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Sigrid Brell-Cokcan
Thomas Adams

AUTHORS

Baiyi Guo
Hangtong Liang
Yibo Dong
Aryan Sani Tourtchi
Jingdi Zhang
Yuchen Deng
Alexandre de Oliveira Ferreira
Fidel Gatimu
Omar Abdelaal
Saad Ahmed
Tobias Grüters
Tikva Schumacher
Görkem Can Ertemli
Gizem Erekinci Atlan
Georgi Tsakov

construction robotics
www.cr.rwth-aachen.de

international M.Sc.programme

www.cr.rwth-aachen.de
cr@ip.rwth-aachen.de

Editors:
Univ.-Prof. Dr.-techn. Sigrid Brell-Cokcan
Dr.-Ing. Thomas Adams

RWTH Aachen University
Chair of Individualized Production
Campus-Boulevard 30
52074 Aachen
Germany
www.ip.rwth-aachen.de

Layout:
David Lukert B.Sc.

Original cover:
Lukas Kirner M.Sc.

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RWTH Aachen University
Templergraben 55
52066 Aachen

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ALEXANDRE DE OLIVEIRA FERREIRA, FIDEL GATIMU, OMAR ABDELAAL

DIY Arduino-Based Smart Window Control System for Mitigating Heatwaves and Enhancing Indoor Comfort

ABSTRACT

This research proposes a Do-It-Yourself (DIY) approach to automatically control windows based on moisture, temperature, and CO_2 levels to improve air conditioning. Using an Arduino microcontroller as the main system to send and receive data, the user can control the system in the palm of their hand using a smartphone or other smart device. Therefore, the research proposes a concept to:

- Control the environment and improve life quality.
- Provide the easiest interface for the user.
- Use a DIY approach that is accessible to non-technical people.

In the paper, a survey is conducted to assess the demand for such a system. The results show that there is a high interest in this type of technology. The prototype system was developed and tested, and the results showed that it was able to effectively control the windows based on the environmental conditions.
This research contributes to reducing heatwaves. By facilitating the regulation of window conditions, the system can assist in the reduction of thermal discomfort and the enhancement of quality of life, particularly for the elderly.

Keywords: Arduino; DIY; Smart home; Heatwaves; Window control.

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1. Introduction

In recent years, there has been a noticeable rise in global temperatures, which has had a significant impact on countries around the world. For example, in 2018, Germany experienced its second warmest summer since record keeping began in 1881 [1]. Additionally, research has shown an increasing frequency and intensity of heatwaves which present significant challenges to the well-being of individuals, particular the elderly [2].

It is estimated that between the years 2018 and 2021, approximately 21,000 heat-related deaths occurred in Germany, within a 95% certain range [1]. In order to prevent these deaths, it was proposed that the German government must implement a series of measures, including the introduction of a colour code system to indicate the level of severity of heatwaves and dissemination of information to the elderly people [3].

Despite these measures, additional actions may be necessary, such as providing cooling rooms and free water dispensers [3]. A passive and efficient way to cool down a room is air conditioning by opening windows, reducing the hours when people have thermal discomfort by over 90% [4]. By opening the windows, we can attain several benefits, such as lower energy consumption in buildings, increased comfort and prevention of overheating [5].

When people start to feel that the condition is “too warm”, they increase the number of mechanical devices for cooling down, such as fans and air conditioning [4], increasing energy consumption. In contrast with mechanical devices, IoT devices can consume nearly zero power depending on their configuration [6] and could be used to control when these machines should or should not be turned on, avoiding excessive energy consumption.

This research develops a survey to analyse which smart devices people have at home that could be used as a user interface, and it found that 79% do not have any smart device such as Alexa, Google Home, or HomePod. When compared to German national data where 98,1% of households have a mobile phone and 88,1% have a smartphone [7], there is a huge gap between both.

Projects using a Do-It-Yourself (DIY) methodology have been used to engage people and empower them. Consequently, the popularity of such projects has increased in the past few years. DIY projects encourage the participation of non-technical people, particularly when there is zero coding [8]. Likewise, Arduino, a simpler microcontroller, offers more benefits to hobbyists, students and teachers compared to other brands, thanks to its working procedures [9].

With this data in mind, this research works using a DIY approach and, using Arduino as the main microcontroller, developed a prototype to send and receive data to automatically control the window based on the temperature, CO_2, and moisture, and set health parameters to control the environment by opening or closing the windows. Hence the main objective of this research is:

- Controlling the environment.
- Improve life quality.
- Easiest interface for the user.
- Using a DIY approach.

2. Literature Review

The rise of smart home devices has significantly grown over the past few years. In 2021, it was estimated that the global smart home market was worth $99.41 billion [10]. The US market for smart home technology was worth $79.13 billion. [10] The smart home market worldwide is projected to grow by 11.43% from 2022 to 2028, resulting in a market volume of $231.6 billion in 2028 [11] and in 2023, as many as 63.43 million households were actively using smart home devices in the US which is a 10.2% increase from 2022 [11]. This growth is linked to the rise of voice control and interoperability in the smart home market [13].

Voice-controlled devices, such as smart speakers, are becoming increasingly popular among consumers. Approximately 34% of U.S. citizens use a search-by-voice feature at least once per month [14]. The worldwide transaction value of purchases made through voice assistants on smart-home devices is expected to rise from $22 billion in 2020 to $164 billion in 2025 [14]. The market size for

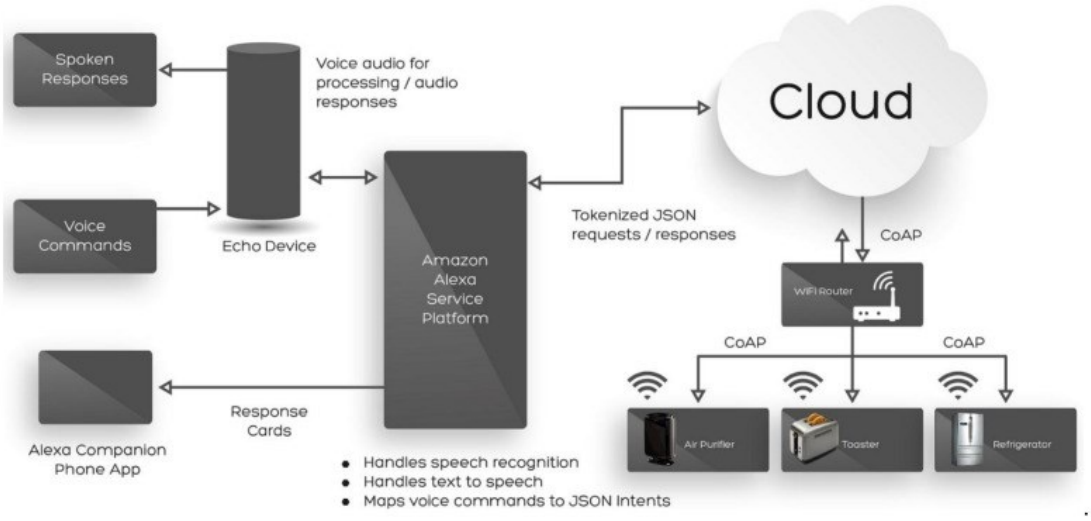

Figure 1: Architecture of Alexa [18]

voice assistants is expected to grow to $99 billion by 2026 [14].

The integration of voice assistants in smart home automation offers hands-free control, allowing users to control various smart devices in their homes without lifting a finger [15]. Companies are developing voice assistants to control smart home devices, with Amazon's Alexa and Google's Google Assistant being prime examples [16]. One of the major benefits of voice-controlled smart home assistants is their ability to integrate with other devices in the home. Once the smart devices are integrated into the home's Wi-Fi network, it is possible to give verbal commands to the assistant to activate the devices [17].

In terms of device usage, nearly 33% of all smart home devices are used for security and lighting [10]. Furthermore, 48% of consumers expressed interest in devices that notify them when a door or window is opened or closed [10].

The integration of IoT services has made smart homes more capable and efficient. IoT capabilities allow smart home devices to communicate with each other and work together to create a remotely controllable network [18]. IoT capabilities also allow smart home devices to be automated, which can save homeowners time and energy.

However there have been concerns about the collection of personal data by voice assistants and storing it. Voice assistants have access to a variety of accounts and passwords making them a potential target for cyberattacks [19]. The security of these devices is crucial, as they have access to sensitive information. There have been data breeches originating from low-quality smart devices such as smart bulbs and locks [20].

Furthermore, there is a high possibility of eavesdropping since voice assistants are always listening for their wake words. This raises the question of the privacy of the conversations within the home or the office. The study by Minder et al. [21], emphasizes the need to address the potential for unauthorized access to voice recordings and the importance of implementing robust security measures to protect user privacy.

Another aspect of concern would be the trustworthiness of voice assistants. In the research [22], it was discussed the need for a reliable voice-based personal assistant. The research also highlighted the challenges associated with voice authentication without an external device. Figure 1 shows the architecture of Alexa.

To address these concerns, there have been various solutions proposed by researchers. [22] suggests the development of voice authentication methods that do not rely on external devices. This would ensure that the security of voice assistants is maintained to the highest integrity.

The use of Telegram in smart home systems has been increasing because of its ease of use and ability to offer secure communication [23]. One of the advantages of using Telegram in smart home systems is its ability to provide instant notification to users [23]. In addition to its control capabilities and ease of use, Telegram also provides secure communication to the user and the smart home system [24].

The number of Telegram downloads has also been on a steady increase from March 2018. Figure 2 below from [25] gives the total number of downloads Telegram has over the course of about 9 years.

The research also reviewed the DIY approach in home projects . DIY projects have gained significant popularity in recent years with a spike in the COVID-19 pandemic [26]. DIY which means "do-it-yourself" encompasses a wide range of activities, from crafting and home improvement to woodworking and electronics [27]. Some of the benefits of DIY projects include cost effectiveness, customization, and learning opportunities [27].

Arduino projects at home have gained popularity because of their versatility, simplicity, and affordability [28]. Arduino, which is an open-source electronics platform, provides a user-friendly interface for creating interactive software and hardware projects [29]. The versatility of Arduino makes it suitable for both beginners and advanced people by providing them with limitless possibilities for project development [28].

3. Research Methods

The project of this paper entails the construction of a smart DIY way to control the atmosphere of your home environment using of the smart devices already owned. The research steps involved in our research are as follows:

3.1 Surveys

We carried out a survey to get feedback of people on what they would want to see improved with the existing sensors in their houses. We also got to ask them what extra features they would want to see incorporated in their homes and the types of devices they would prefer as their user interface. With over a hundred responses some of the questions we sought to find out were the following:

The age of our respondents. We sought to find the most diverse age group among our respondents to see if there would be any discrepancies in their preferences.

Another important question was whether the respondents owned any smart devices in their homes. This was an important question for us because we needed to figure out which is the best technology to develop our project on to reach the maximum number of users while still maintaining the relevance. The final important question to shape our research direction was what type of sensors the respondents would love to see in their devices. Using these questions and the rest from the survey we got a direction for our research.

3.2 Prototype development

The next step was the prototype development using the insights we got from the literature review and the survey. The features we sought to implement on our prototype were as follows:

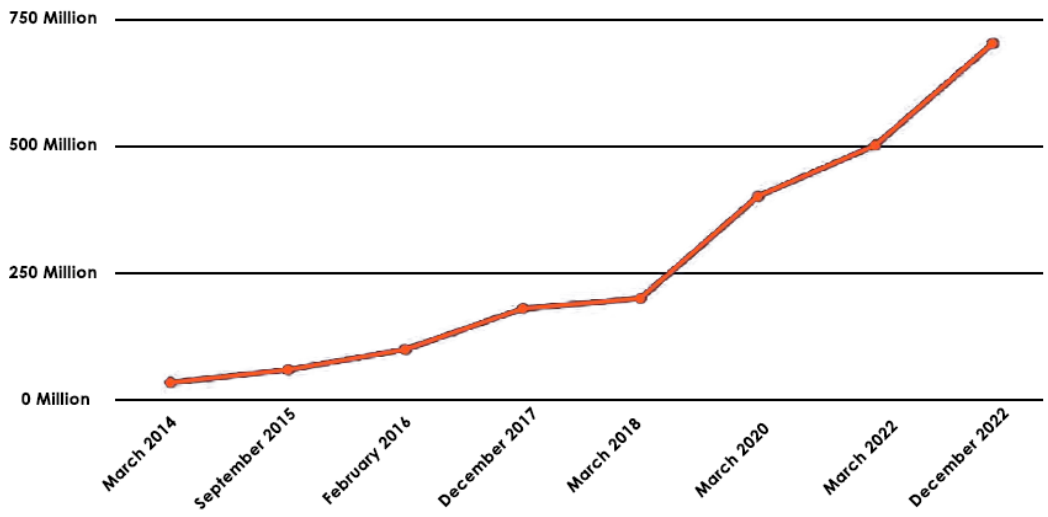

Figure 2: Number of Telegram downloads globally [21]

- DIY approach – this approach was chosen as it engages the people and keeps them invested in the product. This concept is elaborated further in the introduction.
- We incorporated heat, humidity and temperature sensors in our prototype but also ensured the technology we used was scalable and people could customize it as they wished.
- Real time detailed weather updates – at the click of a button the user can get detailed weather updates on their city and this information determines what the sensors do.

User friendly interface – by using a telegram chatbot system, the user can easily get the weather updates, the status of the window and control the mechanism of opening and closing the window. Telegram was selected because it has a public opensource API in comparison to WhatsApp.

According to [30] the number of smart households globally is also steadily increasing over time. As seen in Figure 3 below, over the next 3 years, there is a steady increase in the number of smart households globally and a potential need for a solution that incorporates Telegram.

The following technologies were used to develop the prototype:

- Tinker cad.
- Arduino.
- Telegram API.
- C++.

3.3 Constant feedback on our prototype in the development phase

All through the development of our prototype we were able to get feedback and insights from experts in the form of colloquiums organized at the RWTH Aachen University. We presented the findings and progress in the form of presentations and demonstrations and were able to get feedback and areas to improve and this was helpful in the final development.

Another way to get feedback on our prototype development phase was the failure fast technique. This is an essential aspect of the agile methodology. It encourages teams to quickly identify and recover from failures to enable the process of rapid learning and improvement. So, in the development of our prototype, we worked on small, manageable tasks and delivering a working solution at regular intervals. Using this technique, we were able to test and validate potential areas

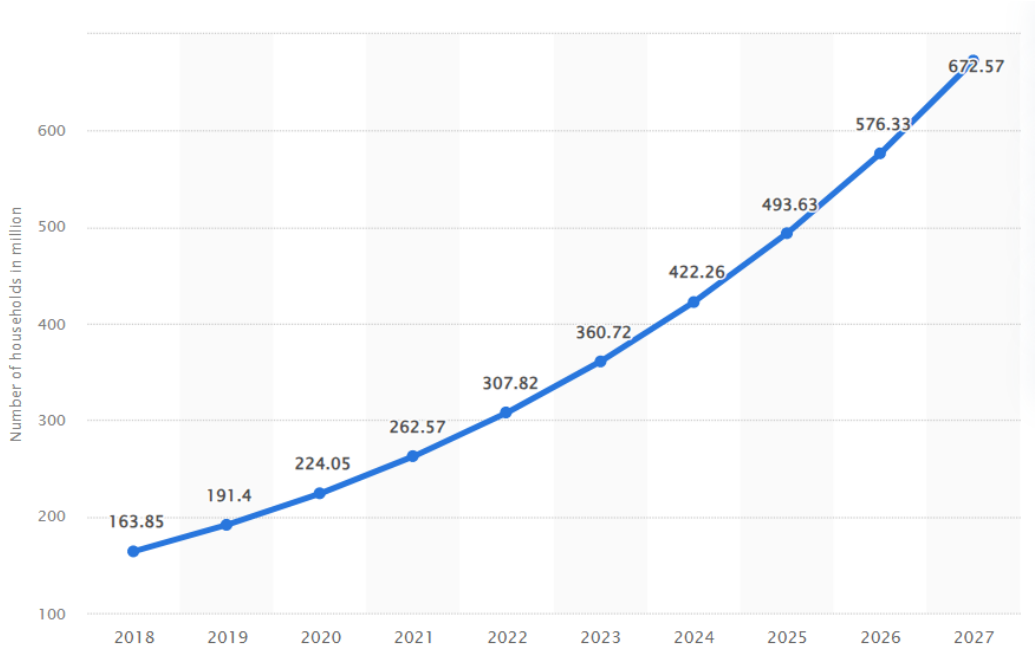

Figure 3: Number of global households with smart devices [26]

where we might fail as soon as possible and try to solve the problem. If it was impossible, we pivoted the idea and found a way to work around the problems.

4. Demonstration sample

To demonstrate this project idea was developed a prototype based on the premise set before, controlling the environment, improving the life quality, an easy interface to the user and have a DIY approach.

The next section will describe in more detail the concept development, the prototype development and finally the prototype presentation. Each part has its value to the outcomes this project had obtained.

Concept development was important for understanding the project needs and how to approach each obstacle with some theoretical background. Meanwhile, prototype development was crucial for producing and collecting data from the sensors, and understanding and addressing any peculiarities they may have. Furthermore, prototype presentation was essential to fit every part together and conduct a final inspection before its public release

4.1 Concept development

Using an Agile methodology to develop every stage, and employing a fail-fast approach, the goal was to fail as fast as possible so that, once unsuccessful, the project could try a different approach and not perpetuate the mistake. Keeping that in mind, the project was named “Airsync: smart air control”, as seen in Figure 4, a clean and simple logo.

The concept of Airsync starts with an idea, and this idea has four main goals: controlling the environment, improve life quality, easiest interface for the user and using a DIY approach.

Regarding environment control, it was decided to use a system able to control and communicate with other smart devices in the Airsync owner’s home, especially the opening and closing mechanisms for windows. Once this communication was established, Airsync will be able to control the moisture, temperature, and CO_2 levels by open or closing the windows according to the parameters pre-determined during the literature review.

Concerning improving life quality, AirSync will help control the environment, so people have a more comfortable atmosphere, avoiding overheating when the temperature increases and communicating to the windows the best hours to open during the day for cooling the rooms. Likewise, if the CO_2 level reaches an unhealthy baseline, AirSync will take action. Furthermore, once the room cools too much, the prototype will also send a closing message to the window to save energy.

To keep it easy for the user, it was decided to use Telegram as the platform for communication between user and Airsync. Each Airsync will have its own conversation in telegram, where the user can send or click into the desired commands.

Airsync’s last main goal was a DIY approach. To achieve this, it was decided to use Arduino microcontrollers to provide all the sensors and boards necessary to build. To start understanding which sensors and boards would be needed, a digital twin was developed using the Tinkercad platform. A platform provided by Autodesk and helps to build digital twins.

In Figure 5, the first sketch of the prototype in Tinkercad can be observed [31], showing a 2 boards system, a fan with a motor, a LCD screen, a temperature, moisture and gas sensor.

Going a little deeper in the explanation, we can note how Airsync works as shown in Figure 6. Airsync has two main functions: sensors analysis and communication. Each sensor was set with a parameter to open or close the window while the communication will be held on telegram.

Airsync was coded in C++, the Arduino programming language.

Figure 4: Logo

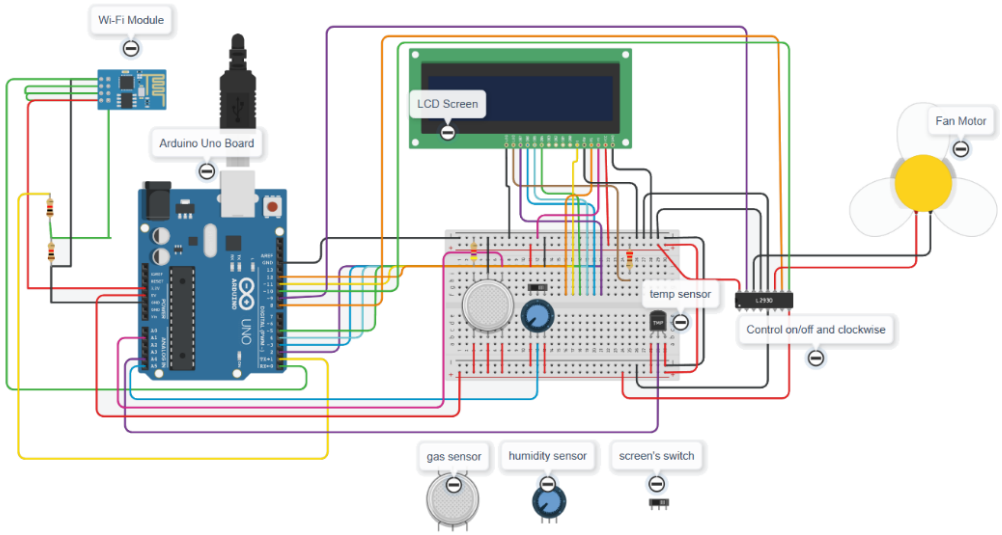

Figure 5: Prototype Sketch

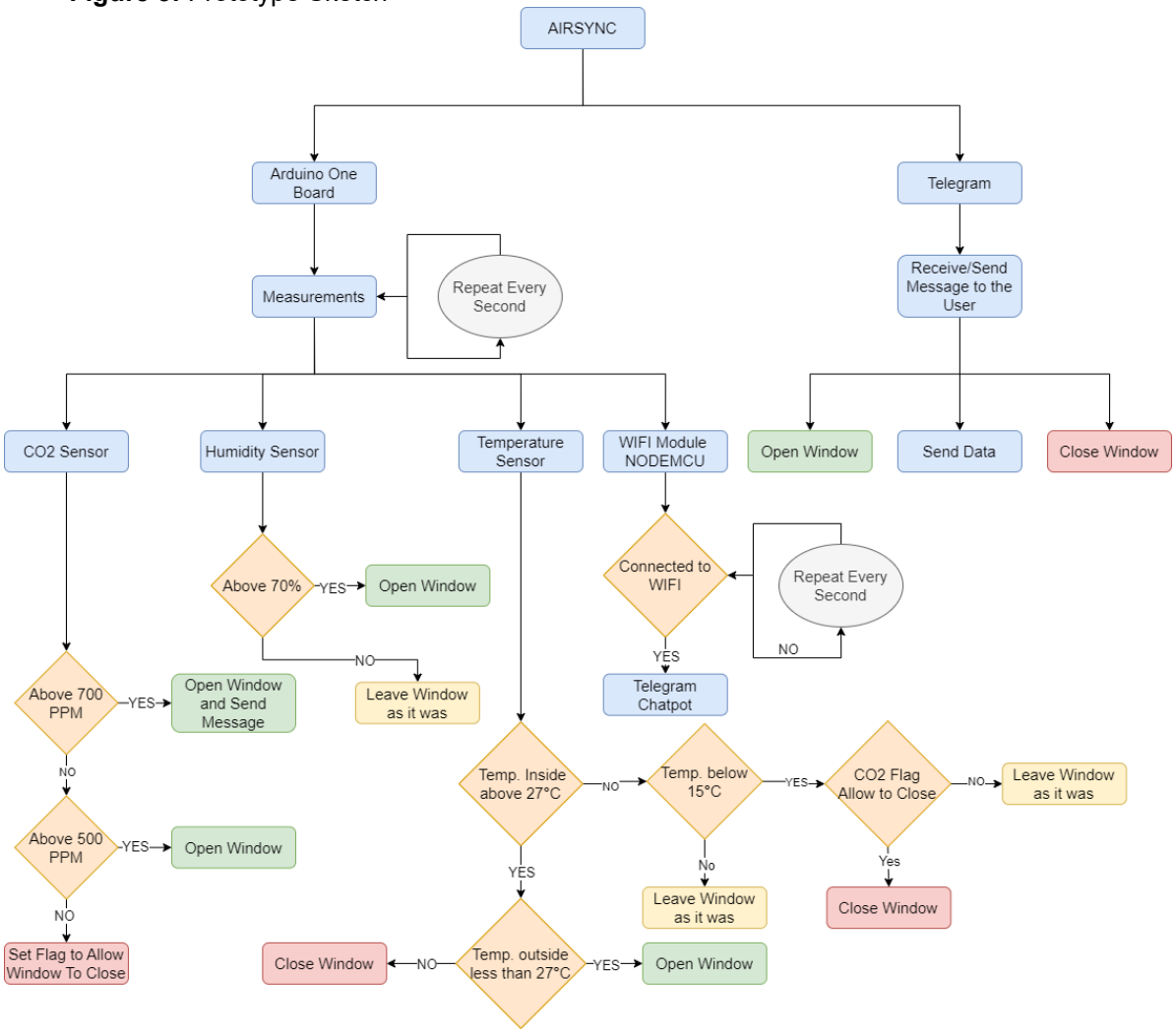

Figure 6: Airsync workflow

To upload the code Arduino IDE was used, Arduino Software which can be used to code and upload the code into the boards.

The Arduino One board was responsible for receiving all data from the sensors and sending it to the NodeMCU board. The NodeMCU board is responsible for the connection with the Wi-Fi. Hence it is accountable for the user communication using

telegram and the communication with the window.

To build the prototype, 5 different Tinkercad projects was used as guidance. One to develop the motor which represent the fan [32], a different to connect to the Wi Fi using a Wi-Fi module esp8266 [33], for the sensors, it was used one for the Gas sensor [34] while for the humidity and moisture was used a DHT11 sensor simulator [35], and our least

4.2 Prototype development

In summary, as can be seen in Figure 5, the project used for guidance was to implement an LCD display [36].

After building this first digital twin [31], shown in the Figure 7, It was examined that there were too many spare parts, and some of them were unnecessary, such as the LCD screen. Consequently, some parts were removed from the prototype as can be seen in Figure 8. Hence, to build the prototype, only the following components are necessary:

- Arduino One.
- NodeMCU board.
- CO_2 gas sensor.
- DHT11 sensor.
- Jump wires.
- Resistors, one with 1 ohm and other with 200 ohm.
- USB cables for the Arduino One and NodeMCU connection
- Breadboard

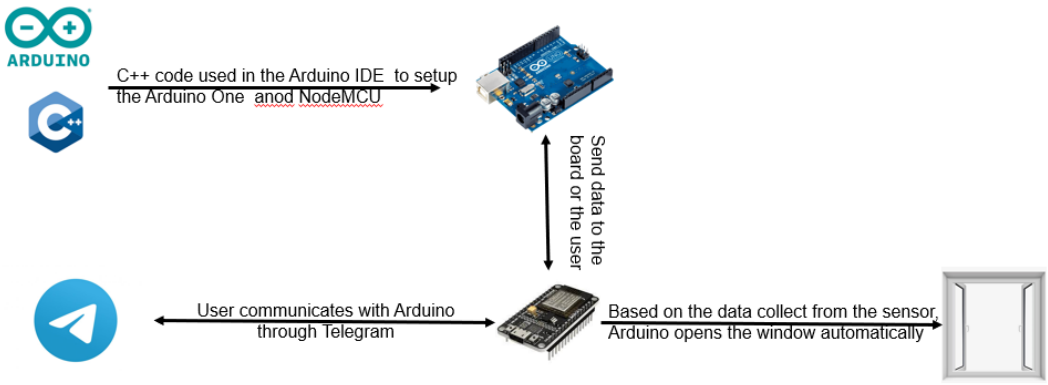

Figure 7: Airsync schematics

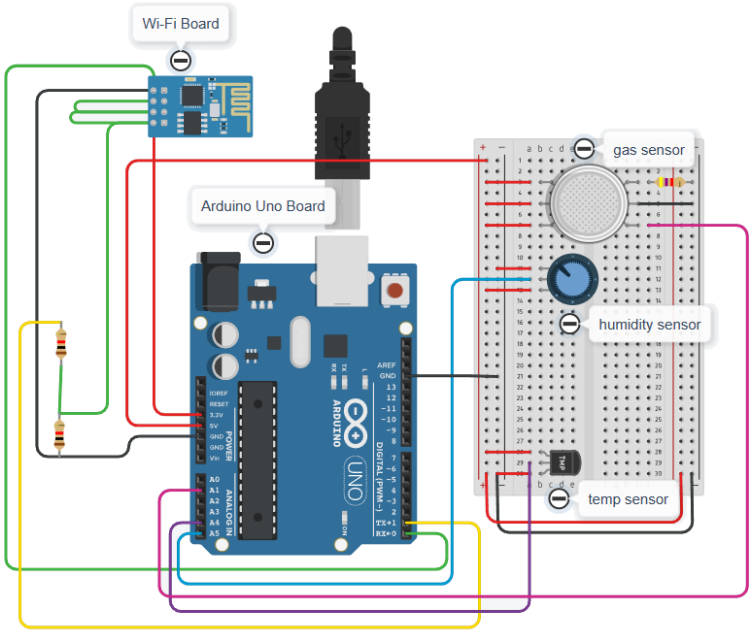

Figure 8: Second digital twin

The jump wire schematics and the code to be used in the Arduino One and in the NodeMCU board are available at Tinkercad under the name of Stunning Migelo-Allis (tinkercad.com).

In the Tinkercad digital twin, the NodeMCU is represented by the ESP8266 board, while the DTH11 are represented by the union of a temperature resistor and a potentiometer

together, whereas the CO_2 sensor is represented by a gas sensor.

To communicate with telegram the first step is downloading the app and starting a conversation with chatbot called BotFather, as the logo can be seen in Figure 9. BotFather is a chatbot from telegram responsible for anyone creating a new chatbot. Once the user follows the 4 simple steps to create the bot, BotFather will give a token to be used into the NodeMCU code.

Once the token, Wi-Fi name and password are updated into the NodeMCU, the user will be able to communicate and receive the data from the environment where the prototype is located as can be seen in Figure 9.By touching the desired request, a message will be sent to NodeMCU which will be responsible for collecting the data from Arduino One and sending it back to the person who sent the request.

To build the case to fit the prototype a 3D model [37] available online was used as base. Once downloaded, it was modified to add two places to hold a screw and scale-up. As soon as the digital model was finished, a 3D printer was used to print in the 2 pieces for the case.

After the 3D print was done, the prototype entered the final stage of assembling. Therefore, it would be necessary to add the boards, with the sensors, the breadboard with the jump wires inside the case. Consequently, it would also be necessary to add a 9V battery to run the boards without the USB cables.

4.3 Prototype demonstration

As the the prototype developed, Airsync stared to take shape. The user can see the Airsync final version, how it is going to look in the end. Moreover in Figure 11, it can be seen how it is going to look inside.

Figure 9: Telegram chat

Figure 10: Airsync cover

Figure 11: Inside the Airsync

The green light in Figure 10, shows that the Arduino board is oand working. While in the Figure 11 can be noticed the Arduino one in the bottom, the battery in the top, in the middle, the NodeMCU board, while the sensors are in the left.

The results were shown in the form of a video and can be watched on YouTube. First video can be watched in the link [48] , in this video you can see the fan, which represents the window, turning on for 5 seconds when the moisture got a value above the parameters. Likewise, it is expected when the temperature goes above 27º C or below 15º, or the CO_2 goes above 500 ppm.

Furthermore, once the fan turns on, which represents closing or opening the window, it automatically sends a message to the user notifying them. The second video can be watched in the link https://youtube.com/shorts/mSYo9rFNJaY?feature=share , this movie shows the interaction between the user and the Airsync through the telegram interface.

By clicking or typing the commands the user can ask for the temperature, the CO_2 levels or moisture levels. Besides that, the handler, can ask for windows status, or request to open or close the windows. Since all the interactions happen in the telegram, the user does not need to be in the same Wi-Fi or even in the same place.

Regarding the data security, each Airsync will have its own bot inside telegram. Accordingly the data collect by the Airsync it is only saved in the conversation. Hence, once the conversation is deleted, all data collected from that environment is also deleted.

5. Scientific Results and Discussions

As a result, after conducting the aforementioned literature review and research methods to implement and gather credible data. The most useful research method was a survey with multiple questions to have an overall view of the user's needs and knowledge about smart homes.

With over 100 answers, the questions in the survey were decisive enough to identify the problems of our targeted audience, their needs, and which gadgets they already have at home, so the prototype could be integrated among them. Besides, the survey results helped to confirm some assumptions from the literature review. As shown in Figure 12, only 21% have a smart control device, whereas 79% do not have any smart control device at home. With these results, it was clear that about 80% of the participants did not integrate any smart home devices at their homes, so this is a huge potential market for Airsync, since Airsync does not require a smart device for installation or to fully function. After receiving the responses of the first question of the survey, the second question was regarding what sensors would be preferred to have installed at their home. There were different responses regarding this question, but as shown in Figure 13, the most requested sensor was the temperature sensor.

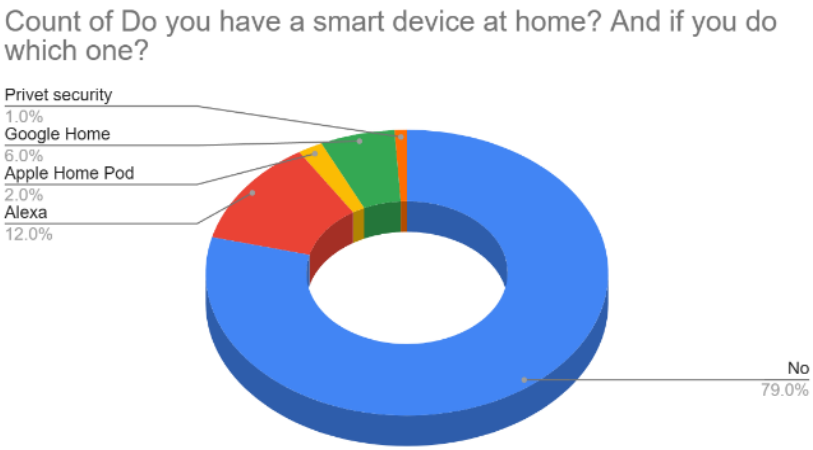

Figure 12: Is there a smart device at home survey answer

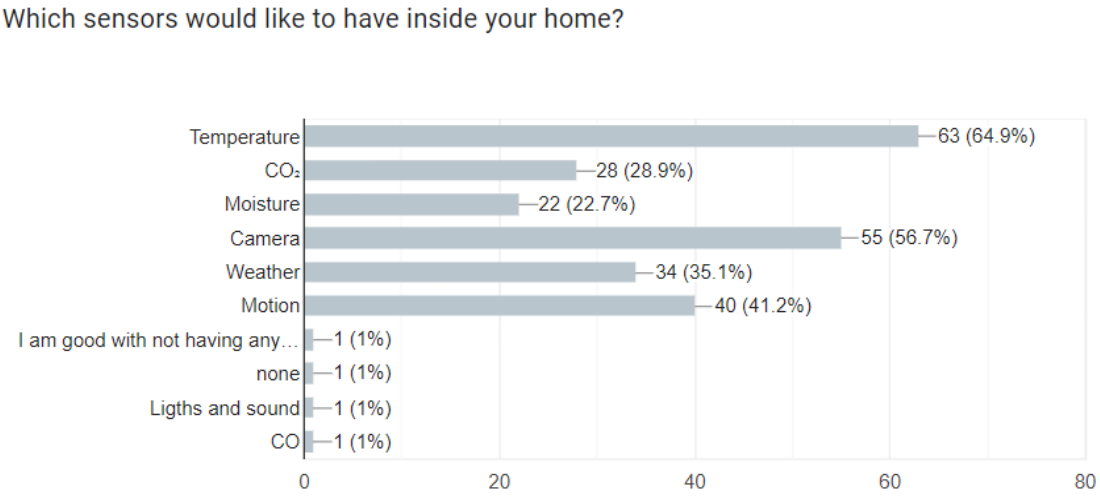

Figure 13: What type of sensor survey answer

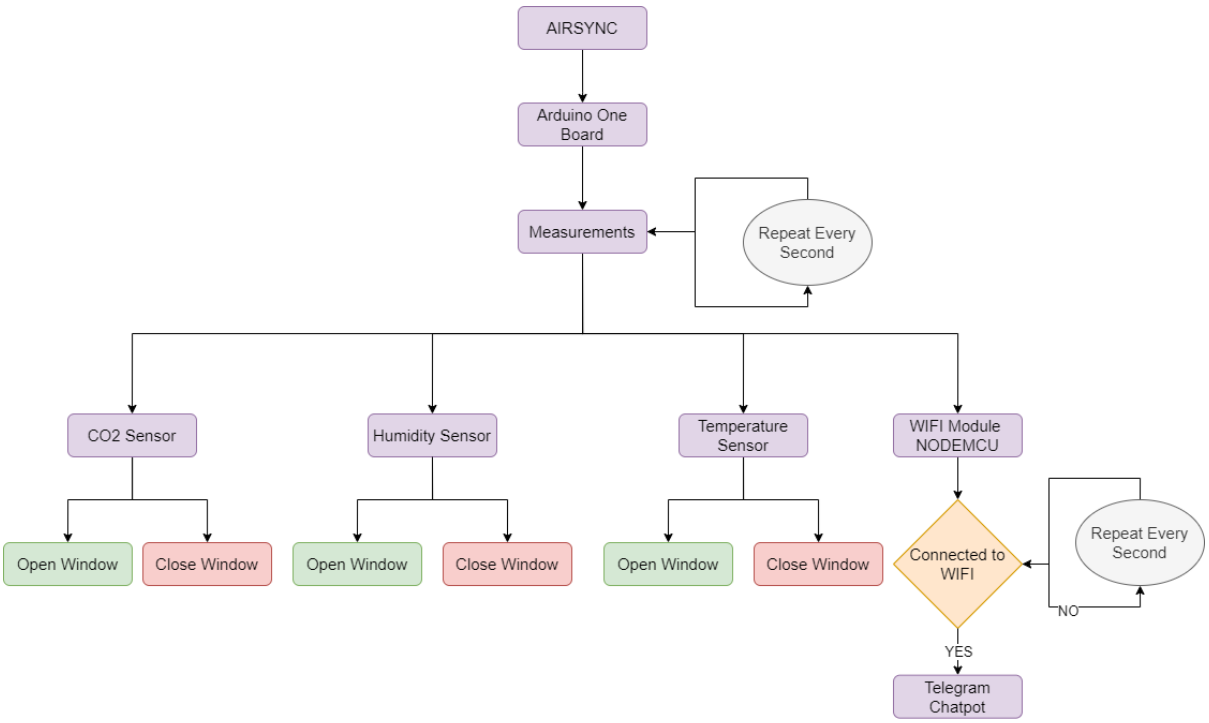

Figure 14: Airsync simplified workflow

With these results, as shown in Figure 13, it was clear that the most preferred and requested sensor is the temperature sensor. The second preferred sensor is a camera which was assumed to be a great addition to Airsync. The weather, motion, Co2, and moisture (humidity) sensors were also demanded by the participants. All the participants, except one participant, prefer to have sensors installed at their home. After receiving the previous responses, the third

question that was in the same survey was regarding whether a user would prefer to be informed about when the most suitable time is to open the windows or not. As shown in Figure 15, about 80% prefer to be informed.

With these results, most of the participants cannot determine when the weather would be suitable for them, so the participants would prefer to receive the information of the most suitable time for opening the windows.

Following the previous results, the next question was the automatic opening of the windows after receiving the information about the weather from smart device. As shown below in Figure 16, also the majority about

70% would prefer the automation of opening and closing the windows.

Following these results, it can be assumed that the participants would prefer an automated control over their windows especially when it comes to the weather. The correlation between the results from Figure 15 and Figure 16 shows that the idea of Airsync is highly demanded by the participants for a better smart control over their homes.

After conducting the previous survey, the development phase started. The Arduino One board is responsible for receiving all data from the sensors and sending it to the NodeMCU board. The NodeMCU board is responsible for the connection with the Wi-Fi. Then, the user accesses the telegram Chatbot to communicate between the Arduino one board and the windows. As shown in Figure 14 a simple connection workflow between the components.

The sensors are one of the key components for Airsync. The sensors are actively working in Airsync without fail, and they keep on getting the readings to send the data gathered to the Arduino one board which then opens or closes the windows. Not only are the sensors working automatically for the Arduino one board, but they can also show the readings precisely if requested by the user through telegram at any time as shown in Figure 19.

The connections between Arduino one board and node MCU are reliable enough and can even have more sensors added to the current ones without compromising the integrity of the results. The Arduino one board

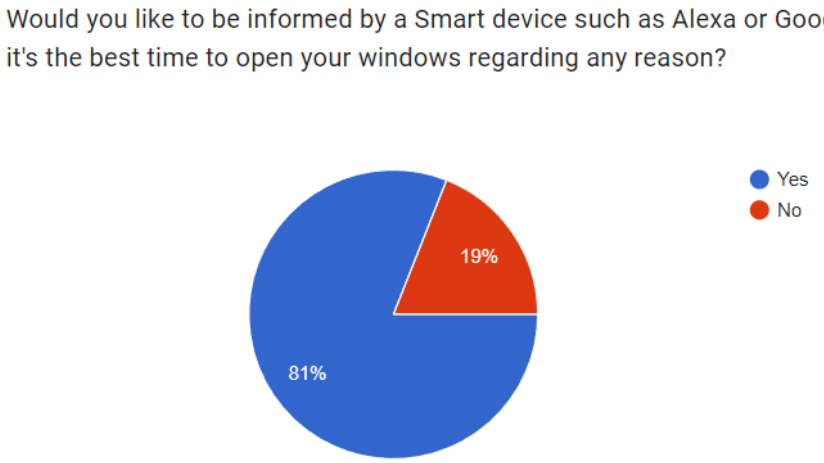

Figure 15: Informed about suitable time to open the windows.

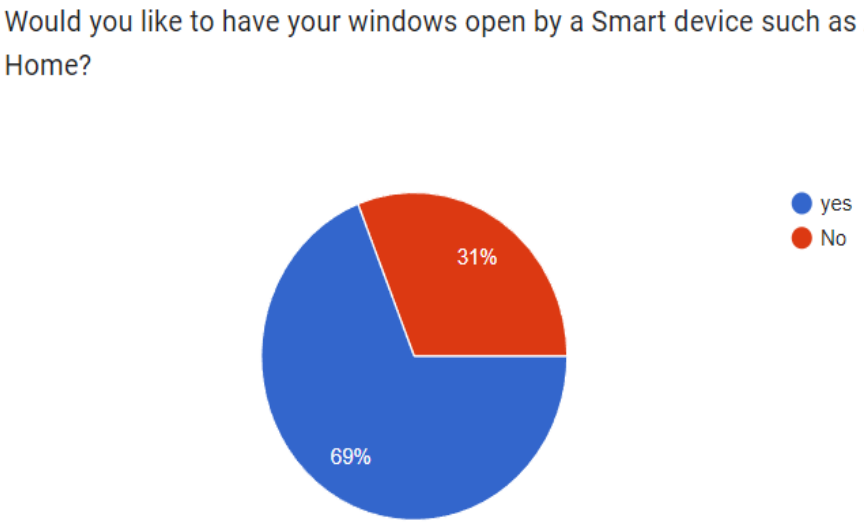

Figure 16: Automatic opening and closing of the windows

Figure 17: QR Code

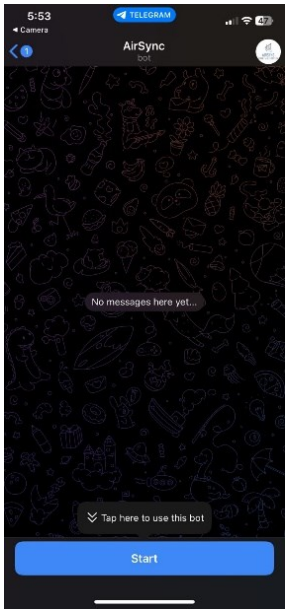

Figure 18: Start Menu

Figure 19: Telegram Chatbot

and NodeMCU are widely used in a lot of products, so depending on them will give Airsync a good start to meet the user's expectations.

After conducting the survey and analyzing the results, the decision on which online platform interface to use for the communication between the users and Airsync had to be decided. Due to the limitations that were faced from Alexa, Telegram was the next suitable online interface to use for Airsync.

The decision of using Telegram instead of Alexa was based on Telegram's user friendliness. Each Airsync product contains its own unique QR code as shown in Figure 17 to access the telegram chatbot connected to the bought Airsync. After accessing the Chatbot, the user will be able to start and communicate with Arduino one to give commands as shown in Figure 18. The users will be able to choose what kind of request they would like to have by clicking on it as shown in Figure 19.

It is assumed that telegram is easily installed and used since it has a similar interface to the typical social applications that are used nowadays. The use of telegram will allow a higher reach to users since it is free to install and can be accessed by all users. If the user is not used to Alexa or does not want to pay for it, the free telegram app is the key to a smart home experience with Airsync.

After reviewing the mentioned above results, Airsync was developed and built based on the users' needs and demands to achieve a convenient level of satisfaction from the users when trying to upgrade to live the experience of the smart homes.

The main objectives and goals which were controlling the environment, improving life quality, easy user interface, and using a DIY approach were successfully achieved by the Airsync product that was built and designed.

6. Conclusion

In conclusion, the DIY approach was successfully achieved with the Airsync technology that was introduced in this research. The limitation of the use of Alexa was avoided by using the telegram as the user interface for communication purposes. Airsync was able to determine the CO2 level, humidity, and temperature in the surrounding and open the windows automatically if any of these conditions exceed the allowed or comforting level to lower the CO2 level, humidity, or temperature in the room.

The survey that was conducted was an efficient way to define the most suitable or preferred features and approaches for Airsync depending on the user's needs. The majority the responses received were supporting the idea of having and automated window opening system to install at their homes. The

sensors implemented in Airsync satisfies the needs of the users for their home installation.

Airsync future improvements:

- Improve Airsync components organization: The components need to be organized better for easy repair in case of malfunction and not to have any component affect another component negatively.
- Scalability: Airsync measures the CO2 level, humidity, and temperature for now. The addition of more sensors like a camera or motion sensor will help in the propagation of Airsync based on the survey's participants.
- Integration with Smart Home Systems: The use of telegram as the user interface is the convenient step for now, but the integration of Alexa would even make Airsync more well known and desired by the users.
- Automatic Window Opening Mechanism: The implementation and design for the windows mechanism hardware are needed to be able to introduce a complete product with Airsync as the main product and the mechanism as the physical attribute for automatic window opening.

The idea of the DIY approach was highly desired and will be integrated into the majority future smart homes. With the addition of the newly intended improvements, the demand on Airsync will be higher for a better chance of success.

7. References

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