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SCOTT ELROD, GENE HALL, RICK COSTANZA, MICHAEL DIXON, AND JIM DES RIVIERES

Responsive Office Environments

A team of facilities staff and computer science researchers at Xerox PARC is exploring applications of ubiquitous computing to energy management and environmental control [1]. By interconnecting PARC's rich computational infrastructure with a computerized building management system (BMS) that controls heating, air conditioning, lighting and desktop appliances, we plan to explore new strategies for energy conservation and office comfort control.

Over the past 20 years, the designers of heating, ventilation, and air conditioning (HVAC) systems have gradually shifted toward the use of digital computers [2], replacing direct manual control and simple analog feedback loops such as thermostats. Digital control makes possible more flexible, precise, and complex control strategies that in turn can provide significant energy savings. For example, most computer-controlled buildings offer automatic temperature setbacks to reduce energy consumption after working hours and on weekends. Many systems also control lighting to save additional energy.

Current progress in low-cost distributed computing, communications, and sensing technologies will enable future building management systems to be much more responsive to individual preferences and activities. The following are examples of the types of enhancements that are possible:

- Small, location-sensing mobile computers such as PARCTabs provide an ideal interface to allow office occupants and maintenance staff to set parameters (such as preferred ranges for temperature and light level) and receive feedback about current conditions.
- Occupancy sensors are already used at PARC to avoid heating or cooling conference rooms when they are not in use. We are now experimenting with user-selectable strategies for switching off lights, computer displays, and other appliances and for setting back the air conditioning when offices are unoccupied.
- Other sensors can be integrated into the system to provide additional automatic functionality, such as adjusting artificial lights and/or closing blinds to compensate for changing natural light levels, lowering light levels while a workstation is in use, and adjusting ventilation depending on whether doors are opened or closed.
- Active badges and on-line calendars may be used to identify periods in which an office's occupant will be away for an extended period of time (e.g., because the occupant is at a meeting, at lunch, or away from the building).

To quantify the potential for energy savings by such strategies, we conducted a detailed one-day energy and occupancy audit of PARC's Computer Science Laboratory. This study revealed that offices are typically vacant for 50% of the average 9-hour workday. Initial calculations suggest that occupancy-based control of lights and computer monitors alone would save $45,000 per year at PARC, and similar control of the air conditioning system could save as much as $90,000.

Encouraged by these estimates, we have constructed a flexible hardware and software testbed to experiment with new energy control strategies. The testbed consists of 13 offices and some adjacent public areas. Within each office we have installed temperature, light level, occupancy, and active badge sensors together with computer-controlled ventilation, heating, electric outlets, and overhead lighting. These devices are connected to a conventional computerized building management system, which in turn is connected to the PARC computer network through a gateway. Using a conventional building management system as the backbone allows us to ensure that the system's basic functionality is highly reliable, while still allowing new control strategies and data analysis to be run from workstations.

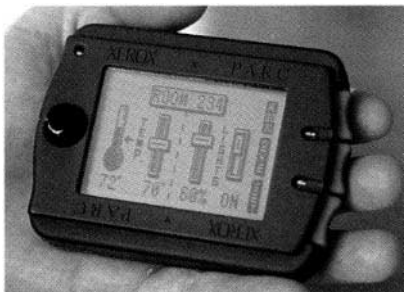
As of this writing (March) the complete system is just coming on-line and we are beginning to collect the baseline data needed to evaluate future energy savings. At present, the system continuously logs over 800 variables from the test area and from other parts of the building. Over the next few months we plan to experiment with a variety of control strategies and user interfaces (UIs) and measure their effects.

In the development of this system we encountered a number of design issues common to many ubiquitous computing systems:

- *reliability and invisibility:* Computer systems entrusted with such basic aspects of comfort as temperature and light levels must obviously be highly reliable.

serious failures could make the building uninhabitable. In fact, the system should do its job well enough that the occupants are usually not aware of its presence.

- *privacy:* The use of occupancy and active badge sensors raises concerns about the possibility of invasive monitoring of employee work patterns. For our project, we are addressing these concerns by developing a privacy agreement between the test area occupants and PARC management which delimits the acceptable uses of occupancy data. We have also installed a wall switch in each office that cuts power to the occupancy sensor and disables all experimental software. This enables the office occupant to ensure privacy when desired and also to regain control in the case of a software failure.
- *access control:* Our gateway to the building management computer implements a simple conventional password scheme to restrict access to particular devices, but this is not ideal. For example, if I am temporarily using your office, I should be able to turn the lights on and off. It is probably undesirable, however, for me to have access to your lights when I am not physically in your office. We believe the appropriate access control for systems like this must be based on location as well as identity.



A PARC Tab handheld computer being used to adjust office temperature and lights.

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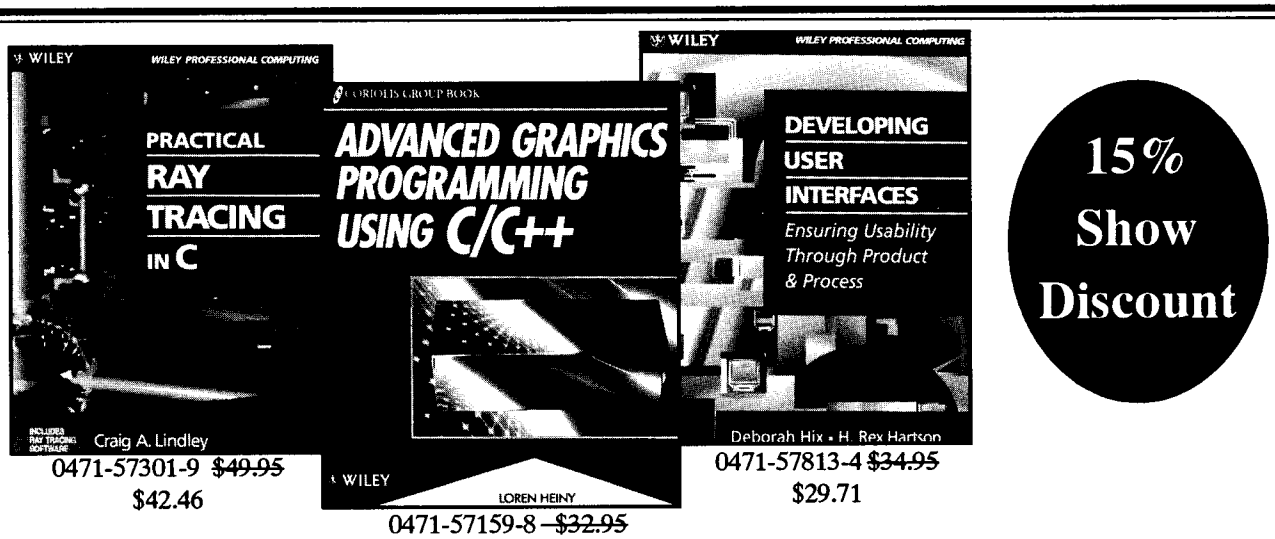

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