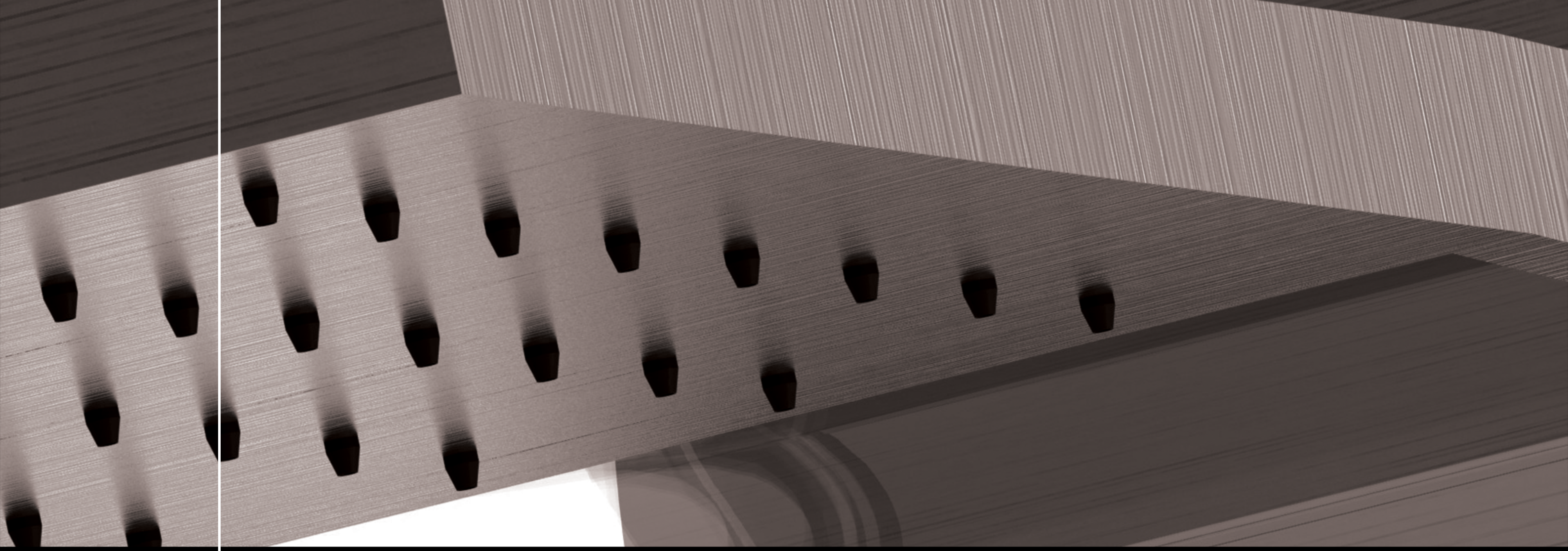

25-03-2013

Bachelor thesis

A DOMESTIC SHOWER

By Elmer Lise

DESIGNING AN ELECTRIC SHOWER USING THIN FILM LAYER TECHNOLOGY

Title page

This report is writen for Carlos Ignacio Zamitti Mammana, Maaike Mulder-Nijkamp, Eric Lutters and Theo Krone.

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A DOMESTIC SHOWER
Designing an electric shower shower using the technology of abinfo

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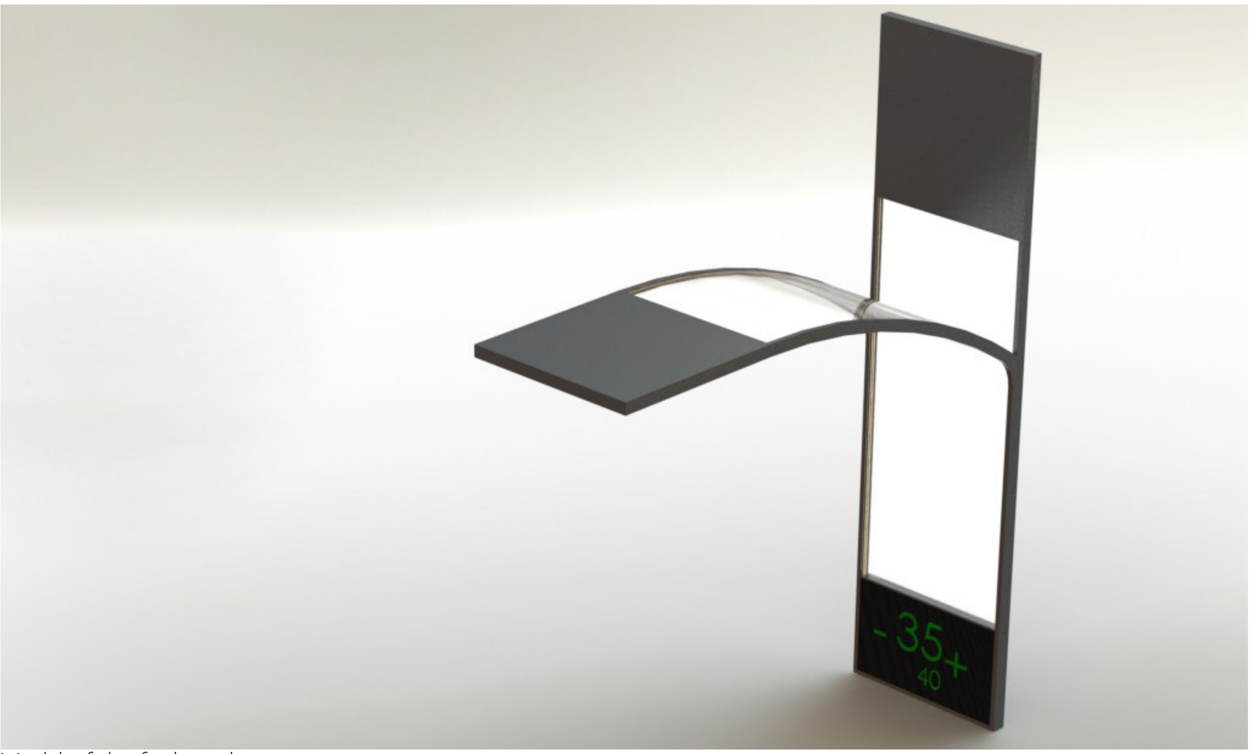
This report is written in the context of my Bachelor assignment of Indutrial Design Enginering.



Model of the final product.

SUMMARY

This report represents a bachelor project about designing an electric shower with the innovative technology, provided by a research organisation. The goal of the project was to design an electric shower for the Brazilian market, using a thin film layer technology. The technology is about using a transparent thin film layer (SnO_2) that is applied to glass; this layer will heat up when electricity runs through. The project starts by analysing the Brazilian market, the products and the mindset. One of the results is the discovery that the quality of the water that runs out of the shower could contain deposits; this will be disturbing because glass is used. The target group where the shower will focus on is upper class people. The environment is also a point of focus, since the technology promises to be efficient. Over 75% of the electricity in Brazil is generated by sustainable energy; this is a suitable theme for the design.

In the design phase the technical elements are pointed out. The shower will be made out of glass. A systematic illustration of the shower is designed. To know what the size of the shower will be, the dimensions of the glass plates are calculated by assuming a particular heat transfer. This results in a space between the glass plates of 2 to 3 mm, and a surface of the glass plates of 0.2 to 0.3 m². The thin film layer will reach a temperature around 50°C, which is favourable because of safety and because there will not be any steam bubbles in the water which negatively influence the efficiency (a problem of nowadays used showers).

The appearance of the shower is generated by using several tools; mind maps, a collage of sustainable energy, form studies of natural and mechanical shapes and a scenario of how to use the shower. From these ideas three concepts are derived. These concepts are elaborated and eventually converted into one concept.

The appearance of the shower became a simplified version of an organic natural shape. This way the shower obtained a clean and elegant appearance. It is a curved shape that protrudes from a rectangular backside and leads to a square water distribution. The water and electricity enter the shower on the top of the backside. A user interface to control the temperature of the water is added on the bottom of the backside. The interface intends to create ecological awareness for the user. The materials that are used are: aluminium for the frame, glass for the heating element and silicone rubber for insulating tracks and the water distribution. The innovative shape and the display will contribute to an economical appearance.

The designed product is meant for a pilot run. There are things that need to be improved. There are several recommendations: The connecting element needs to be elaborated because the current shape cannot be assembled. To avoid the visibility of deposits, the glass could be coloured. When glass is coloured on the inside, the glass will still have its smooth and clean look. Another option is to turn the glasses into mirrors. This will have another advantage. Mirrors can become steamed from the hot water of the shower. When the mirror is heated, which happens when the shower is turned on (because it is the heating element), the water will not condensate. A function that could be elaborated is adaptability of the height of the shower. There also could be a hose with a nozzle added; to have more degrees of freedom of the water spray.

The result is a design of a shower that can be use to show what is possible with the thin film layer technology.

INDEX

Paulista avinue, São Paulo city.

PREFACE

I have been travelling through Europe since I was a little boy, but this time my trip reached beyond the European borders. A fourteen ours flight took me to the fifth-largest country in the world, a country whom is known for its happiness and rhythm, which expresses itself the most in carnival and football, I travelled to Brazil. It is one of the BRICK's, and the economy seems to grow rapidly, especially in the state where I went; São Paulo. My goal was to complete my Bachelor thesis by doing a project at ABINFO. They are focused on enhancing the Brazilian market with their knowledge and expertise; I contributed to this vision by making a design for an innovative shower. I worked on my own and got assistance where I needed it. The result is a design for a shower, which ABINFO can use to show what is possible with their technologic research.

I wanted to get to know the Brazilians and their culture. To accomplish this goal I lived in a 'republica' (a student house) were eleven Brazilians where living. Despite of working at a small sized company, I gathered a lot of Brazilian contacts because the office was located at a university. For three months I lived my live among Brazilians, doing as much Brazilians activities as possible, trying to get to know every detail of this happy and enthusiastic people.

ABINFO

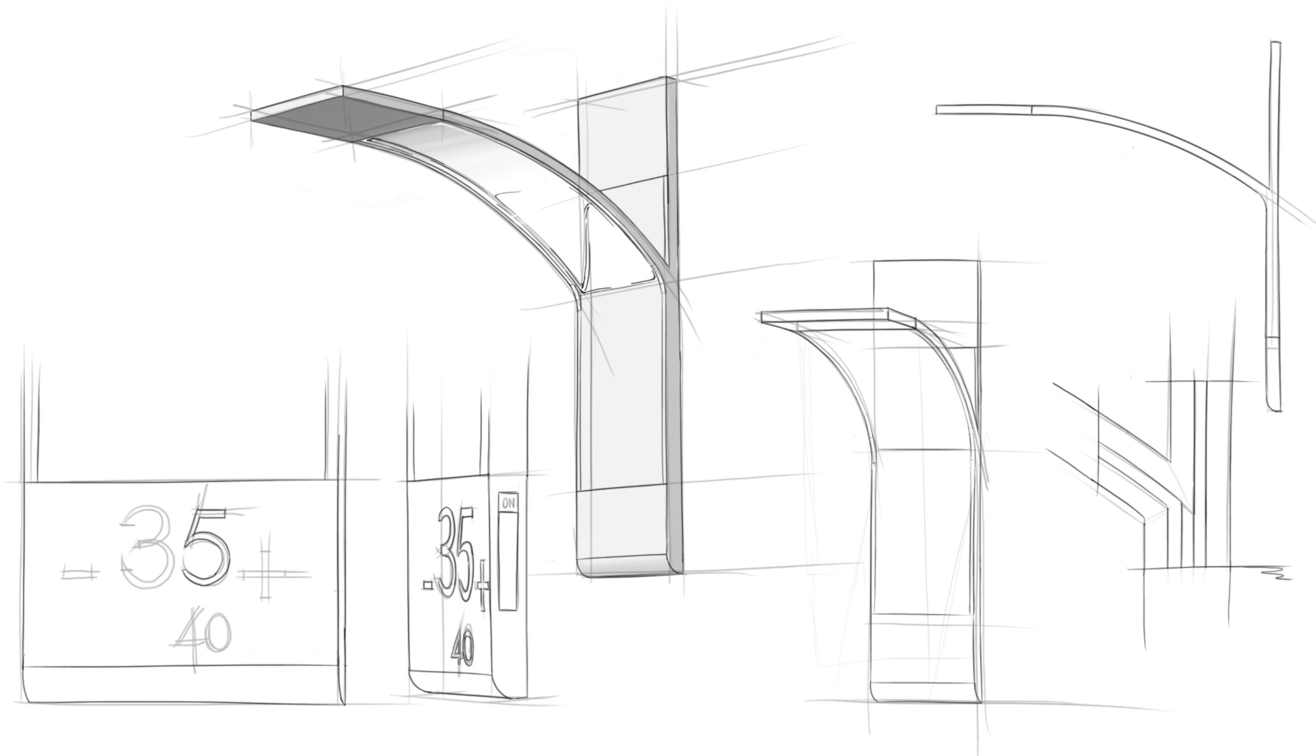
I executed my project at ABINFO, located in Campinas (in the state of São Paulo). This is a non-profit research organization with the goal to strengthen and enhance the Brazilian market. They focus on information technology, technology for energy conservation, ecosystems technologies, technology for improving life and technology for education. ABINFO works in cooperation with several universities, research institutes and companies. Specifically, ABINFO has a laboratory in UNISAL (Universidades Salesianas) that include production engineering formation in its curriculum.

ABINFO is a company that structures collaborative networks involving agents of research, development and industry. They are working on several projects based on electronics. An important occupation is LCD's, they are engaged with the improvement of the quality of LED backlighting of LCD's. Another completed project is a workstation (school desk) for computerized classrooms.

An important quote of Alaide Pellegrini Mammana (President, ABINFO) is: "Our work is to unite efforts in research, development and innovation, aiming to strengthen and enhance the vitality and competitiveness of Brazilian industry in the manufacture of finished goods and materials, devices, instruments, equipment and assets for production resulting in a positive contribution to the areas of life, energy, education and environment."

To work at ABINFO was an exhilarating experience. They gave me the opportunities to broaden my horizon. Being in Brazil itself taught me a lot. But the internship and contact with supervisors, colleagues and Brazilian roommates gave an extra dimension during my stay. Next to my project at ABINFO, I did several other activities. I gave presentations to professors and students from Unisal about my project and about the University of Twenty (I became ambassador of the University for promoting them abroad). Next to that I offered my help for the Latin Display congress which was being organized by abinfo, this work included designing a bag and posters for the congress. Eventually I participated in the congress as well and learned about the top notch of display technology. Next to that I did a cultural research, this ensured me to experience Brazil and its warm and friendly people even more.

I want to say thanks to everybody that helped me in this great experience. My special thanks go to Professor Carlos Mammana, Professor Alaide Pellegrini Mammana and Doctor Daniel den Engelsen who were very inspiring and helped me with all their wisdom. Ricardo Martini who was a great colleague that helped me a lot in my project. And my fellow student and friend Bas Jan Kylstra; I owe this adventure to him; together we had the determination to make it happen.



Base for a presentational drawing

1 INTRODUCTION

Since 2007 ABINFO is doing research on a thin film layer technology used to heat water. This technology is evolved to a concept for a shower. The technology is being tested to proof the principle. There have been successes in the research, but however the technology is not yet fully developed. Besides the technology there is no attention paid to what the appearance of the shower could look like. The last research report is from 2009. Because ABINFO is a nonprofit organization, support from companies or the government is needed to resurrect the project.

The goal of this project is to design a shower using the thin film heating technology. The thin film layer technology is promised to be an efficient water heating method. The physical appearance of the heating element also differs a lot from the frequently used coil heater (which is used nowadays to heat water). It seems that the thin film layer is very suitable for an innovative product. But the technology needs more research; therefore ABINFO wants to show what the possibilities are. The technology will be used to design a new shower, this way they can show the opportunities for this revolutionary technology. If they could get support from companies or the government for more research it would a successful result for this project. This project will ensure that ABINFO will have more tangible matter to show to the rest of the world what their technology is about. As the technology is promised to be efficient, the design process will use a focus on ecological awareness.

To accomplish this goal several disciplines of an Industrial Design Engineer are being used. These includes system design, sketching, form studies, scenario based design, heat transfer calculations, digital drawing and Solid Works modeling. Because the shower supposes to be efficient, an ecologic perspective will be used. In order to achieve the designing, first an analysis is conducted. Sequentially ideas for the shower are generated. These ideas will be refined into one draft. The final draft is elaborated and detailed. The designed shower is linked back to the analysis. Imperfections are discussed by recommendations.

2 ANALYSIS

2.1 Introducing the Brazilian shower

Most of the showers in Brazil are electric; by the word shower, the shower head is meant. Unlike the showers in the Netherlands, the water is heated directly above your head inside the shower head. The water has to be heated in or near the shower because most households in Brazil do not have central heating systems. This is because they do not need to warm the house and it is also due to economical reasons. An electric shower is not a mixing shower, there is only one tap (unless a dwelling has a solar heating system; they are able to mix the solar heated water with tap water). By decreasing the amount of running water, the water will be more heated because the water spends more time in the showerhead. Electric showers are most common all over Brazil[1] (figure 2.02). The diagram shows the northeast of Brazil hardly uses any heating systems for their showers; this is due to the fact that the climate is warm enough that they don't need to heat the water to shower. And this is also a poorer region. In the rest of the country, where it is more usual to heat the shower water, electric showers are dominant. To get a better picture of how these showers are used and what they look like, several bathrooms of Brazilian citizens are visited (figure 2.01 and Appendix A).

Fig 2.01: Common shower.

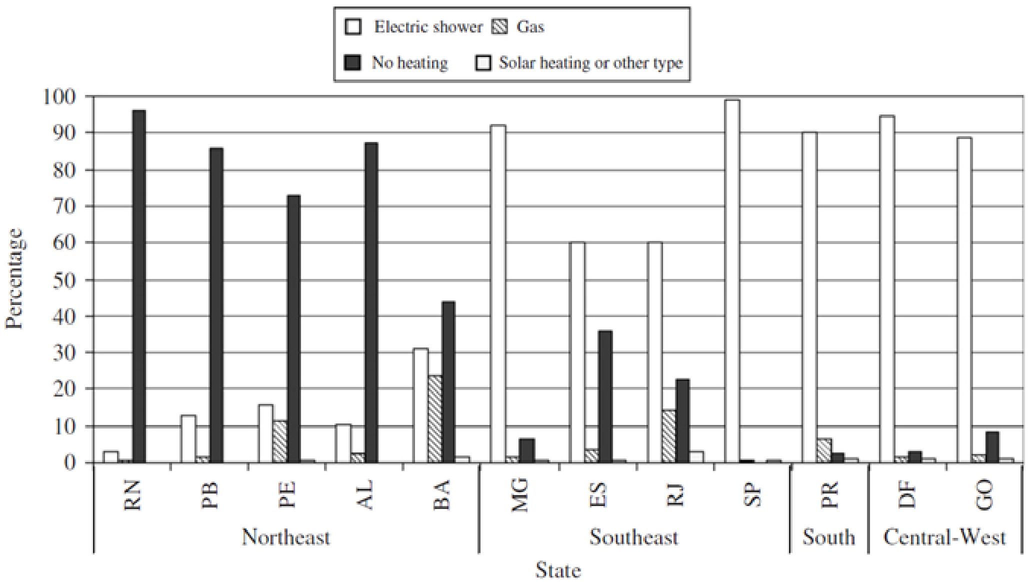


Fig 2.02: Comparison of type heating system for showers in Brazil

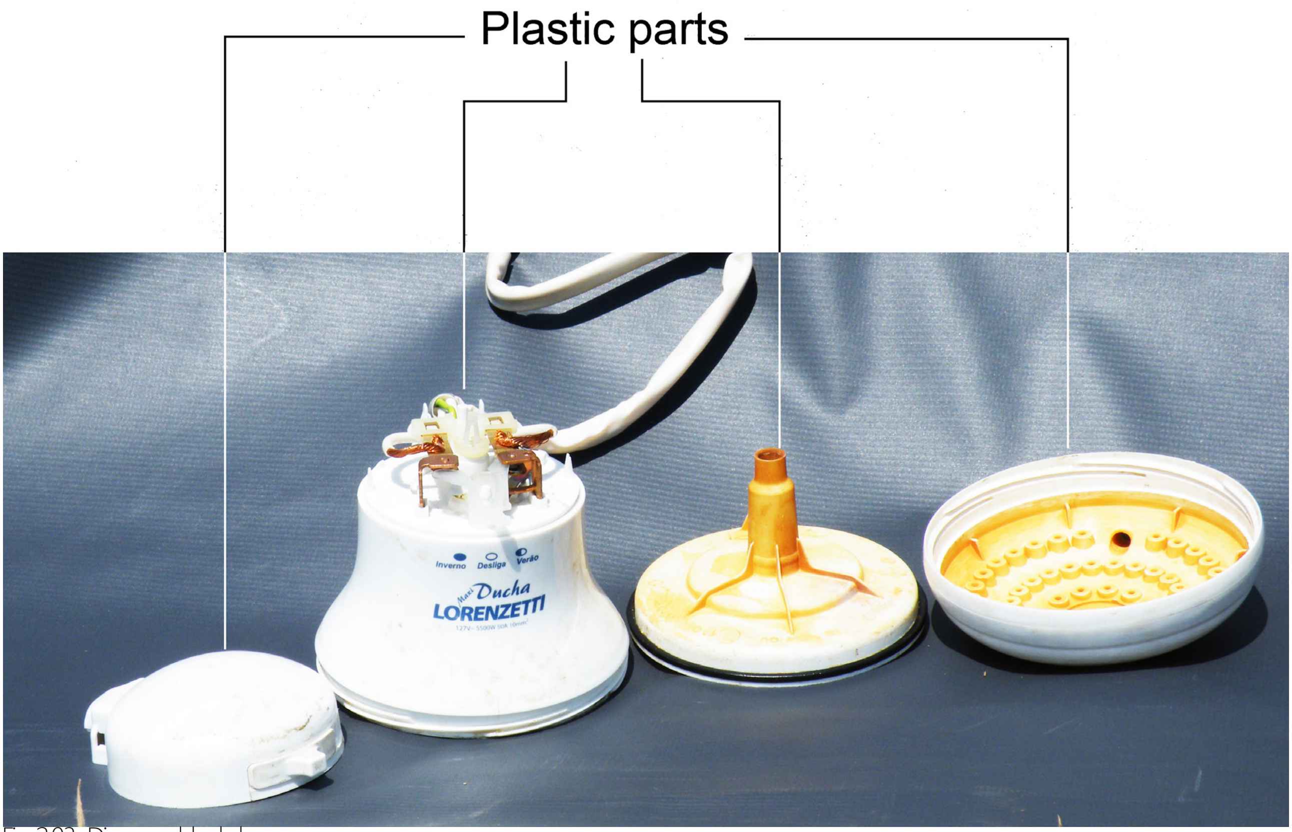


Fig 2.03: Disassembled shower

2.2 The shower dissembled

To discover is principles of a common shower, it is dissembled (figure 2.03). All the parts are examined and analysed thoroughly. Most of the shower consists of plastics. Important is dealing with electricity and water, since both of them together could cause dangerous situations. Next to that an important principle is the power supply; it only works when the water is running. All the parts are described and explained below.

Plastic casing

All parts are being hold together by the casing. It will keep the water inside until it leaves the shower through the holes in the bottom part. And at the same time it will insulate the conductive parts (figure 2.05).

Switch

For the user to choose at what level the water must be heated; there is a switch on the outside of the shower. There are two options: inverno (winter; for a hot shower) and verão (summer, for a shower temperature that is less hot then winter). The switch will ensure the conductive parts to be in the right place.

Rubber disk

When the shower is not used, there must be no electricity running. A rubber disk seals the lower part of the shower from the upper part (where the water comes in). When the tap is opened to let the water run, the force of the water makes the rubber disk to lift. The rubber disk is connected to a conductive part which completes the circuit when it is lifted. This way the coil only heats when the water is turned on (figure 2.04).

Conductive parts

The conductive parts ensure that the electricity runs through the right circuit. These parts contribute to the mechanism of the rubber disk.

Wiring

To get electricity from the power grid there are wires. There are two wires that will power the shower and a third wire reaches to the lower part of the shower. The purpose of the third wire is to ground the shower so there will not be any danger of getting electric shocks touching the shower.

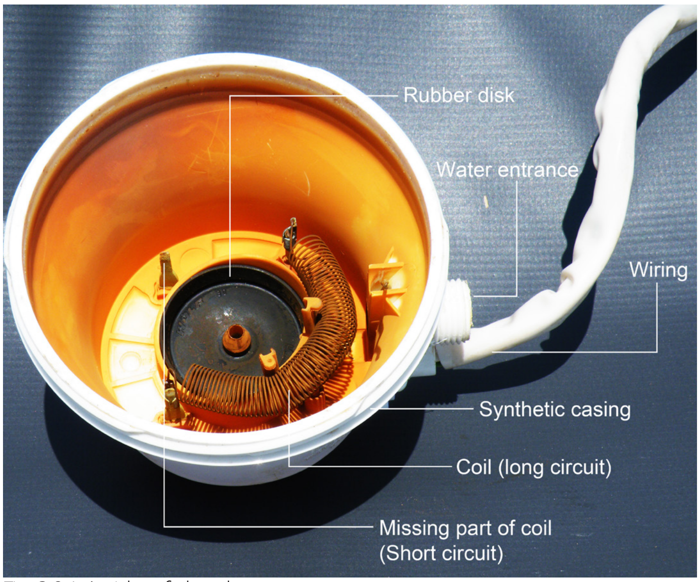


Fig 2.04: Inside of the shower.

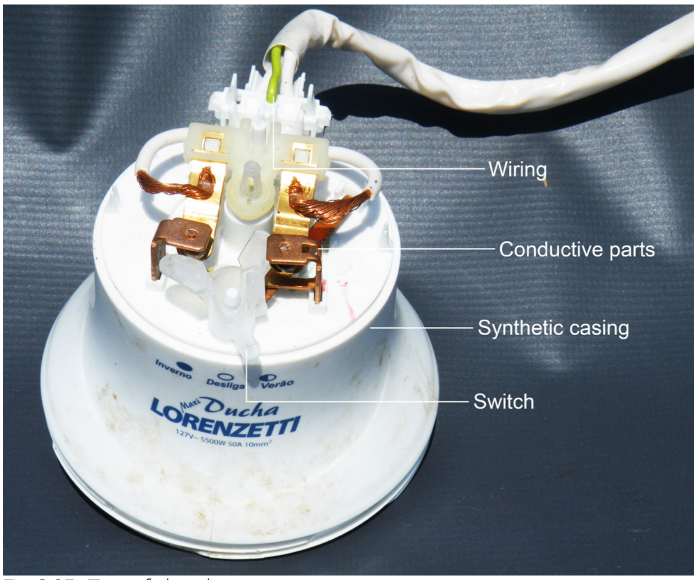


Fig 2.05: Top of the shower.

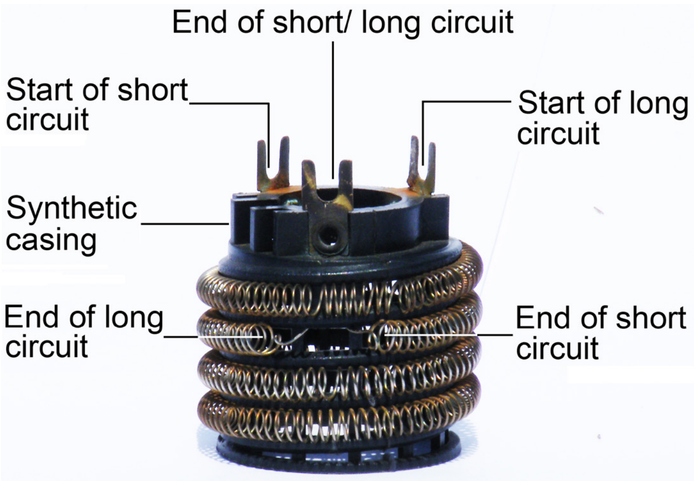


Fig 2.06: A type of coil used in shower

Coil

The part that heats the water is the coil. It is made of Nichrome; an insulating support keeps it in place. The coil has two circuits; a long circuit that heats the water a little (summer mode), and a short circuit that heats the water a lot (winter mode). At the top of the coil there are three contact points. One that leads to the two circuits and other two will determine which circuit is being used (figure 2.06).

2.3 Heating the water

To make sure the water will heat enough, the volume of the upper part of the shower is about one litre. It forms a buffer; the water that comes in to upper part will stay there longer when the space is bigger and it has time to be heated. The size of the coil is relatively small, so there will be a lot of water that will not be near the coil. Therefore the water that is near the coil has to be heated more than the final temperature of the water that runs out of the shower. The temperature will be distributed through thermo conductivity but also by mixing the hot water with colder water running together to the lower part of the shower, this way the water gets the right temperature. Another phenomenon that appears are steam bubbles resulting from the high temperature of the coil.

Fig 2.07: Result of deposits in water

Fig 2.08: Sample of water from a water reservoir.

2.4 Quality of water

The water that is running through the households is not completely clean. During years of showering the result of the water becomes visible, as to be seen in the figure 2.07. Households in Brazil have large water reservoirs, usually located in the top of the house. This tank makes sure that there will always be enough water, and pressure on the water pipes. During the cleanup of this kind of tank, a sample has been taken to see what the water looks like (figure 2.08). Although this sample is concentrated, it shows that the water is not completely clean. Although this dirt could be caused by film on the inside of the tank, which could be broken during the clean up, in consultation about this subject with a professor* it was clear that there are deposits of aluminium and mud in the water.

* Doctor Eliezer Baron

Fig 2.09: Showers in the supermarket.

Fig 2.10: Showers suitable for a central heating system.

Fig 2.11: Two images of advanced electric showers.

2.5 Shower in stores

To get a clear picture of where the costumers buy their showers, a shopping mall is explored. The first place where shower where found was in the supermarket (Figure 2.09). One shelf filled with showers and replacing parts provides the most basic showers. The price range runs from R$ 22,- to R$ 99,- and new coils cost R$ 9,- to R$ 27,-. Power specifications run from 3000 W (economical mode) to 6800 W. In general a main voltage of 127 V or 220 V is used.

The second place where showers are sold is a small sized parts shop. There are more special versions in this shop, but the range is limited (5 different kinds of showers). All showers in both stores are characterized by white plastic casing and relatively large size (because the water has to be heated inside the shower). The place where the largest range of showers is located, is a home products store (called Telhanorte). This is the kind of store that sells lighting, kitchen products, bathroom products and construction materials. There are several stores like this, next to these stores there are also smaller ones (Appendix B show a smaller store where showers are sold). They do not only sell electrical showers but also showerheads for houses which have a central heat system. It is clear that the price range for the central heat showers is higher than for electric showers. This is due to the fact that a central heating system is mostly used by wealthier people**. These are the people that more easily

** Information retrieved from conversations with Brazilian inhabitants with an age of 20 to 30.

want to spent more money for a better looking shower. These showers are all made of metal, and have a chrome appearance. Next to that shapes are more divergent compared to electric showers (figure 2.10). The prices of the central heat showers are R$ 100,- to around R$ 3000,-. This is in great contrast with the electric showers; their price runs up to around R$ 400,-. But most of the electrical showers have a price beneath R$ 100,-. The electric showers can be divided into 2 groups: The basic shower; it is a shower that heats the water with 2 or 3 different levels of heating; this is the shower which is explained earlier in the report. The second group is the advanced shower; these are showers which claim to have something extra. This can be a pump to increase the water pressure, more options for level of heating, or an extra hose with a nozzle to have more degrees of freedom. Figure 2.11 shows two images of advanced electric showers. Figure 2.12 shows a summary of the researched showers.

Financial situation

Figure 1.03 shows how income is distributed per state in Brazil. The groups are divided by multiplications of the minimum wage, the minimum wage in Brazil is R$ 622,-[3]. To specify a middle class the wage of 3 times till 10 times the minimum wage is being used. In the chart it can be seen that there are more poor people in the north and the northeast of Brazil compared to the rest of country. The southeast is the wealthiest region. In general it can be said that there is a lot of difference between the levels of income. There is an upper class with a lot of money. In the Southeast, where Campinas (São Paulo) is located, the upper class is the largest in all Brazil.

	Electric (basic)	Electric (advanced)	Central heat (gas / electric)
Voltage	127 V or 220 V	127 V or 220 V	220 V (if electric)
Power	3000 W to 8000 W	3000 W to 8000 W	x
Price	R$ 20,- to R$ 100,-	R$ 90,- to R$ 400,-	R$ 100,- to R$ 3000,-
Characteristics	-about 1 litre (size) -Plastic -Shapes are similar -2 or 3 heating options	-1,5 to 2,5 litres (size) -Plastic -Several options of temperature -Pressure pump -More attention paid to appearance	-Metal -Size can be small -Wide range of shapes

Fig 2.12: Summary of market research.

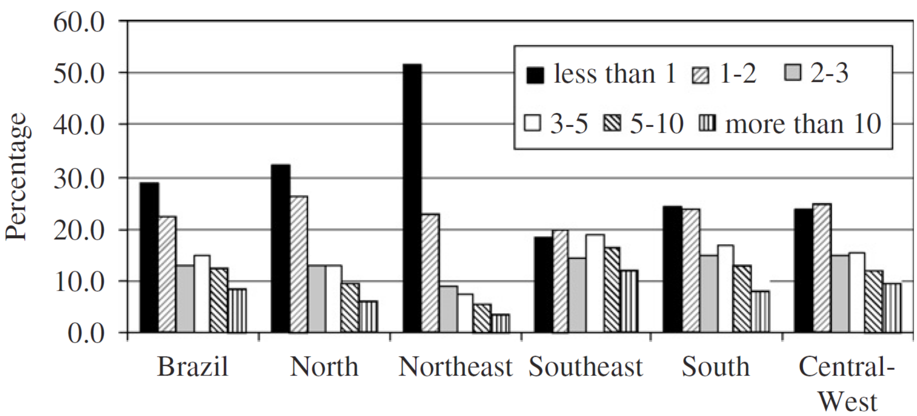


Fig 2.13: Distribution of income in Brazil

2.6 Target group

To determine a target group several aspects must be taken into account. At first there is to be determine in which layers the Brazilian society can be divided. Within these layers there are several groups to name.

At this particular moment in the project, some assumptions are made which later on might be reconsidered; the technique of the shower will be suitable for a proper appearance. Producing the product will be more expensive, caused by a relatively small production quantity and changes in production process. The shower will be in the high class range of electrical showers (advanced shower). So the consumer group can be defined as people who want to pay more for a better looking and more efficient shower. To let the design enter the market, the focus will be on ecology minded. To show that the technique that is used is different en innovative, it is important that appearance of the shower differs from common showers. The ambiance of the target group is shown in a moodboard (figure 2.14).

Fig 2.14: Moodboard of target group.

Summarizing

- Relative high costs
- More attention paid to appearance
- The product will be ecological
- Intent for high class
- Efficiency is a USP (unique selling point)
- Shower will have a different appearance compared to common showers.

3 THE NEW TECHNOLOGY

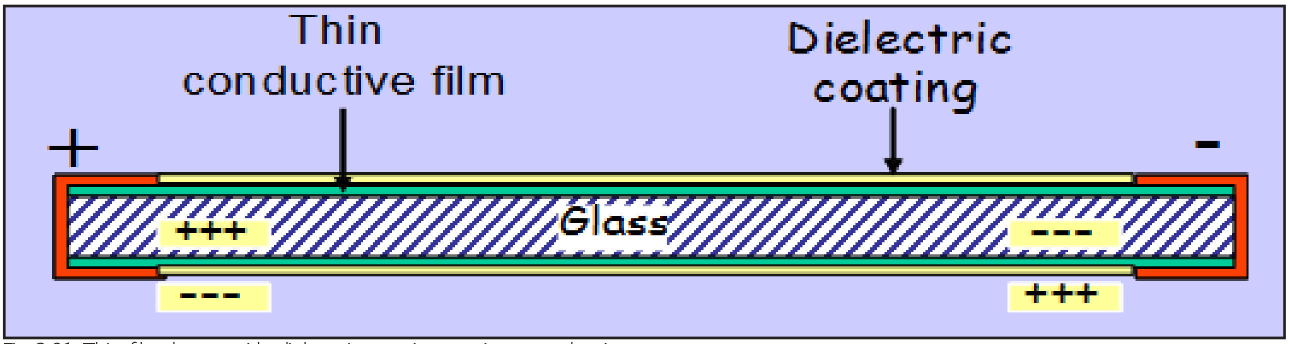


Fig 3.01: Thin film layer with dielectric coating against conductive water.

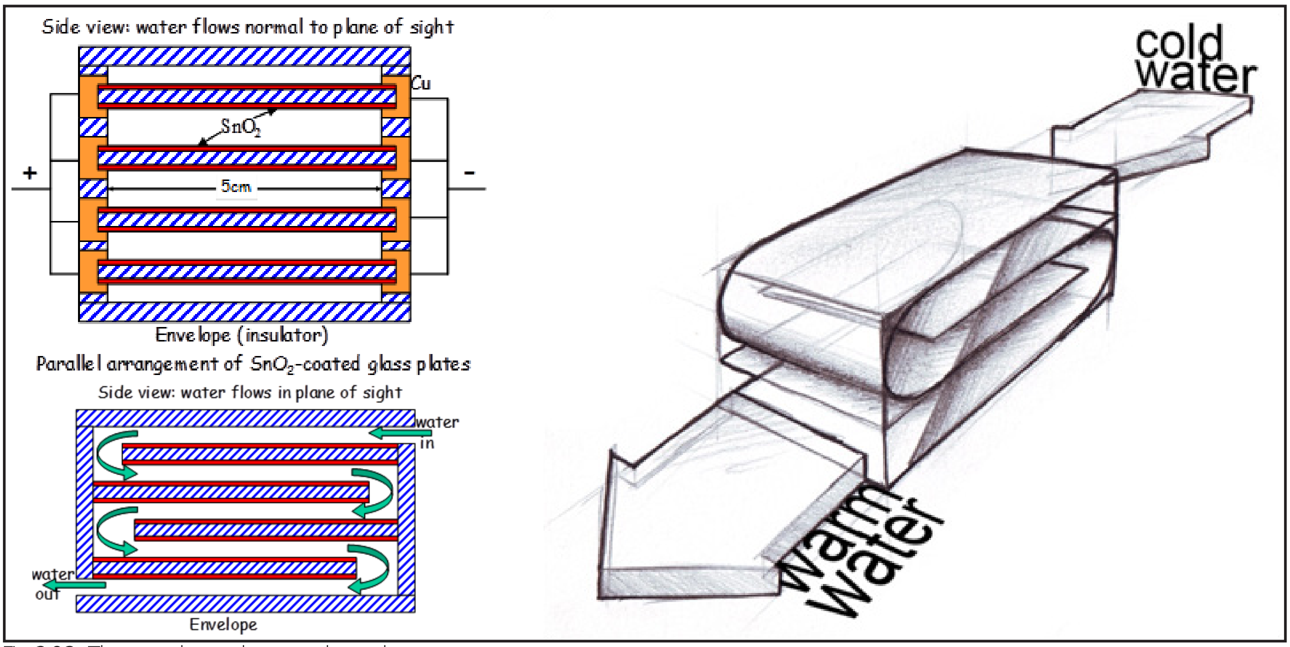


Fig 3.02: The envelope shape to heat the water.

3.1 Thin film layer

Although NiCr-coils are most common in Brazil, the problem is that they corrode (especially in water with high conductivity). Next to that the coil heater has a disproportionate appearance because most of the consisting components are placed inside the shower head.

ABINFO developed a concept for a new shower using thin transparent or opaque resistive films as the heating element. These heating elements can be produced with well-known industrial processes such as CVD, sputtering, silk screen printing, glass parts fabrication, assembly technology and microprocessor control. The thin film heater is cheap, high efficient (>98%), can be designed without corrosion and enables a new way of design (e.g. a transparent shower head).

Glass is coated with SnO2, this layer generates heat when power runs through. The SnO2 layer will be coated whit a thin insulating film (such as transparent silica). The insulating film keeps the SnO2 from corroding (figure 3.01).

To heat the water slowly it needs to go a long way (compared to the common heating). In common shower the temperature of the coil is relatively high to heat the water, due to that fact steam is formed and this will cause heat loss. Because of this the shape of the heating element could be different, for instance the shape of a queue for a theme park ride can be used. In this project this shape is called 'envelope' (figure 3.02). The water flows back and forth, passing the heating element.

Fig 3.03: Test model for thin film heating.

Rough surface

To improve the heating of the water, ABINFO is working on a high roughness of the surface. The rough surface will increase turbulence and convective heat transfer. The scale of the roughness lies in the range of millimetres.

Tests

Numerous tests have been executed in the development of the technology. Figure 3.03 shows a test model to measure the temperature of the water before and after running through the model. The white casing encloses the glass with the thin film which generates heating when electricity runs through[3].

Summarizing

- The temperature of the heating element should be as low as possible: this will maximize the efficiency factor, and it will minimize corrosion during life.
- Water heating will be improved if the roughness of the surface is high, because of the formation of turbulence.
- Shower must stay clean, or is easy to clean.

3.2 Environment

As the new design for the shower will focus on ecologic minded, the environment in relation with the shower will be reviewed. It is said that in Brazil the widespread use of electrical showerheads for providing hot water for domestic consumption contributes to a load curve that peaks in the early evening, imposing a considerable burden to generation, transmission, and distribution utilities. On average, over 73% of Brazilian households use these 3-8 kW electrical resistance showerheads. In some of the more temperate climate regions in the south of the country, where most of the Brazilian population is concentrated, electrical showers are present in over 90% of residential buildings. For the residential consumer, while these high-power heating devices are the least-cost investment alternative, they lead to high running energy costs. Furthermore, due to their very low load factor (typically below 2%), each of these high-power showerheads results in considerably low return on the high investment costs in terms of infrastructure for the electricity sector. Particularly in low-income dwellings, electrical showerheads represent by far the highest electrical loads, resulting in a considerable component in the monthly energy bill[4].

Brazil wants to evolve when it comes to renewable energy. In the future, as natural finite sources are running out and polluting the environment, there will be more focus on environmental consciousness.

Generation capacity (GW).

Year	Annual electricity capacity (GW)							
	Coal	Oil	Natural gas	Hydro	Nuclear	Biomass	Wind	Total
2010	2.42	1.43	13.50	78.74	1.97	6.44	0.65	105.15
2015	2.42	1.43	17.50	95.13	1.97	10.44	1.35	130.23
2020	2.42	1.93	18.00	121.60	3.31	13.44	1.85	162.55
2025	3.42	1.93	20.00	150.06	3.31	13.44	2.85	195.01
2030	3.42	2.43	22.00	169.82	3.31	15.44	2.85	219.27

Fig 3.04: Development of power generation in Brazil.

Renewable energy

Brazil possesses a large variety of climates and the planet's greatest biodiversity. This characteristic places the country in a very advantageous position in terms of the availability of natural resources but, the challenge is to exploit these sources in a good way. The way of generating energy will mutate in the future, figure 1.16 shows the prospect of this changes. Hydro power generation is the leader, and will be the leader in the future[5].

Renewable energy offers a range of options with which to meet the growing demand for energy, particularly in the context of the pursuit (especially in developing countries) of economic development which takes into account social and environmental issues. Brazil has abundant natural sources of renewable energy, such as wind and solar power, hydraulic energy, small hydrœlectric plants, ethanol and biodiesel. These sources form part of the Brazilian strategy aimed at satisfying the demand for 6300 MW of fresh capacity per year arising out of projected economic growth of 5.1% per year over the next 10 years. Renewable energy sources currently provide 47.2% of the internal supply of primary energy in Brazil. Brazil has been pursuing a strategy of maintaining its renewable energy matrix and developing and providing incentives for further low carbon initiatives[6]. More than 85% of the renewable electricity is generated by hydro power sources. Despite this large fraction of renewable energy resources, less than 0.3% of the national energy supply comes from solar or wind sources[7].

Summarizing

- The shower will get focus on renewable energy. The design will communicate renewable (water-, wind- or sun-) energy to the consumer.
- Environmental consciousness could be communicated (amount of water used to shower/temperature of the water).

4 TECHNICAL DESIGN

In the analysis (chapter 2 and 3) several aspects concerning the development of a new shower have been analysed, subsequently a concept for a product is developed. To create ideas for concepts the product is separated into two aspects; the technical design of the product and the appearance design of the product. First the technical aspects are taken into consideration. Secondly the appearance is created (chapter 5). In the first part of the design phase the ideas are diverted to get a wide perspective. Later on in this phase these ideas are converted into three concepts (chapter 6). From these concepts one is chosen and will be further elaborated.

Fig 4.01: Common locations of connections.

4.1 Technical elements

For the shower as a product, the function is a very important aspect. To develop the concepts it is essential to take the aspects that make the shower function into account. Figure 4.01 shows where the connections are located in a common bathroom. In case of the new product the heated water that runs out of the shower is a combination of cold water from the water reservoir (located at the attic) and heated glass; the contact between these two elements ensures that the water that runs out of the shower is the right temperature. To heat the glass there must be a certain electric power running through the thin film layer that is applied onto the glass. It is common that the wiring is located above the water supply. At this moment the electric power is controlled with a simple user interface on the shower head, the user can choose between two options of heating (paragraph 2.2; Switch) and an option to turn off the heating. There are more extensive versions on the market, which are able to control the temperature like a volume control on a stereo (figure 4.02). This kind of control regulates the amount of voltage by changing the resistance. This principle is interesting for the new shower as well. The new shower is supposed to get a more sophisticated interface; the interface will be elaborated later on.

Water supply

Besides the power supply the shower needs a water supply. Normally the water supply is started by opening the water tap. This might be reconsidered because there is a possibility to control this with a user interface. This is an aspect that will be discussed during the concept development. To give the user a good experience of the heated water; the water that runs out of the shower has to be distributed equally over a large enough area. This could be integrated in the glass plates, or it could be a separate part. The decision how to distribute the water is for later concern as well.

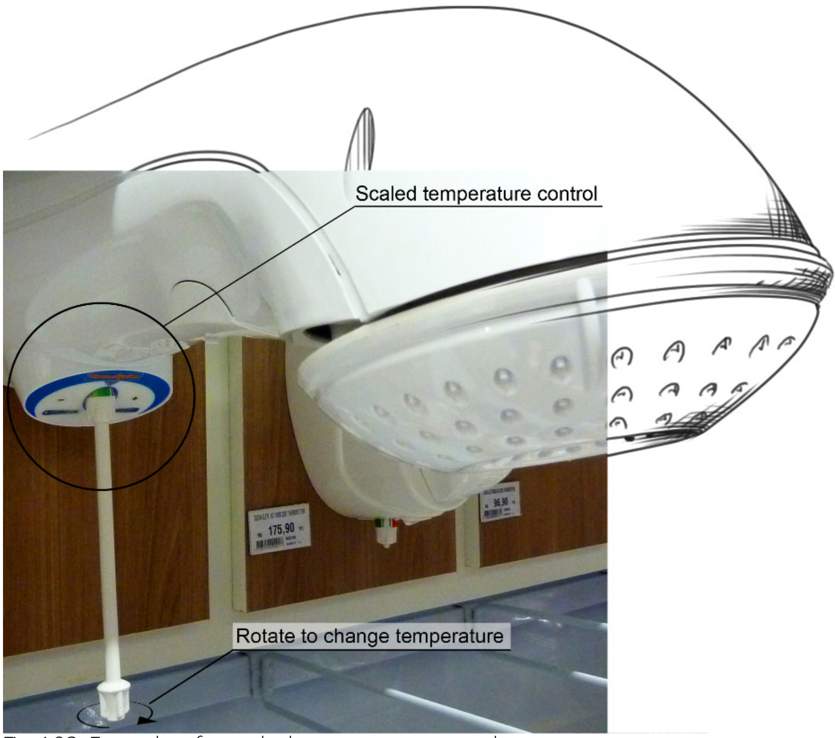


Fig 4.02: Example of a scaled temperature control.

System design

All the elements that will be used in the shower are mapped systematically. Figure 4.03 shows a systematic illustration of the elements of the shower. These elements are all essential for the product. The system diagram will be used to see which parts need to be connected. It is also used to think of what shapes the elements should get. Some parts of the shape is obvious, for instance a power supply will be obtained by wires.

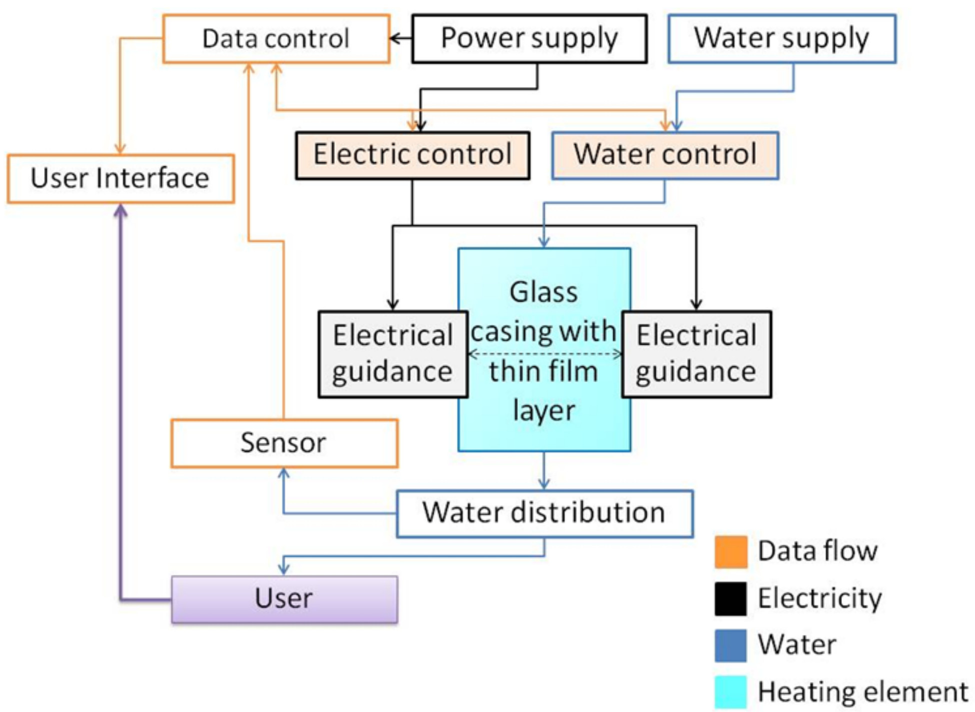


Fig 4.03: System design of the shower.

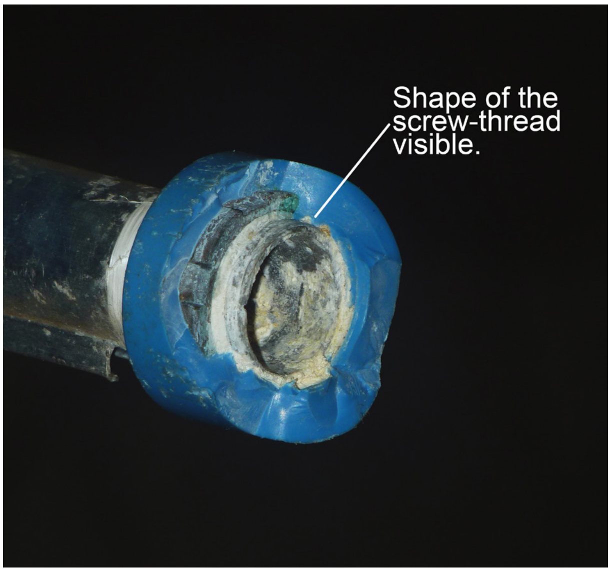


Fig 4.04: Two photos that show the connection of the pipe.

Connections

The most important parts concerning the technical aspects are the electrical parts and the water supply. It is important to supply enough power to the thin film layer, and make the power controllable; because having control over the temperature is pleasant for the customer. The connection to the water supply will be a point of concern as well, because the water supply must be connected properly. Water leakage should be avoided. Regular used showers are connected with a pipe which is mounted to wall through screw-thread. Figure 4.04 shows a broken shower pipe; a piece of the wall is still on the pipe (blue plastic).

Technical requirements

To improve the design process there are requirements defined. Now that the technical elements are explained, the most significant technical requirements are formulated.

- The glass must enclose the water, until the water arrives at the holes for exiting
- The size of the glass will generate enough heat to warm up the water
- The glass must have a strip of metal on both sides to guide the electricity
- There have to be as much turbulence as possible in the water when it runs through the shower.

4.2 Heat transfer

The sizes of the glass plates, which are going to be used for heating of the water, are going to have certain dimensions. To know what range of magnitude has to be used, several equations are used to calculate what the properties are going to be like. The equations are retrieved from the patent of ABINFO[8].

The transfer of heat per unit of time (power) from the heating element (coil or thin film heater) to flowing water is described by the cooling equation of Newton:

$$W = \alpha S(T_C - T_W)$$

W = Power
α = Heat transfer coefficient
S = surface area
T_c = Coil temperature (or thin film heater)
T_w = Water temperature

In this equation is 'W' the power needed to increase the temperature. 'Alpha' is the heat transfer cœfficient of water. 'S' is the surface of the thin film layer which produces the heat. Tc is the temperature of the thin film layer and Tw is the temperature of the water.

To prevent loss of efficiency as much as possible, it is assumed that it is important that TC should be low, preferentially below 100°C (to prevent steam formation). Furthermore, a low TC is favorable to reduce the corrosion of the heater element. This leads us to the first design principle for heaters to be used in domestic showers.
To create an equation which shows the design parameters, the equation for the heat transfer cœfficient is used:

$$\alpha = \frac{k \times Nu}{D_h}$$

α = Heat transfer coefficient
k = Heat transfer of the fluid
Nu = Nusselt number
D_h = Hydraulic diameter

Where 'alpha' is the heat transfer cœfficient of water. 'k' is the heat transfer of the fluid, in this case the fluid will be water. The Nusselt number 'Nu' is the number which represents the level of convection. For a fully developed laminar flow the Nusselt number is 8.235. This is the number which is used in the calculations. The 'Dh' is the hydraulic diameter this is the result of the equation which takes the distance between the two plates into account (figure 4.05). It the width of the channel is far more high then the height, the hydraulic diameter can be defined by multiplying the height (h) by two.

The heat transfer cœfficient equation is implemented in the cooling equation of Newton:

$$W = \frac{k \times Nu}{D_h} \times S(T_c - T_w)$$

Because it is useful to know what the hydraulic diameter and the surface area have to be, the equation is rearranged. The result of the equation will be '$T_c - T_w$', this is the average of the difference between the temperature of the coil and the temperature of the water during the heating (so it can be called ΔT_{av}). It is favourable that this number is low.

$$(T_c - T_w) = \frac{W \times D_h}{k \times Nu \times S} = \Delta T_{av}$$

This equation can be used to determine design parameters. These are the parameters that can be changed within the design, and also partly determines the design. If the surface area has to be big, probably, the shower will be bigger. When there is a solution to the equation, either the hydraulic diameter or the surface area can be chosen. The parameter which is chosen to give a certain value, determines that the other parameter is the output.

Design parameters (figure 4.05):
D_h, S

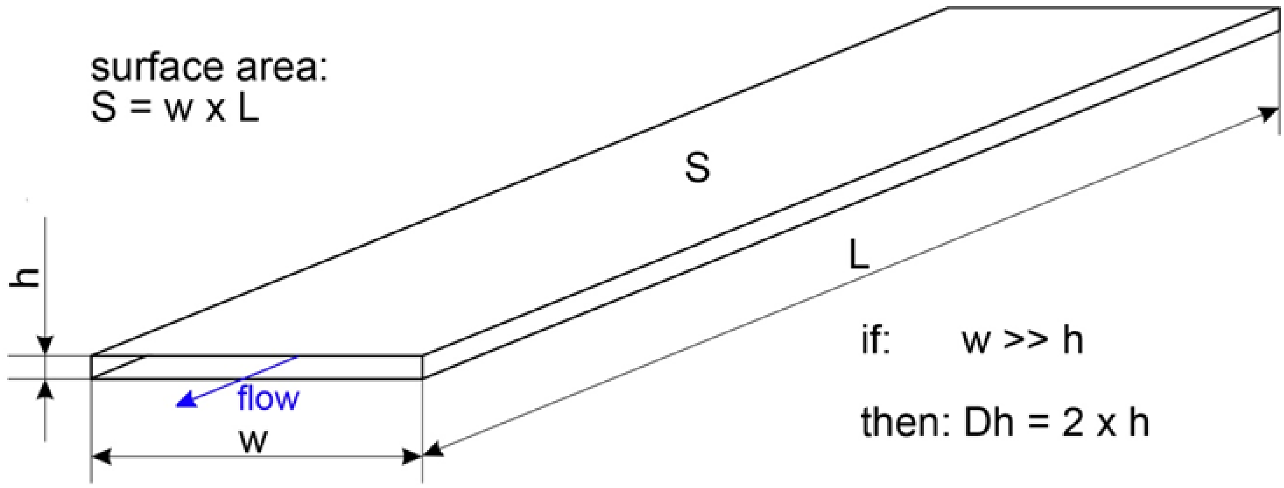


Fig 4.05: Dimensions of the heating element.

Next to the design parameters there are values that cannot be chosen, like the heat transfer of the water. These are the functional requirements. The Nusselt number can differ, depending on a laminar or turbulent flow. But to calculate, it is assumed that there is laminar flow in the water. So the Nusselt number is a fixed value.

Functional requirements:
k, Nu, W

Calculation example

Using the previous equations it is possible to make a calculation example. The power is calculated with the equation of 'heat capacity', using a water flow of 3 L.min-1 to calculate the mass (0.05 kg.s-1), the heat capacity of water which is 4186 J.Kg-1.K-1 and a temperature difference of 24 °C ($T_{e(nd)}$ - $T_{s(tart)}$ = 40 – 16 (this is an assumption in order to calculate the dimensions). The temperature difference will have different values when the shower is being used; this is due to variation of the start temperature of the water and the end temperature which is chosen by the user.

Heat capacity:

$Q = m \times c_p \times \Delta T$ -> $0.05 \times 4186 \times 24 = 5023$ W

To become acquainted with this equation the hydraulic diameter and the surface area are set on a plausible size. The hydraulic diameter is set on 0.010 m (h = 5mm) and the surface area is set on 0.2 m2 (1m x 0.2m).

This gives us the equation:

$$\frac{W \times D_h}{k \times Nu \times S} = \Delta T_{av}$$

$$\Delta T_{av} = \frac{5023 \times 0.010}{0.58 \times 8.235 \times 0.2} = 52.6\,°C$$

This result is the average temperature difference between the thin film layer and the water. The temperature of the water will increase while the temperature of the thin film layer remains the same throughout the entire heating process. In fact the water will never reach the temperature of the thin film layer. Figure 4.06[9] shows that the temperature of the water 'T_w' will approach the temperature of the thin film layer 'T_f' asymptotically.

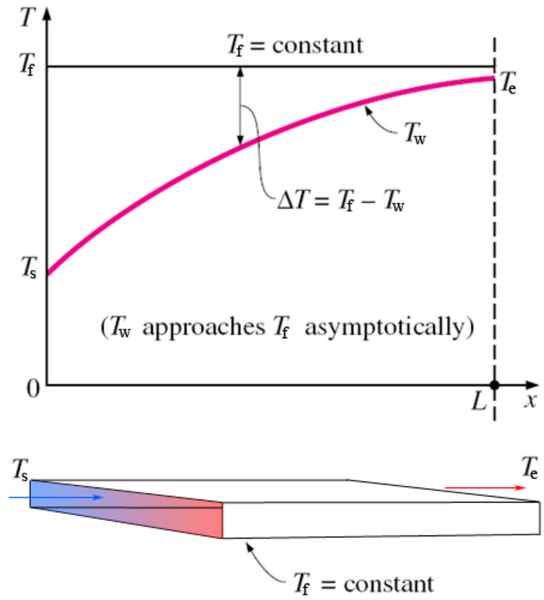


Fig 4.06: Temperature chart.

To calculate what the temperature of the thin film layer 'T_f' itself will be; there is an equation which has to be rearranged. Calculation of the temperature of the thin film layer:

$$\Delta T_{av} = \frac{T_s - T_e}{\ln[(T_f - T_e)/(T_f - T_s)]}$$

$$\frac{T_f - T_e}{T_f - T_s} = e^{\frac{T_s - T_e}{\Delta T_{av}}}$$

$$T_f = \frac{e^{\frac{T_s - T_e}{\Delta T_{av}}} T_s - T_e}{e^{\frac{T_s - T_e}{\Delta T_{av}}} - 1}$$

The previews situation led to a T_{av} of 52.6 °C, this equation will give us the following result:

$$T_f = \frac{e^{\frac{16-40}{52.6}} \times 16 - 40}{e^{\frac{16-40}{52.6}} - 1} = 81.5\ °C$$

The thin film layer will have a temperature of 81.5 °C for this situation. But this is only a calculation example. As said before, it is favourable to keep this temperature low to reduce corrosion. But on the other hand, this way the surface area will become very large. Another way to reduce this value is to minimize the hydraulic diameter; this becomes clear in the following chart.

The result of the equation is a rough result. Because there are more influences, like the cooling factor which is caused by the ambient temperature. And there will be efficiency loss, which will increase the power that is needed. The efficiency factor will probably be between 95 and 99 percent. Because this is a small loss, it will not be taken into account. On the other hand there is a way to improve the heating; by making the surface rough the flow could be turbulent instead of laminar. A turbulent flow will increase the level of convection.

Chart

To see what kind of values can be used for the shower, the equation is calculated several times for different values of 'S' and 'Dh'. The outcomes are placed into a chart (Figure 4.07). Which hydraulic diameter and surface area to use will be of later concern; but it is clear that a surface area between 0.15 and 0.30 is appropriate on the condition that the hydraulic diameter is small.

Temperature threshold

The numbers from the chart do not have a meaning for the design process; unless there is a threshold to define which numbers are suitable. As discussed before, the temperature must be low to avoid steam bubbles. For another way to determine a threshold, the situation of the user is taken into account. Accidently (or on purpose) touching the shower must not cause any problems. Therefore nociception is researched[10], nociception refers to signals arriving in the central nervous system resulting from activation of specialized sensory receptors called nociceptors that provide information about tissue damage. In other words; when does the user feel pain and what kind of pain is it? In this case research has been done on the threshold of thermal pain. From the article 'Nociceptors and the perception of pain' (page 5-1) a temperature threshold of 50°C is derived. This is the threshold where a user can receive signals of pain. Therefore the results around and under 50°C are suitable to determine the dimensions of the glass plates. In figure 4.07 the suitable result are shown in bold.

These calculations are made for a steady state situation. The duration to get from the unused state to the steady state is estimated at about one minute***.

*** An estimation of Doctor Daniel den Engelsen.

S (m^2) \ D_h (m)	0.010	0.008	0.006	0.004
0.15	98.8	85.0	71.2	57.7
0.20	81.5	71.2	61.0	**51.2**
0.25	71.2	63.1	55.1	**47.6**
0.30	64.5	57.7	**51.2**	**45.3**

T_f (°C)

Fig. 4.07: Multiple options for dimensions of the glass plates and corresponding thin film layer temperatures.

5 APPEARANCE DESIGN

To develop an appearance for the shower, several ways of getting inspiration are used. As the environment is a becoming more of an issue in Brazil (as researched in paragraph 3.2); sustainable energy is used as a basis for ideas of shapes. To become acquainted with the shapes and forms, several aspects and details of the collage are used to draw ideas. This way several form studies are made. These form studies are later on converted into more specified concepts.

Another basis for ideas is to make the shower hybrid. This is a more conceptual basis; it is taken into account because this can also result in more ideas. With hybrid; a combination of electrical and solar energy is meant. When the shower is located directly in the roof and made of glass; the sun can heat the water while it runs through the electrical heating element (which is the glass), this way even more power is saved and the customer is able to look at the sky while he showers.

In the point of view of design the most important part of the system is the casing, because the casing heats the water but it will also be used to specify the shape of the shower. The water distribution will be the second part that catches the eye, concerning the appearance of the shower this is an important part too. This is based on the assumption that when somebody enters the bathroom, the first thing he will see is the total view of the shower. When the user approaches the shower, he looks at the display and the water distribution. So it is also important that the position of the user interface fits the design. The electrical parts are preferred to be out of sight if possible. The most ideal shower only shows the glass casing and the water distribution.

The idea generation starts by making mind maps (figure 5.01); three categories are used: 'Sustainable energy', 'functionality' and 'hybrid shower'. Especially the sustainable energy is used to make several form studies. The ideas from the mind map will be discussed during the next paragraphs.

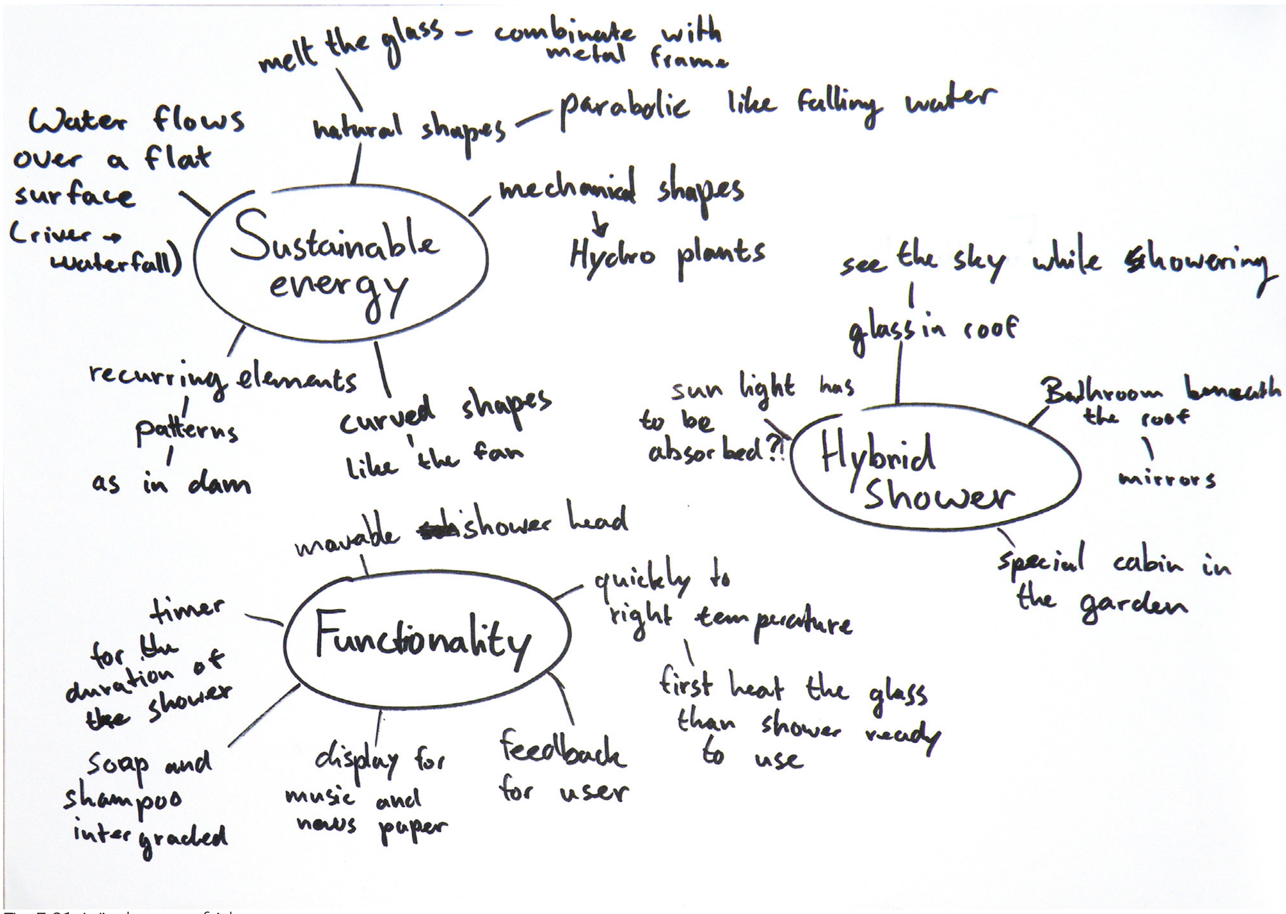


Fig 5.01: Mind map of ideas.

Fig 5.02: Collage to base shapes on.

5.1 Natural based

The first aspect of sustainable energy is 'nature'; the idea's are based on the natural forms in the collage (figure 5.02), where water is the main element. With this basis several shapes are drawn. To become acquainted with the shapes, first details from the collage are imitated to make a sketch (figure 5.03). This sketch is used to create some loose ideas for a shower, for example the use of several sprays instead of one spray. Or to imitate a river where the water in the end drops down like a waterfall (Figure 5.04).


Fig 5.03: Waterfalls, inspired by the collage.

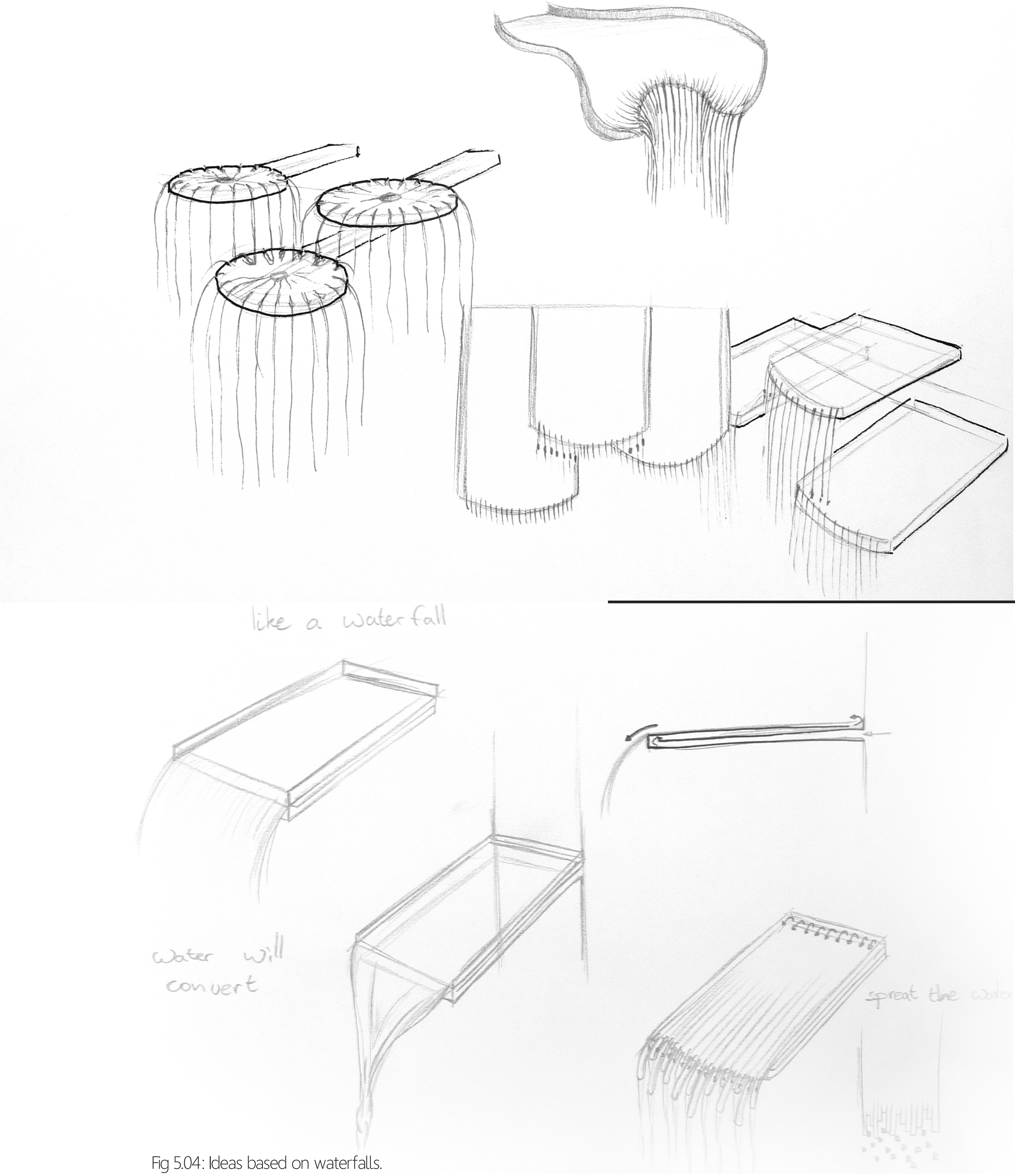


Fig 5.04: Ideas based on waterfalls.

Form study

From the natural forms and 'water' as a subject, a side direction was formed; the whirl. The main goal of this idea is to distribute the water nicely by creating a whirl inside the showerhead. This way the water will come out with a certain centripetal force, which ensures the shower spray to be wider (figure 5.05). This idea could also be interesting for the level of turbulence in the water. Several cones can ensure a better distribution of the water.

In order to increase the possibilities a form study is created. It is used to come up with the basic shape of the shower. From this study (figure 5.06) a rough shape will be chosen, which will be more detailed later on. Another word which is being used is 'subtle'; round, hyperbolic and smooth shapes are used to sketch subtle shapes.

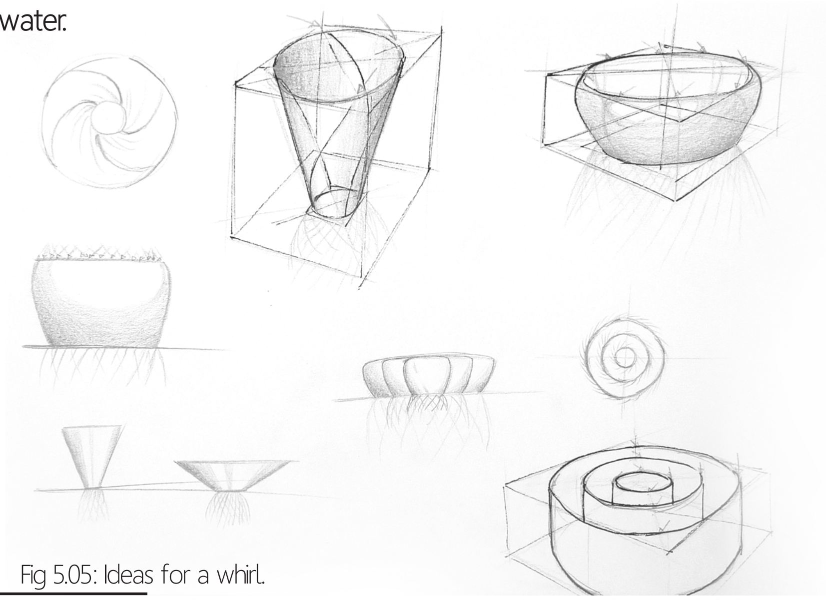


Fig 5.05: Ideas for a whirl.

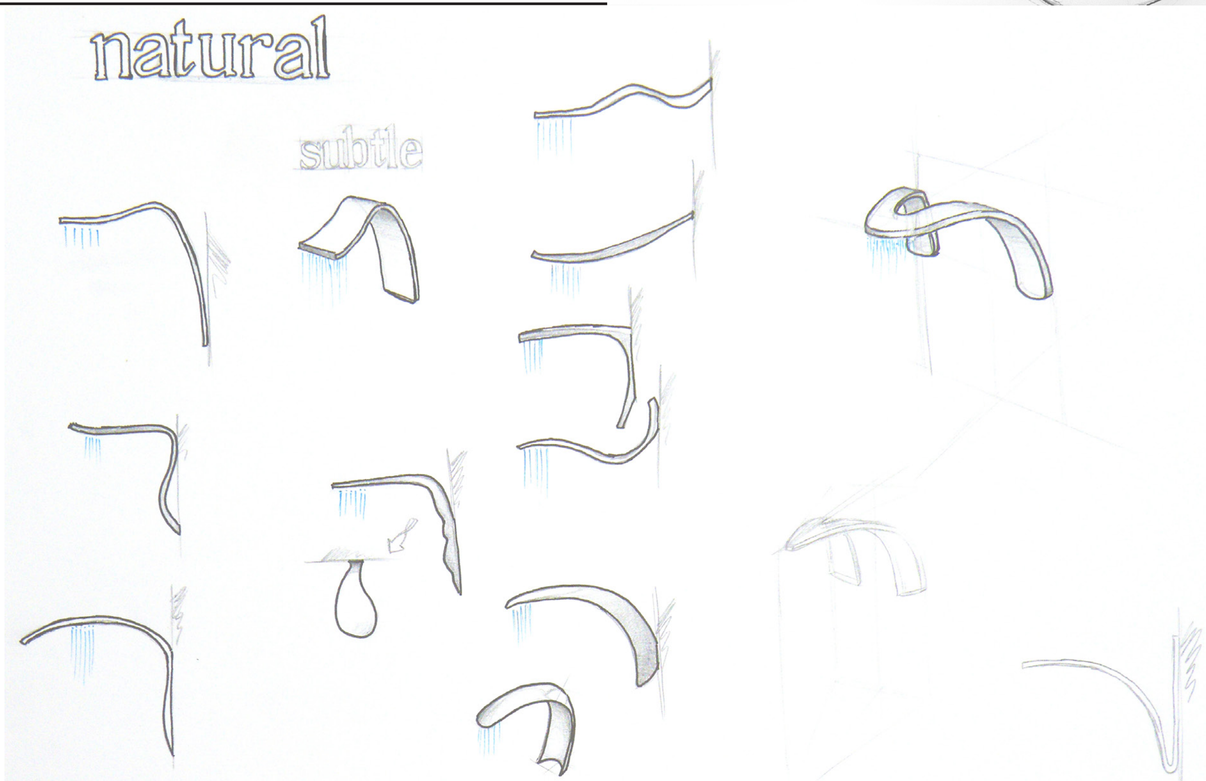


Fig 5.06: Form study about natural shapes.

5.2 Mechanical based

Another aspect of sustainable energy is 'mechanical'; in this case the shapes and aspects of hydropower plants are used; for instance the shapes of the fan (which is the main component to generate the electric energy). To create ideas, similar to the sketches of the natural shapes, details from the collage are imitated to make sketches (figure 5.07). Based on these sketches a couple of ideas are drawn. The shapes are more static, but round details are used as well. There is also thought of how the water could run through the glass plates (figure 5.08).

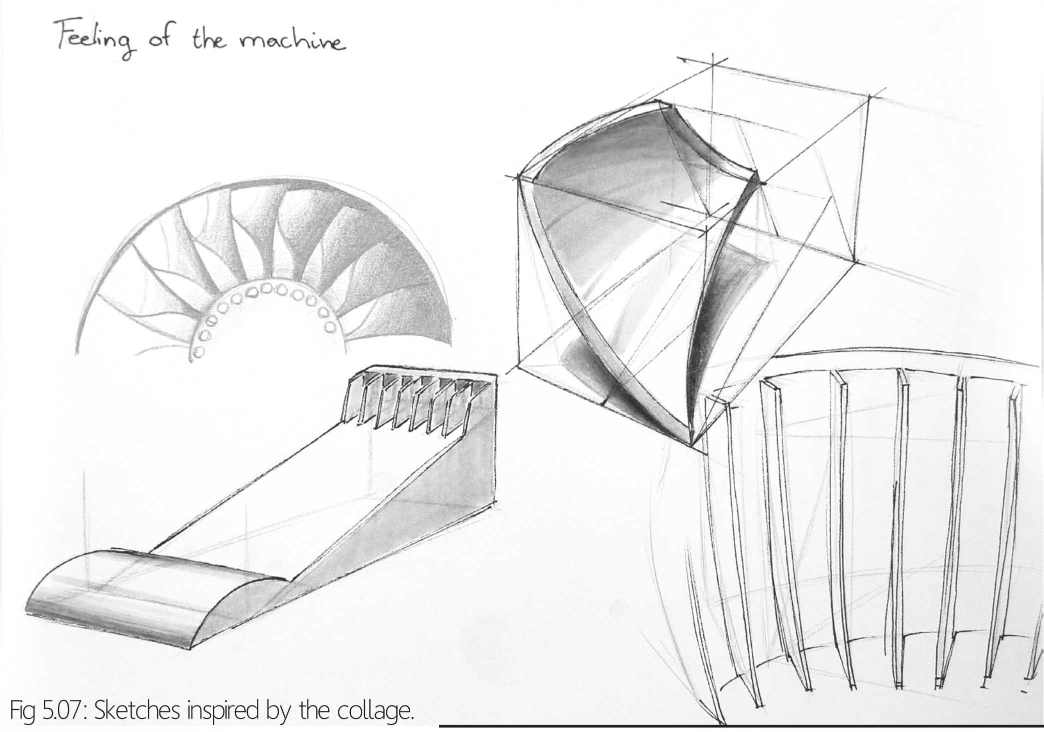


Fig 5.07: Sketches inspired by the collage.

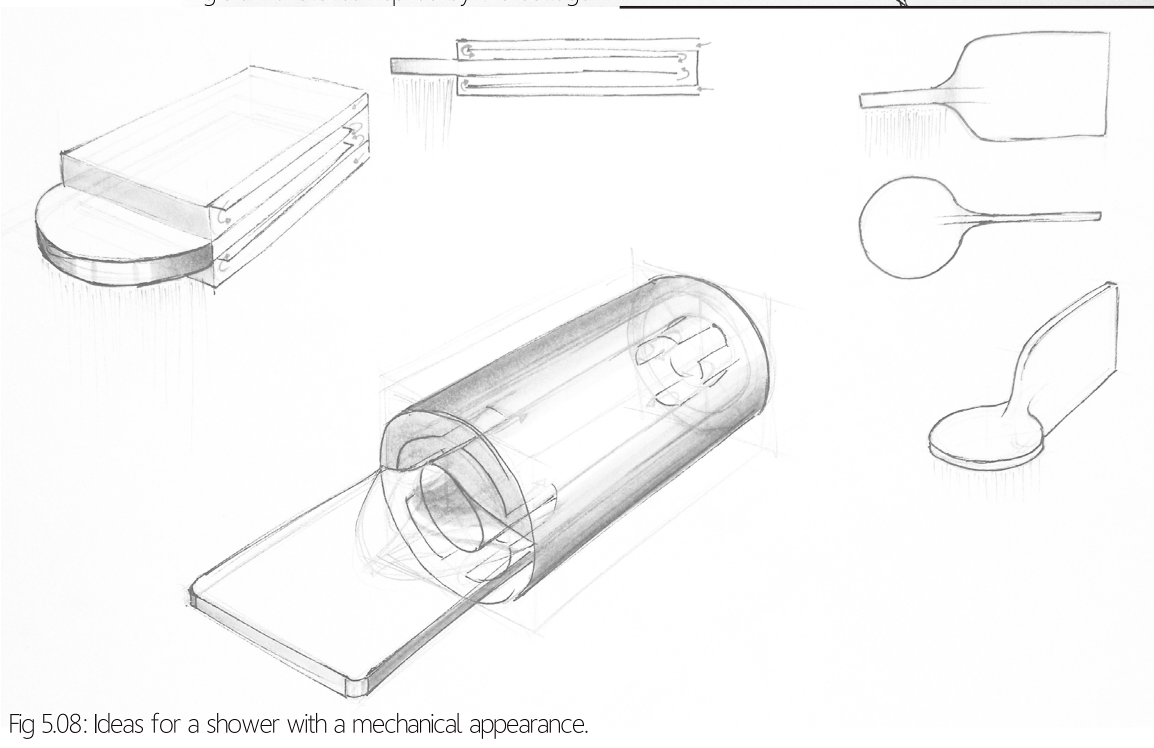


Fig 5.08: Ideas for a shower with a mechanical appearance.

Form study

Similar to the method used in with the natural shapes, a form study is created for the mechanical shapes (figure 5.09). Another basis that is being used is 'pattern': as hydro power plants often shows recurring elements. These repeating elements are used in the sketches.

After the two main subjects to base form studies on, extra sketches are made. These are meant to discover possible other interesting shapes. Both of the subjects, natural as mechanical, are visible in the free sketches (figure 5.10).

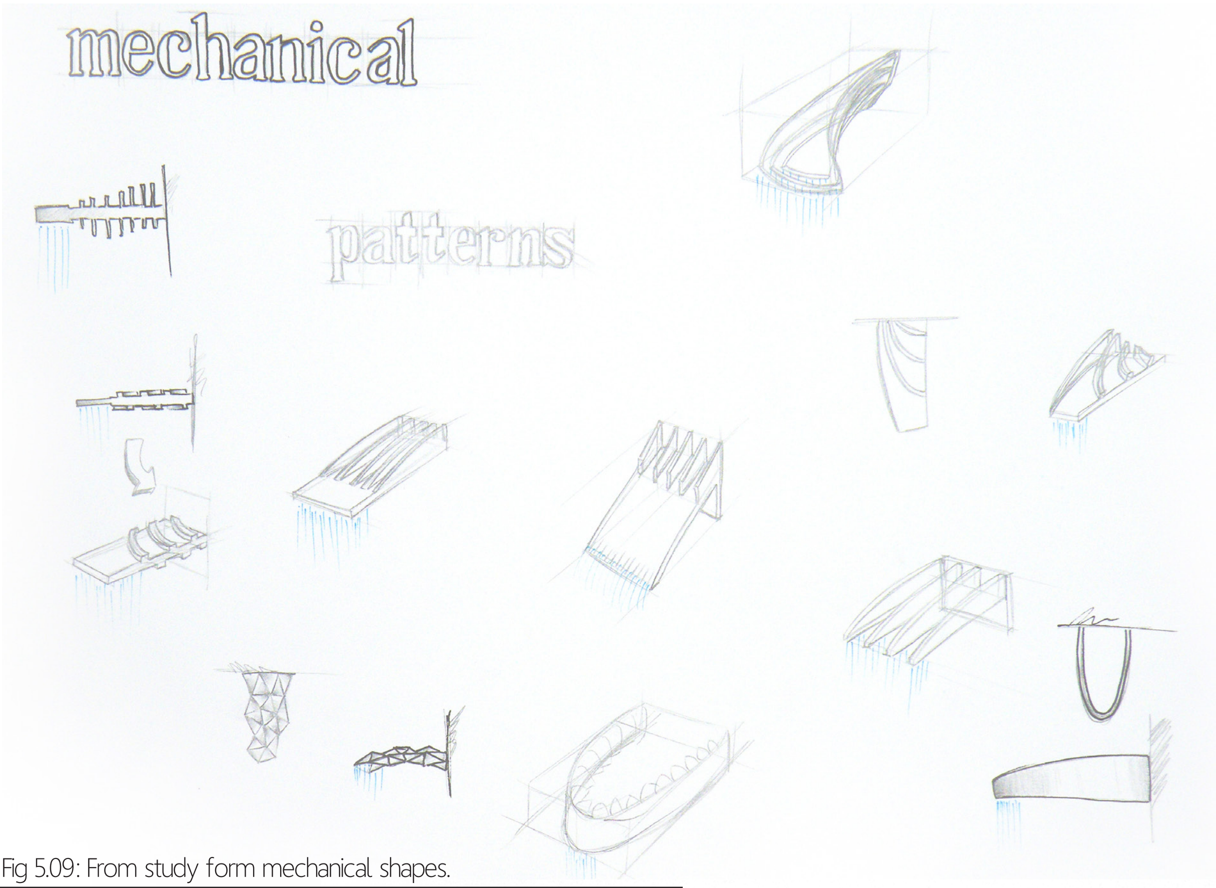


Fig 5.09: From study form mechanical shapes.

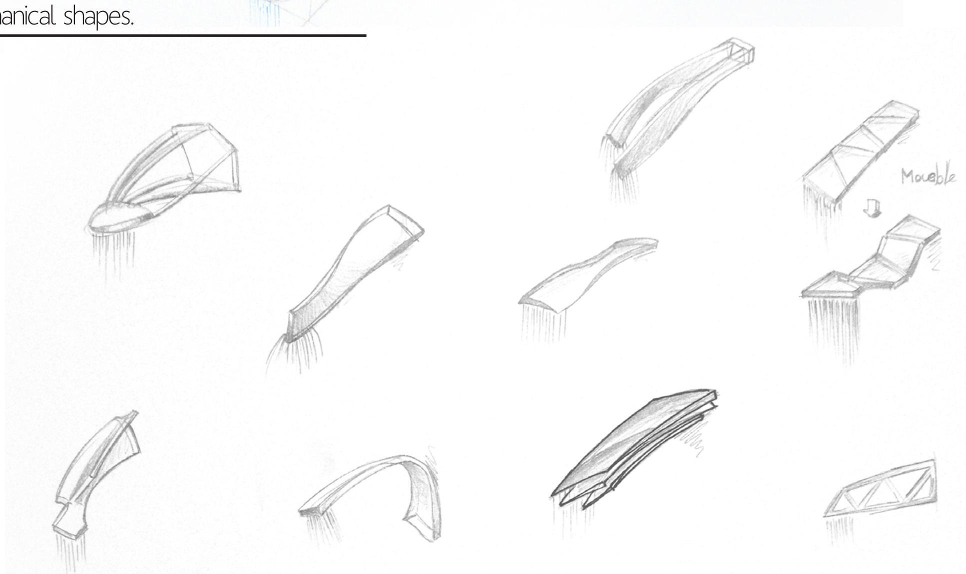


Fig 5.10: Free sketches.

5.3 Functionality

Another way to come up with ideas is to write a scenario (Appendix C). The scenario is focussed on functionality, this way the user interaction can be taken in consideration. The scenario represents a possible future way of using the shower. This way a future perspective is created, which can be used to come up with features for the user interface and other ideas.

Fragment

"Roberto gets out of bed and heads for the bathroom. He opens the water tap and presses 'start' on the shower. Now the water begins to run and soon it will have a nice temperature. On the shower is a bar displayed, which represents his shower time. When the bar is completely gone the shower will not heat the water anymore. Besides that Roberto can get track of the amount of water and electricity he uses."

As the shower is meant to be ecological, the relation between the consumer and the shower has to be considered. The state of mind of the consumer plays a great role in the consumption of water and electricity. If the consumer is more aware of what he consumes he could change his way of showering. For instance the duration of his showering time could be decreased; which safes water, energy and money. Several ideas to communicate with the costumer are described point wise. These ideas can be used in the user interface.

- Timer on shower (stops always after the same amount of time).
- Timer which can be modified (create awareness of the duration of the showering).
- Feedback on time of shower use.
- Feedback on the electricity being used.
- Feedback on the costs of the electricity/ water being used.
- Quantity of water that is already used displayed.
- Quantity of water running displayed.
- Temperature is beign displayed.
- More options of level of heating the water.
- Exact temperature can be chosen by user.

Hybrid shower

Another idea to broaden the horizon of possibilities is the concept that intents to combine solar power with electric power into one product. Because it needs sun, the product has to be located directly onto the roof. So the bathroom has to be directly underneath the roof of the house. The consumer is able to look through the shower into the sky. One of the problems this idea is facing is that solar heating needs to absorb the sunlight. This is usually obtained by using a dark surface. But since the main goal of the hybrid shower is to be able to see the sky during taking a shower; a dark surface is not contributory.

Requirements

During the generation of ideas several requirements are taken into account (The complete set of requirements is found in Appendix D).

- Shower communicates the use of sustainable energy (especially hydropower).
- Shower shows that it has economical power consumption.
- Shower must have a luxurious appearance (as it is meant for a high class price range).
- Shower must have a different appearance compared to an ordinary shower, to show the technology is new and improving.

6 CONCEPTS

Now that several directions are pointed out; it is important to make decisions on which idea to build. The following aspects of the shower are taken into account to convert the ideas into three concepts:

- Shapes of the glass plates.
- The water distribution.
- location of user interface.
- connections to water and electricity.

Concept 1

The first concept is based on mechanical shapes. The glass plates are placed vertically to create the recurring appearance of a dam (figure 6.01; 1.). The shapes of these elements can be reconsidered (figure 6.01; 2.). For the water distribution; two options are chosen. The first one is to use a different material for the part where the water is distributed (figure 6.01; 3.), like aluminium or a glossy poly carbonate for instance. This separate part can also be used as a connection for the plates; it could run along the edges of the sandwiched glass plates. The second way to distribute the water is by using the sides of the vertical elements to put holes (figure 6.01; 4.). Because the sides are at the bottom; since the glass plates are placed vertical. This side will be made of different material to join the sandwiched glass plates. The material poly carbonate could be used for these sides , but this will be determined later on. The position of the interface will be at the backside that is placed to the wall. This way the interface will be right under the water- and power supply and on the right height for the consumer. The water and the power supply runs through the backside of the shower, which is placed against the wall (figure 6.01; 5.).

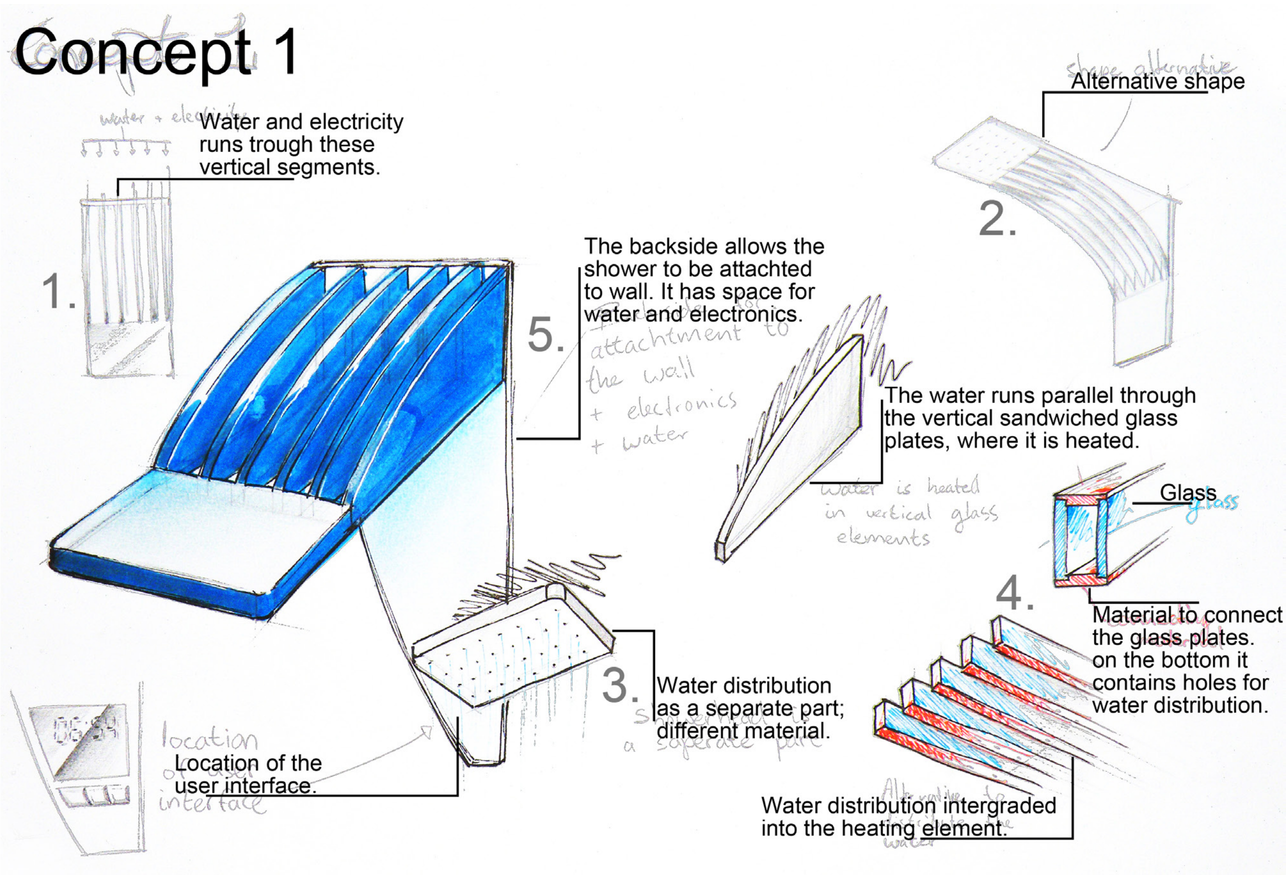


Fig 6.01: Concept 1.

Concept 2

The second concept is based on nature related shapes. The glass plates have smooth and organic shape, based on falling water. For this concept the glass plates need to be bent. At least 2 glass plates have to be bent equally so they will fit each other (figure 6.02; 1.). To distribute the water there are three options chosen. The first one is to use a separate part; equal to the first option of concept 1 (figure 6.02; 2.). The second option is to use several plates; the plates are laying over each other and creating several lines where water runs out. It can be compared to a staircase, but faced downwards (figure 6.02; 3.). The third option is to drill holes in the glass plate, this way the shower is a uniform design (figure 6.02; 4.). The interface will be positioned on the bottom of the backside. This is the place where the interface will be on eye level of the consumer (figure 6.02; 5.). The backside component is useful to guide the electricity and the water from the point where it comes from the wall into the shower (figure 6.02; 6.).

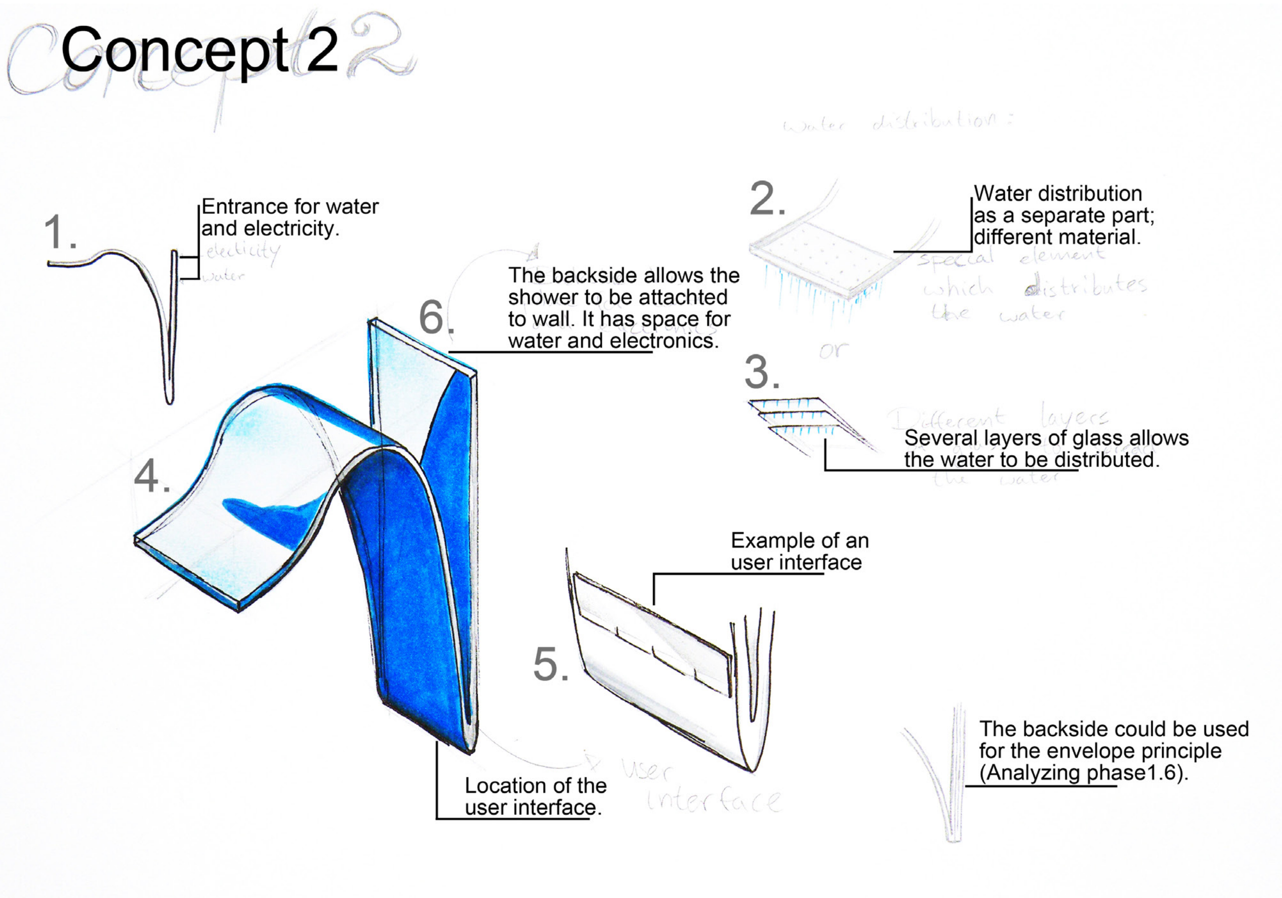


Fig 6.02: Concept 2.

Concept 3

The third concept is directly retrieved from the idea the make the shower hybrid. The glass plates will have flat shapes, especially meant to create a big surface for the solar energy and to see as much of the sky a possible (figure 6.03; 1.). For the water distribution there are two options. The first is to use the same principle as in the other two concepts; to use a separate component made out of a different material (figure 6.03; 2.). Another option is to drill holes in the glass, this way the shower will be entirely transparent. The interface of this concept is not positioned on the shower; it has to have an external position (figure 6.03; 3.). To send the data from the user interface to the shower, there got to be some kind of connection. To connect the shower to water and electricity the glass plates are not only placed in the roof; but also so partly on the wall (figure 6.03; 4.). This way the water will run up into the part that is placed in roof.

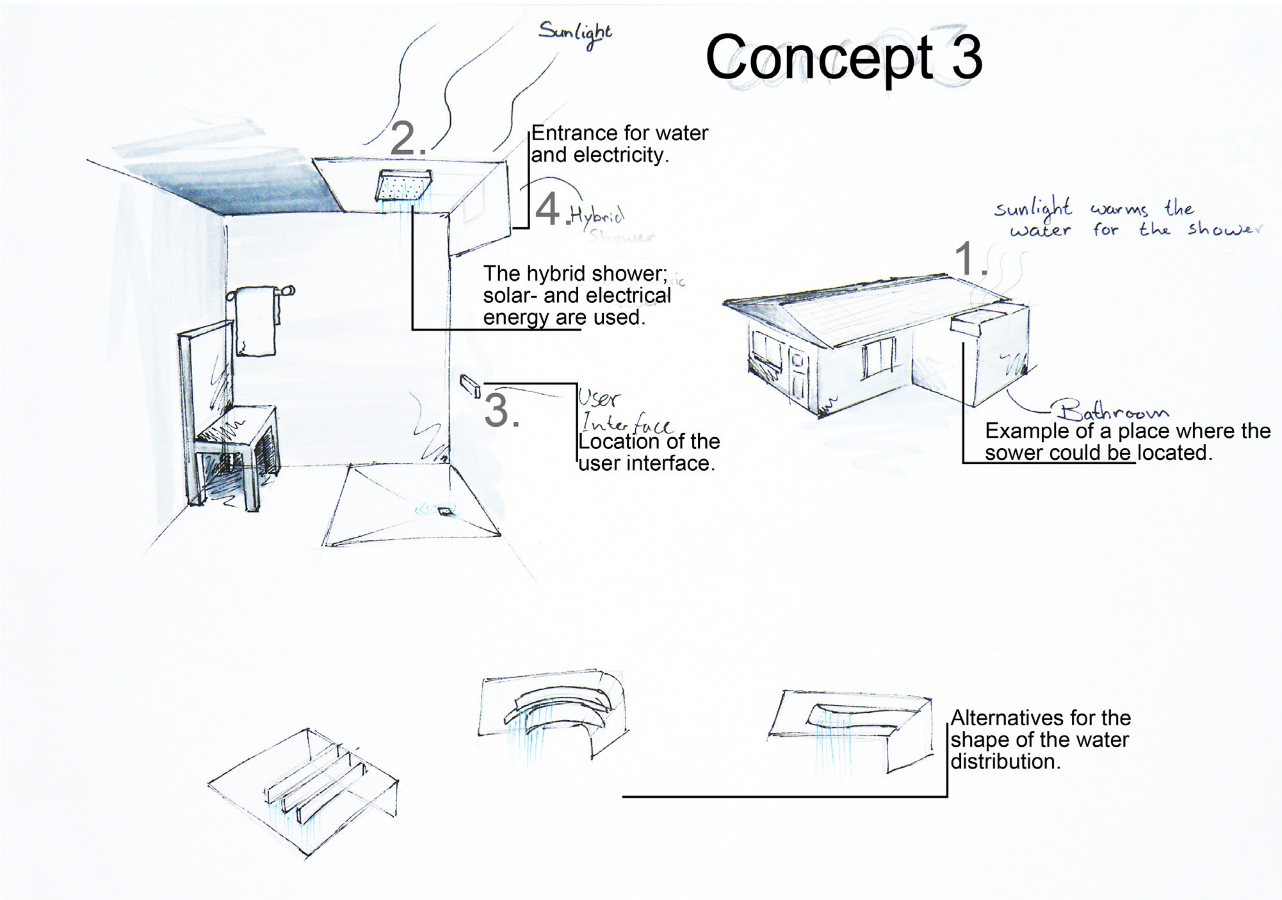


Fig 6.03: Concept 3.

6.1 Position in its scenery

To get a more realistic idea on how the shower is going to look like, a scene is created with Solid Works. This scene is a reproduction of a bathroom. This way the concepts can be sketched in its setting; to show the proportions. Figure 6.04 shows the scenery and some fixed parts. The power- and water connection cannot be displaced under any circumstance. These sketches are used to analyse the concepts. For each concept the pros and cons are discussed.

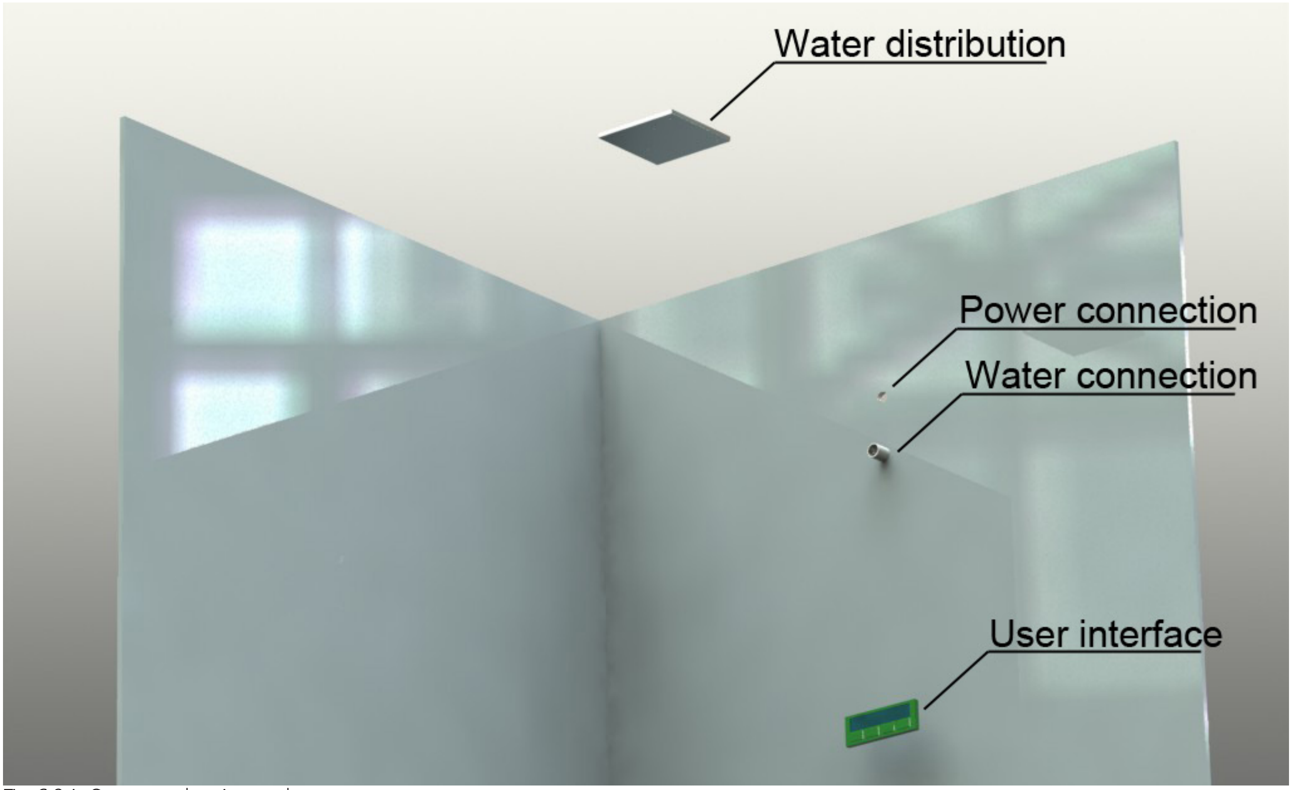


Fig 6.04: Scenery that is used.


Fig 6.05: Concept 1 in scenery.


Fig 6.06: Concept 2 in scenery.

Concept 1 (figure 6.05)
Advantages
- the glass plates are flat; they do not need to be deformed in curved shapes.
- The interface is easy to integrate because the backside allows the interface to be located on a height that is desirable.
- Because of the vertical glass plates, the shower seems to have a strong structure.
- The shower is easy to adopt in a common bathroom.

Disadvantages
- The shower contains a lot of glass parts.
- Cutting the shape in the glass will probably cause waste, because of the round shape.

Concept 2 (figure 6.06)
Advantages
- Consists of a small number of parts.
- The interface is easy to integrate because the backside allows the interface to be located on a height that is desirable.
- The shower is easy to adopt in a common bathroom.

Disadvantages
- Shape of the glass plates could be difficult and expensive to produce.
- This kind of structure might be fragile.


Fig 6.07: Concept 3 in scenery.

Concept 3 (figure 6.07)

Advantages

- It is probably a more efficient shower, because of the use of solar heating.
- More daylight in the bathroom.

Disadvantages

- The technology needs a lot elaboration. For instance; the problem of the absorbing layer of the solar heating needs to be black. But this way, no daylight enters the bathroom.
- The shower is hard to adopt in a common bathroom. It is probably only manageable when a new house is build.
- In most of the households the water pressure is determined by a water reservoir that is located as high as possible in the house. But since the shower has to be placed in the roof, the water pressure will be very low.
- The interface is harder to integrate into the product.

6.2 Choice of concept

At this point, there are three concepts to choose from. Each concept has its pros and cons; as discussed in the previous paragraph. To get to one concept, it is possible to combine several aspects of different concepts. It is clear that 'concept 3' has the most disadvantages. The idea of the hybrid shower is great and there is a lot of potential in it. But it has too many downsides to it at this moment. The problem of installing the shower in a common household is one of them. The product will probably not be able to get in the price range that was envisioned (paragraph 2.5); around R$ 400. For consumers who want to pay a lot more, there is always the possibility of an external solar heating system. But maybe the biggest problem is the dark layer that is needed for heat absorption (from the sunlight); this layer will block the daylight that was supposed to get into the bathroom.

Concept 1 and concept 2 are more likely to be producible and profitable for a sales price of R$ 400. But the question is; which concept is better. Looking from an ecological point of view, concept 2 has its benefits with its natural curves and simplicity. From the perspective of stability, concept 1 seems to be a better solution. The bending of the curves of concept 2 his casing could increase the production costs. On the other hand, the number of parts of concept 1 and the cutting of the shapes could affect the costs negatively as well. Both concepts have the aspects of sustainable energy, one based on the mechanical looks and the other on the natural appearance.

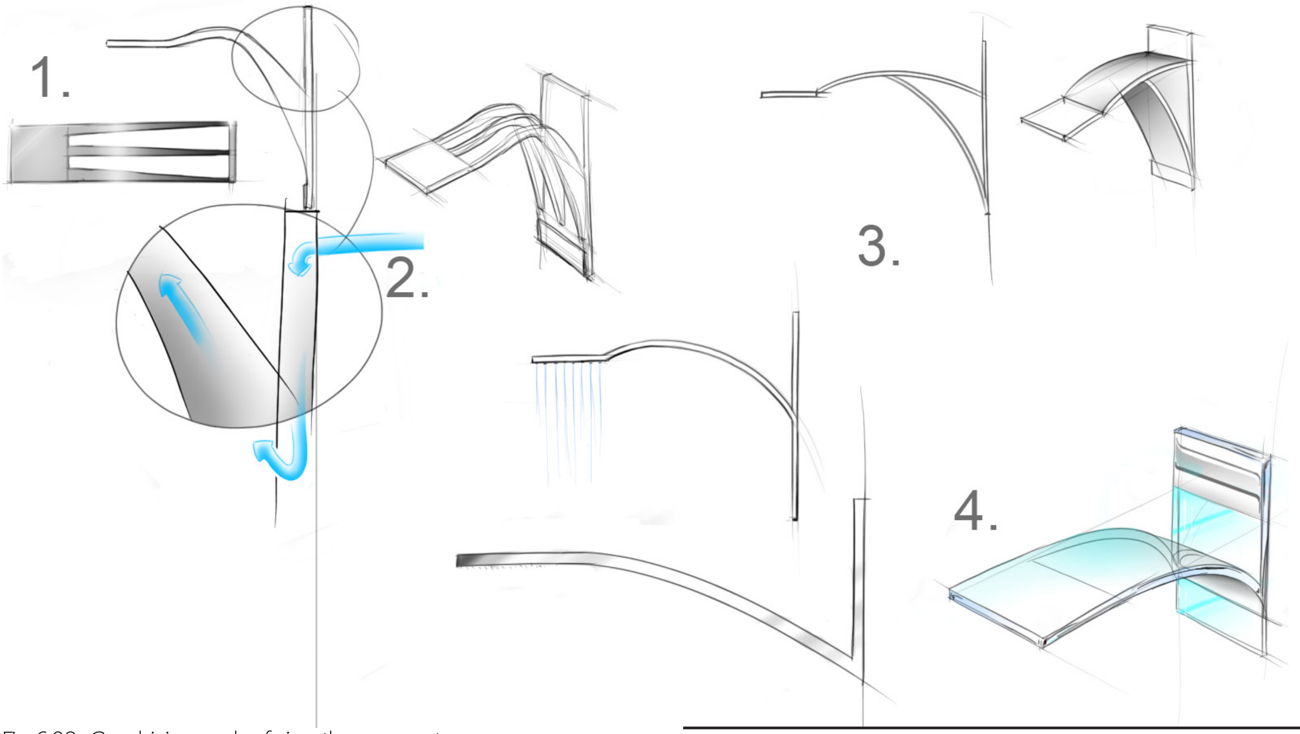


Fig 6.08: Combining and refining the concepts.

6.3 Converting

In order to get to one draft, concept 1 and concept 2 are combined. The advantages of both of the concepts are taken into account. These elements are used to sketch the final shape of the product. First the vertical elements of concept 1 are combined with the curved shapes of concept 2. The number of elements is reduced to three 'sandwiched' glass plates (figure 6.08; 1.). To show how the water runs through the shower, blue arrows are drawn (figure 6.08; 2.). Subsequently there is searched for other ways to simplify the design. Because the shape of concept 2 is probably hard to manufacture, it is important to standardize the shape (figure 6.08; 3.). Eventually a more simplified shape is chosen (figure 6.08; 4.). With this shape, there is the natural look, but the curve is more likely to be producible. To cover up the location where the water and- electricity connections are located, there will be a closed section on the top of the backside. This way the shower looks cleaner and there is no danger of getting an electric shock.

7 THE FINAL DRAFT

Presentational drawing

All the ideas that where gathered are now converted into a final draft. The presentational drawing shows the appearance and some functional aspects of the final draft (figure 7.01). This drawing demonstrates the shapes and proportions; details are explained further on in this chapter.

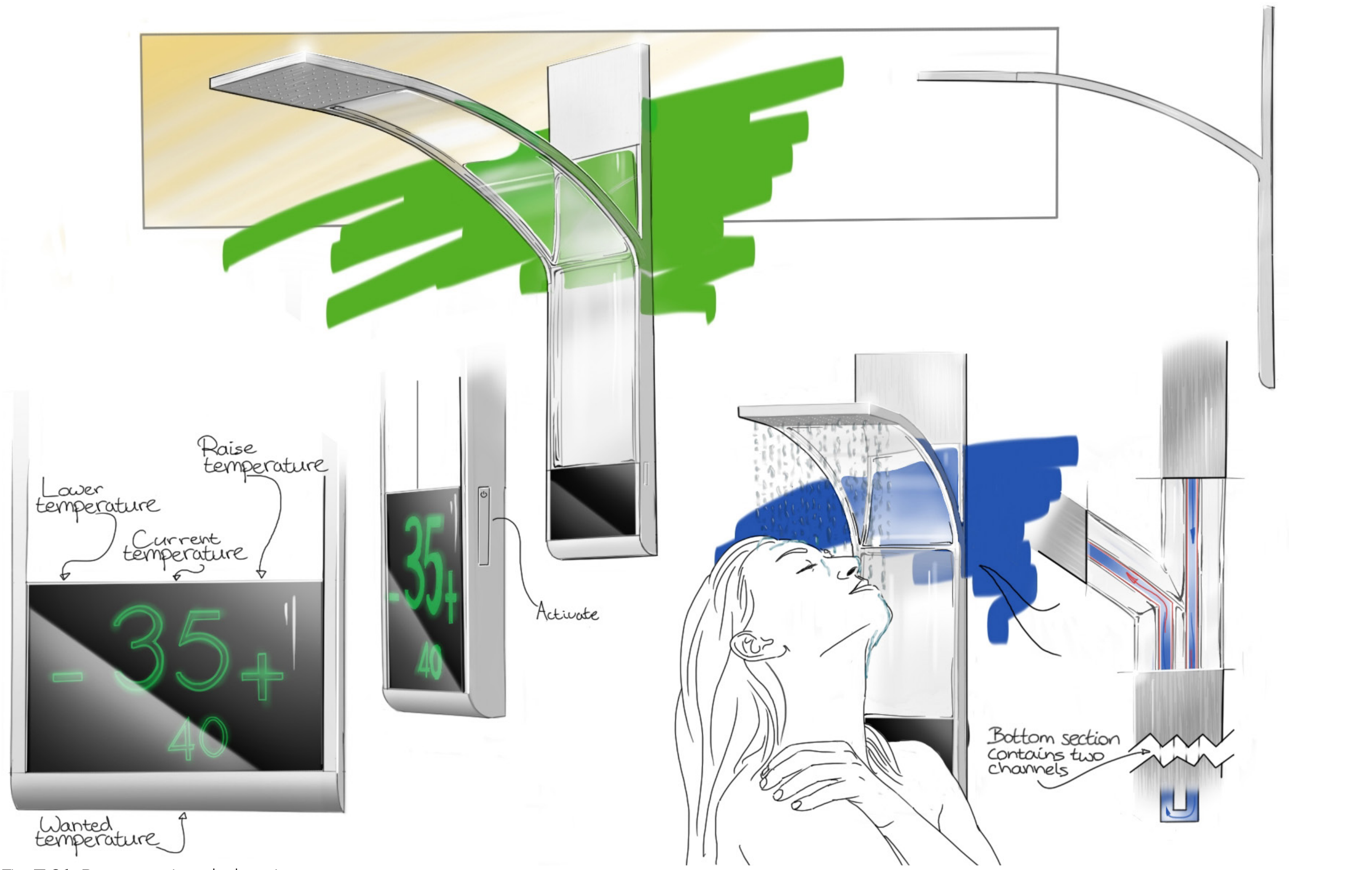


Fig 7.01: Presentational drawing.

7.1 System design

To show the elements of the design the system design is elaborated. Earlier in this report it is suggested that 'water control' could be an option for the shower. The ordinary tab should always be opened, and a mechanism in the shower will take care of the flow. This way the consumer could get his desired water flow by inserting his needs in the user interface. This should be obtained by adding a mechanical mechanism and software to control this system. The software is not the problem, but the mechanism will influence the appearance of the shower significantly and maybe more important; will increase the costs****. Therefore it is chosen to not add the 'water control' function to shower. The new system is shown in figure 7.02. The user needs to open the water tap himself, as it is today.

**** In consultation with professor Carlos I. Z. Mammana.

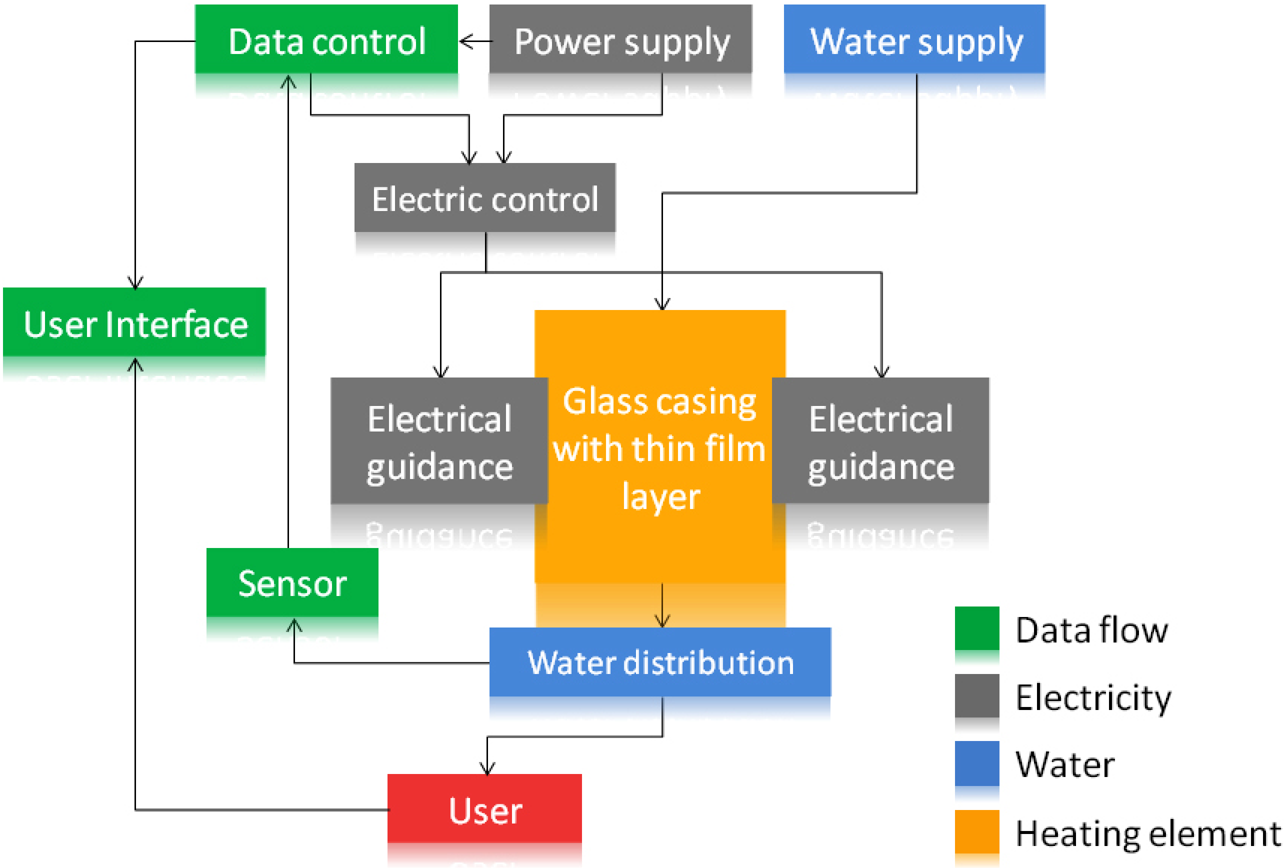


Fig 7.02: Final system design of the shower.

Elements pointed out

To show how this system is elaborated in the final draft the position of each element is pointed out in a cross section render of the solid works model (figure 7.03). The yellow parts in the model are called the electrical guidance (made of rubber). These parts contain the guidance for the electricity that needs to run through the thin film layer, but also contains the power that runs to the user interface.

7.2 Sensor

To give feedback to the consumer and to let him control the shower in a comfortable way, the interface has to know what the temperature of the water is. In order to achieve the desired temperature, the amount of electricity has to be calculated by the 'electric control'. It is most likely to use a PID controller, this consists of three factors. 'P' is the differences between the current temperature and the desired temperature (or amount of electricity). 'I' is the sum of the differences over time, and 'D' is the rate of change between sampled differences. This way the water temperature can be controlled accurately. To ensure the loop works correctly, a sensor is located in the water distribution section. This way the 'electric control' is able to know what the temperature of the water is when it leaves the shower and shortly after will meet the user.

7.3 User Interface

It is clear that the heat sensor will keep track of the temperature of the water just before leaving the shower. The user interface will show the user what the temperature of the water is. When the

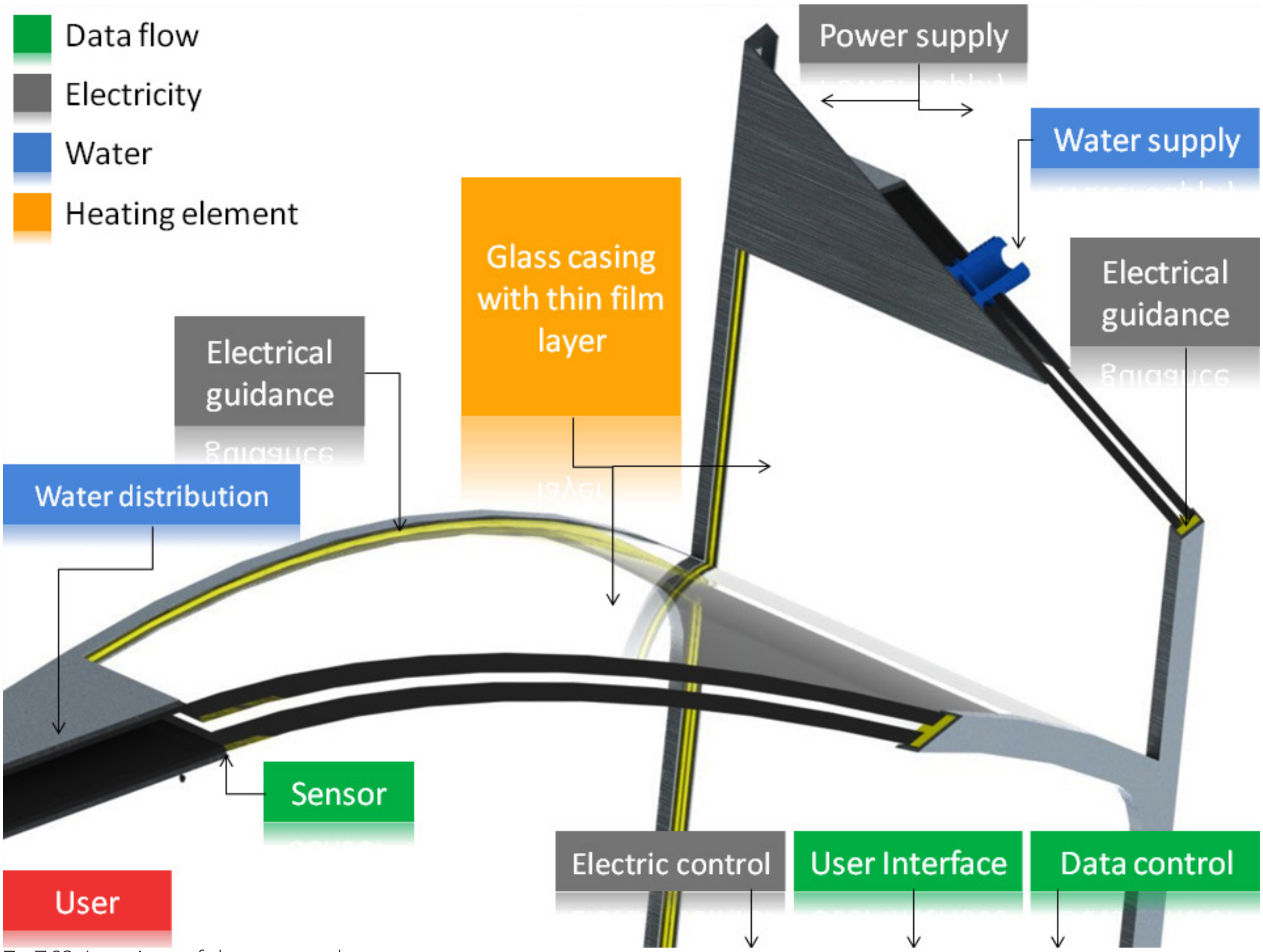


Fig 7.03: Locations of the system elements.

user is not satisfied with the temperature, he is able to adjust the temperature by simply touching the 'plus' symbol to increase the temperature, or touching the 'minus' symbol to lower the temperature (UI; figure 7.04). There are two temperature indications on the UI, one that says what the current temperature of the water is and another that says what the desired temperature is. Once these temperature indications are the same, the lower digit will vanish. The screen will have a simple capacitive touch screen. Water can cause an error for capacitive touch screen which influences the accuracy[11]. But because there are only a small number of regions that have to be defined (plus and minus, and a few regions in between); a little disturbance of the water does not matter. It is also possible to swipe the screen, from left to right or from right to left, to change the desired temperature. By swiping the screen, the temperature will increase or decrease with several steps. The user can change the temperature by half a degree per step.

On the right side there is a power button; this button will activate or deactivate the shower. To use the shower, the user first opens the water tap and then activates the shower. It is also possible to first activate the shower, this way the shower can warm up. Because the heating element only reaches a temperature around fifty degrees, heating the shower without running water will not be dangerous. In contrast with a common coil heated shower. There is a timer on the shower (green bar in the top of the screen), that ensures the shower to deactivate when it runs out. This

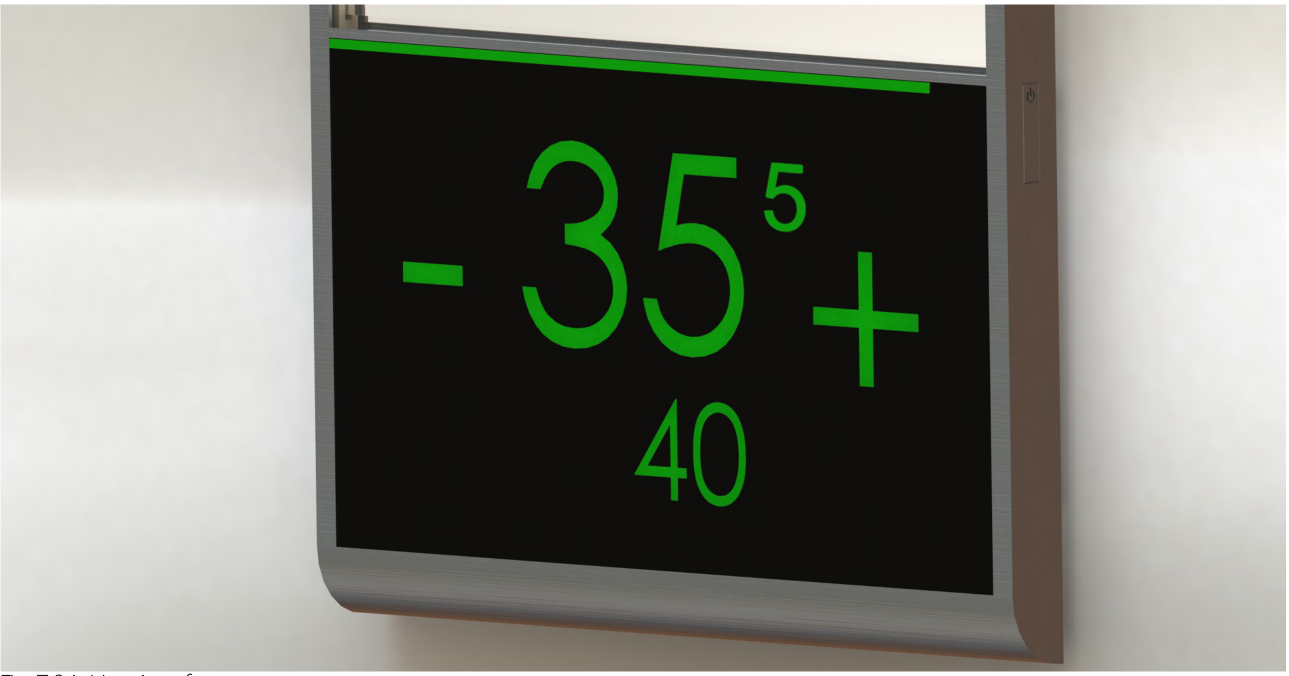


Fig. 7.04: User interface.

way the user is aware of a time limit while he showers. It will also prevent the shower to stay activated while it is not used. The timer is set on ten minutes. It could be made changeable with a smart phone application. The same application can be used to start the 'warm up' when the user just woke up or just before he arrives home and is going to take a shower.

7.4 The route the water travels

In order to make the route of the water longer, and to lower the UI for more ergonomic control; there is an extension of the back face (figure 7.05 section B). The water will enter the shower in section A, will run down and up through section B and will reach the water distribution through section C. Because the water has to run two times through section B, this section cannot have the same sizes like section A and C. There are several options for this section. The first option is: the outline gets the same size as the two other sections (A and C), but the channel for the water will be narrower. So the water will travel faster through this section (figure 7.05 option 1). The second option is: the glass plates will be less thick, so the water will travel at the same velocity (figure 7.05 option 2). The third option is to enlarge the outline and keep the glass and the channel the same size (figure 7.05 option 3).

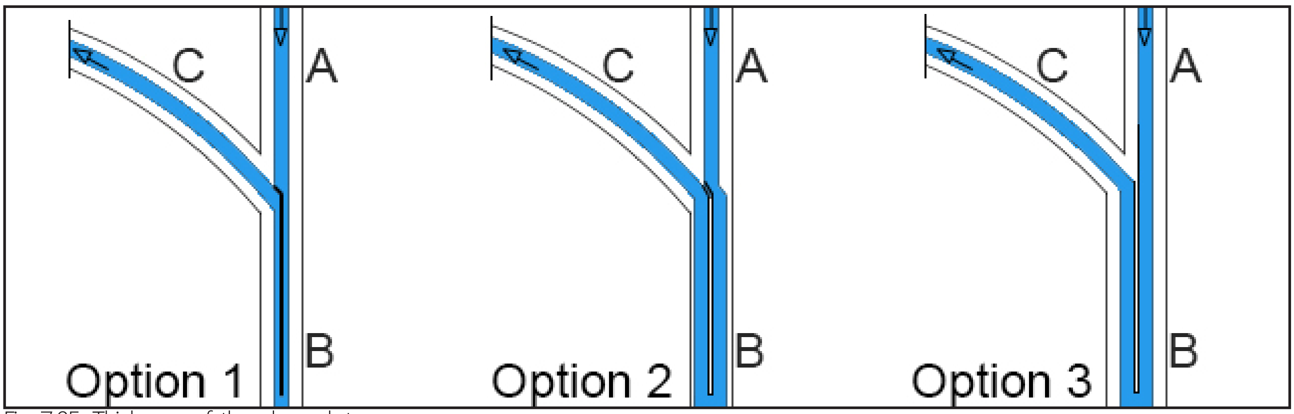


Fig. 7.05: Thickness of the glass plates.

The model

The best option is the third one, because this will preserve the shower its strength and will not give any problems to the water flow. Another reason to choose this option is because it will give a minimum difficulty for the production; the other options will need more different kinds of glass plates. Figure 7.06 shows what the water channel is going the look like realistically. There is a space to allow the passage of water from the rear channel to the front channel. It is located on the bottom of the backside, just above the user interface.

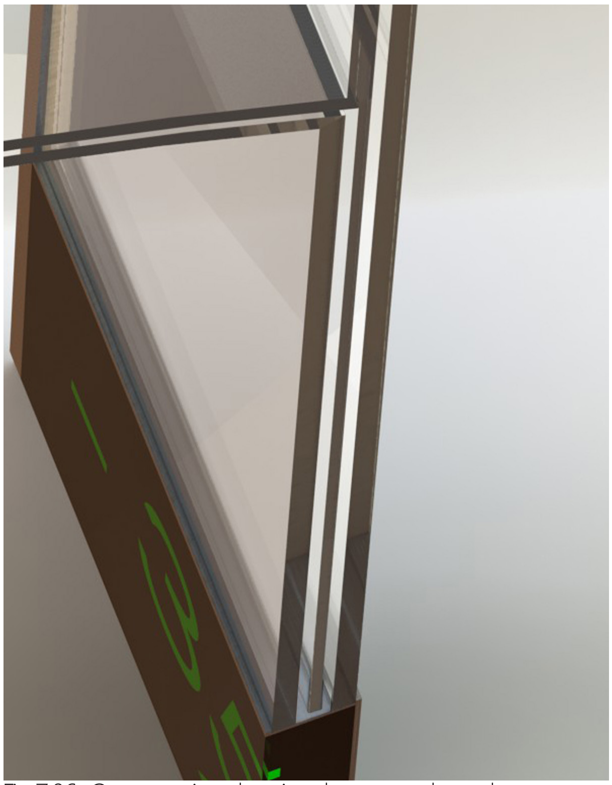


Fig 7.06: Cross section showing the water channel.

7.5 Water connection

To connect the shower to the water system, there is a special element in the shower. This element is called: 'the connecting element'. 'The connecting element' is the part that makes it possible to fasten the shower to the wall. It has screw-threat that fits a usual connection; the element protrudes on the back of the back plane of the shower. For the water to flow through; it is like a hollow bolt. For the water to stay in the shower; 'the connecting element' is able to rotate in the vertical plane, but is tight enough to keep the water inside. Figure 7.07 shows what the idea of the element is; the black arrows are showing the way to screw the element in place and the blue arrows show the way the water enters the shower.

In the sketch there is also thought of a way to cover up the connections when the shower is installed. The way the cover it up is explained in the 'Power connection' paragraph.

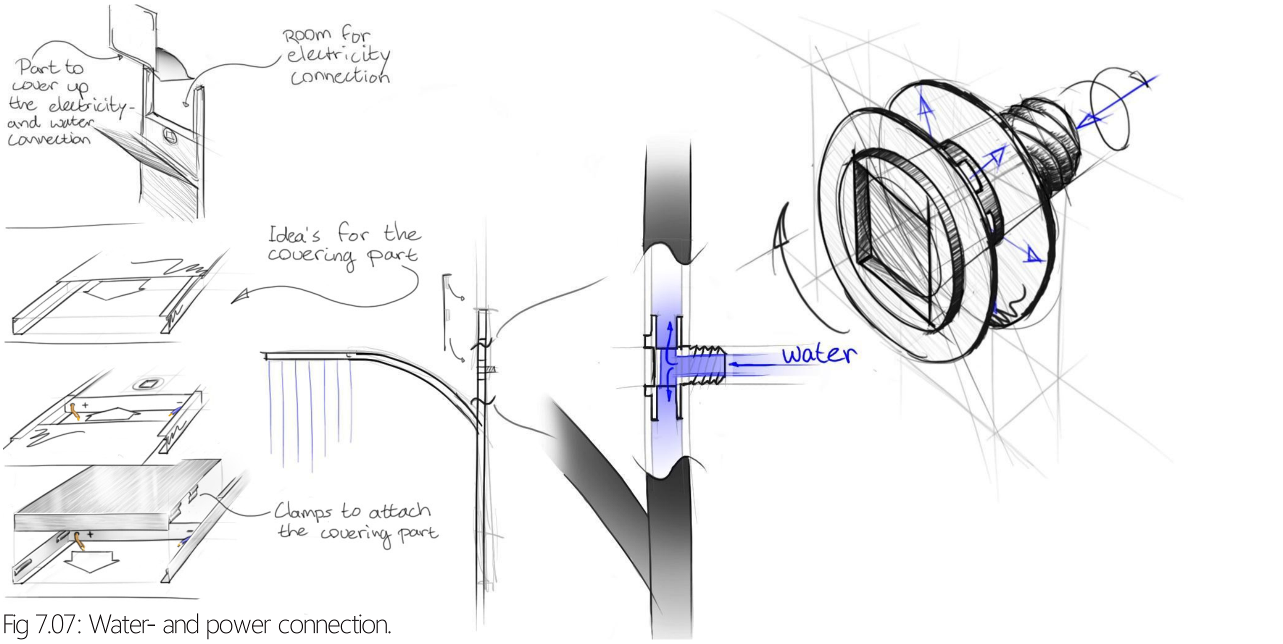


Fig 7.07: Water- and power connection.


Allen key.

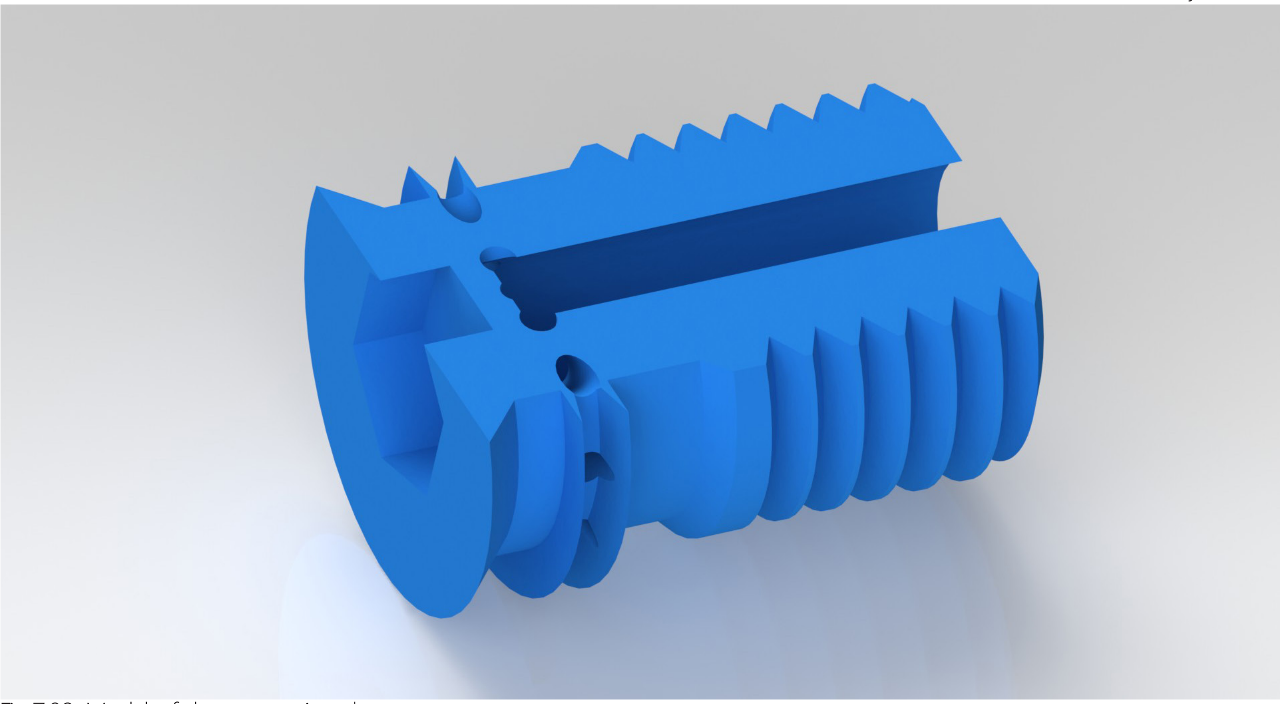


Fig 7.08: Model of the connecting element.

Figure 7.08 shows how the connecting element is elaborated in the solid works model. This part shows the functional meaning. But it is not practical yet; this part cannot be inserted in the product because of the ridges. It probably needs to consist of two or three components. The shower can be fastened with an Allen key.

7.6 Power connection

To connect the shower to the electricity grid, there is a free space in the upper section of the shower. Because the power connection is usually higher located than the water connection (paragraph 4.1), there is enough space preserved for the connection (height of 140 mm). This way the electricity wires are always hidden, this will contribute to a clean appearance and a safer showering environment. In the sketch for the water connection (figure 7.09) there is thought of a way to cover up this space. There will be a separate element that can be attached after the wires are connected and the water connection is fastened. The cover plate is attached by a click system; with a little force the user is able to detach it. The click system contains a guiding chip which ensures the plate to be put in the right place without shifting. Figure 7.10 shows how the electricity runs through the film layer. The copper tracks are also schematic represented to demonstrate in which direction they are placed.

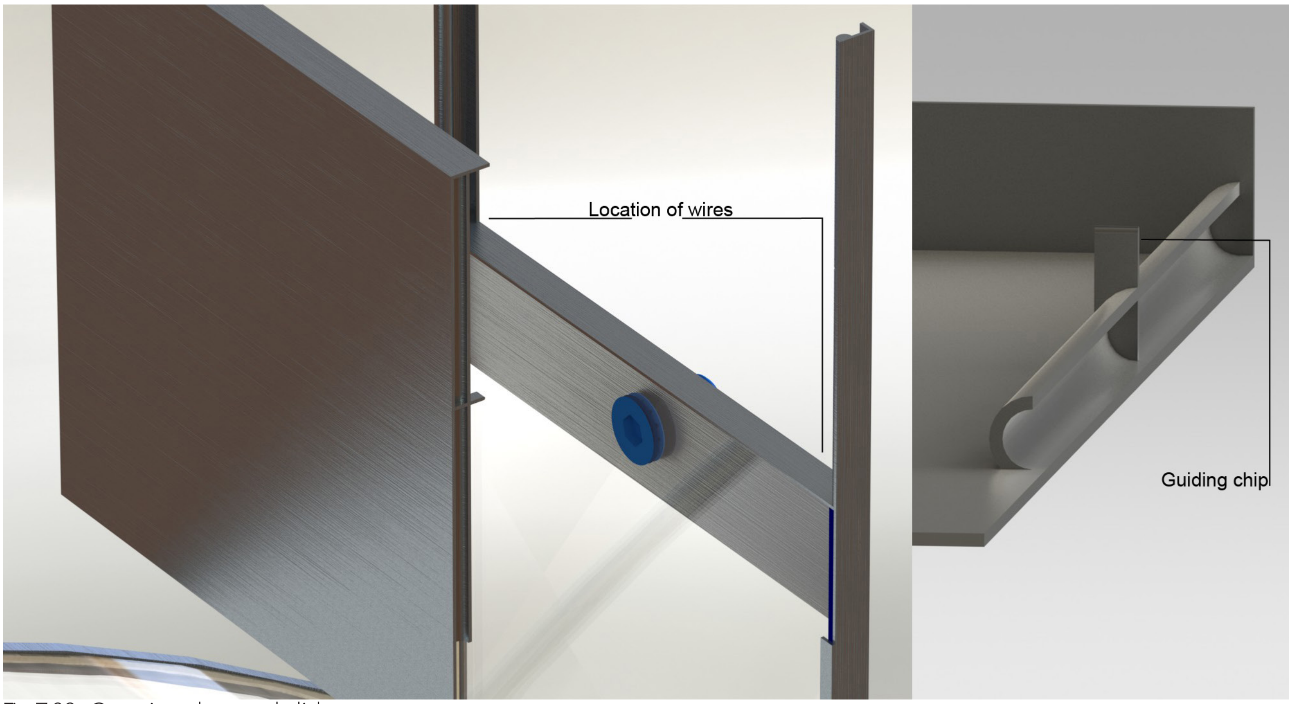


Fig 7.09: Covering plate and click system.

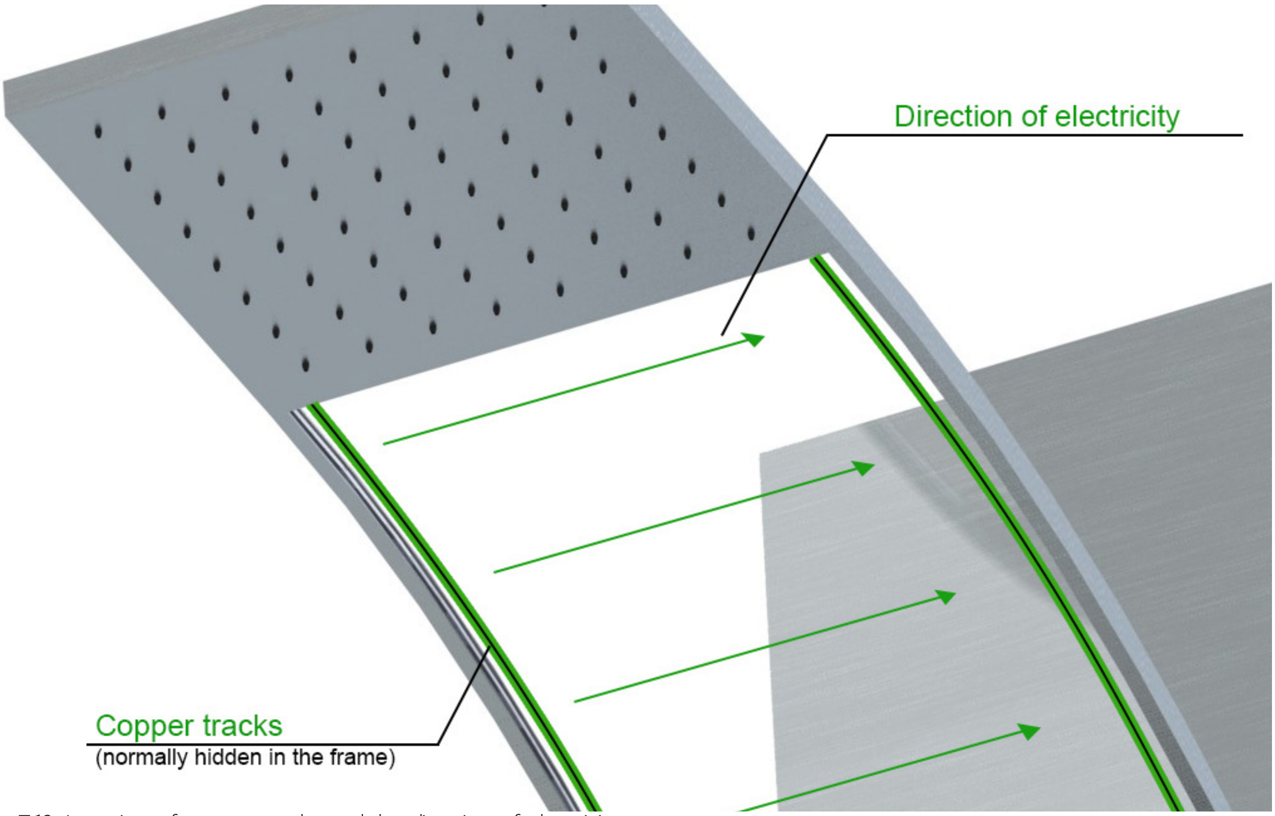


Fig 7.10: Location of copper tracks and the direction of electricity.

Solid Works model

Some elements of the final draft are explained by using a render of a section of a Solid Works model. This model will also be used to show what the appearance of the shower will be. Figure 7.11 shows the model which is installed against the wall. A water tap is visible underneath the model in a common location.

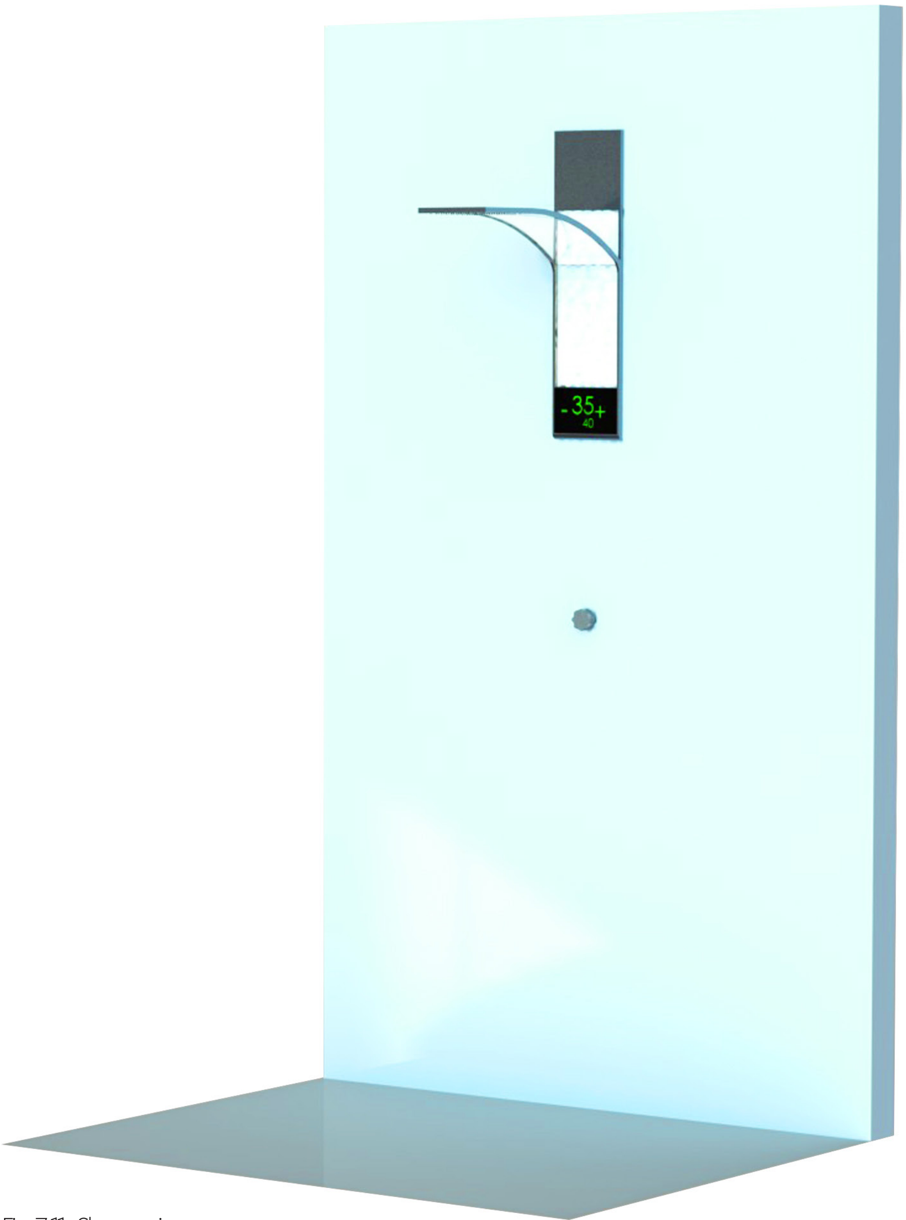


Fig 7.11: Shower in scenery.

7.7 Assembly

The elements of the shower are elaborated. To produce the shower there has to be a way to assemble the elements of the shower. The exploded view (figure 7.12) shows how the elements can be divided. The different elements are discussed one by one; about the material that will be used and the way of assembling it.

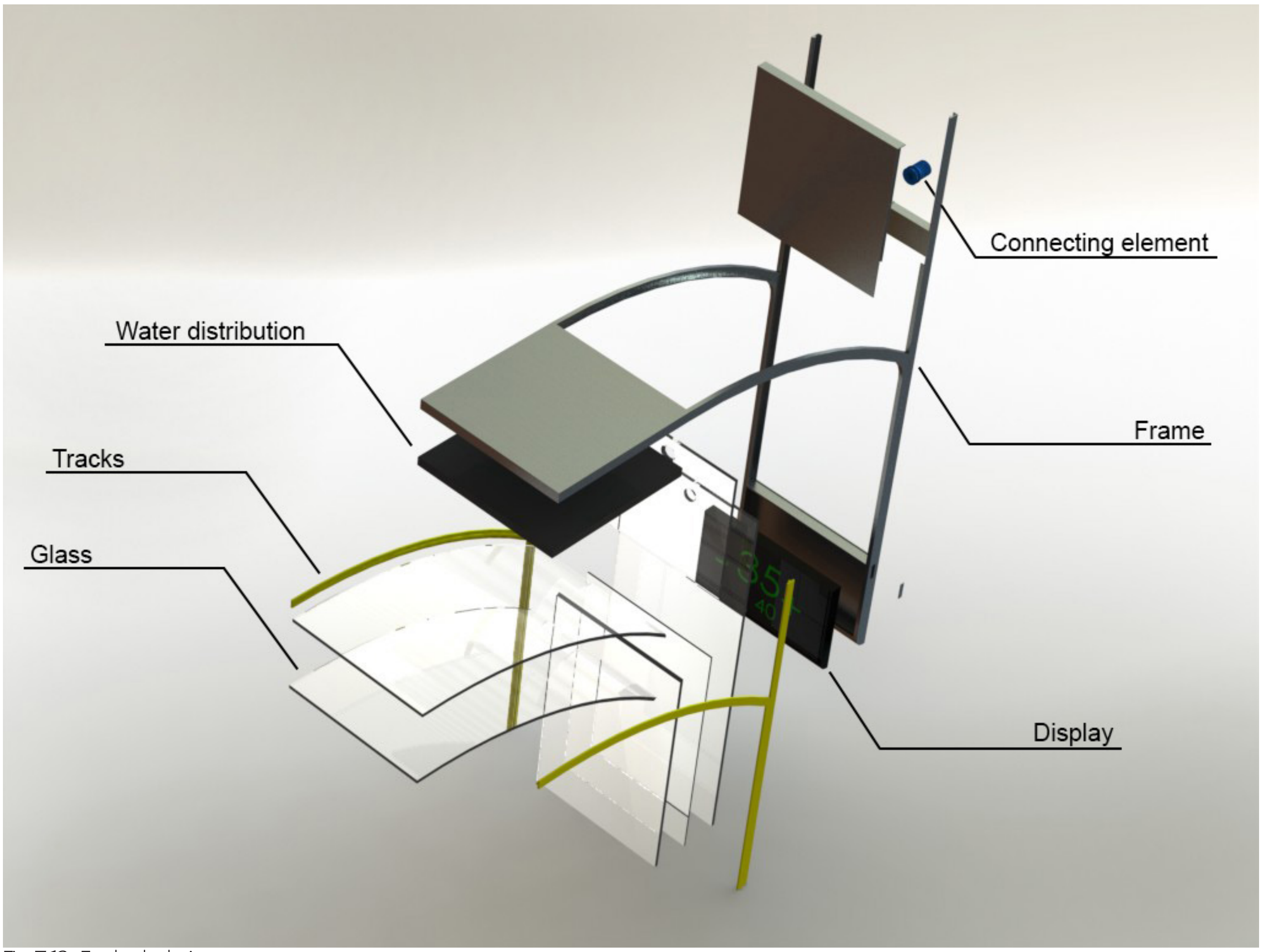


Fig 7.12: Exploded view.

Frame

The frame will consist of aluminium parts. In the exploded view the frame is only one piece (except for the covering plate), but this will not be possible because of the shape. The large surfaces and the side strips will be cut separately. The side strips can be divided in two parts. The edges need to bend to create a holder for the glass. The large surface will connect the two strips to each other. On the bottom section, behind the display, the frame has non-slip silicone strips. These will prevent the shower from moving, since the shower is attached on the top with the connecting element. The force (moment) due to the mass of the shower will keep the shower in place.

Tracks

The yellow parts in the exploded view are the tracks. These are placed in the frame. The two tracks contain all the electricity wires needed. They also have slots where the glasses fit in (figure 7.13). The tracks are made of silicone rubber. At some

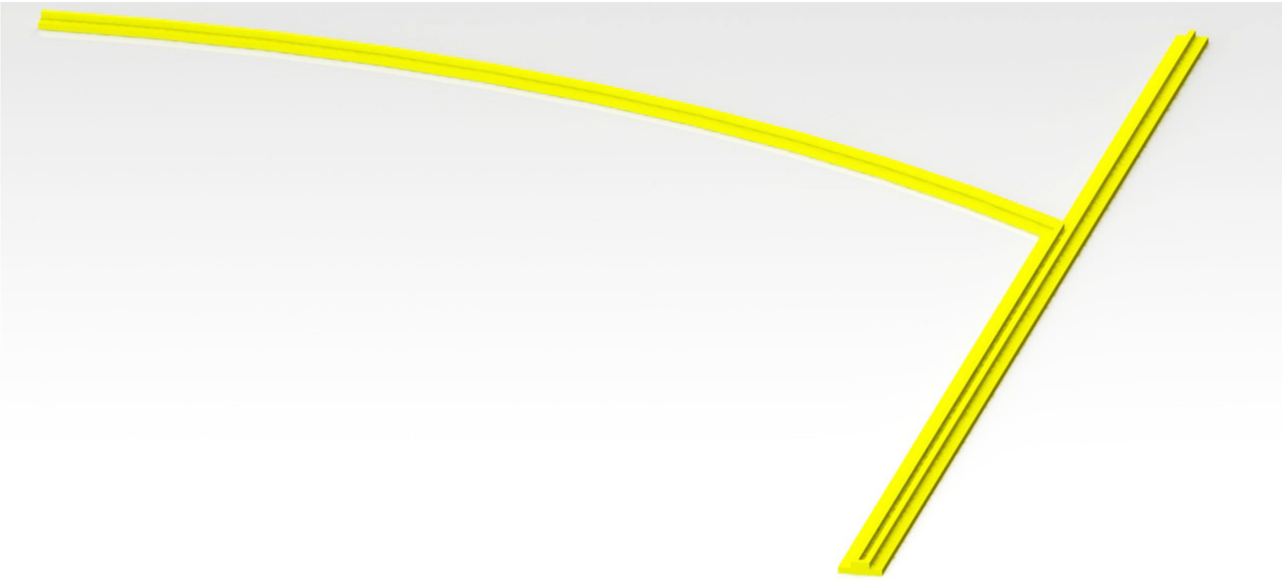


Fig 7.13: A track with slots for the glass plates.

places there are electrical connections to power the thin film layer. They are placed in the frame, after the frame is welded together, deburred and finished. The colour will be dark grey.

Water distribution

The distribution is achieved by sixty four small holes (8 × 8). There are holes in the frame, through the frame rubber studs are visible (figure 7.14). These protrusions belong to the inner part of the water distribution which is made of silicone rubber. These protrusions prevent deposits in the water to create varnish or become clogged; it is easy to clean it with your fingers. Because this inner part is flexible it can be inserted easily. This part could be merged with the tracks.

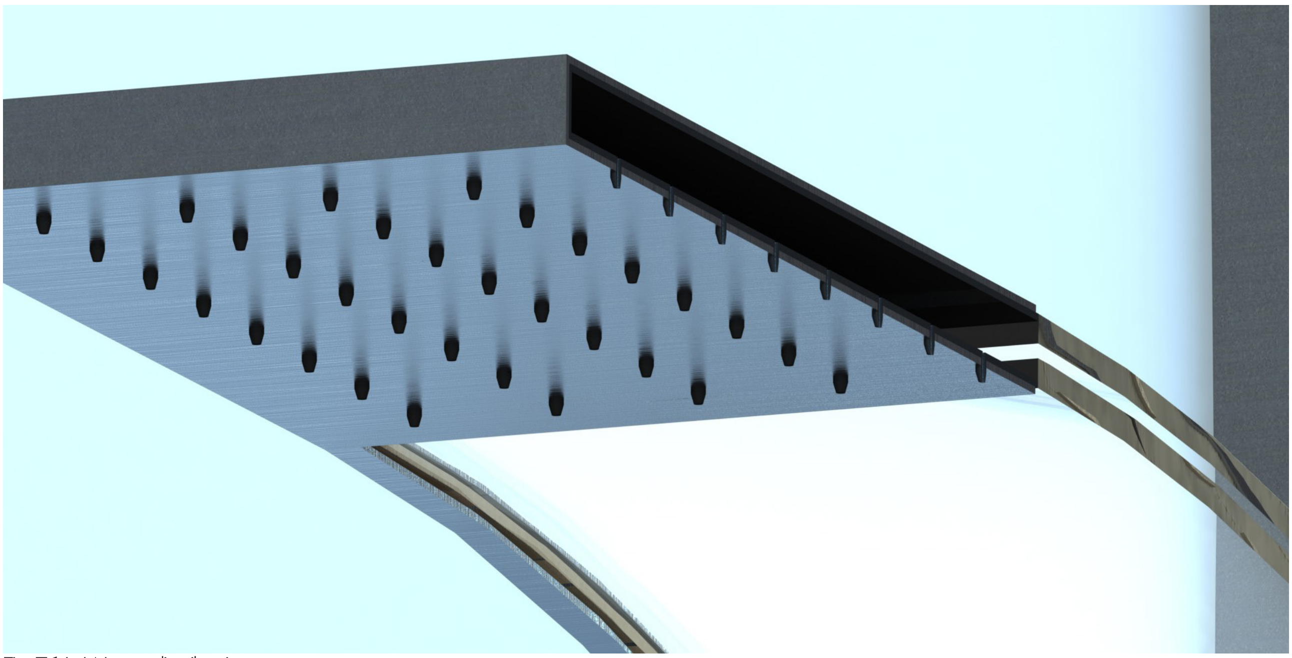


Fig 7.14: Water distribution.

Glass

There are six separate glass plates. It is temperate glass to ensure safety. The glass plates are four millimetres thick and have the thin film layer on the side that is faced to the water. Accept for the plate in the middle of the bottom section; this plate is two millimetres thick and has the thin film layer on both sides (because the water runs on both sides). The plates are all the same width, but differ in length. Once the glass plates are cut, the thin film layer is applied. The two plates connecting to the water distribution need to be bent. Because it is a gentle curve the bending means no harm to the thin film layer (a sharp curve could cause cracks in the thin film layer). The two plates that reach the connection section need to have a hole cut in. These holes are intended for the connecting element (for the water). The front plate needs to have a chamfer to keep the connecting element in place. Each thin film layer gets two copper tracks that are able to touch the silicone rubber tracks; these will divide the electricity properly over the surface. The plates are inserted in the frame with the silicone rubber tracks by gently pulling the frame outwards. The glass plates are fixed with silicone sealant.

Display

A space is added in the aluminium frame to fit the display. An undetachable click connection is used to assemble the display. The interface has a capacitive touch screen on a LCD. The controlling system is located behind the display.

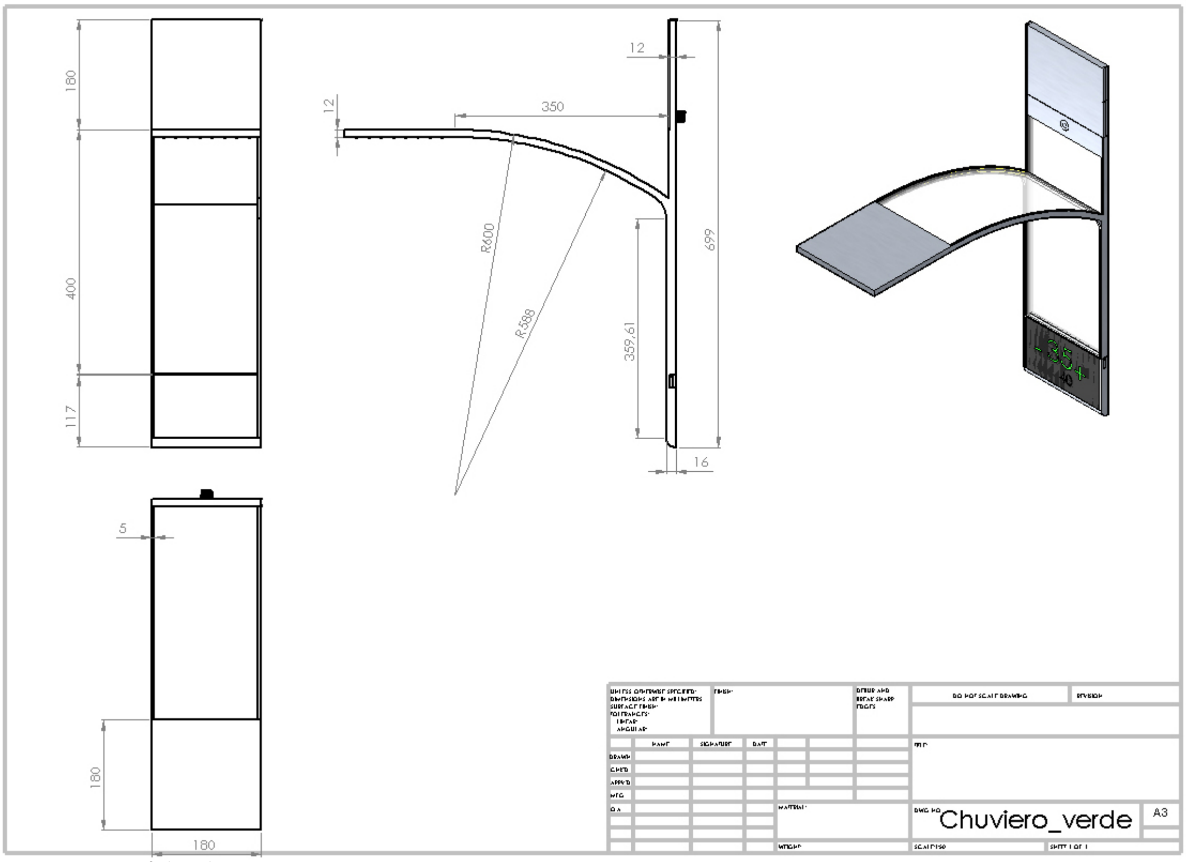


Fig 7.15: Sizes of the shower (mm).

7.8 The numbers

The sizes of the shower are now defined (figure 7.15). With these sizes it is possible to calculate the temperature of the thin film layer when you heat water of 16°C to 40°C. A quick equation gives a surface of 0.19 square metres.

Paragraph 4.2 showed how to calculate the temperature of the thin film layer:

$$\Delta T_{av} = \frac{5023 * 0.004}{0.58 * 8.235 * 0.19} = 22.1\ ^{\circ}C$$

$$T_f = \frac{e^{\frac{16-40}{22.1}} * 16 - 40}{e^{\frac{16-40}{22.1}} - 1} = 52.2\ ^{\circ}C$$

The temperature of the thin film layer will be about 52°C. This temperature is very low in comparison with the coil that is used nowadays. The low temperature will lead to a longer product life. This can also contribute to the efficiency of the shower. The outside of the glass will have a lower temperature, so this will not harm the user when he accidently touches it (as researched in paragraph 4.2). The water distribution is located 35 centimetres from the wall; this is enough to stand underneath the shower properly. This width of the glass plates is in harmony with the width of the water distribution (180 mm); this shows that these are suitable sizes.

8 CONCLUSION

The goal of this project was to design a shower using the thin film heating technology of ABINFO. The result is a design of a shower which ABINFO can use to show the possibilities with their technology. The design intended to get a focus of ecological awareness, the project partly succeeded. The interface creates ecological awareness for the user. The appearance of the shower will contribute to the ecological awareness because of its shape and the material which is being used. The appearance became a simplified version of the organic natural shape (figure 8.01). This way the shower obtained a clean and elegant appearance. Because the thin film layer is on the inside, the outside temperature of the glass plates will be even lower than 52 °C. This temperature will not produce any danger to the user. The use of silicone rubber will prevent the user to get electric shocks.

Fig 8.01: The model.

8.1 Marketing

The shower is designed for the high class costumer. With a prosperous economy, there is a target group in Brazil which wants to pay more for a more luxurious and ecological shower. Because the price of a common plastic shower is very low, it is hard to compete on this level. The low price is due to the enormous quantity of the production and the use of cheap materials. It was a conscious decision not to try competing on price level, but to use materials that give a classy appearance. The shower is meant to approach the market from the top down. First the product will become popular for people that want to pay a high price for innovative products. The percentage of the high class people are best represented in the state of São Paulo, this is the best state to launch the shower. It is favourable to use a policy on which stores are authorized to sell the product (preferably specialty stores). This way the shower will stay a special product. Later on, when the shower has gained enough publicity and fame, the product could be produced with cheaper materials (For instance by using a plastic casing and polycarbonate plates).

8.2 Requirements

The requirements which are determined (appendix C) are a good way to verify if the design is suitable for the goal that was set. The requirements for the appearance are the most appropriate to review.

Appearance

"Shower communicates the use of sustainable energy (especially hydropower)."

Approaching it from the appearance point of view; this is not explicitly present. But the use of aluminium could contribute to a sustainable energy look. It has turned out not to be an important requirement, since the focus was set on a clean and simple design.

"Shower shows that it has economical power consumption."

The innovative shape and the display will contribute to economical appearance. The time bar on the shower will give the user an economical awareness.

"Shower must have a luxurious appearance (as it is meant for a high class price range)."

A luxurious appearance is accomplished; using glass and aluminium. The glass will give a shiny look that will last for a long time; because it is durable.

"Shower must have a different appearance compared to an ordinary shower, to show the technology is new and improving."

The appearance of the shower is definitely different and shows that an improving technology is used. Also the display will contribute to a new and improved experience of the shower.

Technical

Only the technical requirements that are significant are beign discussed.

"Thin film heating element must be heated to the right temperature within 60 seconds."

An estimation of Doctor Den Engelsen says it will take about one minute for the shower to reach a steady state.

"The glass must enclose the water, until the water arrives at the holes for exiting."

The silicone rubber and the silicone sealant will ensure that the shower will enclose the water.

"Shower must have an option to attach to the wall or ceiling."

The shower is attached in a usual way; with screw threat in the wall.

"The weight of the shower may not exceed 5 kilogram."

An evaluation of the Solid Works model indicates that the shower weighs 4.3 kilogram. This will not cause any problem.

"There have to be as much turbulence as possible in the water when it runs through the shower."

There are some turns in the shower which will cause turbulence. But the best thing to do is to develop a rough surface on the thin film layer to create more turbulence.

"Temperature can be scaled in a range of 30 to 45 degree"

The display allows the user to choose the temperature, scaled in steps of one degree.

"Shower must not show signs of dirt in the water"

This is doubtful; probably over time the glass will show deposits in water.

Desires

"Shower does not show the power connection."

The power connection is hidden behind the covering plate

"Thin film heating element is heated to the right temperature within 10 seconds."

This will take about a minute; so this will not be possible.

8.3 Recommendations

The designed product is meant for a pilot run. There are things that need to be improved. To anticipate on the things that need to be improved there are recommendations.

The way of manufacturing the shower needs to be refined. It can be used in order to calculate the costs. The connecting element needs to be elaborated because the current shape cannot be assembled. Another addition for the connecting element is a system that only connects the electricity when the water runs (coil showers have this). A valve positioned could be positioned above the connection element to flush the shower with cleaning materials for keeping the glass bright. A valve could also be used in combination with an air stone (like one that is used in an aquarium) to create air bubbles to show the water flow through the shower. Another way to avoid deposits is to add a filter, but this will take a lot of room. It is also possible to avoid the visibility of deposits; for instance by colouring the glass. When glass is coloured on the inside, the glass will still have its smooth and clean look. Another option is to turn the glasses into mirrors. This will have another advantage. Mirrors can become steamed from the hot water of the shower. When the mirror is heated, which happens when the shower is turned on (because it is the heating element), the water will not condensate. A function that could be elaborated is adaptability of the height of the shower. A hose with a nozzle could be added; to have more degrees of freedom of the water spray.

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APPENDIX INDEX

APPENDIX A

Several photos of a domestic shower.

APPENDIX B

Medium size parts shop in the district Barão Geraldo, Campinas (São Paulo).

Spare parts for an electric shower in a small store for domestic items.

APPENDIX C

Scenario

To come up with ideas a scenario is writen. The scenario is focussed on functionality, this way the user interaction can be taken in consideration. The scenario represents a possible future way of using the shower. This way a future perspective is created, which can be used to come up with features for the user interface and other ideas.

"Roberto is 35 years of age, and has a wife and a child. He works as a process manager in a sugarcane factory. Roberto lives in an average house without a central heating system, so he has an electrical shower to get a nice warm shower in the morning or after he played football.

This morning his alarm on his smart phone rings at 07:00. When he wakes up he gets his smart phone and determines the duration and the temperature of the shower he is going to take. He will take a 7 minute shower to have enough time left for his breakfast. Some days he programs his shower before he goes to sleep, but this morning he wants to adapt the duration and temperature to the feeling he has when he wakes up.

Roberto gets out of bed and heads for the bathroom. He opens the water tap and presses 'start' on the shower. Now the water begins to run and soon it will have a nice temperature. On the shower is a bar displayed, which represents his shower time. When the bar is completely gone the shower will not heat the water anymore. besides that Roberto can get track of the amount of water and electricity he uses. This way he will be more conscious about what his bill at the end of the month is going to be like. When the water starts to get cold, he turns of the shower and dries himself. Most of the time he tries to turn off the shower before the heating time ends."

APPENDIX D

Requirements

The analysis resulted in a set of requirements which are used to design the shower. To structure the requirements they are placed into several categories. As became clear in the analysis there is a focus on the appearance of the product, but to design a working product the technical aspects must be taken into account aswell.

Appearance

- Shower communicates the use of sustainable energy (especially hydropower)
- Shower shows that it has an economical power consumption
- Shower must have a luxurious appearance (as it is meant for a high class price range)
- Shower must have a different appearance compared to an ordinary shower, to show the technology is new and improving.

Technical

- Shower must have electrical contacts for the power
- Shower must have a connection to ground electricity for safety reasons
- Shower uses thin film heating system
- The glass must have a strip of metal on both sides to guide the electricity
- The size of the glass will generate enough heat to warm up the water
- Thin film heating element must be heated to the right temperature within 60 seconds
- The glass must enclose the water, until the water arrives at the holes for exiting
- Shower must have an option to attach to the wall or ceiling
- The weight of the shower may not exceed 5 kilogram
- There have to be as much turbulence as possible in the water when it runs through the shower
- Water may not exceed the temperature of the water leaving the shower
- Temperature can be scaled in a range of 30 to 45 degree
- Shower must not show signs of dirt in the water
- The outside of the shower must not be dangerously hot (60 degrees), or the consumer have to be warned.
- Heat loss on the surface have to be taken into consideration
- The price of the shower may not exceed R$ 400,-

Desires

- Shower dœs not show the power connection
- Thin film heating element is heated to the right temperature within 10 seconds
- The color of the glass will not change

APPENDIX E

Thin film heating patent

AQUECEDOR DE ÁGUA A FILME RESISTIVO

Campo da invenção

Refere-se a presente invenção a um novo tipo de aquecedor elétrico a filmes resistivos depositados sobre substratos de diferentes formatos, aplicável no aquecimento de água, notadamente em chuveiros e torneiras elétricas.

Descrição do estado da técnica

Dois tipos de aquecedores elétricos de água são largamente empregados, quais sejam os aquecedores instantâneos e os aquecedores de reservatório ou centrais. Os primeiros, também chamados aquecedores de fluxo contínuo, são exemplificados nas patentes US 4424767 e US 4282421. Tipicamente consistem de uma câmara contendo um elemento de aquecimento por efeito Joule, de grande potência, que é ativado pelo fluxo da água, podendo a potência ser controlada por um termostato. Assim os aquecedores de fluxo contínuo fornecem água quente somente sob demanda, evitando as perdas que ocorrem nos aquecedores de reservatório ou centrais, nos quais a água é continuamente aquecida.

Os aquecedores elétricos de água para uso doméstico, seja em chuveiros, seja em torneiras, são utilizados há décadas, sendo muito populares no Brasil. Nestes aquecedores os elementos de aquecimento são resistores de metal, predominantemente de uma liga de níquel-cromo (Ni-Cr) com 80% de níquel e 20% de cromo, liga esta que, graças a sua dutilidade, pode ser trefilada bem como seus fios podem ser enrolados na forma de bobinas. Instaladas na câmara de aquecimento por onde passa a água a ser aquecida, e em contato direto com esta, as bobinas de Ni-Cr têm resistência elétrica tal que podem gerar o calor necessário para aquecer a água, quando atravessadas por corrente elétrica (por efeito Joule). No entanto, porque sua área de contato com a água é limitada, os resistores filamentares de Ni-Cr devem ser aquecidos a temperaturas muito altas de forma a transferir suficiente calor para a água. A alta temperatura das bobinas quando em contato com a água das redes públicas de suprimento, especialmente em regiões em que é elevada a concentração de íons de cálcio, magnésio, etc. favorece a formação de depósitos de sais destes elementos na forma de camadas isolantes térmicas insolúveis, como é o caso do carbonato de cálcio e fosfato de cálcio. Estas camadas bloqueiam a transferência de calor do resistor para a água, causando um aumento ainda maior na temperatura da bobina, podendo inclusive provocar seu rompimento.

Outro efeito que ocorre nos aquecedores de bobina que operam em contato direto com a água é a degradação eletroquímica por efeito da eletrólise da água. Esta ocorre porque a voltagem da rede elétrica, aplicada ao resistor da bobina, é muito superior à voltagem de decomposição da água, de apenas alguns Volts (1,3 Volts). O oxigênio liberado na eletrólise é altamente reativo, provocando oxidação da liga metálica que pode levar à degradação da bobina, pelo aparecimento de furos ou mesmo sua decomposição química. Como ocorre com qualquer reação química, a oxidação é favorecida pela alta temperatura de operação da bobina.

Assim, os aquecedores a fios resistivos de Ni-Cr têm pouca durabilidade, requerendo trocas relativamente freqüentes que, em muitos casos, dependem da desmontagem da câmara em que estão contidos. Esta desmontagem requer algum preparo técnico e habilidade para ser realizada. A degradação eletroquímica pode ser evitada pelo emprego de materiais estáveis em presença do oxigênio (O_2) produzido na eletrólise da água, como é o caso dos metais nobres. No entanto estes metais são muito caros, tornando proibitivo seu uso.

Outra desvantagem destes aquecedores a fios de Ni-Cr é que, por operarem com altas temperaturas, produzem ebulição da água, com consumo de grande quantidade de energia na transformação de fase do líquido para o vapor, dado que o vapor pode escapar da câmara, com perda da eficiência térmica do sistema.

Outra desvantagem das bobinas de Ni-Cr está relacionada com o fator de potência, uma vez que elas não são puramente resistivas, mas apresentam indutância que se soma à indutância normalmente presente na rede elétrica devido a motores, transformadores e outros dispositivos indutivos nela conectados. Contribuem, assim, para reduzir ainda mais o fator de potência a valores abaixo de 1.

Uma alternativa seria o emprego de elementos de aquecimento a filmes finos resistivos. Vários materiais para aquecedores a filmes finos são descritos na literatura de patentes. As patentes US 3931496 e US 6962401 descrevem aquecedores a filmes finos de materiais quimicamente inertes, todos eles muito caros, sendo um exemplo o ouro. Por sua vez, as patentes US 4889974, US 5616266, BR 9913812 e US 6859617 descrevem aquecedores a filmes finos de óxidos metálicos, tais como óxido de estanho dopado e não dopado. Os filmes finos resistivos de óxidos metálicos são depositados sobre substratos isolantes, por exemplo de vidro, quartzo, alumina, mica, cerâmicas e aço porcelanizado, como descrito na patente US 5616266.

Os filmes aquecedores de SnO_2 apresentam como vantagem a alta estabilidade química, a resistividade que pode ser ajustada pela dopagem, a facilidade de deposição em substratos de vários formatos, tamanhos e topografia de superfície (relevo, rugosidade, etc.), a resistência a abrasão, (graças à elevada dureza) e o baixo custo.

No entanto o óxido de estanho não é estável em presença do hidrogênio (H_2) produzido na eletrólise da água quando submetida a tensões acima de 2 Volts, dado que o H_2 reduz (decompõe) o SnO_2. Portanto qualquer elemento de aquecimento que empregue filmes de SnO_2 em contato direto com a água sofrerá decomposição. A taxa de decomposição dependerá da condutividade da água sendo que para água da rede pública esta decomposição pode ocorrer em poucas horas, dependendo da localidade.

Deste modo, um aquecedor a filmes finos de SnO_2 que não seja protegido por um recobrimento isolante não poderá ser usado para aquecer água comum em chuveiros e torneiras elétricas. As patentes de aquecedores a filmes finos de SnO_2 não mencionam esta limitação, tão pouco reivindicam a necessidade de uma camada protetora sobre o filme que permita seu uso no aquecimento de água, conforme pode ser visto nas patentes US 4889974, US 5616266 e BR 9913812.

Aquecedores recobertos com uma camada dielétrica são descritos nas patentes US 6762396 e US 6924468. No entanto estas patentes propõem aquecedores a filmes finos cerâmicos para aplicações em altas temperaturas e em presença do ar, como é o caso dos tampos de fogões. Além disto empregam materiais muito caros para serem utilizados em chuveiros e torneiras.

Esta invenção tem por objetivo um aquecedor de água a filmes resistivos que supera todos os problemas acima mencionados.

Objetivos da invenção

Em vista do exposto, constitui o primeiro objetivo da presente invenção um aquecedor de água para uso em chuveiros, torneiras e afins que empregue resistores na forma de filmes para produção do calor por efeito Joule, com grande área de contato com a água sob aquecimento.

Constitui um segundo objetivo da invenção um aquecedor cujos elementos resistivos têm, além de grande área de contato, alto coeficiente de transferência de calor para a água, razão porque operam em baixas temperaturas que minimizam as perdas de calor por ebulição, com ganho na eficiência térmica.

Constitui outro objetivo da invenção um aquecedor cujos elementos resistivos, por operarem em baixas temperaturas, minimizam a formação de crostas salinas mal condutoras de calor em benefício da maior eficiência energética do sistema.

Constitui outro objetivo da invenção um aquecedor cuja impedância equivalente é capacitiva de modo a contribuir para a compensação da impedância indutiva normalmente presente nas redes de energia elétrica.

Constitui outro objetivo da invenção um elemento aquecedor imune à corrosão eletroquímica por efeito da eletrólise da água.

Constitui mais outro objetivo da invenção um aquecedor cuja estrutura é capaz de criar turbulência no fluxo da água de modo a aumentar a convecção térmica e maximizar a transferência de calor do filme resistivo para a água.

Constitui ainda mais outro objetivo da invenção ser ela concretizada com materiais de baixo custo, facilmente encontráveis no mercado.

Outro objetivo da invenção consiste em garantir que o usuário do aquecedor possa utilizá-lo com segurança, seja do ponto de vista elétrico, seja do ponto de vista térmico.

Descrição resumida da invenção

Os objetivos acima são atingidos nesta invenção mediante o provimento de um aquecedor constituído por filmes resistivos depositados sobre substratos isolantes de geometria planar, cilíndrica, tubular ou qualquer outra que, montados, justapostos ou empilhados, formam canais ou dutos para a passagem da água sobre eles.

De acordo com outra característica da invenção, os filmes resistivos transferem para a água o calor produzido por efeito Joule quando atravessados por corrente elétrica.

De acordo com ainda outra característica da invenção, dito filme possui uma grande superfície de contato com a água, substancialmente maior que a das bobinas resistivas convencionais, permitindo sua operação em temperaturas baixas, menores do que 100 ºC.

De acordo com ainda outra característica da invenção, os elementos aquecedores apresentam uma capacitância na interface do filme resistivo com a água, produzindo efeitos benéficos para o fator de potência.

De acordo com ainda outra característica da invenção, dois ou mais elementos aquecedores são montados segundo geometrias e dimensões que maximizam a capacitância do sistema para maior compensação das impedâncias indutivas presentes na rede elétrica.

De acordo com mais outra característica da invenção, por operar em temperaturas baixas, o filme resistivo está menos sujeito a sofrer a deposição de crostas termicamente isolantes, que prejudicam a transferência de calor para a água.

De acordo com mais outra característica da invenção, dito filme resistivo é recoberto por uma película de material isolante elétrico para evitar sua corrosão eletroquímica e degradação.

De acordo com mais outra característica da invenção, dita película isolante elétrica é constituída por materiais de boa condutividade térmica.

Vantajosamente, tal elemento aquecedor não sofre os desgastes típicos das bobinas resistivas tradicionais e, portanto, apresenta durabilidade superior, não necessitando substituições freqüentes.

De acordo com mais uma característica da invenção, os substratos podem conter reentrâncias, elevações e obstáculos sobre eles de forma a criar turbulência que maximize o processo de transferência do calor por convecção.

Descrição resumida das figuras

As características e vantagens da presente invenção serão melhor compreendidas através da descrição de uma concretização preferida, dada a título ilustrativo e não limitativo, e das figuras que a ela se referem, nas quais:

A figura 1 mostra uma vista lateral (figura 1a) e uma vista superior (figura 1b) da configuração básica do elemento aquecedor ilustrando um substrato isolante recoberto com um filme resistivo e seus contatos. A figura 1c mostra uma vista lateral do elemento aquecedor em que o substrato é recoberto com filmes resistivos em ambas as faces.

A figura 2 ilustra a corrente elétrica parasita, paralela ao filme fino, que aparece quando o aquecedor é atravessado pela água

A figura 3 mostra uma configuração de um elemento aquecedor em que filmes finos são depositados em ambas as faces de um mesmo substrato e são recobertos com uma camada dielétrica para isolação da água.

A figura 4 ilustra a acumulação de cargas positivas no filme resistivo e de cargas negativas na água (figura 4a), na região da interface entre eles, quando a tensão no filme é positiva, e de cargas negativas no filme resistivo e de cargas positivas na água (figura 4b), na região da interface entre eles, quando a tensão no filme é negativa.

A figura 5 ilustra um elemento aquecedor composto por vários substratos com filmes resistivos, formando vários canais paralelos para a circulação da água.

A figura 6 ilustra um elemento aquecedor composto por vários substratos com filmes resistivos, formando vários canais conectados em série para a circulação da água.

A figura 7 ilustra o comportamento do fluxo num duto com paredes lisas onde o fluxo se comporta de forma laminar (figura 7a) e o comportamento do fluxo num duto com paredes rugosas (figura 7b) de forma a criar turbulência para aumentar a transferência de calor por convecção.

A figura 8 ilustra um duto com geometria qualquer de forma a aumentar a troca de calor no elemento aquecedor a filmes resistivos.

Descrição detalhada da invenção

A figura 1 mostra a vista lateral (figura 1a) e a vista superior (figura 1b) da configuração básica do elemento aquecedor a filme resistivo, objeto da presente invenção. O elemento aquecedor é constituído por um filme resistivo (1) depositado sobre um substrato plano (2) eletricamente isolante. O filme resistivo é aquecido por efeito Joule quando é aplicada tensão entre seus dois contatos elétricos (3). A água (4) a ser aquecida flui sobre a superfície do filme.

Em outra configuração (figura 1c) o filme resistivo (1) é depositado em ambas as faces do substrato (2) aumentando, assim, a região de aquecimento e a área de contato com a água.

A quantidade de calor transferida para a água pelo filme da figura 1a, por unidade de tempo, ou seja, a potência térmica transferida para a água é descrita pela equação de Newton:

$$W = \alpha . S . (T_C - T_W)$$

em que W é a potência térmica gerada no filme resistivo (1) expressa em Watts, α é o coeficiente de transferência de calor do filme resistivo (1) para a água (4), expresso em $W.m^{-2}.K^{-1}$, S é a área da superfície do filme resistivo (1) em contato com a água (4), em m^2, T_C é a temperatura do filme resistivo (1), em ºC, e T_W é a temperatura da água (4) quente, também em ºC. A expressão acima mostra que quanto maior a área do filme resistivo (1) em contato com a água (4), maior a potência térmica transferida para a água (4).

Na invenção aqui proposta, como o filme resistivo (1) de aquecimento tem uma área muito grande, sua temperatura pode ser inferior a 100 ºC e ainda assim aquecer a água nas temperaturas requeridas para uso humano. Por exemplo, se a vazão da água é de 3 litros/minuto e a temperatura da água é inicialmente de 16 ºC, a potência necessária para que atinja 40 ºC é de 5 kW, se não houver perdas de qualquer natureza. Nestas temperaturas tão baixas, o elemento de aquecimento não produz ebulição da água, evitando assim a geração de vapor e seu escape. Esta é uma das fontes de perda de eficiência no elemento aquecedor convencional constituído por fios de níquel-cromo que, por sua pequena área de contato com a água, devem operar em temperaturas muito altas.

Outra vantagem da operação em baixas temperaturas é minimizar o depósito de crostas salinas sobre a superfície dos filmes resistivos (1) aquecedores, crostas estas que, por serem isolantes térmicas, limitam a transferência de calor do filme para a água. Estas crostas formam-se porque estão presentes na água da rede pública sais minerais, especialmente sais de cálcio, cujo depósito nas superfícies é favorecido em temperaturas altas.

A otimização da transferência de calor não resolve, no entanto, o problema da corrosão eletroquímica no filme resistivo (1) quando em contato com água (4) em que estejam presentes correntes iônicas.

A figura 2 mostra correntes iônicas parasitas (5), fluindo paralelamente ao filme resistivo (1), seu sentido dependendo da polaridade da tensão aplicada aos contatos (3) e sua intensidade dependendo da tensão aplicada e da condutividade da água (4). Apesar dessas correntes parasitas (5) serem pequenas (4 a 5 ordens de grandeza menores do que a corrente (6) que percorre o filme resistivo (1) na água da rede pública), elas promovem a eletrólise da água (4) quando a tensão aplicada entre os contatos do filme resistivo (1) é superior a 2 Volts. Com a decomposição da água (4) são produzidos átomos de hidrogênio e de oxigênio, altamente reativos, que podem oxidar ou reduzir o filme resistivo (1), dependendo do tipo de material de que é composto.

Diferentes materiais podem ser utilizados na confecção dos filmes resistivos (1), a exemplo dos óxidos metálicos e dos metais e ligas. Dentre os primeiros há o dióxido de estanho (SnO_2), o óxido de zinco, o óxido de índio ou suas misturas, com boas propriedades para a aplicação nos elementos resistivos, a não ser porque são passíveis de sofrer redução pelo hidrogênio produzido na eletrólise da água, quando em contato com esta. Por outro lado, filmes de metais como alumínio (Al), cromo (Cr), níquel (Ni), etc., são passíveis de sofrer oxidação quando em presença do oxigênio produzido na eletrólise da água. Este efeito poderia ser evitado pelo emprego de metais nobres como a platina ou o ouro, inertes a oxidação; no entanto seu emprego é proibitivo em aquecedores de água, dado seu elevado custo.

O carbono é um elemento inerte até temperaturas muito altas e seus compósitos a base de grafite são uma opção para compor os filmes resistivos (1) aquecedores. Um compósito bem conhecido é o aquadag, em que o grafite está contido em uma matriz de silicato de sódio e silicato de potássio (Na_2SiO_3/K_2SiO_3). No entanto, como os íons de Na e K podem se difundir na água, essas matrizes podem se degradar, sendo vantajoso utilizar em seu lugar o silicato de lítio, mais estável. Outra alternativa é compor a matriz com silicatos de alumínio (materiais argilosos), como nos lápis.

Para evitar a corrosão eletroquímica dos filmes resistivos (1) pode-se proteger sua superfície com uma camada dielétrica que bloqueie a corrente parasita na água.

A figura 3 mostra uma configuração do elemento aquecedor em que o substrato (2) plano tem suas faces recobertas com filme resistivo (1) e este é protegido por uma camada dielétrica fina (7). Esta camada isolante bloqueia a corrente elétrica parasita que flui na água (4) quando é aplicada tensão nos contatos (3) dos filmes resistivos (1).

Estas camadas dielétricas finas (7) de proteção podem ser constituídas por materiais orgânicos, tais como poliimida, teflon, neoprene, acrilatos, meta-acrilatos ou resina epoxy, com baixo coeficiente de difusão para a água e para íons. Ainda que não totalmente impermeáveis à água, estas camadas evitam, ou pelo menos atrasam, a corrosão do filme resistivo (1). Estas camadas orgânicas podem ser facilmente obtidas por vários processos, como por exemplo serigrafia, impressão, micro-centrifugação (spin coating), mergulho, evaporação, etc.

Camadas inorgânicas de dióxido de silício (SiO_2 ou sílica) ou de óxido de alumínio (Al_2O_3 ou alumina) são mais impermeáveis e podem também ser obtidas por métodos simples, a exemplo do mergulho em soluções de precursoras do tipo sol-gel de SiO_2 e de Al_2O_3 e outros. A impermeabilidade pode ser otimizada com a deposição de duas camadas e seu recozimento em altas temperaturas.

Ainda que alguns destes materiais orgânicos e inorgânicos tenham baixa condutividade térmica, a transferência de calor através deles pode ser alta quando em camadas de muito pequena espessura. Por exemplo, no caso de um filme de poliimida, cuja condutividade térmica é muito baixa, da ordem de 0,125 $wm^{-1}K^{-1}$ (portanto oito vezes menor que a do vidro comum), a diferença de temperatura $T_1 - T_2$ entre suas faces pode ser calculada por:

$$F = \lambda \frac{T_1 - T_2}{d}$$

onde F é o calor transferido através da camada de poliimida, λ é a condutividade térmica do polímero e d é sua espessura. Para transferir 50 kW/m^2 de calor através desta camada isolante, valor razoável para um aquecedor de água doméstico, um recobrimento de poliimida de 2 µm de espessura estaria sujeito a uma diferença de temperatura $T_1 - T_2$ de apenas 0,8 ºC entre suas faces.

Outra consideração diz respeito à ruptura dielétrica da camada isolante. Porque a água da rede tem condutividade elétrica, a diferença de voltagem na camada dielétrica protetora pode alcançar uma fração significativa da tensão aplicada no filme resistivo (1), em virtude da acumulação de cargas. Como a poliimida, em presença de umidade, tem uma rigidez dielétrica de cerca de 100 V/µm, a espessura da camada isolante com ela construída deve ter entre 5 e 10 µm para que não sofra ruptura dielétrica. Pela expressão acima pode-se calcular que o recobrimento do filme resistivo (1) com uma camada de poliimida de 5 µm, implica num aumento de não mais do que 2ºC na temperatura no filme aquecedor, e de 4ºC para poliimida de 10 µm. Este aumento de temperatura no filme aquecedor pode ser reduzido significantemente, misturando-se ao polímero pequenas partículas inorgânicas de alta condutividade térmica, como, por exemplo, alumina. Como a condutividade térmica de alumina (Al_2O_3) sinterizada de alta densidade é 18 $Wm^{-1}K^{-1}$ em temperaturas até 50ºC (portanto duas ordens de grandeza mais alta do que a da poliimida), a adição de 10% em volume de Al_2O_3 no polímero pode elevar significativamente a condutividade térmica da camada isolante, limitando o aumento na temperatura do filme aquecedor a menos de 1ºC.

Os elementos aquecedores a filmes resistivos (1) apresentam uma capacitância na interface dos filmes resistivos (1) com a água (4) como ilustrado na figura 4. Como a impedância capacitiva tem fase oposta à da impedância indutiva normalmente presente na rede elétrica, ela contribui para compensar o efeito desta última no fator de potência, sempre que o aquecedor de água estiver sendo utilizado.

O efeito da capacitância é melhor ilustrado na figura 4a na qual é mostrada a acumulação de carga positiva no filme resistivo (1) e de cargas (8) negativas na água, na região da interface entre eles, quando a tensão no filme é positiva. Esta carga negativa é constituída por íons negativos de OH e de cloro (Cl), normalmente presentes na água da rede pública. Em contrapartida, a figura 4b ilustra a acumulação de carga negativa no filme resistivo (1) e de cargas (8) positivas na água, na região da interface entre eles, quando a tensão no filme é negativa. Esta carga positiva é constituída por íons positivos principalmente de hidrogênio (H) e de sódio (Na), também normalmente presentes na água da rede pública. Esta capacitância é equivalente a um capacitor distribuído em paralelo com o resistor do filme resistivo (1) do aquecedor e seu valor pode ser muito alto, da ordem de 2,5 $\mu F/cm^{-2}$, dependendo da condutividade da água. Esta acumulação de cargas ocorre também quando o filme resistivo (1) é recoberto com uma camada dielétrica protetora, caso em que a capacitância é menor.

Os elementos aquecedores a filmes resistivos (1) podem ser projetados de modo a tirar melhor proveito deste efeito capacitivo pelo aumento da área da interface. Por exemplo, se o elemento aquecedor tem uma área total de 1000 cm^{-2}, esta capacitância pode atingir 2,5 mF, de modo a produzir um efeito significativo no fator de potência. Técnicos familiarizados com o projeto de sistemas aquecedores elétricos podem propor geometrias e formas de montagem e conexão dos elementos de aquecimento que maximizem o efeito da capacitância.

Várias concretizações são possíveis para o aquecedor visando a maximização da capacitância e da transferência de calor e a minimização do volume e peso do sistema completo.

Na figura 5 é mostrada uma configuração do aquecedor em que os filmes resistivos (1) recobrem ambas as faces dos substratos planos isolantes (2), montados num arranjo que forma canais paralelos para a passagem da água (4). Dois contatos (3) na forma de barras (por exemplo de metal) são conectadas à fonte de tensão para alimentar paralelamente os filmes resistivos (1).

Na figura 6 é mostrada outra configuração em que os filmes resistivos (1) recobrem ambas as faces dos substratos (2) planos isolantes, neste caso montados num arranjo que forma um longo canal em meandro. A água (4) entra pela abertura 10, e sai pela abertura 11. Os filmes resistivos (1) podem ser conectados de forma série ou paralela.

A resistência pelicular e a área total dos filmes resistivos devem ser dimensionadas de modo a prover a potência requerida para o aquecimento da água com fluxo, por exemplo, de 3 litros/minuto.

A otimização do rendimento térmico do aquecedor requer uma melhor compreensão de como o coeficiente de transferência convectiva de calor α da equação de Newton depende das condições do fluxo da água (4) ao longo do aquecedor. Dependendo das dimensões e da pressão hidrostática, o fluxo da água pode ser laminar ou turbulento. Este comportamento é descrito pelo número de Reynolds (Re), definido como:

$\mathrm{Re} = \delta.v.D / \mu$

onde δ é a densidade da água, da ordem de 1000 kg.m^{-3}, v é sua velocidade em m.s^{-1}, D é o diâmetro hidráulico equivalente do canal retangular por onde flui a água, em metros, e μ é sua viscosidade em kg.s.m^{-2}. Se Re > 2300, o fluxo é turbulento, caso em que o coeficiente de transferência de calor α, por convecção, do filme para a água, varia entre 250 e 3000 W.m^{-2}.K^{-1}.

Se por um lado a operação do elemento resistivo em muito altas temperaturas poderia favorecer o aparecimento de turbulência, por efeito da ebulição da água – condição em que o coeficiente de transferência de calor é próximo de 10000 W.m^{-2}.K^{-1} – por outro lado a eficiência térmica do sistema seria muito prejudicada pelo escape do vapor produzido. Esta é uma das razões para se manter a temperatura do filme abaixo de 100 ºC. Por outro lado, condições de fluxo turbulento poderiam ser criadas pela aplicação de forças hidrostáticas intensas, mas neste caso os chuveiros e as torneiras elétricas domésticas teriam que suportá-las, em prejuízo de tamanho, peso, durabilidade e custo do sistema e das instalações. Por isso devem preferencialmente operar com a pressão hidrostática da rede pública de água de modo a minimizar custos nos equipamentos e instalações.

Não sendo recomendável aumentar a pressão hidrostática, outras alternativas devem ser buscadas para otimizar a transferência de calor, por exemplo otimizando a geometria e a topografia das superfícies dos canais e dutos por onde flui a água durante o aquecimento.

O coeficiente de transferência de calor α pode ser facilmente derivado do número adimensional de Nusselt (Nu), que exprime a transferência convectiva de calor numa superfície:

$$Nu = \alpha.D_h / k$$

onde α é o coeficiente de transferência de calor do filme resistivo para a água, medido em W.m^{-2}.K^{-1}, k é condutividade térmica do fluido, em Wm^{-1}K^{-1} e D_h é o diâmetro hidráulico do duto, em metros. Para um duto retangular ou cilíndrico o diâmetro hidráulico D_h é definido por:

$$D_h = (2.w.h)/(w+h)$$

onde w é a largura do duto ou tubulação retangular, em metros, e h é sua altura em metros.

O número de Nusselt (Nu) para um fluxo laminar entre placas paralelas pode ser obtido na literatura, e seu valor é 7,541 quando a temperatura é constante ao longo da superfície das placas. Se há gradiente de temperatura ao longo delas, seu valor sobe para 8,235, caso em que o fluido está sofrendo aquecimento por um fluxo de calor constante ao longo do tubo. No caso do aquecedor a filme resistivo (1) objeto desta invenção, o número de Nussellt deve ser tomado entre os dois valores citados acima.

Se o coeficiente de transferência de calor por convecção na equação de Newton é conhecido, a diferença de temperatura entre o filme e a água (Tc-Tw) pode ser facilmente calculada para uma superfície de área total S. Os valores da tabela foram calculados para S = 0,1 m^2, condutividade térmica da água igual a 0,58 Wm^{-1}K^{-1} e sua viscosidade dinâmica a 25 ºC igual a 8,9x10^{-4} Pa.s.

Além do coeficiente de transferência de calor é importante considerar a redução na pressão hidrostática dp/dx no canal ou duto, na direção x de deslocamento do fluxo, perda de carga esta expressa em Pascal (Pa) por metro (Pa/m^{-1}) como sendo:

$$dp/dx = (2.f.\delta.v_m^{\ 2})/D$$

onde f é o fator de fricção ou atrito, adimensional, ō é a densidade da água, igual a 1000 kg.m^{-3}, e v_m é sua velocidade média em m.s^{-1}. Para um duto de placas paralelas o fator de fricção f é dado por:

$f = 24 / \mathrm{Re}$

em que Re é o número de Reynolds definido acima.

Na tabela a seguir são apresentados os parâmetros de transferência de calor para aquecedores a filmes resistivos (1) com a configuração mostrada na figura 5, calculados para dois valores do espaçamento h entre as placas (h = 5 mm e h = 1 mm).

Tabela dos parâmetros de transferência de calor para dutos de placas paralelas com h = 5 mm e 1 mm

	h= 5mm	h=1mm
D_h - Diâmetro hidráulico (mm)	10	2
Fluxo da água φ (litros/minuto)	3	3
Nu - Número de Nusselt	8.235	8.235
v - Velocidade média da água (m/s)	0,1	0,5
Re - Número de Reynolds	1.124	1.124
α – Coef.iciente de transferência de calor (W.m^{-2}K^{-1})	478	2.390
T_c - T_w (ºC)	104	21
$-dp/dx$ (Pa/m)	42,7	5.338

Os valores da tabela permitem calcular que o produto do coeficiente de transferência de calor α pela altura dos dutos h é constante quando o fluxo é laminar. Isto significa que o coeficiente de transferência de calor α aumenta quando a altura h dos dutos diminui, enquanto o fluxo da água é mantido constante.

Para dutos com *h* = 1 mm a diferença de temperatura entre o filme resistivo e a água é em média igual a 21 ºC. Isto significa que uma elevada transferência de calor pode ser obtida num aquecedor cujas placas paralelas têm um pequeno espaçamento entre si. Desta forma pode-se minimizar a temperatura no filme resistivo (1) aquecedor, reduzindo-se assim a deposição de crostas salinas em sua superfície.

Quando a altura h dos dutos é pequena (ou o espaçamento entre as placas é pequeno), é maior a queda de pressão dp/dx da água no duto do aquecedor, conforme mostrado na tabela. Ainda que h seja tão pequeno quanto 1 mm, a perda de carga num duto com 1 m de comprimento é de apenas 5338 Pa ou 0,05 bar, perfeitamente aceitável em chuveiros e torneiras.

Os cálculos acima foram efetuados para um elemento aquecedor cujas placas têm superfícies de baixa rugosidade, sem protuberâncias ou irregularidades, assim como os filmes resistivos (1) que as recobrem. Neste caso o fluxo da água é tipicamente laminar, sendo a distribuição de velocidades na camada líquida caracterizada por altas velocidades na região central do duto e velocidades praticamente nulas na região vizinha à superfície do filme resistivo (1) aquecedor. A figura 7a ilustra a distribuição de velocidades (12) na entrada do duto, quando ainda não se estabeleceu o fluxo laminar. Depois de percorrida uma certa distância no duto, o fluxo assume a distribuição tipicamente laminar (13) de velocidades.

A transferência de calor é sensivelmente maior quando as superfícies internas do duto são rugosas ou contêm protuberâncias ou irregularidades capazes de perturbar o fluxo da água, criando turbulência. Em regime turbulento as velocidades da água na região próxima à superfície do filme resistivo (1) são maiores. Em conseqüência o número de Nusselt é alto e o regime de fluxo laminar (13) não pode se desenvolver completamente.

Superfícies ásperas ou rugosas podem ser produzidas por abrasão com jato de areia, antes da deposição dos filmes resistivos (1). No entanto, como a rugosidade deve ser substancial para conseguir perturbar o fluxo da água (4), que de outra forma seria laminar (13), esta técnica pode não ser a mais eficiente.

Para evitar que fluxo da água assuma um comportamento laminar (13) pode-se preencher, com material altamente poroso, o interior do duto ou canal entre as placas do aquecedor, conforme mostrado na figura 7b. Desta forma, a distribuição uniforme de velocidades na entrada do tubo (12) praticamente será mantida por toda a secção reta da tubulação (15), após o fluido ter atravessado uma camada de material poroso (14). A camada porosa pode ser constituída por lã de vidro ou qualquer outro material isolante na forma de fibras ou particulados ou sob qualquer outra de modo que emule um material altamente poroso.

Em outra concretização o fluxo laminar (13) é evitado através da introdução de obstáculos isolantes entre as placas, podendo ser esferas, postes, barras ou quaisquer outras estruturas que criem turbulência no fluxo.

Uma maneira simples e barata de se construir elementos aquecedores que otimizem a transferência condutiva do calor é criando dutos de formato arbitrário como mostrado na figura 8, concretizados pela justaposição de dois substratos de vidro prensado com relevos arbitrários (16), cujas superfícies foram recobertas com os filmes resistivos (1). Estes substratos arbitrários (16) são montados em arranjos tais que formam meandros para a passagem da água.

É fácil depreender que o aquecedor de água objeto desta invenção não limita o uso de recursos de automação para o controle da potência elétrica aplicada, da temperatura e do fluxo da água hoje empregados nos chuveiros convencionais, bem como de quaisquer outros sistemas eletrônicos para ajuste contínuo e automatizado destes parâmetros que venham a ser desenvolvidos com tecnologias mais avançadas.

Recursos para deixar o aquecedor mais versátil no que se refere ao direcionamento do jato de água são também facilmente aplicáveis por qualquer um que esteja familiar com as técnicas.

Se bem que a invenção tenha sido descrita com base em algumas concretizações exemplificativas preferidas, os técnicos no assunto poderão introduzir modificações dentro do conceito inventivo básico. Assim, o "Aquecedor de Água a Elemento Resistivo" aqui descrito, objeto da presente patente de invenção, pode ter seus elementos básicos construídos com diferentes materiais, geometrias e dimensões, bem como ser montado segundo diferentes configurações conforme a necessidade de cada usuário. Quaisquer concretizações que venham a ser realizadas com base no conceito inventivo aqui descrito beneficiarão seus usuários em termos da segurança, tanto do ponto de vista térmico como elétrico. Isto porque são menores os riscos de queimaduras, graças às baixas temperaturas de operação, como são menores os riscos de choques elétricos, graças à isolação dos elementos aquecedores pelas camadas de proteção dielétrica sobre eles.