IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

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To cite this article: Natalie Waelkens *et al* 2023 *IOP Conf. Ser.: Earth Environ. Sci.* **1256** 012005

Research and design for improved packaging of food during daily use outside refrigerated environment

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Abstract. Food waste has a huge impact on economic losses and climate. One of the leading problems is due to lack of effective refrigeration. Transitioning to alternative cooling technologies, such as passive cooling, can offer a potentially more sustainable solution. Therefore, the research investigates how food can be kept cold without relying on a refrigerator or electrical components utilizing the combination of insulation materials and cooling fluid. Using design thinking as a methodology, first of all a user survey was conducted during the study to understand user behavior regarding the storage of chilled food and to define the target audience. Subsequently, an exploratory study was performed to determine the optimal placement of cooling elements to a cooling box for extended cooling. Further, material research was conducted for the inner and outer layer of the cooling container, considering temperature resistance and insulation effects. In parallel with this, an examination was carried out to identify a cooling fluid with efficient cooling capacity and low environmental impact. After implementing this method, it was discovered that the most efficient approach involved placing an ice cooling element at the bottom and around the side walls of a cooling container. Further, the material PLA was demonstrated as suitable to use for cold environments. In consideration of previous research and the application of cooling media in commercial settings, salt solutions were capable of storing food below 4.4 °C. Consequently, the decision was made to proceed with a 20% NaCl solution mixed with water. Ultimately, a final cooling element was designed that fits into the standard IKEA +365 containers measuring 15 x 15 x 7 cm. The cooling capacity of this product was tested and maintained a temperature below 4.4°C for an average of 1.17 hours. This study contributes to existing literature by providing more insights in how passive refrigeration can be aligned with the needs of end-users in order to design both practical and user-fit solutions. However, further research is required regarding the practical implications; to improve insulation, address condensation issues and evaluate compatibility with dishwashers.

Keywords. *Smart packaging, mobile system, user research, food waste, cooling liquid*

1. Introduction

Globally, ⅓ of the edible food produced annually get wasted before it reaches the consumer. This represents about 1.32 tons of food and has economic, ecological, and social consequences. Poor refrigeration is one of the key causes of this issue, leading to food waste throughout the food supply chain. Further, climate change also has an effect on the safety and quality of the food in the cold chain and increases the demand for cooling systems and energy consumption [1-5]. Consequently, temperature abuse occurs in the cold chain, such as storing food at temperatures higher than the optimal storage temperature of 4.4°C, resulting in spoilage, changes in texture, odor, and foodborne diseases [1]. With the world's population expected to surpass 9 billion people by 2050, it is crucial to find innovative solutions for food storage, sustainable cold chains, and changing consumption patterns to prevent resource depletion, reduce carbon footprint, and use resources more efficiently. Proper temperature control throughout the cold chain is essential to ensure food safety and quality [5], [6]. Passive cooling can be proposed as a viable alternative to refrigeration systems due to its low cost, environmentally friendly nature, and energy efficiency. It involves phase-changing materials that can store and release thermal energy without relying on external energy sources [7], [8], [9]. This paper aims to explore new (smart) materials and develop innovative applications for better food packaging in non-refrigerated settings. Using design thinking as a problem-solving methodology, the aim is to tackle the complex challenge of food waste and answer the question of how intelligence can be integrated into food packaging. The end goal is to create a sustainable product that not only offers efficient cooling but contributes to the area of sustainable food storage and consumption practices. With this research, the aim is to gain more scientific knowledge about passive refrigeration and the way food preservation is managed in a rapidly changing world.

2. Methodology

Design thinking is a powerful methodology that plays an important role in the design process. It can be divided into five parts [10]. The first phase is the empathy stage, where one seeks to understand the needs and perspective of the user. Next, defining where the problem is clearly defined. Further, in the ideate phase, variations of solutions are generated. In the fourth stage prototype, a rough representation of the solution is created. In the test phase, the prototype will be evaluated and refined based on user feedback [11].

2.1 Empathize and define

The objective is to visualize the parties involved in the product by creating a stakeholder map. Furthermore, the aim is to identify the target group more precisely through a survey to gain insights into the behavior and habits of individuals who transport chilled food during their daily commute. A more elaborate view on the selected target groups can be found in the result section. In addition, in-depth interviews were conducted with the target group to find a connection between their behavior, routine, and the obstacles they encounter while commuting. By combining the survey data and findings from the interviews, it is possible to construct a representation of how consumers handle food in realistic scenarios, the types of food they bring, and personas can be developed [12]. Following this, a competitor analysis was conducted on ten different cooling boxes, evaluating them based on various criteria such as weight, volume, grip capacity, etc. Spider diagrams were utilized to visualize the performance of these cooling boxes and identify potential opportunities for designing improved alternatives. Furthermore, in order to gain a thorough understanding of user behavior and their effort to maintain the temperature low of their food, journey maps were generated [13]. These maps provide insights into the various interaction’s users have with their food throughout the day. Subsequently, a function tree is formulated, highlighting the essential functions that must be incorporated in the design of a cooling box. To ensure a comprehensive exploration of design possibilities, a morphological map is then developed. This map offers a diverse array of combinations, facilitating the generation of a wide range of innovative concepts.

2.2 Ideate

In the second part, various concepts were generated and developed based on the insights from the previous phase. To select the most user-friendly concepts, a day-in-life story was created from the perspective of the personas. Each concept was presented in detail to a user to understand how it would function in a real-life scenario. Additionally, users were asked additional questions using the think aloud protocol to capture important remarks and feedback from users. To make the collected data more tangible and assist in decision-making, a trade-off matrix was created. Four users were asked (N=4) to assign weights to nine design criteria. By analyzing this matrix, the best concept for further development can be determined. Furthermore, feedback was sought from stakeholders such as IKEA and Euro point to gather input and make decisions regarding the design direction.

2.3 Prototype

Based on the results obtained so far, a test was conducted to determine the cooling capacity of a standard square IKEA +365 container with dimensions of 15x15x7 cm. During this test, 400 ml of water is added to the container, which is then placed in a refrigerator overnight to simulate daily conditions. Four different test setups were performed to determine the optimal placement of the cooling element: 1. Cooling element inside the container at the bottom, 2. Cooling element outside the container at the bottom, 3. Cooling element at the bottom of the lid inside the container, and 4. Cooling element upright in the middle of the container. Each of these tests were conducted with a cooling element stored in both the refrigerator and freezer. In total, nine tests were conducted, including one test without a cooling element as a reference. Using a DS18b20 temperature sensor and an Arduino Uno, temperature was measured and monitored in real-time for four hours [14]. The goal of this test is to investigate the optimal placement of the cooling element in a lunchbox [15]. Subsequently, based on the results of the cooling experiments, new concepts were formulated, and a trade-off matrix was generated with the input of four users. Then, a material investigation was conducted to determine the suitable material for the inner and outer layers of the cooling element [16]. The most environmentally friendly refrigerant that can provide sufficient cooling power is also examined. To determine the materials for the inner and outer layers, Edupack is used to compare properties such as thermal conductivity and minimum user temperature. Additionally, infill percentages for 3D printing were examined to add additional insulating properties to the material by creating an insulating air layer [17]. Furthermore, a decision is made regarding the refrigerant to be used in the prototype. By researching commercially used refrigerants, the refrigerant with good cooling performance, suitability for temperatures below 4.4 °C, and environmental impact is determined [18] . Factors such as the chemical and physical properties of the solution, including its impact on corrosion, were taken into consideration. Calculations were performed to determine the required salt concentration for creating a phase change material (PCM) solution, as described in equation (1).

$$\Delta Tf = Kf * n == Kf * \frac{m}{M}$$

Equation 1: Freezing Point Depression

In this equation, ΔT_f represents the freezing point depression, K_f is the molar freezing point depression constant, n is the number of moles, m is the mass, and M is the molar mass. For water, K_f is equal to 1.86 °C.kg/mol, which means that 1 mole freezes at -1.86 °C instead of 0.00 °C [19]. Lastly, the determination of the thickness of the cooling element is briefly discussed by considering the heat transfer between the cooling element, the environment, and the food. Using thermodynamic formulas, the total heat transfer of the cooling element is calculated as described in equations (2), (3), and (4).

$$Qtotal = Qwalls + top + Qcooling\ liquid + Qbotton$$

Equation 2: Total heat transfer of the lunch container

$$Q = \frac{(T2 - T1)}{((RA + RB + RC + RD))}$$

Equation 3: Heat transfer by conduction

$$R = \frac{d}{k.A}$$

Equation 4: Thermal resistance of a material

Here, Q represents the heat transfer through the four materials in W, R_A to R_D represent the thermal resistance of each material in K/W, T_1 represents the temperature inside the lunchbox (4.4 °C), T_2 represents the ambient temperature (21°C), k represents the thermal conductivity of a material in W/m.K and A represents the surface area through which heat flows in m². To complete these calculations, the thermal conductivity of the chosen cooling fluid also needs to be determined. This value is obtained from a graph based on research conducted by Thermtest Instrument™ and averages at 0.55915 [20]. Finally, using Siemens NX software, a prototype is developed, which is then 3D printed and filled with the appropriate cooling material.

2.4 Test

Once the prototype is designed, a general evaluation is made, providing an overview of the final product appearance and its practical use in a real-life environment. To further assess its performance, a scenario will be simulated using a storyboard, allowing for a recreated experience with the product. To survey users' perceptions of the prototype, written feedback will be collected, and noteworthy comments carefully documented. This was performed with seven participants (N=7). Subsequently, the prototype will undergo an analysis by repeating the previously conducted cooling test. This evaluation aims to identify any differences with previous setups and measure the effectiveness of the prototype in maintaining the desired temperatures of 4.4 °C. Furthermore, the use of a thermal camera will allow visualizations to be made, enabling the observation of temperature variations in the final product for four hours. Moreover, a study will be conducted on the compatibility of the prototype using it in a dishwasher, examining whether the prototype can withstand cleaning in a dishwasher environment. Finally, a separate section will address the sustainability aspect of the product, examining its environmental impact and sustainability characteristics.

3. Results & discussion

3.1 Survey

The response to the survey included 43 participants from Belgium with a mix of age groups, the majority of whom were between 21 and 25 years old. Specifically, 22% of the respondents were students, while the majority (73%) were working. In terms of socio-economic settings, among the working individuals, a great amount of people works in sectors such as finance, healthcare and IT. Among the students, the majority of the students were pursuing academic studies, while others were enrolled in professional programs. Regarding transportation, 62.5% of the students primarily used bicycles, while 92.6% of the working individuals used cars for their commute. The study examines the types of food the participants carried with them. The majority (78%) indicated that they carried perishable foods that required refrigeration. The main reason for bringing food was to consume it during lunchtime. In terms of food packaging, 34 participants used lunchboxes, while 10 participants used plastic or aluminum containers. Furthermore, it was found that 17.6% of the participants used ice packs to keep their food fresh when refrigeration facilities were not available. On the other hand, 29.4% kept their food at room temperature in their bags throughout the day.

As a result, 37% of the participants discarded their food upon returning home, either because it had not been kept refrigerated or because it no longer seemed appetizing. To understand the relationship between modes of transportation and food waste, the percentage of participants who disposed of their food was analyzed. Out of the 16 participants who disposed of their food, because it had not been refrigerated for an extended period, one-third were students who primarily traveled by bike, while two-thirds were working individuals who primarily used cars. For this group, it is challenging to keep their lunch cool throughout the day as they often lack access to a refrigerator or other cooling options while on the go. Based on these findings, the target audience is divided into two categories: students who travel by bike and employees who travel by car.

3.2 In-depth interviews

To gain a better understanding of user habits, six focus interviews were conducted with respondents to establish a connection between their behavior, routine, and the barriers they face in storing chilled food. The research revealed that consumers do not pay particular attention to storing chilled food they transport from home to work or school. Several users kept perishable foods at room temperature for the entire morning due to the unavailability of a refrigerator. Moreover, most lunches were not transported in an insulated cooler box or with cooling packaging.

3.3 Competitor analysis

Subsequently, a benchmark study was conducted, which was visualized using spider diagrams. All spider diagrams were overlaid to identify areas for potential improvement. The results are presented in Figure (1).

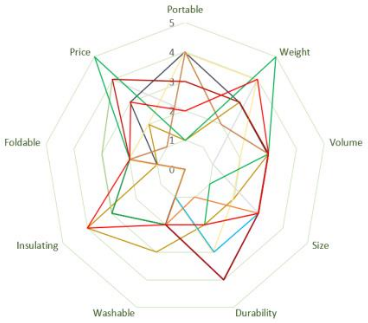

Figure 1: Spider diagram of all benchmark products

The conclusion was that the main features that could be adjusted were the volume and size of the lunchbox. Many of the existing products were found to be excessively large in size. Additionally, the washability of the lunchbox was an important point. The compared products were difficult to clean or couldn't be put in the washing machine. Therefore, in the design process, it will be important to minimize the weight and overall dimensions of the lunchbox. Furthermore, the development of a box or ice pack that can be placed in the dishwasher would be a valuable improvement.

3.4 Journey maps

After analyzing the results of the benchmark study, the next step is to investigate how users handle their food on a daily basis. For this purpose, a schedule was created to depict the daily routine of both students and working individuals, including their commuting times and when they typically consume their meals. An assumed schedule is created, along with estimates of how long food is exposed to ambient temperature. This amounted to at least 5.25-6 hours from 7:00 a.m. to 1:00 p.m. And if they don't consume their meal in the afternoon, this can extend to 10 to 13 hours. It is important to note that this is just an estimate based on travel times and does not account for unexpected delays or other factors that could prolong the time without refrigeration. More user tests need to be conducted to obtain more accurate results. In addition to the limitations, the schedule provides a general idea of how long food remains unrefrigerated in a backpack. By gaining insight into the issues users face on a daily basis, designs can be created that better meet consumer needs, thereby improving the user experience and the quality of the food. Incorporating these findings into the design requirements ensures that the refrigerated packaging effectively addresses the challenges users face and delivers optimal refrigeration performance for food preservation. The design requirements include aspects such as weight, volume, size, durability, washability, insulation, foldability, price, reusability, and cooling efficiency.

3.5 Ideate

Based on the function tree and morphological map, 8 concepts were generated, out of these, 3 concepts were excluded due to the potential integration into the other five concepts. Proceeding with the selected 5 concepts, a "day in the life" scenario is written, explaining to users how the product would work in practice. It was found that some people have no issue leaving their lunch unrefrigerated in their bag throughout the day, while others were aware of potential changes in taste and concerns about food safety. It is proposed to work on an adaptable design that can accommodate different shapes and sizes, utilizing standard containers that users already have at home. The ice packs can be adjusted according to the required cooling capacity. An overview of the total weight provided by 4 users for the 5 different concepts is shown in Figure 2.

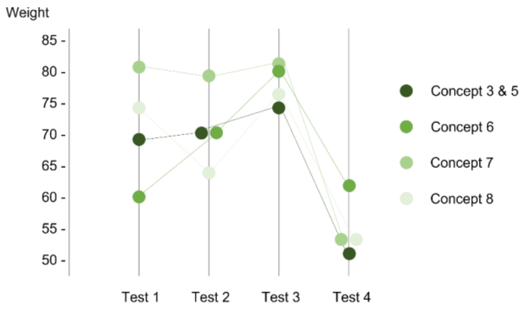

Figure 2: Overview total weight given by four users to five different concepts

Based on these results, it was decided to proceed with concept 7. This decision was based on the findings from the user tests and the information obtained from IKEA and Euro point. It was decided to create an ice pack for an existing lunchbox, such as the standard containers from IKEA. This company already has a modular system where each lid fits different boxes of the same size. It is interesting to develop an ice pack for this purpose, creating a modular cooling system. This approach offers more flexibility so that consumers can continue using their existing containers and only need to add an ice pack. This also reduces waste since there is no need to produce new lunchboxes.

3.6 Prototype

To determine the position at which an ice pack can keep the food cool for the longest duration, temperature measurements were conducted at various positions of the ice packs. The results of these measurements can be found in Table 1.

Table 1: Overview results temperature cooling capacity test

	Min. T(°C)	T after 2 hours (°C)	T after 4 hours (°C)
Position C1	2.50	10.50	14.63
Position C2	5.75	12.50	15.63
Position C3	5.13	12.06	16.44
Position C4	4.88	15.63	19.94
Position F1	1.37	3.44	5.81
Position F2	5.50	9.13	10.94
Position F3	3.25	7.44	9.25
Position F4	2.13	6.13	10.69
Position R	6.45	13.75	18.44

After two or four hours, all positions exceeded the recommended temperature of 4.4 degrees Celsius, except for test F1 where the ice was placed at the bottom of the lunchbox. However, the minimum temperature of the water in test F1 was 1.37 degrees Celsius, which should also be considered in terms of potential effects on taste change. A similar study that has been conducted by Du et al. in 2020, examining the placement of phase-changing panels in a cooler box to generate the longest cooling time. It confirmed that placing the cooling around the box and one at the bottom resulted in the longest cooling time of 9.50 hours [9]. Therefore, the decision was made to proceed with frozen food coolers, as they have greater cooling capacity and longer durability compared to those from the refrigerator. Additionally, placing an ice pack inside a lunchbox with pre-existing food is not user-friendly, which led to the decision to pursue an ice pack on the outside of the lunchbox. Based on Du et al.'s research, it was also decided to include additional ice packs on the sides for extra cooling. However, it is important to note that the available data is incomplete and insufficient for drawing accurate conclusions. Various parameters, such as time, initial temperature, water volume, ambient temperature, and seasonal variations, need to be taken into consideration, and more experiments should be conducted to obtain more reliable results.

Based on this exploratory study, new concepts were generated, and feedback was collected using a trade-off matrix to determine which concept aligns best with the ultimate goal. Concept 7 emerged as the most favorable, and based on that, a 3D model was created in Siemens NX, consisting of three main components. The first part encloses the IKEA +365 box, the second part is placed at a distance of 1 cm to create a cavity between the two parts, and the third component is used to seal the top of the cavity and contain the coolant inside.

Subsequently, a material investigation was carried out. Firstly, the material for the inner and outer layers of the ice pack was determined. Using Edupack, a graph was created considering thermal conductivity and the minimum temperature at which it can operate [21]. This allowed the selection of four polymers: Polyethylene (PE), Polylactide (PLA), Polyvinyl chloride (PVC), and Polypropylene (PP). PVC can withstand temperatures up to -18.2 °C, which falls just outside the range for a freezer. Moreover, PE and PP were found to be less recyclable compared to PLA. Therefore, the decision was made to proceed with the biodegradable polyester PLA, as it is more environmentally friendly and suitable for 3D printing. This material will be used for both the inner and outer layers of the ice pack. To maximize the insulating properties of the outer layer, it was also decided to increase the thickness of the outer wall compared to the inner wall by using a 10% infill percentage during 3D printing. This adds an additional layer of air, which has an insulating effect and slows down heat transfer.

Furthermore, it is important to make a good choice for the coolant of the lunch containers. Several articles have discussed water mixtures with inorganic salts as efficient phase-change materials. These materials are inexpensive and readily available. Eutectic salt-water solutions have a high energy storage density and are within the melting range suitable for cooling food below 4.4 °C. The thermal properties of salt solutions, such as thermal stability, were examined. The article by Yang et al. revealed that solutions of $NH4Cl$ and NaCl remain stable for 150 minutes. As the salt concentration increases, the phase transition period will be longer, which is favorable for food cooling [22]. In terms of physical properties, it is also necessary to consider volume changes during the freezing of the coolant. When water freezes, it expands. By adding salts to the water, the hydrogen-oxygen bonds are disrupted, resulting in less expansion of water during freezing. In terms of kinetic properties, the phenomenon of undercooling occurs when the liquid struggles to freeze as the temperature drops below the melting point. Therefore, it is necessary to significantly lower the temperature below this point. The study by Yilmaz et al. focused on NaCl and KCl, indicating that a NaCl salt solution causes less undercooling than a KCl solution. Particularly, concentrations of 20% NaCl showed the least undercooling [23, 24]. Furthermore, consideration was given to possible chemical reactions between the outer and inner layers of the ice pack, such as corrosion. The effect of corrosion on commonly used materials has already been tested in various articles. Based on the study by Oro et al., it was concluded that polymers such as polypropylene (PP), polyethylene terephthalate (PET), high-density polyethylene (HDPE), and polystyrene (PS) did not suffer damage when exposed to different salt solutions [25]. Subsequently, the freezing point was calculated for the 20% NaCl-water solution using the formula for freezing point depression (1). Adding salt lowers the freezing point. The freezing point depression for the 20% NaCl solution amounts to 12.73 °C. Ultimately, for the design of the end product, this cooling liquid of 20% NaCl solution was used. Additionally, the thickness of the ice pack was calculated based on heat conduction formulas. The results obtained from filling in formulas (2), (3), and (4) are presented in Table 2, along with the thickness of the material.

Table 2: Overview results heat transfer

	Q (W)	Material thickness (mm)
Four sides of the lunchbox in PP	31.27	3
Outer layer in PLA	16.01	4
	8.00	8
Inner layer in PLA	12.74	2
+ PP layer		3
Top lid in PP	22.74	3
Outer layer PLA	93.22 – 151.92	4 – 8
+ cooling media		6 – 2
+ inner layer PLA		2 - 2
+ PP layer inside		3 - 3

From this, it can be inferred that a greater thickness of the outer layer results in a larger insulating effect because there will be less heat transfer. Additionally, a thick layer of coolant reduces heat transfer. It is chosen to proceed with a thickness of 4 mm for the outer layer and a thickness of 4 mm for the coolant. It is important to note that these estimates are incomplete and do not account for numerous other factors that can affect the performance of the ice pack. For instance, different types of food have varying thermal conductivity, which can impact the rate at which they cool. Furthermore, temperature fluctuations due to seasonality, temperature variations within the refrigerator, and temperature transfer from the lid to the food can further complicate the calculations. To obtain more accurate estimates, it is necessary to utilize specialized software that takes all these parameters into account to calculate the thickness of the ice pack. This is beyond the scope of the research but may be interesting to consider for future calculations.

3.7 Test

The final design was tested with the target audience to gather feedback on its usability. The participants were asked to provide written opinions based on a storyboard depicting the user context. The feedback revealed that the product was perceived as useful because it can keep food cool, is compact and portable, but is only compatible with IKEA +365 containers. One of the respondents that commutes every day to his job observation was:

"It is possible to use this item for different containers. For example, you still need to wash your cooling element from Monday and another cooling element can be placed in the freezer. Then on Tuesday you can use the cooling element with another container."

Further there were concerns about potential long-term changes in shape that could make the product fit less well with an IKEA container. Furthermore, condensation occurs during food cooling, necessitating further improvements and tests regarding condensation, wear and tear, and wash ability. Subsequently, the same cooling capacity test was performed twice on the final concept to assess its cooling performance. The same protocol as the previous temperature tests was followed, and the results are presented in Figure 3.

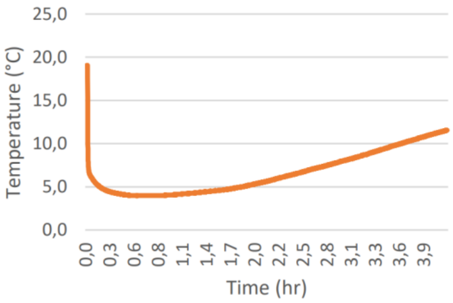

Figure 3: Result final product temperature in function of time, position E1

In Table 3, the values of this test were compared with those of test F3, where an ice pack was placed outside a lunchbox. When using a PCM as a cooling agent, the temperature remains stable below 4.4 °C for an average of 1.17 hours before gradually increasing. In test F3, the temperature rises much faster once the minimum temperature is reached. Over a 4-hour period, test F3 manages to stay below 10 degrees, while the PCM exceeds this threshold. Graphically, F3 exhibits a concave shape, in contrast to the convex shape of the PCM graph.

Table 3: Overview results cooling capacity test final product

	Time x < 4.4 °C	Time x < 7 °C	Time x < 10 °c	After 4 hours
Position E1	1.44	2.62	3.65	11.06
Position E2	0.89	2.03	3.21	11.31
Position F3	0.51	1.74	-	9.25

Based on thermal camera images, a visual representation is shown of the cooling element to assess how the cold spreads across the cooling element over a period of 4 hours. It is evident that the coldest part is located on the inside of the cooling element and becomes warmer towards the outside. After four hours, the temperature has risen from -12.1 to 17.0 degrees. Additionally, the occurrence of condensation remains a challenge when using the product as it can moisten the inside of backpacks. Further research needs to be focused on improving insulation. Furthermore, the possibility of using the product in a dishwasher was considered. Material research indicates that PLA has limitations in terms of its maximum temperature range. A dishwasher operates between 48 and 72°C, while PLA has a maximum operating value of only 54.9°C. Thus, PP and PE are considered more suitable materials. Additionally, further research must be conducted on the cooling performance of the cooling medium after undergoing different temperature cycles, which may vary in duration. Ultimately, a test was conducted in a dishwasher where a tear in the inner PLA layer caused leakage, leading to salt crystallization. Further research should be carried out to improve these areas.

4. Conclusion and discussion

Keeping food cool for a minimum of 4 hours is a challenging issue. The research involved four phases to develop a definitive cooling product through user research. The target audience consists of cycling students and commuting employees, which is consistent with the majority of the survey participants, who mainly travel by bicycle or car. Through routine and behavioral research, including surveys and interviews, it was determined that this target group often does not pay attention to properly cooling perishable food. By conducting cooling capacity tests on food containers with different placements of the cooling element, it was determined that using a freezing element at the bottom and sides of a cooler box is the most suitable alternative cooling method. Through material research, a product made of PLA was developed, employing various thicknesses to optimize insulation. An environmentally friendly cooling medium based on a 20% NaCl solution was chosen as an alternative to more traditional and toxic cooling agents. The final product was validated through the same cooling capacity test, which showed that working with the PCM used in the product results in a more stable and slower temperature rise below 7°C compared to using a more traditional ice pack. This design not only provides insulation for maintaining food freshness but also contributes to reducing food waste. By keeping the temperature stable and under a certain point of 4.4 degrees, the product helps to extend the shelf life of perishable items, reducing the likelihood of food spoilage. However, there are still some side effects that require further investigation, such as condensation, improved insulation capabilities, and possibilities for dishwasher resistance. By addressing these concerns and continually striving for improvement, the product has the potential to make a positive impact on reducing food waste and promoting sustainable consumption practices.

When comparing this research to other technologies, this paper contributes to the exploration of sustainable solutions to food waste. by examining technologies such as passive cooling that can be environmentally friendly alternatives to traditional cooling methods while meeting end-user needs. By analyzing user behavior, solutions are sought that are adapted to the specific selected target groups. In addition, material research ensures the selection of suitable materials for refrigeration containers, with a focus on temperature resistance and insulation. The efficiency and environmental impact of refrigerants are taken into account. Looking at the implementation of intelligent technologies, there is ongoing research on IoT devices and mobile apps that help reduce food waste. By incorporating intelligence into these solutions, potential environmental benefits can be achieved. Passive cooling is one of them and represents a promising area of research with considerable potential.Consequently, with this paper we aim to provide research that can be situated on the nexus of sustainable food waste solutions, user-fit products and intelligent technologies.

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