Project Summary

Text Box 1: Overview, Keywords, and Subtopic Name

Smart HVAC Furniture: This involves Ecological Furniture: personalizing HVAC furniture with self-control processes in an office space. Keywords include Heating, Ventilation, Air Conditioning, Internet of Things, Embedded Systems, Thermal Comfort, Thermodynamics, and PID controllers. The project requires areas of technical expertise in Mechanical Engineering - provision and construction of suitable furniture for physical and thermal comfort, Computer-Vision - identifying a user at their desk space, and Embedded Systems - the technology used to control the HVAC system provided with the furniture. The project will be applied to the fields of Environmental Sustainability – reducing the cost of energy spent on commercial and residential HVAC systems, and Control Systems – the ability to control the ecological furniture using embedded hardware.This project aims to reduce HFC emissions while providing thermal comfort for individuals, bringing about large-scale change in the HVAC industry.

Text Box 2: Intellectual Merit

This Small Business Innovation Research Phase I project produces office furniture that can accurately predict the comfort of individual users using thermal sensors, a thermal imaging camera, and HVAC and embedded systems. To do so, the embedded system must regulate the transfer of temperature-controlled air from the source (the HVAC) to the user - according to the data produced from the thermal sensors and thermal imaging camera (spotting the user's presence and temperature of the environment respectively). The office furniture will be designed to accommodate in-built AC/Heating for microclimate control around an individual, when present, using said furniture.

Text Box 3: Broader/Commercial Impact

According to the U.S. Energy Information Administration (EIA): in 2012, 4 Quadrillion British Thermal Units (BTU) of energy were being consumed in the commercial sector[1], equivalent to charging approximately 5 billion iPhone 5Ss, for a year. This project aims to reduce this value, as it targets the thermal comfort of an individual, while not cooling the space around said individual. This model also follows the technological trend of home and office automation, and can bring about a change in the culture of heating, cooling and ventilation in the respective industry.

[1] https://www.eia.gov/tools/faqs/faq.php?id=86&t=1

Elevator Pitch

By some estimates, the United States spends approximately 40% of its energy on indoor climate control. Much of this is inefficient because large volumes of indoor space are heated or cooled simply to tend to the individuals in it. This project aims to take on this issue by introducing a new concept that targets the operation of HVAC systems and reduces the impact that they have on the environment.

Eco-Flow is a highly effective system that will tend to individual requests for microclimates. By adding a microclimate, a user's immediate area can be tailored to suit them in a manner of ease. Eco-Flow can solve this, as it embeds an HVAC system within every-day furniture. We create controllable, energy efficient heating and cooling that can target the users directly, thus allowing for customization of ideal comforts in a small area, rather than impacting a large area at the cost of more energy. Thermal sensors and thermal imaging cameras are also embedded into the system to produce an accurate reading of the area, as well as detect the presence of the user. This leads to efficient use of the product as well – The product will switch on when a user is present; cooling or heating the user to their liking, or remain switched off if there is no user detected.

The application of this product will be displayed in the office environment – where Eco-Flow can be embedded into office chairs and desks. This is the ideal environment, as there are a large number of users within a single space, each with reserved unique thermal comfort zones. Those comfort zones are often disturbed, since there is only one heat or cool protocol in the entire facility. Eco-Flow can tend to every user, and eliminate the inconvenience of spending energy and money- heating or cooling a large space only to benefit particular users.

Commercial Opportunity

Eco-Flow affects the commercial and residential sector. The commercial sector contains at least 10 million units, as reported by the United States Census in 2015[2]. Areas such as office space (open or closed) or other areas of enclosed space can have the convenience of Eco-Flow in their environment, providing thermal comfort and reducing cost of energy. New and upcoming firms that are in need of constructing office space need not worry about costs in planning and constructing HVAC infrastructure if they obtain Eco-Flow.

As reported by the Census in 2014, there are at least 100 million residential units that can make use of Eco-Flow[3]. Any person that wishes to reduce their power bill or add consistent room temperatures in a residential area can invest in this product. Although users may already have a central heating/wall attached unit, they can still focus on a smaller climate zone by making use of Eco-Flow. If the resident owner is constructing their new home, Eco-Flow can be considered to reduce costs, increase budget, and increase the area available to the owner outside the home.

Eco-Flow can very well apply itself into lab environments, where users are in need of keeping a designated area at controlled temperatures for set periods of time. The ability to easily modify the temperature of the environment around a research project will greatly alter the way researchers can construct experiments. For instance, the inability to house an incubator can be fixed by applying Eco-Flow into the experiment, thereby producing accurate results.

The United States have societal, market, industrial and technological demands to go green, and Eco-Flow can further this movement. As of this year, the United States has also left the Paris Climate Agreement, and have lowered the budget for the Environmental Protection Agency, which provides a much more crucial ground to have a smaller carbon footprint. Citizens must have a way to reduce their impact, and Eco-Flow can provide a step towards this cause.

Energy Star's federal tax credit incentivizes those to have HVAC products that consume less energy[4]. For example, they advocate an Energy Efficiency Ratio (EER): the higher the EER rating, the more energy efficient the product is. This results in lower energy costs. Individuals can be convinced to lower their costs by investing in Eco-Flow, a product that may have energy savings.

In the Commercial Sector, companies are often enticed to conserve energy with the help of the United States Green Building Council (USBGC). They provide what is called the Leadership in Energy and Environmental Design (LEED), the most widely used green building rating system. Building owners that make use of this project can have an easier time establishing the LEED certification.

Eco-Flow keeps up with the ongoing technological trends today. Like many others that are adapting, we apply it to the Internet of Things (IoT) - where individuals integrate technology into their everyday lives. With Eco-Flow as a smart HVAC, it can easily fit into smart home technologies. As the demand for smart home appliances increases[5], more individuals will be inspired to invest into Eco-Flow, and be able to control from their computer and/or smart device.

Like the market, we break down our customers into the commercial and residential sector. For the residential users of our product, we provide another method for controlling an HVAC product. Traditionally, HVAC products only have the ability to be switched on or off. Eco-Flow, on the other hand, has a state in-between on or off. Rather than depending solely on the temperature around the machine, we also depend on the presence of the user. Thus we provide a 'sleep' mode. When the user returns, the machine can resume its work in cooling the user without being switched off. Eco-Flow will

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[2] https://www.census.gov/data/tables/2015/econ/susb/2015-susb-annual.html

[3] https://www.census.gov/housing/hvs/data/histtabs.html

[4] https://www.energystar.gov/about/federal_tax_credits_consumer_energy_efficiency_definitions

[5] https://technology.ihs.com/549694

only switch off when the user has not been present for a while, or the user switches the machine off manually, calling for a more effective use of energy.

Many conventional HVAC machines can affect the temperature around them, but often not the entire room itself. In wall-attached units for instance, the HVAC will attempt to cool the room, but only affect the side where the machine is present. Once that area has obtained the ideal temperature, the machine will switch off. In reality, the temperature around the machine has been affected, but the rest of the area it attempted to cool will still be at the original temperature. If Eco-Flow is to be used in a wider area, it can make use of its Central Sensory Network (CSN) in accordance to other Eco-Flow units. Much like that of the AC unit in cars, Eco-Flow units can detect what areas are at the right temperature and what area is not. Eco-Flow will adjust their units and cool/heat the incorrect areas accordingly.

Business and commercial building owners would greatly benefit from these functions as well. In the office space in particular, there are various unique "thermal comfort zones" that each employee would have. Since there is a large ratio between the number of employees to the options in central heating (typically only one), there would usually be a large amount of discomfort present. As a result, workers would have to either bring their own comfort clothing (which may not be up to standard in the workplace) or, possibly, reduce their productivity, due to the distraction of being too hot or too cold.

According to reports by news sources, HVAC systems, machines that cannot determine individuals, have been reported to be rather "biased" in heating and cooling temperatures: in particular, to men rather than women in the commercial sector[6]. To expand, heating and cooling in central heating had a calculation being practiced. Based on the metabolic rate of a 154 Lb, 40 year old male, the cooling and heating system would adjust to this, times the number of workers present. This was done in the 1960s, before women were in less than equal numbers than men in the workforce. Now that women are much more present than before, this method is outdated, and it is possible that some commercial buildings have not adjusted to this system.

Eco-Flow can assist these issues by providing comfort to each individual worker's preferred microclimate. Rather than settling on a calculated value to have the central AC running to satisfy a few, Eco-Flow can satisfy all by adjusting to each personal preference to generate the ideal microclimate. As a result, there could be an increase in productivity in the workplace, as there are little to zero distractions on how hot or how cold the temperature is. Eco-Flow can also be retrofitted for each user's particular need, whether it can be for a larger nozzle for airflow, or possibly a longer network of tubes from the originating HVAC module. Eco-Flow caters to each customer's desired need and structure.

By combining the residential and commercial sector together, we obtain a large availability of customers in the market to advertise Eco-Flow to. In addition, by making strong use of the market drivers available, we can provide a strong business value behind Eco-Flow while providing a formidable alternative to the currently available HVAC units in the market. Through channels such as Home Depot, Amazon, Apple, Brookstone and our own distribution website, Eco-Flow can be sold in-person or online to individuals based on their preference. Not only do we want to satisfy customer's needs to purchase the product, but a relationship between the customer and the company must be established. To meet these requirements, Eco-Flow intends on having an account management representatives for enterprise. This individual caters to customer's sales questions and preferences, as well as provide benefits to customers (discounted sales, giveaways or other promotional benefits). Eco-Flow will also be providing customer support for consumers that have gone through difficulties in setup, or inconveniences caused by malfunctions behind the product. If the issues are common, Eco-Flow would provide a list of "Frequently Asked Questions" (FAQ) on our website. This website would also provide an "About Us" page, where we can educate possible users on our products in a clear and concise manner. With the addition of white papers, we can provide additional information for customers to educate themselves further.

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[6] https://www.today.com/health/office-air-conditioning-cold-women-science-reveals-why-t36476

The revenue generated will originate from sales online or in-store. This in turn will pay for research and development, technological infrastructure behind Eco-Flow as well as products and salaries provided to the workforce. As a business, our key activities include further research and development for innovating Eco-Flow further, the provision of specialized talent behind the company, customer support and education (through white papers and resource libraries available to users). These are also key resources behind Eco-Flow, with the addition of intellectual property and sales force. Our key partners include those in distribution along with governments to advocate for a greener, healthier alternative to current HVAC systems through tax incentives.

Our competition is limited to the current HVAC industry plus Nest and Dyson, two major competitors, and EcoVent, a startup with a similar approach. Both EcoVent and Nest apply smart logic to current HVAC systems. With additional research and development, both companies can produce their own smart HVAC unit, similar to our approach. Dyson, on the other hand, provides ergonomic, attractive, standalone heating and cooling units but do not have smart logic applied to them. With the addition of smart logic to their products, they can very easily become direct competition with Eco-Flow.
Although Eco-Flow can provide innovation that can change the market, there are associated risks. Eco-Flow advertises for thermal comfort, in which the user is satisfied with the provided temperature setting for their microclimate. However, this is resulted from physiological and psychological comfort. There is no 100% guarantee that consumers will feel complete comfort in our product. Eco-Flow must also maintain energy efficiency to promote itself as the ideal alternative to HVAC units. If it cannot provide this standard, then the product cannot provide itself as a greener alternative. The market must also cater to the value of Eco-Flow as well. If priced too high, it may not receive great recognition and lose value in name. If key competitors decide to release a product similar to Eco-Flow, the likelihood of Eco-Flow gaining speed in the market is limited to possibly none.

As it stands, Eco-Flow currently has an advantage as the only unique smart HVAC unit. With additional research and development, we create a working, successful prototype. With this working prototype, we will devise how to mass-produce Eco-Flow products and budget the manufacturing process. Once we are able to produce promising products, we will be able to promote and receive revenue from the market.

Societal Impact

Economically, we provide an open alternative to HVAC units, innovating others to compete and build alternatives to Eco-Flow, providing for a greener future ahead. This is with the initial assumption that Eco-Flow will save a percentage more of energy than typical HVAC units that are currently in the market.

Eco-Flow tackles the issues of global warming and carbon dioxide emissions by attempting to reduce the footprint that current HVAC units have. ARPA-E recognizes this as a grand challenge program, and acknowledges that HVAC systems could further save energy by going in the direction in which we as Eco-Flow pursue[7].

If Eco-Flow is introduced to the market, there can also be a shift in the HVAC workforce. Due to Eco-Flow's goal of reducing costs to HVAC infrastructure, there could be less of a need for HVAC technicians to be present to maintain and repair large HVAC units. All building structures are affected, therefore all individuals may be influenced by this day-to-day product. However, it must be noted that Eco-Flow will still consume electricity and still emit HFCs to the environment, contributing to the greenhouse effect. Eco-Flow is not appropriate as a children's toy, nor should the product be tampered with, as this may lead to injuries. If placed in the wrong hands, Eco-Flow could provide an unwanted environment to sensitive individuals, which can lead to excessive discomfort. Eco-Flow will be addressing this issue by only providing temperature differences up to 15 degrees Celsius. Eco-Flow cannot be used without an electrical outlet or power source. Therefore, if there is no outlet available for the user, Eco-Flow will be unable to provide them comfort.

Eco-Flow's mission is to provide less harmful emissions to the environment, while still providing the necessary cooling or heating effect for all individuals. It is becoming more crucial to save on energy and protect the environment. The HVAC industry can be considered an untapped market that is not up to date with current technological trends. Through ownership of an Eco-Flow product - a smart HVAC unit for all - it can provide a much more personalized, efficient, and immediate airflow for a user without the worries of energy wastage and cost.

[7] https://arpa-e.energy.gov/sites/default/files/documents/files/DELTA_ProgramOverview.pdf

Technical Discussion

The EcoFlow smart HVAC system is designed to provide seamless control, starting from programmable microcontrollers to the HVAC hardware for their users. EcoFlow provides a gateway to innovative technologies by bridging conventional hardware and software together to provide a means for everyday comfort.

The technology presented shifts the way HVAC systems are traditionally applied in the market. HVAC systems could be localized: instead of using wall-attached or central air systems, EcoFlow units are located in the area you are most present and stationary, as an office setting.

EcoFlow units would be able to automate an individual's thermal comfort – something usually determined by psychological behavior and feeling. EcoFlow aims to reduce user intervention in order to achieve the comfort consumers desire. With the use of artificial intelligence and machine learning, units could have the ability to learn of individual's ideal thermal comfort zones. For example, if a user typically prefers the cold over heat, the EcoFlow HVAC system would cater to cool temperatures generated by it, providing a cooler than usual microclimate for them in particular. The user will have the option to have a manual "Guest Mode" control over the machine, providing the ability to have other uses for the machine, besides their very own customized use for the product. They in turn can use the product as a standalone heater/cooler.

By application of thermal tracking in Flir Lepton cameras, EcoFlow units would be able to detect the presence of users and, in addition, control the operation of their smart HVAC system. Individual profiles can be associated with the images processed from the imaging camera, and thus individual thermal comfort zones can be generated by the profile. By granting this ability, users would not have to interfere with the machine operation and, instead, be automatically identified and cooled/heated according to their profile. The imaging unit can also provide pan-and-tilt features, giving the user the ability to move about their unit, and thus, eliminate the inconvenience of remaining stationary for the sake of the machine.

The CSN feature comprises of sensors embedded into each system, each in which monitors the condition in the environment. By making the system centralized, the products have the ability to communicate preferences to each other. By applying concepts in fluid and thermodynamics in its algorithms, EcoFlow would be able to maintain the requested temperatures around the surrounding area in which they exist. In addition, the onboard sensors would be able to provide diagnostics for maintenance and repair of the unit they are associated with.

The primary objective of Phase I research is to provide a smart, ecological solution for thermal comfort with reduced energy expenditure, providing an ideal alternative to conventional HVAC units. In this, the best possible means of approach must be made to obtain this goal. Challenges and tasks must be faced in order to accomplish Phase I research.

EcoFlow must programmatically determine how to provide thermal comfort for an individual, without user interference. The machine must also have the ability and goal to reduce energy expenditure to a point that is less than conventional HVAC use. Ideally, 5 USD per month: 60 USD annually. This in turn would present itself as a financially cheaper alternative to other units.

The machine must be able to actively follow and tilt to the user in a way to not disrupt the user's thermal comfort zone. To do so, the machine must be able to pan in a full half-circle and tilt based on the user's position. All of this will exist to provide about a half-meter radius of regulated air around the individual. EcoFlow camera units must be able to maintain visibility and image processing as long as the user is visible, and determine the appropriate time to switch off. By keeping good thermal performance, low cost, aesthetics, energy efficiency and sensitivities (such as noise and thermal asymmetry), EcoFlow would be able to present itself as an ideal investment to alternative HVAC providers.

The HVAC unit must also be compliant to government and HVAC auditing services. This means having the ability to protect the health and productivity of the space and its occupants, minimizing energy efficiency and loss. By having the audit, the product would be more likely to adapt to the commercial environment.

In order for the product to be at a point for mass production, several important features must be completed and functional.

The integrated Flir Lepton camera must be able to distinguish between different individuals. This in turn grants the ability for multiple features to be added to the final product, such as allocated personal profiles and customized, automated HVAC preferences. By achieving the automated HVAC preferences, the user will be able to have ideal thermal comfort without having to fiddle with the device at hand. They can simply walk up to the camera, be detected, and have their profile and preferences set to cool, switching on the machine.

The embedded arduino microcontroller should be able to maintain consistent control and communicate with servo components, which control the dampers that open and close airflow vents. In Phase I research, the servo motors used do not provide acknowledgement nor feedback to the arduino microcontroller, which adds greater dependence on arduino to servo communication. In a larger budget for research and development, servo motors with response and acknowledgement can be introduced to the product, providing as a milestone in microcontroller to motor component communications.

In CSN development, the goal is for one EcoFlow unit to communicate with one or more units across the same network. With this, the units will be able to detect presence, distance and programmed thermal comfort in each other, and work to ensure that each of them would maintain their requested temperatures. This in turn would generate “climate zones” in which they are responsible for. By having these climate zones, the user(s) would be granted the choice on whether each climate zone should be the same temperature, or differ from one-another. This is especially useful for the office space as a target for consumers.

All of these features must be accommodated into a small, portable unit. An important goal in Research Phase I is to develop the correct form factor for EcoFlow units. This could produce simplicity in production of the first prototype of EcoFlow’s smart HVAC unit.

R&D Plan

The first plan of Research and Development is to build a budgeted, working prototype of the project in the office space. This should prove the concept that EcoFlow can be a viable option as an operational HVAC unit, based on regulations in HVAC units. By this time, investigation and implementation of all libraries and hardware have been completed, but there is room for feedback and listing of additional resources required for the next phase of development.

Once the prototype is completed and approved for manufacture with a larger budget, it can be released as a soft launch as a means to generate feedback towards EcoFlow's product. With each unique individual testing the product, a spectrum of consumer feedback can be expected. With this, EcoFlow would be able to further develop their units to greater depths.

During this point in time, CSNs will also have been researched and tested with other units. The product should be able to communicate with other versions of itself within the same network, ensuring same climate in different parts of a room, or, alternatively, differing microclimates to suit individual comfort. This will be released as a firmware update to those that have participated in the soft launch in order to receive adequate feedback towards our product to gear EcoFlow units for their Official Release.

In the Official Release, the improved model will be available for release in all office spaces. In addition, FAQ and customer service would be made available to customers. By analyzing the common issues found in released products, EcoFlow can improve and release the next version of their units. This would become a repetitive cycle, providing more innovation and incentive in release of products.

Once EcoFlow has found an ideal model to refer to, it can expand into different applications of the product, to allow for mure customer use. Research into these expansions will be taken to ensure maximum confidence before manufacture of these products. Examples to be taken into consideration include, but are not limited to, items in the living room of a residual unit, in application to cribs for infant care, temperature-sensitive R&D experiments, and wheel chairs.

With each application, a survey for feedback would be made available to each consumer to keep community response active, and for use in further research and development of all EcoFlow units.