CERN IdeaSquare Journal of Experimental Innovation, 2019; 3(2): 18-22
DOI: https://doi.org/10.23726/cij.2019.881

ORIGINAL ARTICLE

Simple, affordable evaporative cooler to reduce food loss in developing countries

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ABSTRACT

Cooling systems in developing countries have a huge impact on health, hunger, food waste and the environment. Refrigerators are the best method for preserving food, but they are expensive, complex, energy-consuming, and unsustainable for some countries. Therefore, there is an interest in simple, cheaper alternatives. For example, evaporative coolers that allow to raise the air humidity, while reducing the temperature present an attractive alternative. The purpose of this work is to design and validate an evaporative cooling system that will allow the storage of perishables, such as fruits and greens, in order to extend their shelf-life. Our case study is focused on Senegal's Tambacounda region. To crack the Senegalese market, an innovative business model has been devised, allowing for the low-cost distribution of the cooler to the local population.

Keywords: developing countries, evaporative cooler, refrigeration, food loss

Received: June 2019. Accepted: September 2019.

INTRODUCTION

Nowadays, about 1 billion people do not have access to sustainable cooling systems, putting their health, productivity and safety at risk (Reuters, 2018). In addition, the planet is warming up, and developing countries are heavily concerned, because in these countries are located the 30 hottest cities in the world (Sivak, 2009).

Therefore, cooling overall is an urgent problem and within food production and value chain it has immediate consequence on food waste. More than a third of all food produced globally 1.6 billion tons worth € 1.2 trillion every year (Turon et al., 2014) is ending up in the trash, wasting water, energy and other resources along the way. According to a study, the amount of food wasted will dramatically grow, reaching in 2030 a loss of 66 tons every 30 seconds (Hegnsholt, 2018).

Food spoilage is not only a humanitarian concern but also an environmental one: it has been calculated that if food waste were a country, it would be the third largest contributor to greenhouse gas pollution on the planet (FAO, 2014).

The type of food that is more susceptible to food waste is the perishable products category, which are those foods that are more likely to decay and become unsafe, such as fruit, vegetables, cheese and meat.

While in affluent economies this problem occurs mainly at the consumer level for food excess (Parfitt et al., 2010), in developing countries the biggest amount of food waste is related to lacking right cooling and refrigerated storage conditions. This is due to the barriers to up-to-date technology access, tight budgeting constraints, lack of electrical continuity and harsh environmental factors such as temperature and exposure to light. Moreover, the lack of skilled people, able to maintain the refrigeration equipment, results in loss of effectiveness.

The purpose of this paper is to ideate a sustainable cooling solution conceived for rural areas in developing countries, using an ideation process that facilitates the fitting of the solution offered to the target region and culture.

THEORETICAL BACKGROUND

It is known that temperature and humidity are two determining factors for food preservation; in the absence of adequate refrigeration systems, a study on tomatoes conducted by Zakari et al. (Zakari et al., 2006) showed that even a partial cooling and humidification allows to prolong the shelf-life of the product.

Fruits and vegetables have specific temperature and humidity ranges that ensure better preservation. Cooling is always a good option, while more distinctions are needed for the humidity increase -although it is generally a sought condition if not extreme (Engineering ToolBox, 2004).

In the developing countries there is an interest in simple, low-cost alternatives to refrigerators. A well-known physical principle, that requires low energy, is the evaporative cooling. A stream of dry warm air -common ambient condition in many developing countries- passes through a porous wet material and, by evaporating the water contained within, increases the humidity of the air flow and cools down. This effect occurs because the water absorbs a great amount of the air's thermal energy to evaporate. The faster the evaporation rate, the better the cooling and the efficiency of an evaporative cooler. For fresh market products, any method of increasing the relative humidity of the storage environment will slow the rate of weight -liquid- loss.

The problem of inadequate storage facilities for fresh vegetables, for example in Nigeria, has been analysed in the past years (Zakari et al., 2006). Inadequate storage facilities have a direct effect on the distribution and consumption of the needed quantity of perishable food products. The purpose of this work is to design, construct and validate an evaporative cooling system that will temporarily store fresh fruit and vegetables in households.

Zakari et Al. (2006) demonstrated that the cooling efficiency of the evaporative cooling system they built loaded with tomatoes was 83.0% on average. For clarification, the refrigerative efficiency of traditional fridges is certainly lower that the one reachable with evaporative phenomena but ideal temperatures and humidity for storage may be attainable.

This detail is extremely relevant: lower efficiency with ideal thermodynamic conditions imply high energy requirements for traditional refrigerators with a significant percentage of energy loss; the evaporative system is highly efficient, i.e. it loses a small percentage of energy in thermal transformations, does not require energy but may not reach ideal conditions for all purposes.

Both the temperature drop and the humidity increase are a function of the external environmental condition and the system efficiency. Arid and hot areas lend themselves very well as ideal scenarios for evaporation based solutions because they allow a significant humidity increase before saturation (100% Relative Humidity, RH). A 35°C and 40% RH ambient condition, with a system efficiency of 0.8, may be able to produce a cooled down airstream of at least 20-25°C at 80-90% RH.

This is one of the reasons why we selected the North-East of Senegal as our area of interest. Specifically, our targeted market is located in the Tambacounda region, where the average temperature is 35 ℃ and the humidity is around 40% during the year (Worldweatheronline, 2019). Moreover, the relative ease of access to the country, the high percentage of rural areas and workforce involved in agriculture, are additional reasons that have brought us to focus on Senegal's Tambacounda (Leighton, 2016).

To better ideate, design and adapt the evaporator design to this market, we decided to apply a Human-centred design approach (Figure 1), which focuses on developing "usable and useful" solutions, as they focus on the users' environment, on their needs and requirements, usability knowledge, and techniques.

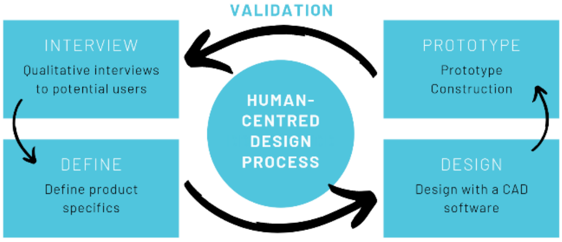

Fig. 1. Human-centred used approach.

METHOD AND DATA

The presented study has been developed in the context of Innovation For Change (I4C), an initiative created by Collège des Ingénieurs (CDI) in partnership with Politecnico di Torino and CERN IdeaSquare.

At the early stages of the development, our goal was to identify the necessary characteristics for the product to be successful. To achieve this, interviews were conducted to different Personas (Miaskiewicz & Kozar, 2011), potential users of our solution shown in Figure 2.

Fig. 2. Interviewed Personas

After the identification of the crucial characteristics of the product, the cooler was designed using a CAD software in order to be easy to build, modular and affordable (Figure 3).

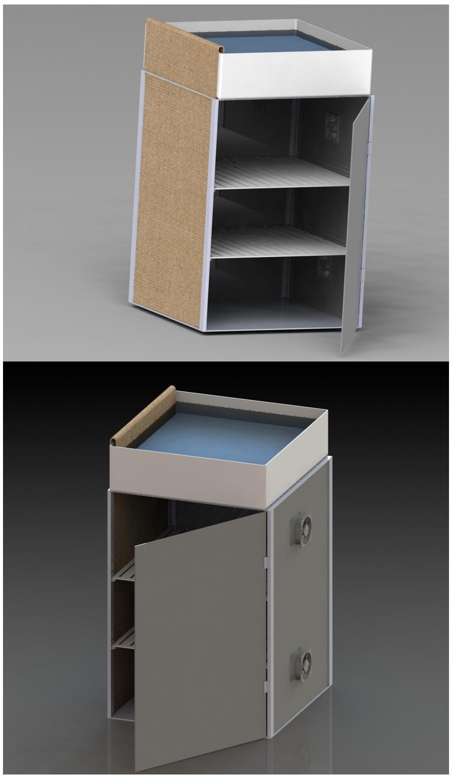

Fig. 3. CAD prototype of the evaporative cooler.

An in-house evaporating cooler was built to test and analyze the basis phenomena of this technology.

The prototype is shown in Figure 4; it is made of wood and jute. Ambient air enters the cooler through the wet jute and it flows out through the fan. Its temperature decreases since the water evaporation removes latent heat from the air. Water may circulate from the bottom of the structure to the top through a pump to refill the container, if needed. The water at the top allows to keep the jute soaked.

Fig. 4. Built prototype of the evaporative cooler.

The results of the first test campaign are reported in Figures 5 and 6.

Figures 5 and 6 show the trend of temperature and RH over a time span of two days. The data was gathered through two distinct sensors equipped with a double thermometer -a probe and an internal one- and a hygrometer. One sensor was placed inside the prototype and the second one to its side -as shown in Figure 4-, properly spaced apart from any external airflow influence.

Figures 5 and 6 contain information on the two sensors; the first one reports the temperature trend, the second one the RH. The collected data confirmed the physical principle described in the previous paragraphs. As soon as the fan is turned on, the temperature inside the prototype decreases and the air RH increases.

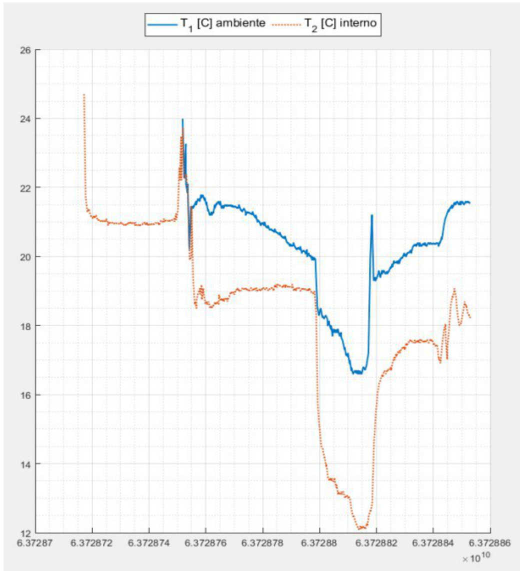

Fig. 5. Results of the first tests on temperature.

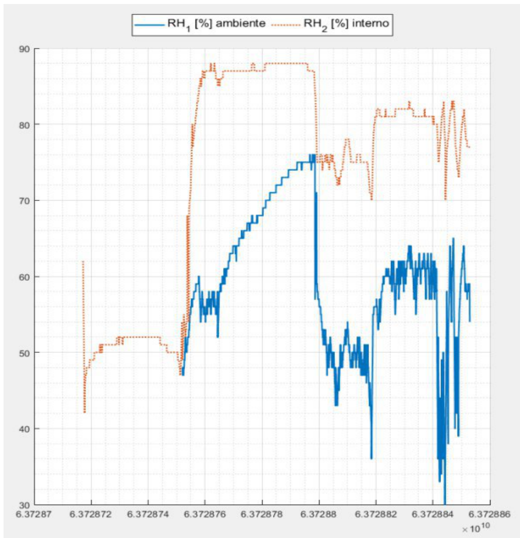

Fig. 6. Results of the first tests on relative humidity (RH).

Further controls on the experiment concern the issue that the room was kept closed, at the beginning; this action saturated the room of humidity and it appeared that the evaporative cooler was able to decrease the inner temperature of just 2 degrees (which was considered, however, a good result given the raw and basic materials and techniques employed). Further, the abrupt change in temperature and humidity – that is the discontinuity observable in both graphs at the halfway of the x-axis, the time coordinate – is due to the window opening. As soon as the room was able to recirculate air, the RH in the room decreased and the cooling efficiency increased.

It is worth to notice that the evaporative cooler is not an isolated system, it is hand made with rudimentary, discarded materials. The reason behind this was to increase confidence that the basic method works and that if in the future pieces will need to be substituted, the better substitutive material will be available, and the evaporative cooler will equally work even better.

To validate the prototype, we conducted interviews addressing again potential users, scientists, university professors and volunteers. Even though interviews are time-consuming and might suffer of cognitive biases (Kahneman, 2011), they capture non-verbal information as well.

When it comes to analyse complex issues, survey gathered data can be misleading and not be particularly representative (Taleb, 2007). Since our aim is to tackle multidimensional problems and act on major impacts, we decided to use interviews and avoid statistical models.

Some of the points important to understand are the following: What are their food habits (related to nutrition, storage, purchase)? What is the perceived value of our solution? How much is the user willing to pay for our technology? How can we improve the solution to better satisfy our user?

The interviews were conducted via Skype conference, phone calls, face-to-face interviews. Amongst the 30 qualitative interviews carried out, more value was given to the information received from our Personas.

RESULTS

The results on temperature decrease from our evaporator show the technology works. The physical principle that uses evaporation to cool down an environment is clearly visible. The drawback we had - namely, the room saturation- allowed us to understand how influential air saturation with respect to the system cooling efficiency is. Nevertheless, once the problem was solved, the results were satisfactory. Further tests will have to be made on site or in climate mimicking chambers which UNIDO can provide.

During the validation process, a minority of the interviewed sample does not comprehend the value of the solution we want to offer, even if they agree that its adoption would allow savings on many aspects.

Our research revealed that tomatoes and cabbage are the most common greens purchased and consumed. Interviews revealed that even though users would be interested, the potential future users do not have the financial means to purchase our product.

Because of this, we have developed a model which allows the evaporator to be given away for free, or little money, by repaying the investment with voluntary sharing of some alimentary data, via text message. This information can lead to: (1) a measurement of the impact of the project (2) customised humanitarian aid to better tackle nutritional challenges and (3) useful reports for the United Nations, who will pay for them.

Given the complexity of the local market, collaboration with non-governmental organizations (such as the United Nations, interested in weekly studies on the eating habits of the studied population) is essential to create value. Their financial support and legitimacy towards the Senegalese population will allow us to produce and, above all, distribute our product, which will benefit the household.

The structure of our business model relies on high penetration of mobile phones even in rural areas and willingness to participate actively. The adherence will be ensured via a rewarding based system. Sending a message, the final user will, in fact, receive back insights on nutritional aspects of their diet and useful suggestions under the form of recipes or other.

DISCUSSION AND CONCLUSIONS

Refrigeration technologies are fundamental to avoid food loss. This is particularly relevant for developing countries. Developing countries with hostile climates, undergoing energy crisis and lack of technical know-how, struggle to adopt these technologies.

To achieve tech-transfer our approach was to design a proof-of-concept and adapting it to our target user community. Our evaporative cooler is simple to build and maintain. Furthermore, the business model will allow us to reduce the price and quantify the impact.

The solution here presented might be remarkably improved by the exploitation of spaces and availability of the institutions that have held or supported the initiative, such as IdeaSquare at CERN or FABLAB in Turin. The ideas presented here might be further experimented and new alternatives might solve some criticalities that arose in this first prototyping phase.

For example, it would be possible to maintain constant environment conditions even while the refrigerator works and produces humidity, eliminating an external variability and improving the results. It would be also possible to use different cheap materials that may improve the thermal capacity. Lastly, on a more technical level, it could be possible to improve the water flow from the upper tank according to the evaporation percentage, to further increase the efficiency. All the above considerations can be included in future works and can provide interesting insights on this promising technology.

ACKNOWLEDGEMENT

The authors wish to express their appreciation to UNIDO for the support and encouragement provided, and to CERN IdeaSquare for the inspiration and valuable insights throughout the ideation process.

We gratefully acknowledge Politecnico di Torino and Collège des Ingénieurs for mentoring us through this process and for the opportunity to attend I4C.

We are also immensely grateful to the field experts who worked alongside us during this project, sharing crucial insights and contacts, namely Edoardo Calizza and Marco Rovagnati. Special thanks go to all the interviewees who dedicated their time to answering our questions.

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