Controls for Multistage Chilled Water System

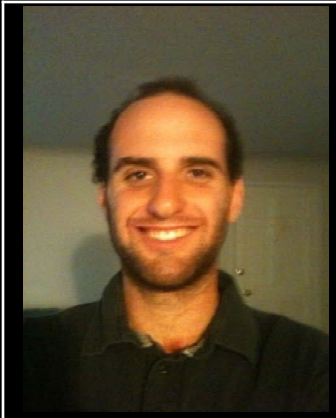
MECH/MECA 440A

Senior Design Project

Final Design Review Presentation

This document has been reviewed and determined NOT to contain export controlled technical data.

Team Members

				
Mike Bertoli MECH	Ryan Higuera MECA	Bryce Peterson MECA	Brendan Reese MECH	Sam Tanaka MECA

Faculty advisor: Dr. Ramesh Varahamurti

Industrial Sponsor

- Our Industrial Sponsor for this project is Jet Propulsion Laboratory – Deep Space Network

The Problem

- The output device of the 80 kW transmitter, a klystron, generates approximately 320 kW of heat that needs to be dissipated.
- The system will not function correctly if the temperature tolerances are not maintained.
- The current cooling system is designed for a smaller transmitter and insufficient for cooling the new transmitter, requiring a new design solution be implemented.

Needs and Goals

- Need: The existing cooling system does not have the capacity to meet the demands of the new 80 kW transmitter.
- Goal: The project hardware and application routines must control a water cooling system, responding to varying loads and varying ambient temperatures, while minimizing energy use.

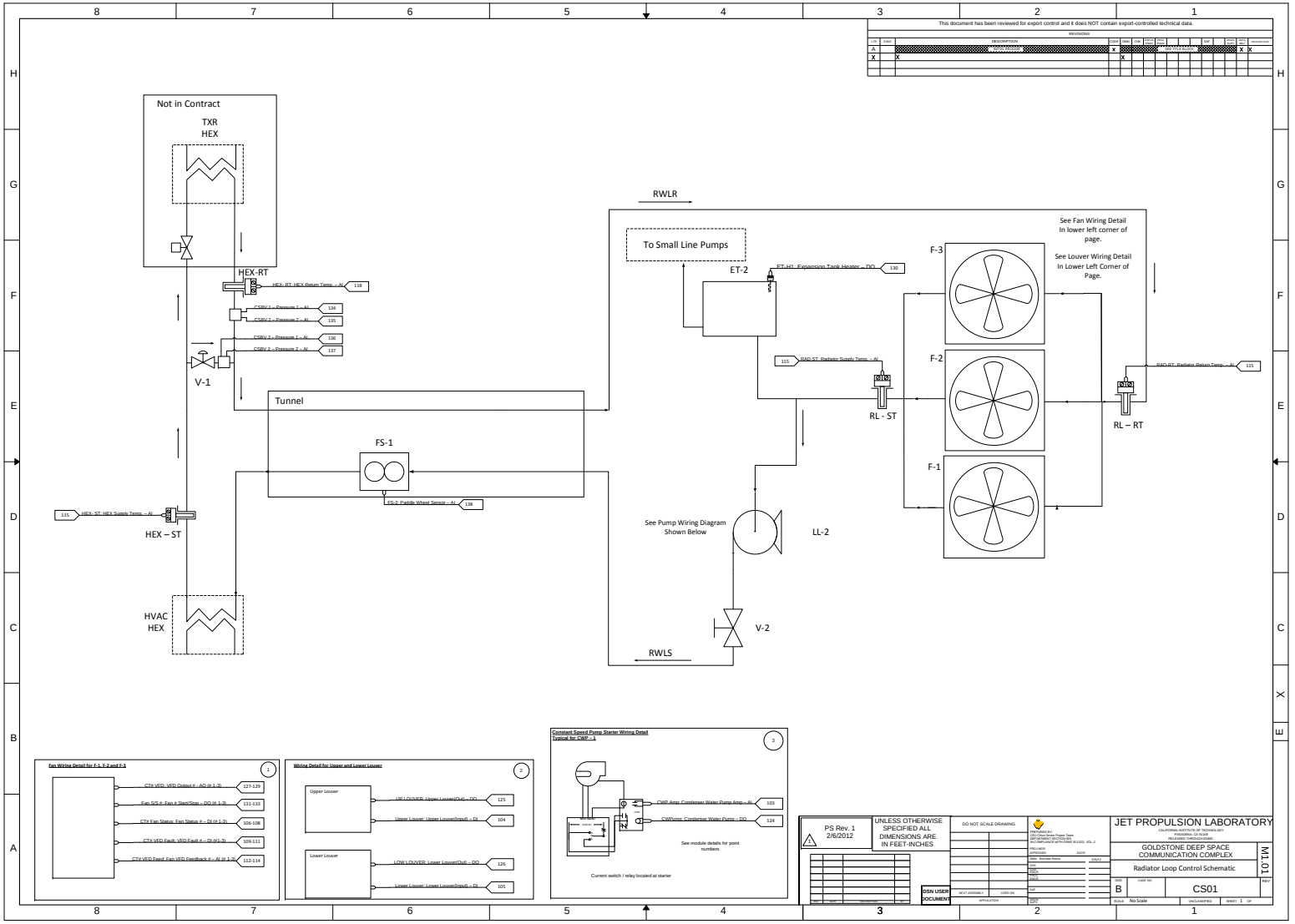
Customer Requirements

- A robust and easy to maintain system
- Run continuously with 5000 hours MTBF
- Built using reliable, commercially available components
- Regulate the temperature around a desired point, that is cross-ambient. (Above ambient in the winter, below in the summer)

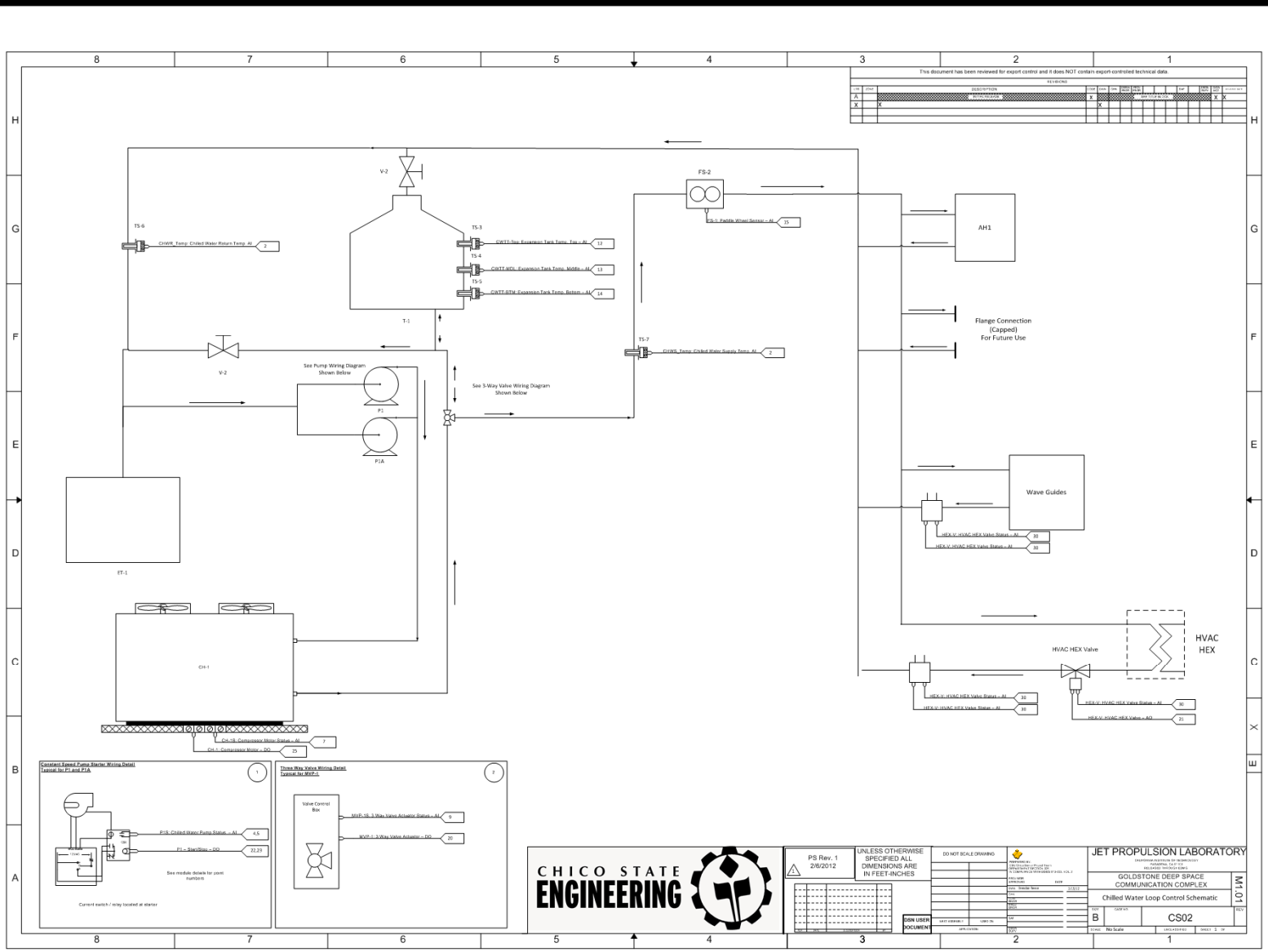
Engineering Specifications

Requirements	Engineering Specification	Metric	Method / Device	Target	Condition
Reliable	MTBF	Hours	MTBF >5000 hours	5000 hours	Continuous use
Maintain constant water temperature	Temperature	^{0}C	Temperature sensors	28°C<T < 36°C	During Transmitter Operation
Maintain pedestal air temperature	Temperature	^{0}C	Temperature sensors	23 ± 2°C	During Occupation
Maintain constant water flow rate	Flow Rate	L/s	Flow Sensor	5.6 ± 0.2 L/s	During Transmitter Operation
Inexpensive	Cost	US Dollars	Total cost of development and implementation	$100,000-$250,000	Inclusive of all parts

System Schematic – Radiator Loop

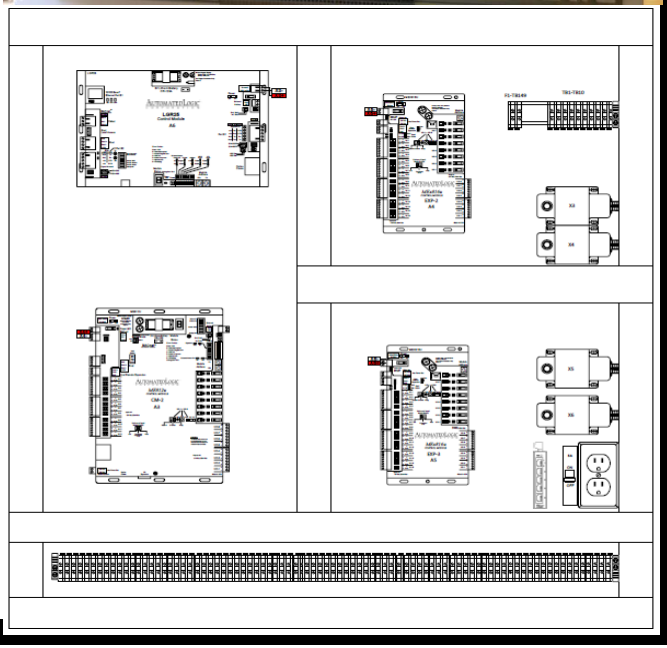


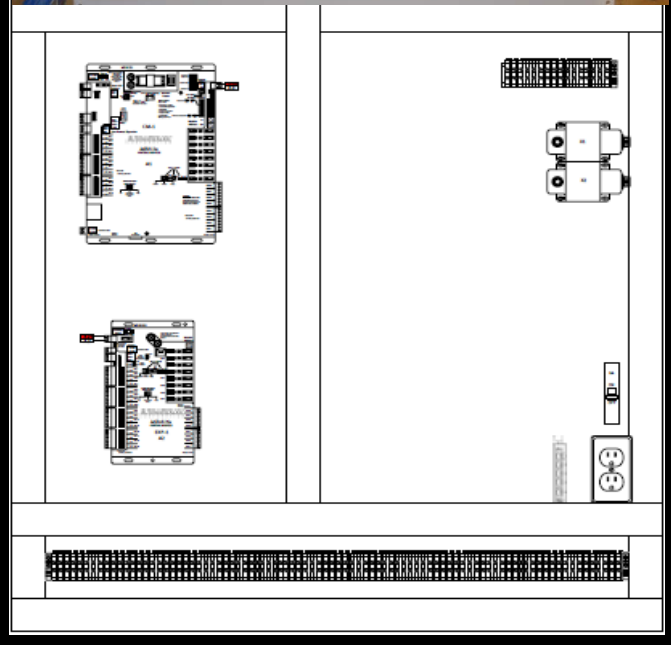
System Schematic – Chilled Water Loop



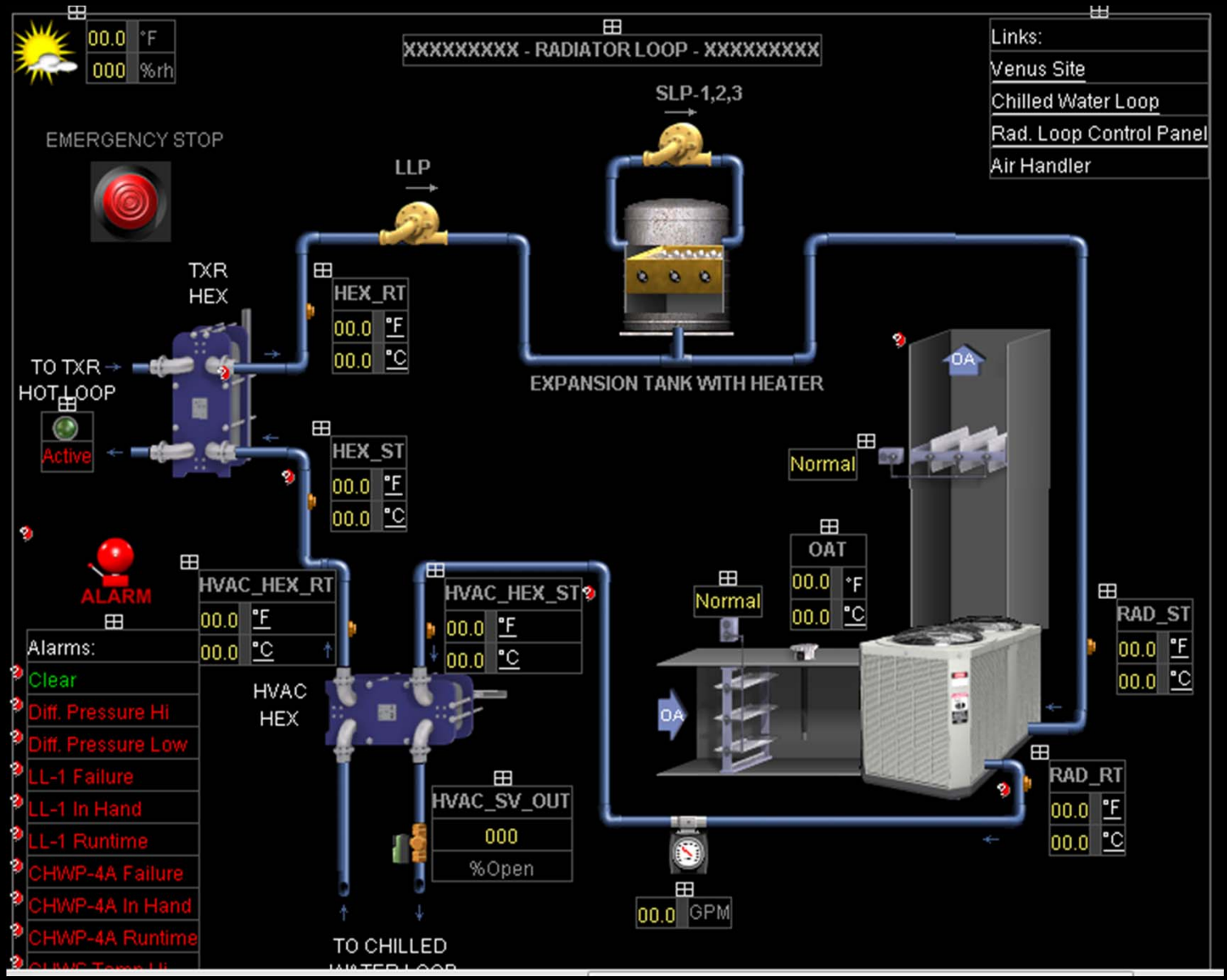
B7

Hoffman Controller Enclosures



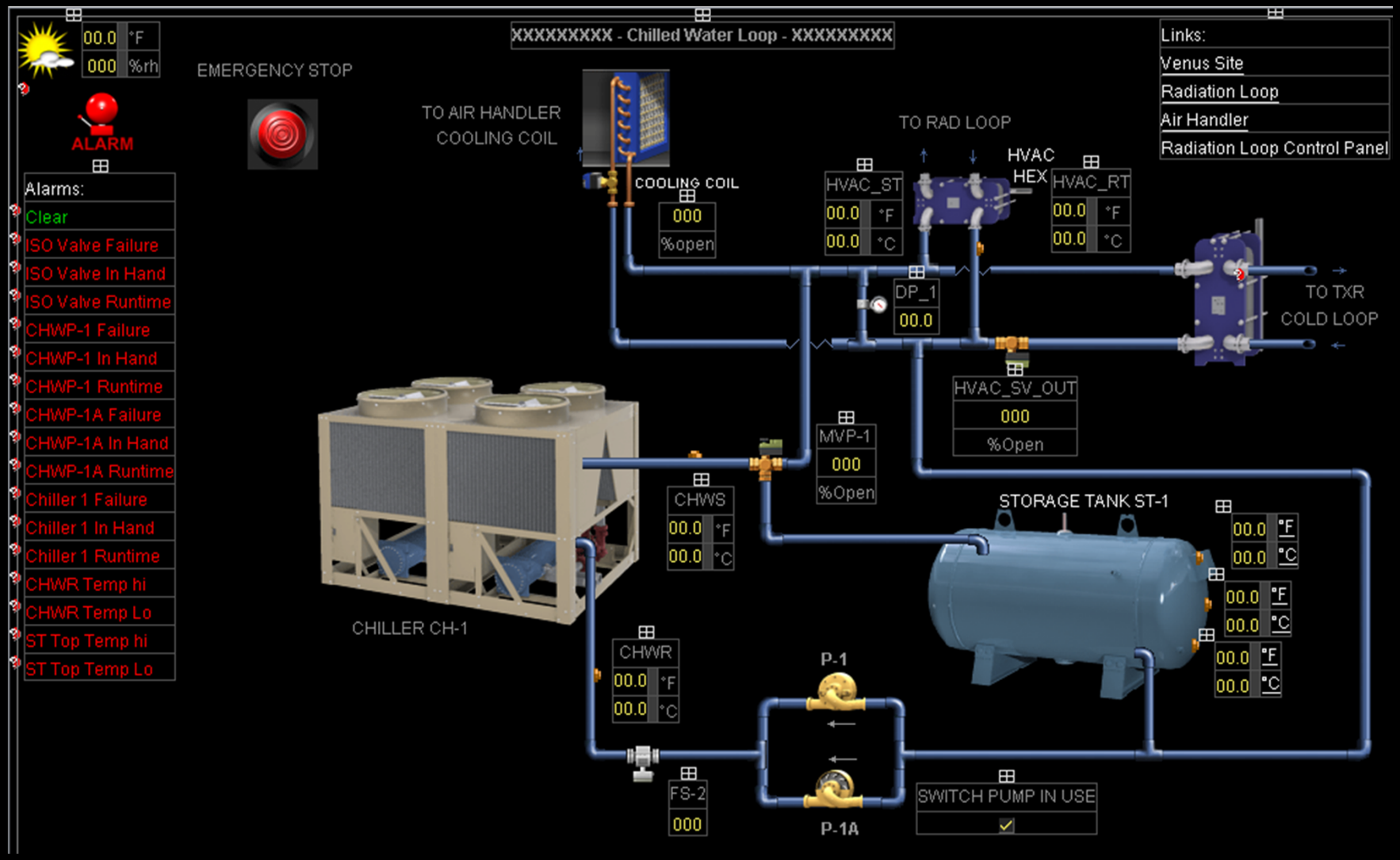


Front Panel Graphics



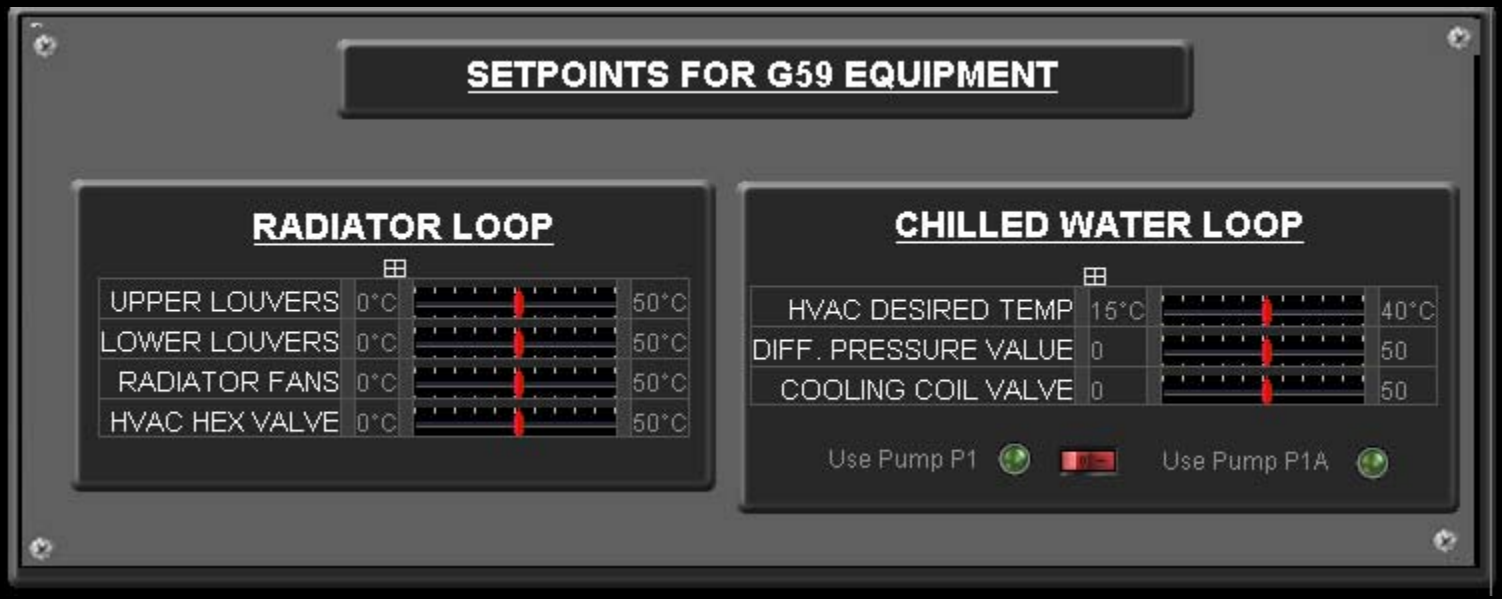
B3

Front Panel Graphics



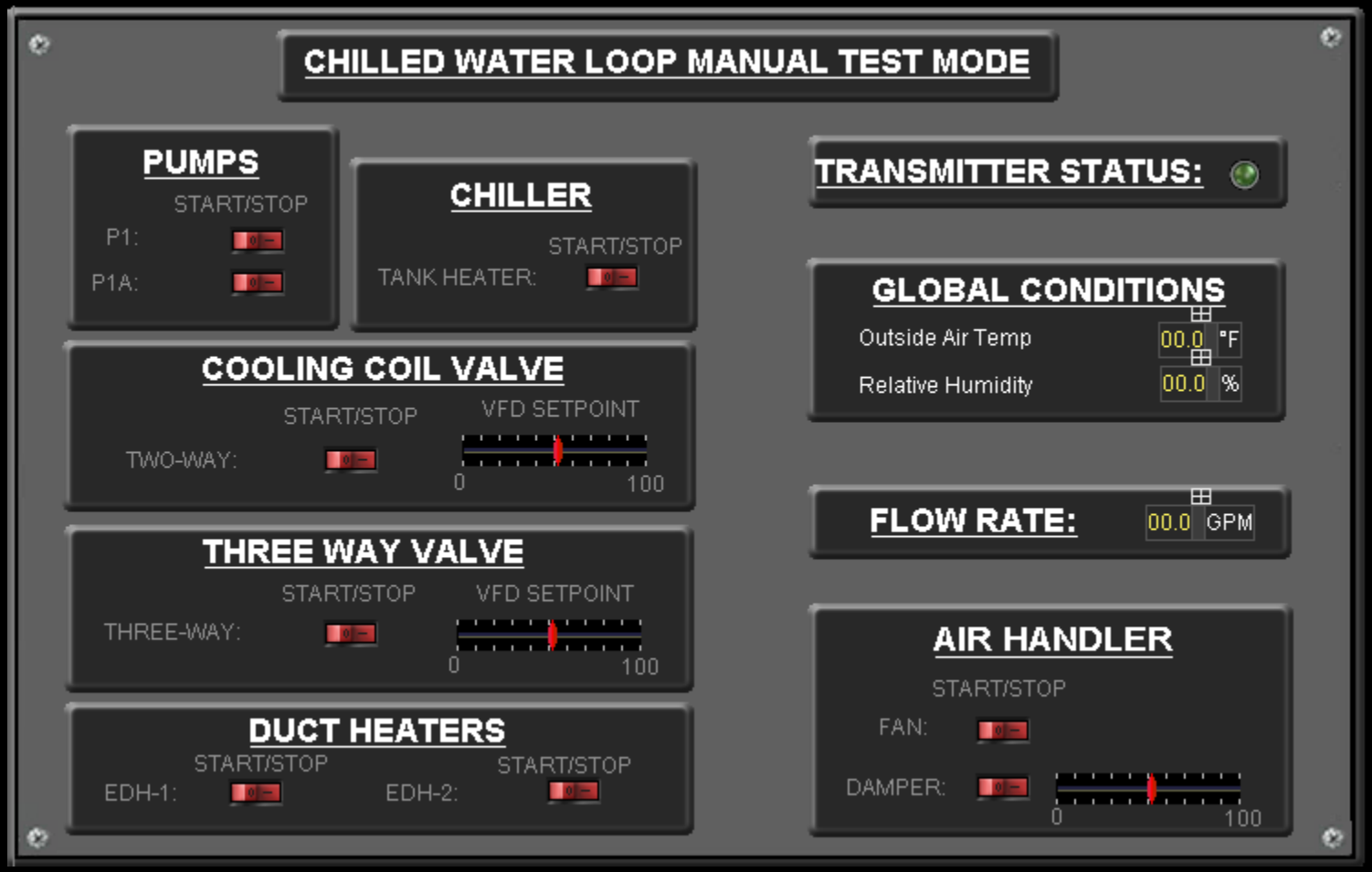
B4

Front Panel Graphics



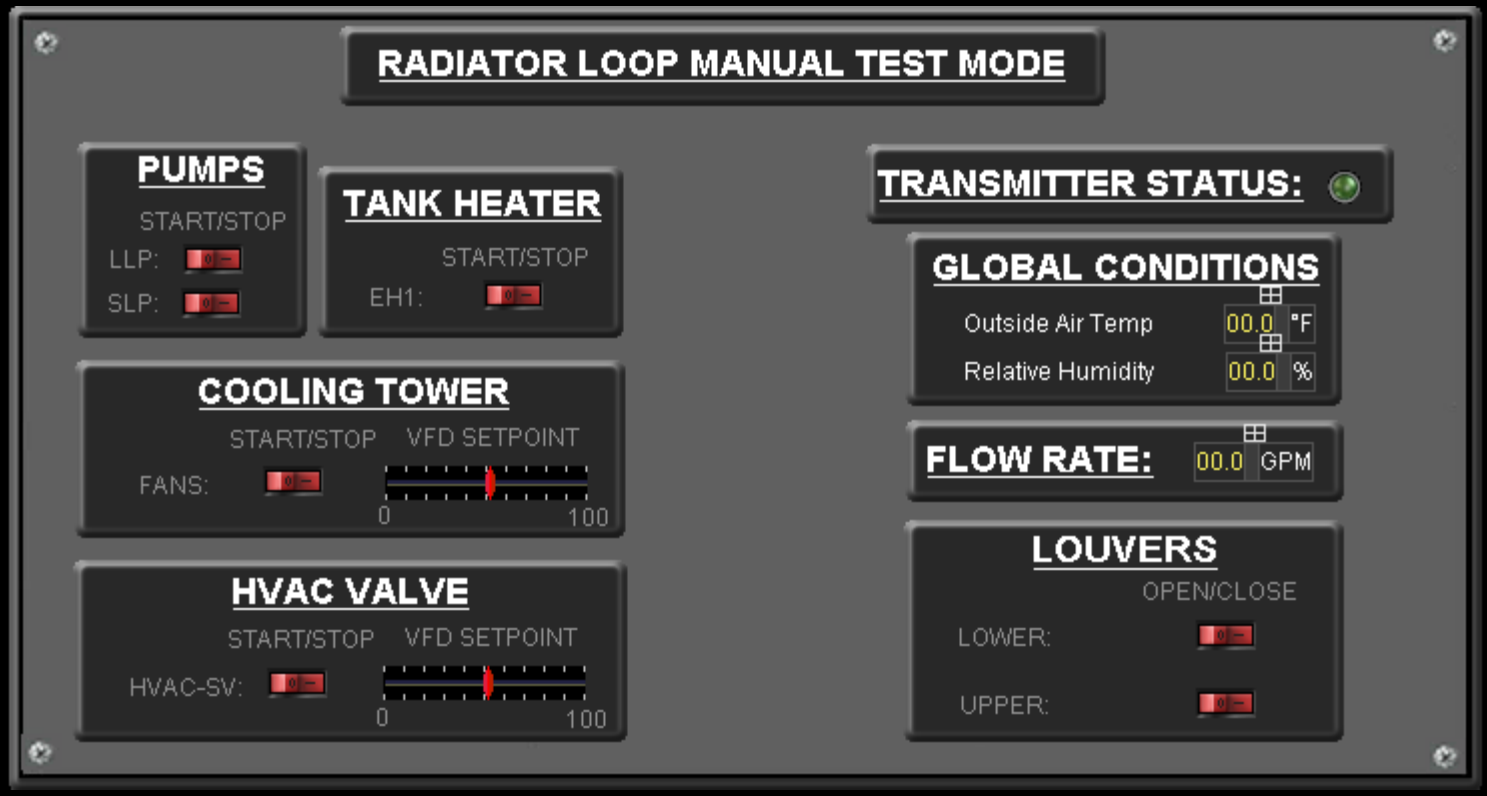
B5

Front Panel Graphics

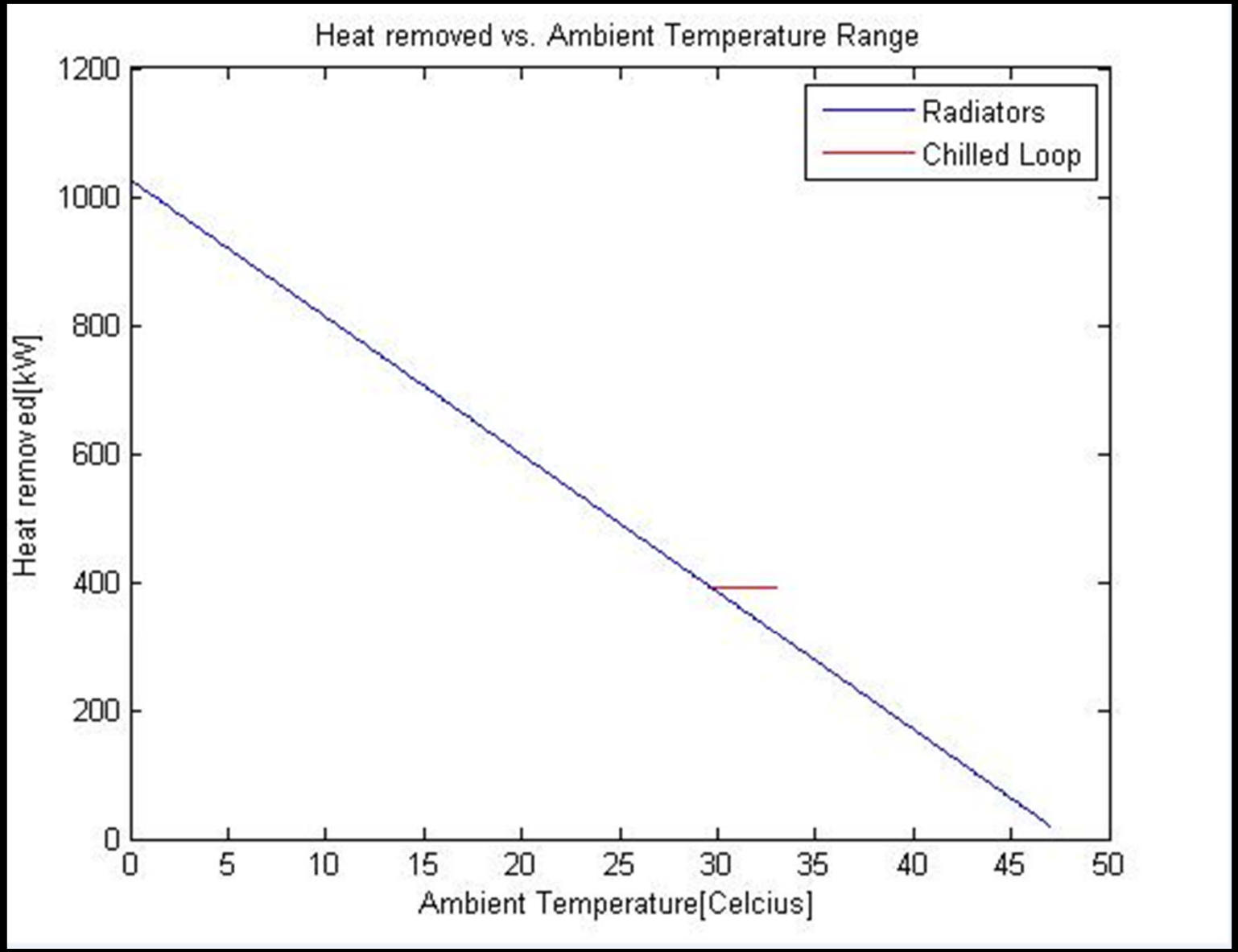


B6

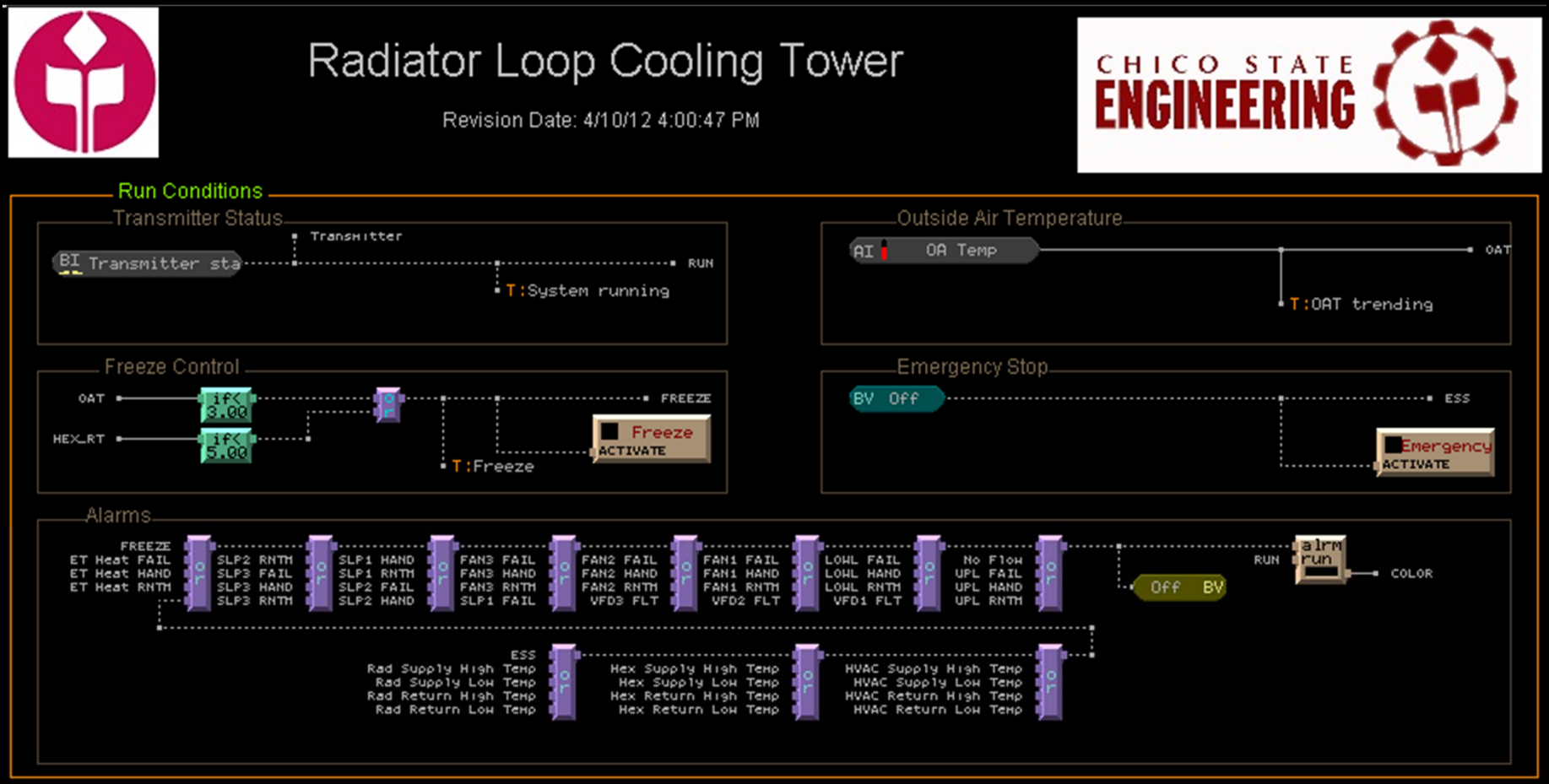
Front Panel Graphics

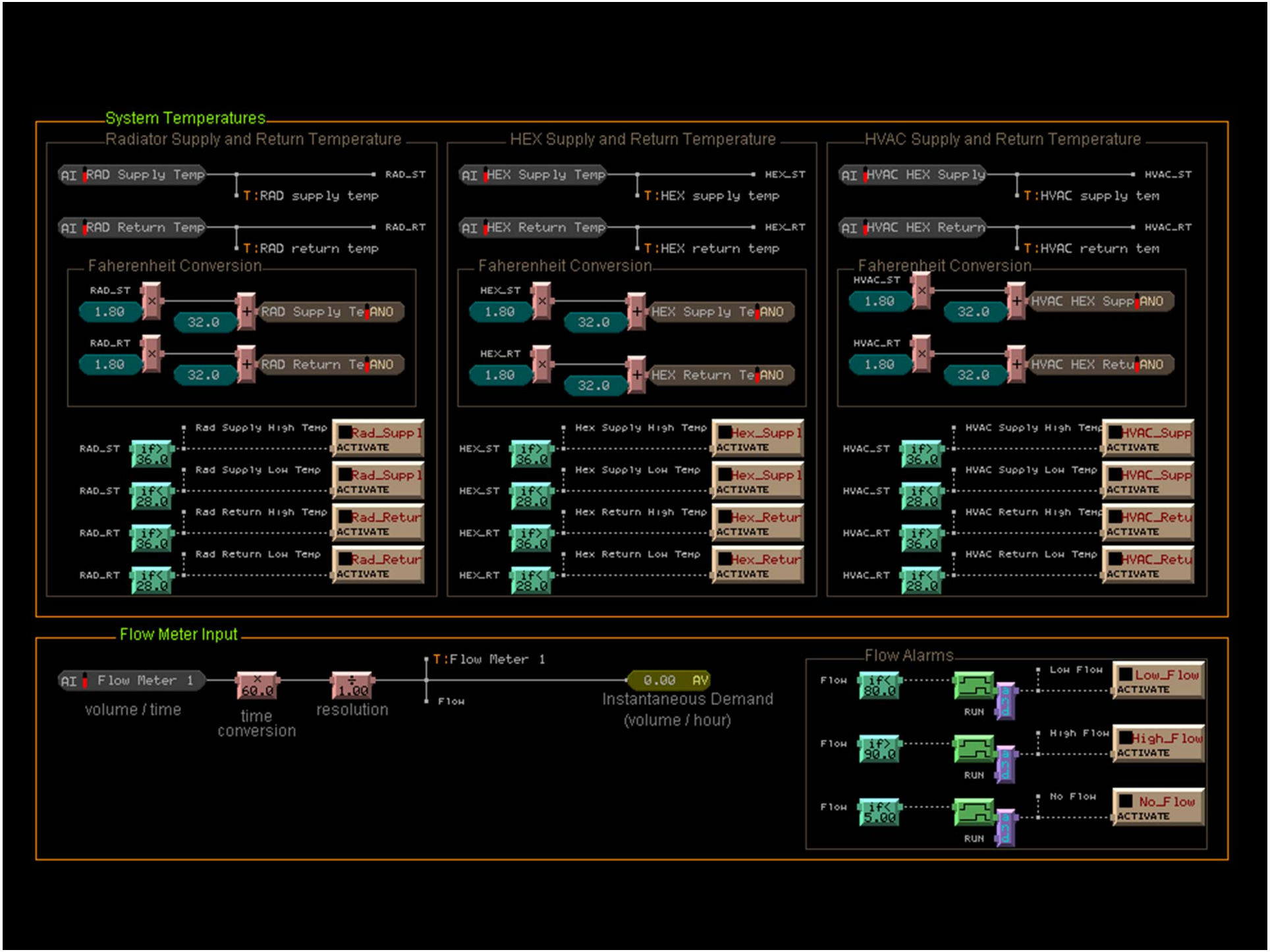


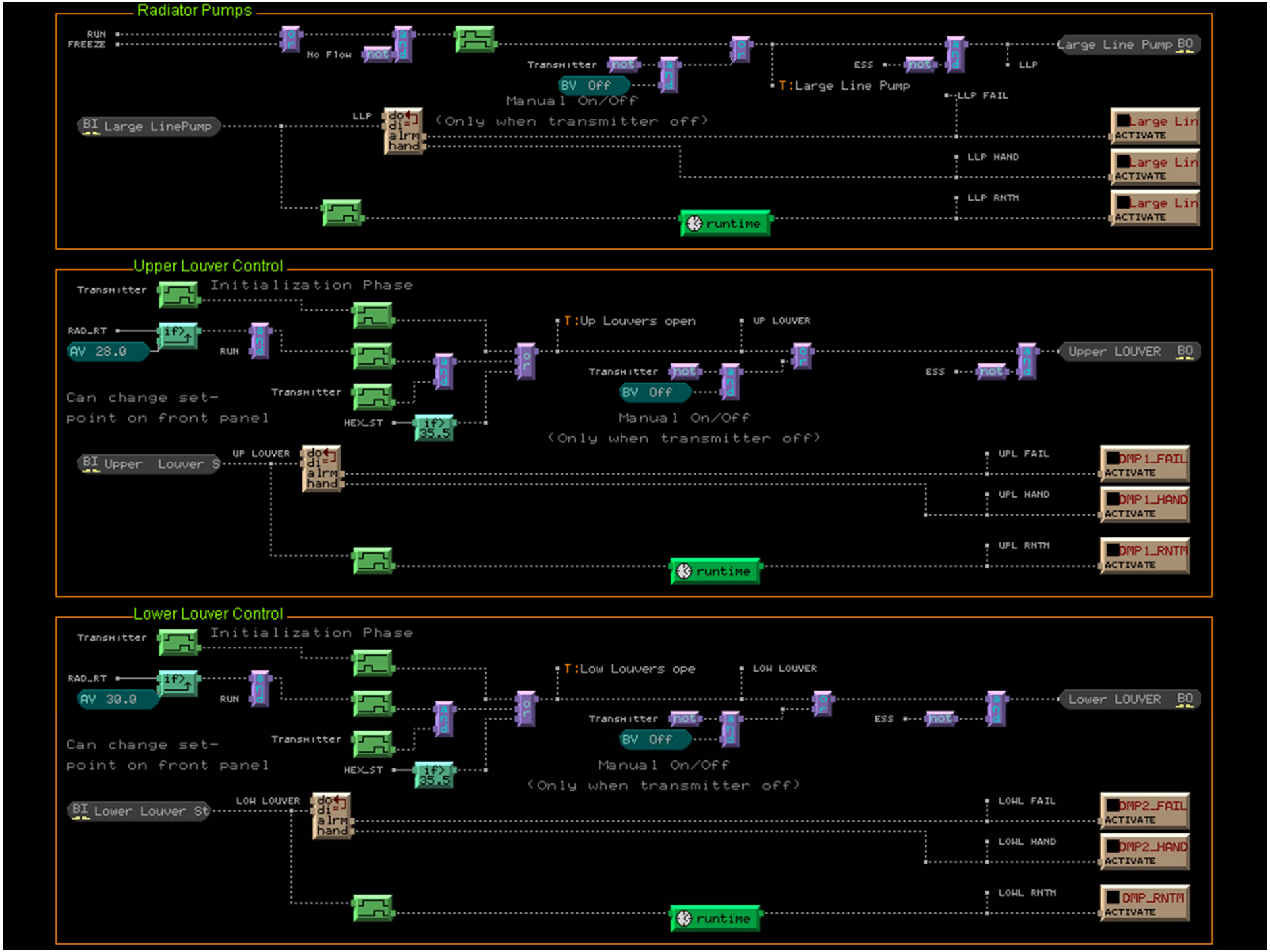
Seasonal Ambient Analysis

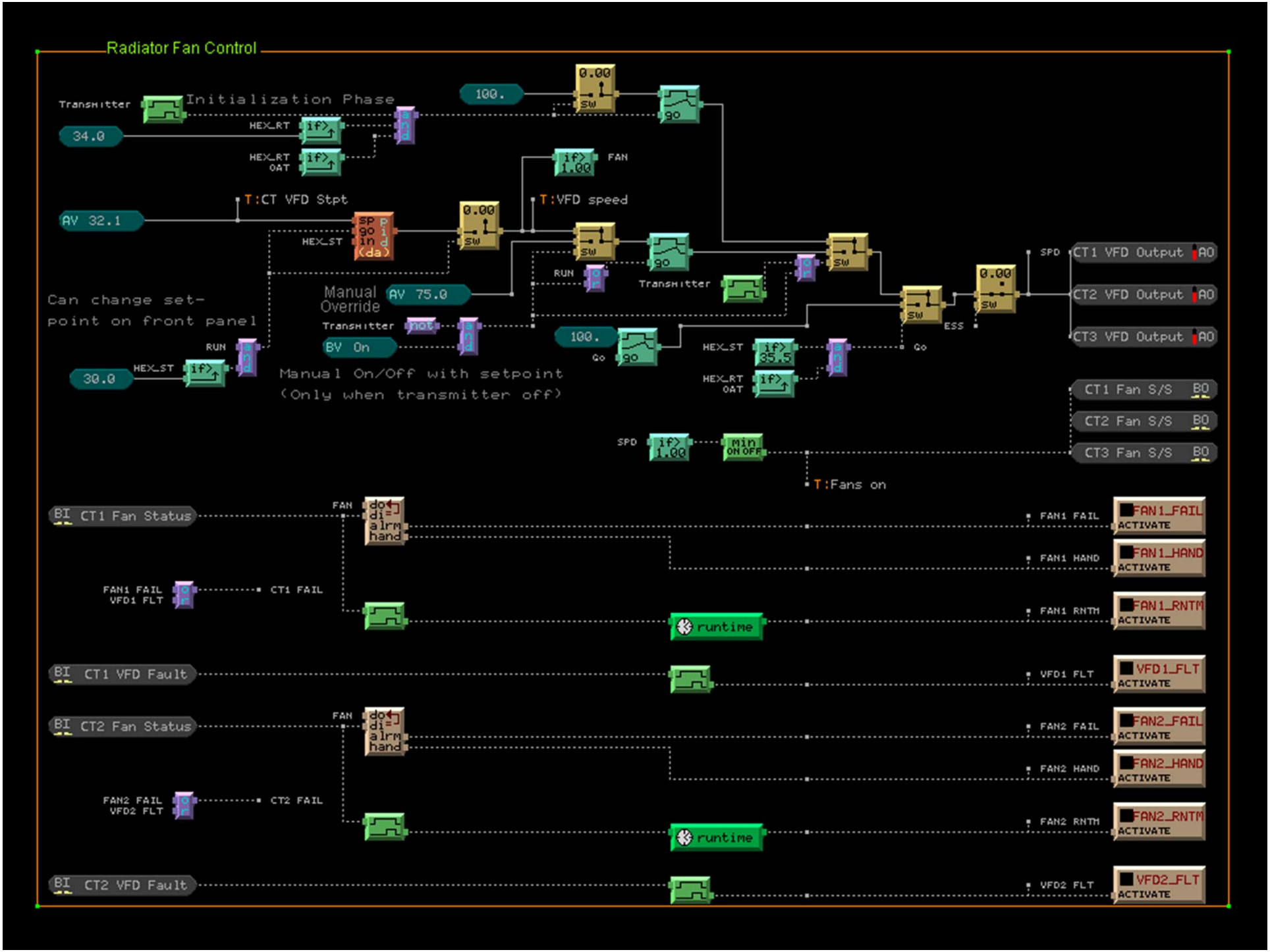


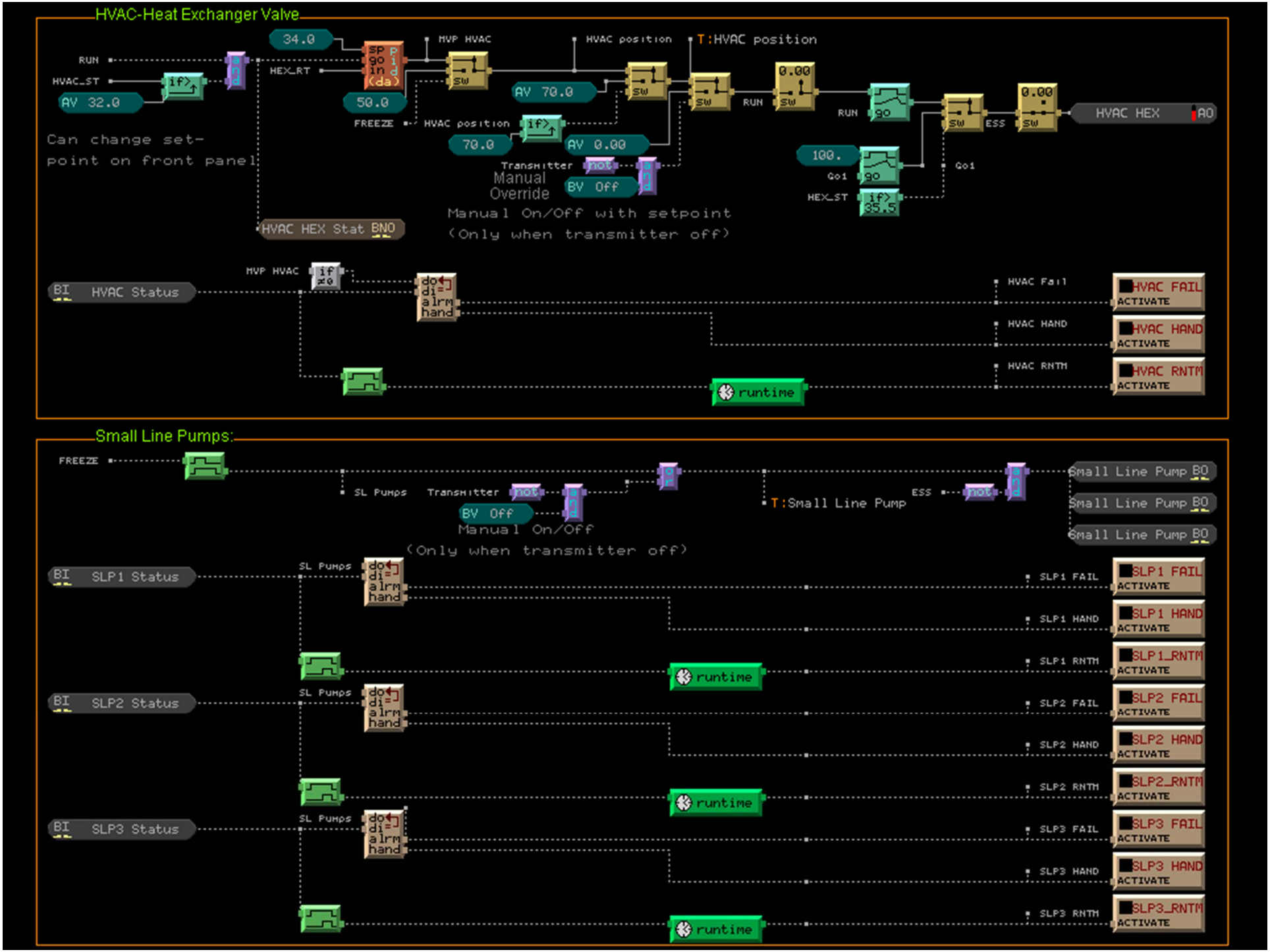
Control Solution

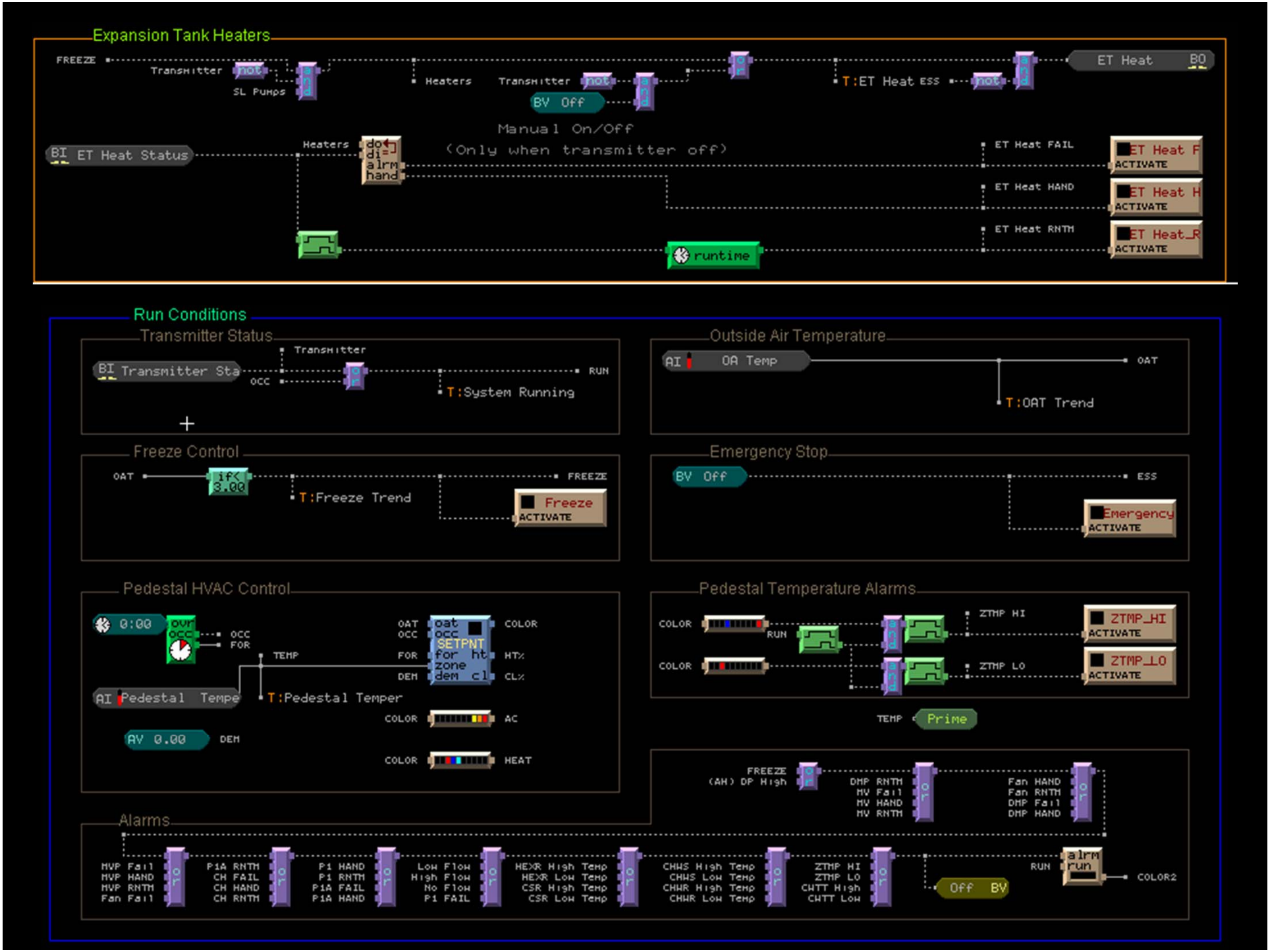


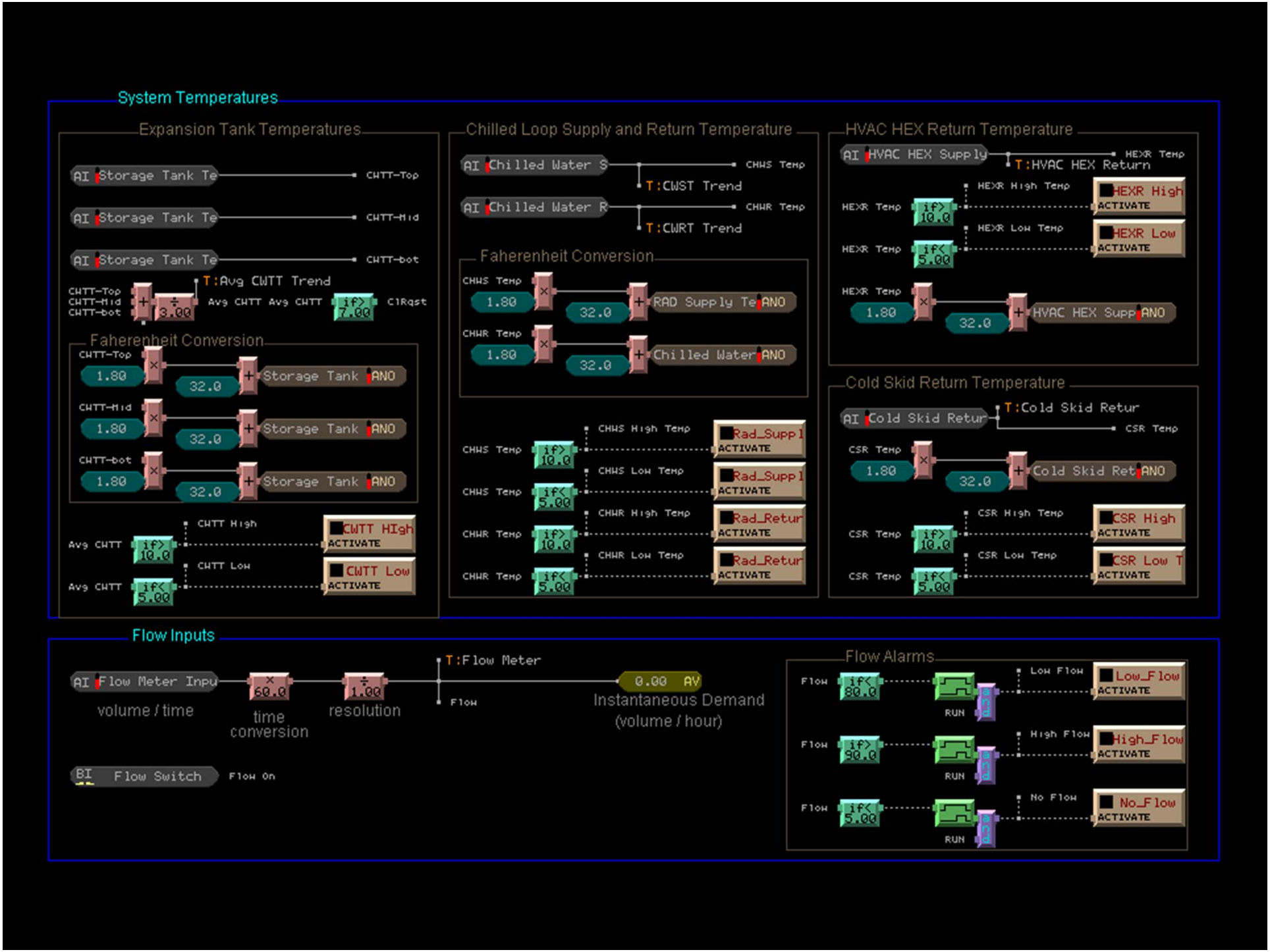

System Temperatures
Radiator Supply and Return Temperature
AI RAD Supply Temp
RAD_ST
T:RAD supply temp
AI RAD Return Temp
RAD_RT
T:RAD return temp
Faherenheit Conversion
RAD_ST
1.80
32.0
RAD Supply Te ANO
RAD_RT
1.80
32.0
RAD Return Te ANO
Rad Supply High Temp
Rad_Suppl
ACTIVATE
Rad Supply Low Temp
Rad_Suppl
ACTIVATE
Rad Return High Temp
Rad_Retur
ACTIVATE
Rad Return Low Temp
Rad_Retur
ACTIVATE
HEX Supply and Return Temperature
AI HEX Supply Temp
HEX_ST
T:HEX supply temp
AI HEX Return Temp
HEX_RT
T:HEX return temp
Faherenheit Conversion
HEX_ST
1.80
32.0
HEX Supply Te ANO
HEX_RT
1.80
32.0
HEX Return Te ANO
Hex Supply High Temp
Hex_Suppl
ACTIVATE
Hex Supply Low Temp
Hex_Suppl
ACTIVATE
Hex Return High Temp
Hex_Retur
ACTIVATE
Hex Return Low Temp
Hex_Retur
ACTIVATE
HVAC Supply and Return Temperature
AI HVAC HEX Supply
HVAC_ST
T:HVAC supply tem
AI HVAC HEX Return
HVAC_RT
T:HVAC return tem
Faherenheit Conversion
HVAC_ST
1.80
32.0
HVAC HEX Supp ANO
HVAC_RT
1.80
32.0
HVAC HEX Retu ANO
HVAC Supply High Temp
HVAC_Supp
ACTIVATE
HVAC Supply Low Temp
HVAC_Supp
ACTIVATE
HVAC Return High Temp
HVAC_Retu
ACTIVATE
HVAC Return Low Temp
HVAC_Retu
ACTIVATE
Flow Meter Input
AI Flow Meter 1
volume / time
60.0
time conversion
1.00
resolution
T:Flow Meter 1
Flow
0.00 AV
Instantaneous Demand (volume / hour)
Flow Alarms
Flow
80.0
RUN
Low Flow
Low_Flow
ACTIVATE
Flow
90.0
RUN
High Flow
High_Flow
ACTIVATE
Flow
5.00
RUN
No Flow
No_Flow
ACTIVATE

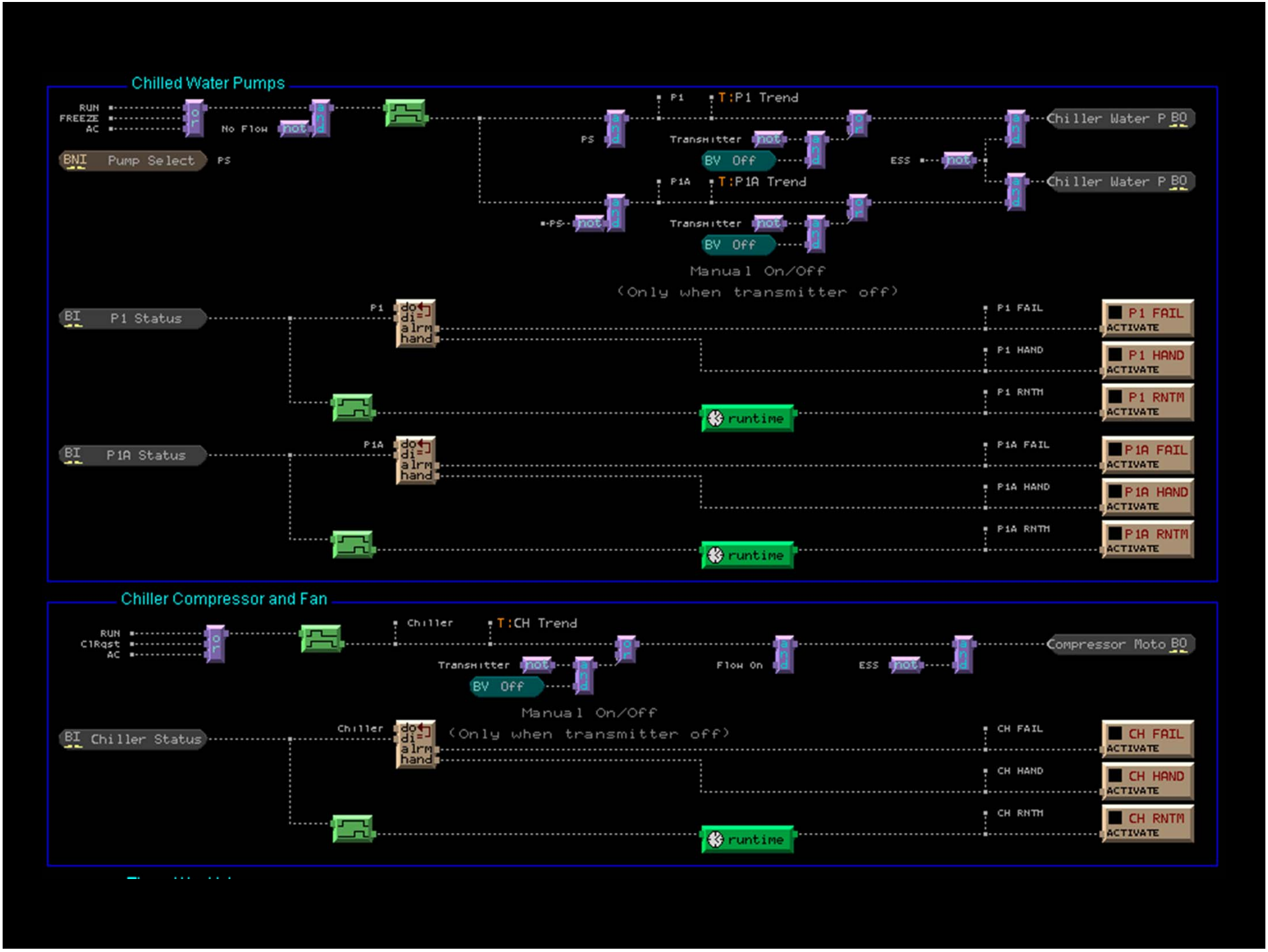

Radiator Pumps
RUN
FREEZE
No Flow
not
Transmitter
not
BV Off
Manual On/Off
(Only when transmitter off)
ESS
not
LLP
Large Line Pump BO
T:Large Line Pump
LLP FAIL
BI Large LinePump
LLP
do
di
alrm
hand
Large Lin
ACTIVATE
LLP HAND
Large Lin
ACTIVATE
LLP RNTM
Large Lin
ACTIVATE
runtime
Upper Louver Control
Transmitter
Initialization Phase
RAD_RT
AV 28.0
if>
RUN
Transmitter
HEX_ST
if>
35.5
Can change set-
point on front panel
T:Up Louvers open
UP LOUVER
Transmitter
not
BV Off
Manual On/Off
(Only when transmitter off)
ESS
not
Upper LOUVER BO
BI Upper Louver S
UP LOUVER
do
di
alrm
hand
UPL FAIL
DMP1_FAIL
ACTIVATE
UPL HAND
DMP1_HAND
ACTIVATE
UPL RNTM
DMP1_RNTM
ACTIVATE
runtime
Lower Louver Control
Transmitter
Initialization Phase
RAD_RT
AV 30.0
if>
RUN
Transmitter
HEX_ST
if>
35.5
Can change set-
point on front panel
T:Low Louvers ope
LOW LOUVER
Transmitter
not
BV Off
Manual On/Off
(Only when transmitter off)
ESS
not
Lower LOUVER BO
BI Lower Louver St
LOW LOUVER
do
di
alrm
hand
LOWL FAIL
DMP2_FAIL
ACTIVATE
LOWL HAND
DMP2_HAND
ACTIVATE
LOWL RNTM
DMP_RNTM
ACTIVATE
runtime

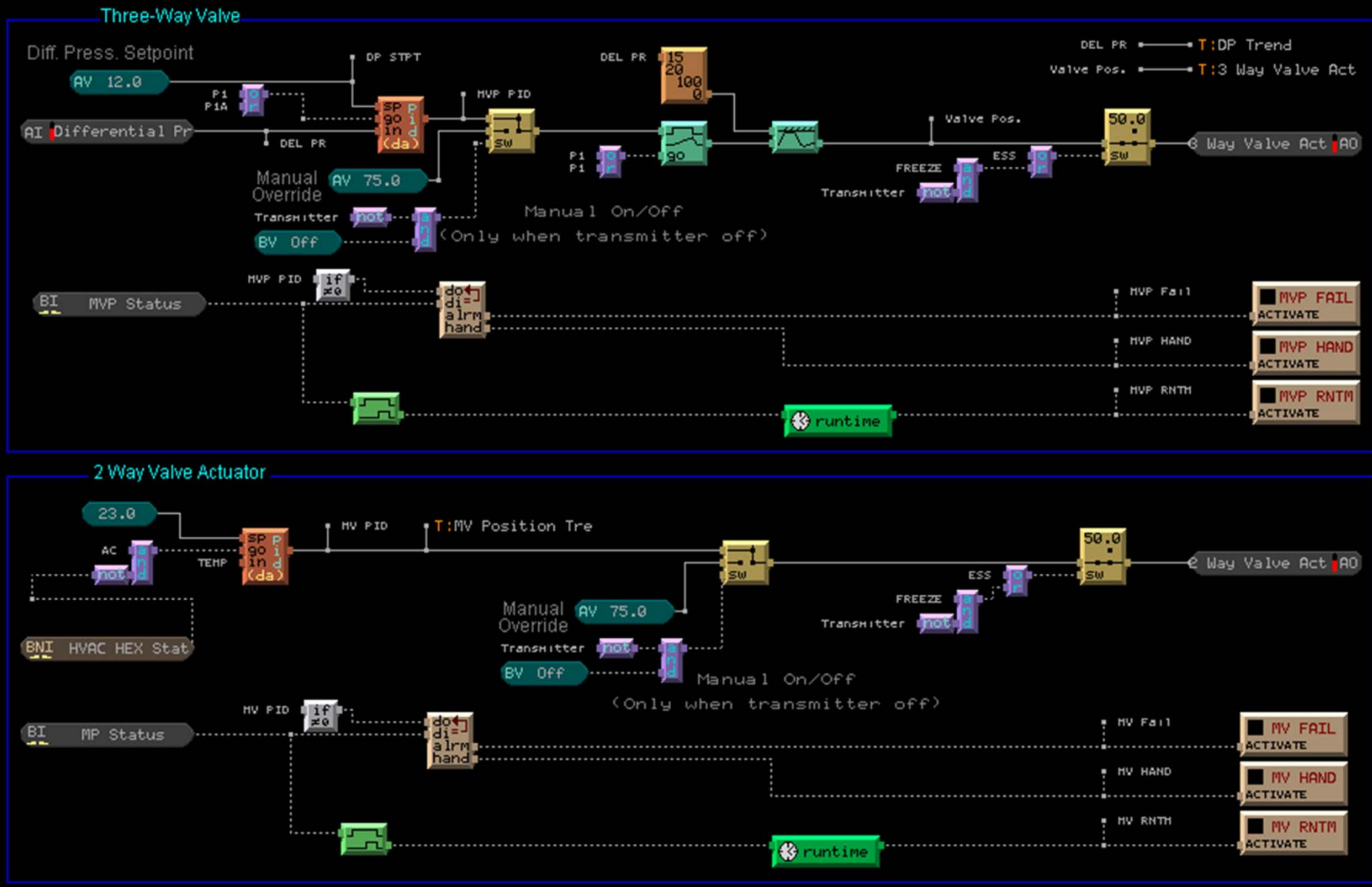

Radiator Fan Control
Transmitter
Initialization Phase
34.0
HEX_RT
HEX_RT OAT
100.
0.00
SW
go
if> 1.00
FAN
T:CT VFD Stpt
AV 32.1
SP
go
in
(da)
pid
HEX_ST
T:VFD speed
RUN
Transmitter
Manual Override
AV 75.0
Transmitter
not
BV On
Can change set-point on front panel
30.0
HEX_ST
RUN
Manual On/Off with setpoint (Only when transmitter off)
100.
Go
HEX_ST
if> 35.5
HEX_RT OAT
Go
ESS
SPD
CT1 VFD Output AO
CT2 VFD Output AO
CT3 VFD Output AO
CT1 Fan S/S BO
CT2 Fan S/S BO
CT3 Fan S/S BO
SPD
if> 1.00
min ON OFF
T:Fans on
BI CT1 Fan Status
FAN
do
di
alrm
hand
FAN1 FAIL
FAN1 HAND
FAN1 FAIL
VFD1 FLT
CT1 FAIL
runtime
FAN1 RNTM
FAN1_FAIL ACTIVATE
FAN1_HAND ACTIVATE
FAN1_RNTM ACTIVATE
BI CT1 VFD Fault
VFD1 FLT
VFD1_FLT ACTIVATE
BI CT2 Fan Status
FAN2 FAIL
FAN2 HAND
FAN2 FAIL
VFD2 FLT
CT2 FAIL
runtime
FAN2 RNTM
FAN2_FAIL ACTIVATE
FAN2_HAND ACTIVATE
FAN2_RNTM ACTIVATE
BI CT2 VFD Fault
VFD2 FLT
VFD2_FLT ACTIVATE

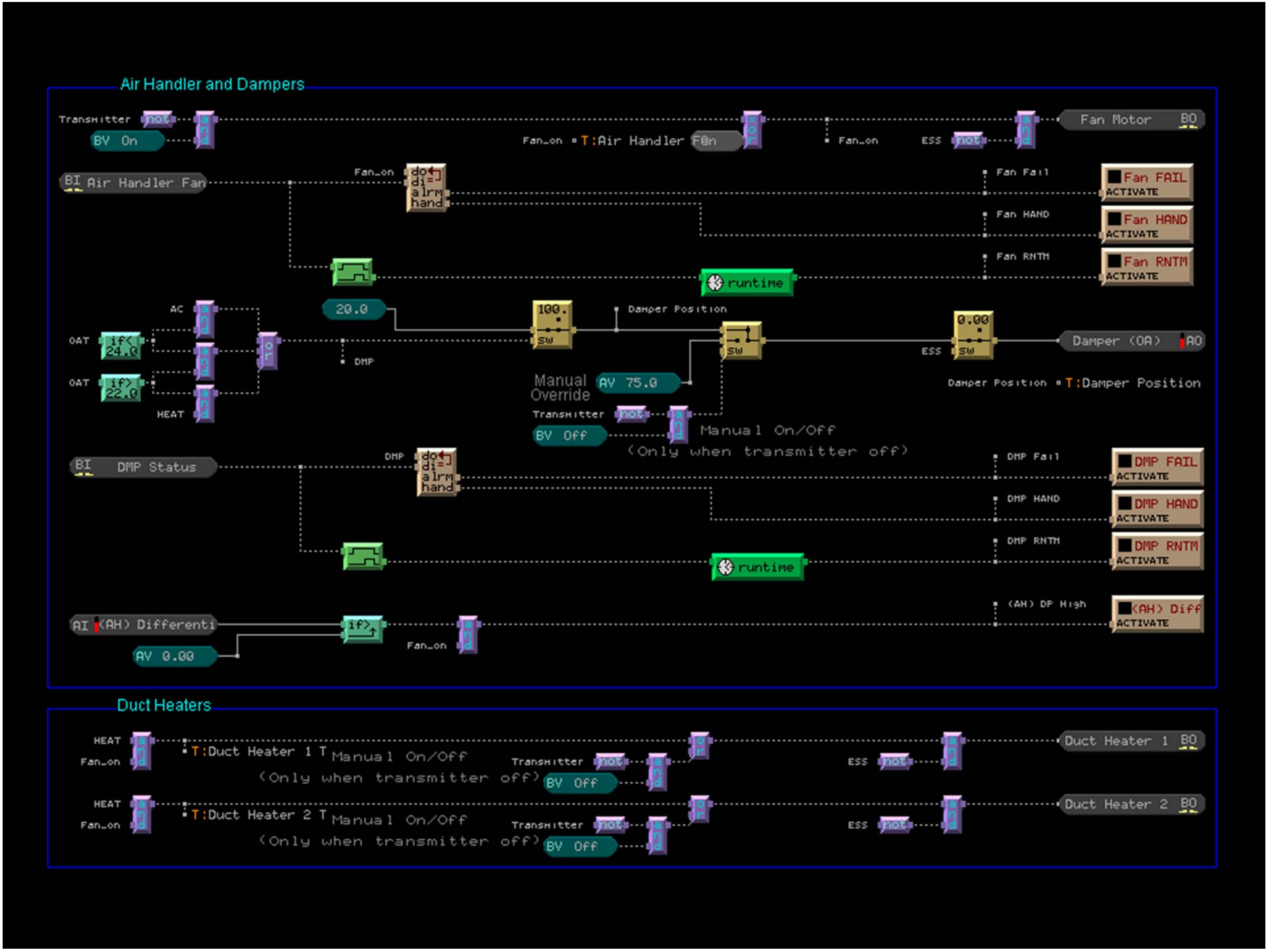

HVAC-Heat Exchanger Valve
34.0
RUN
HVAC_ST
AV 32.0
HEX_RT
50.0
FREEZE
MVP HVAC
HVAC position
T:HVAC position
AV 70.0
HVAC position
70.0
AV 0.00
Transmitter
Manual
Override
BV Off
Can change set-
point on front panel
HVAC HEX Stat BNO
Manual On/Off with setpoint
(Only when transmitter off)
RUN
0.00
RUN
100.
Go1
HEX_ST
35.5
Go1
ESS
0.00
HVAC HEX
AO
MVP HVAC
BI HVAC Status
HVAC Fail
HVAC HAND
HVAC RNTM
HVAC FAIL
ACTIVATE
HVAC HAND
ACTIVATE
HVAC RNTM
ACTIVATE
runtime
Small Line Pumps:
FREEZE
SL Pumps
Transmitter
BV Off
Manual On/Off
(Only when transmitter off)
T:Small Line Pump
ESS
Small Line Pump BO
Small Line Pump BO
Small Line Pump BO
BI SLP1 Status
BI SLP2 Status
BI SLP3 Status
SL Pumps
SLP1 FAIL
SLP1 HAND
SLP1 RNTM
SLP2 FAIL
SLP2 HAND
SLP2 RNTM
SLP3 FAIL
SLP3 HAND
SLP3 RNTM
SLP1 FAIL
ACTIVATE
SLP1 HAND
ACTIVATE
SLP1_RNTM
ACTIVATE
SLP2 FAIL
ACTIVATE
SLP2 HAND
ACTIVATE
SLP2_RNTM
ACTIVATE
SLP3 FAIL
ACTIVATE
SLP3 HAND
ACTIVATE
SLP3_RNTM
ACTIVATE
runtime
runtime
runtime


Expansion Tank Heaters
FREEZE
Transmitter
not
SL Pumps
Heaters
Transmitter
not
BV Off
T:ET Heat ESS
not
ET Heat
BO
Manual On/Off
(Only when transmitter off)
BI ET Heat Status
Heaters
do
di
alrm
hand
ET Heat FAIL
ET Heat HAND
ET Heat RNTM
ET Heat F
ACTIVATE
ET Heat H
ACTIVATE
ET Heat_R
ACTIVATE
runtime
Run Conditions
Transmitter Status
Transmitter
BI Transmitter Sta
OCC
RUN
T:System Running
Outside Air Temperature
AI OA Temp
OAT
T:OAT Trend
Freeze Control
OAT
if< 3.00
FREEZE
T:Freeze Trend
Freeze
ACTIVATE
Emergency Stop
BV Off
ESS
Emergency
ACTIVATE
Pedestal HVAC Control
0:00
ovr occ
OCC
FOR
TEMP
OAT
OCC
FOR
DEM
oat occ SETPNT for ht zone dem cl
COLOR
HT%
CL%
AI Pedestal Tempe
T:Pedestal Temper
COLOR
AC
AV 0.00
DEM
COLOR
HEAT
Pedestal Temperature Alarms
COLOR
RUN
COLOR
ZTMP HI
ZTMP LO
ZTMP_HI
ACTIVATE
ZTMP_LO
ACTIVATE
TEMP
Prime
FREEZE
(AH) DP High
DMP RNTM
MV Fail
MV HAND
MV RNTM
Fan HAND
Fan RNTM
DMP Fail
DMP HAND
Alarms
MVP Fail
MVP HAND
MVP RNTM
Fan Fail
P1A RNTM
CH FAIL
CH HAND
CH RNTM
P1 HAND
P1 RNTM
P1A FAIL
P1A HAND
Low Flow
High Flow
No Flow
P1 FAIL
HEXR High Temp
HEXR Low Temp
CSR High Temp
CSR Low Temp
CHWS High Temp
CHWS Low Temp
CHWR High Temp
CHWR Low Temp
ZTMP HI
ZTMP LO
CHTT High
CHTT Low
Off BV
RUN
alrm run
COLOR2


System Temperatures
Expansion Tank Temperatures
AI Storage Tank Te
CWTT-Top
AI Storage Tank Te
CWTT-Mid
AI Storage Tank Te
CWTT-bot
T:Avg CWTT Trend
CWTT-Top
CWTT-Mid
CWTT-bot
3.00
Avg CWTT Avg CWTT
if> 7.00
ClRqst
Faherenheit Conversion
CWTT-Top
1.80
32.0
Storage Tank ANO
CWTT-Mid
1.80
32.0
Storage Tank ANO
CWTT-bot
1.80
32.0
Storage Tank ANO
Avg CWTT
if> 10.0
CWTT High
CWTT HIgh
ACTIVATE
Avg CWTT
if< 5.00
CWTT Low
CWTT Low
ACTIVATE
Chilled Loop Supply and Return Temperature
AI Chilled Water S
CHWS Temp
T:CWST Trend
AI Chilled Water R
CHWR Temp
T:CWRT Trend
Faherenheit Conversion
CHWS Temp
1.80
32.0
RAD Supply Te ANO
CHWR Temp
1.80
32.0
Chilled Water ANO
CHWS Temp
if> 10.0
CHWS High Temp
Rad_Suppl
ACTIVATE
CHWS Temp
if< 5.00
CHWS Low Temp
Rad_Suppl
ACTIVATE
CHWR Temp
if> 10.0
CHWR High Temp
Rad_Retur
ACTIVATE
CHWR Temp
if< 5.00
CHWR Low Temp
Rad_Retur
ACTIVATE
HVAC HEX Return Temperature
AI HVAC HEX Supply
HEXR Temp
T:HVAC HEX Return
HEXR Temp
if> 10.0
HEXR High Temp
HEXR High
ACTIVATE
HEXR Temp
if< 5.00
HEXR Low Temp
HEXR Low
ACTIVATE
HEXR Temp
1.80
32.0
HVAC HEX Supp ANO
Cold Skid Return Temperature
AI Cold Skid Retur
T:Cold Skid Retur
CSR Temp
CSR Temp
1.80
32.0
Cold Skid Ret ANO
CSR Temp
if> 10.0
CSR High Temp
CSR High
ACTIVATE
CSR Temp
if< 5.00
CSR Low Temp
CSR Low T
ACTIVATE
Flow Inputs
AI Flow Meter Inpu
volume / time
× 60.0
time conversion
÷ 1.00
resolution
T:Flow Meter
Flow
0.00 AV
Instantaneous Demand
(volume / hour)
BI Flow Switch
Flow On
Flow Alarms
Flow
if< 80.0
RUN
Low Flow
Low_Flow
ACTIVATE
Flow
if> 90.0
RUN
High Flow
High_Flow
ACTIVATE
Flow
if< 5.00
RUN
No Flow
No_Flow
ACTIVATE


Chilled Water Pumps
RUN
FREEZE
AC
No Flow
not
BNI Pump Select
PS
P1
T:P1 Trend
PS
Transmitter
not
BV Off
ESS
not
Chiller Water P BO
P1A
T:P1A Trend
PS
not
Transmitter
not
BV Off
Chiller Water P BO
Manual On/Off
(Only when transmitter off)
BI P1 Status
P1
do
di
alrm
hand
P1 FAIL
P1 HAND
P1 RNTM
runtime
P1 FAIL
ACTIVATE
P1 HAND
ACTIVATE
P1 RNTM
ACTIVATE
BI P1A Status
P1A
do
di
alrm
hand
P1A FAIL
P1A HAND
P1A RNTM
runtime
P1A FAIL
ACTIVATE
P1A HAND
ACTIVATE
P1A RNTM
ACTIVATE
Chiller Compressor and Fan
RUN
C1Rqst
AC
Chiller
T:CH Trend
Transmitter
not
BV Off
Flow On
ESS
not
Compressor Moto BO
Manual On/Off
(Only when transmitter off)
BI Chiller Status
Chiller
do
di
alrm
hand
CH FAIL
CH HAND
CH RNTM
runtime
CH FAIL
ACTIVATE
CH HAND
ACTIVATE
CH RNTM
ACTIVATE


Three-Way Valve
Diff. Press. Setpoint
AV 12.0
DP STPT
P1
P1A
AI Differential Pr
DEL PR
MVP PID
DEL PR
15
20
100
0
DEL PR
T:DP Trend
Valve Pos.
T:3 Way Valve Act
Valve Pos.
50.0
Way Valve Act
AO
Manual
Override
AV 75.0
Transmitter
BV Off
Manual On/Off
(Only when transmitter off)
FREEZE
ESS
Transmitter
BI MVP Status
MVP PID
MVP Fail
MVP FAIL
ACTIVATE
MVP HAND
MVP HAND
ACTIVATE
MVP RNTM
MVP RNTM
ACTIVATE
runtime
2 Way Valve Actuator
23.0
AC
TEMP
MV PID
T:MV Position Tre
50.0
Way Valve Act
AO
ESS
FREEZE
Transmitter
Manual
Override
AV 75.0
Transmitter
BV Off
Manual On/Off
(Only when transmitter off)
BNI HVAC HEX Stat
BI MP Status
MV PID
MV Fail
MV FAIL
ACTIVATE
MV HAND
MV HAND
ACTIVATE
MV RNTM
MV RNTM
ACTIVATE
runtime

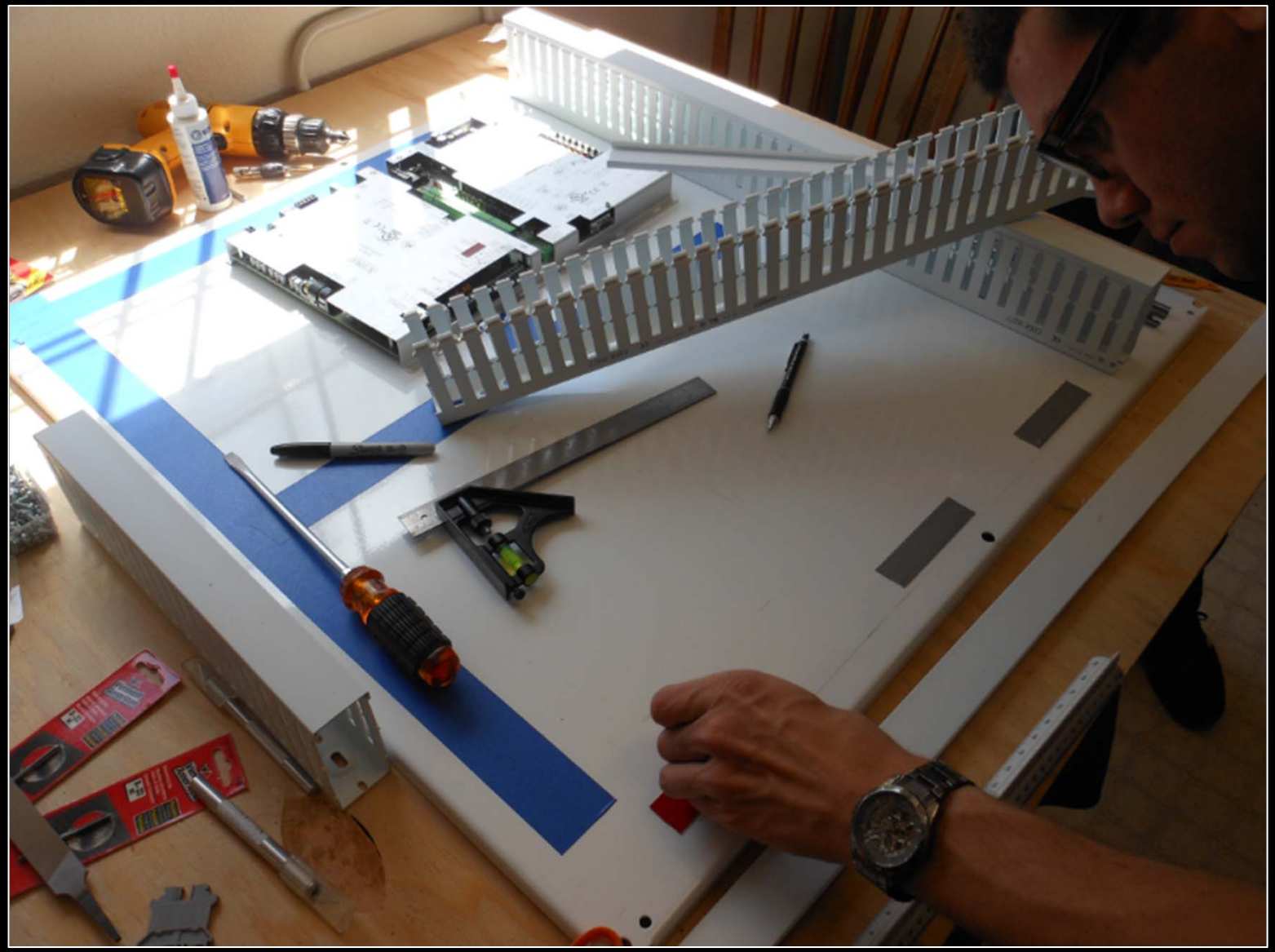

Air Handler and Dampers
Transmitter
not
BV On
Fan_on
T:Air Handler Fan
Fan_on
ESS
not
Fan Motor
BO
BI Air Handler Fan
Fan_on
do
di
alrm
hand
Fan Fail
Fan FAIL
ACTIVATE
Fan HAND
Fan HAND
ACTIVATE
Fan RNTM
Fan RNTM
ACTIVATE
runtime
AC
OAT
if< 24.0
OAT
if> 22.0
HEAT
20.0
100.
SW
Damper Position
DMP
Manual Override
AV 75.0
Transmitter
not
BV Off
Manual On/Off
(Only when transmitter off)
0.00
SW
ESS
Damper (OA)
AO
Damper Position
T:Damper Position
BI DMP Status
DMP
do
di
alrm
hand
DMP Fail
DMP FAIL
ACTIVATE
DMP HAND
DMP HAND
ACTIVATE
DMP RNTM
DMP RNTM
ACTIVATE
runtime
AI (AH) Differenti
if>
AV 0.00
Fan_on
(AH) DP High
(AH) Diff
ACTIVATE
Duct Heaters
HEAT
Fan_on
T:Duct Heater 1 T
Manual On/Off
(Only when transmitter off)
Transmitter
not
BV Off
ESS
not
Duct Heater 1
BO
HEAT
Fan_on
T:Duct Heater 2 T
Manual On/Off
(Only when transmitter off)
Transmitter
not
BV Off
ESS
not
Duct Heater 2
BO

Fabrication

Purchased vs. fabricated parts.

- Purchased:
  - Two Hoffman boxes and back panels.
  - Six control modules.
  - Six transformers.
  - Assorted wire.
  - DIN rail terminal blocks and jumpers.
  - DIN rails and wire ducting.
  - Fuse blocks
  - Assorted machine screws, taps, drill bits, and mounting tape.
- Fabricated:
  - Wire ducting was sectioned and mounted to back panels.
  - Back panels were drilled and tapped for controller mounting.
  - The controllers and the box power was wired.

Fabrication



Fabrication

Fabrication

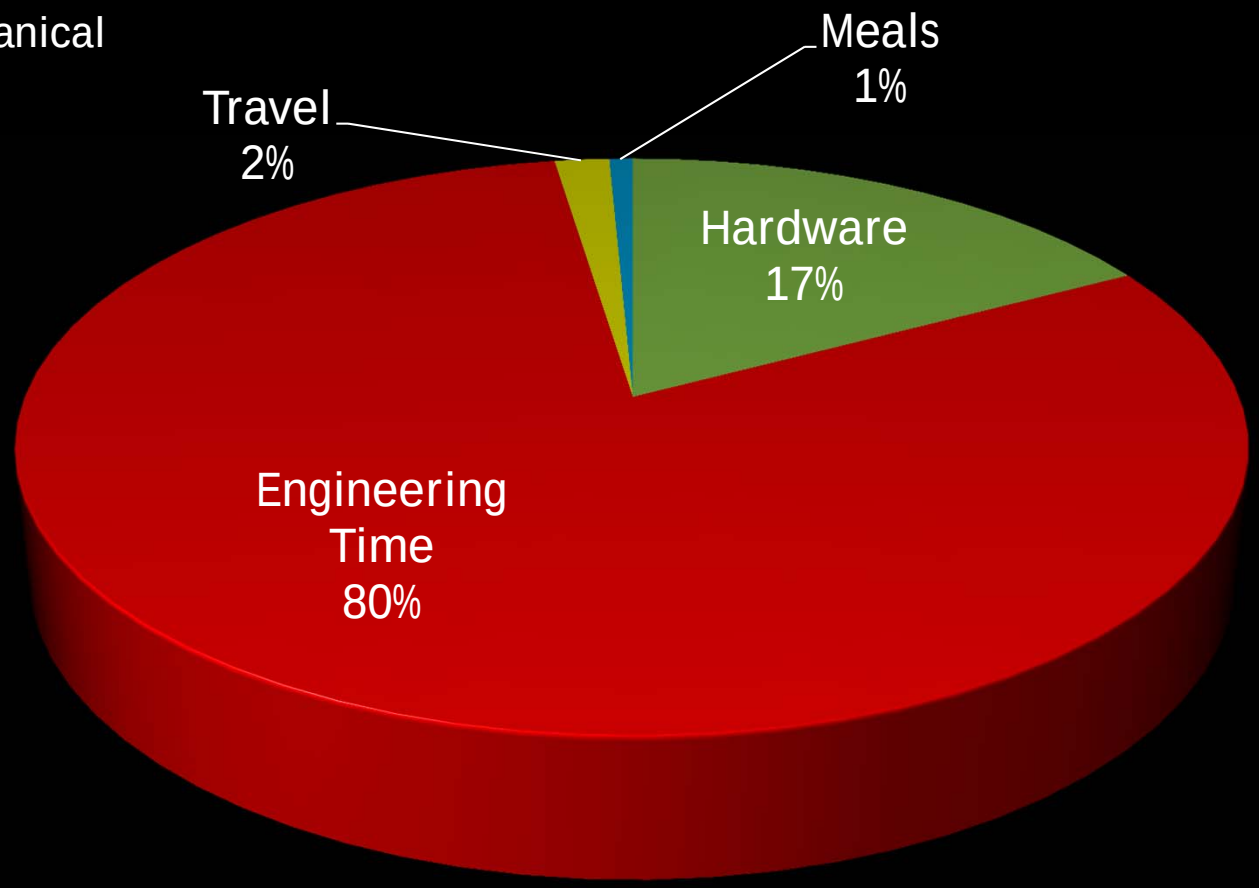
Bill of Materials

Bill of Materials					
Item Description	**Vendor**	**Part #**	**Quantity**	**Cost**	**Sub-Total**
Hoffman Box (NEMA 4) Including Back Panels	Hoffman	CSD36368LG	2	$288.00	$576.00
ALC BacNet Module	Sunbelt Controls	LGR250	1	$1,782.00	$1,782.00
ALC Control Module	Sunbelt Controls	ME812U	2	$2,942.00	$5,884.00
ALC Expander Module	Sunbelt Controls	MEX816U	3	$1,693.00	$5,079.00
Transformers (120AC-24AC)	Grainger	TR20VA001	6	$14.09	$84.54
Wall Boxes	Grainger	6XC56	4	$2.85	$11.40
Recepticals 120 AC - 20 Amp	Grainger	6LP28	2	$2.80	$5.60
Toggle Switches 120 AC - 20 Amp	Grainger	6LP31	2	$5.03	$10.06
Switch Covers (White)	Grainger	1LXT6	2	$0.56	$1.12
Wall Plate Duplex (White)	Grainger	1LYB9	2	$0.56	$1.12
Wire Duct 1.5X4 (White)	Automation Direct	T1-1540W-1	8	$28.25	$226.00
Wire 18GA MTW Stranded Orange	Automation Direct	MTW18OR	1	$33.25	$33.25
Wire 18GA MTW Stranded Purple	Automation Direct	MTW18PL	1	$33.25	$33.25
Wire 18GA MTW Stranded Green	Automation Direct	MTW18GN	1	$33.25	$33.25
Terminal Blocks 100/PK GRY 20A 12AWG 600V	Automation Direct	DN-T12-A	1	$37.50	$37.50
Terminal Block Jumpers 24-POLES 5/PK ORG INSL	Automation Direct	DN-24J2Y	1	$16.00	$16.00
Din Rail 35mm (2 m sections)	Allied Electric	342-0346	4	$17.00	$68.00
Terminal Blocks 22-14AWG, 20A, 600V Grey	Altech Corp	CTS2.5U-N	100	$2.00	$200.00
Fuse Blocks 10/PK 1.25X.25 W/LED 30A 6AWG 110V	Automation Direct	DN-F6L110	1	$54.00	$54.00
Drill Bit, NUM. 21 (0.159)IN., Jobber Length, HSS 10 PK	Automation Direct	2149021	1	$5.75	$5.75
Drill Bit, NUM. 29 (0.136)IN., Jobber Length, HSS 10 PK	Automation Direct	2149029	1	$5.75	$5.75
Scotch Mounting Tape	Lowes		2	$14.07	$28.14
Kobalt Cutting Fluid	Lowes		1	$3.98	$3.98
#10-32 NF Tap	Lowes		2	$4.94	$9.88
#10-3 2 1/2" Machine Screw Pck	Lowes		1	$5.58	$5.58
#8-32 NC Tap	Orchard Supply Hardware		1	$4.29	$4.29
#8-32 NC Tap	Orchard Supply Hardware		1	$4.29	$4.29
#8-32 Machine Screw Pck	Orchard Supply Hardware		1	$2.79	$2.79
				Total:	**$14,206.54**

H1

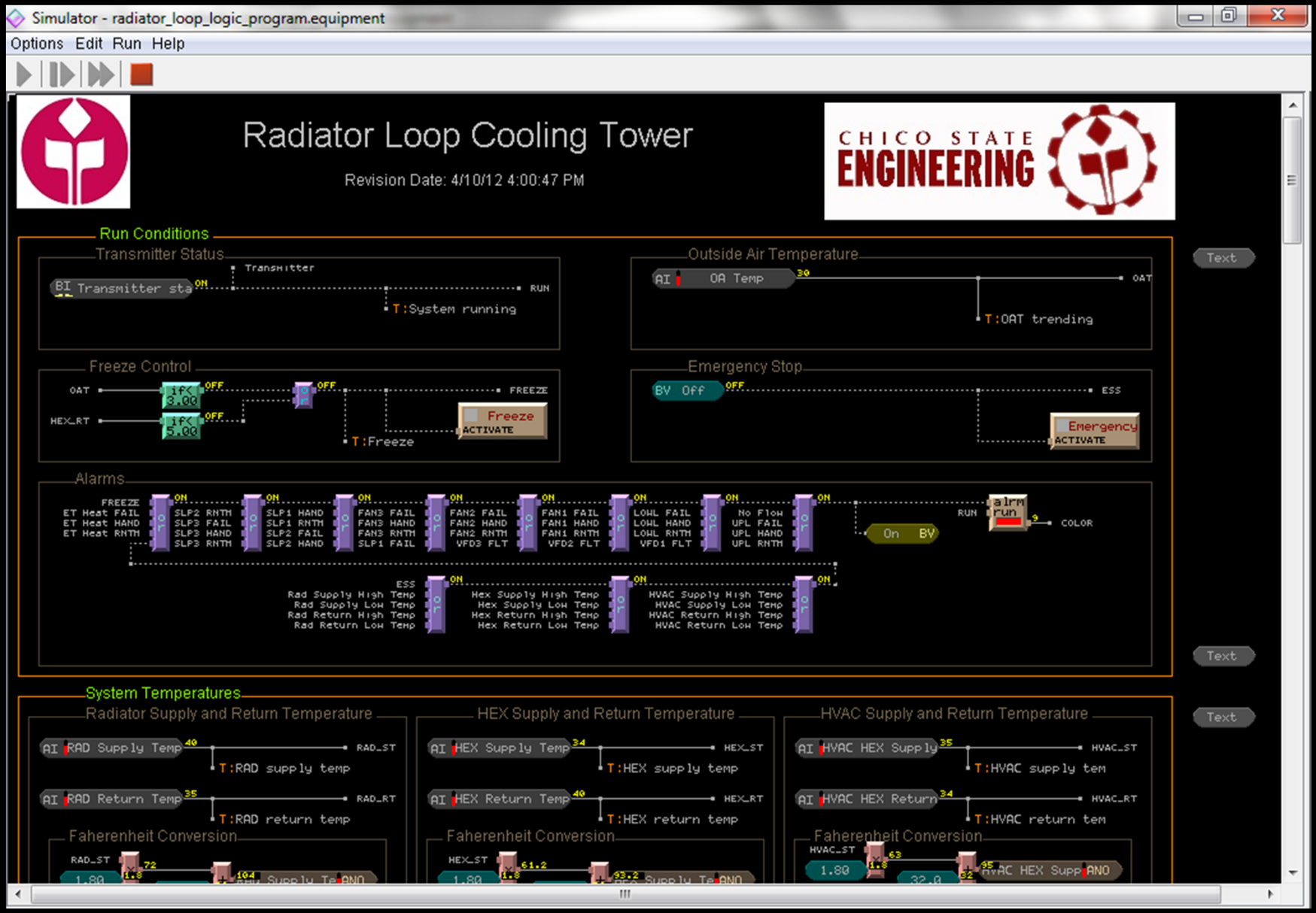
Budget

- Control Hardware: $14,206.54
- Theoretical Engineering Cost: $66,305.61
  - Mechatronic and Mechanical
- Travel: $1,391.57
- Meals: $600.00



- **Project Total Cost: $82,503.72**

Testing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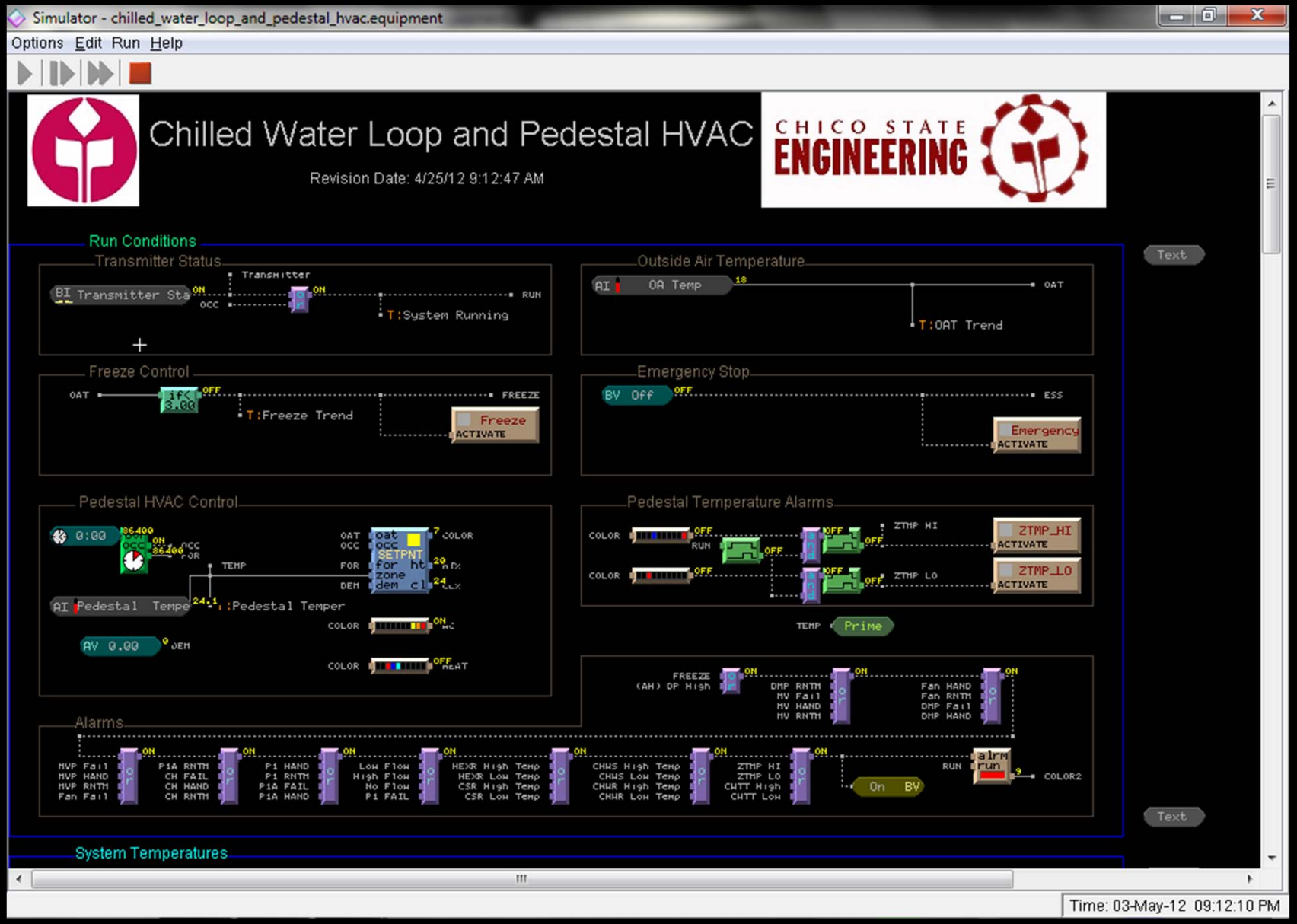
Options Edit Run Help
Radiator Loop Cooling Tower
Revision Date: 4/10/12 4:00:47 PM
CHICO STATE ENGINEERING
Run Conditions
Transmitter Status
Outside Air Temperature
Freeze Control
Emergency Stop
Alarms
System Temperatures
Radiator Supply and Return Temperature
HEX Supply and Return Temperature
HVAC Supply and Return Temperature
Faherenheit Conversion
Text

Testing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Chilled Water Loop and Pedestal HVAC
Revision Date: 4/25/12 9:12:47 AM
CHICO STATE ENGINEERING
Run Conditions
Transmitter Status
Outside Air Temperature
Freeze Control
Emergency Stop
Pedestal HVAC Control
Pedestal Temperature Alarms
Alarms
System Temperatures
Text
Time: 03-May-12 09:12:10 PM

Reflection

Problems Encountered:

- Hardware time delays.
- Meeting time conflicts.
- Project scope additions.
  - Pedestal Air Handler.

Solutions Achieved:

- Worked weekends and nights, flexible time management.
- Created logic and modified existing hardware layouts and point allocation to support additional control scope.

Merits of Design Solution:

- Flexible controls
  - Allows for modification of temperature set points for equipment.
  - Manual control of all equipment for testing.

Reflection

Suggestions for the Future:

- Implement a larger chiller which will allow for the system to run at higher ambient temperatures
- Add evaporative cooling to the Radiator loop allowing for the system to run at higher ambient temperatures
- Create an alarm structure that is prioritized and displays root cause alarms

Acknowledgements

JPL Team:

- Hal Ahlstrom and Peter Hames

ITT Excelis Team:

- Richard Fleig, Oscar Sanchez, Efren Villasenor, Margaret Motagally and Dan Kelly

SunBelt Controls:

- Korey Lawson, Kirk Strobel, Jon Rice and Bob Hamel

Telecommunication Coordinators:

- Grace Ananian and Nancy Park

Research Foundation Project Finances

- Karen Hansen

Faculty Support:

- Dr. Ramesh Varahamurti, Dr. Greg Watkins and Dr. Greg Kallio

Questions?