Fermi National Accelerator Laboratory

D0 ENGINEERING NOTE 3823.000-EN-515

10/8/99

DEVELOPMENT AND DESIGN OF A USER INTERFACE FOR A COMPUTER AUTOMATED HEATING, VENTILATION, AND AIR CONDITIONING SYSTEM

Brent Anderson

Approved By:

Quesella. Theinhi 10-11-99

TABLE OF CONTENTS

	PAGE
LIST OF FIGURES	III
ABSTRACT	1
INTRODUCTION	1
DISCUSSION OF THE HVAC SYSTEM	3
HVAC System	3
System Network	5
System Upgrade	5
System Programming	6
DISCUSSION OF DESIGNING A USER INTERFACE	9
User Interface Design	9
<u>User Interfaces</u>	18
CONCLUSION	26
APPENDIX A – AHU SYSTEM AND CONTROL INTERFACES	27

LIST OF FIGURES

		Page
Figure 1.	HVAC System Main Interface	11
Figure 2.	LCW Interface in Programming Mode	12
Figure 3.	Reheated Water System Interface in Programming Mode	13
Figure 4.	HVAC Pump Control Interface	14
Figure 5.	Valve Control Interface for LCW System	15
Figure 6.	HVAC System Alarm Page	16
Figure 7.	3-D D-Zero Assembly Building Interface	18
Figure 8.	Pond Water System Interface	19
Figure 9.	Pond Water Valve Controls	20
Figure 10.	Chilled Water System Interface	21
Figure 11.	Chilled Water Valve Controls	21
Figure 12.	Deionized Chilled Water System Interface	22
Figure 13.	Deionized Chilled Water Valve Controls	22
Figure 14.	Low Conductivity Water System Interface	23
Figure 15.	AHU 5 System Interface (Includes Glycol Water System)	24

Figure 16.	Reheated Water System Interface	25
Figure 17.	AHU 1 - Collision Hall Temperature Control	27
Figure 18.	AHU 1 Control Interface	27
Figure 19.	AHU 2 - Assembly Hall Temperature Control	28
Figure 20.	AHU 2 Control Interface	28
Figure 21.	AHU 3 - 3rd, 5th, and 6th Floor Temperature Control	29
Figure 22.	AHU 3 Control Interface	29
Figure 23.	AHU 4 - 1st and 2nd Floor Temperature Control	30
Figure 24.	AHU 4 Control Interface	30
Figure 25.	AHU 5 Control Interface	31
Figure 26.	Cathedral Cooling System for Detector	31
Figure 27.	Cathedral Cooling System Controls	32

ABSTRACT

A user interface is created to monitor and operate the heating, ventilation, and air conditioning system. The interface is networked to the system's programmable logic controller. The controller maintains automated control of the system. The user through the interface is able to see the status of the system and override or adjust the automatic control features. The interface is programmed to show digital readouts of system equipment as well as visual queues of system operational statuses. It also provides information for system design and component interaction. The interface is made easier to read by simple designs, color coordination, and graphics.

INTRODUCTION

Fermi National Accelerator Laboratory (Fermilab) conducts high energy particle physics research. Part of this research involves collision experiments with protons, and anti-protons. These interactions are contained within one of two massive detectors along Fermilab's largest particle accelerator the Tevatron. The D-Zero Assembly Building houses one of these detectors.

At this time detector systems are being upgraded for a second experiment run, titled Run II. Unlike the previous run, systems at D-Zero must be computer automated so operators do not have to continually monitor and adjust these systems during the run. Human intervention should only be necessary for system start up and shut down, and equipment failure.

Part of this upgrade includes the heating, ventilation, and air conditioning system (HVAC system). The HVAC system is responsible for controlling two subsystems, the air temperatures of the D-Zero Assembly Building and associated collision hall, as well

as six separate water systems used in the heating and cooling of the air and detector components.

The HVAC system is automated by a programmable logic controller. In order to provide system monitoring and operator control a user interface is required.

This paper will address methods and strategies used to design and implement an effective user interface. Background material pertinent to the HVAC system will cover the separate water and air subsystems and their purposes. In addition programming and system automation will also be covered.

DISCUSSION OF THE HVAC SYSTEM

HVAC System

The HVAC system contains six different water systems each with a specific function, and five air temperature control systems.

The first of the water systems is the pond water system (PWS). The pond water system is used to maintain water temperatures in the chilled, glycol, and reheated water systems. Heat exchangers are used in the chilled water system during the summer, and year round in the reheated water system for temperature control. Chillers are used in the glycol water system year round, and during the summer in the chilled water system.

Water for this system is taken from the Main Ring cooling pond located near D-Zero.

The second system is the chilled water system (CHW). This is a closed loop water system which is used to cool the low conductivity, deionized chilled, and glycol water systems. The chilled water system is also used in cooling the air conditioning units and the air handler units (AHU). Heat exchangers are used to provide heat transfer between each of the three water systems.

The next water system is the low conductivity water system (LWS). This system serves to cool detector components such as the magnets and associated power supplies. The water is specially treated with deionizers to prevent the water from carrying an electric current, which could create shorts in power supplies and cause damage to detector components.

The deionized water system (DCW) is also used for detector equipment. This system's function is to cool electronic equipment that is found in the detector platform located under the detector itself. This system is also responsible for cooling equipment and air conditioners in the movable counting house. This is a four-story structure, which houses electronics for the detector systems. While this building stays within the detector assembly hall it moves closer to the collision hall when the detector is rolled into position. Therefore there are separate water connections for each position of the detector and movable counting house.

The glycol water system (GWS) is used to cool the clean room. This system is cooled either by the chilled water system or a chiller connected to the pond water system. The clean room was used when the D-Zero detector was first constructed. The area, which still bears the name, is no longer used as a clean room. However, it is still controlled by this water system.

The remaining system is the reheated water system (RHW). The reheated water system is used to transfer heat to or away from heat pump units depending upon their mode of operation. Heat pumps are used to cool and heat air in the offices located on the fifth and sixth floors.

The other components of the HVAC system are the AHU systems. AHU 1 is responsible for the heating and cooling of the collision hall. AHU 2 is used to maintain temperature control in the assembly hall. AHU 3 and 4 are used for the office areas.

AHU 3 is for floors three, five, and six. AHU 4 controls the temperatures for the first and

second floors. AHU's handle large air supplies brought in from outside. This is different from the heat pump units, which are used for local temperature control only.

System Network

System control is maintained through a network of electronic and computer equipment. Fans, dampers, valves, heaters, cooling coils, sensors and other system equipment are connected to one of three digital system controllers (DSC). These units collect all the inputs from the system and send out all the outputs to control the devices. Each of these DSC units are connected by a network to the HVAC Programmable Logic Controller (PLC). The PLC is responsible for automated system control. Connected to the DSC and PLC network is a Supervisory Control and Data Acquisition node (SCADA). This node contains a database of input/output (I/O) addresses that are collected from the PLC. Then the SCADA node provides this information to computers connected to an Ethernet network. The user interfaces use the information from the SCADA node to display current information about the status of the system. Each of these system components networked together make up the control system for the HVAC system.

System Upgrade

The upgrade of the HVAC system involves the automation of the HVAC system.

Two thirds of this upgrade have already taken place. The PLC and DSC 1 and 2 were already installed prior to my arrival. DSC 1 and 2 are used for control of the AHU systems. The third DSC unit will control the water systems previously described. The

goal of this upgrade is to program the PLC and create the user interfaces for the water systems prior to installation of the DSC 3 unit. The idea is that the system will be ready for operation when the unit is installed.

System Programming

Primary control of the system is provided by the PLC. There are three forms of programming used to control the HVAC system employed by the PLC. The first is straightforward ladder logic, for simple activation/deactivation of coils by contacts and logic functions. The second is a Proportional Integral Derivative (PID) loop. These loops are used to control equipment that requires constant adjusting to maintain system control. Such equipment would include dampers used to control air flow or valves to control water flow. The loops are programmed to a certain degree of accuracy to maintain system equilibrium. The third form of programming is special function programs. Special function programs serve a variety of functions, from carrying out IF-THEN statements, to rescaling inputs and outputs.

Inputs and outputs are not the only driving forces in the control system. Another factor in the programming are relays. These can be used as contacts or coils in the ladder logic. Sometimes the only purpose they serve is to activate a desired function. Other times they are used as inputs from the user interface to create changes in the system operation. This is one of the ways in which the user can make changes to the HVAC system without reprogramming the PLC.

The PLC also uses variable memory (V memory) to carry out its logic. V memory is used to hold integers or real numbers in calculations. V memory is present in special functions and loops. In special functions input values can be stored in V memory and then used in calculations in the program. The V memory from a calculation can also be equated to an output to be sent by the PLC. Loops also use V memory when special functions are used on the loop calculation. Loops also contain other controllable values for such things as the desired temperature, the high and low limits, and automatic or manual control. In a loop the desired temperature is called the setpoint and the current temperature input used by the loop is the process variable. For instance if a loop was controlling an air damper, the setpoint may be 70 degrees F. Then the high and low limits for the position of the air damper might be 0 to 90 degrees rotation. In automatic mode the PID loop will adjust the air damper between 0 and 90 degrees to maintain a 70 degree temperature. These setpoints can also be controlled and changed through the user interface.

The SCADA node contains a database of all the desired PLC data, which is used in the user interface. In order to accomplish its purpose the database must match the I/O addressing in the PLC. A separate database is used to keep track of inputs and outputs, relays, V memory allocation, and loop controls. This form of documentation is very important since it bridges the gap between the PLC programming and the user interface programming in coordinating the variables used in both systems. The SCADA node database uses tagnames instead of I/O addressing when communicating with the user

interface. This is useful since it allows the programmer to use abbreviations for the tagname so it is easier to understand what data is being gathered or sent to the PLC.

DISCUSSION OF DESIGNING A USER INTERFACE

User Interface Design

The first step in creating the user interface began with a physical mapping of the water systems. The HVAC system has been slowly modified over the past decade. However, system drawings were never changed to reflect these modifications. This meant we had to walk through the system with an older drawing and locate differences in the system. This also provided an opportunity to find sensors and equipment in the system that were missing identification tags so items which might require replacement in the future could be located more quickly.

The next phase was to create interfaces for each water system based off of the mapping process. These system interfaces do not show the actual layout of the system, but rather a simplified look. All the pathways fit the actual system, but they are not necessarily to scale or laid out in the fashion displayed. Each system is centralized so the system design can more easily understood. This is also useful to see how systems are related. Most of the basic system layouts were already created before I joined the project. It was my responsibility to assist in mapping the system, then label the unidentified equipment, and finally update and correct the interfaces accordingly. Creation of the pond water system and glycol water system was my work. However, I was also responsible for extensive modifications to the remaining water systems. The AHU interfaces were already in place since DSC 1 and 2 were already operating.

The program used for the interfaces is Intellution Fix 32. This software incorporates SCADA node operations, database building, and interface drawing and displaying. Systems interfaces are created by drawing tools that are less advanced than a CAD program but better than most included with standard word processing programs. In addition to drawing tools special programming options are available for any item created.

The system interfaces employ several strategies for easier information gathering. Colors used in the interfaces match those of the pipes in the actual system. Also for certain systems source and return water lines are shaded darker and lighter so water flow is easier to see. Water systems are also highlighted by a box for easy identification. Selecting system areas brings up another interface with a more detailed look at the system. Selecting valves, pumps or other equipment will bring up controls to operate the equipment. The main HVAC interface page, fig. 1, illustrates some of these strategies.

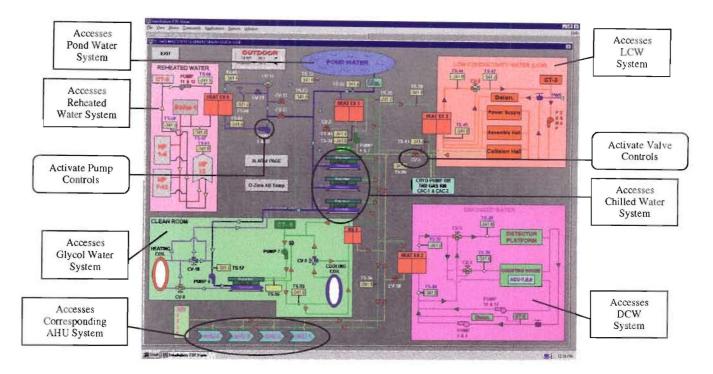


Figure 1. HVAC System Main Interface

After the system diagrams are drawn information links can be created. This is the form of the temperature readouts. These are data links to the database in the SCADA node. Each temperature display is programmed with the tagname for the actual sensor in the system. The interface pulls the data from the database and displays it on the screen. Part of my responsibilities was to add all the temperature readouts to the system interfaces.

The next task is to program equipment such as pumps and valves to indicate their present condition. This is done by programming an image to respond to a given state of the equipment such as on or off, or open or closed. Again the tagname is used to link the object to the actual state of the device in the system. However, instead of displaying a value the object is programmed to change color, flash, appear or disappear when certain

conditions are met. For example, a pump, which is on or off (1 or 0 in binary), is programmed to be green when the input value is 1, and red when the value is 0. This same type of programming is applied to two-way valves. Three-way valves are more detailed where flow arrows are programmed to indicate how water is moving through the valve. Figure 2 shows how temperature sensors, valves, and pumps appear when an interface is in programming mode.

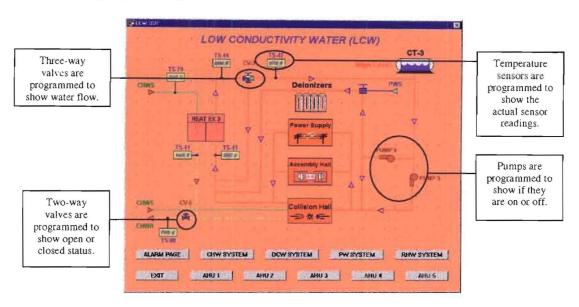


Figure 2. LCW Interface in Programming Mode

Pictures can also be programmed to appear or disappear under certain conditions. The boiler in the reheated water system is an example of this. Bubbles appear only when the boiler is on and OFF appears when it is only inactive. Low and high level alarms on some of the water system expansion tanks will also appear on the user interface when the alarm is triggered. The reheated water system in program mode, fig. 3, reveals these sometimes hidden features.

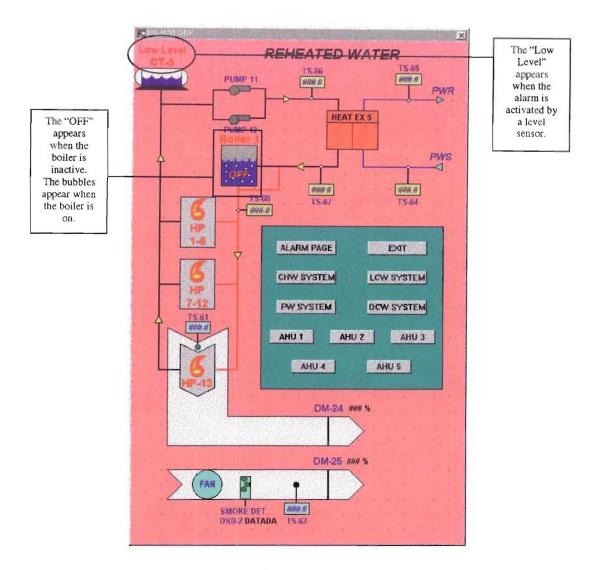


Figure 3. Reheated Water System Interface in Programming Mode

The next step is to create controls for the equipment in the system. All the pumps are controlled on one interface. Each pump is programmed to bring this interface up when selected. The pump control is a simple on/off switch. Figure 4 is the pump control interface for the HVAC system.

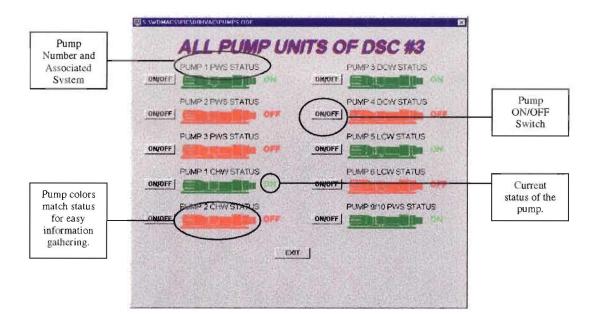


Figure 4. HVAC Pump Control Interface

The valves are more complex since most of them are controlled by loops to control the water temperature in each system. By selecting a valve in a particular system the control display for that system will come up. Loop controls usually have a graphic component and digital readout. On the left side a bar and arrow indicates the process variable setting in the loop. The right side bar show the current position of the valve while the large arrow show the commanded position. This right side bar also has settings for high and low setpoints. These are used as limits for position. In the AHU systems they serve as alarm setpoints to set off an alarm if one of the limits is passed. The bottom and side of the controls have readouts of variables used to control the valve that are pertinent to the calculations. If the valve can be placed in manual control a button will be present to perform that function. Like the temperature readouts and picture responses, everything in the controls are linked to a tagname in the database, which corresponds to an I/O address in the PLC. Figure 5 is a typical example of a control interface for a loop

operated valve. Controls for valves in the PWS, CHW, LCW, DCW, and GWS water systems were part of my assignment.

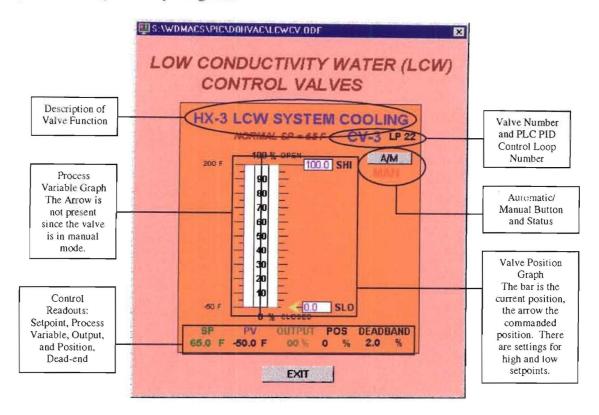


Figure 5. Valve Control Interface for LCW System

Alarms in the system appear on the alarm page. The current state of the alarm is indicated along with information on whether it is enabled or disabled. The alarm itself is usually a coil in the ladder logic, while the enable/disable is a contact on the same rung. Therefore when the alarm is enabled the contact on the rung is closed allowing activation of the coil when alarm conditions are present. A disabled alarm will have an open contact therefore the alarm coil cannot be activated even if conditions warrant it. Figure 6 is the alarm page for the HVAC system.

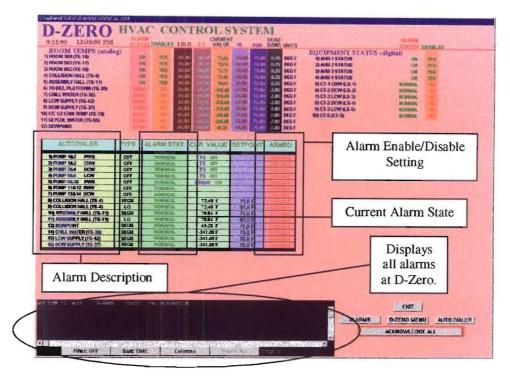


Figure 6. HVAC System Alarm Page

One of the specialized interfaces, which I designed, was the third dimensional view of the D-Zero Assembly Building. The purpose of this interface is to gather information about all the major components in the HVAC system quickly and showing where equipment is located. Everything in this interface had to be drawn in a 3-D perspective since the interface design software only operates in two dimensions. 2-D images and shapes are layered on top of each other to create a 3-D effect.

Data links are programmed into the interface to display temperature, humidity, and heating/cooling percentages. This allows all the areas of D-Zero to be evaluated quickly with regards to air temperature and humidity. These readouts are also programmed to display what sensor the information is gathered from by selecting the value. This allows the user to locate a sensor if it appears to be malfunctioning.

Links are available to each of the water systems and AHU systems. Visible statuses can be seen for each of the controllable pumps in the water system. Pump numbers followed by a red light for off or a green blinking light for on, are programmed and displayed on the appropriate water system pump icon. Access to the AHU systems is provided by the fan icons, each of which are programmed to display a green light with blinking rays if it is activated, or a red light with blinking rays if inactive.

The detector and associated cathedral fans located on the moveable brick wall between the collision and assembly halls are programmed to move with the location of the detector. These fan units also have status indicators, green light for on, and a blinking red light for off. When the detector changes location, room on the interface must be made for the picture. Therefore temperature and humidity readings move to be more easily read depending on the detector location.

The use of blinking indicators is to show a system is operating properly when it is a green light blinking, and that there is a problem when a red light is blinking. That is why the pump indicators do not blink red since only one pump runs at a time. The use of green blinking lights is to catch the user's attention, indicating that the system is running just fine.

The fifth and sixth floors of the interface have icons for the heat pump controllers. Eventually, each unit will provide a link to its control interface. However, at this time we are stilling working on how to control the heat pump with the PLC. The heat pump icons show the mode of operation the heat pump is in. A red flame appears when heating, and

a blue flame when cooling. No flame is present when the system is off. Figure 7 is the 3-D D-Zero Assembly Building interface.

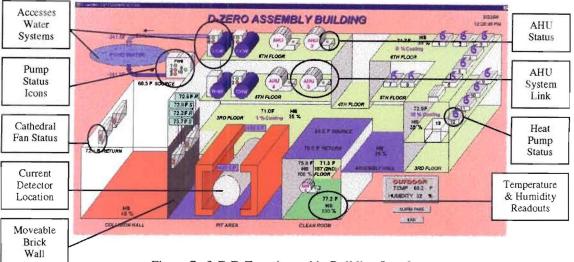


Figure 7. 3-D D-Zero Assembly Building Interface

User Interfaces

Each system interface contains special links, controls, and programming pertinent to that system. Some sensor readouts or programmed status icons may appear anomalous. The reason for the unusual readings is that DSC 3 is not installed and therefore the PLC is not receiving any inputs from the system.

The pond water system interface, fig. 8, gives control to the valves and pumps in the C-4 pump house. Control valves 2 and 14 are adjustable valves and are used to control the amount of water passing though each of the heat exchangers. Since these valves are adjusting they are controlled by loops and the controls reflect this, fig. 9. Control valves 12 and 13 are two position valves open or closed. Therefore there is just an open/close button to change their state. Since valves 12 and 13 also control water flow through heat exchanger one they can be placed under automatic mode and

controlled by automated programming. Another feature of these controls is that controls for valve 14 are not displayed or locked out since the water in the pond is too warm. Pumps in the C-4 pump house can be controlled through the pump control interface. Only one of the two pumps 9 and 10 run at a time. These pumps cannot be completely controlled by the system. Power can be supplied or cut to both. Selection of which pump is running must be done by a manual switch in the system. Because of the complexity of the glycol water system, details of the pond water system in the clean room are displayed on the AHU 5 interface.

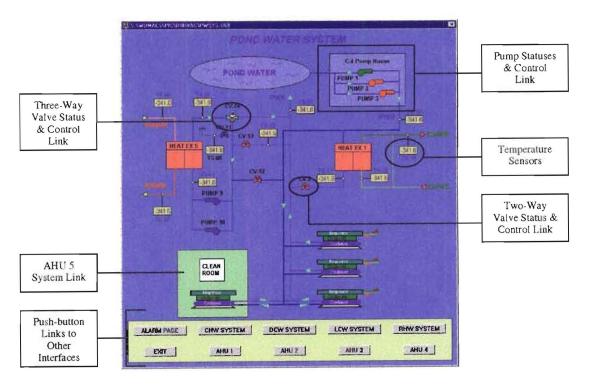


Figure 8. Pond Water System Interface

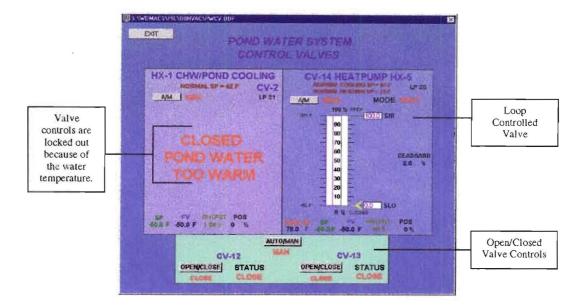


Figure 9. Pond Water Valve Controls

The chilled water system has some of the same programming as the pond water system interface, fig. 10. Valves 6 and 18 can be controlled through the valve interface, fig. 11. Again 18 is a two position valve, and 6 is adjustable and therefore controlled by a loop. Separate controls for pumps 1 and 2 are accessible on the pump interface. The pump icons are programmed to display the current state of the pump, green for on, and red for off.

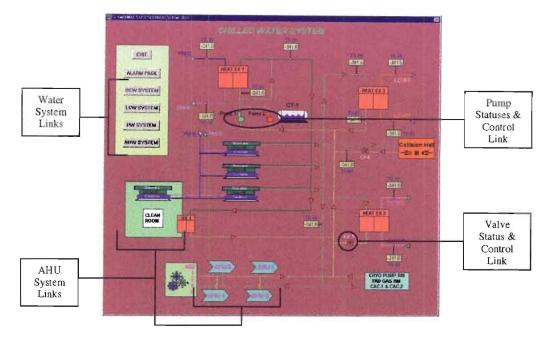


Figure 10. Chilled Water System Interface

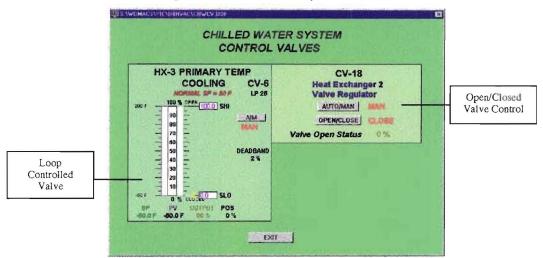


Figure 11. Chilled Water Valve Controls

The deionized water system, fig. 12, includes controls for pumps 3 and 4 and three-way valves 4 and 5, fig. 13. All three-way valves in the HVAC system will be controlled by loops, since there are two paths for the water. The valve controls indicate the presence of a loop control by displaying the specific loop number used by the PLC. Pumps 13 and 14 are not controllable by the system. The present location of the detector

can be seen on this interface as well. The AH located on the Detector Platform and Counting House icons stands for assembly hall. If the detector were in the collision hall a CH would be present.

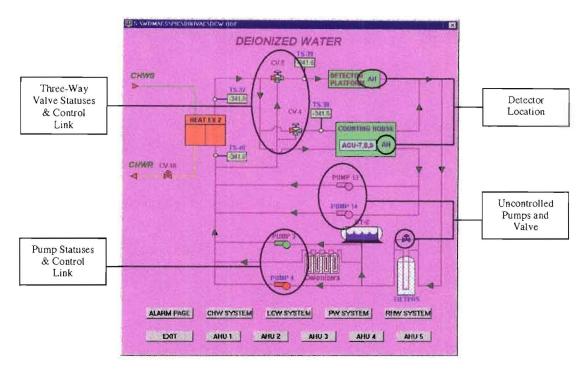


Figure 12. Deionized Chilled Water System Interface

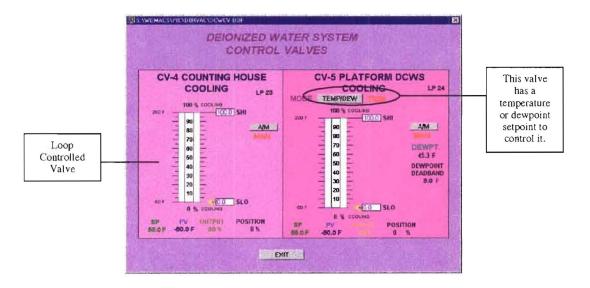


Figure 13. Deionized Chilled Water Valve Controls

The low conductivity water system, fig. 14, contains controls for the two pumps and three-way valve. This system is a good example of how pictures can be used to transfer information to the user more quickly. The power supply, assembly hall, and collision hall locations contain graphics depicting the system. There is a picture of power lines and lightning bolts for the power system. A graphic of the assembly of the detector is used for the assembly hall. An image of a particle collision is used for the collision hall. The graphics relate what each of these areas are without having the user read the words. It also provides for a more interesting interface than simple text.

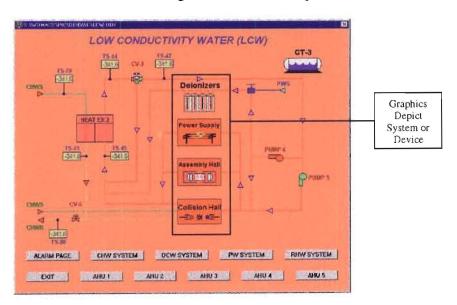


Figure 14. Low Conductivity Water System Interface

The glycol water system interface is combined with AHU 5 and comprises the entire clean room system, fig. 15. Valve, damper, and heating/cooling controls are available through a separate interface. The pumps are not controllable.

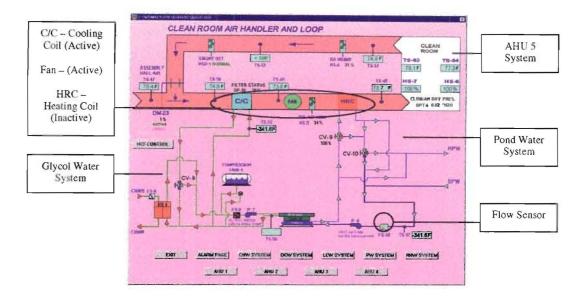


Figure 15. AHU 5 System Interface (Includes Glycol Water System)

The reheated water system interface does not feature any controls like the other systems, fig. 16. The status of the boiler can be seen on this interface. Programming for the heat pumps is under development and will be added later. The pumps for this system are not controllable.

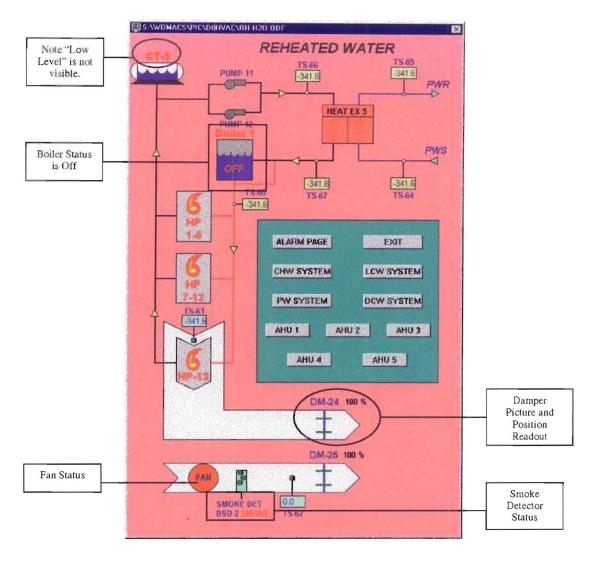


Figure 16. Reheated Water System Interface

CONCLUSION

In designing the user interfaces for the HVAC there are several methods to make it more user friendly. First, systems are laid out as simple as possible. Second, colors are used to identify and link systems together. Third, data is displayed by readouts or color indication. Fourth, graphics are employed to relate information faster than words. Combining these methods yields a user interface that is easy to use, displays necessary information, and still provides system control.

APPENDIX A – AHU SYSTEM AND CONTROL INTERFACES

The AHU system interfaces are included to round out the HVAC system interfaces. These were created by other engineers working on the HVAC system upgrade. Programming techniques are similar to those used in the water systems.

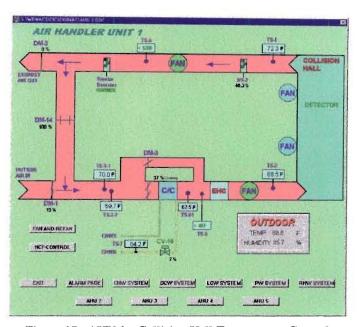


Figure 17. AHU 1 - Collision Hall Temperature Control

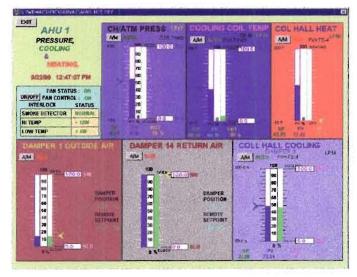


Figure 18. AHU 1 Control Interface

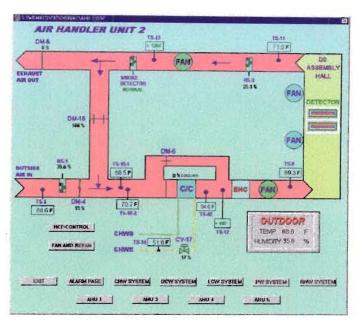


Figure 19. AHU 2 - Assembly Hall Temperature Control

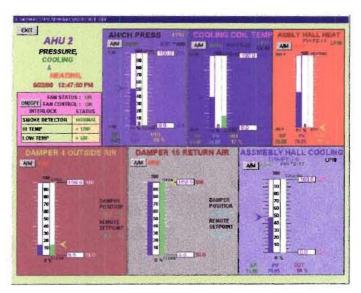


Figure 20. AHU 2 Control Interface

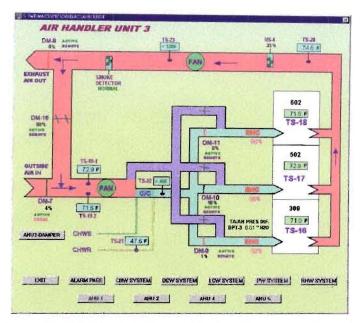


Figure 21. AHU 3 - 3rd, 5th, and 6th Floor Temperature Control

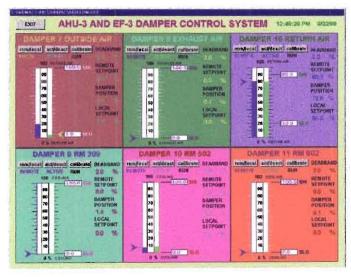


Figure 22. AHU 3 Control Interface

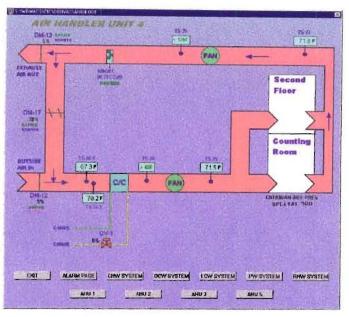


Figure 23. AHU 4 - 1st and 2nd Floor Temperature Control

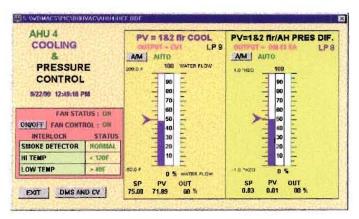


Figure 24. AHU 4 Control Interface

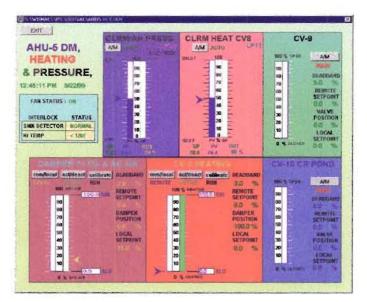


Figure 25. AHU 5 Control Interface

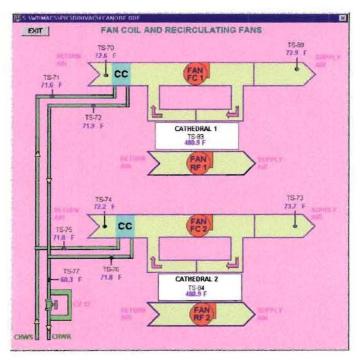


Figure 26. Cathedral Cooling System for Detector

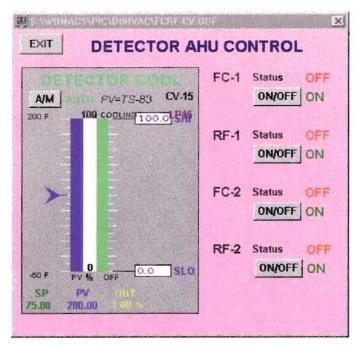


Figure 27. Cathedral Cooling System Controls