Personal Project Brief – IDE Master Graduation Project

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PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT

Complete all fields, keep information clear, specific and concise

Project title Designing a market ready SteamUp; a milk steamer startup in the coffee market

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

Coffee is a beverage that many of us enjoy daily, whether at home, at work or in cafes. Different coffee machines are designed for each of these settings: at work, we typically see fully automatic machines, while cafes showcase elegant, large Italian espresso machines. In cafes, most orders are milk-based drinks, like cappuccinos or lattes. However, replicating this quality of milk texture at home remains a challenge. This insight inspired the development of SteamUp; a stand-alone, steam-powered milk frother that enables coffee enthusiasts to recreate their favourite café drink, from the comfort of their home.

During the past years SteamUp has gained initial traction by engaging with customers and conducting several online conversion tests. Potential customers value an aesthetically pleasing product, which heats up quickly and limits counterspace. It is important that the SteamUp gives them control in generating their perfect milk texture. All this for a reasonable retail price point, currently estimated at €300.

SteamUp is an early-stage hardware startup focussing on a niche market, with limited financial resources.

However, it is important for SteamUp to learn whether it is possible to create a product which fulfils the user ' s needs, while being produced at a sustainable price point, to ensure a profitable business. Especially challenging given the small initial market size, the main rationale behind the MSc project. Currently, a functional prototype (TRL 5/6) with specially sourced components is nearly complete (figure 1), which serves as the foundation of this project.

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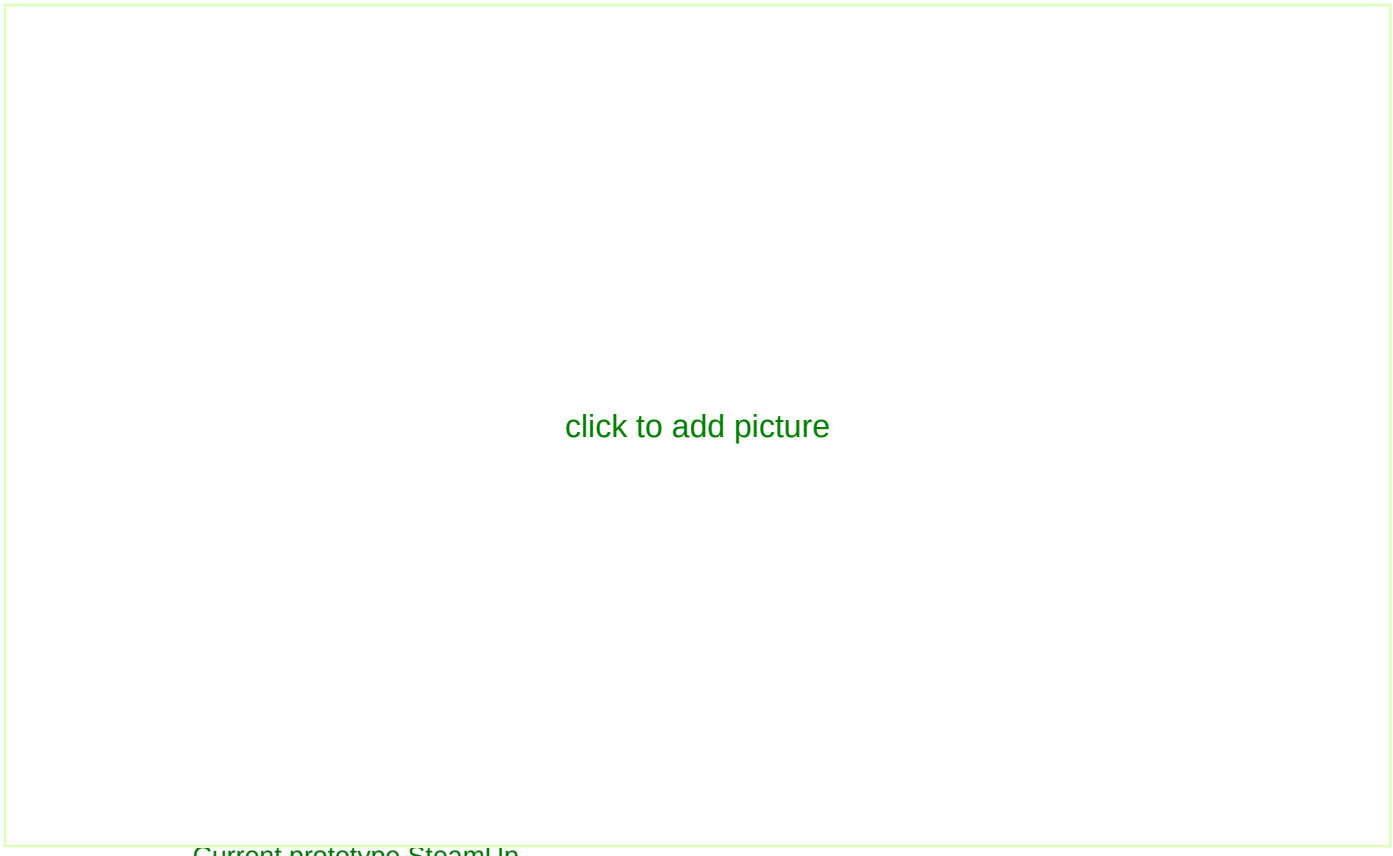


image / figure 1 Current prototype SteamUp

image / figure 2

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

Working on a startup is exciting and fun, but eventually a startup is a business, which should become a long-time profitable company. Generally, early-stage startup research focusses on customer-problem fit. Giving insights in the potential sales the company can achieve, based on customer data. On this topic further research is currently run by another SteamUp founder. This project focusses on the design engineering side of SteamUp. Asking the main question, can SteamUp be designed and produced with competitive advantage and at a reasonable price point? What if people want to buy this product for €300, are we able to go through the full design process and produce the product for less than €150?

To address these questions, SteamUp ' s current prototype will be analysed on its minimal viable product (MVP) readiness, to guide the research and development process. This project will provide a SteamUp MVP and will examine key areas critical to a successful production strategy, including quality function deployment, cost structures, production feasibility and scalability. By analysing these factors, this research will provide a foundation for decision-making on production approaches. Integrating the insights from this production-focused research with customer-focused findings will enable SteamUp to assess its viability as a profitable business and make an informed decision on whether to scale and expand the company.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Design a minimal viable steamer prototype to validate the possibility for SteamUp to become a profitable hardware startup in the coffee sector, moving the current prototype from TRL 5/6 to 7/8.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

This project will assess the viability and feasibility of transitioning the SteamUp product from prototype to market ready. Initially, a detailed current product analysis will break down each component cost, current production type and Technology Readiness Level (TRL), to identify strengths and weakness. User testing with pilot prototypes will examine real-world desirability, providing feedback on the core functionality and importance for the beachhead users. Additionally, interviews with founders of similar hardware startups will offer insights into common challenges on moving from prototype to MVP to production and sales.
Using the gained insights, research of (low volume) manufacturing processes and component selection for SteamUp will be drawn up, guiding decisions for buy in and design parts. All the gained insights will be used to generate the basis of the final SteamUp design, which will be used for initial conservations with manufacturers. Finally concluding with a costs and sales projection to confirm whether SteamUp has potential to scale profitably as a business.

Project planning and key moments

To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a ***kick-off meeting, mid-term evaluation meeting, green light meeting*** *and* ***graduation ceremony****. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	27 November 2024
Mid-term evaluation	week; 14 February 20
Green light meeting	week; 12 May 2025
Graduation ceremony	week; 16 June 2025

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	✔
For how many project weeks	all
Number of project days per week	3 > 4

Comments:
Due to personal and discussed reasons, I will start graduating with 3 days per week. Moving to 4 days per week after the new year break.

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

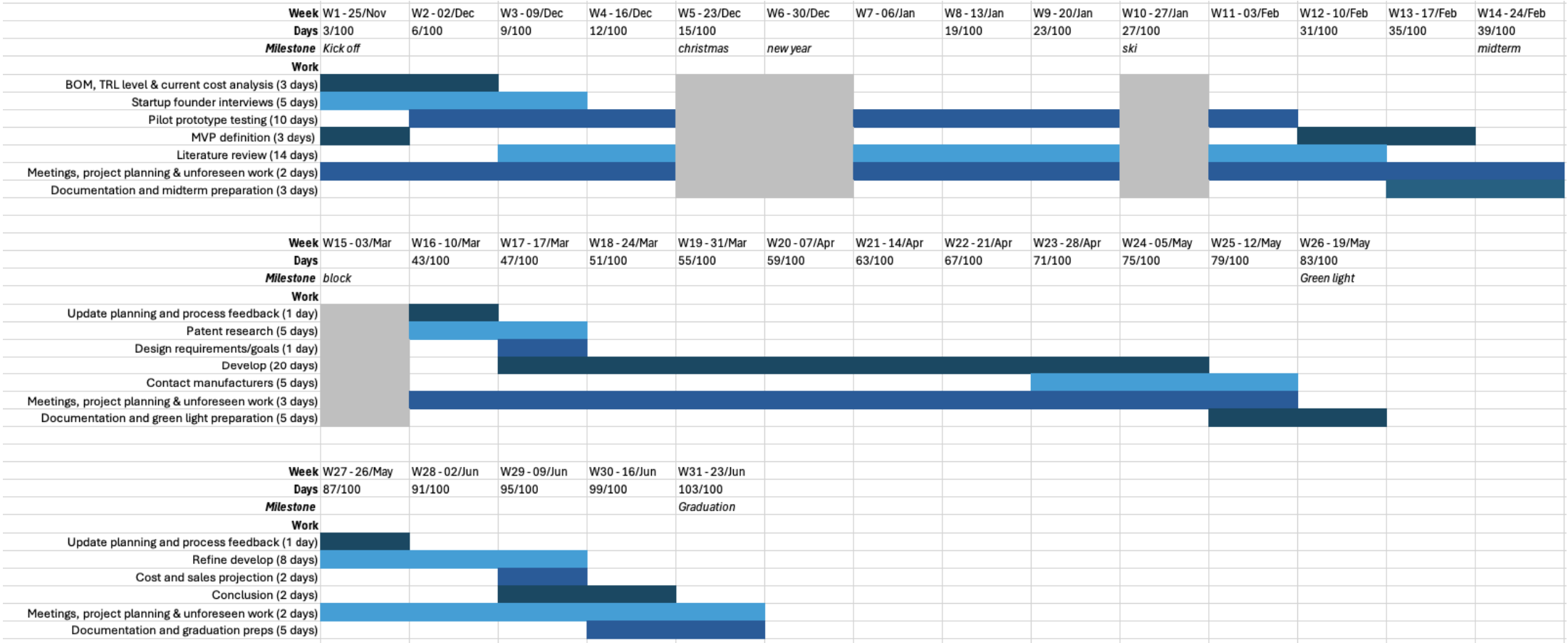
Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

The idea for SteamUp originated from the "Build Your Startup" elective, which sparked my interest in combining industrial design with entrepreneurship. Working on SteamUp has transformed coffee into a hobby, alongside my enthusiasm for design; the project brings me a lot of energy.

During my Bachelor ' s and Master ' s programs, I learned how to manage projects and turn ideas into validated prototypes. With this thesis, I aim to demonstrate my ability to oversee a large project, balance complex trade-offs, and deliver results on time, all while enjoying the process. I feel that my product development experience is currently limited to the proof-of-concept stage, and I ' m eager to expand my theoretical knowledge of production and develop practical skills as well.

Becoming an entrepreneur with a profitable hardware business would be a dream come true. If this thesis yields positive results, I ' ll be one step closer to that goal. If not, I will still gain valuable insights into evaluating and developing a hardware startup, which will be beneficial for future endeavours in both work and entrepreneurship.

PLANNING



Block week will be defined later but falls in period between Midterm and Green Light.

A.6 Fundamentals of milk foam - extended

This appendix chapter presents a comprehensive analysis of milk foam formation, emphasizing the physical and chemical processes that underlie the creation of high-quality foam for espresso-based beverages. Given SteamUp's focus on achieving the perfect milk foam at home, it is essential to understand the mechanisms behind foam generation, the role of milk constituents, and the parameters that define ideal foam characteristics.

2.1 Foam formation

Foam is a colloidal system created by dispersing gas into a liquid medium. Generally, foam formation occurs through mechanical agitation or gas injection, resulting in a two-phase system: a continuous liquid phase that encapsulates a dispersed gaseous phase (Smith & Culbertson, 2000). Two additional factors are crucial for successful foam generation. Surfactants reduce the surface tension between the gas and liquid, facilitating the formation of small, stable bubbles. In the context of milk foam, proteins act as natural surfactants (Hupperz, 2010). Energy is also required to overcome the interfacial free energy generated when the surface area between the gas and liquid increases (Walstra, 2003; Campbell & Mougeot, 1999).

Milk foam is produced by incorporating air into milk, where the proteins present serve as intrinsic surfactants. Interfacial behavior of these proteins is critical: as milk is aerated, proteins disperse in water and reorient their hydrophilic groups toward the liquid while their hydrophobic segments point toward the air bubbles (Ho et al., 2022). This creates a viscous, elastic film that stabilizes the foam. The protein and fat balance also plays a vital role. Figure xx shows a detailed view of the formation of milk foam with steam injection.

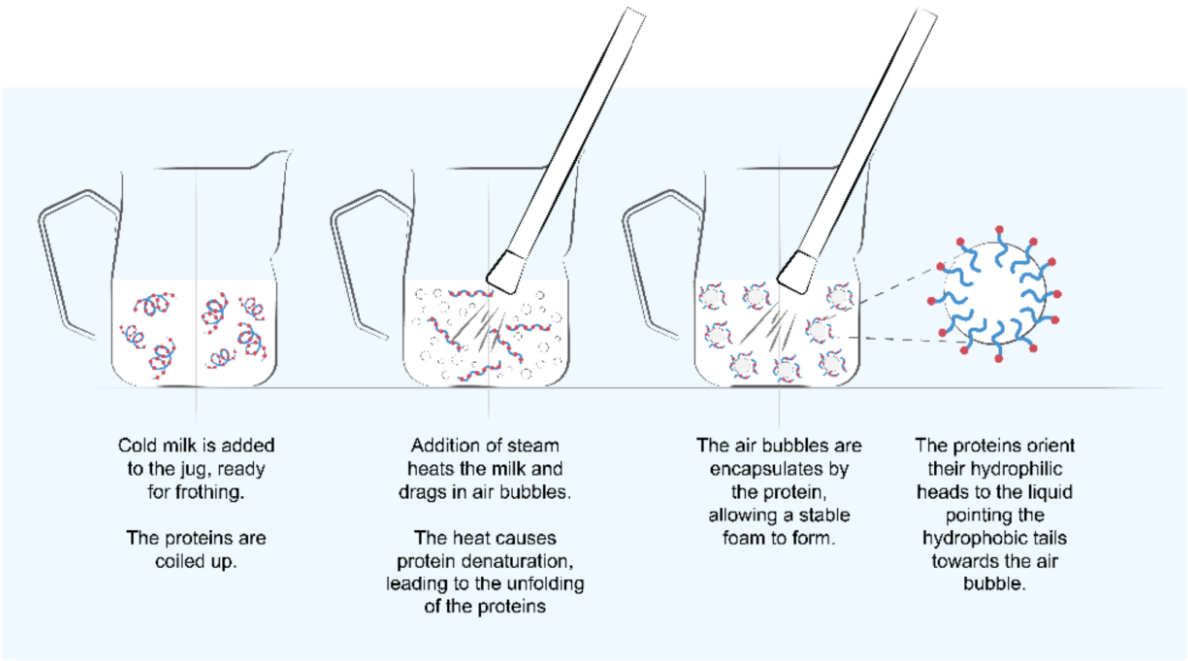


Figure XX

Milk fat negatively impacts foaming ability. At temperatures between 10°C and 40°C, fat remains partially crystalline, which disrupts protein function and reduces foam stability (Hupperz, 2010; Ho et al., 2024). For this reason, milk is typically stored below 10°C and rapidly heated above 40°C during frothing.

Interestingly, the general perception is that whole milk is better for milk frothing than skim milk, which is not scientifically accurate. The preference for whole milk stems from its richer taste and fuller mouthfeel, improving the overall drinking experience (Truong et al., 2020).

2.2 Defining ideal milk foam

Milk foam is often described as soft, creamy, or "microfoam," but according to Huppertz (2010) a more scientific approach evaluates foam according to foamability, foam stability, and air bubble size.

2.3.1 Foamability

Foamability, or the Steam Frothing Value (SFV), measures the volume of foam produced relative to the original liquid volume under specific conditions. The formula is:

$$\mathrm{SFV} = \frac{\mathrm{TV} - \mathrm{LV}}{\mathrm{LV}} \cdot 100$$

Where TV is the total volume (liquid plus foam) and LV is the original liquid volume, measured a few minutes after preparation, typically 3 minutes (Rampini et al., 2007). Foamability is closely linked to protein content and the efficiency of protein adsorption at the air–liquid interface (Marinova et al., 2009).

2.3.2 Foam stability

Foam stability refers to the foam's ability to retain its volume and structure over time. Several processes can lead to foam degradation:

- Liquid drainage: The downward movement of the liquid phase between bubbles due to differences in pressure and density (Hupperz, 2010).
- Bubble coalescence: The merging of gas bubbles as liquid films between them rupture, resulting in fewer, larger bubbles.
- Disproportionation: The transfer of gas from smaller to larger bubbles, causing the smaller ones to shrink and disappear.

Foam stability is also influenced by the initial foam height (taller foams often collapse faster) and the uniformity of bubble size (Klimanova et al., 2022). In the context of espresso-based beverages, foam stability is generally sufficient if it retains most of its volume during the typical 15-minute consumption period.

2.3.3 Air bubble size

The size and uniformity of air bubbles are critical determinants of foam texture and stability. Microfoam, characterized by uniformly small bubbles, offers a smoother mouthfeel and higher foam stability than foam composed of larger or unevenly sized bubbles (Walstra, 2001). Turbulence and shear forces, commonly described by the Weber number, govern the breakup of bubbles: once these forces exceed a critical threshold, larger bubbles fragment into smaller ones (Evans et al., 1992). The maximum bubble diameter (d_m) that remains stable under turbulent flow can be estimated using:

$$d_m = \frac{We_{cr} \cdot \sigma}{\rho \cdot u^2}$$

- $\mathrm{We_{cr}}$ is the critical Weber number,
- σ is the surface tension of the liquid,
- ρ is the liquid's density,
- u is the average of the squares of the velocity differences near the bubbles.

In practice, higher fluid velocity tends to reduce bubble size, but this relationship holds only if the entrainment ratio remains constant (Varley, 1995). Achieving sufficient turbulence without introducing additional air can be challenging, particularly for home baristas, yet controlling these factors is essential for producing the small, uniform bubbles that characterize a stable, high-quality microfoam.

2.2 Other factors influencing the formation

Protein and fat ratio
Casein and whey proteins are the two primary proteins responsible for foam formation. According to Xiong et al. (2020), an ideal casein-to-whey ratio of approximately 80:20 maximizes foamability and stability. Whey proteins, which exhibit high hydrophobicity, effectively reduce surface tension, while casein proteins adsorb and spread at the air–liquid interface to form a robust, elastic film. Although low protein concentrations (as low as 0.5%) can yield good foaming results, higher fat content can interfere with protein functionality, especially when fat is partially crystalline between 10°C and 40°C (Hupperz, 2010; Ho et al., 2024).

pH of the milk
The pH of milk further influences foam formation and stability due to its effect on protein structures. Whey proteins form stable foam around a pH of 4.5, while casein proteins perform better under slightly alkaline conditions (pH 6.8–9.0). Overall, a slightly alkaline pH is most conducive to producing stable dairy milk foam (Ho et al., 2022).

Temperature effects
Temperature significantly influences foamability and foam stability. Foaming is minimal below 35 °C, improving substantially at temperatures above 45 °C. This is largely due to the state of milk fat, which is partially crystalline at lower temperatures. Optimal foam stability is achieved between 55 °C and 65 °C, although temperatures above 60 °C risk whey protein denaturation (Kamath et al., 2008; Klimanova et al., 2022).

Effect of water addition
It is often assumed that adding water impairs the frothing ability of milk. However, Deeth and Smith (1983) found that water additions of up to 15% did not significantly reduce foamability; in some cases, relative foam volume even increased. Nonetheless, the sensory properties of the final beverage can be altered by water addition, requiring careful consideration in product development.

2.4 Rise of plant-based alternatives

In recent years, consumer demand for plant-based milk alternatives has risen significantly, with half of coffee drinkers in 2020 reporting that they consumed plant-based coffee beverages

outside the home (Grant, 2020). Motivations include health and wellness trends, allergen concerns (McCarthy et al., 2017), and environmental considerations (Haas et al., 2019). These drivers underscore the importance of understanding the physical and organoleptic properties of non-dairy products when designing a stand-alone milk frother, as plant-based alternatives often differ markedly from cow milk in terms of protein composition, fat content, and surfactant behavior (Zakidou et al., 2022).

Milk type	Coconut	Soja	Almond	Oat
Protein content	Low	High	Low	Low
Formability	Difficult	Easy	Difficult	Medium
Heat resistance	65*C	65*C	55*C	65*C
Fat content	High	Low	Low	Medium
Taste	Distinctive	Beany	Sweet	Neutral

Figure xx: …

Figure xx highlights four popular plant-based beverages frequently used for frothing. Coconut milk and oat milk, both relatively low in protein, can generally be heated to around 65 °C but often present foam formation challenges. Soy milk, which has a higher protein content, foams more easily and can also be heated to 65 °C. Almond milk, on the other hand, tends to be more heat-sensitive and is typically heated to a maximum of 55 °C. More broadly, many plant-based milks are best kept below 55 °C to maintain favorable foaming and flavor characteristics (Mridul, 2022)

Despite chemical differences, some plant-based beverages can produce foams approaching the quality of dairy milk. Zakidou et al. (2022) observed that soy- and coconut-based drinks demonstrated foaming properties similar to full-fat cow milk, while oat-based products were slightly less successful but still acceptable. However, practical observations from cafés and user tests, indicate that plant-based foams often exhibit larger, more visible bubbles compared to the smooth microfoam typical of cow milk. Ongoing recipe innovation and frequent reformulations mean these products are continuously evolving, so older research may not always capture current performance levels.

From a sensory standpoint, plant-based alternatives also vary in taste, sweetness, and mouthfeel, which can be further influenced by heating temperature (Mridul, 2022). Soy milk, for example, is sometimes criticized for a beany aftertaste, while coconut milk imparts a distinctive flavor profile. Oat drinks generally have a milder flavor, appealing to consumers seeking a neutral taste. As the popularity of plant-based beverages continues to grow, regular assessment

of new formulations is essential to ensure consistent foaming performance and to accommodate the considerable differences across brands (Zakidou et al., 2022).

2.5 Conclusion

A high-quality milk foam is defined by its ability to disperse gas uniformly within a continuous liquid phase, producing a visible volume of foam that remains stable for at least fifteen minutes. Such foam ideally consists of microbubbles so small they are imperceptible to the naked eye, creating a smooth, velvety texture that supports latte art.

Achieving these qualities depends on several interconnected factors. From a technological standpoint, a milk-frothing device must introduce just enough air and supply sufficient energy to generate a vigorous vortex, yet also permit the controlled reduction of air incorporation (entrainment ratio) to avoid large bubble formation.

The choice of milk is equally crucial, as protein and fat content, along with initial cooling and subsequent heating to about 60 °C, strongly influence foam generation and flavor. Equally important is the user's skill in applying these principles, since a lack of knowledge about temperature control, aeration, and milk composition can compromise the final result.
A good product design could reduce the required user skill risks, the user should be guided/nudged to the right method of steaming.

Although plant-based alternatives continue to gain popularity for reasons such as health, allergies, and environmental impact, they generally require different frothing techniques and often yield distinct flavors and foam structures. Ongoing innovations in non-dairy products are gradually narrowing the gap in foaming performance. With a powerful and adjustable steam product, the optimal result for these milk types are within reach.

Overall, understanding the fundamentals of milk foam is key to consistently producing the fine-bubbled, stable microfoam that characterizes an excellent cappuccino at home.

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Thao M. Ho, Xiaoying Xiong, Bhesh R. Bhandari, Nidhi Bansal

(Ho et al., 2024)

Foaming properties of milk protein dispersions at different protein content and casein to whey protein ratios
Xiaoying Xiong, Minh Thao Ho, Bhesh Bhandari, Nidhi Bansa

(Xiong et al., 2020)

Thao M. Ho, Bhesh R. Bhandari & Nidhi Bansal (2022) Functionality of bovine milk proteins and other factors in foaming properties of milk: a review, Critical Reviews in Food Science and Nutrition, 62:17, 4800-4820, DOI: 10.1080/10408398.2021.1879002

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Deeth & Smith (1983)

A.6 Theoretical system model - extended

This chapter explores the heating process of the boiler system, focusing on its ability to reach and maintain equilibrium for effective steam generation. It examines the energy input required, the role of sensible and latent heat, and the efficiency of heat transfer within the system. Additionally, it analyses boiler efficiency, comparing theoretical and real-world performance, and evaluates factors such as pressure control, steam flow rate, and nozzle constraints. Through this analysis, key insights are provided to optimize steam generation, heating efficiency, and usability for milk frothing applications. *The model was reviewed with Dr. R. Delfos, from the faculty Process & Energy (TUD), to check assumptions and calculations.*

7.1 Boiler heating to equilibrium

7.1.1 System description
The steam boiler system analysed in this chapter is based on the latest SteamUp prototype (see chapter xx), designed for milk frothing applications. The boiler has a water volume of 342 mL and a vapour space of 133 mL, creating a 7:3 water-to-air ratio. It is powered by a 2000 W heating element, capable of adjusting pressure between 0.1 and 2.0 barG. To simplify calculations, a static model at 120°C (1.0 barG) is used, as dynamic modelling introduces additional complexity.

The boiler operates by heating water to its boiling point, at which point steam generation begins. This process involves sensible heat, which increases the temperature of the water, and latent heat, which facilitates the phase transition from liquid to vapor.

7.1.2 Vapor generation at equilibrium
At equilibrium, the vapor space is filled with steam. The vapor space has a volume of:

$$\mathrm{V_{vapor}} = 133\ \mathrm{mL} = 0.000133\ \mathrm{m^3}$$

The specific volume of steam at 120°C (~1.0 barG) is:

$$\mathrm{v_{steam}} = 0.885\ \mathrm{m^3/kg}$$

the mass of steam present in the vapor space is:

$$\mathrm{m_{steam_available}} = \frac{\mathrm{V_{vapor}}}{\mathrm{v_{steam}}} = \frac{0.000133\ \mathrm{m^3}}{0.885\ \mathrm{m^3/kg}} \approx 0.00015\ \mathrm{kg}$$

Which is approximately 0.15 grams**.**

7.1.3 Heating calculations to reach equilibrium
To achieve the equilibrium state at 120°C, the boiler water must be heated from an initial temperature of 20°C. This process involves two phases: sensible heating, where the temperature of the water increases, and latent heating, where a phase change occurs as water transitions to steam. Both heating processes determine the total energy input required to bring the system to operational conditions.

Sensible Heating

Given the water volume of 342 mL (assuming a density of ~1 kg/L) and temperature Increase:

$$m_{water} = 0.342\ \text{kg}$$

$$\Delta T = 120°C - 20°C = 100\ \text{K}$$

Sensible Energy Required can be calculated using the specific heat capacity of water:

$$c_{water} \approx 4186\ \text{J}/(\text{K} \cdot \text{kg})$$

The sensible energy required is:

$$Q_{sensible} = m_{water} \cdot c_{water} \cdot \Delta T = 0.342\ \text{kg} \cdot 4186\ \text{J}/(\text{K} \cdot \text{kg}) \cdot 100\ \text{K} \approx 143{,}000\ \text{J}$$

Latent heating
To fill the vapor space, a small fraction of the water must vaporize. As calculated previously, this mass is approximately 0.15 grams. With the latent heat of vaporization given by:

$$L = 2.2 \cdot 10^6\ \text{J/kg}$$

The latent energy required is:

$$Q_{latent} = m_{steam_available} \cdot L = 0.00015\ \text{kg} \cdot 2.2 \cdot 10^6\ \text{J/kg} \approx 330\ \text{J}$$

Total energy required
The total energy required to bring the boiler to equilibrium is the sum of the sensible and latent energies:

$$Q_{total} = Q_{sensible} + Q_{latent} \approx 143{,}000\ \text{J} + 330\ \text{J} \approx 143{,}330\ \text{J}$$

Theoretical heating time
At a heating power of 2000 W, the total heating time is:

$$t_{total} = \frac{Q_{total}}{P} = \frac{143{,}330\ \text{J}}{2000\ \text{J/s}} \approx 71.67\ \text{s}$$

Thus, it takes roughly 72 seconds to bring the boiler to the equilibrium state at 120°C. The latent heating component is minimal compared to the sensible heating energy in this phase.

1.4 Boiler efficiency
Theoretical calculations estimate that heating should take approximately 72. However, field measurements indicate an actual heating time of 135 seconds, suggesting energy losses due to heat dissipation and system inefficiencies. By comparing these values, the effective heating efficiency of the system can be determined:

$$\eta_{boiler} = \frac{t_{calculated}}{t_{meassured}} = \frac{72\ \text{s}}{135\ \text{s}} \cdot 100\% \approx 53\%.$$

This discrepancy arises partly because energy is lost to heating the boiler walls, fittings, and ambient air, and partly because the PID controller's pulse-width modulation does not supply full power continuously. Once the system is fully warmed, meaning all parts in direct and

indirect contact with the boiler have reached the operating temperature, these losses decrease. However, the PID settings still play a role in maintaining the target temperature and pressure.

Since the dominance of these factors is unclear, the heat loss becomes less significant at operating temperature and PWM can and should be optimized in the future. No efficiency factor is included in the calculations. Further research may determine whether this should be accounted for.

7.2 Heat transfer in milk frothing

7.2.1 Energy needed for heating milk
On average, two cappuccinos are made using a large milk jug, containing 200 mL of whole milk (approximately 0.200 kg), which must be heated from 5°C to 65°C.

$$\Delta T_{milk} = 65°C - 5°C = 60\ K$$

Specific heat capacity of milk is:

$$c_{milk} = 4.0 \cdot 10^3\ J\ /\ (kg \cdot K)$$

The energy required to heat up the milk for the prescribed scenario is:

$$Q_{milk} = m_{milk} \cdot c_{milk} \cdot \Delta T_{milk} = 0.200\ kg \cdot 4.0 \cdot 10^3\ J/(K \cdot kg) \cdot 60\ K = 48{,}000\ J$$

7.2.2 Heat transfer by steam
When steam condenses, energy is released by latent heat and sensible heat release. Latent heat is released by the phase change from steam to water:

$$L = 2.2 \cdot 10^6\ J/kg$$

Sensible heat is released after condensation, as the water cools from 100°C to 65°C, it releases additional energy. With the specific heat capacity of water and a temperature drop, sensible energy per kilogram can be calculated:

$$c_{water} = 4.2 \cdot 10^3\ J/(K \cdot kg)$$

$$\Delta T_{cond} = 100°C - 65°C = 35K$$

$$Q_{sensible_cond} = c_{water} \times \Delta T_{cond} = 4.2 \cdot 10^3\ J/(K \cdot kg) \cdot 35\ K = 147{,}000\ J/kg$$

The total energy released per kilogram of steam, when 120°C steam is used to heat milk to 65°C is:

$$Q_{total_{per}kg} = L + Q_{sensible_{cond}} \approx 2.347 \cdot 10^6\ J/kg$$

7.2.3 Required amount of steam
The required steam mass is determined by dividing the energy needed to heat the milk by the total energy released during steam condensation and cooling:

$$m_{steam_required} = \frac{Q_{milk}}{Q_{total_per\ kg}} = \frac{48{,}000\ J}{2.347 \cdot 10^6\ (J/kg)} \approx 0.02045\ kg$$

Approximately 20.45 grams of steam is required to heat the milk jug. Since only 0.15 grams of steam is available in the boiler at equilibrium, additional steam must be generated during the frothing process.

7.3 Maximum steam generation rate

Since the available steam in the boiler is insufficient to heat the milk jug, the boiler's ability to generate additional steam must be analysed. When operating at full power, the maximum steam production rate is determined by the heating element's power output and the latent heat of vaporization:

$$\mathrm{P} = 2000\mathrm{W}$$

$$\mathrm{L} = 2.2 \cdot 10^{6}\ \mathrm{J/kg}$$

$$\dot{\mathrm{m}}_{\mathrm{gen}} = \frac{\mathrm{P}}{\mathrm{L}} = \frac{2000\ \mathrm{J/s}}{2.2 \cdot 10^{6}\ \mathrm{J/kg}} \approx 9.09 \cdot 10^{-4}\ \mathrm{kg/s}$$

Thus, under full-power and efficiency conditions, the boiler can theoretically generate approximately 0.91 grams of steam per second. Note that some energy is also required to maintain the water at boiling temperature, especially after sudden pressure drops, reducing overall efficiency and lowering the actual steam generation rate.

7.4 Nozzle flow analysis

In the system, steam travels through piping from the boiler to the nozzle before being discharged. However, to simplify calculations, pressure losses and heat transfer in the piping are neglected. Steam exits through a single circular nozzle with an orifice diameter of 1.5 mm (0.0015 m), resulting in an effective flow area of:

$$\mathrm{A} = \pi\left(\frac{2}{\mathrm{d}}\right)^{2} = \pi \cdot (0.00075\ \mathrm{m})^{2} \approx 1.767 \cdot 10^{-6}\ \mathrm{m}^{2}.$$

Given the substantial pressure differential between the boiler (approximately 2.0 bar absolute) and the downstream ambient pressure (1.0 bar absolute), along with the high velocities involved, the steam is treated as a compressible fluid. According to isentropic flow theory (Anderson, 2003), if the downstream-to-upstream pressure ratio falls below a critical value, approximately 0.54 for an effective isentropic exponent near 1.3. The flow becomes choked, meaning that the steam reaches sonic velocity at the nozzle throat. Although steam is a non-ideal gas with a Cp/Cv ratio that can vary from 1.3 to 3.0, studies indicate that under our operating conditions the effective isentropic exponent remains close to 1.3 (Buzzard, 2001). Thereby justifying the choked flow assumption.

The mass flow rate through the nozzle is estimated using:

$$\dot{\mathrm{m}}_{\mathrm{nozzle}} = \mathrm{C_d} \cdot \mathrm{A} \cdot \mathrm{p_0} \cdot \sqrt{\frac{\gamma}{R\ \mathrm{x}\ T_0} \cdot \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{2(\gamma-1)}}}$$

where:

- C_d is the discharge coefficient, assumed to be 0.8* (Anderson, 2003),
- $p_0 \approx 2.0$ bar absolute $= 200{,}000$ Pa (boiler pressure),
- $T_0 = 120°C = 393.15$ K is the equilibrium temperature,
- $\gamma = 1.3$ is the isentropic exponent for steam (Buzzard, 2001), and
- $R \approx 461.5$ J/(kg ∗ K) is the specific gas constant for steam.

*C_d In practice, the theoretical mass flow rate through a nozzle is adjusted to account for real-world effects such as friction, turbulence, and jet contraction. The discharge coefficient (Cd) is a dimensionless factor, typically from 0.6 to 0.99, that scales the ideal flow rate to match measurements (Anderson, 2003). A perfectly efficient nozzle would have Cd = 1, while sharp-edged orifices may be as low as 0.6–0.7, and highly optimized designs can reach 0.95. A typical value is about 0.8 for a well-machined, rounded orifice (Munson et al., 2013). Because Cd multiplies the theoretical flow rate directly, small variations in Cd produce proportional changes in mass flow. Optimisation of the Cd has the same impact as optimising A for the mass flow rate of the nozzle.

The calculation shows that the mass flow rate through the specific nozzle is approximately:

$$\dot{m}_{nozzle} \approx 4.4 \cdot 10^{-4} \text{ kg/s}$$

Since steam flow is constrained by the nozzle rather than the full heating element capacity, the time required to generate sufficient steam for heating the milk jug must be determined based on the nozzle's mass flow rate. Given a required steam mass and a nozzle flow rate, the required time can be calculated as:

$$t = \frac{m_{steam_required}}{\dot{m}_{nozzle}} = \frac{0.02045\text{kg}}{4.4 \cdot 10^{-4}\text{kg/s}} \approx 46.5\text{s}$$

Therefore, with the nozzle as the limiting factor, generating enough steam to heat the milk jug would take approximately 47 seconds.

7.5 Comparison between steam generation and nozzle flow rate

To assess the suitability of the boiler for the nozzle, a comparison between the boiler's steam generation rate and the mass flow rate through the nozzle is performed.

Steam Generation Rate: $\dot{m}_{gen} \approx 9.09 \cdot 10^{-4}$ kg/s.

Nozzle Mass Flow Rate: $\dot{m}_{nozzle} \approx 4.4 \cdot 10^{-4}$ kg/s .

Since $\dot{m}_{gen} > \dot{m}_{nozzle}$, the boiler can produce steam at a rate that exceeds its discharge through the nozzle. This indicates that, with proper PID control, continuous full-power operation is not required; rather, the heating input can be modulated to maintain the desired steam pressure and availability.

7.6 Scenario adjustments

Water to air ratio
Reducing the model to a 50:50 water-to-air ratio, with both water volume and vapor space at 237.5 mL, was considered as an alternative to the original 72:28 ratio. Under ideal conditions, this adjustment lowers the total energy required to reach equilibrium with 30% (new energy is 100 kJ, a reduction of over 43 kJ from the original 143 kJ) and decreases the heating time from 72 seconds to 50 seconds. However, while the mass of steam in the vapor space increases from 0.15 g to 0.27 g, the additional 0.12 g is negligible in performance, as the nozzle flow rate remains the primary limiting factor. This suggests that significantly reducing the water volume within the same total space does not substantially improve performance.

These conclusions were supported by the boiler manufacturer, who confirmed that maintaining a relatively large water volume, combined with a sufficiently powerful heating element, ensures consistent steam output (Beltrami, Felice). While a larger water mass enables faster evaporation, the heating element's power is equally critical for replenishing lost energy. Therefore, an optimal balance between water and vapor volumes is necessary to achieve efficient operation and high-quality steam without the risk of droplet entrainment.

Power of the heating element
Earlier calculations estimate the boiler's real-world efficiency at approximately 53%, primarily due to heat losses and suboptimal control software. At this level, reducing heating power further becomes challenging without compromising performance, especially given the current nozzle setup, unless insulation and/or PID tuning are improved to mitigate these losses.

In an ideal model, a 2000 W heating element allows the boiler to reach 120°C in 72 seconds, producing steam at 9.09×10^{-4}kg/s. Lowering the power to 1500 W (standard heating element) proportionally reduces the steam production rate to 6.82×10^{-4} kg/s but increases warm-up time by 33%, from 72 to 96 seconds. Given the boiler efficiency of 53%, the production rate isn't suitable for the current nozzle. Within the theoretical model, efficiency should at least be increate to 64% to maintain stable flow with a 1500 W heating element. This is while still neglecting other factors like piping design and heat loss within the piping. Theoretically with 100% efficiency, around 970 W of purely effective power would match the nozzle flow rate (~4.4×10^{-4} kg/s), but this doesn't compensate for inefficiency.

In general, decreasing heating power results in a proportional drop in steam generation but a disproportionate rise in heating time. From a sustainability perspective, reducing power isn't the important driver, as the total needed energy remains the same. The efficiency of the boiler and piping is most important, as energy losses are compensated by additional energy from the heating element. The main driver for reducing power of the heating element comes from the maximum power usage of a typical fuse box, being around 3500 W. Significant improvements in thermal efficiency and PID control would be required to maintain consistent pressure and short warm-up times, particularly with the current nozzle design.

Nozzle geometry
The nozzle diameter directly affects steam mass flow, as flow area scales with the square of the diameter. Increasing the nozzle from 1.5 mm to 2.0 mm increases mass flow by 78%, while reducing it to 1.2 mm decreases it by 36%. This also impacts heating time: a 1.5 mm nozzle requires ~47 seconds, a 2.0 mm nozzle reduces this by 43% (to ~26 seconds), and a 1.2 mm nozzle increases it by 57% (~73 seconds). At a future efficiency of 70%, a 1.8 mm nozzle would match steam generation; any larger would exceed production, causing a pressure drop. With an 100% efficiency 2000 W heater, the limit increases to 2.16 mm.

While steam flow rate optimizes heating, nozzle geometry affects usability. The vortex created by the nozzle influences how well users can control steam dispersion and frothing, making usability a key design consideration beyond raw heating performance.

Using multiple smaller orifices achieves similar effects. Four 1.0 mm holes match a 2.0 mm nozzle's flow capacity, but real-world performance varies due to discharge coefficients, friction, and jet interactions, highlighting the need for balanced nozzle design beyond just mass flow.

Energy loss at steam release
Practical tests indicate that boiler pressure can drop by up to 0.3 bar when steam is drawn, causing temporary fluctuations in steam flow before gradually returning to equilibrium. This pressure drop is not solely due to sensible heat losses from cooling water but also results from the response delay of the heating element, which does not instantly deliver its full 2000 W capacity. Given that the current model neglects boiler efficiency, such fluctuations are expected in real operation. However, under ideal conditions, the system retains sufficient surplus power to compensate for these losses. Increasing the heating element power could enhance performance by reducing response time, counteracting sensible heat loss more effectively, and accelerating steam recovery. Thereby ensuring a more stable steam output.

7.7 Conclusions

The analysis confirms that the current boiler design is well optimized for milk steaming, balancing steam generation, heating power, and nozzle flow rate effectively. Under baseline conditions, a 7:1 water-to-air ratio and a 2000 W heating element operating at 120°C (1.0 barG), the system reaches steady state in approximately 72 seconds and generates sufficient steam to meet milk heating demands.

Modifications such as adjusting the water-to-air ratio or reducing heating power currently offer limited benefits and may even compromise performance.

Increasing the nozzle diameter enhances mass flow rate but must be carefully balanced to avoid exceeding steam production capacity and usability. Current benefits of increasing the nozzle size are limited, as increasing the heat from the boiler has the same impact.

The key performance factors are the available water for evaporation, the heating element's power, and nozzle design, all of which contribute to maintaining stable steam output. While enhancements in insulation and PID control could further improve efficiency, the fundamental design parameters of the current prototype already provide a robust and effective solution for consistent milk steaming.

A.9 User & Feature testing- extended

This chapter is a detailed version both chapter xx and chapter xx of the main report.

Order of this reports, because it is large.

9.1 User testing plan setup

The prototype used in this research builds upon the graduation work of Jeppe Piersma. His internal component selection and system design remain unchanged, as his findings demonstrated that this configuration best replicates café-quality steam generation in a home setting. However, the embodiment, exterior design, and usability features have been completely redesigned. This decision was driven by two key objectives.

Firstly, the SteamUp team aimed to refine the product's packaging into a more compact and integrated form. This redesign provided valuable insights into the challenges of miniaturization while offering a preliminary understanding of the product's potential final dimensions. This decision was reinforced by feedback from all pilot testers of Jeppe's prototype, who consistently indicated that the original design was too large.

Secondly, the team sought to develop an initial look and feel for the product. Jeppe's prototype primarily featured a cubic wooden construction, as his focus was on internal component selection rather than final aesthetics. Since the original prototype did not yet resemble a finished product, multiple design iterations and market analysis were conducted to define a new visual identity for SteamUp.

This prototype incorporates several design assumptions based on previous discussions with potential customers. To gain deeper insights into user needs and expectations, these assumptions must be validated through testing. The following document outlines the user test setup, ensuring that the study can be replicated by other researchers.

1. Research objectives

- Gain insight into the intuitiveness and usability of the SteamUp prototype, as well as the perceived performance of the prototype. Important for future design changes and considerations.
- Enable a deeper understanding of the key requirements for the Minimal Viable Product (MVP) version of the SteamUp for our expected target audience.

- Understand customer preferences for features and design to inform the first phase of the **Quality Function Deployment (QFD)** process.
- Get some first insights on the desired look and feel of the product.

2. Participant Criteria

- A pre-selected group of 9 participants who represent the target audience for SteamUp. These people made it through the participant selection of Wouter his beachhead market research.
- The participants should already have experience with milk frothing. They don't need to be experts, but they should know how to steam so that they can change their style based of some tips from the researcher.

3. Test Environment

- **Location**: At each participant's kitchen or coffee corner. This allows for realistic feedback about how the product fits into their existing coffee-making setup. It is fine to move to another room for the post testing interview.

- **Test Setup**: Figure A.9.01 shows the test setup. For safety, it is important place the prototype on a flat surface, with 20 cm clearance in all directions and powered trough a power socket with an on/off switch.

- **Facilitator**: The researcher will moderate and ensure safety while collecting insights.

Figure A.9.01: Test Setup

4. Methodology

The test is divided into 3 different phases which will be described in this section.

4.1 Prototype usability test

- **Objective**
  Observe how participants interact with the prototype with limited constructive guidance to evaluate its intuitiveness, usability and perceived performance.

- **Process**
  - Let the participant read and fill in the **consent form**, while they are reading the researcher should **setup the prototype**. Ask for consent to **voice record** and start tracking.

  - Introduce the SteamUp prototype briefly without explaining its functionality.
  - Ask the participant to interact with the prototype and explain what he/she sees/thinks about the product/features, while the prototype is off.
    Assumption: This is a bit awkward but gives first interaction insights, like (lack of) understanding of the buttons/display.

  - The researcher now confirms/explains the basics of the product and turns on the prototype.
  - Again, the participant is asked to interact with the device and think out loud, without frothing milk.
    Assumption: This is a bit awkward, but you can check if the participants register difference in state.

  - The researcher now askes the participant to put the prototype on his preferred pressure and froth one small jug filled with water and soap. (The ideal method to test frothing without wasting milk)
    Note: Write down used setting and any remarks.
  - This step is repeated until the participant feels confident to start with milk. After two go's it is fine to give some tips if the participant asks for/needs them.

  - Now repeat the previous steps with milk.
  - Note: Write down used setting, quality of milk and remarks.

  - Encourage them to think out loud as they use the product to capture real-time impressions and feedback.

- **Data Collection**
  - Record their verbal feedback (audio recording with consent).
  - Note in notebook the key observations about their actions and pressure sets during the test.

4.2 Feature exploration

- **Objective**
  Dive deeper into specific features and assumptions of the SteamUp prototype. Get their opinion.

- **Process**
  Facilitate a discussion about the current features and design choices. Use questions as base, and dive into interesting comments/remarks.

- Explain that we are going to dive into their experience of the prototype based on different features. Emphasize that their honest opinion matters, because that is the only way our product will become amazing.

- **Usability and performance**
  - What is your general experience with the prototype? Dive deeper into key findings.
  - What did you find challenging and what was easy?
  - Why did you choose for the specific pressure settings?
  - How did the performance compare to your own device?
  - What did you think of the performance in general?
    Assumption: It is comparable to dual boiler machines, and takes a few goes to master, but you see big improvements within a few goes resulting in a high-quality cappuccino.

- **Size**
  - What do you think of the current size of the prototype?
  - What would you like to change? Height, width, depth?
  - How much room would you have in your setup?
    (make picture if consent)
    Assumption: Current size is close to what they could fit in their setup. Depth and hight is less important than width.

- **Adjustability and modifiability**
  - Currently the pressure and steam wand orientation can only be adjusted, would you like to adjust more aspects?
  - Would you like to change the nozzle? If so, why?
  - Would you like to be able to open the machine and modify it, and if so, what would you like to modify?
    Assumption: Vary between the specific participant.

- Cleaning
  - What is your current and previous cleaning procedure with appliances?
  - How often would you clean the SteamUp prototype?

        - What would you like to see in cleanability of your steamer?
          Assumption: Purge + wipe every time, and occasionally a good nozzle clean, but not too often.

- Drip Tray
    - Did you notice the absence of a drip tray? Did you mis it?
    - Would you find it useful and if so, why?
      Assumption: Lack of drip tray would make cleaning easier.
      This assumption has been debunked by alfa testing.

- Water Reservoir
    - Did you like a removable reservoir, if so, why? Or fixed fine?
    - How does it work on your current machine? Any remarks?
    - Any changes you would value?
      Assumption: People value the removability of the reservoir.

- Steam wand
    - What do you think of the steam wand?
    - How much did you move it?
    - Would you prefer if the wand only linear, or do you like the ability to move it in all directions?
    - Do you prefer cold touch wand or cold touch rubber?
      Assumption: These answers will be very scattered across users. Hard to make assumptions on mobility of the wand.

- Nozzle preferences
    - How did you like the current nozzle?
    - What are your previous experiences with steam nozzles?
    - Do you prefer a specific nozzle, or would you like to be able to try different configurations?
      Assumption: People want to change nozzles.

- Interface
    - What do you think of the interface?
    - How long did it take you understand how to use it?
    - Do you know what bar setting to use, and if so, how did you know?
    - Do you prefer to adjust the bar, temperature or percentage?
    - Did you look at the timer or bar status while steaming? Why (not)?
      Assumption: People understand Bar but just play around in the beginning. They use Bar like they use grind size, as a measurement. Pressure over temperature.

- **Data collection**
    - Record their verbal feedback (audio recording with consent).

4.3 Feature prioritization exercise

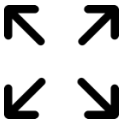
- **Objective**
  Identify which features are most valuable to participants and determine a first estimation of the MVP feature set.

- **Process**
  - Ask participants to create a ranked list of characteristics from most to least important, using the characteristics in table A.9.01. The interviewer will provide physical papers with these characteristics.
  - Ask them to explain the order and their decision making.

  - Looking at this list, which features are must have and which features are nice to have? Put a split at this point or feel free to rearrange the order.
  - Ask them to explain the order and their decision making.

- **Data Collection**:
  - Make picture of the resulted list.
  - Record their verbal feedback (audio recording with consent).

Table A.9.01: Characteristics to rate by the parti

	Steaming time of milk jug		Consistent steaming pressure
	Energy consumption		Compact counter size
	Ease of cleaning		Noise level
	Froth different types of milk		Aesthetic design

	Heating up time		Adjustability of pressure
	Modifiability		

5. Ending

- Just ask a general question about their view on aesthetics of the design?
- Ask if we can contact them again for further research, like look and feel research.
- Keep them involved, ask if they want to join the WhatsApp community?
- Give them a gift. Small cup of beans with SteamUp logo.

6. Tools and Materials

- SteamUp prototype.
- Small and Large milk jug.
- Cow milk and alternative milk.
- Power socket with on/off switch.
- Dish cloth
- Fire extinguisher
- Testing checklist with feature-specific questions.
- Characteristics.
- Pen, notebook and voice recorder (phone).

7. Risk Assessment

- See Appendix xx for risk assessment.
- Moderate all sessions to ensure safe use of the prototype.
- Power the system using a well reachable power socket with on/off switch for immediate power drop.
- Emphasize voluntary participation and allow participants to stop the test at any time.

Update after pilot

Pilot test with P1 revealed some updates:

- People look at the product as an extension of their current setup.
- People want to do good, so they feel pressure with steaming, be clear that there is no need to rush, and be calm and silent during testing.
- First section with interaction with prototype without any guidance is a bit awkward

9.2 Results of all three tests

This chapter presents the findings*, conclusions and recommendations* from the user tests conducted with nine participants, each having different backgrounds in coffee-making and milk-frothing.

Participant specification
The study includes 9 participants, all specifically selected as high priority potential SteamUp clients, on several occasion this estimation was adjusted. 8 out of 9 participants were unknown people to the researcher before the project, this to limit dishonest responses due to personal relation (SOURCE Mom Test). Participants were also selected to variate on home coffee setup and frothing skill, this to cover a wider part of the target audience. When SteamUp's beach head market is defined, this research could be repeated with a better suiting dataset. Table 1 shows their gender, home setup, frothing skill, and final client potential after the research.

Table 1

par.	**Gender**	**Home setup**	**Froth skill**	**Client potential**
P1	Male	Sage home barista	Medium	Medium
P2	Male	La Pavoni	Medium	High
P3	Male	De'Longhi piston	Low	High
P4	Male	Nespresso cup	Low	Low
P5	Female	De'Longhi piston	High	Medium
P6	Male	Single boiler piston	High	High
P7	Male	La Marzocco	High	Medium
P8	Female	Boiler with heat exchanger	High	High
P9	Male	Jura fully automatic	Medium	High

1. Users experience analysis (Test 1)

The research goal was to understand initial usability, intuitiveness, learning curve, and necessary adjustments during the first 3 – 6 uses.

1.1 Analysis setup

In this phase, the focus was on capturing participants' first impressions and their learning process during initial interactions with the prototype. The goal was to identify discrepancies between user expectations and the actual performance of the machine. The study examined how users anticipated the functions of controls compared to their actual behaviour and determined which elements were immediately clear versus those that required multiple attempts or explanation.

Additionally, the analysis tracked the learning curve in frothing, comparing early mistakes with later improvements. The speed at which users adjusted their techniques—either through trial and error or guided instruction—was assessed. Finally, a heatmap was developed to categorize areas of major confusion versus zones of intuitive use, highlighting key targets for usability improvements. All used to draw up final conclusions of the test.

1.2 Results Test 1

a. First impressions

Common expectations vs. reality

- 7 out of 9 participants (P1, P2, P3, P4, P5, P8, P9) struggled to find or correctly identify the power button.
    - Many expected the steam lever or another switch to be the power button.
    - Some did not see the button at all because it was located on the back.

- 5 out of 9 participants (P2, P3, P4, P8, P9) misinterpreted the display values.
    - They were unsure whether the numbers referred to actual vs. target pressure.
    - Some participants assumed the display would indicate temperature rather than pressure.
    - Others were confused by the blinking indicators and did not immediately recognize their purpose.

- 4 out of 9 participants (P2, P4, P8, P9) thought the purge function was necessary before steaming.
    - This assumption came from prior experience with commercial machines or espresso machines with integrated steam wands.

- 3 out of 9 participants (P1, P5, P8) initially assumed the pressure dial was for opening and closing the steam flow instead (instead of setting the value of the pressure).

- 2 participants (P6, P7) immediately identified all the buttons and functions correctly due to prior experience and technological background.

Immediately Understood
- The steam wand and its general function.
- The concept of adjusting settings using the dial, only after short explanation of the interface.
- The importance of cleaning the steam wand after use (P1, P3, P4, P5).

Required trial-and-error or explanation
- How pressure settings affected steaming performance (P1, P2, P3, P5, P8, P9).
- What the blinking pressure indicators meant (P3, P4, P8).
- The exact position of the power button (P1, P2, P3, P4, P5, P8, P9).

b. Frothing learning curve

Most common early mistakes
- Struggling to create a vortex in the milk (P1, P4, P9).
- Not immediately understanding the impact of different nozzles (P1, P9).
- How pressure settings affected steaming performance (P1, P2, P3, P5, P8, P9).

Early improvements
- Lowering steam pressure after first run to gain more control (P1, P2, P5, P8, P9).
- Adjusting the position of the steam wand for better results (P1, P4, P8).
- Learning through trial and error + guidance of the researcher (P3, P4, P9).

Patterns of Improvement
- Participants with barista experience (P5, P6, P7, P8) adjusted almost immediately to the right setting. All created good foam within the first go.
- Participants who had home machines (P1, P2, P9) needed 2–3 attempts before achieving desirable foam texture.
- Participants with relatively little experience (P3, P4) needed more time to create ideal foam from barista's point of view. But they perceived their creations as large improvements and were keen to see better cappuccino's.
- All participants improved over time, but those with less experience took more attempts.

Other insights
- Users need multiple attempts to find their ideal steam pressure. 6 participants (P1, P2, P4, P5, P8, P9) tested different pressures before settling on a preferred setting.
- Vortex creation is a common learning curve issue. 4 participants (P1, P4, P5, P9) struggled to consistently create a vortex in their milk.

- The biggest challenge for beginners is balancing air intake and milk movement. 4 participants (P1, P3, P4, P9) found the timing of air introduction difficult to master.
- Nozzle selection impacts user experience. 3 participants (P2, P6, P7, P9) explicitly changed nozzles to improve control.

c. Heatmap of usability

Major Confusion (Red Zone)
- Power button location (7/9 struggled).
- Display values (actual vs. target pressure) (5/9 confused).
- Finding the ideal steam setting (6/9 adjusted multiple times).

Moderate Hesitation (Orange Zone)
- Steam wand positioning & creating a vortex (4/9 had issues).
- Understanding when the machine is "ready" (3/9 were unsure).

Fully Intuitive (Green Zone)
- General machine operation (adjusting dial, purging).
- Cleaning the wand (most did this without instruction).
- Steam power was perceived as a major strength.

(A separate heatmap graphic can be created to visually highlight confusion points.)

1.3 Conclusion Test 1

The initial user interactions identified key usability challenges, particularly in locating the power button and interpreting the display. Seven out of nine participants initially struggled to find the power button, often confusing it with the steam switch. Additionally, five participants misinterpreted the display values, uncertain whether the bar indicators referred to actual or target pressure. These issues suggest that a lack of clear use clues and labelling contributes to confusion, which could be mitigated with simple text indicators such as “set bar” and “current bar.”

As anticipated, user experience played a significant role in adaptation speed. Participants with barista experience (P5, P6, P7, P8) quickly adjusted to the correct pressure settings and successfully created quality foam within one or two attempts. Less experienced users (P1, P9) struggled to achieve their desired results but remained engaged and motivated by the learning challenge, expressing interest in continued use of the prototype for a longer time span.

Milk frothing technique presented a common learning curve. Four participants (P1, P3, P4, P9) had difficulty consistently creating a vortex, and found it challenging to balance air intake with milk movement. However, steam wand interaction was intuitive, as all participants (9/9) correctly used the rubber handle for reorientation.

Overall, experienced users found the steam power met their expectations, while beginners faced a predictable learning curve in frothing techniques. Addressing interface clarity and providing better visual guidance could enhance accessibility for all user levels.

Key take aways

- Steam power exceeded expectations, but pressure control inconsistencies need improvement.
- 8 out of 9 participants found the prototype too tall, with 3 preferring a more compact design.
- Split preferences on drip trays, steam wand movement, and nozzle options highlight the need for flexibility in design choices.
- The interface requires major refinements to improve clarity and usability.

Aesthetic preferences were positive, but more research is needed to validate long-term appeal.

2. Post-testing interview (Test 2)

The research goal was to understand participant experiences and identify feature strengths, pain points, and areas for improvement.

2.1 Analysis setup

Each feature was evaluated by identifying positive aspects, negative aspects, and common trends in participant feedback. For steam power, pressure, and performance, the analysis focused on whether users perceived the pressure as sufficient or excessive, and if pressure adjustments improved frothing control. Prototype dimensions were assessed to determine if the machine was considered too large or too small, and which dimension (height, width, or depth) was most critical. In addition, opinions on customizability and the desire for swappable parts were examined. Cleaning and maintenance were analysed by evaluating the ease of cleaning and any concerns regarding hygiene or upkeep. Feedback regarding the necessity of a drip tray and the preference for a removable water reservoir was also reviewed. Finally, the steam wand and nozzle were evaluated for flexibility and nozzle type preferences, while the interface and design were assessed for display clarity, intuitiveness, and suggestions for improvements such as indicator lights or simplified controls.

2.2 Results test 2

Power and user experience

- 8 out of 9 participants (P1, P2, P3, P4, P5, P6, P7, P8) noted that the steam power was significantly stronger than what they expected/were used to, which was seen as a positive experience. P1 explicitly mentioned that it allowed them to focus more on technique rather than compensating for weaker steam.
- P9 noted that high steam pressure required better control and was a factor in their learning process.
- Several participants (P2, P5, P6) compared the power to professional café machines and appreciated the speed but noted that the pressure control wasn't always working optimal.

- The high power was generally seen as a major strength, but most participants needed an adjustment period to manage it effectively.
- There was no consensus on whether adjustable pressure is necessary: some appreciated it (P1, P5), while others questioned its necessity.
- The learning curve varied significantly by experience level, with professionals adapting immediately while others had to reduce pressure to gain control.

Prototype dimensions

- 8 out of 9 participants (P1, P2, P3, P4, P5, P6, P8, P9) mentioned the size of the prototype, mainly in terms of height being too much.
- P1: "Hij is vooral heel hoog, zou het minder erg vinden als die wat dieper is."

- P3 suggested reducing the height by 10–20 cm while keeping depth/breadth reasonable.
- 3 participants (P6, P7, P8) preferred a more compact and narrower design for fitting into smaller kitchens.
- P9 suggested that depth is less of an issue than height or width, as most countertops are deep enough to accommodate it.

Customisation and adjustability

- Only 1 participant (P7) was interested in modifying settings/parts.
- P1 requested pre-set modes for different milk types (oat vs. cow milk).
- P5 mentioned that pressure adjustments were interesting to experiment with but not essential.
- 7 out of 9 participants (P2, P3, P4, P5, P6, P8, P9) explicitly said they would not modify or adjust the machine manually and wanted a plug-and-play experience.

Cleaning and maintenance

- All found daily cleaning simple and important (purging & wiping).
- P3 and P6 requested clear descaling guidelines, as water hardness impacts long-term performance.
- 2 participants (P2, P8) suggested a coating/material improvement for easier maintenance.

Drip tray

- 4 participants (P1, P6, P7, P9) explicitly mentioned missing a drip tray.
- 5 participants (P2, P3, P4, P5, P8) mentioned not to mis a drip tray.
- P1: "Die doek moet gewoon niet zo nat worden."
- 3 participants (P2, P5, P8) said they didn’t need one, as they were used to wiping excess water with a cloth.

Water reservoir

- All participants (P1 - P9) preferred a removable reservoir for easier refilling.
- P9: "Als het vastzit, is dat ook geen probleem, zolang het vullen makkelijk blijft."
- P2 and P7 preferred a better-integrated design rather than an external add-on.

Steam wand

- P1, P4, and P8 preferred a stiffer wand that doesn’t move too easily when pressed.
- P6 and P7 found the current movement flexibility useful, especially for positioning with different jugs.
- P1, P5, and P9 were indifferent to full 360° movement, as they mainly used up/down positioning.

- 360° movement preferred: 4 out of 9. (P3, P5, P6, P7)
- Linear movement preferred: 5 out of 9. (P1, P2, P4, P8, P9)

- None of the participants valued a cold touch steam wand over a rubber handle, it would only be a nice addition.

Nozzle preferences

- 6 out of 9 participants (P1, P2, P3, P6, P7, P8) wanted the option to swap nozzles.
- P1: "Ik zou wel een 4 nozzle willen proberen."
- P6 & P7 suggested having two default options (1-hole and 2-hole) with an option to buy extras.
- P3, P5, P9 didn't feel the need to swap nozzles as long as the default one worked well.

Use interface and display

- All participants (P1, P2, P3, P4, P5, P6, P7, P8, P9) found parts of the interface unclear.
    - P1 and P3 had trouble distinguishing between temperature and pressure.
    - P5: "In het begin was het onduidelijk wat het linker getal betekende."
- P6 and P7 mentioned that they wouldn't need it to change the settings as easily as currently. The bar measurement was the correct standard rather than temperature or percentage-based settings.
- P2 and P9 found the timer unnecessary, as they judged readiness based on feel.
- The steam on off switch was found too fiddley by P6 and P7.
- Location of the knob is highly important on the preferred steaming hand (left/right).
- 4 out of 9 participants specifically stated that pressure adjustability should not be too easy or even necessary.
    - P3: Wanted a more visual indicator (LEDs) instead of adjusting exact pressure values.
    - P6 & P7: Stated pressure should not be too easily changeable, preferred a hidden setting.
    - P9: Questioned why pressure should even be adjustable, prefers a fixed setting.
- 4 out of 9 participants preferred a knob or lever over a simple switch:
    - P2: "Had verwacht een hendel te hebben om de stoom te regelen in plaats van een knopje."
    - P3: "Voorkeur voor een hendel in plaats van een klein knopje."
    - P6: Stated preference for more control via a physical steam release mechanism.
    - P7: Wanted a lever for better steam control, rather than an abrupt switch, but did like the directness of this machine.

Design aesthetics (of prototype)

- P1, P3, P7 preferred a more modern, sleek design instead of the current aesthetic.
- P5 and P8 liked the current design, describing it as functional and fitting their current coffee corner.
- 6 out of 9 participants explicitly mentioned the steam wand as aesthetically pleasing:
    - P2: "Een hele grote stoompijp, dat zie je wel aan die hele elegante espressomachines. [...] Ik vind het wel deftig zo bovenlangs."

- 6 out of 9 participants favored a matte black or premium metal finish, aligning with modern espresso trends.
    - P7 referred to Acaia or StoovBar premium looks.

2.3 Conclusion Test 2

The user evaluation highlighted key insights regarding steam power, design preferences, usability, and interface clarity.

Steam performance was positively received, with 8 out of 9 participants noting that the steam power exceeded expectations. P1 explicitly mentioned that the stronger steam allowed them to focus more on technique rather than compensating for weaker output. Three participants (P2, P5, P6) compared the power to professional café machines and appreciated the speed, though they noted that pressure control was not always consistent. There was no clear consensus on whether adjustable pressure was necessary; while all participants appreciated the feature, it was questioned its necessity for such easy adjustment. It can be concluded that adjustment is important but shouldn't be the main characteristic of the interface.

Regarding size, 8 out of 9 participants found the prototype too tall, and three participants (P6, P7, P8) preferred a more compact and narrower design for smaller kitchens. However, the height concern may stem from questioning bias or lack of current aesthetic design of the prototype, as height may not be a practical issue in daily use.

Cleaning was not a major concern, though nozzle maintenance and descaling were frequently mentioned.

User preferences were divided on several design elements. Four participants valued a drip tray, while the other five did not find it necessary. A removable water reservoir was preferred, though a fixed one would not be a deal-breaker. Steam wand movement preference was evenly split, with four favouring single linear motion, while five preferred full 360° rotation, but only if it did not increase cost. Cold-touch steam wands were seen as a nice addition but not a necessity.

Nozzle preferences showed that 6 out of 9 participants wanted the option to swap nozzles, indicating that users rely on their previous experiences with different nozzles. This suggests that offering nozzle variations could be a valuable business model consideration.

The interface was the most critical usability issue, with all participants finding certain elements unclear. 7 out of 9 struggled to interpret the displayed values, though bar pressure was preferred over temperature or percentage-based readings. 6 out of 9 participants disliked the location of the steam on/off switch, and 2 participants (P6, P7) found it too fiddly. The timer feature was rarely used or deemed necessary. These

findings indicate that significant improvements are needed for a more intuitive and user-friendly interface.

Aesthetically, 6 out of 9 participants praised the steam wand’s appearance, associating it with high-end espresso machines. The overall industrial and functional design was generally appreciated, though further research is needed to assess users' true preferences beyond their impressions of a prototype.

3. Feature ranking (Test 3)

The goal is to gain insights into the minimal viable product by quantitatively ranking 11 features, identifying must-haves, and guiding participants in making prioritized feature decisions.

3.1 Analysis setup

This analysis utilizes two complementary data sets to assess user preferences. In the first, participants ranked 11 features from most to least important, with lower aggregate scores indicating higher priority. The second classified each feature as either a must-have or nice-to-have, offering a binary perspective on essential attributes. An additional analysis identified "tossed" features, those ranked relatively high but excluded from must-haves when participants were forced to limit their selection. This dual approach should provide a nuanced view of absolute importance and trade-offs, highlighting key user priorities for the MVP.

3.2 Results test 3

a. Dataset 1: Feature ranking

Participants rank the 11 features from most important (rank=1) to least important (rank=11). Every position was related to the following point system: #1 = 0 points, #2 = 1 point, [....], and #11 = 10 points. This means less points equals higher priority. The Box & Whisker plot in Figure 1 shows the distribution of each feature's rank across 9 participants. Table 2 sums up the ranks for each feature, with the minimum possible total = 0 (everyone ranks it #1) and maximum = 90 (everyone ranks it #11). The list is in order from most important to least important, based on average scoring.

Performance features lead the rankings

- Consistent steam pressure is the top-ranked feature, with a total of 9/90 points, the lowest of any feature, indicating that nearly all participants placed it in their top two, only one outlier was found ranking it at #8.
- Heating up time (25/90) and Adjustability of pressure (26/99) also appear near the top, suggesting that users value immediate operational performance and the flexibility to tweak it.

Secondary features in the mid-range

- Steaming time of milk jug (38/99), Froth different types of milk (39/90), Compact counter size (40/90), and Aesthetic design (40/90) occupy a middle tier, reflecting that participants find them valuable but not as critical as core performance attributes.

Low-priority features

- Ease of cleaning (52/90), Noise level (65/90), Modifiability (74/90), and Energy consumption (87/90) consistently appear lower in the ranking, indicating these aspects are less decisive for most participants.

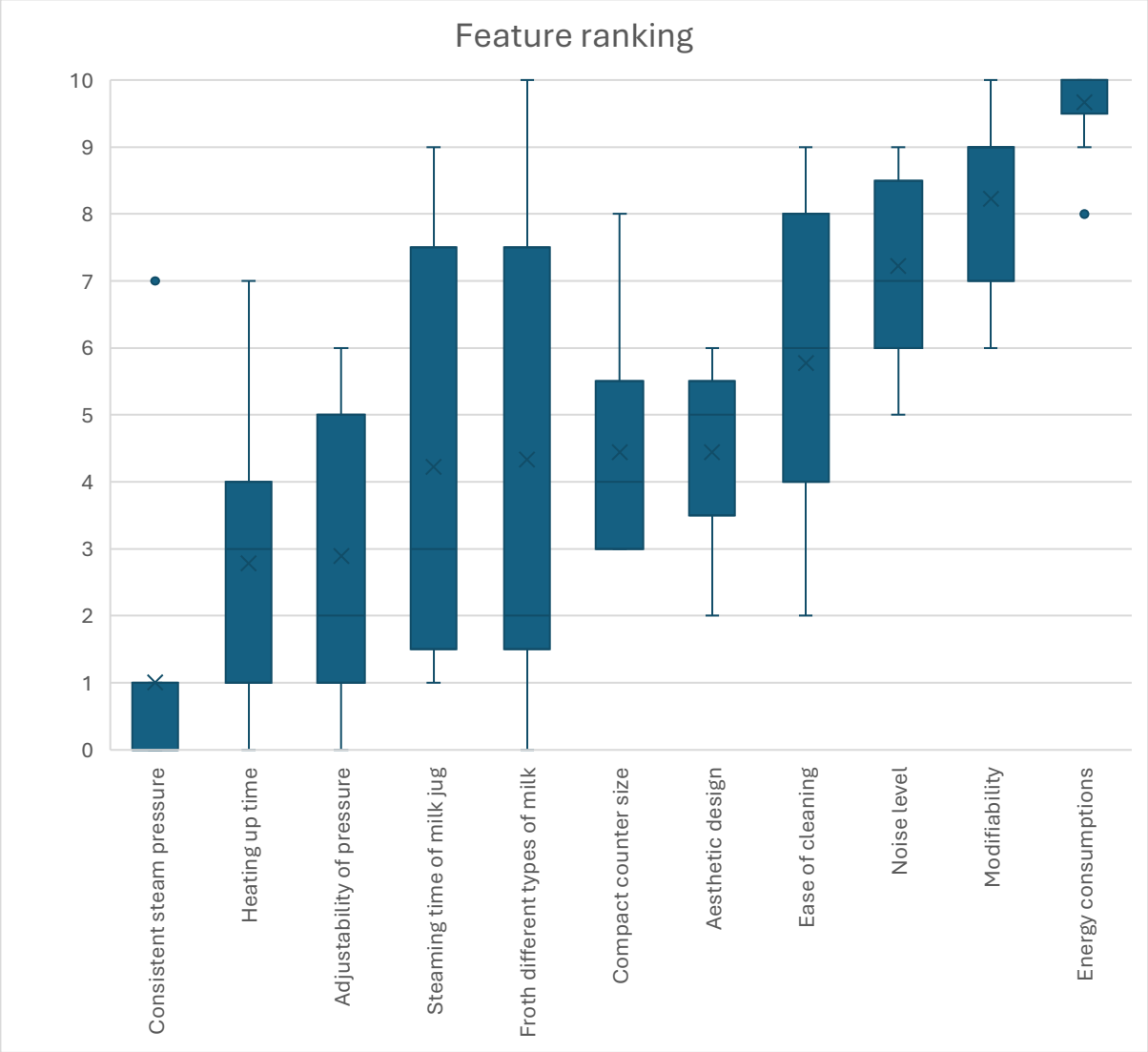


Figure XX

Table XX

Ideal order	Score	Average
Consistent steam pressure	9 / 90	1,0
Heating up time	25 / 90	2,8
Adjustability of pressure	26 / 90	2,9
Steaming time of milk jug	38 / 90	4,2
Froth different types of milk	39 / 90	4,3
Compact counter size	40 / 90	4,4
Aesthetic design	40 / 90	4,4
Ease of cleaning	52 / 90	5,8
Noise level	65 / 90	7,2
Modifiability	74 / 90	8,2
Energy consumptions	87 / 90	9,7

b. Dataset 2: Must have vs. Nice to have

Participants classified each feature from the features list as must-have (score=1) or nice-to-have (score=0). Table 2 shows how many participants considered each feature must-have out of n=9. A maximum score is 9/9, meaning all participants found it essential. The list is in order from most important to least important, based on average scoring. The "tossed" features, shown in Table 3, are those that ranked higher in dataset 1 but did not make the must-have cut in dataset 2 for certain participants.

Highest must-have scores

- Aesthetic design is the only feature with 9 out of 9 must-have votes, highlighting the strong emphasis on visual appeal.
- Consistent steam pressure follows at 8 out of 9, confirming its near-universal importance for ensuring quality froth.
- Compact counter size and Heating up time each score 6 out of 9, showing moderate agreement on these as essentials.

Mid-tier must-haves

- Adjustability of pressure and Ease of cleaning both sit at 5 out of 9, indicating a split opinion: about half the participants see them as crucial, while the others consider them secondary.

Least chosen features

- Noise level (1/9), Modifiability (0/9), and Energy consumption (0/9) rank at the bottom, suggesting that only one or none of the participants considered them "must-have."

Although Heating up time and Steaming time both scored decently in the raw rankings. The tossed list shows, 2 participants ultimately decided they were not essential enough to keep in their final must-have list.

Table 3:

Ideal order by must vs. nice	Score
Aesthetic design	9 / 9
Consistent steam pressure	8 / 9
Compact counter size	6 / 9
Heating up time	6 / 9
Adjustability of pressure	5 / 9
Ease of cleaning	5 / 9
Froth different types of milk	4 / 9
Steaming time of milk jug	3 / 9
Noise level	1 / 9
Modifiability	0 / 9
Energy consumptions	0 / 9

Table 4:

Tossed features	Amount
Steaming time of milk jug	2
Heating up time	2
Froth different types of milk	1
Adjustability of pressure	1
Compact counter size	1

3.3 Conclusions

The analysis reveals that while technical performance is crucial, aesthetic design plays a decisive role in the envisioned purchase decisions. Despite consistent steam pressure ranking highest in free ranking, all participants (9/9) selected aesthetic design as a must-have, suggesting that visual appeal holds significant weight in final purchase decision.

Pressure control adjustability showed mixed priorities. While it ranked joint #2 in free ranking, only 5 out of 9 participants considered it essential, indicating a divide. Some users value customizations, while others expect the machine to function optimally at a default setting.

Compactness and heating time were important but situational. Although compact size ranked mid-range (40/90), 6 out of 9 participants ultimately classified it as a must-have and others strongly considered it. One participant tossed it, and another hesitated to include it. Suggesting that space constraints remain a significant concern, even for users with larger kitchens. Heating time consistently ranked shared #2 or shared #3, but two participants excluded it when forced to prioritize features. Showing that while quick readiness is valued, it is not always a deal-breaker.

Other features received little attention. Energy consumption ranked lowest (87/90) with no must-have votes (0/9), as participants did not prioritize cost-saving or environmental impact. More tech backgrounded participants (P6, P7, P9) noted that the short time span of the usage would already limit the power usage. Similarly, noise level was not widely considered essential, indicating user tolerance for typical machine sounds.

Customization and ease of cleaning showed distinct trends. Modifiability remained unselected in both data sets (0/9), reinforcing that users prefer a ready-to-use product over an upgradable machine. Ease of cleaning, initially a low priority (#8), moved to mid-tier must-have (#6), with 5 out of 9 participants selecting it. This suggests that it isn’t a core value, but a nice final addition.

9.3 Conclusions and recommendations

9.3.1 Conclusion user experience and feature talk (test 1 and 2)

Interface, performance and learning curve
The initial user interactions identified key usability challenges in locating the power button and interpreting the display and controls. 7 out of 9 struggled to interpret the displayed values, uncertain whether the bar indicators referred to actual or target pressure. Bar pressure was preferred over temperature or percentage-based readings. 6 out of 9 participants disliked the location of the steam on/off switch, and 2 participants (P6, P7) found it too fiddly. The timer feature was rarely used or deemed necessary. These issues suggest that a lack of clear use clues and labelling contributes to confusion, which should be mitigated by design for intuitive use of the product.

When the interface was explained, the adjustment of the pressure setting was found to be intuitive, as all participants changed the setting to their liking. Difference in settings was perceived in steaming by 8 out of 9 participants. There was no clear consensus on whether adjustable pressure was necessary; while all participants appreciated the feature, it was questioned its necessity for such easy adjustment. It can be concluded that adjustment is important but shouldn't be the main characteristic of the interface, it can be hidden deeper or show les prominently.

As anticipated, user experience played a significant role in adaptation speed. Skilled baristas were able to create microfoam instantly (P5, P6, P7, P8). Three participants (P2, P5, P6) compared the power to professional café machines and appreciated the speed, though they noted that steam pressure was not always consistent. Less experienced users (P1, P9) struggled to achieve their desired results, tips from the researcher resulted in improvements. They remained engaged and motivated by the learning challenge and expressed interest in continued use of the prototype for a longer time span. Concluding, the current prototypes performance is already close to ideal. Only the consistency of the steam pressure should be slightly improved, as PID imbalance was noticed during testing (mainly by the researcher and P9). Chapter XX also reviews these imperfections. For ease of use for less skilled users, clear instructions or usage indications should be added.
Design choice: do you add use ques, or do you make a clear instruction? (user test result)

Product size, steam wand and aesthetics
Regarding size, 8 out of 9 participants found the prototype too tall, and three participants (P6, P7, P8) preferred a more compact and narrower design for smaller kitchens. However, the height concern may stem from questioning bias and/or lack of current aesthetic design of the prototype, as height may not be a practical issue in daily use. It can be safely assumed that size reduction is a must, especially combined with improved aesthetics.

Conversation about nozzles showed that 6 out of 9 participants wanted the option to swap nozzles. Three participant (P6, P8, P9) had specific preferences based on previous experiences, the others just liked to play around and test different methods. This suggests that offering nozzle variations could be a valuable business model consideration. It also reflects that nozzle design often is compared to previous experience, so innovative nozzle design doesn't necessarily resonate with users. But more validation is needed.

The steam wand interaction was found intuitive, as all participants (9/9) easily positioned the wand in the milk jug and correctly used the rubber handle for reorientation. The design was also perceived as aesthetic, mentioned by 6 out of 9 participants. P2 quoting: “Een hele grote stoompijp, dat zie je wel aan die hele elegante espressomachines. [...] Ik vind het wel deftig zo bovenlangs”. Steam wand movement preference was evenly split, with four favoring single linear motion, while five preferred full 360° rotation, but only if it did not increase cost. Cold-touch steam wands were seen as a nice addition but not a necessity. This concludes that the full redesign of the current wand isn’t needed, it could even be seen as a SteamUp characteristic. It is highly important to keep the steam wans accessible.

Open choices; cleaning, drip tray and water reservoir
User preferences were divided on several design elements. Cleaning was not a major concern, though nozzle maintenance and descaling were frequently mentioned. Four participants valued a drip tray, while the other five did not find it necessary. A removable water reservoir was preferred, though a fixed one would not be a deal-breaker. These features have no big impact, so they are free of design requirements.

9.3.2 Conclusion feature ranking (test 3)

The feature ranking analysis reveals that while technical performance is crucial, aesthetic design plays a decisive role in the envisioned purchase decisions. Despite consistent steam pressure ranking highest in free ranking, all participants (9/9) selected aesthetic design as a must-have, suggesting that visual appeal holds significant weight in final purchase decision.
Since performance was already perceived as good, so minor adjustments should be made. Aesthetics is underdeveloped, so a large afford should be made to improve the design.

Pressure control adjustability showed mixed priorities. While it ranked joint #2 in free ranking, only 5 out of 9 participants considered it essential, indicating a divide. Some users value customizations, while others expect the machine to function optimally at a default setting.
This can be improved by optimizing the display usage. Now the interface has one use case, but this could be improved by layering the display. Especially because the current interface was the biggest pain point in the research of chapter XX, large improvements can be made here.

Compactness and heating time were important but situational. Although compact size ranked mid-range (40/90), 6 out of 9 participants ultimately classified it as a must-have and others strongly considered it. One participant tossed it, and another hesitated to include it. Suggesting that space constraints remain a significant concern, even for users with larger kitchens. Heating time consistently ranked shared #2 or shared #3, but two participants excluded it when forced to prioritize features. Showing that while quick readiness is valued, it is not always a deal-breaker.
Compactness will ultimately be decided by the internal components and aesthetic design choices. As described in chapter xx, there is room for size reduction due to PCB design and optimization of piping and fittings.
Heating up time was already valued as good, so no need for large adjustments

Other features received little attention. Energy consumption ranked lowest (87/90) with no must-have votes (0/9), as participants did not prioritize cost-saving or environmental impact. More tech backgrounded participants (P6, P7, P9) noted that the short time span of the usage

would already limit the power usage. Similarly, noise level was not widely considered essential, indicating user tolerance for typical machine sounds.
Current energy use and noise levels were found suiting, so from a user's viewpoint no need for design changes. Sustainable and technical viewpoint does affect this decision, as mentioned in chapter xx.

Customization and ease of cleaning showed distinct trends. Modifiability remained unselected in both data sets (0/9), reinforcing that users prefer a ready-to-use product over an upgradable machine. Ease of cleaning, initially a low priority (#8), moved to mid-tier must-have (#6), with 5 out of 9 participants selecting it. This suggests that it isn't a core value, but a nice final addition.
No need for special attention for this, comes automatically with a good design.

9.3.3 Research recommendations

The findings from the user tests highlight key areas for improving future evaluations of the SteamUp prototype. Defining the target group more precisely is essential for generating more relevant insights. Future studies should segment participants based on their current coffee machine usage, familiarity with milk frothing, and overall skill level. This refined segmentation would allow for a more detailed understanding of user needs and expectations.

Expanding the sample size is also necessary to enable statistically significant subgroup analyses and capture a broader range of user behaviours and preferences. Additionally, standardizing the research methodology is critical. The iterative nature of testing may have introduced inconsistencies; therefore, conducting at least six pilot sessions before final data collection would help refine and ensure a consistent research approach.

Finally, social desirability bias should be addressed. Given the startup context, participants may have moderated their critiques to be more positive. Future research should encourage unfiltered, constructive feedback by incorporating anonymization methods or emphasizing the importance of honest responses to ensure unbiased, actionable insights.

Appendix C10: All Deisgn Implications

5.4 Design implications
The steam wand and connection system require in-house custom design.
Optimising sourcing and implementing a structured piping design will enhance performance while minimising the number of unique components.
A fully integrated PCB will eliminate wiring complexity, enhance durability, and reduce overall size, improving both assembly and reliability.
The embodiments need transition to manufacturing-ready materials to ensure long-term reliability, premium aesthetics, and cost efficiency.

6.5 Design implications
The system must allow users to modify the amount of air introduced during frothing to accommodate different milk types and preferences.
The device must provide a clear indication to stop frothing when the milk reaches 60°C to prevent overheating and maintain foam quality and taste.
The generated foam must retain its structure and volume for at least 15 minutes to ensure a consistent drinking experience.
The vortex's turbulence and shear forces must be sufficient to produce air bubbles smaller than 200 μm, achieving smooth, stable microfoam.
During the second frothing phase, the system must maintain a stable entrainment ratio to ensure reduction of bubbles.
The device must incorporate visual or functional use cues to assist users in applying the correct frothing technique.

7.4 Design implications
The boiler must be filled to maximise steam availability while preventing water droplets from being drawn into the piping, avoiding wet steam formation and dilution.
PID control and thermal energy losses must be reduced by at least 11%, with a preferred reduction of 25%, to enable the transition from a 2000W to a 1500W boiler without efficiency loss.
The heating element must have a faster response time to compensate for pressure drops when the steam valve is opened, ensuring consistent steam output.

8.4 Design implications
A major interface redesign is required. This includes improving the steam switch placement, removing pressure setting as a primary interface feature, and redesigning the display interface.
Prototype performance is nearly optimal, requiring only minor adjustments such as PID tuning for improved steam consistency.
Clear instructions or usage cues should be added to help novice users achieve the correct steaming technique.
Size reduction is necessary, with an estimated decrease of 10 cm in height and 2.5 cm in width, which should be validated.
The steam wand design is visually appealing and corresponds to the machine's power, current accessibility is ideal, only optimisation adjustments needed.

9 .4 Minimal Viable SteamUp (design implications)

The findings conclude a minimal viable product of SteamUp to be a consistent high-pressure device with an aesthetically appealing look. The interface can be minimised to an indication of readiness and a steam switch. To improve market size, the product must offer fast heating and a compact form factor. Heating up time of two minutes was deemed sufficient (Chapter 08) and proposed boiler modifications are not expected to significantly impact this (Chapter 07). The estimated final product size is expected to be smaller than standard espresso machines (~340 mm in height) and approximately 120 mm in width (a 25 mm reduction), though further validation is required.

At a mass production stage, a more advanced interface with adjustable settings can be introduced. Additional features, such as a removable water reservoir, easy cleaning mechanisms, and customisable nozzle configurations, can also be incorporated.

12.5 Design implications

The product should visually communicate the presence of the premium boiler component through cylindrical geometry and metallic finishes.

The form should convey a sense of strength and stability.

Perceived quality is best achieved through robust metal elements, complemented by thoughtful use of plastic or wood to provide functional or aesthetic contrast.

The design should express powerful performance while maintaining visual calmness through balanced proportions and smooth transitions.

The product should aim to push aesthetic boundaries within the coffee appliance market to establish a distinctive and recognisable identity.

Ciao, mede koffiefanaat

Graag stellen we jullie een paar vragen over onze gezamenlijke hobby!

Het duurt ongeveer **5 min**, alvast veel dank!

als hobbem er het mooie van als je alles 100% eerlijk invult.

Start

"We beginnen makkelijk en nemen een kijkje in je huidige koffie ritueel.

(Description (optional)

Overgaan Druk op **Enter** ↵

Welk type koffie drink jij?*

Tip/Hint: Denk terug, wat heb ik de afgelopen 2 weken aan koffie gedronken?

Espresso
Americano
Filter
Cappuccino
Flat white
Latte
Overige

Add choice

Welk espresso/koffie apparaat heb je thuis?*

Meerdere opposities? vul ze allemaal in!

Hier komt het antwoord...

Een een paragraaf kan te vragen, druk op **Shift** + **Enter** ↵

En welke bonenmaler?*

Meerdere? vul ze allemaal in!

Hier komt het antwoord...

Een een paragraaf kan te vragen, druk op **Shift** + **Enter** ↵

Heb je ook een losse melkschuimer? *

(Description (optional)

Hier komt het antwoord...

Een een paragraaf kan te vragen, druk op **Shift** + **Enter** ↵

Hoe tevreden ben je met je **koffie** resultaat thuis?*

(Description (optional)

0 1 2 3 4 5 6 7 8 9 10

Hoe tevreden ben je met je **melkschuim** resultaat thuis?*

(Description (optional)

0 1 2 3 4 5 6 7 8 9 10

Wat is je droom setup?*

Al tevreden? Vul een "n" in.

Hier komt het antwoord...

Wil je latte art kunnen scheniken?*

(Description (optional)

Kan ik al
Ja heel graag
Nou heeft niet 🤷

Add choice

Nu komt de aap uit de mouw.

We ontwikkelen een losstaande **melkopschuimer** voor thuis.

Een **aparte boiler met stoompijp** voor naast je ideale koffie apparaat

(Description (optional)

Continue Druk op **Enter** ↵

Graag horen we wat jij **mooi** vind, dan kunnen we daarmee rekening houden in ons ontwerp.

Bij de volgende vragen zie je basis renders van ontwerp richtingen. Kies steeds degene die je het meest aanspreekt!

Alle production hebben **dezelfde functionaliteit en features.**

(Description (optional)

Continue Druk op **Enter** ↵

Welke heeft je voorkeur?*

(Description (optional)

Kun je toelichten waarom je keuze op deze is gevallen?*

Wat sprak je aan? Vorm, Kleur, Materiaal, etc.?

Hier komt het antwoord...

Hieronder zie je alle opties nog een keer, welke kies je nu?*

(Description (optional)

Bien je verrranderd van keuze? Zou je dat kunnen toelichten? *

Wat sprak je meer aan bij de andere opties? Vorm, Kleur, Materiaal, etc.?

Hier komt het antwoord...

Een een paragraaf kan te vragen, druk op **Shift** + **Enter** ↵

Oké bijna klaar, tijd om alle varianten los van elkaar te testen.

"Eerlijkheid duurt het langst"

Doorgaan Druk op **Enter** ↵

Hoe mooi vind je deze?*

Antwoorden zijn anoniem.

1 2 3 4 5 6 7 8 9 10

En deze?*

Antwoorden zijn anoniem.

1 2 3 4 5 6 7 8 9 10

Deze?*

Antwoorden zijn anoniem.

1 2 3 4 5 6 7 8 9 10

En de laatste?*

Antwoorden zijn anoniem.

1 2 3 4 5 6 7 8 9 10

Wist je nog welke je het mooiste vond?

Noem dat ontwerp in gedachten voor de laatste vraag!

(Description (optional)

Doorgaan Druk op **Enter** ↵

Zijn er dingen die je niet zo mooi vond aan je gekozen opties?*

Hou bronnen we hem naar die prachtige 10

Hier komt het antwoord...

Een een paragraaf kan te vragen, druk op **Shift** + **Enter** ↵

Dat was hem, heel erg bedankt!

Is er nog iets wat je van je af wil schrijven?

Laat het dan hieronder weten.

Hier komt het antwoord...

Een een paragraaf kan te vragen, druk op **Shift** + **Enter** ↵

Appendix C18

	manufacturing			sheet	other	manufacturing and parts			Other parts		assembly and pakcaging	**Conclusion**				
	injection					*electronics*										
amount	Incl. mold	Ex. Mold	Relative Mold.	Price p. StUp	Price p. StUp	total no boiler	total EU	total China	Price p. StUp		China	amount	abs. and china	rel. and china	abs. and EU	rel. and EU
50	€ 549,83	€ 46,59	€ 46,83	€ 10,32	€ 14,90	€ 27,85	€ 122,85	€ 75,89	€ 18,99		€ 5,73	50	€ 680,36	€ 177,37	€ 727,32	€ 224,33
100	€ 278,07	€ 26,45	€ 26,57	€ 10,32	€ 12,72	€ 26,18	€ 116,18	€ 70,22	€ 18,06			100	€ 399,82	€ 148,33	€ 445,78	€ 194,29
500	€ 60,06	€ 9,74	€ 9,86	€ 10,32	€ 8,87	€ 19,80	€ 104,80	€ 60,34	€ 16,26		Nl social	500	€ 166,29	€ 116,09	€ 210,75	€ 160,55
1.000	€ 32,59	€ 7,43	€ 7,55	€ 10,32	€ 8,59	€ 18,48	€ 93,48	€ 58,12	€ 15,50		€ 10,44	1.000	€ 135,57	€ 110,53	€ 170,93	€ 145,89
5.000	€ 10,55	€ 5,52	€ 5,75	€ 10,32	€ 8,37	€ 18,06	€ 81,06	€ 57,10	€ 14,97			5.000	€ 111,75	€ 106,95	€ 135,71	€ 130,91

			elec no boiler	elec EU	elec China	total no boiler	total EU	total China
	labour china	quality	noPCB	no PCB	no PCB			
	€ 1,73	€ 1,71	€ 21,08	€ 116,08	€ 69,12	€ 46,84	#######	€ 94,88
			€ 21,06	€ 111,06	€ 65,10	€ 44,23	#######	€ 88,27
	labour nl shelter		€ 17,55	€ 102,55	€ 58,09	€ 36,06	#######	x
	€ 6,44		€ 16,94	€ 91,94	€ 56,58	€ 33,99	#######	€ 73,63
			€ 16,81	€ 79,81	€ 55,85	€ 33,03	€ 96,03	€ 72,07
	packaging							
	€ 4,00							

amount	**C_mc**	**C_ma + C_lab**	**C_qp**	**C_inv**	**MC**	MC Investment			
50	€ 166,69	€ 6,44	€ 5,71	€ 554,82	€ 733,66	€ 36.683,04			
100	€ 137,77	€ 6,44	€ 5,71	€ 277,41	€ 427,33	€ 42.732,86	2	1,1649214	0,58246072
500	€ 105,53	€ 6,44	€ 5,71	€ 55,48	€ 173,16	€ 86.582,01	5	2,0261224	0,40522448
1.000	€ 99,97	€ 6,44	€ 5,71	€ 27,74	€ 139,86	€ 139.860,80	2	1,6153563	0,80767815
5.000	€ 96,29	€ 6,44	€ 5,71	€ 5,55	€ 113,98	€ 569.913,58	5	4,074863	0,8149726
30.000	€ 93,29	€ 6,44	€ 5,71	€ 0,92	€ 106,37	############	6	5,5990125	0,93316875

Cost of fabricated parts + Electronics + Off the shelve components

amount	Injection moulded	Metal parts	PCBA	OTS Components	Boiler EU	Boiler China	**Total cost**
50	€ 46,59	€ 25,22	€ 6,77	€ 46,84	€ 95,00	€ 48,04	€ 173,46
100	€ 26,45	€ 23,04	€ 5,11	€ 44,23	€ 90,00	€ 44,04	€ 142,88
500	€ 9,74	€ 19,19	€ 2,25	€ 36,06	€ 85,00	€ 40,54	€ 107,78
1.000	€ 7,43	€ 18,91	€ 1,54	€ 33,99	€ 75,00	€ 39,64	€ 101,51
5.000	€ 5,52	€ 18,69	€ 1,26	€ 33,03	€ 63,00	€ 39,04	€ 97,54

Assembly, packaging and quality check

amount	Assembly NL	Assembly NL Sh	Assembly CH	Packaging	**Total cost**
50		€ 6,44		€ 4,00	€ 10,44
100		€ 6,44		€ 4,00	€ 10,44
500	€ 16,91	€ 6,44	€ 1,73	€ 4,00	€ 10,44
1.000	€ 16,41	€ 6,44	€ 1,68	€ 4,00	€ 8,12
5.000	€ 16,07	€ 6,44	€ 1,65	€ 4,00	€ 8,08

Investment

amount	moulds	**TTM 2 year 5%**
total price	€ 25.162,00	€ 27.741,11
50	€ 503,24	€ 554,82
100	€ 251,62	€ 277,41
500	€ 50,32	€ 55,48
1.000	€ 25,16	€ 27,74
5.000	€ 5,03	€ 5,55
30000	€ 0,84	€ 0,92

amount	**Total cost**
50	€ 738,72
100	€ 430,73
500	€ 173,70
1.000	€ 137,37
5.000	€ 111,17
30000	€ 106,55

Xometry

Direct quote

Base holder		amount	total	mal	per part	mal total parts	parts only	per part full
	PC-ABS	50	€ 7.760,50	€ 7.240,68	€ 155,21	€ 0,24	€ 10,40	€ 10,64
		100	€ 7.847,00	€ 7.240,68	€ 78,47	€ 0,24	€ 6,06	€ 6,30
		500	€ 8.535,00	€ 7.240,68	€ 17,07	€ 0,24	€ 2,59	€ 2,83
		1.000	€ 9.320,00	€ 7.241,68	€ 9,32	€ 0,24	€ 2,08	€ 2,32
		max						
		amount	total	mal	per part	mal total parts	parts only	per part full
	ABS	50	€ 7.713,50	€ 7.240,68	€ 154,27	€ 0,24	€ 9,46	€ 9,70
		100	€ 7.753,00	€ 7.240,68	€ 77,53	€ 0,24	€ 5,12	€ 5,36
		500	€ 8.065,00	€ 7.240,68	€ 16,13	€ 0,24	€ 1,65	€ 1,89
		1.000	€ 8.380,00	€ 7.240,68	€ 8,38	€ 0,24	€ 1,14	€ 1,38
		max						
		amount	total	mal	per part	mal total parts	parts only	per part full
	PC	50	€ 7.732,50	€ 7.240,68	€ 154,65	€ 0,24	€ 9,84	€ 10,08
		100	€ 7.791,00	€ 7.240,68	€ 77,91	€ 0,24	€ 5,50	€ 5,74
		500	€ 8.255,00	€ 7.240,68	€ 16,51	€ 0,24	€ 2,03	€ 2,27
		1.000	€ 8.750,00	€ 7.241,68	€ 8,75	€ 0,24	€ 1,51	€ 1,75
		max						
Cap top	Injection moulding	amount	total	mal	per part	mal total parts	parts only	per part full
	PC-ABS	50	€ 6.338,50	€ 5.863,11	€ 126,77	€ 0,20	€ 9,51	€ 9,70
		100	€ 6.379,00	€ 5.863,11	€ 63,79	€ 0,20	€ 5,16	€ 5,35
		500	€ 6.710,00	€ 5.863,11	€ 13,42	€ 0,20	€ 1,69	€ 1,89
		1.000	€ 7.030,00	€ 5.863,11	€ 7,03	€ 0,20	€ 1,17	€ 1,36
		max						
Connector	Injection moulding	amount	total	mal	per part	mal total parts	parts only	per part full
	PC-ABS	50	€ 6.665,00	€ 6.183,18	€ 133,30	€ 0,21	€ 9,64	€ 9,84
		100	€ 6.714,00	€ 6.183,18	€ 67,14	€ 0,21	€ 5,31	€ 5,51
		500	€ 7.095,00	€ 6.183,18	€ 14,19	€ 0,21	€ 1,82	€ 2,03
		1.000	€ 7.500,00	€ 6.183,18	€ 7,50	€ 0,21	€ 1,32	€ 1,52
		max						
Water reservoir	Injection moulding	amount	total	mal	per part	mal total parts	parts only	per part full
	PC clear	50	€ 7.313,00	€ 6.820,63	€ 146,26	€ 0,23	€ 9,85	€ 10,07
		100	€ 7.372,00	€ 6.820,63	€ 73,72	€ 0,23	€ 5,51	€ 5,74
		500	€ 7.840,00	€ 6.820,63	€ 15,68	€ 0,23	€ 2,04	€ 2,27
		1.000	€ 8.340,00	€ 6.820,63	€ 8,34	€ 0,23	€ 1,52	€ 1,75
		max						
Reservoir lid	Injection moulding	amount	total	mal	per part	mal total parts	parts only	per part full
	ABS	50	€ 4.664,00	€ 4.204,53	€ 93,28	€ 0,14	€ 9,19	€ 9,33
		100	€ 4.690,00	€ 4.204,53	€ 46,90	€ 0,14	€ 4,85	€ 4,99
		500	€ 4.890,00	€ 4.204,53	€ 9,78	€ 0,14	€ 1,37	€ 1,51
		1.000	€ 5.070,00	€ 4.204,53	€ 5,07	€ 0,14	€ 0,87	€ 1,01
		max						

Elevator sheet	Sheet metal forming	amount	total	per part
	Stainless steel	1	€ 197,68	€ 197,68
		5	€ 241,20	€ 48,24
		10	€ 288,00	€ 28,80
		50	€ 516,00	€ 10,32
		max		
	+ powdercoat	50	€ 638,50	€ 12,77
	+ passivation	50	€ 612,00	€ 12,24

Tailered quote

Base holder	Injection moulding	Quantity	Price per 1	Total	Inl. mold	P. part	Mold	Max mold	Mold p. part
	PC-ABS	50	€ 10,80	€ 540,00	€ 7.781,00	€ 155,62	€ 7.241,00	30000	€ 0,24
		100	€ 6,77	€ 677,00	€ 7.918,00	€ 79,18			
		500	€ 2,95	€ 1.475,00	€ 8.716,00	€ 17,43			
		1.000	€ 2,57	€ 2.570,00	€ 9.811,00	€ 9,81			
		5.000	€ 1,95	€ 9.750,00	€ 16.991,00	€ 3,40			
Base holder	Metal moulding	Quantity	Price per 1	Total	Inl. mold	P. part	Mold	Max mold	Mold p. part
	Zamak	50	€ -	€ -	€ -	€ -	€ 10.800,00	10000	€ 1,08
		100	€ 7,25	€ 725,00	€ 11.525,00	€ 115,25			
		500	€ 7,00	€ 3.500,00	€ 14.300,00	€ 28,60			
		1.000	€ 6,75	€ 6.750,00	€ 17.550,00	€ 17,55			
		5.000	€ -	€ -	€ -	€ -			
Cap top	Injection moulding	Quantity	Price per 1	Total	Inl. mold	P. part	Mold	Max mold	Mold p. part
	PC-ABS	50	€ 8,91	€ 445,50	€ 4.145,50	€ 82,91	€ 11.100,00	90000	€ 0,12
		100	€ 4,88	€ 488,00	€ 4.188,00	€ 41,88			
		500	€ 1,66	€ 830,00	€ 4.530,00	€ 9,06			
		1.000	€ 1,17	€ 1.170,00	€ 4.870,00	€ 4,87			
		5.000	€ 0,85	€ 4.250,00	€ 7.950,00	€ 1,59			
Connector	Injection moulding	Quantity	Price per 1	Total	Inl. mold	P. part			
	PC-ABS	50	€ 9,04	€ 452,00	€ 4.152,00	€ 83,04			
		100	€ 5,01	€ 501,00	€ 4.201,00	€ 42,01			
		500	€ 1,79	€ 895,00	€ 4.595,00	€ 9,19			
		1.000	€ 1,31	€ 1.310,00	€ 5.010,00	€ 5,01			
		5.000	€ 0,98	€ 4.900,00	€ 8.600,00	€ 1,72			
Reservoir lid	Injection moulding	Quantity	Price per 1	Total	Inl. mold	P. part			
	PC-ABS	50	€ 8,59	€ 429,50	€ 4.129,50	€ 82,59			
		100	€ 4,56	€ 456,00	€ 4.156,00	€ 41,56			
		500	€ 1,34	€ 670,00	€ 4.370,00	€ 8,74			
		1.000	€ 0,86	€ 860,00	€ 4.560,00	€ 4,56			
		5.000	€ 0,54	€ 2.700,00	€ 6.400,00	€ 1,28			

Water reservoir	Injection moulding	Quantity	Price per 1	Total	Inl. mold	P. part	Mold	Max mold	Mold p. part
	PC clear	50	€ 9,25	€ 462,50	€ 7.283,50	€ 145,67	€ 6.821,00	30000	€ 0,23
		100	€ 5,23	€ 523,00	€ 7.344,00	€ 73,44			
		500	€ 2,00	€ 1.000,00	€ 7.821,00	€ 15,64			
		1.000	€ 1,52	€ 1.520,00	€ 8.341,00	€ 8,34			
		5.000	€ 1,20	€ 6.000,00	€ 12.821,00	€ 2,56			
Elevator sheet	Sheet metal forming								
	Stainless steel								
	Shipping	Plastic parts	€ 296,73						
		Zamak parts	€ 1.671,79						

		Direct quote			**Tailered quote**			
		injection						
		amount	Incl. mold	Ex. Mold	Relative Mold.	Incl. mold	Ex. Mold	Relative Mold.
		50	€ 654,82	€ 48,58	€ 49,59	€ 549,83	€ 46,59	€ 46,83
		100	€ 330,02	€ 26,90	€ 27,91	€ 278,07	€ 26,45	€ 26,57
		500	€ 70,14	€ 9,52	€ 10,53	€ 60,06	€ 9,74	€ 9,86
		1.000	€ 37,26	€ 6,95	€ 7,96	€ 32,59	€ 7,43	€ 7,55
		5.000	€ -	€ -	€ -	€ 10,55	€ 5,52	€ 5,75
		sheet						
		amount	Price per part			Price per part		
		50	€ 10,32					
		100	€ 10,32					
		500	€ 10,32					
		1.000	€ 10,32					
		5.000	€ 10,32					
			All molds			All molds		
			€ 44.793,49			€ 25.162,00		€ 29.128,16
			Mold amound			Mold amound		€ 19,42
			30.000			30.000		
			Relative			Relative		
			€ 1,49			€ 0,84		

metal	500x
elevator	€ 10,32
cylinder	€ 2,68
holder	€ 6,19
sum	€ 19,19

Other

Boiler cylinde	Buy in cylinder	amount	total	part	note	
	120x3x172	1		€ 8,40	Cut	https://www.aluminiumopmaat.nl/checkou
	Aluminium	34	€ 211,52	€ 6,22	6m	https://www.zultnermetall.com/en/alumini
		5	€ 35,40	€ 7,08	1m	https://www.gizom.nl/mijn-offerte/
		510	€ 1.962,00	€ 3,85	15x6m	
		500	€ 1.340,00	€ 2,68	cut	https://www.jmhaluminum.com/
		1000	€ 2.610,00	€ 2,61	cut	
		5000	€ 12.300,00	€ 2,46	cut	
		500	€ 1.185,00	€ 2,37	cut	https://dutch.wuxispecialsteel.com/
		1000	€ 2.320,00	€ 2,32	cut	
		5000	€ 10.500,00	€ 2,10	cut	
				pending		https://www.zhongxin-leadsheet.com/prod
				pending		https://www.billowmetal.com/products/alu
	Labour time	type	amount	time (sec)	total time (h)	
		hole	4	5	0,02	
		chamfer	4	10		
		hour rate	total cost			https://www.government.nl/topics/minimum-wage/minim
	NL assembly	€ 41,50	€ 0,69	NL		
	NL social	€ 12,50	€ 0,31	NL		
	min. Chi	€ 5,00	€ 0,08	China		

Final cost	Quantity	Price p. StUp
	50	€ 8,71
	100	€ 6,53
	500	€ 2,68
	1000	€ 2,40
	5000	€ 2,18

Boiler holder					
aluminum sh	Sheet metal forming	amount	total	per part	
assumption	Stainless steel	1	€ 118,61	€ 118,61	
		5	€ 144,72	€ 28,94	
		10	€ 172,80	€ 17,28	
		50	€ 309,60	€ 6,19	
		100	€ -	€ 6,19	
		500	€ -	€ 6,19	
		1000	€ -	€ 6,19	
		5000	€ -	€ 6,19	

Other overview	
Quantity	Price p. StUp
50	€ 14,90
100	€ 12,72
500	€ 8,87
1000	€ 8,59
5000	€ 8,37

Facturee

Base holder	Metal moulding	Quantity	Price per 1	Total	Inl. mold	P. part	Mold	Max mold	Mold p. part
	Zamak	50	€ -	€ -	€ -	€ -	€ 8.626,98	10000	€ 0,86
		100	€ 49,59	€ 4.959,00	€ 15.759,00	€ 157,59			
		500	€ 29,62	€ 14.810,00	€ 25.610,00	€ 51,22			
		1.000	€ 25,97	€ 25.970,00	€ 36.770,00	€ 36,77			
		5.000	€ 11,73	€ 58.650,00	€ 69.450,00	€ 13,89		1,684.23	

PcbWay

extra pending

PCB	Quantity	Total	per part	
	50	€ 61,65	€ 1,23	
	100	€ 99,73	€ 1,00	
	500	€ 338,64	€ 0,68	
	1.000	€ 595,86	€ 0,60	*Tip:Final price can be negotiated.*
	5.000	##########	€ 0,47	*Tip:Final price can be negotiated.*

Assembly	Quantity	Total	per part	
	50	€ 276,95	€ 5,54	
	100	€ 411,73	€ 4,12	
	500	€ 784,41	€ 1,57	
	1.000	€ 944,70	€ 0,94	*Tip:Final price can be negotiated.*
	5.000	##########	€ 0,78	*Tip:Final price can be negotiated.*

Boiler

Beltrami Felice

Boiler PR00031A 230V 2000W (with thermal-fuses)

An. quantity	500	85,00 €
An. quantity	1000	75,00 €
An. quantity	5000	63,00 €

Boilers China

50	100	500	1000	5000	
€ 48,04	€ 44,04	€ 40,54	€ 39,64	€ 39,04	https://www.alibaba.com/product-detail/YL-Factory-220v-Electric
					https://www.alibaba.com/product-detail/Factory-Price-Coffee-Mac

mail

€ 10,00

€ 30,00

Electronics

dollar to eur 0,86

	Part	Amount		Cost 50	100	500	1000	5000	Reference
Contol electronics	On Off switch	1		€ 0,07	€ 0,07	€ 0,07	€ 0,07	€ 0,07	https://www.alibaba.com/product-detail/10PCS-Push-Button-Switch-10x15
	Power cord	1		€ 0,30	€ 0,30	€ 0,26	€ 0,26	€ 0,22	https://www.alibaba.com/product-detail/Small-Order-Free-Sample-230v-Ac_
	Voltage step down regulator	1		€ 1,15	€ 1,15	€ 1,15	€ 1,15	€ 1,15	https://www.alibaba.com/product-detail/HLK-PM01-HLK-PM03-HLK-PM12_1
	5V 2 Channel Relay Switch	1		€ 0,42	€ 0,42	€ 0,42	€ 0,42	€ 0,42	https://www.alibaba.com/product-detail/New-2-Way-Relay-Module-with_160
	Relais Solid State Dimmer module	1		€ 0,55	€ 0,55	€ 0,54	€ 0,53	€ 0,53	https://www.alibaba.com/product-detail/Relay-Solid-State-5V-1-Channel_16
	PCB assembled	1		€ 6,77	€ 5,11	€ 2,25	€ 1,54	€ 1,26	
interface	Steam push button	2		€ 3,10	€ 3,10	€ 2,41	€ 2,41	€ 2,41	https://www.alibaba.com/product-detail/Langir-IP67-Waterproof-Stainless-S
	20 step rotary encoder	1		€ 0,26	€ 0,24	€ 0,24	€ 0,22	€ 0,22	https://www.alibaba.com/product-detail/Factory-Sales-EC11-Rotary-Encode
	pressure gauge 0 - 5 bar	1		€ 2,58	€ 2,58	€ 0,95	€ 0,95	€ 0,95	https://www.accio.com/d/1601112216804?dataSource=Alibaba.com&accio_
Water, boiler, steam	Italy ULKA NME4 Pump	1		€ 3,44	€ 3,44	€ 2,61	€ 2,61	€ 2,61	https://www.alibaba.com/product-detail/CNKALUN-LP3-24-240V-Steady-Flo
	Italy CEME SERIE 588 AC 230V Solenoid valve	1		€ 3,47	€ 3,47	€ 3,47	€ 3,47	€ 3,47	https://www.alibaba.com/product-detail/DL-3T-2-Way-2-Position_1600719
	3way valve	1		€ 4,21	€ 4,21	€ 3,87	€ 3,87	€ 3,87	https://www.alibaba.com/ https://www.alibaba.com/product-detail/Single-Gr
		1		€ 4,46	€ 4,46	€ 4,46	€ 3,91	€ 3,91	https://www.alibaba.com/ https://www.alibaba.com/product-detail/RFS-DL-6
	boiler EU	1		€ 95,00	€ 90,00	85,00 €	75,00 €	63,00 €	
	boiler China	1		€ 48,04	€ 44,04	€ 40,54	€ 39,64	€ 39,04	
	low volt cables	4		€ 0,41	€ 0,41	€ 0,41	€ 0,10	€ 0,10	https://www.alibaba.com/product-detail/Custom-4-Way-JST-VH-3_1601082
	high volt cables	10		€ 0,99	€ 0,99	€ 0,86	€ 0,86	€ 0,77	https://www.alibaba.com/product-detail/Customized-PVC-Insulated-Wire-Ha
			total no boiler	€ 27,85	€ 26,18	€ 19,80	€ 18,48	€ 18,06	
			total EU	€ 122,85	€ 116,18	€ 104,80	€ 93,48	€ 81,06	
			total China	€ 75,89	€ 70,22	€ 60,34	€ 58,12	€ 57,10	
	high volt cables								
	pump	2							
	boiler	2							
	solenoid valve	3							
	3 way valve	3							
	low volt cables								
	on off switch	1							
	Steam push button	2							
	20 step rotary encoder	1							

All other parts

											dollar to eur	0,86			
Water to boiler to steam															
Part	Amount		*50x*		*100x*		*500x*		*1000x*	*5000x*					
Pump Holder	2		€ 0,71	€	0,67	€	0,67	€	0,67	€ 0,67	https://www.alibaba.com/product-deta				
3 way holder	1		€ 0,04	€	0,04	€	0,04	€	0,04	€ 0,04	https://www.alibaba.com/product-deta				
Reinforced silicone tube 6x10 (m) (4x)	200	mm	€ 0,16	€	0,16	€	0,16	€	0,16	€ 0,16	https://www.alibaba.com/product-deta				
Vacuum valve boiler	1		€ 3,44	€	3,44	€	2,58	€	2,58	€ 2,58	https://www.alibaba.com/product-deta		the safety valve , 50-500, Ex work USD2.5/PC. For 1		
											https://www.alibaba.com/product-deta		For YCGLF11, the cost is Ex work USD12.00/PC for		
Pressure relief valve boiler 1/8 3.0 Bar	1		€ 1,55	€	1,55	€	1,55	€	0,95	€ 0,95	https://www.alibaba.com/product-deta		https://dutch.alibaba.com/product-detail/YONGCHU		
	1		€ 1,81	€	1,63	€	1,55	€	1,42	€ 1,42	https://www.alibaba.com/product-deta				
											https://www	https://www.alibaba.com/			
Copper tube 6x8mm (m)	200	gram	€ 0,21	€	0,17	€	0,15	€	0,15	€ 0,15	https://www.alibaba.com/product-deta				
Brass T-joint fitting G 1/8'' x 8mm	1		€ 0,61	€	0,61	€	0,58	€	0,58	€ 0,58	https://www.alibaba.com/product-deta				
Brass fitting	3		€ 0,72	€	0,72	€	0,72	€	0,67	€ 0,62	https://www.alibaba.com/product-deta				
Reinforced silicone tube 6x10 (m) (4x)	50	mm	€ 0,04	€	0,04	€	0,04	€	0,04	€ 0,04	https://www.alibaba.com/product-deta				
Hose clamp 6-12mm	3		€ 0,90	€	0,90	€	0,72	€	0,72	€ 0,28	https://www.alibaba.com/product-deta				
Screws															
Hexagon Socket Countersunk Head - M2 x 6	9		€ 0,08	€	0,08	€	0,08	€	0,08	€ 0,08	https://www.alibaba.com/product-deta				
Hexagon Socket Countersunk Head - M4 x 2(	3		€ 0,03	€	0,03	€	0,03	€	0,03	€ 0,03	...				
Hexagon Socket Countersunk Head - M4 x 1	6		€ 0,05	€	0,05	€	0,05	€	0,05	€ 0,05	...				
Hexagon Socket Countersunk Head - M3 x 8	2		€ 0,02	€	0,02	€	0,02	€	0,02	€ 0,02	...				
Steam pipe															
Steam pipe and fixation	1		€ 7,74	€	6,88	€	6,28	€	6,28	€ 6,28	https://www.alibaba.com/product-deta				
Ball joint	1		€ 1,28	€	1,28	€	1,23	€	1,18	€ 1,18	https://www.alibaba.com/product-deta		heel nice	https://www.alibaba.com/	
Teflon	500	mm	€ 0,13	€	0,13	€	0,13	€	0,13	€ 0,09	https://www.alibaba.com/product-deta		voor later	https://www.alibaba.com/	
Steam tip	1		€ 1,28	€	1,28	€	1,23	€	1,18	€ 1,18	https://www.alibaba.com/product-deta			https://www.alibaba.com/	
														https://www.alibaba.com/	
Other															
Teflon gasket															
Teflon tape															
		total	€ 18,99	€	18,06	€	16,26	€	15,50	€ 14,97					
sum parts	50														

Assembly

Step	Task description	Qty	Time (sec)	Total		Wage	per hour					
1	Add power cable to base	1	30	30		NL min	€ 14,06				https://en.wikipedia.org/wiki/List_of_Europ	
2	Add PCB to base	1	30	30		Wage assembly	€ 41,00					
3	Add 3-way valve to base	1	30	30		NL sheltered workshop	€ 13,50	off salary			Tromp	https://business.gov.nl/staff/
4	Add pump to base	1	30	30								https://www.europarl.europa.e
5	Add on/off switch to base	1	10	10								
6	Add tubing	3	30	90		Plnd min	€ 7,20				https://www.erieri.com/salary/job/assembl	
7	Connect power wiring	3	10	30		Prtgl min	€ 5,54				https://en.wikipedia.org/wiki/List_of_Europ	
											https://www.salaryexpert.com/salary/job/el	
8	Slide base into elevator	1	10	10								
9	Add front screw	1	20	20		China	€ 4,30				https://www.macrofab.com/blog/is-china-s	
10	Attach tube to connector	1	20	20								
11	Mount connector on sheet	1	15	15								
12	Tighten screws	2	20	40								
						Overhead EU	1,3					
13	Screw boiler into holder	2	20	40		Overhead China	1,1					
14	Assemble steam piping	1	180	180								
15	Connect piping to boiler	1	20	20							https://reshoringinstitute.org/wp-content/u	
16	Assemble steam wand	1	150	150								
17	Attach steam wand to piping	1	15	15								
18	Mount and screw boiler holder to base	4	20	80								
19	Connect boiler wiring	1	10	10		**Production cost**	500		1000		5000	
20	Connect steam piping wiring	1	10	10		Assembly NL comp	€ 16,91	€	16,41	€	16,07	
						Assembly NL shelterd	€ 6,44	€	6,24	€	6,11	
21	Add boiler shell	1	10	10		Assembly Port	€ 2,64	€	2,56	€	2,51	
22	Screw shell into place	4	20	80		Assembly China	€ 1,73	€	1,68	€	1,65	
				0								
23	Add water reservoir	1	10	10								
24	Add reservoir lid	1	10	10								
						Maatwerk BV	€ 42,50				mail	https://www.maakwerk.nl/
25	Add buttons to cap	2	30	60		Additions assembly	1,125					
26	Add pressure gauge to cap	1	30	30								
27	Add sensor to boiler	1	30	30								
28	Add adjustment ring to cap	1	30	30								
29	Add rotary encoder to cap	1	30	30								
30	Connect button and encoder wiring	3	30	90								
31	Screw cap onto product	2	30	60								
			time	21,67	min							
			overhead	0,2								
			Total time	**26,00**	**min**							
			Tromp	22	min							

Packaging

			Total price € 10,44
Size (mm)	320 x 380 x 160		
Premium packagng	€ 4,00		
Component	**Description**	**Estimated Cost (€)**	
Outer box	Double-wall corrugated box (brown, black print)	€0.60–€1.20	
Foam inserts	CNC-cut PE or molded pulp (2-piece support)	€1.50–€2.50	
Labels / print finishing	Black ink print, logo/branding	€0.20–€0.40	
Documentation / manual	Printed guide or leaflet	€0.10–€0.30	
Protective elements (bags, caps)	Small parts packaging, anti-scuff, etc.	€0.10–€0.30	