A Mattress with the Perfect Temperature

Exploring methods to design tickings with a variable thermal insulation value

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ABSTRACT
Being too hot or too cold during the night is reported as the number one problem for not sleeping well. During the night the skin- and core body temperature change. It would be beneficial to have the bed help accommodate for these changes in temperature. However, there are no practical solutions for this yet. This study aims to explore new ways to change the microclimate in bed during the night, by creating a ticking (top layer of the mattress) with a variable insulation value. To achieve this, several exploratory methods are tested to see what effect these have on the insulation value. Three already existing tickings of Auping are tested as well. The values of these measurements are compared to the results of the tickings with the exploratory methods implemented.

The most effective method found to change the insulation value of a ticking was varying the thickness of the ticking by pulling it apart or pushing it together. This method might also be suited for implementation in actual products.

Author Keywords
Ticking; mattress; insulation value; sleep; Auping; origami.

ACM Classification Keywords
E.m. Data: Miscellaneous.

INTRODUCTION
Over history, the way people sleep has changed a lot. Pre-artificial light cultures had a broken up sleep pattern. Currently, the sleep pattern is very defined by societal expectations and work.

In recent years, a lot more research has been done on sleeping and sleeping disorders. Bed and mattress producing companies such as Auping are attempting to implement this knowledge in their products and profit commercially of it.

Research suggests that the number one reason why people have trouble sleeping is because the temperature in bed does not suit their preferences. Research also suggests that the body temperature varies during the night, and therefore the microclimate under the blankets should change as well, to accommodate for this temperature shift.

To raise the temperature in bed, a lot of commercial solutions are available. However, for cooling beds there are not many practical solutions available. Existing solutions use fans, or water-based cooling methods. These solutions are noisy or prone to damage. A technique already implemented by Auping to accommodate for the changing body temperature in bed is the use of Phase Change Materials (PCM), which, through a physical effect, absorb and release energy, resulting in peak-shaving of the bed temperature.

There is not much known about the effect that the different tickings (mattress coverings) Auping manufactures have on the insulation value. To combat the temperature shifts during the night, a ticking with a variable insulation value would be beneficial. This could influence the rate at which the heat of the body gets conducted.

The challenge in this research is to design a ticking with a variable insulation value. To place this insulation change in perspective, the existing tickings of Auping are measured as well. This creates zero values which can be used to compare the tickings. Therefore the research question of this study is: How can exploratory methods be used to create a ticking with a variable insulation value and how do those compare to the existing tickings of Auping?

THEORETICAL BACKGROUND AND RELATED WORK
There is a lot of research concerning sleep and different factors which influence the human sleep. *Effects of thermal environment on sleep and circadian rhythm* [11] is about how the sleep-awake rhythm and the circadian rhythm are linked to the thermal environment. It explains the effects of factors on sleep, such as: thermal environment; ambient temperature (Ta); Humidity; the use of bedding; the use of clothing; skin temperature (Ts-) and body core temperature (Tc). It broadly explains the importance of the changes and the relation in Ts and Tc during the night and the body's mechanisms behind the thermoregulation. For the decrease of Tc during sleep onset Ts increases to lose warmth to the

environment. Therefore it would be ideal if the mattress conducted the heat flow better during sleep onset.

The effects of high and low ambient temperatures on human sleep stages [6] explains the effects of different ambient temperatures on the different sleep stages and shows in which sleep stages thermoregulatory mechanism of the body is the strongest. It shows that during REM sleep this mechanism is less active. During this stage a ticking with a variable insulation value would be ideal, to partly take over the body's thermoregulation mechanism.

The effects of fabric for sleepwear and bedding on sleep at ambient temperatures of 17 C and 22 C [16] treats the effects of different fabrics, sleepwear and bedding on the human sleep at different temperatures. It showed significant differences in sleep onset, related to the use of different materials. It also showed that the ambient temperature had an effect an on the percentage duration of the different sleep stages.

This research, *A study on the thermal comfort in sleeping environments in the subtropics—Measuring the total insulation values for the bedding systems commonly used in the subtropics* [10], also focusses on measuring insulation values of bedding. This research is more elaborated, as it also takes things in account such as: 'percentage coverage of body surface area by bedding and bed'. It also focusses on getting absolute data instead of relative data. In this research, there was also made use of an environmental chamber and there were also no real test-persons during the research.

Circadian and homeostatic regulation of core body temperature and alertness in humans: what is the role of melatonin [9] is about the role of melatonin in the regulation of core body temperature. Figure 1 clearly shows the drop in Tc which is spoken about before. Figure 2 shows the relation between Tc and the melatonin levels in the body. It shows that during sleep onset, when Tc decreases, the melatonin levels strongly increase to help induce sleep.

As can be seen in the papers and patents below, there already exist several methods of cooling fabrics. The shown methods are applied in car seats and astronaut garments [8], [20].

These use either air cooling, water cooling or a combination of both. A downside of applying these methods to mattresses is that it is necessary to constantly have a motor and/ or fans turned on. This is environmentally unfriendly and it makes noise, which can reduce the quality of sleep. Therefore a quiet solution without the necessity of a constant power supply is a matter which needed research.

DESIGN PROCESS

At first the three existing tickings manufactured by Auping were measured to see how these tickings would compare to each other. The results of these measurements are described under 'Findings', however, those results were already used during the process of designing new, exploratory, modified tickings. These results gave an insight about which tickings would be suitable for which exploratory method. That is why these results are shown here as well (figure 1).

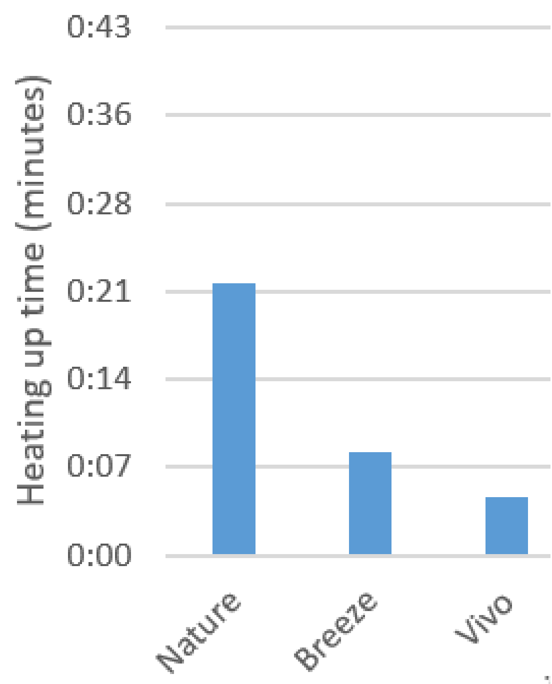

Figure 1. Average heating up times of the existing tickings of Auping

Explorations

During the research we have done explorations with nitinol, a peltier element and different kind of ventilation holes. However, these methods were not suitable as an insulation changing method for tickings because of practical reasons. These explorations can be found in the process booklet in the appendix.

Origami with holes

In the design of the ticking with implemented origami layer, a combination of two insulation changing methods is used. The method is variable, because the origami can be folded flat or closely together, which transforms the structure of the paper (see figure 2).

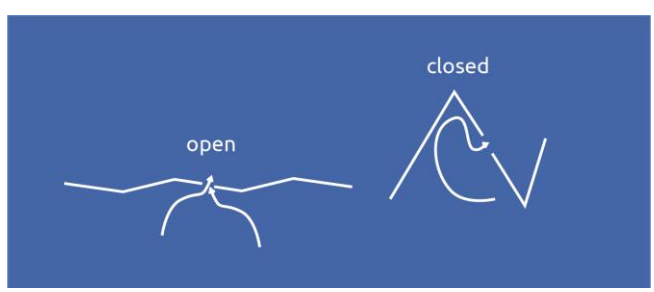

Figure 2. An impression about the air flow through the origami in two states.

We wanted to develop a method that could regulate the heat convection. If convection can be stopped, the measured insulation value will go up in the used setup. If there is a good convection, the measured insulation value will go down.

Because of the placement of the holes in the origami, on the flat areas and not on the folds, the air has to travel a longer way before it can continue to flow to the other side of the ticking. By placing the holes on the folds, it would probably result in a faster heating up of the ticking. By changing how closely the origami layer is folded together, the orientation of the ventilation holes changes, and the amount of air that is trapped inside the ticking changes as well. Presumably the tickings with the origami layer folded flat would have a lower insulation value than if the same tickings would have the origami layer folder up (figure 3).

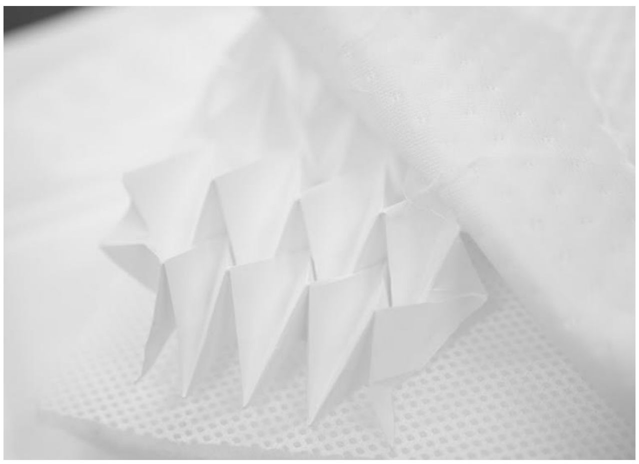

Figure 3. Ticking folded open, showing the origami layer folded up.

Besides that, air has a much higher insulation value than polyether. This means that when the origami is folded closely together, air chambers appear that get filled with extra air, which causes the ticking to be a better insulator.

That is why this method was tested with the vivo ticking, the vivo apparently is, based on our research, the worst insulator. With implementing said method, it should be possible to increase the insulation value.

Vivo with structure changing threads

With this design it was the goal to research the effectivity of the method to change the amount of material the heat had to travel through. The insulation value of a material is dependent on the amount of matter that is there. Two samples of the same material with different thicknesses have different insulation values. The thicker sample insulates probably better than the thinner sample.

This design is variable because the structure of the ticking can be changed by pulling threads that are woven through the layer of climawatt material. When the threads are pulled, the layer of climawatt gets pushed together and the sample gets thicker. If the threads are not pulled, the sample would probably act similar to an unmodified Vivo ticking. This method is tested in the Vivo ticking because it would be increasing the insulation value and the Vivo had the lowest insulation value judging from our research.

Nature with ventilation tubes

The insulating properties of a material can also be reduced if the hot air flow gets redirected better. In this design the effectivity of passive ventilation was tested to redirect the heat flow and to change the insulation properties. This was done by implementing ventilation tubes with holes in them in a ticking, with the tubes ending outside of the sample on the sides.

This design is variable because the ventilation tubes are able to be opened and closed. This method is implemented in the warmest ticking, the ‘Nature’, because it is expected that the ventilation tubes will cause the ticking to insulate less well if the air can move freely. When the tubes are closed, convection is blocked and there is more stagnant air which will probably insulate better than the unmodified Nature.

Nature tested under different pressures

The thermal conductivity of air is a lot smaller than the other insulating material in the ticking; polyether, so when there is less stagnant air in the ticking, it will insulate badly.

For this design we have made a construction that can hold the ticking loosely but also press it densely together for the other test. In this way the amount of air in the ticking can be controlled and make the design variable. By pressing the material together, the insulation value will become lower. That is why the Nature was used, since normally this ticking insulates the best.

STUDY SETUP

The goal of this project is to create a ticking with a variable insulation value and to judge those variable tickings it was necessary to create a frame of reference. This frame of reference is created a by researching if there was a difference measurable between the existing tickings of Auping. A substantial difference was found. The heating up time of the best insulating and worst insulating ticking were used as a reference to assess the newly designed tickings with a variable insulation value.

After the heating up times of the unmodified Auping tickings were found, this information could be used to design the new variable tickings. After these were created, they could be measured and placed in perspective using the created frame of reference. It was chosen to work with the heating up time of the tickings instead of the absolute insulation value, because the measurement setup to measure heating up times was easier to realize and in the design process the heating up time is a more workable unit than the insulation value.

Goal of the measurement setup

The goal of this study is to get insight in the difference in heating up time of various tickings. The goal of the measurement setup is to get data on how long it takes for the testable materials, the tickings, to warm up from 28 degrees

Celsius to 33 degrees Celsius by a climate chamber of 40,5 degrees Celsius.

Testable materials

The materials that were tested in the setup were three unmodified tickings and three modified tickings. All tickings that were used were manufactured by Auping, there were no tickings tested of other manufacturers. The samples of the materials were 15 by 15 cm.

Auping has three main types of ticking. These have the names ‘Vivo’, ‘Breeze’ and ‘Nature’.

The Vivo ticking is designed for temperature stabilization and has an outer layer of 40% Tencel and 60% polyester. The filling consists of a 6,5 mm thick ‘3D-knitting’, 1 cm of polyether and 200 gr/m2 ‘climawatt’ and it has a phase changing material (microencapsulated paraffin) finish. This phase changing material (PCM) is meant to stabilize the temperature.

The Breeze ticking is designed to be cooler than the other tickings and is essentially the same as the Vivo ticking, but does not contain the climawatt material and the PCM. It has an outer layer of 40% Tencel and 60% polyester. Inside is 6,5 mm thickness of 3D-knitting and 1 cm of polyether.

The Nature is designed to be warm and the ticking has an outer layer of 70% cotton, 15% polyamide and 15% viscose. Inside it has 600 gr/m2 50% wool, 45% polyester and 5% of wild silk.

Based on the measurement results of the unmodified tickings, for each exploratory method the best existing ticking was chosen to implement the method. For example, if it was expected that the exploratory method would result in a lower insulation value, the existing ticking with the highest insulation value was chosen to implement this method.

In the ‘Nature’ ticking, ventilation tubes were implemented. These tubes were made of plastic straws with a diameter of 4 mm. Over the length of the tube every 2 cm a hole was cut out, for ventilation purposes. The end of these tubes could be closed with tape in the test to see what kind of effect that had. This ticking is called the ‘Nature with ventilation tubes’.

In one ‘Vivo’ ticking a layer of origami was placed. This layer was made of 80 grams paper and a herringbone pattern was used to fold the paper. This resulted in a structure that could expand and contract almost in a horizontal plane. On the flat areas of the structure, ventilation holes were made of 4 mm diameter. This ticking is called ‘Vivo with origami’.

In another ‘Vivo’ ticking, the layer of climawatt material was cut into strips of 3 cm. Through those strips, woolen thread was woven every 3 cm which could pull together the climawatt material. This changes the structure of the ticking. This ticking is called ‘Vivo with structure threads’.

The setup

For the measurement setup we used a climate chamber (figure 4), an insulating hood (figure 4), two temperature sensors (figure 5), and a container to hold the testable material (figure 6). This was arranged as in the diagram (figure 7).

Figure 4. The insulating hood attached to the climate chamber.

Figure 5. One of the used temperature sensors

Figure 6. The brace that hold the testable material. Sensors are attached as well.

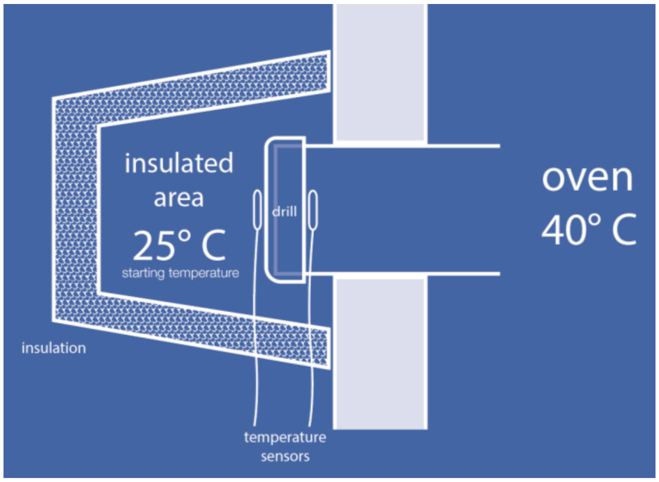

Figure 7. A diagram of the measurement setup, section view. In a hole in the climate chamber a tube is fitted, with the testable material attached to the end. On both sides of the material temperature sensors are placed. An insulating hood is placed over the outside to make sure the measurements are not influenced by the outside.

The climate chamber used is a Weiss type SB111, designed for precise temperature control. The used temperature sensors had a sensitivity of 17,63 µV/(W/m2) with a correction factor of 0,0220 (µV/(W/m2))/°C. The temperature sensors were connected to a Squirrel SQ2020 Series Data Logger, which sent the data of the temperature over time to the computer.

The insulation hood consisted of two buckets, one small and one big, inside each other. Between those buckets there was a layer of PUR-foam for insulation purposes. In the hole of the climate chamber a piece of plastic tubing was fitted, with a piece of rubber to make it airtight. At the end of this tubing there was a wooden brace with wing nuts to hold the testable material. The insulation hood was placed over this brace to make ensure no significant influence from the outside. There were magnets fitted in the hood to attach it to the side of the climate chamber. Around the edges it was taped to make sure no air would flow through.

Procedure

Firstly, in the setup three unmodified Auping tickings were tested. These are called 'Breeze', 'Vivo' and 'Nature'. Following that, three modified tickings were tested, in two states (open and closed). At last we also tested with one unmodified ticking, the 'Nature', what influence it had to pack the material very densely together compared to it being very loose.

There exist several methods to measure the insulation value of a material. Because tickings consist of a combination of different materials, a method using a probe could not be used. The used method, is better suited for the purpose of this research. It does not give an absolute insulation value, but allows the tickings to be compared to each other accurately.

First, a temperature sensor was placed on the inside of the climate chamber, close to the hole in front of which the tickings were placed. This sensor gave clear data about the inside temperature, to make sure it was consistent during measurements.

Second, the hole in the climate chamber was closed from the inside with a stopper. This ensured the climate chamber could not cool down during the preparation of the measurements and the ticking would not heat up before the measurement was started.

After that, the climate chamber was warmed up to 40,5 degrees Celsius, this temperature is significantly higher than room temperature and is close to the maximum temperatures that naturally occur in bed. 40,5 degrees gave enough difference in temperature from room temperature to analyse the difference between the tickings, but ensured that the measurements would not take longer than 50 minutes, which was practical.

Following-up, the sample of the material was placed between the brace and screwed down with a constant thickness of two centimeter. This was done to make sure the thickness of the ticking wouldn't influence the measurements.

This brace was subsequently attached to the hole in the climate chamber from the outside. On the ticking on the outside, a second temperature sensor was placed.

Thereafter, the insulation hood was placed over the brace and material against the side of the climate chamber, making it a closed environment. The small gap between the hood and the climate chamber was closed with tape, to prevent airflow. A tripod was placed beneath the insulation hood to keep it in its place.

To start the experiment, the stopper on the inside of the hole in the climate chamber is removed, and at that time, the measurement starts.

After a temperature of 35 degrees Celsius on the coldest side was accomplished, the measurement was stopped. The stopper was placed back in the hole so the climate chamber would not cool down during removal of the brace with the material and during the placement of a new sample.

The modified tickings have two states, one in which they presumably would have a higher insulation value, and one in which this would be lower. Both states were tested three times. The existing tickings of Auping only had one state which was measured three times.

All tickings were oriented so that the side that normally faces the body was faced towards the climate chamber. At last we also tested with one ticking, the 'Nature', what influence it had to pack the material very densely together compared to it being very loose. This was done by screwing the brace, in which the material was placed, more closely together, which resulted in a thickness of the ticking of 0,5 cm, and a second time the opposite was done by screwing the holder very loosely, resulting in a thickness of the ticking of 2,8 cm.

Analysis

To analyse the gathered data, a file has to be exported to an excel sheet. This results in a file with a single column, so the data has to be parsed. Subsequently, the data has to be identified as numbers, since this does not happen automatically. From the data a line graph is created that gives an overview of how the tickings had heated up over time. The general shape all measurements show is a line that starts steeply sloping, and loses its steepness, approaching an asymptote at 40,5 degrees Celsius. Three measurements of each ticking are done, if one of those measurements is not consistent with the other ones, an extra measurement is performed.

The measurement of the ticking that started at the highest room temperature, was chosen as starting point of the other measurements (point A) (see figure 8). The measurement that was stopped at the lowest temperature, was chosen as the ending point of the other measurements (point B) (see figure 8). In this way, the time it cost to heat up the tickings can be compared. The time measurements of the unmodified tickings of Auping are used as reference points. With those measurements the times of the modified tickings can be placed in perspective. The gathered data was placed in a bar chart to give a clear overview of the times it costs to heat up the tickings and how those compare to each other. (see figure 9).

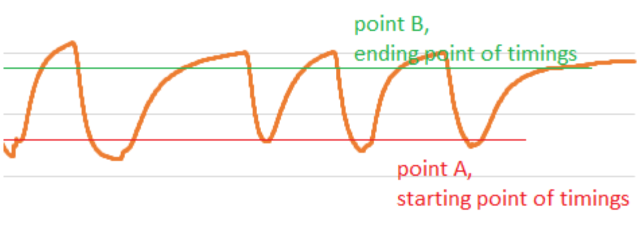

Figure 8. How the measurement data is cut to make sure the starting and ending point are the same.

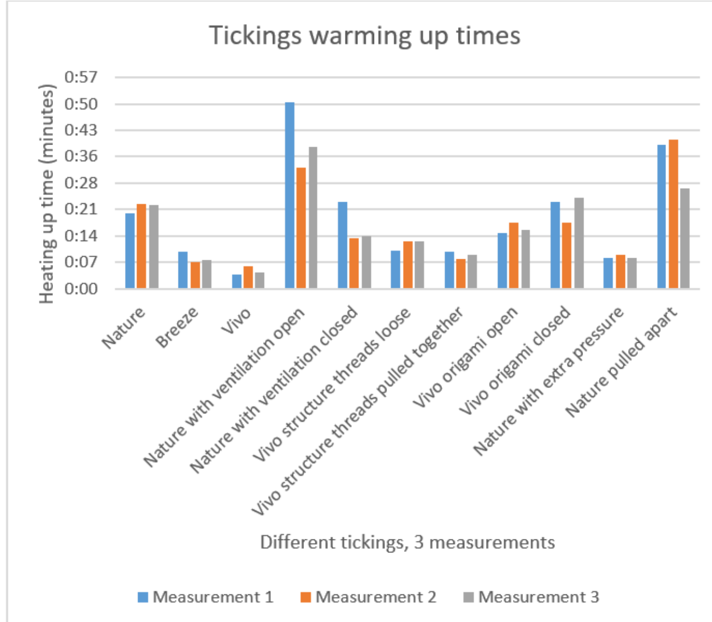

Figure 9. All measurements placed in a bar chart.

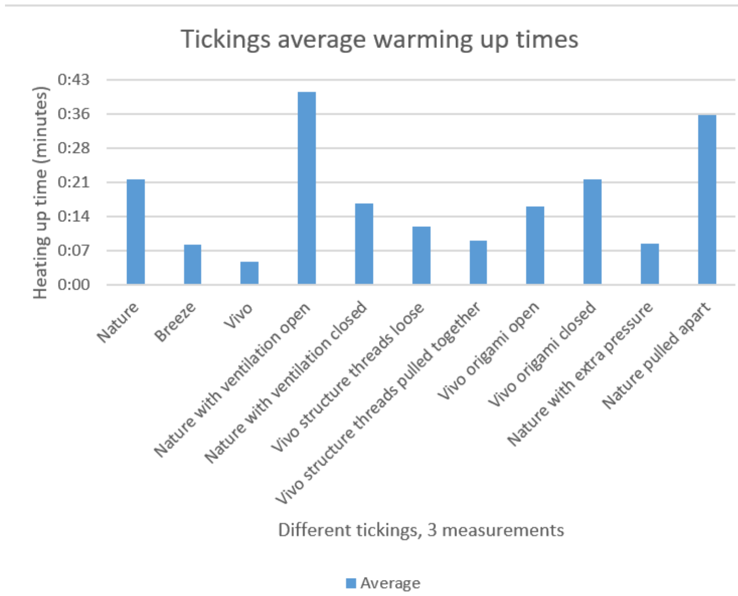

Figure 10. Average warming up times of the tickings in a bar chart.

FINDINGS

In the graph (figure 10) you can see the average heating up times of the tickings. The first three bars are the data from the unmodified tickings. These results were used as a frame of reference to judge how the variable tickings performed. The other bars in the chart are the results of the modified tickings in two states. The last two bars show the results of the 'Nature' ticking tested with two different amounts of pressure applied to the material.

Existing tickings

From the existing tickings there is noticeable difference between the 'Nature', the 'Breeze' and the 'Vivo'. The measurement of the ‘Nature’ is the most noticeable, with a long heating-up time compared to the ‘Breeze’ and the ‘Vivo’. It has a heating-up time of 22 minutes and 12 seconds. The 'Breeze' follows with a heating-up time of 8 minutes and 21 seconds and the ‘Vivo’ takes the shortest time to heat up: 4 minutes and 50 seconds. The 'Breeze' and the 'Vivo' show a measurable difference, but the difference is not significantly big.

Nature with ventilation tubes

The 2 measurements of the 'Nature' with the ventilation either opened or closed show a significant difference. The 'Nature' with the ends of the tubes open showed an average time of 40 minutes and 46 seconds before the equilibrium was reached. The same ticking, but with the ventilation tubes closed took a time of 17 minutes and 11 seconds. This is a difference of 23 minutes and 35 seconds. The already existing 'Nature' takes a time of 22 minutes and 12 seconds, which is in between the two states of the modified 'Nature'.

Vivo with structure threads

The modified 'Vivo' shows a higher warm-up time than the already existing ticking in both of its states. The difference between the 2 states of the 'Vivo' with structure thread is small. The 'Vivo' structure with threads loose shows a warm-up time of 12 minutes and 7 seconds. The 'Vivo' structure with threads pulled together shows a warm-up time of 9 minutes and 14 seconds. The normal 'Vivo' had a warm-up time of 4 minutes and 50 seconds, which is lower than both of the measurements of the modified ticking.

Vivo with origami

When the origami is folded open, close to being flattened out, the warm up time is 16 minutes and 50 seconds. When it is folded together it shows a significant difference with a warm-up time of 22 minutes and 8 seconds, which is similar to the unmodified 'Nature'. The unmodified Vivo has a warm-up time of 4 minutes and 50 seconds, which is lower than both of the measurements of the 'Vivo' with origami.

Nature with a difference in pressure.

The 'Nature' was also tested with different amounts of pressure applied to it, which caused the thickness of the ticking to change. With a thickness of 0,5 cm the warm-up time was remarkably lower than the normal 'Nature', namely: 8 minutes and 37 seconds. With the 'Nature' pulled apart to a thickness of 2,8 cm the warm-up time was 35 minutes and 44 seconds. With the normal pressure applied and a thickness of 2,0 cm the warm-up time was 22 minutes and 12 seconds, which is in between the warm-up time of the other two measurements.

DISCUSSION

Existing tickings

A big difference was measured between the ‘nature’ and the two other tickings, the ‘breeze’ and the ‘vivo’. The insulation values of the ‘breeze’ and the ‘vivo’ are close to each other, this is most likely due to their similar structure. The structure of wool insulates better than the structures of plastic materials.

Nature with ventilation tubes

Interpretation of the results

It is surprising to see that the measurement with open ventilation tubes insulates a lot better than when the tubes are closed. This could be due to our measurement set-up.

The big difference was measured consistently during different measurements, but with the measurement setup we could not discover the causation of this big difference. It could be caused by the air in the tubes heating up and leaving through the ends of the tubes, which causes the air around the ticking to also heat up, instead of only the ticking heating up. This may have resulted in the huge difference in results of the ‘nature with ventilation’.

Limitations

In our measurement set-up we were not able to measure the direction of the heat flow in a ticking. The amount of heat which escaped through the tubes was not possible to measure in the setup. Therefore we were not able to quantify the effectiveness of the tubes.

Vivo with structure threads

Interpretation of the results

It can be seen that the ‘vivo with structure threads’ gave results which are relatively close to each other in both states, open and closed. It is surprising, however, that the structure when the wires are pulled have a lower insulation value than when the wires are loose. This could be because when there is more material in the same place, there is less room for air. This would mean that it would be more effective to put more air into materials with this kind of structure than to make this structure denser, in order to create a higher insulation value.

Vivo with origami

Interpretation of the results

It can be seen that the ‘vivo origami’ give results which are relatively close to each other in both states, open and closed, similar to the vivo with structure threads. There is however, a difference which can be measured consistently.

Limitations

During this research only one origami structure, the herringbone pattern, is measured. Other structures have not been measured and could result in different findings.

Speculation

It could be possible that when other patterns, other materials or when the filling of the ticking is attached to the origami, the insulation value could change even more and result in a greater effect.

Origami has a lot of potential, because the created structures are relatively strong keeping in mind the amount of material that is used. In the future it could potentially be combined with other methods, so that the effect of both methods can be improved.

Nature with a difference in pressure

Interpretation of the results

There is a huge difference in insulation values when comparing both states of the ticking. The effect is as desired, it reached the result of the best insulating existing ticking and almost the result of the worst insulating existing ticking. It can be seen that when more air is trapped inside the structure, the insulation value increases. We have tested the effectivity of this method and it can be seen that with a relatively small pressure difference, only about a centimeter, the insulation value doubles.

Limitations of the research

Consistency

For the measurements, samples of approximately 15 x 15 cm were cut out of the tickings. These samples each gave consistent results. What was not tested is whether or not the whole surface area of the ticking gave consistent values, or if for example stitched areas or the upper part had a higher insulation value than the lower part of the ticking.

Humidity

During the performed measurements, the humidity of the environment was not taken into account. The humidity could influence the measured insulation value. However, the humidity did most likely did not differ much during our measurements, because the climate of the testing environment did not change a lot. In addition, the measurements were performed multiple times at different moments, and the results were mostly close to each other, so probably the humidity did not have a significant effect on the measurements. Otherwise a deviation in the measurements based on the time of measurement would be noticed.

Noticeability for the user

During the conducted research it is not tested whether or not the achieved differences in insulation values are noticeable by the user. This is something which could be looked into in future research.

Auping

We only worked with tickings of Auping as a frame of reference. It is possible that ticking from other manufacturers give different values.

Integration

When researching and designing the new methods, we have not accounted for the technical achievability of implementing the solutions into a ticking that can be manufactured.

Materials

We have only researched possible methods. We have not yet done research about material properties and which materials are most suitable for implementing the designs into a ticking.

Lifespan

We have not looked at whether the tested methods have potential for a long lifespan. More research would have to be conducted to test if the solutions could be turned into a real product and implemented into the tickings.

Units

It was chosen to do a comparative research, in which the insulation value is expressed in heating-up time rather than *W/m2K* which is the standard unit used to express insulation values. This means that our results are hard to compare to materials and products which are not used or researched during this study.

CONCLUSION

To recap, the research question in this study is: How can exploratory methods be used to create a ticking with a variable insulation value and how do those compare to the existing tickings of Auping?

From the measurements of the existing Auping tickings, a significant difference in heating up time was found. The ‘nature’ ticking turned out to be the best insulator of the existing tickings. The worst insulator was found to be the ‘vivo’. The results of the ‘breeze’ were very close those of the ‘vivo’, however, it consistently gave a slightly longer heating-up time.

4 methods were tested to see how big of an effect they had on the insulation value of the tickings. A ticking with an origami layer was tested, a method with ventilation tubes was tested, a ticking with structure changing threads was tested and finally the effect that pressure had on the insulation value of the ticking was tested.

The modified variable tickings show a clear measurable difference in heating-up time if the state is changed.

In the ticking ‘vivo with structure threads’ the least amount of difference between the two states was measured. It was expected that when the threads were pulled, the structure would yield a higher insulation value. However, it turned out to be that when the threads were pulled, the sample insulated less well compared to when they were loose. This reveals that actually the amount of air trapped inside a ticking is more important to yield a higher insulation value than the density of the filling. Aside from this insight, this method is not very interesting to pursue research in, because of the smallness of the effect that it has.

In the ticking ‘vivo with origami’, the amount of difference that was measured in heating-up time between the two states was similar to the ‘vivo with structure threads’. However, the difference was slightly bigger. Still, it is suspected that the difference that was measured is not noticeable by the user. This method has a lot more aspects that can be researched in further studies. These aspects are the origami pattern that is used, the material the origami is made out of, the combination of origami and other methods and the strength in relation to its structure changing properties.

The results that were obtained of the ‘nature with ventilation tubes’ were not expected. There turned out to be a very big, measurable difference between the two states of the ticking. We expected the ticking to insulate better when the ventilation tubes were closed, however, the insulation value turned out to be significantly higher when the tubes were open. There was a big change measured, being a difference in heating-up time of about 23 minutes. The cause of these counter intuitive results is not discoverable by the used measurement setup. Further research is required to get a clear image of the thermal behaviour of this ticking.

The last method that was tested to come to a variable insulation value was very effective and resulted in a big difference in insulation value. The unmodified ticking ‘nature’ was tested when it was pressed together at 0,5 cm and tested again when the material was pulled apart at 2,8 cm. This resulted in a difference of heating-up time of around 27 minutes. When pushed together the heating-up time was similar to those measured of the unmodified ‘breeze’. This method of pulling and pushing the ticking is a quite simple method that might have many possibilities for implementation. For example electronic systems in bed with cables that pull the ticking tight or push them out. This also might be a very interesting area for our client to pursue research in. The ventilation tubes method also showed a very big difference, however, since the results of this tests are counter intuitive, further research is needed as to what is the cause of this difference.

In addition, this research arises other new questions, such as: Is the difference in insulation values during the night noticeable by users and how does it influence the sleeping experience of people? Can these new techniques be implemented into tickings in a comfortable way? What materials would have to be used? How can these methods be used to reach insulation values that are comfortable for the user? How can the temperature of the users be monitored and how can a decision be made as to what a suitable insulation value of the ticking would be? Are the designed solutions durable enough or do they wear out too fast? More research would have to be conducted to test if the solutions could be turned into a real product and implemented into the tickings.

To answer our research question: of the tested methods, adjusting the thickness of the ticking, caused by the changing the amount of applied pressure, has a lot of effect on the insulation value of the ticking. This would also be an interesting area for our client to pursue research in.

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APPENDIX

Unprocessed measurement results

Since these files are not clear when placed in this document, using the following link you can view these files.

https://drive.google.com/drive/folders/1Ltq7t16Ekh8bgtsafjNiXL3LLACNva_k?usp=sharing

Process booklet

Since these files are not clear when placed in this document, using the following link you can view these files.

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Photos of the project

Since these files are not clear when placed in this document, using the following link you can view these files.

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Reflection Joppe Schutselaars

Introduction

This is a reflection of my first research project as an industrial design student. In this reflection my learning experiences, role in the group, contribution to the project, points of improvement and the project process will be discussed.

My first 2 projects were design projects and this was the first research project. For this another mindset was needed and we had to look at things from different perspectives as usual, I found this quite challenging in the beginning, but as the project went along I started to understand better where our focus should be on.

During the first quartile of the semester I was absent for a long time due to several medical complications and a scooter accident, due to this I had to work from home a lot. During this time I took on the responsibility of finding and reading relevant literature and background information.

During the second quartile of the semester I did a lot of different things and helped where needed. Things such as: measuring the drills, testing smart materials, making samples, folding the origami, collecting data and writing the report.

In the end I think we can be proud of what we have accomplished and the progress we have made

Learning experiences

During this project my main goal was to learn how to do reliable measurements and learn about all steps that have to be taken when conducting research. Another goal was to improve my report writing skills and learn to better understand what the purpose of each sub-topic is. I feel that those goals are achieved. I wrote and helped write in a lot of different parts in the report, at first I sometimes had difficulties understanding what the exact purpose was of each part, but after writing a part and receiving feedback on it, I gradually started to better understand this.

Another big learning experience is the fact that during a research project, a person cannot expect to research a wide range of aspects of the topic. First one aspect should be thoroughly researched, after which those results can be used for conducting further research. We wanted to first create the 'perfect' ticking which could immediately be implemented into a ticking. But we first had to only focus on whether or not our designed methods functioned properly and afterwards focus on their usability in real products. If we knew this in an earlier stage we could have started testing earlier, which would have given us more results. This learning experience is very useful for future projects.

Expertise areas and learning experience

Creativity & Aesthetics
This expertise area was partially developed during this semester, mainly during the last quartile when the prototypes had to be made. For this I taught myself how to fold the origami structure needed for our measurements.

Technology & realization
This expertise area mainly developed during the initializing of the measurements. Here W. Van Bommel, an employee of the department 'Building Physics and services'. He told us about the available technologies for measuring insulation values and how each of them functioned. This helped us in finding the best applicable measurement technique for our research.

Math, Data & computing
This is the expertise area which is developed the most during this project. I learned a lot about the use of sensors, collecting data and processing this data. At first I had difficulties correctly transferring the data into a useable excel data and turning these huge amounts of data into usable graphs, but after some extra explanations from Serge I now know how to do this. This knowledge has already shown to be useful for the course 'Making sense of sensors'. I also learned how to work with the referencing tool Mendeley, which has proven to be very useful for referencing in different styles.

Points for improvement
For a next research project there are some things which I would approach differently from what we have done now. I would start of by making a more elaborated planning and try to get an idea of what exactly we want to achieve from the beginning. During this project we sometimes were doing lots of things and gathering as much as information as possible, but without knowing what the exact purpose of those actions was. I feel everything could have been more efficient if we had a clear goal straight from the beginning of the project.

Another big point of improvement is the communication, due to the fact that I was absent for more than half of the first quartile, we had to communicate a lot through Whatsapp or by calling. This made communication more difficult and caused it to often be lacking. I often was not up to date with new developments and new ideas or explorations and when asking questions it often took a few days before I received answers. This in turn made it harder for me to take initiative or think of new tasks for myself, which caused to keep looking into literature and search for background information. This could be improved by for example planning a skype meeting on a set time, 2 times a week every week. In this way everyone would know what each group member is doing at the moment and tasks can be divided more evenly.

Reflection Maxime Vallentin

Introduction with learning objectives
For me this was the first big research project during my study ID. As a result, I clearly got to know the difference between a design project and a design research project. The process that our group has gone through was much more challenging compared to the design projects that I have done so far. The challenge was mainly in finding the right designs for applying the methods we developed. Designing the right process for our research was harder than expected. When we finally had the right process in mind, we were able to get started quickly. Because we had already done a lot of useful preliminary work, we were able to apply the results in our research. This enabled us to accelerate the process and ultimately succeeded in putting our research on different methods into practice within the given time. Moreover, we have obtained interesting measurement results. I am satisfied with the final result.

Expertise areas
During this project I learned a lot in Math, Data and Computing. It is the first project where I have learned to work with very large quantities of numbers. During the measurement we have collected every two second values. This gave us an enormous amount of data that needed to be processed. I have learned how to process these large amounts of data in Excel.

I have also learned a lot in the field of Business and Entrepreneurship. It was interesting to get to know a company as large as Auping from within. I have learned what considerations are made before something is taken into production. Auping sometimes is not taking products into production if the company thinks they do not fit their image well.

In the field of Creativity and Aesthetics I am very challenged in the design and production of different ticking with different variable insulation values.

With regard to Technology and Realization I have made all the Instruments for the measurement setups that we used. It was quite a challenge to think up and produce those instruments.

For the User and Society section, I learned that it is sometimes better for the results to involve the user and society aspect only at a later stage of the research in the process.

Learning goals

An important learning objective was learning to work with a measurement set-up with concrete technical values as result and in which the human factor plays no role at all.

In a design process, a design is first made and tested afterwards. By the delivered data, the bias is often caused by the persons examined. This type of research often involves the experience of the involved people. Moreover, people are very controllable. Also each person is different. In a research project (technical measurement set-up) it is important to consider at a very early stage how the research can be carried out with as little bias as possible. This means that in a research project the causes and types of bias must be mapped out in advance as much as possible and it must be considered how this bias can be prevented. It was very instructive for me to gain insight into this difference in research objects and the differences in bias that arise from this.

Through this project I have learned to identify the factor bias at an early stage and to eliminate it as much as possible in future studies.

Lessons learned

The most important lesson I learned during the project is that research consists of many different sub-studies. Several studies are needed before a method can be integrated into a design.

We have been trying for a long time to take into account the practical feasibility of our methods. Something that is not at all important in the search for methods in an research project. It can therefore also mean that research does not yield applicable results. Something that is almost unthinkable in a design process. Usability is always a very important factor there. Our approach has ensured that we have been looking for a relatively long time for methods to create variable insulation values and only started to measure relatively late. A most important lesson expensive lesson, but a very important lesson. If we had previously thought of this, we would probably have been able to do more tests. However, because we had done so much research, we were fortunate enough to catch up.

I have also learned that when you do research for a company, this does not mean that a perfect design is required from the research. The results can also be very interesting for a company without the results being directly implementable.

During the visit to Auping, we went through a lot of current techniques and discussed many conditions that integrated sleeping comfort systems must meet. After this visit we have become very enthusiastic and because of this we have been trying for a long time to incorporate all conditions that a system must meet in our design process.

I also learned that when you do research for a company, this does not mean that research immediately has to deliver a perfect design. The results can also be very interesting for a company without the results being directly implementable.

During the visit to Auping, we went through a lot of current techniques and discussed many conditions that integrated sleeping comfort systems must meet. After this visit we have become very enthusiastic and because of this we have been trying for a too long period to incorporate all conditions that a system must meet in our design process.

Team dynamics

At team level this was also a more challenging project. Joppe has not been present for almost the entire first quartile due to various circumstances. Even working from home was not really possible for him in those circumstances. During this period communication with Joppe was not always good, partly because it was a fairly long period. The settlement of this came later, because I felt that Joppe never completely mastered the project and therefore did not take as much responsibility and initiative. This was sometimes very difficult and it was quite heavy because it cost me a lot of extra energy. I would really do this differently in the future. I would then try to involve the absent person more in the various decisions.

Reflection Serge Gruson

By means of this reflection, I want to describe, analyse and evaluate relevant topics being my contributions to the project, the collaboration in this project, the design research process and how these relate to the expertise areas and my learning goals.

Learning goals

My most important learning goals were centred around doing reliable and valuable research. In the past I felt like the results of user tests were always a little bit biased, and therefore not as valuable as they could have been. This project was the ultimate opportunity to focus on exact and uninfluenced measurements. I also wanted to develop my skills in writing a research paper, being able to create a clear structure that results in an easy-to-follow paper.

Contributions and the design research process

In this project I have contributed in several ways. I would describe my main role as keeping an overview over the project. I did this by continuously communicating if and how the progress that was made related to the research question. This was very important to keep the project on the right track. Also discussions with our project coach were necessary to keep the right focus in the project. By executing this task I developed the professional skills *Communicating, Collaborating* and *Planning and Organizing*.

Since I was the only group member that had experience and some confidence in writing a research paper, I needed to keep an overview and had a leading role in writing the paper. This strongly developed my abilities to create a clear structure in the paper and therefore I developed a lot in *Research*

Processes. This contribution relates to my learning goal of creating a clear structure and an easy-to-follow paper.

Designing the measurement setup was a group effort. During the project, we discovered that measuring absolute insulation values of the tickings was not realizable given the time and resources we had. Therefore we made the choice to switch from absolute values to comparing the tickings between themselves. This choice allowed us to make more valuable judgements from the done measurements. This choice made me very conscious about how to come to reliable and valuable results, a realisation which I did not have before this project. This helped me *Dealing with Scientific Information* and accomplish my learning goal of getting experience in doing reliable and valuable research.

An expertise area I have spent a lot of time on during this project is *Math, Data and Computing*. I have learned a lot about managing large datasets and how to process them. The datasets obtained by our measurement setup contained data points every second for over a period of 6 hours. This resulted in excel sheets of over 20.000 data points. I had never worked with this before and had little experience in excel, but because of this I learned how to graph this data and quickly analyse it and make charts out of it that we could use in our research.

In the expertise area *Creativity and Aesthetics* there was not a lot of challenge in this project, since no final product was designed. However, during the designing of the different exploratory methods for the tickings, a lot of creativity and perspective changing was necessary to come up with original ideas. Besides that, I also created all the visuals during this project. I have a lot of experience with that and it felt natural to fulfil this role during the project, although it did not challenge me on new levels.

For me it was very valuable to work with a client during this project. The visit to the production facility gave us a very good insight in how the product that we were researching was made and from the conversations with the client I got a clear image of how our research was valuable to the company and which of their customers would be interested in it.

Collaboration

During this project there were a lot of setbacks on a personal and group level which caused the collaboration to be hard. During the first quartile of this project, we missed one group member, Joppe, for the majority of the time. Since the group already was small, this resulted in quite a workload on me and Maxime. It also made us hesitant to start making real progress, as we felt the third member should not miss out on the process. This turned out to be a mistake and resulted in a lot of work later on. After the group member returned, we did not accomplish to involve him completely in the project. I think this was due to a lack of communication from both sides. At the end of the project, when there was quite a big workload, I had several unforeseen personal problems, which resulted not only in less time that I could spent on the project, but also in a less productive way of working due to a lack of concentration. The combination of all those factors lead to a lot of stress within the group. Since I was the only group member with a little experience and insight in writing research papers, I became essential in this part of the project, which increased my workload as well. Therefore the extended deadline that we were thankfully given, was really needed. The learning points that I take from this is that there has to be a very clear planning beforehand and clear communication between all group members, to make sure that, in the worst case scenario, the project will not be jeopardized.

Keeping in mind the major setbacks we experienced during this project, I am very proud of the results that we have obtained and the resulting paper.