AABC Commissioning Group

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Case Study Using a Variable Flow Chiller in a Central Plant

Course Number: CXENERGY1823

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SAMPLE OPTIONAL SLIDE

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Course Description

This case study covers a central plant serving chilled water to Air Handling Units in the central plant, a medical office building, and a hospital. This presentation will cover an overview of the system operation with three 1250 ton chillers and an overview of the bypass system and how to size bypass valves. Attendees will learn why the owner and engineer wanted to add a temporary chiller.

Learning Objectives

At the end of the this course, participants will be able to:

1. Provide an overview of the system operation with three 1250 ton chillers.
2. Provide an overview of how the 3 chilled water pumps will be staged.
3. Provide an overview of the bypass system and how to size bypass valves.
4. Explain why the owner and engineer wanted to add a temporary chiller.

System Description

The System is a Variable Primary Flow Chilled Water

Number of Chillers	Tonnage	Evaporator Maximum GPM	Evaporator Minimum GPM	Design Entering Water Temperature	Design Leaving Water Temperature
3	1250	1875*	500**	55.94°F	40.00°F*

*User Specified Input

** The minimum allowable velocity per the manufacturer is 1.5 ft./s

Number of Chillers	Tonnage	Condenser Maximum GPM	Condenser Minimum GPM	Design Entering Water Temperature	Design Leaving Water Temperature
3	1250	3750*	Constant Volume	86.00°F*	95.34°F

System Description

Chilled Water Pumps

Number of Pumps	Design GPM	Design Duty Head	Motor Horsepower	Break Horsepower at Design
3	1875*	200 Ft	150	116.16

*User Specified Input

Number of Pumps	Design GPM	Design Duty Head	Motor Horsepower	Break Horsepower at Design
3	3750*	85 Ft	125	100.60

Design Review

Design Review Comments

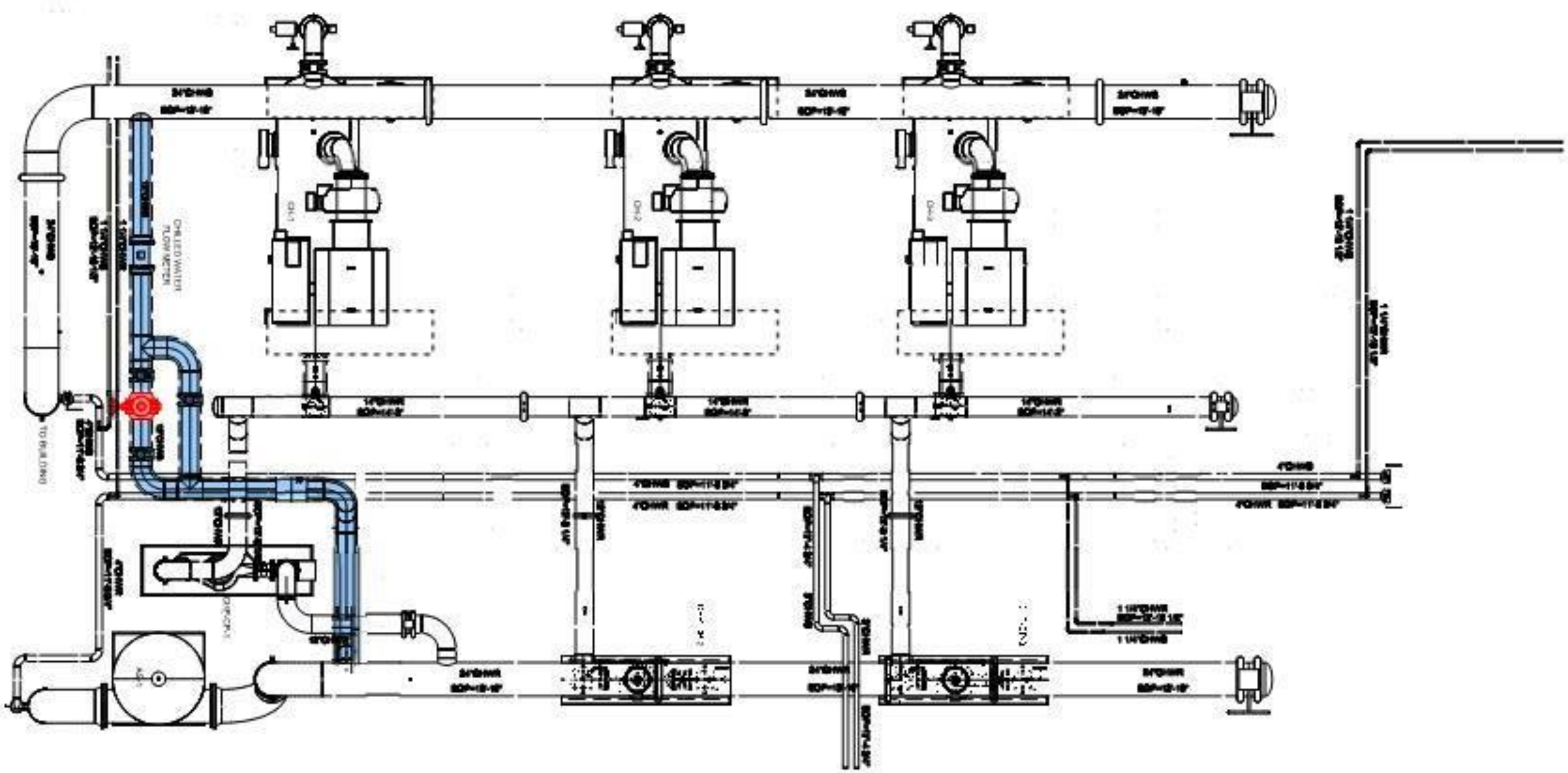
1. Construction team told the owner to operate the CUP and MOB will require a temporary Chiller.
2. Why have a temporary chiller when you have a variable primary system?
3. There was one problem for the system to operate under light loads.

Design Review

Bypass Control

1. When should the bypass open? All chilled water valves in the buildings are 2-way.
   a. On chiller start up.
   b. With three chillers operating.
   c. With two chillers operating.
   d. With one chiller operating.

Drawing of Chiller System



Design Review

12” valve C_v fully open is 6682, 50° open is 1449 and 20° open is 192
The manufacturer recommended minimum evaporator tube velocity is 1.50 Ft/s. . The minimum flow is 497.8 GPM, The design documents state minimum flow is equal to the manufacturer’s minimum plus 100 GPM. The minimum design flow is 600 GPM. The piping loss is approximately 1.8 PSI.

Fully open GPM = 6682x $1.8^{1/2}$ = 8965 GPM
80° open GPM = 5085 x $1.8^{1/2}$ = 6822 GPM
70° open GPM = 3470 x $1.8^{1/2}$ = 4655 GPM
60° open GPM = 2288 x $1.8^{1/2}$ = 3070 GPM
50° open GPM = 1449 x $1.8^{1/2}$ = 1944 GPM
40° open GPM = 899 x $1.8^{1/2}$ = 1206 GPM
30° open GPM = 509 x $1.8^{1/2}$ = 683 GPM
20° open GPM = 192 x $1.8^{1/2}$ = 258 GPM

The valve manufacturer states a butterfly valve is uncontrollable up to 20° rotation.

Chiller Operation

Tube Velocity with Variable Primary Chilled Water Flow			
Percent Load	Net Capacity (Tons)	Evaporator Flow (GPM):	Evaporator Velocity (ft./s):
100.0	1250.0	1875.0	5.70
90.0	1125.0	1687.5	5.10
80.0	1000.0	1500.0	4.50
70.0	875.0	1312.5	4.00
60.0	750.0	1125.0	3.40
50.0	625.0	937.5	2.80
40.0	500.0	750.0	2.30
30.0	375.0	562.5	1.70
20.0	250.0	497.8	1.50
10.0	188.0	497.8	1.50

Design Review

The bypass piping was changed to a 6" valve, the C_v values are shown below

The manufacturer recommended minimum evaporator tube velocity is 1.50 Ft/s. The minimum flow is 497.8 GPM, The design documents state minimum flow is equal to the manufacturer's minimum plus 100 GPM. The minimum design flow is 600 GPM. The piping loss is approximately 1.8 PSI.

Fully open GPM = $1580 \times 1.8^{1/2}$ = 2120 GPM

80° open GPM = $1450 \times 1.8^{1/2}$ = 1945 GPM

70° open GPM = $1160 \times 1.8^{1/2}$ = 1556 GPM

60° open GPM = $810 \times 1.8^{1/2}$ = 1086 GPM

50° open GPM = $510 \times 1.8^{1/2}$ = 684 GPM

40° open GPM = $295 \times 1.8^{1/2}$ = 396 GPM

30° open GPM = $145 \times 1.8^{1/2}$ = 195 GPM

20° open GPM = $47 \times 1.8^{1/2}$ = 63 GPM

The valve manufacturer states a butterfly valve is uncontrollable up to 20° rotation.

Design Review

Recap

The bypass piping was changed to a 6” valve. The manufacturer recommended minimum evaporator tube velocity is 1.50 Ft/s. The minimum design flow is 600 GPM.

60° open GPM = 810 x $1.8^{1/2}$ = 1086 GPM

50° open GPM = 510 x $1.8^{1/2}$ = 684 GPM

40° open GPM = 295 x $1.8^{1/2}$ = 396 GPM

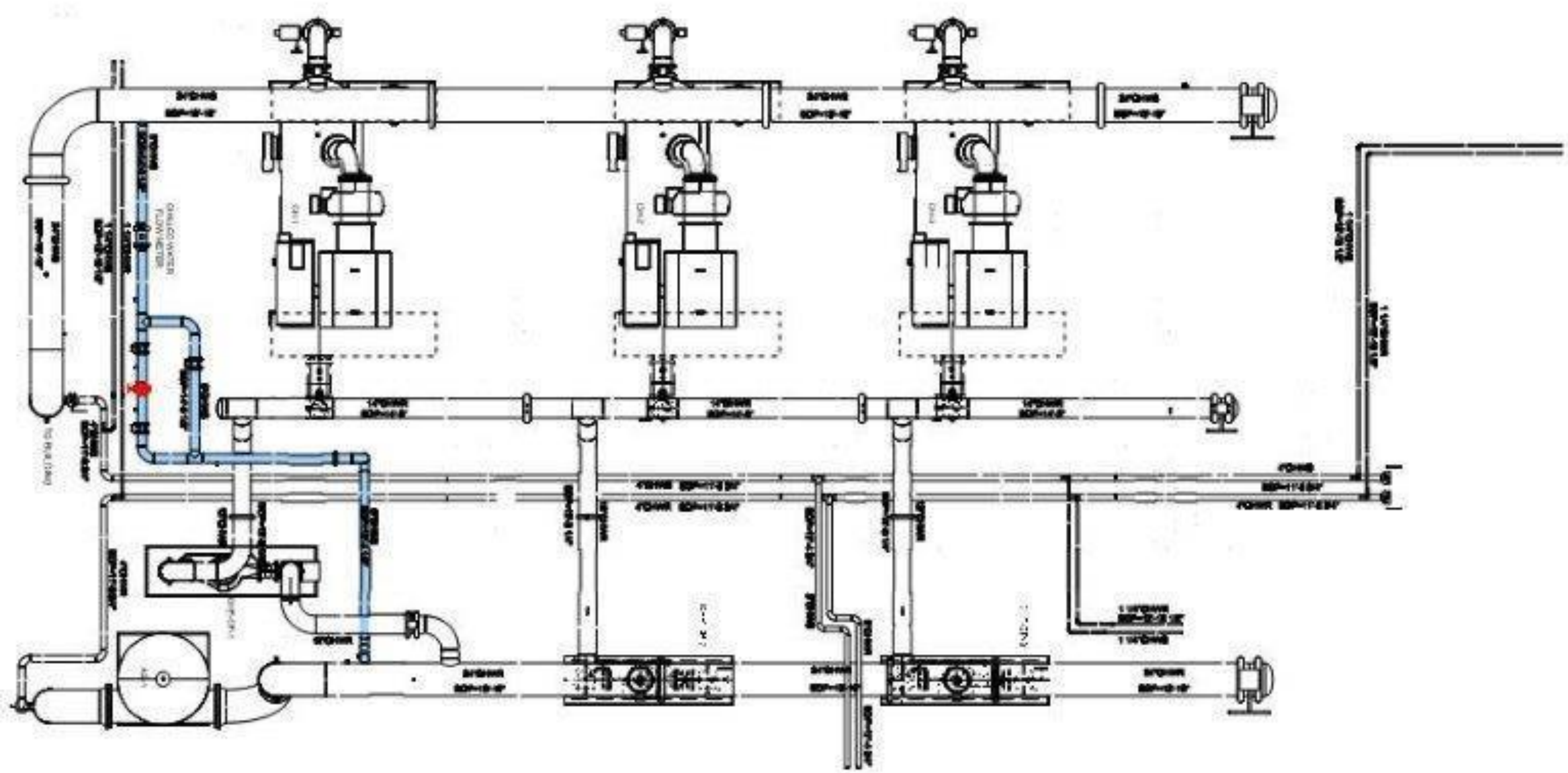
30° open GPM = 145 x $1.8^{1/2}$ = 195 GPM

20° open GPM = 47 x $1.8^{1/2}$ = 63 GPM

The valve manufacturer states a butterfly valve is uncontrollable up to 20° rotation.

When the chiller flow is equal to 750 GPM the bypass should start to open so by the time the chiller flow reaches 600 GPM the bypass will be 30°open.

Drawing of Chiller System With Revised Bypass



Testing Sequences

Staging the chillers on sequence is:

a. On a call for cooling (by operator command or automatically, indicated by one or more selected cooling coil valves being open more than 15%) the lead chiller is enabled.

	Isolation Valves Open	Chilled and Condenser Pumps	Proof of Flow Across the Chiller Tube Bundle	Chiller Start /Stop Commanded On
Lead Chiller Enabled	After 45 Seconds (adj.)	Start	After 30 Seconds (adj,)	Chiller Operates Under its Operating and Safety Controls

WHAT IS GOING ON WITH THE BYPASS?

Testing Sequences

WHAT IS GOING ON WITH THE BYPASS?

a. The valve has a fast acting modulating actuator with position feedback. The valve shall fail open and be powered close during normal use.
b. The flow meter (GPM) measurements across each chiller evaporator shall be used to vary the bypass valve position to maintain the minimum chiller flow rate (adj) + 100GPM (adj)

Testing Sequences

WHAT IS GOING ON WITH THE BYPASS?

a. The valve has a fast acting modulating actuator with position feedback. The valve shall fail open and be powered close during normal use.
b. The flow meter (GPM) measurements across each chiller evaporator shall be used to vary the bypass valve position to maintain the minimum chiller flow rate (adj) + 100GPM (adj) **WHEN THE CHILLER IS THE LEAD CHILLER**

Design Review

Bypass Control

1. When should the bypass open? All chilled water valves in the buildings are 2-way.
   a. On chiller start up.
   b. ~~With three chillers operating.~~
   c. ~~With two chillers operating.~~
   d. With one chiller operating.

Testing Sequences

Bypass Valve Operation

50° open GPM = 510 x $1.8^{1/2}$ = 684 GPM
40° open GPM = 295 x $1.8^{1/2}$ = 396 GPM
30° open GPM = 145 x $1.8^{1/2}$ = 195 GPM
20° open GPM = 47 x $1.8^{1/2}$ = 63 GPM
The valve manufacturer states a butterfly valve is uncontrollable up to 20° rotation.
The bypass control sequence should be tested when the plant is operating with one chiller.

Testing Sequences

When the lead chiller cannot handle the load on its own as indicated by a rise in the chilled water supply temperature with reference to the chilled water supply set point + and offset of 1.0° F (adj.), and the run load amp (RLA) is greater than 80% (adj.) for 20 minutes (adj.) the lag chiller is enabled by the following sequence:

	Chilled and Condenser Pumps	Isolation Valves Open	Proof of Flow Across the Chiller Tube Bundle	Chiller Start /Stop Commanded On
First Lag Chiller Enabled	Start	After 35 Seconds (adj.)	After 30 Seconds (adj,)	Chiller Operates Under its Operating and Safety Controls

Testing Sequences

i. A current maximum limit set point of 100% (adj.) is sent to all the operating chillers.
ii. The chilled water pump differential pressure setpoint will be fixed to prevent the VSD's having erratic operation to a change in low demand during the startup of the lag chiller.
iii. The differential pressure setpoint is released once the chillers are operating stably above minimum flow for five minutes (adj) and the RLA for each chiller is above 30%.

Testing Sequences

When the lead and lag chillers cannot handle the load as indicated by a rise in the chilled water supply temperature with reference to the chilled water supply set point + and offset of 1.0° F (adj.), and the run load amp (RLA) is greater than 80% (adj.) for 15 minutes (adj.) the second lag chiller is enabled by the following sequence:

	Chilled and Condenser Pumps	Isolation Valves Open	Proof of Flow Across the Chiller Tube Bundle	Chiller Start /Stop Commanded On
Second Lag Chiller Enabled	Start After 45 Seconds	After 2 Minutes (adj.)	Go to Next Step	Chiller Operates Under its Operating and Safety Controls

Testing Sequences

i. A current maximum limit set point of 100% (adj.) is sent to all the operating chillers.
ii. The chilled water pump differential pressure setpoint will be fixed to prevent the VSD's having erratic operation to a change in low demand during the startup of the lag chiller.
iii. The differential pressure setpoint is released once the chillers are operating stably above minimum flow for five minutes (adj) and the RLA for each chiller is above 30%.

Testing Sequences

With three chillers operating and the demand drops where each chiller RLA is less than 43% (adj.) for 15 minutes (adj.) the second lag chiller start/stop points shall be commanded off.

	Chiller Start /Stop Commanded Off	Chilled and Condenser Pumps	Isolation Valves Closed	Proof of Flow Across the Chiller Tube Bundle
Second Lag Chiller Disabled	Second Lag Chiller Off	After 10 Seconds the Condenser Pump is stopped, Chilled Water Pump Continues to Operate	After 2 Minutes (adj.)	Indicates No Flow

Testing Sequences

With two chillers operating and the demand drops where each chiller RLA is less than 32% (adj.) for 15 minutes (adj.) the second lag chiller start/stop points shall be commanded off.

	Chiller Start /Stop Commanded Off	Chilled and Condenser Pumps	Isolation Valves Closed	Proof of Flow Across the Chiller Tube Bundle
First Lag Chiller Disabled	First Lag Chiller Off	After 10 Seconds the Condenser Pump is stopped, Chilled Water Pump Continues to Operate	After 2 Minutes (adj.)	Indicates No Flow

Testing Sequences

There's a major problem with this sequence. The chiller's KW/ton changes with the entering water temperature to the condenser. At 86°F entering water temperature (EWT) and 40% load (500 tons) the KW/ton is 0.638. At 50°F EWT and 40% load the KW/ton is 0.220. This means the RLA changes with the condenser's EWT.

W= (Volts x Amps x 1.73)/ Power Factor
At 0.638 KW/ton and 40% load (500 Tons), assume Power Factor is 1
(638x 500)/ (480 x 1.73)= 221.6 RLA
At 0.220 KW/ton
(220 x 500)/ (480 x 1.73)= 132.5 RLA

Partload Data (Minimum Condenser Water Temperature)

% Load	CEFT (°f)												
	86°	85°	80°	75°	70°	65°	60°	55°	54°	53°	52°	51°	50°
100%	0.617	0.604	0.545	0.493	0.451	0.412	0.386	0.379	0.381	0.383	0.388	0.370	0.378
90%	0.604	0.591	0.529	0.474	0.423	0.378	0.346	0.328	0.327	0.328	0.331	0.335	0.342
80%	0.599	0.586	0.519	0.459	0.403	0.355	0.315	0.286	0.283	0.280	0.279	0.279	0.281
70%	0.597	0.584	0.517	0.454	0.395	0.342	0.295	0.257	0.251	0.246	0.241	0.237	0.234
60%	0.616	0.601	0.523	0.456	0.396	0.339	0.287	0.239	0.231	0.225	0.219	0.212	0.207
50%	0.622	0.608	0.538	0.454	0.400	0.341	0.285	0.240	0.234	0.227	0.222	0.216	0.210
40%	0.638	0.624	0.550	0.480	0.416	0.344	0.288	0.250	0.242	0.238	0.232	0.228	0.220
30%	0.680	0.664	0.581	0.507	0.437	0.373	0.301	0.267	0.259	0.256	0.251	0.245	0.240
20%	0.784	0.764	0.668	0.580	0.496	0.420	0.356	0.316	0.308	0.300	0.296	0.292	0.288
15%	0.894	0.872	0.761	0.654	0.564	0.479	0.404	0.367	0.362	0.356	0.346	0.340	0.335
	Values above are KW/Ton												

Suggested Sequences

Chilled Water System Start Sequence – when there is a call for chilled water by either operator command, and air handling unit sequence or other control events as specified, the DDC system shall perform the following sequence:

- Start the chilled water pumping system
  - Open the lead chiller's chilled water isolation valve
  - Start the lead chilled water pump VFD after isolation valves are proven open
  - Verify the lead chilled water pump is started and is operating as proven by the amps of the VFD via the VFD network interface or by the current sensor switch
  - The building differential pressure will control the chilled water pump speed to maintain the differential setpoint
  - The isolation valves will maintain the maximum flow through the evaporator

Suggested Sequences

Chilled Water System Start Sequence – Continued

- Start the condenser water pumping system
    - Open the lead chiller's condenser water isolation valve
    - Start the lead condenser water pump VFD after isolation valves are proven open
    - Verify the lead condenser water pump has started and is operating as proven by the amps of the VFD via the VFD network interface or by the current sensor switch
    - The isolation valves will maintain the maximum flow through the condenser
- Start the Lead Chiller when all the following is true, the DDC system will command the chiller start/stop on

Suggested Sequences

Chilled Water System Start Sequence – Continued

- Start the Lead Chiller when all the following is true, the DDC system will command the chiller start/stop on
  - Lead chilled water isolation valve is fully open
  - Lead chilled water pump has started
  - Lead cooling tower isolation valves is fully open
  - The evaporator flow through the lead chiller is greater than the minimum flow sensed by the differential pressure sensors
  - The condenser flow through the lead chiller is greater than the minimum flow sensed by the differential pressure sensors
  - All lead chiller internal safeties or proven

Suggested Sequences

Adding Chillers- based on tonnage calculated by the DDC System

	Lead Chiller	Initiate	Lag Chiller Start	
Add Lag Chiller	Cannot Maintain 1070 Tons for 15 Minutes (adj.)	Initiate the Chilled Water System Start Sequence for the Lag Chiller	When Flow is Proven Through the Evaporator and Condenser Above Minimum	Both Chillers Maintain 535 Tons up to 2000
Add Second Lag Chiller	Lead & Lag Chiller Cannot Maintain 2000 Tons for 15 Minutes (adj.)	Initiate the Chilled Water System Start Sequence for the Second Lag Chiller	Start the Second Lag Chiller When Flow is Proven Through the Evaporator and Condenser Above Minimum	Three Chillers Maintain 665 Tons up to 3750 Tons

Suggested Sequences

Removing Chillers- based on tonnage calculated by the DDC System

	Chiller Tonnage	Initiate	Lag Chiller Stop	
Drop Second Lag Chiller	1880 Tons for 15 Minutes (adj.)	Initiate the Chilled Water System Stop Sequence for the Second Lag Chiller	Second Lag Condenser pump is stopped, Isolation Valves Closed	Both Chillers Operate at 940Tons
Drop Lag Chiller	950 Tons for 15 Minutes (adj.)	Initiate the Chilled Water System Stop Sequence for the Lag Chiller	Lag Condenser pump is stopped, Isolation Valves Closed	Chiller Operates at 950 Tons

Suggested Sequences

If load continues to drop the bypass valve will start opening at 750 GPM (adj.) through the evaporator and maintain 600 GPM as a minimum.

Sample Last Slide

This concludes The American Institute of Architects Continuing Education Systems Course

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