Poster Abstract: Well-Connected Microzones for Increased Building Efficiency and Occupant Comfort

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ABSTRACT

Personal Comfort Systems (PCS) are capable of maintaining occupant comfort in buildings despite large deviations from recommended "comfortable" temperatures. We present a novel digital controller for a well-studied (previously analog) PCS, allowing it to report real-time telemetry and respond to programmatic actuation requests. This enables the established capabilities of a PCS to be synergistically combined with occupant-aware building applications, providing new methods of comfort and energy efficiency maximization.

Categories and Subject Descriptors

C.3 [**Special-Purpose and Application-Based Systems**]: Microprocessor/microcomputer applications

Keywords

Building Application; Microzone; Personal Comfort System

1. PERSONAL COMFORT SYSTEMS

Occupant comfort is currently addressed by defining a range of temperature and humidity that *should be* comfortable and keeping the indoor environment within this zone [3]. But despite massive energy expenditure—10-20% of energy in developed countries [8]—a large portion of occupants remain dissatisfied. A survey of 215 buildings in North America and Finland showed that only 11% of buildings achieve ASHRAE's target thermal satisfaction rate of 80% [9][6].

The disparity between energy spent on HVAC and occupants' dissatisfaction is partially explained by heterogeneity of thermal comfort needs. Comfort requirements vary according to factors such as age, gender, body mass, metabolism and thermal adaptation [9]. The thermal preferences of even a single individual vary according to outdoor climate and clothing factors. Psychological aspects—like perceived control over one's environment—also play an important role [4].

BuildSys'15, November 4–5, 2015, Seoul, South Korea.
ACM 978-1-4503-3981-0/15/11.
DOI: http://dx.doi.org/10.1145/2821650.2830312.

One way to cope with varied thermal needs is to create *microzones* that maintain each occupant's environment separately from the rest of the building. Microzone environments are maintained by devices such as space heaters and local air conditioners. However, these devices may also significantly impact the macrozone maintained by the HVAC system. When a person, for example, turns on a space heater, the building HVAC system may detect the change in space temperature in the macrozone and attempt to "fight" it. One of the principal arguments against microzones is that the improvement in occupant comfort does not justify the inefficiencies that result from their opacity [2].

The issues with conventional microzones are partially solved by *Personal Comfort Systems* (PCS). PCS achieve higher levels of occupant comfort by manipulating occupants' perception of their environment without significant heat transfer—a concept known as *Task-Ambient Conditioning*, or more recently, *Personal Environmental Control* [5][1][9]. Studies [9] have shown that PCS can significantly extend the range of temperatures that occupants perceive as comfortable.

2. CONNECTED MICROZONES

Although PCS allow for proper microzones whose thermal impact is local to a single occupant, they are still opaque to the HVAC system. While the HVAC system would not sense any ambient temperature difference due to the use of PCS, they could still "fight" via simultaneous heating in the microzone and cooling in the macrozone, or vice versa. A solution is to *connect* the microzone to the building. If microzone devices are integrated with building control applications, the macrozone can synergistically combine with the microzones to more efficiently maintain occupant comfort.

In this work, we present hardware and software infrastructure that enables integration of a PCS into macrozone control processes. The advantage to creating a connected microzone from a PCS is that, by design of effecting comfort with minimal heat transfer, PCS are very power efficient. Unlike traditional microzone devices like space heaters, PCS make it possible to simultaneously realize significant energy savings and enhance occupant comfort.

3. DESIGN AND IMPLEMENTATION

To create a well-connected microzone based on a PCS, we designed and programmed an advanced controller for an existing PCS used in previous studies [7][9]. A PCS chair was chosen as it is energy-efficient, easily deployable, and successful in human trials, keeping 92% of subjects comfortable over a temperature range from 18 C to 29 C [7]. The mechanical design of the chair consists of two heating strips and three fans installed in a mesh-type office chair.

We augmented the chair with a digital controller running software to control the heaters and fans, and equipped with an IEEE 802.15.4 radio and a Bluetooth transceiver that allow telemetry of usage data and actuation from a user's phone or from control applications. A temperature and relative humidity sensor is attached to each controller, allowing measurement of these quantities near each occupant.

Although the power requirements of the fans and heating strips dominate the energy usage of the chair, they are only on when the chair is occupied. The rest of the controller is continuously on and sending telemetry, so it is advantageous to minimize its power use. The Storm module is used due to its ultra-low operating current: an unoccupied chair, or a chair occupied by a person comfortable with his or her environment, consumes less than 1 mA on average.

Users interact with the chair via an Android app. The phone uses Bluetooth to actuate the chair, but can also do so via the Internet and the 802.15.4 radio if the Bluetooth connection is lost. Similarly, remote actuation requests from the microzone control suite may be sent to the chair via either the phone or the 802.15.4 radio. Figure 1 summarizes the platform we developed.

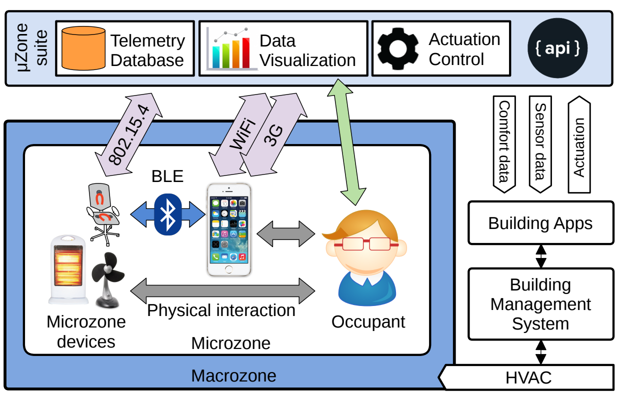

Figure 1: Our microzone-aware building control system

4. IMPACT

Currently, building HVAC control systems are stifled by a lack of feedback data. Algorithms often base control decisions over several spaces on the readings from a single thermostat and fail to account for spatial temperature gradients. Building operators only receive feedback from dissatisfied occupants who complain about the ambient temperature, prompting reactive fixes instead of methodical changes. Occupants have no way to provide feedback to control algorithms, "overcooling" being one result [2]. Our platform supplies algorithms with distributed temperature and humidity readings, provides building operators with device usage data indicative of comfort levels, and enables intelligent control algorithms that bring the occupant into the loop.

A control algorithm running on our platform can not only adjust the temperature setpoint based on chair usage data, but also leverage the bi-directional interaction our platform supports. One such algorithm would be to wait for a majority of the occupied chairs to indicate they are too cold or too warm, adjust the setpoint and wait for equilibrium, and then reset the chairs' settings and repeat the process. The chairs can also be used to transparently handle demand response by adjusting the macrozone temperature setpoint to save energy, but also actuating the chairs to maintain occupant comfort. We have experimentally verified that our system can support such algorithms.

Aside from intelligent control of HVAC, control algorithms can identify an occupant by mode of interaction—a mobile phone for example—and learn about each occupant's thermal comfort needs. This allows not only for personalized models of occupant comfort, but also for "empathetic" building applications. For example, the building can read a shared calendar, and pre-heat or pre-cool a meeting room according to the profiles of those attending the next meeting.

It is clear that well-connected microzones offer many potential advantages and are worth exploring further. We believe that this platform is a critical step in the evolution of both Personal Comfort Systems and microzones.

5. ACKNOWLEDGEMENTS

This work is supported in part by the National Science Foundation under grant CPS-1239552 and by the California Energy Commission under grant PIR-12-026.

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