the system design of a new electronic mixing valve for an instant boiling water dispenser

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MSc. Integrated
Product Design

I would like to thank everybody at Quooker B.V. for their active support and enthousiasm during the project. I felt free to ask questions to everybody and praise the knowledge available in a good working atmosphere.

I would like to thank my graduation committee for mentoring me throughout this project. Dr. ir. E. Tempelman for his useful insights and expertise. ir. H.E.C. Crone for helping me putting findings into perspective during the project, critically assess gained information and the importance of planning.

I would like to thank my family in supporting me throughout not only this project, but my entire academic career (so far). Your supportive thoughts and critical comments help me to strive for better results and explore new opportunities.

image [1]
front cover

This thesis describes the development of a new electronic mixing valve for Quooker B.V., manufacturer of instant boiling water dispensing systems. A mixing valve is able to control the blending of different liquids to ensure a predetermined outcome. By integrating electronics into a mixing valve and turning it into a mechanic product the user will be able to better control and monitor the temperature, flow rate and volume of dispensed water. Furthermore, a new electronic mixing valve is a foundational piece for future innovations.
During the project an initial research has been carried out. Findings of this research have been used in the design of three concepts, which were built and tested. The best concept has been further embodied. Through testing, simulations and research a viable and feasible product has been created with the aid of Computer Aided Design (CAD). The final result of the thesis is a simplified prototype and an assessment proposal for further development, as well as a realistic electronic mixing valve concept for Quooker B.V.

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MSc. Graduation Project
Msc. Integrated Product Design
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1. Table of contents

2. Introduction

Modern society partakes in the information age. This age is characterized by a rapid shift from economies concerned with traditional industry to a global economy based on information technology [1]. Not only does this shift allow for new products and services, but it also leads to significant improvements within existing industries.

Quooker B.V. is a company operating in the latter category. The company has radically modernized the process of preparing boiling water. What used to be an extensive ritual has been renewed to immediate gratification by being able to always instantly dispense boiling water. The company develops and sells immediate boiling solutions for kitchen faucets [2].

Quooker B.V. was the first to offer this solution to consumers, leading to being one of the limited number of companies within the market to have a protagonist image. The company is keen on maintaining this competitive advantage. In order to do so, it is essential to continuously innovate. Quooker B.V. sees opportunities in the development of an electronic mixing valve to integrate into its current portfolio. The company therefore wants to explore the potential of this solution.

A mixing valve is a valve that blends liquids and dispenses a mix of these liquids as outlet. In the case of Quooker B.V., a mixing valve is used to mix different temperatures of water and dispense a homogenous temperature of water. These type of mixing valve are essential in all modern kitchen faucets, allowing the user to dispense water at a specific temperature. By implementing electronics into a mixing valve and turning it into a mechatronic product, the user will be able to better control and monitor the temperature, flow rate and quantity of dispensed water.

User’s benefits when using an electronic mixing valve are, amongst others, less fluctuation and more control of the different variables important when tapping water. The solution will result in more design freedom, eliminating the mixing system from the faucet and removing it to the kitchen cabinet. Using an electronic mixing valve will remove the need for a mechanical user operation, reducing the product’s physical complexity. Lastly, less iterations for reaching a specific water temperature and flow rate will likely result in a more energy-efficient and water saving dispensing system.

Besides ensuring an innovative and competitive image, an electronic mixing valve allows Quooker B.V. to further differentiate its products without large investments, thanks to the modular nature of its current product portfolio. An electronic mixing valve does not only directly provide potential significant positive changes, it also serves as an essential foundational part for Quooker B.V.’s future products and services.

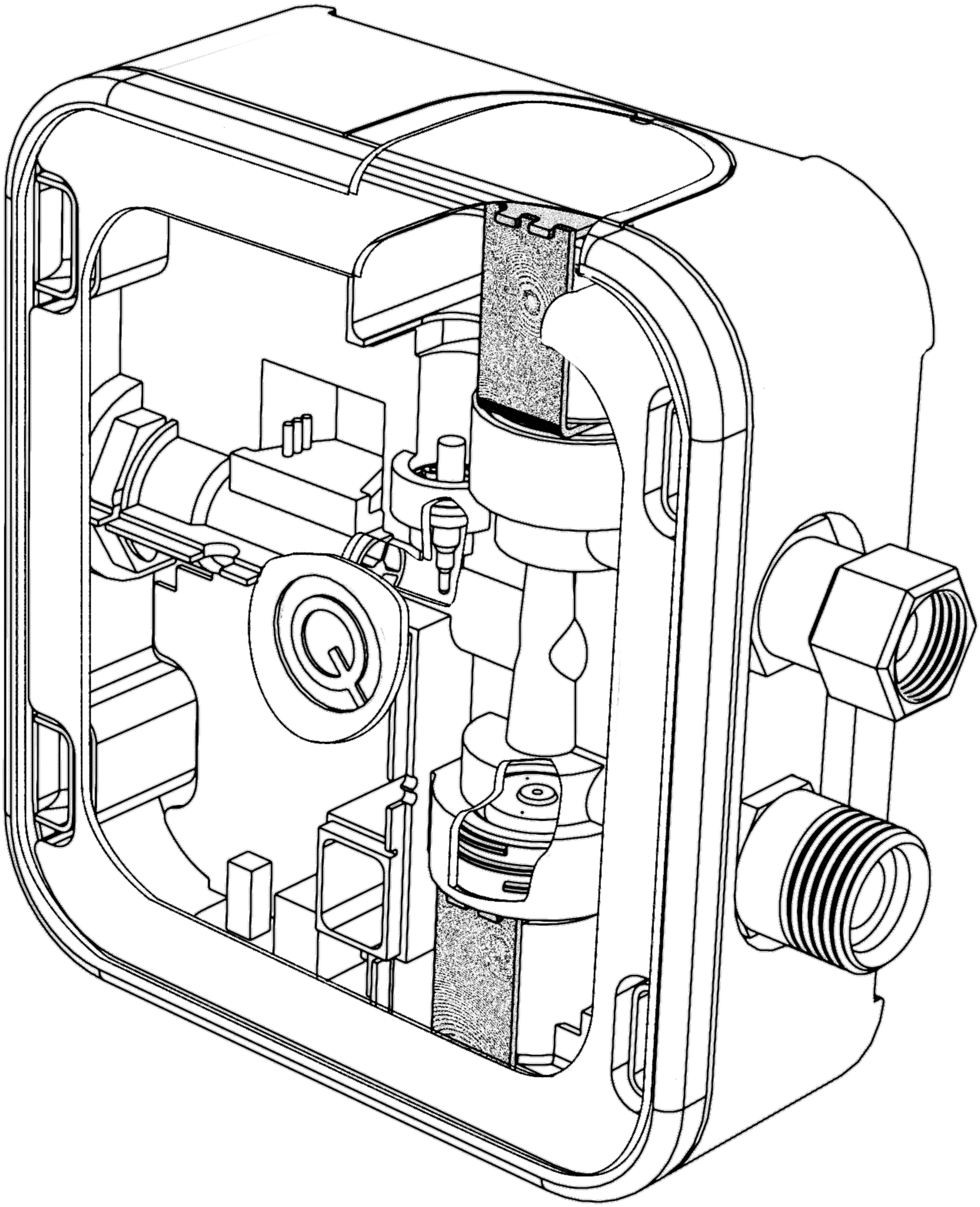
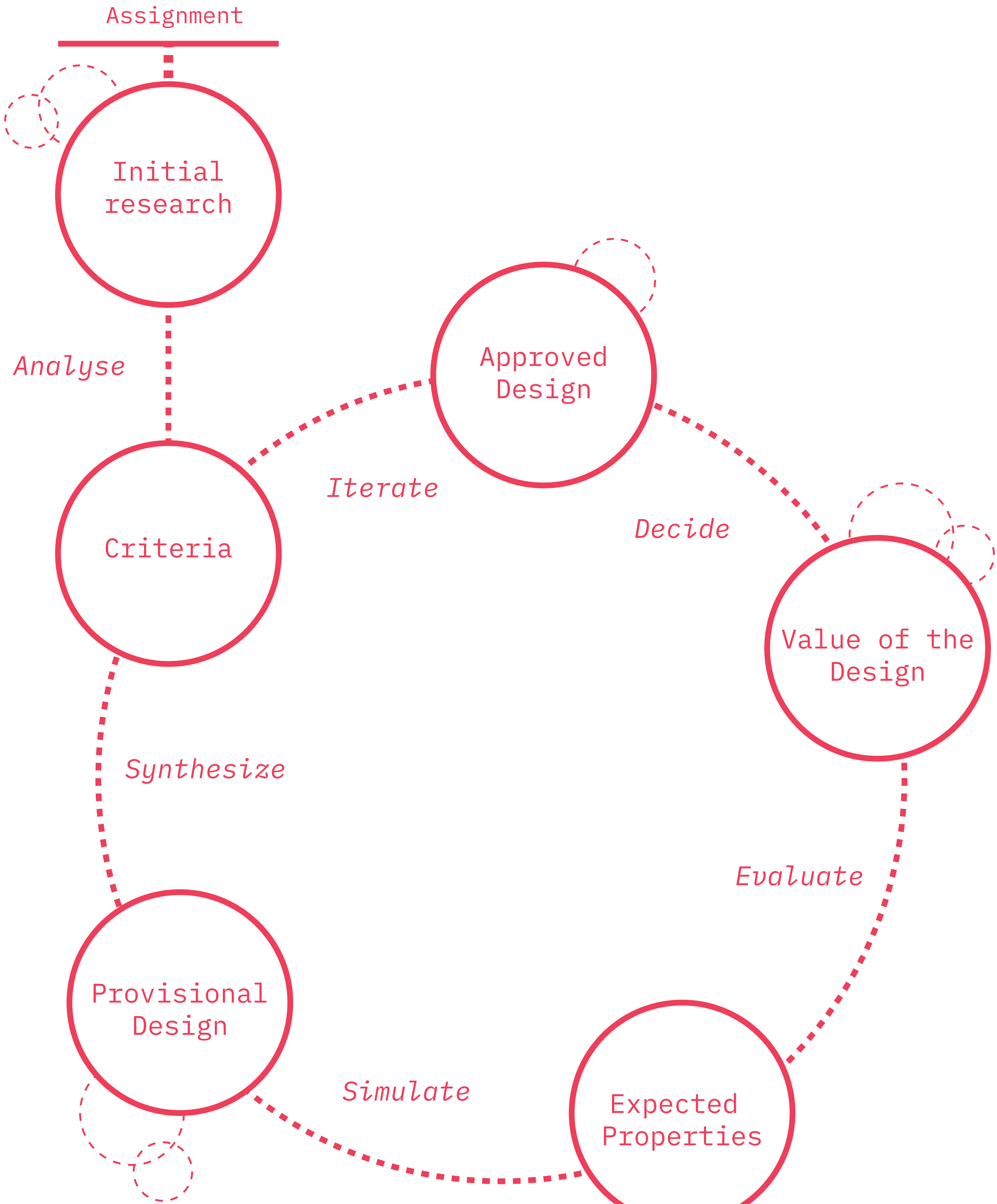


image [2]

a cutaway drawing of the final concept


Assignment
Initial research
Analyse
Criteria
Iterate
Approved Design
Decide
Value of the Design
Synthesize
Evaluate
Provisional Design
Simulate
Expected Properties

3. Assignment

image [3]

Basic Design Cycle by Roozenburg and Eekels

Goal of this thesis is to obtain a suiting solution for both the company as well as its customers, by extensively researching opportunities for an electronic mixing valve. This solution will be tested and evaluated in regard to the customer's experience and the product's performance.

The road to fulfilling this assignment follows the development cycle presented in this thesis. The development cycle concentrates on an electronic mixing valve especially designed for Quooker B.V.
An analysis concerned with the current corporate, use, product and market context is performed. Furthermore an investigation into the procedure of mixing and additional relevant factors are executed.
This information is concluded into a summary consisting of different elements. Five main drivers describe the essential needs of the electronic mixing valve. A programme of requirements and a programme of wishes complete the list of required and preferable specifications of the product.
This material is used as foundation for an ideation and conceptualisation of different ideas. Through a methodological assessment, a product direction is chosen.
This direction is further embodied. This embodiment focusses on system-related, experience and performance design cycles. Research is implemented in simplified prototypes to validate findings.
The thesis is concluded by a prototype, a proposal for assessment of this prototype and recommendations for future research.

As shown in the thesis structure, the approach towards this assignment follows the basic design cycle as proposed by Roozenburg and Eekels [3]. The analysis performed and its synthesis serves as the criteria leading up to a provisional design. This provisional design is simulated ("Expected properties") and the result is evaluated ("Value of the design"). The approved design is then iterated through a new design cycle.

Subsidiary design challenges encapsulated within the larger assignment are approached through the same method, although sometimes streamlined. These challenges are first clearly defined, after which potential solutions are created. Through assessment a suitable solution is found, which is implemented in the larger assignment design cycle.

Lastly, this assignment is part of the innovation trajectory "Electronic Mixing" of Quooker B.V. Together with employees, (graduate) interns contribute to the progression through this trajectory. Each thesis can be considered stand-alone, but does contribute. Because of this structure, *"System Design of an Electronic Mixing Valve for an Instant Boiling Water Dispenser"* is based upon previously performed initial market research and the validation of its business case. Furthermore, parallel work is performed regarding the user interaction in this new "Electronic Mixing" context and how to embody these findings, as well as the specific electronic functioning in this new context.
Result is the fact that a significant part of knowledge and research used in this thesis has been or is validated by others. This allows for an emphasis on the functional and experience embodiment design of the electronic mixing valve. However, it is inevitable that decisions taken have an impact on the general "Electronic Mixing" context. For this reason it will still be discussed throughout the thesis.

Research

4. Company context

4.1. Company introduction

Triggered by the fact that instant soup still requires a significant preparation time due to boiling water in a kettle, Henri Peteri started workin on an instant boiling water solution for home kitchens in 1970. In 1992 Quooker B.V. presented its first Quooker system, becoming the first company to introduce a commercially available instant hot water tap [4].

Nowadays, Quooker B.V., and its Quooker tap and reservoir are a recognisable name with a wide product portfolio. The company sells up to 150.000 systems per year (2019) and its products are available in 11 different countries. Quooker B.V. develops and assembles its products in-house in Ridderkerk, the Netherlands.

Being the first to introduce a commercially available instant boiling water tap, Quooker B.V. is proud of its protagonist and innovative image. Especially within the Netherlands, the name "Quooker" is synonymously used for instant boiling water taps [5].
Since its founding, the company has kept on providing improved and new products. Currently, a Quooker system is able to deliver up to 7 litres of instant boiling water, as well as carbonated and filtered water depending on the chosen configuration [6].

image [5]
Quooker's Main office in Ridderkerk

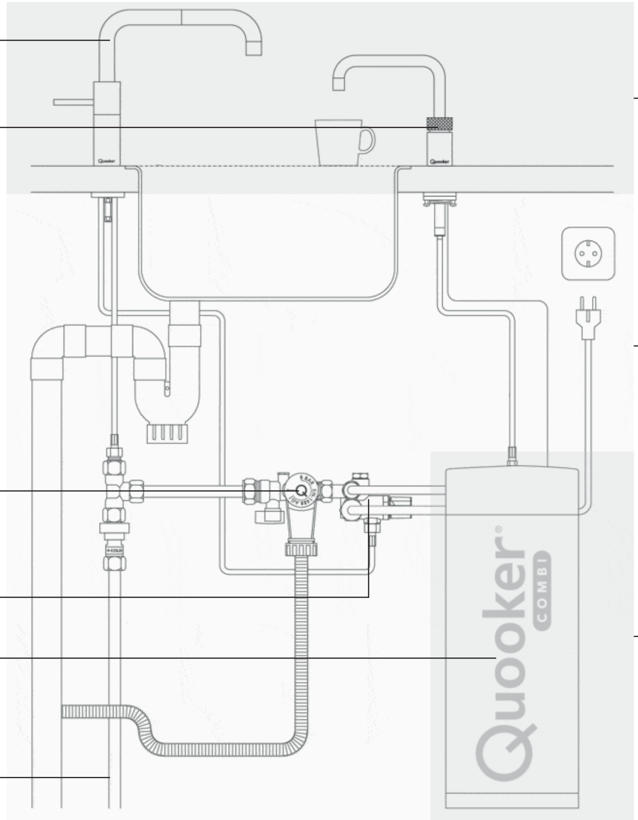


image [6]

A system using a 7-litre COMBI-reservoir with Nordic Twin Taps

4.2. Product system

A Quooker system has elements both on the kitchen counter and in the cabinet underneath. The system can be divided into three subsystems. The "upper subsystem" communicates with the "lower subsystem" through the "middle subsystem" and vice versa.
The upper subsystem consists of one or multiple taps responsible for the dispensing of water and user interactions.

The lower subsystem consists of one or multiple reservoirs responsible for preparing the various types of water for the upper subsystem. The reservoir responsible for the preparation of boiling water is connected to the main cold water line. A heating element in combination with sensors ensures that the temperature of the water inside of the reservoir is constant at 110 [˚C]. The water does not boil, since it is stored at an overpressure of 1.2 [bar]. When communicated by the upper subsystem, the reservoir opens. Because of to the overpressure a combination of steam and boiling water instantly leaves the reservoir and is dispensed. Through travelling through water lines to the faucet the water and steam cool down, resulting in the dispensing of water just below its boiling point accompanied by some steam to indicate its high temperature. Because of the high temperatures, the channel through which the water flows boils dry. This means that almost no "dead water" of a cooler temperature remains. This way the dispensation of boiling water is almost instant. Additionally, a second reservoir can be purchased. This reservoir, named the CUBE is equipped with additional filtration and a carbon dioxide cylinder. This configuration allows the user to dispense filtered and carbonated water as well.

The middle subsystem consists of connections in between the other subsystems. The most relevant product within this subsystem is the mixing valve. This valve is responsible for combining boiling water from the reservoir with cold water from the main water line. This way the user is able to receive instant warm water, instead of waiting for the central heating to heat up water.

An extensive explanation of the systems functioning and different available configurations can be found in appendix B.

5. Product context

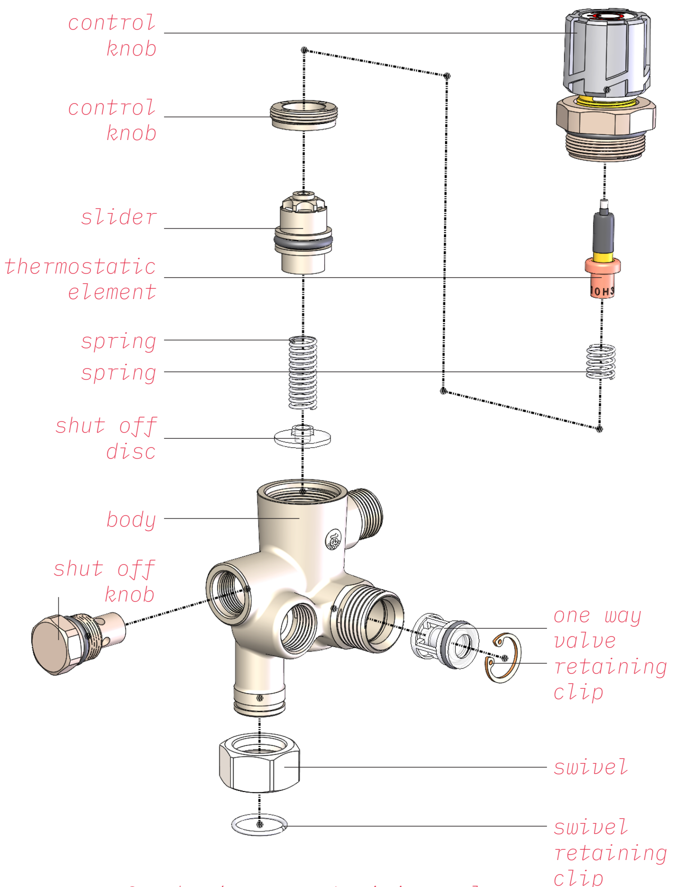
5.1. Quooker's current mixing valve

The mechanical mixing valve currently used by Quooker B.V. has two inlets and two outlets. One inlet is reserved for the main water line, the other is used for boiling water from the reservoir. One outlet is used to supply water for the reservoir, the other dispenses the mixed water.

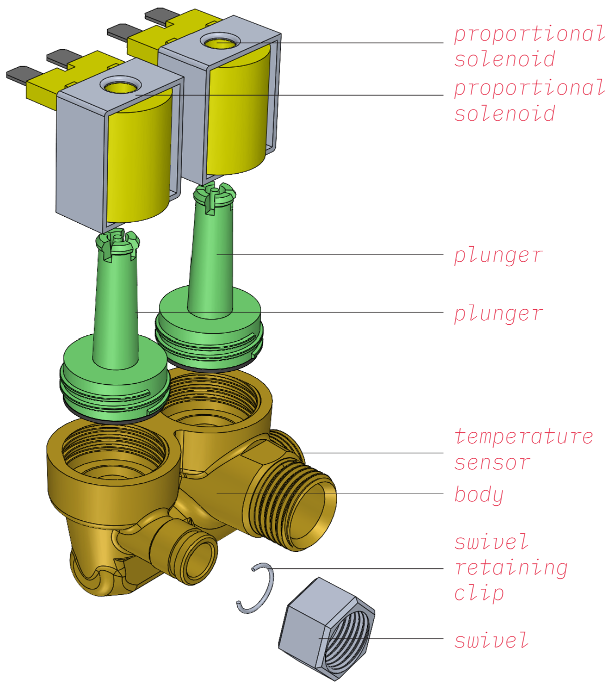
A thermostatic element inside controls the ratio between the inlets, ensuring a constant temperature output. This constant temperature is set by the user through an external knob. This knob does not indicate a specific temperature, but a temperature within a case specific range, since the inlet temperature of the main water line is unknown and there is no active control. An extensive analysis of its components can be found in appendix C.

Tests have been conducted regarding the performance of the mechanical mixing valve. During these tests, the time for a specific temperature change has been recorded. These results are shown in table 1.
Furthermore, tests regarding the flow rate of the mixing valve have been performed at a constant pressure of 2,5 [bar] (typical Dutch household main water line pressure) [6].
These values give a status quo which the electronic mixing valve has to exceed in order to provide a significant benefit.
The cost price of this mixing valve is confidential. However, in the rest of the thesis, this cost price is regarded the status quo, being 100%.

image [7]
image left: Quooker's current mixing valve
image right: P.o.P. prototype



Quooker's current mixing valve



Proof-of-Principle mixing valve

5.2. Proof-of-Principle mixing valve

A provisional Proof-of-Principle electronic mixing valve has been developed by Quooker B.V. in order to investigate fundamental potential of this added functionality. This valve makes use of two plungers controlled by solenoid coils. By altering the current through these coils, the position of the plunger can be controlled. This way two flow rates can be independently controlled. The two flows come together in a mixing chamber in which a temperature sensor is located as well. Its measured values are fed back into the control loop for the solenoid coils, ensuring a constant predetermined temperature output.
Using this Proof-of-Principle model, some initial comparison tests are performed, similar to the ones performed with the mechanical valve. Results are shown in table 1.
The data shows promising behaviour, with an improvement in both response and actual change time.
However, this prototype has been created with the proofing of principle in mind. This means that, although the functional principle could be interesting, the execution and further embodiment are not set in stone. This prototype does not account for aspects such as performance longevity, material and production, flow behaviour, integration of components and its power supply.
Furthermore, this prototype does not include a flow rate sensor, which means that it is not able to control both flow rate and volume. These are functionalities the new concept should possess.
The cost price of this system is estimated at 157% of the status quo.

table [1] Performance of different mixing valves

System	Initial tempterature [˚C]	Desired temperature [˚C]	90% of change [s]	100% of change [s]
Current valve	20	65	3.5	11
	20	35	5	5
	65	20	3.5	8
P.o.P.	20	65	3	3.5
	20	50	5.5	4
	20	35	3.5	3.5

Reason for this quicker changing time is likely the fact that there is no energy transistion resulting in movement of the thermostatic element. As the temperature difference between the desired temperature and the actual temperature becomes smaller, the energy transition between the two elements becomes slower. Using a temperature sensor results in more linear changing behaviour, which in this case is quicker.

Important to note is the fact that these tests have been performed with largely similar taps, therefore the length of channels is close to identical. When different would be used, the channel length could have been different. This results in a difference in "dead water" remaining in the channel, which influences the change time. This water has already left the mixing valve and can therefore not be controlled regarding temperature. This is a problem inherent to the mixing valve. Contrary to the boiling water line, water in this output line does not evaporate. Minimising the length of the output channel is kept into accound during further development and embodiment, e.g. the location of the mixing valve within the kitchen cabinet.

6. Use context

6.1. Use cases

In order to find suitable specifications for an electronic mixing valve, the context of use is examined. Through interviews and desktop research, different use cases are found. Boiling water use cases are excluded, since the Quooker system uses this as a separate function from other temperatures. These use cases show a wide variety of different volumes, flow rates and temperatures. This creates the assumption that a mixing valve should be able to handle the full range of liquid water temperatures.

As one can see from table 2, all use cases above the typical highest temperature of mixed water (65 [˚C]) consist of the brewing of specific drinks. This raises scepticism, since it is expected that typical consumers do not attach a significant amount of value to these different temperatures for different types of brews. In order to find a conclusive answer, a tea sommelier has been contacted. Although the sommelier was familiar with the Quooker system, it was immediately indicated that this is not being used for specialistic brews. Not the system itself is regarded the bottleneck, but the quality of the water used, due to the high levels of limescale. These specific brews as indicated in the table are to be brewed with purified water only.

image [8]
A tea sommelier controversially using a Quooker to prepare a brew

Furthermore, one can conclude that the most critical temperature range for the mixing valve is likely to be in between 30 and 40 [˚C]. Not only are the most common uses within this range, this is also the range where the user is likely to be in direct contact with the dispensed water. Temperatures above 40 [˚C] are too hot and can result in scalding, temperatures below 30 [˚C] are too low for most intended purposes involving direct contact (e.g. disinfestation).

Concluded from these arguments it is decided to focus on the mixing range of mechanical mixing valves (cold to 65 [˚C]), with optimal behaviour in a smaller range (30 – 40 [˚C]). The mixing valve however will still be specified for temperatures up to 100 [˚C]. This way the device is suitable for potential future applications involving higher temperatures and is less likely to fail in case of an error.

6.2. Functionalities

The use case table shows a differentiation on three different aspects: temperature, flow rate and quantity. In order to provide a benefit in this use cases, the device should be able to actively control these variables (which is the unique functionality of an electronic mixing valve). To do this, the product should be able to measure these variables.

Temperature control requires temperature measure. This means that the mixing valve should be able to measure the degrees Celsius of the liquid.

Flow rate control requires measuring the amount of water that is leaving the mixing valve during a specific time frame, e.g. litres per minute.

In order to measure the quantity of liquid leaving the mixing valve, both the time of disensing and flow rate during this dispensing are required.

It can be concluded that the electronic mixing valve should be able to measure temperature [˚C], flow rate [L / min] and time [s] in order to fulfil its intended functionality.

table [2] Use cases at different temperatures, flow rates and quantities

Task	Subtask	Temperature (˚C)	Volume (l)	Flow rate
Brewing coffee				
	Dark coffee	88-93	± 0.1-1	LOW / MEDIUM
	Medium coffee	96	± 0.2-1	LOW / MEDIUM
	Light coffee	96-100	± 0.2-1	LOW / MEDIUM
Washing hands		30-38		MEDIUM / HIGH
Sous-vide cooking		55-60	± 2-3	MEDIUM
Brewing Tea				
	Green tea	65-82	± 0.2-1	LOW / MEDIUM
	White tea	70	± 0.2-1	LOW / MEDIUM
	Black tea	82-100	± 0.2-1	LOW / MEDIUM
	Oolong tea	88-93	± 0.2-1	LOW / MEDIUM
	Pu-Erh tea	96-100	± 0.2-1	LOW / MEDIUM
	Morrocan tea	100	± 0.1-1	LOW / MEDIUM
	Herbal tea	100	± 0.2-1	LOW / MEDIUM
Preparing baby milk		37	± 0.3	LOW
Steaming face		40	± 0.5	MEDIUM
Rendering fat out of pan		65		HIGH
Activating yeast		40	± 0.05	LOW
Mopping bucket		55	± 5	HIGH

7. Mixing

7.1. Mixing theory

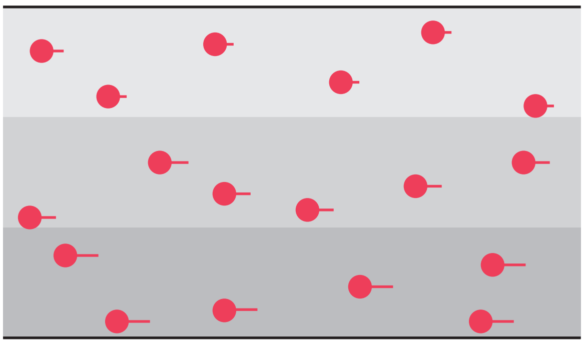
The core functionality of the electronic mixing valve is the controlled mixing of water at two different temperatures in order to create a uniform output. Research into this topic is therefore important. When the output would not be uniform, sensors would measure a local temperature which can differ from the rest of the flow. Not only would this feedback incorrect information back into the system, it could also lead to dangerous situations (e.g. scalding because of a higher dispensed temperature than the user expected).
Mixing is defined as manipulating a heterogenous system with the goal of it resulting in a more homogenous system. In the case of this liquid-liquid mixing system, this manipulation or agitation results in a heat transfer between the two liquids [7].

The standard agitation method used in both industry and society is turbulent agitation, commonly known as stirring. Through swirling a turbulent flow is created [8].
Within fluid dynamics, two types of flow can be considered: laminar flow and turbulent flow. In a laminar flow, molecules flow in smooth parts along a specific layer and hardly interfere with adjacent layers. Molecules can be moving at different velocities (which means different energy levels and thus different temperatures) with minimal mixing [9]. In a turbulent flow however, disruption between these fluid layers happens. This way the contact area between different flow layers increases, meaning that more molecules of different velocities come in contact with each other [10]. This increased contact results in an increased convective energy transfer. Therefore, a turbulent flow is preferred for efficient blending of liquids.

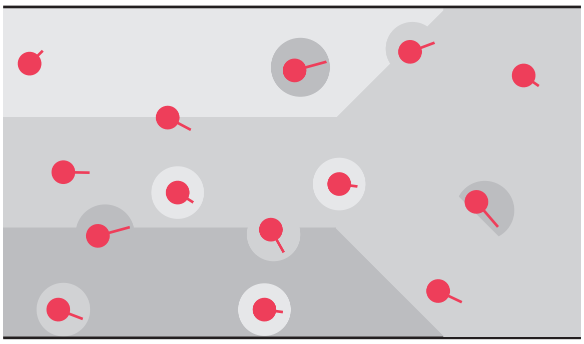
This principle also applies for liquids of identical temperatures but different compositions. A turbulent flow will lead to disruption of flows, however no energy transfers will then occur.

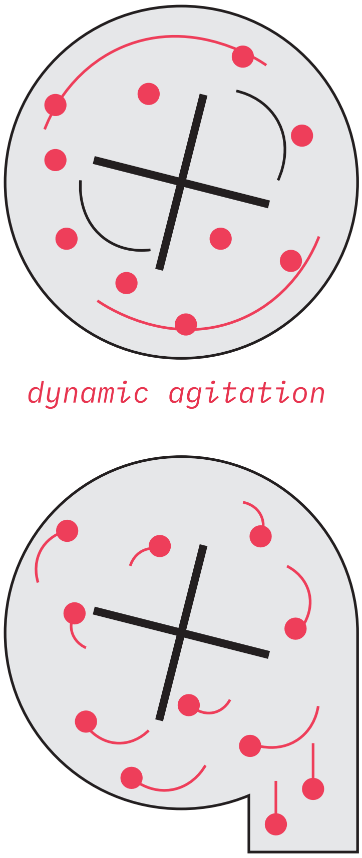
image [9]
Type of flows

laminar flow



turbulent flow





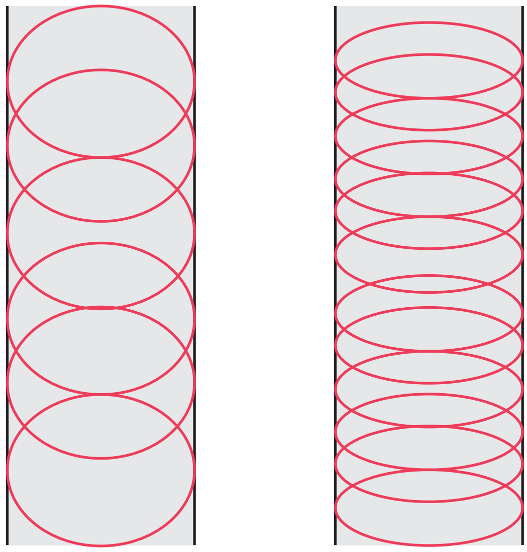


image [10]

image left: active and passive agitation image right weak and strong vortex

7.2. Important notes

Other examples of achieving agitation of liquids involve vibrating (constant movement) and shaking (inconsistent movement) [11]. All these methods come down to the same principle, disruption between fluid flows.

An important note is the fact that mixing principles often consider two static, non-moving, liquids that need active agitation through a moving component. However, in the situation where both liquids are already flowing, the agitation component does not necessarily have to move to achieve agitation [12].
Another important difference to note is the fact that, different from typical mixing applications, the flow system is not closed. Both the liquid inlets are pressurized (cold from the main water line and boiling from the over pressure inside of the Quooker reservoir and the main water line filling this reservoir) and the outlet is continuously opened. This means that axial movement of the swirls which is turbulence will automatically occur. Different from stirring vessels, this turbulence does not necessarily have to be promoted. An increase turbulence would result in less swirls over the length of the mixing area, decreasing the distance for convective energy transfers between the layers.

An extensive analysis of mixing of liquids at different temperatures and how to further influence mixing behaviour can be found in appendix D.

8. Market analysis

8.1. Competitors

Quooker B.V. is not the first company to introduce an electronic mixing valve, several are available already. However, none of them make use of boiling water. A selection of competitive products has been taken apart, analysing its construction and functionality.

The working principle for all systems is identical, two flows are combined into a final output. However, the actuation that controls the combination differs. Furthermore, the extent of functionality of each system differs as well. This is shown in table 3
Some systems make use of configurations where both the streams are controlled by one actuator. Similar to typical tap cartridges, these systems are able to control the respective ratios of hot and cold water. These systems are not able to control flow. Other systems make use of configurations with two actuators, independently controlling inlet flows. This way the systems are able to control both the relative and absolute flow rate of each inlet.
Actuation differs as well, some systems make use of motorized actuation (stepper and servo controls), whilst other systems use solenoids.

One system makes use of a separate actuation for proportioning the output flow (dispensing a specific volume). In this case a solenoid valve is used. Other systems could potentially offer proportioning by independently controlling both inlet flows, however none do so.
The systems were quickly tested regarding their general performance. The systems appeared to be functional fine, however a more thorough assessment would require extensive testing of different scenarios.

An extensive explanation of the analysis can be found in appendix E.

table [3]

competitive products with similar functions

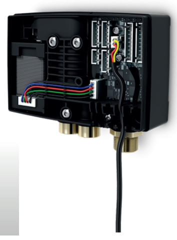
Brand	Image	Functioning
Sedal	1.	2 proportional valves, temperature sensors at each inlet
Grohe	2.	2 shut off valves with servo motors, temperature sensor at outlet
Miscea	3.	Cartridge and solenoid, no sensors
Blanco	4.	Solenoid valve and stepper motor
Oblamatik	5.	cartridge with stepper motor, temperature sensor at outlet

1


2


3


4


5

8.2. Patents

A landscape patent research can give great insight into the range of applicable principles for liquid-liquid mixing, blending and proportioning . Interesting findings serve as a starting point for ideation.

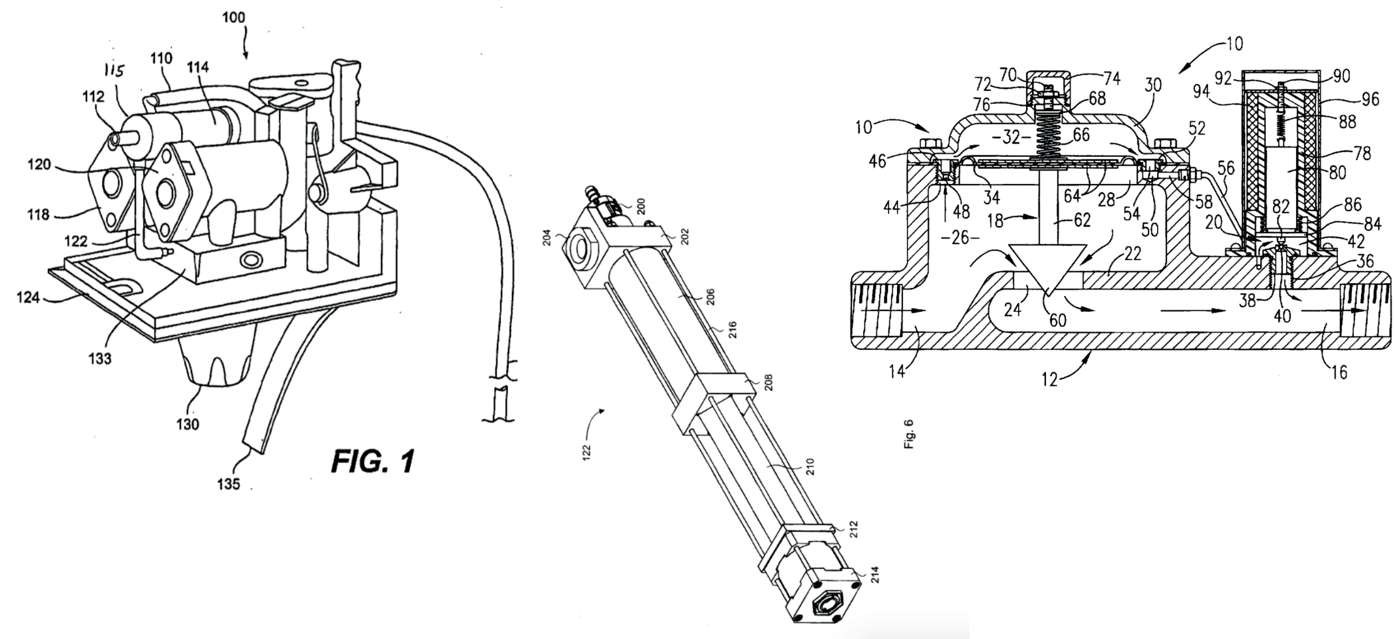
Patent EP 1.460.029.B1 describes a soft drink dispenser using a venturi tube for even distribution of liquid in another liquid. The motive force of the main liquid “sucks” in the other liquid. By controlling the orifice for the secondary liquid, the ratio can be determined [13].

Patent CA 2.501.127 describes a dispensing machine making use of displacement pumps. These displacement pumps, consisting of a plunger, rod and stepper motor are able to make small movement and accurately dispense a predetermined amount. The system described does include a lot of transmissions and is bulky [14].

image [11]

different patent drawings

Other found patents used configurations similar to competitive electronic mixing valves and are therefore not discussed here.



Patent WO 2016 / 087849A1 describes proportional solenoid controlled valves which are incorporated in electronically controlled shower heads. An interesting patent, since solenoids are known for their two-way functionality (either being open or closed). With proportional control, the position of the plunger can be accurately changed, proportioning the flow [15].

Patent US 5.687.759 describes a similar functionality, but using a different working principle. The solution has a valve controlled by a servo motor, allowing for low-power accurate control. What is interesting is the fact that the system makes use of a pressure sensor for an integrated feedback loop. The system measures and controls each flow independently, instead of measuring the output flow [16].

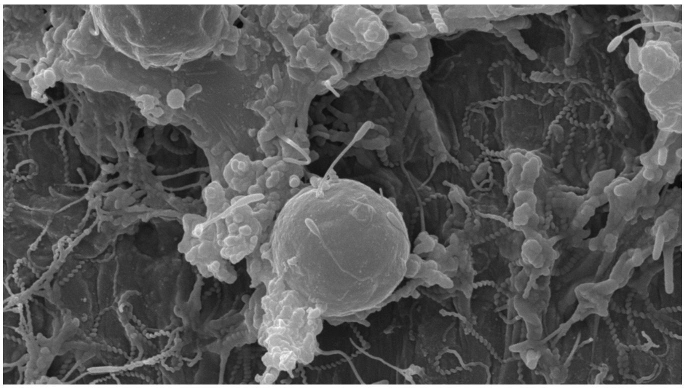
An extensive explanation of the patents can be found in appendix F.

9. Additional research

Through research and discussion with stakeholders, both inside Quooker B.V. and externally, additional factors are identified. These factors are deemed crucial in the correct development of an electronic mixing valve.

9.1. Legionella

Legionella are bacteria associated with water related installations. When inhaled it can lead to Legionnaires disease. The legionella pneumophila can occurs most rapidly in still water within the temperature range of 6 to 63 [˚C] [17]. Several factors increase the growth and therefore need to be taken into account. First of all, “dead water” (which is mixed water not dispensed), should be kept to a minimum. This still water is the ideal growing environment for the bacteria. Furthermore, the surface quality of the channels through which the water flows is of influence as well, both on a geometrical and microscopical level. More obstruction of flow will lead to more “dead water spots”, resulting in quicker growth. This is also applicable on a smaller level. A rougher surface finish (especially on plastics) will help in creating a bacterial film on the inside of the valve [18].



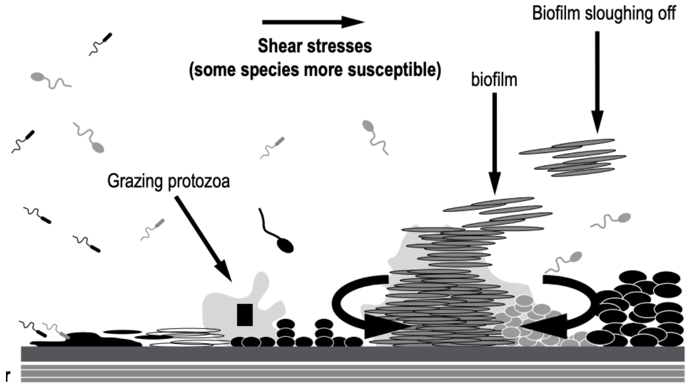


image [12]

Image left: Microscopical image of a biofilm containing a type of legionalla bacteria.
Image right: offset of biofilm in a pipe

9.2. Limescale

Limescale is a combination of minerals that builds up on the walls of orifices that have hot water in them. It consists of a hard deposit and starts growing at a temperature of 35 [˚C] [19]. As the temperature rises, the growth is quicker. Main water line water is below the critical temperature, therefore not considered a problem. However, the boiling water inlet could cause problems. The Quooker reservoir has an activated carbon HiTAC filter, combatting limescale inside of the reservoir [20]. This means that filtered water will enter the mixing valve. Only when the flows blend will the temperature of unfiltered water rise above the critical level. Effects would need to be tested. However, measures similar to the prevention of legionella can help: minimising the obstruction of flow.

image [13]

Image left: Microscopical image of a limescale forming
Image right: Limescale blocking flow in a pipe

9.3. Legislation

Combining water and electricity is generally considered risky. Therefore, an exploratory research into legislative measures is performed. Initial insights are presented here.

The KIWA is a Dutch institution inspecting and certifying water solutions. KIWA certification guarantees a certain standard [21]. All Quooker B.V.'s products have this certification.

For taps, the KIWA states that no harmful materials may be in direct contact with water, due to contamination. The KIWA uses a list of materials which have drinking water certification. Furthermore, the KIWA states a temperature change should start within 0.5 seconds after the user initiates. Furthermore, the predetermined temperature and flow may not vary more than 4% (2% up and 2% down) when dispensing [22].

In regard to boiling water solutions, the KIWA requires the system to work on a 50 [Hz] 220-240 [Volt] supply. The system must also have backflow prevention and a flow rate of at least 1 [L/min] at a temperature of 65 [˚C]. Besides the KIWA, the German DEKRA certification is important regarding safety. Some important requirements known within Quooker B.V. are integrated safety features to prevent accidentally dispensing boiling water. Furthermore, electronic and water related connections need to be appropriately separated.
Lastly, Quooker B.V. uses own regulations regarding the performance of their systems, e.g. a minimal interval of 5 years for maintenance and a minimum lifespan of 10 years.

More information regarding regulations can be found in appendix G.

Where possible, these regulations will be taken into consideration during the development process.

image [14]
different types of certifications within Europe

Synthesis

10. Main drivers

In line with the method used for this product development, a programme of requirements and wishes is created, which can be found in appendix H. Besides these, a list of 5 main drivers is created. These serve as the corner stones of the further design process. They are used for preliminary assessment, conceptual decisions and should encompass the values of the final product. The programme of requirements is used for concrete problems and a final assessment of the product.

Functionality

The electronic mixing valve must be able to dispense a predetermined amount of water (minimum of 100 millilitres) at a predetermined temperature (within the range of the cold main water line to 65 [˚C].
This driver comes from both the discussed use cases and consultation with engineers within Quooker B.V.

Reliability and Robustness

The electronic mixing valve must function safely with a minimal average maintenance interval of 5 years or more with a minimal lifespan of 10 years. Furthermore it should comply with applicable regulations.
This driver comes from standards Quooker B.V. sets for their own products and the found legislation.

Cost difference

Compared to a current complete Quooker system, the mixing valve must not have a cost increase of more than 100% and these costs need to be justified by a reduction elsewhere. The new upper and middle subsystem should cost as much as the current upper and middle subsystem.
This driver comes from consultation with engineers within Quooker B.V. and the before set business case of the product [23].

Modularity

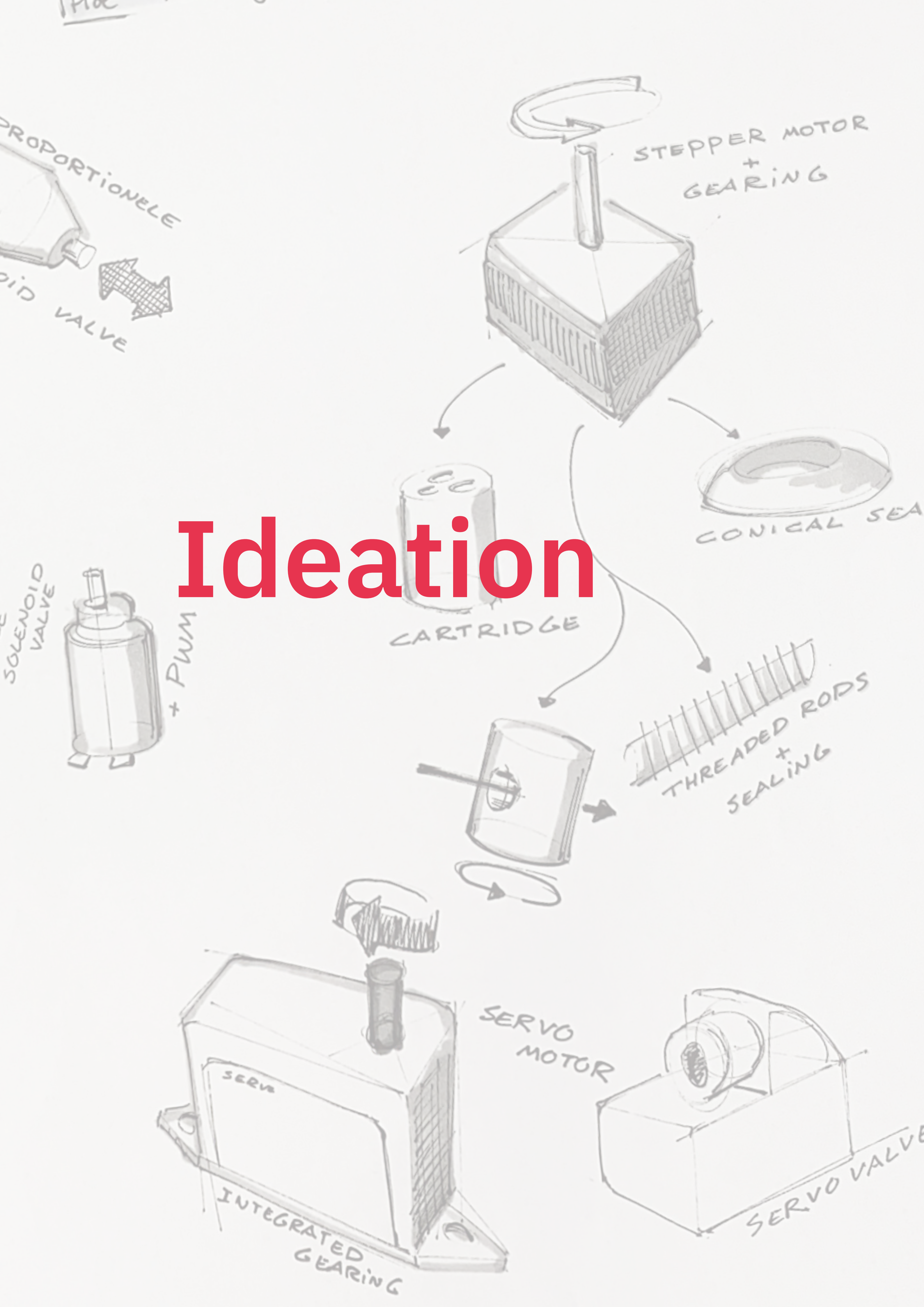
The new electronic mixing valve must be compatible with but not limited to Quooker's current reservoirs.
This is a set requirement from the predetermined business case.

Design for manufacture and assembly

The materialisation and assembly of the new electronic mixing valve must be within abilities expected of Quooker B.V. A predicted production volume is taken at 20.000 pieces per year for 5 years.
This is a set requirement extracted from the predetermined business case, as well as consultation with internal stakeholders.

The electronic mixing valve is expected to be just a part of a future product configuration for Quooker B.V. This configuration also includes a new tap and accompanied interactions. Throughout the thesis this topic will be handled when deemed necessary. However, the system boundaries for detailed development include the mixing valve only.

Ideation


STEPPER MOTOR
+
GEARING
VALVE
CARTRIDGE
SOLENOID
VALVE
+ PWM
THREADED RODS
+
SEALING
SERVO
MOTOR
SERVO
INTEGRATED
GEARING


SLIDER
-extreme small movements
KLASSIEKE CARTOUCHE
DOUBLE CHANNEL CARTRIDGE
BUTTERFLY VALVE
VENTURI PRINCIPLE
-complexities in control
CONTROLLING DRAW
CHECK VALVE
GLOBE VALVE
BALL VALVES
CONICAL SPINDLE
+ VARIATIES
ROTARY SHOE VALVE
DOORLOOP PLUNGER
DIAPHRAGM VALVE.
-Bulky
-complex

11. Ideation

A structured top-down approach is taken for ideation. First differences in mixing systems are explored. A selection of these mixing systems are further detailed by adding different sub-solutions. By doing this, vastly different prototypes can be created which can be assessed on multiple variables.

11.1 Functionality

In order to be able to fulfil the functionality set in the main drivers, the electronic mixing valve is expected to at least have the following:

- *Inlet ratio control*
- *Flow rate control*
- *Volume control*
- *Temperature sensing*
- *Flow sensing*
- *Safety feature in case of power outage.*

11.2 Mixing configurations

Four different mixing configurations are identified, which have all the expected features. These are presented in image 17. Three are selected for further development.

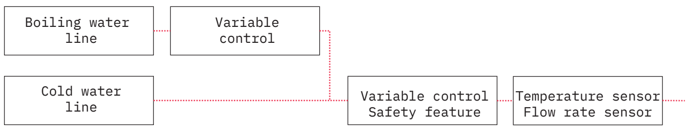
- *Configuration 1*
  A variable control on the boiling water line and a variable control on the combined line, followed by a safety feature, and flow and temperature control. Controlled addition of hot water. It uses less actuators, but does not allow for independent flow, temperature and volume control.

- *Configuration 2*
  One variable control responsible for the ratio of boiling and cold water, a variable control afterwards and flow rate and temperature sensing. Comparable to cartridges used in normal taps.

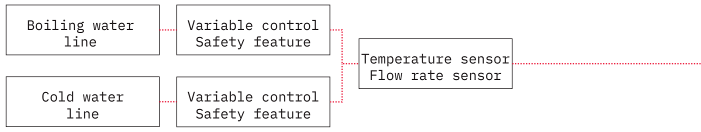
- *Configuration 3*
  Independent variable control and safety feature for both flows. Flow and temperature sensing afterwards.

- *Configuration 4*
  Independent variable control for both flows, followed by a safety feature and volume control. Flow and temperature sensing afterwards.

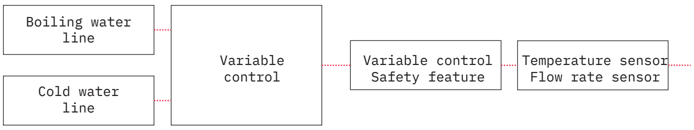
Configurations 2, 3 and 4 are deemed interesting enough to further explore.



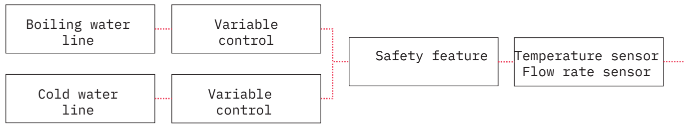
Configuration 1



Configuration 3



Configuration 2



Configuration 4

image [17]
mixing configurations

Further subsidiary ideations are performed into two topics.
First, principles for controlling flow rate are explored. Different types of cartridges and plungers are deemed the most suitable thanks to their durability and simplicity.
Second, the actuation of these principles is analysed. Most interesting actuation methods found are servo and stepper motors and proportional solenoids. These actuation principles are considered standard and best performing within the industry.

An extensive description of the ideation process can be found in appendix J.

A morphological chart is created displaying all possible solutions and their viability. This chart is shown in image 18. Using this chart, three systematically different combinations of ideas are found which are turned into concepts.

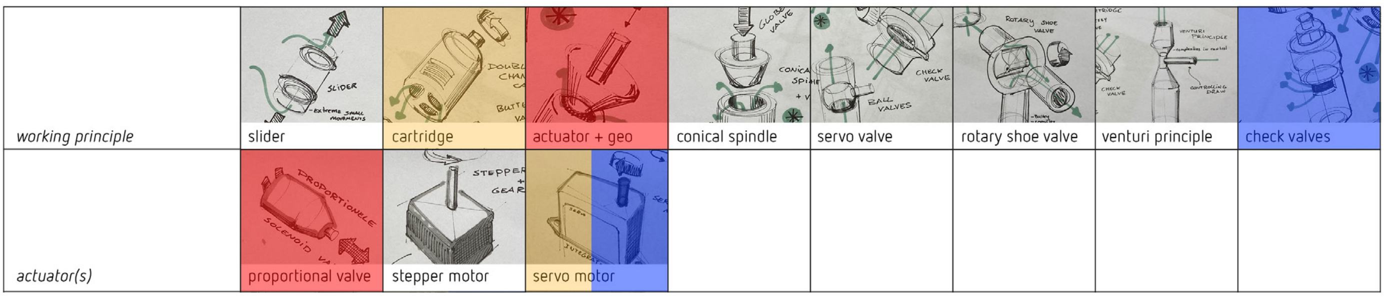


image [18]
morphological chart with the chosen combinations

12. Concepts

Three different concepts are prototypes. All of these make use of a different mixing configuration, working principle and actuation. This way a broad range of ideas can be tested with a limited number of prototypes. Each of the concepts will be discussed here.

12.1 Concept 1: Two Proportional Valves

This prototype makes use of two plungers controlled by proportional solenoid valves, allowing for both water flows to be controlled independently. This allows for control over temperature, flow rate and volume. During usage the valves are continuously turned on. As soon as the power supply stops, the valves will close thanks to the spring in the plunger. This is also considered the integrated safety function. A prototype (shown in image 19) is created using a printed body and two already available proportional valves. The streams come together in a mixing chamber.

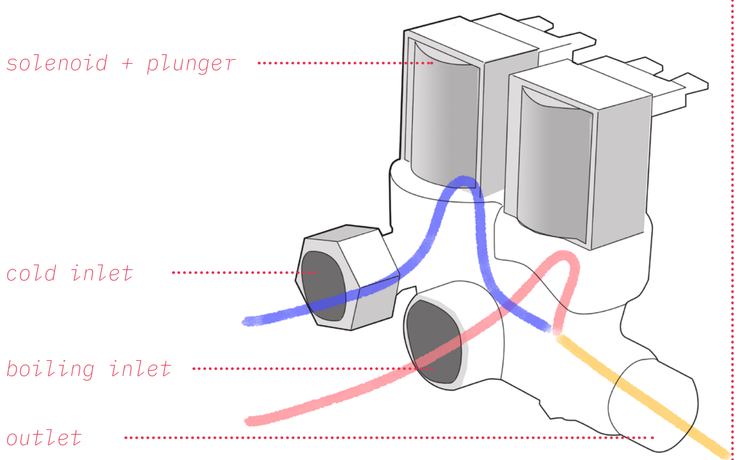
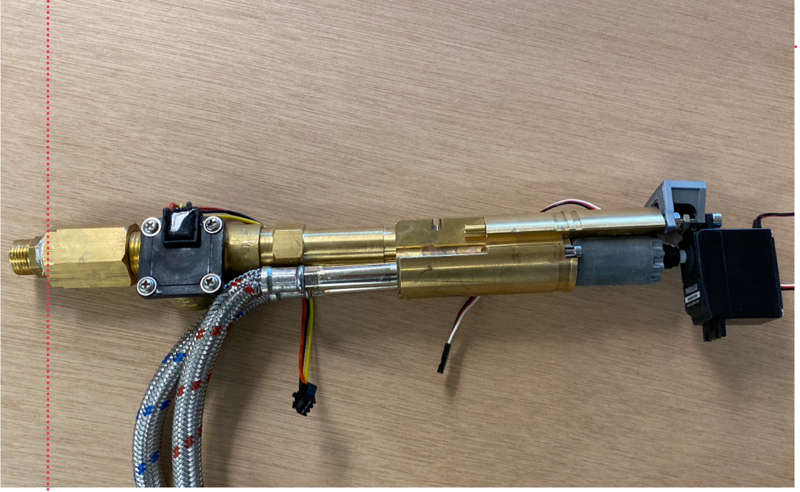


*image [19]
Concept 1
(the prototype is not equipped with plungers and valves*

12.2. Concept 2: Single Motorized Cartridge

Different from concept 1, the prototype of concept 2 makes use of a single working principle and actuation for temperature control. A servo motor connected to a cartridge controls the ratio of boiling and cold water being mixed. Using a servo motor (a stepper motor with integrated gearing) allows for precise control, especially since most of the time only small adjustments are needed to maintain a constant temperature. Another benefit of using a servo motor is the fact that it will draw a minimal amount of power when not adjusting. The flow leaving the cartridge goes through a proportional solenoid valve. This valve is responsible for controlling the absolute flow rate and volume dispensed. Furthermore, similarly to concept 1 it serves as a safety feature.



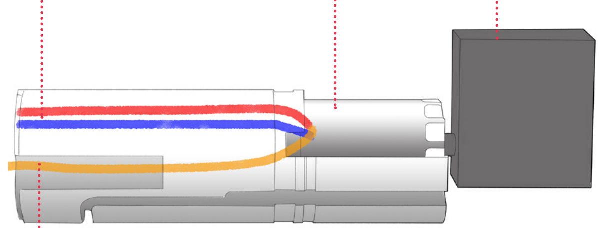
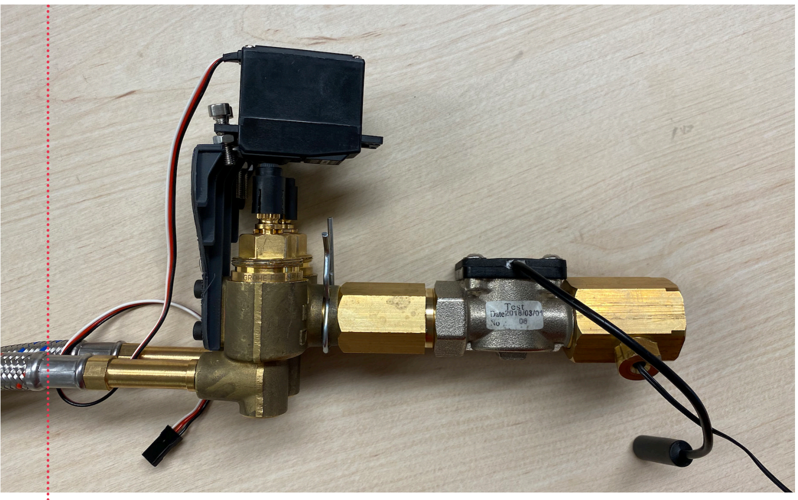


image [20]
Concept 2 including the measuring unit

12.3. Concept 3: Two Motorized Controls

This prototype shares similarities with both the first and second concept. Both flows are controlled independently, allowing for temperature and flow rate control. However, instead of using a plunger and solenoid, check (one-way) cartridges and servo motors are used. It shares benefits of the first concept (independent flow control) with a lower power usage (thanks to servo control). The two flows are combined and go through a normal two-way solenoid and plunger combination. This combination is used as a safety feature, since it will automatically shut off, and as a volume control feature (since servo motors do not react quick enough due to their internal gearing).



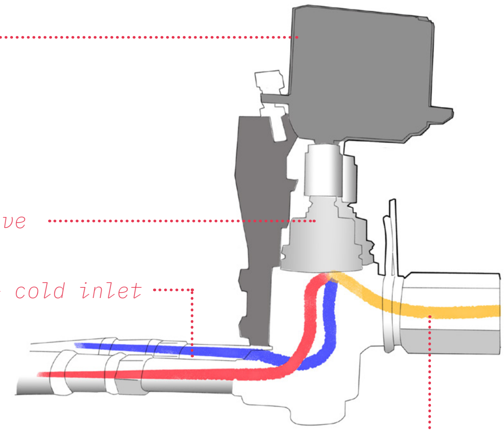


image [21]
Concept 3 including the measuring unit

All of the prototypes are created with a combination of custom made parts integrated into existing Quooker components. This way the prototypes can be quickly created. Downside of this method is the fact that the results are of too low resolution to perform a side by side comparison. Furthermore, each of the different systems require a slightly different control and tuning variables. Finding an optimum for each concept is time consuming and not realistic. Regardless of these factors, significant differences will show.

A testing procedure is created which simulates a variety of use cases for all intended functionalities of the electronic mixing valve. This simulation is computer controlled, excluding possible human errors. A separate temperature and flow rate measuring unit is custom made to fit all of the prototypes. This way differences in measuring behaviour between different sensors can be excluded.

13. Assessment procedure

The assessment procedure is divided into two segments: a practical procedure and desktop research. The practical procedure focuses on the performance of each concept, whilst the desktop research involves analyses into other important assessment factors.
The assessment factors are extracted from the main drivers presented before. These drivers cover the most important requirements and wishes for the electronic mixing valve. Using the drivers will allow for a leaner assessment, instead of getting lost in an extensive programme of requirements and wishes.
Research found in the assessment are discussed within a meeting with two experienced R&D engineers of Quooker B.V. Changes will be evaluated and implemented.
Weighted scores are given to each driver per concept. This way an assessment following the "Weighted Objectives" method is performed [23].

table [4]
performance scenario

Task	Duration	Temperature
Initialisation	10 seconds	30 ˚C
Change to warm water		50 ˚C
Warm water	20 seconds	50 ˚C
Change to lukewarm water		30 ˚C
Lukewarm water	20 seconds	30 ˚C
Change to cold water		10 ˚C
Cold water	20 seconds	10 ˚C
Change to lukewarm water		30 ˚C
Lukewarm water	10 seconds	30 ˚C
Altering between lukewarm and warm water as quick as possible (5 times)		30 - 50 ˚C
Change to lukewarm water		30 ˚C
Lukewarm water	10 seconds	30 ˚C
Altering between lukewarm and warm water as quick as possible (5 times)		30 - 10 ˚C
Change to lukewarm water		30 ˚C
Stop		

13.1. Practical procedure

The practical test will mostly focus on the main drivers functionality and reliability and robustness. Each concept is put through an identical performance scenario, following all steps deemed important to assess these drivers. This scenario is shown in table 4. The procedure is performed with a standard Quooker reservoir and simplified tap, in order to minimise variables that could be of influence. Furthermore, the steps throughout the scenario are initiated by software, counting out human control variables.

Important factors assessed are: the performance speed and the stability of the system.

Each of the concepts will use the same foundational software, developed by an electronical engineer of Quooker B.V. Through a quick trial-and-error procedure, variables are changed to ensure somewhat optimised controls. However, finely tuning the software for each concept takes a significant amount of time and is not deemed relevant enough in this stage. Therefore, the performance test's assessment resolution is not extremely high. However, significant changes in performance are likely to be noticed. Furthermore, a electronical engineer of Quooker B.V. will be controlling and assessing the tests as well. His input, consisting of his ease of tuning the software and ease of control, will be taken into account.

13.2. Desktop research

The desktop research mostly focuses on the main drivers functionality, cost difference, modularity and design for manufacture and assembly. Due to the low resolution of the concepts, it may be difficult to find concrete differences throughout these factors. For this reason it is decided to mainly focus on the functional components currently in each concept. For example, a power consumption analysis only focuses on the components existing in the concept, and not on additional functionality not yet apparent in the concept. It is expected that these additional factors will be largely identical for all concepts. When this is not the case it will be explicitly noted. Desktop research regarding the driver cost difference concerns the costs of components used in the concept, as well as their power consumption (which will result in a cost difference for the consumer). Research into the modularity driver considers the number of used components and the space claim of a potentially optimal configuration. Research into the driver design for manufacture and assembly considers the general complexity of components and their connections as well as potential implications of a configuration.

An extensive analysis of for each driver can be found in appendix K.

14. Assessment

As stated before, to ensure a fair assessment, the "Weighted Objectives" method is used. Each concept will receive a score between 1 and 9 per driver. This score is then multiplied by the importance ("weight") of the driver. Following this, each concept will receive a final score. The highest scoring concept will most likely have the highest potential and therefore used for continuation.
The main drivers as presented before are standing in a hierarchical order, with functionality being the most important driver. This order is also used for assigning the weight for each driver. An explanation for these weights can be found in appendix L. Important findings determining the score for each driver will be discussed below.

14.1. Functionality

Graphs regarding the behaviour of the concepts throughout the scenario can be found in appendix M. These graphs do not show a significant difference in performance which can be blamed on the physical design of the concept. The electronics engineer spoke out a preference for the first concept, thanks to its freedom in software control. Both additive and comparison control loops can be implemented.

14.2. Reliability and Robustness

Again, the tests show similar performance for all concepts. However, through consultation with Quooker B.V.'s R&D engineers a preference for the first concept is established. The actuation and working principle consist of less moving parts than motorized controls. This is expected to decrease the failure rate. These arguments are substantiated by research into cycle life of different components. In order to assess lifetime, the use scenario in requirement 4.1 (appendix H) is used. Although the functional lifetime of motorized controls is much higher, this value is deemed unrealistic. The expected functional lifetime of a motorized control is a maximum of 10 years with average use, due to deterioration of internal gears and grease.

Concepts	Service life (h)	Life cycles	Theoretical lifetime [years]	Actual expected lifetime [years]
Concept 1	unknown	250,000	11.4	11.4
Concept 2	5000	unknown	41	max. 10, due to deterioration of components
Concept 3	5000	unknown	41	max. 10, due to deterioration of components

table [5]

lifetime of concepts

14.3. Cost difference

Table 6 shows the cost price calculation of each functional concept. Only components that differ between the configurations are used. Concept 1 is the most cost efficient. Furthermore, their average power consumption over lifespan is calculated and presented in table 6 as well. Concept 3 has the lowest power consumption over its lifetime.

table [6]

cost price and energy costs for each concept

Concepts	**Components**	**Amount**	**Price**	**Total**	**Energy Consumption per use (J)**	**Total (kWh)**	**Costs**
Concept 1							
	Proportional Solenoid Valves	2	50 %	100 %			
					360	22	56 %
				100 %			**56 %**
Concept 2							
	Proportional Solenoid Valve	1	50 %	50 %			
	cartridge	1	35 %	35 %			
	servo	1	35 %	35 %			
					186	11.24	29 %
				120 %			**29 %**
Concept 3							
	Solenoid Valve	1	50 %	50 %			
	check valve	2	18 %	18 %			
	servo	2	70 %	70 %			
					72	4.4	11 %
				138 %			**11 %**

14.4. Modularity

Table 7 shows the number of components and the space claim of each configuration. Concept 1 has the least components, concept 2 has the smallest space claim.

table [7]

number of components and space claims

Concept	**number of key components**	**space claim [cm 3]**
Concept 1	2	110*70*70 [mm] (539 cm3)
Concept 2	3	40*110*100 [mm] (484 cm3)
Concept 3	5	90*60*120 [mm] (648 cm3)

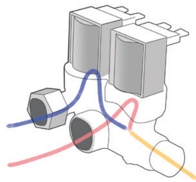
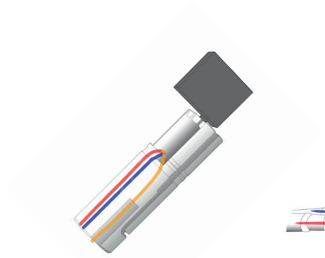
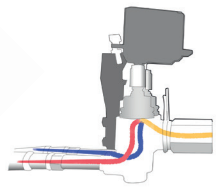
14.5. Design for manufacture and assembly

Through consultation with R&D engineers and desktop research, it was found that concept 1 has the highest preference, due to the simplicity of components and their connections.

14.6. Assessment matrix

Values are assigned to each concept as shown in Table 8. In order to ensure differentiation in values it was decided that each score can only be given once per category, forcing ranking of the concepts. Evaluation the scores shows concept 1 with the most potential. The assessment method and results were accepted by all stakeholders. Therefore, it is decided to continue with the embodiment of concept 1.

table [8] assessment matrix

Driver	**Weight**	 **Concept 1**	 **Concept 2**	 **Concept 3**
Performance	30 %	8	7	6
Reliability and Robustness	15 %	8	6	5
Price difference	25 %	6	7	8
DFM & DFA	20%	8	6	4
Modularity	10%	6	7	5
Total	**100%**	**7.3**	**6.7**	**5.9**

Next chapters will focus on the embodiment of this concept for an electronic mixing valve. First, a systematical approach is taken to determine an ideal system architecture and configuration, as well as a component sourcing and selection. This can be considered the meta product development.
Second, the embodiment is split up into two parts: a performance embodiment section and experience embodiment section. These can be considered the macro product development. Within these two sections, smaller details which are designed can be considered the micro product development.

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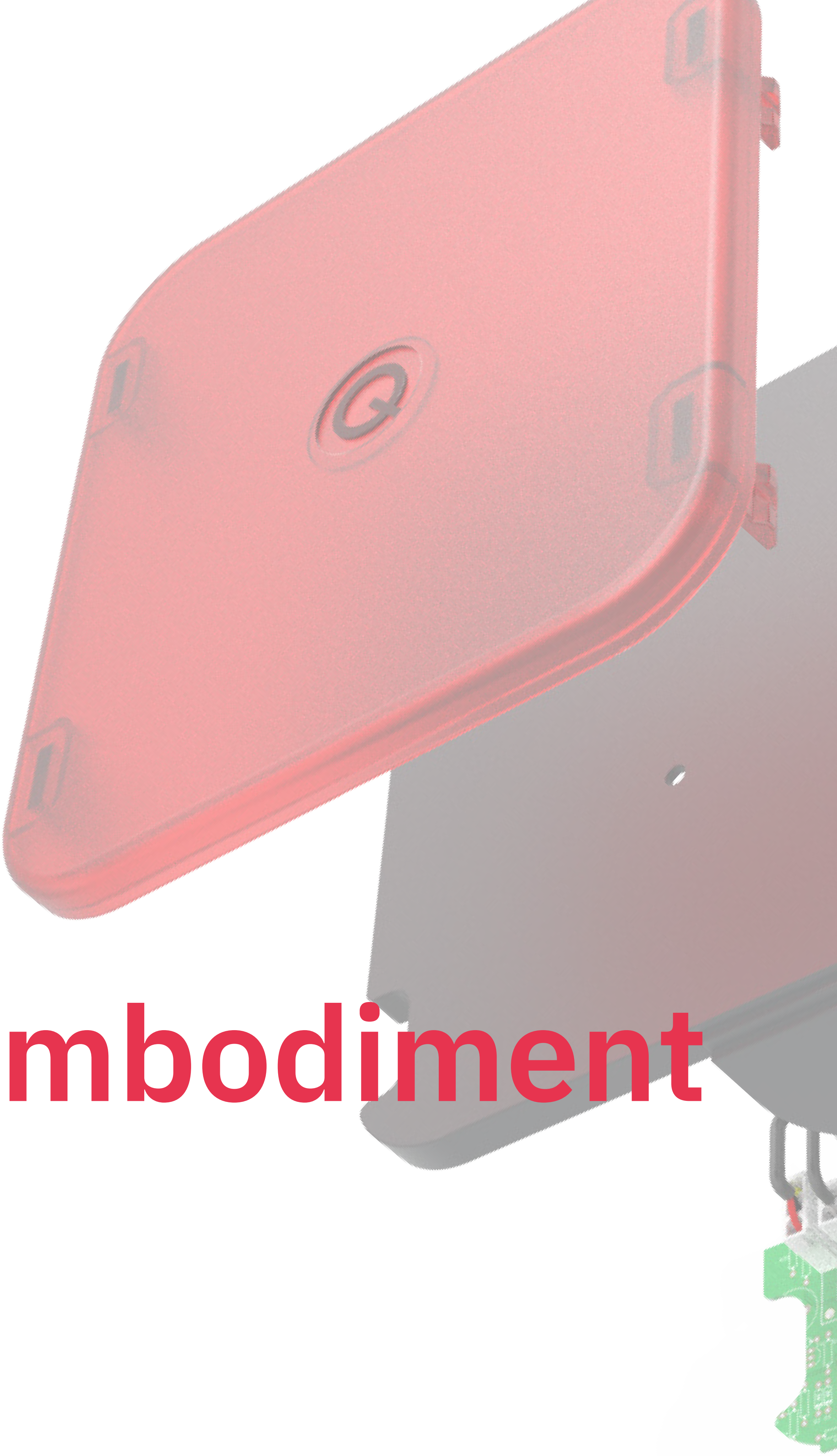
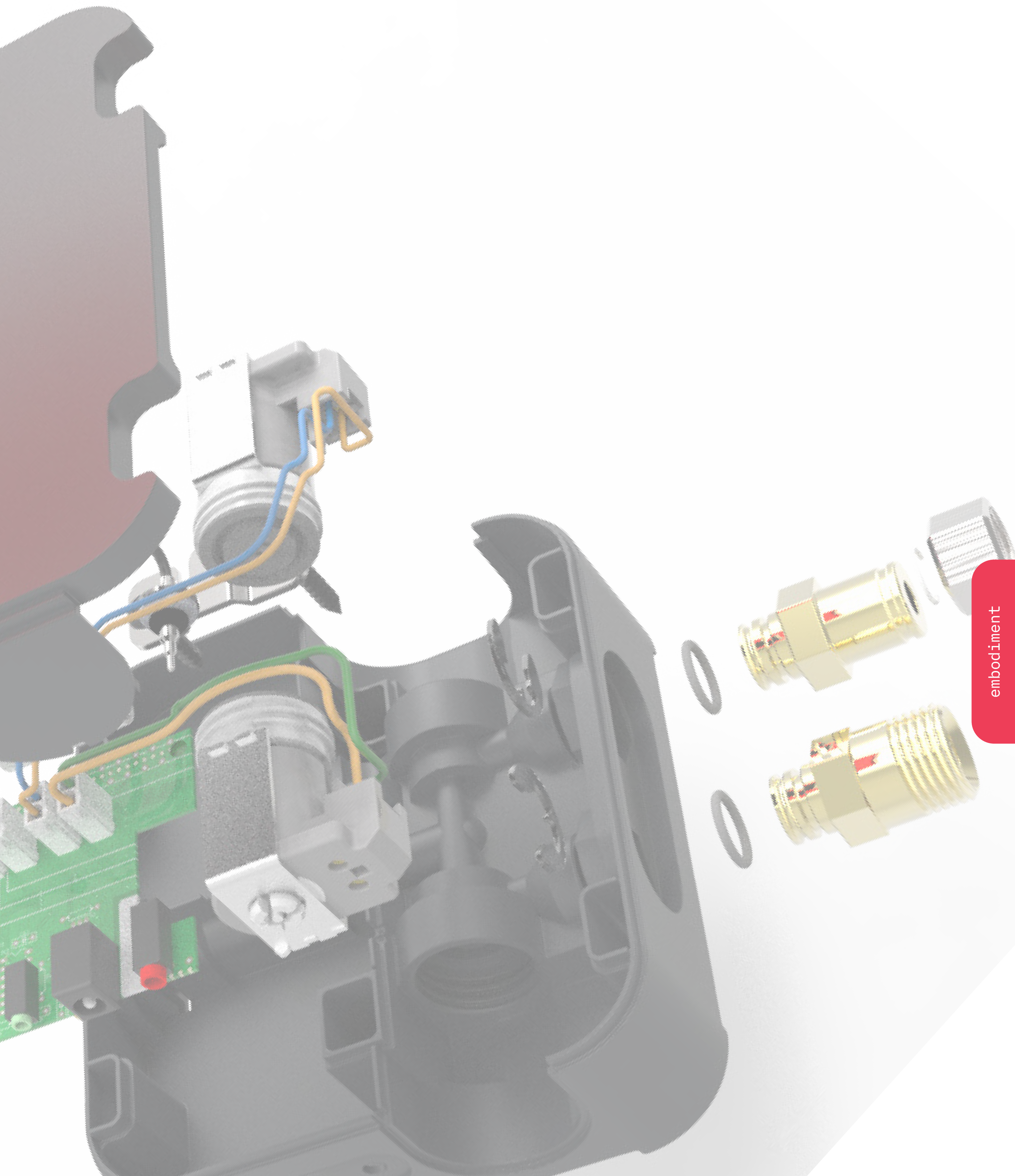


Embodiment



15. System architecture

As stated before, the electronic mixing valve as a whole is a component of a new, electronically controlled way of dispensing water. Besides the valve, this system will also introduce a new tap. This tap is developed in parallel to the mixing valve. However, it is deemed interesting to discuss the tap's functionalities and architecture, since it will influence the design of the mixing valve.

15.1. Electronically controlled tap

This tap will make use of a separate control interface. This interface, consisting of a knob is used to control both a Quooker's special features as well as dispensing mixture water. This knob wirelessly communicates with and charges through the base of the faucet. The faucet is relatively simple, consisting of two channels: one for dispensing mixed water and one for dispensing the special water features. The mixed water channel will be connected to the electronic mixing valve. Furthermore, the tap will have to communicate with the mixing valve in order to dispense the requested temperature, flow rate and volume of water.
The tap is considered outside of the system boundaries for this embodiment cycle. However, recommendations in regard to the design will be proposed.

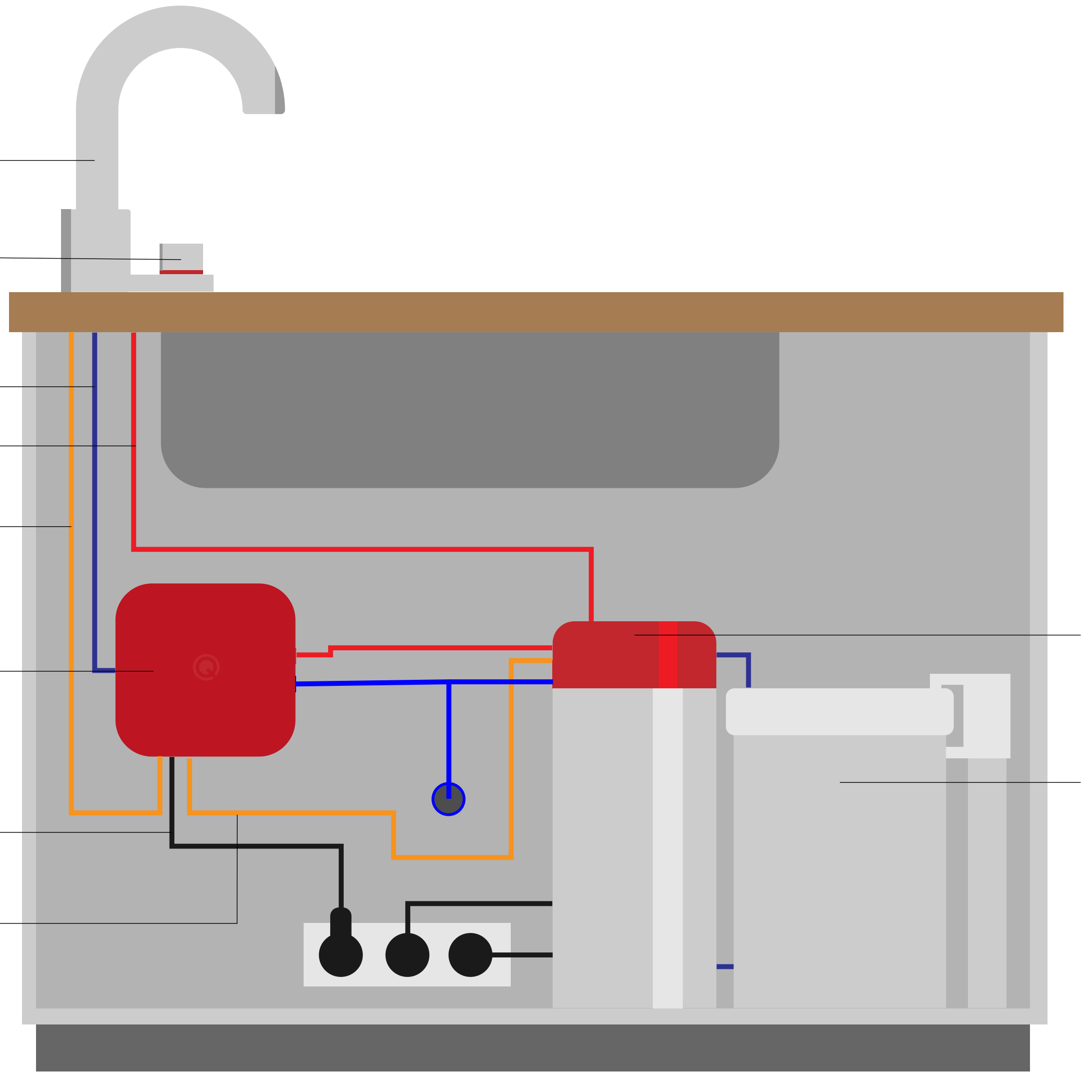
15.2. Reservoir

As stated before, modularity is an important requirement within this new system. This is largely due to the fact that current COMBI reservoirs will be used. The COMBI reservoir has a physical communication line and two dispensing channels. One will be connected to the mixing valve, one will be used for instant boiling water.

15.3. Configuration

Different components will need different power and communication lines. A variety of system architecture concepts were created. During a meeting with different stakeholders (the project manager of innovation trajectory "electronic mixing", electronics engineer and manager of electronic product management) a configuration was decided.
In this configuration the electronic mixing valve becomes the intelligent hub for electronic dispensing. The tap will only communicate with the mixing valve through a physical line (which also supplies power to the tap). The mixing valve will then control the dispensing of mixing water and communicate special water features to the reservoir. A direct line from the reservoir to the tap will ensure instant boiling water without "dead water" remaining in this water line. The mixing valve has a separate power supply. This may be less ideal, but ensures that no changes to the reservoir are required. Furthermore, Quooker B.V. already sells a power switch which prevents overloading the electricity group to which all the devices are connected.
Using this configuration the electronic mixing valve can be implemented straight away and is ready for future optimisations (as discussed in the final recommendations).

image [23]
system architecture



Note: This is schematic does not respresent the actual dimensions of components

16. Key components

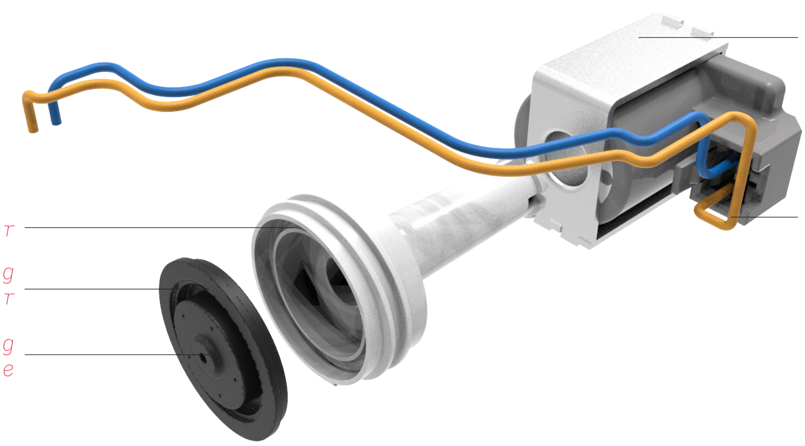
Multiple components will be needed to ensure correct functioning of the electronic mixing valve. The majority of these components are purchase parts. Advantage of purchase parts is the fact that these parts require no development costs and their functioning has been proven. Together with stakeholders of Quooker B.V. it is decided to use purchase parts for complex components. Using all custom parts would likely increase the costs of the mixing valve, raising the cost price of the product. These complex purchase parts are relatively cheap, thanks to the large amount of pieces produced by factories. Downside of purchase parts is the fact that they are not optimised for a specific application.
For all purchase parts a sourcing analysis has been performed. These parts have been deemed optimal for this solution because of their functionality, price, size as well as their availability.
The most important purchase parts are the following:

- *Plunger and solenoid for controlling each water stream*
- *Temperature sensor for measuring the temperature*
- *Flow rate sensor for measuring the flow rate and volume*

16.1 Plunger and solenoid

This mechanism is responsible for controlling the flow of a channel. The electronic mixing valve needs two of these. The sourced plunger and solenoid are made by Hydralectric [25]. Main reason for this is the fact that they are the only company producing proportional solenoids (having a variety of opening sizes, instead of just open and closed). Through consultation with the company some components have been changed. The sealing for the plunger is changed to a new elastomer (VMQ-60-TEC-27). This grade is particularly suitable for hot water environments [26]. The material of the plunger is changed to a PPA-Glass fibre resin (Zytel FG70G30HSLR2). This resin is exceptionally resistant to higher temperatures and hydrolysis [27]. The product is shown in image 24.

image [24]
Plunger and solenoid assembly



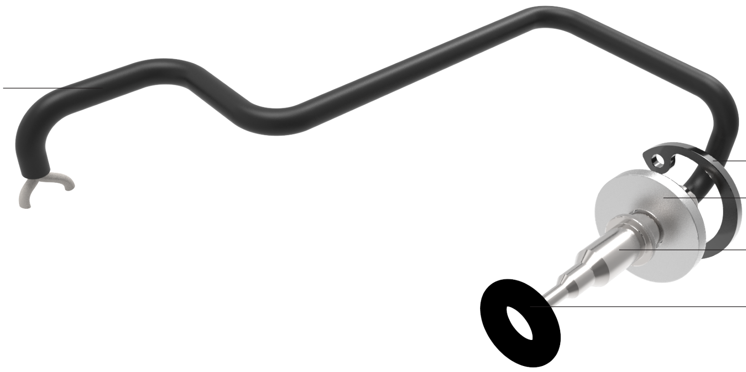


image [25]
Temperature sensor assembly

16.2 Temperature sensor

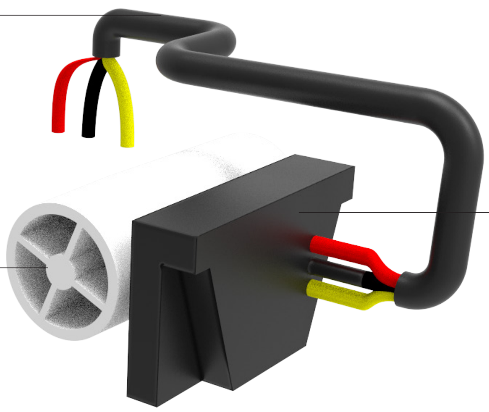
Through consultation with Quooker B.V.'s electronics engineers a specific NTC temperature sensor has been picked: a Mitsubishi WTS-15. These thermistor sensors are especially designed for applications with water and have a quick response time [28]. The NTC itself is molded in a compact stainless steel casing. Full specifications are shown in image 25.

16.3. Flow rate sensor

The majority of flow rate sensors consist of two components: One component's movement is influenced by the flow rate, whilst the other measures this movement. In this application it is decided to use a tube turbine and a standard hall sensor. Tube turbines are relatively small and cost efficient. Furthermore, using this configuration allows it to be integrated into a custom housing, instead of using a separate housing specific for the flow rate sensor. The blades inside of the turbine will move at a specific frequency depending on the flow rate. These blades are equipped with magnets. By coming in close proximity of the hall sensors current, it creates a voltage difference (which is the Hall-effect) [29]. The frequency of these voltages occurring (which is equal to the rotations of the blades inside the turbine) can be used to determine the flow rate of the liquid passing through. Multiple flow sensor combinations were sourced, with the best being a Chinese supplier: SAIER Sensors. The company's turbines can resist high temperatures and are made out of drink water proof material (POM) [30].

Other standard components (such as O-rings) will be sourced later on in the embodiment.

image [26]
Hall sensor and Flow rate turbine



17. Configuration

With the required components known, an internal space claim can be decided. This internal space claim can be directly translated to an outside space claim (since the product should be as small as possible).

17.1. Solenoid and plungers

By far the most critical components determining the size of the space claim are the solenoid and plungers. These are the largest components. Furthermore, their orientation decides the location of the inlets and outlets. Different orientations were tried, with the one presented in image 27 deemed most ideal. This way, both valves are in-line with all of the channels. This results in an internal space claim being as thin as possible, which is beneficial in cramped kitchen cabinets. Furthermore, this means that inlet and outlet channels are located on opposing sides, further minimising potential user confusion during installation. Lastly, when making a custom housing, having all geometrical aspects that require moving cores (such as the channels) in one plane means that they can all be integrated in one of the two main mold halves, which is cost efficient. Using this geometrical orientation means that both the inlet channels and mixing chamber are T-shaped. The company producing the solenoid and plungers advices similar geometry, but does warn for placing inlets directly opposite. The flow rate of one inlet could potentially influence the forces working on the other plunger (as shown in image 27).

17.2. Outlet channel

Following the orientation of the solenoid and plungers means that the outlet channel will be located in between the two inlet channels their components. This configuration creates a natural sense of "liquid flow" throughout the mixing valve. This is preferred for the product's cognitive ergonomics (as explained in appendix N). Within this outlet channel, the temperature sensor and flow rate sensor are located. The chosen temperature sensor is molded into a probe. This probe will be inserted into the outlet channel and retained. The flow rate sensor consists of two parts which do not have to be physically connected. The turbine will be inserted through the outlet. The hall sensor unit will be retained against the channel wall, being able to detect turbine movement through the housing.

17.3. Printed Circuit Board

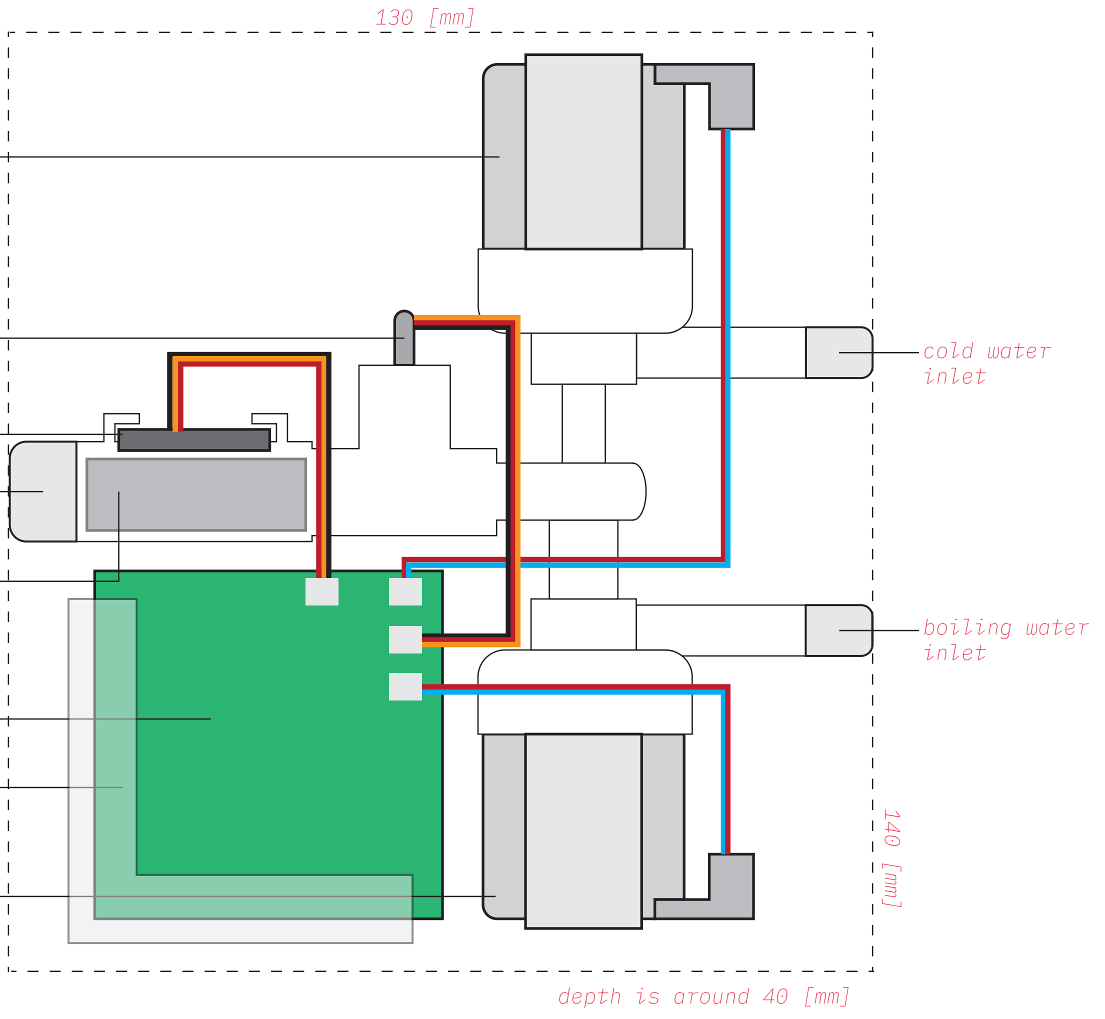
Creating a preliminary space claim with the known orientation and components, space on one side of the outlet channel remains. This space will be used for placing the printed circuit board (PCB), the "brain" of the mixing valve. All components will be wired to the PCB. Furthermore, adapters for communication and power lines will be located on the board. Placing the adapters directly on the board requires less wiring (resulting in less failure prone components and assembly time) and is more cost efficient (surface mounted adapters (SMT) are generally cheaper than panel mounted adapters) [31]. Downside of mounting the adapters directly on the board is the limited freedom for placing these connections.

17.4. Space claim

Knowing the orientation of the components, a space claim for the electronic mixing valve can be created. This space claim allows further experience embodiment (the aesthetics and interactions with the electronic mixing valve) to happen in parallel with further performance embodiment. This allows for efficient progress and up-to-date exchange of information.

image [27]

internal space claim



18. Aesthetics

Although presented in a sequential manner, both the experience and performance embodiment happened simultaneously. For the sake of clarity these two topics are presented separately.

Knowing the general shape of the product, its aesthetical appearance can be optimized in order to fit in with Quooker B.V.'s product portfolio and emphasize its functional aspects.

An analysis regarding current and future Quooker products has been performed. These show a clear product form language. For this analysis taps are excluded, focus is solely on products placed in the kitchen cabinet, since this is where the electronic mixing valve will most likely be placed. Quooker B.V.'s product language is summarized in the following statements:

- *Simple geometric shapes with large radii, which are rarely interrupted.*
- *Red translucent covers with different surface finishes indicate the primary side of a product.*
- *Usecues are kept to an absolute minimum for the sake of styling. When apparent they are integrated in the red elements.*

A visual collage showing Quooker B.V.'s form language for kitchen cabinet products is shown in image 28.

image [28]

Quooker B.V.'s style guide

Using this style guide, different visual concepts are developed, shown in image 29.

Non-obtrusive & subordinate *Basic & compact* *Simple but statement*

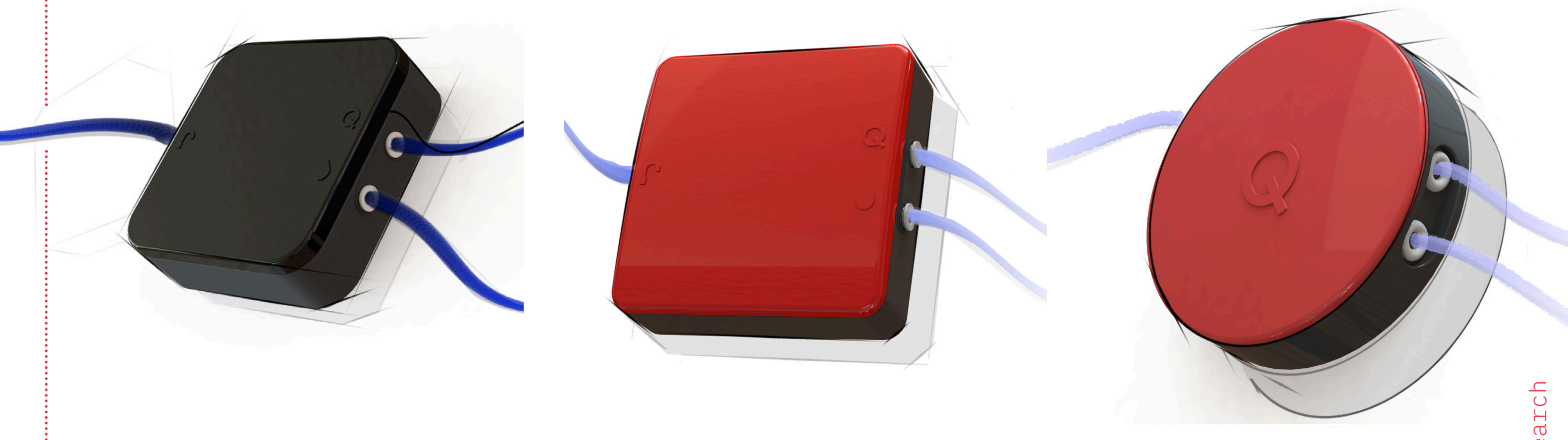


image [29]

Visual concepts

18.1. Non-obtrusive & subordinate

By excluding red elements from the mixing valve, it becomes a subordinate component within a Quooker configuration. It emphasized the importance of the reservoir inside cabinet. The concept follows the geometric space claim, with a simple geometric shape with large radii.

18.2. Basic & Compact

Largely similar to the first concept, this valve differs in having a translucent cover indicating its primary side. Radii on the corners are slightly smaller and the concept has a central Quooker logo.

18.3. Simple but statement

This concept closely follows the form language of the reservoir, which has a cylindrical shape as well. Moving away from a "boxy" shape the mixing valve will become a statement within the kitchen cabinet. The implications of the internal geometrical shape are however that the shape is significantly larger.

18.4. Assessment

Together with internal stakeholders, the three concepts were assessed. Two main assessment criteria were deemed important: dimensions and having a "Quooker" look, being of equal importance. A "Weighted Objectives" method is used, shown in table 9. The second concept is identified as having the highest potential.

table [9]

Assessment of visual concepts

Concept	Weight	Concept 1	Concept 2	Concept 3
Dimensions	50%	8	7	4
Quooker looks	50%	5	7	8
Total	100%	6.5	7	6

Together with the internal stakeholders, some additional features were evaluated and added to the concept.

- *The Quooker logo should be placed in the centre of the cover, with its negative shape having a different surface finish.*
- *The cover should be translucent*
- *No other use cues on the cover to emphasize the minimal aesthetic.*

Implementing these changes results in a final visual concept. This visual concept determines the final look of the product.

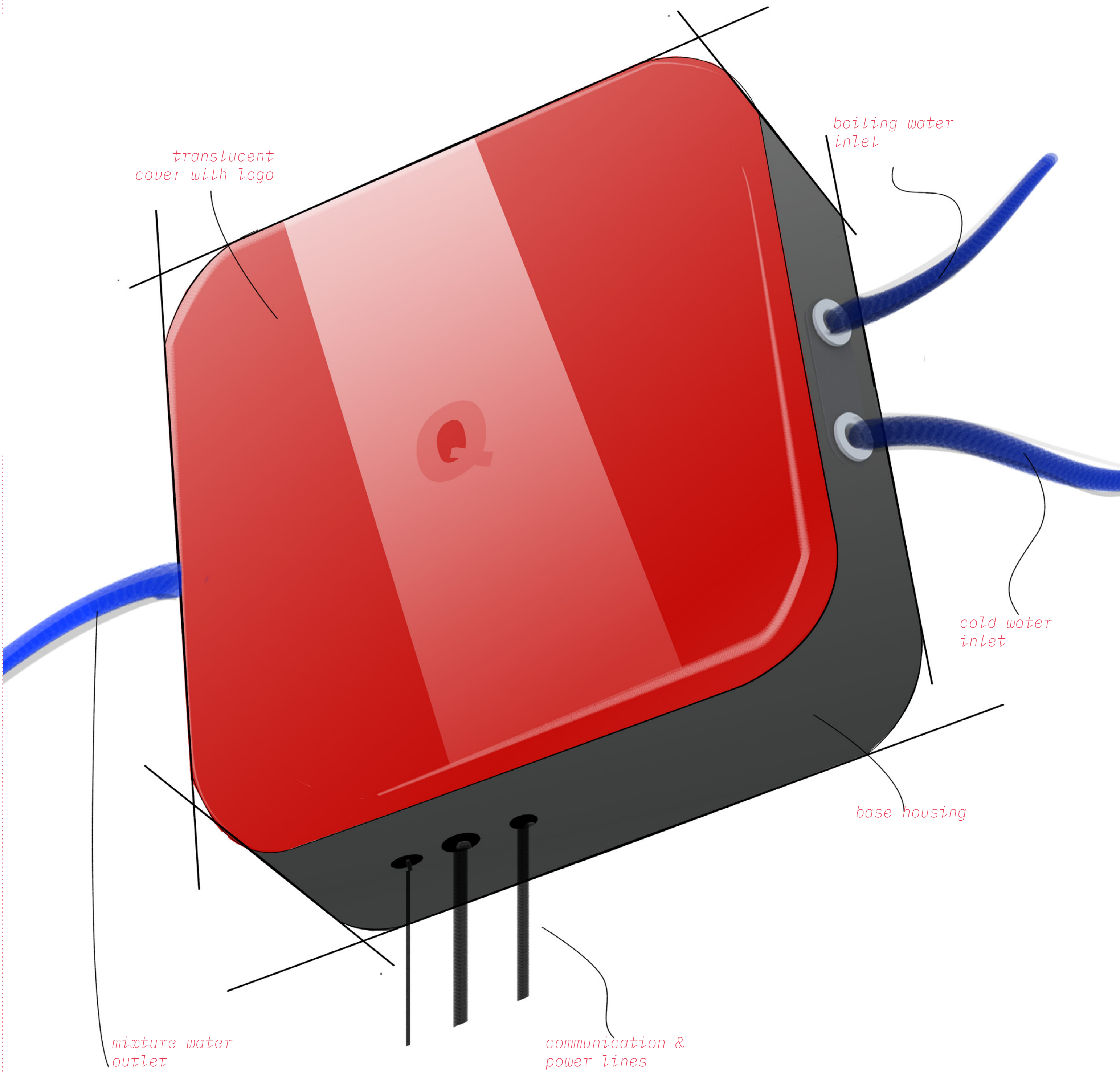

translucent
cover with logo
boiling water
inlet
cold water
inlet
base housing
mixture water
outlet
communication &
power lines

image [30]

Final visual concept

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19. Location & communication

19.1. Location

The electronic mixing valve is part of the middle subsystem, meaning that it is placed in between the reservoir and the faucet, inside of the kitchen cabinet. Within this cabinet, four different locations are identified:

- *Integrated into the reservoir top*
- *Connected to the reservoir*
- *Connected to the tap*
- *Placed in between tap and reservoir*

An extensive evaluation of these options can be found in appendix Q. It is decided to place the mixing valve in between the tap and reservoir. Main motivation is the ease of installation, the larger flexibility in placing and the modularity aspect (no changes required in other products). Furthermore, by separating the valve from other subsystems it becomes more of a distinctive configuration differentiation feature for Quooker B.V.

Knowing the space claim of the product, the intended location is evaluated. This evaluation gives insight whether the location is feasible in critical situations and it allows for narrowing down preferred installation locations.

A critical scenario is created with the aid of CAD. This critical scenario makes use of the smallest standard dimensions for a kitchen cabinet [32]. It is argued that, if the valve would fit in this scenario, it is likely to fit in less critical situations. Image 31 shows the 3D-model and its dimensions. Besides these dimensions, space claims for both the Quooker reservoir and cleaning products. By including these, one can ensure that the mixing valve will not compete with these products inside the limited available space. The filled space claim is shown in image 31 as well.

image [31]

the available strip indicating the preffered location

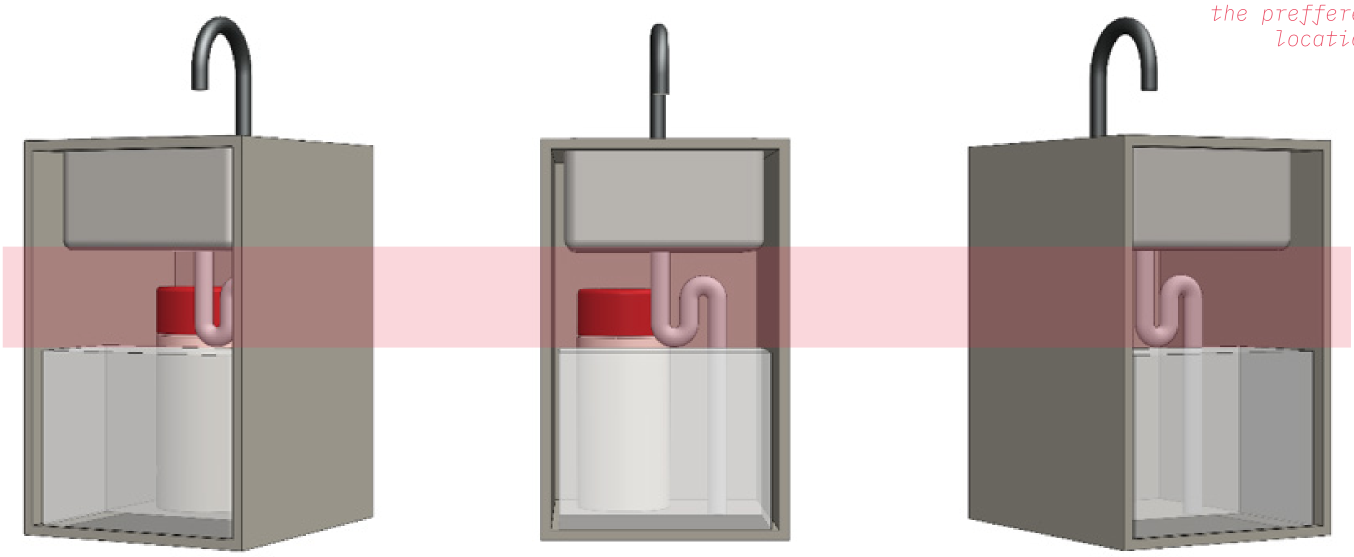


image [32] evaluation of the mounting location in a variety of kitchen cabinets. A physical space claim was made and used for this.

This image clearly shows a "strip" along the inner walls which is clearly visible for the user, without competing with other supplies. This strip has a height of 200 [mm], meaning that the mixing valve can be installed on these walls and still be fully visible when opening the cabinet.

Together with stakeholders it is decided to indicate the preferred installation location for the mixing valve on the back wall of the kitchen cabinet, along the identified stroke. This way the cover is clearly visible when opening the cabinet. If necessary however, the valve can be installed elsewhere.

19.2. Communication

All mechatronic Quooker products are equipped with an LED to indicate its functioning. Signalling with this LED will help the user identify where the problem may be during a malfunctioning of the entire system. This LED is especially important since the valve will be installed on the back side of a dark kitchen cabinet.
Through an explorative analysis, two main categories of communication between the valve and user were identified: monitoring and troubleshooting. Similarly two other Quooker products, the following communication procedures are established:

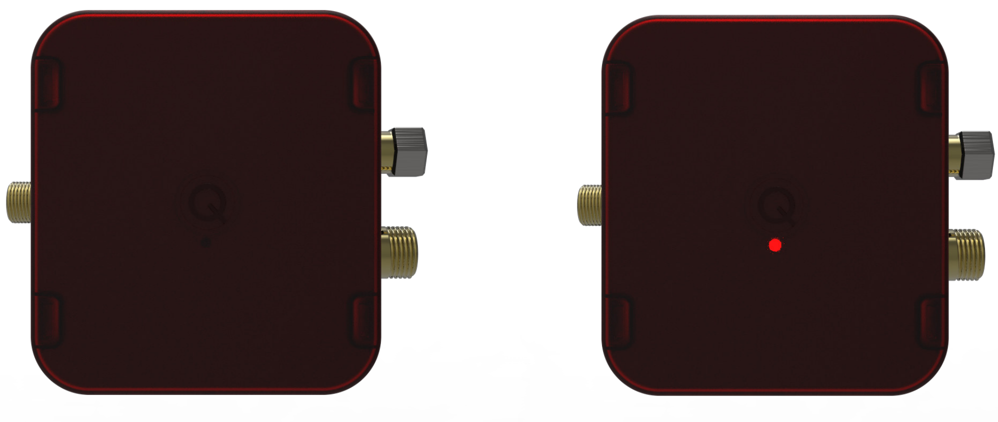
Monitoring

When dispensing, the LED will be continuously on. If not, the LED will be off. This will save power and increase the longevity of the LED.

Troubleshooting

In case of recognized malfunctioning by the mixing valve, it will indicate this with a blinking signal, similarly to the other Quooker products. This will tell the user whether the problem has something to do with the valve or whether other products are malfunctioning.
A list of malfunctioning possibilities that could indicate this signal can be found in appendix R, as well as a further explanation of the visual communication.

image [33] Computer generated rendering of the LED-communication on the valve in a dark kitchen cabinet



When the device is not being used, or when power is off

Constant on: device is actively dispensing water.
Blinking: failure notification

20. Mixing principle

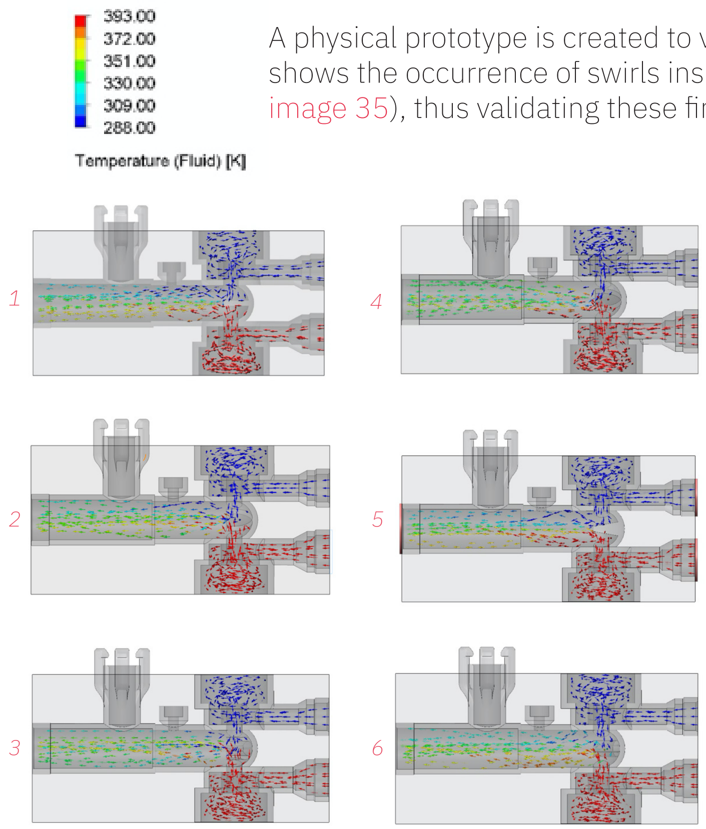
20.1. Principle

Efficient mixing of the different water temperatures is crucial for a correct measurement of the temperature sensor. Having a uniform water temperature will result in a true value, instead of a local optimum in the water flow. This will lead to the most precise temperature control. Not only is this a performance feature, but also a safety feature. Measuring a local optimum in the water flow could lead to the water being dispensed being significantly warmer than measured, which could lead to scalding.
The company supplying the plungers and solenoids made a first proposal for the mixing configuration. In this proposal the plungers are placed symmetric, with a partition in the middle. This partition is necessary to prevent the flow of one plunger to influence the behaviour of the other plunger (by increasing the pressure on its surface). This is shown in image 34. First simulation results of this mixing principle did not show a satisfactory result, the partition forces both flows to take on a laminar pattern, which is not preferable.

A variety of shapes for the partition were simulated, all with unsatisfactory results. The partition appears to break up the “natural flow” of the water streams, resulting in a laminar flow.

Inspired by industrial mixers, a new configuration is proposed. Industrial mixers often have a central rotating blade, responsible for agitating the liquids inside. This rotational movement can be mimicked by locating both inlets opposite but eccentric from each other. Benefit of this geometry is the fact that no partition is needed, since the outlets do not directly oppose each other. By placing the inlets eccentric, a swirling motion of both water streams is created. A multitude of CAD simulations shows this configuration to have significantly better mixing behaviour.

A physical prototype is created to validate these findings. The test setup shows the occurrence of swirls inside of the mixing chamber (shown in image 35), thus validating these findings.



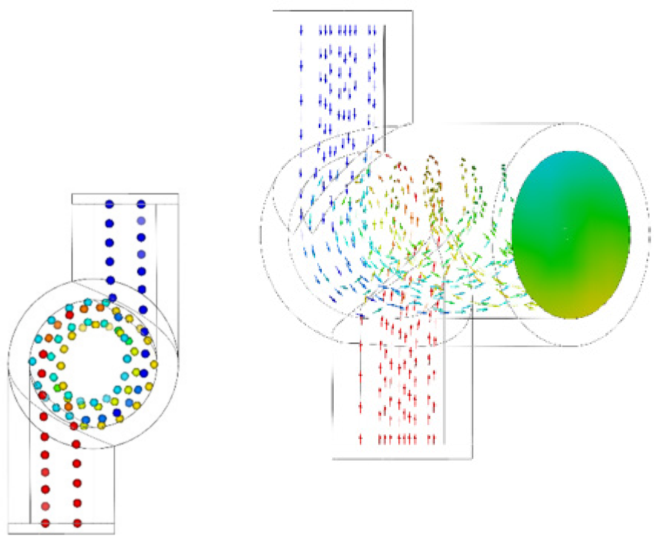


image [34]

CAD-simulations finding an optimal mixing geometry

*image [35]
Testing setup
and images
showing the
swirling motion
inside of the
mixing chambers*

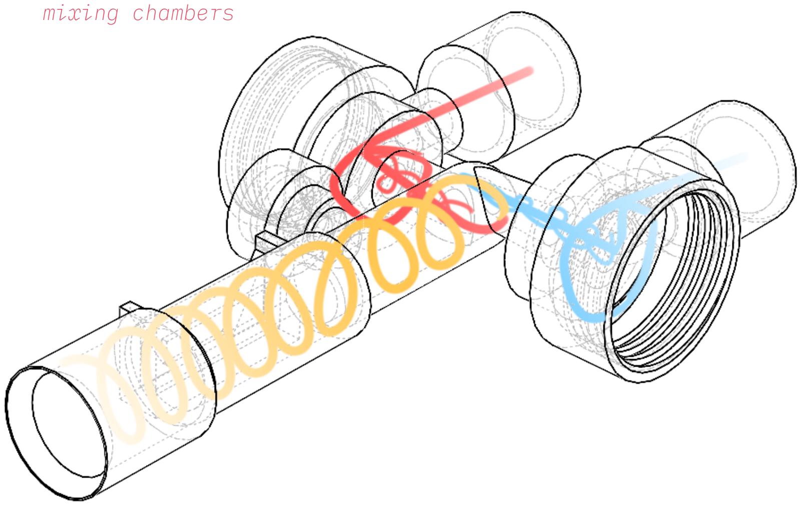


image [36]

Scenario	% +/- 5 [˚C]	Upper lim. [˚C]	Lower lim. [˚C]
Status quo 6 [l/min] 30 [˚C]	18	52	16
Swirl 6 [l/min] 30 [˚C]	45	40	21
Swirl 6 [l/min] 40 [˚C]	37	49	24
Swirl 6 [l/min] 50 [˚C]	32	55	22
Swirl 6 [l/min] 60 [˚C]	23	62	22

table [10]

20.2. Optimisation

Similar to industrial agitation vessels, different baffle geometries were added inside of the mixing chamber. These did however not have a preferable result. In regular vessels, the liquid has now where to go, meaning that vertical translations are no problems, the liquid will come down again. In the case of the mixing valve however, promoting vertical translations is not ideal, since the liquid will move out of the valve. Therefore, nothing should obstruct the swirling motion of the mixed flow, maximizing the number of swirls and hence energy transition (as shown in chapter 7).

A second eccentric configuration is proposed. By eccentrically placing the inlets into the plunger chambers, a vortex is created within these chambers. This will result in the two different flows already having an internal swirling motion and swirling with each other, maximizing contact surface between hot and cold and maximizing heat transfer efficiency (shown in image 36).

Through simulations, a geometry is created which has its behavioural optimum for mixing at a temperature range of 30 to 40 [˚C]. Within these temperature range both inlet flows have a similar velocity without creating excessive pressure within the plunger chambers. This will result in a uniform swirling motion, promoting optimal mixing behaviour. Table 10, shows the variety in temperature at the temperature sensor at different temperatures. Higher dispensing flow rates are preferable, since a higher velocity promotes the amount of swirls over a specific linear distance.

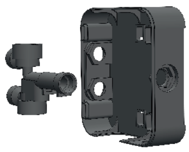
21. Housing

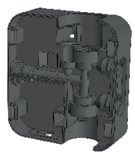
21.1. Housing concept

The majority of competitive mixing valves have a similar construction. A separate inner work, consisting of channels and connections for actuators and sensors, is placed inside a box with a lid. This box has several openings through which the inner work is connected with water and electricity lines.
This housing concept is deemed archetypical and different alternatives are explored. Benefits of this housing concept, as well as the alternative housing complex are presented in table 11.

table [11]

comparison of housing concepts





Multi-part concept	**Integrated concept**
Only the critical component needs to be produced out of a high performance plastic.	Less components, hence less assembly steps
In case of failure, only one of the two parts would need to be replaced	Only one higher complexity mould, instead of two complex moulds with sliders
	No tolerance complexities connecting the inner works and outer housing
	A minimal number of openings between the housing and channels, reducing the potential of leakage

Motivated by the lack of further benefits, an alternative housing concept is developed to compare with the archetypical solution.
This solution integrates the inner works with a part of the outer housing. This way, less components are used, there is less risk of leakage inside of the housing, there is no tolerance complexity between the two parts. Instead of using two complex molds, one mold with higher complexity is used. Downside of this configuration is the fact that in case of failure, the entire component needs replacement, whilst the housing needs to be produced out of the same high performance material as the inner works.
It is difficult to determine the absolute cost and efficiency difference between both concepts. However, together several internal engineers at Quooker B.V., as well as other stakeholders agreed to implement an integrated inner work into the housing. Both separate parts contain a degree of complexity where it is actually viable to integrate the two. An efficient cost price indication of two injection molded parts of separate materials compared to one integrated part of high performance material shows that at the numbers indicated in the programme of requirements (20.000 pieces per year for 5 years, so 100.000 in total), material costs are a fraction of the price, with aspects such as mold tooling still being significant and processing time being more influential on the cost price.

table [12]
cost price
indication
comparison

Concept	Volume	Material	Material costs	Estimated cost per part
Outer housing	95 cm3	ABS	€ 0,45	€ 0,95
Inner works	38 cm3	PPA GF40	€ 0,32	€ 0,81
Integrated housing	110 cm3	PPA GF40	€ 0,94	€ 1,55

Cost differences are shown in table 12. This calculation does not account for sliders. However, this would likely result in a more favourable result for an integrated housing, since the total number of sliders would be lower.

21.2. Housing components

Using this configuration results in three housing components, instead of four as would be required in the archetypical configuration.

Back housing

Houses the inner works, all actuators and sensors, connectors for the water, power and communication lines, as well as the PCB.

image [37]
Back housing

Internal cover

The internal cover is required to cover up the slots in the back housing, as well as protecting the electronics from leakage. Image 42 shows the back housing designed in such a way that it consists of two compartments, a “wet” compartment and a “dry” compartment. The wet compartment houses all components that could possibly leak, whilst the dry compartment houses the electronics. Separating the two protects the electronics from leakage and condensation.

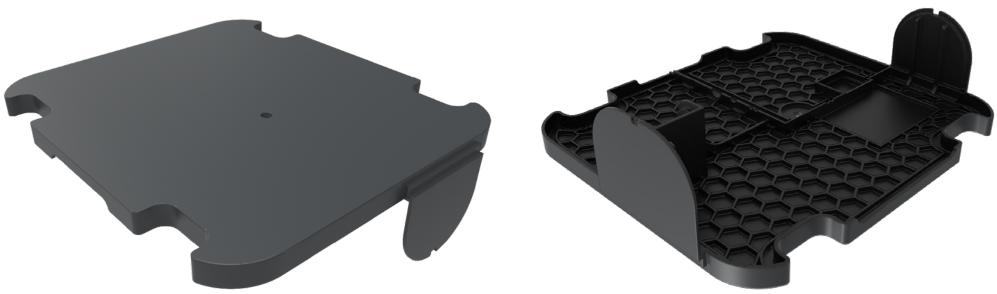
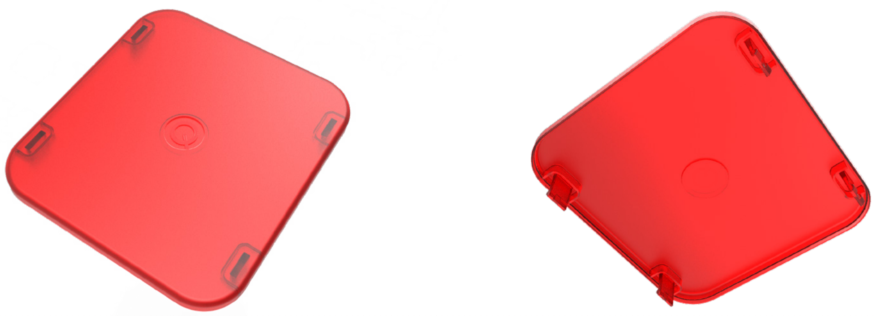


image [38]
internal cover

Front cover

The front cover fastens the internal cover into place, as well as making sure the product fits in with Quooker’s form language and has a recognizable red, translucent cover.

image [39]
front cover

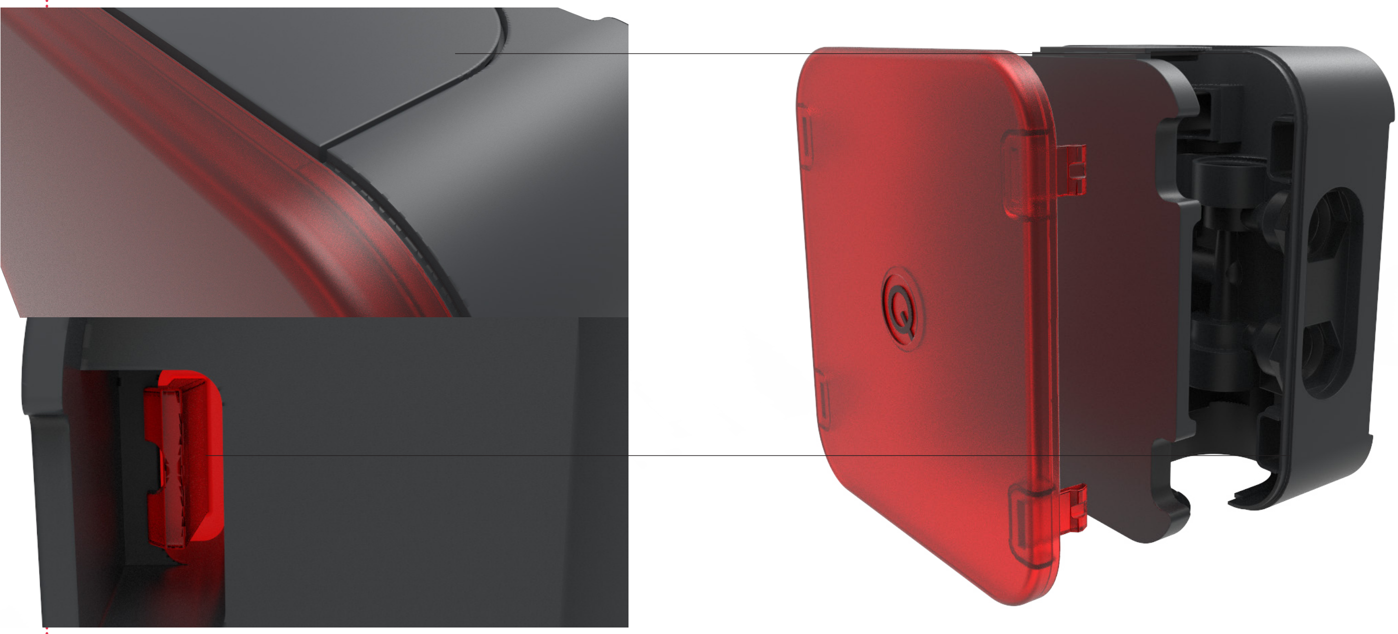


22. Detailing of the housing

22.1. Connecting components

All of the components besides the housing are mounted on the integral back housing part, making for a more straight forward assembly which does not require extensive subassemblies to all be connected correctly to each other. Instead, the assembly is a linear additive process, which is preferable [33].
In the chapter before it is stated that the internal cover is placed underneath the front cover, with its main functions being the covering up of orifices in the back housing and creating separate compartments within the housing. This means that, in case of disassembly there is no useful situation in which only the front cover would be removed, since then still nothing can be reached. In all cases where the front cover needs to come off, this case needs to come off as well. Therefore, it was decided that this cover does not require a separate fastening geometry, but instead can be shaped in such a way that it is clamped in between the back housing and front cover. This eases the assembly procedure and reduces part complexity. The internal cover is locked into shape by its geometry and then clamped down with the front cover. The cover has multiple support surfaces around the back housing for correct alignment before clamping.
The front cover is clamped down with four snap fits, located at the outer rim of the cover, where space in the back housing allows them to be. They are designed in such a way that they can be removed if necessary, allowing opening of the electronic mixing valve (disassembly). The middle of each snap fit has a indentation allowing for prying open with a screw driver or similar tools.

image [40]
Connection of the housing components



22.2. Design features

The internal cover is required to be relatively stiff, since it should maintain its shape within the set tolerances when clamped down. The general shape of the cover however is not optimal, consisting of a thin flat surface with surfaces placed perpendicular on both top and bottom. Stiffness and rigidity is added through multiple geometrical features, shown in image 41.

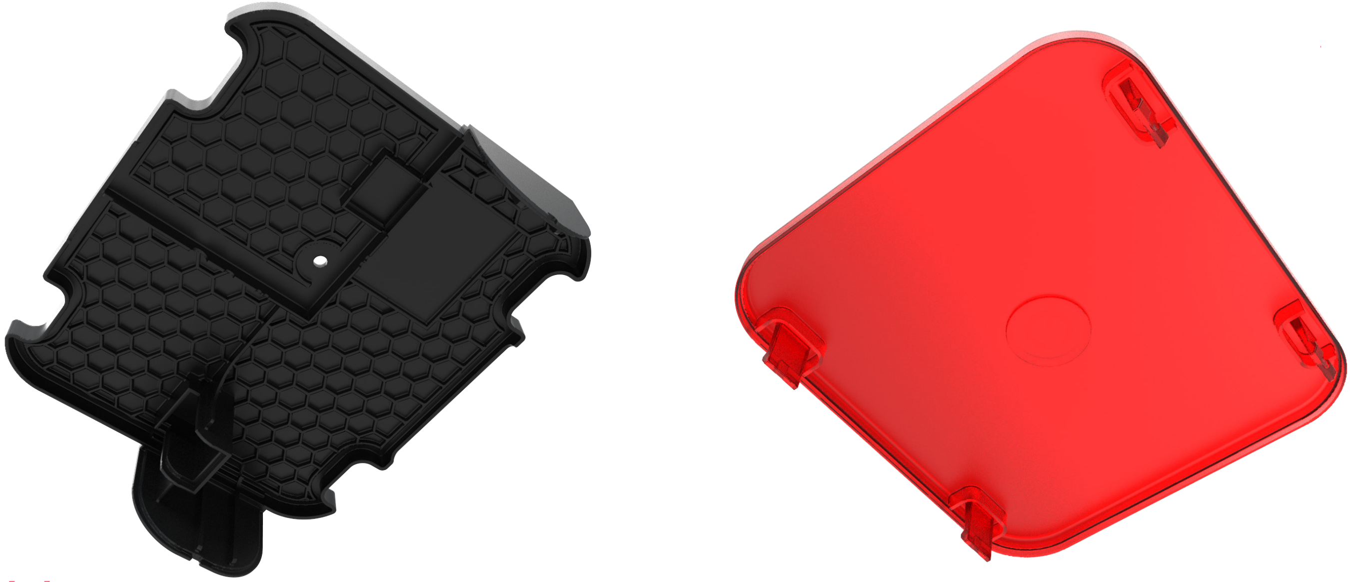


image [41]

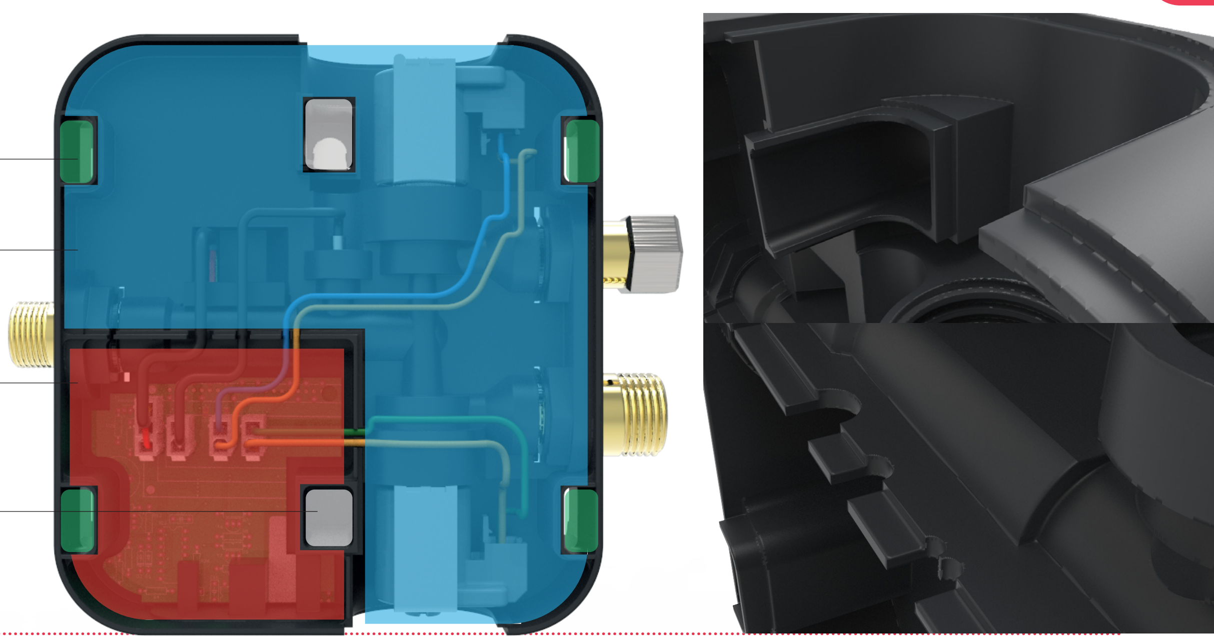
details of the internal cover and front cover

Contrary to the internal cover, the front cover is required to have some flexibility. It needs to flex when snap fingers are pushed out, without permanently deforming. Furthermore, adding extra geometry to this component will be directly visible for the user. For these reasons, the geometrical features of the front cover are kept to a minimum.

22.3. IP44 rating

As stated in the programme of requirements, the mixing valve should comply with an IP44 rating, which is typical for kitchen and bathroom appliances. This means that the internals should be protected from splashes of water, as well as have no openings larger than 1 [mm] diameter after complete assembly [34]. This rating is mostly critical for the PCB with exposed components. All other components are able to withstand water to some extent, since they are made for these specific applications. In order to protect the PCB from exposure to condensation and steam (internal) or water splashes (external) a separate chamber geometry is designed in the back housing. This chamber is closed with a sliding geometry between the back housing and front cover. Small orifices remain in the chamber wall, allowing for electrical wiring (but within IP44 rating orifices). Besides this big chamber, separate chambers are created for the mounting geometry (shown in image 42) and the click fingers of the front cover. All these chambers are shut off by sliding geometries, ensuring the internal components are protected and the product complies with IP44 rating. In case of leakage inside of the product during usage, small drainage orifices are designed, allowing for condensation and steam to escape.

image [42]
Image left: The separate chambers inside of the back housing
Image right: Some sliding geometries ensuring IP44 enclosing



23. Materialisation & production

A sufficient material decision should be a balance between costs, performance and producibility. Each of the custom components used for construction of the electronic mixing valve is discussed here. More critical components get a more extensive explanation. The full analysis can be found in appendix S. Together with engineers at Quooker B.V., knowing the amount of products that will be produced, the required type of materials and the complexity of components, injection molding is deemed the most feasible option.

23.1. Front cover

The front cover is the distinct face of the product, therefore the main requirement is visual. The component should be translucent (as other Quooker covers). Furthermore, the material should be used in an injection molding process. Knowing these requirements, three potential materials were selected. These are presented in table 13.
All data is obtained via CES Edupack 2019.

table [13]
Front cover material properties

Material	PC	M-ABS	PMMA
E-modulus [GPa]	2.3	1.9	2.2
Yield Strength [MPa]	59	43	54
Water durability	Excellent	Excellent	Excellent
Cost [€ / m3]	3475	2050	4365
Max. Service Temp. [°C]	112	82	50
Transparency	Transparent	Transparent	Transparent

Table 13 shows that PMMA is significantly more expensive than both PC and MABS, without offering significantly better performance. This table shows a cost-wise preference for MABS. However, some important notes:

- *Contrary to PC, MABS is not as commonly used [35], which could influence its availability.*
- *All of Quooker's other covers are produced out of PC, which means that a manufacturer and the material would be directly available (and most likely cheaper than indicated by CES Edupack 2019).*
- *MABS has a lower maximum service temperature. Accidents involving boiling water (which is not preferable but could be likely in a Quooker configuration) could lead to permanent failure. PC's maximum service temperature is higher than the temperature of boiling water. Constant exposure to water is not preferable for both polymers.*

Motivated by these arguments, it is decided to produce the front cover out of PC-COM through injection molding. More specifically "Lexan 123R Red 5206" would result in a front cover mechanically and optically identical to Quooker's other covers.

23.2. Internal cover

Through discussion with stakeholders it is decided to produce the internal cover out of similar material as the back cover, thanks to the following arguments:

- Visual properties: both the internal cover and back housing will be part of the same external surfaces, with identical colour and surface finish. Picking the same material will ensure their similarity over time.
- In case of extreme leakage within the mixing valve, the internal cover will be exposed to the same extremities as the back housing during normal use.
- Picking a similar material will ensure that the internal cover will not fail in these unpreferable scenarios.
  Identical material would most likely mean identical production process, which means an identical supplier and minor changes to machinery when changing molds, as well as bulk volume advantage when ordering raw material.

23.3. Back housing

The extensive material analysis can be found in appendix S. A first selection was made through discussion with Quooker B.V.'s R&D engineers and an explorative research using different material databases. This selection is based on the following criteria:

- *Drink water certification*
- *High temperature resistance against both boiling water and steam*
- *The material should be able to be used in an injection molding process*
- *Total raw material costs per part not to exceed €1,-. This limit is motivated by an educated guess, keeping cost price of other components as well as further material processing in mind.*

This selection is shown in table 14.

table [14] First material selection for the back housing

Material	PC, PES	PPSU	ASA+PC	PF	PPA	DAP
Main reason for unsuitability	Transparent or Translucent	Too expensive	No drink water certification	Health Issues	Too weak	Starting > 50%GF Poor mouldability

PSU, PPA GF% remain suitable

The table show to materials remaining suitable: PSU and PPA GF blends. Through CES Edupack 2019 information regarding these materials is collected. Two different PPA GF blends are used, with different Glass Fibre (GF) percentages. 15% appears to be the minimal amount of GF required to show a significant difference in performance, whilst 40% is the maximum percentage without introducing production implications. Relevant properties of these three materials are shown in table 15.

table [15] Properties of the selected materials

Material	PSU	PPA GF15%	PPA GF40%
E-modulus [GPa]	2.7	16	24
Yield Strength [MPa]	79	92	187
Max. Service Temp. [˚C]	160	221	225
Cost [€ / m3]	12.9e3	10.4e3	11.6e3
Recyclability	Yes	No	No
Embodied Energy [MJ / kg]	192	171	144
Density [kg / m3]	1.24e3	1.32e3	1.48e3

Performance wise PPA blends appear to be preferable over PPU, since they are superior in every specification and a cheaper alternative. In order to achieve identical performance, the amount of PSU would most likely be higher. Major benefit of PSU is its recyclability, which is a property not to be underestimated with the increased attention towards the footprints

of newly produced products and the slowly changing ethical standards. However, in order to properly assess its recyclability, a more thorough analysis is performed.
A preliminary space claim of 110 [cm3] is used. Using this volume, the weight of each materialisation option can be calculated. This weight can then be multiplied with the embodied energy (the amount of energy it takes to produce this specific part). Typical recycling rates worldwide vary. The United Nations has a calculated estimation that states that in 2018 around 9% of all plastics worldwide were being recycled [36]. In 2014, the European Commission set increased recycling targets, aiming towards a percentage of 65% of plastics being recycled by 2025 [37]. Currently, Western European countries have an average recycling rate of 50% for all plastics [38]. Depending on the product, recycling rates are either higher or lower. Since the majority of Quooker products are sold in Western European countries, this recycling rate is used. This rate is used as following: The typical maximum recycling amount of such a higher performance plastic is 2.5 times, the third time it will already degrade too much to be used in a similar application [39]. Furthermore, recycling also requires energy. Therefore, the average embodied energy of a recycled component is the addition of the principal energy required to obtain the material and the energy required to recycle, divided by the number of recycling cycles. Implementing this calculation results in the outcome presented in table 16.

table [16]

Energy and recycling related properties for the selected materials

Material	PSU	PPA GF15%	PPA GF40%
Weight [grams]	109	116	131
Embodied Energy [MJ]	20.9	19.8	18.7
Produced	100.000	100.000	100.000
of which recycled	50.000	-	-
Recycling cycles	2.5	-	-
Energy required for a recycling cycle [MJ]	6.7	-	-
Total embodied energy per part accounting for recycling cycles [MJ]	15.1	-	-
Total energy required to produce the material for 100.000 pieces [TJ]	1.80	1.98	1.87

Because of the higher embodied energy for the production of virgin material and the required energy to recycle, the total difference in energy costs is deemed insignificant in regard to the performance differences. PSU parts would require 4% less energy in comparison to PPA GF40. Parts produced out of PPA GF40 would be 11% cheaper however, not even accounting for the fact that, thanks to better mechanical properties, less material will be required. Therefore, it is expected that this price difference would be even more significant. Other significant differences between the materials which are also relevant for this application have not been found. Therefore, these arguments form the deciding factor to pick PPA GF40% (or similar percentages) for the materialisation of the back housing and hence the internal cover.

image [43]
EMS- Grivory

table [17]
Material properties of both the Zytel blend and Grivory blend

23.4. Material sourcing

Through engineers at Quooker B.V. as well as an external suppliers of PPA were found. From each supplier a blend was selected which has the predefined specifications. These are shown in table 17.

Material	DuPont Zytel 70G30HSLR	GRIVORY HT1VA-4
E-modulus [GPa]	10.0	14.5
Yield Strength [MPa]	200	220
Percentage Glass Fibre	30	40
Maximum service temperature [˚C]	184	200
Molding shrinkage normal [%]	1.1	0.6

The EMS Grivory-blend has slightly better performance, with mostly the aspect of mold shrinkage being interesting. A smaller molding shrinkage could hint towards better creep performance over changes in temperatures. This can be logically explained by the increased percentage of glass fibres, since these will show less creeping and shrinking behaviour during temperature changes. This is a feature which is of relevance in a product which constantly warms up and cools down during usage. It is however difficult to assess this behaviour based on material properties. Therefore, for now it is not expected that these differences in properties will be of significance during performance.

Through a Quooker B.V. engineer, contact was sought with a representative of Grivory, for principal feedback and insight. Through this consultation, a more specific grade of material suitable for this specific application was found: EMS Grivory HT1VA FWA.

This material is even more suitable for applications involving hydrolysis and high temperatures (above 85 [˚C]). A lifetime indication is given at at least 10 [years[, although lifetime strongly depends on design, stress, temperature profiles and processing of the parts. Furthermore, according to EMS, the product has excellent creep resistance and complies with all the widely known water certifications, such as KTW (Germany), ACS (France) and WRAS (United Kingdom)

Through EMS the datasheet of this material is obtained. Guidelines from this datasheet (such as drafting angles and minimum wall thickness) are used in the final part design.

It is decided that for this resolution of concept this materialisation is sufficient. A specific blend choice will be the result of an extensive evaluation process with the supplier and multiple long term tests.

Lastly, EMS is working on even higher performance PPA blends, which have increased life times or operating temperatures. For now these materials are considered a ‘ development areas’ and not applicable in consumer products. However, they could be an interesting improvement in potential future updates.

Datasheets of all materials can be found in appendix T.

24. Design management

24.1. Steel safe tolerances

The intermediate assembly of components has been made with nominal measurements. Within this measurement approach a first step towards "steel safe" design measurement has been taken. All interlocking components make use of sliding geometries with two contact areas. Through the addition of different tolerance rates at these contact areas, contact with only one surface is realized, ensuring correct fitment. This principle has been applied all around the border of the back housing and "non-IP44 cambers" in the model. This, together with other geometrical novelties is shown in image 44.

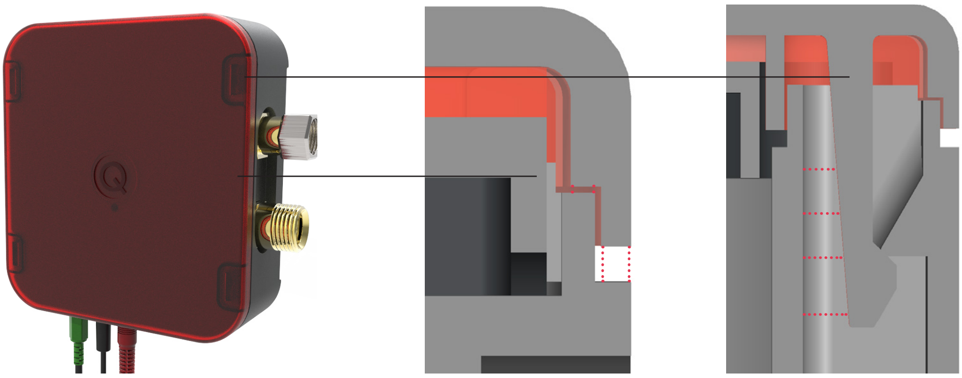


image [44]
Left image: Mixing valve concept
Middle image: The sliding geometry with different tolerances to ensure a fit at all times.
Right image: Extra space indicated for geometrical changes in the snap fits

For now, these tolerances have deliberately been amplified within reason. This is likely not to lead to a perfect fit with the first mold results, but does allow for inexpensive mold modification (since material will be removed) as shown in image 45.
It is however expected that the fitment of the three injection molded components will not be of the biggest concern, since they are not the most critical for correct functioning of the device.

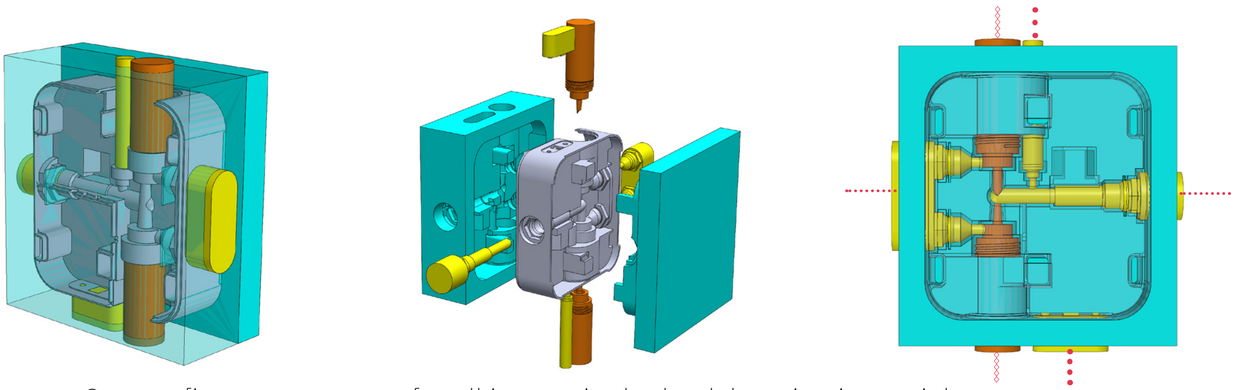


image [45]
Initial Mold design, 6 sliders are used, all located in one mold halve. Orange sliders will rotate on removal to not damage thread geometry

Correct fitment geometry for all inserts in the back housing is crucial to ensure correct functioning and prevent leakage. A great benefit of the chosen mold orientation is the fact that all of these insert orifices are created with the aid of mold inserts, which are separate moving parts within the mold. For now the applied fitment tolerances are amplified within reason, allowing for the removal of extra material from these inserts, narrowing the fitment of the components.
Another benefit of this approach is the fact that the geometry where fitment is most critical (because of water tightness) the consequences of mold wear will be more severe. The replacement of inserts is then a more economical approach.

24.2. FMEA

A Failure Mode and Effect Analysis is a systematic method of mapping all possible dysfunctionalities within the product. A complete FMEA can be found in appendix V. Only some major concerns are discussed in table 18.

table [18]

Short synthesis showing the most important findings from the FMEA

Component	Failure mode	Consequences	Severity
Plunger	Leakage	Boiling or cold water could enter mixing chamber, tap starts dripping	Outlet water line will always be filled with water which cools down the drippage. Detectable issue
Housing failure	Leakage	Boiling or cold water could drip into the kitchen cabinet	Detectability is low, since it will occur in the kitchen cabinet. Other appliances nearby could be damaged (although most appliances underneath sink are waterproof
Several Components not fitting correctly	Leakage	Boiling or cold water could drip into housing or kitchen cabinet	Electronics are protected, extreme amounts of water will result in permanent damage. It is expected that the user is able to intervene before this happens. Indication is lower flow rate at tap / wet kitchen cabinet.
Electronics	Short circuit / general failure	Device will shut down, user cannot tap normal water	Tap will be unusable, hence the boiling water from the reservoir cannot be removed. Further research into bypassing this issue is definitely required.

As stated, due to the number of components and connections there is a reasonable amount of potential failures. A thorough further embodiment towards pre-production and production could solve the majority of these. This also includes consultation with suppliers and potentially alteration of purchase parts to minimise risk. Extensive testing and thorough quality control will be required for components.

25. Full-body Concept

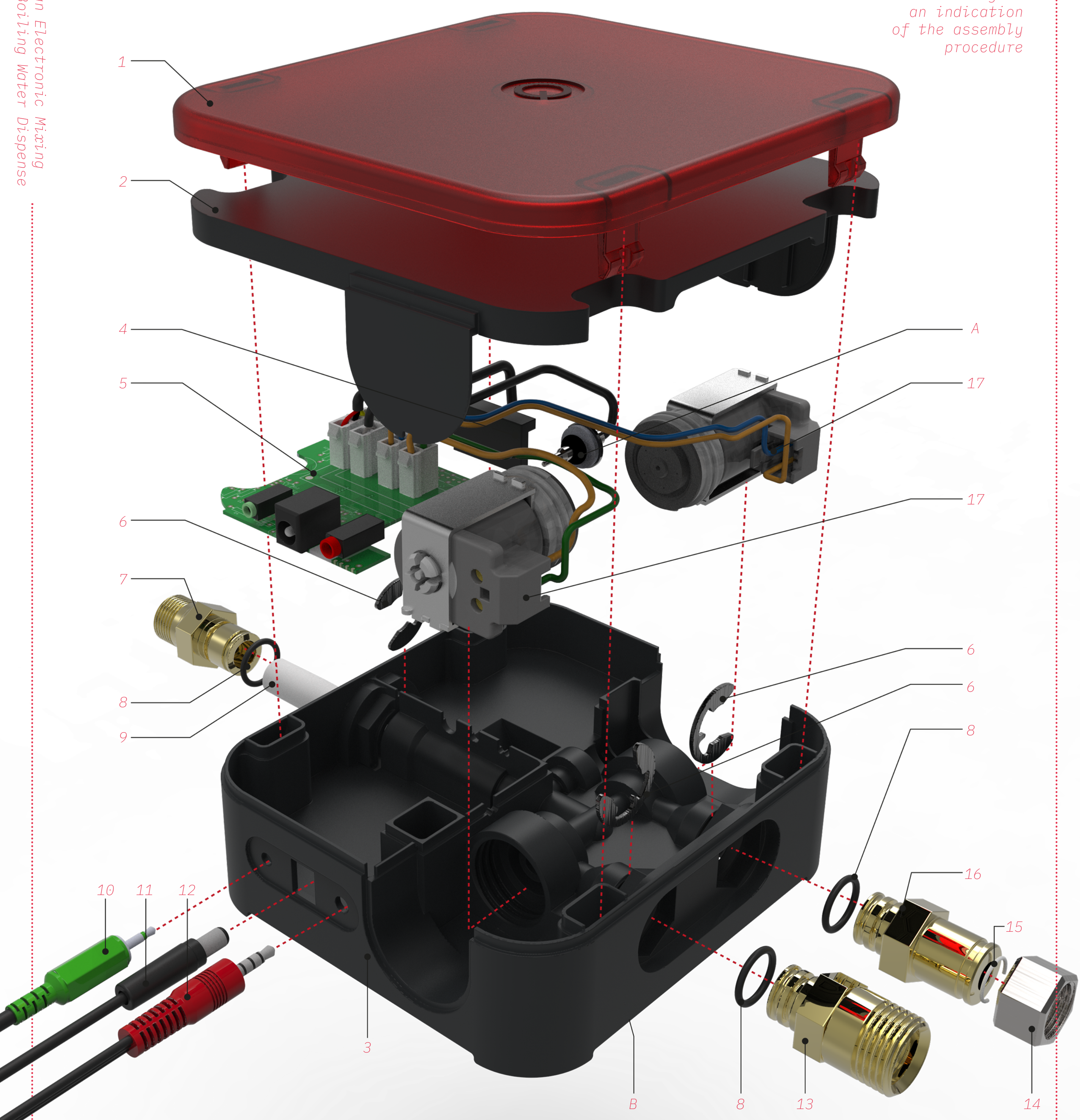
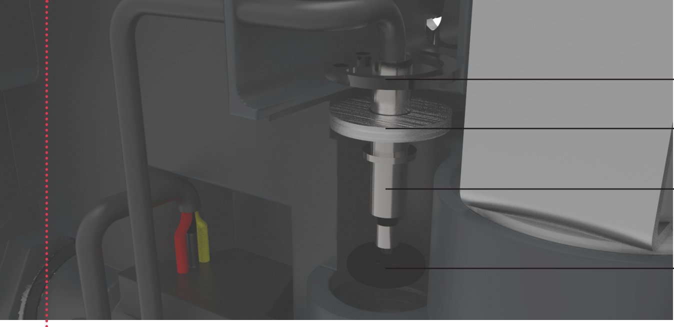


image [46]

An exploded view of the full-body concept. Each unique component is numbered. The red lines give an indication of the assembly procedure



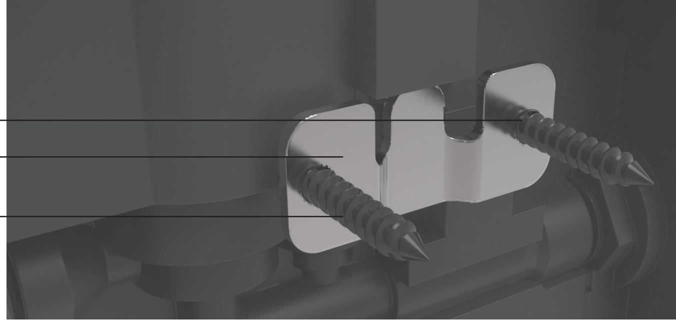


image [47]
Left image: detail A, components for the temperature sensor fastening
Right image: Bracket used for mounting the mixing valve inside the cabinet

25.1. Cost estimation

Table 19 shows a cost estimation for the full concept. An extensive analysis for this cost estimation can be found in appendix U.

No.	Component Name	Material	cost / piece [%]	total cost [%]	Comments	Source
1	Front cover	PC-COM	2,2	2,2	Quooker Red Visual surfaces VDI 3400 REF 33. Logo details SPI A2	BASF Injection moulding calculator
2	Internal cover	GRIVORY HT1VA FWA	3,1	3,1	RAL 7021 Visual surfaces VDI 3400 REF 12.	BASF Injection moulding calculator
3	Back housing	GRIVORY HT1VA FWA	5,2	5,2	RAL 7021 Visual surfaces VDI 3400 REF 12.	BASF Injection moulding calculator
4	Hall sensor	Purchase part	3,0	3,0	Including wiring	Saier
5	PCB + Wiring	Multiple materials	22	22	-	Estimation EPD Quooker B.V.
6	E-clip dia. 12 [mm]	Purchase part	0,1	0,3	Black DIN 6799	RS-PRO
7	Outlet connector	Brass	1,3	1,3	CNC-machining	Quooker B.V.
8	O-ring 14x1.5 [mm]	Purchase part	0,2	0,6	EPDM	ERIKS
9	Flow rate Turbine	Purchase part	3,8	3,8	Food grade POM Up to 85[°C]	Saier
10	Jack 2.5 [mm]	Purchase part	0	0	Part of tap assembly	Farnell
11	Power plug 12V DC	Purchase part	9,8	9,8	-	D.X.E.T.
12	Jack 3.5 [mm]	Purchase part	0	0	Part of reservoir assembly	Farnell
13	Cold water inlet connector	Brass	1,3	1,3	CNC-machining	Quooker B.V.
14	Swivel	Purchase part	0,4	0,4	Steel	ERIKS
15	Swivel retaining clip	Purchase part	0,1	0,1	Spring steel	ERIKS
16	Boiling water inlet connector	Brass	1,3	1,3	CNC-machining	Quooker B.V.
17	Prop. control assembly	Purchase part	13	26	Multiple components	Hydralectric
18	O-ring 2x2.4 [mm]	Purchase part	0,2	0,2	EPDM	ERIKS
19	Thermistor	Purchase part	4,4	4,4	NTC + Housing + Wiring	Mitsubishi
20	Washer M4	Purchase part	0,1	0,1	Steel	ERIKS
21	Retaining clip 12 [mm]	Brass	0,1	0,1	CNC-machining	Quooker B.V.
22	Screw M5x12 [mm]	Purchase part	0,2	0,4		ERIKS
23	Mounting bracket	Purchase part	0,6	0,6	Steel	Xunengsun Technology
	Subtotal			86%		
	Assembly Costs	Labor	14	14	Estimation based on current costs	Quooker B.V.
	Total			100%		

table [19]
Cost price estimation

image [48] Computer generated image of the product within Quooker's configuration

This cost price estimation accounts for all parts and the assembly of these parts into the final product. An extensive analysis of the assembly including a assembly tree is shown in appendix W.

25.2. Purchase parts

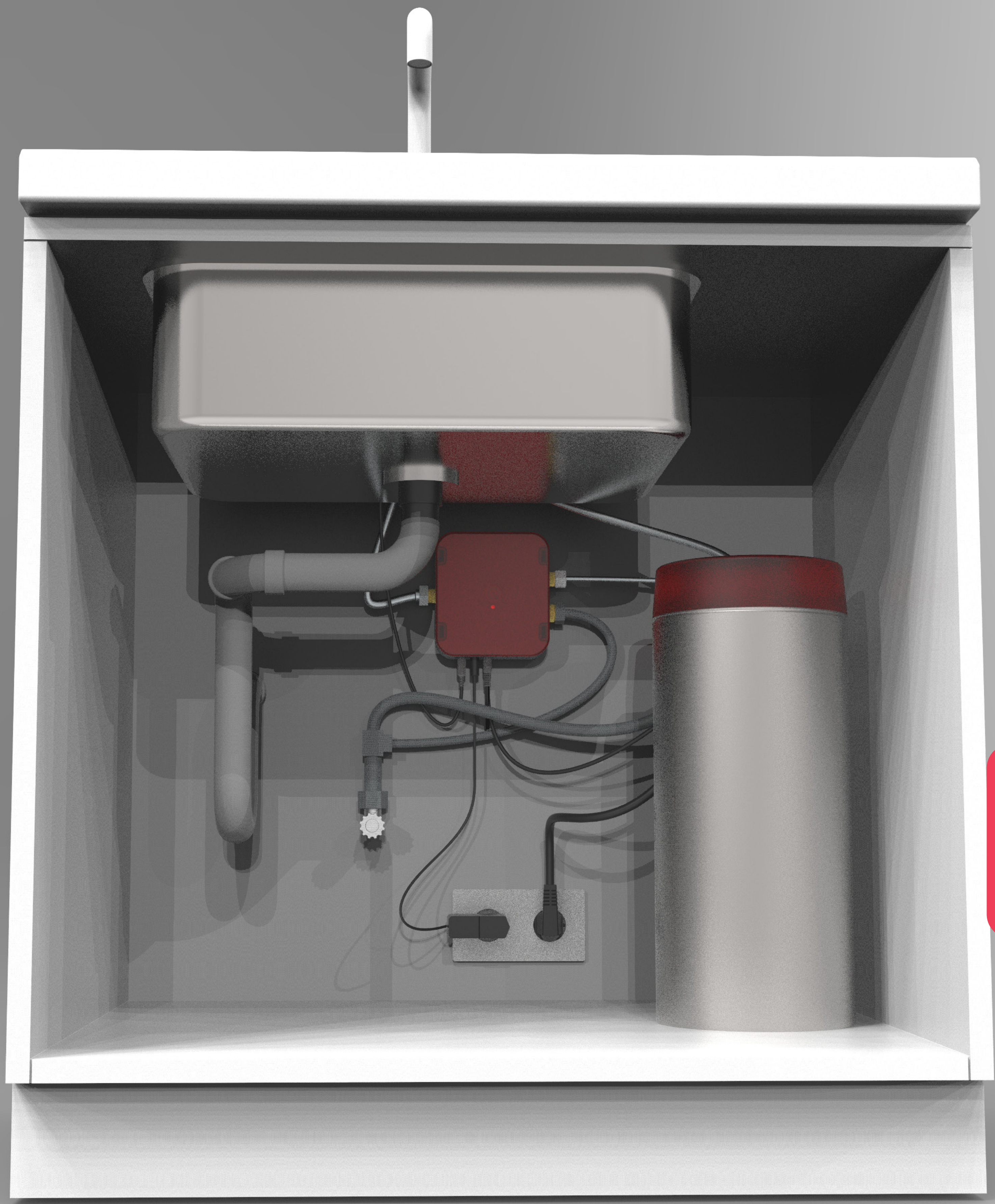
Interesting is the fact that 63% of the cost of components comes from standard purchase parts. For now an efficient supplier analysis has been performed, which resulted in price estimations. Upscaling of order quantities has been taken into account to some extent, although the savings achieved by upscaling are hard to predict and differ from supplier. This analysis does however stress a thorough supplier analysis, which could potentially lead to a more economic product.

25.3. Custom parts

Cost savings can be reached by further optimising the custom injection molded components, however it is expected these savings will be marginal. 60% of the custom part costs is the PCB. This stresses the importance of this component being well designed.

25.4. Assembly costs

An efficient assembly cost analysis has been performed. The number of assembly steps and their respective complexity has been compared to the current assembly procedure and cost of the mechanical mixing valve. Thanks to the design for assembly integration, the difficulty of the assembly steps is lower. However, the number of steps is higher. In order to be on the safe side, the assembly costs are multiplied by a factor to account for this.



26. Prototyping & evaluation

26.1. Subsidiary and intermediate prototypes

Throughout the embodiment a multitude of prototypes have been constructed. Different iterations of the inner works were created in order to validate mixing behaviour. The fitting of different components has been evaluated by efficiently constructing parts of the housing. Furthermore, subsidiary models have been created to evaluate user experience elements. A selection of subsidiary prototypes is shown in image 49.

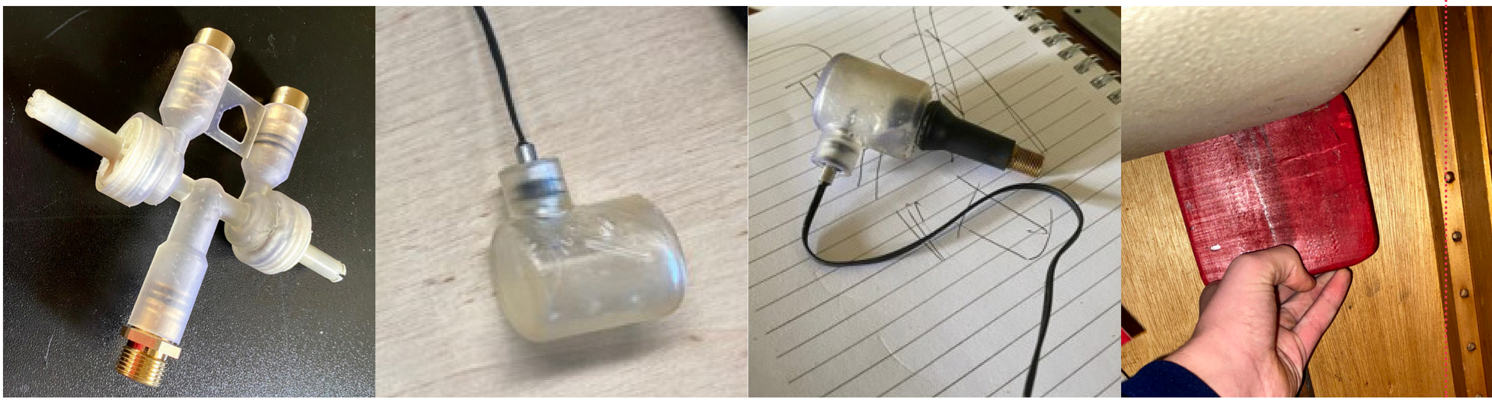


image [49]
A variety of intermediate and subsidiary prototypes validating different findings

Results of these prototypes have been generally positive and it has allowed for efficient evaluation. However, in order to properly assess the concept, it is deemed important to integrate these subsidiary prototypes and new features and evaluate the model as a whole. Therefore, the construction of a full concept prototype is proposed.

26.2. Full concept prototype

The main reasons for construction of this prototype are the following:

- *Evaluation of the general shape within the context of a physical kitchen cabinet.*
- *Evaluate mixing performance with the additional changes made.*
- *Evaluate the performance of all components assembled together.*
- *Evaluating the assembly procedure.*
- *Creating a prototype for more extensive user experience and performance evaluation (as proposed in chapter 27).*

Through Quooker B.V. a prototyping company in China was contacted. The custom components presented in chapter 22 were sent, including material, colour and surface finish preferences.
Both the internal cover and front cover can be prototyped within reasonable costs and with sufficient specifications. However, due to the geometry and material specifications of the back housing, this component would turn out significantly more expensive than the other components. Reason is the fact that the lowest investment prototyping solution for this complex geometry is CNC milling. However, CNC milling is a process of material removal, which means that a lot of high specification material is used to start out with, as well as a lot of processing time (contrary to the final product intended to be injection molded which is an additive process). The costs were deemed to high. After consultation with stakeholders a new prototype configuration is proposed. In this configuration the inner

Prototype concept	1.	2.	Comments
Integrated housing with channels	86%	-	CNC-milled PPSU, finishing VDI 3400 REF 12, RAL 7021 on visible surfaces
Internal cover	5.7%	5.7%	Somos 128 (ABS) SLA, finishing VDI 3400 REF 12, RAL 7021 on visible surfaces
Front cover	7.6%	7.6%	PMMA CNC Milled, Quooker red, surface VDI 3400 REF 12, logo polished SPI A2
Separate back housing	-	6.0%	Somos 128 (ABS) SLA, finishing VDI 3400 REF 12, RAL 7021 on visible surfaces
Separate inner works	-	34%	CNC-milled Brass
Total	100%	**53%**	

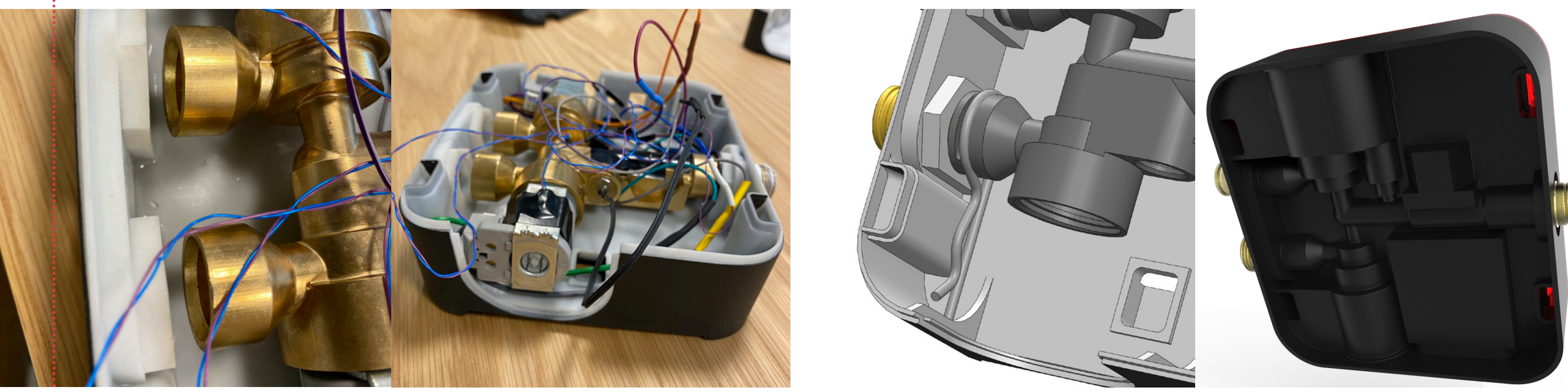
table [20] prototyping costs

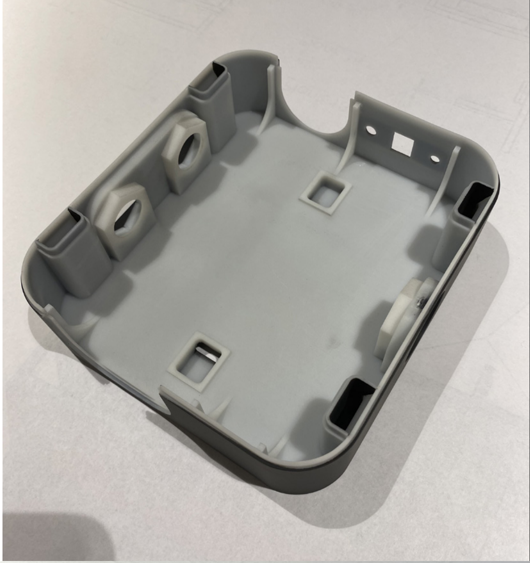
works and the housing are separated. This allows for a cheaper prototyping method for the housing and an alternative (cheaper) material for the inner works, including less CNC machining. Resulting in a cost saving of 46%. This prototype does include some concessions. The assembly procedure is different, as well as the performance of separate components. However the test deemed most important, the extensive user experience and performance evaluation can still be performed.

26.3. Evaluation

Because of correct tolerances application (ISO 2768 for CNC milling, mK category), the majority of the fitment was sufficient. On one location the inner cover is getting deformed by the front cover in such a way that it sticks 1 [mm] out of its slot (shown on the next page, bottom right). This can be easily altered in a new prototype. For now it does not influence the performance and is not changed, not risking permanent damage.
Different surface finishes were chosen for different surfaces, trying to mimick Quooker's other translucent covers as much as possible. These surface finishes turned out excellent. The matte finish on the opaque housing components (VDI 3400 Ref 12) makes the product appear like it could have been injection molded, which is what is aimed for.
Connectors were custom made in Quooker B.V.'s workshop. During installation however, one flaw occured. The increased pressure inside of the boiling water line tried to push the connector out of the inner works. This connector is however fastened through the geometry of the housing. The housing (SLA printed) has a weak hinge point due to the slots and its flat backs side. Therefore it is not stiff enough to resist this force and deformed in such a way that fitment is incorrect. A change is proposed, in which the connectors are fastened to the inner works (which is CNC machined out of brass and is expected to be stiffer).
This is a prototype specific problem (the concept has integrated housing and inner works), but does show that extensive testing is required. In the integrated housing the geometry is stiffer and ribs can add extra rigidity.

image [50]
Left images: the deformed housing.
Middle right image: a new proposal which fastens on the brass inner works.
Right image: In the concept this would not likely be a problem, especially with the addition of ribs.

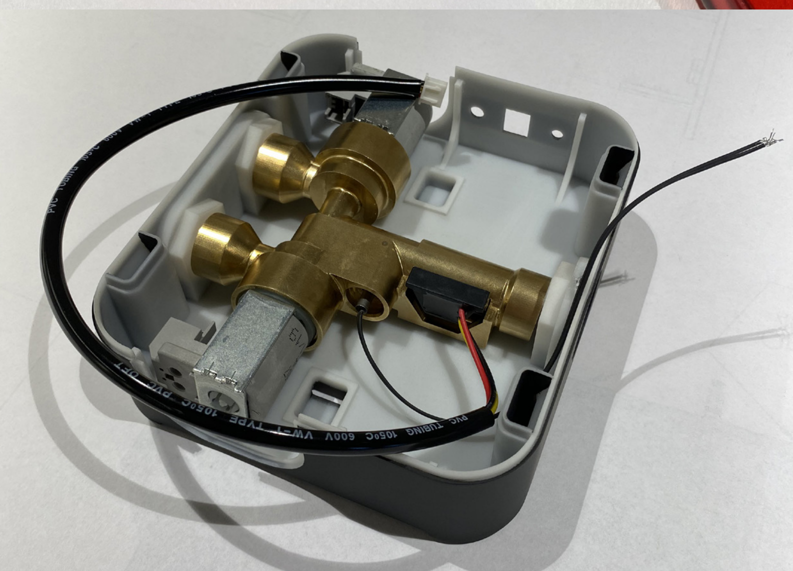


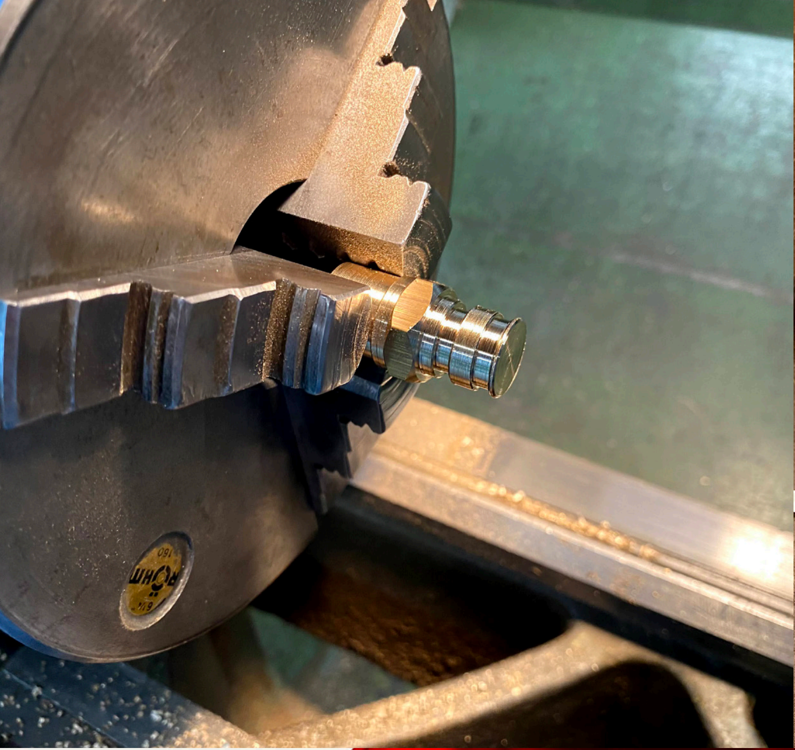
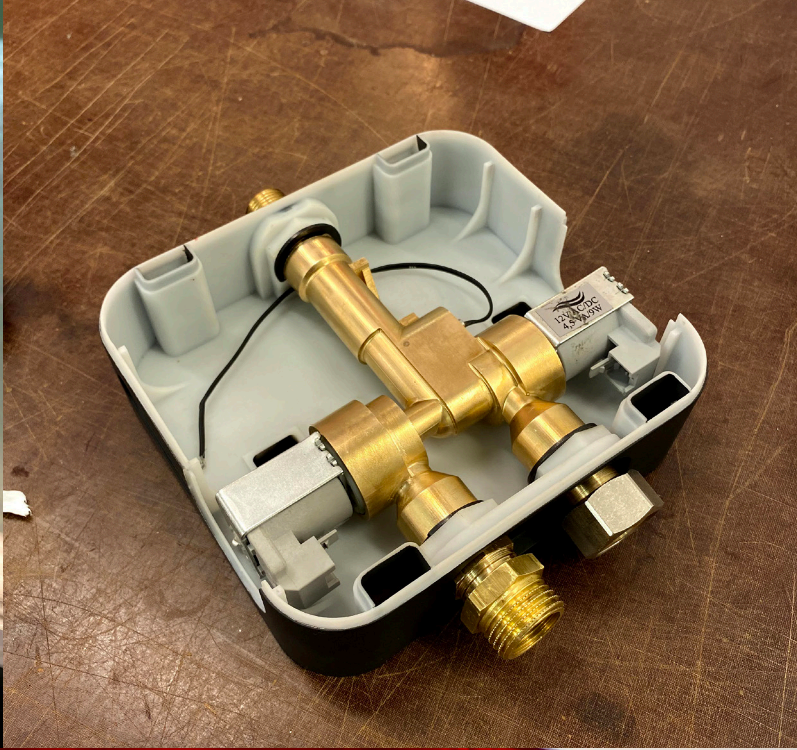




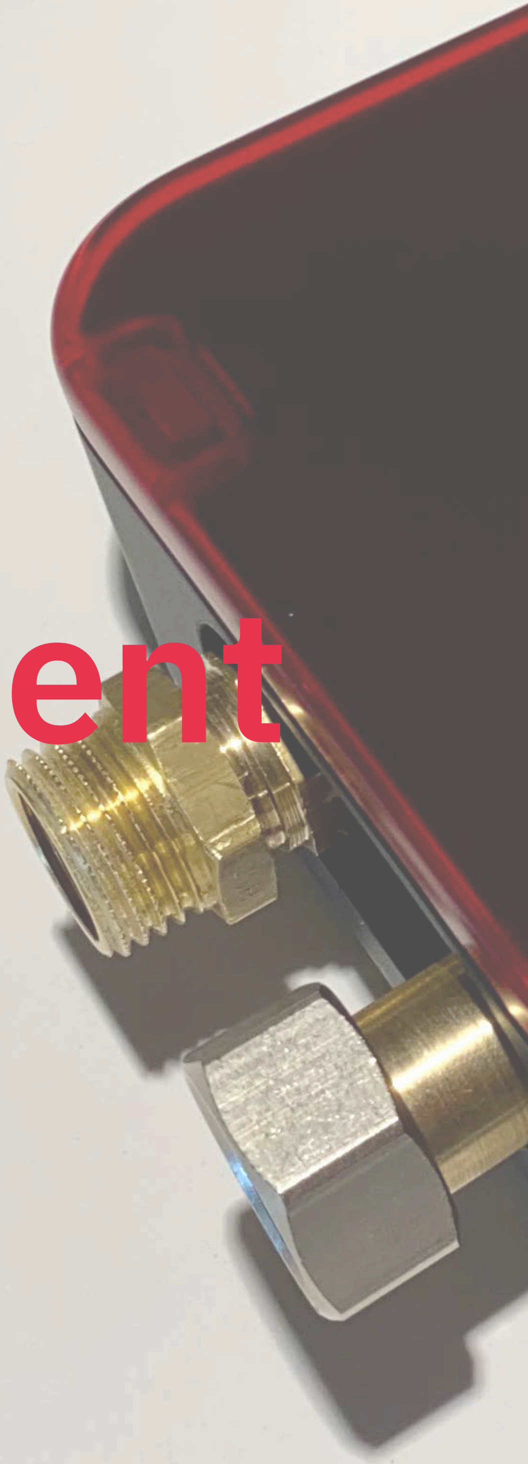





Assessment



27. Assessment proposal

Together with Quooker B.V. engineers, an assessment procedure is proposed. This assessment procedure is divided into two parts: Performance evaluation and experience evaluation. The full proposal can be found in appendix X.

27.1. Performance evaluation

The main goal of this performance evaluation is as following:

- *Gain insight into the behaviour of the Quooker electronic mixing valve in comparison to existing alternatives.*

Results of this evaluation will be the strengths and points of improvement for the mixing valve.

A predetermined scenario is designed in such a way that the performance criteria (precision and speed) can be assessed under different circumstances. If possible, this scenario will be automated electronically, removing the chance of human error. Each of the mixing valves will be put through this scenario for multiple times.
Besides the practical test, an assessment of other performance criteria (number of functions, energy usage and price) will be performed.

All obtained data is mapped in a table. Scores for performance criteria are converted to be comparable and each of the criteria receives a specific weight. By filling in the scores for each concept, a complete assessment between all valves can be made.

27.2. Experience evaluation

Contrary to the performance evaluation, the experience evaluation does not try to be objective, but focuses on the experience of the user when interacting with the mixing valve. This assessment has two goals:

- *Evaluate whether the mixing valve can replace a normal tap.*
- *Mapping changes noticed by the user (negative, neutral and positive).*

Results will give insight on whether the electronic mixing valve is an innovation (significant positive improvement) in comparison to the current situation.

Again, a predetermined scenario is designed in such a way that tasks of a broad variety can be performed. The user is asked to perform these tasks on two configurations which are visually identical. However, one of the configurations will be equipped with an electronic mixing valve inside of the kitchen cabinet. A specially modified mechanical tap will be used that translates the users movements into communication for the mixing valve.

All obtained data is mapped in a large table with all of the changes categorized appropriately.

27.3. Long term testing

The before mentioned assessments will be performed internally. However, as the embodiment of the mixing valve will continue, further long term oriented assessments have to be developed. These can again be divided in similar categories.

The long term performance assessment will consider deterioration of material and components due to usage and constantly heating up and cooling down (creep), giving insight into the longevity of the system.

The long term experience assessment will prove whether users are able to work with a new system and the length of the learning curve to do so.

28. Validation & limitations

28.1. Limitations
Due to unforeseen external circumstances the proposed performance and experience assessments cannot be performed. This limits the ability to make a thoroughly substantiated validation of the main drivers. For the majority of the drivers physical validation is crucial.

28.2. Functionality
The electronic mixing valve must be able to dispense a predetermined amount of water (minimum of 100 millilitres) at a predetermined temperature (within the range of the cold main water line to 65 [˚C]).
Throughout the design and embodiment this driver has been kept in mind. The selection of required sensors allows volume, flow rate and temperature control. The selection of materials ensures the product will function at higher temperatures. This has all been mainly theoretical research, subsidiary aspects (e.g. fitment, controls) have been tested. However, the final prototype, which synthesizes all findings has not been extensively tested as proposed. Therefore, this driver can not be validated.

28.3. Reliability and Robustness
The electronic mixing valve must function safely with a minimal average maintenance interval of 5 years or more with a minimal lifespan of 10 years. Furthermore, it should comply with applicable regulations.
Even more than the driver before, this one can not conclusively validated. Components, material and design have been chosen in such a way that in theory these maintenance intervals and lifespan should be within reach. However, extensive test cycles will surely introduce new problems. Regarding the applicable regulations, the design and materials have been carefully selected in such a way that certification institutions will not deny the product up front. However, the process of certification is extensive, especially since the product cannot be categorized easily (similarly to the hot water taps themselves). It is therefore safe to state that, at the point that the product is standing right now, there is potential for validation.

28.4. Cost difference
Compared to a current complete Quooker system, the mixing valve must not have a cost increase of more than 100% and these costs need to be justified by a reduction elsewhere. The new upper and middle subsystem should maximum cost as much as the current upper and middle subsystem.
The cost price indication of the new electronic mixing valve is 197% of the mechanical mixing valve and therefore barely within the margin of a 100%. However, this cost price is just an indication, implications of further detailing and testing can lead to different components, changing the price. For now the estimations have been made carefully to ensure being on the safe side. An actual cost price of the electronic mixing valve could potentially be lower. Regarding the price limit for both the tap and valve together, this limit has not been met. The combined system is 129%, thus 29% more expensive. The electronic mixing valve takes up 27% of this estimation. A cost-down analysis on the mixing valve could make a difference, but not enough for the whole system to come within the limit. Instead of not validating the driver however, the driver should be questioned. Electronically tapping is intrinsically different from mechanical tapping, therefore these systems cannot easily be compared. Electronic

tapping removes the hassle of finding a temperature and introduces variables which can be quantifiably changed by the user. The mindset and approach to the product should be entirely different. Furthermore, a comparison like this, not involving users, is invaluable. Testing with users would quantify and test the value proposition, prove the innovativeness (a significant positive improvement, user feedback is required! [40]) and from here the cost price estimations should be evaluated. Comparing with an entirely different system does not make sense. This feeling of it being an entirely different system should however be clearly communicated towards the user and other stakeholders, in order to substantiate not using this comparison.

28.5. Modularity

The new electronic mixing valve must be compatible with, but not limited to, Quooker's current reservoirs.

Both electronic connections and water lines are designed in such a way that the product can directly be integrated in the current product line. Therefore, right now there are no clear arguments to not validate this driver, within the limitations stated before. It is however the question whether this configuration really is preferable. Further optimisations proposed within the embodiment are postponed because of this driver, e.g. the implementation of pushfit connections and easier electronical communication lines. Implementing changes in the rest of the system is expected to increase the value proposition of the mixing valve (this of course needs to be validated with all stakeholders). Some design choices taken feel disputable. A correct balance between changes within different parts of a whole Quooker system and separate components needs to be found. It is expected that only then the electronic mixing valve will truly feel seamlessly integrated in Quooker's product line.

28.6. Design for manufacture and assembly

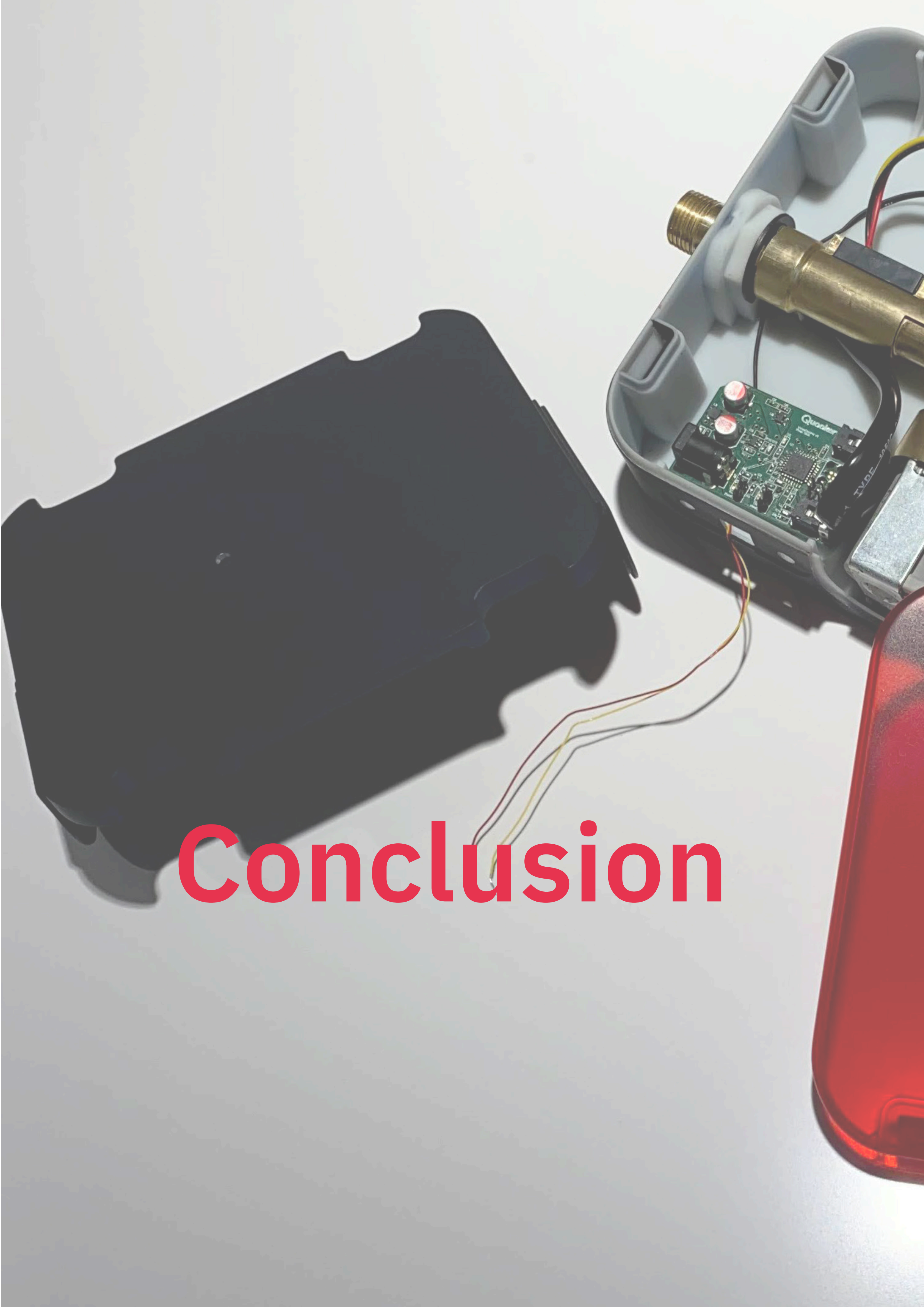
The materialisation and assembly of the new electronic mixing valve must be within abilities expected of Quooker B.V. A predicted production volume is taken at 20.000 pieces per year for 5 years.

During the embodiment, DFM and DFA aspects have strictly been kept in mind. The product's materialisation and configuration are adapted to the number of products expected to be made. Furthermore, the designed assembly procedure does not involve intricate proceedings and can be performed fully by hand and hand tools. Lastly, 63% of the costs consists of standard components, which means that these components are already available and hence do not require large investments (although the price per component will be relatively higher).

Within the resolution developed in this thesis, one can state that this driver is validated. However, the final product might me vastly different due to regulations, materials and component availability. Therefore, a conclusive validation can not yet be given. However, in the current state there are no clear limitations and there is potential for validation.

28.7 Validation programma of requirements

The validation of the programme of requirements can be found in appendix Y.



Conclusion


PVC TUBING 105°C 600V VW-1 TYPE

image [51]
Electronic mixing valve prototype connected inside a kitchen cabinet

29. Conclusion

As stated at the beginning, the goal of this thesis is as following:

Obtain a suiting solution for both the company as well as its customers by extensively researching opportunities for an electronic mixing valve.

With a "suiting solution" being a concept open for interpretation, five drivers were introduced to quantify this goal. A validation of these drivers is shown in the previous chapter. Overall the results are mixed. Not a single of the drivers can be conclusively validated, however only one driver can be declined based upon the findings in the thesis. This driver is also open for discussion.
Similar to the drivers, validation of the programme of requirements shows the potential of the product, but does not allow conclusive decisions regarding its validation.

The lack of conclusive validation can be assigned to two factors.
First of all, the resolution of the project is not high enough to make conclusive decisions. This is a problem that could have been identified beforehand. Although the project started with a vast amount of knowledge already available within the company, essentially giving a "head start" and hence more time for embodiment, it could have been known that a complete embodiment is not feasible within the given time frame. As is typical within product development, especially in the latter stages, "the more you know, the more you realize you do not know" as famously written by Aristotle [41]. Pushing a concept to a certain resolution opens a whole new variety of new questions. In order to create a final, production-ready prototype, all these questions, and the questions following, need to be answered. And even then, during production the product's use, new questions and challenges will present themselves.
The second factor is the fact that no user related evaluation could be performed. Unfortunately, external influences did not allow for external user evaluation. Consequence of this fact is that drivers can be somewhat validated from the company's perspective, but not from the user's side. The corporate value proposition is clear, but user validation is still missing.

When zooming out, this project is part of Quooker B.V.'s innovation trajectory looking into the "potential" of electronic mixing. This thesis adds to this trajectory as following.
The resolution of the potential has been increased, without finding definitive limitations. Instead of finding positive closure, a number of potential negative outcomes have been removed. All whilst also introducing new potential negative outcomes (due to its higher resolution).

Concluding, one could state that a step towards a suiting solution for both the company as well as its customers has been made. However, validation of the drivers accompanied with the set goal shows the importance of user involved testing in this stage of the product development process.
In a more detailed solution as before, the potential of "electronic mixing" appears to be apparent, viable and feasible, but does require further research.

30. Recommendations

30.1. Critical recommendations

Critical recommendations are those that directly influence the project in its current state and that block the product development from making further progress.

User involved assessment

As could be expected from the validation and conclusion, the first and foremost recommendation for further development is "user involved assessment". When placing the development process in a stage-gate process, a so called "gate" is now reached. The amount of information gathered is deemed enough for a full "stage". Adding more information would further complicate the assessment, blurring concrete results. Furthermore, the performed development can not yet be used as a substantiated foundation. This means that progressing further in this specific direction is a relatively risky investment.

30.2. Future recommendations

Future recommendations are recommendations that should be performed after the critical recommendations. For now, typical recommendations necessary for a higher resolution are not discussed here. These recommendations are relevant for every project and therefore less interesting to explicitly discuss.

Stakeholder consultation

It is likely that completing the critical recommendations will result in a more substantiated product, which can be discussed with internal stakeholders at Quooker B.V. Both the internal and external value proposition will be clearer and together a future strategy can be decided. This is essential for making the electronic mixing valve a more integrated product within Quooker B.V.'s current and future product portfolio.

FMEA and certification

Although the FMEA might have resulted in a lot of potential risks for the product in its current state, these challenges are inevitable in developing an entirely new product. It is essential that all these questions are to be thoroughly researched and answered in the next product development stage. Furthermore, extensive research into certification for intended markets should be performed. This way, inevitable measures resulting from these certifications can be more seamlessly integrated into the product.

User mindset

Throughout design and embodiment it began to show just how different this way of dispensing water is. It requires a whole different ritual, instead of working towards a specific goal (a temperature, volume or flow rate) this goal is instantly there. This may not seem too different, but this "working towards" process is ingrained into every human that makes use of mechanical taps on a daily basis. Changes will always involve a learning curve and the value proposition must be made clear for the user to consider partaking in this learning curve. This also means extensive research into the interface (the tap) of these new configurations with a mixing valve. The importance of this interface can not be underestimated, since it will largely determine the learning curve for users and could potentially be detrimental for the product's success.

Corporate mindset

This particular mindset towards electronic mixing should not only become apparent with users, but also needs to be ingrained within the other stakeholders and corporate mindset. Nailing this interface requires close collaboration between user experience, physical development and electronic specialists. Only this way, small nuances, which could be of great importance in the final product can be thoroughly analysed.

30.3. Future development

Conclusively, even if all of these recommendations are sufficiently executed, it is highly unlikely that the product will seamlessly integrate when first introduced. Introducing new technologies and their different ways of functionalities and interactions inevitably takes time and iterations. It could easily take years for the consumer to fully accept this solution. However, this also stresses the importance of product development. Introducing a sufficient (but not perfect) product will help create consumer acceptance. Switching to electronic mixing opens up a whole new world of opportunities and creating the foundation for these now will ensure these can be introduced more efficiently in the future. This will ensure that Quooker B.V. maintains its competitive "innovative" advantage and will remain a protagonist in its segment.

31. Reflection

Besides concluding the performed work on a content related level, a personal reflection is also deemed relevant. This chapter aims to give a personal reflection regarding the process followed and the outcome of the thesis.

First of all, the starting point of the project was clearly determined by Quooker B.V., with previous work being executed by another graduate intern. This greatly helped reducing the required research into business and strategy related aspects and allows for more focus towards the design and embodiment of the electronic mixing valve. I think this was a good fit for both the company and me.
In general the process of making this thesis has left a positive impression. I started out with a tightly knit schedule, which was kept in place for the first half of the project. Unfortunately, due to external factors, the second half of the scheduled activities could not be performed as intended. However, after the midterm a revised schedule was made, which proved to be sufficient. The biggest downside of this adaption is the fact that an extensive validation with users could not be performed. In my personal opinion therefore the thesis is missing an integral part of a sufficient performed development process. For now, this user validation is still planned by the company, just not within the thesis schedule. One could state that this schedule is even more beneficial for this user validation, since more embodiment work is performed. This means that a higher resolution prototype can be evaluated, which creates more valuable results.

One major benefit of which I am really thankful is the collaboration I have received during this project. From the start of this thesis, several other (graduate) interns as well as employees of Quooker B.V. have been working on segments of this innovation trajectory. This meant that there always were plenty of sparring partners as well as work that could be performed in collaboration. Working together helps both reflect on performed work and remain critical. Furthermore, other engineers working at Quooker B.V. were always available for giving feedback or new insights into the thesis, even when they were busy themselves. This open attitude towards interns is something I truly appreciate.
Unfortunately, due to external factors, this collaborative element significantly reduced in the second half of the project. Mainly working from home shifted the approach towards the thesis, with it becoming more individual and helping me maintain focus towards my academic goal.
I became more hesitant in asking questions or feedback to peers and perhaps unconsciously became even more individualistic in my approach, which was not necessary good for the project as well as myself. This is something that I will definitely take with me in future projects. Even when obstacles might be there, communication is still the quickest way of receiving useful information.

I am content with the outcome of the project as I believe the results are both useful for Quooker B.V. as for me as an individual. The project has even more showed me how I would like to develop myself professionally and I look forward to doing so in the future.

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