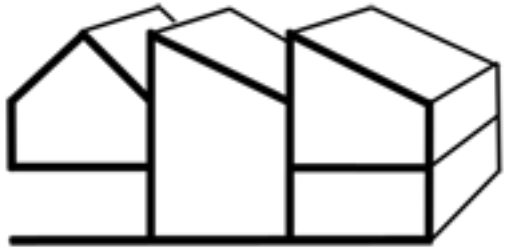
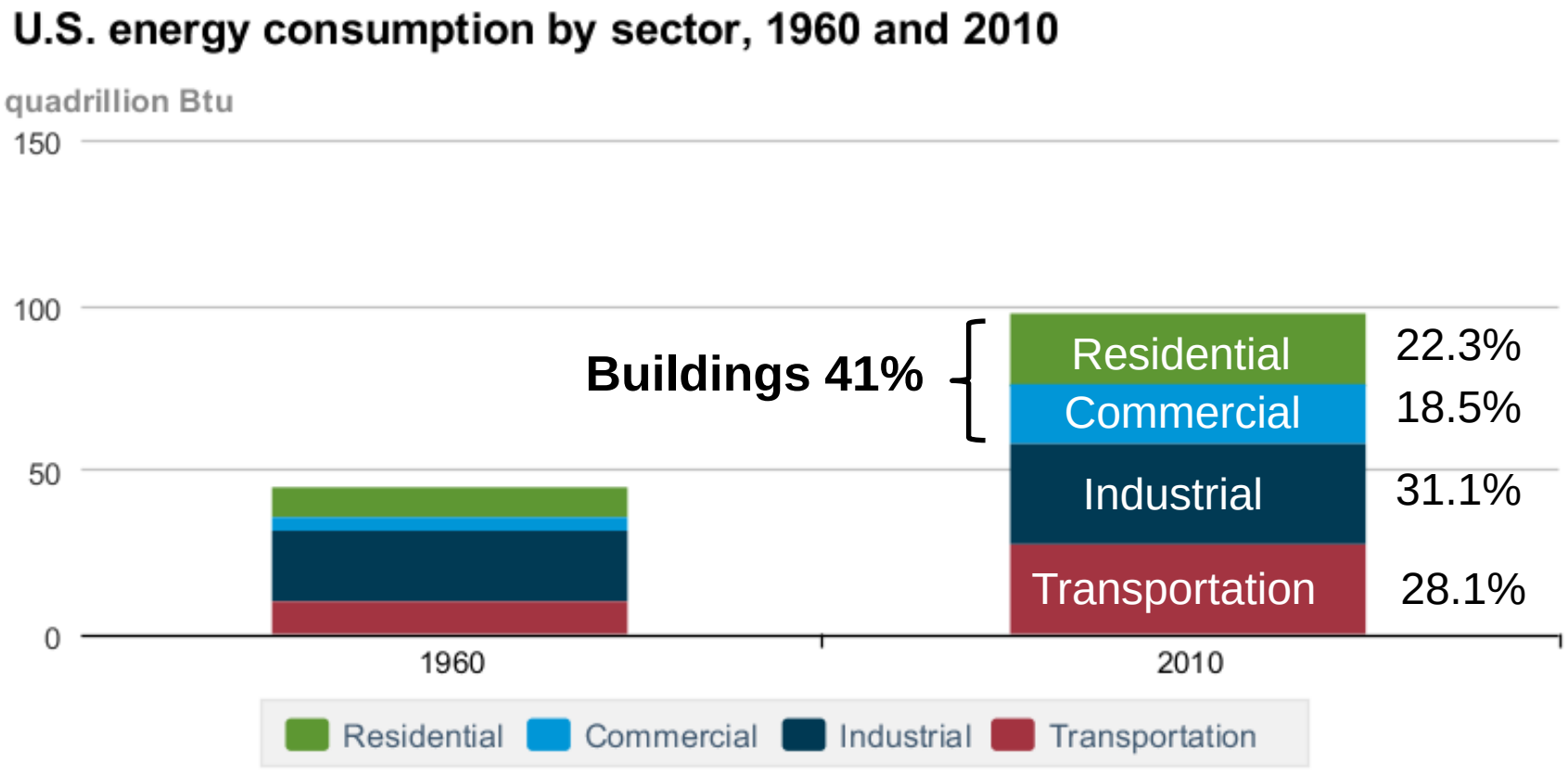


Software Defined Buildings

Building Application Stack

Andrew Krioukov

Buildings: 41% U.S. Energy Use



eia Source: U.S. Energy Information Administration, State Energy Data System 2010

Huge Sensor Networks

151 Temperature Sensors

50 Electrical Sub-meters

12 Variable Speed Fans

138 Air Dampers

> 6,000 Sense and Control Points

Sutardja Dai Hall
Built in 2009
140k sq. ft.

312 Light Relays

6 Variable Speed Pumps

121 Controllable Valves

Controls are Widely Available

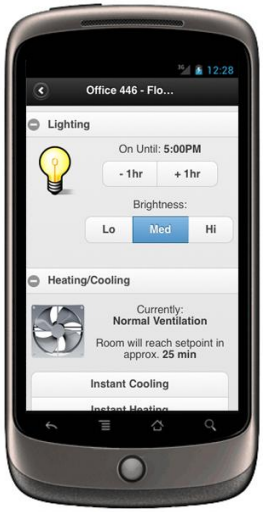
Bancroft Library:

- Built in 1949
- 100k sq. ft.
- 5,000 points

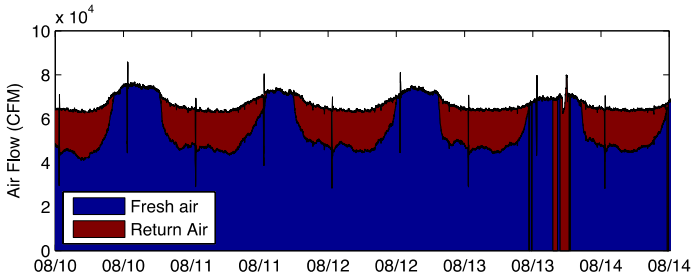
>70% of large buildings have digital controls

U.S. Energy Information Administration, 2009

Applications



Occupant Controls



Ventilation Optimization:
17% energy savings

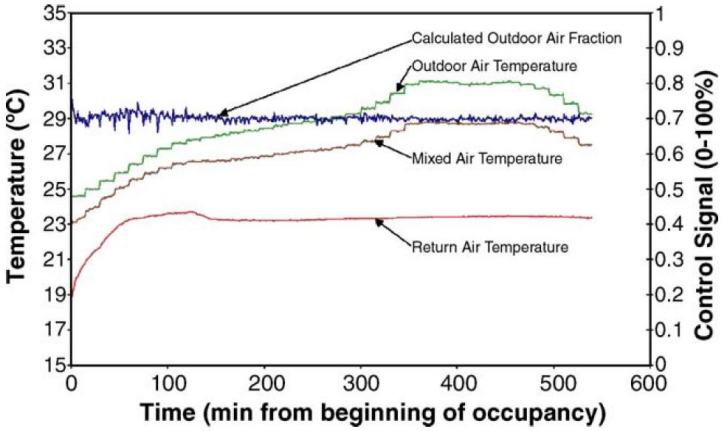


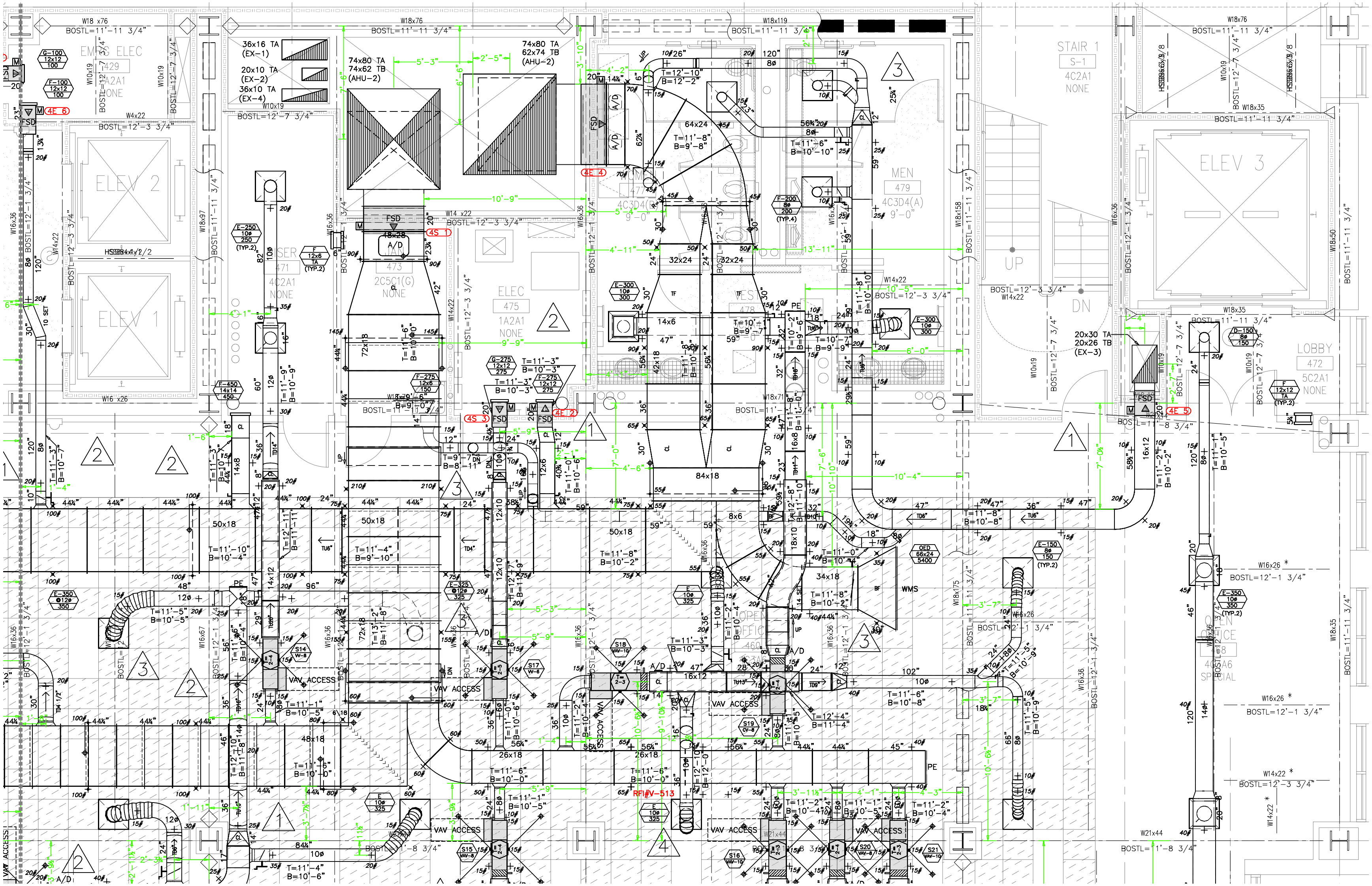
Fig. 4. Emulation study AHU recirculation damper stuck closed.

Automated Fault Detection:
10 - 40% energy savings

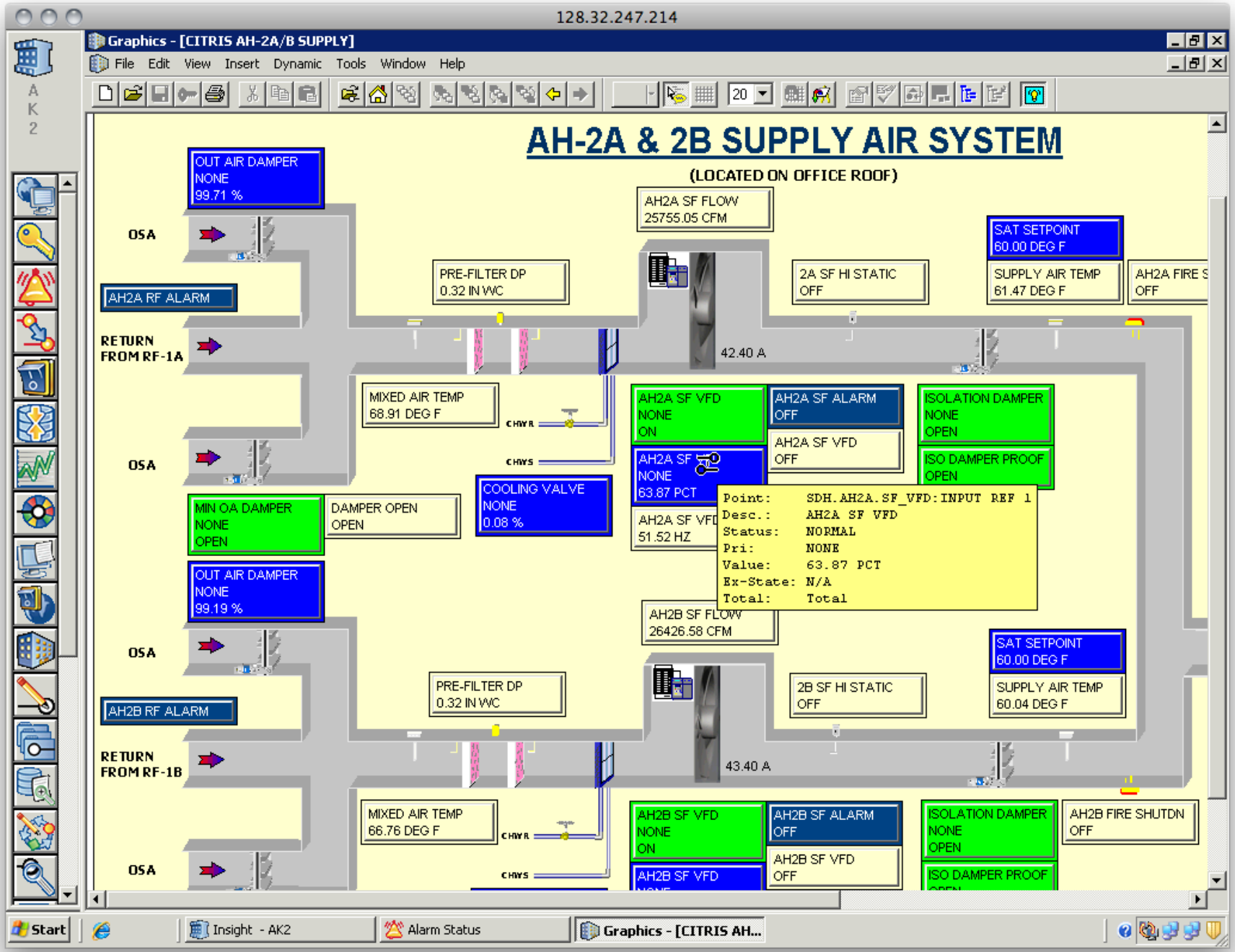
ERICKSON, V. L., CARREIRA-PERPIN, M. ., AND E.CERPA, A. *OBSERVE: occupancy-based system for efficient reduction of hvac energy.* In IPSN'11
SCHEIN, J., BUSHBY, S. T., CASTRO, N. S., AND HOUSE, J. M. *A rule-based fault detection method for air handling units*. In Energy and Buildings (2006).
KRIOUKOV,A.,DAWSON-HAGGERTY,S.,LEE,L.,REHMANE,O., AND CULLER, D. *A living laboratory study in personalized auto-mated lighting controls*. In BuildSys'11 (2011).

Challenge: Portability

Buildings are custom designed



W18 x76
BOSTL=11'-11 3/4"
EM ELEC
429
1A2A1
NONE
G-100 12x12 100
F-100 12x12 100
4E 6
FSD
W4x22
BOSTL=12'-3 3/4"
ELEV 2
ELEV 1
W16 x26
36x16 TA (EX-1)
20x10 TA (EX-2)
36x10 TA (EX-4)
W10x19
BOSTL=12'-7 3/4"
74x80 TA
74x62 TB
(AHU-2)
74x80 TA
62x74 TB
(AHU-2)
W18x76
BOSTL=11'-11 3/4"
5'-3"
2'-5"
10'-9"
W14 x22
BOSTL=12'-3 3/4"
4S 1
48x28
A/D
JAN
473
2C5C1(G)
NONE
ELEC
475
1A2A1
NONE
F-250 10ø 250 (TYP.2)
F 12x6 TA (TYP.2)
SER
471
4C2A1
NONE
72x18
T=11'-6"
B=10'-0"
F-450 14x14 450
F-275 12x6 150
G-275 12x12 275
F-275 12x12 275
T=11'-3"
B=10'-3"
4S 3
4E 2
4E 4
W18x119
BOSTL=11'-11 3/4"
120"
8ø
64x24
T=11'-8"
B=9'-8"
56x20
T=11'-6"
B=10'-10"
MEN
479
4C3D4(A)
9'-0"
F-200 8ø 200 (TYP.4)
32x24
32x24
F-300 10ø 300
14x6
42x18
84x18
W14x22
BOSTL=12'-3 3/4"
E-300 10ø 300
STAIR 1
S-1
4C2A1
NONE
UP
DN
ELEV 3
W18x35
BOSTL=11'-11 3/4"
20x30 TA
20x26 TB
(EX-3)
D-150 8ø 150
LOBBY
472
5C2A1
NONE
F 12x12 TA (TYP.2)
4E 5
BOSTL=11'-8 3/4"
50x18
T=11'-10"
B=10'-4"
T=11'-4"
B=9'-10"
T=11'-8"
B=10'-2"
8x6
18x10
34x18
T=11'-8"
B=10'-2"
OED 66x24 5400
E-150 8ø 150 (TYP.2)
WMS
E-350 12ø 350
T=11'-5"
B=10'-5"
E-325 12ø 325
VAV ACCESS
S14
S17
S18
S19
16x12
T=11'-3"
B=10'-3"
OPEN OFFICE
468
W16x26
BOSTL=12'-1 3/4"
E-350 10ø 350 (TYP.2)
OPEN OFFICE
4C6A6
SPECIAL
102"
10ø
T=11'-6"
B=10'-8"
48x18
26x18
T=11'-6"
B=10'-0"
RFI#V-513
T=12'-4"
B=11'-4"
PE
W14x22
BOSTL=12'-3 3/4"
W21x44
BOSTL=11'-8 3/4"
T=11'-2"
B=10'-4"
T=11'-1"
B=10'-5"
S15
S16
S20
S21
T=11'-4"
B=10'-6"


128.32.247.214
Graphics - [CITRIS AH-2A/B SUPPLY]
File Edit View Insert Dynamic Tools Window Help
AH-2A & 2B SUPPLY AIR SYSTEM
(LOCATED ON OFFICE ROOF)
OUT AIR DAMPER
NONE
99.71 %
OSA
AH2A RF ALARM
RETURN
FROM RF-1A
PRE-FILTER DP
0.32 IN WC
AH2A SF FLOW
25755.05 CFM
2A SF HI STATIC
OFF
SAT SETPOINT
60.00 DEG F
SUPPLY AIR TEMP
61.47 DEG F
AH2A FIRE S
OFF
42.40 A
MIXED AIR TEMP
68.91 DEG F
CHWR
CHWS
AH2A SF VFD
NONE
ON
AH2A SF ALARM
OFF
AH2A SF VFD
OFF
ISOLATION DAMPER
NONE
OPEN
ISO DAMPER PROOF
OPEN
AH2A SF
NONE
63.87 PCT
AH2A SF VFD
51.52 HZ
COOLING VALVE
NONE
0.08 %
MIN OA DAMPER
NONE
OPEN
DAMPER OPEN
OPEN
Point: SDH.AH2A.SF_VFD:INPUT REF 1
Desc.: AH2A SF VFD
Status: NORMAL
Pri: NONE
Value: 63.87 PCT
Ex-State: N/A
Total: Total
OUT AIR DAMPER
NONE
99.19 %
OSA
AH2B SF FLOW
26426.58 CFM
SAT SETPOINT
60.00 DEG F
SUPPLY AIR TEMP
60.04 DEG F
AH2B RF ALARM
RETURN
FROM RF-1B
PRE-FILTER DP
0.32 IN WC
2B SF HI STATIC
OFF
43.40 A
MIXED AIR TEMP
66.76 DEG F
CHWR
CHWS
AH2B SF VFD
NONE
ON
AH2B SF ALARM
OFF
AH2B SF VFD
OFF
ISOLATION DAMPER
NONE
OPEN
AH2B FIRE SHUTDN
OFF
ISO DAMPER PROOF
OSA
Start
Insight - AK2
Alarm Status
Graphics - [CITRIS AH...

```
00030   C       ######################################################¶
00040   C       ###            UCB DAVIS HALL            ###¶
00050   C           ###                  BERKELEY, CA            ###¶
00060   C           ###               MBC03                  ###¶
00070   C       ###      CHILLED WATER SYSTEM PPCL      ###¶
00080   C       ###                                      ###¶
00090   C       ######################################################¶
00100   C¶
00110   C¶
00120   C         $LOC1  = BOTH CHILLERS RUNNING EVAPORATOR BUNDLE DELTA T LOAD CALCULATION¶
130   C     $LOC2  = CONDENSER WATER PUMP 1/2 PROOF OF RUNNING TRIGGER¶
00380   C ********************************************************************************¶
00390   C¶
00400   C *** POWER FAILURE AND DEFINE STATEMENT CONTROL ***¶
00410   C¶
01000   ONPWRT(1020)¶
01010   GOTO 1040¶
01020   SET(0.0,SECNDS)¶
01030   LOCAL(LOC16)¶
01040   DEFINE(A,"SDH.CHW1.")¶
01045   $LOC16 = "SDH.CH1.CHW.FLOW"¶
01050   IF("SDH.CH1.CHW.FLOW" .OR. "SDH.CH2.CHW.FLOW") THEN ON("SDH.CHX.CHW.FLOW") ELSE OFF("SDH.CHX.CHW.FLOW")¶
01052   "SDH.CHW_BYPASS_VLV_LOOPOUT" = $LOC13¶
01060   C IF("!PXCM03:BATT" .EQ. DEAD) THEN ON("MBC03.BATTERY") ELSE OFF("MBC03.BATTERY")¶
01070   C *** CHILLER EMERGENCY POWER LOAD STAGGER CONTROL ***¶
01080   C IF("SDH.ATS_E01.NORM" .EQ. OFF .AND. "SDH.CH1.START.STOP" .EQ. @OPER) THEN RELEAS(@OPER,"SDH.CH1.START.STOP")¶
01090   C IF("SDH.ATS_E01.NORM" .EQ. OFF .AND. "SDH.CH2.START.STOP" .EQ. @OPER) THEN RELEAS(@OPER,"SDH.CH2.START.STOP")¶
01100   C IF("SDH.ATS_E01.NORM" .EQ. OFF .AND. "%A%CH_SEQ" .EQ. @OPER) THEN RELEAS(@OPER,"%A%CH_SEQ")¶
01110   C IF("SDH.ATS_E01.NORM" .EQ. OFF .AND. "%A%CHP1_SS" .EQ. @OPER) THEN RELEAS(@OPER,"%A%CHP1_SS")¶
01120   C IF("SDH.ATS_E01.NORM" .EQ. OFF .AND. "%A%CHP2_SS" .EQ. @OPER) THEN RELEAS(@OPER,"%A%CHP2_SS")¶
01130   C IF("SDH.ATS_E01.NORM" .EQ. OFF .AND. "%A%CHP3_SS" .EQ. @OPER) THEN RELEAS(@OPER,"%A%CHP3_SS")¶
01140   C IF("SDH.ATS_E01.NORM" .EQ. OFF .AND. "%A%CWP1_SS" .EQ. @OPER) THEN RELEAS(@OPER,"%A%CWP1_SS")¶
01150   C IF("SDH.ATS_E01.NORM" .EQ. OFF .AND. "%A%CWP2_SS" .EQ. @OPER) THEN RELEAS(@OPER,"%A%CWP2_SS")¶
01160   C IF("SDH.ATS_E01.NORM" .EQ. OFF .AND. "%A%CWP3_SS" .EQ. @OPER) THEN RELEAS(@OPER,"%A%CWP3_SS")¶
01170   C IF("SDH.ATS_E01.NORM" .EQ. OFF .AND. "%A%CWP4_SS" .EQ. @OPER) THEN RELEAS(@OPER,"%A%CWP4_SS")¶
01180   C IF("SDH.ATS_E01.NORM" .EQ. OFF .AND. "%A%CWP34_LEAD" .EQ. @OPER) THEN RELEAS(@OPER,"%A%CWP34_LEAD")¶
01190   C¶
01200   C IF("SDH.ATS_E01.NORM" .EQ. OFF .AND. "SDH.ATS_E01.EMER" .EQ. OFF) THEN OFF(@EMER,"%A%CWP34_LEAD","%A%CHP2_SS","SDH.CH1.START.STOP")¶
01210   C IF("SDH.ATS_E01.EMER" .EQ. ON) THEN ON(@EMER,"SDH.CH1.START.STOP")¶
01220   C IF("SDH.ATS_E01.NORM" .EQ. OFF) THEN OFF(@EMER,"%A%CWP1_SS","%A%CWP2_SS","%A%CHP1_SS","SDH.CH2.START.STOP")¶
01230   C¶
01240   C IF("SDH.ATS_E01.NORM" .EQ. ON .AND. "SDH.CH1.START.STOP" .EQ. @EMER) THEN RELEAS(@EMER,"SDH.CH1.START.STOP")¶
01245   C IF("SDH.ATS_E01.NORM" .EQ. ON .AND. "SDH.CH2.START.STOP" .EQ. @EMER) THEN RELEAS(@EMER,"SDH.CH2.START.STOP")¶
01250   C IF("SDH.ATS_E01.NORM" .EQ. ON .OR. "SDH.ATS_E01.EMER" .EQ. ON) THEN RELEAS(@EMER,"%A%CWP34_LEAD","%A%CHP2_SS")¶
01255   C IF("SDH.ATS_E01.NORM" .EQ. ON) THEN RELEAS(@EMER,"%A%CWP1_SS","%A%CWP2_SS","%A%CHP1_SS")¶
01260   C¶
01270   C *** CHILLER SEASONAL SEQUENCE CHANGE CONTROL ***¶
01280   IF(MONTH .GE. 4.0 .AND. MONTH .LE. 9.0) THEN ON("%A%CH_SEASON") ELSE OFF("%A%CH_SEASON")¶
01290   IF(("%A%CH_SEASON" .EQ. ON .OR. "%A%CH2_FAIL" .EQ. ON) .AND. "%A%CH1_FAIL" .EQ. OFF) THEN "%A%CH_SEQ" = 12.0¶
01300   IF(("%A%CH_SEASON" .EQ. OFF .OR. "%A%CH1_FAIL" .EQ. ON) .AND. "%A%CH2_FAIL" .EQ. OFF) THEN "%A%CH_SEQ" = 21.0¶
01310   C
```

“Assembly Language”

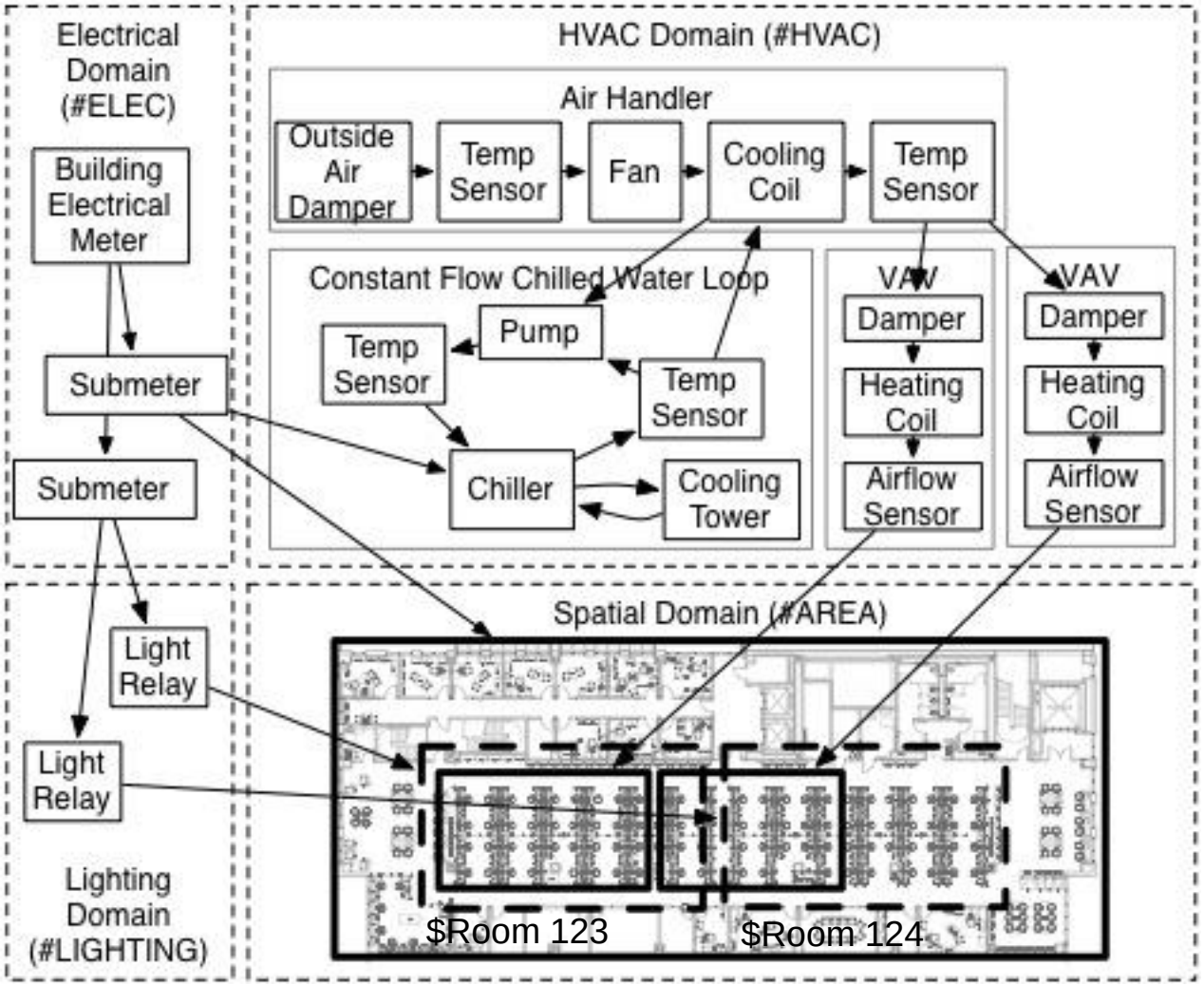
Today app programmers must understand:

- Building architecture
- HVAC design
- Control system connectivity and function

For ***each*** building

Goal: write once, run anywhere

Building Model



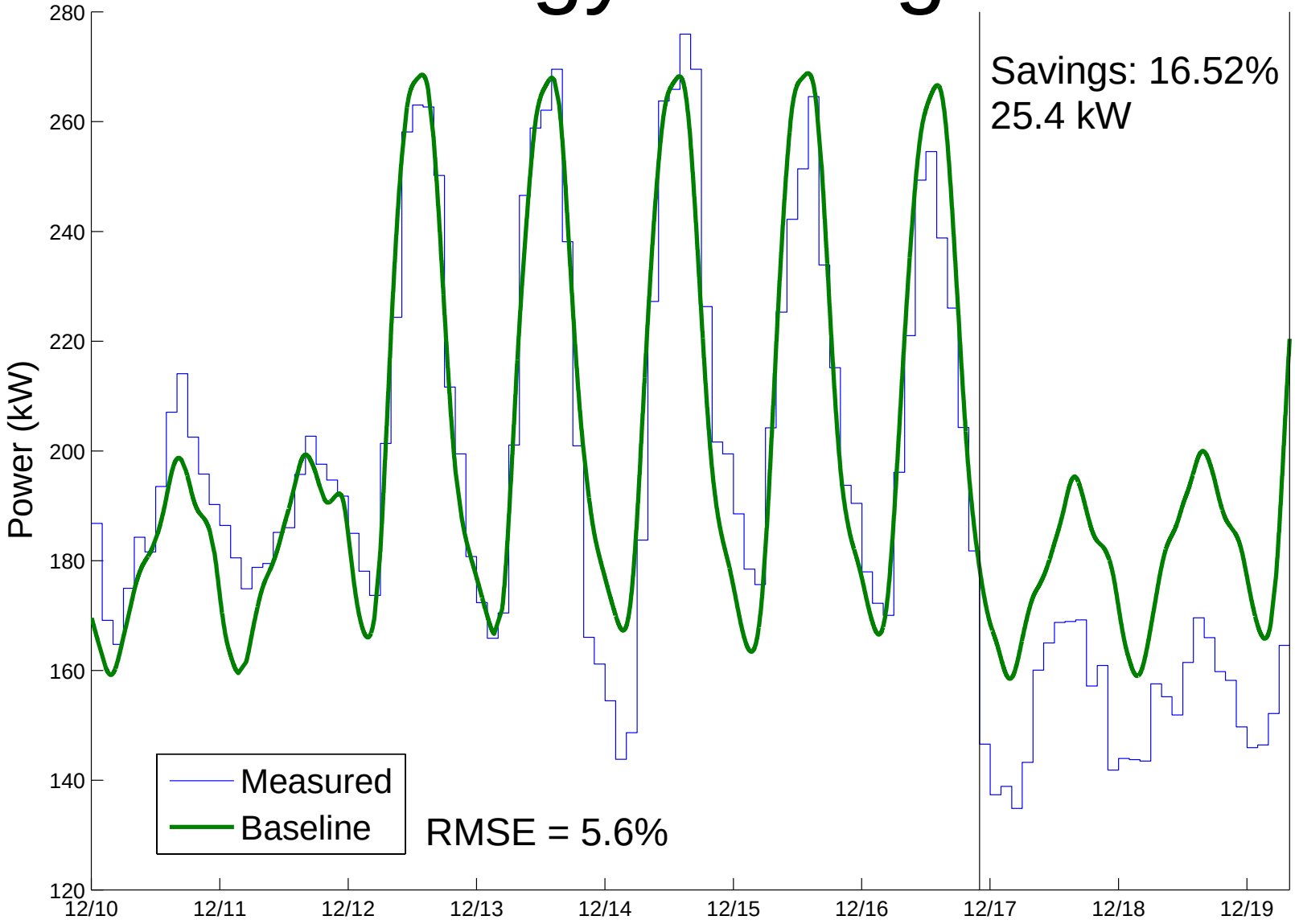
Code: BACnet

```
1  #Using direct BACnet
2  import bacnet
3  #damper setpoints for each outside air damper
4  oad_to_dmp_stpts = {
5    'SDH.PXCM-01 SDH.AH1A_OAD': [
6      'SDH.PXCM-04 SDH.S1-20:CTL FLOW MIN',
7      'SDH.PXCM-04 SDH.S1-19:CTL FLOW MIN',
8      ...],
9    'SDH.PXCM-01 SDH.AH1B_OAD': [
10     'SDH.PXCM-11 SDH S2-04:CTL FLOW MIN',
11     ...],
12   'SDH.PXCM-08 SDH.AH2A_OAD':[
13     'SDH.PXCM-11 SDH.S4-03:CTL FLOW MIN',
14     ...]
15   }
16 for oad in oad_to_dmp_stpts.keys():
17   device = bacnet.find(name=oad)
18   oad_airflow = bacnet.read_prop(device, object_type=bacnet.OBJECT_ANALOG_OUTPUT, \
19     instance_number=device.instance_number, property=bacnet.PROP_PRESENT_VALUE)
20   for dmp in oad_to_dmp_stpts[oad]:
21     damper = bacnet.find(name=dmp)
22     old_setpoint = bacnet.read_prop(device, object_type=bacnet.OBJECT_ANALOG_OUTPUT, \
23       instance_number=damper.instance_number, property=bacnet.PROP_PRESENT_VALUE)
24     new_setpoint = old_setpoint / oad_airflow
25     bacnet.write_prop(device, object_type=bacnet.OBJECT_ANALOG_OUTPUT,\
26       instance_number=damper.instance_number, property=bacnet.PROP_PRESENT_VALUE, \
27       value=new_setpoint, value_type=bacnet.BACNET_APPLICATION_TAG_REAL)
```

Code: BAS

```
1  #Using BAS
2  import appstack
3  api = appstack.Appstack()
4  ah_dampers = api('#OUT_AIR_DMP > #AH')
5  for dmp in ah_dampers:
6    for vav in api('#VAV < $%s' % dmp.name):
7      vav.set_min_airflow(vav.min_fresh_air() / dmp.get_percent_open())
```

Energy Savings



Thank You