



CONTROL
SEQUENCE
FUNDAMENTALS

Course Workbook

1st Edition

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Succeed in this course

Over the past year I've created several training courses for my students. As I look back at my past students I've pinpointed three things that make my students successful:

1. Access the program, watch the videos three times, and comment on the videos. The action of watching the videos and engaging with me and fellow students will naturally increase the amount of information you retain.
2. Work through this workbook. This workbook was designed to help you retain key pieces of information that have a direct impact on your performance as a BAS professional. As you move through each lesson I will ask you questions in the workbook that will help you to further expand your knowledge.
3. Attend the live office hours. These calls are your opportunity to interact with your instructor (me) and ask questions related to Control Sequences.

Don't skimp on these three actions. The reality is learning anything takes work. Fortunately for you, I've condensed that learning into the shortest time possible.

When you follow the three steps above you will see massive results as you work through this course.

Remember, I am here for you at any time via the discussion section and live office hours.

I look forward to hearing about your success story.

To your success,

-Phil

Note From Your Instructor

A lot of my courses (and their lessons) can be approached in any order. This is not one of those courses.

It is vital that you follow each lesson in order. Even if you think you know the subject matter you must go through each lesson.

Otherwise you will find subjects that you do not fully understand, and this will make things very tough.

You do not want to be the person at the jobsite spouting off about a concept only to realize later that you were wrong.

Consider yourself warned.

Module 1: Control Sequence Overviews

In this module we will discuss the core information you need to know prior to embarking on this course. This lessons in this module are:

- Lesson 1: What is a Control Sequence
- Lesson 2: How are Control Sequences Built

Here's the deal. Control sequences can seem quite complicated. The reality is 99% of the population has gone through life without seeing anything like a control sequence...

Or have they?

I want you to realize that you deal with sequences every day. They are called procedures and they guide you through how to do things. That is all a control sequence is, a procedure...

Once you mentally accept that we are able to move through sequences really fast. Because the reality is, even the most complex sequence is simply a procedure. You have a set of inputs and outputs and a set of tasks that utilize these inputs and outputs.

Now I get it, that's easy for me to say. After all I've been working in this field for years. But that wasn't always the case. I can tell you without a shadow of a doubt that if I had known what you are going to learn in this course, I would have been years ahead of where I am now.

Heck I even learned a thing or two while creating this course. So, let's get started.

Lesson 1: What is a Control Sequence

Lesson Objectives:

- Explain how a controls sequence works

What are the three most common forms of sequence of operations?

Why is it important to pay attention to where the control sequence comes from?

What is the main difference between the three versions of the sequences?

What are the categories that sequences fall into?

Lesson 2: How are Control Sequences Built

Lesson Objectives:

- Understand the four important control sequence categories
- Explain the purpose of each control sequence category

What are the four things control sequences tell you?

What is a control mode?

Why does it matter what control mode you are in?

Why would you want to move your sequence chunks around?

What red flags should you look for in sequences?

How do you determine if an auxiliary control mode is linked to the BAS?

What are the 5 steps used during the programming process?

MODULE 2: INTERPRETING SEQUENCES

In this module we will go through how to interpret control sequences. This is a short module, but it is also very important. The lesson in this module is:

- Lesson 1: The Process of Turning a Sequence into a Controls Drawing

The success (or failure) of a design, scope, install, program, service call (and the list goes on), comes down to one thing. How well did the person doing the task interpret the sequence of operations?

A well interpreted sequence of operations will shave hours of head banging and frustration that would be spent trying to undo a poor interpretation.

In this module I want you to focus on the thought process behind the act of interpreting a sequence. It is this mentality and thought process that will carry you through the rest of the course.

It's time to let go of any ego and of any I know what I'm doing attitude. It's time to go back to the basics and embrace the role of a learner.

Don't worry, I'm here with you every step of the way.

Lesson 1: The Process of Turning a Sequence into a Controls Drawing

Lesson Objectives:

- Describe how to translate a controls sequence to a controls drawing
- Explain how each component is used in the design

Why do we take a control sequence and implement it into a control drawing?

What stencils should you add for creating control drawings?

Why do I set properties and names on my controls drawings?

NOTE: Visio drawings for sequences will be in a separate module titled Visio sequences that will be at the end of the course. As I moved through the course I chose to do whiteboard videos based on the initial student feedback.

MODULE 3: COMMON SPACE SEQUENCES

In this module we will dive into space control. The lessons in this module are:

- Lesson 1: Space Control Overview
- Lesson 2: Colling Only VAV Control
- Lesson 3: Reheat VAV Control
- Lesson 4: Series and Parallel Fan VAV Control

I teach from a systems thinking perspective. Every time we unpack a new sequence we will think about how does this system relate to any systems upstream and downstream.

We will constantly be thinking to ourselves how a change here could affect something else and is a change somewhere else affecting my space right here.

It is this thinking that will save your butt on service calls, crazy designs that defy the laws of physics, and requests for design or scope expertise.

This module may be just spaces. But spaces are the key to it all.

Lesson 1: Space Control Overview

Lesson Objectives:

- Explain the fundamental concepts of space control

What are the important variables that effect space control?

How does airflow impact the conditions in a space?

Why is airflow the primary concern of space control?

How does air enter and leave a space?

What are the two methods for controlling airflow?

What are the three ways to control space temperature?

Lesson 2: Cooling Only VAV Control

Sequences

- Cooling Only VAV Boxes.pdf

Lesson Objectives:

- Describe the purpose of cooling only boxes
- Explain how cooling only boxes are controlled

What are the three main parts of a VAV box?

What are the process variables and modes VAV boxes need?

What is deadband and how does it affect VAV control?

Lesson 3: Reheat VAV Control

Sequences

- Reheat VAV Boxes.pdf

Lesson Objectives:

- Describe how reheat boxes are controlled
- Explain why reheat boxes are used

What are the two reasons for reheat boxes?

What are the three kinds of reheat?

What are the three big changes that we must account for with reheat boxes?

What variables are used for VAV reheat control?

What is the benefit of having a discharge air temperature sensor in a reheat box?

Describe how this lesson's sequence implements polling and why polling is used?

Lesson 4: Series and Parallel Fan VAV Control Sequences

- M3-L4 Sequence Fan.pdf

Lesson Objectives:

- Describe how fan powered boxes are used with VAV systems
- Explain why fan powered boxes are controlled

What are the two types of fan powered VAV boxes?

What is the purpose of putting fans in our VAV boxes?

What changes occur when we add fans to our VAV boxes?

What are the differences between parallel and series fan powered VAV boxes?

How are series fan powered boxes controlled?

How are parallel fan powered boxes controlled?

MODULE 4: COMMON AIRSIDE SEQUENCES

In this module we are taking a step up from spaces and looking at the systems that supply those spaces. The lessons in this module are:

- Lesson 1: Air Handling Concepts Overview
- Lesson 2: Rooftop Unit Controls
- Lesson 3: 100% OA AHU Control
- Lesson 4: Mixed Air AHU Control
- Lesson 5: Fan Coil Units
- Lesson 6: Makeup Air Unit Control
- Lesson 7: Exhaust Fans

There are so many golden nuggets of knowledge in this module. If I had to send someone out into the field with only one skill it would be understanding airside sequences.

What you will learn in this module will help you understand how to keep occupants comfortable, safe, healthy, and most importantly (asking for you on the next project!)

Lesson 1: Air Handling Concepts Overview

Lesson Objectives:

- Describe the main concepts of air handling systems

What makes a system a “air handling” system?

What are the four main variables of air handling systems?

Why does life safety come first?

What are some of the most common safety types?

What are the two main kind of dampers?

What are the two main categories of fans?

What are the main types of coils?

Lesson 2: Rooftop Unit Controls

Sequences

- Single Zone Rooftop Unit SOP.pdf

Lesson Objectives:

- Describe the different parts of a rooftop unit
- Explain how to control a rooftop unit

What are the airside fundamentals you should focus on? (Hint Lesson 1)

What are the 5 main parts of a RTU?

Why is it important to have an open air path?

Where are the different dampers located and what are they called?

How do you control a damper?

What are the different types of coils?

How do you control coils?

What are the differences between safeties and sensors?

What are the two modes of a RTU?

How do engineers come up with setpoints?

What is economizer? Why does it matter?

What points are often inside a RTU?

Why can you often only change the setpoints of a rooftop?

What is the ASHRAE 55 standard?

Why is ASHRAE 55 important?

Lesson 3: 100% OA AHU Control

Sequences

- 100-OA-SOP.pdf

Lesson Objectives:

- Describe how to control a 100% OA AHU
- Explain the purpose of a 100% OA AHU

Why are 100% OA Units used?

What are the 6 main safeties that you find in AHU's?

How do you implement each safety?

What is the purpose of each safety?

What happens when each safety trips?

How is a 100% OA unit controlled per this lessons sequence?

How does discharge air static pressure reset work?

Why do we often use a 55-degree discharge?

What is the difference between reheat and preheat?

Why do we preheat air?

What is the purpose of the recovery wheel in this sequence?

What points do we commonly have in a 100% OA AHU sequence?

How do you determine the amount of outdoor air you need?

What is the name of the standard that helps you determine this?

Why is setting the minimum outdoor air not as simple as just setting a damper %?

How do you maintain your minimum outdoor airflow when you are using a variable speed drive?

Lesson 4: Mixed Air AHU Control

Sequences

- MA-SOP.pdf

Lesson Objectives:

- Describe how a mixed air AHU works
- Explain how to control a mixed air AHU

Why do we use mixed air units?

What are the benefits of mixed air units?

What are some of the nuances of mixed air units?

What is building static pressure?

Why do you want positive building pressure?

What is the difference between positive and negative building pressure?

How is mixed air temperature controlled in a mixed air unit?

What is the purpose of an economizer on a mixed air unit?

What is the mixed air temperature calculation? Why does this calculation matter?

Why do you want to reset airflow with a VAV system and not discharge temperature?

How can you reset discharge air temperatures for a CV unit based on space temperature?

How do you control a mixed air unit based on this lessons sequence?

How do you interpret the damper and CO₂ control based on this lessons sequence?

Lesson 5: Fan Coil Units

Sequences

- FCU-SOP.pdf

Lesson Objectives:

- Describe how a fan coil unit works
- Explain what a fan coil unit is

What are the two differences between an air handling unit and a fan coil?

What is the benefit of a fan coil unit?

What are the three areas to pay attention to when dealing with fan coils?

How do you control a fan coil unit according to this lessons sequence?

What is the big no-no when dealing with fan coil units?

Lesson 6: Makeup Air Unit Control

Sequences

- mua-sop.pdf

Lesson Objectives:

- Explain what a makeup air unit is
- Describe how a makeup air unit works

What is the purpose of a makeup air unit?

How is a makeup air unit different than a 100% outdoor air unit?

How do you control a makeup air unit according to this lessons sequence?

Lesson 7: Exhaust Fans

Sequences

- EF-SOP.pdf

Lesson Objectives:

- Explain the purpose of exhaust fans
- Describe how exhaust fans work

What is an exhaust fan?

What are the three main control sequences for exhaust fans?

How do we implement each of the three control sequences?

MODULE 5: HOT WATER SYSTEMS

In this module we will be looking at heat, specifically hot water. The lessons in this module are:

- Lesson 1: Hot Water Concepts
- Lesson 2: Single HW Boiler Control
- Lesson 3: Multiple HW Boiler Control
- Lesson 4: Steam Boiler Control

It's quite funny, when I was recording this module my hot water boilers at my house failed. You don't realize how important heat is, until you don't have it!

In these lessons we will discuss proper control methods to effectively, efficiently, and safely exchange heat from our hot water systems to our air streams.

And each of those things are important. I've seen too many sequences, designs, and implementations that were not effective, efficient, or safe.

Let's change that!

Lesson 1: Hot Water Concepts

Lesson Objectives:

- Describe the major concepts needed to understand hot water systems
- Explain the reason for using hot water systems

What is heat?

Why is water used to transfer heat through a building?

What are boilers used for?

What are the different ways of producing heat with boilers?

What are the different parts of a boiler?

Why do we need to maintain minimum and maximum hot water temperatures?

What is temperature drop and why does it matter for boilers?

Why do we slowly warm up a boiler's primary loop before mixing it with secondary loops?

What are the different methods of bringing on boilers?

Lesson 2: Single HW Boiler Control

Sequences

- Single HW-SOP.pdf

Lesson Objectives:

- Explain how to control a single boiler

What are the three things we need to run a boiler?

What is the purpose of maintaining flow in a boiler?

What is the start up control process for a boiler?

Why is it important to understand the fuel source of your boiler?

What are the three ways to control a boiler's hot water setpoint?

What are the different ways of resetting hot water setpoints?

Describe how this lesson's single boiler hot water control sequence works.

Lesson 3: Multiple HW Boiler Control

Sequences

- Lead-Lag Boiler Control.pdf

Lesson Objectives:

- Explain how multiple hot water boiler control is implemented

What are the three main ways to control multiple boilers?

How does unison control work?

What assumptions do we make with unison control?

What is the difference between staging control and unison control?

What are the three conditions that can determine when the lead and lag boiler shift?

What are the two forms of lead | lag control?

Describe how this lesson's sequence stages multiple boilers.

Lesson 4: Steam Boiler Control

Sequences

- Steam-SOP.pdf

Lesson Objectives:

- Describe how steam control works
- Explain why steam is used

Describe why steam is dangerous and should be respected.

What is steam and why is it used?

What kind of steam do we use in our control sequences and why do we use that kind of steam?

What are two ways that heat can be transferred from steam to buildings?

What is the difference between a plate and tubular heat exchanger?

How do 1/3rd and 2/3rd valves work?

How do we control heat transfer in this lesson's sequence?

MODULE 6: CHILLED WATER SYSTEMS

In this module we will be stepping into the big leagues of chilled water control. The lessons in this module are:

- Lesson 1: Chilled Water System Concepts
- Lesson 2: Air Cooled Chiller Control
- Lesson 3: Water Cooled Chiller Control
- Lesson 4: Lead | Lag and Partial Load Chiller Control

Most folks are comfortable airside systems. Some folks are even comfortable with hot water systems.

But when you start talking about chillers... Forget about it!

Condensers, cooling towers, compressors, lift, gain, Delta T...

Man can this stuff be intimidating.

But the good news is that you already have the foundations built to understand this!

Now I'm going to ask you to make a mental shift. Up to this point we've thought about systems from the bottom up. Now I need you to think about the top down...

Take time to consider how your changes at a chiller will effect everything downstream from that chiller. Don't worry if you don't have the answer yet. You will after this module.

Lesson 1: Chilled Water System Concepts

Lesson Objectives:

- Explain how chilled water systems work
- Describe the main terms and concepts for chilled water control

What are the differences between the condenser and evaporator sides of the chiller?

What is the refrigeration cycle?

How is the refrigeration cycle used in chillers?

What are the two main categories of chillers?

What are two factors that can negatively affect air cooled chillers?

What are the four main parts of the condenser side of water cooled chillers?

What is the purpose of cooling towers?

What is the difference between lift and load?

How is load used as part of a staging and control strategy?

Lesson 2: Air Cooled Chiller Control

Sequences

- AC-Chiller-SOP.pdf

Lesson Objectives:

- Describe how air-cooled chillers are controlled
- Explain when air-cooled chillers should be used

How does an air-cooled chiller work?

What points do we need to control an air-cooled chiller?

What are the three variables that can enable a chiller?

What are three ways to control a chillers supply water temperature setpoint?

Why is it important to open your isolation valves before enabling a chiller?

What are the common points and parts that can cause a chiller to fail out of its control mode?

What is the purpose of booster pumps?

Lesson 3: Water Cooled Chiller Control

Sequences

- WC-Chiller-SOP.pdf

Lesson Objectives:

- Explain how water cooled chillers function
- Describe how water cooled chillers work

What is the purpose of cooling tower control?

What do the terms range and approach mean?

What are the different ways of controlling cooling towers?

What are the two forms of condenser water bypass control?

Describe the on and off conditions for controlling the chiller in this lesson's sequence.

What is the difference between a reverse and direct acting reset?

Why is it important to maintain the water level within a cooling tower?

Lesson 4: Lead | Lag and Partial Load Chiller Control

Sequences

- WC-Multi-Chiller-SOP.pdf

Lesson Objectives:

- Describe the different methods for dealing with chiller staging
- Explain the purpose of partial load chillers

What is a partial load?

What are the two conditions that a partial load system addresses?

What new variables are added with partial load control?

What is the purpose of lead and lag in chillers?

How is lag chiller staging accomplished in this lesson's sequence?

What are some other methods for staging lag chillers?

How does chillers being staged on and off affect pump GPM?

MODULE 7: PUMPING SYSTEMS

In this module we will be looking at pumping and piping. The lessons in this module are:

- Lesson 1: Pumping and Piping Concepts
- Lesson 2: Primary Pump CV and VFD
- Lesson 3: Primary Secondary Loop Control
- Lesson 4: Decoupled Loop Control

Yes, the moment is finally here! We are now ready to dive into the pumping and piping concepts that we've talked around for most of this course.

Now that we are here, you need to focus on one thing and one thing only.
Flow.

Now I'm not talking about GPM, I'm talking about the flow of the system.

When we look at piping and pumping we so often get confused. Should the water be going here?

Or should it be going there?

Don't worry I'm going to teach you arm you with some powerful knowledge bombs that I only wish I had early on in my career.

Get ready to ramp it up because this train isn't slowing down!

Lesson 1: Pumping and Piping Concepts

Lesson Objectives:

- Explain how pumping and piping effect the flow of water and transfer of BTU's

What is Tee's law?

How does adding a valve or pump to a loop effect it's flow?

What is the purpose of a mixing valve in a loop?

What is the purpose of a VSD pump on a loop?

How does low Delta T syndrome occur?

How do mixing valves and variable speed pumps address low Delta T syndrome?

Lesson 2: Primary Pump CV and VFD

Sequences

- AC-Chiller-SOP.pdf

Lesson Objectives:

- Describe how primary loops operate

What are the two methods of controlling pumps on primary loops?

What is our start condition and safety(ies) for pump control?

How does valve design effect loop flow?

Why is it important to use three-way valves with constant volume loops?

Lesson 3: Primary Secondary Loop Control

Lesson Objectives:

- Explain the differences between primary and secondary loops
- Describe how primary secondary loop control works

What are the main variables added with primary secondary loops?

What is the purpose of using primary secondary loops?

How are primary secondary loops implemented?

What are the different ways of controlling primary secondary loops?

What is differential pressure and how does it affect our control of the loop(s)?

Why is it important to look at the valve state versus just assuming the valve loop is direct acting or reverse acting?

How are mixing valves controlled?

What is the relationship to pressure and flow/speed?

Lesson 4: Decoupled Loop Control

Lesson Objectives:

- Describe how decoupled loops work

What is a decoupler?

How does a decoupled loop work?

What is the effect of flow on a decoupled loop?

How do we modulate the flow on a decoupled loop?

MODULE 8: UNITARY SYSTEMS

In this module we will unpack what unitary systems are. The lesson in this module is:

- Lesson 1: Unitary Overview

Unitary systems are often forgotten. Until you spend a day trying to figure out why a space is hot only to realize that the hot water radiator is not connected to the VAV box and is fighting your cooling efforts.

Then you start to appreciate why it is so important to focus not just on the big systems but also the little ones.

In this module the name of the game is conflict. Focus in on how these systems can conflict with your existing control strategy if not properly controlled.

Lesson 1: Unitary Overview

Lesson Objectives:

- Explain how unitary systems work
- Describe the different kinds of unitary systems

What are the different kinds of unitary systems?

What does systems conflict mean?

What do you need to be aware of when you have unitary buildings in an existing building that you are retrofitting?

MODULE 9: 2-PIPE SYSTEMS

In this module we will be looking at 2-pipe systems. The lesson in this module is:

- Lesson 1: Two-Pipe Control

No single system type has caused me quite as much heart-burn as 2-pipe systems.

And for good reason, if you don't REALLY understand how these systems work you can get yourself in a lot of trouble. I'm talking premature equipment failure, intolerable temperatures, and just plain ole complexity...

But it doesn't have to be that way.

These systems despite all their nuances are rather easy to control.

And you will learn how in this module.

Lesson 1: Two-Pipe Control

Lesson Objectives:

- Explain how two-pipe control works
- Describe how heat pumps work and why they are used with two-pipe systems

How do two-pipe systems work?

What enables heating and cooling?

Why do you need to use open or close control and not proportional control for the changeover valve?

Why must the pump be downstream from the changeover valve?

What are the three issues with two-pipe systems?

What is a heat pump?

What is the purpose of a reversing valve?

What are the two states of the reversing valve?

MODULE 10: CRAC UNITS

In this module we will look at Computer Room Air Conditioning or (CRAC) units. The lesson in this module is:

- Lesson 1: CRAC Units

CRAC units begin to expose us to two difficult concepts.

The first concept is how do you implement a control sequence on a system that often precludes you from having direct control over inputs and outputs?

The next concept is how do you take those systems and tie into them.

As you move into advanced sequences, integration, and all around good complex BAS work, you will find that these two concepts come up time and time again.

I want you to focus in on:

- The strategies for controlling sequences without control of the I/O
- How to tie in systems that don't speak your BAS's language

Lesson 1: CRAC Units

Lesson Objectives:

- Describe how CRAC units work
- Explain how CRAC units interface with a BAS system

What is the purpose of a CRAC unit?

What is the difference between CRAC and CRAH units?

When would you use a CRAH instead of a CRAC unit?

What are the two ways CRAC units cool racks?

How do you control a CRAC unit without voiding its warranty?

What are the gotchas you need to be aware of when integrating a CRAC unit?

What is a guide specification?

What are the two main issues that occur when trying to monitor a CRAC?

How are these two issues resolved?

MODULE 11: VRV SYSTEMS

In this module we look at Variable Refrigerant Volume (VRV) systems. The lesson in this module is:

- Lesson 1: VRV Control

In this module we will look at a system that is giving a lot of BAS professionals heartburn, VRV systems. In this lesson, we will talk through how the VRV system works and how we communicate to it.

Once again, we will be focusing in on how we control a system without direct control of the I/O and how do we tie into other vendors systems.

Lesson 1: VRV Control

Lesson Objectives:

- Explain how a VRV system works
- Describe the three different types of VRV systems

What is the benefit of a VRV system?

What are three potential issues when tying in VRV systems into existing buildings?

How do we solve each of the potential issues with a VRV system?

What is the purpose of an interface?

Why do we need an interface when we are connecting to VRV systems?

MODULE 12: HEAT RECOVERY SYSTEMS

In this module we will discuss how heat recovery systems work. The lesson in this module is:

- Lesson 1: Recovery Unit Control

I remember my first time working on heat recovery units. I was doing the controls for the film studio that created the Matrix films and they wanted the building to be LEED Platinum.

Part of this required the building's AHUs and Chillers to have heat recovery units.

When I first heard the term heat recovery I was a little intimidated. But as you'll see from this Module. Heat recovery is quite simple.

Lesson 1: Recovery Unit Control

Lesson Objectives:

- Explain the purpose of recovery units
- Describe how recovery units work

What are the three types of recovery units?

Describe how each type of recovery unit works.

What are the different variables that you would expect to monitor during a heat recovery sequence?

MODULE 13: INTEGRATION SEQUENCES

In this module we will look at how integration sequences work. The lessons in this module are:

- Lesson 1: Integration Overview
- Lesson 2: The Integration Specification Process
- Lesson 3: Sample Integration Specifications

System Integration.

These two words can allow you to charge 10% more margin on projects and they can also create years of legal disputes debating what was “properly integrated”.

The good news is that systems integration isn’t that bad if you have a process. And in this module, I’m going to take you through that process step-by-step.

Lesson 1: Integration Overview

Lesson Objectives:

- Explain what systems integration is
- Describe how systems integration works between BAS devices

What are the three main protocols used in systems integration?

What are the differences between network and field level protocols?

What are the three types of systems integration?

When would you use each of the three different system integration types?

Lesson 2: The Integration Specification Process

Lesson Objectives:

- Explain the process of systems integration
- Describe the steps of the systems integration processes

What questions should you be able to answer during the first step of the integration process?

What is main outcome that comes from the first step of the integration process?

How do you find out what the as-is (existing) systems are?

When are integration specifications and projects developed?

Why is it important to have a process to maintain integrations?

Lesson 3: Sample Integration Specifications

Course Files:

- Sample Integration Sequences.zip

Lesson Objectives:

- Demonstrate the ability to digest integration sequences
- Learn shortcuts for scanning through sequence documents

What are some of the “tricks” that you can use when analyzing specifications?

How can you find integration sequences within a greater specification document?

How does the integration type effect how you read the specification?

Give an example of how knowing the integration type enables you to reduce the cost of a project?



NOTES:

Use this section to write down any notes you learn as you move through the course.



