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FIELD EVALUATION OF HOTEL/MOTEL THROUGH-THE-WALL HVAC SYSTEMS SUPERVISORY CONTROLLER

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ABSTRACT

Several potential energy-savings devices are available for through-the-wall HVAC (heating, ventilation, and air-conditioning) systems but independent test data quantifying their savings are sparse. This field evaluation and demonstration study quantifies the potential energy savings and assesses the impacts on occupants and staff of using a supervisory HVAC controller in the lodging industry. The supervisory controller operates according to the occupancy status of each room in a hotel or motel. The controller is a plug-in device installed between a wall outlet and the room HVAC unit. Preliminary tests in laboratory simulated environmental conditions suggest that energy savings ranging from 50% to 80% are possible in unoccupied lodging rooms employing the controller (Fisher, 1999). The field study objective was to quantify and verify these estimates and to identify impacts on occupant comfort. The controller was developed as a tool for reducing energy consumption and lowering operating costs in the lodging industry. This paper describes results from a field evaluation of the performance of a supervisory HVAC controller. During the test period, the uncontrolled rooms HVAC energy consumption averaged 2632.2 kWh monthly while the controlled rooms HVACs consume an averaged 1684.6 kWh, which equates to the uncontrolled rooms HVAC consuming an averaged of 947.6 kWh (56.3%) more energy than the units in the controlled room monthly. Due to intermittent inoperability of the controllers and other energy loads (controllers controlled approximately 50% of the hotel's conditioned space), comparison analysis of the energy cost over a three-year period for the entire hotel does not reveal any discrete savings during the test period over prior years.

INTRODUCTION

The commercial sector in the USA consumed 32% of the total electrical energy, which equated to 15.4 quads of energy in 1998, and the sector's energy consumption is estimated to increase to 18.2 quad by 2020 (DOE/BTS, 2000). HVAC accounts for 31.8% of the total energy consumed in the sector. Packaged HVAC systems make up 82% of the HVAC equipment being utilized in the sector. The lodging industry is 9% of the sector, and its HVAC usage accounts for 30.8% of the total energy used by the industry. Laboratory tests of the controllers in an environment simulation room indicate that energy savings ranging from 50% to 80% are possible during unoccupied periods. A one-year field evaluation of the controller was initiated in September 2000 at a Tennessee hotel. A total of 163 controllers were installed in suites and single rooms, and 24 of these locations were monitored. Data downloads were conducted nightly and automatically using an on-board, dial-out modem inside the monitoring-DAS device. The hotel was the first test site for the controller. A second test is underway at a small resort motel in Florida, which allows evaluation of the controller in a more severe cooling-demand climate.

The primary functions of the supervisory control unit are to: monitor the power supply of the HVAC unit (protect it from high or low voltages), respond to room temperature extremes and/or an alarming smoke detector (by generating a phone call followed by an alarm code), and enable remote programming and control of various dial up commands and functions. If a power interruption or brownout occurs a programmable timer delays power transmission to the unit after site power is restored to prevent damage to the unit. Power to a unit can be terminated indefinitely via dial up access to the controller. If Temperature Control Mode is selected an air conditioning unit would be powered off if the room temperature was within the high and low temperature setpoint limits. If the room temperature were not within these limits, the controller would allow the HVAC to turn on to prevent damage to the room. The room controller also can detect a smoke alarm beeping. The controller will dial and beep if a smoke detector is alarming or if the temperature in the room is very hot or cold.

INSTALLATION AND TECHNOLOGY DESCRIPTION

The supervisory controller units and the monitoring-DAS units were installed in a hotel in Pigeon Forge, Tennessee in September 2000. A total of 163 supervisory control units, one per room, and 24 monitoring-DAS units were installed. Of the 24-monitored rooms, 12 reference rooms were not equipped with supervisory controller units. Since the hotel had various room configurations (whirlpool tub, fireplace, kitchenette, etc., see Figure 1), rooms with controllers and reference rooms were matched based on size and orientation. After installation, the controller manufacturer made several software and hardware modifications to their units during the one-year test period. Data downloads from the 24 monitored rooms were conducted nightly and automatically using an on-board, dial-out modem

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inside the monitoring device. The field study test at the hotel ended October 2001.

Figure 1. Test Site (Pigeon Forge, Tennessee)

The supervisory controller unit was developed as a tool for reducing energy consumption and protecting the HVAC units in low and high voltage situations; therefore lowering operating costs in the lodging industry. The primary functions of the supervisory controller unit are to: monitor the power supply of the HVAC unit (protect it from high or low voltages), respond to room temperature extremes and/or an alarming smoke detector (by generating a phone call followed by an alarm code), and enable remote programming and control of various dial up commands and functions. A communication link via telephone (computer modem or touchtone phone keypad) is established between each supervisory controller unit and the front desk, using the in room phone line and a phone line splitter. When a PC is used, the software and host interface unit is required. A desktop PC is located at the hotel front desk as shown in Figure 2. When the software is activated a dialog box appears which allows the user to enter a password that determines the managers or the front desk clerks entry level, as shown in Figure 3. The managers security code begins with the asterisk key '*' followed by four numerals ending with the pound ' #' key. This level permits programming and/or modification of the supervisory controller's parameters and dial up commands (setup room controller). The front desk clerks security code has four numerals and ends with the pound '#' key, giving access to dial up commands only (Check In or Out).

Figure 2. Front desk computer at front desk, installed controller, controller circuit board

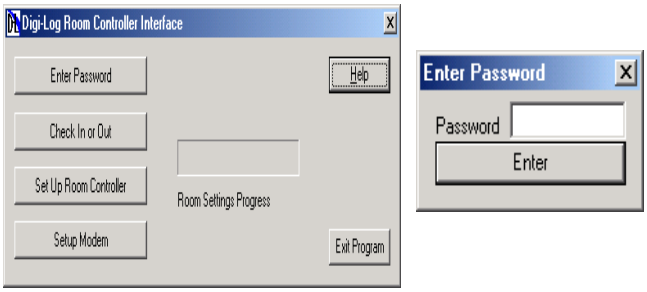

Figure 3. Supervisory controller interfacing software initialization

Filling in information requested by the menus in Figure 4 completes the room setup. If the temperature control mode is "on" and the "unoccupied" mode selected, the HVAC unit will be powered off if the room temperature is within the unoccupied high and low programmed temperature limits. If the room temperature is above or below these limits, the power controller unit would allow the HVAC unit to be activated tosatisfy the temperature limit setpoints. If the Temperature Control Mode is "on" and the "occupied" mode selected the HVAC unit will be powered off if the room temperature is within the occupied high and low programmed temperature limits. However, if the room temperature goes below the low temperature limit or above the high temperature limit the HVAC unit will be powered on to maintain the temperature limits. The winter or summer mode is automatically selected by the Power Controller's software and will change as outside temperatures dictate. However, at a guests request the summer/winter mode can be reversed or the temperature control mode can be turned off giving the guest complete control of the HVAC unit.

After the manager has entered and completed Set-Up (filling in the Room Check In or Out, Room Parameters, and Modem Setting, Room Heat Pump Enable), all rooms are

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programmed. The front desk clerk can now enter the Check In or Out Status by choosing the Check In or Out button on the Room Heat Pump Enable menu as hotel guest checks in or out, as shown in Figure 4. In order for the Power Controller Unit to function properly the housekeeping staff must make sure the HVAC unit is turned to the "on" position as they leave the room. If a power interruption or brownout occurs, the Power Control Unit interrupts the power supply to the HVAC unit. The HVAC unit will not be reconnected until site power has been restored and the programmable time delay period expired, this prevents short cycling of the compressor and prevents restart load damage.

The Power Controller Unit will call a pre-programmed call back number, generating a dual tone alarm code, if the temperature in the room is more than 5 degrees above or below the programmed high or low temperature limits of the unoccupied mode or if an in room smoke detector is alarming. The recipient of the call acknowledges the alarm, causing the alarm to cease, by pressing the '7' on the telephone keypad. If the recipient hangs up the phone without acknowledging the alarm, the controller will immediately call back and continue to generate the dual tone alarm codes. After the alarm has been acknowledged the alarm function will be cleared allowing another alarm to occur.

Monitoring Method and Device

The approach taken to carryout the field evaluation study was as follows:

- Develop an instrumentation plan and data acquisition (DAS) hardware
- Identify test sites based on climate, complex size and historical energy consumption
- Rooms selected for evaluation was based on occupancy, exposure, orientation, and location within the complex
- Install controller and monitoring-DAS devices (boxes beneath HVAC unit shown in Figure 2),
- Monitor room conditions and HVAC performance for one year
- Use survey tools to determine impact on occupants and hotel staff
- Analyze system performance and publish findings

A monitoring-DAS packaged device that was compatible with the controller was developed to monitor the controller performance during the study. It records: (1) electrical current to the HVAC unit, (2) room temperature, (3) room humidity, and (4) occupancy status/voltage to the HVAC unit. A data logger was included in the packaged device, which must be preprogrammed using Pace's software prior to field installation. Data must be entered into two menus - one to program the device and the other to program the host computer, as shown in Figure 5. Data in spreadsheet format was downloaded from the 24 monitored rooms nightly and automatically using an on-board, dial-out modem inside the monitoring-DAS device. The device facilitates collection of performance data on the HVAC controller and is shown in Figure 6. Spreadsheet utilities were used to reduce and analyze data.

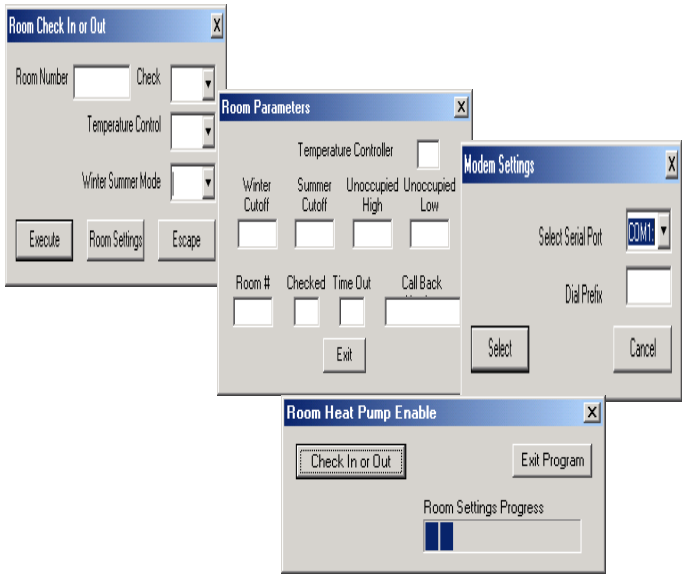

Figure 4. Check-in & out, room parameters, modem settings, and executing (heat pump enable) menus

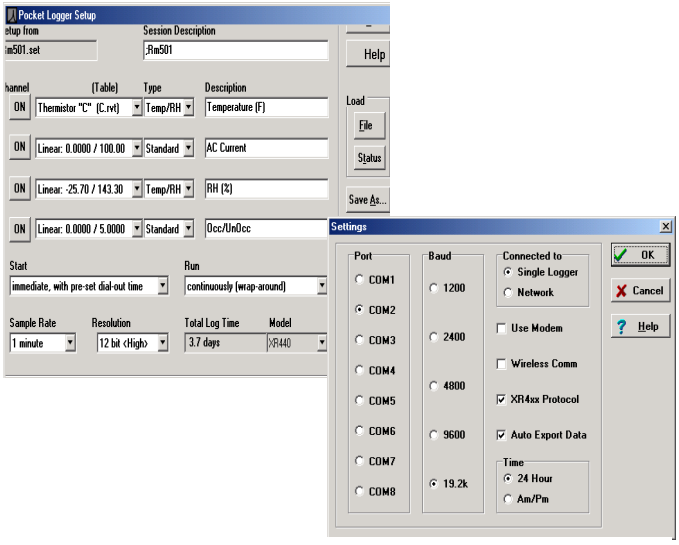

Figure 5. Data logger setup for monitoring-DAS device and host computer (right)

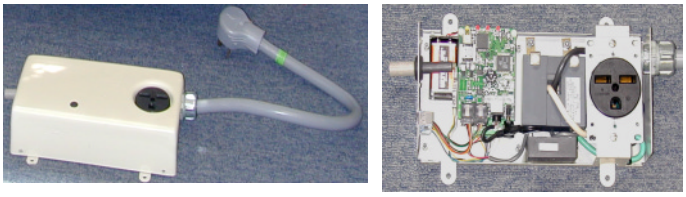

Figure 6. ORNL monitoring-DAS device

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TECHNOLOGY PERFORMANCE RESULTS

Test Rooms Analysis

The yearly occupancy and energy use for the hotel rooms with controllers (controlled) and rooms without controllers (uncontrolled) was determined from data acquired by our laboratory monitoring-DAS devices. Data illustrated in Figure 7a shows that rooms equipped with controllers were occupied roughly the same number of days as those without controllers except during December 2000 and February through April 2001. The HVAC energy consumption in the controlled rooms is consistently less than that in the uncontrolled rooms. The uncontrolled rooms HVAC energy consumption averaged 2632.2 kWh monthly while the controlled rooms HVACs consume an averaged 1684.6 kWh, which equates to the uncontrolled rooms HVAC consuming an averaged of 947.6 kWh (56.3%) more energy than the units in the controlled room monthly during the test period. Figures 7b and 7c show the averaged daily energy consumption per HVAC unit monthly for the controlled and uncontrolled rooms during occupancy (temperature limits: 69°F minimum—summer, 76°F maximum—winter) and vacancy (temperature limits: 83°F maximum—summer, 50°F minimum—winter). When controlled rooms are occupied, the daily averaged energy consumption per HVAC unit ranges from 3.5 to 10.6 kWh/day, averaging 6.7 kWh/day as reveal in Figure 7b. Whereas during occupancy for the uncontrolled rooms, the energy use ranges from 5.5 to 14 kWh/day, averaging 8.8 kWh/day. On average, each HVAC unit in the uncontrolled rooms consumes 32.1% more energy than those in the controlled rooms during occupancy. During vacancy, the uncontrolled rooms HVACs averaged daily energy use per unit ranges from 3.5 to 13.6 kWh/day, averaging 8.3 kWh/day as shown in Figure 7c. When the controlled rooms are vacant, the HVACs energy consumption ranges from 2.7 to 10.2 kWh/day, averaging 5.8 kWh/day. Each HVAC unit in the controlled rooms consumed 43.1% less energy than the HVAC units in the uncontrolled rooms when the hotel room is unoccupied. During the test period, there were not any significant comfort differences between the controlled and uncontrolled rooms, indicating that the controller did not compromise comfort.

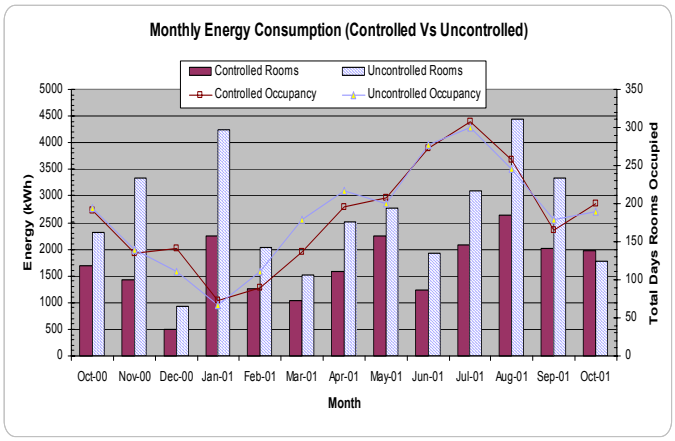

Figure 7a. Energy consumption and occupancy of controlled and uncontrolled rooms

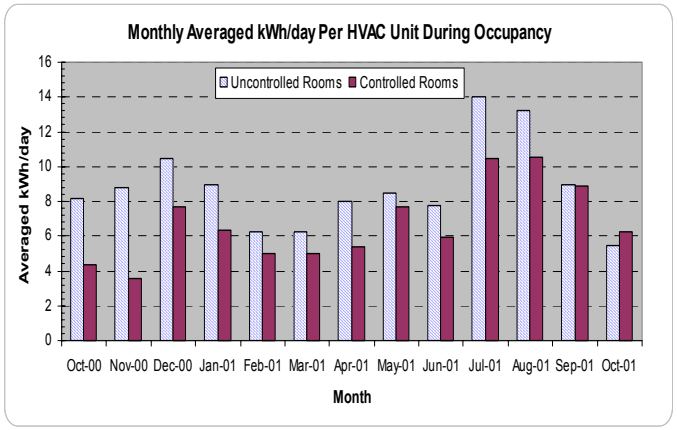

Figure 7b. Averaged daily energy consumption per room (HVAC unit) during occupancy of rooms

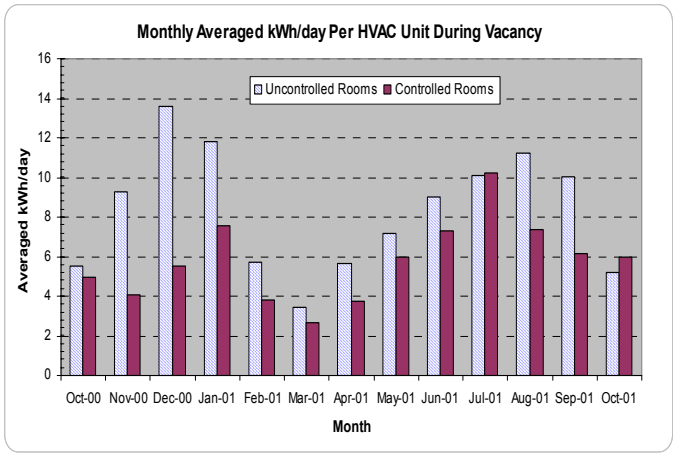

Figure 7c. Averaged daily energy consumption per room (HVAC unit) during vacancy of rooms

Hotel Analysis

All hotel rooms were equipped with supervisory controllers (163 rooms, one per room, excluding 12 uncontrolled rooms) for the duration of the test period. The total energy impact on the hotel was evaluated by comparing the kW usage on the electricity bills over the last three years. During the test period (2000/2001), the kW usage was lower for seven of the 12 months (January-February, May, and July-October) than the previous year (1999/2000) during the same interval, as shown in Figure 8. For the test period, the hotel consumed 30395 kW (1.5%) less energy than it used the previous year (1999/2000). During 1998/1999, the energy usage was higher 5 of the 12 months than that consumed during the test period (2000/2001), with comparable usage for March and May. The small energy consumption differences are partially attributable to 1) the higher number of heating degree-days (HDD), shown in Figure 9, during November 2000 through January 2001 than for previous years, 2) having supervisory controllers managing around 50% of the hotel

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conditioned space, and 3) the total hotel energy usage not only accounts for the HVAC energy but also for energy use of lighting and other electrical accessories and appliances. Each room is outfitted with a microwave, television, and refrigerator. The 1998/1999, 1999/2000, and 2000/2001 cooling degree-days (CDD), sited in Figure 10, are roughly within 50 CDD of each other during the core-cooling season (June – August) and appear to have minor differentiating influence on the energy usage. Table 1 shows the calculated energy cost per HDD and CDD. The averaged energy $/HDD is less during the October 2000-2001 test period than that of the previous two years. But, the averaged energy $/CDD is higher during the test period than that of the previous two years.

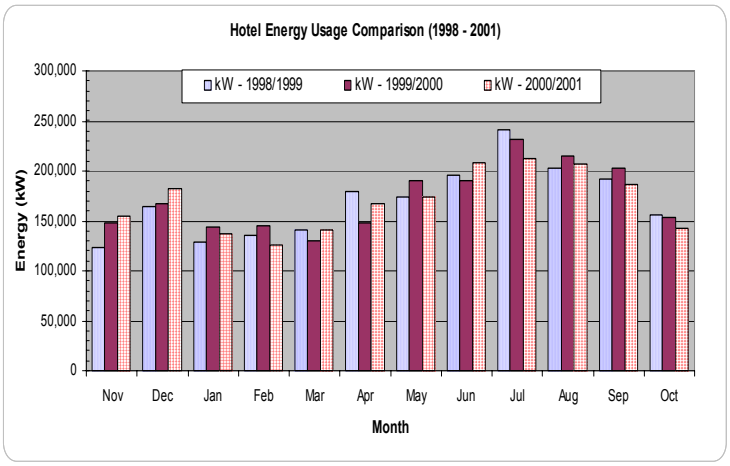

Figure 8. Monthly kW Usage of the Hotel (October 1998 – 2001) (furnished by Hotel's CFO, Alvin Adams)

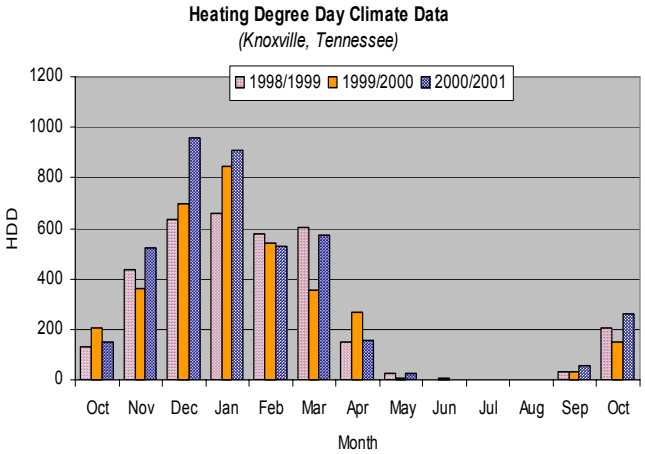

Figure 9. Monthly Heating Degree Day for Knoxville (October 1998-2001)

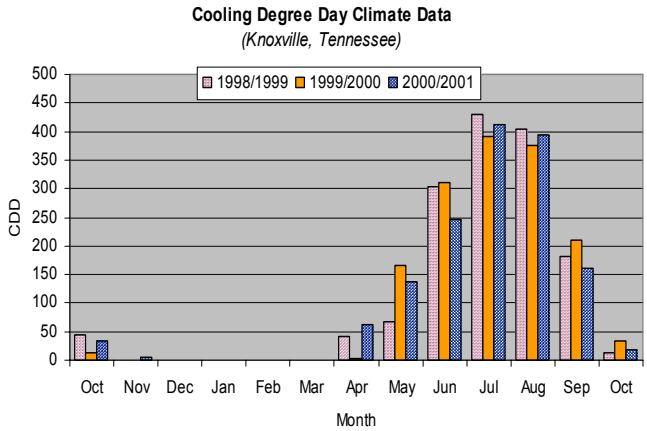

Figure 10. Monthly Cooling Degree Day for Knoxville (October 1998-2001)

Table 1. $/HDD and $/CDD for Music Road Hotel (Knoxville, TN Climate Data (1998 – 2001)

	1998/1999		1999/2000		2000/2001	
	$/HDD	$/CDD	$/HDD	$/CDD	$/HDD	$/CDD
Oct						
Nov	16.49		23.45		16.70	
Dec	14.97		13.38		10.46	
Jan	11.78		10.87		12.11	
Feb	15.14		17.79		14.14	
Mar	14.17		21.16		13.85	
Apr						
May						
Jun		34.62		33.65		45.19
Jul		28.91		30.98		27.98
Aug		27.31		30.77		28.33
Sep		56.11		51.47		64.42
Maximum	16.49	56.11	23.45	51.47	16.70	64.42
Minimum	11.78	27.31	10.87	30.77	10.46	27.98
Average	***14.51***	***36.74***	***17.33***	***36.72***	***13.45***	***41.48***

DISCUSSION AND CONCLUSIONS

On average, each HVAC unit in the uncontrolled rooms consumes 32.1% more energy than those in the controlled rooms during occupancy. Each HVAC unit in the controlled rooms consumed 43.1% less energy than the HVAC units in the uncontrolled rooms when the hotel room is unoccupied. The kW usage for the total hotel was reduced by 1.5% over that of the previous year. The rationale for dissimilar energy reductions between the data results for the 24 monitored rooms and that for the entire hotel is that the controllers were inoperative for several intervals of the test period. Periods when controllers were not functioning are delineated in Table 2. Inoperability that incorporated all controllers was caused by power glitches, brown outs, and software/controller adjustment. There was a direct relationship between power interruptions

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and occupant complaints. Initially about 5 to 6% of the hotel occupants complained after a power interruption. After modifying the software, complaints were reduced to between 3 to 5%. Subsequent to making the first component change to the control board the occupant complaints were reduced to roughly 1%. Since the final circuit modification, there are no records of guest complaints. Random inoperability involving a limited number of controllers was hotel occupant, housekeeping, and/or maintenance staff dependent. The controllers were deactivated after room occupant complaints about the HVAC system, thereby causing inoperative intervals. The 12 monitored controlled rooms device deactivations were minimized, because the monitoring-DAS units would not call in if they were unplugged. Therefore, the status of the controllers was checked daily. Also, the controllers were inoperative when housekeeping or occupants turning the HVAC unit off. The unit must be in the 'on' position to be supervised by the controller.

Table 2. Problems and Inoperability of Controller

Date	Problems, Complaints, and Modifications
Nov – Dec 2000 & Jan 2001	There were 5 to 6 complaints per month from occupants, because the staff was becoming familiar with operating the system. Procedural problems occurred when front desk staff entered incorrect information (i.e. check out instead of check in, temperature controller off rather than on). These problems were more prevalent during training of a new front desk member. There were fewer complaints because there were few power interruptions.
Feb 2001	The first month that a brownout occurred; the HVAC units went off during the brown out and most came on when the proper voltage returned. When there was a power outage of extremely short duration approximately 5-6 percent of the units would not come on when the power returned and maintenance unplug the controllers. The power was out three to four times (up to 30 minutes per event) over a 12-hour time period. No occupant complaints regarding the HVAC during the 12-hour period was received.
March - May 2001	During this period there were approximately 12 to 15 power glitches that resulted in 2 to 10 of the controllers having to be unplugged by maintenance when interruptions occurred. Attempting to correct the problem of the HVAC not coming back on after a brownout, the software was changed and the microprocessors were replaced in the controllers. These changes were made four times and each time the percentage of failures dropped but there were still HVAC units not come on after a short power glitch.
	The majority of the occupant complaints were limited to the units not coming back on after power interruptions and/or units not coming on at initial check-in to room. Both problems were a result of the microprocessor not resetting.
June 2001	A circuit component problem on the control board of the controllers was discovered. The controllers were removed floor by floor, in order to take them to the shop to be repaired. All of the controllers were repaired and reinstalled by August 2001. This appeared to resolve the microprocessor reset problem that occurred during very short power interruptions.
Sept – Nov 2001	During installation of controllers in another hotel test site, a different circuit component problem was discovered. It was detected because of the site uncommon transformer-wiring configuration. The total voltage of the power supply is 240 V across the line, 209 V on one leg and 107 V on the other leg. Assuming that this circuit component problem was contributing to the microprocessor-reset problem at Music Road Hotel, the site controllers were reworked again. Controllers were removed two floors at a time reworked and reinstalled. The modification was done from September through November.

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