NREL seeks to optimize individual comfort in buildings

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Scott Jensen and Grace Brown were the first volunteers to take part in testing in NREL's Comfort Suite (C-Suite). Credit: Dennis Schroeder

On a typical early fall morning in Golden, Colorado, the temperature outside was about 70 degrees Fahrenheit. Tucked inside a unique structure at the Energy Department's National Renewable Energy Laboratory (NREL), two volunteers felt considerably cooler than that, but would soon be pushed past the outdoor conditions. The volunteers were participating in an experiment inside NREL's newly constructed Comfort Suite (C-Suite) designed to reveal the connection between

human comfort and energy systems.

The C-Suite is an experimental environmental chamber capable of making its occupants shiver or sweat. Standing 10 feet tall and 16 feet wide by 16 feet deep and located in NREL'S Thermal Test Facility, the C-Suite is designed to rapidly adopt a wide range of environmental conditions. The interior is teeming with banks of sensors that provide data about everything from the current concentration of carbon dioxide within the room, to a real-time three-dimensional map of all occupants' body positions. The C-Suite is designed to allow the rapid development of efficient energy systems that increase human comfort and performance. The space is able to simulate a range of environments that will allow different technologies to be evaluated and optimized.

Scott Carmichael, an NREL postdoctoral research fellow and project lead for the C-Suite work, said a convergence of technologies provide new opportunities for the lab to explore ways to maintain or even enhance people's quality of life while reducing their energy requirements. Wireless communications, the ubiquitous computing capabilities that come with smartphones, and advanced devices for heating and cooling open unexplored avenues to creating intelligent, adaptable, and contextually aware energy systems.

"These technologies enable entirely new ways for people to interact with the energy systems around them," he said. "The C-Suite gives us a platform to understand how humans fit into all of this."

This new room is specially designed to explore human comfort in a novel way, in order to enable vast energy-saving potential from existing building systems. Prior simulations have shown that as much as 40% of energy used by a building's heating, ventilating, and air-conditioning (HVAC) systems can be conserved by letting the building temperature float through a 5–10-degree wider range. That's not likely to make the

people living or working in that building happy, so NREL is tackling the practical problem of maintaining comfort in a highly local and personalized way. Research in the C-Suite asks test subjects to maintain their own comfort with simple automated controls, while researchers manipulate the room across a variety of temperatures.

To understand how individuals respond to changes in indoor air temperature, a custom-designed experimental apparatus was needed.

"We oversized this quite a bit," said Chuck Booten, a senior engineer at NREL whose specialties include HVAC system analysis and testing. He designed the HVAC system for the C-Suite. "In a normal house, you'd typically have two registers for a room this size, and we have 20."

The C-Suite experiments fall under Human Centered Energy Services, a Laboratory-Directed Research and Development (LDRD) program that marks the first time NREL has integrated human subjects into its research. Related experiments ongoing or about to start in Human Centered Energy Services involve testing volunteers on issues surrounding consumer products and transportation choices.

The White House is encouraging the use of behavioral science techniques, and in September issued an executive order intended to incorporate how people make decisions into policies and programs—including as a way to move the nation toward greater energy efficiency.

Overcoming Hurdles Before People Could Be Involved

NREL's Doug Arent, Stuart Macmillan, and Dane Christensen share the role of principal investigators in the Human Centered Energy Services

project, which has been extended for a second year. Much of the first year's work was spent on preparations necessary before people could be involved in this type of indoor climate testing.

The C-Suite is located in the Thermal Test Facility on NREL's campus. A convergence of technologies makes now the time for NREL to explore how people can meld concerns about energy usage with the desire to be comfortable. Credit: Dennis Schroeder

"We have to make sure that as we're doing experimentation with people we're actually protecting them," Christensen said. "Participant safety and informed consent are very critical when you're doing something like this. While this research doesn't have the same potential for harm that medical research might, we still have to go through the same steps to

prove that our subjects are safe."

Grace Brown, a recent graduate of the University of Denver, and Erik Jensen, a doctoral student at the University of Colorado, are the first volunteers. During the course of five hours inside the C-Suite, they are subjected to a trio of experiments and asked to periodically use a smartphone app to rate how comfortable they are as the temperature climbs. Sitting in a specially designed chair that is capable of sensing its environment and autonomously heating or cooling its occupant according to his or her preferences, Brown and Jensen eventually get the chance to put the controls to use to stay comfortable.

Brown said she doesn't usually give much thought to the temperature in a room: "Only if I am too hot or too cold. I think it's one of those things you don't really notice until it's a problem. If I'm too cold, I put on another layer that I hopefully brought with me. If I'm too hot, I'll try to find a fan or fan myself with something."

Dressed in slacks and a sleeveless top, Brown is already rubbing her arms in an attempt to warm herself up as the experiment begins with the temperature inside the C-Suite at 62 degrees.

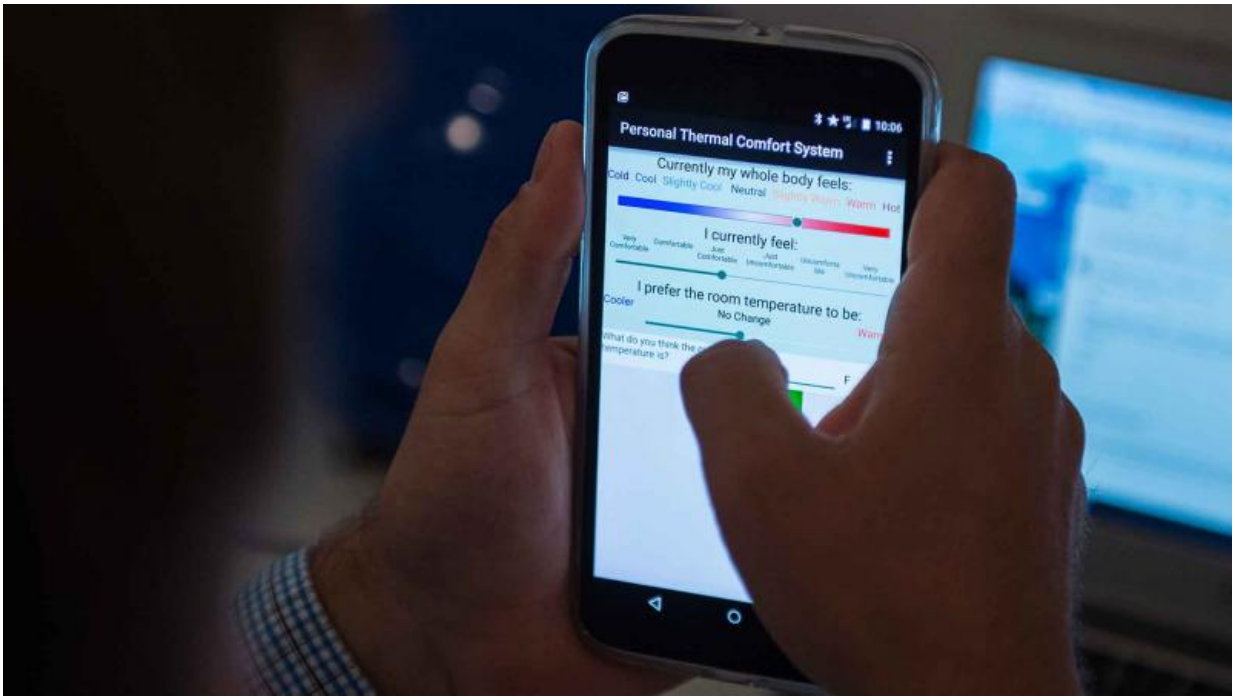
Heating, Cooling Offices Can Be Inefficient

Comfort is highly subjective. Even a person who's fine with the office temperature in the morning may find it uncomfortable by the afternoon. Trying to make an entire office of people comfortable is a major challenge. Humidity, temperature, and airflow all affect thermal comfort level, as do individual factors such as metabolism and clothing. Research published in August in the journal *Nature Climate Change* found office air-conditioning is biased toward men, because men have a faster metabolism, and women would prefer the temperature to be at least a few degrees warmer.

On the technical side, researchers are delving into new ways to keep office workers comfortable without having to ramp up heating or cooling for the entire space. So-called "personal comfort systems"—such as foot warmers and hand warmers—are among the strategies that allow someone to remain comfortable even with the building temperature as low as 61 degrees and as high as 84 degrees.

"Generally speaking, you'll be able to let the building temperature float so you use a lot less HVAC energy, and instead you use something that just conditions around a person," Booten said.

Booten said these personal systems aren't as efficient as a building's HVAC system—but they don't have to be. "You're conditioning 1% of the space, and that's a lot of energy savings. That's the ultimate goal: use the HVAC system in your building less, and still keep people comfortable."



A volunteer enters his comfort level on a smartphone app while sitting in the C-Suite. Research in the C-Suite asks test subjects to maintain their own comfort with simple automated controls, while researchers manipulate the room across a variety of temperatures. Credit: Dennis Schroeder

If everyone in an office could use a personal comfort system, Booten said, the temperature of the entire office could be as much as 6 degrees cooler or warmer. "That's a big drop in HVAC cost."

Last year, the Energy Department's Building Technologies Office consulted with about 50 people from various organizations, including Michael Deru from NREL, to help determine the best ways to halve the amount of energy used by buildings by 2030 compared to 2010 levels. As part of that overall reduction, the Department wants to see the energy consumed by HVAC systems drop by 24%. NREL's project has started to address one of the priorities: "Develop energy efficient ventilation and space conditioning techniques that reduce HVAC loads through the use of microclimates, personal comfort devices, or other small-scale comfort devices to control specific parts of a room."

Deru manages the Systems Performance section in NREL's Commercial Buildings research group. He's not involved with the experiments in the C-Suite, but he knows the inefficiencies that come from heating or cooling a large space. He explained that some HVAC systems, particularly those serving buildings in hot and humid climates, must dehumidify the outside air. Humid air is cooled considerably so that the water turns into condensation and the humidity then condenses on the cooling coil, making the air even colder. The air must be reheated before it can be blown into an office space.

"In some cases, when you turn the thermostat up to a higher temperature

you actually are using more energy than if you leave it at 72 degrees," Deru said. "Some building managers will avoid turning it up to save energy because of this reheat system."

Where NREL Research May Lead

The C-Suite is one of several new capabilities NREL is developing to investigate human comfort in buildings by improving the design and operation of these services and the energy systems that enable them. Future work will study the system-scale impacts of personalized comfort systems. The current experiments in the C-Suite are intended to provide an understanding to guide the design of larger-scale experiments. Results obtained in the C-Suite will provide information needed for the design and operation of enabling energy systems.

Arent said the C-Suite will allow NREL to conduct other experiments, including investigating how lighting, humidity, and airflow affect comfort levels.

Although it's widely known that airflow can be cooling, Arent said: "Do you know exactly how much airflow is ideal? Where should that air be? Should it be on your face or your arms or should it be on your feet? There's all sorts of things to learn about."

More information: "Energy consumption in buildings and female thermal demand." *Nature Climate Change* (2015) DOI: 10.1038/nclimate2741

Learn more about the Thermal Test Facility: www.nrel.gov/docs/fy12osti/53657.pdf

Learn more about NREL's buildings research: www.nrel.gov/buildings/

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