Smart Personal Environment Regulator

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I. Abstract

This project investigates the effects of personal environmental conditions on the productivity level and well-being of room occupants, and introduces the Smart Personal Environment Regulator (SPER) as a solution for the purpose of improving these conditions. The problem concerning our personal environment is that productivity and comfort may be reduced if the room temperature, humidity and carbon dioxide levels are either too high or too low. Additionally, smaller occupant spaces, such as a desk or classroom, may not be accurately monitored by the general heating, ventilation, and air ventilation (HVAC) system that exists in a building. Thus, we aim to monitor and adjust the environmental conditions of an occupant space for optimal productivity and comfort.

The cyber-physical system consists of three sensing nodes that will monitor temperature, humidity, and carbon dioxide levels, a cyber layer that processes the data collected by the sensors, and a fan-heater combo that will adjust the environmental conditions according to the processed data if necessary. With such functionality, the system can be implemented in places such as classrooms, offices or homes where productivity and comfort matter.

II. Introduction

Motivation and Background

Our team noticed that environmental conditions in the classroom can often be too hot, too cold, or too stuffy, which can be distracting for studying or working purposes. This can affect the occupant by causing a decrease in concentration and the urge to fall asleep when working, and can ultimately lead to a loss in productivity. We want to prevent unsuitable environmental conditions in working spaces, such as on a college campus where productivity and efficiency is highly valued.

The current system of thermal comfort regulation in buildings can be energy inefficient because usually there is only one thermostat to control the temperature in a very large area. This is inefficient because not all rooms need to be at the same conditions. By tackling the thermal comfort problem in a smaller working space, working productivity will increase, but energy consumption will also likely decrease.

Relevant Literature

Research has found that carbon dioxide levels in working spaces are often much higher than outdoor levels. According to a study in 2012, outside carbon dioxide levels average around 400 ppm, but indoor levels can often be up to 1000 ppm and even 3000 ppm in offices and classrooms respectively. The study further showed that the carbon dioxide levels were directly related to the performance of the occupants within the room.

In addition to carbon dioxide, temperature and humidity also play a big part in human comfort, and thus their performance to work. According to the Canadian Centre of Occupational Health and Safety website, the comfortable temperature range for a working environment is between 21 to 23 degrees Celsius, and should be adjusted higher when the outdoors temperature is warmer to minimize the discrepancy between indoor and outdoor temperatures. There are also recommended temperature settings for varying humidity levels.

The ASHRAE-55 standard is a widely used indoor thermal comfort standard that specifies conditions for acceptable thermal environments and is intended for use in design, operation, and commissioning of buildings and other occupied spaces. It determines acceptable comfort “envelopes” based on several factors, such as the air temperature, mean radiant temperature, humidity, metabolic rate, clothing level, and even air speed. For the purposes of this project, we will be using a simplified model based on the ASHRAE-55 standard by varying only 2 of the 6 parameters and holding the rest as constants, as shown in Table 1.

Parameter	Value
Air temperature	Varying
Humidity	Varying
Mean radiant temperature	25.0^{o}C
Metabolic rate	1.1 met
Clothing level	Summer indoor clothing
Air speed	0.1m/s

Table 1: Varying parameters and constant parameters.

Focus of this study

The focus of this project seeks to improve the productivity and comfort in more of such working spaces by targeting three parameters: temperature, humidity, and carbon dioxide. We hope that this project will further increase awareness of the significance of indoor air quality and comfort, and that future renovation and construction projects will place more emphasis on improving these conditions for occupants.

III. Technical Description

Method

The overall cyber-physical structure of SPER is shown in the flowchart below (Figure 1), depicting the implementation of the various layers of a cyber-physical system. The process begins with data collection by the three sensors powered by an Arduino microcontroller. This information collected are passed by the Arduino via serial port, and collected by a Python script that uploads them to the web server, storing them as streams in a database. Another Python script will then collect these data from the server, and checks if the latest parameters collected are within the comfort envelope. If the latest conditions are determined to be outside the comfortable range of values, a Python script will send the appropriate signal to a second Arduino that controls the power relay of the fan-heater.

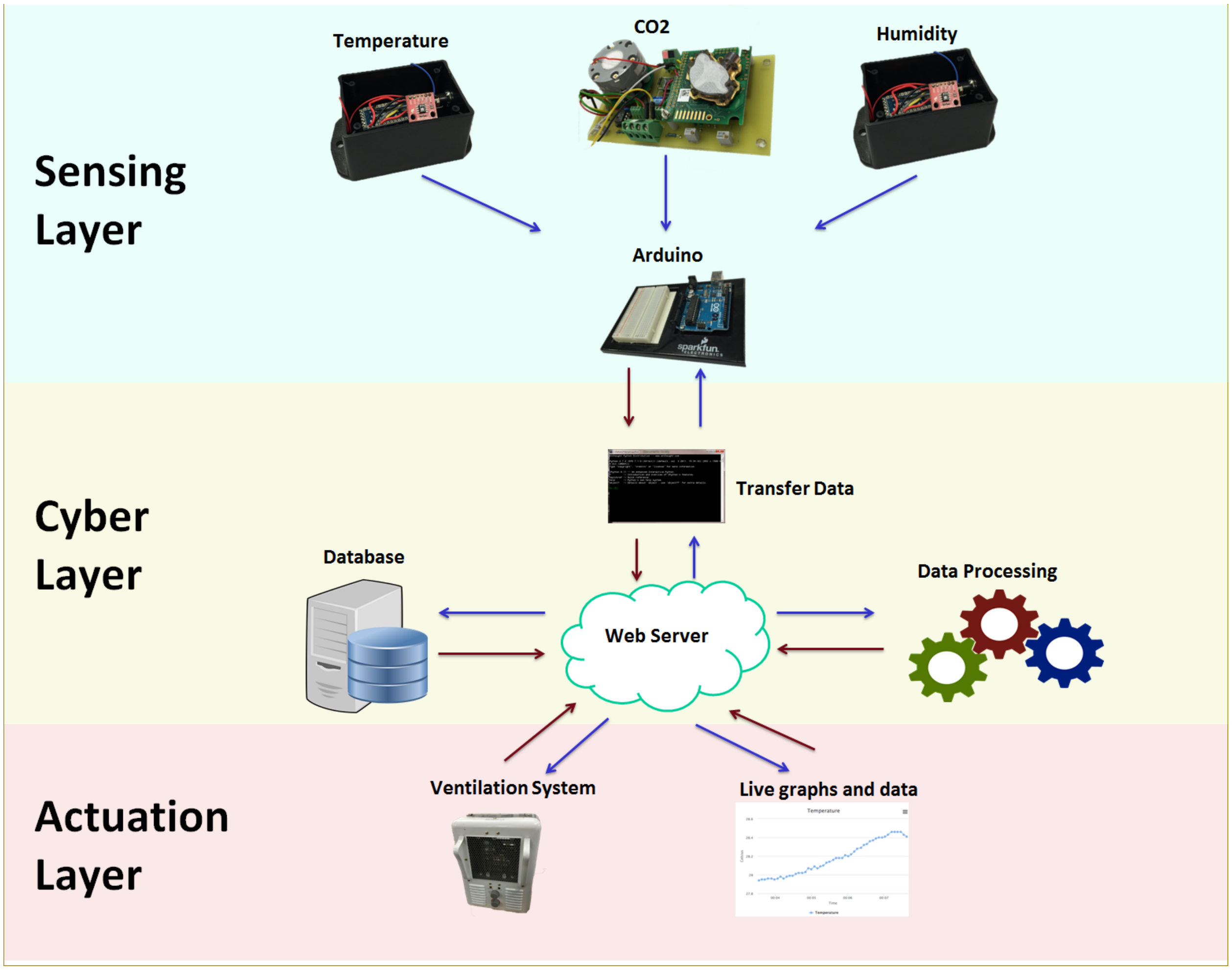

Figure 1: Structure of SPER cyber-physical system

To build our system, we used the following hardware components:

- Arduino Uno
- Temperature and humidity sensor node (mini Arduino included)
- Carbon dioxide sensor
- Fan-heater combo
- X-Bee mesh network

We used the following software programs to complete our cyber layer:

Arduino sensor code

We used the Arduino microcontroller to control the temperature, humidity, and carbon dioxide sensors. We used an existing code for reading the HIH6130 temperature/humidity sensor, and we created a simple code function using analogRead to read the K-30 CO_2 sensor.

ListenandSend.py

This program reads the serial output from the Arduino and sends this information to the web server and database. It also acts as a message relay in the other direction by sending the signal created by ProcessData.py to the actuator.

ProcessData.py

This program receives data from the database and runs it through an algorithm to determine if the current environmental conditions fall within the comfort envelope. Our criteria are an approximation established by the ASHRAE 55-2013 standard that assesses the temperature and humidity. Since there are no explicit standards for carbon dioxide levels, we set the upper limit of carbon dioxide concentration to be 600 ppm; if this limit is exceeded, we consider the room conditions to be unsuitable as well.

A status variable is initialized in this program that serves as a signal for actuation:

- Status = 0 → Good conditions, no need for fan or heater
- Status = 1 → Turn on fan
- Status = 2 → Turn on heater

In cases where room conditions are quickly oscillating around the edge of the comfort envelope, we prevent a back-and-forth oscillation between status signals by checking to see that the last 5 points of the status are consistent before making a change to the signal. This ensures that the actuator only responds to stable and clear-cut conditions.

<u>SendData.ino</u>

SendData reads the signal produced by the cyber layer and carries out the proper actuation. There is a 10 second delay implemented in between readings to prevent a frequent turning on and off of the fan-heater combo.

<u>dashboard.js</u>

This JavaScript file mainly defines the functions that can be activated in the website. Firstly, it has functions such as loadContent and loadPlot to load html structure. Secondly, it has functions such loadData and loadStreamplot that can access the web server, fetch the data and display the data in the form of graphs. Temperature, humidity, and carbon dioxide are the three variables displayed as separate graphs, and a comfort envelope based on the ASHRAE standard is also being loaded in the website. The comfort envelope visualization is drawn using the D3 library.

<u>nanodashboard.html</u>

Nanodashboard file gives the layout to our website, and adds static elements to the webpage. The dashboard is based on bootstrap Dashboard example. Bootstrap JS framework, high charts library and custom JS are all included in the html file. The webpage has a navigation sidebar and a main content container. The navigation sidebar enables a user to learn different sections of project: brief introduction, plotting or our team profiles.

Data Analysis

The ASHRAE 55-2013 standard is used to create a “comfort envelope” for evaluating the environmental conditions in the personal workspace. Referencing the CBE Thermal Comfort Tool, the graph was approximated for our own data analysis, assuming a mean radiant temperature of 25^{o}C (since this parameter cannot be measured using our available equipment). This graph plots the relationship between temperature and humidity so both parameters determine if we are in the comfort zone. When the temperature is either too low or too high for a given humidity, the heater and the fan will turn on, respectively.

However, since there is no existing standard for carbon dioxide concentration indoors, we used a recommended maximum indoor limit of 600 ppm. Beyond this concentration, we will operate the fan to simulate ventilation purposes. When scaling up this prototype, an actual ventilation system may be used instead.

The following screenshots (Figures 2-4) show what is displayed on our webpage. We display and track the levels of temperature, humidity on the plots juxtaposed by the comfort envelope. The red dot represents our current state in the room and in this example, we are within the comfort envelope so no actuation is needed. However, if the dot were right of the envelope, or if CO_2 concentration is above 600 ppm, then the fan will turn on. If the dot were left of the envelope, the heater will turn on.

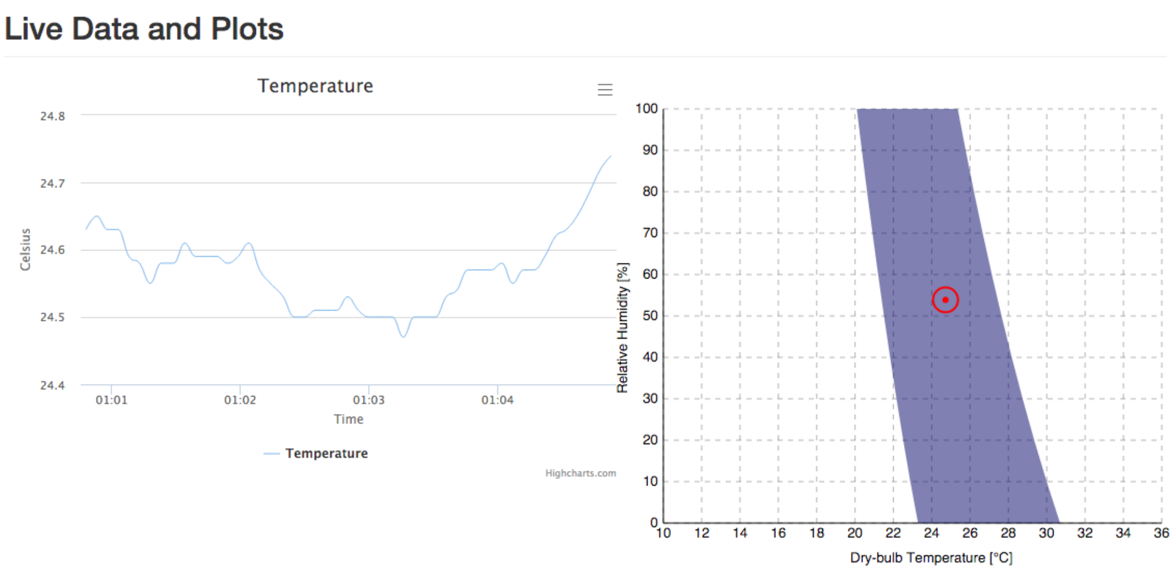

Figure 2: Live stream of temperature data

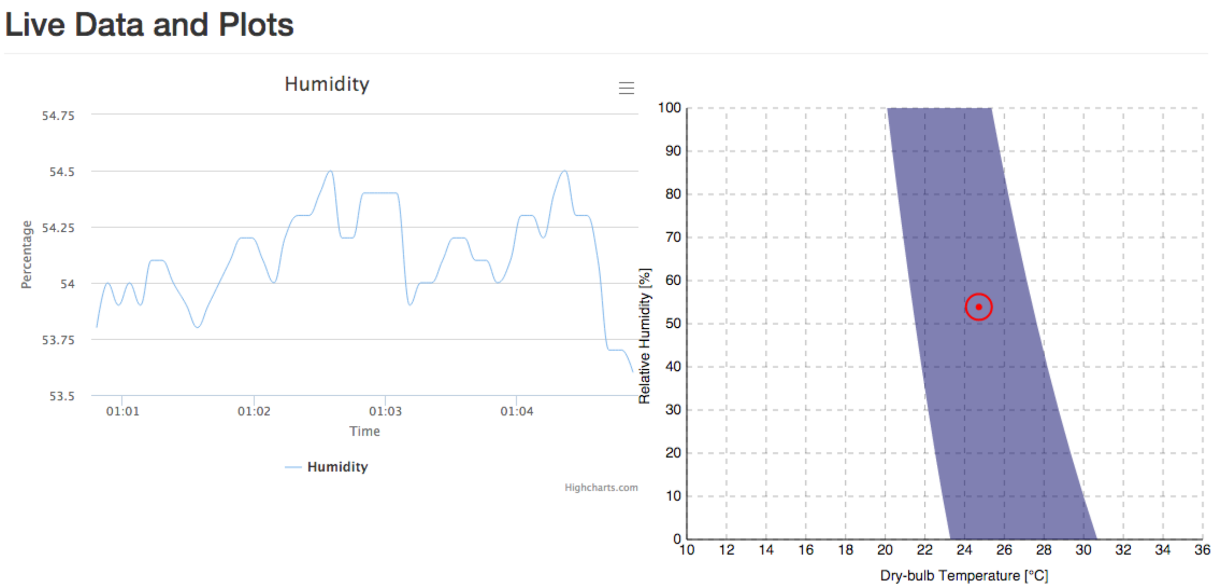

Figure 3: Live stream of humidity data

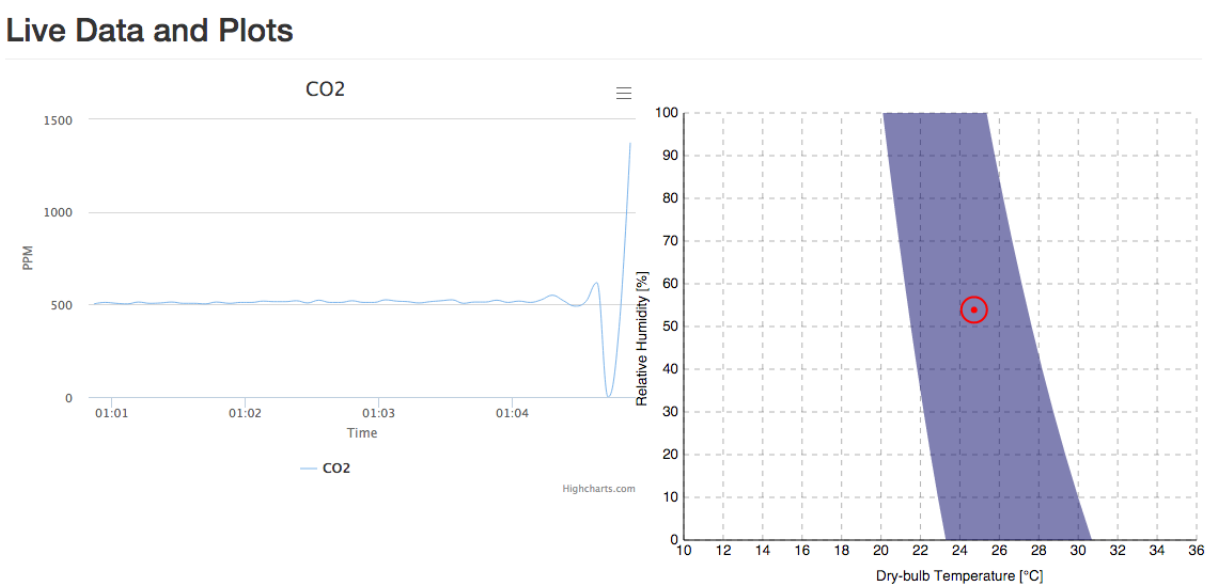

Figure 4: Live stream of carbon dioxide data

Web Visualization

The web page serves as the visualization tool for users to monitor the status of room environment and its associated comfort level, as well as displays past collected data. Figure

5 shows the overall layout of the webpage. Along the menu bar, there are options to look at the project details and background, or information on our student team. Across the top of the page, there is an option to select which plot you want to view.

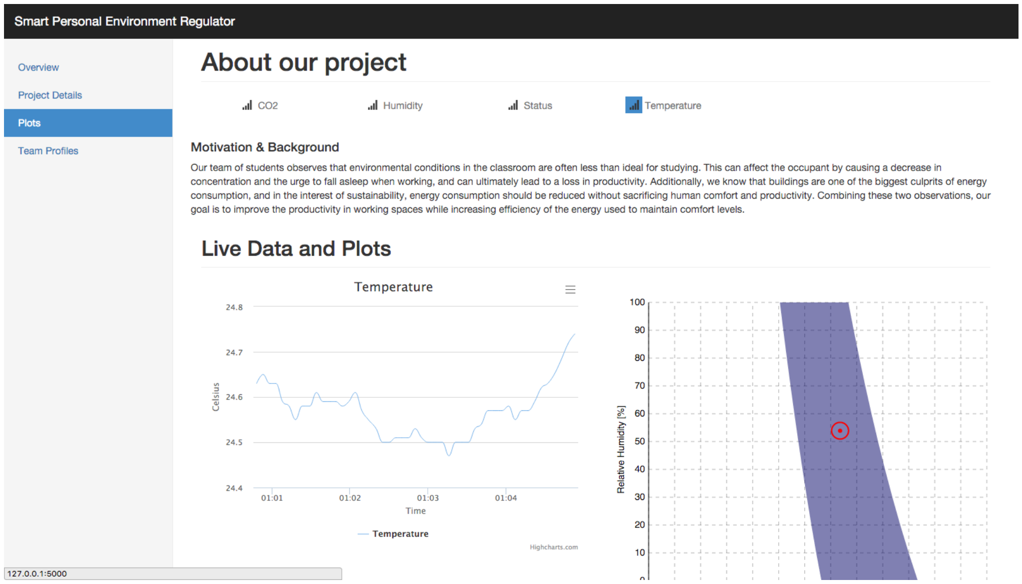

Figure 5: Screenshot of a web page that visualizes data collected

In the case that the current conditions are outside the comfort envelope like in figure 6, we can see that the red dot is right of the envelope. There is also an alert above the plots that tells the user that the fan-heater combo should be in fan mode.

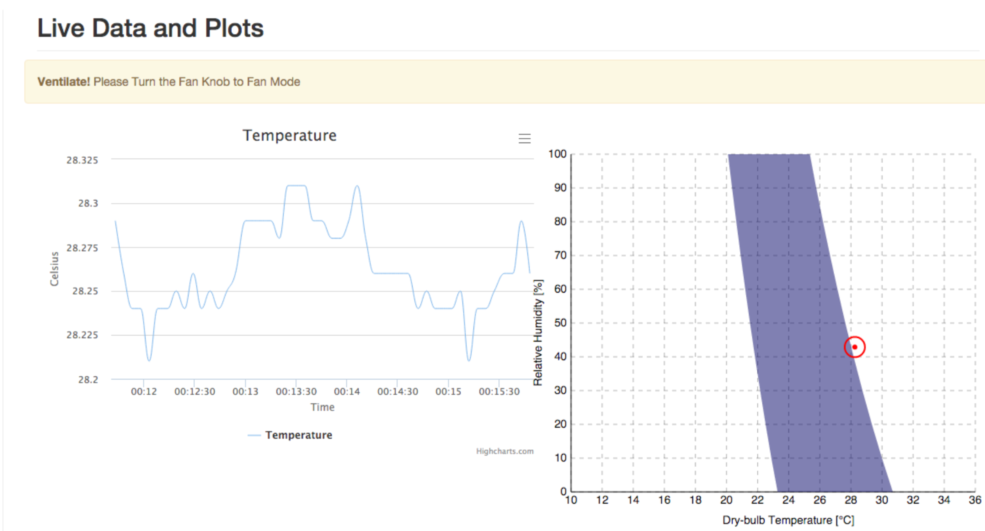

Figure 6: User alert when environment conditions are out of comfort envelope

Final Product

Our final product is shown in the figures below. The environmental sensors and the Arduino controller are placed into a customized case (Figure 7), which has holes to allow air to pass through. The data collected by the SPER module is processed and used to actuate the fan-heater (Figure 8) via toggling of a power relay.

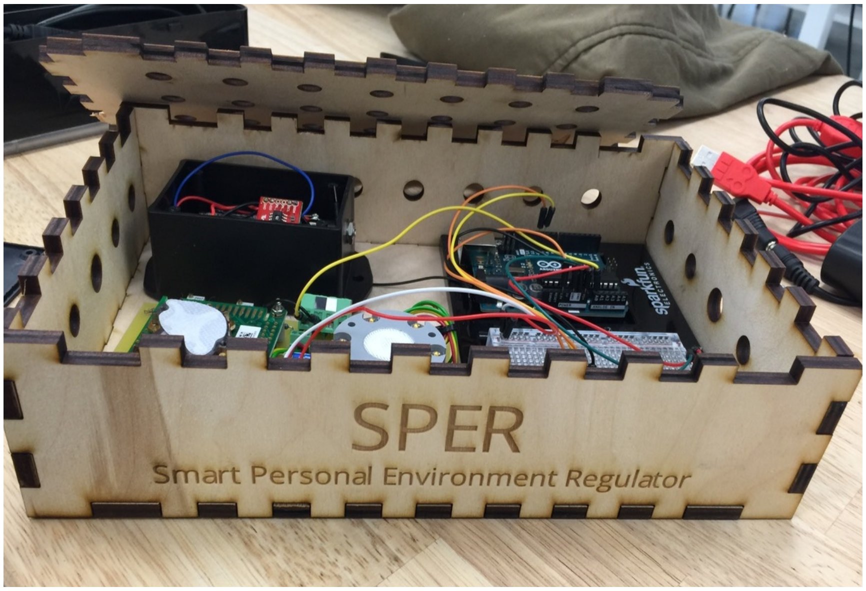

Figure 7: Customized case containing sensors and controller

Figure 8: Fan-heater actuator with controller

IV. Discussion

The SPER project addresses the problem of indoor environmental quality and its correlation to working productivity and energy efficiency. This was done using a group of sensors measuring temperature, humidity, and carbon dioxide levels and processing this data to find if the environmental conditions comply with the suggested standards.

In this project, we tested SPER in small working spaces such as a desk or a room, but it has the opportunity to be scaled up and implemented in larger working spaces. This will require multiple sensing nodes, actuating devices, and a bigger X-Bee mesh network, but will provide increased monitoring capability and potential energy savings. Furthermore, the fan-heater combo in our prototype serves as a representation of actuating devices, and can also be scaled up to include more advanced devices, such as air-conditioning or a ventilation system. By customizing the settings for the devices, a user can save energy by only controlling the actuator when occupants are in the indoor space, instead of letting the actuators run constantly.

One major limitation to a large-scale implementation of SPER is the high cost of individual carbon dioxide sensors. As such, it is recommended that carbon dioxide sensing should only be performed in areas highly susceptible to congregations of people in confined spaces for prolonged periods of times, such as in classrooms, lecture halls, underground labs and conference rooms. For all other areas, occupant comfort can be maximized through the use of humidity and temperature sensors alone.

V. Summary

The final product of the Smart Personal Environment Regulator (SPER) achieves temperature, humidity and carbon dioxide sensing and generates a signal to fan-heater combo to alter the environmental conditions if they are uncomfortable. Using the ASHRAE 55-2013 standard as a reference, we developed an algorithm to determine if current working space conditions are outside the "comfort zone," and we use this information to power the fan or heater.

Our cyber-physical system is the first prototype and it encompasses many of the initial features of a indoor air quality monitoring system. With further research and improvements, we strongly believe that this product can become useful in occupant spaces to increase productivity and comfort, but to lower energy consumption as well.

References

Canadian Center for Occupational Health and Safety (2015). *Thermal Comfort for Office Work.* Retrieved from:
http://www.ccohs.ca/oshanswers/phys_agents/thermal_comfort.html

The Huffington Post (2012). *Carbon Dioxide Levels In Meeting Rooms, Classrooms Could Affect Decision-Making: Study.* Retrieved from:
http://www.huffingtonpost.com/2012/10/25/carbon-dioxide-decision-making-meeting-rooms-classrooms_n_2006289.html

ASHRAE (2015). *ASHRAE 55 Standard.* Retrieved from:
https://www.ashrae.org/resources--publications/bookstore/standard-55

Hoyt Tyler, Schiavon Stefano, Piccioli Alberto, Moon Dustin, and Steinfeld Kyle (2013). *CBE Thermal Comfort Tool.* Center for the Built Environment, University of California Berkeley, Retrieved from:
http://cbe.berkeley.edu/comforttool/

Roonak Daghigh, Nor Mariah Adam, Barkawi Sahari, Basharia A.A. Yousef. *Thermal Comfort Study and Ventilation Evaluation of an Office*.