Dynamic Ventilation Control System

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1 Introduction

1.1 Objective

Controlling heating and cooling in a home or apartment typically relies on a single thermostat. The temperature sensor determines the necessary temperature changes for the rest of the rooms. With this configuration, there is a chance that several rooms are not meeting temperature expectations for a variety of reasons (more exposure to sunlight, poor insulation, etc) [4]. These straggling rooms consequently determine the overall user comfort level based on how frequently the rooms are occupied. Similarly, two individuals may prefer slightly warmer or slightly cooler temperatures for their independent rooms, so without multiple layers of feedback, the temperature regulation system will not be able to handle both requests. Our product aims to solve these problems by dynamically controlling airflow into every room of the building as well as providing intelligent and scheduled operation of the central heating/cooling system. This provides users with comfort and convenience within their occupying areas.

1.2 Background

There are several airflow controlling vents already on the market, such as Keen Home and Ecovent [7,20]. Both products utilize a mobile application that allows a user to create zones in the house and set temperature preferences. However, both of these products require professional installation and/or high upfront cost [8]. In addition, Keen Home has received mixed customer reviews [1], meaning either the implementation or the physical configuration is flawed.

Intelligent thermostats are another element to the design that make an impact on overall energy savings. Nest and ecobee [2,5] are examples of Wifi-enabled thermostats that can be scheduled remotely to adjust temperature based on time of day, weather conditions, user presence in home, and several other factors. In our proposed design, we can potentially interface with these intelligent thermostats by forwarding data collected by our temperature sensors, and the end result could create a better day-to-day heating/cooling system adjustment.

1.3 High Level Requirements

- The vent unit (described in detail in the next section) must have an energy-efficient design. It is important to maintain the lifespan of the vent unit and only require changing batteries every 3 years (minimum).

- The communication protocol between units must be reliable (<1% bit error rate) and secure (AES encryption).
- All sensor readings and user preferences should reflect the output of either the thermostat or the dampers. For example, if the user prefers a room to be 72° F and the temperature sensor in the room reads 70° F, a combination of the thermostat temperature increasing and damper adjustment should occur.

2 Design

This design consists of two primary units: a vent unit and a hub unit. The vent unit is powered by regular batteries through a voltage regulator to ensure continuous supply of required voltage. The hub unit is powered by any common power outlet through an AC-DC converter and voltage regulator circuit. The vent unit and the hub unit communicate with each other through Bluetooth 4.2 (BLE) communication between the two BLE transceivers. Bluetooth Smart Technology has the capability of 100 m distance range of communication that covers most of house sizes [18]. In this design, however, we assume the distance between the vent unit and hub unit is no greater than 10 m. The two BLE transceivers both communicate with their associated microcontrollers through the UART interface [19]. Additional sensors monitor the air pressure and temperature.

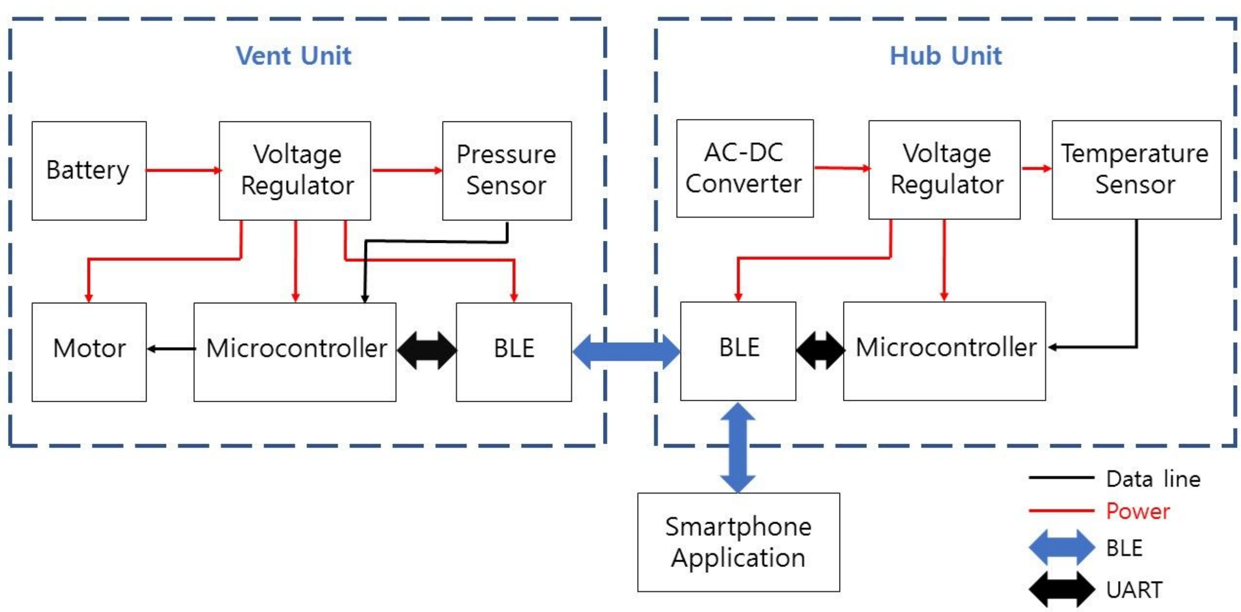

Figure 1: A high level block diagram of the proposed design.

2.1 Vent Unit

The vent unit is responsible for controlling the state of the dampers. A microcontroller decides the state based on commands received from the hub unit and the data received from the pressure sensor.

2.1.1 Battery- Voltage Regulator

The vent unit is powered by 4 AA batteries, and the voltage regulator would ensure continuous supply of voltage. AA batteries will provide 6 V. The microprocessor is able to work in a voltage of that order so it won't be necessary to build a regulator but the motor will need a different voltage so this system will have to be built.

Requirement 1: the batteries must be replaceable and last 3 years minimum.
Requirement 2: the voltage regulator must ensure that all components meet their supply voltage requirements. In our design, this will be to 5 V.

2.1.2 Pressure Sensor

The pressure sensor detects the level of air pressure of the heating or cooling air that comes from the main HVAC ventilation system of the house. The level of air pressure is used to decide the state of the vent to avoid damaging the HVAC by closing all of the vents while the air comes out of the HVAC system.

Requirement: the sensor must be accurate to 0.01 kPa because HVAC static pressure is typically rated at 0.5 wc" [11], or roughly 0.124 kPa.

2.1.3 Motor

The motor operates based on commands from the microprocessor. The state of the vent is set by running the motor in certain amount of time in desired direction (open and close).

Requirement 1: the motor must operate with at least 3 V supply voltage.
Requirement 2: the motor must have quiet operation at under 40 dB.

2.1.4 Microcontroller

The microcontroller controls the state of the vent based on commands from the hub unit and the pressure data from the pressure sensor. It communicates with the BLE transceiver via UART.

Requirement 1: the MCU must be at least 8-bits to handle data from the BLE transceiver more efficiently.
Requirement 2: the MCU must operate under 5 V.
Requirement 3: the MCU must support low-power sleep or hibernate modes.

2.1.5 BLE

The BLE transceiver connects the vent unit and the hub unit through BLE (Bluetooth 4.2) interface. It communicates with the microcontroller via UART.

Requirement 1: the transceiver must have a range of at least 10 m.
Requirement 2: the transceiver must use encrypted messaging of 128-bit AES or equivalent.

2.2 Hub Unit

The hub unit is the control center of this product. Based on the temperature sensor's data, it decides which command to send to the vent unit to control the room's temperature. It is powered by a voltage regulator connected to a power outlet.

2.2.1 Power Supply

The power supply ensures sufficient energy is being provided to the microprocessor, temperature sensor, and the BLE module.

2.2.1a AC-DC Converter

A commercial AC-DC converter will be bought to ensure the safety of the electric installation of the laboratory and building.

Requirement: the AC-DC converter must convert 120 V from a standard power outlet into sufficient voltage.

2.2.1b Voltage Regulator

We'll use a switching voltage regulator (DC-DC converter). It will be installed in order to eliminate noise created by the AC-DC converter and to nullify any ripple created by the AC-DC converter, in order to obtain a truly constant DC constant voltage. A DC-DC converter will be used, because of its good efficiency and regulation. A voltage

Requirement: the regulator must be able to maintain at least 5 V to the entire circuit.

2.2.2 Temperature Sensor

The temperature sensor detects the room's temperature where this product is installed and send the data to the microcontroller.

Requirement: The temperature sensor must be accurate to the nearest 0.5° C, *since this temperature is about 0.9*° F and close to 1° F granularity.

2.2.3 Microcontroller

The microcontroller of the hub unit communicates with the BLE module via UART. It reads data from the vent unit and the temperature sensor, then it decides a command to send to the vent unit for controlling the state of the vent. It also processes user requests sent via the BLE module.

Requirement 1: The MCU should be at least 16-bit to process larger pieces of data than the vent unit MCU.
Requirement 2: The MCU should have integrated flash of at least 128 KB to store data of user scheduling and to gather statistics on temperature fluctuations.

2.2.4 BLE

The BLE transceiver communicates with the vent unit, the hub unit, and the smartphone application through BLE (Bluetooth 4.2) interface. It communicates with the microcontroller via UART.

Requirement 1: the transceiver must have a range of at least 10 m.
Requirement 2: the transceiver must use encrypted messaging of 128-bit AES or equivalent.

2.3 Smartphone Application

To provide user input, we create a standard application for a mobile operating system such as Android or iOS. The interface is simplistic, and sliders allow adjustment of the temperature within a given room. Any potential hazards created by closing too many vents (explained in detail in section 3) are mitigated by providing error messages to the user that settings for the zone cannot be applied.

2.4 Risk Analysis

The power electronics of the voltage regulator of the vent unit is the most significant risk to the successful materialization of our idea. The power electronics of the hub unit is a big concern for us too. The vent system should be able to change the voltage to up to 5 V for most of microcontrollers (Some models may be 3.3 V), or to the electric motor voltage (3 V) . It should be ensured that they are able to provide enough power and current to fit the motor and microprocessor needs. If the system stops working or is any other malfunctioning the microprocessor won't burn or explode, but it may get really hot and get damaged [9]. For the motor, we're not using a shunt motor as they are more suitable for bigger industrial applications, and that reduces safety concerns about the motor, since shunt motors when they get no input current, their speed tends to infinity[10]. In our case, if our DC motor stops getting input current it will stop after some time, but if it gets higher current than its requirements, it will overheat and shorten the life of the motor[12]. The system of the hub unit should be able to convert 120 V AC to 5 V used in the hub MCU. It should feature a AC-DC converter and a voltage regulator in order to eliminate the ripple obtained in the AC-DC converter.

Some possible solutions in order to make the power electronics safer would be building a transformer in the hub unit in order to achieve galvanic isolation. That way, we won't be affected or affect the plug or electric system in case of anything happening.

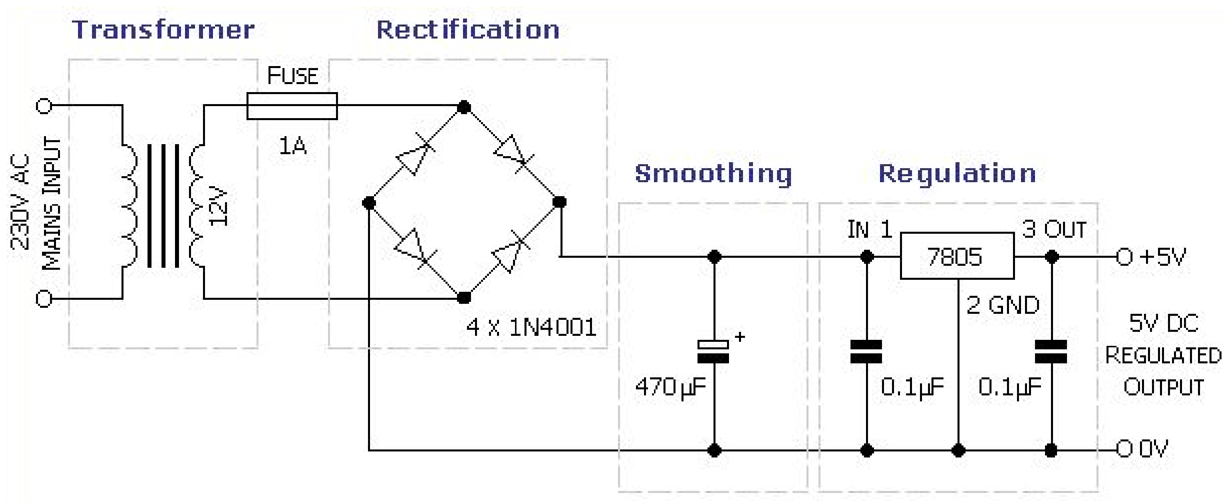

Figure 2: A simplified circuit diagram that regulates an AC input into consistent 5V DC output [13].

Safety for the DC-DC converter of the vent unit can be ensured in many ways. Some of them include fuses or using a circuit that in case of the switch breaking, opens the path to the load [14], or using Mosfet transistors instead of diodes (helps a lot with energy saving) [15]. More complex (and more expensive) solutions would be integrated converters with PWM modulation systems. However, if designed correctly, DC-DC converters' chance of failure under normal conditions are slim to none[16].

3 Safety and Ethics

3.1 Safety

Since this product operates on electricity, there is always a chance for fires. There is a serious risk of injury or death if the user misuses the electrical components, especially ones directly connected to the power source [17]. This product must remain dry in order to avoid any chance of malfunction caused by a short circuit.

One of the largest concerns by closing drafters within a HVAC system is the increased pressure within the ducts, causing potential breakdown [4]. It is critical to relay to the consumer that dampers should not be shut off manually, for the pressure sensor within the vent unit will be able to automatically detect the static pressure and prevent the aforementioned hazard by opening the dampers accordingly.

3.2 Ethics

All members of our team must comply to the latest iteration of the IEEE Code of Ethics [6]. One of the important points on this list for our design is #3, that is “to be honest and realistic in stating claims or estimates based on available data.” When we identify the power consumption of our circuit, we cannot create any false statistics that suggest an unusually long battery life if that is not truly the case. Another emphasis is placed on #7, which is “to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others”. As members of the University of Illinois, we must adhere to all class policies regarding plagiarism and we should strictly cite any external resources.

Points #8, #9, and #10 are related to group interactions, and since this project is worked on as a group, it is important to remind ourselves that we must create an atmosphere where we respect one another. As painfully simple as it may seem, conflicts do arise, and it is best to resolve any such issues in a professional manner. Examples of potential conflicts include irregular distribution of work and disagreement on implementation decisions. Engagement of the course staff will be required if more serious issues arise.

The rest of the points in the Code of Ethics should be adhered to, however, either we do not need to put much emphasis on them or their importance is already covered in this proposal (#1). General training (#6) is covered through lab safety seminars online. We do not see any potential conflicts of interests (#2), nor do we expect any form of bribery to occur (#4). As students, it is assumed that #5, which is “to improve the understanding of technology, its appropriate application, and potential consequences,” is constantly being adhered to.

4 References

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