Smart RVAC Project

Francisco Martinez, Sergio Perez, and Claudio Afonso

Dept. of Electrical Engineering and Computer Science, University of Central Florida, Orlando, Florida, 32816-2450

***Abstract* — This project will expand and serve customers who are interested in monitoring the health and preservation of their RV's AC system with an easy to use a mobile app to interface with. The AC system has four critical parts: The evaporator, condenser, compressor and its fans. To be able to assess the RV AC system we needed to measure the temperatures of the condenser and evaporator. That way we can see the desired temperatures of normal operation and when it fails. Fourier Analysis was implemented on both vibration and current usage on the fan and compressor lines.**

***Index Terms* — Ceramics, coaxial resonators, delay filters, delay-lines, power amplifiers.**

I. Introduction

Traveling in an RV can be one of the best experiences in the world, especially traveling with family or loved ones. However, the fun can come screeching to a halt if the RV's AC system breaks down. For this project design, a device monitor will hook up to an RV's AC system. This device will provide real-time monitoring to allow the user to effortlessly find points of failure in the unit in case of any system malfunction. This real-time monitoring will consist of key performance statistics of the AC, overall health, and data on temperature, voltage, power consumption, and vibrations felt through the system. Besides monitoring, the device will also provide real-time control, thus allowing the user to remotely operate the AC unit. Both operations of the device will be displayed to the user through the use of an user-friendly web application. This application will be converted into native mobile application, thus utilizing the Bluetooth hardware accessory of a cellphone to communicate with the device.

In this project, there will be three critical points in the structure of the design, two being software and the last electrical. The data gathering obtained from the sensors will be transmitted across the various locations on the AC unit to the microprocessor. The microprocessor will then interpret, calculate any derivations and algorithms and send that data to the Amazon Web Server (AWS) over an internet connection.

In the first block, we have the electrical side where the microprocessor must read data points from sensors placed on the AC unit. The AC unit itself is a very electrically noisy environment made so by the fan and the compressor by the physical characteristic of superposition. Therefore, the decision was made to use the RS-485 standard because of the standard's immunity to electromagnetic interference. That data will be passed along through, the now resilient, communication lines and directed to the microprocessor.

The MCU have two routes to send data out to the server, one the route is thru WIFI and the second is sending the data to the mobile app using the Bluetooth low energy protocol, latest one been the prefer route. The Bluetooth stack provides several formats to transmit data one of the streaming modes (SM) that utilizes the L2CAP. It easy to implement but a drawback is that it does not offer data reliability. The first step to establish a connection is to start the service discovery protocol (SDP) and decide which Bluetooth profile to use. The SDP profile is identified by the Universally Unique Identifier (UUID) that tells what the device connecting behavior. The first time the Bluetooth communication is use it must go thru the pairing and bonding process. One way the pairing can be achieve is using the secure simple pairing (SSP) utilizing the just works method for a device with limited input output capability and require very little user interaction. Once the device is paired is bonded and saved in listed of trusted devices. Every time the devices are closed it looks at the bonded list to see if there and complete the handshake. The data is sent to the phone and is prepared to send to the server or if need it to alert the user of about the AC.

The other way the MCU sends data is using a WIFI network. The device must implement TCP/IP to communicate over the internet with the server. When the user setup the account it provided the mac address or serial number. When the device authenticate it does so by using it mac address or serial numbers since this are unique and have been register to a user the server knows which user data it is receiving. If a device has not been registered the session is not initialized. When the connection has been established or denied the server send back a message to let device know the next steps. Is the connection being establish the device starts sending data until it determines is done and send a message to terminate the session.

II. Background

The most standard, common way an air conditioner works is using two physical concepts: the relationship of pressure and temperature and the phase of state changes in certain types of chemicals. When a liquid turn into a gas, it takes heat away from its environment and vice versa when the gas reverts to a liquid. AC systems take advantage of endothermic reactions caused by this phase change. AC systems take a refrigerant pumped inside a metal tubing and change the pressure inside the tubing using a compressor. AC systems indirectly control temperature inside the tubing using pressure by using the property, founded by Gay-Lussac, where pressure is proportional to temperature.

The standard chemical used in these AC systems is R-410A or R-22 refrigerants. R-22 Refrigerants are now an outdated refrigerant due to its effect on depleting the ozone layer but are still found in antiquated systems. These refrigerants are special because their boiling points and condensation points are designed so that the pressure needed to hit those points are within the capabilities of modern compressors.

The compressor causes the pressure to rise in the evaporator which will cause an increase in temperature in the coil lines. Heat will be taken from its surroundings because of the phase change. The expansion valve in the next part of the system will inhibit the pressure and cause the temperature to decrease. This will cause a reverse reaction in the environment and dispel heat. The fans across the evaporator and condenser will channel both the unwanted hot air outside and the cool air through the air ducts to the RV.

III. AC Unit Critical Failure Points

An important point of failure is the health of the compressor. The compressor is the heart of the AC system and can a costly blow when it breaks down. That is why two important data points were considered when analyzing the compressor's health: current consumption and vibration. The current consumption can be analyzed over time using a Fourier analysis as well as the vibration running through the compressor. Through the life cycle of the compressor, there will be certain harmonics that the compressor will show in its life. Using a Fourier analysis, we can visualize the different stages as the compressor deteriorates in health. For instance, the compressor will show a different harmonic in a year's usage compared to when it first started to work. It can also show a defining change in output current when the system starts to lose refrigerant and must start working hard to pressurize the gas. In conjunction with the current data we can also see immediate effects with the temperature sensors applied to the evaporator, condenser and expansion valve. When one part of the system starts to fail, symptoms will point to what is causing the issue. For instance, the compressor can be working fine, and all the pressure is normal but if the fans are failing, we will be able to see current variances in the current data measurements on the fan lines and check the airflow sensor to see if the flow is correct.

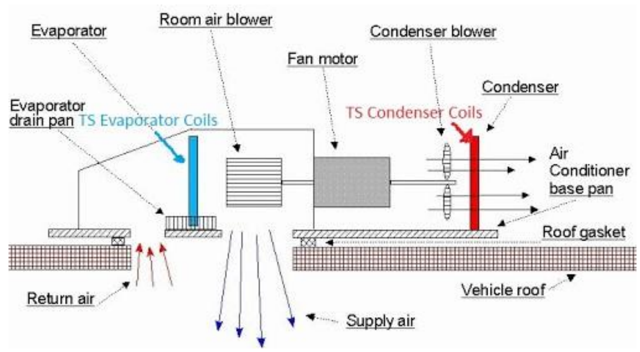


Fig. 1. Estimated Recreational vehicle air conditioning unit diagram with highlighted critical points of an AC system.

IV. Discrete Fourier Series

The Fourier Series can essentially be explained as a breakdown of a time domain signal and represent that signal with the summation of infinitesimal sinusoidal waves. These sinusoidal waves can be broken down into different spectrums of frequencies. Recurring patterns in the signal can be observed and analyze what is the dominant frequency of the signal. For instance, a perfect 1kHz sine wave will have a spike at the 1 kHz frequency bin in the frequency domain. The Fourier series can be explained in this great analogy explained by “”, the light coming from the sun is white light but can be separated using a prism. When the prism is used, the spectrum of the rainbow appears. The different colors of the rainbow are different frequency of light but together can make the white light from the sun. The Fourier series gives a powerful insight on the periodicity of the signal being analyzed.

A. Discrete Fourier Transform/Fast Fourier Transform

Since the board is using a microcontroller, it will be taking data in a discrete manner at a certain, consistent time. Because of this, the method of doing a continuous time signal analysis is not practical and the Fast Fourier transform is needed on the application side of the software to processes the data and both display to the user and alert to any changes. This strategy of using the discrete Fourier transform is documented well in a research project to detect faults in compressors. The take the mechanical functions of the compressor to deduce that any faults occurring in the compressor will appear in the mechanical integrity of the compressor and affect its output. This output factor will also show up in the frequency domain because the vibrations of the parts in the compressor will appear periodic due to the mechanical design of the compressor. Both mechanical (accelerometer) and electrical (power monitoring device) sensors.

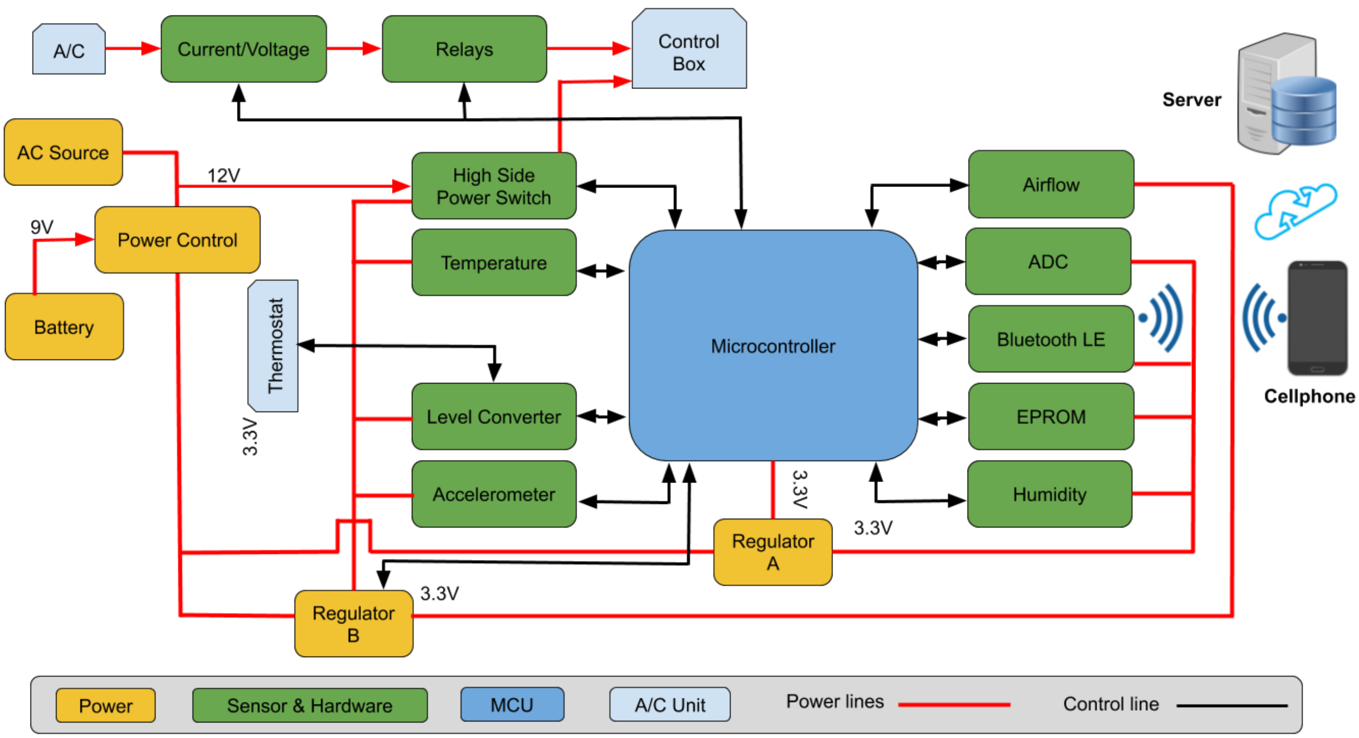


Fig. 2. Hardware System Block Diagram.

IV. System Components

The system is composed of different components that were purchased and some design that composed the final product. This section goes over the components to provide an introduction of them. paper for specific situations.

A. Microcontroller

The brain of the system is the Cypress PSoC 4, model CYBLE-012011-00. This PSoC have an ARM M0 core that runs at 48 Mhz, 2 op amps, a 12 Bit SAR ADCs at 1 Msps, 2 DACs, 4 comparators, 128 Kb Flash, 16 Kb SRam, 2 serial blocks for I2C,I2S, SPI and UART, BLE chip, the BLE antenna is pcb trace, RTC and 23 GPIOs. This PSoC offers all the characteristics the project requires. PSoC Creator IDE is used to write the code for the project and the KitProg CY8CKIT-043 with the PSoC Programmer is used to program the microcontroller.

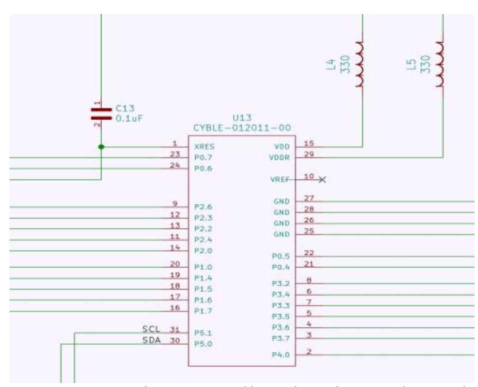


Fig. 3. Cypress's microcontroller that is used on the board with BLE capability.

B. Power Monitor

To monitor the voltage, current and frequency that the compressor, fan and "   " are operating the project uses a power monitoring IC from Microchip, model MCP39F521. this shows the unit function and the degradation of the components over time.

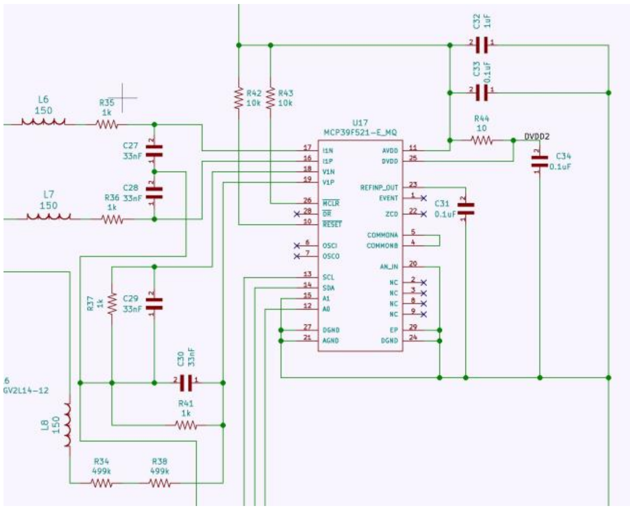


Fig. 4. Microchip's power monitor device that reads the voltages of a shunt resistor.

C. Humidity

The humidity sensor is used to monitor the relative humidity inside the RV. The American Society of Heating, Refrigeration, and Air-Conditioning (ASHRAE) recommends that the humidity level should be around 20 to 50 percent for both human comfort and minimizing the risk of mold, bacteria, and disease to grow since those listed like to thrive in humid environments. An increase of the humidity while the A/C is on is an indication that he unit evaporator is not working correctly. the sensor use is from Silicon Labs, model Si7006-A20.

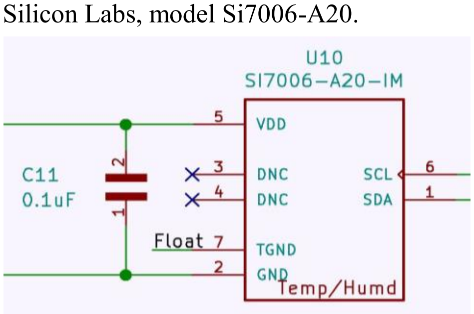


Fig. 5. Silicon Lab's Temperature and Humidity Sensor.

D. Temperature

Two I2C temperature sensors are used to measure ambient temperature and measure the expansion valve, evaporator and condenser. Measuring the difference on return air coming from the inside, and the air being supplied by the evaporator let the device see if the evaporator is working correctly. The difference in temperature should be within 20 deg Celsius or 68 deg Fahrenheit. Another measurement point is on the condenser side, the temperature sensors should be placed on the exhaust of the fan, and another on the outside to read the heat exchange between the two. The temperatures should have a differential where the condenser heat is being transferred to the cooler air on the outside. If the differential is too small, then there may be a problem of too low refrigerant. The sensors are from Texas Instruments, models TMP431 and TMP 432.

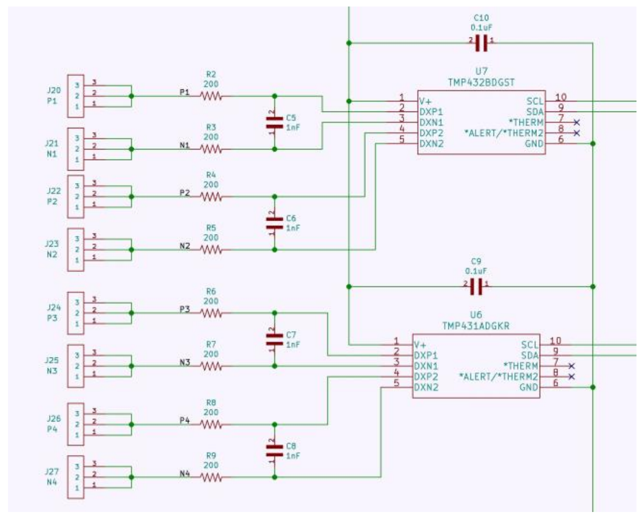


Fig. 6. Texas Instrument's remote and local temperature sensors.

E. Level Shifter

The level shifter is used to read the thermostat input from the user. The Texas Instruments level shifter, model CD4504BM96 provides those inputs and the product acts upon those commands and sends the values to the mobile application.

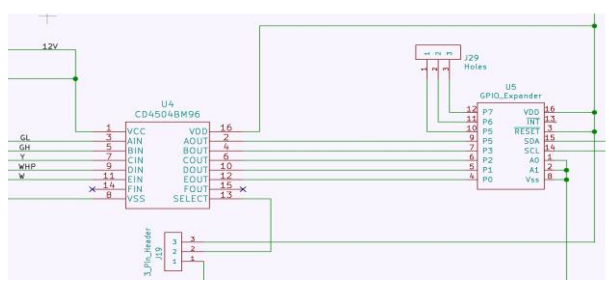


Fig. 7. Level shifter that reads the thermostat's 12V lines and outputs a safe 3.3V signal to the GPIO expander.

F. Relays

Three relays from TE Connectivity, model T9GV2L14, are used to control the compressor, high fan and low fan of the A/C unit. These relays let the user run tests and provide the way for the mobile app to work as a thermostat. A snubber is used at the coil side of the relays to avoid any feedback loop that might cause a problem.

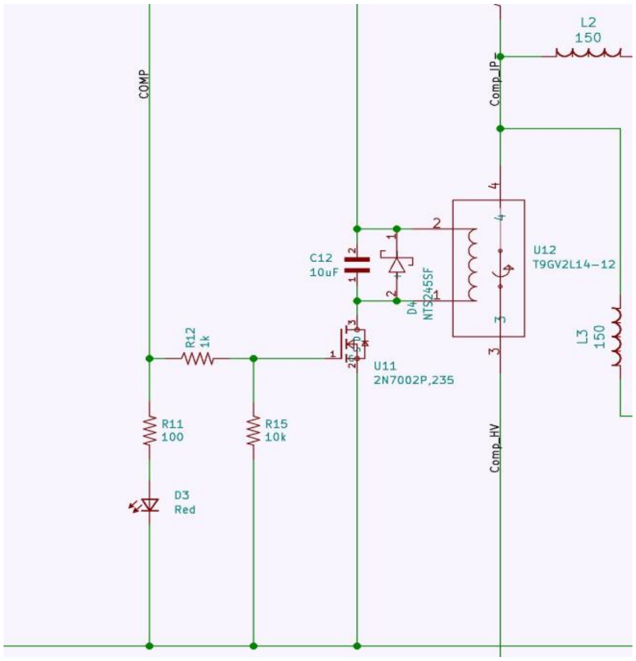


Fig. 8. One of the relay devices that controls the continuity of the three power lines of the compressor and fan levels.

F. Accelerometer

The Bosch Triaxial Accelerometer sensor, model BMA 253 is used to the vibrations of the compressor in the three axes. each axis stream of data will be use in to display frequency spikes on the mobile app generated by the fast Fourier transform.

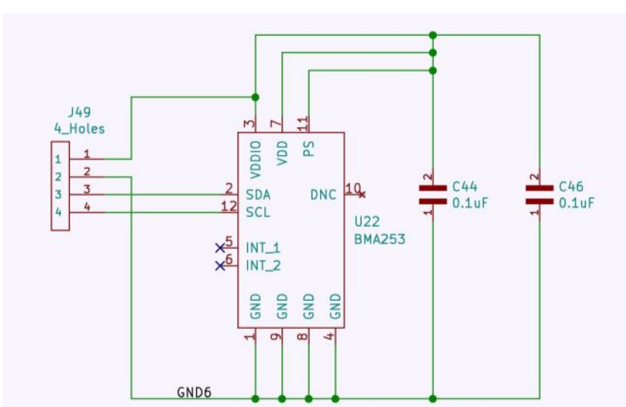


Fig. 9. Remote board that contains the accelerometer chip that will provide vibration data to the main board to the mobile app.

IV. Software

The product has two software parts, the firmware and the mobile application. the firmware interfaces with A/C unit, collected the data and send using Bluetooth low energy. the mobile app receives the data from the board and shows to the user. Also, sends the user commands to the board. The following sections goes more in depth in both areas.

A. Firmware

The development is done using the PSoC Creator IDE in the C language.

The firmware runs in a loop, collecting data from the sensors and send to the mobile application. When the board is plugged to power it checks if the voltage source is 12v to turn on the second voltage regulator. this done using the ADC on the PSoC. Once is one, it runs a method to check on the sensors. If one or more sensors do not respond during the check is consider to be faulty and the operation of board is stop.

When the voltage source is 9v, the second voltage regulator is off leaving only the essential components, microcontroller, the lever shifter, and EEPROM powered on. the ADC is constantly checking the power source for changes.

Every second the program collects a new read from sensors, saves it in the EEPROM and if the user the mobile app has notification on it sends to the app thru BLE. The device also takes user inputs thru the mobile app. These include individual tests for each of the components, compressor, high fan and low fan as well as thermostat commands.

The figure above shows the firmware flowchart for the device.

F. Mobile Application

The application is build using Ionic 4 with AngularJS. the main function of the application is to serve as the interface between the board and the user.

The design of the app takes in consideration different navigation. the user can access the pages using the tabs navigation or by the collapsing menu. this makes sure user can use the app the way they feel most comfortable and that all data is easily accessible to them.

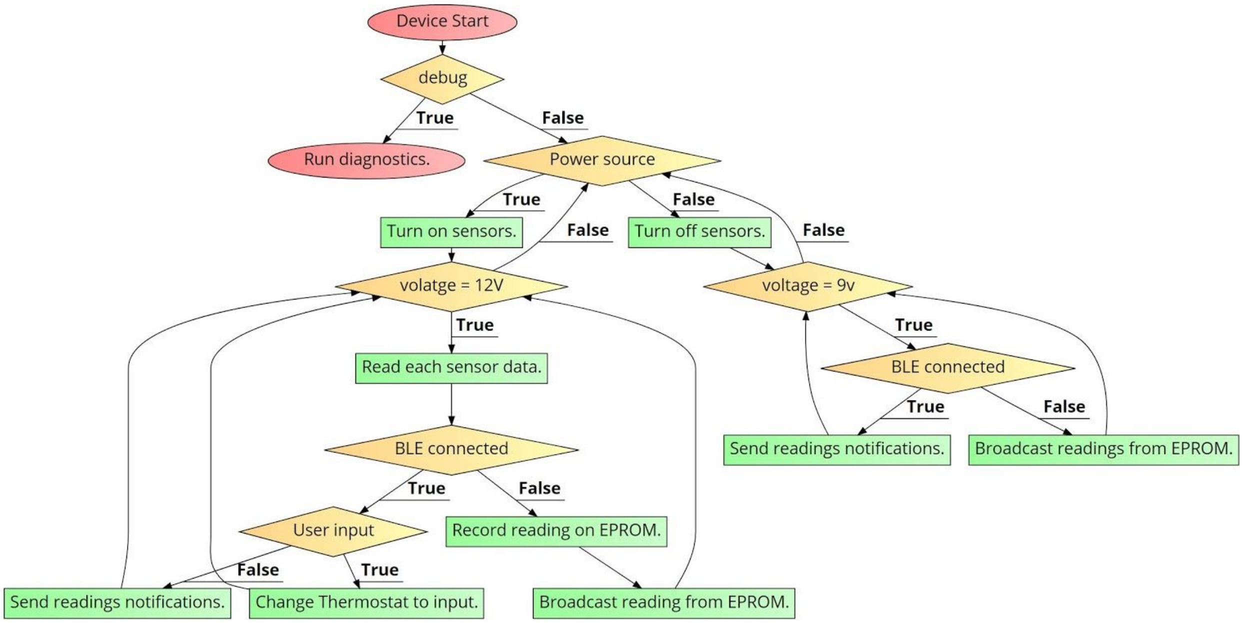


Fig. 10. Flowchart logic for the main board.

BLE is used to communicate with the board to populate the fields for each of the sensors, show the FFT graphs, runs test for the A/C components and for the thermostat function.

The images below show a preliminary rendering of the application user interface.

Fig. 11. Mobile app's graphical user interface home screen.

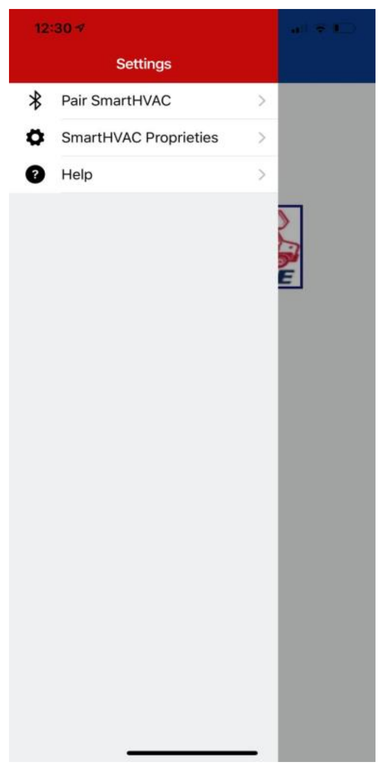


Fig. 12. Mobile app's graphical user interface collapsing menu.

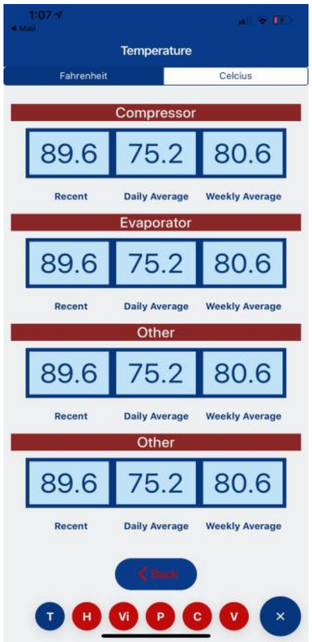


Fig. 13. Mobile app's graphical user interface temperature page with tabs menu.

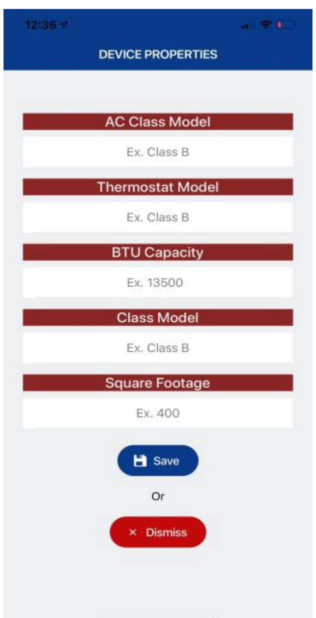
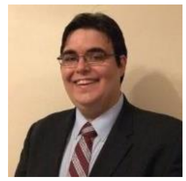


Fig. 14. Mobile app's graphical user interface device properties page.

THE ENGINEERS

Claudio Afonso is a graduating Computer Engineering student who hopes to pursue a career in embedded software development, research and design for companies such as Microsoft, Intel.



Sergio Perez is a 33-year-old graduating Computer Engineering student with a passion for embedded software. Worked with associations in SHPE and is aspiring to work for companies such as AMD or L3Harris.

Francisco Martinez is a 25-year-old graduating Electrical Engineering student who hopes to work for companies such as Intel or L3Harris.

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