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UNIFIED FACILITIES CRITERIA (UFC)

LONWORKS® DIRECT DIGITAL CONTROL FOR HVAC AND OTHER LOCAL BUILDING SYSTEMS

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U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	Date	Location

FOREWORD

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CHAPTER 1

INTRODUCTION

1-1 BACKGROUND

Designers, installers, and operation and maintenance (O&M) staff have struggled with the complexities and incompatibilities of multi-vendor building automation direct digital control (DDC) systems almost since they were introduced in the 1980's. DDC systems are routinely designed and procured on a building-by-building or sub-system by sub-system basis, most notably for heating, ventilating, and air-conditioning (HVAC) systems. In the absence of specifications and criteria for Open systems, Government procurement rules which require competitive bidding make it extremely difficult if not impossible to procure new DDC systems that are compatible with existing ones and that are also compatible with a basewide or campus-wide supervisory system.

In the absence of sole-source procurement, new but incompatible DDC systems result at best in inefficiencies and at worst in complex and non-functioning systems. This is a problem with system-to-system data sharing and is a problem where multiple individual systems need to communicate with a supervisory monitoring and control (front-end) system such as a Utility Monitoring and Control System (UMCS) specified by UFGS 25 10 10. This inability to interoperate is a result of Closed systems due to vendor-specific proprietary elements.

In contrast, Open DDC systems are now available. An Open DDC system is characterized by the ability for any qualified entity to readily modify, operate, upgrade, and perform retrofits on the DDC system. An Open system:

- Permits multiple devices from multiple vendors to readily exchange information.
- Provides the capability to easily replace any device with another device procured from multiple sources.
- May have proprietary components within devices, but these proprietary components must be a small percentage of the overall device.
- May have fees associated with use of certain components.

In short, an Open system is one (integrated, multi-vendor) system where there is no future dependence on any one Contractor or controls vendor.

Open communications and data sharing between multi-vendor systems and with a third party supervisory system is necessary to achieve effective system operation. Some of the benefits and capabilities of Open multi-vendor DDC systems include:

- Competitive procurement, most notably at the building and sub-system level.

- An operator workstation/user interface that provides for the same look and feel for monitoring and control regardless of which vendor's DDC system or sub-system an operator is viewing. As a result, system operators need only become proficient with one user interface.

- An operator workstation/user interface (software) that provides for management of base-wide system operations such as: remote alarm reporting, remote scheduling (on/off control), remote set point override, data logging and reports, energy management including load shedding, utilities monitoring/measurement for the purpose of monitoring energy performance contracts, and initial diagnosis of service calls. As a result, through a single user interface, system operators and managers are afforded the means to efficiently and effectively manage base-wide operations.

- A whole-building approach to systems integration. This includes the efficient inter-connection of HVAC control sub-systems. For example, terminal unit equipment, such as VAV boxes can be readily interfaced to the servicing air handler to provide a call for cooling. In addition, the whole-building approach provides the capability for integrating non-HVAC sub-systems such as fire and security

- Groundwork for establishment of a non-proprietary and openly accessible 'point-database' in support of communications-network management requirements. The Open database approach further insulates the government from the possibility of single vendor lock-in and resulting proprietary procurement.

1-2 **PURPOSE**

This UFC is intended to be used with UFGS 23 09 23 (LonWorks® Direct Digital Control for HVAC and Other Local Building Systems). The design concept described in this UFC provides definitive guidance intended to streamline DDC system design and installation leading to maintainable, interoperable, extensible, and non-proprietary control systems. The purpose of this UFC is two-fold;

- Commonality. Describe a definitive methodology for the design of building-level control systems and strategies (primarily for HVAC) where the intent is to achieve at least a degree of commonality in systems designed and procured through different channels.

- Compatibility. Describe a definitive methodology to obtain multi-vendor systems that can communicate and interoperate with each other and with a supervisory monitoring and control system such as a basewide UMCS through the use of an Open communications protocol.

The Open systems approach described in this UFC is based on ANSI/CEA standard 709.1-B communications protocol (sometimes referred to as LonTalk®) and on LONWORKS® Network Services (LNS®) network operating system. The standard protocol supports Open communications while LNS supports Open network management.

The design of an Open system is not simple. It requires attention to a great deal of detail. This UFC, the specifications, and accompanying drawings were developed to minimize the time and effort required on the part of the designer.

The level of detail contained in this UFC is necessary because of the variety of approaches that can be used to implement ANSI/CEA-709.1-B where, in the absence of this detail, would very likely result in incompatible systems.

'CEA-709.1' is used in this UFC as the shorthand reference to the ANSI/CEA standard 709.1-B communications protocol. In this UFC the term LONWORKS® is used to loosely describe a collection of technologies (including hardware, and software), vendors and installers relating to or based on the CEA-709.1 communications protocol.

1-3 SCOPE

This UFC describes the design of HVAC control systems and the associated building control network that can interface to a UMCS in an Open and non-proprietary manner. The guidance also provides a foundation for the design of other Open building systems.

1-3.1 HVAC control

This UFC provides Open DDC systems guidance for the design of heating, ventilating and air conditioning (HVAC) control systems and other building-level systems, sub-systems and equipment including: primary (air and water) built-up systems, terminal units, and packaged equipment.

1-3.2 Building control network

This UFC describes designer selections for the Building Control Network (BCN) communications including data exchange, architecture, and cabling.

1-3.3 UMCS interface

The DDC system can function as a stand-alone system with reduced functionality (limited user interface, no trending etc.) but is intended to be integrated with a UMCS in accordance with the UMCS guidance (UFC 3-401-01 and UFGS 25 10 10) to provide for remote supervisory monitoring and control of the DDC system. This UFC (3-410-02) and UFGS 23 09 23 helps to ensure that the building-level control system is capable of being interconnected with a UMCS. Even in the absence of a UMCS, this UFC describes the methodology for designer selection and specification of data exchange parameters including requirements that will facilitate subsequent non-proprietary UMCS interface.

1-3.4 **Other systems**

Although not directly addressed or specified in the UFC or UFGS the methodology, approach, and many of the requirements defined in this UFC and UFGS 23 09 23 can be used to design other (non-HVAC) Open DDC systems such as water and sanitary sewer systems, electrical systems, lighting, and other utility systems and equipment.

1-4 **APPLICABILITY**

This UFC and accompanying UFGS 23 09 23 are for use on all USACE and AFCESA projects and for additions or retrofits to existing NAVFAC LONWORKS systems. New NAVFAC systems should use UFGS 23 09 23.13 20. At the discretion of and with approval from the assigning government agency (such as the responsible Corps of Engineers District) the control system designer may deviate from the approach defined in this UFC. When deviating from this guidance, systems based on an Open communications protocol are recommended and systems that lead to subsequent proprietary procurement or single-vendor systems are discouraged.

1-5 **REFERENCES**

American National Standards Institute/Consumer Electronics Association:

- ANSI/CEA-709.1-B, Control Network Protocol Specification, 2002
- ANSI/CEA-709.3, Free-Topology Twisted-Pair Channel Specification, 1998.
- ANSI/CEA-852, Tunneling Component Network Protocols Over Internet Protocol Channels, 2001.

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- UFGS 25 10 10, LONWORKS® UTILITY MONITORING AND CONTROL SYSTEM (UMCS), 2008.
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CHAPTER 2

CONTROL SYSTEM NETWORK

2-1 INTRODUCTION

This chapter describes building-level Open-communications control system architecture, device functionality, and control devices for HVAC and other building-level monitoring and control applications. The communications network and devices are based on LonWorks® technology and CEA-709.1 communications protocol.

Design of an Open-communications building-level control system does not require an extensive familiarity with the CEA-709.1 protocol, but it is critical that the designer understand that the protocol can be implemented in a manner that is not Open and thus can lead to incompatible systems. Therefore, this chapter contains information pertinent to the design of an Open system that designers likely are not familiar with due to the complex nature of modern networked control systems. While many design decisions have already been made, this chapter describes concepts and selections that the designer should be familiar with when developing a project-specific design.

2-2 ARCHITECTURE

As illustrated in Figure 2-1 a basewide system consists of a UMCS (specified by UFGS 25 10 10) connected to one or more building-level DDC systems (specified by UFGS 23 09 23). The network architecture consists of a basewide IP network and one or more building-level TP/FT-10 networks. DDC UFGS 23 09 23 refers to the building-level TP/FT-10 network as the Building Control Network (BCN). A building point of connection (BPOC) provides an interface between the IP and BCN networks.

Generally, the UMCS will be a basewide system, but it may initially consist of only one (or a few) building control networks with the capability of being expanded to include additional buildings where multiple building control networks can be connected to a single UMCS via a BPOC router at each building.

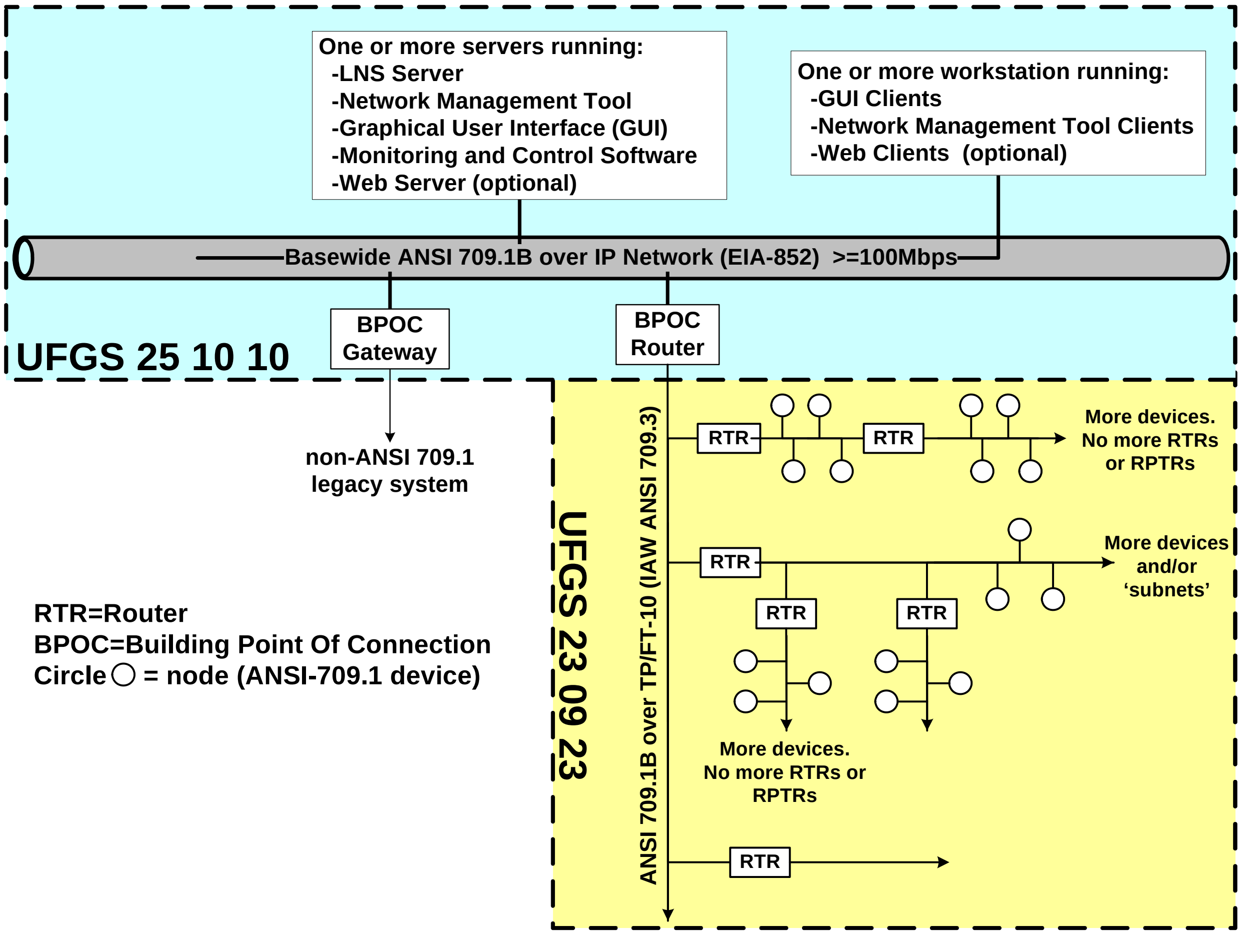

Figure 2-1. UMCS and DDC System Architecture.

2-3 BUILDING CONTROL NETWORK

2-3.1 General

As illustrated in Figure 2-1 UFGS 23 09 23 specifies the building control network (BCN) and requires the use of CEA-709.1 communications protocol over a TP/FT-10 network (in accordance with CEA-709.3) connected in a doubly-terminated topology. The BCN consists of a *backbone* with one or more *local control buses* connected to it via routers. This produces a logically flat network in the building where each node can communicate directly with any other node without the intervention of another controller.

2-3.2 TP/FT-10 media

TP/FT-10 defines a network media and transceiver type:

- The TP in TP/FT-10 stands for Twisted Pair. This is a description of the media that is used to connect the controllers. In this case, a twisted pair of wires is used. CEA-709.3 requires that this twisted pair meet the requirements of CAT-5 cable. While the protocol will work over a variety of cable types, CAT-5 (or better) cable is such a widely used standard that requiring the use of it will help avoid incompatibility problems later.

- The FT in TP/FT-10 stands for Free Topology and indicates the transceiver type that controllers on the network will use. The transceiver is responsible for actually transmitting information across the network. Note that while this allows for Free Topology, the specification further restricts the network to a doubly-terminated bus topology.

- Doubly-Terminated Bus Topology requires that the bus be daisy-chained from one device to another with no branches (stubs under 3 meters in length are allowed in accordance with CEA-709.3) with terminators at both ends of the bus. The spec requires doubly-terminated bus topology in order to maintain consistency and since this topology is the easiest to understand and work with.

The protocol communicates at 78 kbps, which translates to roughly 250 packets per second before the network begins to saturate. The specification places specific requirements on how the network is structured and how devices communicate on the network to avoid saturating the network.

For very small systems, a single network segment may be sufficient; you will not need a building network backbone. In this case, the specification may be edited manually to remove the requirements for a building backbone Note that there other reasons (explained below) why it might be advantageous to use multiple sub networks in a building.

2-3.3 **Other media types**

In addition to TP/FT-10, there are two media types that are part of the CEA-709 standard; Power Line (CEA-709.2) and Fiber Optic (CEA-709.4). Furthermore, there are many media/network types available that are not included in the CEA standard. Many of these media types should be avoided, but some such as Radio Frequency (RF) may be useful in some applications.

The IP network is not part of the BCN therefore UFGS 23 09 23 does specify IP media. IP networks are specified in UFGS 25 10 10 'Utility Monitoring and Control System'.

2-3.4 **Media selection**

UFGS 32 09 23 specifies TP/FT-10 because it the most common media and thus the most supported and Open option. Use of other media types may limit future competition by giving an advantage to the limited number of vendors whose products support the non-standard media. Therefore alternative media (with the possible exception of Power Line) should only be specified or permitted when it is used in conjunction with TP/FT-10:

- To bridge two TP/FT-10 segments

- As a local control bus connected to a TP/FT-10 backbone

The decision to specify or allow alternative media types is best made by asking “What is gained by using this media instead of TP/FT-10?” and “What Is lost by using this media instead of TP/FT-10”? Often the answer to the first question will be that it is a matter of convenience, while the answer to the second will be that the system will become less Open. In these cases, it is likely worthwhile to proceed with TP/FT-10 despite the additional cost/time, as it will prove to be more convenient in the long term.

In general, if the alternative media type requires installation of the media, then there is likely little or no benefit to using the alternative media. If the alternative media permits use of existing media such as power line (PL), radio frequency (RF) or fiber optic (FO), then it may be justified, but the impact on the Openness of the system must be considered.

Specifying or allowing an alternate media type may be warranted where it is needed to meet bandwidth requirements

2-3.5 **Building control network - backbone**

In accordance with UFGS 23 09 23 routers are the only devices to be connected to the backbone. In addition, only traffic to/from the front end (via the BPOC) is allowed on the backbone. (Note that these requirements may be relaxed for a very small building.) This helps to ensure that ample bandwidth is initially available on the backbone and also helps to accommodate bandwidth needs due to system modifications or future expansions. The backbone is available for connection to the UMCS network via BPOC router as specified by UFGS 25 10 10.

In rare cases, the available bandwidth of the building backbone will be insufficient to accommodate the required traffic between the building and the UMCS. In this case the building Contractor will provide a single TP/FT-10 backbone which the UMCS Contractor (***not*** the DDC Contractor) will later break into multiple TP/FT-10 backbones connected by an IP network. A drawback to multiple backbones is that each one requires a BPOC where the BCN is connected to the UMCS network.

Multiple buildings can share a common building-level backbone. For example, two or more adjacent buildings can be physically linked by a common TP/FT-10 backbone as long as network restrictions such as cable length and the total number of nodes as described elsewhere in this UFC and in UFGS 23 09 23 are adhered to. In this case, if the backbone is connected to a UMCS a single BPOC can then be used to connect these buildings to the UMCS. The need for a single BPOC assumes that more than one BPOC is not needed to accommodate network bandwidth usage constraints.

2-3.6 **Building control network - local control bus**

In accordance with UFGS 23 09 23 the local control bus is the only portion of the BCN where DDC Hardware such as controllers may be connected. This helps to ensure that ample bandwidth is available on the backbone.

2-4 CONNECTION TO A UMCS

The BCN will perform all necessary control functionality in a stand-alone mode but does not provide an operator interface for monitoring and control of the network. If the building is to be operated in a stand-alone mode for an extended period and monitoring and control functionality are required, the designer should use the applicable portions of UFGS 25 10 10 to obtain a local monitoring and control system. If the building is to be connected to the UMCS, the UMCS Contractor will be responsible for installation and configuration of the BPOC and integration of the building system into the UMCS.

2-5 NETWORK DESIGN AND LAYOUT

Network layout is left largely to the building-level controls Contractor as specified in UFGS 23 09 23.

2-6 NETWORK HARDWARE

In addition to media, the control network may contain the following types of hardware.

2-6.1 Repeater

A repeater is a device that has two or more input/output ports, connects two (or more) pieces of media, and performs signal regeneration. Signals showing up on an input port get cleaned up, amplified, and sent out of the repeaters output port(s). Repeaters may allow for longer cable runs in some cases, but not others.

2-6.2 Media converter

A media converter is a repeater that changes media types (i.e. TP/FT-10 to PL). Use of non-standard media will likely require the use of media converters where the non-standard media connects to another media type or to a device that supports another media type.

2-6.3 Router

A router is similar to a repeater, but performs the additional function of packet filtering based on destination address. A router can look at the destination address of an incoming packet. If the destination DDC Hardware is accessible via media connected to a different output port, the packet will be sent out the appropriate output, otherwise the router will do nothing with the packet.

A router maintains a routing table consisting of a list of the domains and subnets that exist on its output ports. A router typically will also contain a “default” entry, which essentially says “If the destination doesn't show up in any routing table entry, forward the packet to another (specified) device (and hope that device can forward it properly).”

A router may be classified as a configured or learning router. A configured router has its routing tables assigned by the installer. A learning router will “learn” its routing tables. Initially, a learning router simply functions as a repeater and forwards all messages. As messages pass through the router, it looks at the source subnet address and learns which of its input ports connects to that subnet; it can then use that information to build a routing table entry for that subnet. While the choice of learning vs. configured router is left to the building Contractor, configured routers are generally preferred.

A router provides two very important functions in a control network:

- It greatly reduces network traffic. By placing devices that need to communicate frequently on a common subnet and isolating that section with a router, the base-wide (or UMCS) network will not be bogged down with local communications between the devices on the subnet.

- It allows devices to send messages to a “distant” controller without knowing the detailed network topology. A device that measures and communicates outside air temperature in one building and that sends this outside air temperature measurement to another device in another building only needs to forward the message to its router. The router is then responsible for knowing how to send the message on towards the destination device.

2-6.4 **Network bandwidth**

In accordance with UFGS 23 09 23 the Contractor is responsible for selecting the details of the architecture and ensuring that the proposed system (devices, network bindings, and network architecture) does not saturate the network.

While it is the Contractors responsibility to design and propose a network that does not exceed the network’s bandwidth capacity, UFGS 23 09 23 provides additional requirements to help ensure those limits are not exceeded:

- Use the UFGS 23 09 23 specified backbone and local control bus architecture

- Group devices that need to communicate often on a common local control bus

- Limit the amount of information sent to the UMCS. A modern UMCS can easily demand data from the local controls faster than the building network can deliver the data. Coordinate with the UMCS installer to limit “always-active” data requests from the UMCS such as trending to those really required by the installation.

- Ensure the Contractor is careful in selecting data transfer rates and integrity methods. Use “Send on Change” with reasonable change values to avoid sending data more often than required. Limit “Unacknowledged Send Multiple” and “Send Acknowledged” transmissions to critical data only.

Segmenting the network into local control buses and a backbone is the easiest way to manage network traffic and not overload the network. The intent is to place devices that need to communicate frequently on a common local control bus. The requirement that only routers be connected to the backbone ensures that traffic from a (potentially) congested local control bus does not clog the backbone – the router will keep local traffic on the local control bus and off the backbone. Traffic between devices and the front-end UMCS will utilize the building backbone. The specification requirement that no node has more than two routers between it and the backbone helps ensure that the installer doesn't bog down a local control bus by forcing traffic from a second local control bus to traverse the first local bus to get to the backbone.

2-6.5 **Other architecture issues**

2-6.5.1 **Multiple controllers per HVAC system versus single controller**

The LONWORKS industry supports the notion of “distributed control”. In a conventional DDC system, a single relatively powerful controller with ample inputs and outputs is often used to implement a complete sequence of operation. While there are CEA-709.1 controllers that support this approach, another possibility is the use of multiple simpler interconnected controllers. For example, instead of using a single controller to control an air handler, the mixed air dampers may be controlled by a dedicated controller (or even a so-called “smart actuator”) which obtains relevant temperatures from other sensors on the network (“smart sensors”), obtains occupancy status and other information from other devices on the network and drives the dampers. Similarly, the cooling coil valve could be driven by a simple controller whose only output would be a 4-20 mA control signal to the valve.

While this approach to HVAC control is not necessarily unique to CEA-709.1 based hardware, this approach does seem to be better supported by LONWORKS than other protocol technologies. As with any approach, distributed control has its own set of advantages and disadvantages.

Advantages:

- Simple controllers. Programmable controllers are not needed, which eliminates custom programming and programming software. A small selection of simple controllers can be used for all control schemes. This would allow an installation to standardize on a set of controllers and ease the training requirements for the O&M Staff.

- Supportable by multiple vendors. Since the devices have simple functionality it is easier to find a replacement device from a different vendor with the same functionality.

- Documentation. It is easier to document the actual controller and controller functions/settings.

- No long home-runs of wire. Controllers may be located at the sensors/actuators they interface, or the sensors/actuators may be the controllers (‘smart’ sensors/actuators) which reduced the wiring requirements.

Disadvantages:

- Execution of the system sequence may require communication between multiple controllers which in turn may require a functional network. One work-around to this issue is to create a local control network dedicated to the system and isolate this from the rest of the building with a router (this will protect the local network from most network failures elsewhere in the building).

- Harder to document. While the individual controllers were easier to document, the system sequence may be harder to document since it is distributed among multiple controllers.

- Controllers not in one location. The controllers for a single system may be scattered about the mechanical room, or even outside the mechanical room.

UFGS 23 09 23 places the burden on the Contractor to decide when distributed control should be used.

2-7 ADDRESSING, DATA TRANSMISSION, AND DATA INTEGRITY

2-7.1 Addressing

All network protocols, including CEA-709.1, define an addressing scheme: a method of delivering messages to a specific device on the network. CEA-709.1 defines several such methods. The Domain/Subnet/Node method is shown and used in the current UFGS/UFC criteria. While it requires more care to set up than the use of NodeIDs (another common method) the advantage of the Domain/Subnet/Node method is that the addressing scheme can and should reflect the logical organization of the control network and is therefore more readily managed. For example, a large building may consist of subnets 105 – 110, with a large AHU controller at subnet 108, device 1 and its associated VAV boxes at subnet 108 including devices 2-35. In comparison, if NodeIDs were used, the addresses would all essentially be random numbers between 1 and 281 trillion. The specification requires the use of the Domain/Subnet/Node addressing scheme with documentation of the NodeIDs for DDC Hardware.

The installer should assign the Domain/Subnet/Node address to DDC Hardware according to installation-specific guidelines established for the UMCS. The choice of whether or not to put all devices on a single domain is complex. In concept the use of a single domain base-wide is straightforward, but in practice there are a number of issues to be considered:

- Devices that need to communicate with each other should be on the same domain, as you cannot bind network variables across domains. You can have the front end read a value from a controller on one domain and write it to a different controller on another domain, but this is discouraged. This “limitation” is seldom an issue; controllers that need to talk to each other are generally on the same subnet and almost never required to be on different domains.

- There are performance issues associated with large domains. The network configuration tool will open a 500 device domain faster than it will a 2000 device domain, so in this regard, it is better to have four 500 device domains than one 2000 device domain.

- A typical installation may have a few vendors (say four or five) who install the vast majority of building networks on the installation. While the specification is designed to allow multiple vendors to work with a single base-wide LNS database, there may be advantages to allowing each major vendor to have a separate LNS database (reduced potential for finger pointing, less potential for device renumbering, easier LNS database merging, perhaps easier for building vendors to use their own network configuration tool, etc.). This is not a problem, as the UFGS requires that the Monitoring and Control software support multiple LNS databases. This will require multiple domains, as a single domain cannot span multiple LNS databases.

As a practical matter, any single DDC project will almost certainly use a single domain; it is highly unlikely that multiple domains will be used within a single contract. The subnet address will often reflect some logical grouping within the system. A single subnet will often suffice for a smaller building; larger buildings may require several subnet addresses. At the lowest level are individual node addresses; each DDC Hardware device on a subnet must have a unique node address.

2-7.2 **Data transmission**

The CEA-709 data transmission speed is 78.1 kbps and there are 2 primary mechanisms through which data transfer data occurs; polling and binding. These data transfer aspects of the protocol along with the quantity of data transferred govern how much bandwidth is used.

Polling occurs when a receiver of data requests data from a transmitter. This is generally a periodic event with a defined period. Collection of trend data is an example of polling where every 15 minutes a UMCS front-end workstation requests data from several DDC hardware devices. Polling can occur at any time and a device can always poll another device for data.

Binding is used to create another form of data transfer where bindings between one or more devices are set up during network configuration. As a result of binding, a data source sends (on its own initiative) data to a recipient. There are several parameters that control the frequency of this transfer:

- Change of Value (COV). The transmitting device can be configured to only send the data if it changes by a minimum specified amount. For example, a controller that is measuring outside air temperature might be configured to transmit a new temperature value only if the current value changes, from the last value transmitted, by greater than 0.5 degrees. UFGS 23 09 23 requires use of COV whenever possible (some DDC Hardware, particularly ASCs, may not support use of COV in all situations).

- Minimum send time. The transmitting device can be configured not to send the data more often than once every ***X*** seconds. This is an important parameter for limiting network traffic; most HVAC control applications (except for example pressure or flow control applications) do not require “real-time” data and therefore data need not be transmitted more often than once every couple of seconds even if it is rapidly changing. UFGS 23 09 23 requires a minimum send time of 5 seconds for traffic between DDC Hardware

- Maximum send time. The transmitting device can be configured to send the data at least once every ***X*** seconds, even if the value is not changing. This is generally a good practice just in case something goes wrong. For example, if the receiving device is reset, it may not “remember” older data and therefore may not have the value until it is retransmitted. A typical maximum send time might be 20 minutes. UFGS 23 09 23 requires a maximum send time of 20 minutes for traffic between DDC Hardware

While binding is almost always preferred to polling due to better network efficiency, there are several cases where polling is recommended:

- When the data transmission is of a temporary nature, such as points on a graphic. If the points were bound to the graphic, all points on all graphics would be bound and all the devices would send all the data to the Monitoring and Control server constantly, even if the graphic was not being viewed. By polling, the Monitoring and Control server can request only the data it needs – i.e. data for the graphics pages currently being viewed.

- When the device does not support binding. Frequently, the Monitoring and Control server and Local Display Panels will not support binding data to them. In this case, polling is the only option for data transmission.

2-7.3 **Data integrity**

There are several parameters that govern data integrity: how the protocol ensures reliable data communication with less-than-perfect hardware, noisy lines, “glitches” and other real-world events. With binding, there are several common means to send data and each has advantages and disadvantages:

- Unacknowledged send once. The data is sent one time and one time only. This requires the least network bandwidth, but does not provide any assurance that the data reaches the recipient.

- Unacknowledged send multiple. The data is sent multiple times (typically three). It is up to the recipient to deal with receiving the same data multiple times. This requires more bandwidth than the send once option but is still fairly fast because the transmitter does not wait for any acknowledgement. It simply sends the data ***X*** times and moves on.

- Acknowledged send. The data is sent once. Upon receipt of the data, the receiver must send an acknowledgement message back to the transmitter. If the transmitter does not receive the acknowledgment within a pre-determined period of time (the “timeout”), the transmitter will resend the data. This is the slowest method, but is a good trade-off between reliability and network bandwidth usage. This is typically used for alarms, where it is essential that the data gets transferred. This is the required method for traffic between DDC Hardware. (Communication between DDC Hardware is almost always part of a control sequence.)

CHAPTER 3
DIRECT DIGITAL CONTROL HARDWARE AND CONTROL DEVICES

3-1 INTRODUCTION

This chapter describes control devices and the DDC Hardware specified in UFGS 23 09 23 including the extended requirements needed to implement an Open system. It also describes the related terms and concepts pertaining to LONWORKS technology and the underlying CEA-709.1 communications protocol (more commonly known as LonTalk®). For additional technical information on LONWORKS, see:

https://eko.usace.army.mil/fa/bas/

3-1.1 SNVTs

During inter-communication, nodes share data and information by transmitting and receiving network variables (the messages exchanged between devices). Specifically, UFGS 23 09 23 requires the use of the Standard Network Variable Types (SNVTs) as defined by LonMark International. In general a SNVT is a command, a status, or a variable (such as temperature, pressure, humidity, etc.), but a SNVT can contain other types of information.

3-1.2 Functional profile

LonMark International defines Functional Profiles for LonWorks devices or nodes. A Functional Profile describes standard node communications and consists of mandatory and optional input and output SNVTs, mandatory and optional configuration properties, and finally a manufacturer specific section.

Functional profiles are useful in that they help define communication/data exchange requirements and network interfaces, but they do not go far enough to ensure that devices will interoperate with other devices in accordance with UFGS 23 09 23. At issue is that control sequences in UFGS 23 09 23 require SNVTs that are only optional in the corresponding Functional Profile. Therefore, the Functional Profile, in itself, is not sufficient to ensure that a device has the required inputs/outputs for a specific sequence of operation. Points Schedule drawings, as specified in UFGS 23 09 23, are used to define these extended requirements.

While there is a LonMark Functional Profile available for scheduling of devices, it is unsuitable for the control sequences defined in DDC UFGS 23 09 23 and should not be used.

3-2 DDC HARDWARE

Any device, other than network hardware, that communicates over the CEA-709.1 network is considered DDC Hardware. In general, the term DDC Hardware is used interchangeably with the term controller, but there are devices such as smart sensors and actuators that are considered DDC Hardware but are not traditionally called controllers even though they may in fact have control functionality (like a feedback control loop). Another term commonly used is “node”, where a LonWorks node is any device that resides on the LonWorks network and communicates via the CEA-709.1 protocol. This includes smart sensors, smart actuators, and controllers, along with a variety of other microprocessor-based devices.

There are several requirements that all DDC hardware must meet. They must:

- Be locally powered: Basically, there are two ways to provide power to a piece of DDC hardware. A link powered device receives its power from the same wire that is used for communication. A local powered device receives its power on a separate set of contacts. Note that a local powered device does not typically include it’s own transformer, the requirement is simply that the device be connected to a local power source, not one over the network. This specification requires that one method be used for consistency and ease of O&M. As the more common and more intuitive option, local power was selected.

- Communicate only using CEA-709.1B

- Meet the LonMark Interoperability guidelines. These guidelines provide a foundation for interoperability and devices meeting these guidelines are readily available.

- Use a TP/FT-10 transceiver for use on a TP/FT-10 network

- Support 78.1 kbps data transmission

- Be provided with an external interface file (XIF file). This is a text file that tells a Network Management Tool what the interface (inputs, outputs, configuration settings) of the controller is.

- Meet accuracy requirements. Requirements for I/O accuracy are not given directly; instead the requirement is that end-to-end error (i.e. accuracy at the SNVT value) be no worse than 150% of the allowed sensor error. This allows the Contractor flexibility in matching sensor ranges and controller A-to-D converters to the application.

Some of these requirements may be difficult to confirm for some devices, specifically programmable controllers. Product data sheets can provide a good indication of whether a device, particularly an application specific controller, meets LonMark Guidelines. In addition, LonMark International has a self-certification checklist that vendors can use to certify that a device meets the LonMark Guidelines.

DDC Hardware is further broken down into three categories, Application Specific Controllers, Application Generic Controllers, and General Purpose Programmable Controllers, each of which has additional requirements it must meet.

3-2.1 **Application specific controller**

An application specific controller (ASC) is supplied with a factory-installed (and fixed) application program. Example ASCs include VAV box controllers, fan coil unit controllers, ‘smart’ actuators and ‘smart’ sensors. An ASC is *configured* for the specific application in which it is used. This configuration does not change the function of the device, but changes settings within the device such as setpoints and other operational settings. The specification requires that ASCs meet several requirements in addition to the general DDC Hardware requirements. For example:

- An LNS® Plug-in must be provided to perform device configuration and all configuration needed for the device must be able to be performed either via this Plug-in or physical settings on the device itself (such as jumpers or dip-switches). The purpose of this requirement is to prevent the need for proprietary configuration tools. Note that UFGS 23 09 23 allows this requirement to be waived in cases where a device with a plug-in is not available (where there is no commercially available device that contains a plug-in) and the Government has approved the exception.

- The ASC must be LonMark Certified. Again, an exception can be made for cases where there is no certified device available for a specific application.

Depending on the needs and requirements of the project or specific applications, such as minimal cost and simplicity, the designer may choose to prohibit the use of General Purpose Programmable Controllers (GPPCs) described below and instead require the use of ASCs. In doing so, the designer should first ensure that appropriate products are commercially available for the application.

3-2.2 **Application generic controller**

An application generic controller (AGC) is similar to an ASC, but has a limited programming capability. Programming these controllers does not change the controller ProgramID, so these controllers can be (and often are) programmed through an LNS plug-in. UFGS 23 09 23 has separate requirements for AGCs which includes a mix of ASC and GPPC requirements.

While in general, these controllers are limited in power and flexibility compared to GPPCs, most of these controllers are capable of executing the sequences specified in UFGS 23 09 23. Further, since they can be re-programmed remotely and without changing the program ID, they are often preferred to GPPCs.

3-2.3 **General purpose programmable controller**

A general purpose programmable controller (GPPC) comes from the factory without a fixed application program (i.e. has no application program installed, or the program may be over-written). This type of controller must be *programmed* for the application in which it is used. This makes the GPPC more flexible and powerful than an ASC, but more complicated and costly as well. The specification requires the GPPC to meet several requirements in addition to the general DDC Hardware requirements:

- The programmed GPPC shall conform to the LonMark Interoperability Guide. This requirement is in lieu of the requirement (for ASCs) to be LonMark certified.
- The software that is required to program the controller must be provided. This software will be needed if it is ever necessary to reprogram the controller.
- A copy of the program that is installed in the controller must be submitted. This copy needs to be in the form of source code readable by the provided programming software. Not only can this program can be loaded into a replacement controller, it can be modified to change the functionality of an existing controller. The intent of this requirement is so that the installation can later modify the program or replace the controller without requiring assistance from the original vendor.

3-2.4 **Local display panel**

The local display panel (LDP) is an ASC with a small display screen and some navigational buttons used to view and/or change the value of network variables. Although the functionality of an LDP is limited as compared to an operator workstation computer, it can be a useful diagnostic tool for maintenance staff.

There is potential for conflict between the LDP and the Monitoring and Control Software when using an LDP to change (override) a network variable. The device receiving the override will be overridden to whichever source most recently "spoke" to it which may result in some confusion. The value of specifying LDP override capability may be sufficiently beneficial to compensate for the potential confusion, but this should be coordinated with the project site.

3-2.5 **CEA-709.1 sensors and actuators**

Sensors and actuators may communicate using the CEA-709.1 protocol over the TP/FT-10 Building Control Network. These sensors and actuators are considered to be ASCs (or possibly GPPCs as appropriate) in addition to being actuators or sensors and therefore must meet the requirements of both the sensor/actuator and of an ASC (or GPPC). A common example of this device is a variable frequency drive unit containing a TP/FT-10 network interface. The use of sensors and actuators that contain a TP/FT-10 interface, in accordance with UFGS 23 09 23, is left to the discretion of the

Contractor. Project specific requirements may dictate that the Designer require a TP/FT-10 interface.

3-2.6 **Building management interface**

A small scale building-level network might call for a building management interface (BMI) node. The BMI should only be used in the absence of a UMCS, and is not specified in either UFGS 23 09 23 or UFGS 25 10 10. The BMI provides web services and can also perform scheduling, logging (trending), alarming, and other supervisory interface functions. A disadvantage of the BMI is that, while it is an Open protocol device at the building level, it likely will not support Open standard communications over the IP network in accordance with UFGS 23 09 23 or UFGS 25 10 10. Specifically, the BMI does not perform routing functions. If it is later decided to connect the building to a UMCS, the BMI will need to be replaced and any functionality in the BMI will need to be accomplished in an Open manner in accordance with UFGS 23 09 23 or UFGS 25 10 10. At the very least, an EIA-852 router will need to be installed as the BPOC.

3-3 **FIELD DEVICES**

3-3.1 **Sensors (input devices)**

Many of the control sequences have, as a designer option, a safety reset button (RST-BUT). In the event that a safety input to the DDC Hardware is activated, resulting in control system shutdown, the RST-BUT is used to reset the control system. Exact requirements and function are dictated by the specific sequence of operation. When determining whether to require a button or allow reset from an operator workstation, consideration should be given to the convenience of reset from an operator workstation versus the safety of initiating a reset by a technician with “eyes-on” the system.

Night stat is the common name for the building temperature (BLDG-T) low-limit sensor. This is typically just a temperature sensor placed in a representative location that acts as a safety to turn on the heat if the building gets too cold. In a single-zone system, the night stat may simply be the zone temperature sensor (ZN-T).

3-3.2 **Actuators (output devices)**

Electric actuation is recommended for all new construction and for any location where a source of control-grade compressed air does not already exist. Where the installation requires pneumatic actuation, ensure that a compressor is specified.

3-3.3 **Multi-function devices**

Thermostat (STAT). While the technical definition of a thermostat is a self-contained controller that generates a control output, this UFC uses a more loose definition. In this UFC and in the accompanying specifications a thermostat is defined as a space mounted device with inputs and outputs to and from a piece of DDC hardware. Ordinarily a STAT will contain a room/space temperature sensor and provide display of space temperature. Depending on the application, it might also provide for occupant (user) adjustment of the space or room setpoint. The STAT might also contain a momentary contact button (input to DDC Hardware) that permits the occupant to override the unoccupied mode so as to temporarily place the control system into the occupied mode. This is sometimes referred to as OCC Override. Alternatively, the STAT might contain an occupancy sensor to provide the OCC Override function. Some sequences have additional operator inputs (typical mode or fan controls) that require additional input(s) at the STAT. In many cases, a STAT will fall under the definition of an ASC, in which case it must meet the DDC Hardware requirements.

CHAPTER 4

TYPICAL CONTROL LOOPS

4-1 INTRODUCTION

This chapter describes typical control loops including designer selections such as control setpoints. Part of the intent is to describe preferred or definitive control loops where commonality from designer-to-designer and project-to-project will aid in the operation, maintenance, and support of the installed control systems. The development of control logic diagrams, used to define detailed control sequences, is also described.

4-2 BASIC CONTROL LOOP

A basic control loop schematic, as shown in Figure 4-1, is comprised of a sensor, a DDC, and the controlled device. A sensor is the input component of the control loop that measures the controlled variable (such as temperature, relative humidity, pressure, air flow rate, or carbon dioxide). A controller is the decision-making component of the control loop that compares the controlled variable to the setpoint and provides a corrective output signal. Controlled devices are output components of the control loop and typically include valves or dampers.

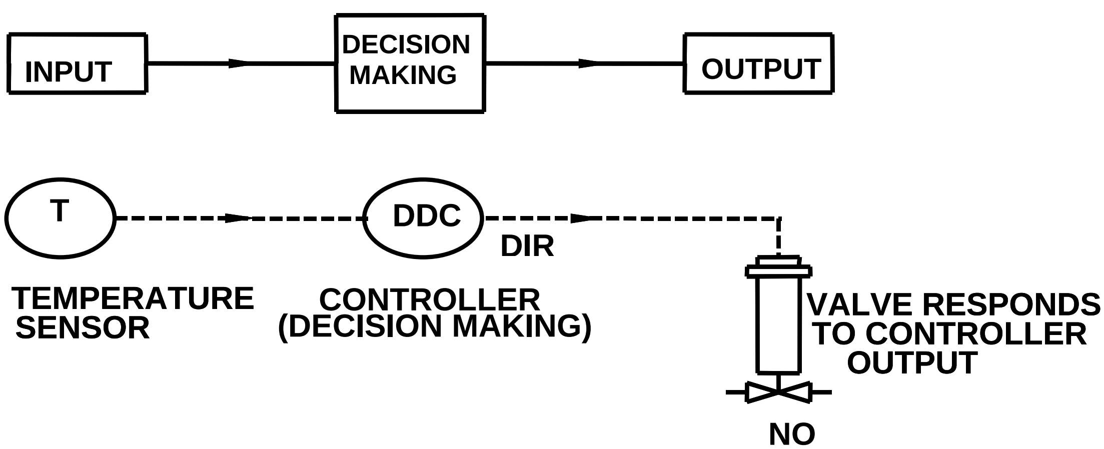

Figure 4-1. Basic Control Loop.

4-2.1 Control action and device failsafe

If the power source or control signal to an actuator (or other device) is lost or disconnected it may be desirable for the device to move to a failsafe position. The intent is to provide for equipment protection, such as protection against freezing, and must be selected/specified by the designer. Failsafe positions can be: normally open (NO), normally closed (NC), or Fail-In-Last-Position (FILP). A NO device will move to the open position and a NC device will move to the closed position. In the case of an actuator, movement to the NO or NC position is accomplished under the power of a spring internal to the actuator. A FILP device ordinarily has no spring and as a result, upon loss of actuator power or control signal, the device remains fixed at its last position. FILP is generally not useful nor advised as a failsafe but is usually the most inexpensive option for an electric actuator and is intended for applications where a true failsafe is not needed such as terminal unit actuators. Generally, terminal units do not require NO or NC actuators; FILP is sufficient. Valve and damper failsafe positions are to be specified. When a device is specified as either NO or NC, the corresponding direct (DIR) or reverse (REV) action of the controller should also be specified such that the action pairs up with the specified failsafe position.

4-2.1.1 **Direct control action**

A controller that has been configured to provide DIR control action will generate an output that moves in the same direction as the controller input. An example control loop that uses DIR control action with a normally open valve is shown in Figure 4-1. Figure 4-2 shows how the controller output changes as the temperature input changes. As the temperature input increases, the DIR acting controller output increases, and the normally open valve will move towards the closed position.

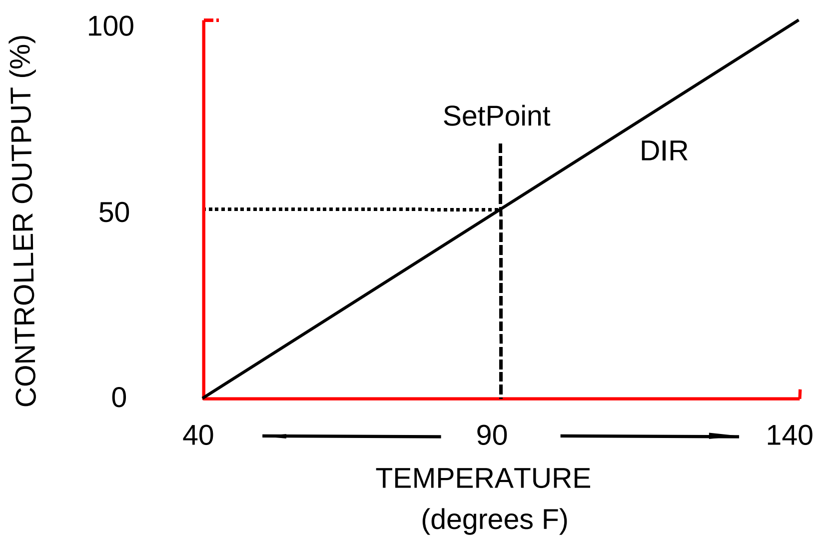

Figure 4-2. Direct Control Action

4-2.1.2 **Reverse control action**

A controller that has been configured to provide REV control action will generate an output that moves in the opposite direction as the controller input. Figure 4-3 shows how the controller output changes as the relative humidity input changes as a result of REV control action. An example of REV control action would be a humidifier application with a normally closed valve. As the humidity input increases, the REV acting controller output decreases, and the normally closed valve will move towards the closed position.

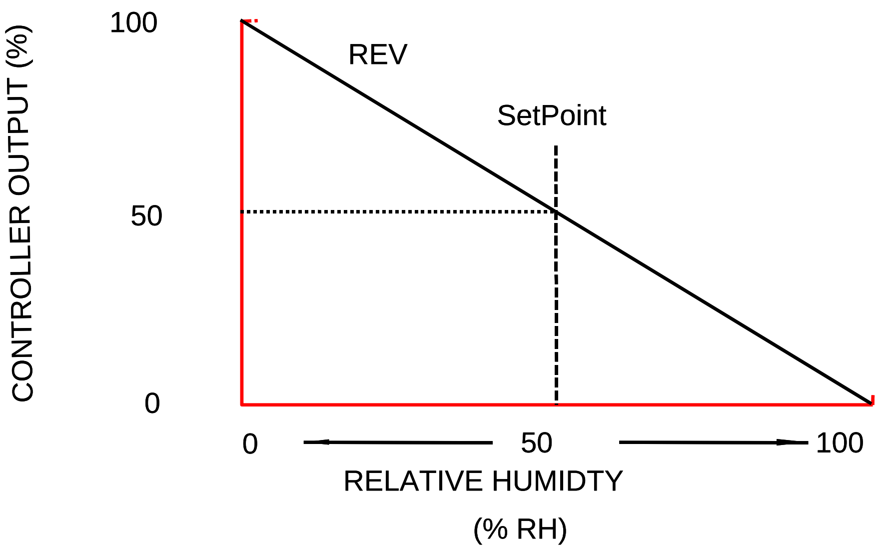

Figure 4-3. Reverse Control Action

4-3 CONTROL LOGIC DIAGRAMS

A control logic diagram (CLD) is a detailed graphical and functional representation of the control system sequence of operation. The CLD supplements the written sequence of operation. Designer use of a CLD is optional, but recommended.

Ordinarily, the CLD will consist of a basic sequence that describes a control loop. In addition it will include enabling logic used to activate the loop. The enabling logic used depends on the loop and on the requirements of the application. An example of basic enabling logic for a mixed air control loop is: 1) the economizer must be ‘on’, and 2) the air handling unit fan(s) must be running.

4-3.1 **Control logic diagram basic sequence**

The procedure for developing a CLD begins with a basic sequence which typically includes a proportional-integral-derivative (PID) control loop with a process variable and a setpoint (SP) input along with a control signal output. Figure 4-4 shows an example of a basic PID block. It has two analog inputs, one analog output, one (shown) configuration property, and one binary input:

- SA-T: Supply Air Temperature, an analog (A) hardware input.

- SA-T-SP: Supply Air Temperature, an analog input from "elsewhere". This signal may be defined elsewhere on the CLD for that system, it may be an output from another system, or it may be shown as an input to the system on the Points Schedule drawing. In this case, SA-T-SP is a configured setpoint and would be shown as such on the Points Schedule drawing.

- CLG-V-C: Cooling Valve Command, a hardware analog (A) output. Note that the CLD does not distinguish between NO and NC valves nor DIR or REV control action. These details are specified/shown in the control schematic drawing. From the perspective of the CLD, a 10% signal output corresponds to the valve being 10% open, it is irrelevant whether this corresponds to 9 Volts, 8 PSI, or any other "physical" value. Similarly, the CLD does not distinguish DIR acting versus REV acting control – the CLD treats all controllers as direct acting where the output moves in the same direction as the controller input.

- CLOSED: A default value; the value assumed by the PID output when the loop is disabled. This will be a configuration property whose value will also be shown on the Points Schedule. Note that there are many other configuration properties associated with a PID loop; the others are not necessary for a basic understanding of the operation of the system and are not shown on the CLD.

- CLG-ENA: Cooling Enable, a binary input from "elsewhere". In this case, CLG-ENA will be defined/generated in the system enabling logic portion of the system CLD. When this signal is TRUE, the loop is enabled, active, and controlling CLG-V-C to maintain SA-T at SA-T-SP. When this signal is FALSE, the PID loop output will assume the (shown) default output.

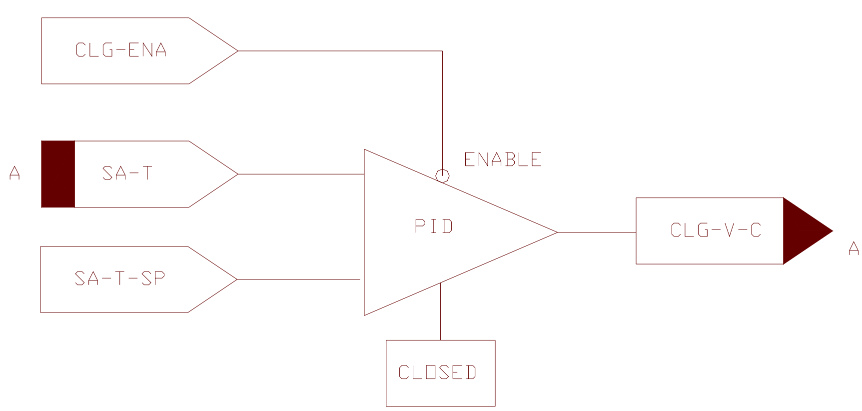

Figure 4-4. Basic Sequence for a Cooling Coil Control Loop.

4-3.2 **System enabling logic**

Figure 4-5 shows enabling logic at the system level, including the logic that enables the cooling loop (CLG-ENA) as shown in the lower right hand corner of Figure 4-5. This block has multiple inputs and outputs:

- SF-S: Supply Fan Status; a hardware binary (B) input proof that the supply fan is running. This can be from a current sensing relay, flow switch, or feedback from a variable frequency drive unit; the exact mechanism is unimportant.

- RF-S: Return Fan Status; a hardware binary (B) input.

- FAN-DIS: Fan Disable; a binary signal from the "Alarms and Shutdown" block; this is TRUE when an alarm occurs and the air handling unit should be shutdown.

- SYS-OCC: System Occupancy; a network binary signal from the system scheduler providing system occupancy status.

- BLDG-T-LL-SP: Building Temperature Low Limit SetPoint; a configured analog input. This is the night-setback temperature.

- BLDG-T: Building Temperature; a hardware analog (A) input from the night stat

- FAN-FAIL: A binary signal (to the "Alarms and Shutdown" block diagram) indicating a fan has failed (not running when it should be).

- SYS-ENA (and SF-SS): A binary signal indicating that the system is enabled and running. Note this same signal is also used as a hardware binary (B) output to the fan. This signal is true whenever the system is commanded to be on (either due to occupancy or night stat) and the system is not being shutdown due to an alarm condition.

- CLG-ENA (and ECO-ENA): A binary enable signal to the cooling block and economizer blocks, respectively, enabling those loops. This signal is enabled whenever the SYS-ENA is TRUE and the occupancy is OCCUPIED or WARM UP / COOL DOWN.

- MINOA-ENA: A binary enable signal to the MIN-OA control block. This signal is enabled whenever the SYS-ENA is TRUE and the occupancy is OCCUPIED.

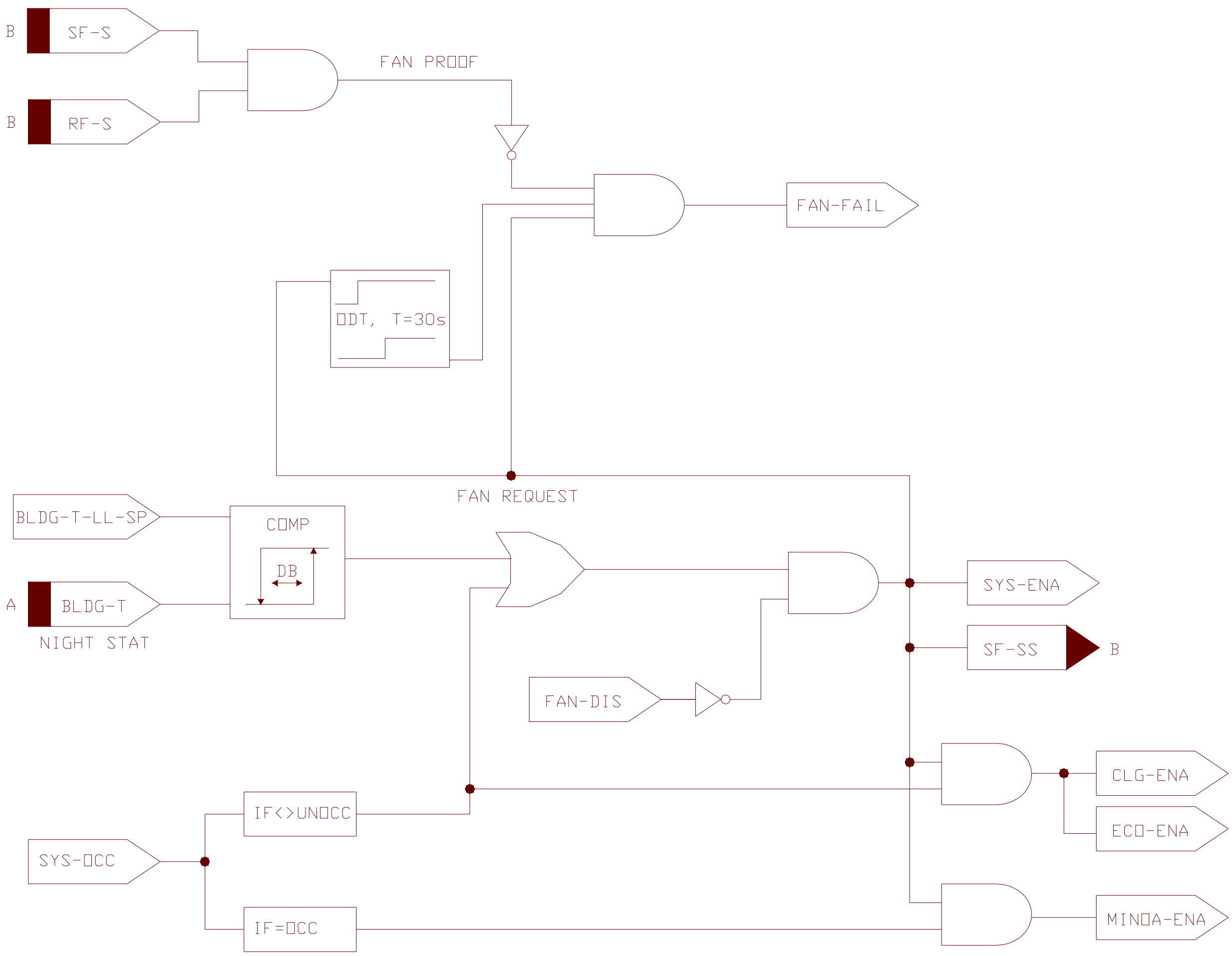

Figure 4-5. System Enabling Logic.

4-3.3 **Alarms and shutdown CLD**

Figure 4-6 shows logic used to shut the system down in case of an alarm condition. It has multiple inputs and outputs:

- PH-T-LL: Preheat Temperature Low Limit; a hardware binary (B) input from the freeze stat. This will be from a contact that closes upon a drop in temperature below the freeze stat setpoint. Therefore this signal is true when the freeze stat "trips". Note there is an implied setpoint here: the freeze stat trip setting. This is not shown in the CLD because this as a hardware configuration setting (something that gets adjusted via setscrew at the freezestat) and is shown in the Points Schedule. Note that the example CLD shows a freeze stat for the preheat coil. In the absence of a preheat coil the freeze stat would be in a different location (such as at the cooling coil).

- SA-P-HL: Supply Air Pressure High Limit; a hardware binary (B) input from the duct high pressure limit safety switch located at the outlet of the fan. This input is from a contact that closes upon a rise in pressure above the pressure switch setpoint. As with the PH-T-LL the SA-P-HL setpoint is implied in the CLD and its setting is shown in the Points Schedule. Note that while the example CLD shows a SA-P-HL this only applies to a VAV air handler and (ordinarily) should not be shown in a non-VAV system.

- SA-SMK and RA-SMK: Supply (Return) Air Smoke; hardware binary (B) inputs from the smoke detectors.

- FAN-FAIL: A binary signal from the System Enabling Logic indicating fan failure.

- RST-BUT: Reset Button; a hardware binary (B) input (to the DDC control logic) from a pushbutton located at the AHU (or AHU control panel). This signal clears the system failure and resulting shutdown due to any of the above alarms.

- FAN-DIS: Fan Disable: A binary (B) signal which goes to the System Enabling Logic to disable the system.

The CLD shows one other component, a set/reset (S/R) Latch used to “remember” the system failure until the failure is cleared via the RST-BUT input. The designer needs to specify the setpoints for the PH-T-LL and SA-P-HL alarms.

Note that the alarm conditions are dealt with directly by the sequence running in the DDC Hardware. As a general rule, alarm conditions must be dealt with in the control system sequence of operation. While an alarm should be sent to the M&C server, the sequence must place the system in a “safe” mode and not rely on operator intervention.

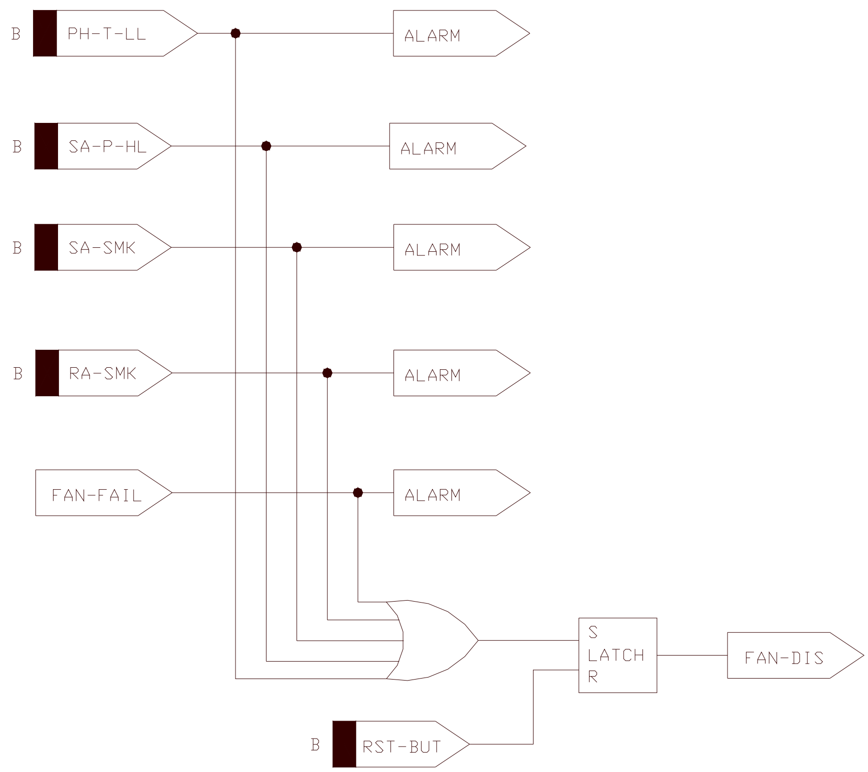

Figure 4-6. Alarms and Shutdown CLD.

4-4 CONTROL LOOPS

4-4.1 Preheat coil control loop

A minimum amount of outside air (OA) must always be used in HVAC systems. In cold climates preheating the OA avoids the freeze-up of coils and raises the temperature of the OA before using it in the system. Preheated OA is usually mixed in the return air plenum with a setpoint between 40° and 55°F depending on the application. For example, a 40°F setpoint might be used when there is a downstream coil to further condition the air while a 55°F setpoint might be used when there is no downstream coil. Figure 4-7 shows the preheat coil temperature loop schematic, and Figure 4-8 shows the CLD for preheat coil control. Designer selections for this loop include: (1) Preheat coil discharge air temperature setpoint (2) Preheat coil temperature low limit (PH-T-LL) (referred to as the Freeze stat) setpoint, (3) Valve size (C_v), (4) valve shutoff pressure/force, and (5) Control action of the controller. Note that the freeze stat is shown on the Preheat Coil Loop Control Schematic because that is **physically** where it is located and is shown on the Alarms and Shutdown CLD (not the Preheat Coil CLD) because that is where it is **logically** located.

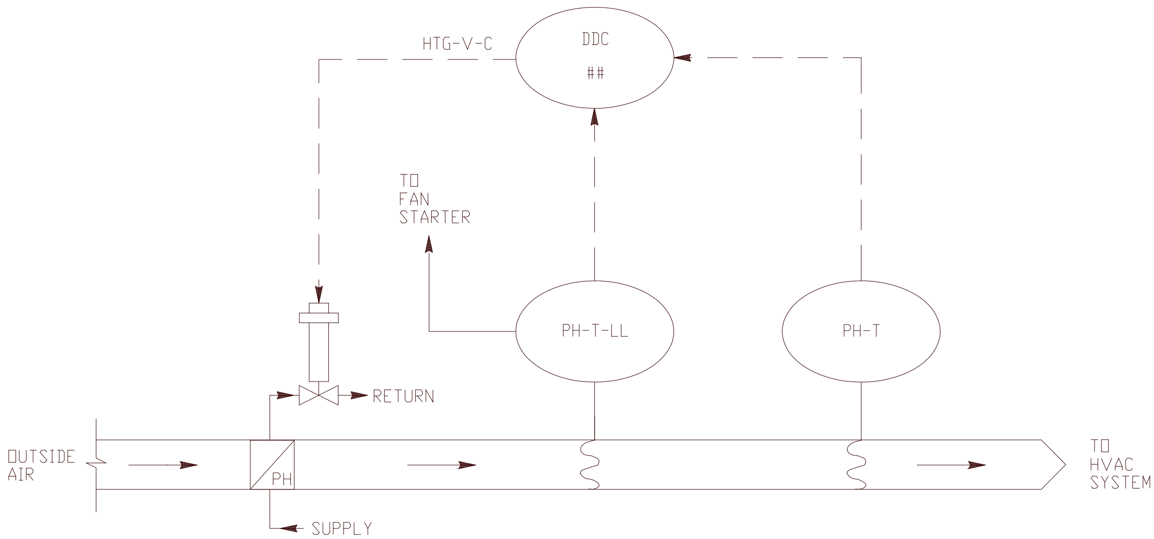

Figure 4-7. Preheat Coil Control Schematic.

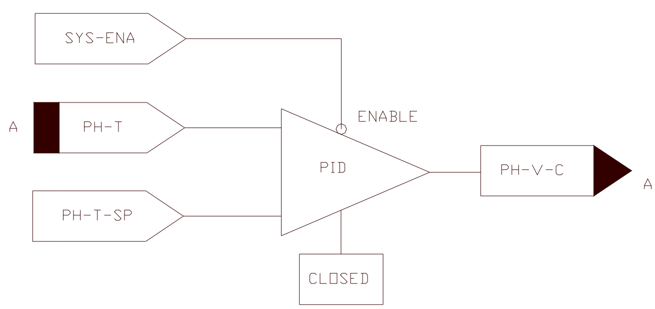

Figure 4-8. Preheat Coil CLD.

4-4.2 **Cooling coil control loop**

The cooling coil control loop is a constant-temperature control loop. The cooling coil valve is ordinarily chosen to be NC as an energy conservation measure and the corresponding control action will be DIR. As a failsafe against freezing, the designer might choose to select a NO valve with a corresponding REV control action (where if the AHU shuts down on freeze stat) since a fully open coil is less likely to freeze than a closed coil. A typical setpoint for the cooling coil control loop is 55°F, but will depend on the application requirements. In the event there is a mixed air temperature control loop, the cooling coil loop setpoint might be chosen to be slightly higher than the mixed air temperature setpoint. This slight difference in setpoints helps to keep the cooling coil valve closed while the mixed air temperature economizer is active. The cooling coil valve will open when the economizer loop does not maintain supply air temperature at or below the cooling coil loop setpoint. Figure 4-9 shows the cooling coil control loop schematic, and Figure 4-10 shows the CLD for cooling coil control. Ordinarily the control loop is enabled when: (1) the supply fan is proven to be on, and (2) the system is in the occupied mode. Note that the freeze stat is shown downstream of the cooling coil. This is to prevent false trips where upon system startup (such as at the beginning of the day) a surge of outside air is drawn into the air handler but after short amount of time becomes mixed with warmer return air. The designer my choose to locate the freeze stat upstream (such as in the mixed air section) particularly in the case where there is a heating coil upstream. In this case the cooling coil need not have a freeze stat but the heating coil should. As a rule, only one freeze stat is required per system. Designers are advised to check with local O&M staff for freeze stat location preferences. Suggested designer selections include the following: (1) Supply air temperature control setpoint (typical value of 55ºF), and freeze stat setpoint in the Points Schedule; (2) Values for valve size (C_v) and valve shutoff pressure/force in the Valve Schedule; and (3) Control action notation in the Control Schematic Drawing.

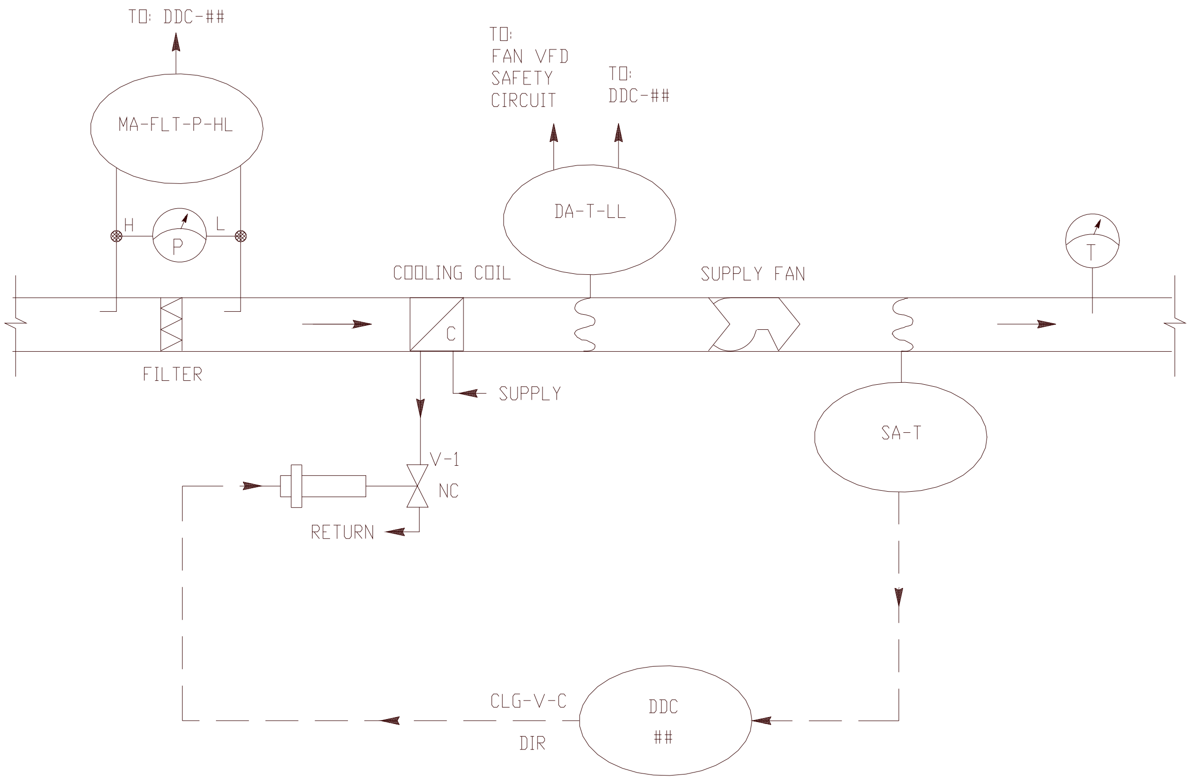

Figure 4-9. Cooling Coil Control Schematic.

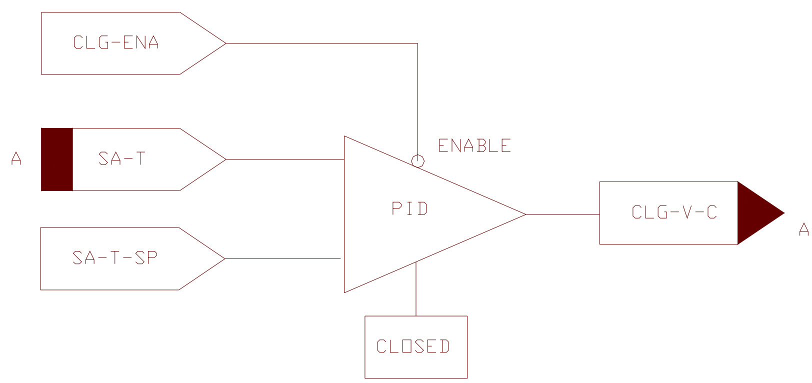

Figure 4-10. Cooling Coil CLD.

4-4.3 **Heating coil control loop with setpoint reset**

This control loop involves the control setpoint being adjusted (reset) based on a system variable (usually outside air temperature). Typical applications are (1) Heating hot water temperature (hydronic) and (2) Heating coil discharge air temperature.

A *reset schedule* defines the relationship between outside air temperature and setpoint temperature. Figure 4-11 shows an example of setpoint reset control, with the following characteristics: (1) heating coil discharge air temperatures of 120°F at 0°F outside air and below; (2) 90°F at 60°F outside air and above.

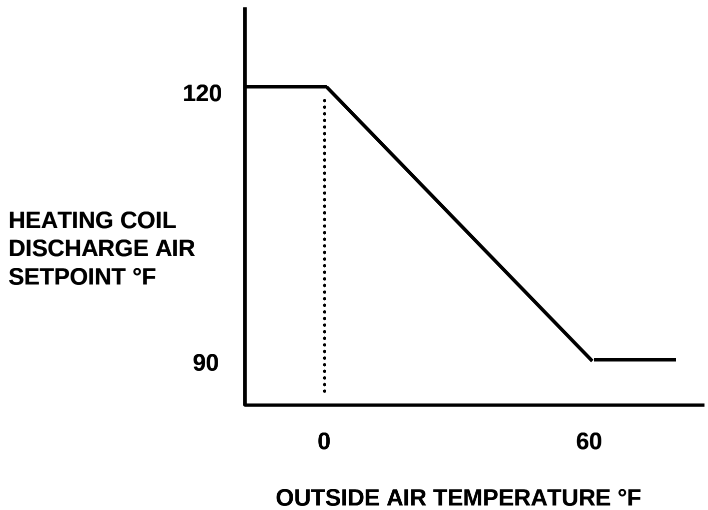

Figure 4-11. Typical Setpoint Reset Schedule for Heating Coil Air Temperature.

Figure 4-12 shows the heating coil with outside air reset control loop schematic. Suggested designer selections include the following: (1) Values for setpoint and freeze stat setpoint in the Points Schedule; (2) Reset Schedule, if setpoint reset is used; (3) Values for valve size (C_v) and valve shutoff pressure/force in the Valve Schedule; and (4) Control action notation in the Control Schematic Drawing.

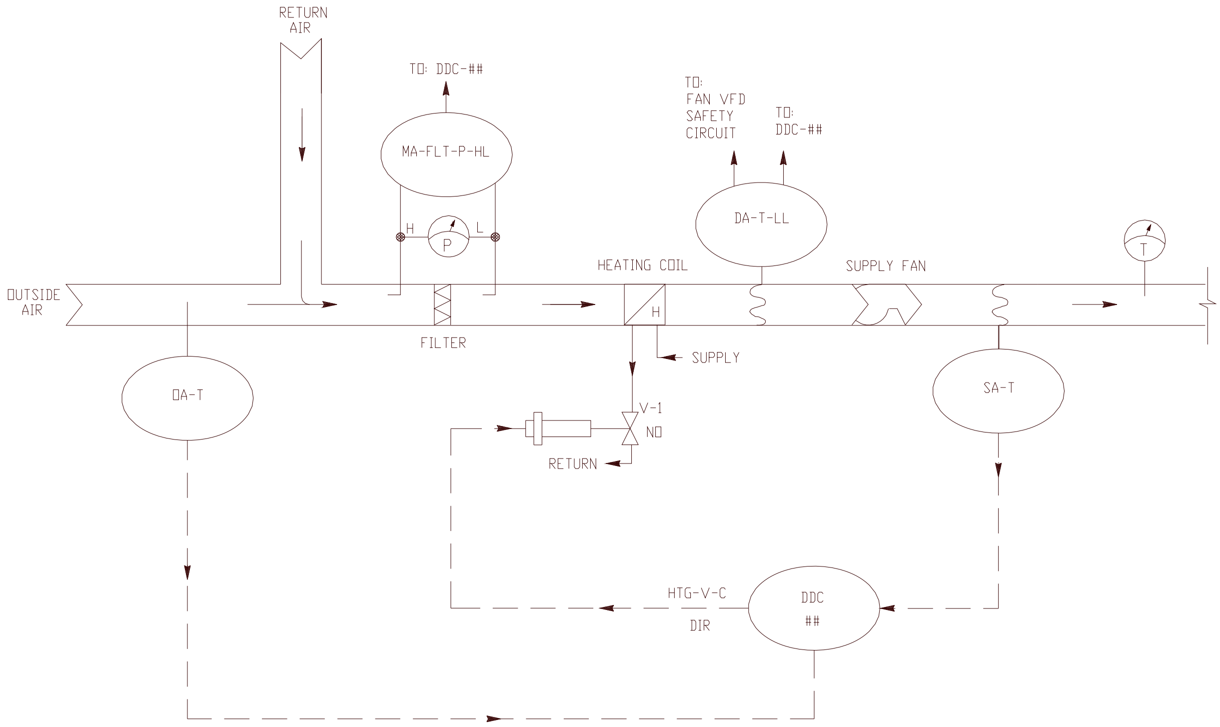

Figure 4-12. Heating Coil with Outside Air Reset Control Schematic.

4-4.4 **Mixed air temperature control with economizer**

An economizer functions as a switch to introduce outside air for “free cooling”. When the economizer is “on”, the mixed air temperature control loop DDC controller modulates the outside, return, and relief dampers. Modulation of the outside and return dampers regulates mixed air temperature (MA-T) to its specified setpoint while modulation of the relief damper serves to exhaust the additional outside air delivered to the building/spaces. When the economizer is “off” the economizer outside air damper is closed.

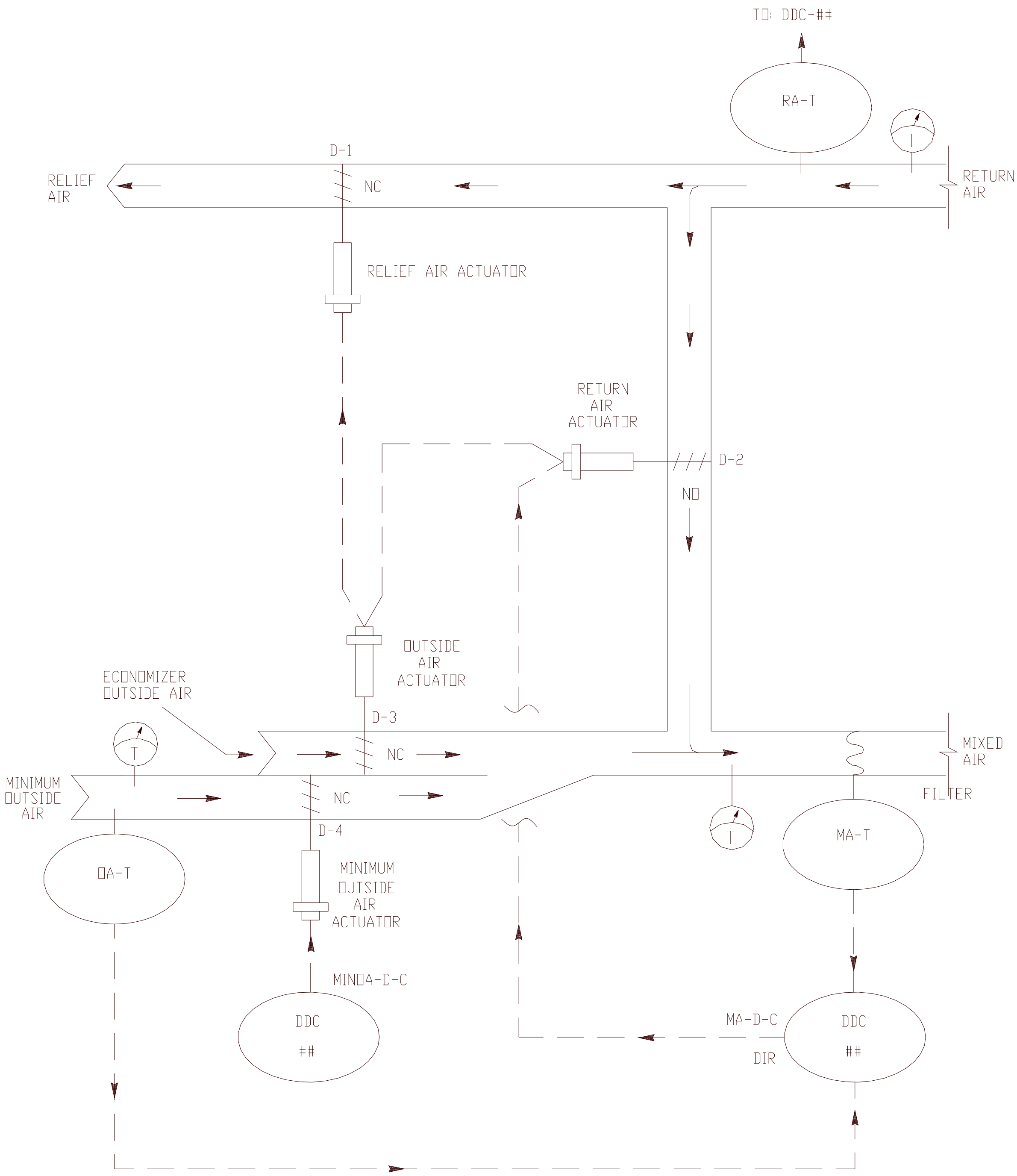

Figure 4-13. Economizer/Mixed Air Temperature Control Schematic.

4-4.4.1 **OA-Only dry bulb economizer**

Although there are many ways to perform the economizer on/off decision, a control system that uses only an outside air dry bulb sensor is recommended based on its simplicity and long term reliability as compared to other methods.

Figure 4-13 shows the OA-only dry bulb economizer control loop. It uses an OA dry bulb sensor and DDC controller to make the economizer on/off decision. When the Economizer is on, the controller sends a mixed air damper command (MA-D-C) to modulate the relief, return, and outside air dampers. When the economizer if off, the DDC moves the three dampers to their failsafe positions. Minimum outside air quantity is maintained by a separate control loop. The return air temperature sensor shown in figure 4-13 is optional and would be used only for temperature monitoring purposes.

Figure 4-14 shows the CLD for the OA-only dry bulb economizer. As described previously, the System Enabling Logic provides the SYS-ENA signal (based on occupied mode and fan proof). When the outside air temperature is less than the economizer high limit setpoint (ECO-HL-SP) a 'true' output is generated by the comparator (COMP). Similarly, when outside air temperature is greater than the economizer low limit setpoint (ECO-LL-SP) a true output is generated by the other comparator (COMP). When all three conditions are true the AND gate generates a true output enabling the MA-T PID loop. When the PID is not enabled the default output closes the OA economizer damper.

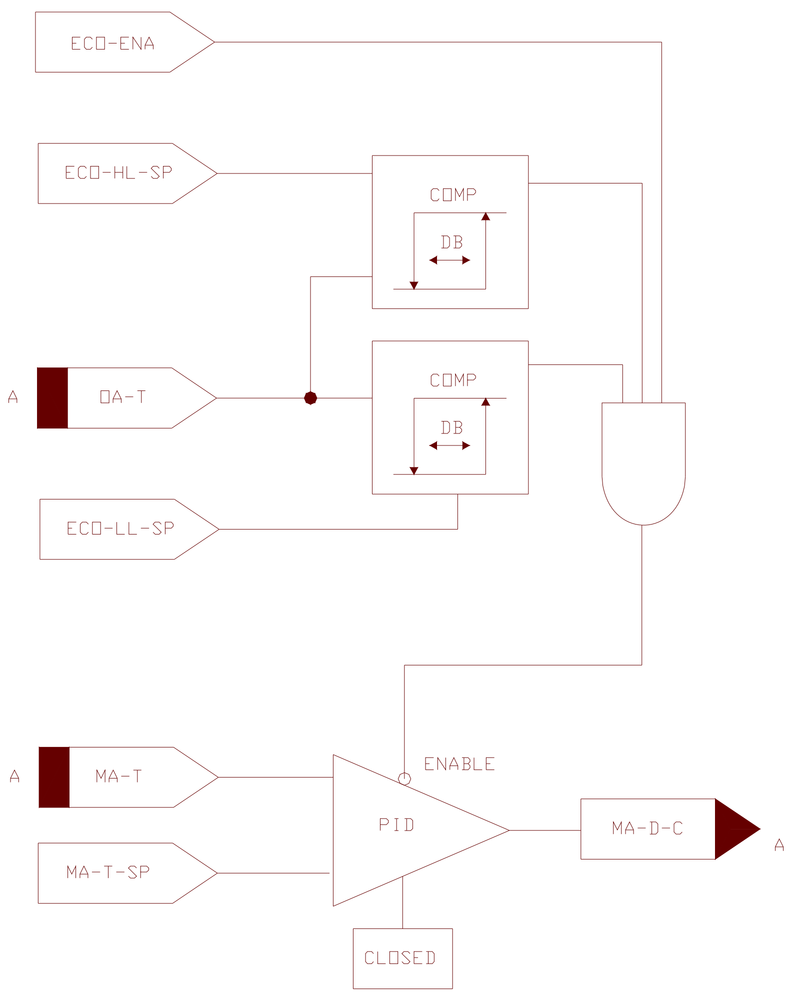

Figure 4-14. OA-Only Dry Bulb Economizer CLD.

4-4.4.2 OA-Only dry bulb economizer designer selections

The designer must select the economizer high limit setpoint (ECO-HL-SP), the low limit temperature setpoint (ECO-LL-SP), and the mixed air temperature setpoint (MA-T-SP).

4-4.4.2.1 Economizer high limit setpoint selection

Economizer high limit setpoint (**ECO-HL-SP)** is the dry bulb temperature below which the OA-only economizer turns "on". The objective is to select it low enough so that the economizer turns on when the OA enthalpy is lower than the return air enthalpy, thus achieving free cooling. Since neither the return air enthalpy nor outside air enthalpy are being measured, assumptions must be made. Outside air enthalpy can be estimated based on the outside air dry bulb temperature using (local) average weather data. The ECO-HL-SP is then selected based on this estimation. Due to the assumptions made a margin of safety is then applied to the selection of ECO-HL-SP.

Figure 4-15 illustrates selection of the **OA-only economizer** setpoint for Greenville, NC:

1. Plot a constant enthalpy line through the return air design dry bulb temperature & relative humidity (A-B). In this example, 78°F and 50% RH. Caution: Give careful consideration to the return air condition. For example, if you follow this procedure for 78°F and 50% RH condition but the actual condition is 72°F and 50% RH, the economizer (on average) will turn on about 4°F or 5°F sooner than it should, resulting in wasted mechanical cooling energy.

2. Plot a weather line (C-D) for the worst case month, in this case July, using the midpoint of each OA dry bulb bin and corresponding mean coincident OA wet bulb. To help select the worst case month, you may choose to plot the average weather line for two or three summer months and then proceed to step 3. Wet bulb and dry bulb weather data is available through UFC 3-400-02 "Design: Engineering Weather Data" which references a data download site at **http://www.afccc.af.mil.**

3. Draw a vertical line down from the intersection of lines A-B and C-D to the dry bulb axis. This is Point E. (If you plotted multiple average weather lines, draw the vertical line down from the month that places Point E furthest to the left.)

4. For the **OA-only economizer**, the economizer high limit setpoint (ECO-HL-SP) is point E, or 67°F. Again, note the additional caution in step 1.

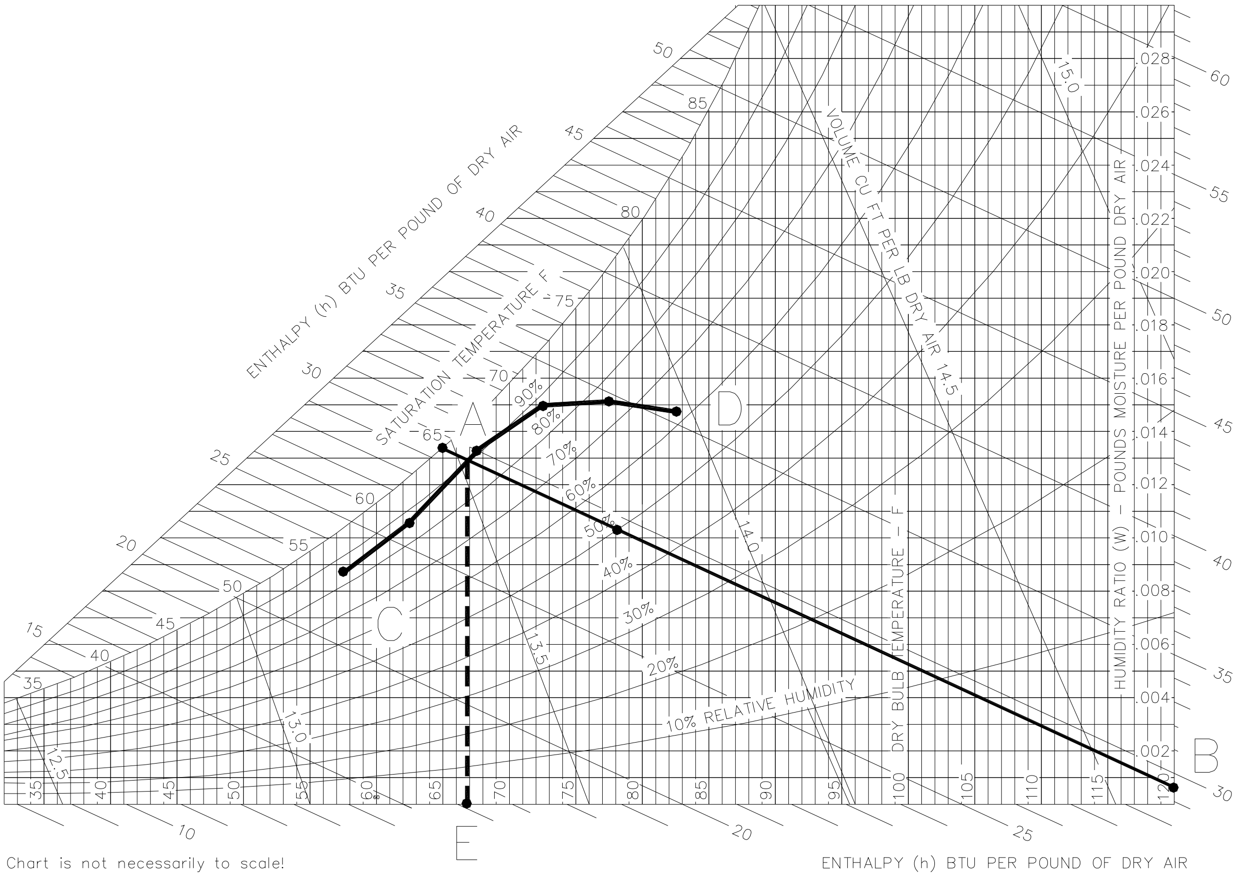

Figure 4-15. OA-Only Economizer Setpoint Selection Example for Greenville, NC.

GREENVILLE–SPARTANBURG APRT SO CAROLINA

LAT 34 54N LONG 82 13W ELEV 957 FT

MEAN FREQUENCY OF OCCURRENCE OF DRY BULB TEMPERATURE (DEGREES F) WITH MEAN COINCIDENT WET BULB TEMPERATURE (DEGREES F) FOR EACH DRY BULB TEMPERATURE RANGE

Temperature Range	MAY Obsn Hour Gp 01 to 08	MAY 09 to 16	MAY 17 to 24	MAY Total Obsn	MAY MCWB	JUNE Obsn Hour Gp 01 to 08	JUNE 09 to 16	JUNE 17 to 24	JUNE Total Obsn	JUNE MCWB
100/104										
95/99		0		0	69		3	1	4	74
90/94		7	2	9	69		21	6	27	74
85/89		33	12	45	68	0	49	21	70	72
80/84	0	49	25	74	67	4	64	41	109	70
75/79	4	50	41	95	65	19	53	55	127	68
70/74	25	43	62	130	64	74	31	67	172	67
65/69	83	31	52	166	62	97	16	38	151	64
60/64	70	23	33	126	58	37	4	8	49	59
55/59	37	9	15	61	53	9	0	1	10	54
50/54	17	3	6	26	48	1	0	0	1	50
45/49	10		1	11	43					
40/44	2			2	39					
35/39	0			2	35					
30/34										

Temperature Range	JULY Obsn Hour Gp 01 to 08	JULY 09 to 16	JULY 17 to 24	JULY Total Obsn	JULY MCWB	AUGUST Obsn Hour Gp 01 to 08	AUGUST 09 to 16	AUGUST 17 to 24	AUGUST Total Obsn	AUGUST MCWB
100/104							0		0	75
95/99		2	1	3	74		3	1	4	74
90/94		27	7	34	74		32	8	40	74
85/89		75	28	103	73	0	73	30	103	74
80/84	3	79	53	135	72	3	70	57	130	72
75/79	34	47	82	163	71	35	45	77	157	71
70/74	152	17	66	235	69	134	19	57	210	69
65/69	52	2	11	65	65	63	5	16	84	65
60/64	6		0	6	59	12	1	2	15	60
55/59	1			1	55	1			1	55
50/54										
45/49										
40/44										
35/39										
30/34										

Temperature Range	SEPTEMBER Obsn Hour Gp 01 to 08	SEPTEMBER 09 to 16	SEPTEMBER 17 to 24	SEPTEMBER Total Obsn	SEPTEMBER MCWB	OCTOBER Obsn Hour Gp 01 to 08	OCTOBER 09 to 16	OCTOBER 17 to 24	OCTOBER Total Obsn	OCTOBER MCWB
100/104										
95/99		1		1	73					
90/94		9	2	11	71					
85/89		34	10	44	72		1		1	70
80/84		51	27	78	70		17	2	19	66
75/79	4	53	51	108	68		36	10	46	64
70/74	70	44	66	180	67	4	44	27	75	62
65/69	72	29	46	147	63	20	52	44	116	60
60/64	48	12	23	83	58	44	50	61	155	56
55/59	30	5	10	45	54	59	27	46	132	52
50/54	13	1	3	17	50	45	15	36	96	48
45/49	3	1	1	5	46	44	6	16	66	44
40/44						23	1	5	29	39
35/39						8	0	1	9	34
30/34						2		0	2	30

Figure 4-16. Greenville SC Weather Data for OA-Only Economizer Setpoint Selection Example.

4-4.4.2.2 **Low limit temperature setpoint selection**

Economizer low limit setpoint (**ECO-LL-SP**) is the dry bulb temperature below which the OA-only economizer turns ‘off’ when the OA temperature is cool/cold (e.g. 50ºF). As a practical matter, while the economizer is ‘on’, the mixed air control loop will modulate the dampers to maintain the mixed air setpoint. Therefore this low limit function is theoretically not needed, but it can help prevent nuisance tripping of the freeze stat and can also help stabilize the minimum outside air flow control loop by eliminating interaction between these two competing airflow paths. Selection of the ideal setpoint selection would require modeling to identify the heat/cool *balance point* of the building where, below the balance point, the building only needs heating. Modeling can be expensive and therefore not practical. An estimate of the ECO-LL-SP (balance point) is acceptable, usually 50ºF. Applications with high internal cooling loads may benefit from a lower setting.

4-4.4.2.3 **Mixed air temperature setpoint selection**

The mixed air temperature setpoint (MA-T-SP) should be selected to be the same as the cooling coil control loop discharge air setpoint (CC-DA-T-SP), typically 55°F, or 1°F to 2°F less than CC-DT-SP. A lesser setpoint helps to reduce or eliminate mechanical cooling while the economizer is ‘on’.

4-4.4.3 **OA/RA dry bulb economizer**

The OA/RA dry bulb economizer is a refinement of the OA-only economizer in that it takes into account the return air condition by sensing return air dry bulb. This economizer should be used with caution but can be beneficial where the return air condition is not constant such as in variable load and/or variable occupancy applications. More importantly, proper operation is highly dependent upon seasonal changes in space temperature setpoints in that heating mode space setpoints must be lower than cooling mode space setpoints. This is further discussed as part of the Condition 2 setpoint selection.

Figure 4-13 and Figure 4-17 illustrate the OA/RA dry bulb economizer. Unlike the OA-only economizer the OA/RA economizer uses both the outside and return air temperature sensor measurements. It operates when *both* of two temperature conditions are met:

1. Condition 1: The difference between return and outdoor air temperatures (RA-T and OA-T, respectively) is sufficient to use OA for free cooling. Specifically, RA-T minus OA-T is greater than the economizer differential setpoint (ECO-DIFF-SP)

2. Condition 2: RA-T indicates that there is a cooling load. Specifically, RA-T is greater than the ECO-HL-SP. Note that RA-T is not the only mechanism by which the economizer can determine if there is a cooling load. The designer may choose an alternate mechanism such as the status of the cooling coil valve position (where if it is not closed, Condition 2 is met).

In addition, as described previously, the economizer enable (ECO-ENA) signal must be ‘true’. This signal is generated by the System Enabling Logic (when the system is in occupied mode and supply fan proven ‘on’).

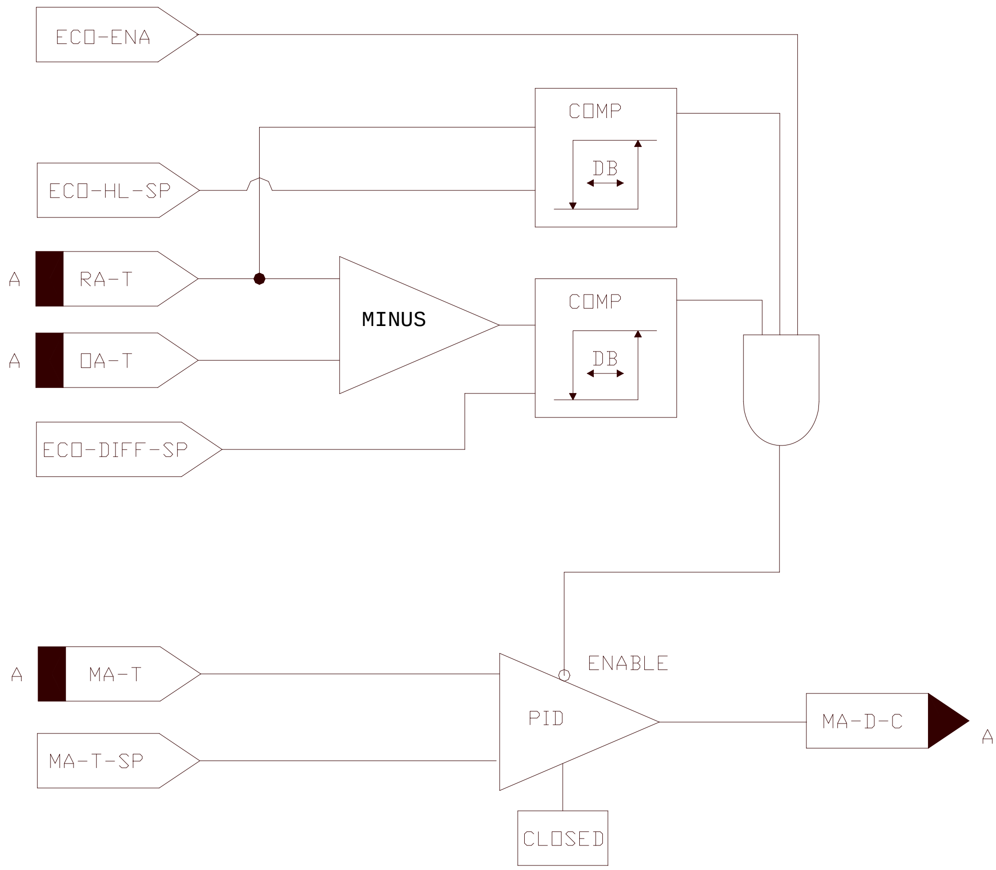

Figure 4-17. Mixed Air Temperature Control with RA/OA Activated Economizer CLD.

4-4.4.4 **OA/RA dry bulb economizer designer selections**

The designer must select the ECO-DIFF-SP and the ECO-HL-SP.

4-4.4.4.1 **OA/RA economizer differential setpoint selection**

Selection of the switching ‘Condition 1’ ECO-DIFF-SP is based on annual average (wet bulb) weather data which takes enthalpy into account, thereby optimizing the dry bulb economizer’s on/off decision. In summary, the designer uses a psychrometric chart and BIN weather data to correlate OA enthalpy to OA dry bulb along with an assumed RA condition (%RH and dry bulb) to correlate RA enthalpy to RA dry bulb. This results in a measure of OA and RA *dry bulb* temperatures that, in effect, provides for an enthalpy-based economizer decision.

Figure 4-18 illustrates selection of the OA/RA economizer Condition 1 setpoint (ECO-DIFF-SP) for Greenville, NC using weather data shown in Figure 4-16:

1. Plot a constant enthalpy line through the return air design temperature & relative humidity (A-B). In this example, 78°F and 50% RH.

2. Plot the average weather line (C-D). Use the midpoint of each OA dry bulb bin and corresponding mean coincident OA wet bulb from TM-5-785.

3. Draw a vertical line down from the intersection of lines A-B and C-D. This is point E.

4. Draw vertical line (G) down from constant enthalpy line return air condition to dry bulb temperature.

5. The **OA/RA economizer** ECO-DIFF-SP is the difference between point E and point G.

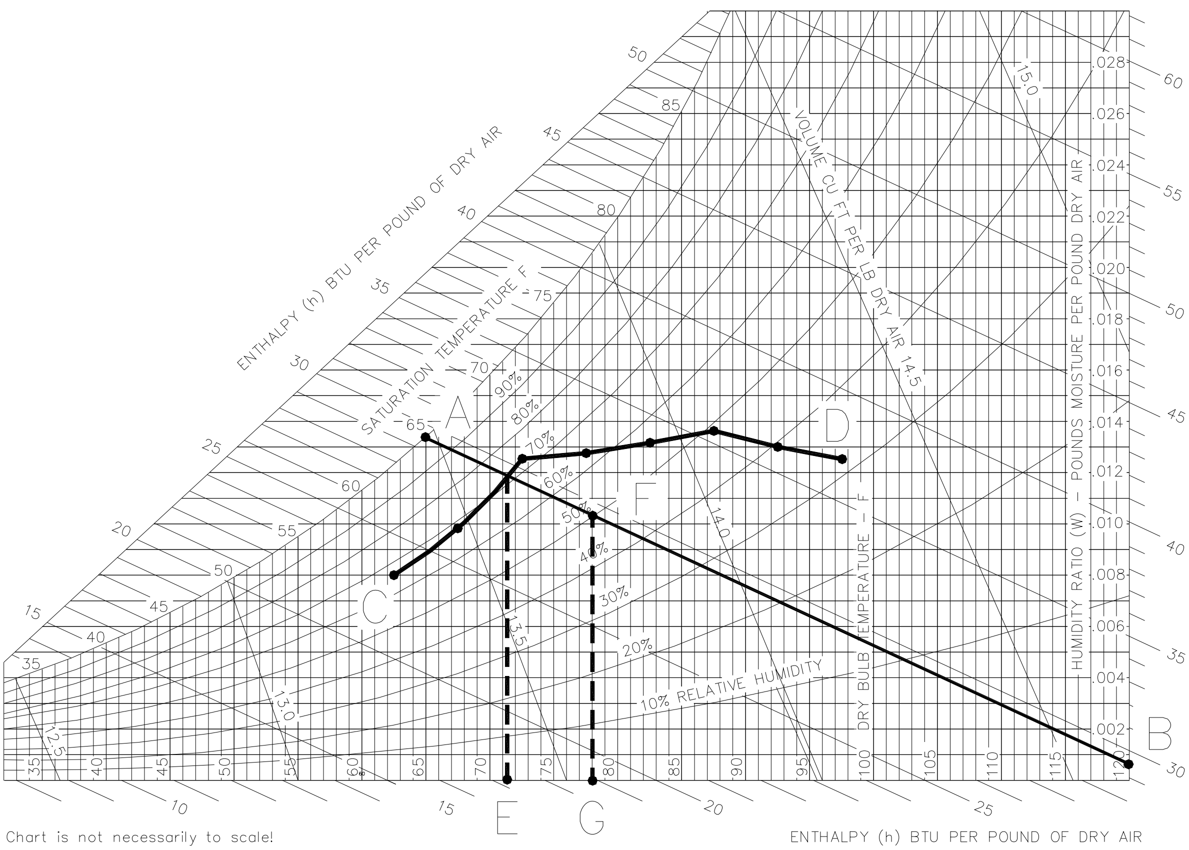

Figure 4-18. OA/RA Economizer Differential Setpoint Selection.

GREENVILLE–SPARTANBURG APRT SO CAROLINA

Temperature Range	NOVEMBER Obsn Hour Gp 01 to 08	NOVEMBER 09 to 16	NOVEMBER 17 to 24	NOVEMBER Total Obsn	NOVEMBER MCWB	DECEMBER Obsn Hour Gp 01 to 08	DECEMBER 09 to 16	DECEMBER 17 to 24	DECEMBER Total Obsn	DECEMBER MCWB	JANUARY Obsn Hour Gp 01 to 08	JANUARY 09 to 16	JANUARY 17 to 24	JANUARY Total Obsn	JANUARY MCWB	FEBRUARY Obsn Hour Gp 01 to 08	FEBRUARY 09 to 16	FEBRUARY 17 to 24	FEBRUARY Total Obsn	FEBRUARY MCWB
100/104																				
95/99																				
90/94																				
85/89																				
80/84		2	0	2	66															
75/79		2	1	10	64		1		1	62							0		0	66
70/74		21	6	27	60		4	0	4	58		2	0	2	62		4	1	5	59
65/69	4	36	19	59	58	1	12	2	15	57	1	6	2	9	57	0	10	5	15	56
60/64	23	46	32	101	56	5	22	12	39	56	4	14	7	25	55	3	18	11	32	54
55/59	27	39	46	112	50	12	26	22	60	51	7	24	14	45	50	13	31	28	72	51
50/54	41	34	46	121	46	16	33	32	81	46	9	32	25	66	45	18	33	30	81	46
45/49	43	27	40	110	42	25	41	37	103	42	24	42	39	105	41	25	37	41	103	42
40/44	43	16	27	86	37	37	45	45	127	37	32	46	50	128	37	36	37	41	114	37
35/39	34	6	16	56	33	44	33	45	122	33	51	39	50	140	33	50	29	34	113	33
30/34	18	2	6	26	28	49	21	34	104	29	52	27	36	115	29	39	15	20	74	28
25/29	6	1	2	9	24	36	7	14	57	24	38	11	18	67	24	22	5	8	35	24
20/24	3	0	0	3	20	16	2	4	22	19	20	4	6	30	19	10	2	3	15	19
15/19	0			0	18	5	1	1	7	15	8	2	2	12	14	5	1	1	7	14
10/14						2	0	1	3	10	2	0		2	10	1	0	1	2	10
5/9						1			1	6	0			0	6	1	0		1	5
0/4																0			0	3

Temperature Range	MARCH Obsn Hour Gp 01 to 08	MARCH 09 to 16	MARCH 17 to 24	MARCH Total Obsn	MARCH MCWB	APRIL Obsn Hour Gp 01 to 08	APRIL 09 to 16	APRIL 17 to 24	APRIL Total Obsn	APRIL MCWB	ANNUAL TOTAL Obsn Hour Gp 01 to 08	ANNUAL TOTAL 09 to 16	ANNUAL TOTAL 17 to 24	ANNUAL TOTAL Total Obsn	ANNUAL TOTAL MCWB
100/104												0		0	75
95/99							0		0	72		9	3	12	74
90/94							0		0	65		96	25	121	73
85/89							8	2	10	67	0	273	103	376	72
80/84		2	1	3	60		22	9	31	65	10	356	215	581	70
75/79		7	2	9	62		28	17	45	62	96	329	336	761	68
70/74	0	16	8	24	59	3	36	29	68	60	462	281	389	1132	66
65/69	2	23	16	41	56	20	39	44	103	58	415	261	295	971	61
60/64	12	36	27	75	53	48	40	49	137	55	312	266	265	843	56
55/59	18	44	41	103	49	52	34	39	125	51	266	239	262	767	51
50/54	33	39	46	118	46	44	20	25	89	46	237	210	249	696	46
45/49	46	35	43	124	42	38	10	18	66	42	258	199	236	693	42
40/44	54	26	32	112	38	23	3	7	33	38	250	174	207	631	37
35/39	46	10	20	76	33	12	0	1	13	33	245	117	167	529	33
30/34	24	6	7	37	28	1			1	29	185	71	103	359	29
25/29	40	3	3	14	24						110	27	45	182	24
20/24	4	1	2	7	21						53	9	15	77	19
15/19	1	0	0	1	16						19	4	4	27	15
10/14	1			1	12						6	0	2	8	10
5/9											2		26	2	6
0/4											0			0	3

Figure 4-19. Greenville SC Weather Data for OA/RA Economizer Setpoint Selection Example.

4-4.4.4.2 **OA/RA economizer high limit setpoint selection**

Selection of the switching 'Condition 2' ECO-DIFF-SP, and thus proper operation of this economizer, is premised on the **assumption** that the return air temperature will vary based on the need for heating or cooling and, to a lesser extent, based on load changes. In other words, there must be a seasonal swing in the return air temperature. This swing can be achieved by defining and implementing zone/space heating and cooling thermostat setpoints (i.e. 68°F heating and 78°F cooling). If this is not desirable or achievable, the OA/RA dry bulb economizer is not recommended. With a heating mode setpoint of 68°F and and a cooling mode setpoint of 78°F, the midpoint is 73°F. To account for return air heat pickup from lights and other sources, add 2°F to this midpoint. The ECO-HL-SP setpoint is then 75°F.

4-4.4.4.3 **Mixed air temperature setpoint selection**

The mixed air temperature setpoint (MA-T-SP) should be selected to be the same as the cooling coil control loop discharge air setpoint (CC-DA-T-SP) (typically 55°F) or 1°F to 2°F less than CC-DA-T-SP. This lower setpoint helps to reduce or eliminate mechanical cooling while the economizer is 'on'.

4-4.5 **Outside air flow control**

This section describes the three preferred methods that may be used to accomplish outside air flow control:

1) Two-Position Damper
2) Flow Control
3) Demand Controlled Ventilation

In each case, a separate/dedicated ventilation outside air duct should be specified. A dedicated duct provides for a more accurate setting and better control of the outside air flow. 100% outside air systems and systems that do not contain an economizer do not require this separate/dedicated duct.

The control system design must be accomplished in accordance with ASHRAE Standard 62, “Ventilation for Acceptable Indoor Air Quality”, which describes how to provide indoor air quality that will be acceptable to human occupants and is intended to minimize the potential for adverse health effects. Standard 62 also contains guidance on managing sources of contamination, controlling indoor humidity, and filtration of the building air.

4-4.5.1 **Ventilation air versus make-up air**

Design of the outside air flow control loop and the specified minimum outside air (MINOA) flow quantity must take into account two basic considerations;

1) Ventilation air for building occupants, and
2) Make-up air required to offset building exhaust and to provide pressurization for exfiltration flow

The MINOA quantity selected by the designer must be sufficient to meet the ventilation air flow requirements as defined in ASHRAE Standard 62. In addition, the minimum outside air quantity must be sufficient to provide make-up air for all sources of exhaust flow (Exh Flow) from the areas served by the air handler and to provide for a degree of building pressurization by creating exfiltration flow (Exf Flow). The larger of these two outside air quantities should be selected and specified as the MINOA quantity. In summary:

If Ventilation Air Flow > (Exh Flow + Exf Flow), then: MINOA = Ventilation Air Flow
If Ventilation Air Flow < (Exh Flow + Exf Flow), then MINOA = Exh Flow + Exf Flow

The exfiltration flow component is intended to help ensure that that the MINOA flow exceeds the building exhaust flow. This in turn helps to create a positive pressure in the zones/spaces served by the air handler. Exact calculation of the exfiltration flow that is required to create positive building pressure is a non-exact science due to uncertainty in inter-zonal flows and year round variations in wind-induced pressure on the external