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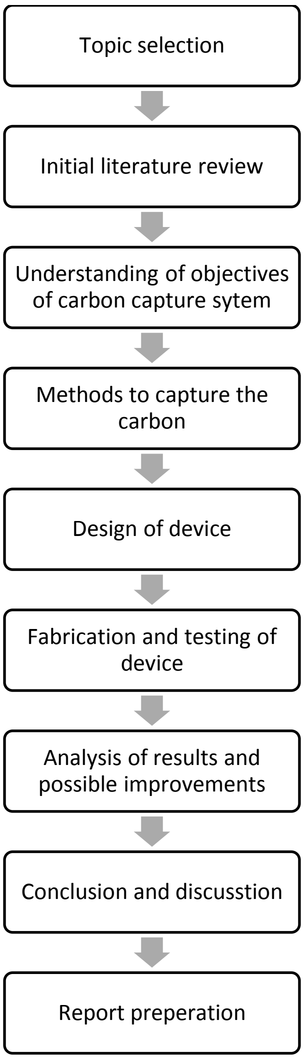
Chapter 3

3 Methodology

This section is to highlight and discuss the research methods used which is available for the project in correlation with the problem statement. Increasing carbon content in the atmosphere is causing the severe problems like increasing average earth surface temperature, disturbing the rainfall pattern and reducing the strength of the soil. Moreover, this report will display the procedure and techniques used to remove the carbon content from air. This report will specify the methods used, merit and demerit of the methods, design procedure, tools used, description of project and evaluation on design.

3.1 Flow chart of work



3.2 Quality function deployment procedure

QFD employs concurrent engineering concepts by including cross-functional teams in all stages of the design. A matrix is used in each of the four phases of the QFD process to transfer client requirements from the original planning stages into production control. Each phase, or matrix, denotes a distinct component of the product's specifications. For each step, the relationships between components are assessed. In the next paragraphs, just the most crucial components of each phase are discussed in following sub section.

3.2.1 Survey

The marketing team launched the construction of the House of Quality, and Phase 1 is also known as The House of Quality. Many businesses only make it thus far in the QFD process. Customer needs, warranty information, competition opportunities, product measures, competition for product measurements, and the organization's technical competence to satisfy each customer demand are all documented during this phase.

3.2.2 Customer and engineering requirment

The engineering department initiates this phase. Product design necessitates ingenuity on the part of the team. During this phase, product notions (aims and outcomes) are developed, and part of the requirements are recorded.

3.2.3 House of quality

Manufacturing engineering is in charge of process planning next. Process planning, manufacturing procedures, flowcharts, and process variables (Target Values) are all recorded at this time.

3.2.4 Morphjological diagram

Finally, performance indicators are generated in production planning to monitor the manufacturing process, maintenance plans, and operator skill training. In addition, at this phase, choices are made on which processes represent the greatest danger, and controls are implemented to avoid this.

3.3 Method of carbon capturing from air

Many methods of extracting the carbon from the air developed. The primary test that as of now accessible carbon dioxide catch techniques face is a high energy consumption.[1] A couple of mature, non-electrochemical carbon dioxide catch advances e.g., retention, adsorption, film detachment and cryogenic catch are as of now accessible in modern scales [2]. These techniques frequently rely upon the accessibility of nuclear power, which makes them less appropriate for carbon dioxide catch from weaken sources e.g., air and sea. Moreover, the expense of direct air catch by means of conventional advancements has been assessed in the writing from $200 to $1500 per ton of caught carbon dioxide.

Because electrochemical methods may target molecules directly, they have the potential to be very energy efficient (instead of the medium surrounding them). [3] Electrochemical carbon dioxide collection technologies may now be used on any carbon dioxide -containing stream, regardless of concentration. There have been reports of direct air capture [4]. These capturing devices are plug-and-play processes that have a compact footprint and are geometrically adaptable. They do not require external heat or high pressures/vacuum to operate, and no sorbent material deterioration is envisaged. Since, the concentraition for the air volume is thin in the residential buildings, the electrochemical methods by pH swing, is most suitable to design the air capture tool.

Electrochemical approaches have the extra benefit of being able to combine carbon dioxide capture and utilisation [5]. The flexible, sequential carbon dioxide collection and conversion system, for example, leverages the pH-swing idea to electrochemically manufacture carbon dioxide. Responsive carbon dioxide capture, wherein the carbon dioxide collecting medium well before the dilute feed and creates advantageous local micro-environments, has also emerged as a promising sector for integrated carbon dioxide collection and conversion employing electrochemical methods.

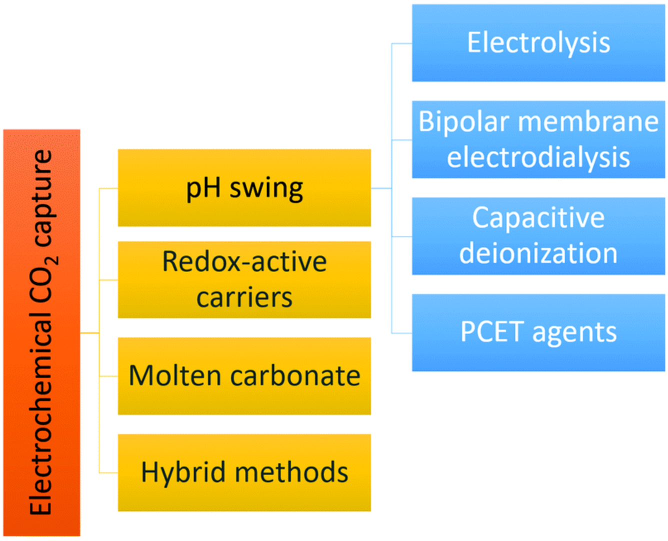


Figure 1 Summary of the different ways to Electrochemical CO2 capture

3.3.1 Electrochemical pH-swing concept

Electrochemically incited pH-swings for carbon dioxide catch have been exhibited through (film) electrolysis, bipolar layer electrodialysis, reversible redox couples, capacitive deionization and half and half cycles that consolidate at least two techniques as displayed beforehand in Fig. 1. These catch techniques have frequently energy utilization >310 kJ mol−1 carbon dioxide. As an examination with ordinary strategies, the energy utilization of carbon dioxide catch (from vent gas) by means of fluid monoethanolamine (MEA) utilizing a warm swing, as of now the most experienced catch technique, is between ~175-295 kJ mol−1 CO2. [6]

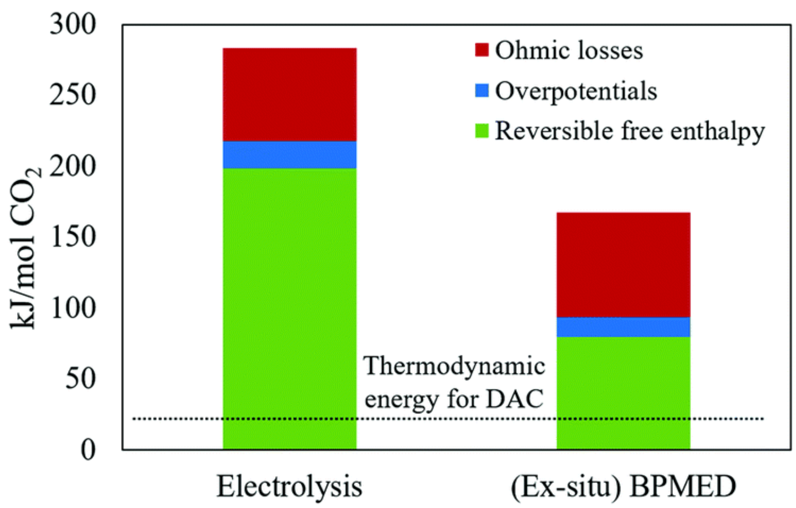


Figure 2 comparison of energy required to capture the co2 [http]]

Roughly ~85% of this energy is the commitment of the warm recovery, remembered for the reboiler heat obligation. Most regular and electrochemical catches are energy serious, when contrasted with the burning energy of different energizes and the radiated carbon dioxide per mole of the fuel. According to a financial perspective, carbon dioxide catch is possibly fascinating on the off chance that the energy utilization of the catch is <66 kJ mol−1 carbon dioxide. [7]

It is clear from Fig. 2 that the energy utilization for BPMED is lower than that of electrolysis while focusing on carbon dioxide catch. Considering the electrolysis restricted choices arwe accessible for electrocatalytic material (e.g., platinum and ruthenium), which can act asset impediments like a generally enormous cathode region is required. Going against the norm, up scaling should be possible effectively for BPMED catch strategy by rehashing different cell matches inside a solitary anode pair.

3.3.2 About BMPED (Bipolar membrane electrodialysis)

An anion (AEL) and cationic (CEL) exchange layer is laminated together to form a bipolar membrane (BPM). The BPM separates water into OH and H+ when a significant magnetic current is applied, resulting in a controlled pH across the membrane. Figure 3 depicts a schematic illustration of BMPED. The theoretical minimum voltage required for the this water dissociation using a bipolar membrane is 0.829 volts for a generated pH = 14.

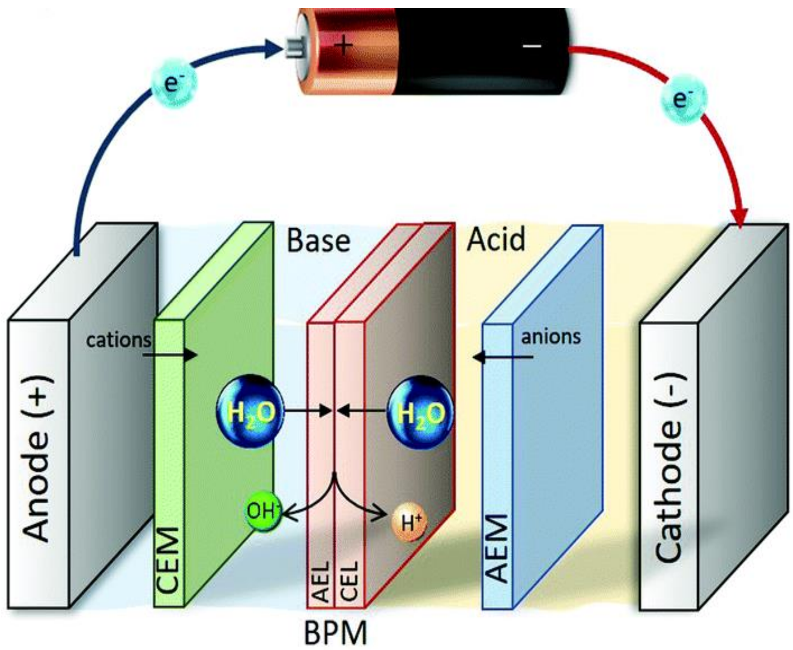


Figure 3 Schematic representation of BMPED [8]

There is a trade-off in BPMED between energy consumption and process rate, which is dictated by the current densities. Because of the increased salt ion leakage through to the BPM and hence the decreased water dissociation rate, operating at extremely low high current density is ineffective.

BPMED's present minimal economic cost is at least double that of its wet-scrubbing competitor. However, if advancements in the cost for renewable energy, the cost & accessibility of ion exchange membranes, membrane life time, and membrane selectivity are made, the cost can be greatly reduced. To optimise the decrease in net carbon emissions and to harness the benefit of electrifying the carbon dioxide capture process, renewable sources would be preferable over coal and oil for driving electrochemical carbon dioxide capture. At the same time, because renewable energy sources lack flue gas from power plants, dispersed carbon dioxide sources (such as the atmosphere and saltwater) would be the most obvious input for electrochemical carbon dioxide collection methods.

3.4 Utilization of captured carbon dioxide

Figure 4 shows how carbon dioxide can be kept or used once it has been caught. carbon dioxide is a low-cost, non-toxic, and renewable resource. By 2030, the carbon dioxide market is expected to rise from 0.24 gigatonnes (Gt) per year to 7.5 Gt per year..

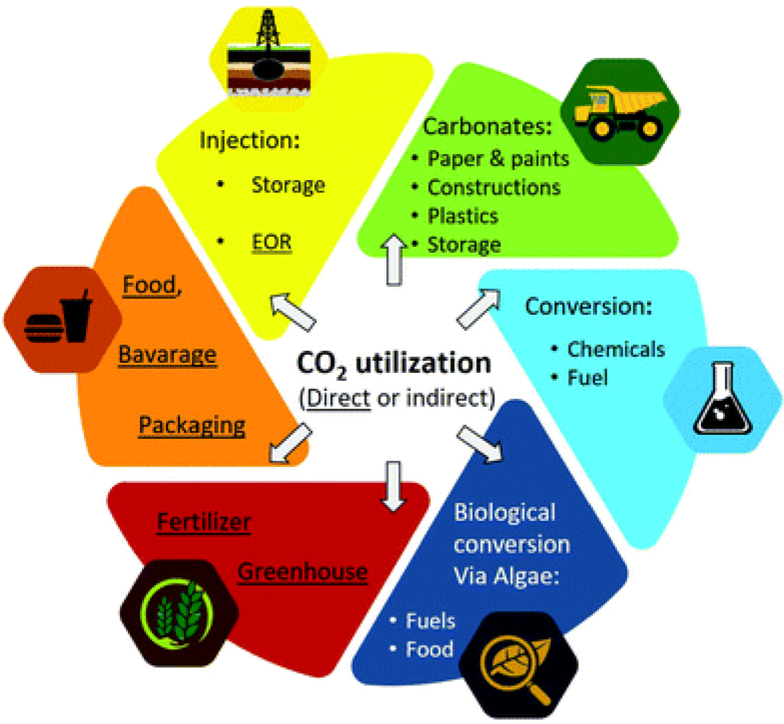


Figure 4 Schematic representatiobn of the CO2 utilization

The figure 4, shows the market size and price of other gases with carbon dioxide .

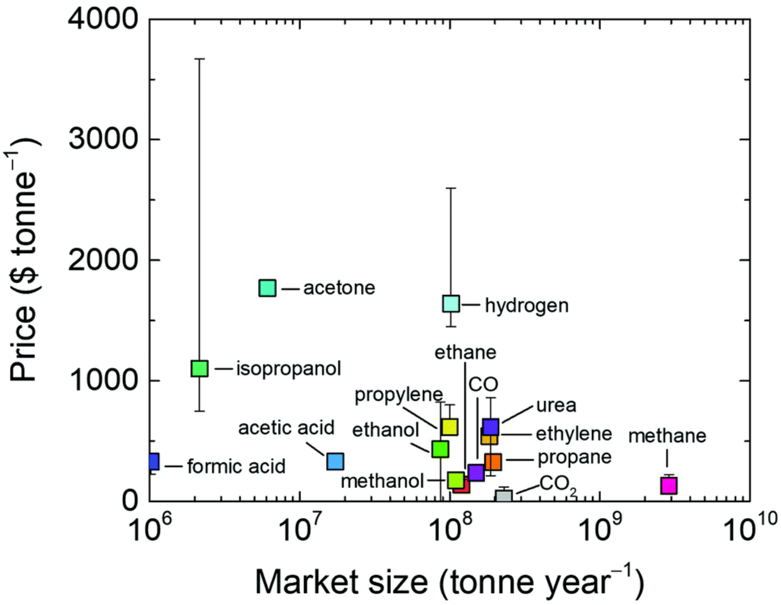


Figure 5 Market size and price band for different gases, Image credit:[9]

DAC has potential carbon feedstock benefits notwithstanding its natural advantages. With the rising chance of carbon dioxide use as a synthetic feedstock for the amalgamation of significant worth added items, the capacity of DAC innovation to give a course to on location carbon dioxide age anyplace on the globe for use applications is worthwhile. The most ordinarily researched approaches are the immediate catch of carbon dioxide from the air and ensuing transformation to deliver powers. Be that as it may, different roads of purpose are additionally conceivable, including compound change to create manufactured intermediates for drugs or other worth added synthetic items as well as taking care of nurseries or green growth establishments for farming or biofuel creation. The central issue to be made is that while DAC combined with carbon dioxide sequestration is being investigated as a carbon negative innovation. It might likewise be utilized for blend of significant worth added items in the close to term (which, nonetheless, would insignificantly affect environmental change), with an extreme ultimate objective of topographical sequestration once the above vulnerabilities are tended to.

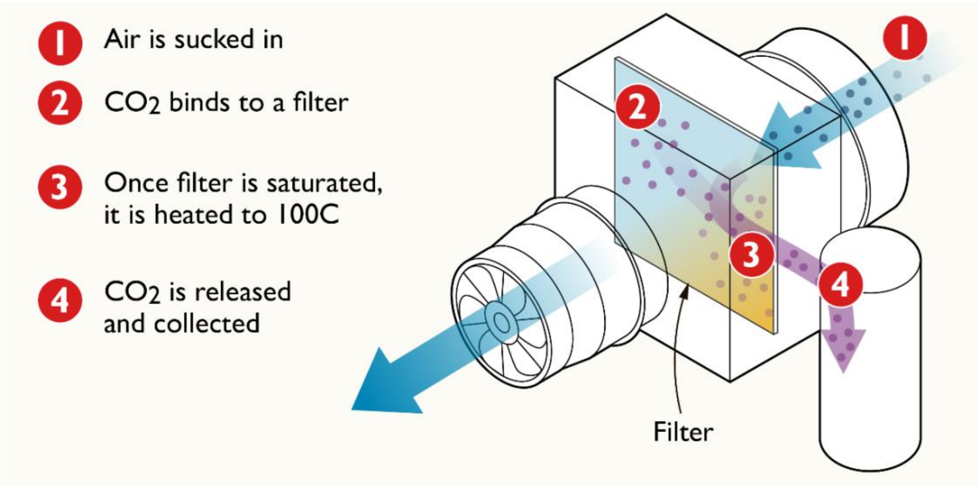


Figure 6 A schematic diagram of CARBON DIOXIDE capturing device

3.5 Existing products

The detailed conceptual design for a passively direct air carbon dioxide collecting system has begun at Julie Ann Wrigley Global Futures Laboratory. When carbon dioxide is exposed to air, a resin inside a fabric captures it, and the carbon dioxide is released into a contained harvest chamber by a water spray. The developed gadget currently achieves a capture percentage of 5% in the air. To produce larger carbon dioxide concentrations in the air, back-end concentration technologies are available. [10]

Figure 7 Device designed by Julie Ann Wrigley Global Futures Laboratory [10]

Engineers at MIT have developed a novel method of removing carbon dioxide from the atmosphere. The gadget is simply a big, specialised battery that takes carbon dioxide from the atmosphere (or other gas stream) flowing over its terminals as it charges up, then releases it when it discharges. The device would simply switch among charging and discharging modes, using fresh air or feed gas pumped through the circuit during the charging cycle and pure, pure carbon dioxide expelled out during the discharging cycle. [11]

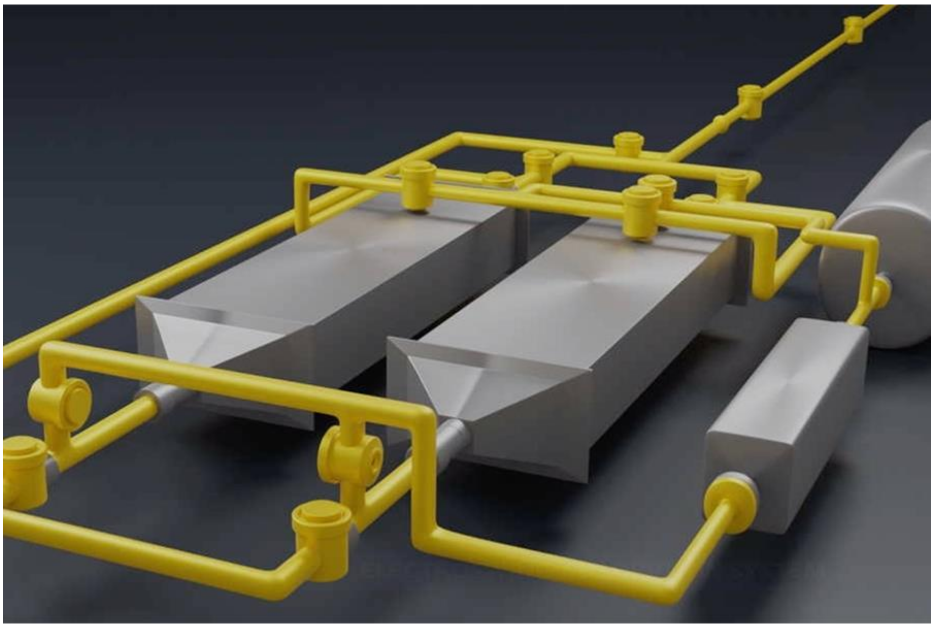


Figure 8 Design of device developed by MIT engineers [11]

Several other universities and companies developed the carbon capturing devices based on the different methods shown in the figure 1. The feasibility of these devises can be measured on the basis of how much electricity they consume and there efficiency to extract the carbon from air.

3.6 Conceptual design

3.6.1 Survey Analysis

The online poll took around one week to complete and was designed to gauge public knowledge of growing carbon levels in the atmosphere. Appendix A is an copy of the online survey. The online survey was delivered using a Google form that was developed after the survey was produced. 100 people responded to the survey. The survey has been selected to be disseminated to customers of all ages and economic levels.

The rationale for this is that the results gained provide a wide range of options for groups of high, moderate, and low income individuals, which plays a significant role in determining the product design of carbon dioxide collecting devices. The product design is influenced by the customer's income and knowledge of growing carbon levels. The majority of those polled are working professionals, with only a few students and older persons among them.

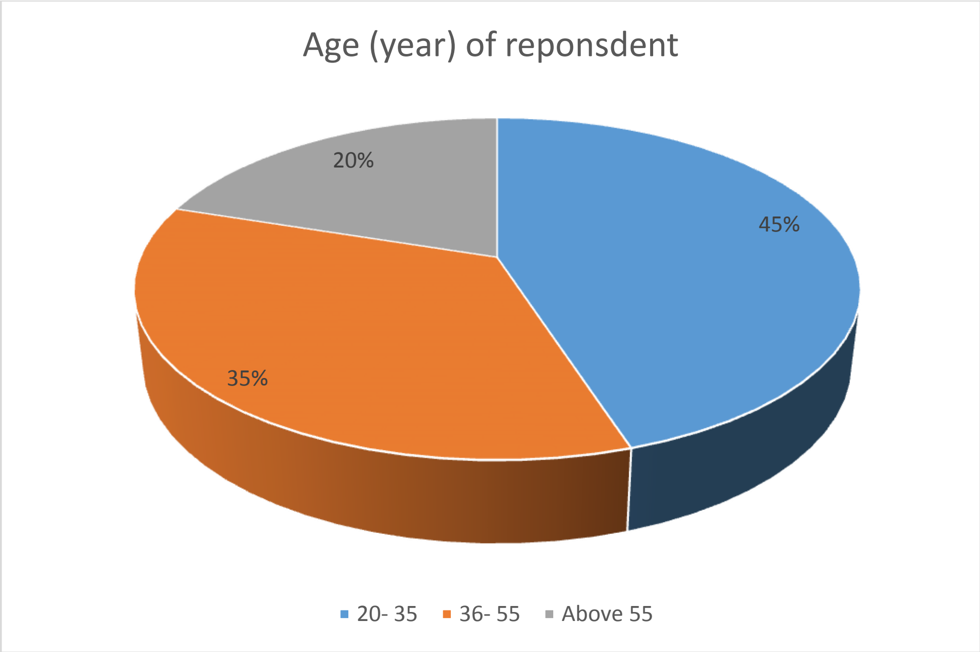


Figure 9 Percentage of respondents according to age

The figure 9 represents the age of the respondents. 35 percent people participated from the age group of 36 to 55 year and the maximum participation is from the 20 to 35 year age group. The minimum participation (= 20 percent) is from the age group of the above 55 years.

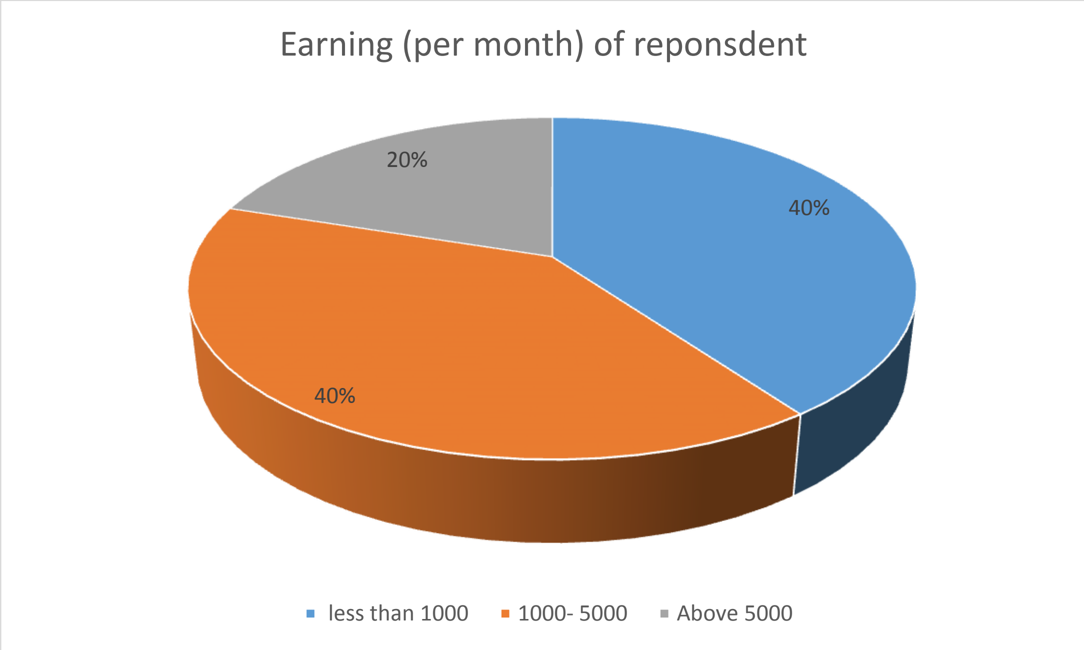


Figure 10 Percentage of respondents according earning

The earning results shows the maximum peoples participating in the survey is from the middle economic class. Equal participation is from the lower middle economic class. The figure 10 represents the age of the respondents.

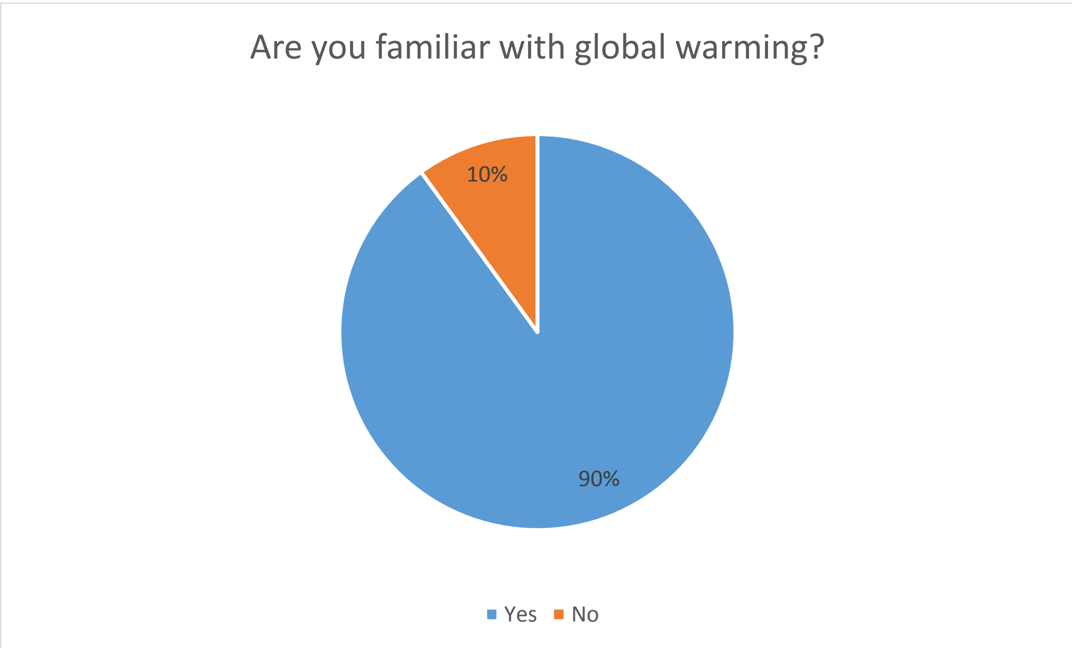


Figure 11 Survey results on knowledge about global warming

To check the most basic fact that are peoples aware about the term global warming? We asked the question, Are you familiar with global warming? The 90% respondents replied in yes.

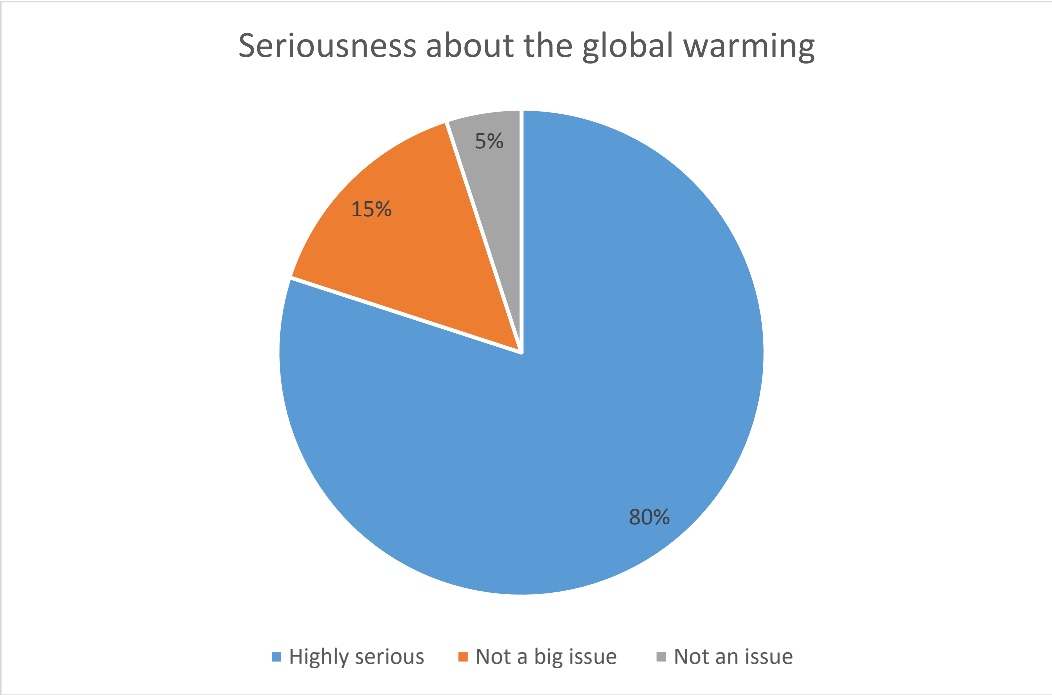


Figure 12 Survey results on Seriousness about the global warming

The knowing the global warning and acknowledging it as an issue is two different things. To measure the seriousness of the global warming, we asked question with three option. The most of the people responds as a major issue. The 15 % of the people considers it not a big issue and the 5 % does not considered global warming as an issue.

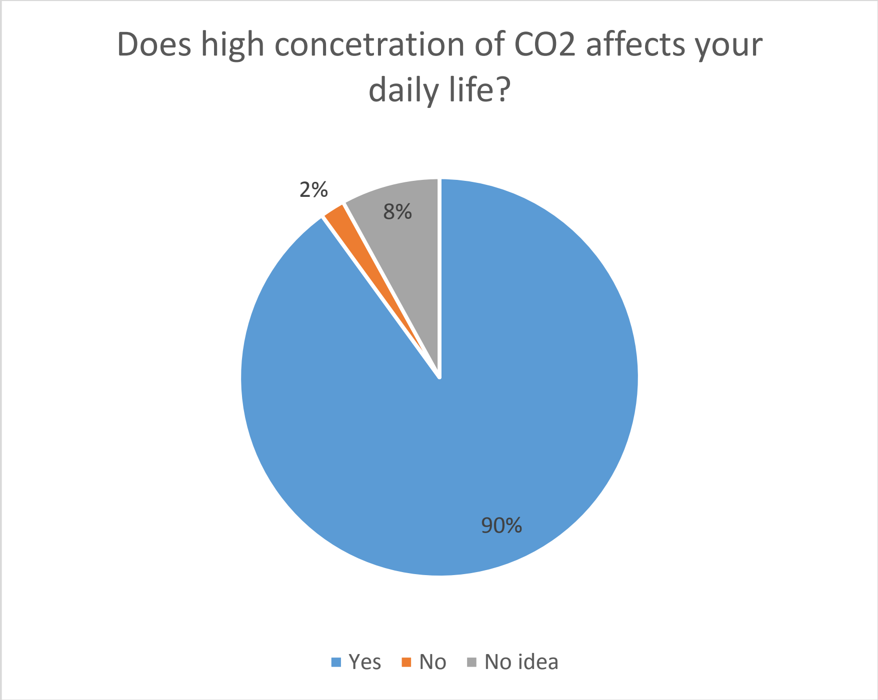


Figure 13 Responses on survey question, "Does high chigh oncetration of CO2 affects your daily life?"

To relate the global warming with our device's concept, we asked people about the high concentration of carbon dioxide in air. From figure 13, we can see that 90% people acknowledge that the high concentration of carbon dioxide affects their daily life.

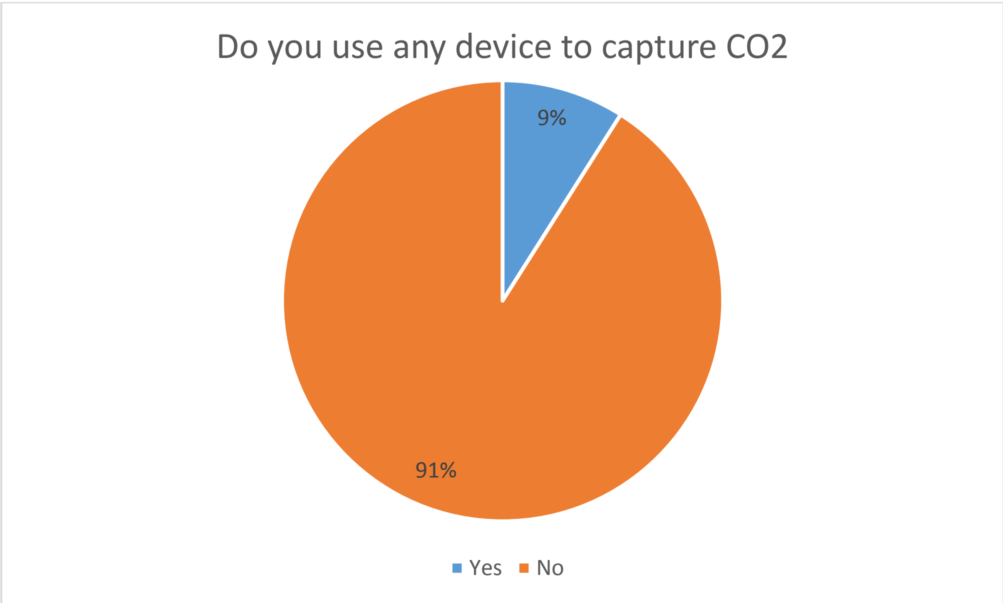


Figure 14 Response on survey question, "Do you use any device to capture CO2"

From the figure 14, we can see that the most of the people responded in ''No" when they asked about the device capturing the CO2.

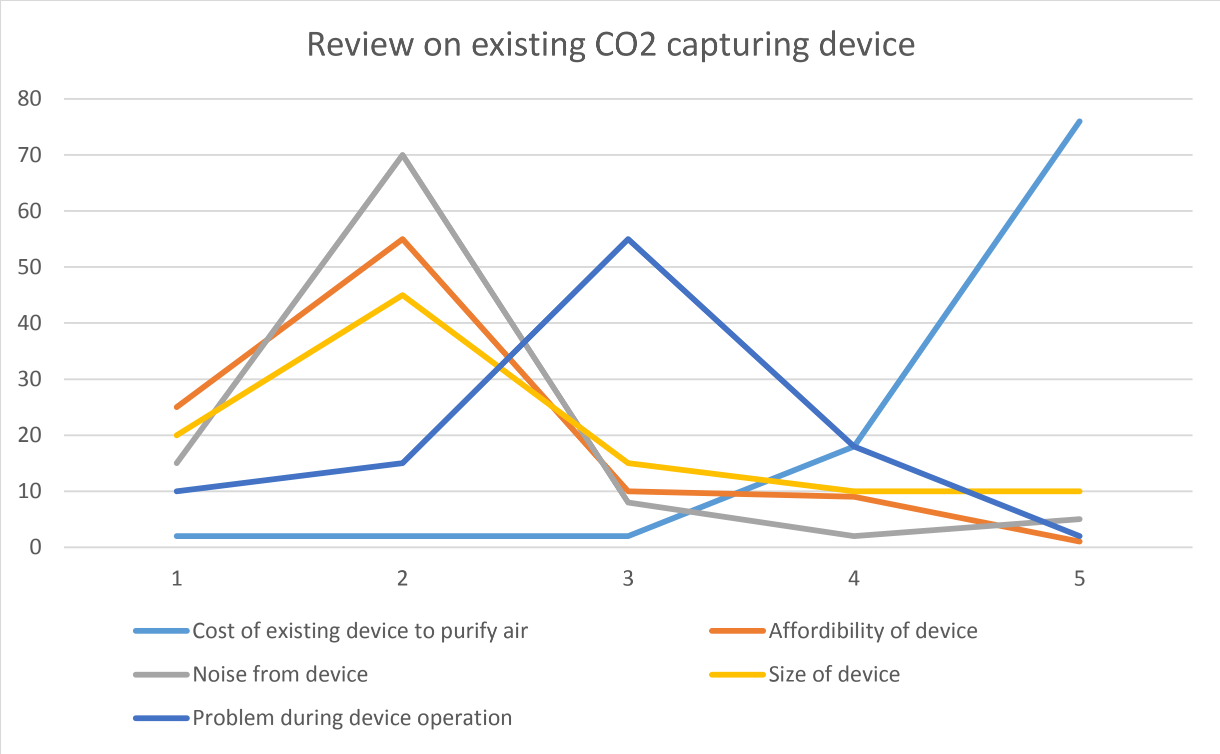


Figure 15 Responses of people on existing CO2 capturing device

We asked set of five questions regarding the existing CO2 capturing devices (Figure 15). The responses are measured from 1 (low) to 5 (high), as shown on the X axis of the figure 15. The cost of the existing devices are the major issue hence the affordability of the CO2 capturing devices is very low. People also complained about the noise from the devices, size of device and the problem occurred during operation of device.

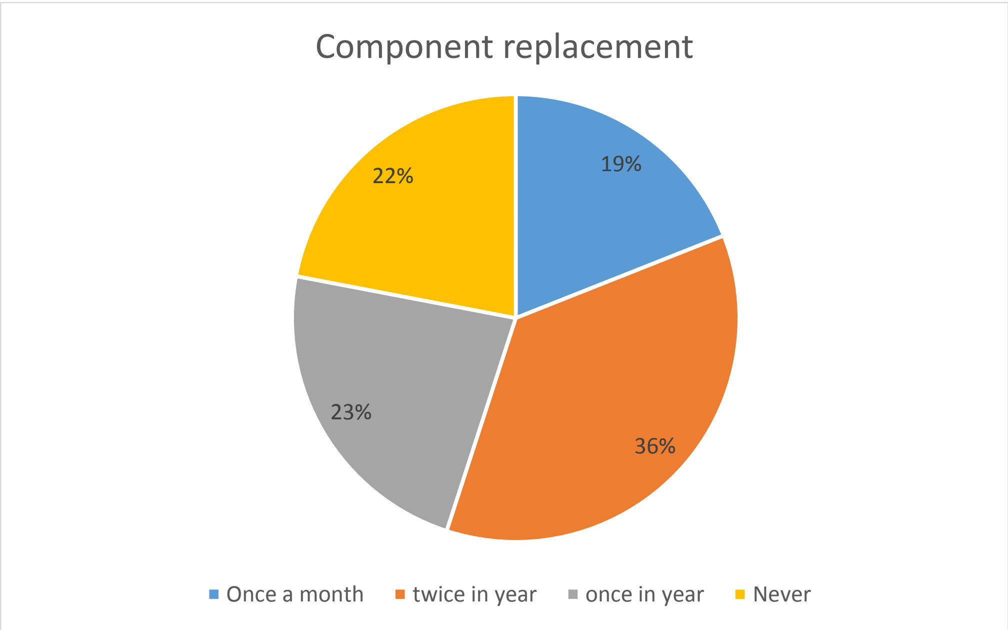


Figure 16 Survey response on "Component replacement"

The carbon-capturing device needs some component replaced at some interval. The replacement is compulsory because the captured CO2 is accumulated inside the device. We asked about the frequency of the components replacement required. The figure 16 results shows that most of the people are agreed on the twice replacement in a year.

The figure 17 shows the people's response on consumption of electricity of the CO2 capturing devices. Most people responded in negligible consumption of electricity from the device. Since device operates for 24 hours hence consuming large electricity make operational cost very high for the device.

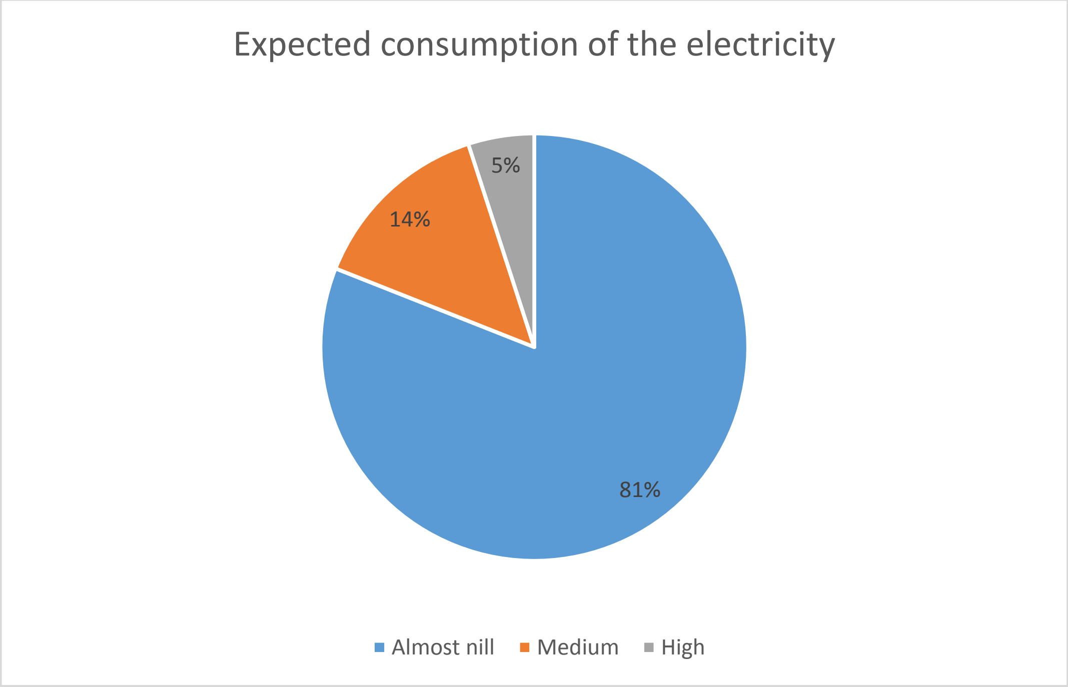


Figure 17 Survey results on consumption of electricity

The figure 18 shows the people's willingness to install the CO2 capturing device. 74 percent people responded in yes to install the carbon capturing devices.

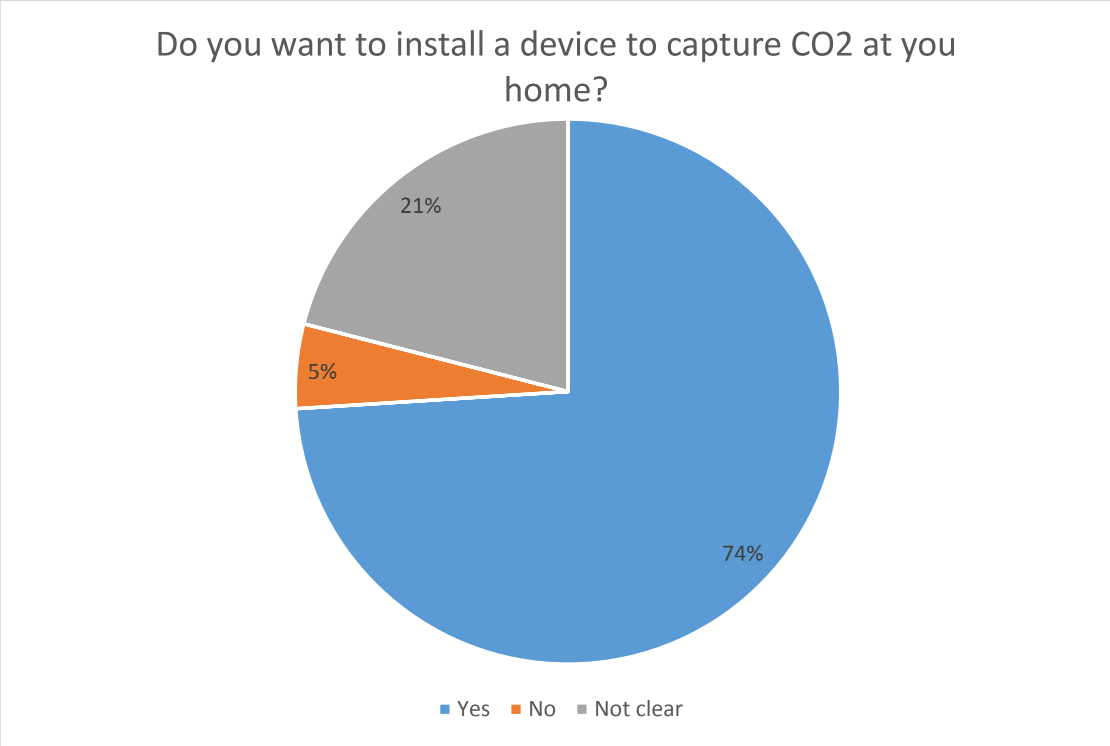


Figure 18 Survey results on people's willingness to install the CO2 capturing device

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3.7 House of quality

The QFD analysis perform to discuss the expected outcome of the work.

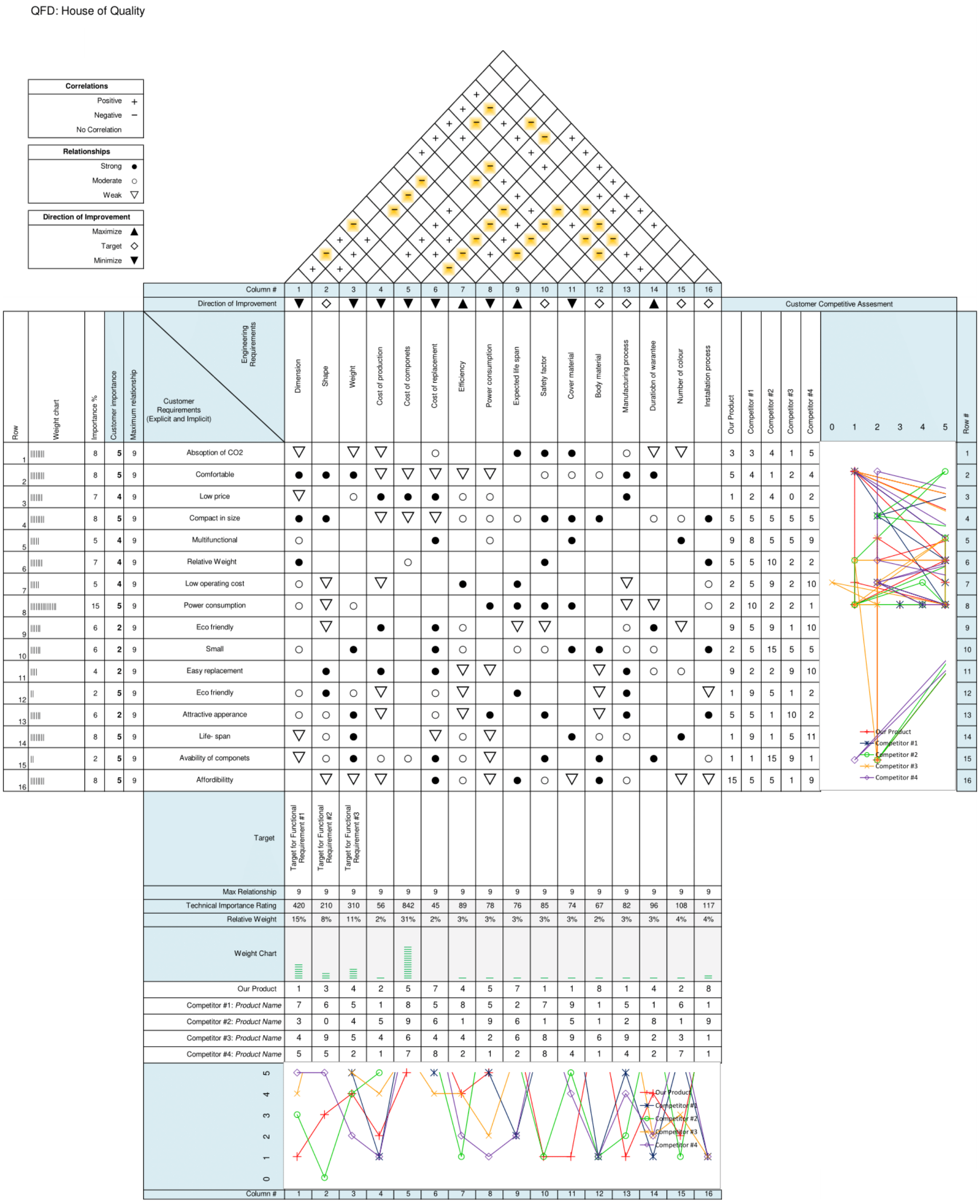

Figure 19 House of Quality

Top 8 Customer Requirements:

1. Carbon absorption method

2. Affordable
3. Low Price
4. Good look
5. User Friendly
6. Compact in size
7. Easy replacement of components
8. Light Weight

Top 8 Functional Requirements:

1. Shape
2. Cost of Material
3. Cost of Production
4. Manufacturing Process
5. Material Used
6. Efficient capturing system
7. Expected Life Span
8. Safety Factor

It can be deduced from of the HOQ chart that one of the finest marketing and design strategies is the final look and pricing in terms of matching the consumers' criteria. The achievement of completing the criterion was further aided by the consistency and integration of communication between the team members.

It might also be argued that the professional parameter mentioned in the conversation is one of the customer's most critical requirements. It also aids in the analysis of how to meet the aim and the customer's desire. Finally, it is demonstrated that by completing the survey and constructing the HOQ from of the survey results, the desired result is obtained..

3.8 Morphological diagram

This approach of problem-solving is being utilised to discover the most important function or mechanism in design creation. The morphological diagram functions by reducing the number of alternative solutions for each component. Those solutions can be presented with in morphological diagram by referring to the current design and any product that is already on the market. Table shows the many options for developing the conceptual design.

Table 1 Morphological Diagram

Function	Solution 1	Solution 2	Solution 3
Shape	Conic	Cylindrical	Rectangular
Air Intake	Self	Fan	Fan
Power source	Electricity	Battery	Battery
Carbon dioxide absorption method	BPMED	Electrolysis	Deionization
Air outlet	Fan	Fan	Self

In general, having more solutions will result in a viable conceptual design combination. However, it is a good idea to have an average amount of concepts to ensure that the design you create isn't excessively complex or basic. Table 2 following, based on morphological diagram, will go over the function or process of the suggested solution in further depth.

Function	Description
Shape	The shape of device is important because it can affect the air flow, device handling etc. We have three following shapes. Conic Cylindrical Rectangular
Air Intake	There is two possibility of air intake, one is through forced medium (using fan etc) other is natural. Self Fan
Power source	A power is required to operate the device it may be Electricity

	Battery
Carbon dioxide absorption method	As discussed in section 3.3, there are many way for the Carbon dioxide absorption. Electrolysis BPMED Deionization
Air outlet	There is two possibility of air outlet, one is through forced medium (using fan etc) other is natural Fan Self

3.8.1 Conceptual design 1

Conceptual design 1 is shown in the following figure.

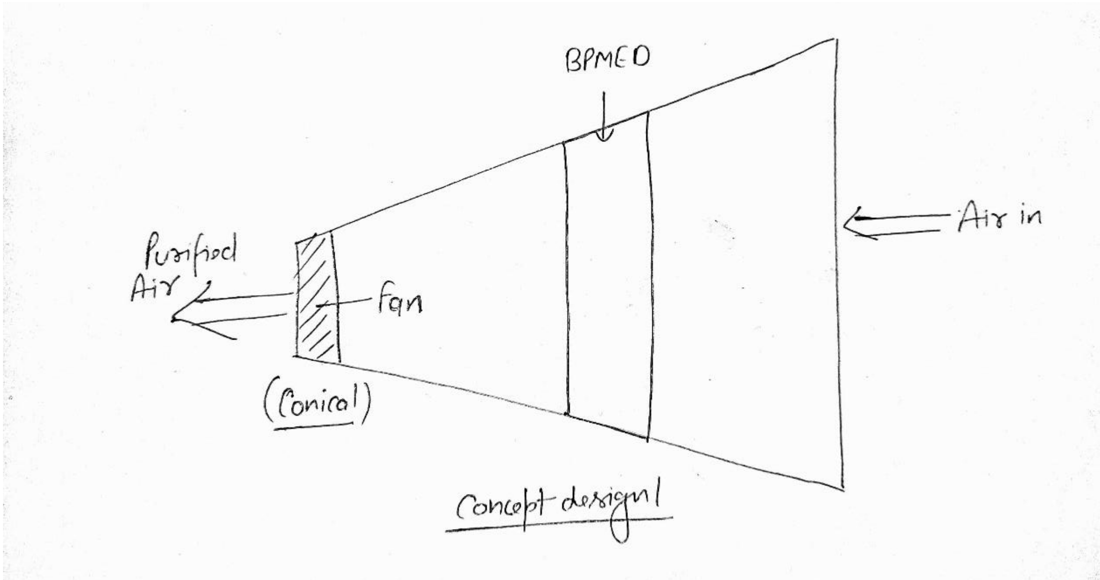

Figure 20 Design 1

Table 2 Concept Design 1 Specification

Requirement	Description
1. Carbon absorption method	Electrolysis
2. Size	1 m * 0.3 m * 0.2 m
3. Weight	5 kg
4. Power source	Electricity

5. Safety	All safety standards satisfied
6. Replacement of collect CO2	Component change
7. Advantage	Cross section is conic hence, airflow will be smooth. Fan is used at outlet hence efficiency will be better.
8. Disadvantage	Electrolysis is power-consuming method. Due to cone shape, device will be difficult to install.

Table 3 Morphological Diagram for Concept Design 1

Function	Solution 1	Solution 2	Solution 3
Shape	Conic	Cylindrical	Rectangular
Air Intake	Self	Fan	Fan
Power source	Electricity	Battery	Battery
Carbon dioxide absorption method	BPMED	Electrolysis	Deionization
Air outlet	Fan	Fan	Self

3.8.2 Conceptual design 2

Conceptual design 2 is shown in the following figure.

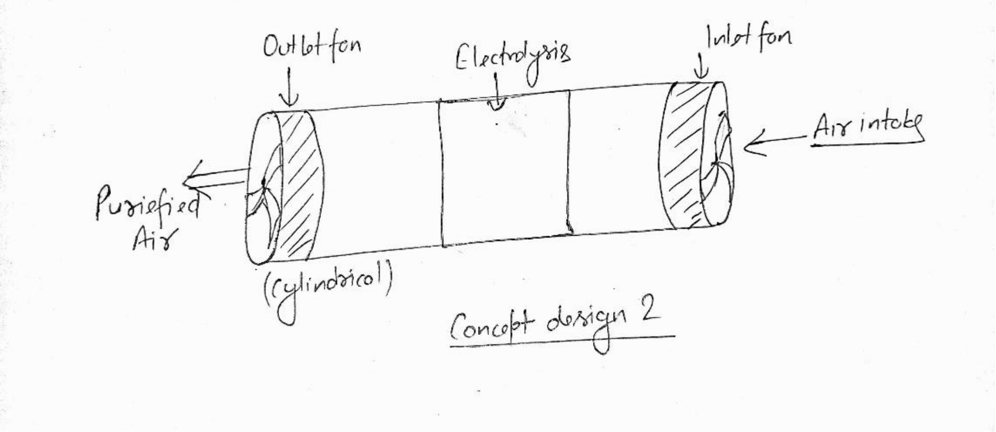

Figure 21 Design 2

Table 4 Concept Design 1 Specification

Requirement	Description

1. Carbon absorption method	Deionization
2. Size	1 m * 0.4 m * 0.3 m
3. Weight	6 kg
4. Power source	Battery
5. Safety	All safety standards satisfied
6. Replacement of collect CO2	Component change
7. Advantage	Cross section is cylindrical hence, airflow will be smooth and easy to install. BPMED is less power consuming process. Fan is used at outlet and inlet both hence efficiency will be better.
8. Disadvantage	Two fans are used hence power consumption will increase. Since power is supplied from battery, hence not suitable for long hours of operation.

Table 5 Morphological Diagram for Concept Design 2

Function	Solution 1	Solution 2	Solution 3
Shape	Conic	Cylindrical	Rectangular
Air Intake	Self	Fan	Fan
Power source	Electricity	Battery	Battery
Carbon dioxide absorption method	BPMED	Electrolysis	Deionization
Air outlet	Fan	Fan	Self

3.8.3 Conceptual design 3

Conceptual design 3 is shown in the following figure.

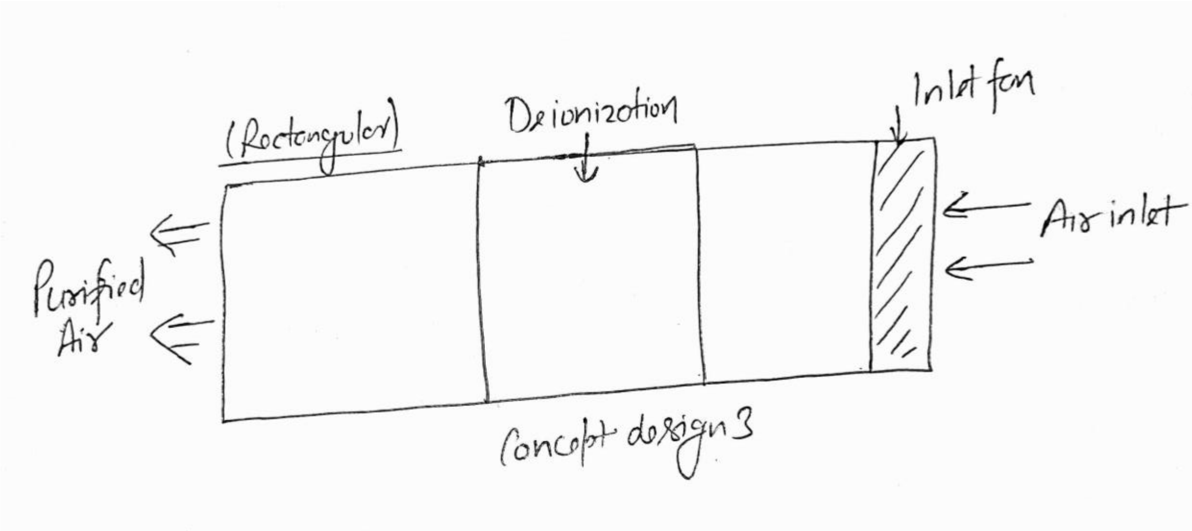

Figure 22 Design 3

Table 6 Concept Design 1 Specification

Requirement	Description
1. Carbon absorption method	BPMED
2. Size	1 m * 0.3 m * 0.2 m
3. Weight	3.5 kg
4. Power source	Battery
5. Safety	All safety standards satisfied
6. Replacement of collect CO2	Component change
7. Advantage	Easy to install. Fan is used at inlet both hence efficiency will be better.
8. Disadvantage	Cross section is rectangular hence, turbulent airflow may be generated hence efficiency will be reduced. Ionization is power-consuming process. Since power is supplied from battery, hence not suitable for long hours of operation.

Table 7 Morphological Diagram for Concept Design 2

Function	Solution 1	Solution 2	Solution 3
Shape	Conic	Cylindrical	Rectangular
Air Intake	Self	Fan	Fan
Power source	Electricity	Battery	Battery
Carbon dioxide absorption method	Electrolysis	Electrolysis	Deionization
Air outlet	Fan	Fan	Self

3.9 Final design selection

3.9.1 Pugh Matrix

The Pugh Matrix is a key stage in assisting a disciplined & team-based approach for concept development and choosing the best design concept from all those provided previously. The Pugh Matrix table below shows numerous alternative combinations of functions again for concepts to help you distinguish between them.

Table 8 Concept Design 1 (D1) Set as Datum

	Weightage	Design 1	Design 2	Design 3
Dimension	9		1	-1
Shape	7		0	-1
Weight	5		-1	-1
Cost of production	5		0	1
Cost of components	10		-1	0
Cost of replacement	14		0	0
Efficiency	14		0	-1
Power consumption	20		0	1
Expected life span	8		0	0
Safety factor	8		1	1
			2	-2

Table 9 Concept Design 2 (D2) Set as Datum

	Weightage	Design 1	Design 2	Design 3
Dimension	9	1		-1
Shape	7	1		-1
Weight	5	0		-1
Cost of production	5	-1		1
Cost of components	10	0		0
Cost of replacement	14	0		0
Efficiency	14	0		-1
Power consumption	20	1		1
Expected life span	8	0		0
Safety factor	8	1		1
		39		-2

Table 10 Concept Design 3 (D3) Set as Datum

	Weightage	Design 1	Design 2	Design 3
Dimension	9	1	1	-
Shape	7	1	0	
Weight	5	0	-1	
Cost of production	5	-1	0	
Cost of components	10	0	-1	
Cost of replacement	14	0	0	
Efficiency	14	0	0	
Power consumption	20	1	0	
Expected life span	8	0	0	
Safety factor	8	1	1	
		39	2	

Selecting and analyzing the concept design based on the three concept designs above has been done to evaluate and this is better or worse when compared to other designs that are accounted for as datum. The final examination determined as design 1 is the best design, receiving the highest scores and being the most practicable to construct.

Table 11 Concept Selection Based on Pugh Matrix

Design	1	2	2
1		2	-2
2	39		-2
3	39	2	
Total	78	4	-4

3.9.2 Final design

We discussed the process required for the capturing the carbon dioxide from air. However, in final design, we will focus on the complete device to absorb the carbon dioxide from air. The final design of the device should include the following components:

- Supply of the purified air: To supply the air from device, we need to install the fan.
- Carbon dioxide absorption unit: Bipolar membrane electrolysis based.
- Inflow of the air naturally.
- Removal of carbon dioxide from carbon dioxide absorption unit.

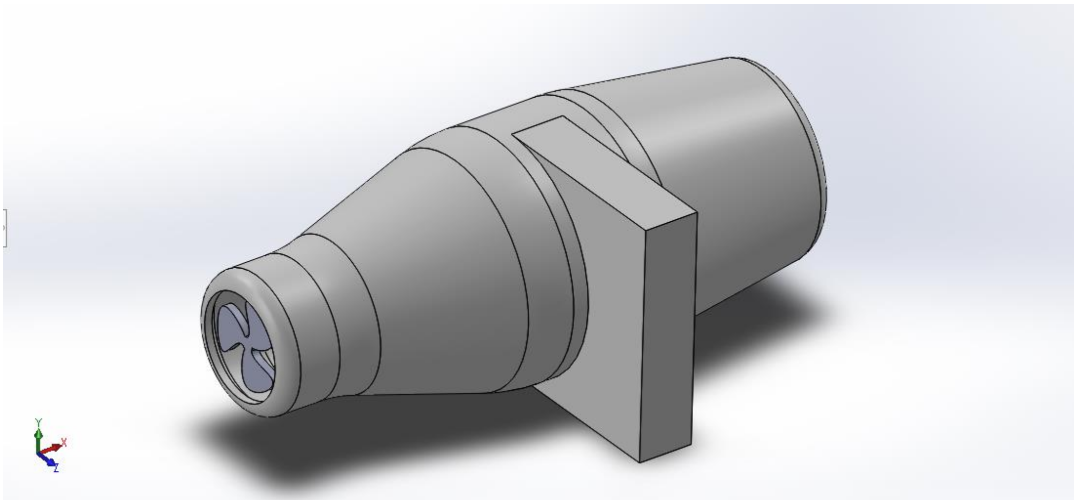

Figure 23 CAD model of final design prepared on SolidWorks

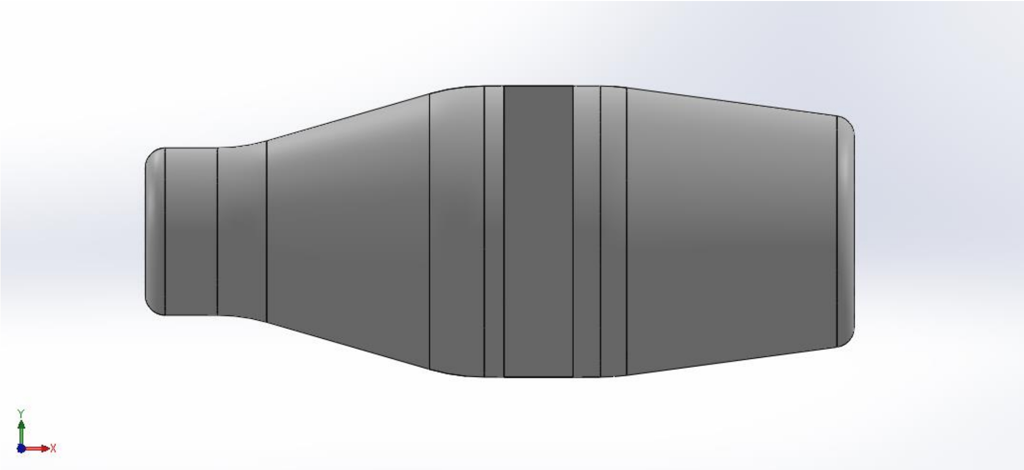

Figure 24 Side view of device

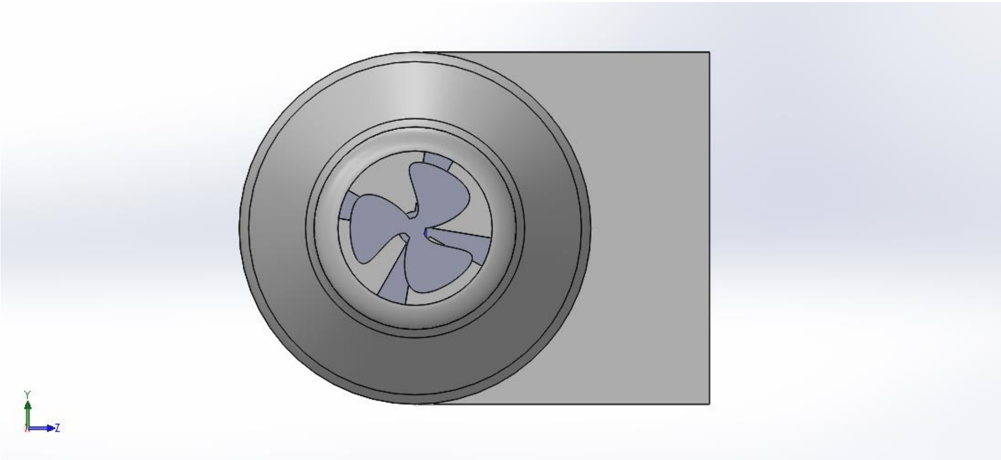

Figure 25 Front view of device

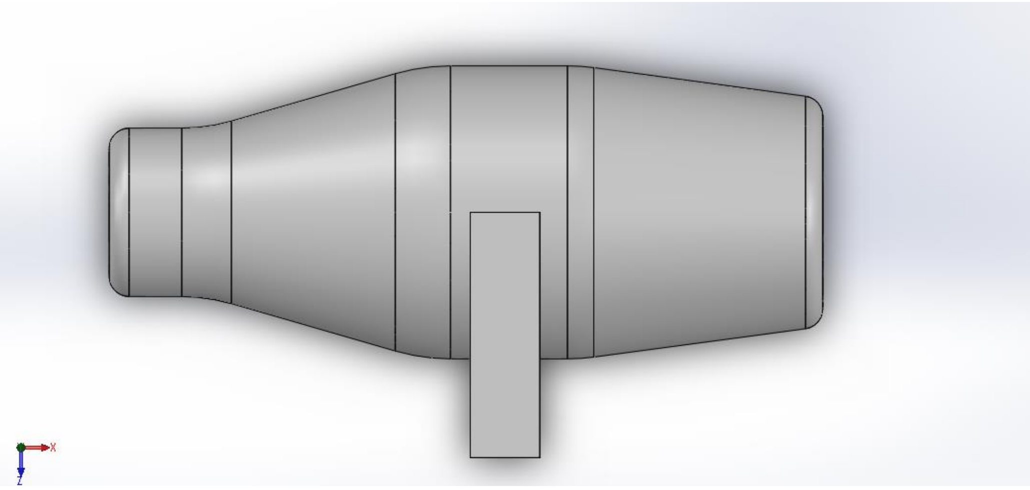

Figure 26 Top view of device

3.10 Summary

The concentration of carbon dioxide in the air is the same everywhere throughout the planet. This implies that, unlike carbon capture systems, which extract carbon dioxide from manufacturing processes at the source, DAC devices may be placed everywhere. DAC has the potential to play a key role in the jigsaw of carbon dioxide removal technologies and processes, which includes natural-based solutions like forest planting, as well as bioenergy combined carbon capture and storage (BECCS), soil sequestration, and 'blue carbon' marine projects.

In this section, we discussed house of quality based on survey results. The survey is conducted using google form. Three concept models are discussed and after pugh matrix analysis final design of device has been selected. The CAD model of device prepared using the SolidWorks.

3.11 Reference

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4 Appendix A

Survey Question	Responses				
Age (year) of respondent	20- 35	36- 55	Above 55		
	45	35	20		
Earning (per month) of respondent	less than 1000	1000- 5000	Above 5000		
	40	40	20		
Do you know about global warming?	Yes	No			
	90	10			
Seriousness about the carbon emission	Highly serious	Not a big issue	Not an issue		
	80	15	5		
Does high concentration of CO2 affects your daily life?	Yes	No	No idea		
	90	2	8		
Do you use any device to purify the air	Yes	No			

	9	91			
Do you want to install a device to capture CO2 at you home?	Yes	No	Not clear		
	74	5	21		
Expected consumption of the electricity	Almost null	Medium	High		
	81	14	5		
Component replacement	Once a month	twice in year	once in year	Never	
	19	36	23	22	
	Minimum →				Max
	1	2	3	4	5
Cost of existing device to purify air	2	2	2	18	76
Affordability of device	25	55	10	9	1
Noise from device	15	70	8	2	5
Size of device	20	45	15	10	10
Problem during device operation	10	15	55	18	2