**Review of *Duty-Cycling Buildings Aggressively: The Next Frontier in HVAC Control***

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**Summary**

The paper is about the effects, of HVAC control system, on the energy consumption of a modern building. The Computer Science and Engineering (CSE) building in UC San Diego is taken as an example which the HVAC system is applied to. In this paper, there are four main aspects:

First, the paper presents the general HVAC system effect on the CSE building. The authors use figures to show the Power consumption breakdown for the CSE building and HVAC power consumption. From an experiment, the authors concludes that the closer the HVAC system is to maximum cooling, the more costly cooling each floor becomes. The phenomenon implies that reducing HVAC loads during the workdays for even a few zones can potentially have significant savings in energy.

Second, the paper introduces a kind of system architecture. The system consists of occupancy nodes, data collection network, and data analysis and control. For occupancy nodes, there are two requirements, which are ease of deployment and accuracy of detecting occupancy. For data collection network, deploying dedicated base stations in a star topology can relay data from the sensor radios to the rest of the infrastructure and the base stations are placed carefully in order to ensure good radio coverage to all occupancy nodes. For data analysis, the analysis can be performed in a different PC and server and requires long term trending and sensor data storage. Control is based on the data analysis and the entire system is controlled and monitored by Energy Management System that can send command for each zone.

Third, the paper describes the system’s implementation. This implementation is composed of building test bed, wireless occupancy-node network, occupancy sensor module, back-end infrastructure and HVAC control. They conducted the test bed experiment on the second floor. They placed nine base stations for complete coverage and chose the single-hop star architecture. Then they configured the nodes to connect to the nearest base station with extended PAN ID and to start sending data to its parent. The Occupancy Data Analysis server (ODAS) runs a process that retrieves zone temperatures from the Windows server and stores it in the ODAS database. To control the building HVAC the ODAS sends a zone HVAC command back to the Windows server. If a new command arrives the actuator client will write the value for the OPC item to the BACNet OPC server. Two programs are used to implement the system. One is to check the occupancy of every zone and it will turn off unoccupied zones. The other is used to check the temperature for every occupied zone and it will turn on HVAC if the temperature is above 76deg F or below 66deg F.

Fourth, the paper provides an evaluation of such a system in two aspects. One is testing the accuracy of occupancy nodes; the other is testing the efficiency of energy saving. In the first testing, a figure shows the comparison between ground truth and sensor results over a day for three representative nodes in three rooms. With another figure the paper presents occupancy patterns of seven representative rooms, i.e. staff, meeting room, post doc, researcher, faculty, test lab and grad student, over four days. In the second testing, three figures present the comparison of energy consumption between the first test day and the baseline and that between the second test day and the baseline day. In the first day, the HVAC- electrical savings are 11.59% while the HVAC-thermal savings are 12.41% and 9.59% for cooling and heating loads respectively. In the second day, the HVAC- electrical savings are 9.54% while the HVAC-thermal savings are 12.85% and 11.51% for cooling and heating loads respectively.

**Strengths and Contributions**

First, a low-cost and high-accuracy wireless occupancy sensor node is designed and implemented. The total cost of the custom wireless board is less than USD$10 in quantities of a thousand including parts and assembly. The authors implemented the base stations using inexpensive $100 Linux based plug computers. To increase the accuracy they used multiple sensors to eliminate false or inaccurate detection.

Second, the well-functioning control architecture is used to actuate individual HVAC zones based on occupancy information. The occupancy sensor nodes are able to accurately detect presence of occupants. A wireless network infrastructure is able to reliably collect data from occupancy nodes and relay it to the back end server infrastructure for data collection and analysis. The control architecture interfaces with the existing building EMS systems to actuate the HVAC system selectively based on occupancy.

Third, system evaluation, in terms of energy savings, is enabled by the HVAC system described in the paper. They conducted experiment in two sets. One in late October 2010, and the other in late February 2011, gives us data over two seasons (fall and spring). Running the experiments over these two seasons offered us the opportunity to determine how the system is effected by different outside temperatures.

Fourth, how to deploy the occupancy nodes and how the nodes work are described. Nine base stations are deployed for complete coverage and single-hop star architecture is used. They configure the nodes to connect to the nearest base station with extended PAN ID and to start sending data to its parent. Once the wireless nodes are connected, the nodes will send event messages whenever an occupancy event happens. In addition, the nodes transmit a heartbeat status message every fifteen minutes so that the base station and central server can determine if a node has fallen off the network. This heart beat period can be made even longer to conserve energy and further increase node lifetime.

**Weaknesses**

First, only second floor is allowed to deploy the experiment of HVAC control system on. However, controlling all four floors will lead to even more savings.

Second, the occupancy nodes were placed in poor positions because gusts of air could actuate the sensors. If they increase the distance between door and sensor, this detection error will reduce considerably.

**New Research Opportunities**

First, combining HVAC with IT resources, driven by occupancy information, presents another optimization opportunity. Accuracy and real-time occupancy information is critical to detection of occupants, especially those with limited mobility or accessibility. Thus, how to increase the accuracy and how to make the occupancy information more real-time are important.

Second, new function will be added so that users can adjust their preferences in real time to remotely adjust their HVAC preference.

Third, more sophisticated control methods will be used. Such control methods, processing greater amount of available data, can drive very optimal HVAC schedules that conserve energy and increase comfort.