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Use of the quality function deployment tool for the design of a humidity transformer system in drinking water

Uso de la herramienta despliegue de la función de calidad para el diseño de un sistema transformador de humedad en agua potable

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Abstract

Water is a resource of vital importance for the life of living beings, the demand required is so great that in some areas of the planet it has begun to be scarce or to restrict use and consumption. In spite of the technological advances and the procedures to send this liquid, zones are detected in which the supply does not arrive, on the other hand every day the world population keeps increasing and generating a greater consumption of the same. The present study makes use of the deployment of a quality function better known as QFD as a way of listening to the voice of users and specifically determining the different aspects that must be addressed for the design of a moisture sensing device, as well as an estimation of the demand focused on the southern zone of Tamaulipas Mexico is also presented in order to know the potential market.

QFD, moisture collection, design engineering

Resumen

El agua es un recurso de vital importancia para la vida de los seres vivos, es tan grande la demanda requerida que en algunas zonas del planeta ha comenzado a escasear o a restringirse el uso y consumo. A pesar de los avances tecnológicos y los procedimientos para hacer llegar dicho líquido se detectan zonas en las que no llega el suministro, por otro lado cada día incrementa la población mundial generando un mayor consumo de la misma. En el presente estudio se hace uso del despliegue de función de calidad mejor conocido como QFD como una forma de escuchar la voz de los usuarios y determinar de forma específica los aspectos que deben ser atendidos para el diseño de un dispositivo captador de humedad, así como también se presenta una estimación de la demanda enfocada a la zona sur de Tamaulipas México con el propósito de conocer el mercado potencial.

QFD, captación de humedad, ingeniería de diseño

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Introduction

Water is a vital element for life on planet Earth, as it plays a decisive role in various biological, geological, meteorological, chemical and physical processes. (Blanca Jiménez Cisneros, 2010) The main form of atmospheric water is water vapour; when reference is made to the quantity of water vapour in the air, it is called "humidity". Having air as a source of origin, which is free and inexhaustible, and humidity that has very low amounts of mineral salts, allows obtaining high quality water (Jahan, 2015).

In rural communities in Mexico, access to purified water is lacking due to technological deficiencies, with consequences for people's well-being; the United Nations Development Programme (UNDP, 2015) indicates that around 1.8 million children die each year from diarrhoea, cholera, fever, polio, hepatitis and other diseases caused by unsafe drinking water and poor sanitation conditions.

70% of water vapour floats in the atmosphere as a result of evaporation from rivers, seas, plants and living things. Altitude, temperature, orography, geography and water masses are important factors that make water levels in the air very different across the globe. This vapour can be condensed naturally and artificially and in this way it is possible to transform the air into a source of drinking water.

Air contains different gases such as water vapour which is produced by the change of temperature and pressure, changing from liquid to gas. Conversely, if condensation takes place, the state changes from vapour to liquid through temperature change (Quintanilla et al., 2018).

The lack of water has as a consequence negative effects on biodiversity which subsequently has the effect that natural sources of water diminish. Due to water scarcity various consequences start to appear in the population such as: repercussions on health, hygiene, nutrition, lifestyle, etc. The lack of water has become an even more complicated challenge for low-income people, as these are usually the areas most affected by the lack of drinking water, thus leading this sector of the population to find their access to the natural resource very complicated or, failing that, the sources they use for their consumption are contaminated. (Úsuga, 2022).

According to the World Health Organization (2018) worldwide, around 3 in 10 people, or 2.1 billion people, lack access to safe and available water at home, and 6 in 10, or 4.5 billion, lack safe sanitation, according to a new report by the World Health Organization (WHO) and UNICEF (United Nations Children's Fund).

Contaminated water is responsible for the deaths of half a million people from diarrhoea each year. However, the problem is not only concentrated in poorer areas, but in richer countries, water in groundwater aquifers and watersheds is declining at a rate that is outstripping water replenishment (BBC News World, 2018).

On the other hand, there is the Quality Function Deployment tool known as QFD which is used for the design and development of a new product in the context of Total Quality Control.

Akao Yoji (1972) envisioned a deployment method that would address the important points to be taken into account during the design phase of the new product that would lead to the elimination of defective parts that would otherwise appear in the production phase.

Dr. Mizuno (1978) produced the first publication entitled "Quality Function Deployment". In it, he defined the methodology for carrying out QFD through the systematisation of objectives and means.

In the following, we will use this methodology to design a new product for the collection of humidity and which is capable of transforming this humidity into drinking water.

Methodology to be developed

Quality function deployment (QFD) is a methodology that translates customer requirements into a set of technical requirements, and does so at every stage of the design and production of a product or service (Garibay, Gutiérrez & Figueroa, 2010). QFD is often identified as the methodology for listening to the voice of the customer. QFD is considered a key tool for product development and for improving product quality in both service and manufacturing processes (Abu-Assab, 2012).

Quality function deployment (QFD) is defined as: "the conversion of consumer demands into quality characteristics and the development of design quality for the finished product by systematically deploying relationships between demands and characteristics, starting with the quality of each functional component and extending the deployment of quality to each part of the process" (Zapata, 2013).

In the design phase, use was made of quality function deployment. In the first instance, the list of customer needs was made, consisting of 25 requirements that are essential for consumers to purchase such a system, among them are:

That the equipment captures enough moisture to obtain water, durable, the process is visible, easy to handle, easy to use, economical, white colour, does not consume light, firm structure, water quantity indicator, light, portable container, made with stainless materials, protection of the container, that it has visual appeal, easy to use, easy to maintain, not too ostentatious, portable, operation anywhere, good capacity, easy to move, resistant, not too bulky and finally that it can be adapted to any medium.

The requirements with the highest percentage were:

- That it captures sufficient moisture with 8.5%.
- Easy to use with 8.1%.
- Lightweight at 6.5%.
- Economical at 6.2%.

Once the client's requirements were finalised, the technical and operational characteristics, also known as "how to's", were made, which are shown below:

Optimal functioning, performance, materials, storage, design, absorption, weight, container protection, hardness, velocity control, filtering, visibility, tenacity, thermal conductivity, expansion, supply, foldability, durability, stability, size, minimum production cost, firmness, moisture control and filter adhesion.

For the construction of the roof, the correlation between the quality characteristics was evaluated, in which the following symbology was used:

┼┼ indicates strong positive correlation.

┼ indicates positive correlation

- indicates negative correlation

▼ indicates strong negative correlation

The optimal performance has a strong positive correlation with the materials as for the prototype to work it is necessary to use metals preferably, another characteristic that has a strong positive correlation is the size, as it can be neither too bulky nor too light.

Weight has a strong positive correlation with size, and a positive correlation with firmness. Size is another characteristic that has a strong positive correlation with absorption, as the blades need to be tall enough to capture the highest percentage of relative humidity present in the environment in order to transform it into purified water.

Absorption has a strong positive correlation with performance, because the system will be more efficient the higher the percentage of water uptake in the environment. Similarly, filter adhesion has a strong positive correlation with durability, as the system is intended to be maintained for proper operation.

Supply has a strong positive correlation with both humidity control and speed control, as these two parameters are indispensable for the optimal functioning of the prototype.

However, stability and collapsibility have a strong negative correlation, as it is not possible for the prototype to be collapsible and stable at the same time, but it can be stable and light.

Thermal conductivity has a strong negative correlation with supply, the materials to be used with the design also have a negative correlation. The fact that it is collapsible will not necessarily indicate optimal performance, so these two characteristics have a strong negative correlation.

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Performance and firmness have a strong negative correlation, however, firmness has a positive relationship with storage, because the water that will be stored in the container must be kept in its original position, in order to avoid overflow or contamination of the water. Therefore hardness and storage have a positive correlation.

Hardness has a strong negative correlation with visibility, while design has a strong positive correlation with visibility, the process is intended to be sufficiently visible to detect any anomalies that may occur, as well as to change the filtrate when necessary.

Optimal performance has a strong positive correlation with visibility, because the more visible the process is, the easier it is to detect faults in the process.

Expansion has a strong negative correlation with moisture control, while expansion has a positive correlation with durability. It should be noted that the environment in which the system will be operating will have a high percentage of humidity, so it is important to choose materials capable of functioning normally under these conditions.

To make the correlation matrix between customer requirements and quality characteristics, the following symbology was used:

Θ Indicates strong correlation, the value of which is 9.

O Indicates moderate correlation, the value of which is 3

▲ Indicates poor correlation, the value of which is 1

The columns that obtained high relative values were:

Column 1 with a relative value of 8.8 and column 10 with the same relative value.

Once the matrix analysis was completed, the competitive assessment was carried out the device has 3 strong competitors at present, which are shown below:

Competitor 1:

Eolewater is an innovation which allows water to be produced by extracting moisture from the air through a condensation process. (Parent, 2010) "Firstly, energy is extracted from the wind to generate electricity, and this is used to run an air conditioning system where moisture from the air is condensed to produce water." The machine sucks in air to deposit it in a system that cools a series of plates on which the moisture in the air condenses, forming water that flows into a collecting tank. "This is nothing more than a machine that produces rain," Parent pointed out.

Competitor 2:

Researchers from the University of Engineering and Technology (UTEC) in Lima collaborated with advertising agency Mayo Peru DraftFCB developed a panel that produces drinking water using air as a resource.

The panel is strategically located in the village of Bujama, an almost desert-like area south of Lima, where some residents have no access to drinking water. However, despite the harsh weather conditions, the air contains 98% humidity (UTEC, 2013).

The panel fulfils its traditional function as an advertising platform, while including the special task. Internally, the piece consists of five machines that convert the humidity in the air into water through the use of filters and a condenser. The water is stored in tanks at the top of the structure and, once filtered, flows through a pipe to the tap, to which everyone has access News Mundo [2013].

Competitor 3:

Fresh Water, on the other hand, is a technology that allows water to be obtained from the atmosphere by simply connecting it to a 220V electrical source, or through its own battery or solar source, without having the need to connect to a drinking water network, or rely on the logistics and supply of bottles or water trucks. What this system does is to recover the water suspended in the air through the phenomenon of condensation at ambient pressure. Subsequently and by employing filtering, purification and sterilisation stages, it provides purified water with high quality standards, (CENTER, 2014).

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Competitive analysis:

In conducting the competitive analysis, values from 0 to 5 were given where 0 indicated the worst and 5 the best. Customer requirements were evaluated and it was concluded that the biggest competitor to the system is Eolewater, because it meets most of the requirements that the customer requests in order to acquire a system capable of transforming moisture into purified water. However, this device is not within the reach of the strategic sector at which it is aimed. For the marketing phase, the sample size was determined, then a survey was designed and applied, with the purpose of knowing the market's opinion about a device capable of producing water through humidity, as well as the percentage of acceptance by consumers in order to determine the potential market and based on this to make the projection of the demand under the three scenarios. The subjects surveyed were rural families in the city of Altamira, Tamaulipas.

Sample size determination:

$$n = \frac{Z^2pqN}{e^2(N-1)+Z^2pq} \quad (1)$$

Ecuation 1. Sample size calculation

Where:

n= Sample size

Z= Confidence level (1.96)

p= Probability in favour (0.5)

q= Probability against (0.5)

N= Population (4000)

e= Estimation error (0.05).

Substituting obtained:

Substitution of the sample size calculation.

Subsequently, an estimation of the demand was made and surveys were applied, with the purpose of knowing the percentage of acceptance that the product in question would have.

Results

Figure 1 shows the application of the quality function deployment of the environmental humidity sensor device.

Some requirements have a greater impact which are: that it captures sufficient humidity (8.5%), that it is easy to use (8.1%), that it is light (6.5%) and finally that it is economical (6.2%). Therefore, the technical and operational characteristics to be considered for the design of the system will be: optimal performance, size, firmness, weight, filter adhesion and stability. On the other hand, in the competitor analysis it can be seen that the device has three strong competitors that meet most of the requirements of the customers. However, the only disadvantage is the inaccessible prices towards the targeted market segment.

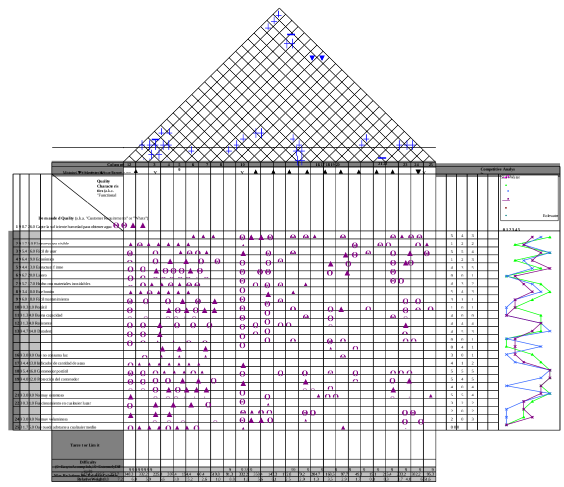

Figure 1 Deployment of the quality function of the system for the transformation of moisture into drinking water
Source: own production

Once the quality function deployment was performed and analysed, it was possible to carry out the implementation of the prototype taking into account the characteristics of the client and the operational techniques. This system will be able to collect the moisture present in the environment and transform it into purified water, benefiting families in rural communities, preventing diseases such as polio, hepatitis and other diseases caused by the ingestion of unhealthy water and poor sanitation conditions.

The following figure shows the proposed design considering the information obtained in the QFD, as well as the table of raw material costs.

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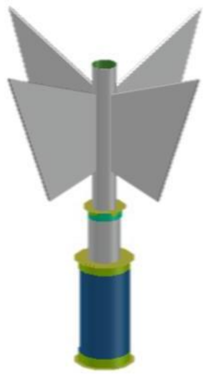

Figure 2 Prototype of the device
Source: the authors

Product	Quantity	Unit Cost	Total Cost
Shade netting	1.5 m	$ 118.90	$ 178.35
40mm PVC pipe	6 m	$ 10.80	$ 64.80
1" PVC pipe	0.5 m	$ 17.70	$ 8.85
10mm PVC pipe	1 m	$ 27.00	$ 27.00
3cm perforated PVC pipe	1 pza	$ 14.90	$ 14.90
3cm ball bearing	1 pza	$ 77.94	$ 77.94
3cm coupling	1 pza	$ 12.00	$ 12.00
Filter	1 pza	$ 15.00	$ 15.00
Funnel	3 pza	$ 16.00	$ 48.00
Acrylic sheet	4 pza	$ 74.90	$ 299.60
Hinge	2 pza	$ 3.00	$ 6.00
Total Cost			**$ 752.44**

Table 1 List of materials to make the prototype
Source: the authors

The results of the most relevant questions asked in the survey are presented below:

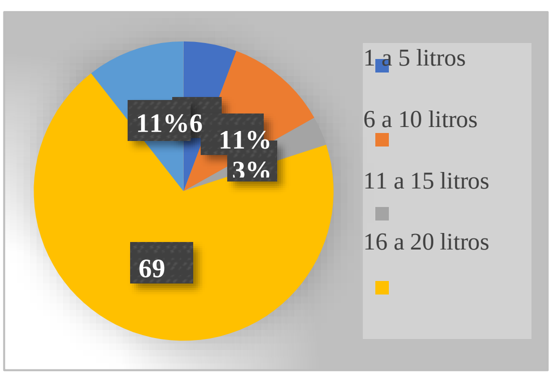

Figure 3 Quantity of purified water consumed
Source: the authors.

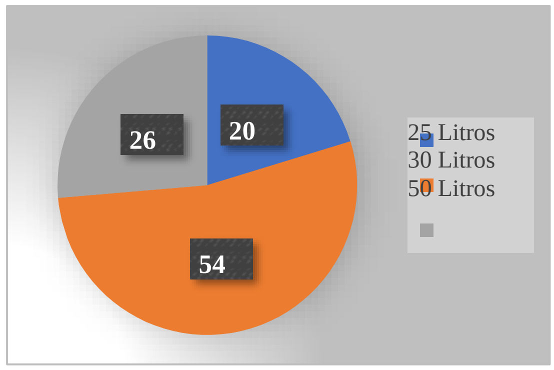

Figure 4 Litre capacity required
Source: the authors

Estimation and volume of demand.

Table 2 shows a sales projection of the ambient humidity sensor device.

Year	Madero	Tampico	Altamira	Total Anual
2023	201,251	240,755	298936	740,942
2024	201,362	246,515	297,846	745,723
2025	201,426	252,214	296,711	750,351
2026	201,512	257,944	295,598	755,054
2027	201,650	263,612	294,485	759,747
2028	201,732	269,374	293,372	764,478

Table 2 Estimated demand in the southern suburban area of Tamaulipas

In order to understand the various scenarios in which demand may occur, the following calculations were made.

Year	Σ	% aceptación	% cobertura	Frec. De compra por semana	Penetración	Optimista	Escenarios Realista	Pesimista
		0.9	0.35	2	25%	80%	45%	30%
2023	740,942	666,847.80	233,396.73	466,793.46	116,698.37	93,358.69	52,514.26	35,009.51
2024	745,723	671,150.70	234,902.75	469,805.49	117,451.37	93,961.10	52,853.12	35235.41
2025	750,351	675,315.90	236,360.57	472,721.13	118,180.28	94,544.23	53,181.13	35,454.08
2026	755,054	679,548.60	237,842.01	475,684.02	118,921.01	95,136.80	53,514.45	35,676.30
2027	759,747	683,772.30	239,320.31	478,640.61	119,660.15	95,728.12	53,847.07	35,898.05
2028	764,478	688,030.20	240,810.57	481,621.14	120,405.29	96,324.23	54,182.38	36,121.59

Table 3 Demand scenarios

The estimated sales volumes up to the year 2023 under the three demand scenarios approach, it can be seen that the projected sales are attractive.

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Conclusions

Through the application of the tools it was possible to apply the marketing for the elaboration of the design to the project mentioned above, with the deployment of the quality function in addition to analysing the customer's expectations, allowed the analysis of the technical and operational characteristics that the system of transformation of moisture in purified water could offer to the communities lacking the vital liquid, because the cost of production will be reduced to the maximum the selling price will be minimal, and as a result more families in the state of Tamaulipas may have access to this device.

Once the market segmentation, the application of the surveys, the design and manufacture of the device had been carried out, it was proven that it is possible to produce up to 12 litres of water per day, under optimal conditions of parameters such as percentage of relative humidity and wind speed, satisfying the rural communities of the vital liquid.

It should be noted that among the design characteristics to be considered, it was taken into account that the client requires it to capture sufficient humidity, be easy to use, light and economical. With regard to the market study, it was found that there is a 90% acceptance rate and in the demand projection, carried out under three scenarios, the market viability can be appreciated as there are projections with a positive trend.

Although there are already devices capable of fulfilling this function, they are usually very expensive and are manufactured with sophisticated technology, generating a limitation for the acquisition of the same, it could be seen that with $752.44 it is possible to acquire the necessary inputs for the manufacture of the device.

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