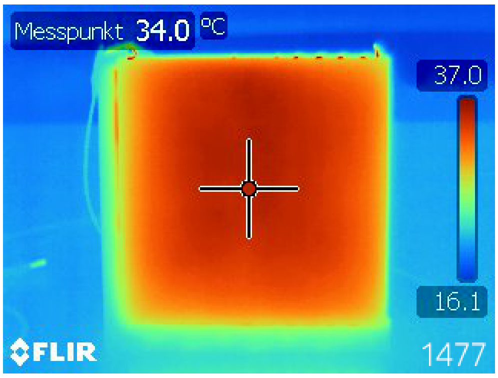
8mm + copper foil + 3mm neoprene
painted
32.2 V
0.20 A



8mm + copper foil + 5mm neoprene
painted
32.2 V
0.20 A



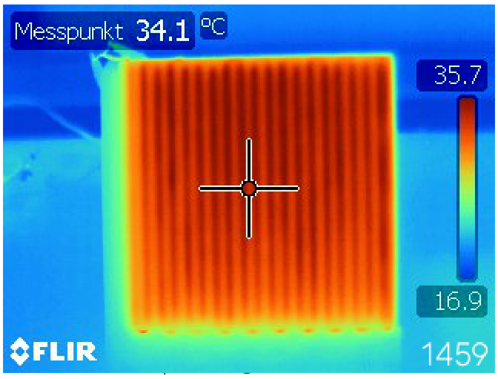
8mm + copper foil + 8mm neoprene
painted
32.2 V
0.20 A



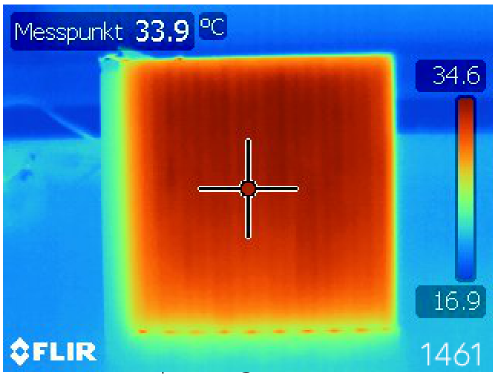
These experiments showed us that neoprene would be the ideal material to homogeneously distribute and emit the heat and result in a uniformly radiating surface as seen in the thermal images above. The next step was to see how far we could push it- what thickness of neoprene and what combination of other factors would result in us being able to use 10mm for the wire wrap density? We needed to optimise the upcoming process of wrapping the final manikin by using the least wire, whilst also keeping in mind how to fix the wire in place before applying the neoprene.

10mm wire spacing (wrap density)

We began by then testing 10mm wire wrap density with the plain neoprene. As expected, this resulted in less-than-ideal thermal transfer, with the individual heating elements clearly visible with 3mm thick neoprene. At 5mm, however the neoprene started performing better, and the homogeniety increases visibly. Our best hopes were confirmed when the 8mm neoprene showed excellent homogeniety with no individual wires being visible. We then decided to try and use a single layer of copper tape between the block and the neoprene, to also simulate the order of operations in the final wrap, as we would need to use some form of tape to hold down the thermowire after wrapping it.

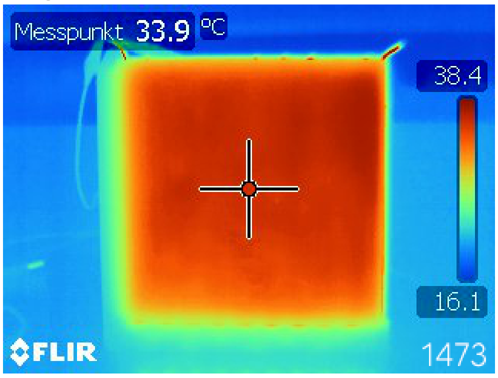


32.2 V
0.23 A



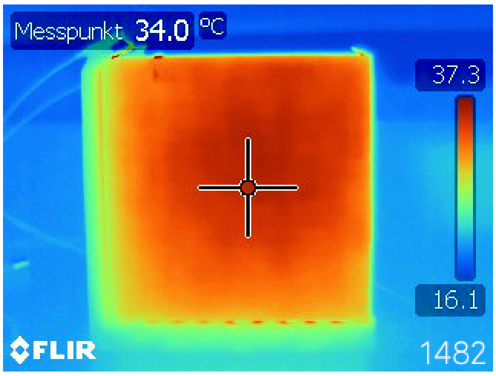
32.2 V
0.23 A

10mm + 8mm neoprene
32.2 V
0.23 A

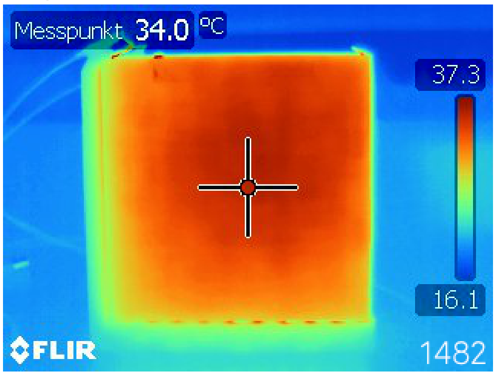


10mm wire spacing (wrap density)

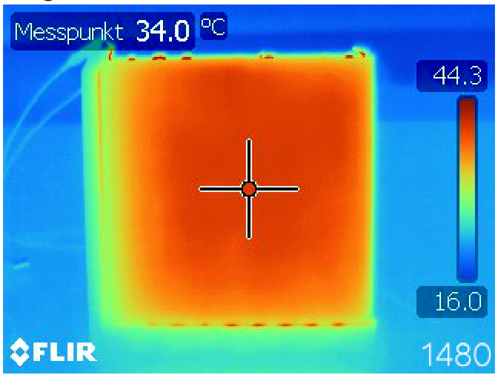
10mm + copper foil + 3mm neoprene
32.2 V
0.23 A



10mm + copper foil + 5mm neoprene
32.2 V
0.23 A



10mm + copper foil + 8mm neoprene
32.2 V
0.23 A

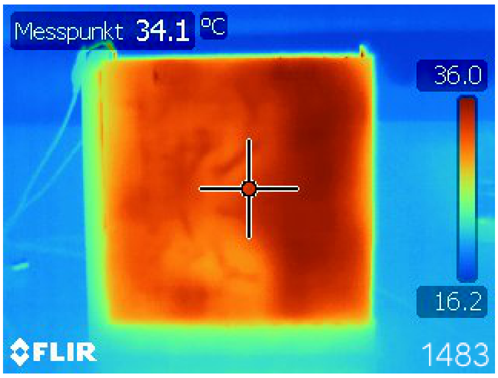


The results from this were surprisingly good. Even at 5mm neoprene thickness, the homogeniety had increased greatly. This left us confident that with a 7mm thick neoprene suit and a now finalised order of operations, the work on the final dummy could start.

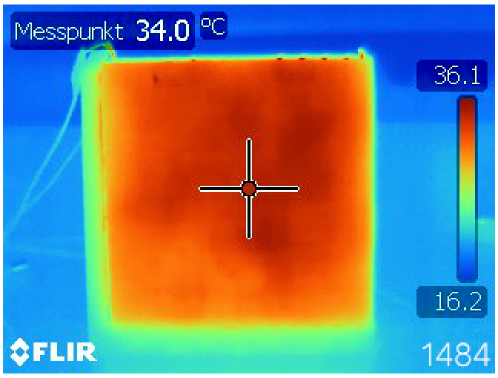
Copper tape test

Before we moved on from our blocks and tested our results on a human form, we wanted to find out what the results would be when the copper foil was crumpled. After all, we wouldn't be able to transfer it to the human body in a perfect state. This resulted in two tests. One with crumpled copper foil, and the other with crumpled foil, which was pressed flat. Fortunately for us, the results of the crumpled and pressed foil hardly differed from the clean and smooth applied foil in the first tests. So we were able to chalk this up as a success and go one step further.

8mm + copper foil not pressed down
3mm neoprene
32.2 V
0.20 A



8mm + copper foil pressed down
3mm neoprene
32.2 V
0.20 A



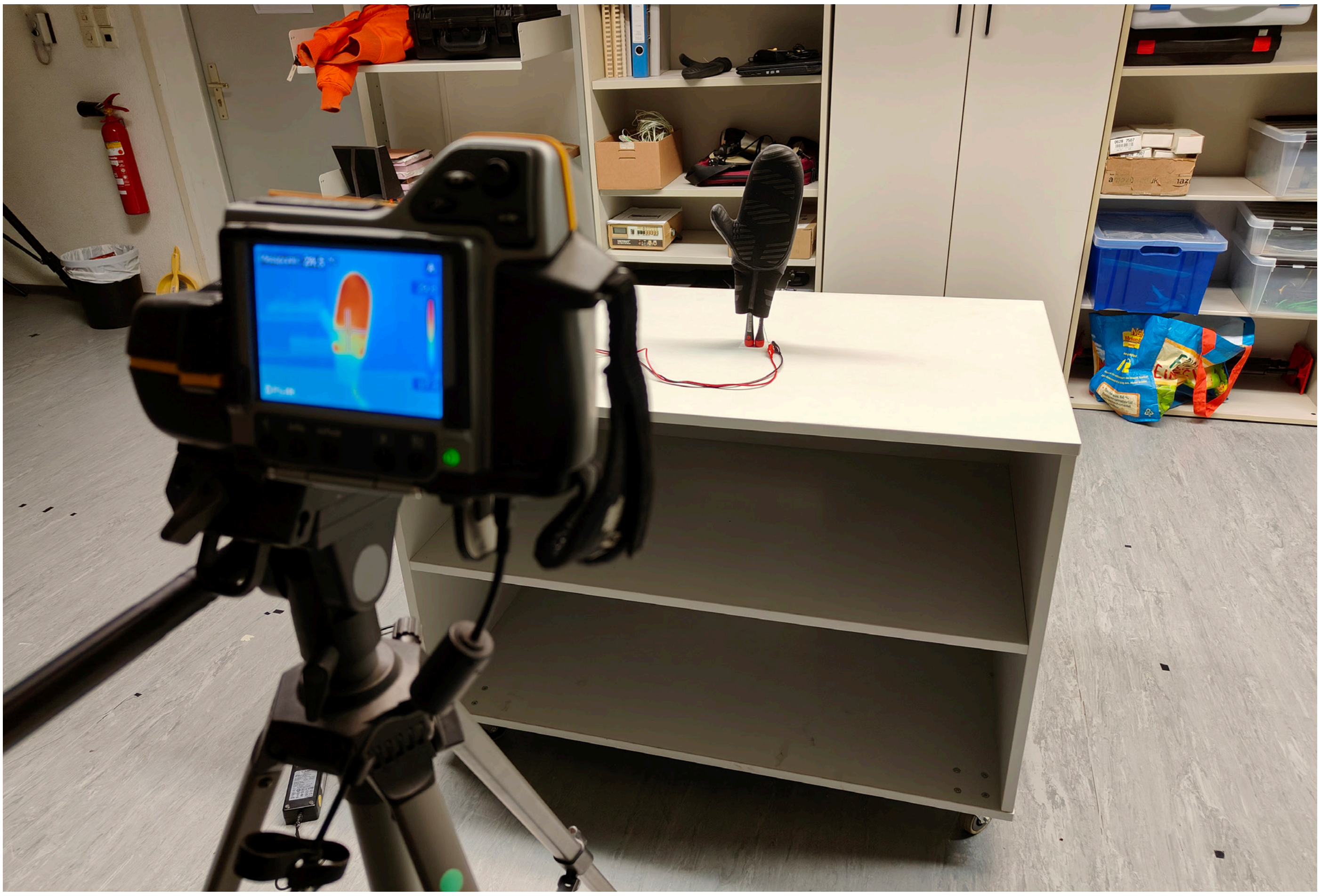
Hand test

We decicided to perform a small scale test of the final process on the hand of the dummy. We puchased two off the shelf neoprene mittens in 5mm thickness to use as the covering material. We were excited to see whether the material differences (commercial suit-neoprene is slightly more rubbery and less dense) and the geometric differences would play out negatively in the results.

We began by making two hands from the same pink foam we had used for the tests, and manually shaped them to fit snugly into the mittens. We then inlaid the wire in 8 and 10mm spacing (as the mitten was 5mm and not 7, so we weren't sure if the thickness would suffice for 10mm wire wrap density) and fixed it in with the copper tape.

Shaping the hands

Copper wrapping

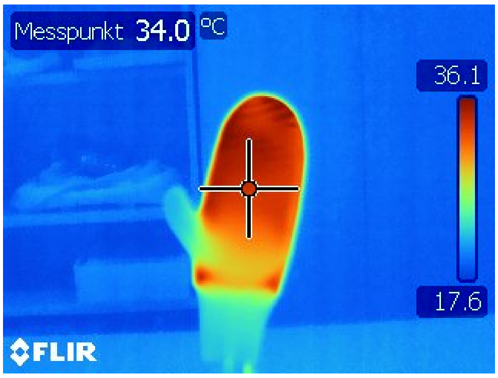


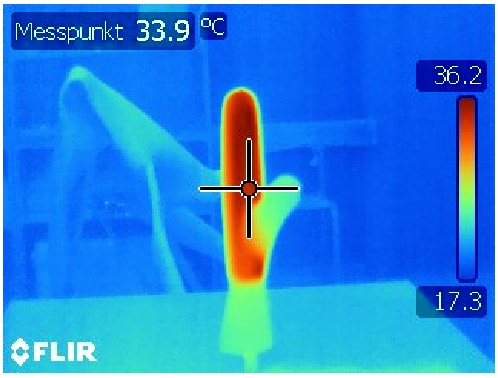
Experiment setup

Hand test

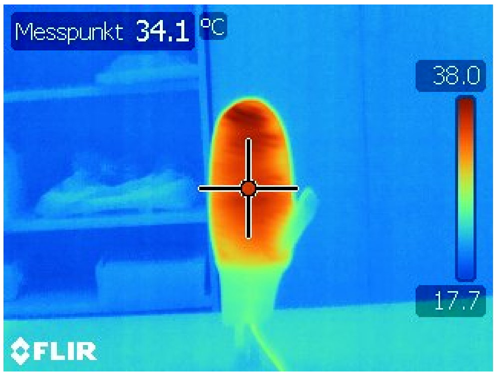
The results show only a very slight difference, if any, in the results between the two wire wrap densities. This left us feeling confident that the material, the process and the order of operations could be scaled up to work on the full scale dummy.

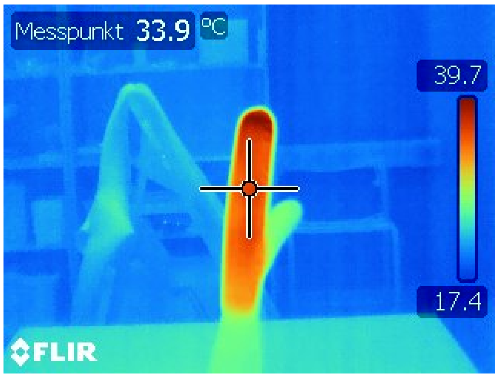
10mm + neoprene mitten 5mm +
copper foil
32.2 V
0.35 A





8 mm + neoprene mitten 5mm +
copper foil
32.2 V
0.28 A





Final preparations and build

We contacted various companies for a sponsorship for the suit itself- one of which alone would have completely blown past our budget goals. Mares was kind and generous enough to send us a 7mm suit of theirs free of charge, solving this rather large worry of ours.

The final steps included the following calculations to determine the final requirements and parameters such as the lengths of the individual circuits based on the resistance they would reach and the current they would draw, the amount of circuits per body part, the surface area per body part and the target wattage.

Typ T Ausgleichsleitung (Cu-CuNi) 0,2 mm

Body Segment	Body Segment Name	Area (m2)	Wire Length needed(m)	Total Resistance (Ω)	Target Power (W/m2)	Absolute Power (W)	Required Voltage (V)		Number of Required Heating Segments (n)	Current of individual Heating Segment (A)	Current of Body Segment (A)	Real Voltage of Body Segment [V]
1	Head	0,19	19	307,80	150,0	28,5	93,66	3,122	**4**	0,30	**1,22**	23,42
2	Torso	0,46	46	745,20	150,0	69	226,76	7,559	**8**	0,30	**2,43**	28,34
3	Left arm + hand	0,23	23	372,60	150,0	34,5	113,38	3,779	**4**	0,30	**1,22**	28,34
4	Right arm + hand	0,23	23	372,60	150,0	34,5	113,38	3,779	**4**	0,30	**1,22**	28,34
5	Left leg + foot	0,44	44	712,80	150,0	66	216,90	7,230	**8**	0,30	**2,43**	27,11
6	Right leg + foot	0,44	44	712,80	150,0	66	216,90	7,230	**8**	0,30	**2,43**	27,11
			199			**298,5**			**36**			

Parameters		
Name	Quantity	Unit
Wire thickness	0,2	mm
Wire resistance	16,2	Ω/m
Wire wrap width	10	mm
Wire wrap density	100	m/m2
Target Power	150	W/m2
Max. PSU Voltage	30	V

Typ T Ausgleichsleitung (Cu-CuNi) 0,3 mm

Body Segment	Body Segment Name	Area (m2)	Wire Length needed(m)	Total Resistance (Ω)	Target Power (W/m2)	Absolute Power (W)	Required Voltage (V)		Number of Required Heating Segments (n)	Current of individual Heating Segment (A)	Current of Body Segment (A)	Real Voltage of Body Segment [V]
1	Head	0,19	19	136,29	150,0	28,5	62,32	2,077	**3**	0,46	**1,37**	20,77
2	Torso	0,46	46	329,98	150,0	69	150,89	5,030	**6**	0,46	**2,74**	25,15
3	Left arm + hand	0,23	23	164,99	150,0	34,5	75,45	2,515	**3**	0,46	**1,37**	25,15
4	Right arm + hand	0,23	23	164,99	150,0	34,5	75,45	2,515	**3**	0,46	**1,37**	25,15
5	Left leg + foot	0,44	44	315,63	150,0	66	144,33	4,811	**5**	0,46	**2,29**	28,87
6	Right leg + foot	0,44	44	315,63	150,0	66	144,33	4,811	**5**	0,46	**2,29**	28,87
			199			**298,5**			**25**			

Parameters		
Name	Quantity	Unit
Wire thickness	0,2	mm
Wire resistance	7,2	Ω/m
Wire wrap width	10	mm
Wire wrap density	100	m/m2
Target Power	150	W/m2
Max. PSU Voltage	30	V

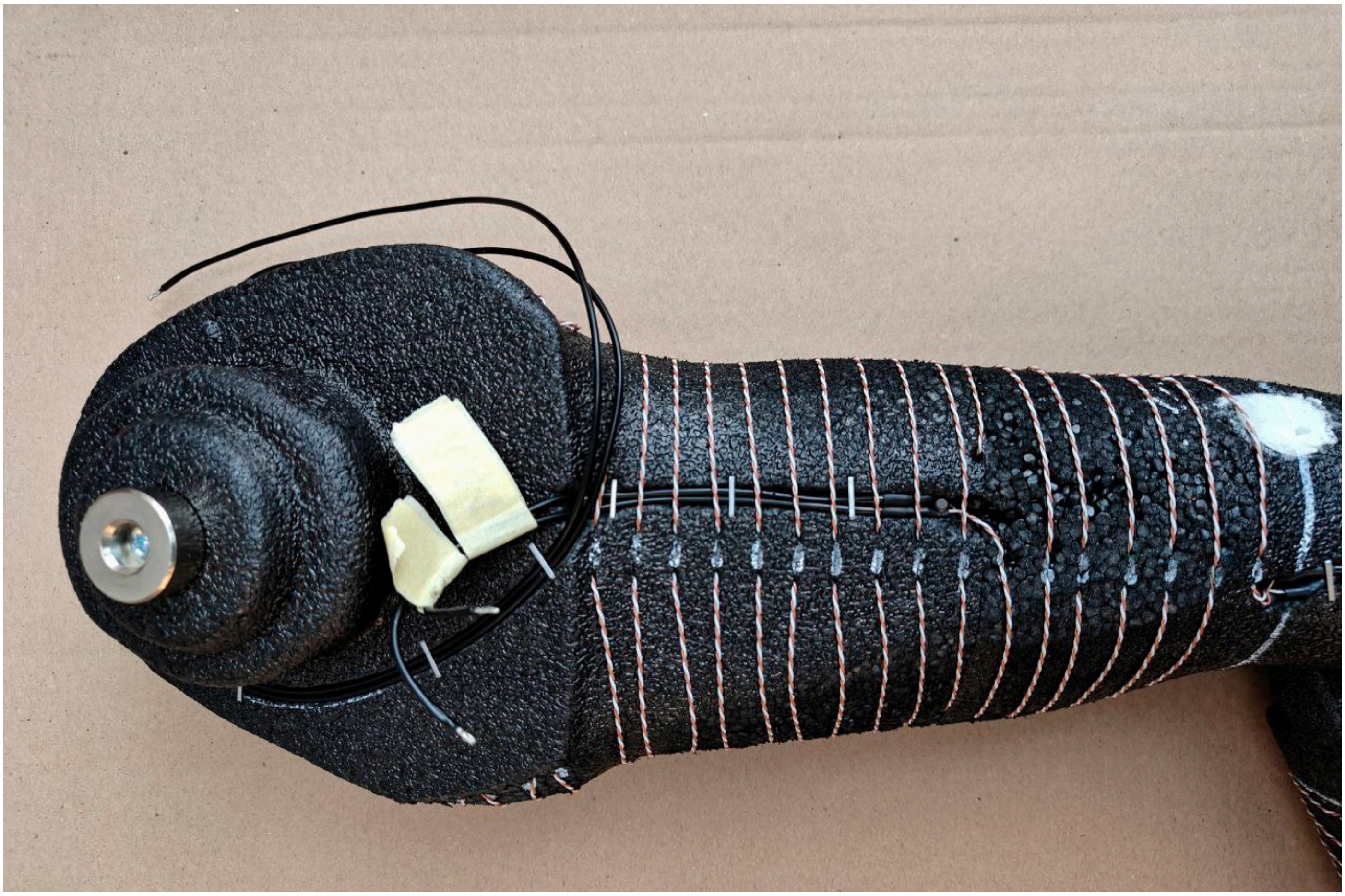
The plan was to wrap the manikin with the same 0.2mm diameter type K resistance wire by pressing it into pre cut grooves 10mm apart. Every 9 m, the coil would have to be cut and a new one started, the connections being run in parallel to the tailbone region of the dummy, which is where the cables would exit the suit and body. After pressing in and routing all wires, they would be fixed using the same copper tape that would aid in heat dissipation underneath the neoprene, which is the final component to come on.

So far the theory, at least. The actual building of the dummy proved more difficult than imagined. In the interest of reducing the amount of effort one would have to go through, it was decided to fix the dummy's limbs in the only position it would be resting in for almost all of the simulations; seated with a straight back, with its arms resting before it on a desk, simulating the use of a computer in a corporate job, for instance. The dummy had been designed in a way to allow for movement between the limbs. This movement, however, would create large gaps between the two components whenever these were moved to any point which wasn't resulting in the dummy standing straight upright. This meant that we had to, after fixing the limbs in their desired place, fill these gaps with polyurethane foam, or construction foam, to provide a smooth contact surface into which the wire could be placed and the neoprene laid.

After trying the suit on the dummy for the first time, it became abundantly clear that donning the suit was going to be a lot more complicated than initially imagined. It was for this reason that the suit had to be cut apart and the individual pieces pulled onto individual body parts, leaving the joints free in most cases for it to work.

Mares 7mm wetsuit

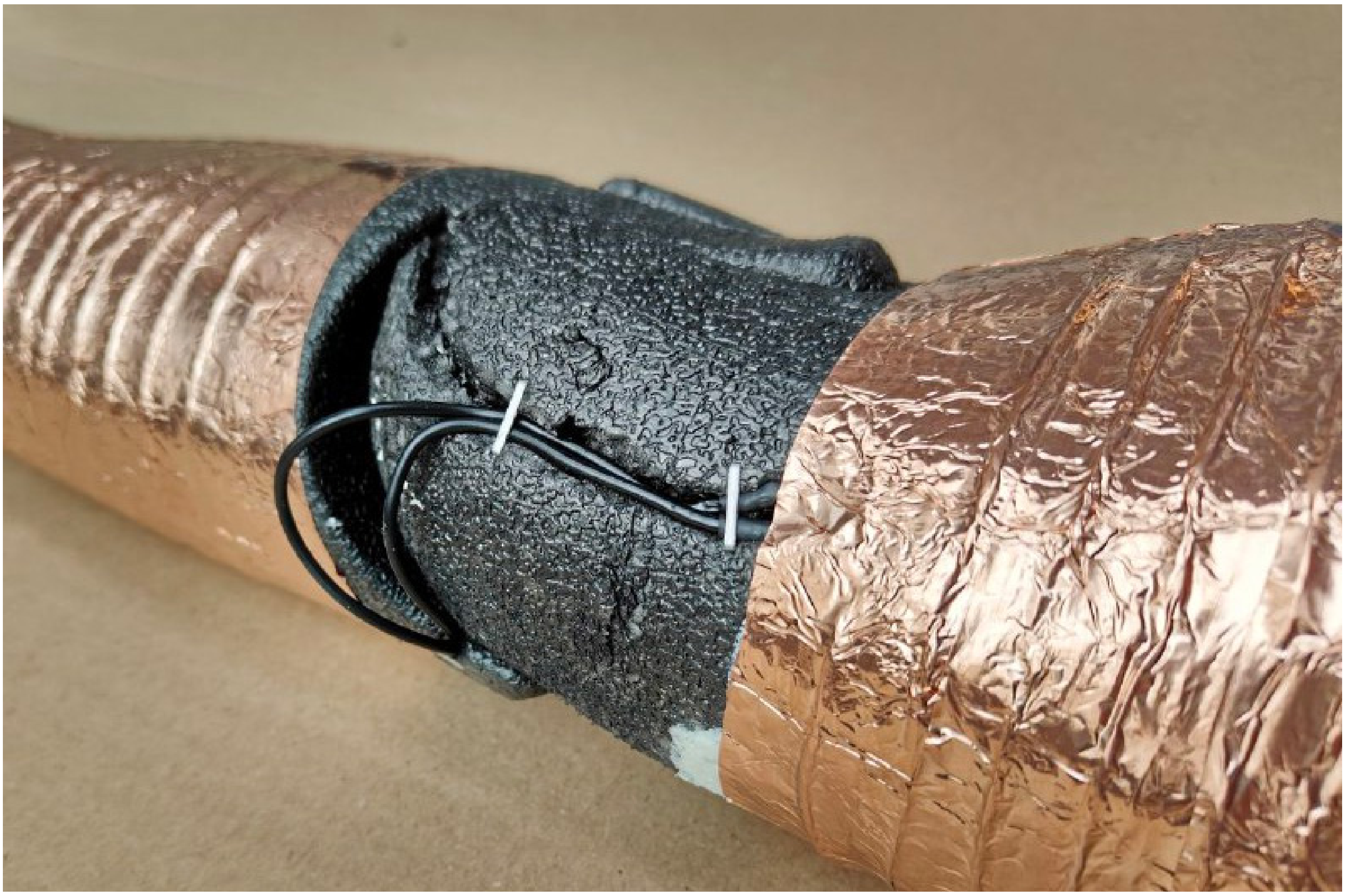
Wrapping the limbs



Wiring connections

Arm ready for tape wrap

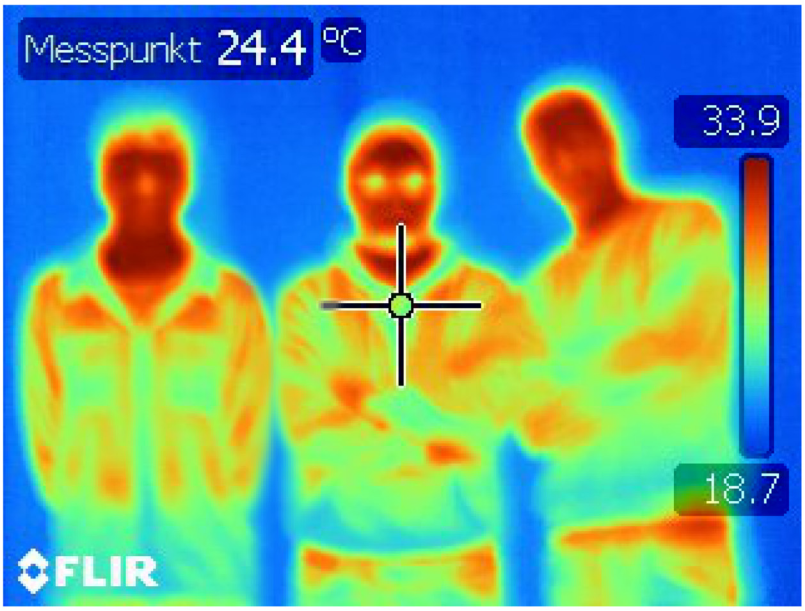
Copper taped arm



Elbow joint

Shoulder joint

Overall, we consider our approach to have been reasonably successful in finding a viable alternative to the expensive commercially available thermal manikin. We believe that the with the material we settled on, given more time and some experience, one would be able to craft a suit that would allow for the creation of a thermal manikin from any common dummy.



Regrettably, this was the extent to which our work reached within this semester. The dummy will now be handed over to the university for the completion of the electrical system and the sensors to complete the control loop to regulate its temperature. We wish to continue to be involved with the completion of the dummy and would love to see it in action next to its more expensive counterpart. Until then, this is the end of our documentation.