FaST - Jurnal Sains dan Teknologi, Vol.xxx, No.xxx, Bulan Tahun
e-ISSN 2598-9596
DOI: https://doi.org/xxx.xxx - Available online at: https//xxxx.xxx

# User-Centered Development of a Skincare Refrigerator Using the Generic Product Development Process and Quality Function Deployment: Integrating Functionality and Aesthetics

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**ABSTRACT**

Existing skincare refrigerators have limitations in storage capacity, product accessibility, multifunctionality, and the integration of functional and aesthetic features. These limitations highlight the need for a product design that better addresses consumer requirements. This study aims to develop a user-centered skincare refrigerator by integrating Quality Function Deployment (QFD) into the generic product development process proposed by Ulrich, Eppinger, and Yang. A mixed-methods approach was employed, incorporating user research, competitive analysis, customer requirement assessment, QFD through House of Quality (HoQ) Levels 1 and 2, product design, and prototype evaluation. The development process covered the stages through Testing and Refinement. The resulting prototype has a design capacity of 3.5 L and incorporates a Peltier TEC1-12706 cooling system, digital temperature display, integrated LED mirror, detachable shelves, and a dedicated compartment for skincare tools. Functional testing showed that the prototype accommodated a 3-L storage load and reached 15°C from an ambient temperature of 24.3°C within 41 minutes. Preliminary evaluation by 10 Industrial Engineering students yielded positive mean scores for quality in use (4.4), emotional appeal (4.3), product maintenance (3.9), material use (4.7), and product differentiation (4.4). Improvements are still needed in thermometer accessibility, interior appearance, and material durability. The estimated production cost is IDR 811,259 per unit.

**ARTICLE INFO**

**Keywords**
Quality Function Deployment (QFD), Skincare Fridge, House of Quality (HoQ), User-Centered Design, Functional Aesthetics

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**Article history**:
Submitted 5 Oct 2026
Revised 12 Nov 2026
Accepted 17 Nov 2026
Online Available 19 Nov 2026
Published 20 Nov 2026

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## 1. Introduction

Skincare has become an increasingly important concern among Indonesian consumers, driven by growing interest in facial care and the increasing availability of cosmetic and cosmeceutical products [1]. The domestic cosmetics sector has also expanded considerably, with cosmetics accounting for the largest share of product registrations over the past five years, reaching 411,410 registered products [2]. A 2022 survey by Populix reported that 77% of consumers in major Indonesian cities, including Jakarta, Surabaya, Bandung, Medan, and Semarang, purchased skincare products at least once a month, with an average expenditure of approximately IDR 250,000. Commonly purchased products included moisturizers, serums, and sunscreens from both local and international brands [3]. Female consumers, in particular, purchase skincare products to address various facial skin concerns, including acne, dryness, dullness, and wrinkles [4].

The increasing use of formulations containing active ingredients, including antioxidants, vitamin C, retinoids, and hyaluronic acid, has further emphasized the importance of appropriate product storage. These ingredients are widely used for their potential roles in photoprotection, skin-barrier maintenance, hydration, and collagen-related functions. Previous studies have also examined the chemical stability and degradation of active ingredients in cosmetic formulations, indicating that storage conditions can influence product stability [5]. Accordingly, appropriate storage conditions are an important consideration for maintaining the quality and stability of selected skincare formulations. Previous studies have examined the chemical stability of ascorbic acid in commercial skincare products, highlighting the importance of formulation characteristics and delivery conditions in maintaining its bioactivity and stability [13]. Accordingly, appropriate storage conditions are an important consideration in maintaining the quality and stability of selected skincare formulations.

The growing interest in temperature-controlled skincare storage has contributed to the emergence of dedicated skincare refrigerators. However, cooling functionality alone may not adequately address users' broader storage requirements. The literature and product-related evidence reviewed in this study indicate that storage organization, accessibility, and flexibility remain relevant design considerations. Existing products may provide limited flexibility in accommodating skincare products with different

FaST - Jurnal Sains dan Teknologi, Vol.10, No.2, Nov 2026
e-ISSN 2598-9596
DOI: https://doi.org/10.19166/jstfast.v10i2.11865
Available online at: https://ojs.uph.edu/index.php/FaSTJST/article/view/11865

sizes and shapes, while the organization and accessibility of stored products can also affect user convenience. These considerations were further examined through the preliminary investigation conducted in this study. Preliminary observations, focus group discussions, questionnaire responses, and competitor analysis identified several recurring user concerns, including limited storage capacity, difficulty accessing products, instability of products placed on tiered shelves, limited flexibility of internal storage configurations, door stability, variation in product sizes, and relatively high product prices.

These findings were further supported by a preliminary questionnaire involving 40 respondents, which identified storage capacity, ease of product access, adjustable shelving, multifunctionality, and affordability as important requirements for a skincare refrigerator. The findings suggest that skincare refrigerator development needs to consider not only its cooling function but also its ability to accommodate users' requirements for storage capacity, accessibility, organization, and multifunctionality. Therefore, these requirements need to be systematically identified, prioritized, and translated into specific product design characteristics to ensure that the resulting design addresses users' actual needs.

Previous studies have demonstrated the application of Quality Function Deployment (QFD) in various product development contexts, including multifunctional footwear, furniture, conveyor systems, and other consumer products. However, based on the literature reviewed in this study, the application of QFD specifically to skincare refrigerator design remains limited. This provides an opportunity to apply a customer-oriented product development approach to systematically translate skincare refrigerator users' requirements into prioritized technical characteristics and product components. QFD was therefore adopted as an analytical approach within the product development process because it provides a structured method for translating customer requirements into product design characteristics and guiding subsequent development decisions [6, 7, 15]. The House of Quality (HoQ) serves as an initial matrix in this process by establishing relationships between customer requirements (WHATs) and technical responses (HOWs), thereby supporting the prioritization of design requirements [7, 15]. In this study, HoQ Levels 1 and 2 were applied during the Concept Development phase to translate customer needs into prioritized technical responses and critical product components.

Francis [14] also demonstrated the application of QFD in an engineering context through a case study involving the development of an ABET-accredited program. This illustrates the applicability of QFD in translating stakeholder requirements into structured priorities for engineering-related improvement.

Accordingly, this study aims to identify and characterize user requirements and limitations associated with existing skincare refrigerators and to develop a user-centered skincare refrigerator using the generic product development process proposed by Ulrich, Eppinger, and Yang, with QFD integrated into the Concept Development phase. The study covers the product development activities from planning and concept development through system-level design, detail design, and testing and refinement. The proposed design is evaluated through functional and user-based testing to examine its performance and the extent to which the identified user requirements have been addressed, as well as to identify opportunities for further improvement. Through this approach, the study contributes a structured application of customer-oriented product development to skincare refrigerator design, connecting user requirements, prioritized technical characteristics, critical product components, detailed design, and prototype evaluation.

A key strength of this study lies in integrating Quality Function Deployment (QFD) with the generic product development process proposed by Ulrich, Eppinger, and Yang [8]. By incorporating HoQ Level 1 (product planning) and HoQ Level 2 (part deployment) into the Concept Development phase, customer requirements are systematically translated into prioritized technical responses and critical product components that guide product architecture, detailed design, and prototype development. The study further employs a staged mixed-methods approach, combining user research, quantitative customer assessments, competitor analysis, and prototype evaluation. Through functional testing and preliminary user evaluation, the approach establishes a systematic link between customer needs, engineering decisions, and prototype performance while identifying areas for further improvement

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## 2. Research Method

This study employed a mixed-methods approach to support the user-centered development of a skincare refrigerator. The research methodology was structured based on the generic product development process proposed by Ulrich, Eppinger, and Yang [8], comprising five phases within the scope of this study: Planning (Phase 0), Concept Development (Phase 1), System-Level Design (Phase 2), Detail Design (Phase 3), and Testing and Refinement (Phase 4). The study was limited to Phase 4 because its primary objective was to develop and evaluate a product prototype rather than prepare the product for mass production. Quality Function Deployment (QFD), particularly the House of Quality (HoQ), was integrated into the Concept Development phase to translate customer requirements into prioritized technical characteristics [7]. Figure X illustrates the overall research framework and the activities undertaken in each development phase

**Phase 0: Planning**

The planning phase focused on identifying the product development opportunity, target users, research objectives, and development constraints. The development opportunity was identified through the need for a skincare storage solution that could accommodate users' storage requirements while addressing limitations associated with existing skincare refrigerators. The target users were skincare consumers who required an appropriate storage solution for their skincare products. A preliminary examination of existing products and a review of relevant literature provided an initial understanding of the product development context and established the direction for the subsequent research stages.

**Phase 1: Concept Development**

The concept development phase focused on identifying customer needs, examining existing products, and translating user requirements into prioritized technical characteristics. This phase began with a qualitative Focus Group Discussion (FGD) involving four skincare product users, two of whom had direct experience using existing skincare refrigerators. The FGD explored users' experiences, storage practices, difficulties encountered with existing products, and unmet product needs.

The qualitative findings were subsequently used to develop a quantitative questionnaire administered to 40 skincare consumers. The questionnaire collected information regarding skincare usage patterns, storage-related problems, user expectations, and the types and quantities of skincare products commonly stored. These findings provided an empirical basis for identifying customer requirements and determining the required storage capacity and internal spatial configuration of the proposed product.

In addition, a literature review was conducted to examine previous studies concerning product development, product design, and the application of QFD in translating customer requirements into technical characteristics. The reviewed studies demonstrate that QFD can be used to identify customer needs, determine their relative priorities, and establish corresponding technical responses in various product development contexts. The literature also highlights the importance of incorporating functional, usability, and design considerations into product development. However, based on the literature reviewed in this study, relatively few studies specifically address the application of QFD to skincare refrigerator development, particularly in translating requirements related to storage capacity, product accessibility, storage flexibility, and aesthetics into prioritized technical specifications. The findings from the literature review, together with the preliminary user research, provided a basis for examining existing skincare refrigerator designs and identifying product characteristics requiring improvement or modification.

The identified customer requirements were subsequently evaluated through two separate respondent groups. First, 100 skincare consumers assessed the Importance to Customer of the identified product requirements. Second, 10 respondents who had previously used or were currently using skincare refrigerators evaluated the Customer Satisfaction Performance of existing products. These assessments provided the customer-related inputs for constructing the House of Quality (HoQ).

QFD was employed as the principal method for translating customer requirements (WHATs) into technical responses (HOWs) [7]. The HoQ was constructed by establishing the relationships between customer requirements and technical characteristics, incorporating customer importance and satisfaction assessments, and determining the relative priorities of the technical responses. The resulting technical priorities served as a basis for subsequent product concept development and design decisions. Thus, the HoQ functioned as an analytical tool within the Concept Development phase rather than as a separate product development framework.

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**Phase 2: System-Level Design**

In the system-level design phase, the prioritized technical requirements obtained from the HoQ were translated into the overall product architecture. This stage focused on defining the functional and physical elements of the skincare refrigerator, including its main components, functional configuration, and internal storage arrangement. The objective was to establish a product architecture that addressed the prioritized customer requirements while ensuring the integration of the product's functional elements.

**Phase 3: Detail Design**

The detail design phase involved developing the specific product specifications required for prototype construction. This stage included determining product dimensions, material selection, component configurations, storage arrangements, and other detailed design characteristics. The technical priorities identified through QFD were considered during the development of these specifications to maintain consistency between customer requirements and the proposed product design. The resulting detailed design served as the technical basis for constructing the physical prototype.

**Phase 4: Testing and Refinement**

The testing and refinement phase focused on evaluating the developed prototype through functional testing and user-based assessment. The physical prototype was constructed based on the specifications established during the detail design phase. Functional testing was conducted to assess the prototype's storage-load capacity and cooling performance. The storage-load test involved six 500-mL bottles, representing a total storage load of 3 L. Meanwhile, the cooling performance test measured the time required for the prototype to reduce its internal temperature from an ambient temperature of 24.3°C to the target temperature of 15°C.

Following the functional tests, a preliminary user evaluation was conducted with 10 Industrial Engineering students. The respondents were selected based on two considerations: their accessibility for direct prototype demonstration and their academic background, which provided relevant familiarity with product design and product characteristics. The evaluation involved a direct demonstration of the prototype followed by the administration of a structured questionnaire.

The respondents assessed the prototype across five product dimensions derived from industrial design quality metrics [8]: quality in use, emotional appeal, product maintenance, material use, and product differentiation. Quality in use addressed the functionality and usability of the prototype; emotional appeal considered its aesthetic characteristics and user experience; product maintenance assessed the ease of cleaning and maintaining the product; material use considered the appropriateness and perceived quality of the materials employed; and product differentiation examined the distinctive characteristics and value offered by the proposed product.

The evaluation was intended to obtain preliminary feedback on the prototype's functional and design characteristics rather than to represent the perceptions of the broader skincare consumer population or establish market acceptance. The functional testing results and user evaluation responses were subsequently analyzed to identify the strengths and remaining design limitations of the prototype. Particular attention was given to aspects receiving relatively lower evaluations, as these indicated potential areas for improvement. The findings provided a basis for identifying the refinements required in the proposed design. Accordingly, this phase established the extent to which the prototype addressed the prioritized customer requirements and identified aspects requiring further development.

Overall, the research adopted five phases of the generic product development process proposed by Ulrich, Eppinger, and Yang [8], from Planning (Phase 0) through Testing and Refinement (Phase 4). Within this framework, QFD and the HoQ were incorporated into Concept Development to establish the relationships between customer needs and technical specifications. The prioritized technical requirements subsequently guided system-level design, detail design, and prototype development. Finally, functional testing and user-based evaluation provided an empirical basis for assessing the developed prototype and identifying opportunities for further refinement. The study therefore focused on the development and preliminary evaluation of the skincare refrigerator prototype without extending to the Production Ramp-Up phase.

The methodological strength of this study lies in integrating user research, QFD-based prioritization, product design, and prototype evaluation within a single development framework. This sequential approach ensures that customer needs are translated into product specifications, implemented in a physical prototype, and evaluated through functional and user-based assessments, providing

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traceability between customer requirements, engineering decisions, and prototype performance while identifying opportunities for further improvement.

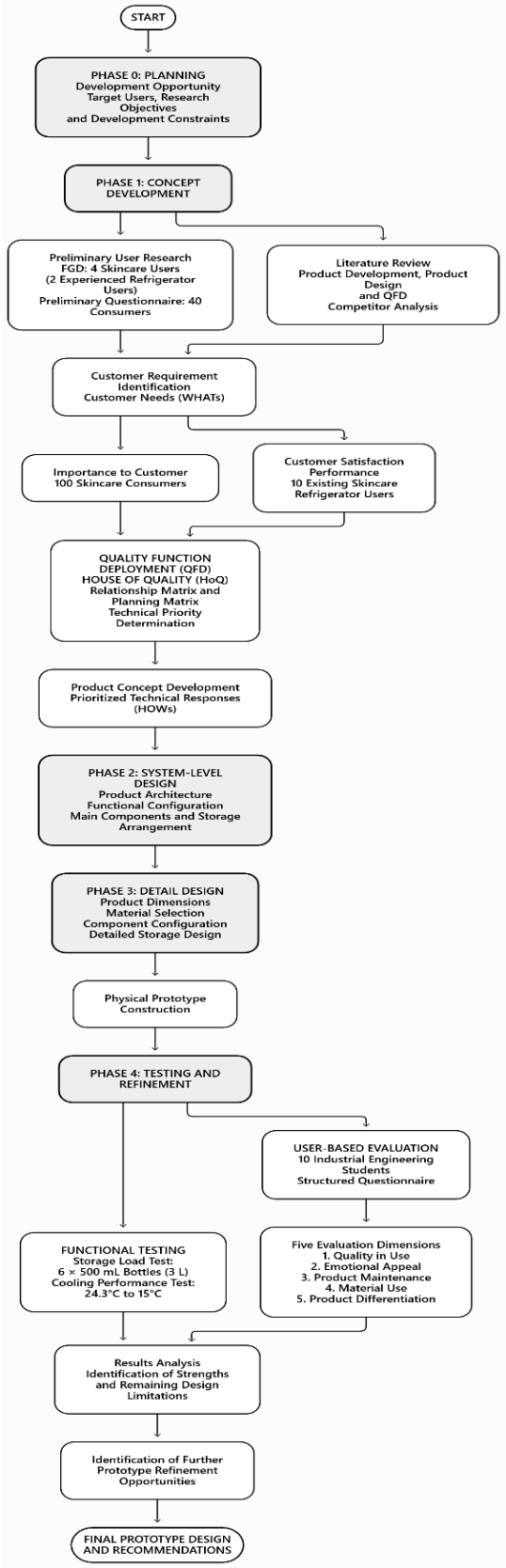



**Figure 1:** Flowchart Research Method

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The flowchart summarizes the activities and outputs of each development phase. Planning (Phase 0) defines the development opportunity, target users, objectives, and constraints, producing the mission statement. Concept Development (Phase 1) combines FGD, the preliminary survey, competitor analysis, customer-priority assessment, and HoQ Levels 1 and 2, producing prioritized customer requirements, technical responses, and critical product parts. System-Level Design (Phase 2) translates these priorities into the product architecture and functional configuration. Detail Design (Phase 3) specifies dimensions, materials, components, and fabrication procedures and produces the physical prototype. Testing and Refinement (Phase 4) evaluates storage-load capacity, cooling performance, and preliminary user perceptions, producing performance evidence and a list of potential design improvements. The process ends at Phase 4 and does not include Production Ramp-Up.

## 3. Result and Discussion

Based on the phases in the research methodology, this research will explore the application of Quality Function Deployment in order to identify issues related to the existing skincare fridges to propose improvements in design elements.

### 3.1 Planning

The product planning phase encompasses opportunity identification, project evaluation and prioritization, resource allocation, and pre-project planning. A formal mission statement (see Table 1) is developed, articulating the product description, core value proposition, business objectives, target markets, assumptions, constraints, and key stakeholders.

**Tabel 1.** Mission Statement

| | **Mission Statement** |
|---|---|
| Product Description | • The product to be developed is a skincare fridge designed to meet the need of customers |
| Core Benefit Proposition | • The skincare fridge product can serve as a solution for individuals seeking storage options for their products at temperatures ranging from 4.44°C to 15.55°C. |
| Key Business Goals | • The skincare fridge product is expected to be realized by December 2023.<br>• The product is capable of precisely meeting the needs of consumers.<br>• The resulting product will have added aesthetic value, innovation, as well as new features or improvements to meet customer needs. |
| Assumptions & Constraints | • The design and development of the product will be carried out within a timeframe of 5 months.<br>• The final product will not use materials that were not intended. |
| Stakeholder | • **Primary users:** Individuals who use facial skincare products and require appropriate storage solutions to maintain their products.<br>• **Potential users:** Individuals who use body and hair care products or seek convenient storage solutions for personal care products at controlled temperatures |

### 3.2 Concept Development

The Concept Development phase was conducted to translate identified consumer requirements into product concepts and technical specifications. In accordance with the generic product development process, this phase involved user research, customer needs identification, competitor analysis, customer-priority assessment, technical-response formulation, and component planning. Quality Function Deployment (QFD), particularly the House of Quality (HoQ), was employed as a structured approach to translate customer expectations into technical requirements and critical product components.

The process began with qualitative and quantitative user research to identify users' experiences, expectations, and difficulties related to skincare product storage. An initial Focus Group Discussion (FGD) was conducted with four skincare product users, two of whom had previous experience using

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skincare refrigerators. The discussion explored users' experiences, storage practices, difficulties with existing storage methods, and expectations for an improved skincare refrigerator. The FGD findings were subsequently complemented by a questionnaire administered to 40 skincare consumers. This questionnaire was used to identify storage-related problems and consumer expectations more broadly and also collected information regarding the types and quantities of skincare products stored by respondents. The resulting information provided a basis for determining the required storage capacity and configuration of the proposed skincare refrigerator.

The user research identified several recurring storage-related problems. Consumers who stored skincare products at room temperature reported insufficient storage space, difficulty accessing products, the risk of products being spilled or knocked over, exposure to dust, and concerns regarding exposure to inappropriate temperatures or sunlight. Some respondents also reported using conventional food refrigerators as an alternative storage method, which created inconvenience because they needed to retrieve skincare products from the kitchen. Among existing skincare refrigerator users, difficulties included retrieving products stored at the rear of tiered compartments and limited storage space that reduced the effectiveness of removable shelving.

The qualitative and quantitative findings were subsequently translated into customer statements and customer needs. The identified requirements included temperature information, multifunctionality, an integrated mirror, sufficient storage capacity, ease of product retrieval, adjustable shelving, dedicated storage for skincare tools, an appropriate product colour, ease of cleaning, and affordability. These customer needs formed the basis for the subsequent QFD analysis.

A competitive analysis was conducted using two existing skincare refrigerator products, Unixso (12 L) and NVMEE (8 L), as presented in Figure X. The two products were examined to identify their existing design configurations, functional features, storage arrangements, and potential limitations in relation to the identified customer needs.




(a) Unixso (12 L) (b) NVMEE (8 L)

**Figure 2.** Existing skincare refrigerator products used in the competitive analysis

The Unixso product incorporates a dual-door configuration, an LCD panel displaying temperature and time, LED interior lighting, adjustable temperature control, and a portable handle. However, the analysis identified several limitations, including the absence of an integrated mirror, the possibility of door imbalance when the weight distribution between the two doors differs, relatively high price, and limited storage space.

The NVMEE product has an 8-L capacity and three storage sections and incorporates an integrated mirror, three-mode LED lighting, cooling and heating functions, removable shelving, and a door-locking mechanism. However, the product provides limited variation in colour and size. The competitor analysis therefore provided a basis for identifying product characteristics that could be retained, improved, or incorporated into the proposed design.

The competitor findings were mapped against the ten customer needs to distinguish features already available in existing products from requirements that could guide further design development.

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Unixso has a nominal capacity of 12 L and provides temperature information through an LCD panel, adjustable temperature control, and LED interior lighting. These features relate to the needs for storage capacity, temperature information, and product functionality; however, the product does not incorporate an integrated mirror. The observed dual-door configuration, relatively high price, and reported storage limitations were also considered in identifying opportunities for improvement. NVMEE has a nominal capacity of 8 L and incorporates an integrated mirror, three storage sections, three-mode LED lighting, cooling and heating functions, removable shelving, and a door-locking mechanism. These features relate to the requirements for an integrated mirror, multifunctionality, storage organization, and adjustable shelving, while its limited colour and size variations indicate an opportunity for greater aesthetic and dimensional choice. For requirements such as ease of product retrieval and ease of cleaning, the available product information did not provide sufficient standardized evidence for a definitive comparative performance rating. Affordability was considered qualitatively because the available price information was not assessed using a standardized cost-performance method. The comparison therefore informed the selection of design opportunities but was not treated as a quantitative competitor-rating exercise. These findings were considered together with the customer-priority assessment in constructing the HoQ.

To quantify the relative importance of the identified customer needs, a separate questionnaire was administered to 100 skincare consumers. The questionnaire measured the Importance to Customer of the ten identified product requirements using a five-point Likert scale. The mean score for each requirement was calculated and subsequently incorporated into the House of Quality (HoQ) as the quantitative representation of customer priorities.

In parallel, the Customer Satisfaction Performance of existing skincare refrigerators was assessed using 10 respondents who had previously used or were currently using a skincare refrigerator. The respondents evaluated the extent to which existing products fulfilled the identified customer requirements. The resulting satisfaction scores were compared with the importance ratings to identify gaps between customer expectations and the perceived performance of existing products.

The Importance to Customer and Customer Satisfaction Performance data were subsequently incorporated into the planning matrix of the House of Quality. This process enabled the research to identify customer requirements that were considered important but were not fully satisfied by existing products. The resulting priorities were then used to establish technical responses and guide subsequent product-development decisions. Table 2 presents the average Importance to Customer and Customer Satisfaction Performance scores for the ten identified customer needs.

**Table 2.** Average Importance to Customer and Customer Satisfaction Performance

| Customer Needs | Average Importance to Customer | Average Customer Satisfaction Performance |
|---|---|---|
| Temperature information for the interior of the skincare fridge | 3.0 | 3.5 |
| Multifunctional product | 3.7 | 2.5 |
| Integrated mirror | 4.3 | 3.4 |
| Large capacity | 4.0 | 2.8 |
| Easy product retrieval | 3.7 | 3.6 |
| Adjustable shelves | 4.4 | 3.6 |
| Dedicated storage for facial care tools | 4.2 | 3.1 |
| Natural colour | 3.5 | 3.8 |
| Easy to clean | 4.2 | 2.8 |
| Affordable price | 3.8 | 3.6 |

Following the assessment of customer importance and satisfaction performance, the planning matrix of the House of Quality (HoQ) was developed to determine the relative priorities of the identified customer needs. This process involved establishing a target goal for each customer requirement, calculating its improvement ratio, and assigning a sales point. These parameters were subsequently used to calculate the raw weight of each customer need.

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The improvement ratio indicates the extent of improvement required to achieve the established target relative to the performance of existing products. It was calculated by dividing the target goal by the Customer Satisfaction Performance, as expressed in Equation (1):

$$\text{Improvement Ratio} = (\text{Goal}) / (\text{Customer Satisfaction Performance}) \quad \ldots\ldots \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

For the requirement concerning interior temperature information, the design team assigned a Goal of 3 because this feature was considered essential but not a priority for substantial improvement. The existing-product Customer Satisfaction Performance was 3.5; therefore, the Improvement Ratio was 3 / 3.5 = 0.86. A ratio below 1 indicates that the existing performance already exceeded the deliberately established target for this particular requirement. It does not indicate a calculation error; rather, it reduces the improvement priority assigned to this requirement in the planning matrix. The Goal value should therefore be interpreted as a design-team target, not as a score that must automatically exceed the current satisfaction score. Subsequently, the raw weight was calculated by multiplying the Importance to Customer value by the assigned sales point and the improvement ratio. The calculation is expressed in Equation (2):

$$\text{RawWeight} = (\text{ImportancetoCustomer}) \times (\text{ImprovementRatio}) \times (\text{Sales Point}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

For the same customer requirement, the Importance to Customer value was 3 and the assigned sales point was 1.2. Using the improvement ratio of 0.86, the raw weight was calculated as follows: Raw Weight = 3 × 0.86 × 1.2 = 3.09

The same calculation procedure was applied to all ten customer requirements. The resulting raw weights were subsequently used to determine the normalized importance of each customer need in the HoQ planning matrix. These normalized values provided the basis for prioritizing customer requirements and calculating the contribution of the corresponding technical responses.

Following the quantitative assessment, customer needs were translated into quantifiable technical descriptors or engineering characteristics. This translation was essential for operationalizing qualitative requirements within the product development process. Subsequently, a relationship matrix within the House of Quality (HoQ) was constructed to map the relationships between customer needs and the corresponding technical responses. The strength of each relationship was categorized using a symbolic scale: a strong relationship (◎), moderate relationship (○), weak relationship (△), or no relationship (blank) [7]. This matrix provided a structured representation of how specific design parameters addressed consumer demands, as summarized in Figure 3.

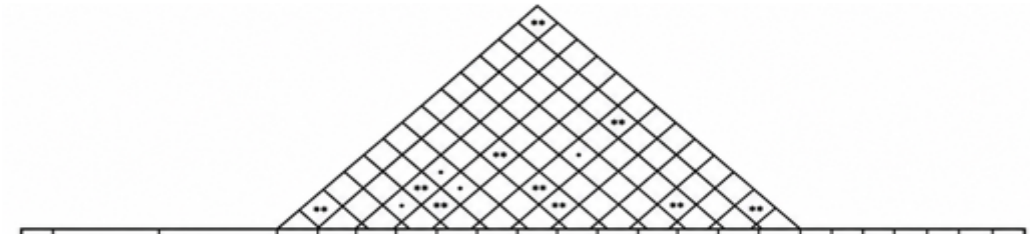
| No. | Customer Needs \ Technical Response | Temperature Sensor | Temperature Display Screen | LED Lights | Adopting vanity table function | Mirror | Interior Design | Product Storage Method | Detachable Shelf | Skincare Tool Compartment | Color | Exterior Material | Interior Material | Cooling System |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Temperature information for the interior of the skincare fridge | ○ | ○ | | | | | | | | | | | |
| 2. | Multifunctional product | | | ○ | ○ | ○ | △ | | | | | | | |
| 3. | Integrated mirror | | | | ○ | ○ | | | | | | | | |
| 4. | Large capacity | | | | | | ○ | ◎ | | ○ | | | | |
| 5. | Easy product retrieval | | | | | | ○ | ○ | ◎ | | | | | |
| 6. | Adjustable shelves | | | | | | | | ○ | | | | | |
| 7. | Dedicated storage for facial care tools | | | | | | | | | ○ | | | | |
| 8. | Natural color | | | | | | | | | | ○ | | | |
| 9. | Easy to clean | | | | | | | | ○ | | | | ○ | |
| 10. | Affordable price | ○ | | | | ○ | | | | | | ○ | ○ | ○ |

**Figure 3.** Relationship Matrix

Following the establishment of the relationship matrix, the subsequent step in constructing the House of Quality (HoQ) involves calculating the contribution values for each technical response. These

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values are derived by multiplying the relationship strength score (assigned to each matrix cell) by the absolute weight of the corresponding customer need and summing the results for each technical descriptor. The resulting contribution value quantifies the relative priority of each technical response; a higher value signifies a greater potential impact on overall customer satisfaction, thereby highlighting critical areas for focused development and implementation in the final product design. The outcomes of these calculations are integrated into the completed HoQ, as presented in Figure 4.



| No. | Customer needs i | Technical Response → | Temperature Sensor | Temperature Display Screen | LED Lights | Adopting vanity table function | Mirror | Interior Design | Product Storage Method | Detachable Shelf | Skincare Tool Compartment | Color | Exterior Material | Interior Material | Cooling System | Importance to Customer | Customer Satisfaction Performance | Goal | Improvement Ratio | Sales Point | Raw Weight | Normalized Raw Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Temperature information for the interior of the skincare fridge | | ○ | ○ | | | | | | | | | | | | 3.0 | 3.50 | 3 | 0.86 | 1.2 | 3.09 | 0.05 |
| 2. | Multifunctional product | | | | ○ | ○ | ○ | △ | | | | | | | | 3.7 | 2.50 | 4 | 1.60 | 1.2 | 7.01 | 0.11 |
| 3. | Integrated mirror | | | | | ○ | ○ | | | | | | | | | 4.3 | 3.40 | 4 | 1.18 | 1.5 | 7.99 | 0.12 |
| 4. | Large capacity | | | | | | | ○ | • | | ○ | | | | | 4.0 | 2.80 | 5 | 1.79 | 1.5 | 10.77 | 0.17 |
| 5. | Easy product retrieval | | | | | | | ○ | ○ | • | | | | | | 3.7 | 3.60 | 4 | 1.11 | 1.5 | 6.08 | 0.10 |
| 6. | Adjustable shelves | | | | | | | | | ○ | | | | | | 4.4 | 3.60 | 4 | 1.11 | 1.5 | 7.35 | 0.12 |
| 7. | Dedicated storage for facial care tools | | | | | | | | | | ○ | | | | | 4.2 | 3.10 | 5 | 1.61 | 1 | 6.76 | 0.11 |
| 8. | Natural color | | | | | | | | | | | ○ | | | | 3.5 | 3.80 | 3 | 0.79 | 1 | 2.75 | 0.04 |
| 9. | Easy to clean | | | | | | | | | ○ | | | | ○ | | 4.2 | 2.80 | 4 | 1.43 | 1 | 5.99 | 0.10 |
| 10. | Affordable price | | ○ | | | | ○ | | | | | | ○ | ○ | ○ | 3.8 | 3.60 | 3 | 0.83 | 1.5 | 4.78 | 0.08 |
| Contribution | | | 1.17 | 0.45 | 0.99 | 2.07 | 2.79 | 2.54 | 1.41 | 2.28 | 2.52 | 0.36 | 0.72 | 1.62 | 0.72 | | | | | | 62.12 | |
| Percentage | | | 5.06% | 1.29% | 5.06% | 10.54% | 14.21% | 12.93% | 7.18% | 11.61% | 12.83% | 1.83% | 3.67% | 8.25% | 3.67% | | | | | | | |

**Figure 4.** House of Quality

The five planning-matrix columns shown at the right side of the HoQ summarize the target and improvement priority for each customer need. Goal records the target selected by the design team; Improvement Ratio compares this target with current Customer Satisfaction Performance; Sales Point reflects the perceived market-attractiveness contribution of meeting the requirement; Raw Weight combines customer importance, improvement ratio, and sales point; and Normalized Raw Weight expresses each raw weight as a proportion of the total. The equations and calculation examples are presented above and are not repeated here. The resulting planning matrix assigned the highest normalized priority to large capacity (0.17), followed by adjustable shelves (0.12), integrated mirror (0.12), multifunctionality (0.11), and dedicated skincare-tool storage (0.11). These priorities indicate that storage capacity, storage flexibility, and additional functionality were the most prominent customer concerns and informed the subsequent technical-response and part-deployment analyses.

### 3.3 Part Deployment (HoQ Level 2)

Following the development of the product planning matrix (HoQ Level 1), the QFD process continued with part deployment (HoQ Level 2). This stage translated the prioritized technical responses into critical product components that would guide subsequent design and development activities. Five critical parts were identified for the skincare refrigerator: cooling system, product capacity, interior design, exterior design, and product size.

The relationship matrix was developed to map the connections between the prioritized technical responses and the identified critical parts, as presented in Table 3. The relationships were assessed using the same weighting scale applied in the preceding QFD analysis: 9 for strong, 3 for moderate, and 1 for weak relationships [7].

The Contribution column represents the importance weight of each technical response carried forward from HoQ Level 1. These values were used to calculate the relative importance of each critical part by multiplying the technical response contribution by its corresponding relationship score and

FaST - Jurnal Sains dan Teknologi, Vol.10, No.2, Nov 2026
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DOI: https://doi.org/10.19166/jstfast.v10i2.11865
Available online at: https://ojs.uph.edu/index.php/FaSTJST/article/view/11865

summing the resulting values. The calculation is expressed in Equation (4): Critical Part Weight = Σ (Technical Response Contribution × Relationship Score)

For example, the Cooling System obtained a total weight of 248.40, calculated by aggregating the weighted contributions of all technical responses related to this critical part. The same calculation was applied to the other critical parts. Subsequently, the Column Weights were normalized to determine the percentage contribution of each critical part to the overall part deployment priorities.

**Table 3**. A relationship matrix is constructed to map the strength of connections between prioritized technical responses

| | | Critical Part | | | | | |
|---|---|---|---|---|---|---|---|
| **No.** | **Technical Response** | **Cooling System** | **Product Capacity** | **Interior Design** | **Exterior Design** | **Product Size** | **Contribution** |
| 1. | Temperature Sensor | 9 | | 3 | | | 5.96 |
| 2. | Temperature Display Screen | 9 | | | 3 | | 2.29 |
| 3. | LED Lights | | | | | | 5.04 |
| 4. | Adopting Vanity Table Function | | | 9 | 9 | 9 | 10.54 |
| 5. | Mirror | | | | | | 14.21 |
| 6. | Interior Design | 9 | | 9 | | 9 | 12.93 |
| 7. | Product Storage Method | | 9 | 9 | | | 7.18 |
| 8. | Detachable Shelf | | 1 | 9 | | | 11.61 |
| 9. | Skincare Tool Compartment | | 9 | 9 | | 9 | 12.83 |
| 10. | Colour | | | | 9 | | 1.83 |
| 11. | Exterior Material | | | | 9 | 9 | 3.67 |
| 12. | Interior Material | 3 | | 9 | | 9 | 8.25 |
| 13. | Cooling System | 9 | 9 | 9 | 9 | 9 | 3.67 |
| | **Column Weight** | **248.40** | **224.73** | **620.97** | **184.26** | **467.01** | **1745.37** |
| | **Percentage** | **14.23%** | **12.88%** | **35.58%** | **10.56%** | **26.76%** | **100%** |

Based on the part deployment results, interior design received the highest relative priority (35.58%), followed by product size (26.76%), cooling system (14.23%), product capacity (12.88%), and exterior design (10.56%). These findings indicate that the interior configuration and overall product dimensions were the most important technical considerations in translating customer-oriented requirements into product components. The cooling system also represented a substantial design priority because it directly supports the product's primary function of maintaining the required internal temperature.

The HoQ analysis identified large capacity, an integrated mirror, and adjustable shelves as among the primary customer needs. Corresponding technical priorities included mirror integration, interior design, and a dedicated compartment for skincare tools. The HoQ Level 2 results further quantified the relative importance of the critical product parts, highlighting interior design, product size, and the cooling system as the three highest priorities. These findings informed the subsequent product specifications, including a storage capacity of 3.5 L, detachable tiered shelves inspired by cosmetic organizers, and a multifunctional lid incorporating an integrated mirror [9]. The cooling mechanism employed a TEC1-12706 Peltier thermoelectric module, selected to support temperature regulation within the specified storage volume [10]. Overall, the integration of these design features was intended to address the identified user requirements, particularly storage flexibility, product accessibility, and functional aesthetics.

### 3.4 System Level Design

A product architecture can be understood through two complementary domains: the functional domain and the physical domain [8]. The functional domain represents the operations and transformations required to achieve the overall performance of a product. These functions are initially defined at a conceptual level before being translated into specific technologies, components, and physical implementations. In the context of the proposed skincare refrigerator, the primary functions include

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Available online at: https://ojs.uph.edu/index.php/FaSTJST/article/view/11865

cooling skincare products to support the stability and quality of selected active ingredients, maintaining appropriate storage conditions, reducing the potential for chemical changes or degradation under unsuitable temperatures, providing an organized storage space, and enhancing the user experience through the refreshing sensation associated with cooled skincare products. These functions are consistent with the functional elements identified in the original product development process

The physical domain consists of the tangible components and structural elements that implement the identified functions. For the proposed skincare refrigerator, these elements include the external and internal structure, such as the frame, door, and shelving system, which contribute both to product functionality and visual appearance. The physical architecture also incorporates the refrigeration subsystem required to achieve and monitor the desired internal temperature. This subsystem consists of a Peltier TEC-12706 thermoelectric module, heatsink, fans, and a thermometer, which work together to support heat transfer and provide information regarding the internal temperature.

The cooling subsystem consists of several interconnected components, each performing a specific function. The Peltier TEC-12706 thermoelectric module serves as the primary cooling element by generating a temperature difference between its cold and hot sides when electrical power is supplied. The heatsink facilitates heat dissipation from the hot side of the module, while the fan supports airflow to improve heat removal. On the cold side, the cooling element transfers heat from the refrigerator's interior, thereby reducing the internal temperature. Meanwhile, the digital thermometer monitors and displays the internal temperature, allowing users to observe the cooling performance. The integration of these components establishes the functional relationship between the cooling mechanism, heat dissipation, and temperature monitoring.

Accordingly, the system-level design process translated the prioritized functional requirements into corresponding physical elements and subsystems. This functional-to-physical mapping provided the basis for determining the product architecture and subsequently guided the detailed selection of materials, components, dimensions, and configurations in the detailed design phase. The resulting architecture was therefore intended to ensure that the physical configuration of the skincare refrigerator could adequately support the functions prioritized through the preceding QFD process.

### 3.5 Detailed Design

This phase focused on developing the detailed product design, defining component specifications, fabricating the prototype, and estimating the production cost of the proposed skincare refrigerator. The detailed design was developed based on the customer requirements and technical priorities established during the preceding QFD and system-level design stages. The production-cost estimate is summarized separately after the process deployment mapping; its itemized breakdown must be completed using the original cost records.

The component specifications were organized into three main sections: the interior structure, exterior structure, and cooling subsystem. The interior section employed a 2-cm-thick expanded polystyrene (styrofoam) layer as thermal insulation. The insulated interior was equipped with detachable acrylic shelves to provide flexible storage and an internal aluminium lining to facilitate cleaning and support hygienic maintenance [11,12]. The exterior structure was constructed from plywood, which served as the supporting frame for the insulated interior while also providing a neutral wood-grain appearance. The exterior structure additionally accommodated the digital thermometer interface for monitoring the internal temperature.

The active cooling subsystem consisted of a Peltier TEC1-12706 thermoelectric module, supported by axial fans, heatsinks, a cold plate, and protective grilles. These components were configured to facilitate heat transfer and heat dissipation and to support the achievement of the desired internal cooling temperature. The integration of the thermal components was designed to ensure that the cooling subsystem could operate within the physical configuration established during the system-level design stage.

Prototype fabrication began with the development of a detailed three-dimensional computer-aided design (CAD) model using Fusion 360. The modelling process was performed sequentially, beginning with the insulated styrofoam body, followed by the integration of the cooling system and digital temperature display, and subsequently the addition of the plywood structural frame. The resulting digital

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Available online at: https://ojs.uph.edu/index.php/FaSTJST/article/view/11865

model is presented in Figure 3 and served as the reference for the subsequent fabrication and assembly processes.

After the three-dimensional model had been completed, the plywood components were converted into 1:1-scale two-dimensional drawings and prepared on A2 sheets for laser cutting. The styrofoam components forming the insulated interior were then cut to the required dimensions using a hot-wire cutting tool. The cooling subsystem was subsequently assembled by integrating the Peltier module with the heatsinks, fans, cold plate, and associated protective components. The final fabrication stage involved assembling the structural, insulation, electrical, and thermal components according to the specifications established in the CAD model.

### 3.6 Process Deployment Mapping

Following the identification of critical product parts through the preceding QFD analysis, process deployment was considered to examine how these parts were translated into the manufacturing and assembly activities required to construct the prototype. The mapping was developed based on the component specifications and prototype fabrication activities documented in this study. It covered the fabrication of the interior storage structure, preparation of the product frame, assembly of the cooling subsystem, arrangement of storage components, and assembly of the exterior structure.

More specifically, the interior design and product capacity were addressed through the fabrication of the insulated storage compartment and the arrangement of internal storage elements, including the detachable shelves. Product dimensions were translated into the preparation and fabrication of the plywood structural components, followed by their assembly. The cooling system involved the integration and assembly of the Peltier thermoelectric module, heatsinks, fans, cold plate, and associated protective and insulation components. Meanwhile, the exterior design was addressed through the fabrication and assembly of the plywood enclosure.

It should be noted that, unlike the preceding QFD deployment stages, this process mapping was not supported by a separate quantitative assessment of the relationships between critical product parts and manufacturing processes or by a manufacturing-process prioritisation survey. Therefore, it is presented as an analytical mapping derived from the documented prototype development activities rather than as a quantitatively validated HoQ Level 3. This distinction ensures that the process deployment reflects the actual scope and empirical evidence of the study without implying that additional relationship assessments were conducted.

The completed physical prototype incorporated the structural, thermal, and functional elements defined during the detailed design stage. The resulting skincare refrigerator prototype is presented in Figure 4 and was subsequently subjected to functional and user-based evaluation in the testing and refinement phase.




**Figure 4.** 3D visualization

FaST - Jurnal Sains dan Teknologi, Vol.10, No.2, Nov 2026
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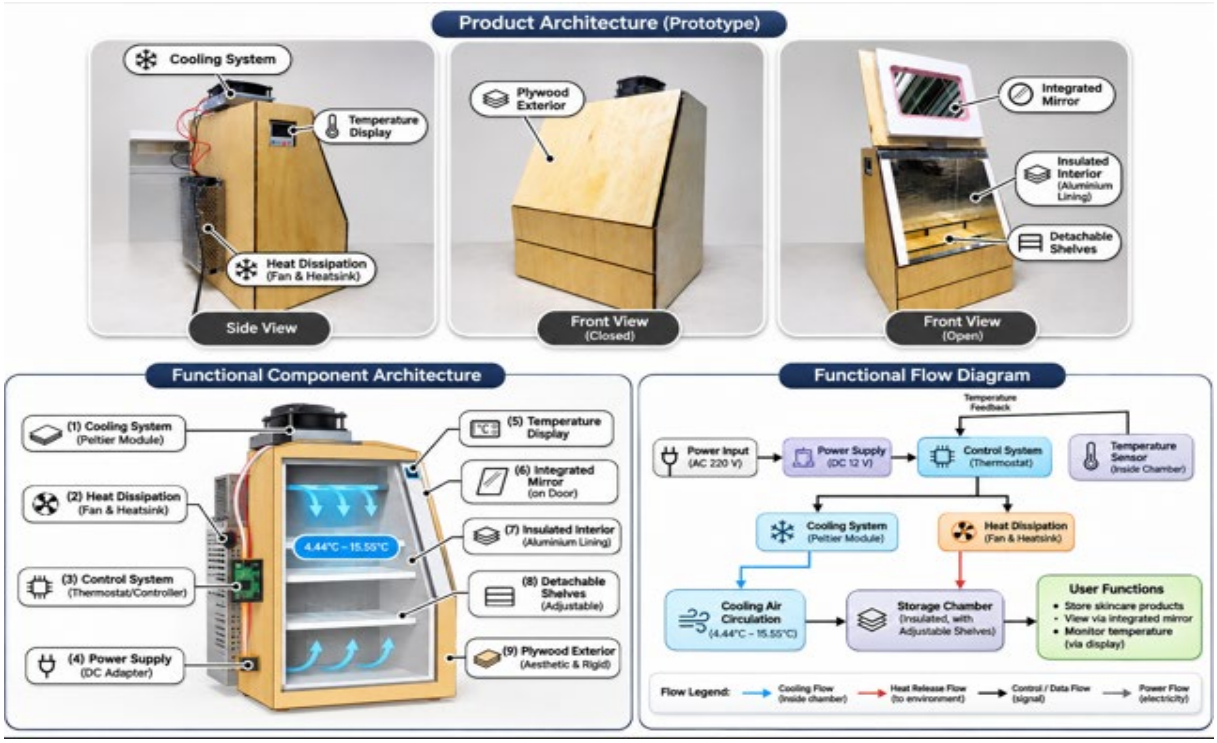



**Figure 5.** Skincare Fridge Prototype

### 3.7 Prototype Testing and Refinement

The prototype underwent functional and user-based evaluation to assess its performance against the established product specifications and identify potential areas for further refinement. Functional validation comprised two tests. First, a load-resistance test was conducted using six 500-mL bottles to evaluate the structural capacity of the storage compartment, representing a total storage load of 3 L. The test demonstrated that the prototype could accommodate the tested load. However, further testing would be required to verify its full design storage capacity of 3.5 L. Second, a thermal performance test was conducted to measure the time required for the cooling system to reduce the internal temperature from an ambient temperature of 24.3°C to the target temperature of 15°C. The prototype successfully reached the target temperature within 41 minutes, indicating that the cooling system achieved the specified temperature under the tested conditions. Nevertheless, further testing is required to establish temperature stability over an extended operating period.

Following the functional tests, a preliminary user evaluation was conducted with 10 Industrial Engineering students. The respondents were selected based on two considerations: their accessibility for direct prototype demonstration and their academic background, which provided relevant familiarity with product design and product characteristics. The evaluation involved a direct demonstration of the prototype followed by the administration of a structured questionnaire.

The respondents assessed the prototype across five dimensions derived from industrial design quality metrics [8]: quality in use, emotional appeal, product maintenance, material use, and product differentiation. Quality in use addressed the functionality and usability of the prototype; emotional appeal considered its aesthetic characteristics and user experience; product maintenance assessed the ease of cleaning and maintaining the product; material use considered the appropriateness and perceived quality of the materials employed; and product differentiation examined the distinctive characteristics and value offered by the proposed product. The mean scores for these five dimensions were 4.4, 4.3, 3.9, 4.7, and 4.4, respectively, indicating an overall positive preliminary evaluation of the proposed prototype. This evaluation was intended to obtain initial feedback on the prototype rather than to represent the perceptions of the broader skincare consumer population or establish market acceptance.
Despite the positive overall evaluation, the assessment identified several aspects requiring further improvement. Within the quality-in-use dimension, accessibility to the thermometer received a relatively lower score of 3.6, indicating that the placement of the temperature display could be improved. In the emotional-appeal dimension, the interior visual appearance received a score of 3.5, suggesting the

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need for improvements in the interior layout and visual presentation. The product-maintenance evaluation also identified material durability as an area for improvement, with the interior material receiving a score of 3.5 and the exterior material receiving a score of 3.9.

Based on these findings, several refinement measures were identified to address the observed design limitations. These included improving portability through a battery-power option, refining the exterior plywood finishing to achieve a smoother appearance, selecting less visually intrusive interior materials, reinforcing frame joints, applying silicone sealant to improve door insulation and thermal stability, and incorporating user-adjustable temperature control. These measures represent potential design improvements derived from the prototype evaluation and were intended to address the identified issues while maintaining the functional requirements established during the earlier design stages.

Overall, the functional and user-based evaluations provided preliminary evidence of the extent to which the proposed design addressed the customer requirements identified through the earlier QFD analysis, particularly storage capacity, product accessibility, adjustable storage, and multifunctional use. The proposed skincare refrigerator incorporated a design storage capacity of 3.5 L, an integrated LED mirror, detachable shelves, a temperature display, and a dedicated compartment for skincare tools. These features reflected the translation of prioritized customer requirements into the product configuration. However, the evaluation did not establish that all limitations of existing skincare refrigerators had been completely eliminated. Instead, the testing process demonstrated that several previously identified user requirements had been incorporated into the proposed design while also revealing additional aspects requiring refinement. Therefore, prototype testing and refinement served not only to assess the functional performance and user-related characteristics of the prototype but also to identify remaining design limitations and establish directions for subsequent product improvement.

## 4. Conclusion

This study developed a user-centered skincare refrigerator by integrating Quality Function Deployment (QFD) into the generic product development process proposed by Ulrich, Eppinger, and Yang. QFD was applied during the Concept Development phase through product planning (HoQ Level 1) and part deployment (HoQ Level 2) to translate customer requirements into prioritized technical responses and critical product components. These priorities subsequently guided the system-level design, detailed design, and prototype development. The study was conducted through the Testing and Refinement phase (Phase 4), without extending to production ramp-up.

The resulting prototype has a design storage capacity of 3.5 L and dimensions of 24 × 21.5 × 38 cm. It incorporates a Peltier TEC1-12706 thermoelectric cooling system, expanded polystyrene insulation, a plywood exterior, a digital temperature display, an integrated LED mirror, detachable shelves, and a dedicated compartment for skincare tools. These features were developed to address the customer requirements identified through preliminary user research and QFD analysis, particularly storage capacity, product accessibility, storage flexibility, multifunctionality, and aesthetic considerations.

Functional testing demonstrated that the prototype could accommodate six 500-mL bottles, represent a tested storage load of 3 L, and reduce its internal temperature from 24.3°C to the target temperature of 15°C within 41 minutes. The preliminary user evaluation involving 10 Industrial Engineering students also indicated positive assessments across five dimensions: quality in use (4.4), emotional appeal (4.3), product maintenance (3.9), material use (4.7), and product differentiation (4.4). Nevertheless, the evaluation identified aspects requiring further improvement, particularly thermometer accessibility, interior visual appearance, and material durability. These findings indicate that the prototype addressed several identified customer requirements, although not all limitations of existing skincare refrigerators have been resolved.

The estimated production cost of the proposed product is IDR 811,259 per unit. Future development should focus on improving temperature monitoring and control, enhancing the accessibility of the temperature display, investigating more durable and hygienic interior materials, and refining the interior design. A battery-power option may also be considered to improve portability. Further evaluation involving a broader population of skincare consumers is recommended to obtain more representative feedback and assess the product across different user segments. Additional testing of product safety, energy efficiency, durability, storage capacity, and long-term temperature stability is also necessary before further production or commercialization.

Overall, this study demonstrates how QFD can support the generic product development process by systematically translating customer requirements into prioritized technical characteristics and critical product components. The resulting prototype provides a preliminary product development outcome that integrates functional and aesthetic considerations while addressing several limitations identified in existing skincare refrigerators. The findings also establish directions for further refinement and validation before the product can be considered for broader implementation.

### 4.1 Limitations of the Study

This study has several limitations. First, the relatively small respondent groups, particularly the 10 existing skincare refrigerator users and 10 Industrial Engineering students involved in prototype evaluation, may limit the generalizability of the findings. Second, the competitive analysis covered only two products, Unixso and NVMEE. Third, functional testing was limited to a 3-L storage load and cooling performance under the tested ambient conditions; the full 3.5-L capacity, long-term temperature stability, energy efficiency, safety, and durability remain to be verified. Furthermore, process deployment was based on documented fabrication activities rather than a separate quantitative relationship assessment. Finally, the study covered only the Testing and Refinement phase and did not include production ramp-up or commercial validation.

### 4.2 Future Research Directions

Future research should involve a larger and more diverse population of skincare users to obtain more representative assessments of product acceptance and preferences. Further testing should verify the full 3.5-L storage capacity, long-term temperature stability, energy efficiency, product safety, and durability. Product development should also focus on improving temperature monitoring and control, thermometer accessibility, interior materials, storage configuration, and structural strength. A battery-power option may be explored to enhance portability. Finally, future studies should extend to production ramp-up, manufacturing feasibility, cost optimization, and commercial evaluation to establish the product's technical reliability and readiness for wider implementation

### Policy on the Use of Generative Artificial Intelligence (AI)

Generative Artificial Intelligence (AI) tools were used during the preparation of this manuscript to assist with language editing, grammar checking, improving clarity, and refining the academic structure and presentation of the manuscript. AI tools also assisted in improving the articulation of methodological descriptions, results, and discussions based on the authors' research data and inputs. AI was not used to generate empirical data or replace the authors' research activities and scholarly judgment. The authors reviewed and verified all AI-assisted content and take full responsibility for the originality, accuracy, interpretation, and integrity of the manuscript.

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