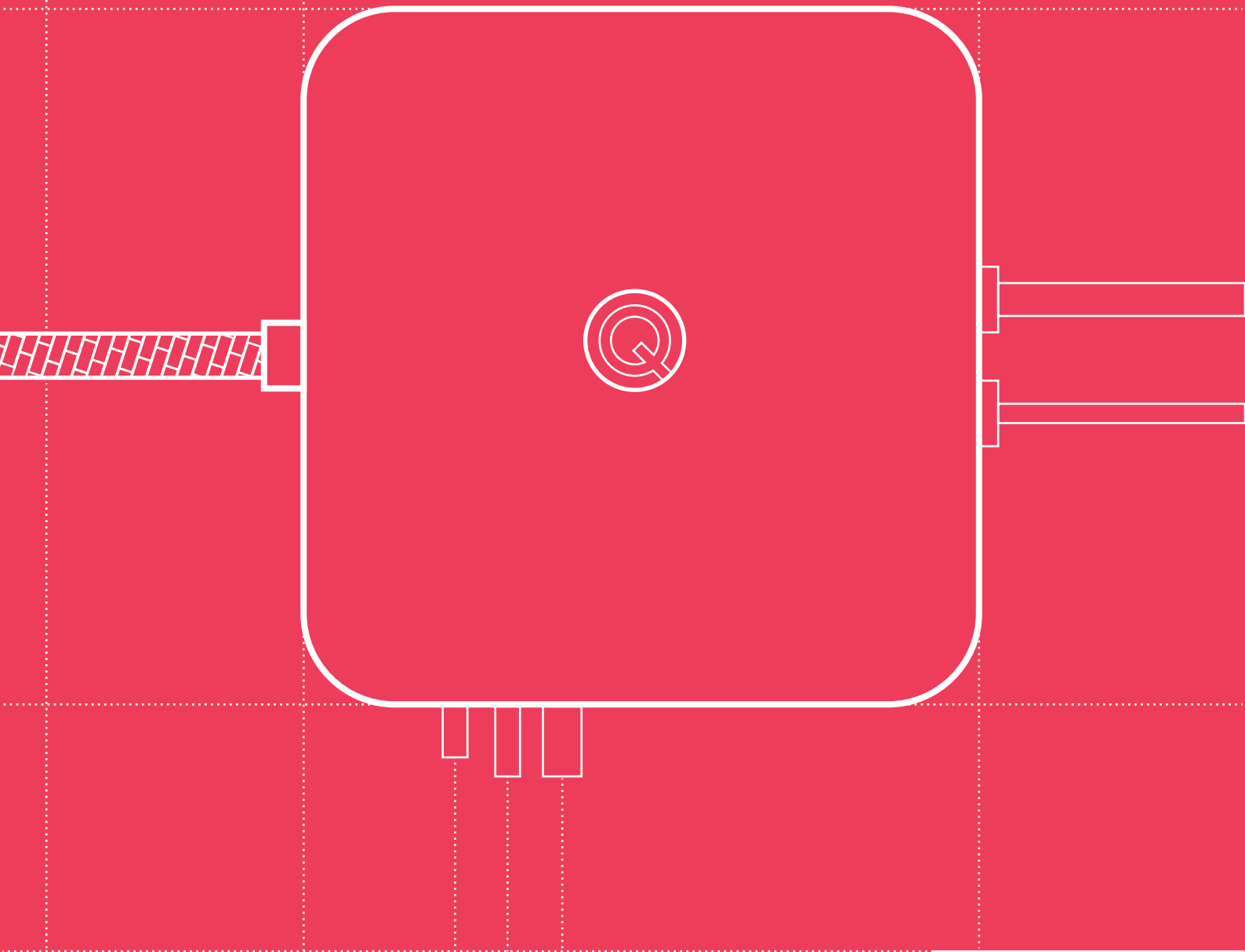


appendices



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

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MSc. Integrated
Product Design

This additional report consists of appendices belonging to the thesis:

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

Note: Original sources referenced in the thesis are not double referenced again in the appendices. Only additional sources are referenced.

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June 24th, 2020

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Table of contents

A. Graduation assignment	6
B. System explanation	14
C. Component analysis	22
D. Mixing	34
E. Competitor analysis	38
F. Patents	42
G. Regulations	44
H. Programme of Requirements	46
I. Programme of Wishes	48
J. Ideation	50
K. Assessment drivers	56
L. Assessment	68
M. Performance throughout scenarios	72
N. Cognitive Ergonomics	76
O. Location	80
P. Communication	86
Q. Material decision	88
R. Material datasheet	92
S. Cost price estimation	94
T. FMEA	98
U. Assembly tree	100
V. Assessment proposal	102
W. Validation programme of requirements	110
X. Renders and pictures	114
Y. Sources	120

B. System Explanation

History

Triggered by the fact that instant soup still needs significant preparation time due to the boiling of water in a kettle, Henri Peteri in 1970 started working on an instant boiling water solution for home kitchens. Two years later he filed his patent. His first product, a separate tap providing instant boiling water was a great success with friends and family. In 1992, after years of intensive development and iterations the first Quooker was introduced to the market. At this time, the Quooker was globally the first to introduce a commercially available instant hot water tap. Over time the Quooker slowly became more popular and really hit off within the Netherlands in 2000, becoming a great success. The company has started the export of its product since 2004. Over time the company has introduced various versions of both taps and reservoirs with optimized and new functionalities. Nowadays, the company is an internationally recognisable name with a wide product portfolio [1]

Quooker B.V. in 2020

Currently, Quooker sells up to 150.000 systems per year, in 11 different countries. The company has more than 300 employees with the majority working at its headquarters and production in Ridderkerk, the Netherlands. All of the systems are developed and assembled in-house. The majority of components is supplied by external suppliers, however critical parts are produced at site. The company achieves an average revenue growth of 33% per year and is expanding its presence worldwide [2].

Corporate image and values

Being the first company to introduce an instant boiling water tap, Quooker holds an protagonist and innovative image. It tries to maintain and emphasize this image by continuously improving its products' performance and offering new solutions. Within the Netherlands instant boiling water taps are unanimously called Quookers, showing how successfully this image has integrated into society.

Quooker sees it as their mission to develop high quality products that are safe and reliable.

Quooker's innovation trajectories

Quooker has a large Research & Development department being responsible for improvements and new innovations. Long term innovations are anchored within their own innovation trajectory. One of these innovation trajectories for Quooker is the topic of 'Electronic Mixing'. Together with employees, graduate interns contribute to this trajectory, slowly progressing towards a potential opportunity or solution. Each thesis written is in principle stand-alone, but does to some extent contribute. This allows both Quooker and graduates to have more depth in their projects and fulfill their interest and potential.

As stated before, this thesis is contributing to Quooker's 'Electronic Mixing' innovation trajectory. The system design of an electronic mixing valve for an instant boiling water dispenser is based on previously performed initial market research and the validation of a business case. Furthermore, separate (parallel) work is performed regarding the interaction of the

user with electronic mixing and the embodiment of these interactions. Result is that a significant part of knowledge and research has already been performed, allowing more focus on the embodiment design of the functional element of the solution, which is the electronic mixing valve.

Quooker's working principle

A Quooker system has elements both on top and in a kitchen cabinet. In order to provide a clear overview of the instant water dispenser, the system has been separated into three different subsystems. Furthermore, the core working principle of the Quooker is explained [3].

Upper subsystem

The upper subsystem consists of one or multiple taps. This is the subsystem responsible for letting the user interact with the Quooker, as well as dispensing water. Depending on the lower subsystem (the reservoir) the taps provide instant boiling water, carbonated water, cold water and continuously warm water.

Lower subsystem

The lower subsystem consists of a reservoir responsible for the supply of boiling water for the upper subsystem. It is connected to the main cold water line to ensure a constant input of water. A heating element and temperature sensors make sure that the water inside of the reservoir is always at 110 [°C] in order to provide instant boiling water to the user. The user does hardly interact with the lower subsystem. Only when the Quooker may not be used for a long time, the user can turn off the reservoir to save energy. The regular water supply of hot and warm water will then still be functional.

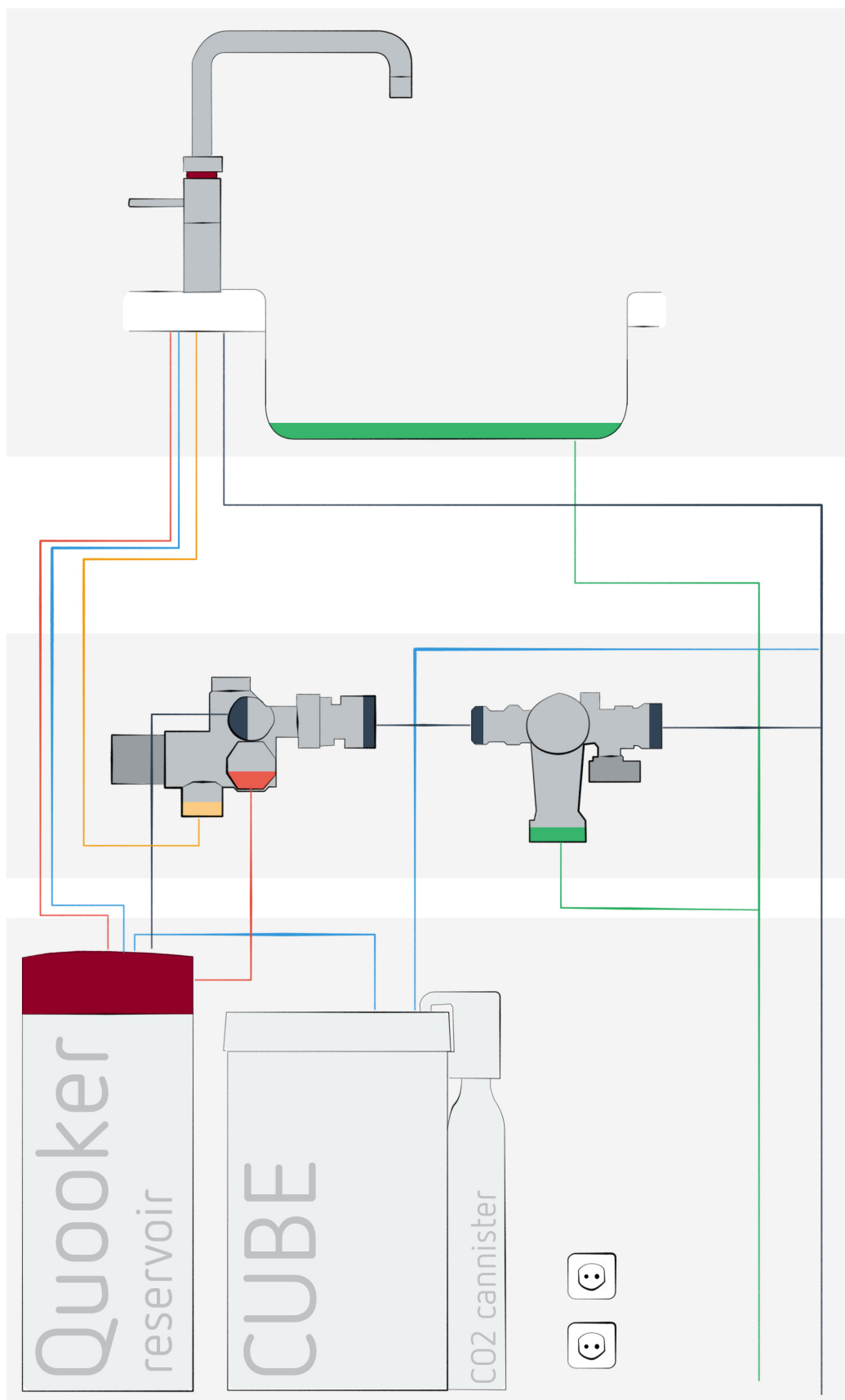
Additionally, the lower subsystem may be equipped with a Quooker Cube as well. Equipped with a filter and carbon tank the Cube enables the user to instantly dispense carbonated and filtered water from their tap.

Middle subsystem

The middle subsystem consists of the various connections responsible for transporting the water from the main water line to the reservoir and from the Quooker to the taps. Besides all of the lines, an inlet combination and a mixing valve are used. The inlet combination protects the main water line from high pressure (up to 8 bar). The mixing valve is responsible for combining boiling and warm water to ensure the user to instantly have warm water, instead of waiting for the central heating boiler to provide this warm water.

Controls

Depending on whether the Quooker uses a separated or all-in-one tap controls can differ slightly. The 'normal' functionalities of the Quooker (dispensing cold and warm water) are similar to other faucets. Rotating the handle changes the temperature of the water dispensed, whilst translating the handle outwards changes the flow rate. In the current situation the operated temperature range by the handle is between 20 and 65 [°C]. Next to these controls a Quooker tap is equipped with a dedicated Q-button. This button can be recognized by its diamond-cut pattern



and the coloured LED-light that is emitted below when in use. All of the functionalities unique to a Quooker are controlled with this Q-button. Depending on the system used, a Quooker may dispense boiling, carbonated and filtered water. When boiling water is requested, the user double-pushes the button down and turns it clockwise. The LED-light will turn red and the system dispenses boiling water. For carbonated water, a single 'push and turn' is needed. Filtered water is dispensed after a 'single push, hold and turn movement'. For both these procedures the LED-light will turn blue. All of the functionalities can be stopped by rotating the Q-button anti-clockwise [4].

Instant hot water

Depending on the reservoir used, a Quooker system can dispense up to 7 litres of instant boiling water. It does so by making sure that the water inside of the reservoir is continuously at a temperature of 110 [°C]. This water within the reservoir is at an overpressure (around 1,5 bar), to make sure that this temperature is reached without the water boiling. The output orifice is located at the top, ensuring that only the hottest water will leave the reservoir. Cold water enters the reservoir through an orifice located at the bottom of the reservoir, therefore there will be zero to none mixture of hot and cold water (since hotter water will rise to the top of the reservoir). The reservoir is equipped with a heating element at the bottom, making sure that the cold water entering is immediately heated. Due to the reservoir's high insulating capabilities a minimal heat loss from the water to its outside environment is ensured. Therefore, minimal energy is needed to make sure that the water maintains its temperature and the heating element will provide just enough energy to heat up the cold water within the reservoir when dispensing.

As soon as the output orifice is opened, the water coming out will experience a pressure drop resulting into immediate boiling water accompanied with steam. When the orifice is closed again, the remaining water within the discharge conduit is boiling and will evaporate. Due to the expansion of molecules when turning from a fluid (water) to gas (steam), the majority of the remaining water will be pushed out of the tap. A negligible amount of water within the conduit will condensate again and remain inside of the conduit. This water will then instantly heat up again when new boiling water is dispensed.

From boiling to cool water

A Quooker tap is able to provide instantly boiling water even if cold or warm water has been used before, as well as the reversed procedure. This is due to the fact that a Quooker tap uses two different water channels. The outer channel provides cold to warm water, functioning similarly to a regular faucet. The inner channel provides boiling water, directly from the Quooker reservoir. As stated before, the boiling water conduit is almost empty after usage, meaning that no boiling water remains. This means that the water dispensed from the outer channel (cool to warm water) does hardly experience any influence from remaining water and will therefore be able to immediately dispense cool to warm water. Naturally, the cool to warm water that remains within the tap during the dispense of boiling water will experience some rise in temperature, although exact information

regarding this data is unknown.

Quooker configurations

Quooker offers different taps and reservoirs, as well as different combinations between the two.

Taps

The different taps offered by Quooker can be divided into two different functional categories: boiling water only and all-in-one taps. Within these categories different finishes and styles are available, however these do not influence the performance of the tap. All of the different tap configurations are shown in the image on page 20.

Boiling water only

This is where the Quooker originally started, a separate tap dedicated to providing boiling water. This tap only has one water line which is directly connected to a reservoir. Therefore these taps can simply only provide boiling water.

All-in-one

These taps combine all the possibilities of a Quooker system with a basic tap. The Quooker functionality is integrated into the tap, allowing the user to dispense boiling, carbonated or filtered water from the same tap as usual with the use of the dedicated Quooker button on the device. Besides

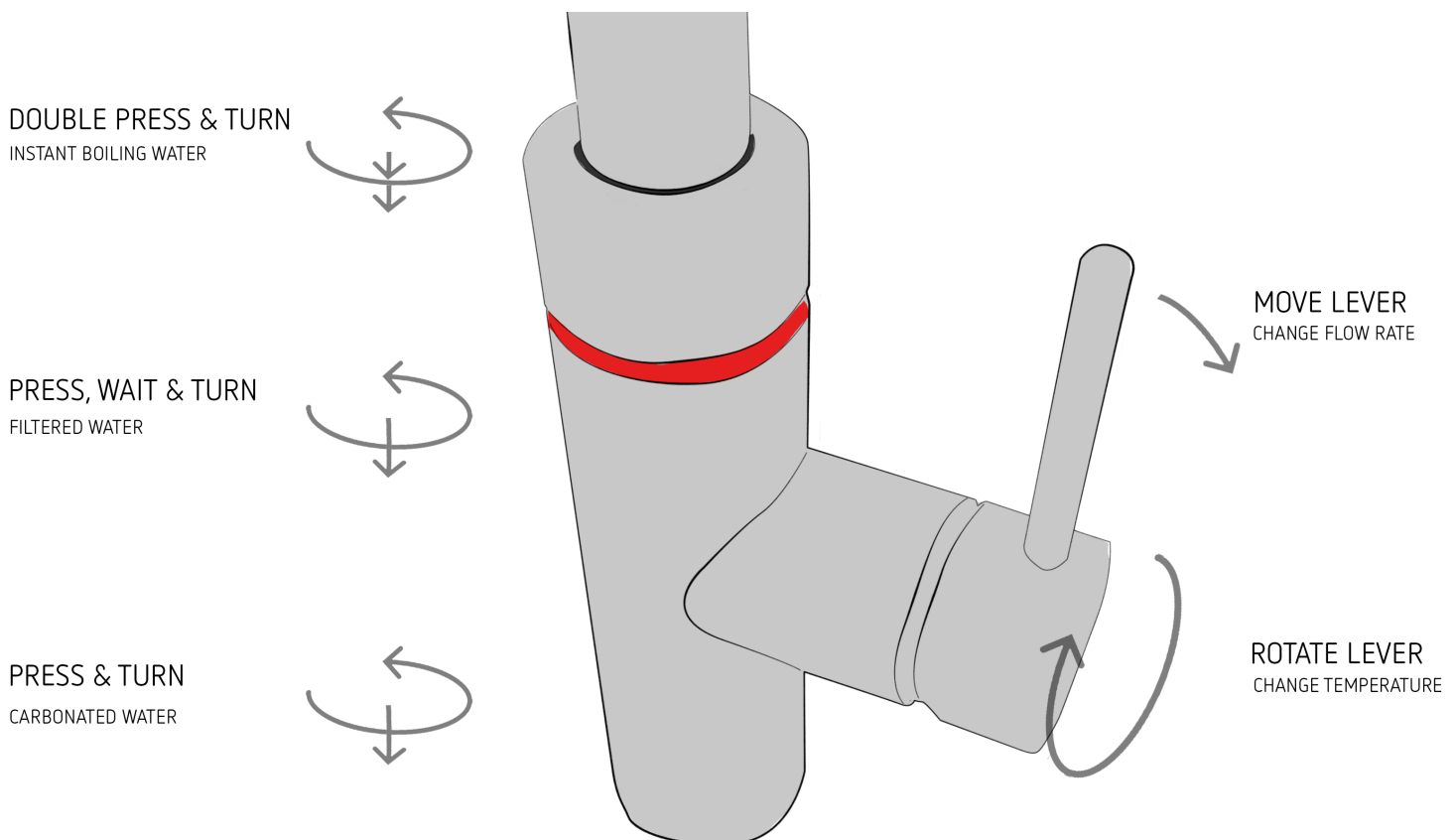


image [2]

a standard fixed tap, a tap with a flexible and extendable hose is available. When this hose is in use the tap will only provide cool and warm water, due to safety reasons.

Reservoirs

Quooker current product portfolio offers three different reservoirs, being the PRO3, the COMBI and the COMBI+, shown in image [3]. Functioning of the reservoirs is similar, although some provide extra features. Different Quookers are suitable for different house configurations, depending on the distance to the main house boiler or the presence of a kitchen boiler.

PRO3

The PRO3 is the smallest reservoir offered by Quooker, being able to instantly offer 3 litres of boiling water. This reservoir is suitable for homes where the distance to the main house boiler is not long and hence the warm water supply is relatively quick.

COMBI

The COMBI is a bigger reservoir, instantly offering 7 litres of boiling water. Alternatively, the COMBI is able to instantly offer up to 15 litres of warm water (up to 60 [°C]) by mixing. It does this by mixing cold water from the cold main water line with boiling water from the Quooker, through a dedicated mixing valve. This reservoir is a great solution for homes which do not have a dedicated warm water line and can replace dedicated kitchen boilers.

COMBI+

The COMBI+ is similar to the COMBI, being able to instantly offer 7 litres of boiling water. However, instead of instantly offering up to 15 litres of warm water (of up to 60 [°C]), it is able to provide unlimited warm water. The home needs to be equipped with a main house boiler. When the user requests warm water, the Quooker will combine boiling water and then cold water from the warm water line through the dedicated mixing valve, to instantly provide the requested temperature. As the water coming from the boiler through the warm water line heats up the ratio between warmer water and boiling water changes so that a constant temperature is dispensed. When the home boiler on its own provides the correct temperature the Quooker system will stop combining the now warm and boiling water.

Quooker CUBE

Besides providing boiling water, Quooker also offers a system that offers filtered and carbonated water. The CUBE system is installed next to the other reservoir. It uses a combination of two filters in order to provide pure water. Furthermore, the CUBE uses separate CO2 cylinders to dispense sparkling water. The CUBE does not need a separate tap but can be integrated into all-in-one taps.



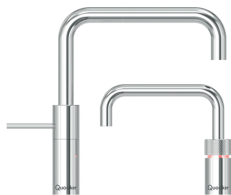
FUSION



FUSION SQUARE



FUSION ROUND



NORDIG SQUARE
TWINTAPS



NORDIC ROUND
TWINTAPS



NORDIC SQUARE
SINGLE TAP



NORDIC ROUND
SINGLE TAP



BASIC



CLASSIC



DESIGN



MODERN



PRO 3



COMBI



COMBI +



CUBE

image [3]

Installation

In principle, users should be able to install a Quooker themselves. This is also what Quooker aims for, by making all of the configurations directly available from their website, accompanied with installation videos. Furthermore, installation manuals are included with every Quooker order. This means that the installation does not require any specific tools and that specific knowledge is not required.

Quooker also provides the service of installing a specific configuration at home. For an extra fee the tap and reservoir are delivered and immediately installed. This procedure happens most often when a new system is installed in an older kitchen.

The last option is the installation of a Quooker by third-party servicemen, from e.g. a kitchen retailer or plumbing company. These servicemen must complete a specific installation course provided by Quooker themselves, to ensure that these systems are installed correctly.

Maintenance

The most common maintenance for Quooker is the replacement of the HiTAC filter inside of the reservoir. Over time this filter gets clogged and loses its functionality due to a build-up of lime inside. Quooker provides maintenance packages. These can be purchased by the user. However, when users do not feel comfortable maintaining the product themselves or when the system has other malfunctions, Quooker's own servicemen are called in. All warranty related issues are Quooker's responsibility, which is why it is decided to perform all maintenance and service with internal servicemen. This also gives Quooker the option to assess malfunctions, collect user data and refurbish malfunctioning systems.

C. Component analysis

Introduction

In some configurations (using COMBI and COMBI+ reservoirs) a Quooker is able to instantly provide warm water. Regular taps often take significant time to provide warm water, since all the lines towards the tap contain cool or cooled down water and warm water needs to be provided by the boiler, which can take time to heat up. By combining boiling and cold water warm water can be instantly dispensed from the tap. Quooker uses their own thermostatic valve to ensure a constant warm water temperature is dispensed, even when the main water line temperature is changing.

Working principle

The image on page 23 shows Quooker's current mixing valve with its out- and inlets and other functionalities.

The mixing valve has two inlets and two outlets. Inlet [1] is connected to the main water inlet. Depending on whether the a COMBI or COMBI+ is used and whether a main warm water inlet is available, this inlet is either used for the cold water inlet or warm water inlet from the main water line. Inlet [2] links the reservoir with the mixing valve and provides boiling water for mixing with the cold or cooled down water in order to provide warm water. The mixing valve is also equipped with two outlets. Outlet [3] is directly connected to the cold water inlet and supplies cold water to the reservoir. The other outlet [4] dispenses the mixture water to the tap. Besides these orifices the mixing valve has a turning knob which is used to set a predetermined temperature. This temperature is the maximum temperature that the tap will dispense in its warm mode.

Inside the main cavity of the valve a control slider is placed. This slider is controlled by both a thermostatic element and the knob visible on the outside. With the knob the user moves the slider to a specific ratio of warm and cold water. The thermostatic element inside of the knob makes small adjustments according to the temperature of the mixing water, ensuring its temperature to remain constant.

Thermostatic principle

As shown before, the current mixing valve has no external powersource to control the output mixture. However, it is still able to adapt itself when a temperature change occurs. Reason for this is the fact that the mixing valve is equipped with a thermostatic element. The thermostatic element is part of a device that controls the relative proportions of hot and cold water before the two mix with each other inside of the mixing valve. Varieties of materials for these elements exist, however they all function in a similar manner. The device inside the valve controls the amount of water it lets through for mixing. When the temperature changes, the dimensions of the thermostatic element change, altering the amount of water that is let through. A temperature increase leads to an expansion of the thermostatic element and more obstruction of the flow rate (because of a smaller orifice) which results in less water let through. A temperature decrease will lead to shrinkage of the thermostatic element, resulting in less obstruction of the flow rate (because of a larger orifice) and thus more water let through.

A different materialization of the thermostatic element and different internal mechanics can lead to different temperature ranges and mixing

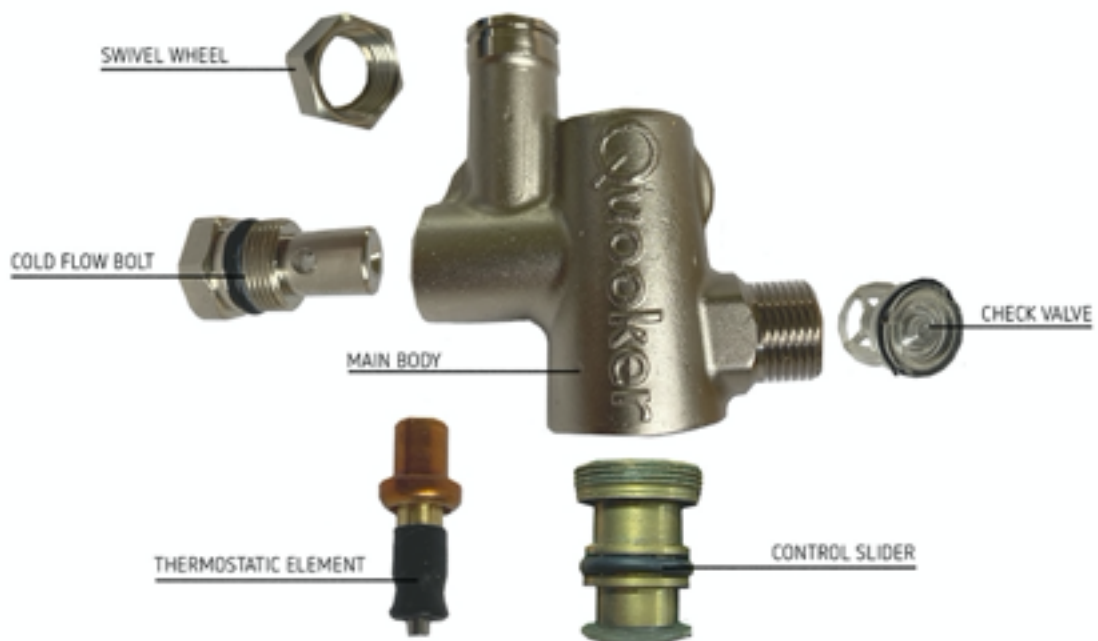
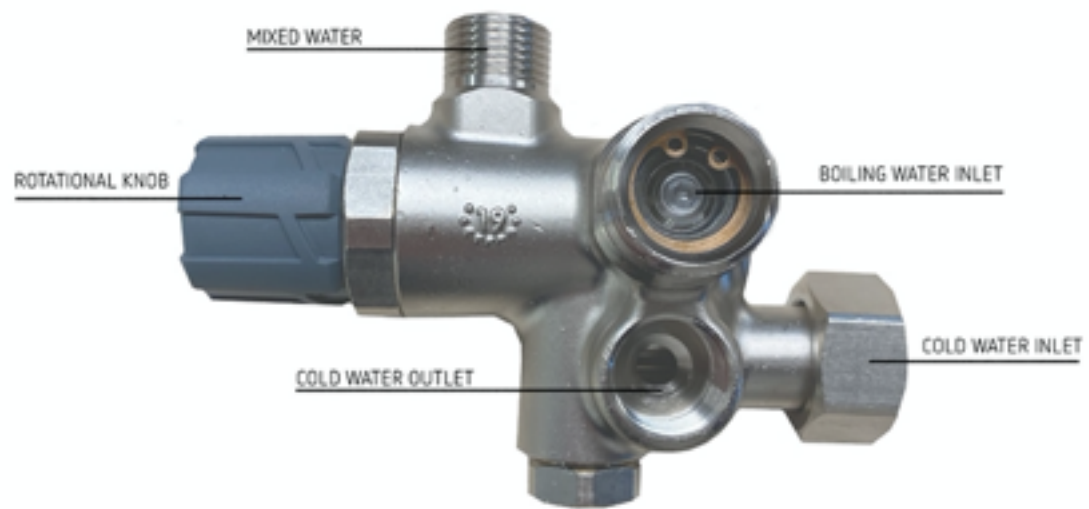


image [4]

behaviour, however the principle stays the same.

The most common material used as a thermostatic element is a wax, due to its phase change being around the typical temperature of warm water in households. This phase change results in a significant change in volume and is therefore more suitable for thermostatic purposes around this temperature.

Components and materialization

Quooker's current mixing valve consists of 13 parts, of which some are standard parts and some are produced specifically for Quooker. Some of the parts deemed most important and interesting are discussed here.

Main Body

The main body of Quooker's current mixing valve is produced out of brass, a copper alloy, CuZn33Pb1 to be exact. Brass is commonly used in water related applications (such as valves and fittings) due to its excellent corrosion resistance and machinability. The part is hot pressed. Although tolerances might not be optimal when hot pressing, this is not a big issue, since the body is machined afterwards. Using machining all of the cavities that allow the water to flow are created and connected. Furthermore, during the machining inner and outer threads are created to connect a variety of other internal parts or hoses. Using machining, narrow tolerances can be achieved only on the parts where needed, reducing the overall processing costs. After the part is machined it is electrolytically plated with nickel (around a 15-20 micrometer thickness). By plating the part with nickel the wear resistance, hardness and protection against corrosion of the surface significantly improve. Although nickel plating has great benefits, it does raise a health concern, since it is deemed carcinogenic by the WHO [5]. However, it is essential to increase the parts properties. Furthermore, by using a relatively thick layer or plating the nickel molecules stick together and the layer becomes less porous, minimising the release of molecules into the drinking water.

Control slider

The control slider consists of two parts, a body and a O-ring to securely position and close the slider inside of the cavity. Similarly to the main body, the control slider's body is produced out of brass, just with a slightly different ratio of components (CuZn36Pb2As). The slider is produced in a similar manner to the main body, first being hot pressed and then machined all around to ensure the right tolerances. Machining is crucial for this part, since it has extremely narrow slots that control the water flow. The part receives an identical nickel coating, just slightly thinner (around 12 micrometers). By using almost the same materials, problems are unlikely to occur during heating up and cooling down of the valve, since both materials have a similar thermal expansion rate. This to ensure that the slider will always freely slide.

Thermostatic element

The thermostatic element, responsible for slight translations of the control slider, is a part bought from an external supplier (Vernet). This part is not specifically designed for Quooker, but used in a wide variety of

thermostats. Held in place by various springs, the element is only able to slightly expand in one direction.

Check valve

The check valve is another part bought from an external supplier but however essential for the correct functioning of the product. This valve is placed on the boiling water insert and ensures that water will only be able to flow out of the top of the reservoir. The housing and pivot are all produced out of PSU (Polysulfone). Definitely not being the cheapest option, PSU has some specific characteristics that make this check valve suitable. It remains having high stiffness and strength through a temperature range of -100 to 150 [°C], making it a suitable check valve to function with cavities involving boiling water.

O-rings

The mixing valve is equipped with several O-rings, to minimise the change of leakage during use. All of these O-rings are produced out of EPDM (ethylene-propylene-diene-monomer). Main motivation for using EPDM is its excellent resistance to water and high temperatures (temperature range of -50 to 150 [°C]). This makes the material suitable for being in contact with boiling water, which is inevitable within the Quooker system.

The mixing valve is one of the parts that is not assembled in-house, but by an external company. To ensure proper functioning of the valve they are tested in an air leakage test. Two tests are performed. The check valve is tested at 1 bar with a flow rate of < 99,99 cc per minute, whilst the full assembly is tested at 3 bar with a flow rate of < 2,5 cc per minute. Performing air tests is preferable, since they are more critical than water tests, due to the viscous nature of water. Therefore, a product that succeeds in an air test is extremely unlikely to fail a water test.

Assembly Installation and service

Through following a Quooker B.V. serviceman during a day of maintenance, information regarding the installation and maintenance of the mixing valve is obtained. This information has shown some potential points of improvement. For now the configuration uses a variety of connections and hoses, which is perceived as confusing. Especially within a smaller, cramped kitchen cabinet this can lead to potential uncertainty, delaying the installation procedure.

Maintenance is currently (almost) never performed on mixing valves. When one is malfunctioning it is often replaced by a new model. Returned valves are then not repaired but recycled. Due to the relatively low costs of a mixing valve repair is currently not deemed interesting for Quooker B.V.

Performance

Within Quooker B.V. several tests have been conducted to check performance specifications of the current mixing valve. The time for both increases and decreases of the requested dispensed temperature have been recorded. Data regarding these tests is shown in table 1.

Initial temperature (°C)	Desired temperature (°C)	90% of change (t)	100% of change (t)
20	65	3.5	11
20	35	5	5
65	20	3.5	8

table [1]

Besides this information, several tests have been performed to evaluate the flow rate of dispensed water at different temperatures for different taps. These values may differ since taps may have a different internal architecture, resulting in different flow rates. These tests were performed at different pressures. All of the flow rates are from taps connected to a COMBI reservoir, because this system uses the mixing valve. Table 2 presents the flow rates in litre per minute at a pressure of 2,5 [bars] which is the typical main line water pressure at ground level in Dutch households. This table also includes the flow rate of boiling water, when applicable. Although boiling water does not use the mixing valve, it can still provide some insight into the flow rate of boiling water that enters the mixing valve. The Nordic tap is similar to a conventional tap and is included to show the difference of Quooker systems with a normal tap. This tap has only been tested with cold water.

Type of tap	Cold water (16°C)	Warm water (35°C)	Warm water (55°C)	Boiling water (100°C)
Flex	6.7	5.3	5.6	3
Fusion	6.1	4.9	5.3	3
Nordic	7.7	-	-	-

table [2]

Proof-of-principle prototype

Within Quooker B.V. a proof-of-concept for an electronic mixing valve has already been developed. This concept is created to show the feasibility of the idea of electronic mixing, focusing on the principal functionality. Logically, this concept will serve as one of the starting points for further development. Therefore an extensive analysis of this proof of concept is performed, considering its improvements and benefits.

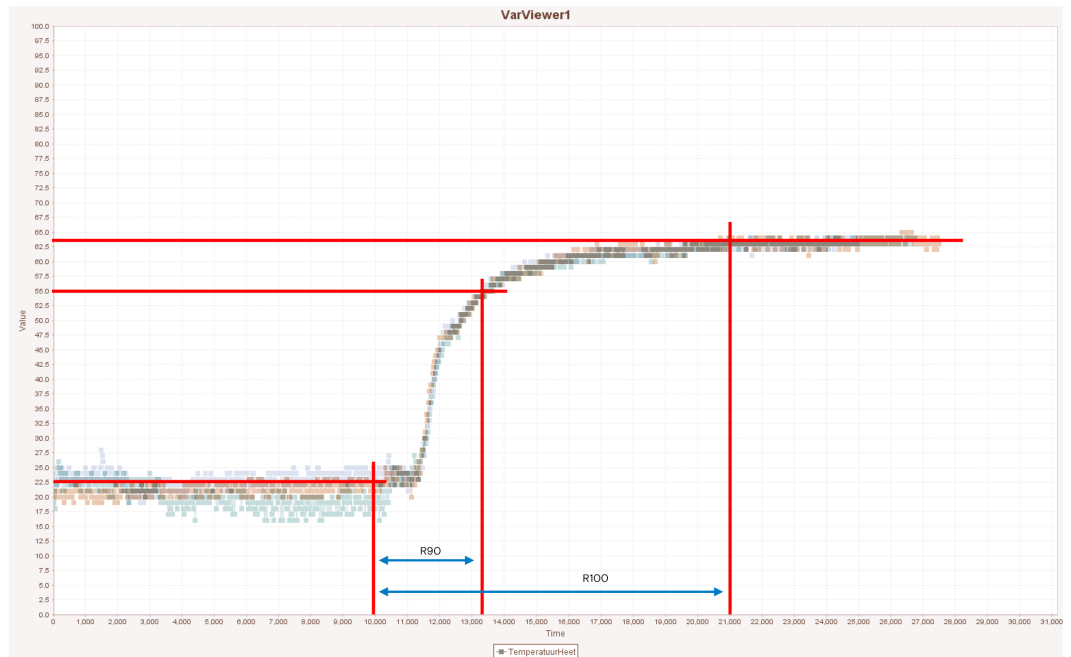
Working principle

The current PoC uses two valves which each control one of the inlets. This means that there is one valve dedicated to the control of cold water and one dedicated to the control of boiling water. With these two valves the output temperature and flow can be controlled. By adjusting the ratio between the two valves the temperature changes. Altering the opening distance of the valve changes the output flow.

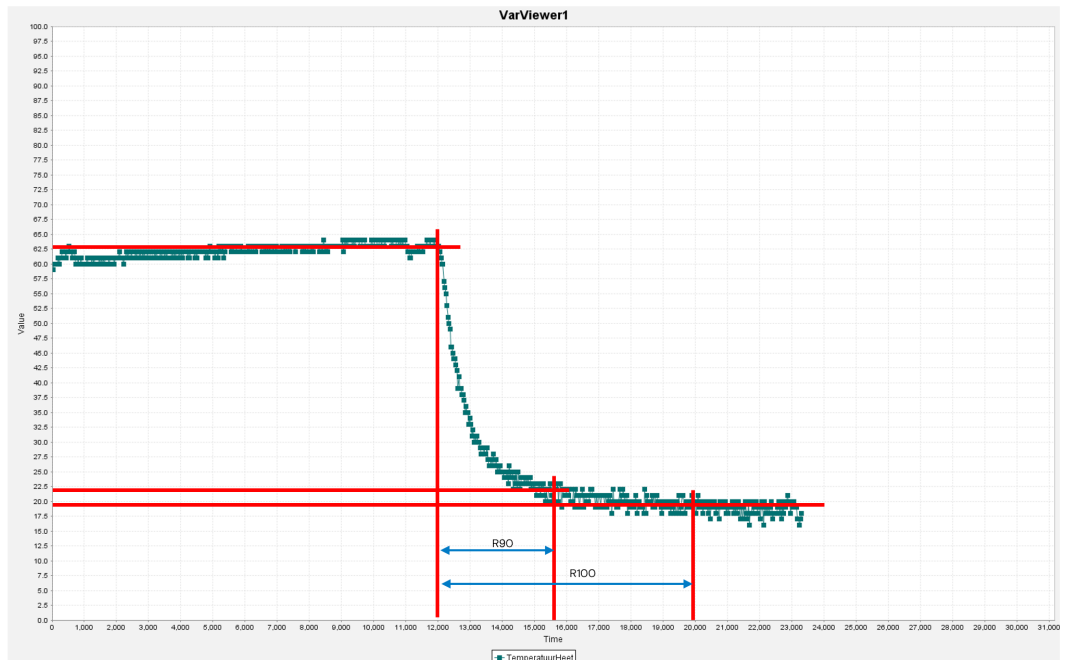
Both the valves are connected to different channels, which come together in the 'mixing zone'. The temperature of the combined flow is then measured by a temperature sensor. This temperature sensor provides feedback for the control of the valves. This feedback is interpreted into change in behavior for one or both of the valves, ensuring a constant temperature.

The PoC is relatively simple, consisting of 5 different parts. Each of these

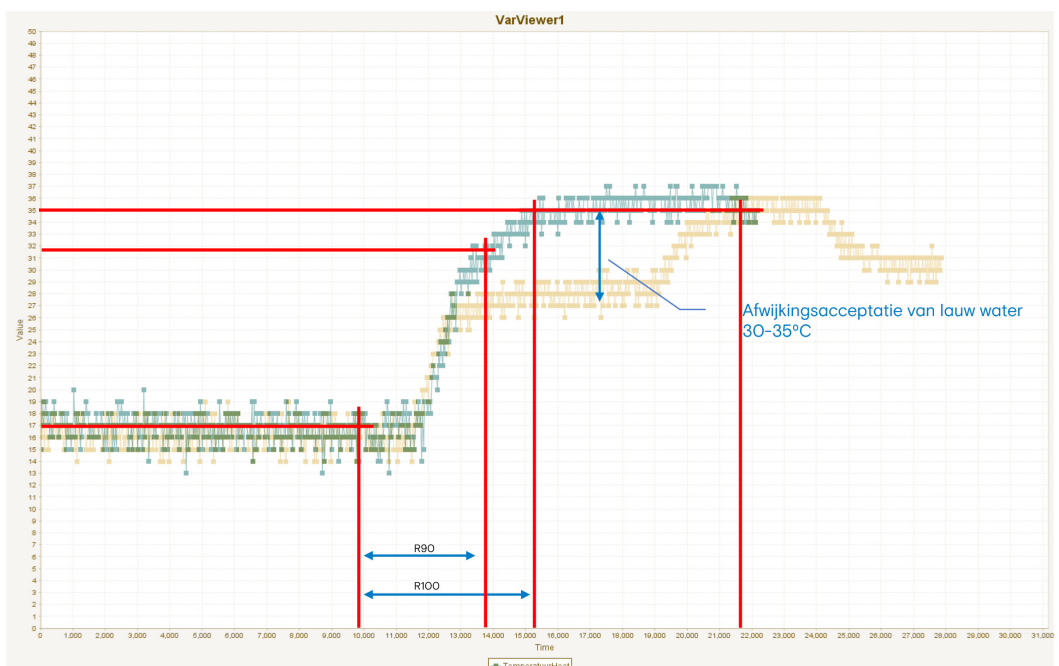
Mechanical
mixing valve
from 20 degrees
Celsius to
65 degrees
Celsius. 90% is
reached in 3.5
seconds, 100%
in 11 seconds.



Mechanical
mixing valve
from 65 degrees
Celsius to
20 degrees
Celsius. 90% is
reached in 3.5
seconds, 100%
in 8 seconds.



Mechanical
mixing valve
from 20 degrees
Celsius to
25 degrees
Celsius. 90%
is reached
in 4 seconds,
100% in 11.5
seconds.



Components

parts will be discussed below.

Main body

Everything in the PoC is connected to the main body. This is where the liquids combine. The body has several orifices. One for each of the water inlets, one for each of the valves controlling these inlets. Furthermore, the main body has an outlet for the mixture water as well as a small orifice in which the temperature sensor is located. The body is machined out of brass.

Proportional solenoid valves

The concept is equipped with two proportional solenoid valves. These proportional valves control the flow within the channels. These solenoids have a body produced out of Polyamide reinforced with glass-fiber [7]. The part is sealed in place with the aid of EPDM O-rings. Minimum operating temperature is indicated as being 25 [°C]. Maximum operating temperature is indicated as being 90 degrees, in which the valve is warranted to function 3-5 minutes. Typical operating temperature is indicated at 60 [°C]. Furthermore, the flow rate range of the valve is 0.5 up to 10 liters per minute. Lastly the burst pressure, which is the pressure at which the valve would fail is indicated to be at least 80 bar (Eki, 2020). A major advantage of using solenoid valves is the fact that these will automatically close themselves in case of a power outage. This means that the flow would automatically stop when a power outage occurs, which would be the most safe.

Compression swivel

For correct fastening of the cold water line a compression swivel is used. This is a standard part used for this connection.

Temperature sensor

A small temperature sensor is screwed into the main body. This temperature sensor is a thermocouple. It will produce a different voltage at a different temperature. Differences are interpreted as a specific temperature.

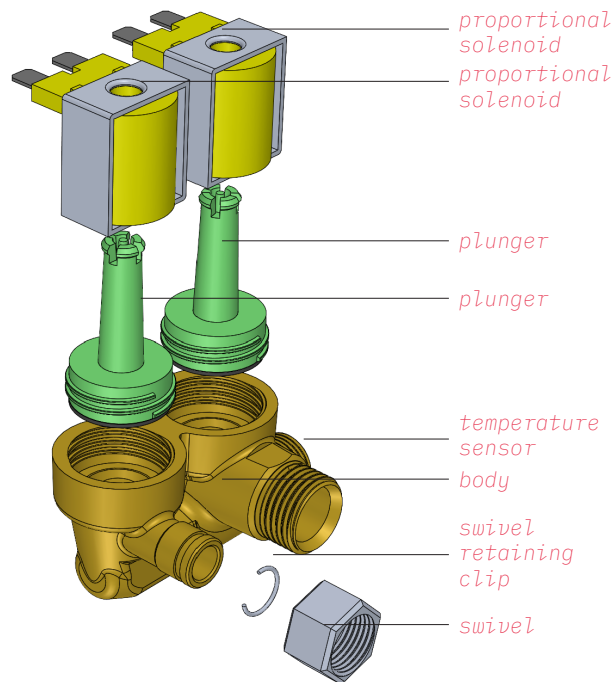


image [5]

Insights

Some initial tests regarding the behavior and performance of the PoC have been performed. The most significant test has been an analysis of the time it takes to change the dispensed temperature from one predetermined setting to another. The obtained data is shown in table 3.

Initial temperature (°C)	Desired temperature (°C)	90% of change (t)	100% of change (t)	Response time (t)	Adjustment time (t)
20	65	3	5	1.5	3.5
20	50	5.5	6	2	4
20	35	3.5	6	2.5	3.5

table [3]

In comparison to the data shown in table 2, one can see that the changing time of an electronic mixing valve is about 50% quicker than the current mechanic valve, which is promising. Furthermore, combined changing time seems to be relatively constant and independent of the difference in temperature. Even the response and adjustment time on their own appear to be relatively constant and independent of the change in temperature. Even though the performed test gives great insight into the initial behavior of the current electronic mixing valve, new tests are proposed.

One important flaw to notice from these tests is the fact that the flow rate has not been measured and is therefore unknown. It is expected that the flow rate has a significant impact on both the response and adjustment time of the system. For now, a hypothesis is that the response time is the time that it takes the water that has already passed the mixing valve but not yet been dispensed to be dispensed from the tap. This water has still

been mixed according to the previous setting, or has been sitting in the tap. A high flow rate is expected to reduce the response- and adjustment time of the dispensed water. A lower flow rate however is expected to reduce the total amount of water that does not yet have the desired temperature, since all of the water at different temperatures will have more time to mix inside of the tap. Flow rate could therefore be a significant value, not only relating to performance but also to the user. What is a desirable dispense rate for water at different temperatures?

The data obtained from this new test is shown in table 4.

Initial temperature (°C)	Desired temperature (°C)	90% of change (t)	100% of change (t)	Response time (t)	Adjustment time (t)	Flow rate (l/m)
10	40	2.5	5	1.5	3.5	± 6.8
10	40	12.5	15	6	9	± 1.5
40	10	2.5	5	1.6	3.5	± 6.8
40	10	8.5	10	2.5	7.5	± 4.0

table [4]

From the data one can conclude that the flow is of significant influence on the response and adjustment time of the water. With a lower flow it takes significantly longer to reach the desired temperature. This is expected to be caused by the water that has already passed the mixing valve but is not yet dispensed. When the mixing valve adjusts itself, this water first needs to be dispensed before a change in temperature will be measured. This so called 'dead water' has a significant impact on the performance of the system. Combining the flow rate and change time, the volume of dead water in the system can be calculated. This data is shown in table 5.

Initial temperature (°C)	Desired temperature (°C)	100% of change (t)	Volume (l)	Flow rate (l/m)
10	40	5	± 6.8	0.6
10	40	15	± 1.5	0.4
40	10	5	± 6.8	0.6
40	10	10	± 4.0	0.6

table [5]

One can conclude that the volume of dead water is relatively constant at around 0.6 liters. This volume depends on the type of faucet and the length of the connections from the mixing valve to this faucet. At the lowest temperature a lower volume was noted. This could indicate that using a lower flow rate will allow for more conduction between the water of different temperatures. The dead water already heats up somewhat in the faucet due to conduction from the hot water just leaving the valve. This could be an interesting lead, although a flow rate of 1,5 liters per minute is quite low.

Performance longevity

Introducing new moving parts into the electronic mixing valve immediately raises the question of longevity of the new concept. During testing so far the concept appears to be functioning fine. However, in such a short time the impact of time on its functioning cannot yet be determined. Factors such as material deterioration have not been introduced or researched. This requires a thorough and extensive analysis as well as use case experiments to gain more insight in the product's long term.

Material and production

The current PoC prototype has been milled out of brass, without any specific coatings. Due to the lead content in the brass the dispensed water is generally presumed not safe to drink. This could potentially also be one of the reasons that the Quooker's current mixing valve has a plated coating. Furthermore, specific materials may encourage a significant build-up of limescale which could influence its functionality.

Installation

Orientation of all of the connections on the proof-of-concept differs from those on the original mixing valve. Hypothetically, the orientation on the concept looks preferable, since no connections are out of sight. Unclear separation however can also lead to mistakes as an undesirable consequence. Furthermore, depending on the location of the reservoir in regard to the faucet connection, the current setup might lead to more confusion. Lastly, the potential space claim of the mixing valve and connected lines could be too big for kitchen cabinets.

Connections

The current mixing valve uses screw-on connections. For testing purposes the electronic mixing valve uses exactly the same connections as the current valve. These connections are fastened using tools common to plumbers and servicemen.

Flow behaviour

Flow behavior could be significant for aspects such as limescale and listeria control and an even distribution of temperature along the mixed water. Currently the mixing behavior the valve has been tested through temperature differences. However, flow inside of the valve itself remains unknown. Insight into this flow behavior could help develop better behavior and less build-up of material, which would increase the lifespan of the product.

Integration of components and design

The current PoC uses a separate electronic module, however this component is not yet integrated into the part. An integrated part would result in a cleaner and easier installation, but would require a more complex housing.

Leakage

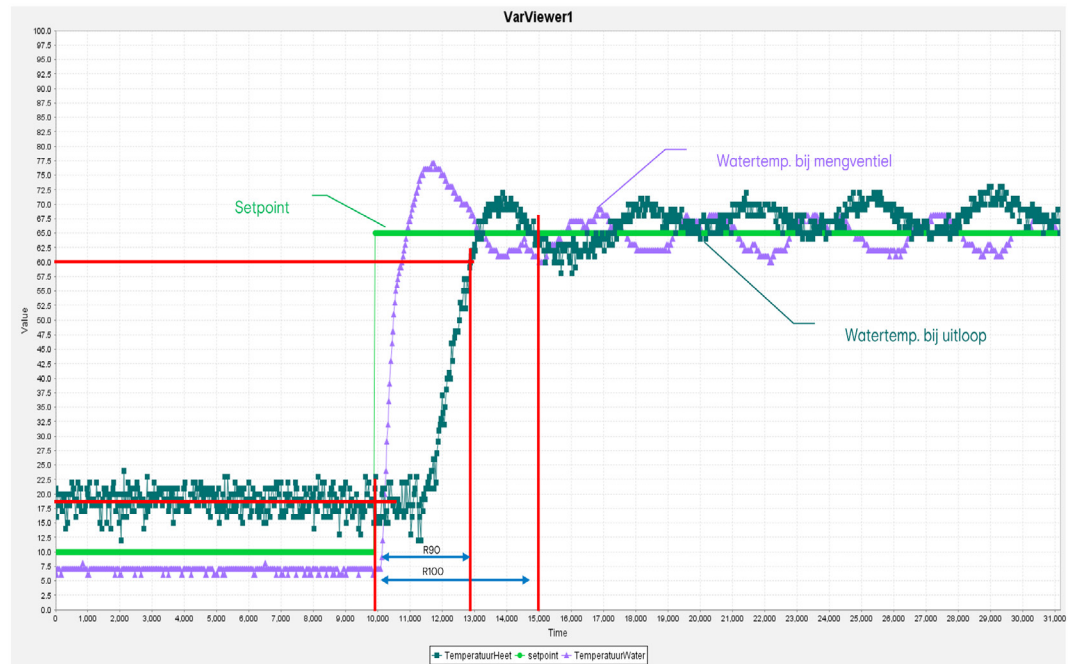
The current PoC appears to not leak when testing. However, more critical situations still need testing. Potential leakage relates to other analyses, such as the connections, material and flow behavior. The new electronic mixing valve uses components, materials and configurations yet unknown to the company. Therefore new leakage tests are important.

Power supply

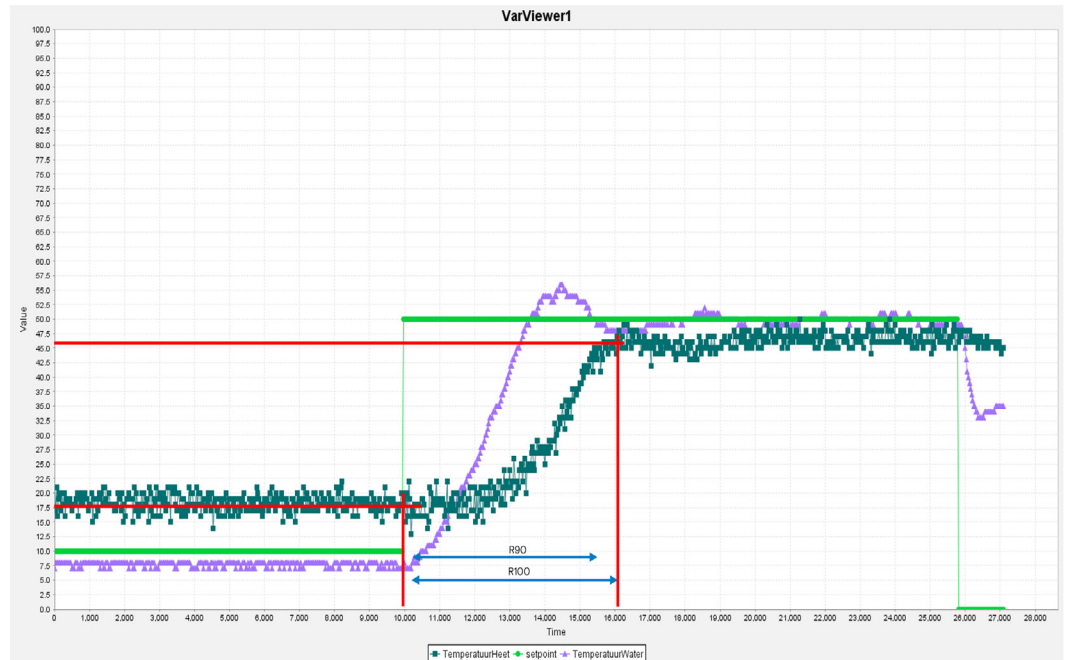
Quooker B.V.'s mixing valve works according to a thermostatic principle and does not require an external power source. An electronic mixing valve will include controlled actuators, which need a power source. The PoC

makes use of valves consuming 9 Watt each, as specified by Quooker B.V. Quooker's reservoirs are able to deliver a power of 12 Watt, (12 Volt, 1 Ampere), which is too low for the current PoC setup.

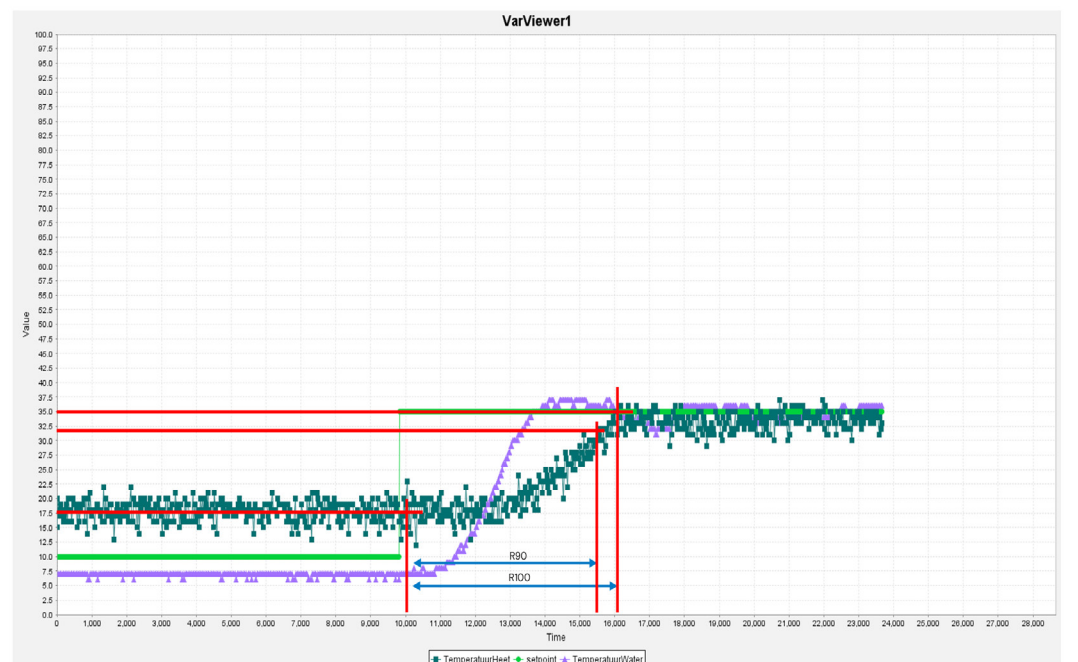
Electronic
mixing valve
from 20 degrees
Celsius to
65 degrees
Celsius. 90% is
reached in 3
seconds, 100%
in 5 seconds.



Mechanical
mixing valve
from 20 degrees
Celsius to
50 degrees
Celsius. 90% is
reached in 5.5
seconds, 100%
in 6 seconds.



Mechanical
mixing valve
from 20 degrees
Celsius to
35 degrees
Celsius. 90% is
reached in 5.5
seconds, 100%
in 6 seconds.



D. Mixing

One of the corner stones of a mixing valve is the fact that it mixes. In order to properly design a new mixing valve, one should first thoroughly understand the principle of mixing.

Mixing

Mixing is defined as manipulating a heterogeneous system with the goal of it resulting in a more homogeneous system. By mixing the system is agitated and transfers (mass and/or heat) between different components within the system occurs [8].

As stated before, the core feature of a mixing valve is the fact that it is able to combine incoming liquids. It is desirable for this output to be of a uniform temperature and flow, with predictable behavior. Not only does this lead to a better ability to correctly measure variables by sensors, but it also would result in a generally more stable system.

It is desired for the dispensed flow to be as uniform as possible as quick as possible after the mixing of water at different temperatures. Sensors that could potentially be located within the mixing valve would then have a higher chance of measuring correct data. Significant temperature changes within the flow of water would mean that a temperature sensor might sense a temperature that is different from the total combined temperature of the flow intersection, as is shown in image 6.

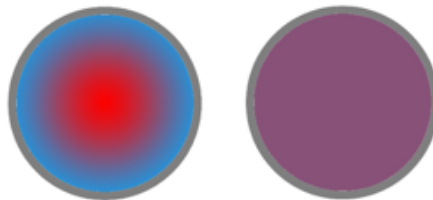


image [6]

One important factor to note in the mixing valve system is the fact that it is a pressurized system. Behavior of fluid in unpressurized systems is quite straight forward. The implications of a pressurized system need to be tested through simulations and real life experiments. Furthermore, all of the assumptions and hypotheses stated here are based on theoretical knowledge. This is great for initial insight, however in order to be certain more testing is essential.

Heat exchange

Although the water may be at different temperatures, it is the same material. The transferring of energy between different temperatures is identified as being conduction. One aspect to note is the fact that both the liquids are moving along a channel at a certain velocity, which could influence the temperature exchange behavior. For now this should not matter, since the situation is analyzed on a fundamental level.

The equation describing energy exchange through conduction can give great insight into the variables that matter for optimization.

$$q = (k / s) * A * dT$$

In this equation q describes the conductive heat transfer in J/s. For the mixing behavior it is desirable to have a high value for q , since this

would mean the heat exchange is quicker. The variable k is the thermal conductivity of the specific material. This variable is temperature dependent, although because of the small temperature range in the mixing valve this is deemed not significant for the equation. This is also a value that cannot be changed, since the boiling water input will be (close to) 100 [°C] and the cold water input will be the main water line temperature (10-15 [°C]). Table 6 shows the different thermal conductivity coefficients at these temperatures [9].

Temperature (°C)	Thermal conductivity (W/(m*K))
10	0.579
99.6	0.677

table [6]

The variable s considers the thickness of the material. The way it is positioned in the equation indicates that a higher thickness of the material would lead to a slower heat transfer.

The variable A indicates the heat transfer area. In this case it would be the ‘contact area’ between the different water temperatures. Increasing the contact area between the different water temperatures would result in a quicker heat transfer.

The last variable is dT , describing the difference between the two temperatures. A higher temperature difference would thus lead to a quicker heat exchange. However, the total amount of energy to be exchanged (to reach a uniform temperature) would then also be higher. Therefore, a higher temperature difference would not indicate a shorter mixing time, or vice versa. In the context that this equation is used currently the dT can be treated as a constant, since the boiling and cold water temperatures are set outside of the boundaries of the mixing valve. Although the equation is an extreme simplification of reality, it does give some insights into variables that can be changed in order to improve mixing behavior, namely the “thickness” of the material and the “contact area” between the two different temperatures. Some research and insights regarding these two variables are discussed here.

Improving the heat exchange area

Different variables are expected to influence the heat transfer areas. These will be discussed here. This discussion provides some initial insight into what might be interesting for further research.

Density of water at different temperatures

Depending on the temperature of the water, a different density may be applicable. Table [7] shows the density at different temperatures [9].

Temperature (°C)	Density (kg / m3)
10	999.7
99.6	958.4

table [7]

The table shows a significant difference. This results in separation of

layers. The water with a higher temperature will rise or stay at top of the stream, since it has a lower density. Colder water would sink or remain at the bottom of the flow since it has a higher density. This difference in density could be used as an advantage to increase the contact area between water at different temperatures. Orientation and location of inlets could thus be of influence on the mixing time. Image 7 illustrates possible adjustments.

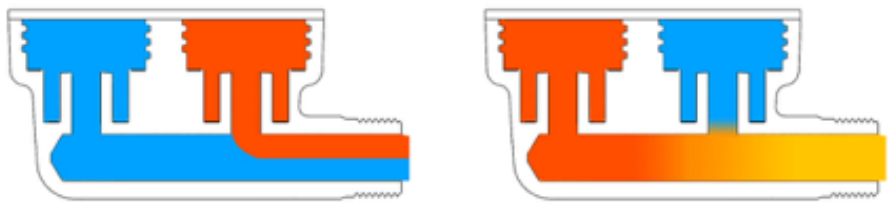


image [7]

Viscosity at different water temperatures

Mixing hot and cold water is not as straightforward as it seems, multiple variables play a role in its mixing behavior. Since water (like all fluids) has a different viscosity at a different temperature, the order of mixing could influence the mixing time.

Table 8 shows the viscosity of water at the two different input temperatures.

Temperature (°C)	Viscosity (mPa*s)
10	1.32
99.6	0.28

table [8]

Although both viscosity variables are deemed low, there is a difference between the two which could be optimally used to control mixing behavior. D.S. Dickey (20150835) states that adding a high viscosity liquid to a low viscosity liquid is usually preferable when mixing. This is motivated by the fact that a low viscosity liquid is more likely to become turbulent, which would increase the dispersion of the high viscosity liquid.

Turbulent and laminar flow

Whether the different water flows are in a turbulent or laminar flow is expected to be of influence on the mixing behavior. In a laminar flow the molecules flow in smooth paths along specific layers and hardly interfere with the adjacent layers. These layers may differ due to amongst others different energy of molecules or different densities. This minimal interference means minimal mixing of the layers. This is undesirable within the mixing valve, since maximum mixing of the layers would result in a quicker uniform temperature amongst the flow. Therefore, a turbulent flow would be preferable.

Within a turbulent flow there are chaotic changes in velocity and pressure amongst the flow, resulting in more disturbance of the different layers and hence a more uniform temperature amongst the layers.

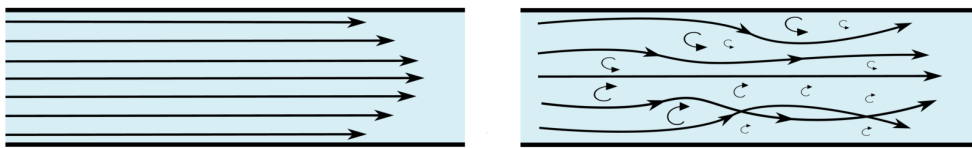
A turbulent flow would thus be preferable. Examining the equation which determines the Reynold's number Re of a flow gives us insight into variables which could potentially be changed to influence the flow's

behavior. This equation is presented below.

$$Re = \rho \cdot v \cdot l / \mu$$

Increasing the Reynold's number leads to more likeliness of a turbulent flow. Three different flows are identified. Besides the turbulent and laminar flow a transitional flow is identified. Within the transitional range the flow may be turbulent or laminar. The different ranges and the according values are shown in image 8.

image [8]



The variable ρ describes the density of the fluid. This variable cannot be changed, due to the fixed type of fluid (water).

The variable v describes the flow speed of the liquid in m/s. An increased flow speed results in more likeliness of a turbulent flow.

The variable l describes the flow length. The equation shows that a longer flow length is more likely to result in a turbulent flow, due to shearing resistance on the borders of the flow.

Variable μ describes the viscosity of the fluid. With set temperatures for both inputs this variable could be considered constant in this context.

E. Competitor analysis

The landscape of companies offering boiling water solutions has been ever expanding since the introduction of the Quooker. The patent on the idea has expired, which allows other faucet and boiler producers to introduce their own instant boiling water solutions.

Analysing these competitors and alternative systems can give great insight in the potential of the solution and different approaches to the problem. For this reason the benefits, downsides and interesting matters are explicitly noted below.

IthoDaalderop

IthoDaalderop does not offer an electronic mixing valve or similar solutions, but does have an interesting configuration of its mixing valve. The company's system consists of three different components: the tap, the reservoir and the so-called 'Easy-Box' (image 9). The Easy-box combines a mixing valve, overflow valve and filtration into one box. Benefit of the system is the reduction of different components inside of the kitchen cabinet. This allows for a quicker overview and less connection lines between components. Downside of this configuration however is the fact that the Easy-Box itself is of considerable dimensions (200 mm in depth and width, with a height of 400 mm), which is less flexible than separate components within the limited space of a kitchen cabinet. Furthermore, connections for all of the different lines are in close vicinity of each other and it is not clear which connection belongs to which internal component. A manual is necessary during installation and confusion might occur. Another downside is the fact that when one of the components within the Easy-box fails, the whole box needs replacement. Nonetheless, it does result in a 'cleaner' and clearer kitchen cabinet [10].

Moen

Although not yet available to customers, Moen offers a tap that is claimed to be able to dispense a predetermined amount of water at a predetermined temperature. It is to be expected that this tap, the 'U by Moen Tap' shares its working principle with the 'U by Moen shower'. Just like the tap this shower control unit is able to control the amount of water dispensed and the temperature of this water. This system makes use of the 'U by Moen thermostatic valve'. This valve is depicted in image 9. The valve makes use of spindles connected to stepper motors. These spindles have a conical component at their end which controls the flow of a particular inlet, by translating towards and from this inlet [11].

Blanco

Blanco offers both boiling water taps and dispensing predetermined amount of water, just not at the same time in the same system. It is able to do this through its 'Dynamic Flow Control System', which is an electronically controlled mixing and proportioning valve. The valve is able to dispense amounts of 100 to 5000 ml. The Blanco valve is depicted in image 9. The system makes use of two flow sensors, a solenoid valve and a stepper motor. It is expected that the solenoid valve, in combination with the different flow sensors, is responsible for proportioning of the dispensed water. The stepper motor is responsible for controlling the ratio between warm and hot (not boiling) water [12].

Grohe

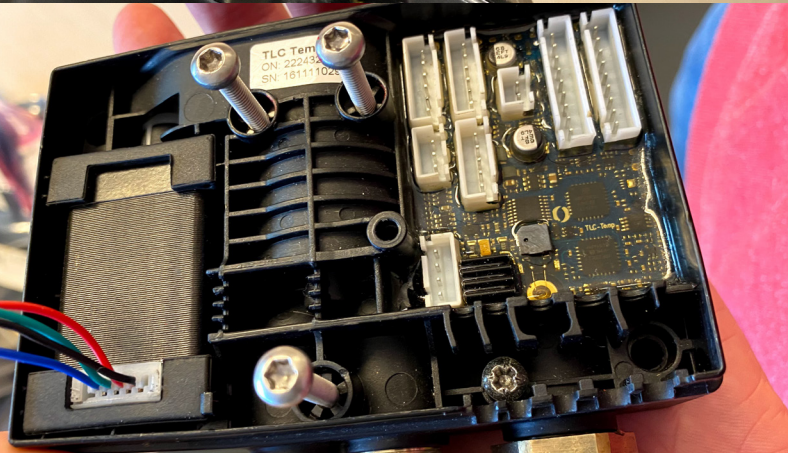
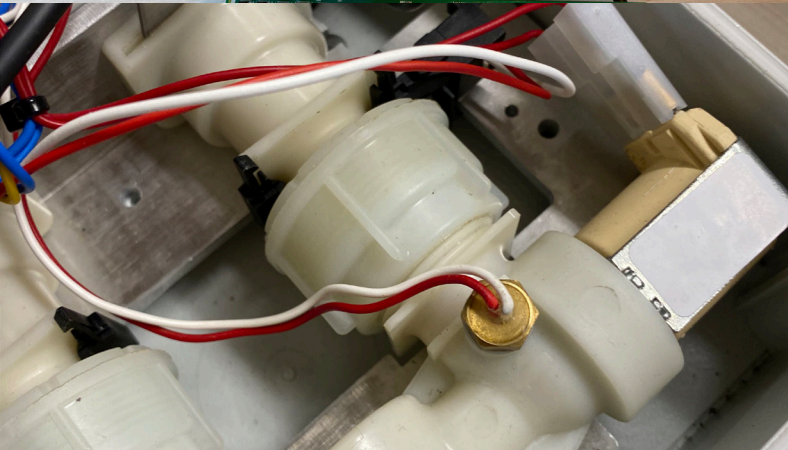
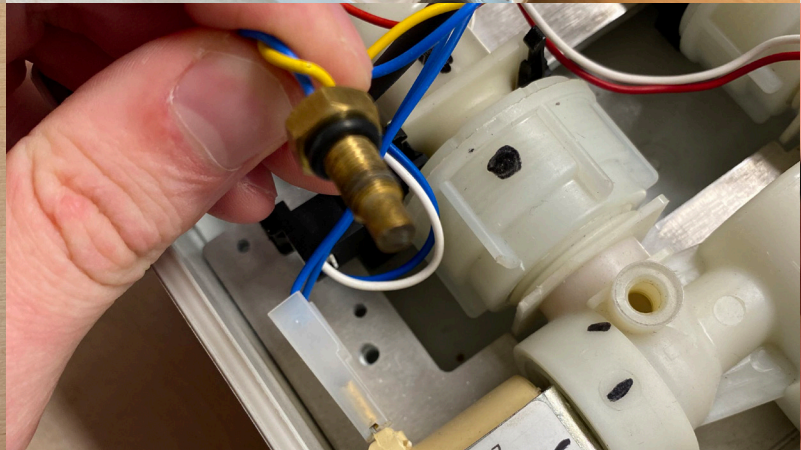
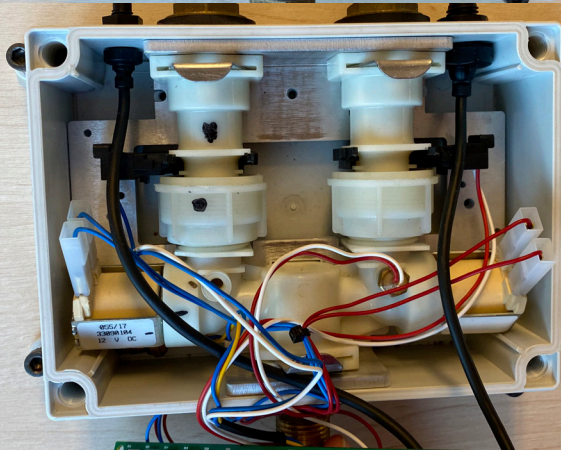
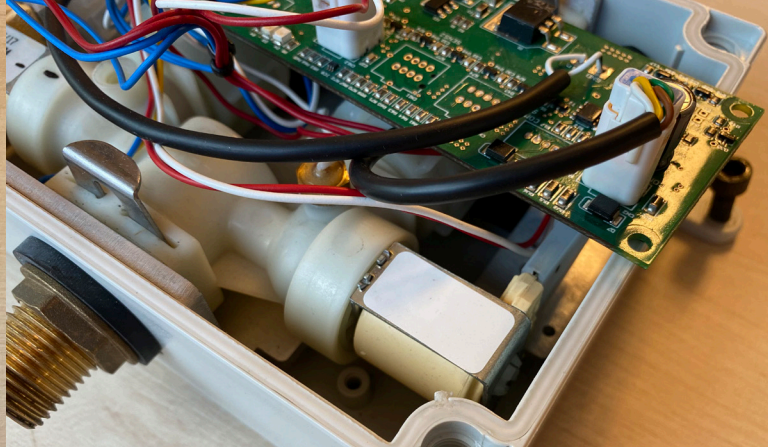
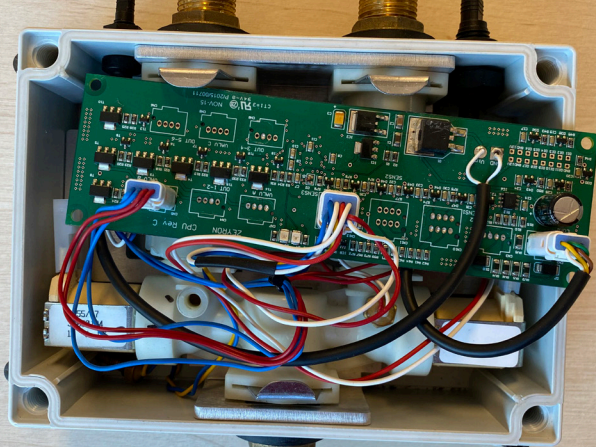
Initial research performed within Quooker already has shown that Grohe already makes use of an electronic mixing valve, as shown in image 9. The mixing valve controls the flow of two different chambers (hot and cold) through the rotational actuation of cartridges inside of these chambers. The valve comes with a temperature sensor connected to the outlet of the mixing chamber. The PCB as well as both the stepper motors are casted into resin to create a waterproof entirety. Interesting to note is the fact that the valve has a clear location in all of Grohe's presented configurations. The valve is placed within the kitchen cabinet, but as close as possible to the tap's outlet. Analysing Grohe's user interfaces which work with the valve, one can see that these do not offer specific temperature setting, but more a change of temperature to warmer or colder from the initial temperature [13].

Sedal

Although not a producer of taps, Sedal offers technical solutions for the functionality of taps. They produce different types of cartridges for regular faucets, but also offer an electronic mixing valve, which is shown in image 9. This valve is equipped with multiple temperature sensors and flow sensors. It measures the flow and temperature for both lines coming in, but does not measure after the two have mixed. The flow sensors appear to be relatively small. Proportional control of flow of different water inputs is done with the aid of proportional solenoid valves. Using a Sedal valve the user should be able to set temperature and flow to a predetermined value [14].

Oblamatik

Similar to Sedal, Oblamatik does not produce their own taps, but are responsible for the technology inside of some other parties's taps. They offer a variety of mixing valves, which they have developed in collaboration with Flüh's, a Swiss supplier of cartridges. Like the Moen valve, they make use of stepper motors to control the ratio of different temperature water. However, Oblamatik uses just one stepper motor which controls an archetypical cartridge. Just like a normal faucet handle, moving the handle will result in changes in the cartridge which result in a different ratio. Benefit of this system is the fact that only a single stepper motor is needed. The Oblamatik does not offer flow control [15].



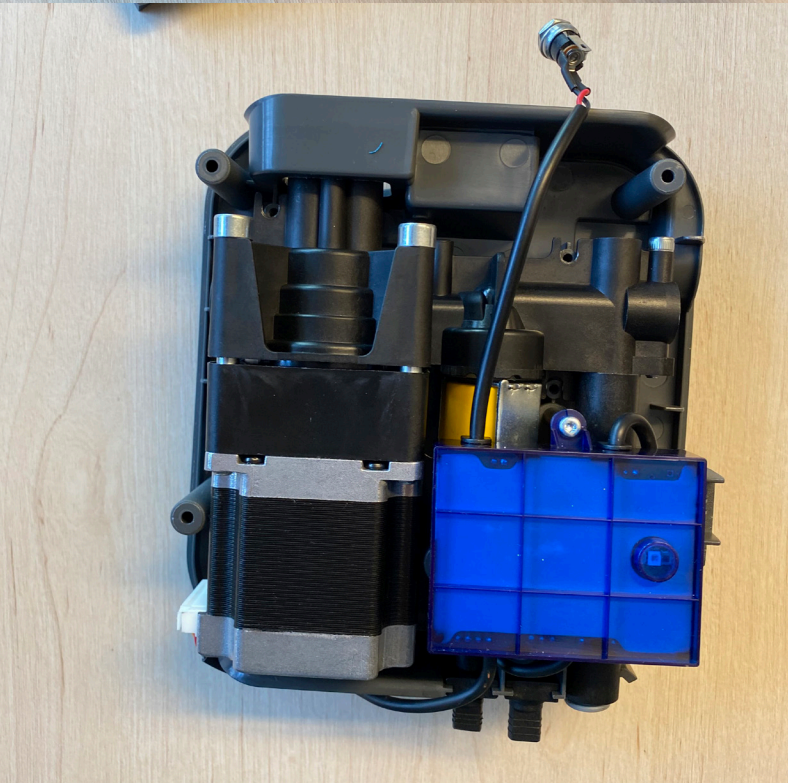
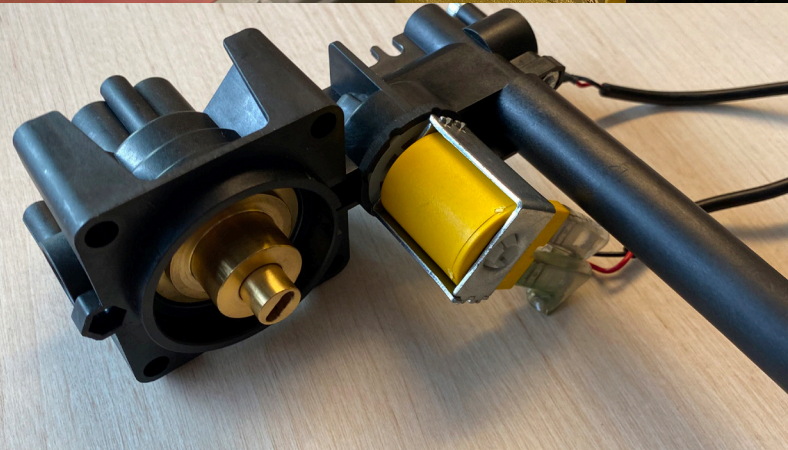
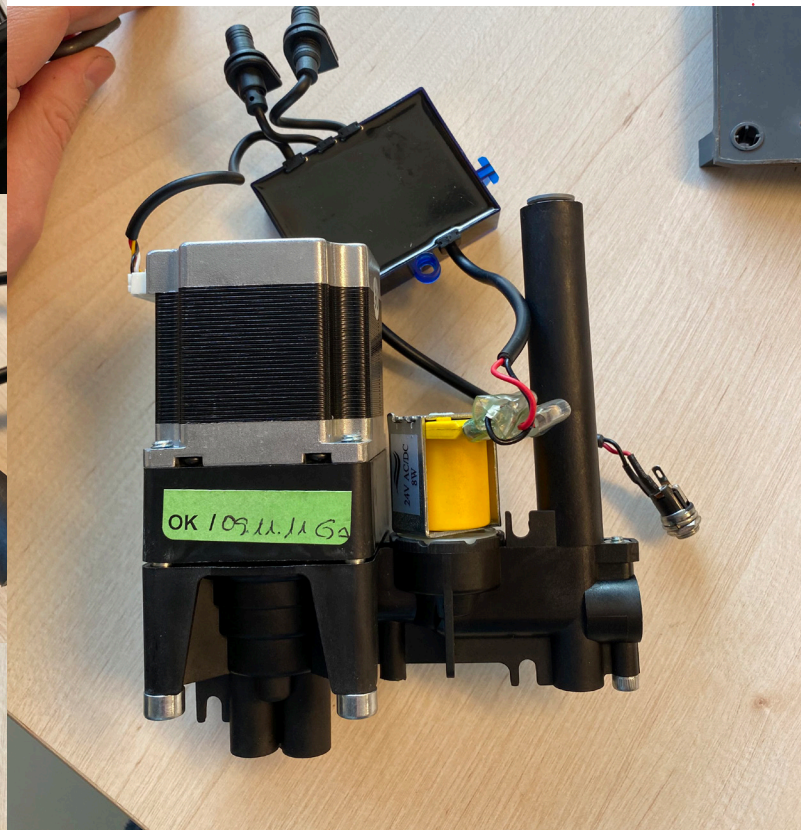
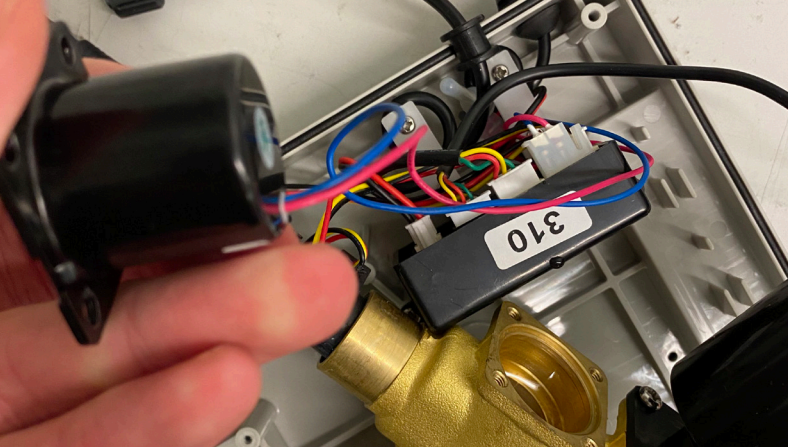
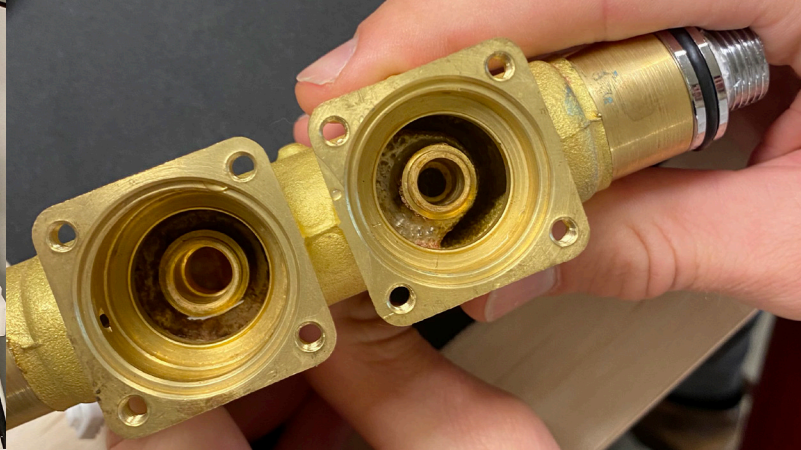
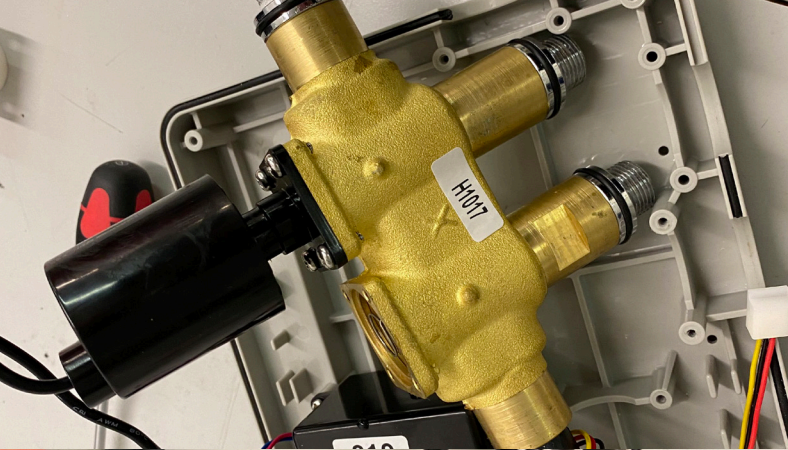


image [9]

Images top left: Sedal electronic mixing valve

Images middle left: Grohe mixing valve

Images bottom left: Oblamatik mixing valve

Images top right: Blanco mixing valve

Images bottom right: Miscea mixing valve

F. Patents

In order to research different working principles with similar applications as the concept proposed here, a patent research is performed. Benefit of a patent research is the fact that it can give great insight into the range of applicable principles. The research can give a sense of direction, since more successful working principles will likely have a larger variety of patents. Furthermore, a patent research enables to research what others are doing, but not publishing.

For now a landscape patent search is performed. Within this patent research different applications of proportioning and mixing are explored. Within each of these applications different principles are analysed. Interesting findings are documented and will be used to create a general landscape of working principles as well as support development later on.

Some interesting applications of proportioning and mixing are identified. These may not be directly applicable to homogeneous liquid-liquid mixing but are nonetheless still deemed interesting. Examples of applications are: beverage proportioning systems, paint mixing machines, current faucet cartridges and metering pumps.

Beverage proportioning systems

A large variety of patents related to beverage proportioning and dispensing systems exist. In principle these systems function identical. A main liquid is mixed with a secondary liquid (the flavouring), according to a predetermined ratio. A predetermined amount of mixture is dispensed. Depending on the type of secondary liquid, the system may make use of homogeneous liquid-liquid mixing (addition of concentrated essences). However, mixing with different viscosities also occurs (through addition of syrups).

Patent EP 1.460.029.B1 describes a soft drink dispenser using a mechanism based on the venturi effect. Here a Venturi valve is used with a 'feeding' line which can be opened and closed. Using the motive force of the main liquid, secondary liquid is drawn into the diffuser of the valve and mixes with the main liquid.

One should note that this working principle is used in a setup which has a fixed ratio between the two liquids. The majority of the liquid in this case will always be the main liquid and the question arises whether ratios with a more significant part of secondary liquid still function with this principle. Nonetheless it is an interesting way of controlling the mixing of two liquids. Another interesting dispensing machine patent is CA 2.501.127, which uses displacement pumps to precisely dispense different a predetermined amount of liquids. Benefit of this system is the fact that it is claimed to be extremely precise, being able to dispense just a few milliliters. The system makes use of stepper motors and threaded drive rods to control a piston located in an outlet, in this way controlling the flow. Using the threaded drive rods increases the accuracy of the stepper motors. However, response time and the general dimensions of the system raise questions. Increased precision (hence a finer threading) would increase response time.

This example may therefore not be suitable for an electronic mixing valve

application, however the principle and other ratios could be interesting to test and implement.

Proportional valves

Patent WO 2016 / 087849.A1 describes a patent for proportional valves incorporated in electronically controlled showers and taps. The discussed valve is a proportional solenoid valve, which functions similarly to a regular solenoid valve. Regular solenoids are described as being two-way, meaning that they are only able to open and close. This particular valve however is able to 'proportion' the movement of its plunger, hence controlling the inlet orifice.

Patent US 5.687.759 describes a solution with a similar functionality, however a different working principle. A low operating power, fast response valve is presented. This solution has an integrated feedback loop, making use of a pressure sensor to adjust the valve opening. The valve is controlled through a servo motor, thus differing from the solenoid presented before. The rotational signal of the servo motor is converted into linear actuation, allowing to move a plunger up and down. In this way the plunger controls the size of the orifice and hence the liquid let through. Main difference with a solenoid valve is the actuation, which with the aid of a servo motor.

Throughout the design cycle, multiple patent researches will be performed. Not only to explore the landscape, but also to validate certain decisions or see whether solutions exist already.

G. Regulations

An exploratory research into regulations regarding taps and instant boiling water systems was performed with the aid of colleagues at Quooker B.V. Although strict regulation does not exist, there is a central European institution that tests, inspects and certifies water related solutions: the KIWA (Keurings Instituut voor Waterleiding Artikelen or Judging Institute for Water Supply Articles). A KIWA certification guarantees a certain quality standard of a system.

They have regulations for both taps as boiling water solutions. Important requirements will be discussed below.

Taps

The KIWA states that products and materials in direct contact with water should not contaminate the water to the extent that it is harmful for the consumer. They do not allow Zinc-Aluminium alloys in contact with drinking water. Furthermore, when applying a plastic coating, this coating should at least be 25 μm .

The institution states that a change of flow rate should be achieved within 0.5 seconds, as well as a maximum time span of 1 second for the temperature to restore after this change.

They state that a change in temperature should happen within a time span of 0,5 seconds .

When dispensing at a constant temperature and flow, the temperature is not allowed to change more than 2 degrees C for a period of 2 seconds [16].

Boiling water solutions

The KIWA requires the system to function correctly on a 220-240V, 50 Hz supply and should comply with the necessary standards. The solution should have integrated safety features to prevent accidentally dispensing boiling water. The solution must have a backflow prevention. The housing of the solution may not exceed a temperature of 45 degrees C. Furthermore, the system should be able to dispense water at a temperature of 65 degrees C with a flow rate of at least 1 litre per minute [17].

Since KIWA certification is an important quality standard the electronic mixing valve should comply with these requirements. Therefore the majority of these guidelines are integrated into the programme of requirements

H. Programme of Requirements

Below the program of requirements for the electronic mixing valve is presented.

1. Functionality

1.1 The electronic mixing valve must be able to provide water with a minimal temperature of the cold main water line and a maximum temperature of 95°C, with a typical main water line temperature of 10 degrees°C.

KIWA regulations regarding thermostatic taps.

1.2 The electronic mixing valve must be able to dispense water at a predetermined temperature indicated by the user, with a tolerance of 2°C.

EN 1111 article 10.9

1.3 The electronic mixing valve must be able to dispense a predetermined amount of water indicated by the user, with a minimum of 100 millilitres.

1.4 The change in temperature initiated by the electronic mixing valve must not take longer than the current Quooker taps.

2. Performance

2.1 The flow rate of water dispensed from the electronic mixing valve must be no less than 7 litres per minute for a temperature of 15°C and a pressure of 2,5 bar.

Quooker B.V.'s guidelines regarding taps.

2.2 The flow rate of water dispensed from the electronic mixing valve must be no less than 3 litres per minute for a temperature of 95°C and a pressure of 2,5 bar.

Quooker B.V.'s guidelines regarding taps.

2.3 All of the parts in direct contact with water in the mixing valve should be able to withstand a temperature of 110°C. (for a period of maximum 5 minutes per 20 minutes).

Quooker B.V.'s guidelines regarding taps.

2.4 All of the parts in direct contact with water in the mixing valve should be able to withstand a minimum temperature of 4°C.

Quooker B.V.'s guidelines regarding taps.

3. Leakage

3.1 The complete assembly of the electronic mixing valve must be able to withstand an air leakage test with a flow rate of 2,5cc per minute at a pressure of 3 bar.

3.2 If applicable, the check valve must withstand an air leakage test with a flow rate of 100 cc per minute at a pressure of 1 bar.

3.3 The housing of the mixing valve unit should be dust and water resistant compliant with a IP44 rating.

4. Usage

4.1 The electronic mixing valve should be able to withstand wear during a period of at least 10 years, with an average use of 20 minutes per day. (With an average use span of 20 seconds this equals around 220.000 uses).

Quooker guidelines for development of a new tap

5. Safety

5.1 In case of a power outage the electronic mixing valve should immediately shut down, not letting any boiling water through.

5.2 Materials used in the electronic mixing valve should comply with the regulations regarding drinking water from the RIVM.

Regulations issued by the State Secretary for Infrastructure and the Environment.

5.3 The housing of the electronic mixing valve may not exceed a temperature of 45°C when in use.

KIWA k14040 4.2.5.7. Stored water temperature.

6. Dimensions

6.1 The electronic mixing valve must fit in every kitchen cabinet configuration used currently by Quooker B.V.

7. Aesthetics

7.1. The electronic mixing valve must be one complete assembly with no separate parts.

7.2. The electronic mixing valve must be identifiable by a Quooker logo.

8. Installation

8.1 The electronic mixing valve must be usable in the current COMBI reservoir and foreseen configurations offered by Quooker based on a mixing valve.

8.2. The electronic mixing valve must be able to be installed with only common household working tools.

8.3. The electronic mixing valve should use standardized connections for Quooker B.V.

9. Maintenance

9.1 The electronic mixing valve must have an average maintenance interval of at least 5 years.

Average maintenance interval of a Quooker reservoir and tap

9.2 The electronic mixing valve must be serviceable with common household working tools.

10. Assembly

10.1 The electronic mixing valve must be able to be assembled within Quooker's current abilities.

11. End of life

11.1 The electronic mixing valve must have a minimal lifespan of 10 years.

11.2 The electronic mixing valve must have the possibility to partly be disassembled in metal and plastic parts.

12. Costs

12.1 The electronic mixing valve must not have a cost increase of more than 100% in comparison to the current mixing valve. A further cost increase needs to be justified elsewhere in the product.

I. Programme of Wishes

1. Functionality

- 1.1 The electronic mixing valve should be able to dispense at a predetermined temperature as precise as possible.
- 1.2 The electronic mixing valve should be able to dispense a predetermined amount of water as precise as possible.
- 1.3 The electronic mixing valve should be able to control the flow rate of water as precise as possible.

2. Performance

- 2.1 The variety in flow rate of water dispensed from the electronic mixing valve should be as big as possible.
- 2.2 The power consumption of the electronic mixing valve should be as low as possible.
- 2.3 The flow of water within the mixing valve should be as smooth as possible in order to prevent legionella and limescale.

3. Leakage

- 3.3 The electronic mixing valve should be as water- and dustproof as possible.

4. Usage

- 4.1 The electronic mixing valve should function as long as possible without maintenance.

5. Safety

- 5.1 The electronic mixing valve should remain as cold as possible during use.
- 5.2 The electronic mixing valve should influence the composition of incoming and dispensed water as least as possible.
- 5.3 Limescale build-up in the electronic mixing valve should be minimized as much as possible.
- 5.4 Bacteria growth in the electronic mixing valve should be minimized as much as possible.
- 5.4 The mixing valve should comply with as much CE certification guidelines as possible.

6. Dimensions

- 6.1 The electronic mixing valve should be as small as possible.
- 6.2 The mixing zone should be as small as possible.

7. Aesthetics

- 7.1 The electronic mixing valve should fit into Quooker B.V.'s style as much as possible.

8. Installation

- 8.1 The installation of the electronic mixing valve should be as quick as possible.
- 8.2 The installation of the electronic mixing valve should be as easy as possible.

8.3 The electronic mixing valve should fit as many of Quooker B.V.'s configurations as possible.

9. Maintenance

9.1 The electronic mixing valve should require as little as possible maintenance during its lifespan.

9.2 Potential maintenance should be as easy as possible.

10. Assembly

10.1 The electronic mixing valve should consist of as little parts as possible.

11. End of life

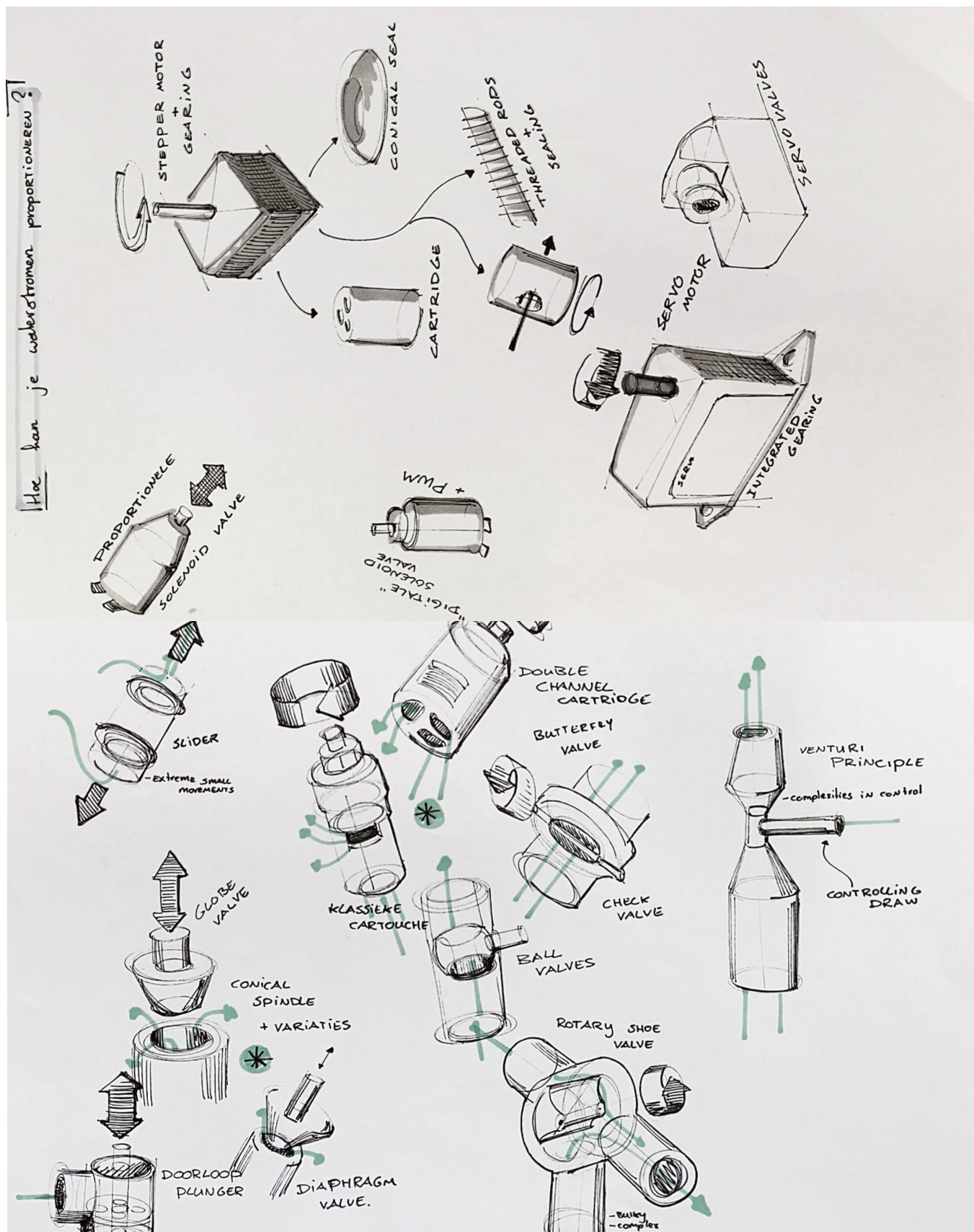
11.1 The electronic mixing valve should be as recyclable and reusable as possible.

12. Costs

12.1 The electronic mixing valve should be as cheap as possible without concessions on its performance.

J. Ideation

Below ideation sheets are presented.



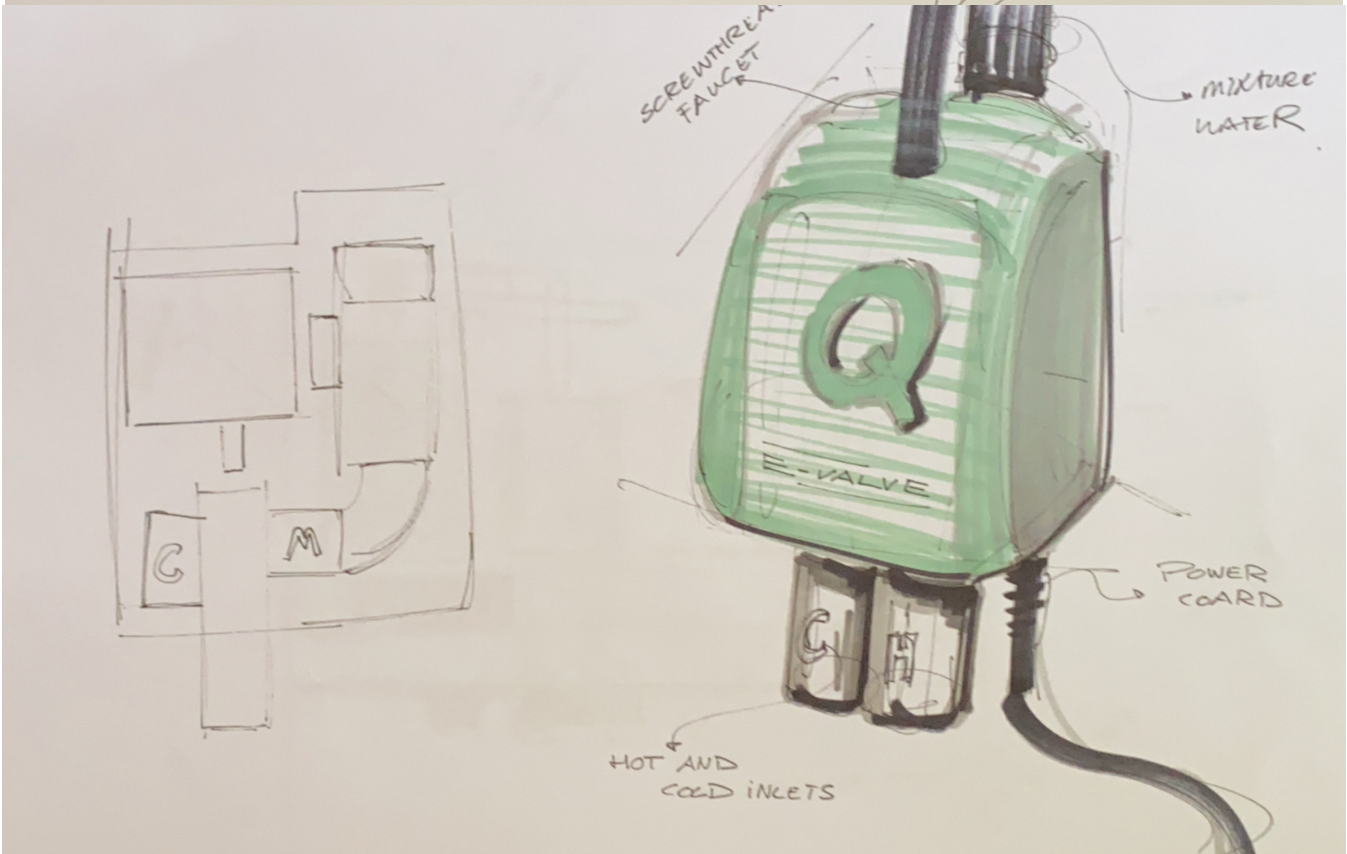
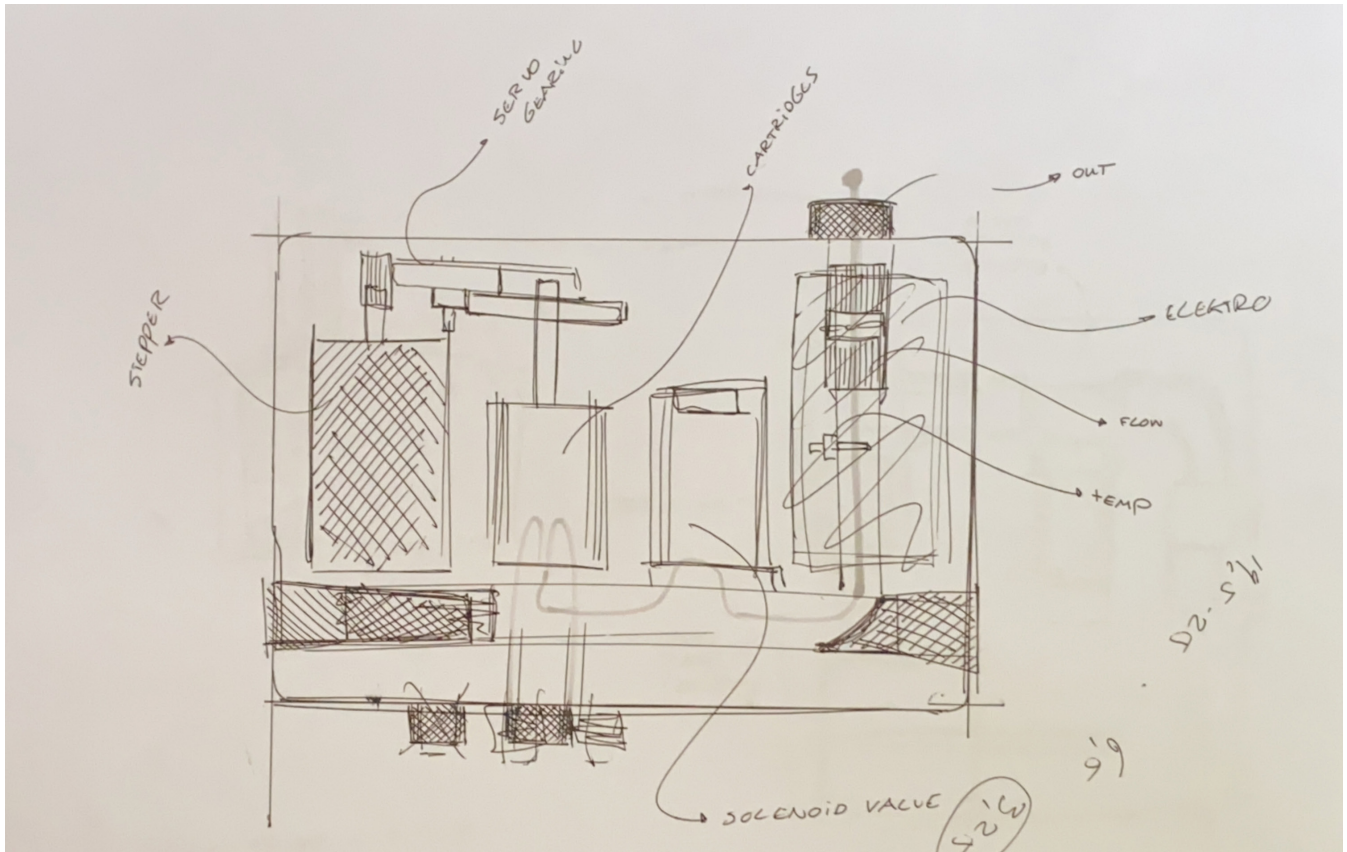
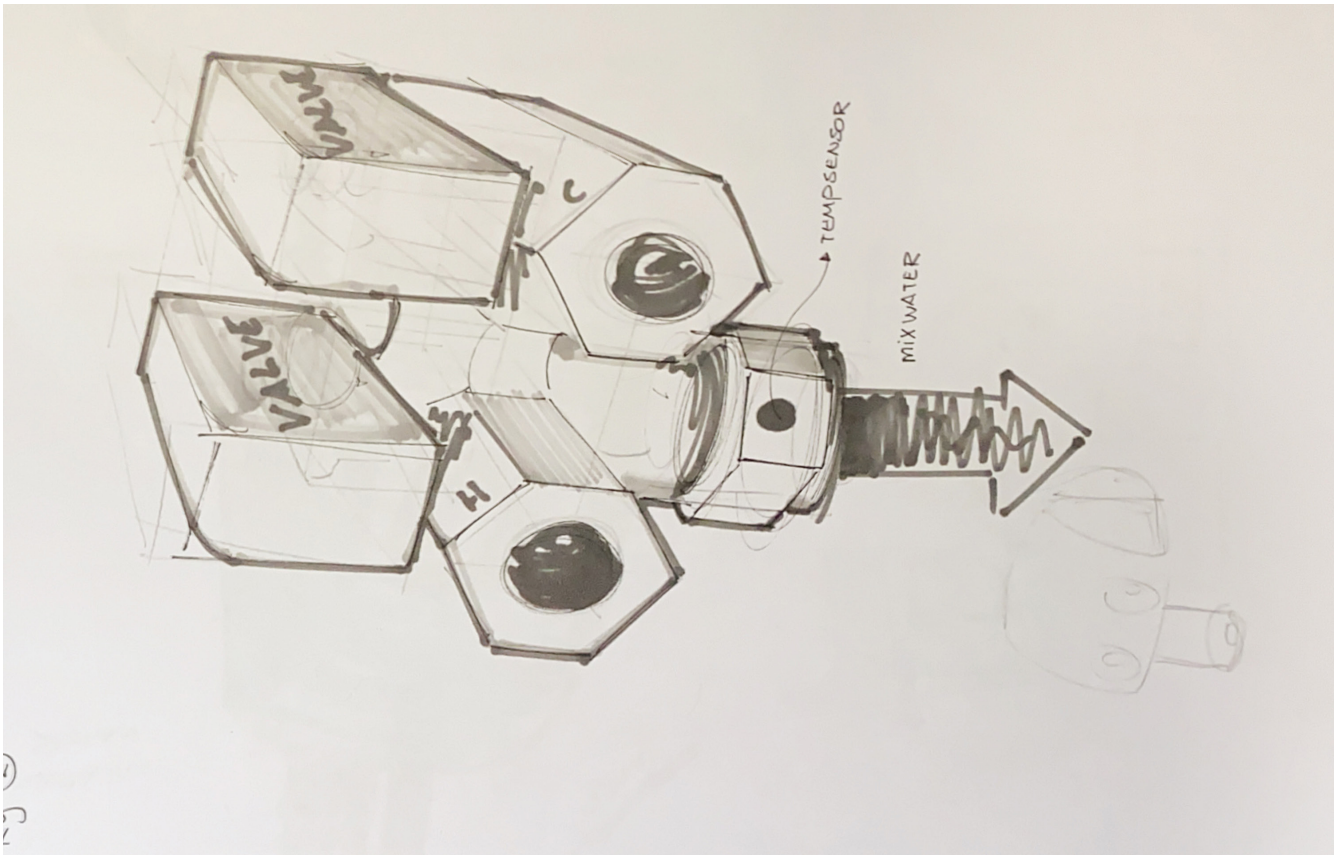
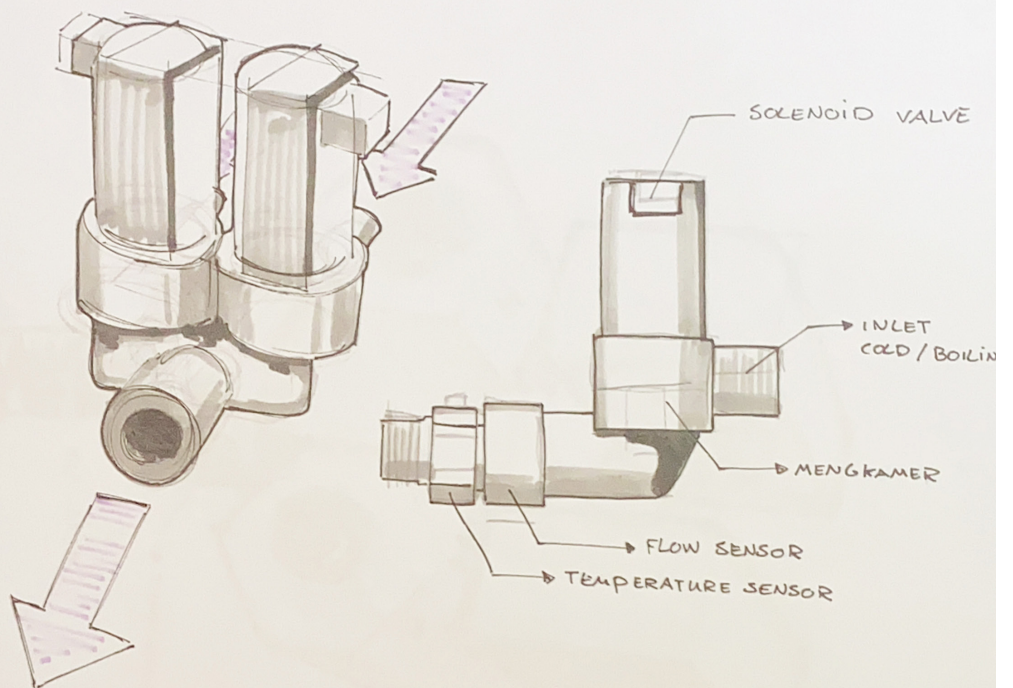
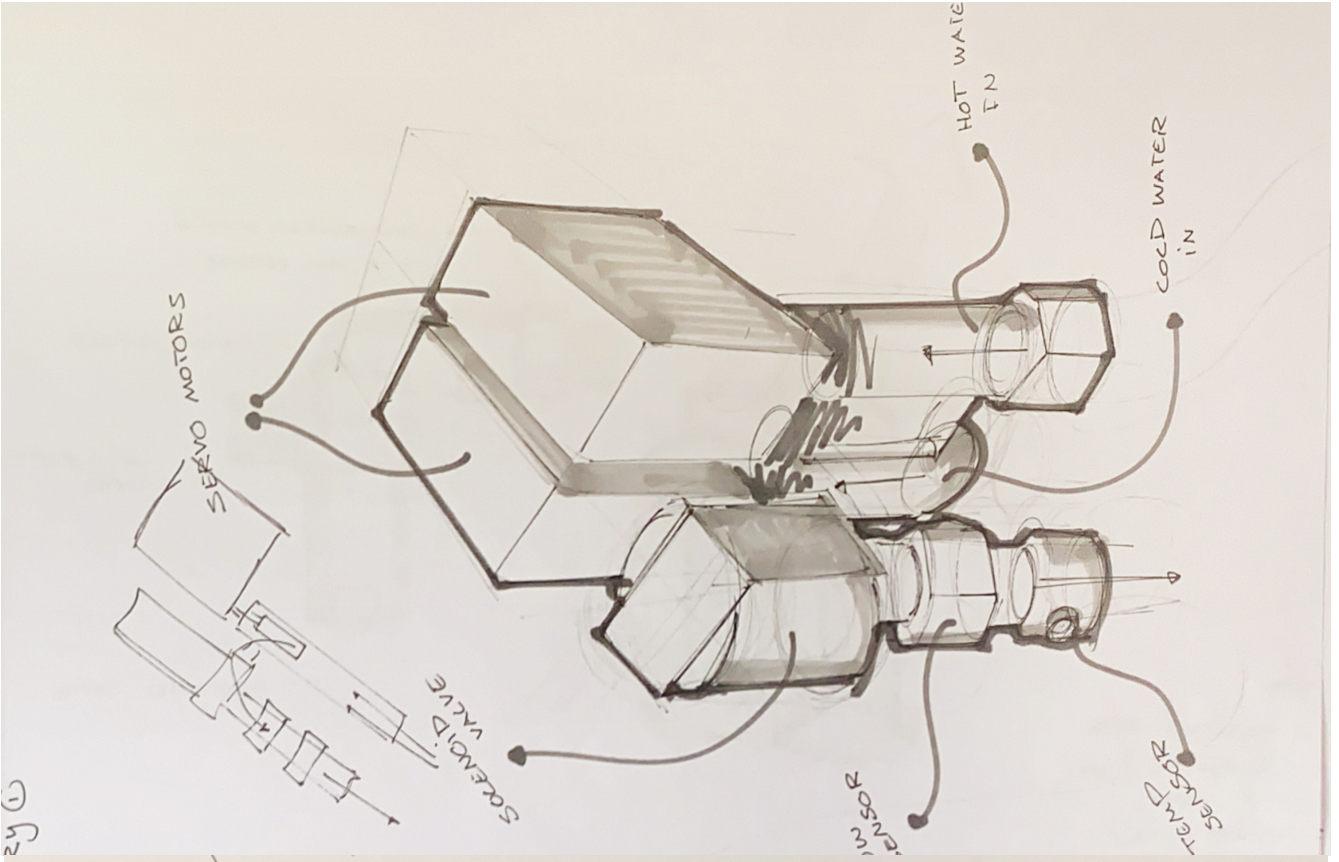
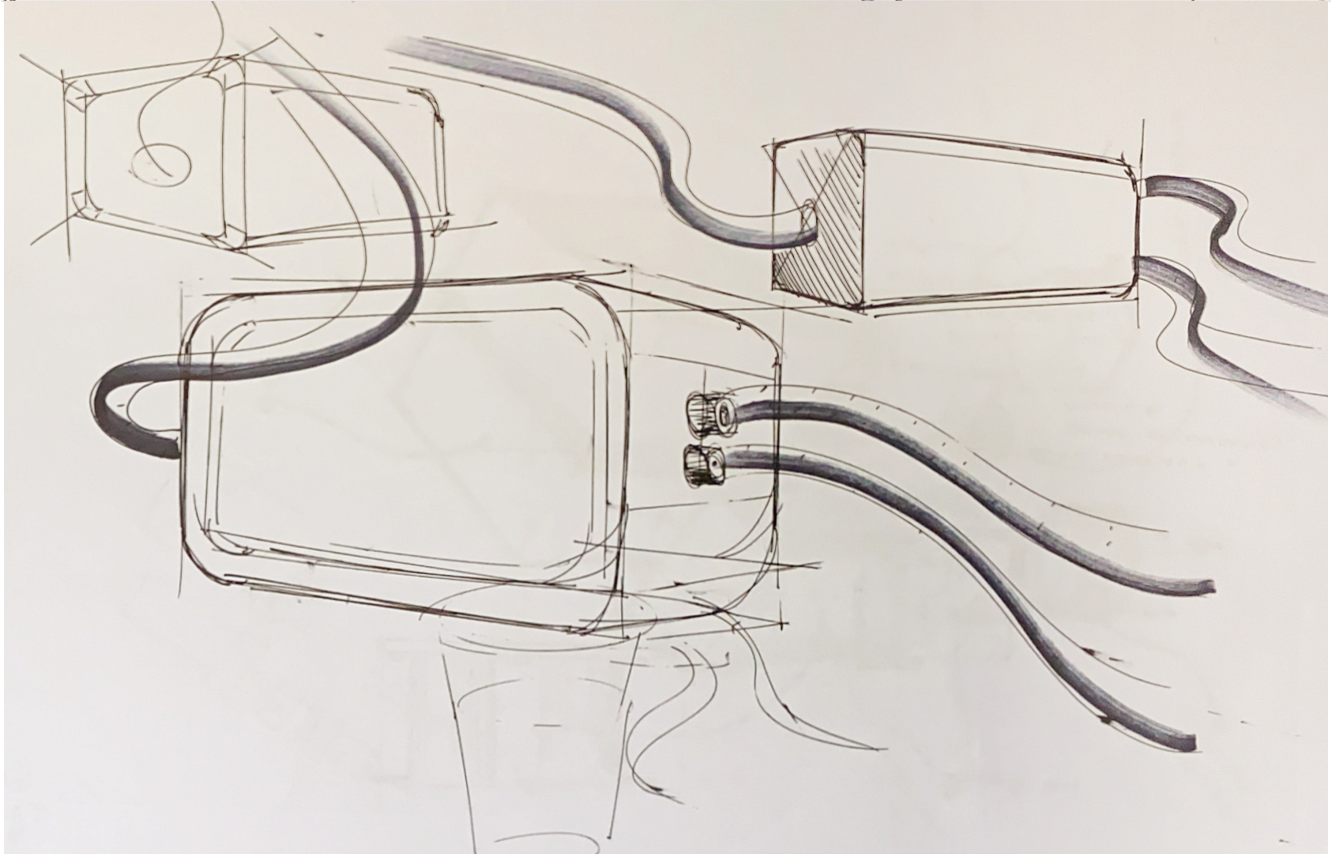


image [10]



kitchen cabinet
temperature + flow
no emergency valve
↓





solenoid & motorisch + solenoid

voordeel:

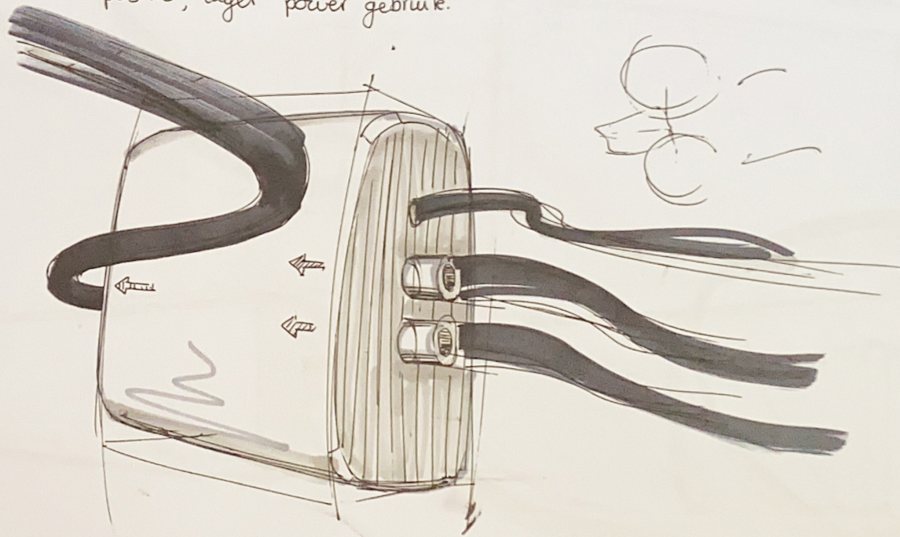
integreerde functionaliteit (proportioneren/temperatuur & debiet)

nadeel/voordeel

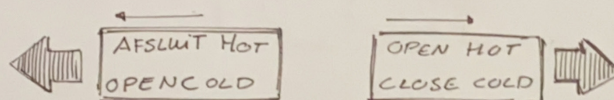
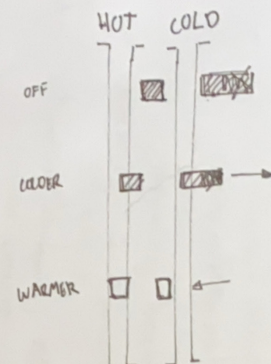
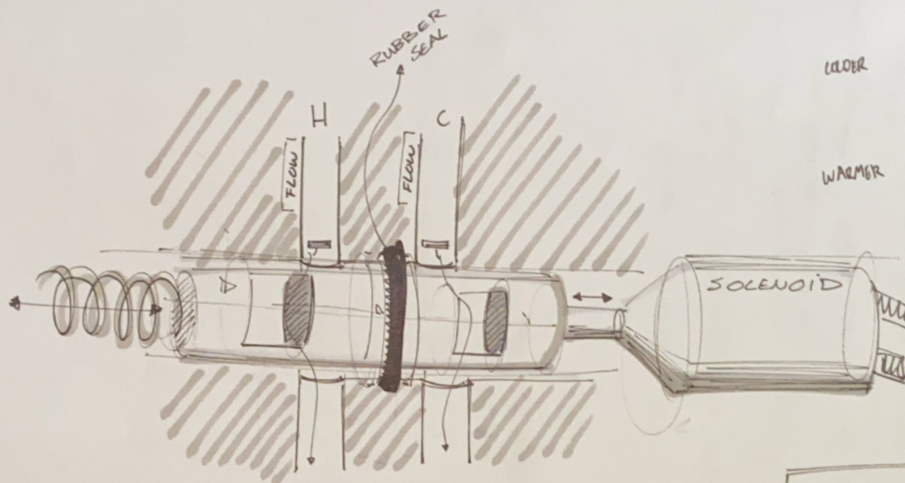
sluiten wanneer geen power, hierdoor hoog power gebruik maar safety feature

servo/stepper
principe zelfde, alleen formaat
technisch servo interessanter
(torque issue)

wanneer geen power - blijft in positie, lager power gebruik.

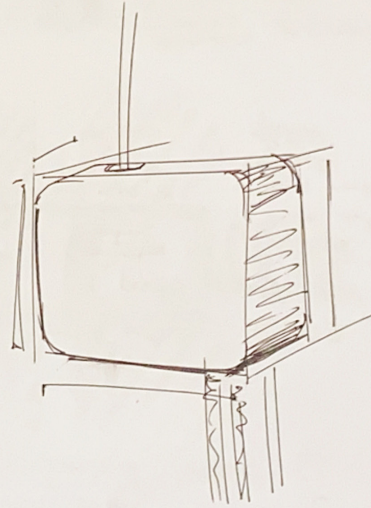
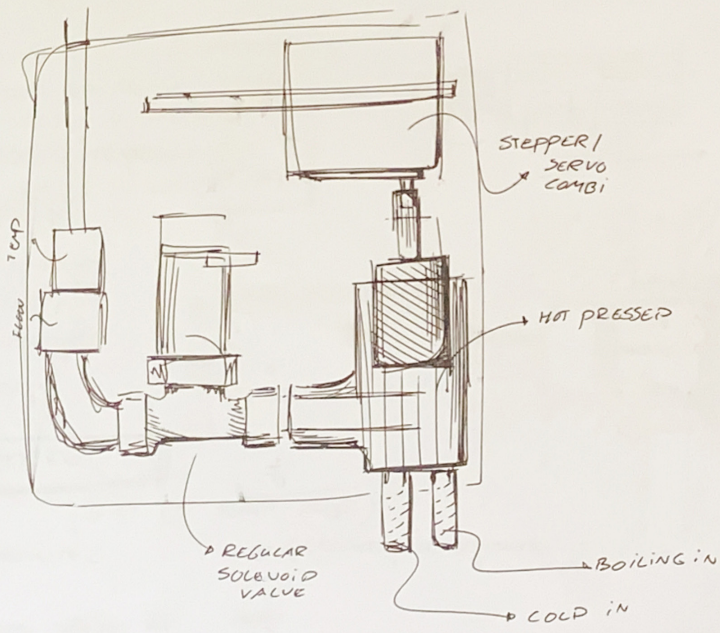


POTENTIAL CONCEPT
SINGLE SOLENOID
CONCEPT



AUTOMATIC FLOW CONTROL, SINCE DIFFERENCE FLOW RATE HOT AND COLD

SKINC + ORIENTATIES



K. Assessment drivers

The developed concepts focus solely on working principle and actuation. Other factors have not yet been taken into account. It is therefore difficult to create a high resolution assessment which focusses on other topics besides the working principle and actuation. However, even though low resolution prototypes are used, some insight can be obtained. These insights come from experiments, specialist inputs and desktop research. It is decided to correlate the assessment criteria with the main drivers obtained from the analyses. These drivers contain the most important criteria for a successful product and therefore should be suitable for assessment. Within each driver different requirements and wishes are incorporated, ensuring that a large spectrum of these are assessed, just not explicitly. Furthermore, using these main drivers means that no extensive list of wishes is required which could clutter the assessment. Instead a limited amount of criteria is used, which ensures a clear overview can be maintained.

1. **Functionality:** the electronic mixing valve should be able to dispense a predetermined amount of water (minimum of 100 millilitres) at a predetermined temperature (within the range of 10 to 65°C).
2. **Reliability and robustness:** the electronic mixing valve must have an average maintenance interval of 5 years or more and a minimal lifespan of 10 years.
3. **Design for manufacture and assembly:** The materialization of the new electronic mixing valve must be able to be produced and assembled within Quooker B.V.'s abilities.
4. **Modularity:** the new system must be compatible with the COMBI reservoir and optimized for future reservoirs.
5. **Price difference:** compared to the current mixing valve, the 'baseline', the new system must not have a cost increase of more than 50%, or these costs must be justified elsewhere in the product.

These drivers already have a high resolution. They do however give insight in assessment criteria and their hierarchy. Below assessment criteria for each of these drivers are formulated.

Functionality

The concepts' performance speed when changing temperatures and the flow behaviour whilst doing so.

Reliability and Robustness

The concepts' stability, ease of control and power consumption during usage as well as expert's input on the different configurations.

Design for manufacture and assembly

The manufacturing freedom of each design, complexity in assembly and customization possibilities.

Modularity

The number of components and initial space claim.

Price difference

Cost price indications of the different working principles and actuations, as well as power consumption.

Each of these drivers will be discussed in regard to the different concepts. A conclusion is drawn per driver. These conclusions are then combined into a final assessment for all the concepts. This assessment will then serve as a foundation for further concept development.

Functionality, Reliability and Robustness

Within Quooker B.V. a test setup is created similar for all of the three prototypes. The setup makes use of a Quooker COMBI reservoir and a heavily simplified tap to ensure minimal external influence. Each of the different concepts is connected to a measuring unit (consisting of flow rate and temperature sensor), a main cold water line and a boiling water line from the COMBI.

The measuring unit consists of a probe temperature sensor and a flow sensor. This unit will be used in all of the configurations tested to eliminate possible variety in sensing.

Each of the configurations is put through a predetermined performance scenario. This scenario is not initiated by the user but through software, to exclude a possible human error. Temperature and flow rate, as well as the actuator control signal will be recorder during this scenario. The resulting graphs will be analysed in regard to some aspects.

One has to note that a large part of performance differences will most likely be due to the fact that the software used in all of the prototypes is similar and hence not optimized for a specific configuration. The feedback loop incorporated into the software makes use of a PID-principle. Different values will work better for the different configurations, however finding the optimal values is time consuming. A try-and-error approach is used to obtain values that are somewhat close to the optimum. For this reason, quantifiable conclusions can be difficult to draw.

The predetermined performance scenario is shown in table 9. This scenario tests the configuration at different temperatures and quick alterations between those.

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		

table [9]

The following aspects are examined during the experiments.

Performance speed

Is there a difference in performance speed so extreme that it can not be blamed on software related optimisation? Do configurations act strangely when raising or lowering temperature?

Stability

Does the system require a lot of PID-tuning to reach somewhat of an acceptable behaviour and how stable is this behaviour? Is there a lot of fluctuation in both temperature and flow? During constant temperature flow as well as altering temperatures?

Besides these aspects, input from the electronic specialist aiding throughout the experiments is incorporated in the assessment. This input may not be quantifiable, but the specialist's gut feeling and intuition does have some fundament in his experience and knowledge and can therefore be used.

Results

Graphs regarding the behaviour of the prototypes throughout the scenario are shown in appendix M. These graphs do not show significant changes in flow behaviour which cannot be blamed on software. All of the configurations are relatively quick when altering temperatures, both when rising and declining. Differences in flow behaviour are noticeable however. The second concept makes use of a single cartridge, which means that the flow significantly decreases when temperature increases and vice versa. The other concepts control both inlets independent, resulting in less fluctuation. This change could be altered by correct tuning of the proportional solenoid valve in the second concept, which is responsible for flow control. All of the configurations reach acceptable behaviour in regard to the PID control.

The experiments do show that the cartridge hardly alters when a set temperature is reached, confirming the hypothesis that flow rate and temperature of the inlets is constant throughout usage. This means that the motorized temperature and flow controls require an insignificant amount of energy when dispensing a constant stream.

Feedback from the electronics engineer aiding in the experiments showed a preference for the sequential controls apparent in the second and third concept. Splitting the different tasks (temperature, flow rate and volume control) into different controls means that different feedback values do not necessarily interfere with each other. This is the case in the first concept. When a flow increase and temperature decrease are required, values obtained from different feedback loops are both used to control a single component. This makes controlling the behaviour slightly more tricky. Regarding the sequential motorized controls, the third concept has a preference from the electronics engineer. This is due to the fact that both streams are independently controlled, further splitting the different tasks (and feedback loops) per component.

In order to obtain more technical feedback, a special session with two

senior R&D engineers from Quooker B.V. was initiated. During this session feedback was given regarding the different configurations and potential issues were identified.

In regard to robustness a clear preference for proportional solenoid valves was expressed. Having less moving components than motorized (and geared) counterparts. In their experience the failure rate of previously used motorized configurations was higher than those using solenoid valves. Increased software related complexities were within acceptable margins for them.

Desktop research to confirm specialists' arguments is executed. Through contact with Hydraelectric they confirmed that their solenoid valves have been tested up to 200,000 cycles. Servo motor's life span is calculated differently. Within most of the servo motor configurations, (integrated) bearings, gears and potentiometers are more likely to fail than the motor itself. The servos used in the prototypes (by the brand Parallax), do not have a specified minimal service life. However, comparable brands show a minimal rated service life of 5000 hours in action. When one use cycle would take 1 min, this would mean a total of at least 300,000 use cycles. Some sources however claim that due to the lower component quality, small servos average a lifespan of 3 to 4 years due to deterioration of the gears and grease. Higher quality components would increase life span, but also cost price. For now, the simple assumption of less parts, less failure prone is used, in which solenoids would be preferable, substantiated by Quooker B.V.'s internal feedback.

During the experiments, average and peak power consumption of the configurations has been measured in order to compare. Depending on the configuration, peak and average power consumption can differ. Values are shown in table 10.

Configurations	Average power consumption (W)	Peak power consumption (W)
Concept 1	18	18
Concept 2	11	9
Concept 3	9	3

table [10]

One has to note that for these configurations standard components were used. Having customized components would most likely result in a lower power consumption. It can however give some insight into relative power usage. Interesting is the fact that average and peak power consumption are identical for concept 1, since the solenoid valves continuously require power to maintain their position. The cartridges do require power when in a steady state, only when adjusting. This results in lower average and power consumptions. Furthermore, due to the gearing the servo motors use significantly less power than the proportional solenoids. The last concept makes use of a different type of solenoid, not being proportional. This solenoid is specified at only 3W, using significantly less power than its proportional counterparts. This is most likely due to the strength of the spring pushing back the plunger. A proportional solenoid valve is expected to use a stronger spring, to be more precise in specifying its position. A

regular solenoid just has two positions meaning precise control is not necessary, resulting in a weaker spring.

Another topic regarding performance is the maximum flow rate a certain configuration would be able to dispense. In this case concept 1 and 3 are preferable, since they are both able to independently control the input orifices and hence flow rates. The second makes use of a cartridge controlling both streams. This means that increasing the orifice of one will decrease the orifice of the other. This means that both orifices will never be opened at a maximum. Therefore it is expected that this concept is not able to reach a similar maximum flow rate as the other concepts.

DFM & DFA

It is difficult to collect quantifiable data regarding this topic due to the low resolution of the concepts. However, desktop research combined with input and feedback from senior engineers within Quooker B.V. has resulted in some notions regarding the different concepts. These will be discussed here.

Design for manufacture

All of the concepts would likely require some sort of custom housing. In this scenario, less parts and less complex connections are preferable, since it is expected to result in less complexities and issues during production and assembly. A custom housing would allow for integration of certain complexities and can ease assembly. In the case of the three concepts, it is expected that all of them will have similar complexities. Concept 2 and 3 have certain complexities incorporated into the cartridge, meaning that the housing itself can be relatively simple. The first concept requires a certain, more critical housing design to properly function. In this situation concept 1 would therefore be less preferable. Concept 1 does however use less components, resulting in an easier housing in regard to the other concepts.

One major note regarding concept 1 is the fact that the proportional solenoid valves from Hydraelectric are not yet specified for temperatures up to 110 °C and steam. Within Quooker B.V. these solenoids have been tested, however long term effects are still unknown.

Cartridges as used in the other concepts have been widely applied in systems up and over 110 °C and are therefore more proven.

Furthermore, depending on the materialisation and type of cartridge used, it is either equipped with brass or ceramic moving parts, or both. These materials are known to be bacteria repellent. Plastics as currently used in the proportional valves might be more prone for the development of bacteria films on the inside. Plastics with drink water certification and temperature resistance do exist, but could potentially be expensive. It is however an opportunity, or possible drawback of the concepts.

Design for assembly

In general, less parts and less complex parts would result in a better assembly procedure. In this case the first concept would be the most preferable, since it uses the least parts. The plungers need to be screwed on, after which the coils of the solenoids can be snap fit over the plunger. Therefore only the up and down side of the coils matter, not rotational orientation it might have during installation.

Cartridges need to be assembled in a specific position, since they will otherwise not be waterproof and function properly. This could require more precision during assembly and hence more time. Depending on the motorized control orientation matters, however it is expected that this will always take more time due to the correct positioning of the motor and its gearing. In this situation the first concept would therefore be preferable over the other two, with the second concept being more preferable than the third simply because of the smaller number of components.

Modularity

Due to the low resolution of the prototypes, two aspects are taken into account regarding this topic: the absolute number of components per configuration and the initial space claim of the configuration.

Number of components

Again, the number of components is solely focussed on numbers required in the working principle and actuation. The third concept uses the most components, 5 parts in total. The second concept utilises 3 components and the first concept uses just two. These estimations exclude small components, such as O-rings and connectors. It is expected however that these will increase relatively to the current amount of components, maintaining an identical hierarchy in component numbers. Table 11 shows the different components per concept.

Concept	Part
Concept 1	Proportional Solenoid Valve
	Proportional Solenoid Valve
Concept 2	Cartridge
	Servo Motor
	Proportional Solenoid Valve
Concept 3	Servo Motor
	Servo Motor
	Check Cartridge
	Check Cartridge
	Solenoid Valve

table [11]

Space claim

Hydraelectric offers housing in which two proportional valves are already integrated. Different configurations are available. These are combined with a space claim for a temperature sensor and flow sensor, resulting in final volumes. Some additional volume is claimed for connections. The total volume is not simply an addition of the components, since the components need to be in a correct location to properly function..

Components	Dimensions and volume
2 Proportional Solenoid Valves	77*60*58mm (266 cm ³)
Temperature Sensor	30*25*20mm (15 cm ³)
Flow Sensor	30*25*20mm (15 cm ³)
Total	110*70*70 (539 cm³)

table [12]

Similar to the first concept, the second concept makes use of a proportional solenoid valve, as well as a temperature and flow rate sensor. Besides these components, the system uses a servo motor and cartridge. Dimensions and volume of the components are shown in the table below.

Components	Dimensions and volume
Proportional Solenoid Valve	31*31*40mm (38 cm ³)
Cartridge	30*30*50mm (45 m ³)
Servo motor	20*40*40mm (32 cm ³)
Temperature Sensor	30*25*20mm (15 cm ³)
Flow Sensor	30*25*20mm (15 cm ³)
Total	40*110*100mm (484 cm³)

table [13]

Lastly, the dimensions and volume of the components for the third concepts are shown in the table below.

Components	Dimensions and volume
Solenoid Valve	31*31*40mm (38 cm ³)
2 Check Valve Cartridges	60*25*50mm (75 cm ³)
2 Servo Motors	60*40*40mm (96 cm ³)
Temperature Sensor	30*25*20mm (15 cm ³)
Flow Sensor	30*25*20mm (15 cm ³)
Total	90*60*120mm (648 cm³)

table [14]

The last concept has the largest space claim, followed by the first concept. The second concept makes use of the smallest space claim, although the differences are not deemed to be extremely large.

Cost difference

A rough cost estimation is made for each of the three concepts, focussing on actuation and working principle. This could give some insight into the relative cost investment for each of the concepts. More however, it will help in identifying a potential outlier in costs. If one working principle proves to be significantly more expensive than the others, investing more research into this concept could be a waste of time.

It is expected that more expensive working principles have a better performance, however this is not guaranteed. Furthermore, there has to be some pivot point, in which the investment does not outweigh the performance benefits anymore.

Below a cost analysis for each of the different working principles is presented. For each part there is a specification whether it is a product specific component or standard component. Some cost prices are derived from other buy-in parts already used within Quooker B.V. These can be identified by their source being SUMATRA, which is an internal product management tool. Some parts might have a price range depending on the supplier. This is indicated.

	Concepts	Components	Amount	Price	Total	Energy Consumption per use (J)	Total (kWh)	Costs
table [15]	Concept 1							
		Proportional Solenoid Valves	2	50 %	100 %			
						360	22	56 %
					100 %			56 %
table [16]	Concept 2							
		Proportional Solenoid Valve	1	50 %	50 %			
		cartridge	1	35 %	35 %			
		servo	1	35 %	35 %			
						186	11.24	29 %
					120 %			29 %
table [17]	Concept 3							
		Solenoid Valve	1	50 %	50 %			
		check valve	2	18 %	18 %			
		servo	2	70 %	70 %			
						72	4.4	11 %
					138 %			11 %

As component numbers increase, the price increases as well. This makes the first concept the cheapest, followed by the second and third concept, with similar price differences accordingly.

Although the price increase, research performed before has shown that the power consumption drops. It can therefore be interesting to see whether this reduction in power consumption justifies an increase in price. From the programme of requirements, the expected life expectancy of the system can be identified. Requirement 4.1. indicates that the valve should be able to withstand wear during a period of at least 10 years with an

average use of 20 minutes per day. This would equate to around 220.000 uses averaging 20 seconds. Per use it is indicated that 10% will be at peak power consumption (initialisation and adjustment of temperature and flow), whilst the rest will be at average power consumption. The price of a kWh is specified at €0,22 [18]. Table [15], [16] and [17] show the power consumption and cost during the lifetime of the mixing valve.

L. Assessment

In order to ensure a correct and fair concept assessment, established assessment methods are being used. In order to gain initial insight into whether one of the concepts is significantly better than the others, a Harris profile is used.

Besides collected information, a Harris profile will help make to make certain intuitions more explicit. Each concept will be given a score of either --, -, + or ++, ranging from negative to positive. The visual representation of these scores should give initial insight. Furthermore, the overall score of each alternative can be quickly identified and compared.

Table 20 shows the Harris profile created for the three concepts.

	Concept 01				Concept 02				Concept 03			
	--	-	+	++	--	-	+	++	--	-	+	++
Functionality												
Reliability & Robustness												
DFM & DFA												
Price difference												
Modularity												

table [20]

The Harris profile shows a slight preference for the first concept, however this is not deemed enough to make a thorough decision.

Besides the Harris profile, a Weighted Objects method is being used. The weighted Object method enables a sum up of scores for all the different criteria. The obtained numerical values will give insight for each concept. The method differs in the fact that each of the different criteria has a specific weight, totalling at a score of 100%. This way the hierarchy in importance of drivers becomes more apparent than in the Harris profile. Argumentation for the weight of these drivers is shown below.

In the assessment Performance, Reliability and Robustness were combined into one topic. This is deemed the most important, since it entails the essence of the product. Without correct functioning it will never be a success. Furthermore, these aspects need to be apparent from the beginning of the development process, since they can not be added later on. Furthermore, it is expected that optimisation in regards to these topics will have the main focus in further development. For this reason these drivers share a heaviest weight of the assessment matrix, totalling 40%. For now it is decided that this sum is divided into 25% for the Performance driver and 15% for the Reliability and Robustness driver. Argumentation for this is the fact that performance needs to be inherently there, whilst the other driver can largely be optimised through tuning of the embodied concept.

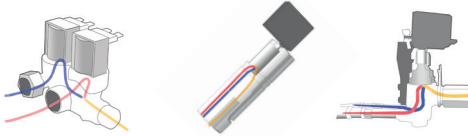
The second most important driver is the Design for Manufacture and Assembly driver, since these are essential for further embodiment of the

concepts. Limitations already identified here could cause extensive and expensive problems later on in the product embodiment cycle. Therefore the weight for this driver is 25%.

The price difference driver has a value of 20%, meaning it falls behind the other drivers. Reason for this is the fact that engineers within Quooker B.V. have implied some flexibility in regard to the costs. As long as the costs are not extremely high, the other factors are simply of more importance.

Lastly, the modularity driver is given the lowest weight, since its core values are already apparent in other drivers. Furthermore, due to the low resolution this driver is not easily quantifiable. For this reason some wariness in attaching importance to this driver. Therefore the remaining percentage of 15% is assigned to this driver, totalling the weight of the drivers to 100%.

Using these weights and the before presented information, the following score tables were created.



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

table [21]

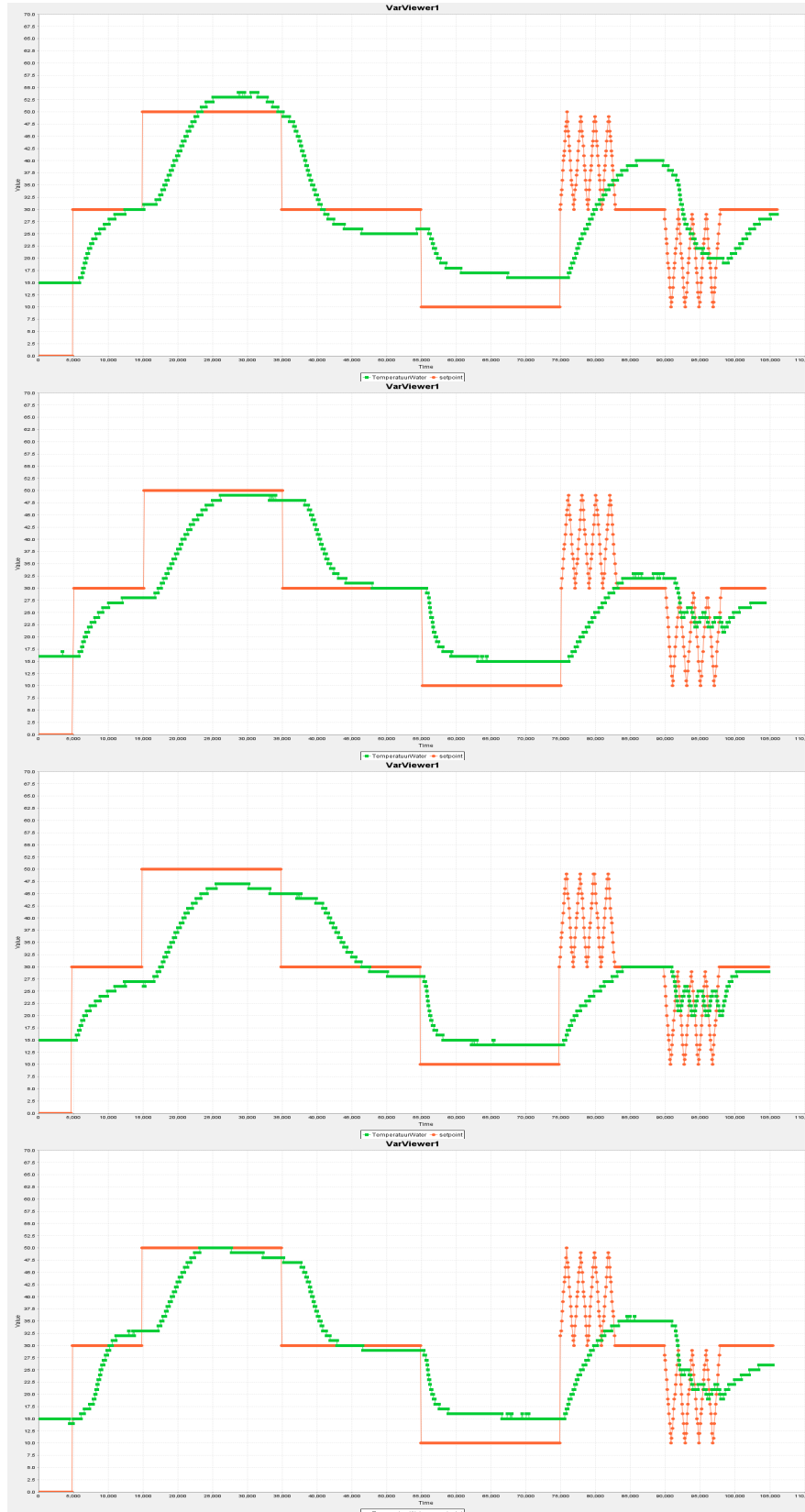
The ‘Weighted Objectives’ method shows a preference for concept 1. This information was used in a feedback meeting with internal stakeholders and R&D engineers. The assessment method and end result were accepted, with concept 1 having the most potential. For these reasons it is therefore decided to continue with concept 1, using 2 proportional valves.

Although the assessment seems totally objective, intuitiveness and personal preference are apparent in the assessment. Due to the low resolution of the concepts, quantitative data is difficult to obtain. The concepts can be compared with a status quo, however small differences in performance should not be used for the assessment. However, these experiments and analysing the different concepts creates some sort of intuitive feeling for each concept. This feeling is somewhat subjective and somewhat objective, but mostly difficult to substantiate. Being involved in the project and analysing all different solutions available should influence subjective feelings, meaning that there is somewhat of an objective substantiation for these feelings. For this reason it was not attempted to

exclude these feelings from the assessment, but recognizing them. These decisions are never 100% waterproof, but at this point in the product development cycle, the feeling is there that this decision can be made. In order to further substantiate this feeling it was extensively discussed with stakeholders within Quooker B.V. Furthermore, feedback upon the process and decisions were obtained from senior R&D engineers. Therefore, this decision is solid at this point in the product development process. However, only through gaining more knowledge and continuing in the development process, the right decision can be further confirmed.

M. Performance throughout scenarios

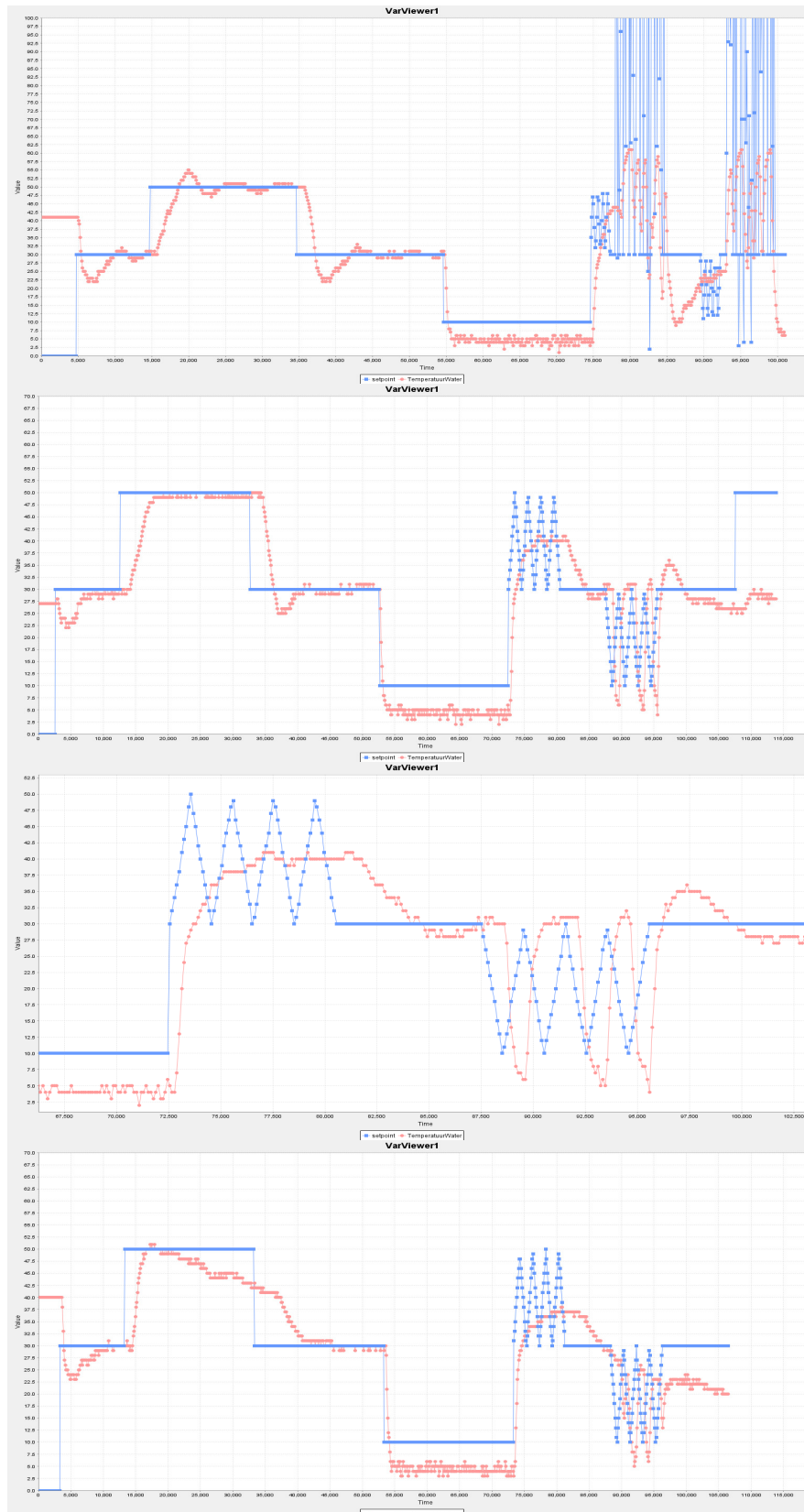
Concept 1



the orange line describes the input signal, the green line describes the temperature change. All graphs perform the same scenario, however with different PID values.

Concept 2

the blue line describes the input signal, the orange line describes the temperature change. All graphs perform the same scenario, however with different PID values.



Concept 3



the blue line describes the input signal, the red line describes the temperature change. All graphs perform the same scenario, however with different PID values.

N. Cognitive Ergonomics

Although an electronic mixing valve might not seem like a product that is heavily involved with cognitive ergonomics, it is essential in the complete system. Cognitive ergonomics play an immense role in coming up with a good solution for a renewed interface of the tap on top of the kitchen cabinet.

However, these ergonomics are also deemed interesting in the design of just the electronic mixing valve itself. Although limited interactions are involved with the valve, consequences of wrong moves can be large, due to safety concerns.

Different types of interactions concerning the mixing valve can be identified.

Installation: During installation the electronic mixing valve will be installed in the kitchen cabinet and connected to other parts from the Quooker system. This installation is handled by servicemen from Quooker B.V., kitchen retailer servicemen or customers themselves. This is important to know, since this means there is a large range in skill level during different installations.

Monitoring: During normal usage there might not be any issues at all. Still a consumer could open their kitchen cabinet and inspect the system.

Troubleshooting: issues might occur during normal usage, the consumer is then likely to inspect the whole of the Quooker system inside the kitchen cabinet. Alternatively, Quooker B.V. servicemen might be called in to inspect the system when malfunctioning.

The final product is likely to become some sort of 'black box', hiding its internal functionality from consumers. Showing too much of its functionality is likely to interfere with Quooker B.V.'s minimal product appearance. However, clarifying the boundaries of this black box are believed to generally help throughout the identified interactions. For this reason, the boundary conditions of the electronic mixing valve are analysed.

Location of connections

Image 11 shows different connections and locations as used by competitive products. Due to the fact that all these connections look similar, confusion is ought to arise.

The main goals of analysing the location of connections on the electronic mixing valve is limiting possible confusion and easing installation. For this reason, it is important that the connections are placed intuitively.

The electronic mixing valve is likely to have four different connections, being:

- Inlet boiling water
- Inlet main cold water line
- Outlet mixture water
- Power supply

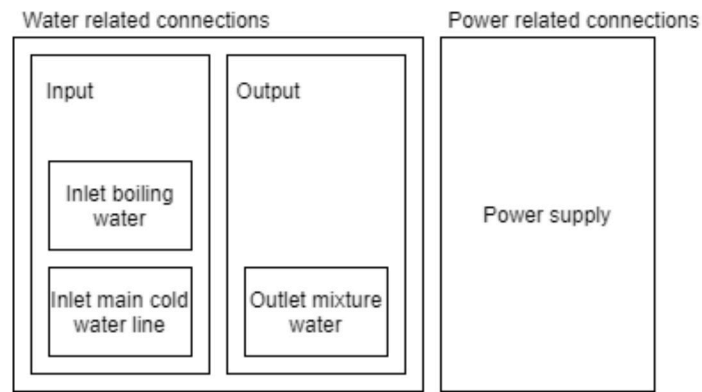


image [11]

According to D. Norman in the 'Design of Everyday Things' [19], besides having a logical order of connections, mapping and grouping similar functionalities can help in preventing confusion for the user. The different connections are mapped accordingly:

Water related connections

The water related connections can be categorized into two types, inlets and outlets. Separating these two categories can help in creating clarity. Furthermore, locating the connections in intuitive locations to each other can help.

For now the assumption is made that the electronic mixing valve will have six distinct surfaces: a front, back, upper, lower, left and right surface. A final mixing valve might have more or less surfaces, however this analysis can then still give a sense of direction.

Mapping the connections within the field of sight when looking inside of the kitchen cabinet can clarify the product. For this reason the backside is not suitable for connections.

Different possibilities are shown below:

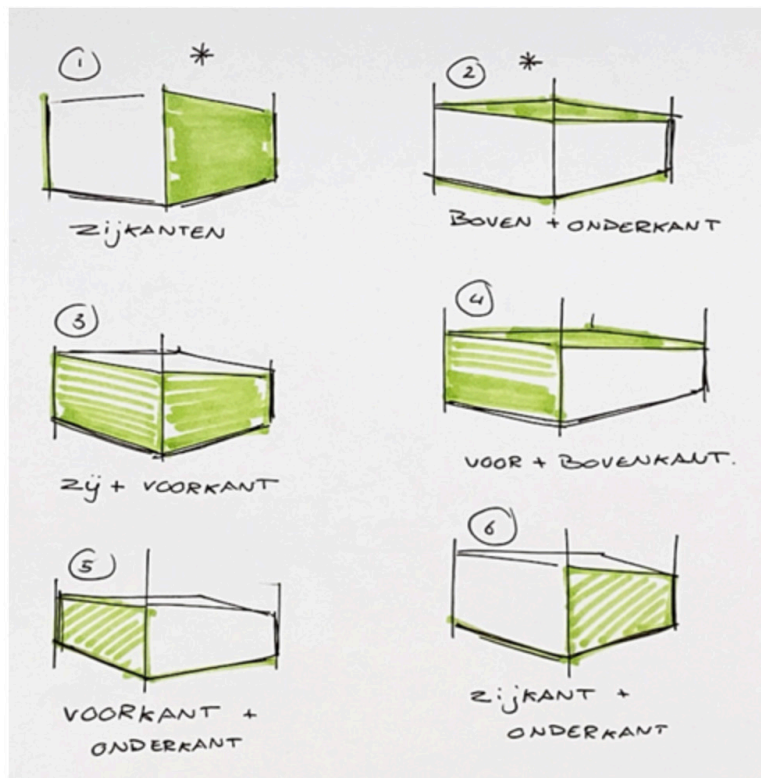


image [12]

From these different opportunities 1 and 2 have a preference, for a multitude of reasons.

Locating the connections on opposing sides gives a 'natural' linear feeling of flow. This could help in further emphasizing what the inlets and outlets of the product are.

This way the connections are less likely to be in one field of sight when analysing them more closely. By simply not allowing the connections to be in the same field of sight, likeliness of wrongly connecting lines becomes less likely.

Depending on the design of the electronic mixing valve's inner work it would be possible to incorporate both opportunities, allowing the box to be installed in several ways.

Indicating Locations

With locations determined, it is important to ensure that the user will be able to quickly and clearly identify these locations of connections. Logical use cues can help generate trust from the user, since they will create a better understanding of the product.

Having the connection locations on opposing sides creates the opportunity of creating a product that can be shaped to indicate these locations. The product can then still be symmetrically shaped, resulting in an aesthetically more pleasing end result.

An explorative analysis into different outer and inner shapes is conducted. This analysis focusses on portraying the 'natural feeling' of flow in the product and by this way indicating the locations of the connections.

The majority of these shapes focusses on having some sort of directional flow, clearly indicating an in- and output. This is tried to be achieved by having a more emphasized input side, which slopes down to the output side.

Inspiration for this sloped down shape is taken from archetypical products which combine different flows into one single output. Large mixers, hourglasses and the like often have a larger orifice at the input side, with a smaller orifice at the output side. Turning these in- and outputs around feels illogical. For this reason it is tried to incorporate the typical shape of these products into the electronic mixing valve housing.

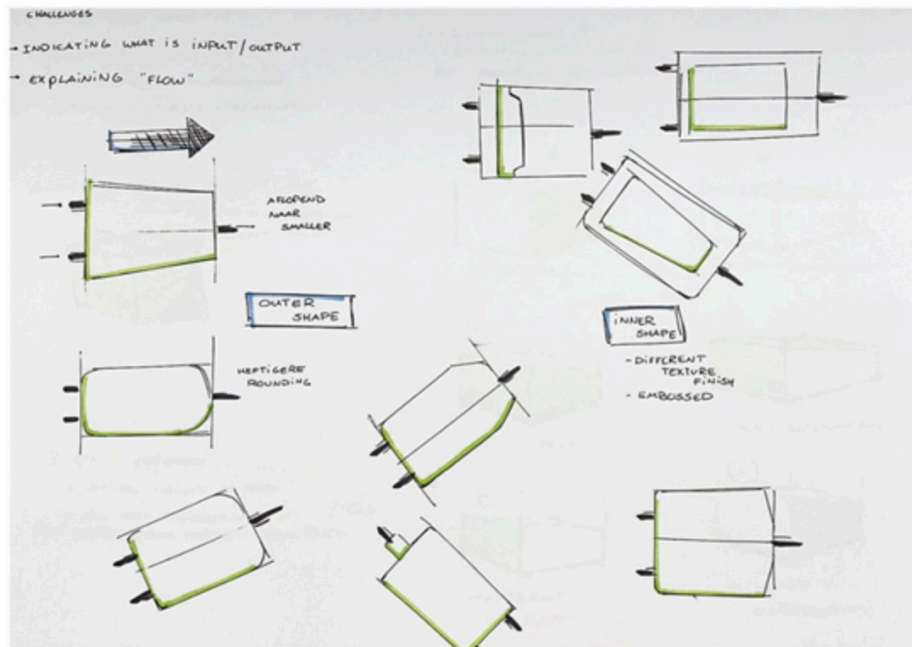


image [13]

This sloping done can be done by creating sloping lines, but also by creating chamfers on the output side or emphasizing roundings in the product on the output side. Inner shapes were added within the shape of the housing to indicate some sense of direction. These inner shapes could be placed asymmetrically in within the outer boundaries of the product or can be sloped down as well.

Although these shapes do supply some sense of direction, a satisfactory shape indication could not be found. Often the shapes already become too busy, not suiting Quooker's minimal product language. Furthermore, it was found that these shapes on their own are not a strong enough indication of flow and connections. Therefore, additional elements to indicate correct use of the connections would be needed, diminishing the need for a specific outer shape.

O. Location

With the electronic mixing valve being an object that is placed in between the tap and the reservoir / water lines, the amount of possible locations is limited. For installation purposes, as well as simplicity and aesthetically motivated arguments the kitchen cabinet underneath the faucet is the space where the electronic mixing valve should be installed. Within the kitchen cabinet, four different possible locations are identified. Each of them will be shortly explained here.

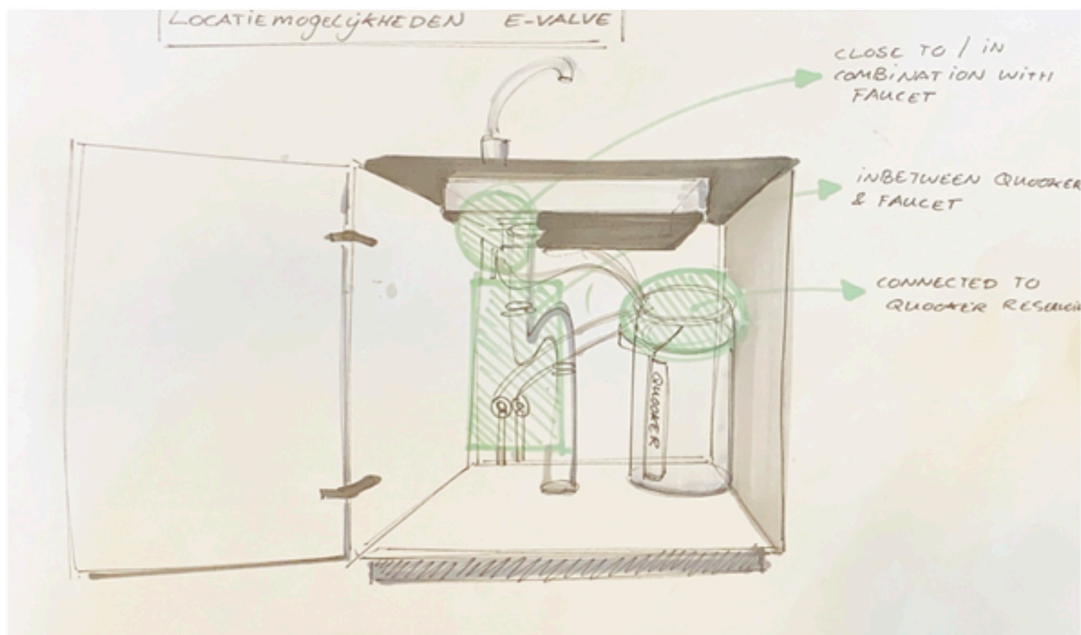


image [14]

Integrated into the reservoir top

This option seems great. Integrating the electronic mixing valve would make installation of the system easier for servicemen and create a less complex system inside the kitchen cabinet, since some lines to and from the electronic mixing valve could be placed within the reservoir configuration. This configuration however does come with some complexities.

First of all, integrating the system into the reservoir would mean that a whole new reservoir top needs to be designed as well. This is likely to result in high investments and an extensive research and development trajectory. Furthermore it reduces the modularity of the system. When an electronic mixing valve would need to be replaced, it will be significantly more work, if possible at all.

Motivated by these arguments it is decided that integrating the electronic mixing valve into the reservoir top is not a suitable option for now.

Connected to the reservoir

Connecting the electronic mixing valve to the outside of the reservoir could be an option. The system would be more modular, since the valve can easily be removed. Furthermore, it will still result into a visually less complex system, since the electronic mixing valve could be seen as part of the reservoir configuration.

A major downside however is the fact that the water lines from the electronic mixing valve to the tap will be quite long, increasing the amount

of 'dead water' in the system (since these lines will always be filled with water). Furthermore, connecting the electronic mixing valve to the reservoir, whilst still having external connections on both the reservoir and the valve (since it is modular) is likely to increase difficulty of installation, since a multitude of lines are close together and could interfere with each other.

Motivated by these arguments it is decided that connected to the reservoir is not a suitable option.

Connected to the tap

Motivated by reducing the amount of 'dead water' in the system, connecting a mixing valve to the tap itself (just inside of the kitchen cabinet) could be an interesting option. Not only is this expected to reduce the visual complexity within the kitchen cabinet, it would also decrease the amount of lines in the cabinet, since the valve could be directly connected to the tap.

An important aspect to note however is the availability of space close to the tap. Most of the time the tap is located closely to the sink, meaning that space can be limited. Furthermore, the location of the tap in relation to the sink means that the tap is often located close to the sides of the kitchen cabinet. This further limits the available space for an electronic mixing valve directly connected to the tap. Cabinet, tap and sink configurations of users vary a lot, which makes it difficult to estimate a minimal space claim. Lastly, as the CAD-models in further analyses show, a clear view of the connection of the faucet connection is often not available. This is due to obstruction by the kitchen sink. Having a relatively complex installation without a clear view would only complicate the installation.

Motivated by these arguments it is therefore decided that it is too risky and too limiting to develop an electronic mixing valve that is directly connected to the tap.

Placed in between the tap and the reservoir

This location is currently also used by Quooker's mechanical mixing valve. Furthermore, all of the competitive electronic mixing valves also make use of this configuration.

Downside of placing the mixing valve in between the tap and the reservoir is the fact that the system as a whole requires more lines, because there is less integration of parts. This will create a more complex looking system, likely to result in a tangle of lines. Furthermore, placing the mixing valve in between the tap and the reservoir means that something is needed to securely fasten the mixing valve in its location, since it is unlikely it will be able to float in between the other components.

Placing the mixing valve here however has some great advantages.

First of all, placing the mixing valve separately increases the modularity of the system. It can be easily removed, repaired and replaced.

Secondly, it allows for more flexibility. There are more separate components, but with a smaller space claim. These components can be placed at different locations, with flexible lines running in between. This enables more installation opportunities, even when the available space might be limited.

Third, by leaving the mixing valve as a separate product within the

configuration, no large investments into redeveloping the other components are necessary.

Lastly, by placing the mixing valve as a separate product in between the tap and reservoir, it is argued that it becomes more of a distinct feature and allows for more product differentiation possibilities for Quooker B.V.

For these arguments, as well as the counterarguments regarding the other possible locations, it is decided that the placement between the tap and the reservoir is the most ideal.

This location will be used as starting point for further analyses

Location detailing

Automatisch gegenereerde beschrijving Although a kitchen cabinet is often used for storing cleaning products, it is generally not the most organized cabinet in a kitchen. When using a Quooker, the space underneath the sink quickly becomes cramped. In critical cases, minimal space is available. In order to optimally use the then available space, the electronic mixing valve should have a predetermined location in the kitchen cabinet. Not only will this minimize confusion for the user during installation, it could also assist in a better overview of the Quooker system and a better understanding of the system as a whole.



image [15]

Due to external influences, it is decided to perform this analysis through CAD (Computer Aided Design). Benefit of a CAD design is the fact that it can quickly give insight into the available space, and that dimensions can quickly be altered for different scenarios. Two models will be created, a critical scenario and a normal scenario.

Critical scenario

The critical scenario evaluates a situation in which a large amount of (largely dimensioned) products is used inside of a minimum available space. By evaluating this situation, it is expected that we can validate that the electronic mixing valve can be used in every kitchen.

Normal scenario

The normal scenario makes use of a typical Quooker configuration and typical kitchen cabinet and accessories dimensions. This will further validate the location found in the critical scenario and can help in determining an optimal location.

Critical dimensions

A typical kitchen sink has a square size, with a length and width of 400 [mm] and a depth of 200 [mm]. This means that a kitchen cabinet has to be of at least similar dimensions to properly fit the sink. In this case a kitchen cabinet width of 450 [mm] was decided. A standard kitchen counter has a height of 900 [mm]. With kitchen cabinet standing off the ground, this means that a height of 750 [mm] for the kitchen cabinet can be considered. This is again a standard dimension. The standard (and minimal) depth of a regular size kitchen is around 600 [mm]. This will also be used as depth for the kitchen cabinet. Using these dimensions creates the kitchen cabinet shown below.

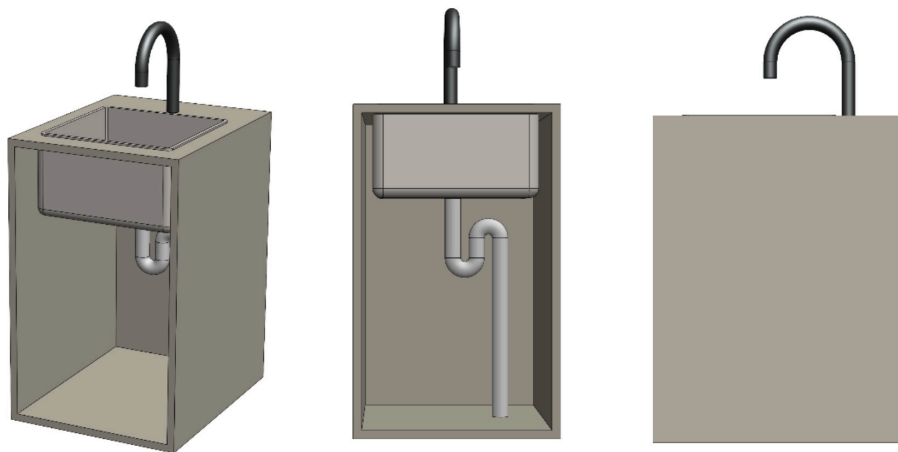


image [16]

Evaluating the 3D-model, it was deemed realistic for a critical scenario and will therefore be used for further analysis.

In order for the installation of an electronic mixing valve to even make sense, a Quooker reservoir would need to be installed in the kitchen cabinet. This is the first space claim that is added to the model. The largest available reservoir was chosen, which has a diameter of 200 [mm] and a height of 470 [mm]. This reservoir is placed 50 [mm] from the back side of the cabinet, in order to account for main water line connections.

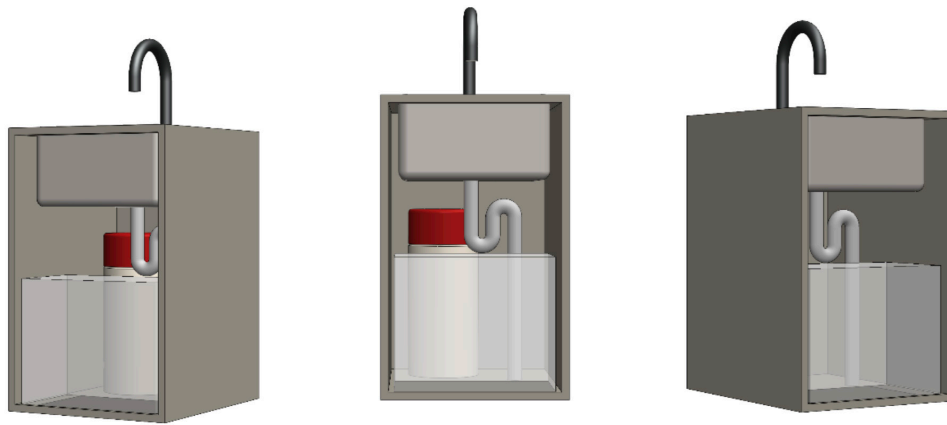


image [17]

Besides the reservoir, an additional space claim was added accounting for a variety of (cleaning) supplies placed in this cabinet. Through a quick analysis in an available kitchen cabinet, it was found that this space claim can be deemed sufficient with a height of 350 [mm]. The full width and depth available in front of the Quooker reservoir is used for this space claim. This results in the following images.

From this model it is clear to see that there is a 'stroke' along all the inner walls of the kitchen cabinet that is still free. When connected within this area the mixing valve would most likely not interfere with any other space claims inside of the cabinet. This stroke has a height of around 200 [mm], which would be enough for the space claim of the electronic mixing valve determined before ($135 * 135 * 50$ [mm]).

Analysing the available space shows that the electronic mixing valve will still be easily reachable when located on either of the sides of the kitchen cabinets. However, placing the mixing valve on the backside would further minimize the claimed space. Furthermore, the backside is closest to the faucet, minimizing the required line and hence minimizing the amount of 'dead water' in the system.

Conclusion

This stroke motivates indicating connections on the front of the electronic mixing valve, since it is on the front when within obstructed view (the backside of the kitchen cabinet). Furthermore, placing them on the front means all of the indications of connections are within the same field of view, ensuring that they will be visible wherever the valve is placed inside of the kitchen cabinet.

Since the ground floor is more precious space to claim inside of the kitchen cabinet, the mixing valve should be designed in a way that it can be fastened on the side of the wall with minimal effort. This way a minimal space claim within less valuable space within the kitchen cabinet can be claimed for the valve. Minimizing this claim minimizes the compromises users will have to make when opting for an electronic mixing valve.

P. Communication

A communication style similar to other Quooker products is chosen. Using this style of communication will ensure that the user will be able to identify which product within their configuration (tap, valve or reservoir) is not functioning.

LED is turned off when not dispensing

Normal functioning, resting state

LED is turned on when dispensing

Normal functioning, active state

Failure, blinking LED

Leakage at plungers

Temperature sensor + Flow sensor

Flow sensor: Determines leakage

Temperature sensor: Determines which plunger

Leakage at temperature sensor

Significant difference between position of plungers and measured flow rate

Leakage at brass inlet connectors

Significant difference in flow rate regarding the position of the plunger

Flow rate is relatively low when plungers are open

Leakage at brass outlet

No communication from mixing valve, visual identification by user, due to low flow rate when maximum open.

Failure communication reservoir

No special features, Mixture water is normal

Failure communication tap

No features at all

Indication at both mixing valve and tap

Failure, no signal when communication from tap

Electronical failure

Plungers are automatically closed

No power to mixing valve

No signal, plungers closed, no dispensing

Q. Material decision

The electronic mixing valve makes use of several custom made components. Each of these components is likely to have a different materialisation, fitting to the specifications required. Some requirements are identical for all components.

Quantity of produced goods is 20.000 per year. For now the expected production span is 5 years, resulting in a total of 100.000 electronic mixing valves.

Inner channels and housing combination

The likely critical custom part within the electronic mixing valve assembly is the combination of the inner channels and the housing. Not only are all external components connected to this piece, it will also be the part that will be constantly exposed to a combination of different temperatures water. Furthermore, sections of this part will be directly visible to the user, meaning it should aesthetically fit in. The volume of this component is extracted from an initial CAD-file and estimated at $8.9E-5$ [m³].

Three variables deemed critical are used as selection criteria.

A high temperature resistance against both boiling water and steam
Certification of the material to be drinking water safe.

Total raw material costs per part not to exceed € 1,00. It is expected that materials fulfilling both requirements stated before will have a large range in costs, therefore this threshold is set. This limit is motivated by an educated guess, with cost price of other components, as well as further material processing in mind as well.

The material should be suitable for an injection molding process.

Material selection

A first explorative research involving R&D engineers working at Quooker B.V. already presented a variety of potential materials used in current products. These are the following:

PPSU: A high performance polymer especially suitable for food and drinks related applications. The virgin material is transparent, composites will be translucent.

PSU: A high performance polymer with similar specifications to PPSU, but less high performance. It is considered a less expensive alternative. It is also transparent, blends will be translucent to opaque.

PEI: A high performance polymer which often serves as a cheaper alternative to PEEK. The material is transparent to opaque, depending on the composition. Adding reinforcements resulting in a composite will reduce transparency.

PPA: A subset of PA. In comparison to PA, PPA blends are likely to have a higher strength and stiffness at higher temperatures, a better creep resistance and sensitivity to moisture absorption. Virgin material is translucent, blends are opaque.

Furthermore, a website specifically developed for material selection was used: Plasticprop.com. Through an array of questions, this website comes up with a list of potential materials. This website presented the following materials as suitable for this specific application:

PSU
PPSU
PES
PPA (GF reinforced)

Besides this preliminary selection, a chart was created within Cambridge Engineering Selector 2019, Level 3 Polymers using the set variables. This analysis resulted in blends of the following polymers:

ASA+PC
DAP
PC
PF
PPA
PSU

This combination of preliminary selections can be used for a first filter of suitable materials. PPSU and PEI are likely to be too expensive for the application decided here. A volume cost price indication was integrated in the CES selection criteria (knowing the volume of the CAD-file). Both PPA and PSU are options named by both Quooker B.V. employees and CES Edupack, meaning that the materials are in principle suitable, as well as known within the company already.

All of the remaining materials out of CES were analysed in order to assess their suitability.

DAP

Although DAP fulfils the set requirements, it has a relative high percentage of glass fibre in its blend, starting at 50%. This is not beneficial for its recycling potential (which is noted as “unsuitable” by CES). Another downside is the fact that CES only names one supplier of the polymer blend. This raises availability and supplier dependency questions. Therefore, this material is not deemed suitable.

ASA+PC

Although having excellent resistance against water, the majority of ASA+PC blends do not have drink water certification. The limited remainder raises questions about its suitability. Furthermore, after initial research it was found that this material is not used for similar applications, further substantiating scepticism towards this option.

Amongst others, these reasons were decided to not further explore this option.

PC

PC is often used because of its transparent ability. Blends often have BPA, which is not preferable for a long term drinking water related product. Furthermore, just deemed unsuitable due to its behaviour over long term (creep, fatigue and exposure to moisture).

PF

The material has poor recyclability, with 99,9% of available bulk material being virgin. Furthermore, a critical report of the World Health Organization was found, discussing the presence of Formaldehyde (the F in PF) in drinking water. Mainly for this reason it is deemed unsuitable.

Through this selection, two potential material compositions remain, being PSU and PPA.

Virgin PPA does most likely not require the specifications set. However, using a Glass fibre blend is a good option. Table 22 presents different properties of PSU and PPA with different glass fibre blends.

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

table [22]

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. In 2014, the European Commission set increased recycling targets, aiming towards a percentage of 65% of plastics being recycled by 2025. Currently, Western European countries have an average recycling rate of 50% for all plastics.

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. 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 below.

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

table [23]

R. Material datasheet

PROPERTIES

Mechanical Properties

		Standard	Unit	State	Grivory HT1VA-4 FWA Black 9225
Tensile E-Modulus	1 mm/min	ISO 527	MPa	dry cond.	14'500 14'500
Tensile strength at break	5 mm/min	ISO 527	MPa	dry cond.	250 230
Elongation at break	5 mm/min	ISO 527	%	dry cond.	2 2
Impact strength	Charpy, 23°C	ISO 179/2-1eU	kJ/m²	dry cond.	70 70
Impact strength	Charpy, -30°C	ISO 179/2-1eU	kJ/m²	dry cond.	65 65
Notched impact strength	Charpy, 23°C	ISO 179/2-1eA	kJ/m²	dry cond.	11 11
Notched impact strength	Charpy, -30°C	ISO 179/2-1eA	kJ/m²	dry cond.	11 11
Ball indentation hardness		ISO 2039-1	MPa	dry cond.	300 300

Thermal Properties

Melting point	DSC	ISO 11357	°C	dry	325
Heat deflection temperature HDT/A	1.8 MPa	ISO 75	°C	dry	280
Heat deflection temperature HDT/C	8.0 MPa	ISO 75	°C	dry	160
Thermal expansion coefficient long.	23-55°C	ISO 11359	10 ⁻⁶ /K	dry	15
Thermal expansion coefficient trans.	23-55°C	ISO 11359	10 ⁻⁶ /K	dry	45
Maximum usage temperature	long term	ISO 2578	°C	dry	140
Maximum usage temperature	short term	ISO 2578	°C	dry	250

Electrical Properties

Dielectric strength		IEC 60243-1	kV/mm	dry cond.	30 30
Comparative tracking index	CTI	IEC 60112	-	cond.	600
Specific volume resistivity		IEC 60093	Ω · m	dry cond.	10 ¹⁰ 10 ¹⁰
Specific surface resistivity		IEC 60093	Ω	cond.	10 ¹⁰

General Properties

Density		ISO 1183	g/cm³	dry	1.53
Flammability (UL 94)	0.8 mm	IEC 60695-11-10	rating	-	HB
Water absorption	23°C/sat.	ISO 62	%	-	3.5
Moisture absorption	23°C/50% r.h.	ISO 62	%	-	1.5
Linear mould shrinkage	long.	ISO 294	%	dry	0.10
Linear mould shrinkage	trans.	ISO 294	%	dry	0.55

Product nomenclature: ISO 16396-PA6T/6I,GF40,M1H,C12-140

S. Cost price estimation

In this chapter, the cost price per component is explained. Custom parts may have a more extensive explanation, whilst the explanation of cost for purchase parts is pretty straight forward. Again, prices are only given in percentages.

Back housing

The screenshot shows the BASF injection molding calculator interface. It is divided into several sections:

- Design new part:** A dropdown menu.
- Material Properties:**
 - Specific Gravity of New Material: 1.38
 - Volume of Material in New Part (cm³): 110
 - Weight in New Material (Kg): 0.15
 - Cost of New Material (\$/Kg): 6.2
 - Estimated Material Cost per part is: 0.94
- Part Dimensions and Production:**
 - 1. Annual Number of Parts*: 100000
 - 2. Wall Thickness (millimeters): 2
 - 3. Projected Area of Part (cm²): 1105
 - 4. Enter the press size w/ operator:
 - Yes (\$/hr): 50
 - No, calculate based on 2005 nat'l avg.
 - 5. Enter the number of cavities:
 - Yes: 1
 - No, calculate from annual volume
 - 6. Overhead Contingencies (%): 20
- Select One:**
 - Cycle Time (sec) (Recommended): [empty]
 - Estimated Based on Wall Thickness (Quick): 25
- Calculate Part:** A button.
- Results:**
 - Number of Cavities: 1
 - Cycle Time (seconds): 25
 - Press size per Cavity: 856.38
 - Parts per Hour: 144
 - Press Cost (\$/hour): 50
 - Processing Cost Per Part: 0.35
 - Contingencies/Overhead Costs: 0.26
 - Total Estimated Cost per Part: 5,2%**
- Reset Form:** A button.

The cost figures offered by BASF in this estimate are intended only to indicate order of magnitude, based on preliminary design, to determine the feasibility of a specific plastic application. Because of such variations as labor rate, overhead, individual production techniques, accounting procedures, and available equipment among fabricators, this estimate should not be construed as a firm cost figure, or a quotation to manufacture.

image [18]

Calculation the injection molding costs can be difficult and calculating principles vary largely. Through consultation, the BASF injection molding calculator was deemed sufficient for an estimate in price calculation. This calculator accounts for volume, surface area, material costs and processing times. Complexity of the mold is accounted for by multiplying the estimated cost per part by a specific factor. This factor accounts for the number of parts produced and the costs of mold production. Using these values, the total estimated cost per part is 5,2 % of the total costs [20]

Front cover

Again, the BASF injection molding calculator is being used. This component is relatively simpler (not involving any sliding mold parts) and makes use of a cheaper material. Therefore, the total costs is just 2.2 %

All O-rings and washers

A local supplier, as well as multiple sources from the internet resulted in an estimated cost price for each O-ring. These estimations showed that there is hardly any variety in the costs due to the size. Each of the O-rings in the final assembly is estimated to be 0,2 % of the total cost estimation. The washer is estimated at 0,1 %.

Swivel and swivel retaining clip

These components are already used by Quooker in their current mechanic mixing valve. Therefore, the current cost price is being used. This results in the swivel being 0,4 % and the retaining clip being 0,1 % of the total cost price estimation.

Design new part

Specific Gravity of New Material

1.5

Volume of Material in New Part (cm³)

44.7

Weight in New Material (Kg)

0.07

Cost of New Material (\$/Kg)

2.9

Estimated Material Cost per part is

0.19

1. Annual Number of Parts*

100000

2. Wall Thickness (millimeters)

2

3. Projected Area of Part (cm²)

472

4. Enter the press size w/ operator

☒ Yes (\$/hr) 50
☐ No, calculate based on 2005 nat'l avg.

5. Enter the number of cavities

☐ Yes
☒ No, calculate from annual volume

6. Overhead Contingencies (%)

10

Select One:

☐ Cycle Time (sec) (Recommended)
☒ Estimated Based on Wall Thickness (Quick)

25

Number of Cavities

1

Cycle Time (seconds)

25

Press size per Cavity

365.8

Parts per Hour

144

Press Cost (\$/hour)

50

Processing Cost Per Part

0.35

Contingencies/Overhead Costs

0.05

Calculate Part

Total Estimated Cost per Part: 2,2%

The cost figures offered by BASF in this estimate are intended only to indicate order of magnitude, based on preliminary design, to determine the feasibility of a specific plastic application. Because of such variations as labor rate, overhead, individual production techniques, accounting procedures, and available equipment among fabricators, this estimate should not be construed as a firm cost figure, or a quotation to manufacture.

Reset Form

image [19]

Internal cover

Again, the same calculator is being used. The internal cover is produced out of the same material as the back housing, but uses significantly less material and has more surface compared to its volume (reducing cooling time). These factors conclude in a total estimated cost per part of 3,1 %.

Design new part

Specific Gravity of New Material

1.38

Volume of Material in New Part (cm³)

95

Weight in New Material (Kg)

0.13

Cost of New Material (\$/Kg)

3.4

Estimated Material Cost per part is

0.45

1. Annual Number of Parts*

100000

2. Wall Thickness (millimeters)

2

3. Projected Area of Part (cm²)

877

4. Enter the press size w/ operator

☒ Yes (\$/hr) 50
☐ No, calculate based on 2005 nat'l avg.

5. Enter the number of cavities

☒ Yes 1
☐ No, calculate from annual volume

6. Overhead Contingencies (%)

20

Select One:

☐ Cycle Time (sec) (Recommended)
☒ Estimated Based on Wall Thickness (Quick)

25

Number of Cavities

1

Cycle Time (seconds)

25

Press size per Cavity

679.68

Parts per Hour

144

Press Cost (\$/hour)

50

Processing Cost Per Part

0.35

Contingencies/Overhead Costs

0.16

Calculate Part

Total Estimated Cost per Part: 3,1%

The cost figures offered by BASF in this estimate are intended only to indicate order of magnitude, based on preliminary design, to determine the feasibility of a specific plastic application. Because of such variations as labor rate, overhead, individual production techniques, accounting procedures, and available equipment among fabricators, this estimate should not be construed as a firm cost figure, or a quotation to manufacture.

Reset Form

image [20]

Brass connectors

Quooker B.V. already has similar brass connectors in other products. Therefore, a cost price estimation can be made using the cost of these already existing products. The brass pieces are mass machined. Cost price per part is estimated at around 1,3 % of the total costs.

Hall sensor + Flow rate turbine

Through extensive sourcing, a company was found who is able to deliver the components with the specifications as requested. A quotation was given for the total amount of pieces that would be required to produce all of the electronic mixing valves (100.000). These quotations showed the cost of the hall sensor to be 3,0 % and the flow rate turbine to be 3,8 % of the total costs.

E-clips (Circlips)

Similar to the O-rings, a local supplier, as well as multiple sources from the internet resulted in an estimated cost price.. Different prices were combined to result in an estimation of **0,1 %** per part.

Jacks and power line

Different online suppliers were sourced to find competitive pricing for all of these components. Sufficient configurations were found, and the cost price estimation for large quantities is taken. This results in a cost price estimation of **9,8 %** for the power cord and adapter. Although cost estimations of the jacks are known, they are not taken into account, since they belong to other subsystems. The jack for the tap would most likely be permanently connected to the tap's PCB. The jack for the reservoir is deemed crucial for the reservoir and not functioning of the mixing valve. Therefore both these components are not included in the cost price estimation. For clarity they are however included in the image.

PCB

Through consultation with electronical engineers working at Quooker B.V. a cost price estimation of **22 %** was deemed realistic. This includes all of the connectors mounted on the PCB and the collection of wiring to connect all the components to the PCB, unless wiring is already included with the standard component configuration and hence purchase price.

Proportional control assembly

There is only one supplier who produced this proportional control assembly: Hydraelectric. Through consultation with the company a quotation is proposed accounting for the amount of components required. Furthermore, some of the parts of these components are custom materialised to perform within the proposed environment. The estimated cost price of one assembly is **13 %** of the total cost price estimation. This includes both the solenoid and plunger.

Thermistor

Through direct digital contact with a representative of the thermistor supplier, Mitsubishi, a quotation was given accounting for the number of pieces required. using this quotation, the cost price estimation of one thermistor is **4,4 %** of the total cost price estimation.

Assembly costs

Being aware of the current assembly costs of a mechanical mixing valve, an estimation for the assembly costs of the new electronic mixing valve is made. This estimation accounts for the increase in assembly steps and the complexity of these steps. The estimated assembly costs are **14 %** of the total cost price estimation of the electronic mixing valve

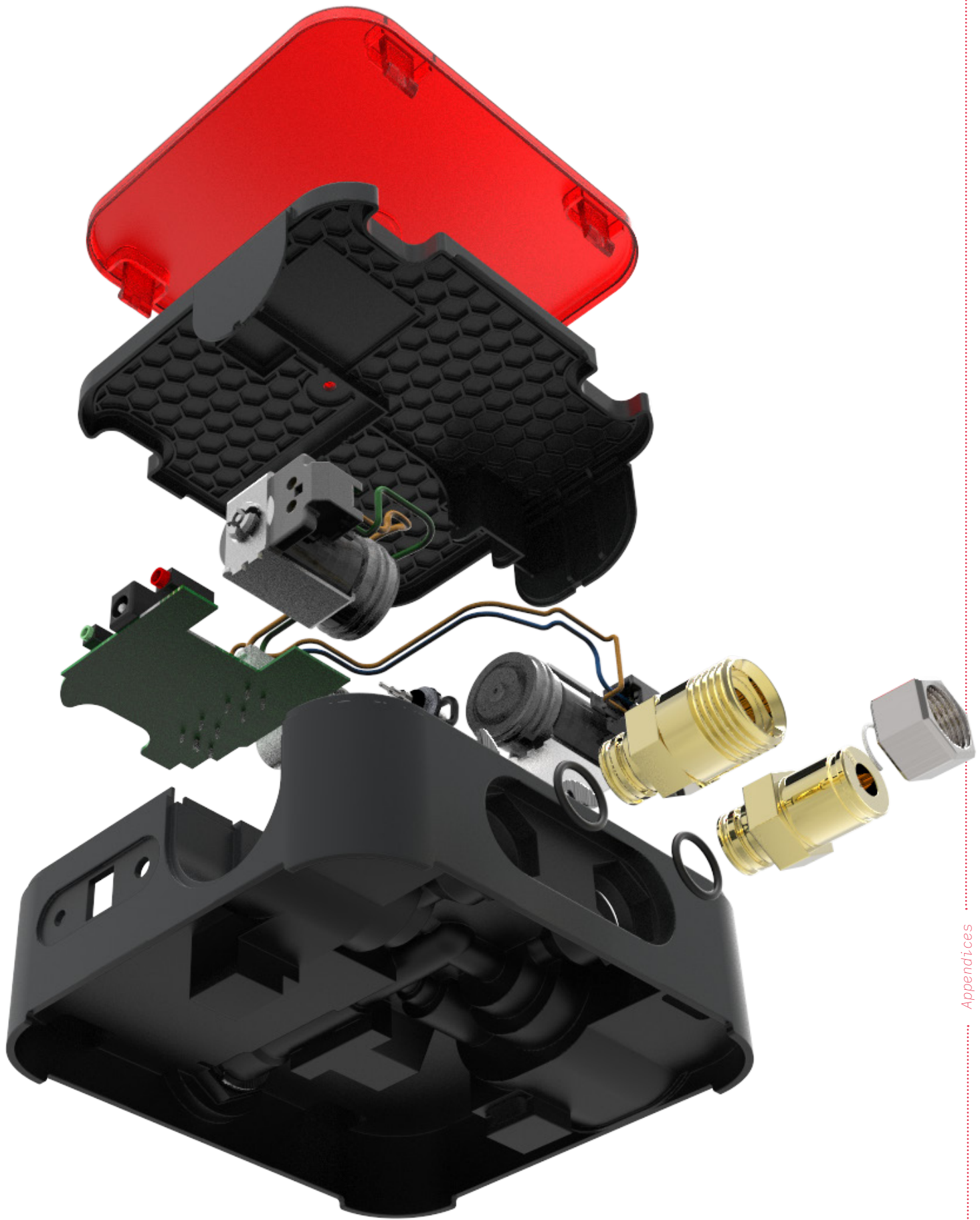


image [21]

T. FMEA

Below the Failure mode and effect analysis of the electronic mixing valve is presented. This FMEA was performed after embodiment of the concept but before ordering of the prototype. Therefore, other failure possibilities that might occur during the construction and testing of the prototype are not included.

7	Thermistor	Incorrect installation	Tolerances Creep	Leakage of mature water Loss of flow rate	4	4	1	How to let the hot water flow out before somebody asked for the opening valve? This is a serious issue Same as above
		Incorrect measurement	Incorrect assembly Production Assembly	Internal condensation / water, resulting in short circuiting Incorrect water temperature Scaling	3	4	3	
		No measurement	Limescale buildup Production Assembly	Incorrect water temperature Scaling	3	5	2	
8	PCB	Dirt buildup (Limescale, Bacteria etc.)		Incorrect water temperature Scaling	4	7	4	
		Short circuit	Water Production failure	No control	6	3	8	
		Malfunctioning	Water Production failure	Scaling Incorrect water dispensing No IP44 + consequences	4	9	4	
9	Front cover	Tear in housing	Failed production Dropping	Housing falls apart	1	7	8	
		Geometrically incorrect	Incorrect assembly Incorrect tolerances Creep	Housing falls apart	4	7	9	
			Failed production Dropping	NO IP44 + consequences Housing falls apart	4	7	8	
10	Mounting bracket	Fails	Material failure Incorrect fastening Incorrect mounting Too much pressure Material distortion Rust	Damage to mixing valve Leakage	4	7	6	Visually not the best, however products functioning does not change
			Material failure Incorrect fastening Incorrect mounting Too much pressure Material distortion Rust	Leakage	1	3	6	
			Material failure Incorrect fastening Incorrect mounting Too much pressure Material distortion Rust	Leakage	7	3	7	
11	Circuits	Breaking or deforming	Material failure Incorrect fastening Incorrect mounting Too much pressure Material distortion Rust	Water pressure loss Short circuiting	4	8	3	
			Material failure Incorrect fastening Incorrect mounting Too much pressure Material distortion Rust	Water pressure loss Short circuiting	2	8	1	
			Material failure Incorrect fastening Incorrect mounting Too much pressure Material distortion Rust	Water pressure loss Short circuiting	5	6	6	

image [22]

Ref.	Item / Function	Potential Failure Mode(s)	Potential Cause(s) / Mechanism(s) of Failure	Potential Effect(s) of Failure	Probability	Severity	Detectability	Risk Priority Number	Remarks / Mitigations / actions
1	Back Housing	Tear in back housing	Failed production	Leakage inside housing / leakage inside kitchen cabinet	1	7	8		
			Dropping		4	7	9		
			Incorrect assembly		5	7	6		
			Incorrect tolerances		4	7	2		
2	Purger + Solenoid	Undrinkable water	Bacteria Growth inside channels	Poisoning	3	9	1		Hardly measurable, severe consequences, needs more extensive long term research Same as above Same as above
			Limescale buildup		3	9	1		
			Incorrect material composition	Poisoning	2	9	1		
			Valve does not close properly	Dripping / Sealing	4	7	5		
			Scaling		3	7	5		
			Obstruction from dirt		3	7	5		
			Tolerance failure		2	7	5		
			Spring is too weak		1	7	5		
			No power from PCB	No Water deposit / too hot water deposit / incorrect temperature	6	5	5		
			Internal electronic failure		5	5	5		
3	Hall Sensor	Valve does not open properly	Spring is too strong		1	5	5		
			Magnet is too weak		1	5	5		
			Tolerance failure		2	5	5		
			No Power from PCB		6	4	3		
			Internal electronic failure	No Flow control	5	4	3		
			Electronic failure	Constant Flow / No Flow when required	6	4	3		
			Incorrect installation	No Flow control	3	4	3		
			Constant Flow / No Flow when required	Constant Flow / No Flow when required	3	4	3		
			Falling out during usage	No flow control	4	3	3		
					4	3	3		
4	Flow turbine	Not functioning	Limescale deposition	No Flow control	3	4	3		
			Bacteria Growth	Constant Flow / No Flow when required	3	4	3		
			Material Failure		2	4	3		
			Parts missing		2	4	3		
			Parts coming loose during usage		2	4	3		
			Limescale deposition	No Flow Control	2	4	3		
			Bacteria Growth	Incorrect flow rate measurement	2	4	3		
			Material Failure		2	4	3		
			Parts start moving		4	4	3		
			Magnetic forces change		2	4	3		
5	Internal cover	Incorrect installation	Turbine only flows one way	No Flow control	5	4	3		
			Failed production	No IP44 + consequences	1	7	8		
			Dropping		4	7	9		
			Incorrect assembly		4	7	6		
			Incorrect tolerances		5	7	4		
			Creep		4	7	2		
			Failed production	NO IP44 + consequences	1	7	8		
			Dropping		4	7	9		
			Incorrect assembly		4	7	6		
			Incorrect tolerances		5	7	4		
6	Each brass connector	Material failure	Creep		4	7	2		
			Failed production	Leakage of boiling water	2	7	4		
			Dropping	Loss of flow rate	5	7	3		
			Incorrect assembly	Leakage of water into housing	3	7	5		
			Incorrect tolerances		3	7	5		
			Creep		6	7	2		
	Undrinkable water	Incorrect installation	Bacteria Growth inside channels	Poisoning	2	9	1		Hardly measurable, consequences could be severe Same as above Same as above Leakage means hot water into kitchen cabinet, problems with disassembly of the product Same as above
			Limescale buildup		2	9	1		
			Material detrition		2	9	1		
	Incorrect assembly	Incorrect tolerances		Leakage of boiling water	6	8	7		
				Loss of flow rate	6	8	4		
				Leakage into housing					

U. Assembly tree

MAIN MONTAGE TREE

Step no.	Assembly procedure	Time	Type of action
A	<i>Grab back housing</i>		Hand action
	1 Mount on assembly surface		Clamping tool
B	<i>Grab 2 plungers</i>		Hand action
	2 Mount Plunger 1.		Screwdriver + designated tool
	3 Mount plunger 2.		Screwdriver + designated tool
C	<i>Grab 2 solenoids</i>		Hand action
	4 Place solenoid 1 on plunger 1		Hand action
	5 Rotate solenoid 1 to correct position		Hand action
	6 Place solenoid 2 on plunger 2		Hand action
	7 Rotate solenoid 2 to correct position		Hand action
D	<i>Grab temperature assembly</i>		Hand action
	8 Press temperature assembly in orifice (SUB A)		Press tool
E	<i>Grab Hall sensor</i>		Hand action
	9 Place Hall sensor in designated spot		Hand action
1A	SWITCH TO RIGHT SIDE		Move mounting tool
F	<i>Grab boiling inlet combination</i>		Hand action
	10 Press boiling inlet combination (SUB B)		Press tool
G	<i>Grab main water line inlet</i>		Hand action
	11 Press Main water line inlet (SUB C)		Press tool
1B	SWITCH TO LEFT SIDE		Hand action
	12 Press in flow rate turbine		Press tool
H	<i>Grab Mixture water outlet</i>		
	13 Press in mixture water outlet (SUB D)		Press tool
1C	SWITCH TO TOP SIDE		Move mounting tool
I	<i>Grab 3 Circlips</i>		
	14 Place Circlip around boiling water inlet		E-clip mounting tool
	15 Place Circlip around main water inlet		E-clip mounting tool
	16 Place Circlip around mixture water outlet		E-clip mounting tool
J	<i>Check fastening of brass inlets</i>		Hand action
K	<i>Check airtight mounting of components</i>		Airtight tester
L	<i>Grab PCB</i>		Hand action
	17 Place PCB in position		Hand action
	18 Connect solenoid 1 to PCB		Hand action
	19 Connect solenoid 2 to PCB		Hand action
	20 Connect thermistor to PCB		Hand action
	21 Connect Hall sensor to PCB		Hand action
M	<i>Grab internal cover</i>		Hand action
	22 Place and align internal cover on top of back housing		Hand action
N	<i>Check alignment internal cover</i>		Hand action
O	<i>Grab front cover</i>		Hand action
	23 Align front cover		Hand action
	24 Push down front cover untill snap fits click into place		Hand action

SUB A MONTAGE TREE

Step no.	Assembly procedure	Time	Type of action
AA	Grab temperature sensor		Hand action
AB	Grab washer		Hand action
	1 Cable through washer, pull washer up untill flange		Hand action
AC	Grab retaining clip		Hand action
	2 Retaining clip around thermistor housing		Pliers
AD	Grab O ring		Hand action
	O-ring around thermistor housing mounting		
	3 against flange		Hand action / tool

SUB B MONTAGE TREE

Step no.	Assembly procedure	Time	Comments
BA	Grab Brass boiling inlet piece		Hand action
BB	Grab O ring		Hand action
	1 O-ring around brass piece		Hand action / tool

SUB C MONTAGE TREE

Step no.	Assembly procedure	Time	Comments
CA	Grab Brass main water line inlet piece		Hand action
CB	Grab swivel		Hand action
	1 Place swivel on brass piece		Hand action
CC	Grab Swivel retaining clip		Hand action
	2 Place swivel retaining clip on brass piece		Press tool
	SWITCH TO BOTTOM		Hand action
CD	Grab O ring		Hand action
	3 O-ring around brass inlet		Hand action / Tool

SUB D MONTAGE TREE

Step no.	Assembly procedure	Time	Comments
DA	Grab Brass mixture water outlet piece		Hand action
DB	Grab O-ring		Hand action
	1 O ring around brass piece		Hand action / Tool

V. Assessment proposal



Evaluation electronic mixing valve - April 2020

In order to validate the potential of electronic mixing for Quooker B.V., a prototype has been constructed. This prototype will be used to perform two different tests.

1. An internal qualitative experience test.
2. A quantitative performance evaluation.

With the aid of the qualitative experience test the use of the electronic mixing valve will be compared to Quooker B.V.'s current mechanical mixing valve. When obtained results prove to be positive, a quantitative performance evaluation will be performed. Within this test, the performance of the electronic mixing valve will be compared to other already available electronic mixing valves.

Assessment proposals for both tests are presented below.

Assessment proposal qualitative experience test.

Introduction

This research will evaluate the experience of users with the electronic mixing valve in comparison to Quooker B.V.'s current mechanical mixing valve. Only user experience will be considered. We will look at the experience in regard to the mechanical mixing valve and whether potential changes are positive, negative or neutral.

Goal I

Prove whether the new electronic mixing valve with proportional valves would be able to replace the mechanical mixing valve of Quooker B.V. If so, would the current portfolio allow introduction of this valve. This would result in more design freedom, less critical tolerances, less components etc. And allow for the exploration of new product interactions.

Scenario	
Current	Electronic mixing is not being used
Digitale cartridge + Electronic mixing valve	Product interaction remains the same.
New tap + Electronic mixing valve	Using a new tap will allow for a reduction of components and critical tolerances, Further research regarding the acceptance and ease of use is required. This is not included in the assessment.

The core potential of the mixing valve is not its new interface, but the increased repeatability. The user would not be required to guessimate a specific temperature and flow rate, but has the ideal values almost instantly.

Hypotheses

1. The new electronic mixing valve is quicker in dispensing the correct temperature and flow rate.
2. The new electronic mixing valve has more fluctuations when the user does not interact with the interface.
3. The electronic mixing valve in combination with a digital cartridge is a sufficient replacement for Quooker B.V.'s current system.
4. H1 and H3 are dependent on the functioning of the digital cartridge and communication to and from the electronic mixing valve.

Method

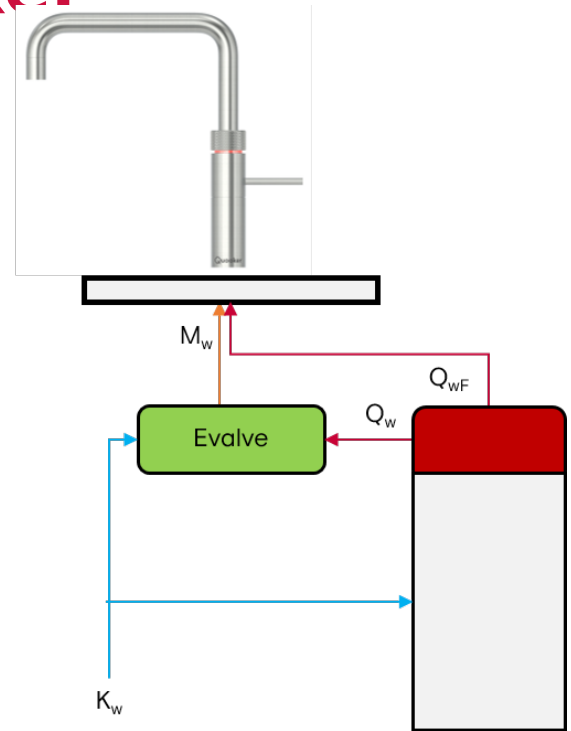
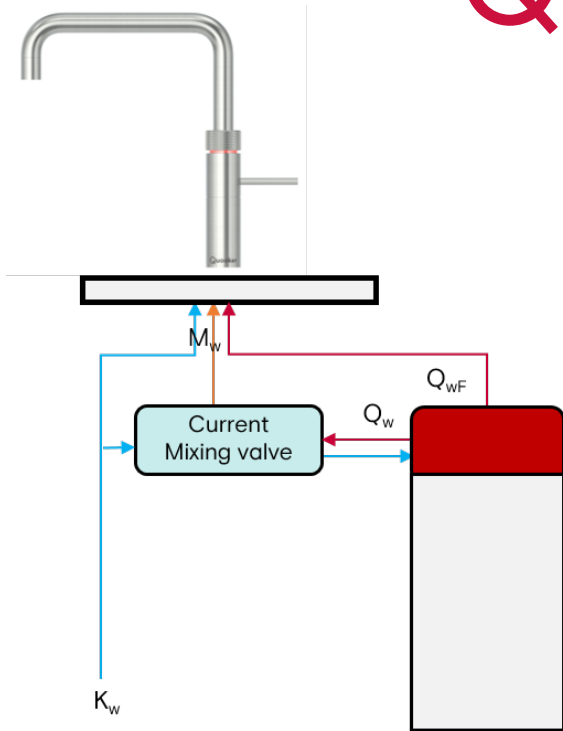
Measurements

Following actions need to be performed for both taps.

- Grab a glass of cold water.
- Wash ones hands.
- Wash the cutting board.
- Grab another glass of cold water.
- Prepare a mixture of soap and water for cleaning.
- Measure 100 ml in a measuring cup.

Setup

It is important that all people performing the testing procedure do not know which one of the two configurations has a digital or mechanical cartridge



Necessities

- Tap setup
- 1x Fusion, Combi+, mechanical mixing valve
- 1x Fusion with digital cartridge, Combi+, electronic mixing valve
- Glass, Soap, Dish soap and a measuring cup
- Around 20 people, it is important to include internal stakeholders.

Research proposal qualitative performance assessment

Introduction

Developing an electronic mixing valve involves many different performance related challenges. Similar mixing valves already available on the market have (as expected) withstood these challenges. By means of a quantitative test, the Quooker electronic mixing valve will be compared with other available products.

Goal

The aim of this research is to gain insight into how the Quooker electronic mixing valve measures itself with existing alternatives. Results of the research show the strong and possible improvement points of the current electronic mixing valve. Furthermore, the research provides insight into the extent to which one can go performance-technical in terms of electronic mixing.

Criteria

The electronic mixing valve developed within Quooker has three main functions:

- Releasing water at a specific, preset temperature.
- Releasing water at a specific, preset flow rate.
- Releasing a specific, preset amount of water.

The different mixing valves will be judged, per function, on the following performance criteria:

- Speed
Speed is defined as the time it takes for the mixing valve to move from a predetermined starting situation to a predetermined final situation.
- Precision
Precision means how exactly the mixing valve is able to hold a predetermined situation. Verder worden de volgende performance criteria vergeleken:
- Hoeveelheid functies
Here we will look at the amount of functions compared to Quooker's electronic mixing valve.
- Energieverbruik
The energy consumption of the various mixing valves will be taken into account. A distinction will be made between the standby power and the average power during use.
- Prijs
A price comparison will be carried out looking at the price of an electronic mixing valve as such, without additional accessories. A cost estimate will also be made for each mixing valve.

Comparison

For now, the choice has been made to compare Quooker's electronic mixing valve with three other available solutions:

- **Sedal**
This electronic mixing valve, like Quooker, uses proportional solenoid valves to independently control water flows. These solenoid valves are supplied by Hydraelectric, just like the prototype of Quooker.

- **Oblamatik**

This electronic mixing valve has been developed in cooperation with Flühs, cartridge manufacturer. It is the most compact solution with an optically very robust appearance. The system uses a cartridge driven by a stepper motor.

- **Grohe**

This electronic mixing valve uses two separate servo-controlled valves. This makes both water flows independently controllable. As a major competitor of Quooker, this is an interesting system to compare.

Necessities

In order to carry out this research, a number of supplies are required:

- Different mixing valves available on the market (consumer and B2B).
- A Quooker electronic mixing valve.
- A tap and water installation to which all these different mixing valves can be connected.
- A flow meter which can be mounted on the outlet of each mixing valve.
- A temperature gauge which can be mounted on the outlet of each mixing valve.
- A scope for measuring the energy consumption of the mixing valves.
- A measuring cup to collect the water that leaves the tap.
- A scale for determining the volume.
- A video camera or other recording equipment.

Procedure

Parts of the research can be carried out separately. For this reason, the research has been divided into two segments:

- Niet-praktisch onderzoek
Values for each mixing valve will be obtained by means of different analysis and research methods.
- Praktisch onderzoek
Different measurement values will be obtained by carrying out practical scenarios.

Non Practical research

The non-practical research will compare the number of functions and the price of each mixing valve.

Number of functions

A function is defined as the manipulation of a variable. So far, three manipulable variables have been identified:

- Temperature (degrees Celsius)
- Flow rate (Liter per minute)
- Volume (Liter)

First of all, we look at how many of the variables mentioned above can be checked with each mixing valve. After this it is checked whether a mixing valve is still able to influence other variables. It is important that these variables are specified by the manufacturer as a feature.

Price

As far as possible, a sales price and cost price will be determined for each product separately, without accessories. Where the selling price is easy to find, a standard price for the cost price will be determined.

cost calculation sheet are used. In the case of Quooker's own electronic mixing valve margins that are comparable to other products within the Quooker range, in order to arrive at a realistic sales price.

Practical research

Within the practical research we will look at measuring values that are obtained by executing a scenario that is the same for each mixing valve. This research focuses on the speed and precision of setting a temperature, setting a flow rate, setting a certain volume of water and the energy consumption during these operations.

Prior to this test, the minima and maxima of temperature, flow and volume settings will be determined for each mixing valve chosen. These will be noted separately. After this, a minimum and maximum range will be set up for all three functions, so that each mixing valve can meet these requirements.

Function	Minimum	Maximum
Temperature	... [°C]	... [°C]
Flow rate	... [L / min]	... [L / min]
Volume	... [L]	... [L]

A starting position will be selected for both temperature and flow. This position will be used as the initial value. Each mixing valve must first release this initial value for XX seconds before making a set change.

Function	Initial value
Temperature	... [°C]
Flow rate	... [L / min]

Once these values have been determined, the following scenario will be executed for each functionality that the mixing valve possesses.

Starting from the initial value. ... [°C] or [L / min] should change the mixing valve to ... [°C] or [L / min] as soon as possible. This value should be held for ... number of seconds, after which the mixing valve should change the water flow back to the initial value of ... [°C] or [L / min].

Depending on the size of the ranges found, intermediate values can be taken in addition to the minimum and maximum values. These intermediate values can also be selected for frequently used temperatures and/or flow rates. For each mixing valve, each procedure must be carried out 3 times.

As it is very likely that not every electronic mixing valve with a similar control can be controlled (computer controlled or manually controlled), every execution of a scenario should be recorded with the help of recording equipment. In the case of outliers, a possible 'human error' (or other system-related error) can then be recorded.

For each whole scenario, the following variables should be recorded in the form of graphs:

- De temperatuur in [°C] over tijd [s]
- Het debiet in [L / min] over tijd [s]

For the volume, a separate test must be carried out, in which different volumes must be tapped several times. These volume tests should be carried out at the initial values for temperature and flow. Each volume should be tapped 3 times.

Data processing

Quooker®

All obtained values should be summarized in a clear table. From the non-practical research the following values are added:

- Amount of functions [n]
- Selling price [€]
- Cost estimate [€]

From a practical research point of view, the following values should be added to the table:

- Minimum and maximum temperature of the mixing water from the mixing valve [°C].
- Minimum and maximum flow rate of mixing water from the mixing valve [L / min].
- Minimum and maximum volume of mixing water from the mixing valve [L]

The averages for the following values should be added for each of the 3 equally applied scenarios:

- Duration to reach the set temperature [s]
- Duration of reaching the initial value from the set temperature [s]
- Duration to reach a set flow rate [s]
- Duration of reaching the initial value from a set flow [s]
- Maximum deviation while maintaining the set temperature [% vs. set temperature].
- Maximum deviation while maintaining a set flow [% vs. set flow].
- In addition to these values, a separate table should show the average value of all mixing valves together per category.

Evaluation

After filling in these values per mixing valve, the most favourable value per category should be indicated with a green marking. The least favourable value should be indicated with a red marking. The value per category that is closest to the average should be indicated by an orange marking.

After this a ranking can be made per category using different assessment methods (think of a weighted values method or something similar). By classifying the categories hierarchically, a total performance ranking can be drawn up for all mixing valves.

Important notes

- **With which electronic mixing valves do we want to compare? Initially look at cost price in order to come to a fairer comparison.**
- **Can we check each mixing valve in use and connect it to the same faucet?**

W. Validation P.o.R.

The structure of validating the programme of requirements is as following: Each of the requirements is given an initial score, being: Sufficient, Not definite, Fail. The score “Sufficient” is given when the requirement can be conclusively validated, not requiring significant extra research. “Not definite” is given when further research/ analysis or testing is required. it is no positive nor a negative conclusion. Lastly, “Fail” is given when the requirement has not been met. Each of these scores is accompanied with an explanation and/or discussion.

1. Functionality

1.1 The electronic mixing valve must be able to provide water with a minimal temperature of the cold main water line and a maximum temperature of 95°C, with a typical main water line temperature of 10 degrees°C.

Not definite. All of the materials and components have been chosen in such a way that they should be able to function under determined circumstances. However, extensive testing is required to conclusively validate this. Long term deterioration of materials and components could presumably lead to failure.

1.2 The electronic mixing valve must be able to dispense water at a predetermined temperature indicated by the user, with a tolerance of 2°C.

Not definite / Fail. Throughout testing it was found that it is extremely difficult to achieve such a small error margin, because the configuration of the user might be vastly different from the conditions the mixing valve is used to. Longer water lines or a colder environment could lead to a differentiation from the predetermined temperature by the user, since the water would leave the mixing valve at the correct temperature, but would cool down too much or too little on its way towards the tap. The dispensed temperature would be unknown by the mixing valve and hence it would not be able to alter it accordingly.

1.3 The electronic mixing valve must be able to dispense a predetermined amount of water indicated by the user, with a minimum of 100 millilitres.

Sufficient / Not definite. Preliminary testing with the solenoids and plungers have shown that dispensing a predetermined amount of water should be possible. However, this functionality has not yet been tested in the final prototype, meaning that a conclusive sufficient can not be given.

1.4 The change in temperature initiated by the electronic mixing valve must not take longer than the current Quooker taps.

Sufficient / Not definite. The first prototype was already quicker than Quooker’s mechanical taps, thanks to active changing instead of waiting for a thermostatic element. However, this has not yet been tested extensively in the current prototype. Functionality largely remains the same, if not improved. Therefore, expectation is that it will be able to meet the set requirement.

2. Performance

2.1 The flow rate of water dispensed from the electronic mixing valve must be no less than 7 litres per minute for a temperature of 15°C and a pressure of 2,5 bar.

Not definite. Throughout CAD simulations pressure drops were calculated.

These never went above 0.1 [bar] for the whole system when completely opened. It is therefore expected that the mixing valve will be able to dispense this flow rate. This is however heavily dependent on the input pressure of both the boiling water and main cold water line. Further research would need to be required.

2.2 The flow rate of water dispensed from the electronic mixing valve must be no less than 3 litres per minute for a temperature of 95°C and a pressure of 2,5 bar.

Not definite Similarly to requirement 2.2

2.3 All of the parts in direct contact with water in the mixing valve should be able to withstand a temperature of 110°C. (for a period of maximum 5 minutes per 20 minutes).

Not definite. Similar to requirement 1.1. Each component and material is specified to withstand this. However, long term testing will show whether this requirement can be conclusively validated.

2.4 All of the parts in direct contact with water in the mixing valve should be able to withstand a minimum temperature of 4°C.

Not definite. Similar to requirement 2.3.

3. Leakage

3.1 The complete assembly of the electronic mixing valve must be able to withstand an air leakage test with a flow rate of 2,5cc per minute at a pressure of 3 bar.

Not definite. First testing has shown the prototype to be water proof and air tight. However, pressure increase resulted in failure. This is however in the prototype that has a lot more connections between connections than the concept. Therefore it is still expected that the concept will be able to withstand these pressures, when correct tolerances are used.

3.2 If applicable, the check valve must withstand an air leakage test with a flow rate of 100 cc per minute at a pressure of 1 bar.

Not definite. Similar to requirement 3.1.

3.3 The housing of the mixing valve unit should be dust and water resistant compliant with a IP44 rating.

Sufficient / Not definite. This IP44-rating has been important throughout the embodiment of the housing and should be functional. Tolerance refinement would most likely result in an IP44 rating. With the theoretical knowledge known currently, one would state that this requirement is met sufficiently.

4. Usage

4.1 The electronic mixing valve should be able to withstand wear during a period of at least 10 years, with an average use of 20 minutes per day. (With an average use span of 20 seconds this equals around 220.000 uses).

Not definite. All components should be able to, however only extensive long term testing can give a conclusive validation

5. Safety

5.1 In case of a power outage the electronic mixing valve should immediately shut down, not letting any boiling water through.

Sufficient. Throughout testing it has shown that the plungers always return to their closed position in case of a power outage. This is thanks to their

integrated springs. This is a mechanical safety operation which is not influenced by other components or water in any way and therefore expected to be sufficient.

5.2 Materials used in the electronic mixing valve should comply with the regulations regarding drinking water from the RIVM.

Sufficient. For now all of the chosen materials and components have drink water certification. Performance of these materials in regard to drinking water has hence already been proven. Therefore it is safe to conclusively assume that this requirement is sufficiently met.

5.3 The housing of the electronic mixing valve may not exceed a temperature of 45°C when in use.

Fail. Some parts, for example the brass connector on the boiling water inlet, will exceed this temperature. However, this also happens in current products within this category. This requirement is set by the KIWA. Close consultation with this institution will most likely show the importance of this requirement. For now the product does not succeed, but it is the question whether this requirement is fair.

6. Dimensions

6.1 The electronic mixing valve must fit in every kitchen cabinet configuration used currently by Quooker B.V.

Sufficient. Thanks to the communication lines, power lines and water lines and their connectors the product fits in every configuration currently used by Quooker B.V. It does however require a new tap.

7. Aesthetics

7.1. The electronic mixing valve must be one complete assembly with no separate parts.

Sufficient. All the components of the electronic mixing valve are in some way fastened to each other. Therefore the whole valve is one assembly.

7.2. The electronic mixing valve must be identifiable by a Quooker logo.

Sufficient. The Quooker logo is located on top of the translucent cover.

8. Installation

8.1 The electronic mixing valve must be usable in the current COMBI reservoir and foreseen configurations offered by Quooker based on a mixing valve.

Sufficient, see requirement 6.1.

8.2. The electronic mixing valve must be able to be installed with only common household working tools.

Sufficient. All of the installation that is required for this mixing valve is similar to that of the mechanical mixing valve. Only an extra power socket is required.

8.3. The electronic mixing valve should use standardized connections for Quooker B.V.

Sufficient, see requirement 8.2.

9. Maintenance

9.1 The electronic mixing valve must have an average maintenance interval of at least 5 years.

Not definite. In principle components should be able to survive such

maintenance intervals. However, only extensive long term testing can show whether this is the case in practical scenarios.

9.2 The electronic mixing valve must be serviceable with common household working tools.

Not definite. Similar to requirement 9.1.

10. Assembly

10.1 The electronic mixing valve must be able to be assembled within Quooker's current abilities.

Sufficient. Knowing Quooker B.V.'s current assembly possibilities, the electronic mixing valve should be able to be assembled within the facilities of Quooker B.V. and their partners. No complex tools are required, all of the assembly procedures can be performed with hands or hand tools.

11. End of life

11.1 The electronic mixing valve must have a minimal lifespan of 10 years.

Not definite. Similar to requirement 9.1.

11.2 The electronic mixing valve must have the possibility to partly be disassembled in metal and plastic parts.

Sufficient. Theoretically the electronic mixing valve is able to be completely disassembled into both metal and plastic parts. Whether this is economically viable in reality is a different question.

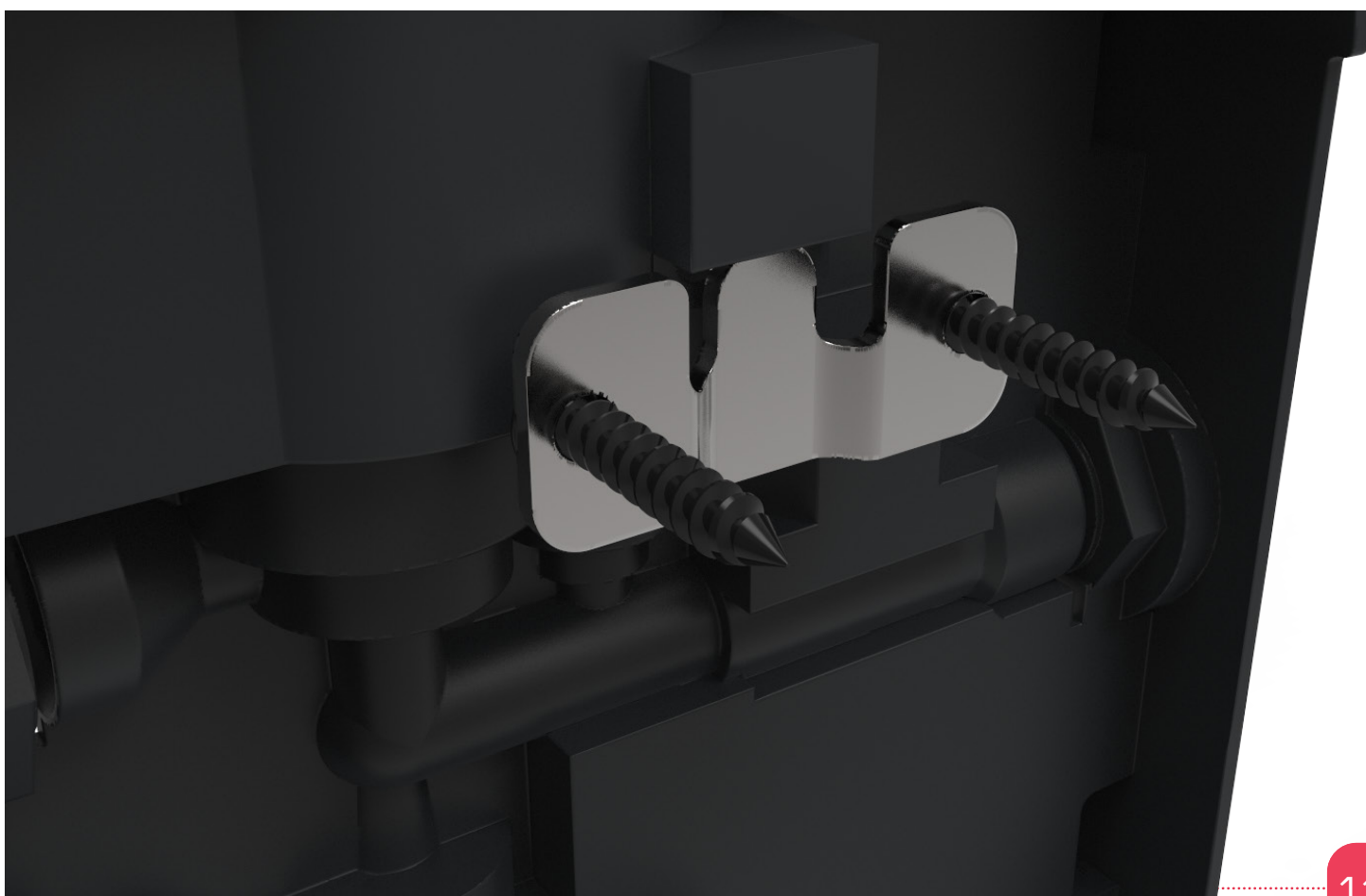
12. Costs

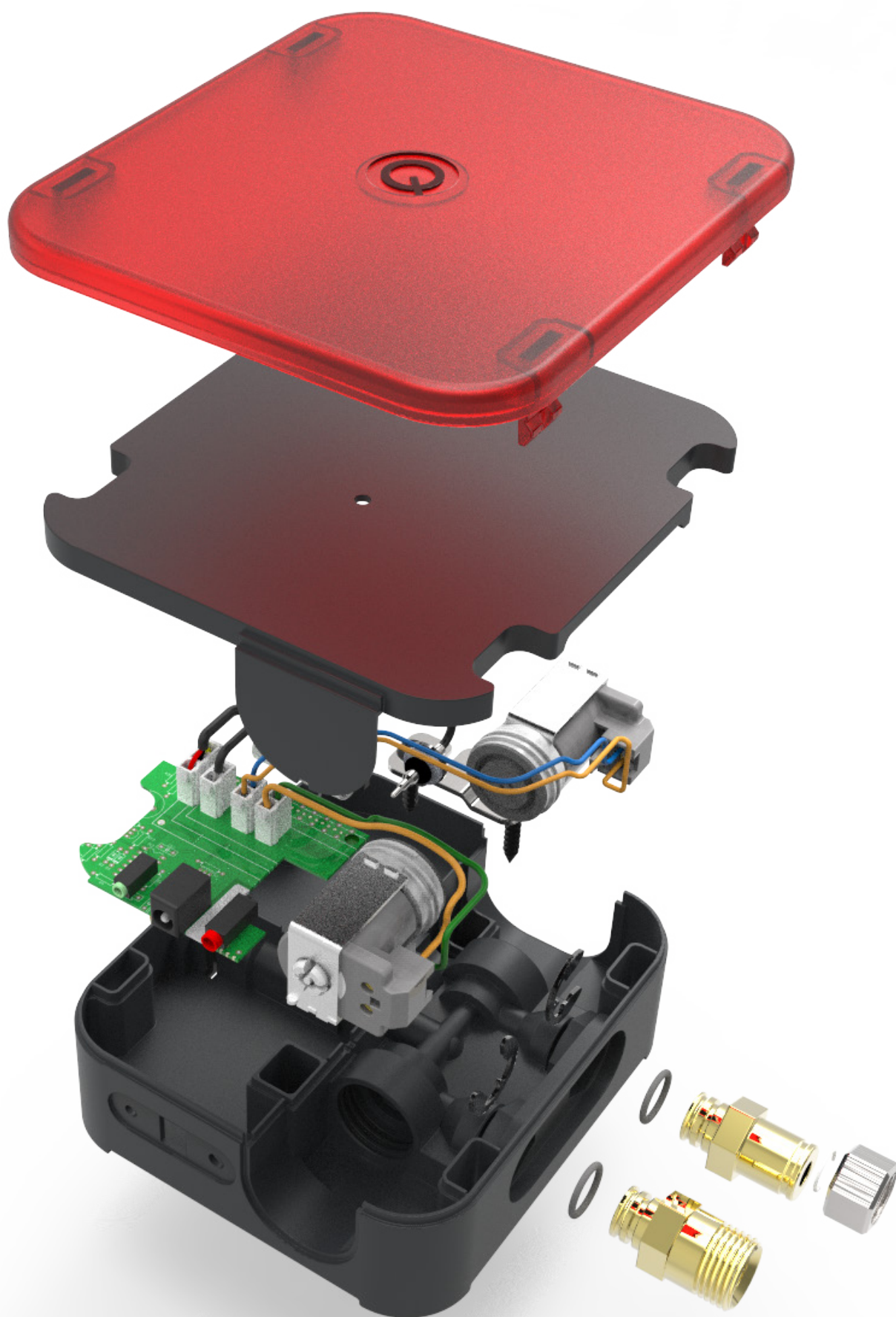
12.1 The electronic mixing valve must not have a cost increase of more than 100% in comparison to the current mixing valve. A further cost increase needs to be justified elsewhere in the product.

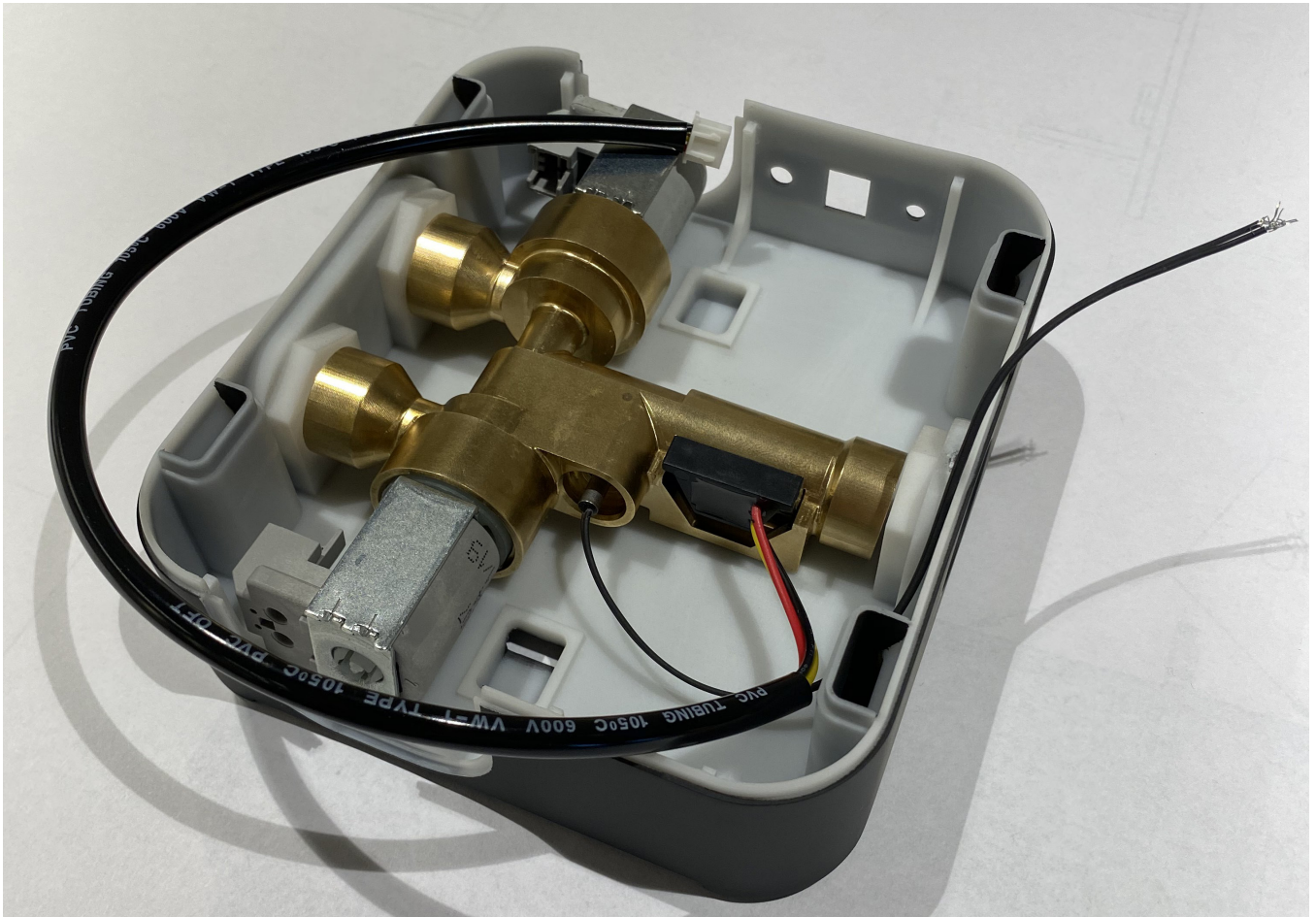
Sufficient / Not definite. The current concept has a cost price increase of 97%, which is below the bar of 100 %. However, with the estimation being this close to the bar, the final product might be slightly different resulting in a cost price above the set bar. Therefore, a conclusive sufficient validation cannot be given.

To conclude, 44 % of the requirements are conclusively sufficiently met. Second, 50 % of the requirements is not definite, which means that there is large potential of these requirements becoming sufficient. Lastly, only 6 % of the requirements has not been met. This requirement however is questionable and open for discussion.

X. Renders and pictures

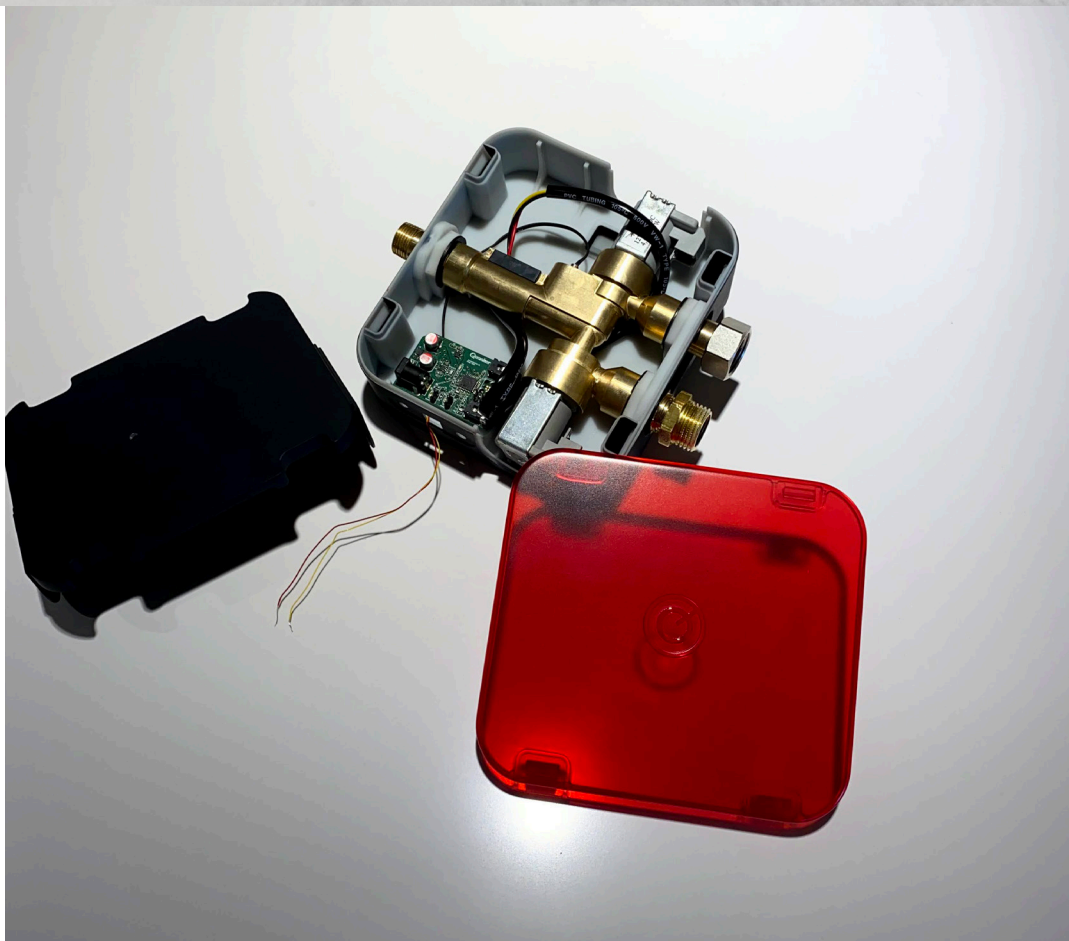












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