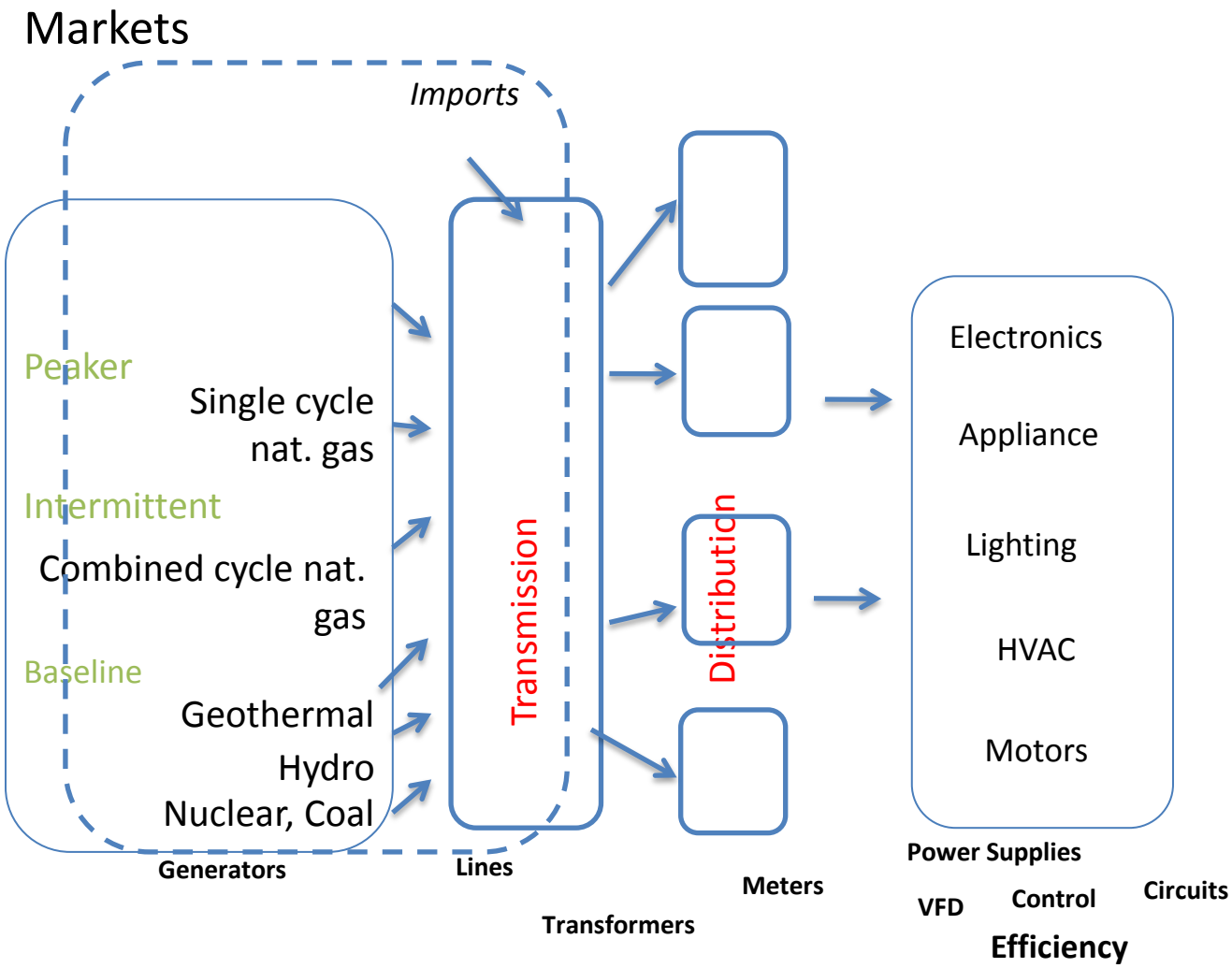
Towards a Reference OS Architecture for CPS's in buildings and grids

David E. Culler
UC Berkeley
2/26/24

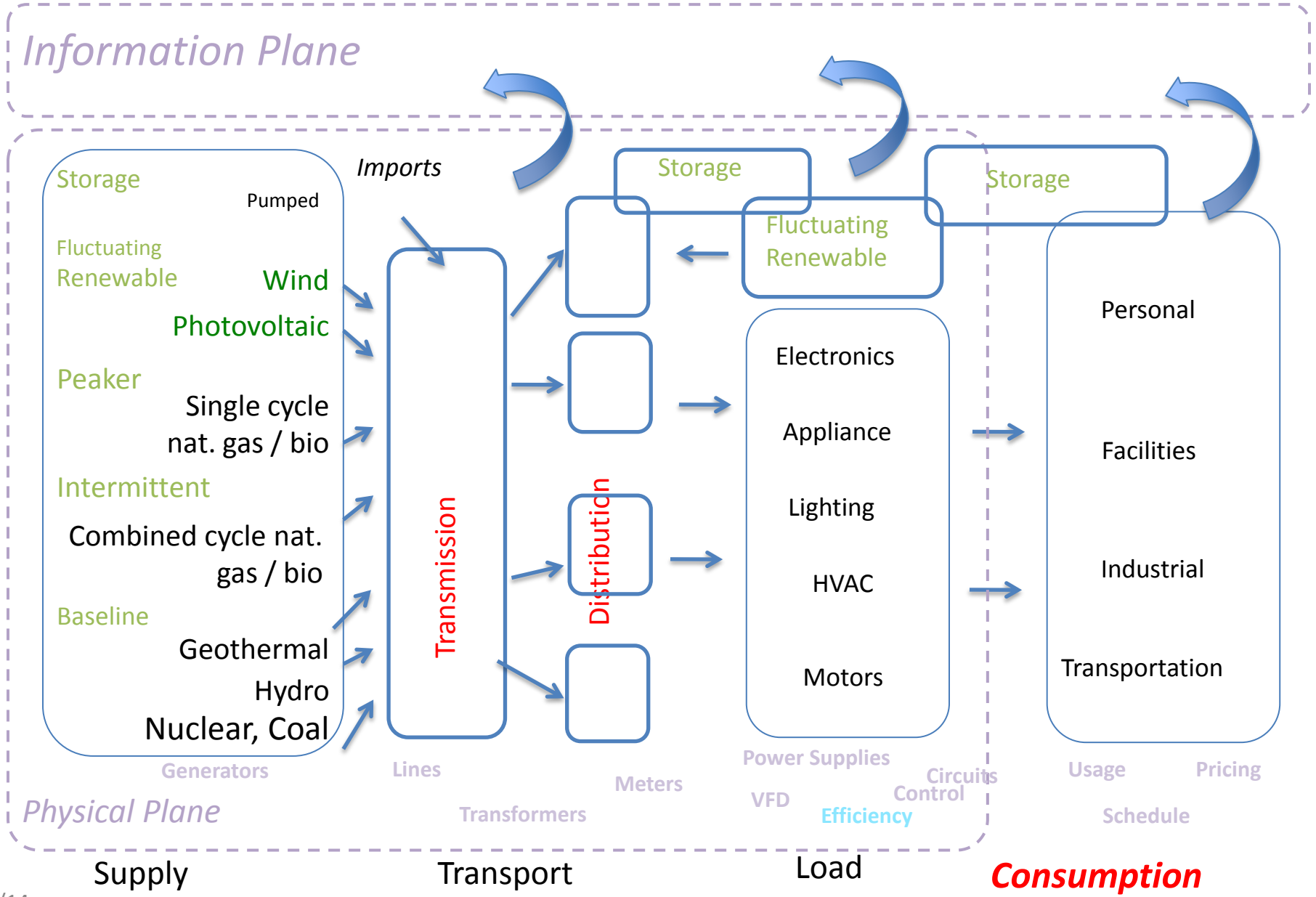
Outline

- Setting Context
  - 4 sample drivers
- Components of a CPS OS Arch - BOSS
- Current Explorations
- Discussions and Pathways

Classical view of the Energy Challenge



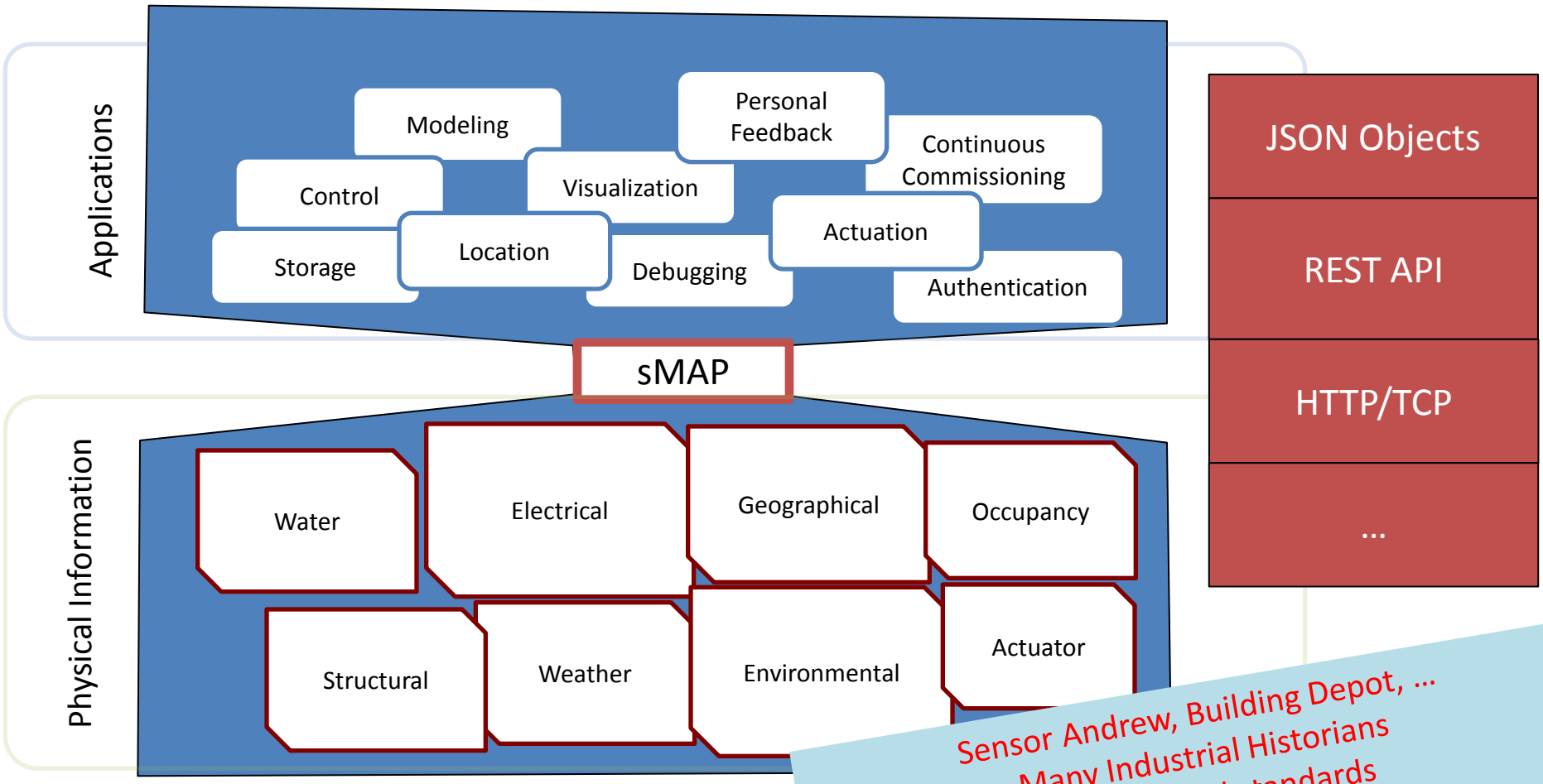
CPS Energy Network System Challenges

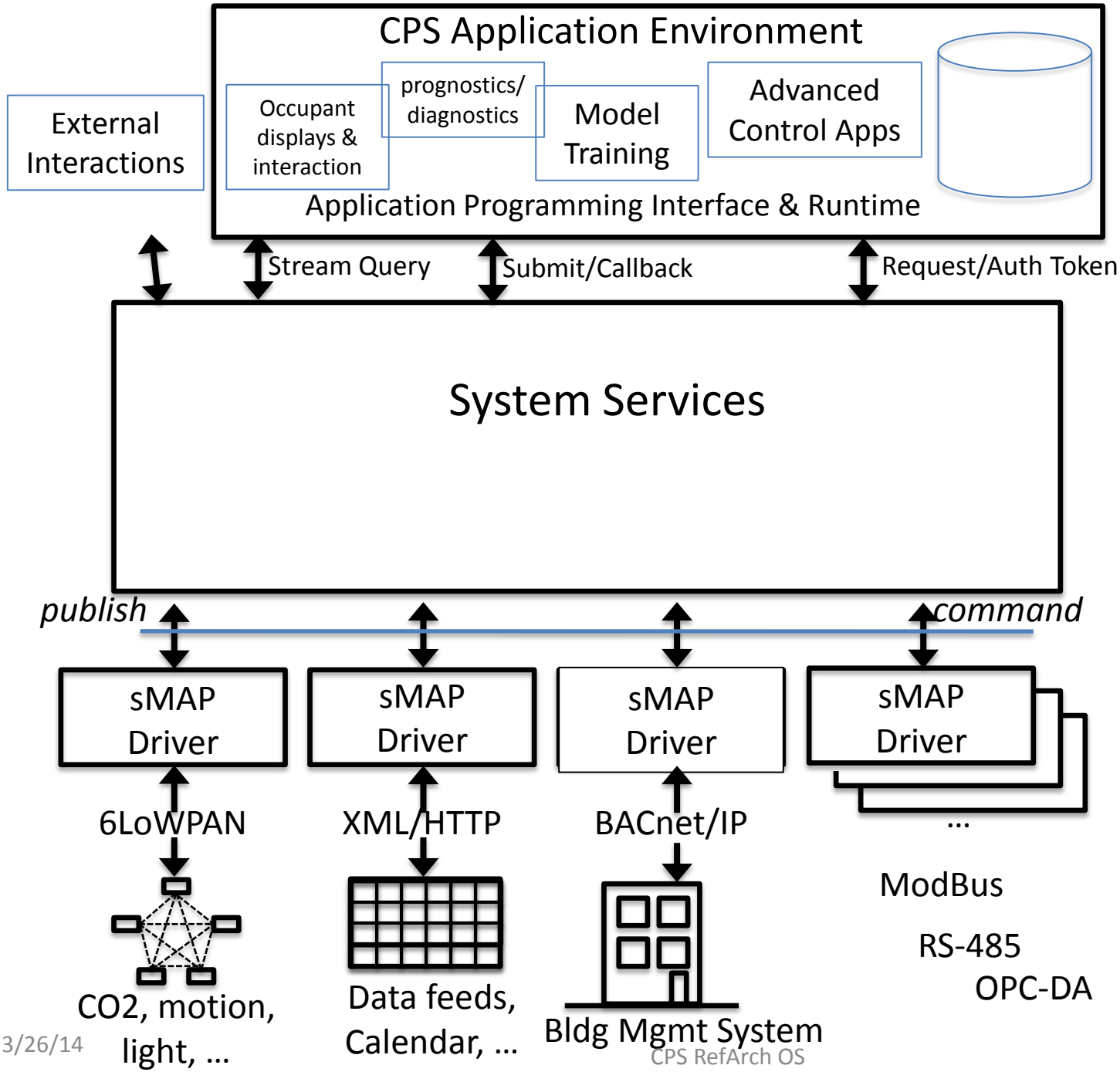


Model Problems

- **Dispatchable Demand**: utilizing *slack* in consumption to balance fluctuating renewables and grid constraints
  - Thermal mass (buildings), electrical storage (EVs), PCM (refrigeration), production schedule (mfg, computing)
- **Optimized building performance**: energy efficiency, comfort, agility
  - Integrated control, MPC, personalized conditioning
- **OpenBAS** in the "Internet of Stuff"
  - Networked thermal, lighting, furniture, …
- **μSynchrophasers**: distribution tier management
  - Time synchronized phase angle measurement and reaction

Uniform Access to Diverse Physical Information

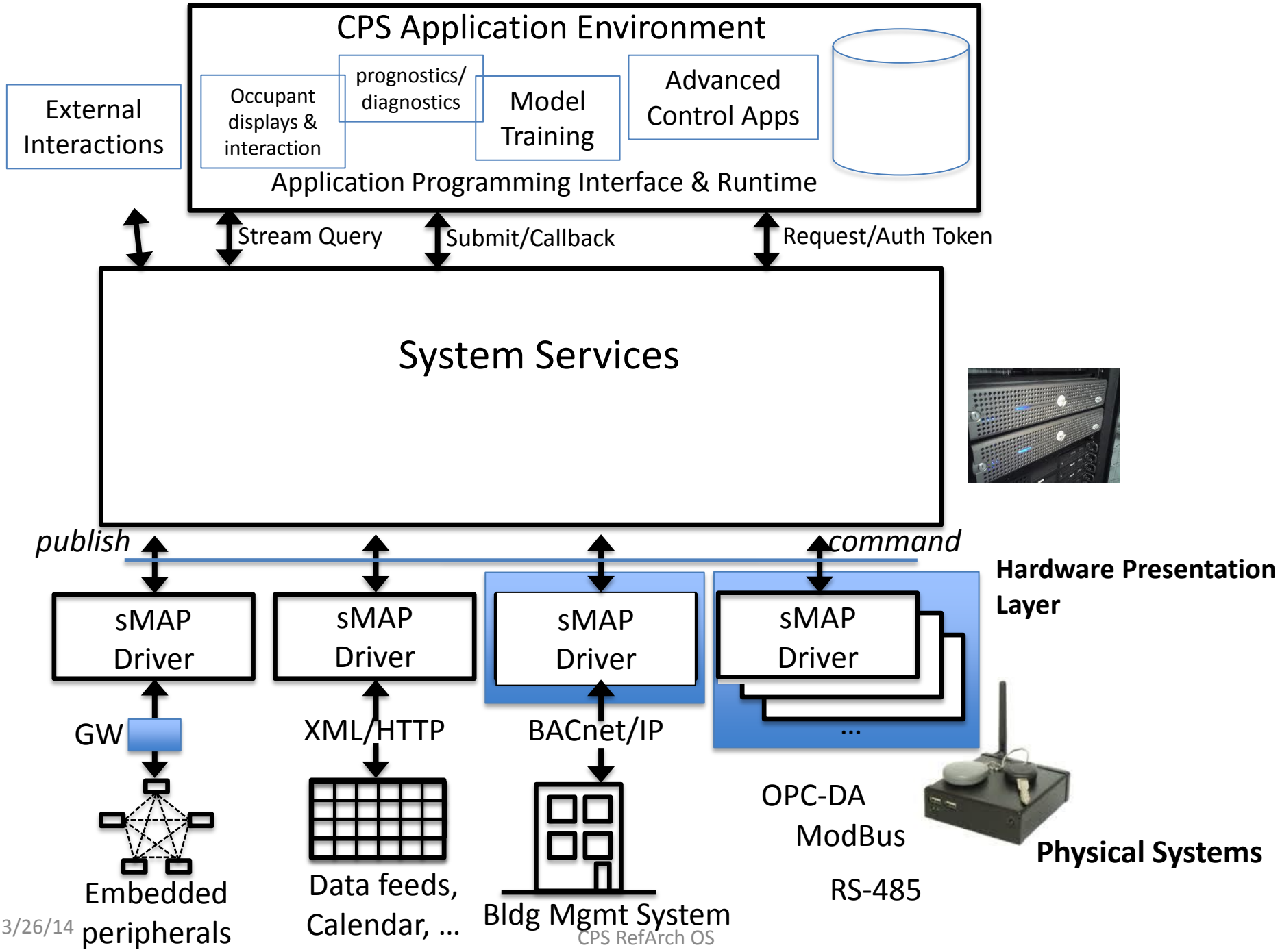




Hardware Presentation Layer

- JSON data stream + attribute metadata as resource-oriented web services

Physical Systems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External Interactions
Occupant displays & interaction
prognostics/ diagnostics
Model Training
Advanced Control Apps
Application Programming Interface & Runtime
Stream Query
Submit/Callback
Request/Auth Token
System Services
publish
command
sMAP Driver
sMAP Driver
sMAP Driver
sMAP Driver
...
Hardware Presentation Layer
GW
XML/HTTP
BACnet/IP
OPC-DA
ModBus
RS-485
Physical Systems
Embedded peripherals
Data feeds, Calendar, …
Bldg Mgmt System

Commercial buildings (~10m US): Huge Sensor Networks

151 Temperature Sensors

312 Light Relays

> 6,000 Sense and Control Points

50 Electrical Sub-meters

6 Variable Speed Pumps

12 Variable Speed Fans

121 Controllable Valves

138 Air Dampers

Controls are Widely Available

Bancroft Library:

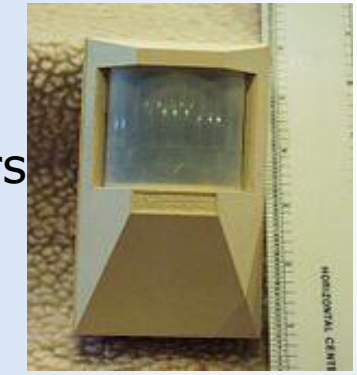
- Built in 1949
- 100k sq. ft.
- 5,000 points

>70% of large buildings have digital controls

U.S. Energy Information Administration, 2009

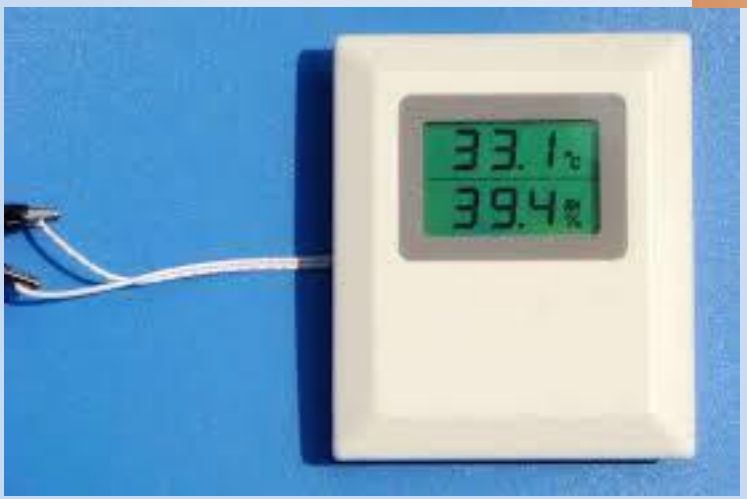
Additional sensor networks

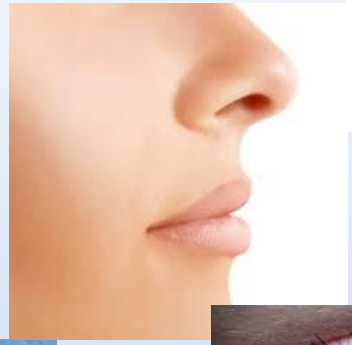
PIR sensors



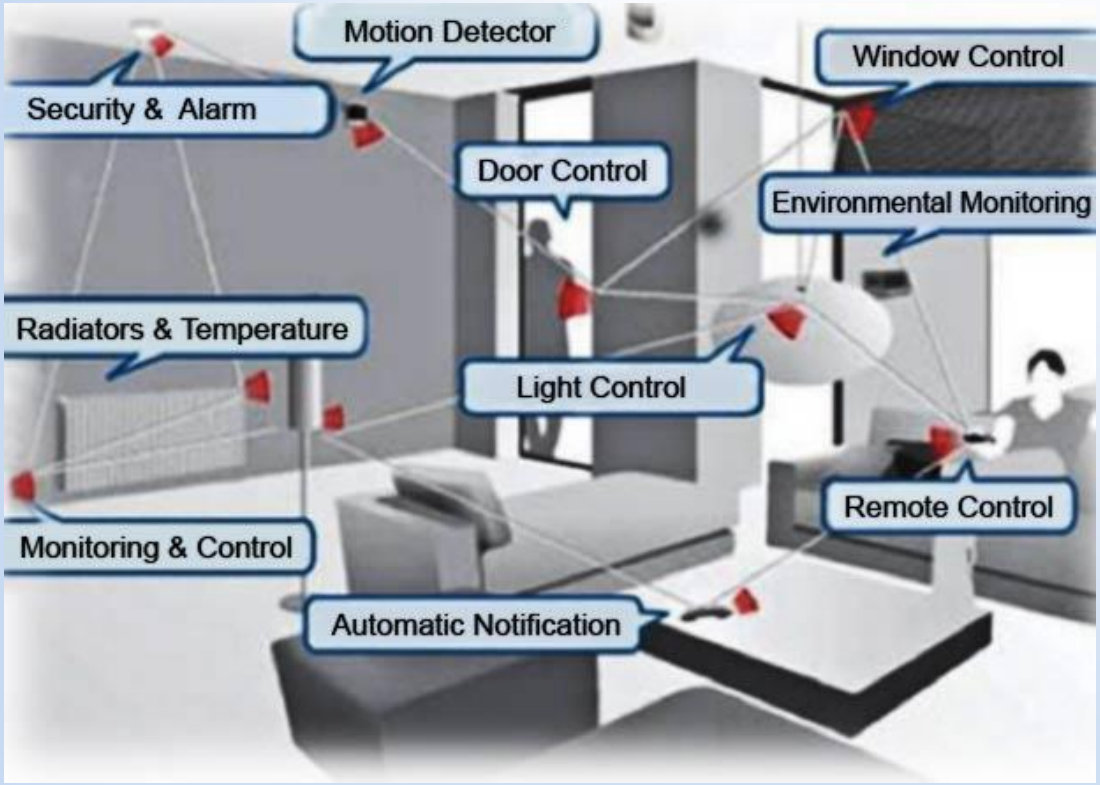
CO_2 sensors

Temperature &
Humidity sensors

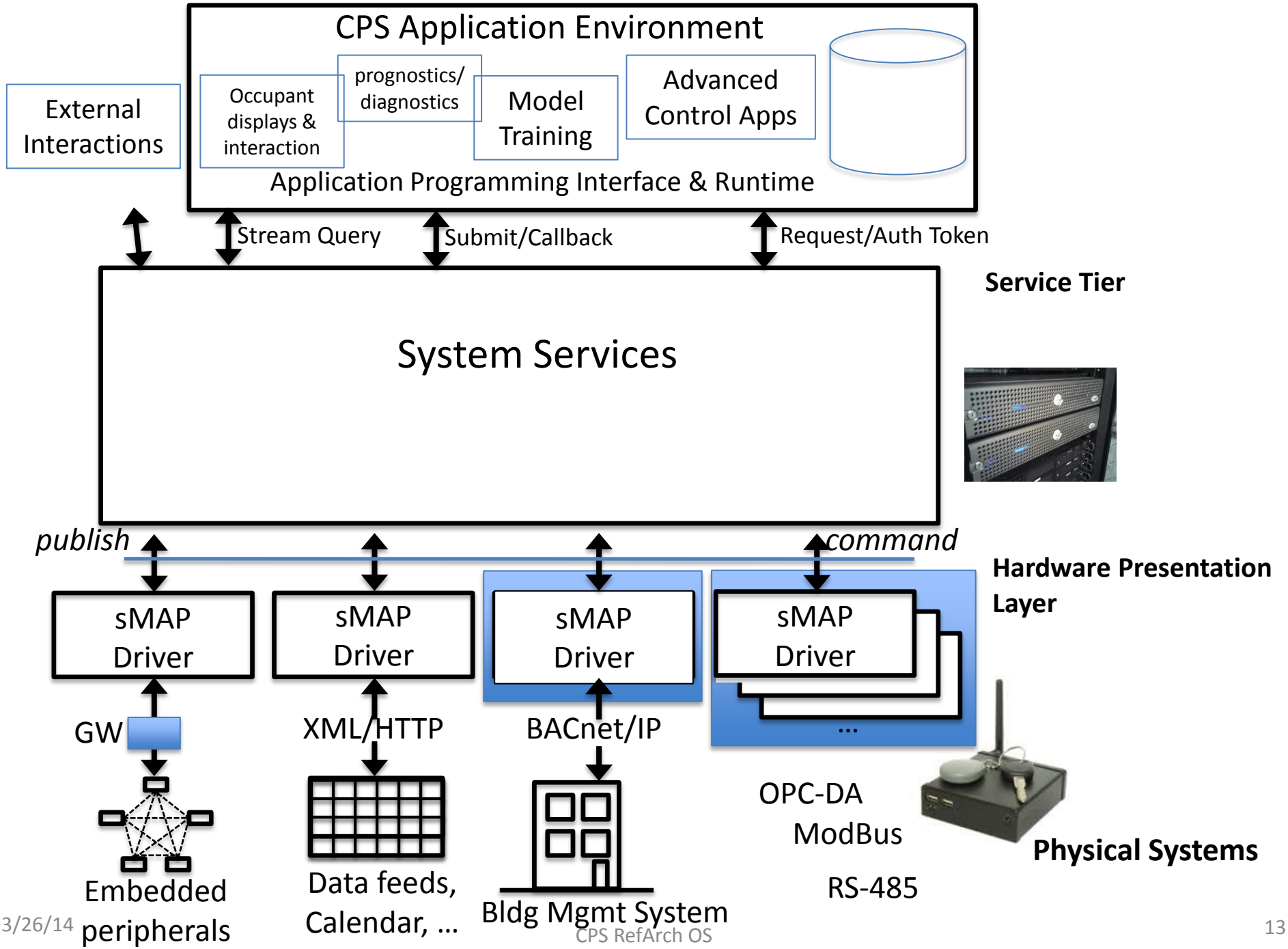




Residential Buildings (~100m US)



10s of sensors / actuators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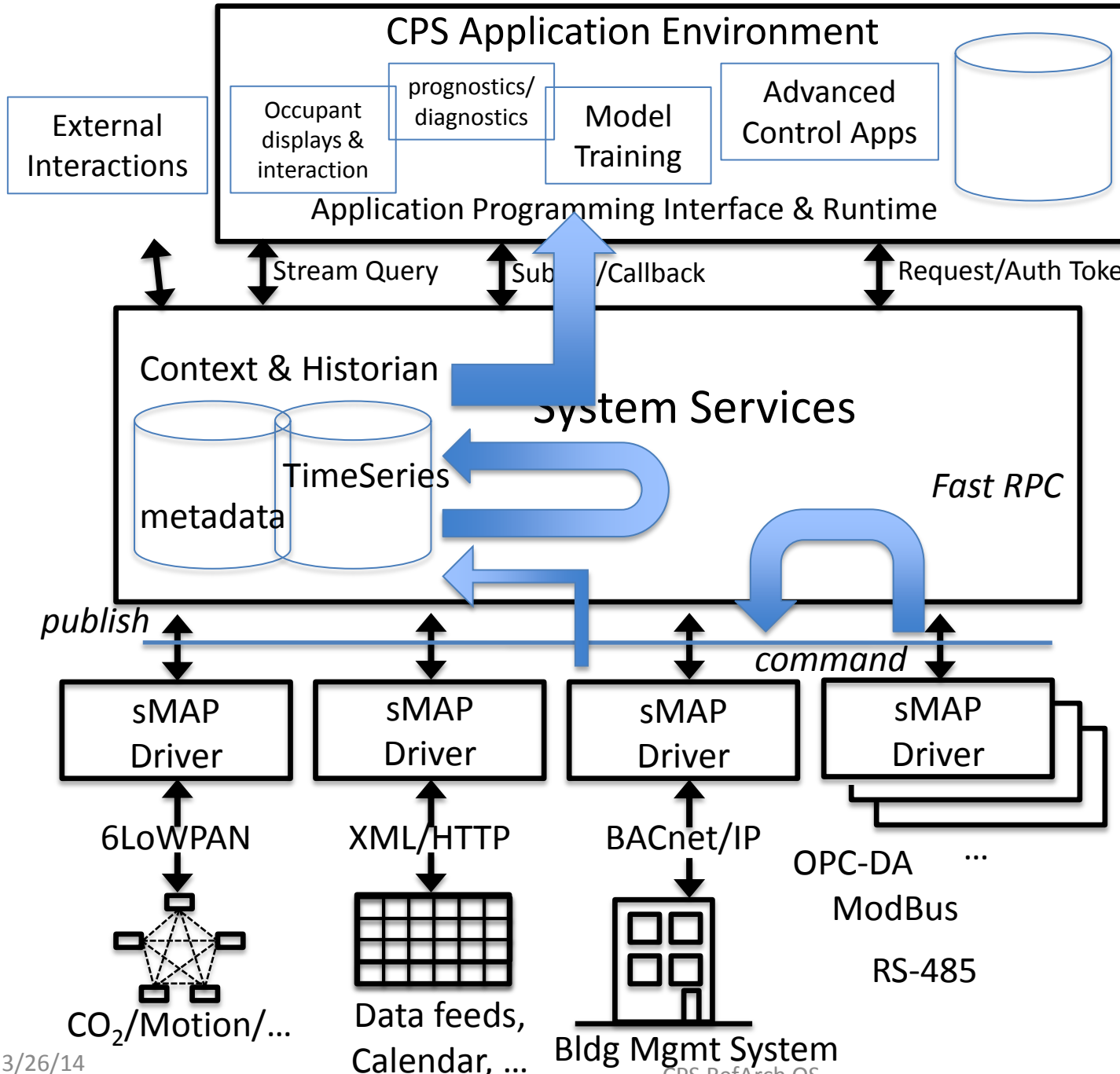


Hardware Presentation Layer

- JSON data stream + attribute metadata as resource-oriented web services

Physical Systems

sMAP Drivers database :

Name	Sensor Type	Access Method	Channels
ISO Data	**CAISO, NYISO, PJM, MISO, ERCOT, BPA**	**Web scrape**	**15081**
ACme devices	Plug-load electric meter	Wireless 6lowpan mesh	344
EECS submetering project	Dent Instruments PowerScout 18 electric meters	Modbus	4644
UC Berkeley submetering feeds	ION 6200, Obvius Aquisuite; PSL pQube, Veris Industries E30	Mosbus/Ethernet, HTTP	4269
Sutardja Dai, Brower Hall BMS	**Siemens Apogee BMS, Legrand WattStopper, Johnson Control BMS**	**BACnet/IP**	**4064**
UC Davis submetering feeds	Misc., Schneider Electric ION	OPC-DA	34 (+)
Weather feeds	Vaisala WXT520 rooftop weather station; Wunderground	SDI-12, LabJack/Modbus, web scrape	33
CBE PMP toolkit	Dust motes; New York Times BMS	CSV import; serial	874
NOA Weather Forecast	**Meteorological (window, solar, cloud, etc)**	**Web**	**166000**
SDH Air Quality	CO2, Temp, TSR, PAR, Hum	Wireless 6lowpan mesh	50
Soda Hall BMS	**Temp sensors, air flow sensors, other building infrastructure sensors**	**RPC**	**1600**
Campus BMS (near future)	Barrington BMS data	RPC	22000

Stats

- Total number of sensor streams : ~270,000
- Total number of readings : ~40 billion
- Write load : 300-600 / sec
- Total size of database : 150GB compressed ~10x

https://code.google.com/p/smap-data/

sMAP 1 resource structure

```
/                    # list resource under URI root [GET]
  /data              # list sense points under resource data [GET]
    / [sense_point]    # select a sense point [GET]
      /meter           # meters provide this service [GET]
        / [channel]    # a particular channel [GET]
          /reading     # meter reading [GET]
          /format      # calibration and units [GET/POST]
          /parameter   # sampling parameter [GET/POST]
          /profile     # history of readings [GET]
```

➔ Represent units, sampling parameters of the underlying device, for each channel

➔ Expose over HTTP

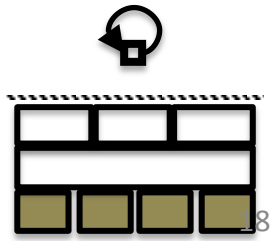
sMAP2 HPL: Represent sensors and actuators

- Objects are *time-series* and *collections*
- Represent the underlying sense and actuation points
- Expose over HTTP
- *Time-series* are durably identified
  - A collection of structured key-value pairs, data
  - Data is (time, value[, seqno]) vector

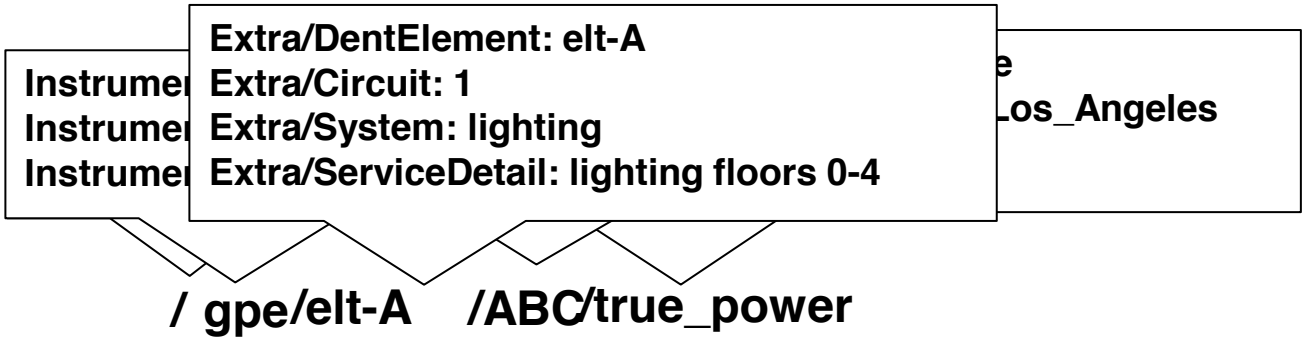
collections

timeseries

```
/data/                          # all timeseries and collections
    {
        "Contents" : ["sensor0"],
        "Metadata" : { "SourceName" : "Example sMAP Source" },
    }
/data/sensor0
    { "Contents" :["channel0"] },
/data/sensor0/channel0
    {
        "uuid" : "a7f63910-ddc6-11e0-8ab9-13c4da852bbc",
        "Readings" : [ [1315890624000, 12.5 ] ]
    }
/reports/                       # data destinations
```

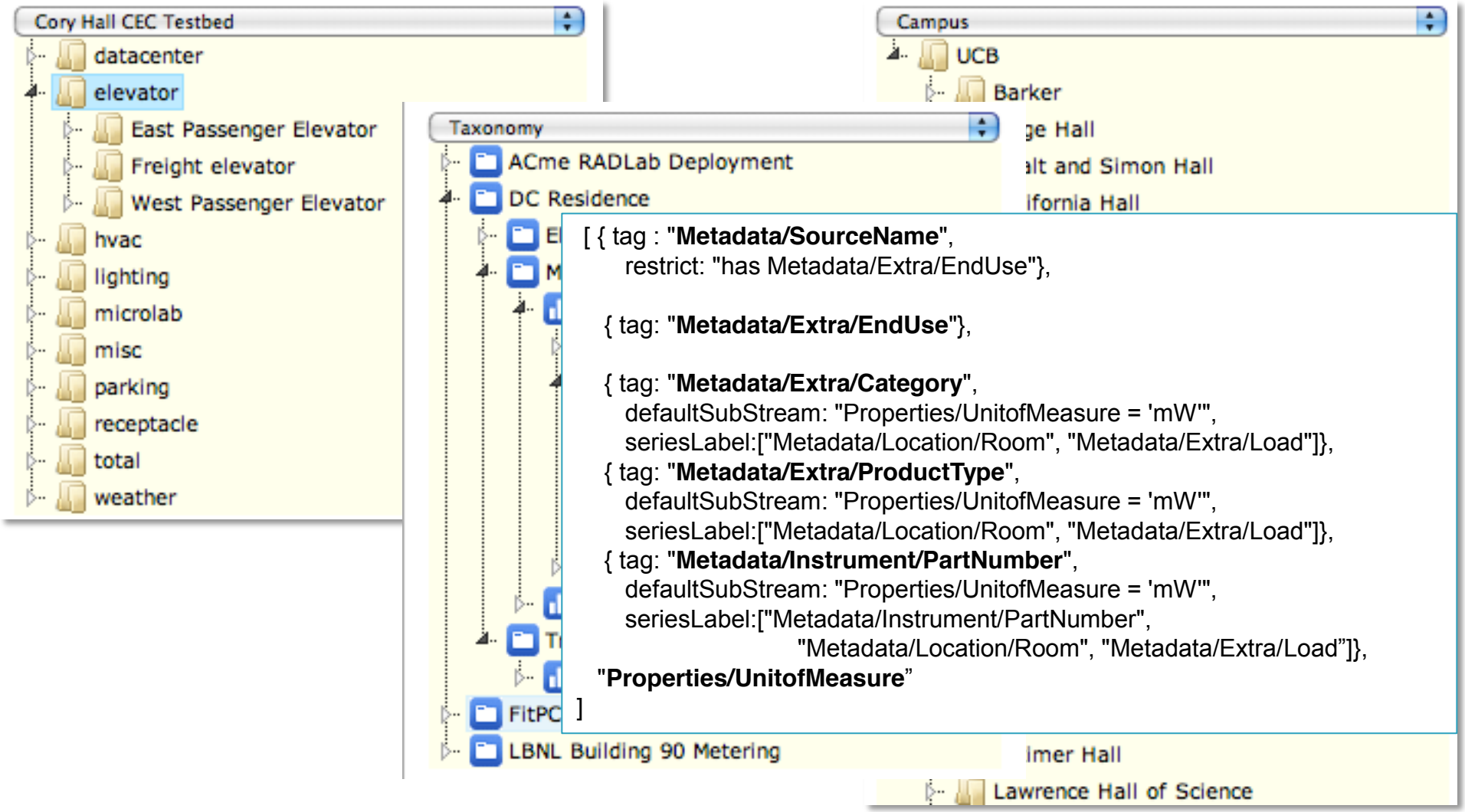


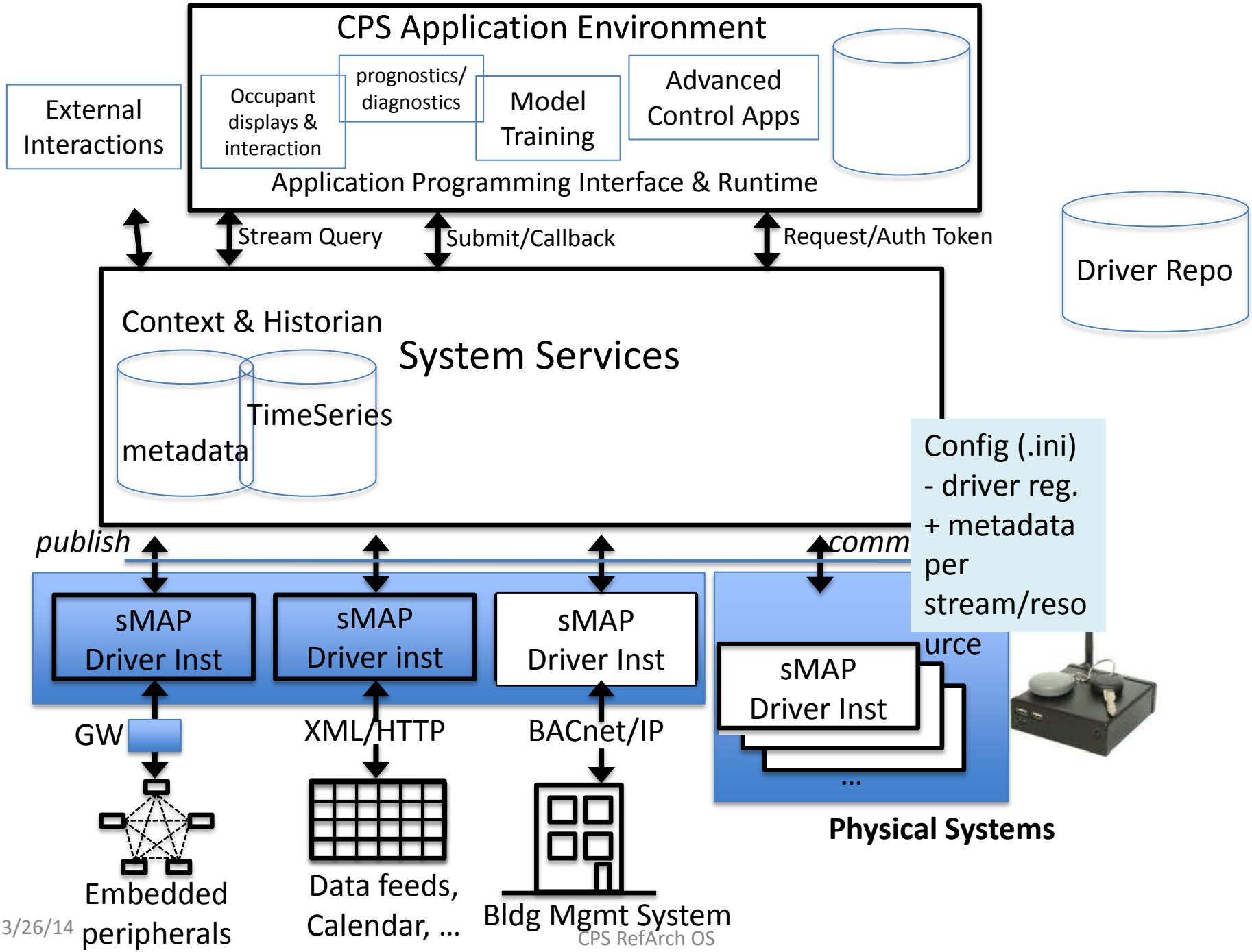
sMAP 2: Simple Metadata



- Each stream can be “tagged” with key-value pairs
- Easy to tag related collections of points (hierarchy)
- Natural way to represent “subset of” relation

Tags Generate Multiple Views

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Driver Repo
Context & Historian
System Services
metadata
TimeSeries
publish
comm
Config (.ini)
- driver reg.
+ metadata per stream/reso urce
sMAP Driver Inst
sMAP Driver inst
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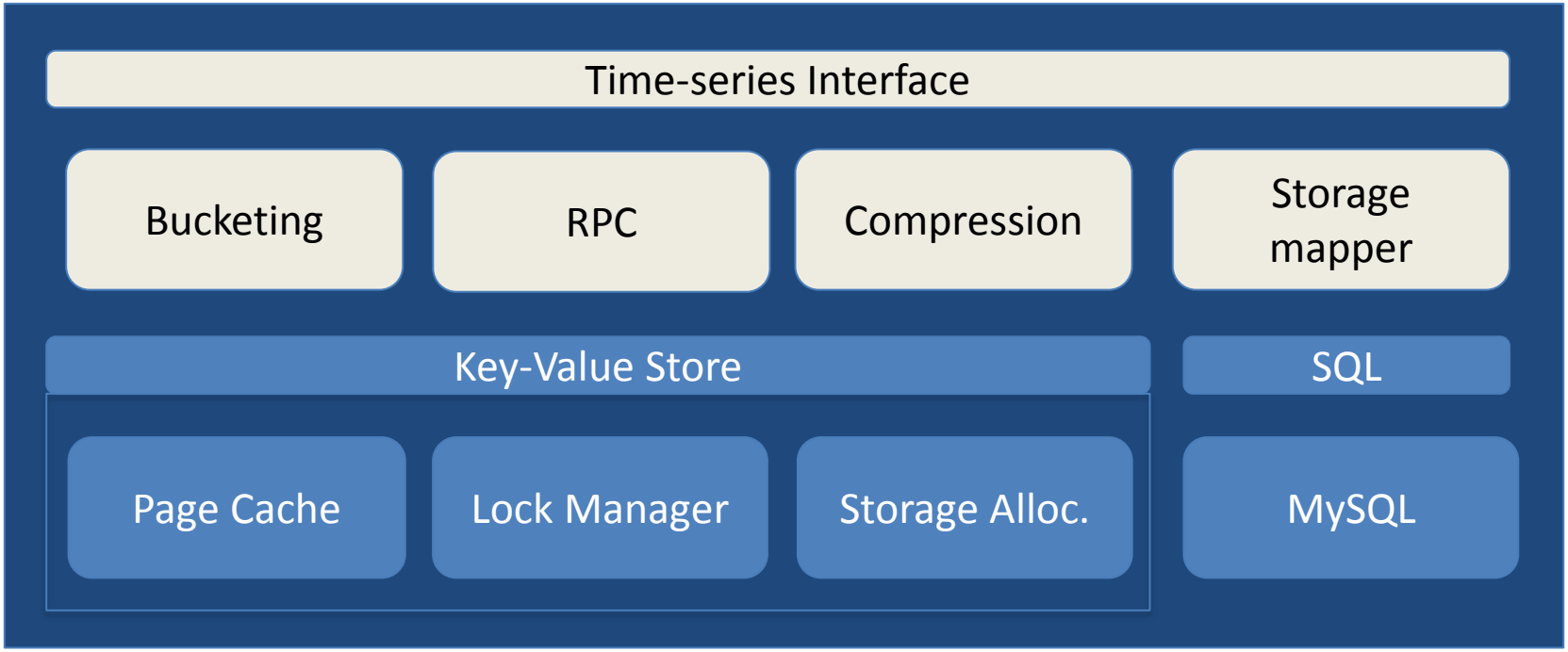
Bldg Mgmt System

High-performance Storage Service

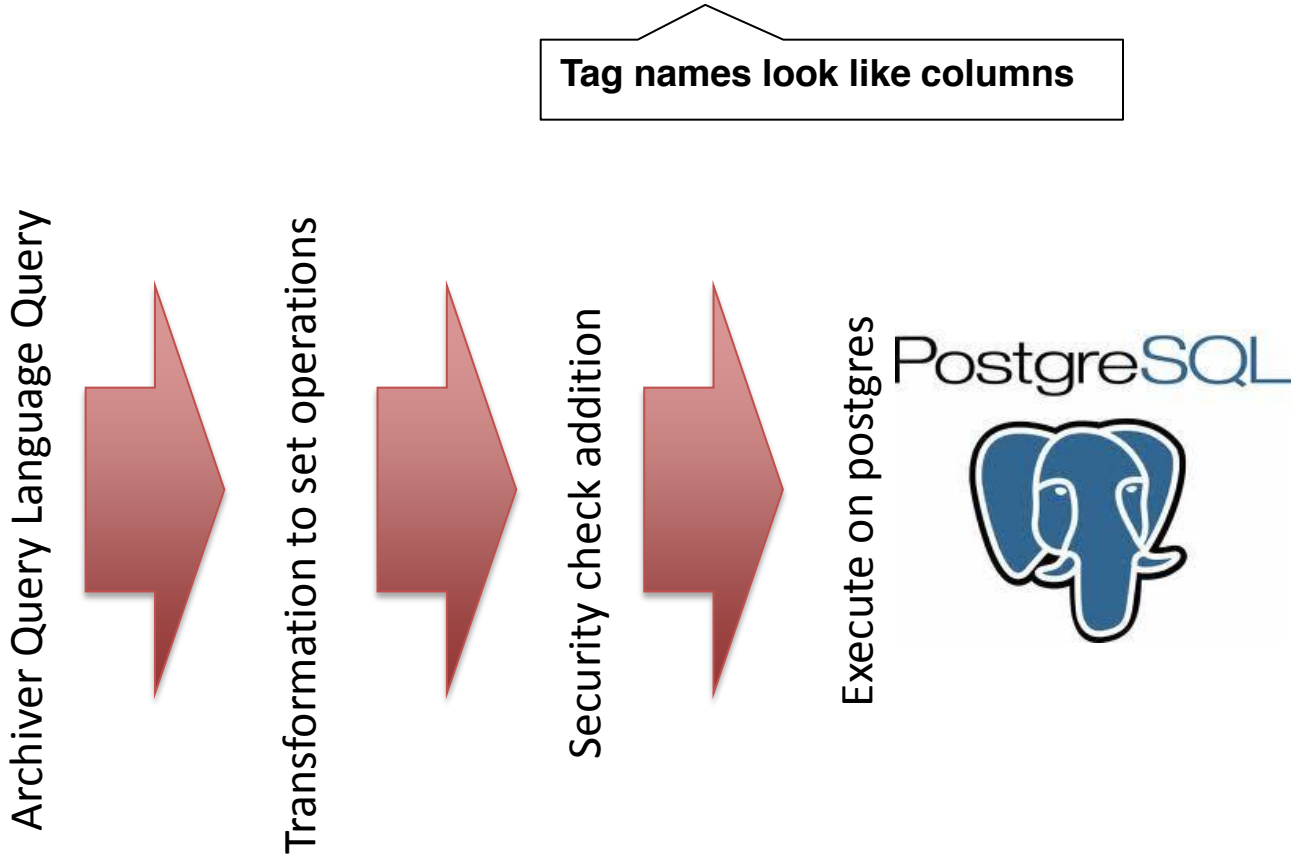
- Low-latency, high speed access to archived readings
- Billions of readings, 3.5 bytes/reading on disk

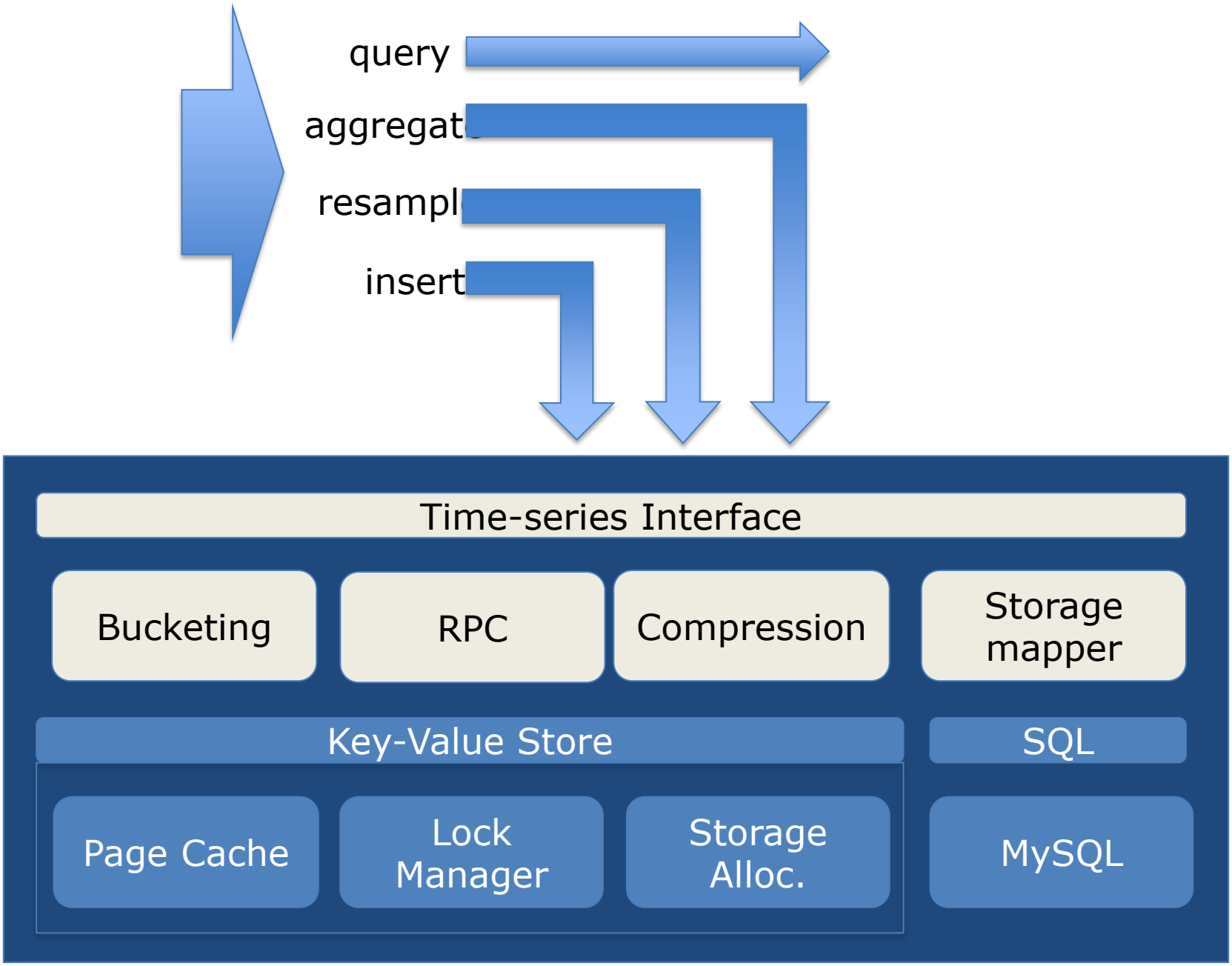


Archiver Query Language

- Column-like store with SQL-like interface

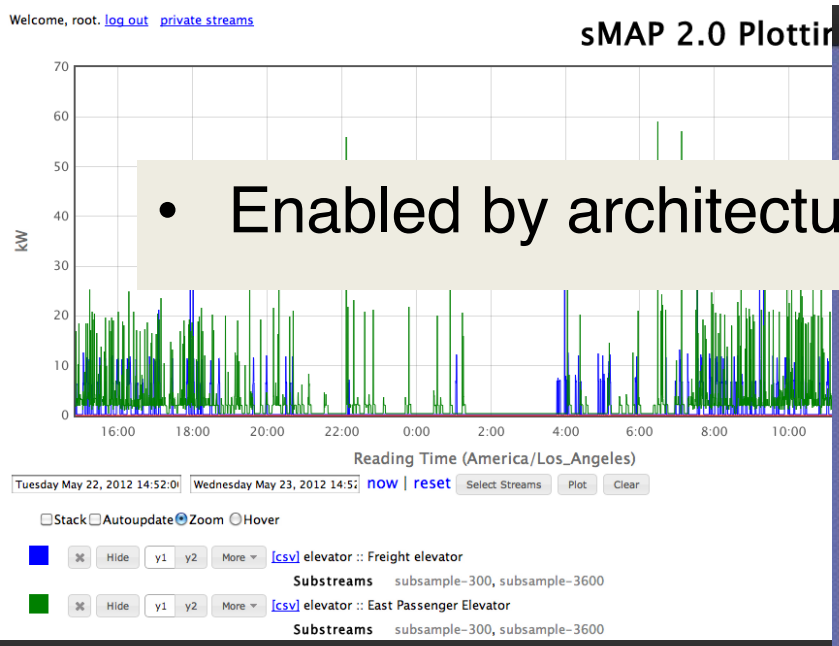
select distinct Metadata/SourceName

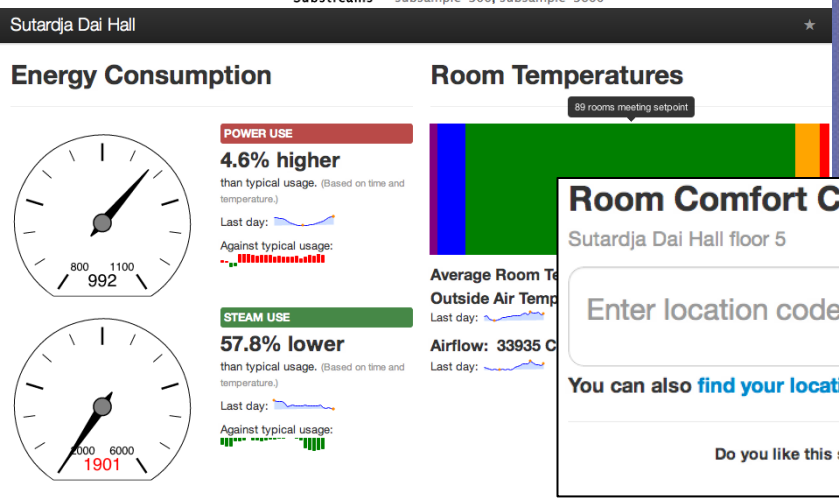


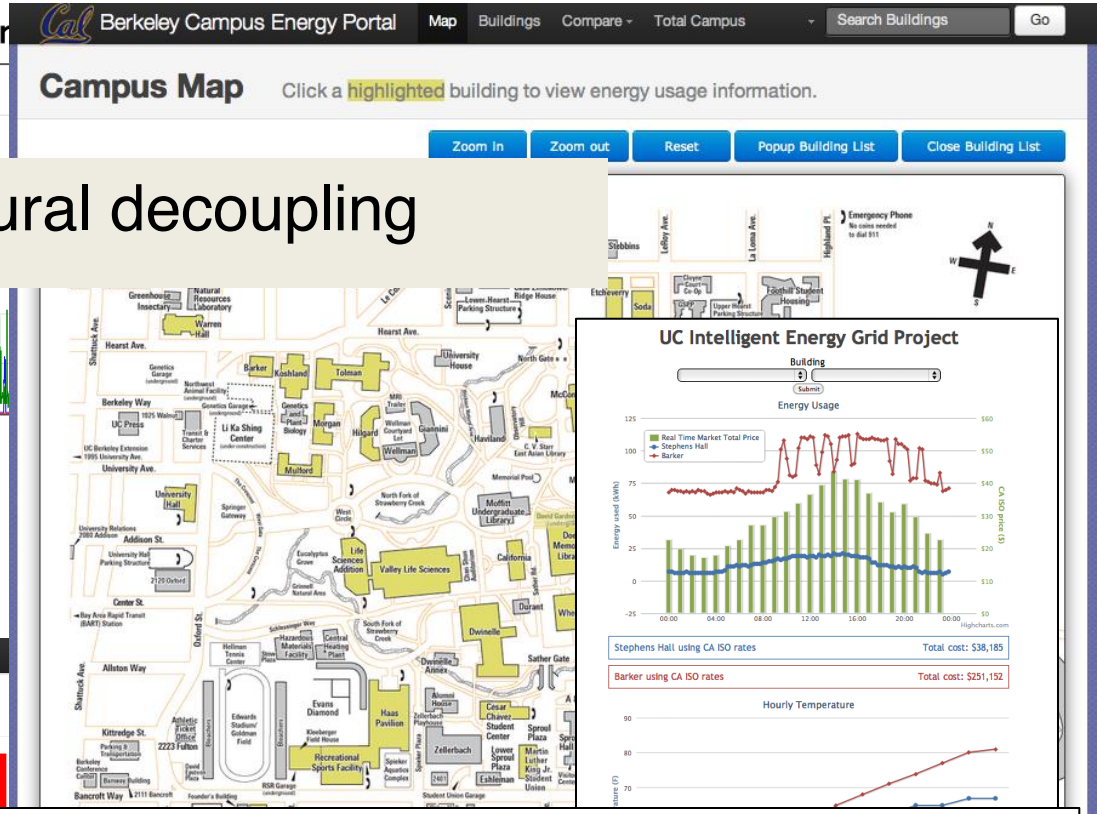

query
aggregat
resampl
insert
streaming pipeline
Time-series Interface
Bucketing
RPC
Compression
Storage mapper
Key-Value Store
SQL
Page Cache
Lock Manager
Storage Alloc.
MySQL
readingdb

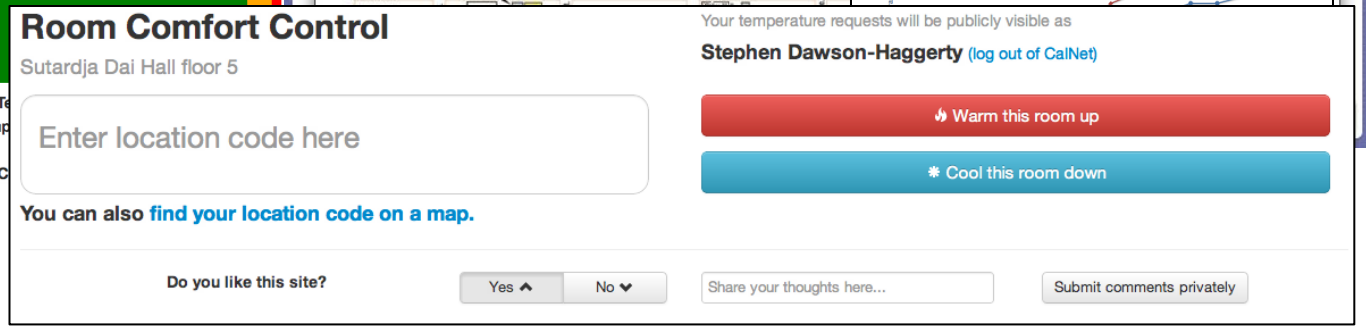
sMAP frontends / apps

- Enabled by architectural decoupling









what is an operator?

- An operator reads a set of input streams
- And produces a set of distillate streams
  - May mutate any of the dimensions
  - Each output stream is uniquely named

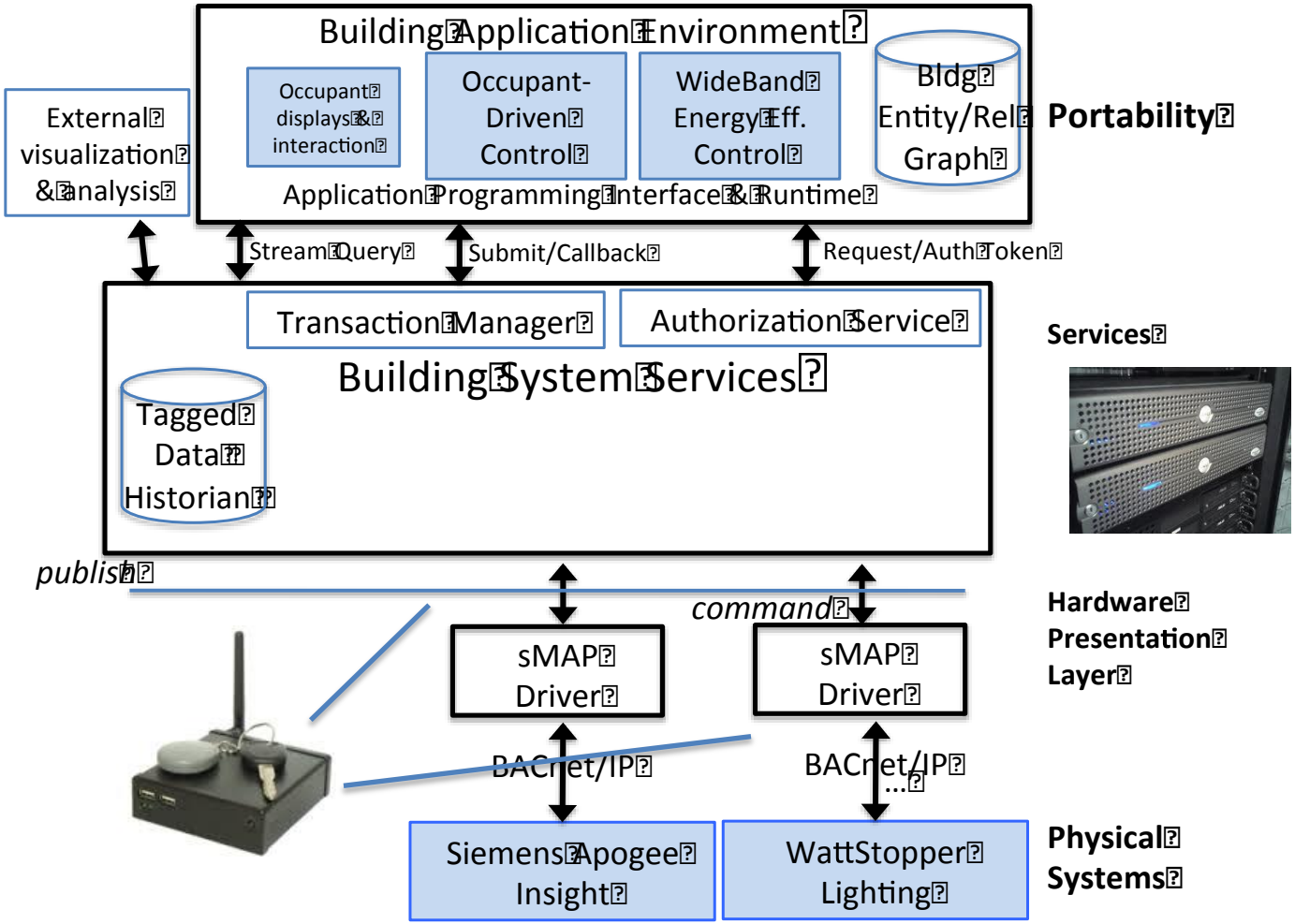
Example: unit

Read a set of input streams
and apply a common set
of unit conversions

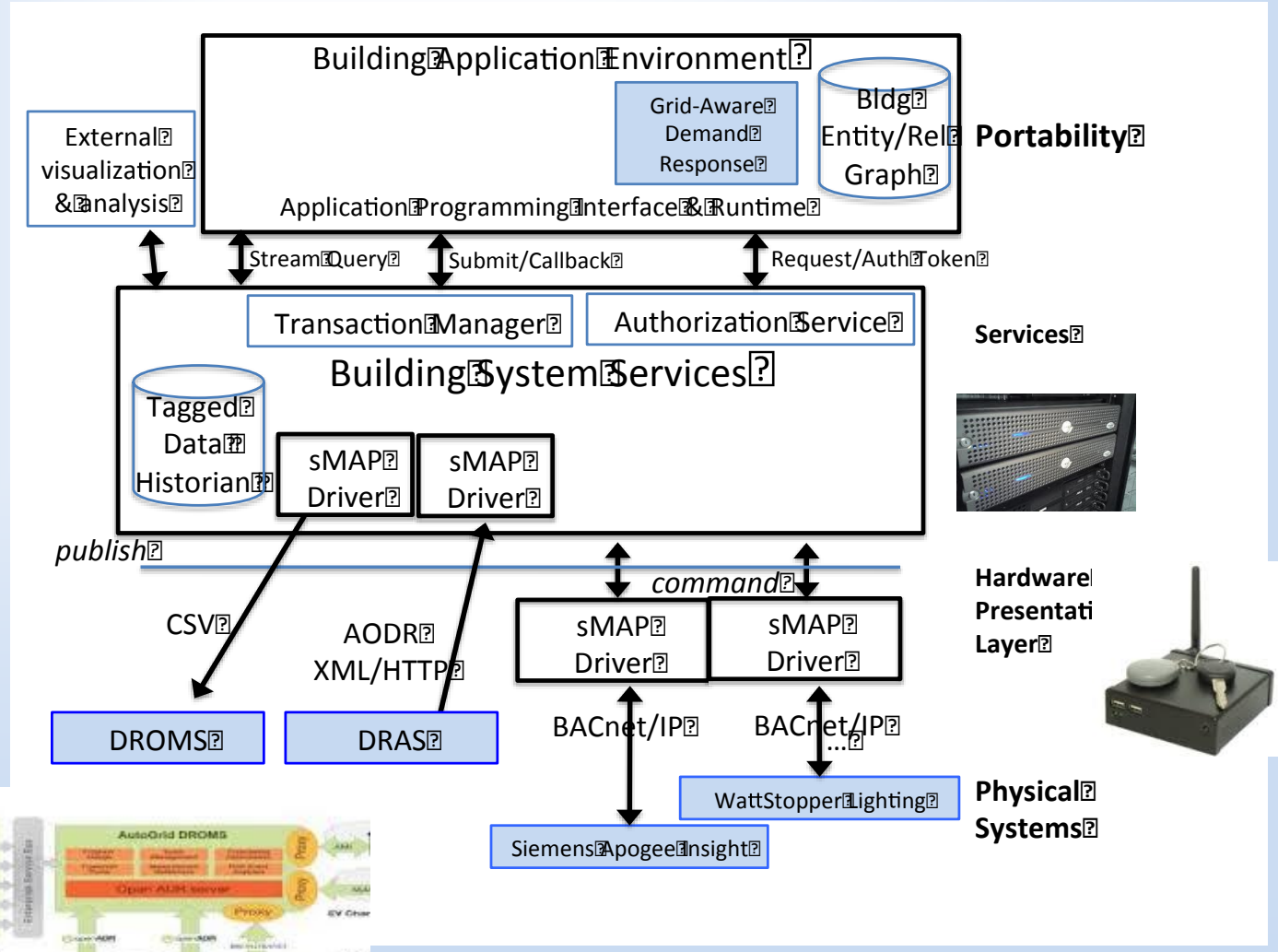
unit (S, **T**, **W**) → (S, **T**, **W**)

Operator	Description
`window(`*op*`)`	apply inner operator to windows in time
`sum(`*axis=0,1*`)`	compute the sum across time or streams
`units()`	convert input data to a canonical set of engineering units
`workday()`	filter data to return only data within a workday
`ewma(`*alpha=1.0*`)`	smooth data using an EWMA
`meter(`*period="day"*`)`	compute usage during a time period from a sequence of meter readings
`missing()`	filter rows where data are missing

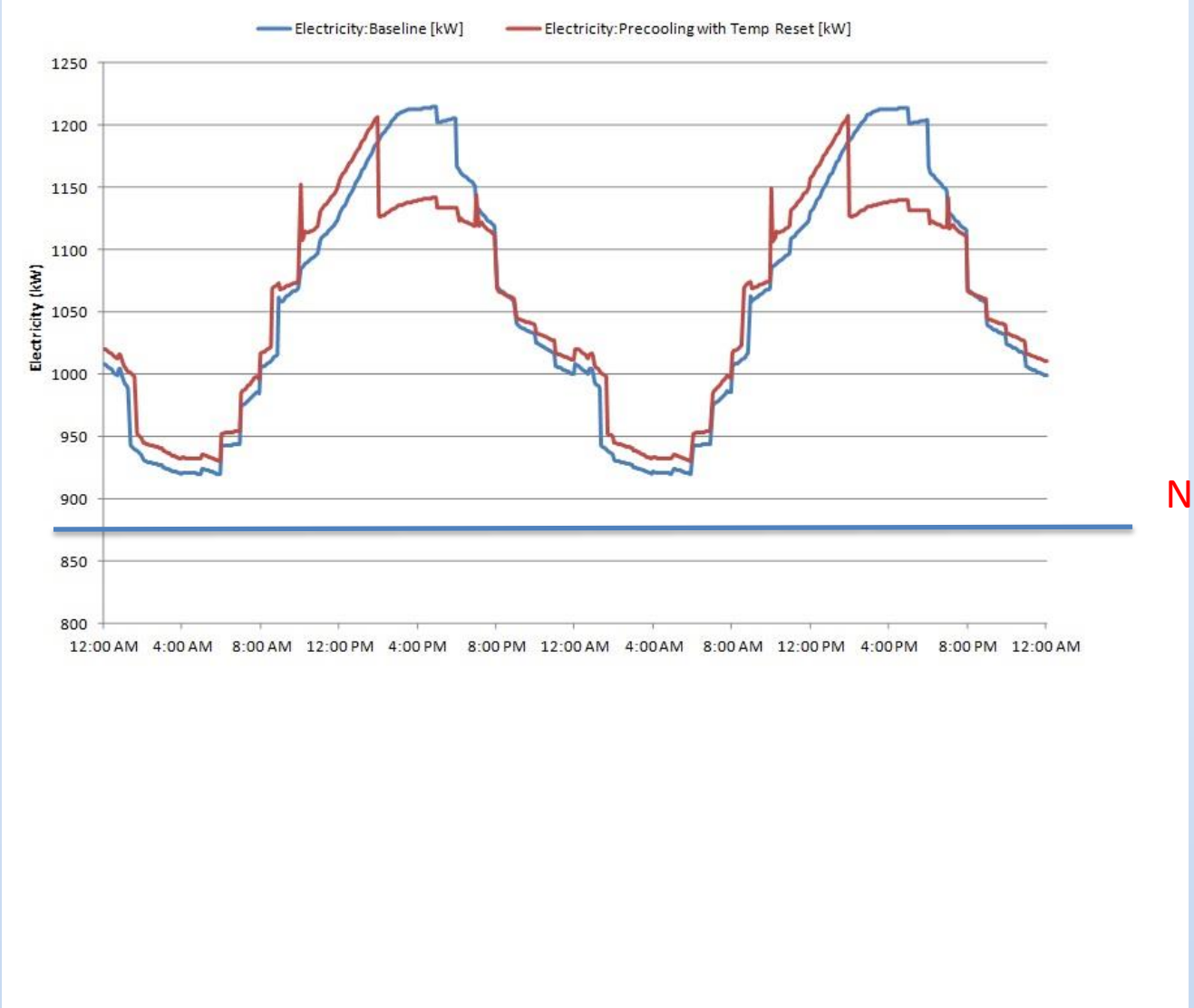
Basic BOSS in SDH



Auto-DR under BOSS

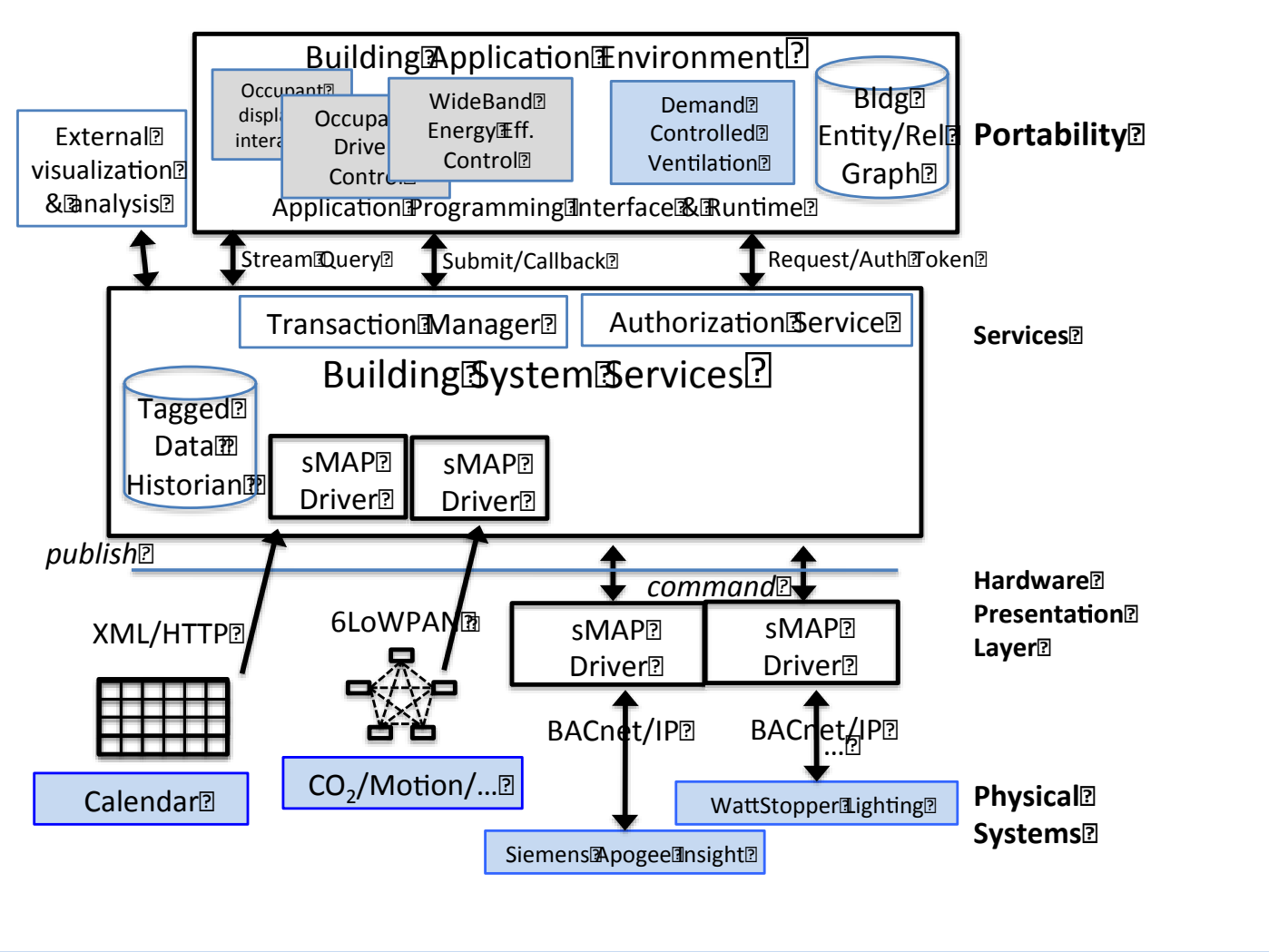


Whole building DR Simulation



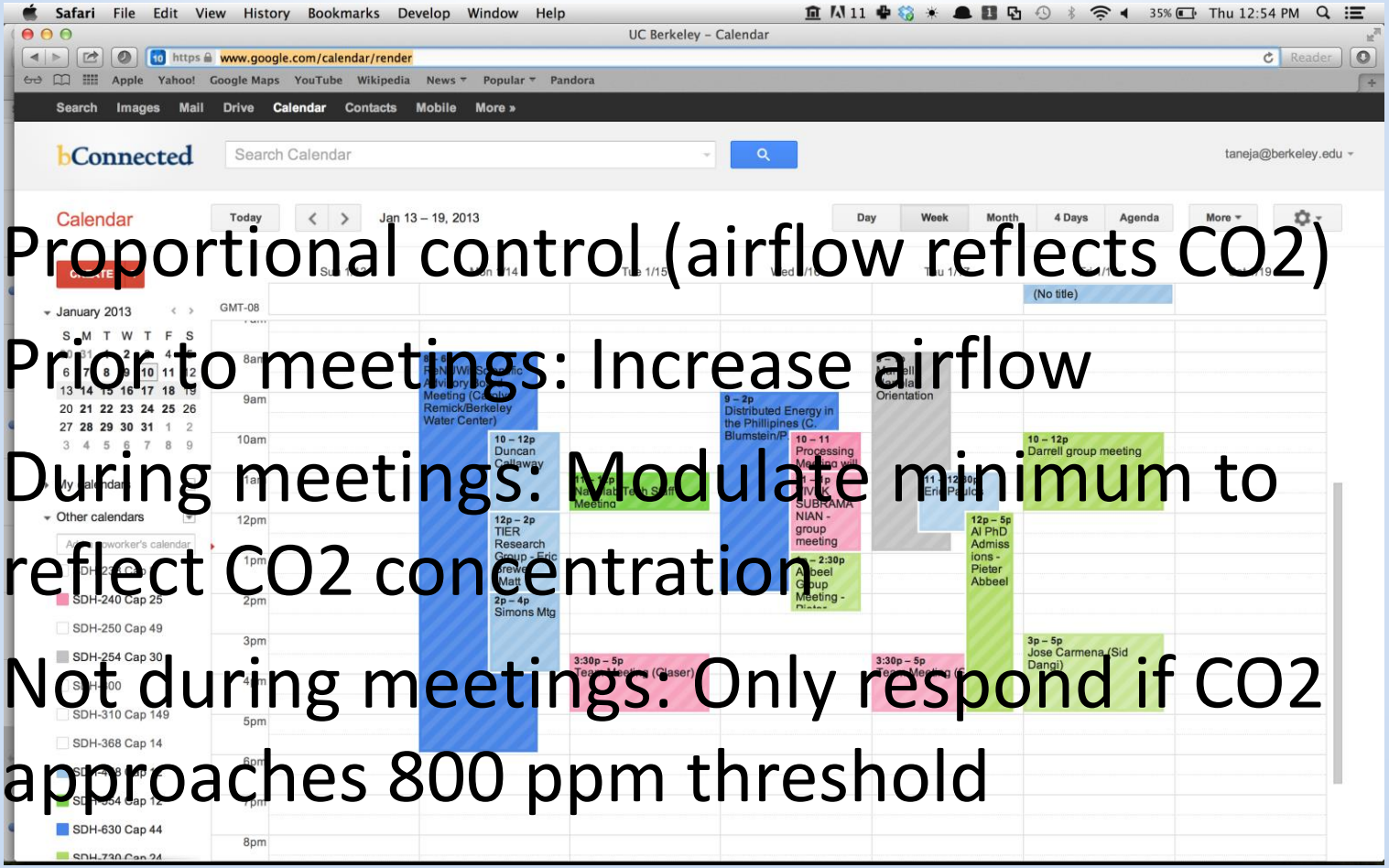
Nanofab

Integrating Advanced Networks



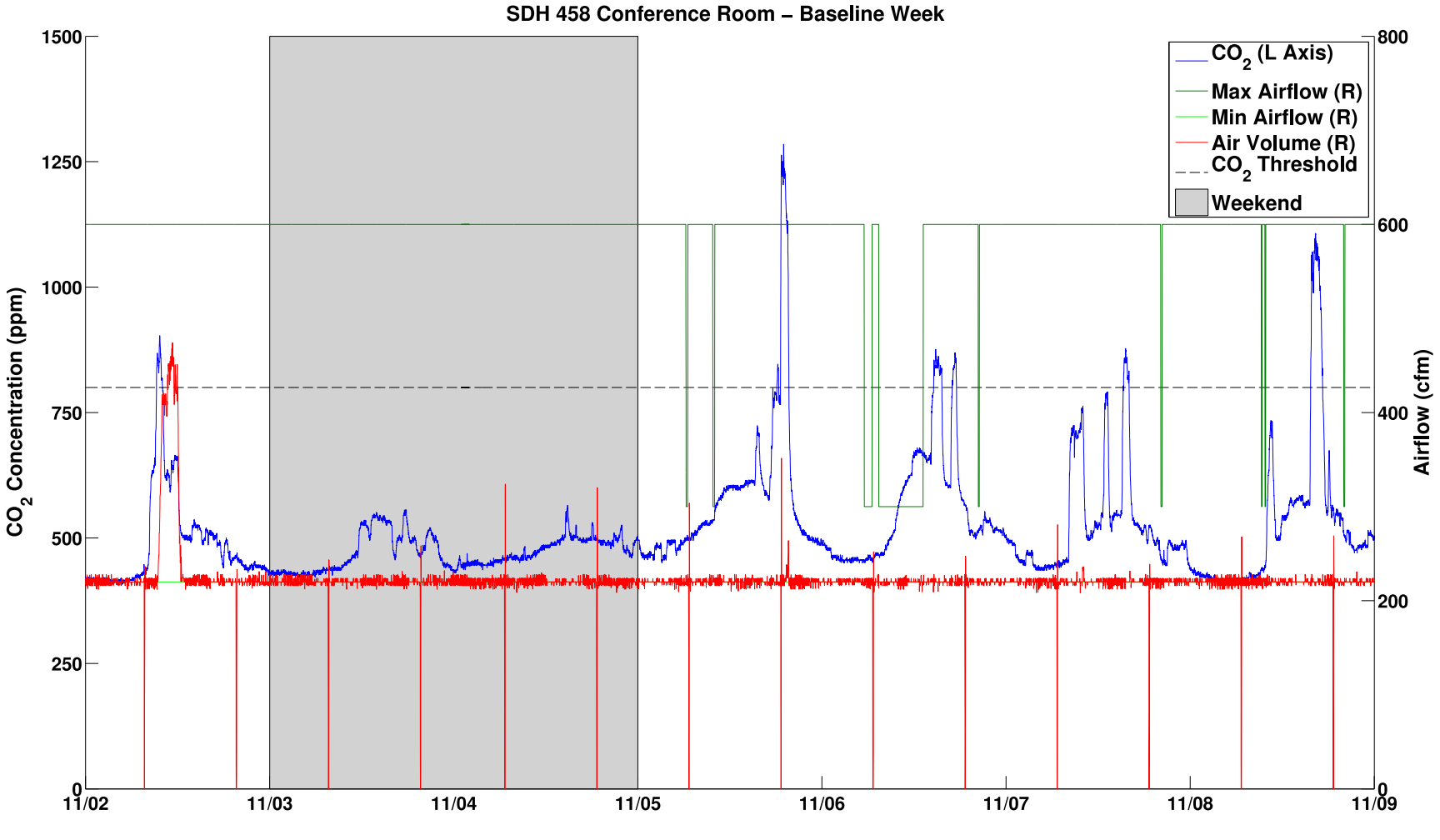
DCV Description

- Incorporate Google Calendar data

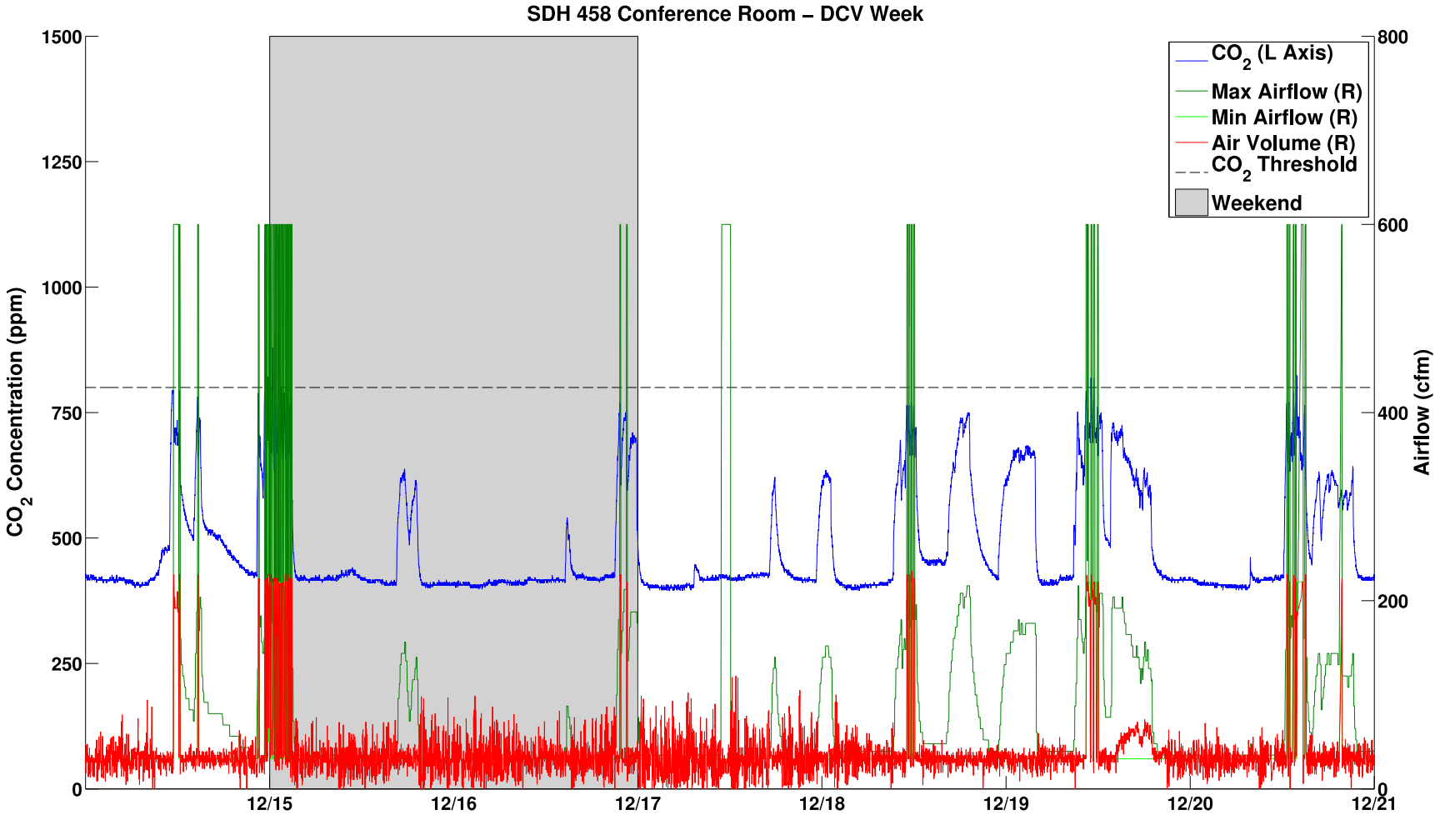


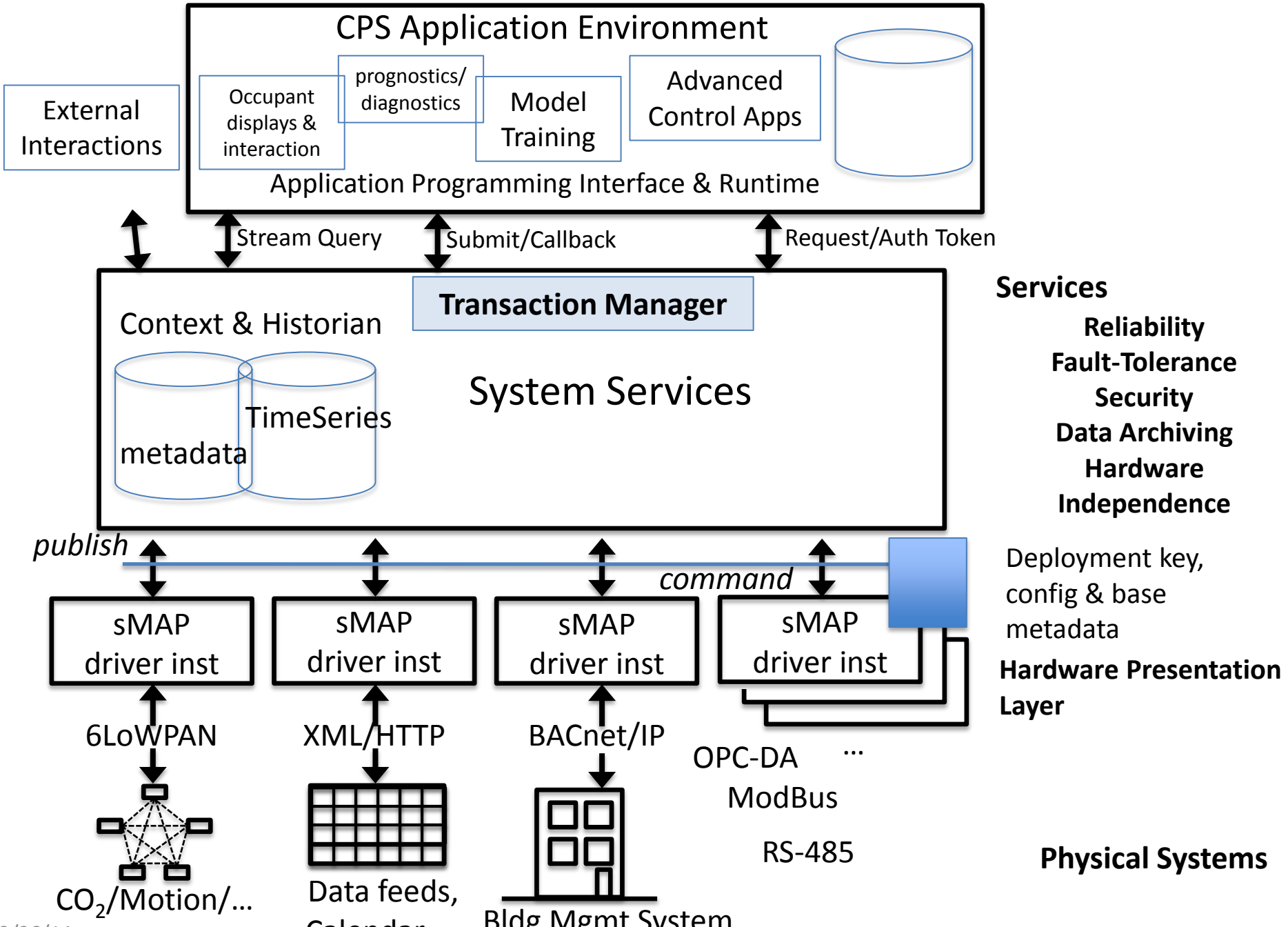
- Proportional control (airflow reflects CO2)
- Prior to meetings: Increase airflow
- During meetings: Modulate minimum to reflect CO2 concentration
- Not during meetings: Only respond if CO2 approaches 800 ppm threshold

Baseline Ventilation



Demand-Controlled Ventilation

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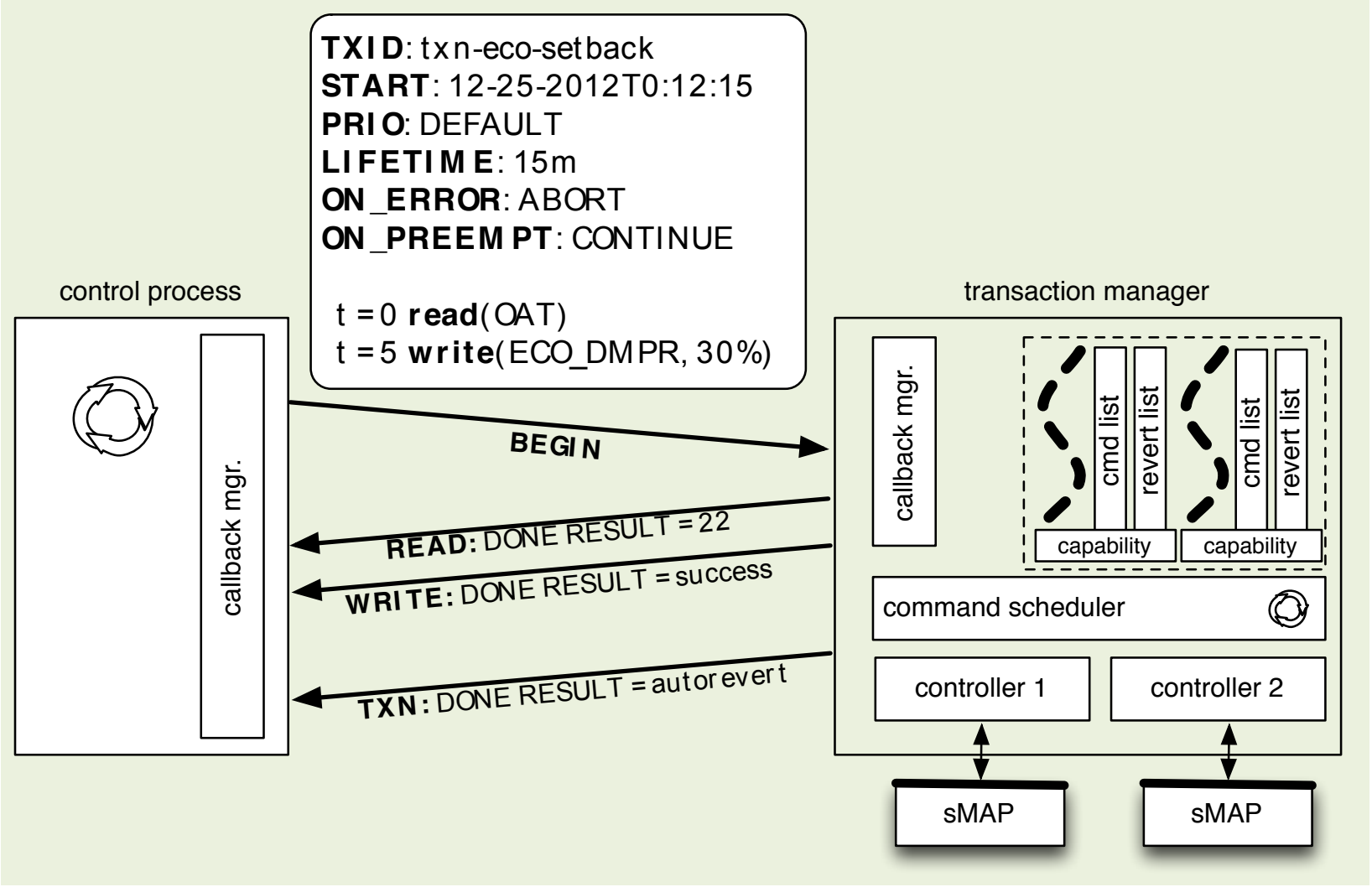
...
CO_2/Motion/...
Data feeds, Calendar, ...
Bldg Mgmt System
Services
Reliability
Fault-Tolerance
Security
Data Archiving
Hardware Independence
Deployment key, config & base metadata
Hardware Presentation Layer
Physical Systems

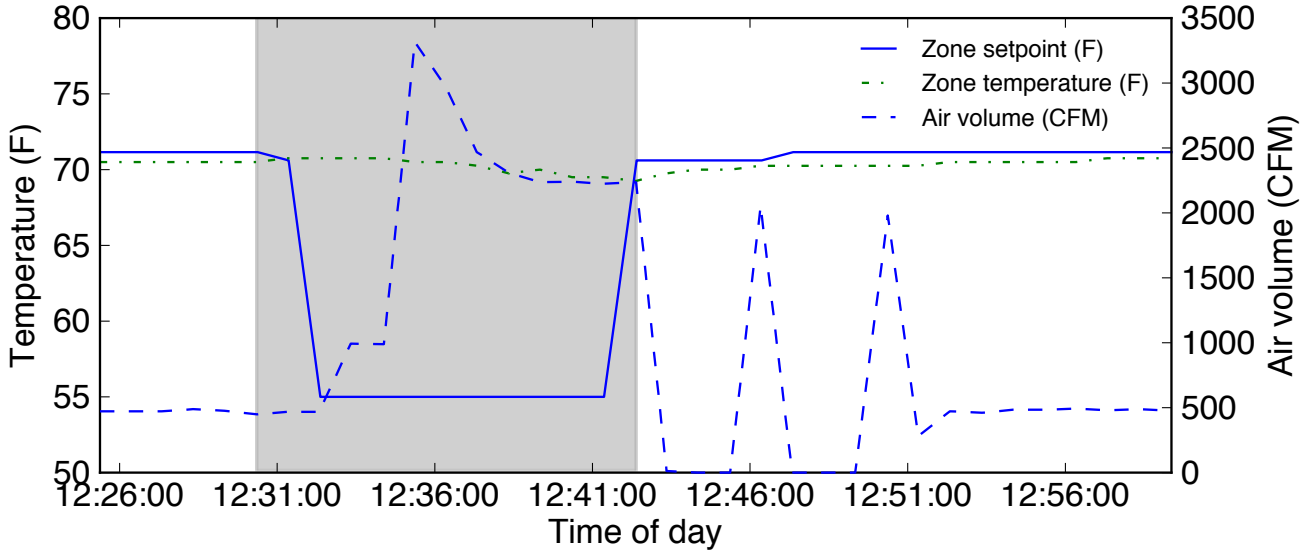
BOSS Transaction Manager

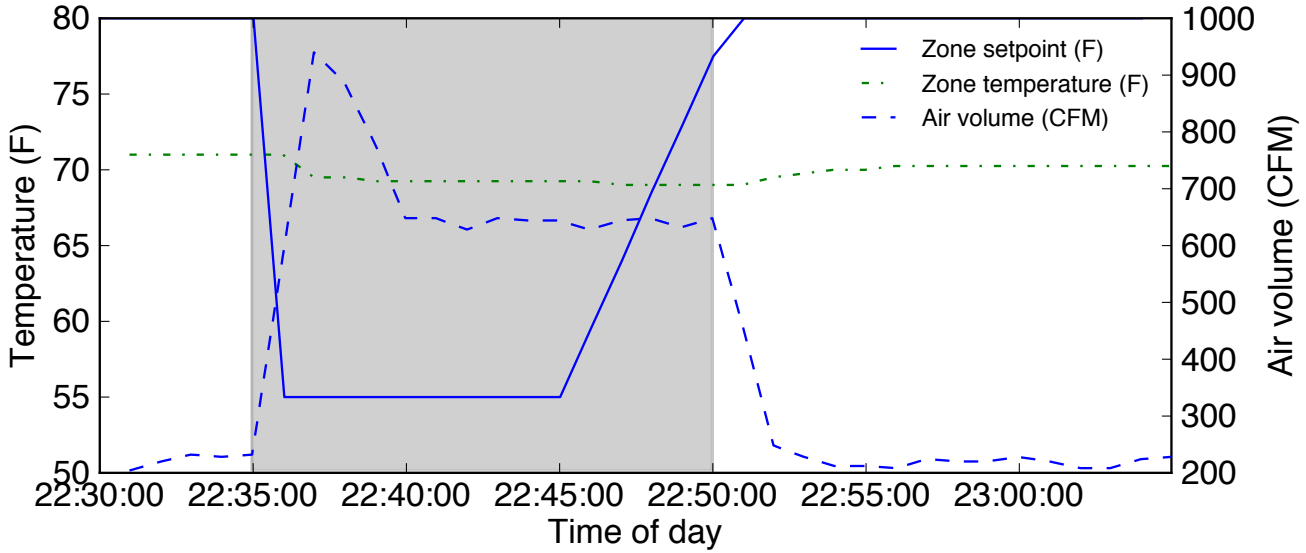
- Applications
  - coordinate control of multiple resources
    - normally operate independently
  - Or extend control beyond the building
    - Personalized control or grid responsive
  - Need consistency guarantee (all or nothing)
- Control transaction
  - Set of actions to be taken at a particular time
    - Operate at the level of “points”
  - Lease time
  - Revert sequence
  - Error Policy
- Multiple applications
  - Resolve potential conflicts

Example: DR

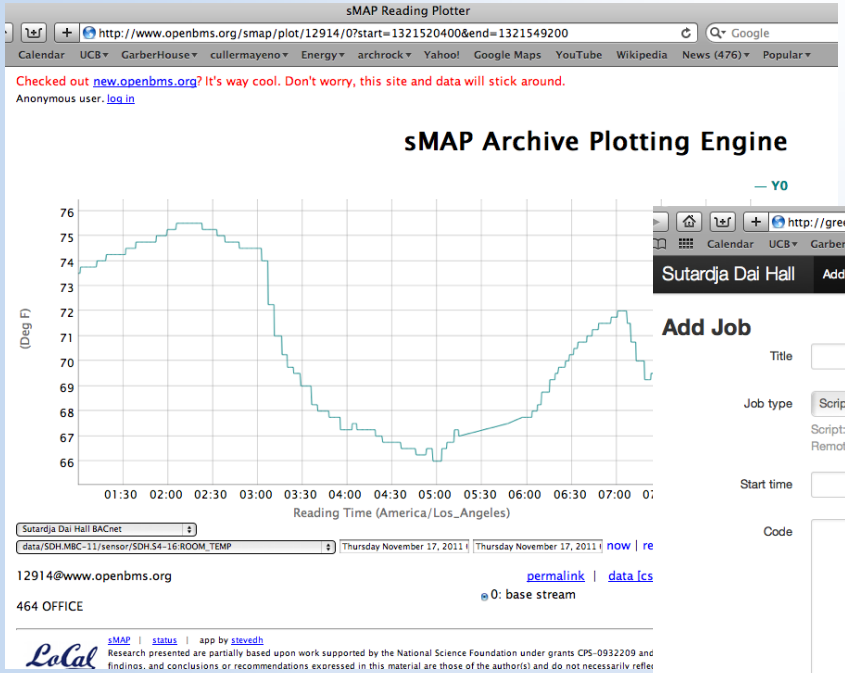

TXID: txn-eco-setback
START: 12-25-2012T0:12:15
PRIO: DEFAULT
LIFETIME: 15m
ON_ERROR: ABORT
ON_PREEMPT: CONTINUE
t = 0 read(OAT)
t = 5 write(ECO_DMPR, 30%)
control process
callback mgr.
transaction manager
callback mgr.
cmd list
revert list
cmd list
revert list
capability
capability
command scheduler
controller 1
controller 2
sMAP
sMAP
BEGIN
READ: DONE RESULT = 22
WRITE: DONE RESULT = success
TXN: DONE RESULT = autorevert

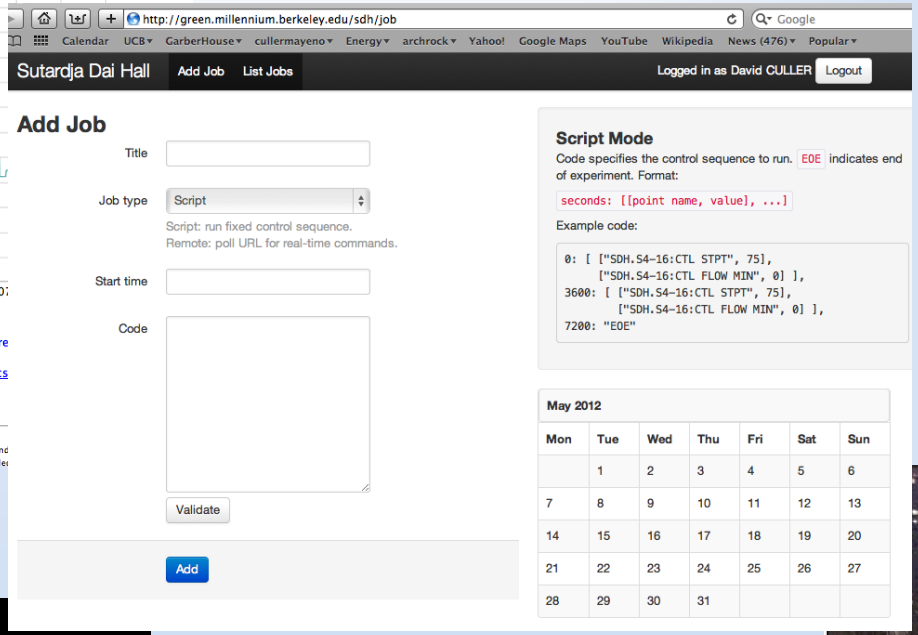
Transactions and physics …



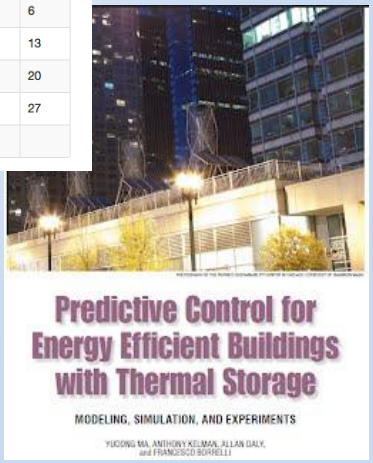


Live Step Test for Model Building

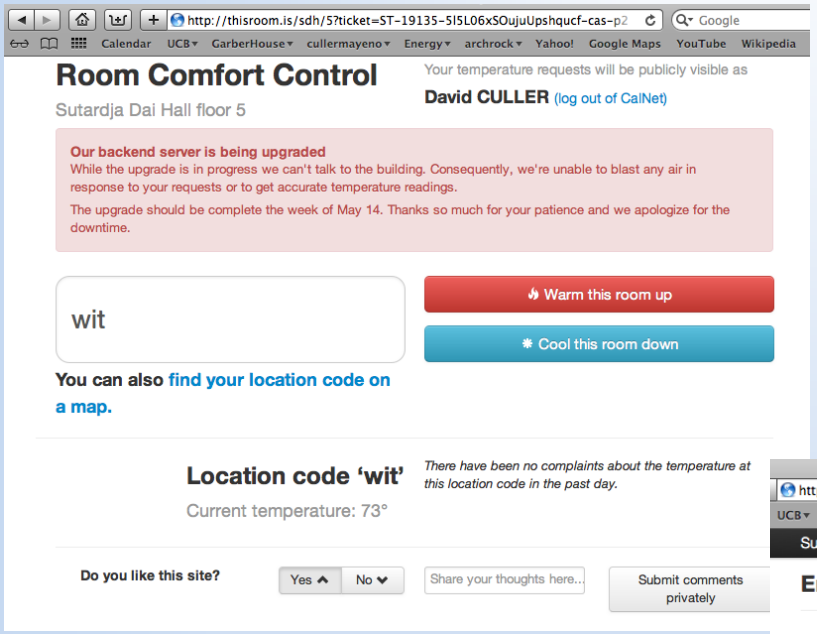


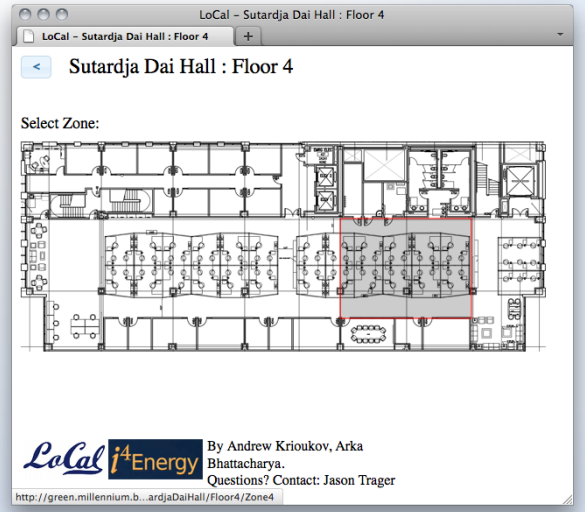


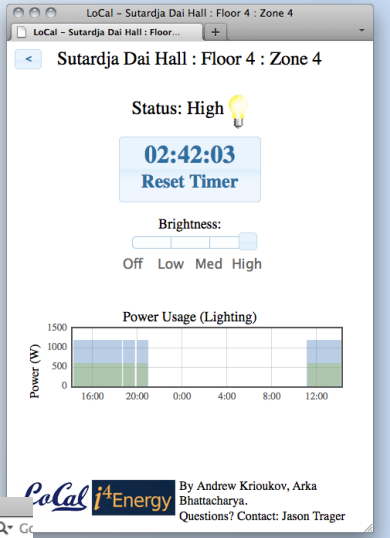
The control sequence as follows:
11/17/11 01:00:00 Set airflow to 200 , set reheat to 50
11/17/11 02:00:20 Set airflow to 200 , set reheat to 10
11/17/11 03:00:24 Set airflow to 1000 , set reheat to 0
11/17/11 04:00:35 Set airflow to 1000 , set reheat to 0
11/17/11 05:00:36 Set airflow to 300 , set reheat to 5
11/17/11 06:00:50 Set airflow to 300 , set reheat to 20
11/17/11 07:01:09 Set airflow to 750 , set reheat to 0

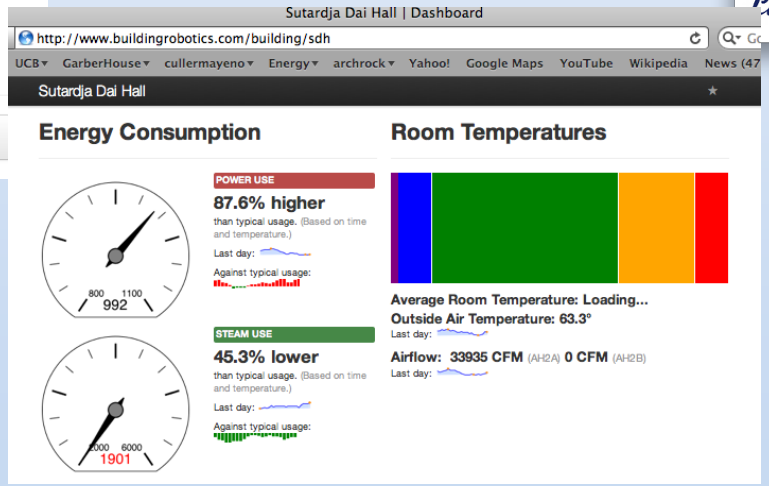


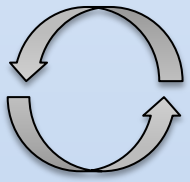
Personalized Environmental Control (and feedback)







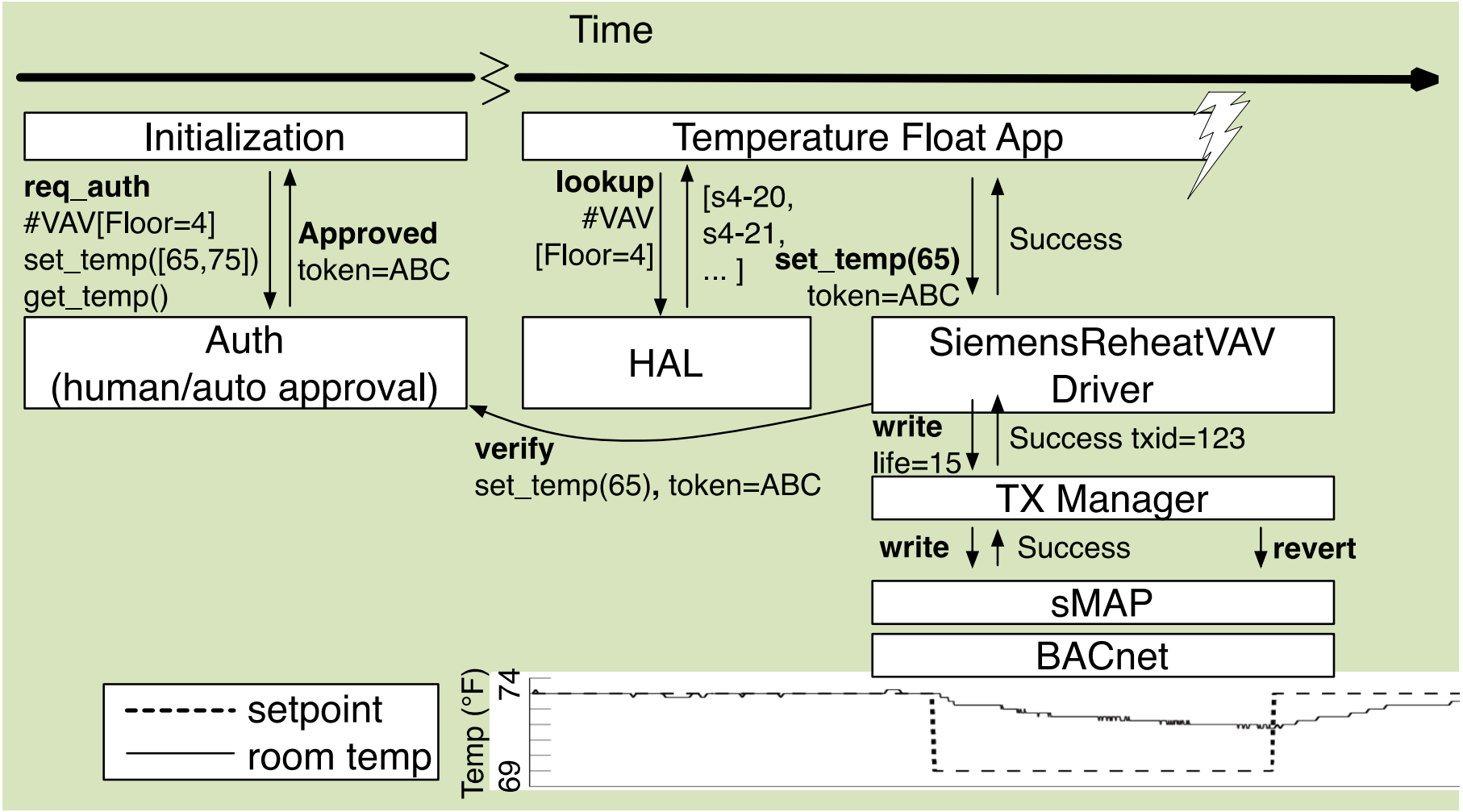




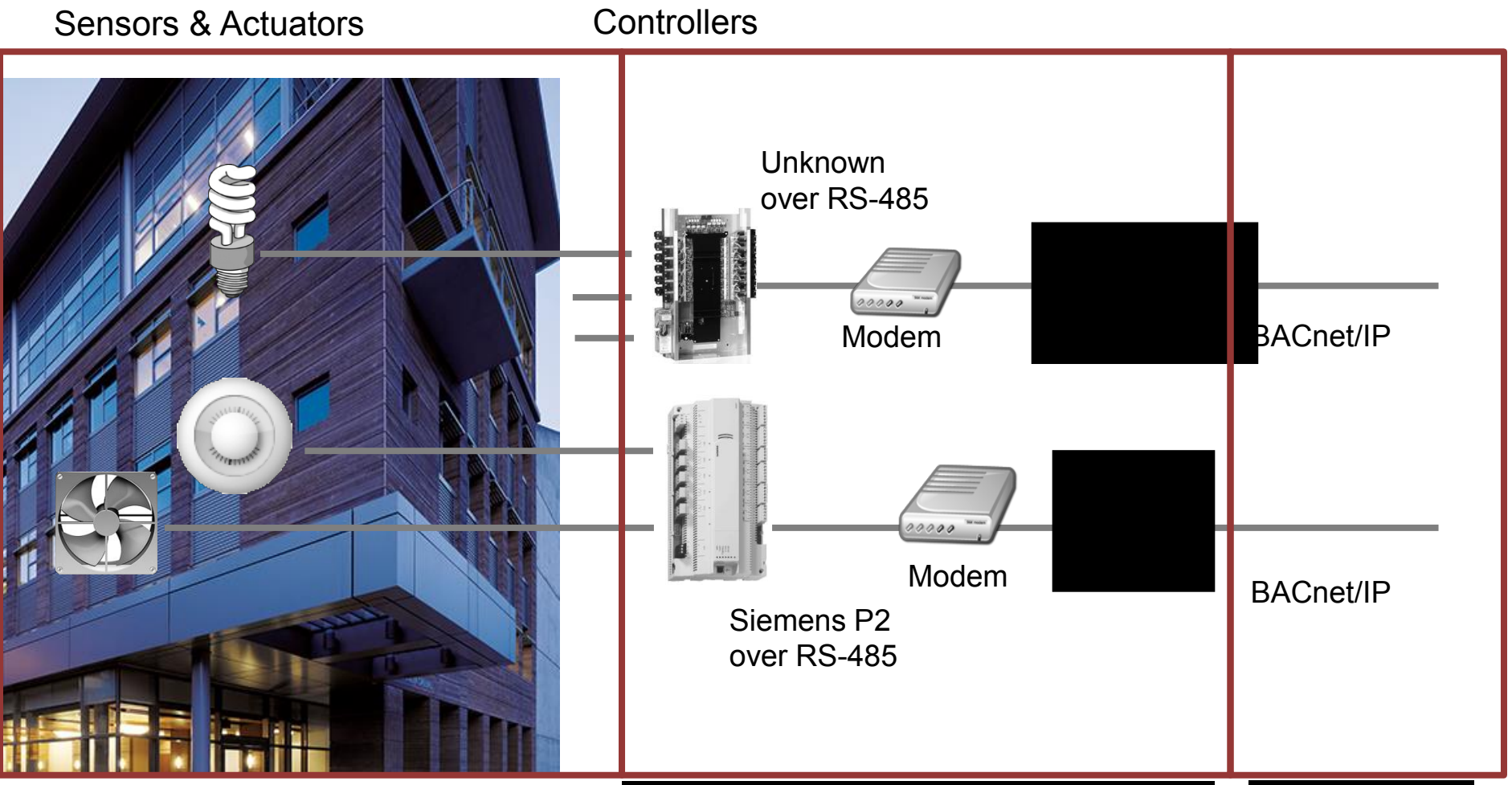
Authorization Service

- Tension between expressive access and building management safeguards
- Want access control at the semantic level of the operations
  - "rooms on 4th floor", "lights down to 50%"
- Checks on methods and points
- Two stage verification process
  - Register intent to access with potential arguments
    - Authorized through modeling or manual
  - Security and Safety checks at time of use

Blast App with Auth & Failure



Portability Challenges



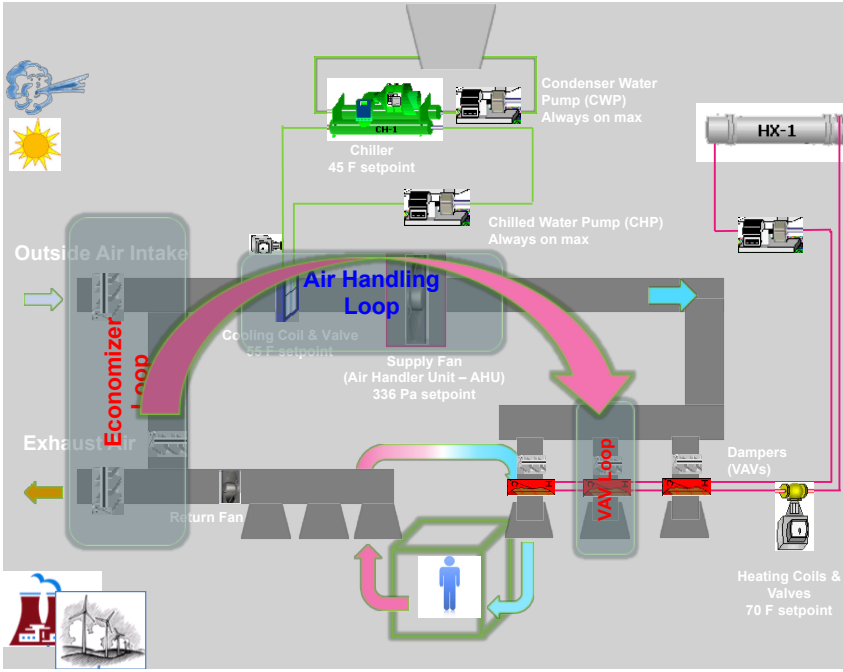
Different Building Design

Different Controller Config & Component Function

Different Protocols

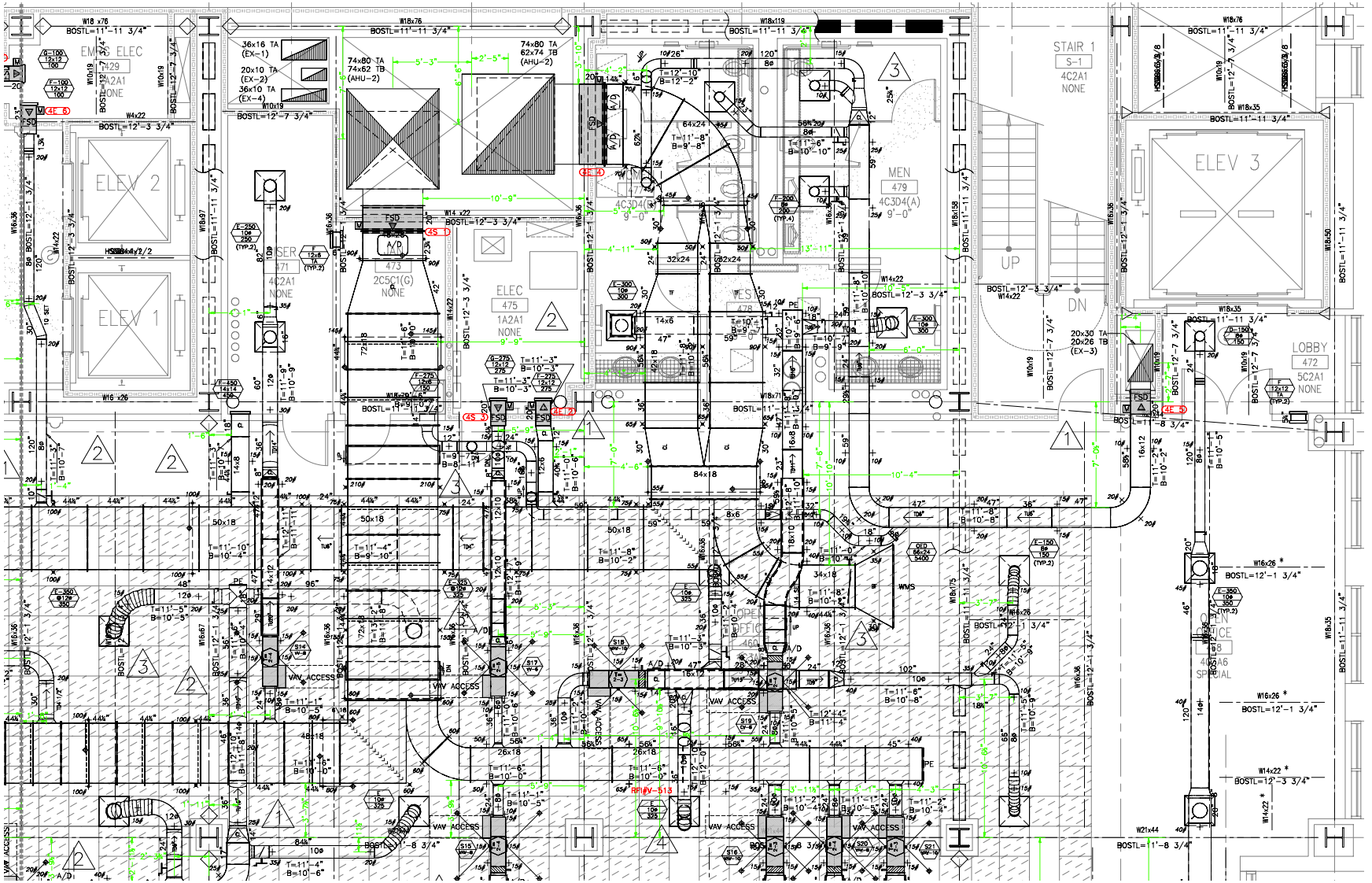
Whole-Building Optimization

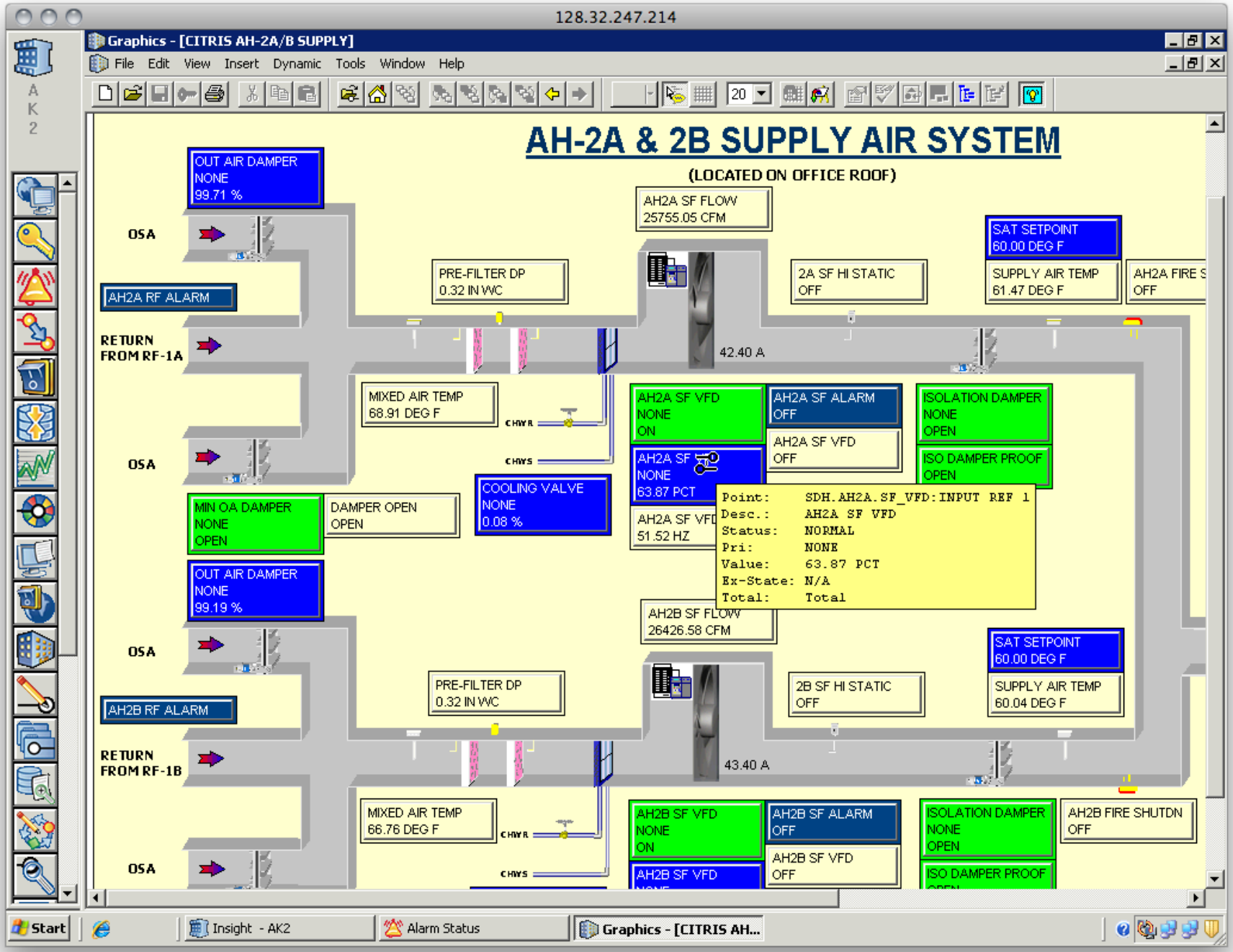
- ASHRAE & TITLE 24: “Minimum required ventilation rate of **outside air** is 15 *cfm* per occupant.”
- Typical: Conservatively assume minimum outside air intake and push *lots of air*
- Cross-system optimization:
  - Vary minimum ventilation rate based on fresh air intake.



Challenge: Portability

Buildings are custom designed


ELEV 2
ELEV 1
ELEV 3
ELEC
475
1A2A1
NONE
MEN
479
4C3D4(A)
9'-0"
STAIR 1
S-1
4C2A1
NONE
UP
DN
LOBBY
472
5C2A1
NONE
473
2C5C1(G)
NONE
478
A/D
FSD
VAV ACCESS
W16x26 *
BOSTL=12'-1 3/4"
W14x22 *
BOSTL=12'-3 3/4"
W21x44
BOSTL=11'-8 3/4"


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
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 %
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
AH2B SF VFD
NONE
ON
AH2B SF ALARM
OFF
AH2B SF VFD
OFF
ISOLATION DAMPER
NONE
OPEN
AH2B FIRE SHUTDN
OFF
ISO DAMPER PROOF
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
```

“CPS Assembly Language”

Today must understand:

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

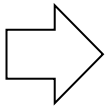
For ***each*** building

Goal: write once, run anywhere !!!

Portability : 2 key ideas

1) Approximate Semantic Queries

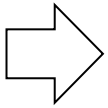
"WS86007:RELAY01"



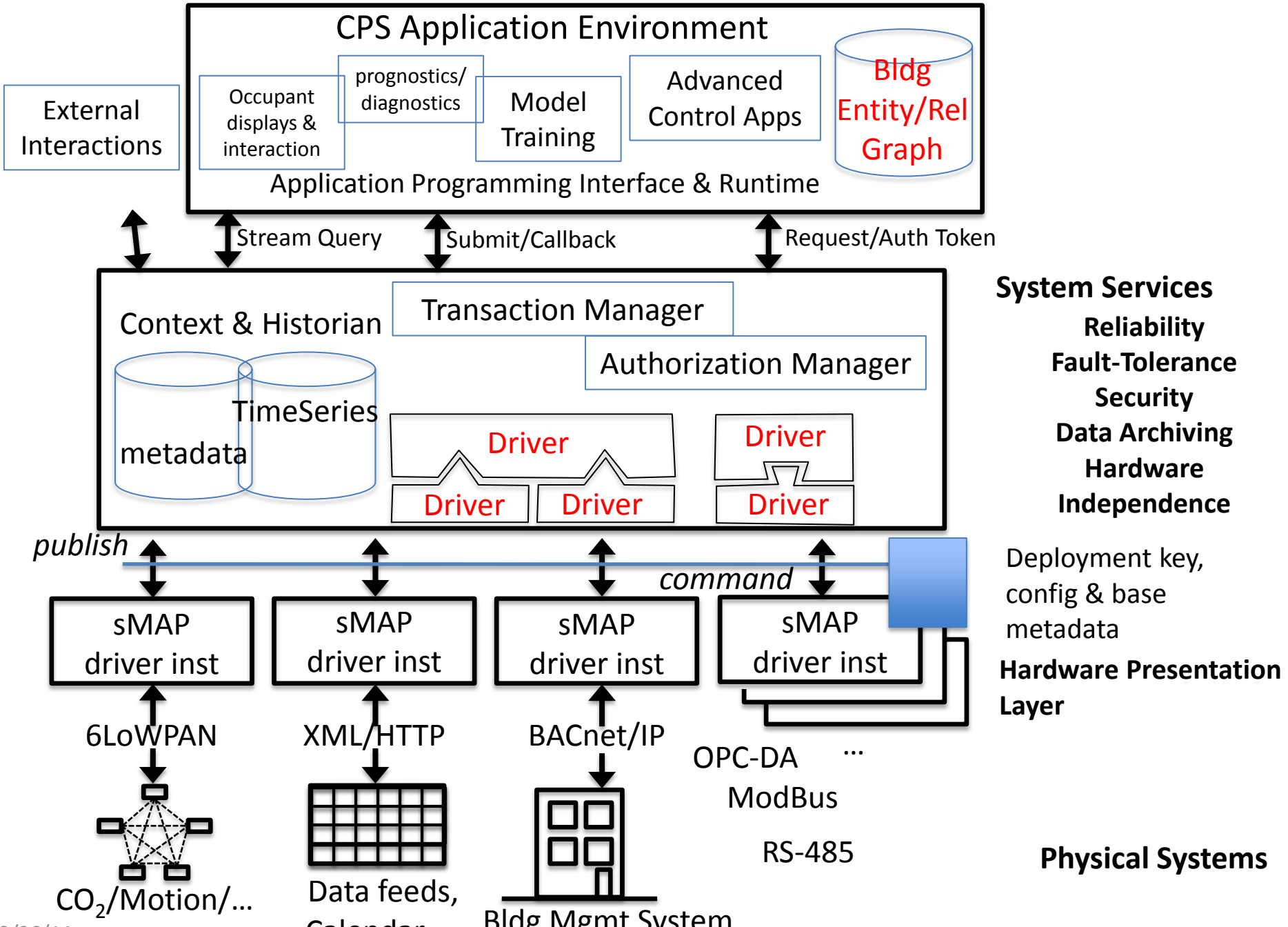
"Rooms on the top floor"

2) Hierarchical drivers

```
bacnet.write(
  device-instance = 86007,
  object-type = OBJECT_BINARY_INPUT,
  object-instance = 1,
  property = PROP_PRESENT_VALUE,
  priority = 16,
  index = 0,
  tag = TAG_ENUMERATED,
  value = 1);
```

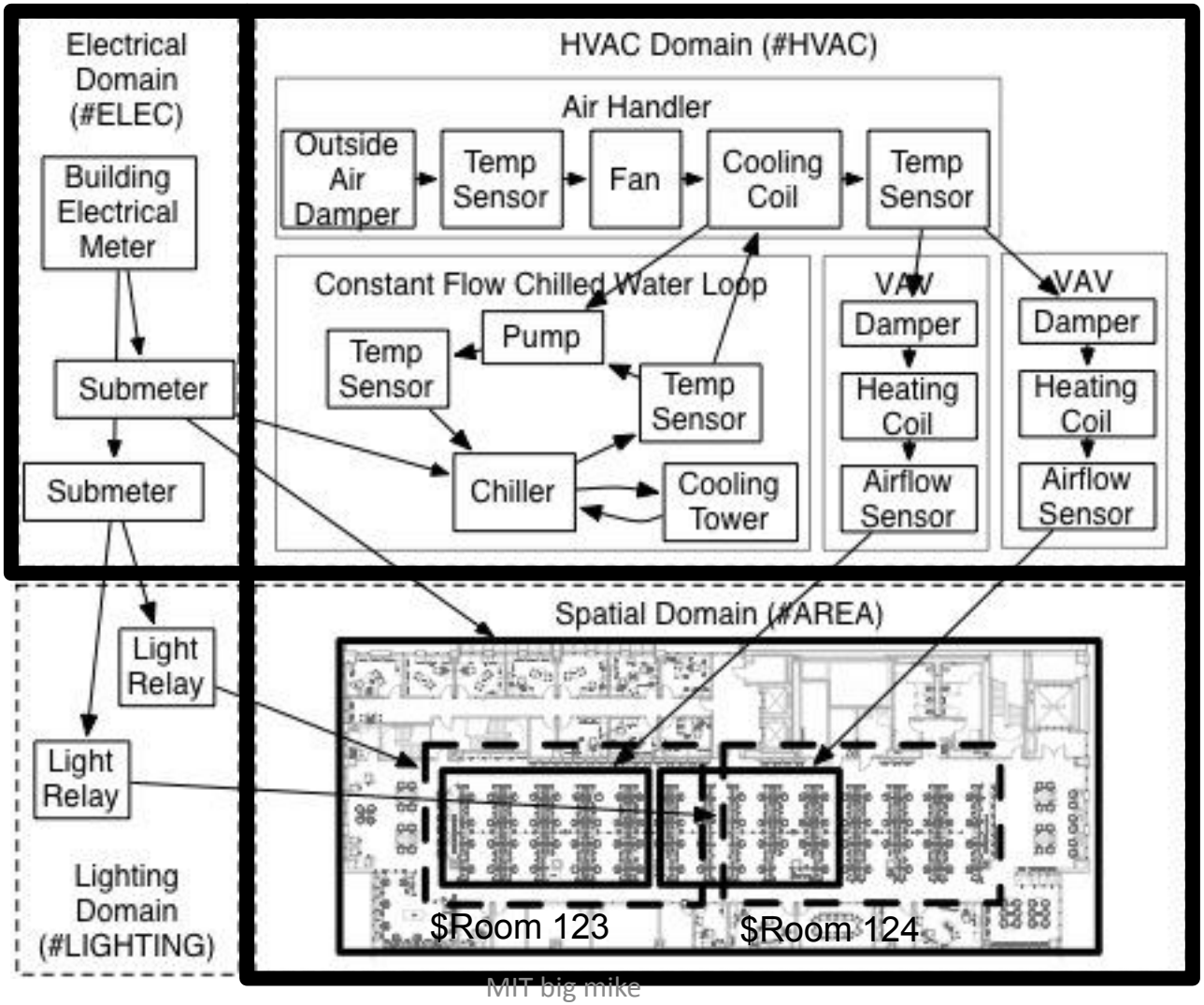


light.set_brightness(100);


CPS Application Environment
External Interactions
Occupant displays & interaction
prognostics/ diagnostics
Model Training
Advanced Control Apps
Bldg Entity/Rel Graph
Application Programming Interface & Runtime
Stream Query
Submit/Callback
Request/Auth Token
Context & Historian
Transaction Manager
Authorization Manager
TimeSeries
metadata
Driver
Driver
Driver
Driver
Driver
publish
command
sMAP driver inst
sMAP driver inst
sMAP driver inst
sMAP driver inst
6LoWPAN
XML/HTTP
BACnet/IP
OPC-DA
ModBus
RS-485
...
CO_2/Motion/...
Data feeds, Calendar, ...
Bldg Mgmt System
System Services
Reliability
Fault-Tolerance
Security
Data Archiving
Hardware Independence
Deployment key, config & base metadata
Hardware Presentation Layer
Physical Systems

Apps Navigate Building Model

#LIGHT <- #AREA -> $Room 123



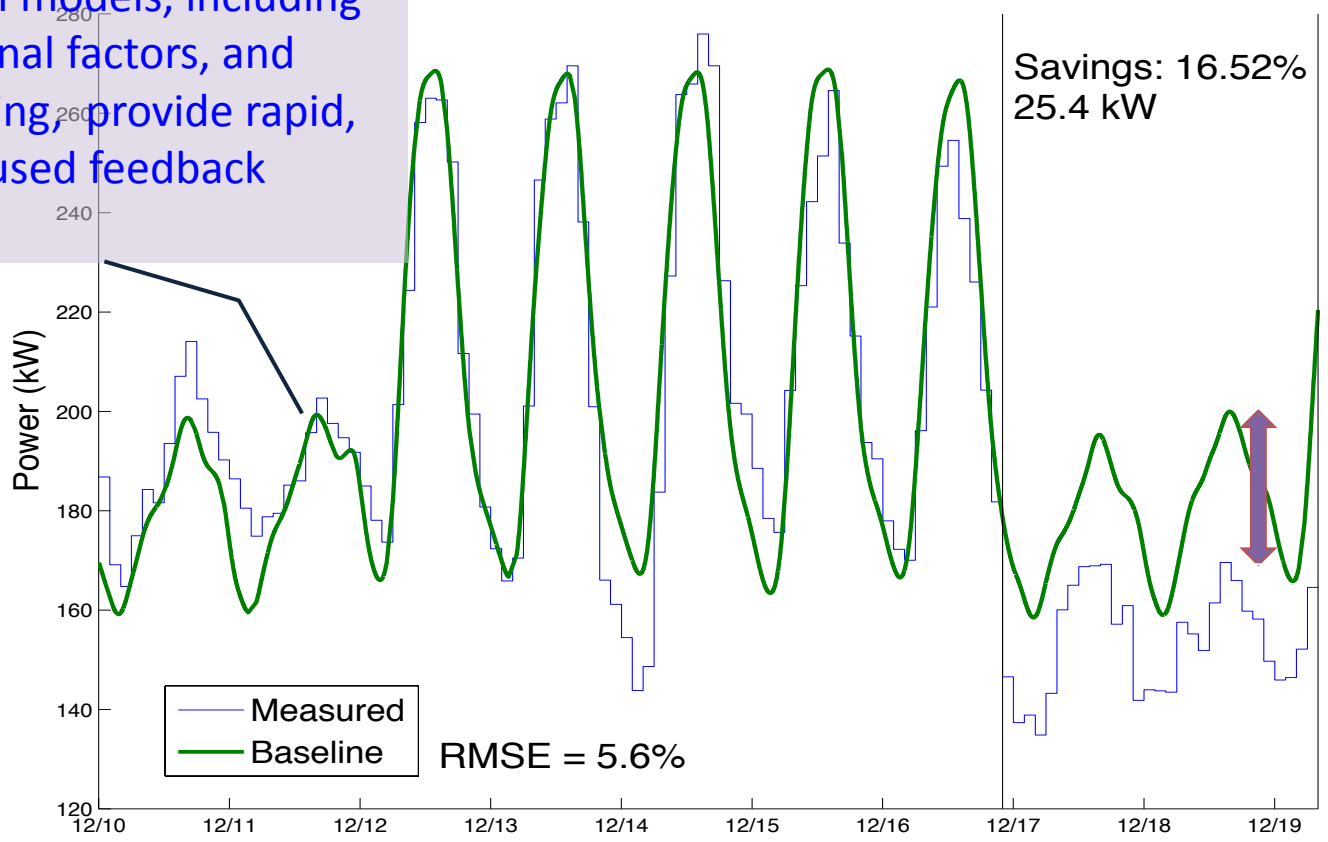
Programming a building app …

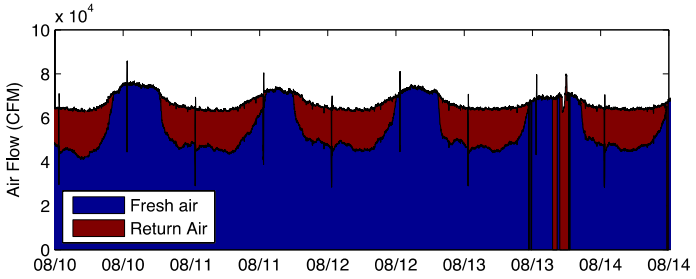
```
#Using BAS
import appstack
api = appstack.Appstack()
ah_dampers = api('#OUT_AIR_DMP > #AH')
for dmp in ah_dampers:
  for vav in api('#VAV < $%s' % dmp.name):
    vav.set_min_airflow(vav.min_fresh_air() / dmp.get_percent_open())
```

```
#Using direct BACnet
import bacnet
#damper setpoints for each outside a
oad_to_dmp_stpts = {
  'SDH.PXCM-01 SDH.AH1A_OAD': [
    'SDH.PXCM-04 SDH.S1-20:CTL FLOW MIN',
    'SDH.PXCM-04 SDH.S1-19:CTL FLOW MIN',
    ...],
  'SDH.PXCM-01 SDH.AH1B_OAD': [
    'SDH.PXCM-11 SDH S2-04:CTL FLOW MIN',
    ...],
  'SDH.PXCM-08 SDH.AH2A_OAD':[
    'SDH.PXCM-11 SDH.S4-03:CTL FLOW MIN',
    ...]
  }
for oad in oad_to_dmp_stpts.keys():
  device = bacnet.find(name=oad)
  oad_airflow = bacnet.read_prop(device, object_type=bacnet.OBJECT_ANALOG_OUTPUT, \
    instance_number=device.instance_number, property=bacnet.PROP_PRESENT_VALUE)
  for dmp in oad_to_dmp_stpts[oad]:
    damper = bacnet.find(name=dmp)
    old_setpoint = bacnet.read_prop(device, object_type=bacnet.OBJECT_ANALOG_OUTPUT, \
      instance_number=damper.instance_number, property=bacnet.PROP_PRESENT_VALUE)
    new_setpoint = old_setpoint / oad_airflow
    bacnet.write_prop(device, object_type=bacnet.OBJECT_ANALOG_OUTPUT,\
      instance_number=damper.instance_number, property=bacnet.PROP_PRESENT_VALUE, \
      value=new_setpoint, value_type=bacnet.BACNET_APPLICATION_TAG_REAL)
```

Holistic HVAC optimization

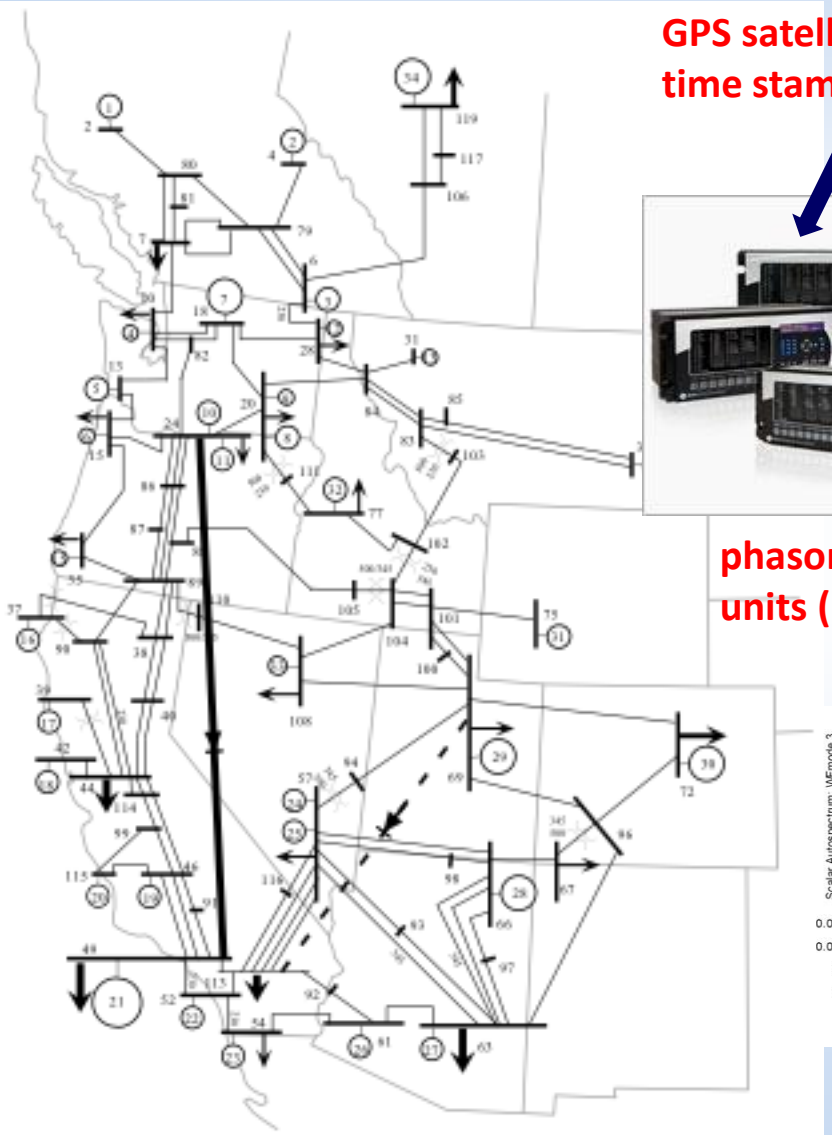
Empirical models, including external factors, and monitoring, provide rapid, focused feedback





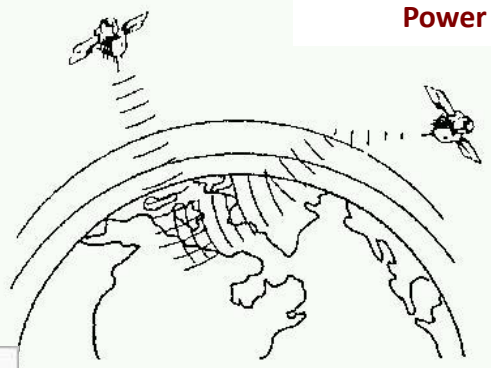
Dynamically set economizer, supply air temp, min airflow, reheat

Synchrophasors

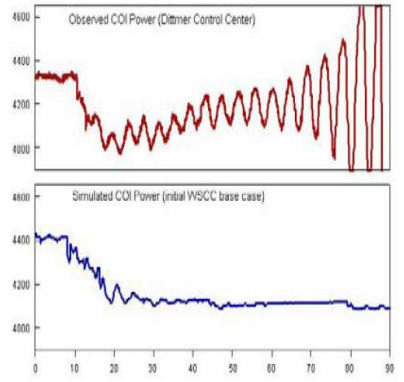


GPS satellite time stamp

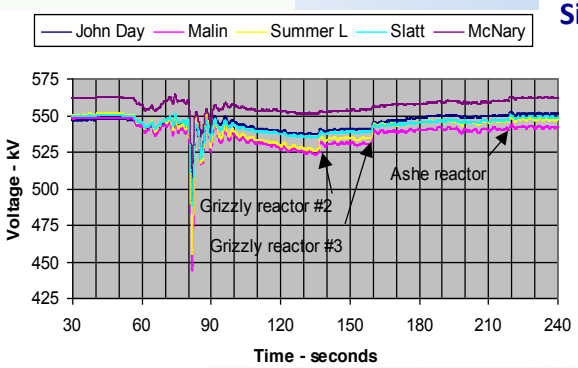
phasor measurement units (PMUs)

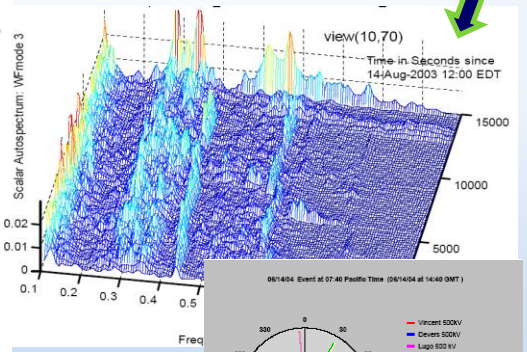


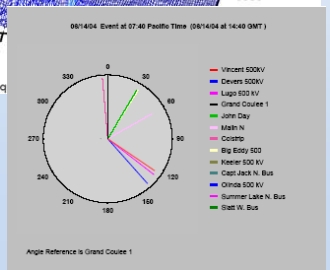
Observed COI Power

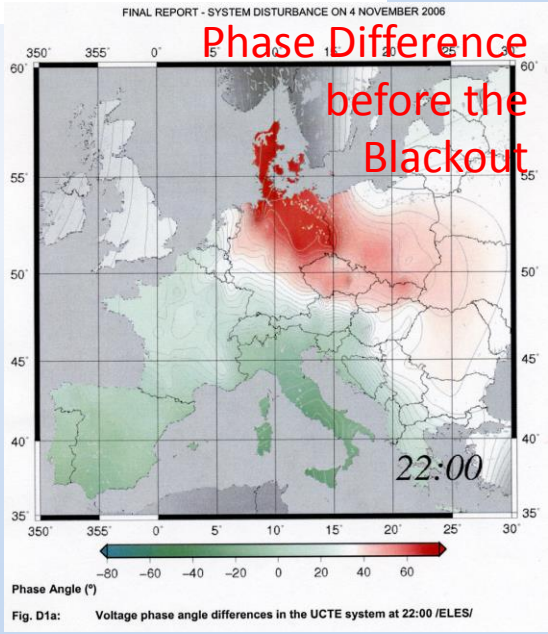


Simulated COI Power

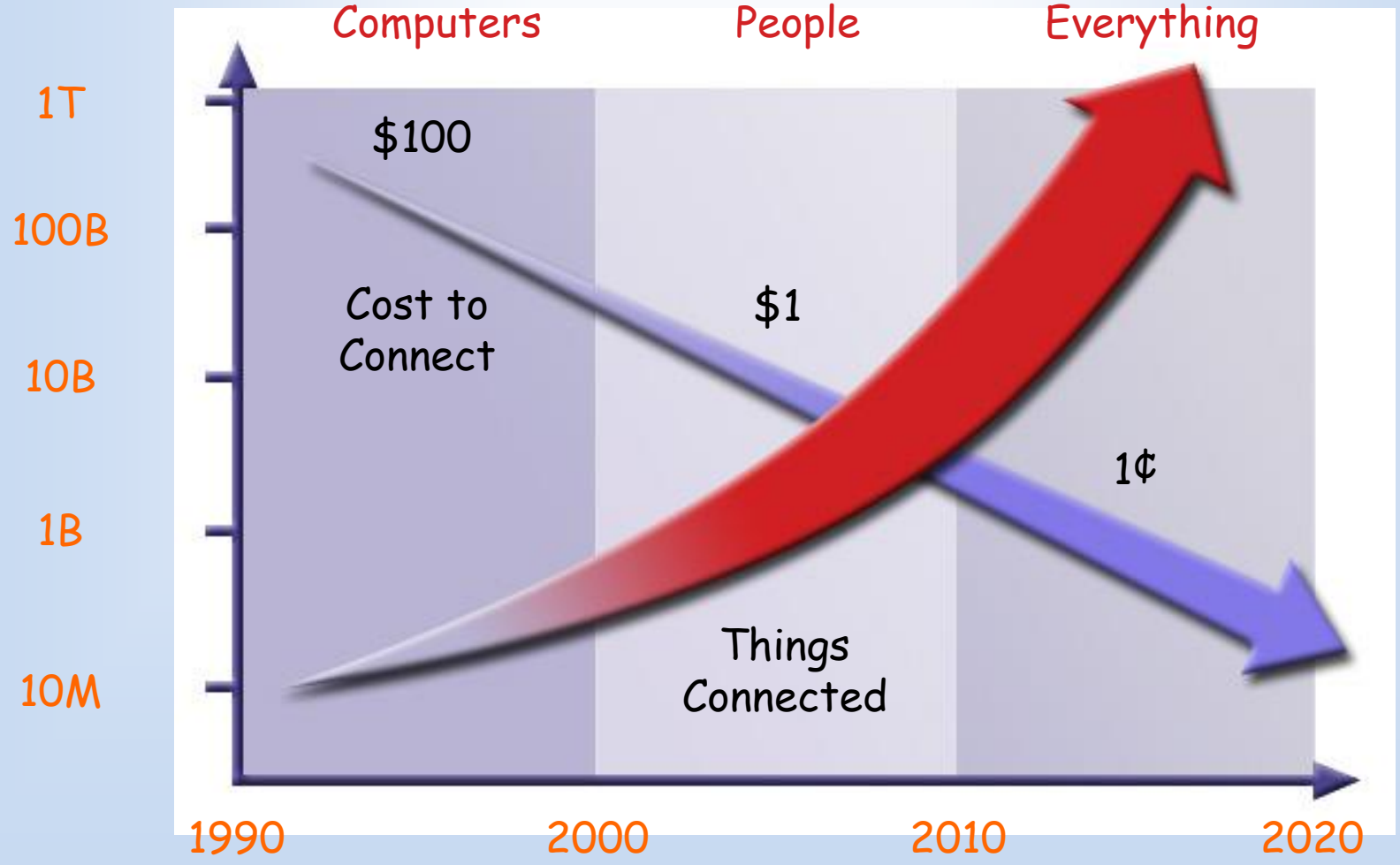








The Revolution



Oct 2012


telstra.net
sprintlink.net
att.net
other ISPs
bbnplanet.net
ans.net
alter.net
eu.net
Burch/Cheswick map of the Internet
showing the major ISPs. Data collected 28 June 1999
http://www.cheswick.com/map/index.html
Copyright (C) 1999, Lucent Technologies

PHILIPS
hue

2014


SUNROLED
CE RoHS


COOPER Wiring Devices
Enjoy Wireless Plug-In Lighting or Appliance Control
Cooper Wiring Devices RF9505-TDS ASPIRE RF 15A Split Control Duplex Receptacle - Desert Sand


WiFi
LED CONTROLLER


RGB LED Controller
WiFi
HOTOOK
CE


Add Z-Wave Control to Your Incandescent or Fluorescent Appliances
GE 45605 Z-Wave Wireless Lighting Control Duplex Receptacle

2013

2014


Honeywell


70.0
Solidyne


70
COOL
NETWORK thermostat


ROOM TEMPERATURE
67
70
AUTO MODE
AUTO FAN
ON/OFF
F/C


AKE
25.0°C


55° 65° 72° 75° 85° 95°
72°
Current
Cool
Fan Auto
ecobee

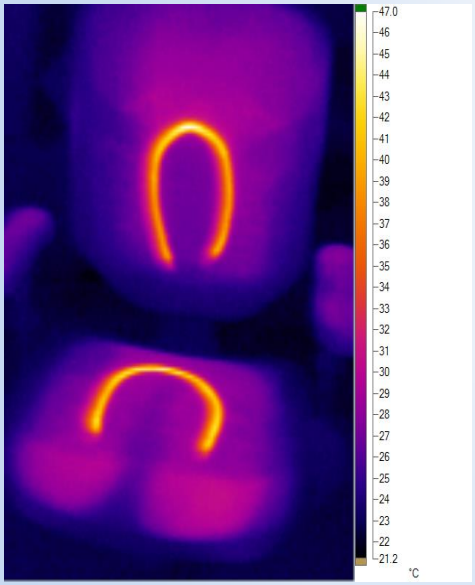

72

2014 Will Be The Year Of Wearable Technology

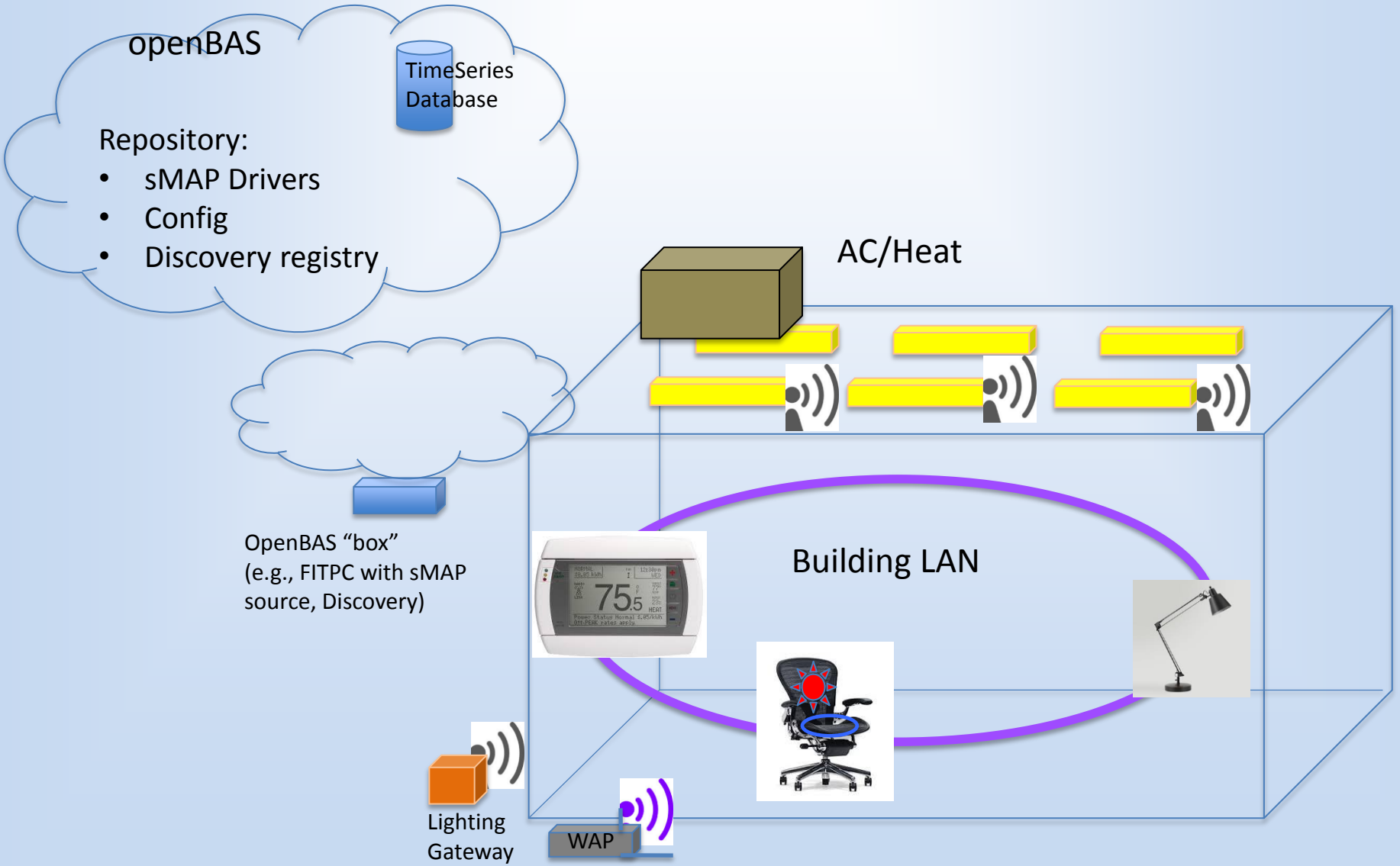

BARRINGTON

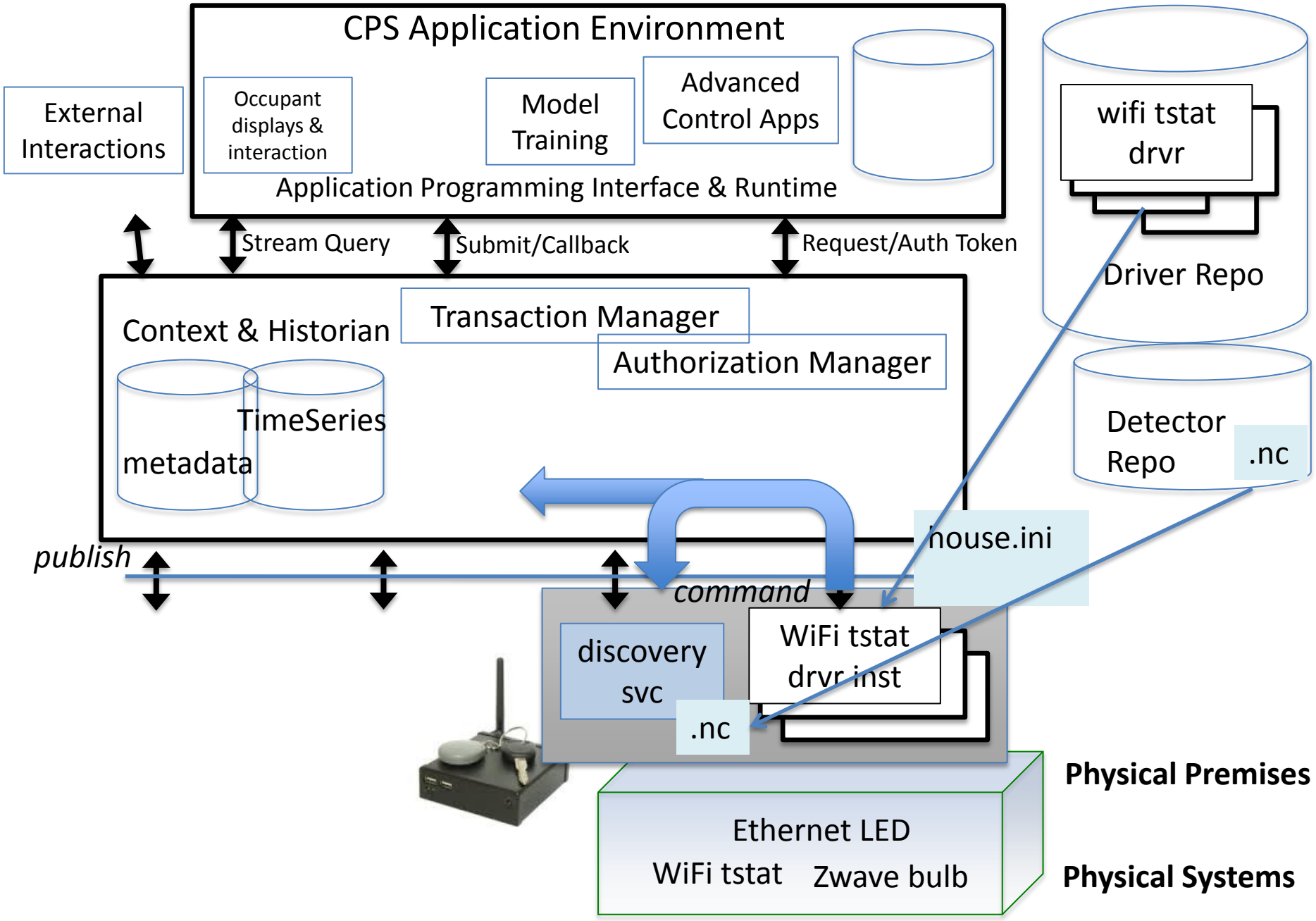

OFF
10
9
8
7
6
5
4
3
2
1
COMFORT

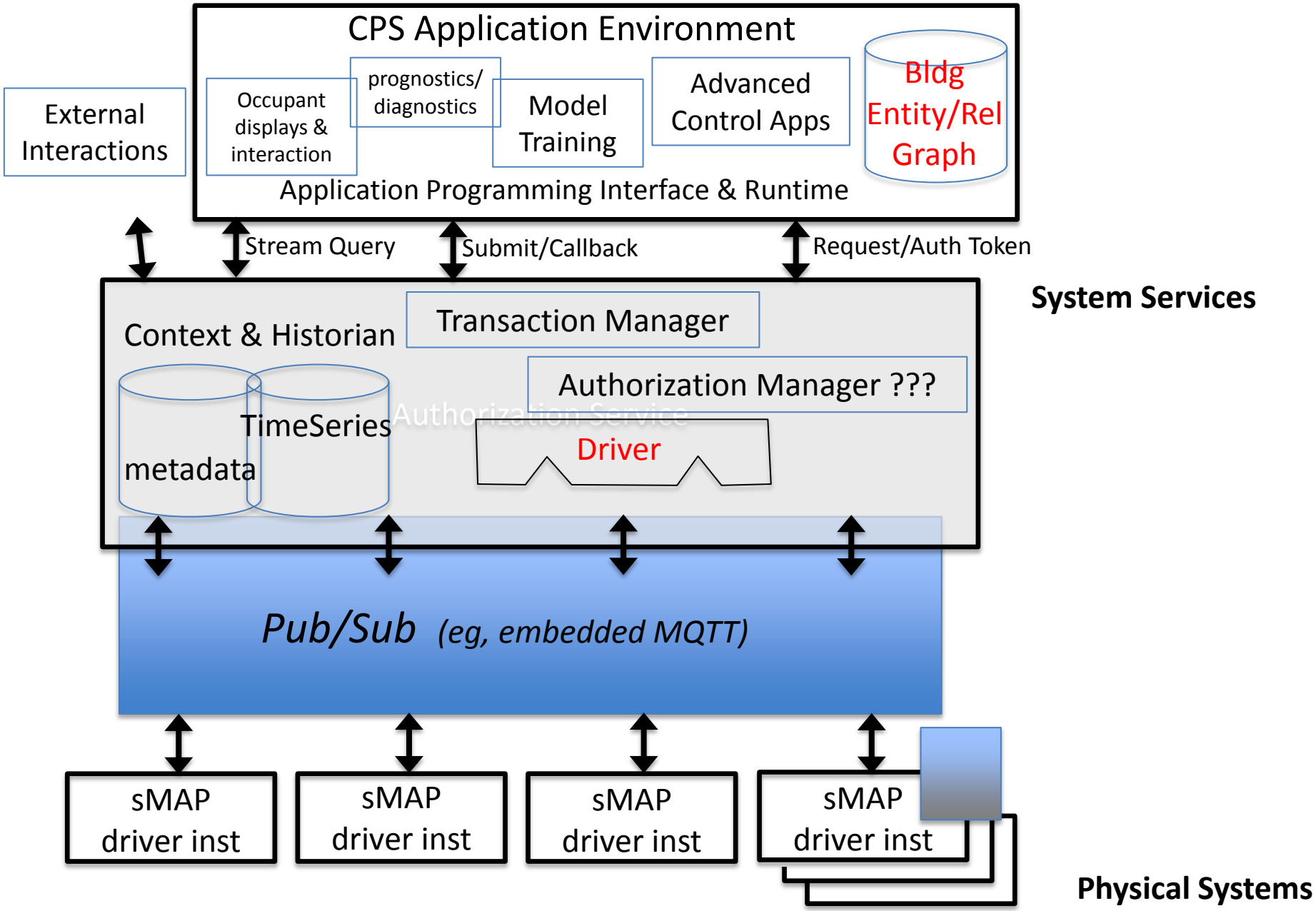
Personalized Comfort Control



Occupant in the Loop – IOS style




CPS Application Environment
External Interactions
Occupant displays & interaction
Model Training
Advanced Control Apps
Application Programming Interface & Runtime
Stream Query
Submit/Callback
Request/Auth Token
Context & Historian
Transaction Manager
Authorization Manager
TimeSeries
metadata
publish
command
discovery svc
WiFi tstat drvr inst
.nc
house.ini
wifi tstat drvr
Driver Repo
Detector Repo
.nc
Ethernet LED
WiFi tstat
Zwave bulb
Physical Premises
Physical Systems


CPS Application Environment
External Interactions
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Advanced Control Apps
Bldg Entity/Rel Graph
Application Programming Interface & Runtime
Stream Query
Submit/Callback
Request/Auth Token
System Services
Context & Historian
Transaction Manager
Authorization Manager ???
Authorization Service
TimeSeries
metadata
Driver
Pub/Sub (eg, embedded MQTT)
sMAP driver inst
sMAP driver inst
sMAP driver inst
sMAP driver inst
Physical Systems

BOSS Wide Area Verified Exchange

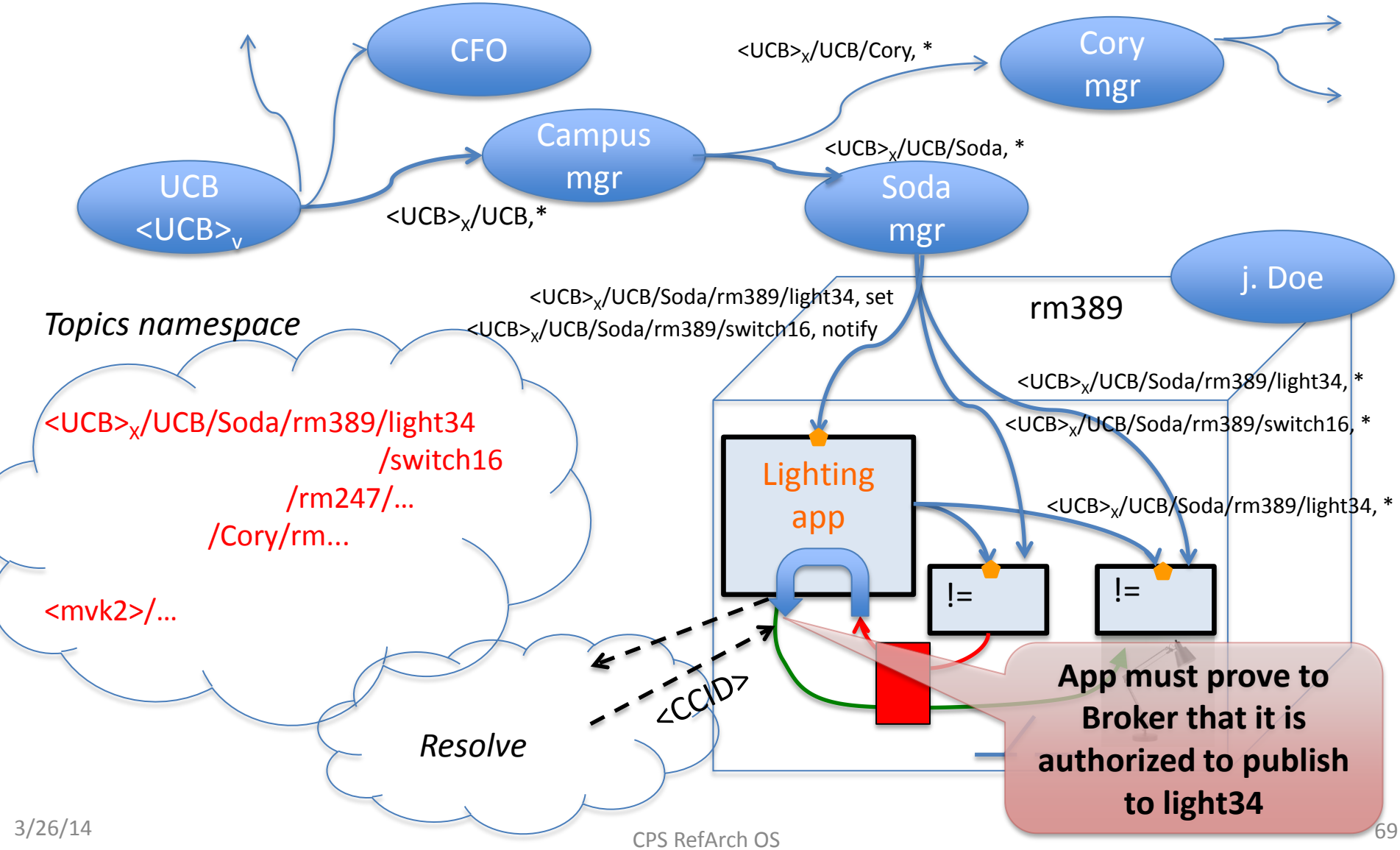
- Web of trust model
- Decentralized
- Push to (multiple) subscribers – not poll
- Revocation
- Verify
  - Origin, Authorization of Operation, Target
- Limit
  - Processing of unauthorized ops, BW of fanout
- Tolerate
  - Intermittent connection

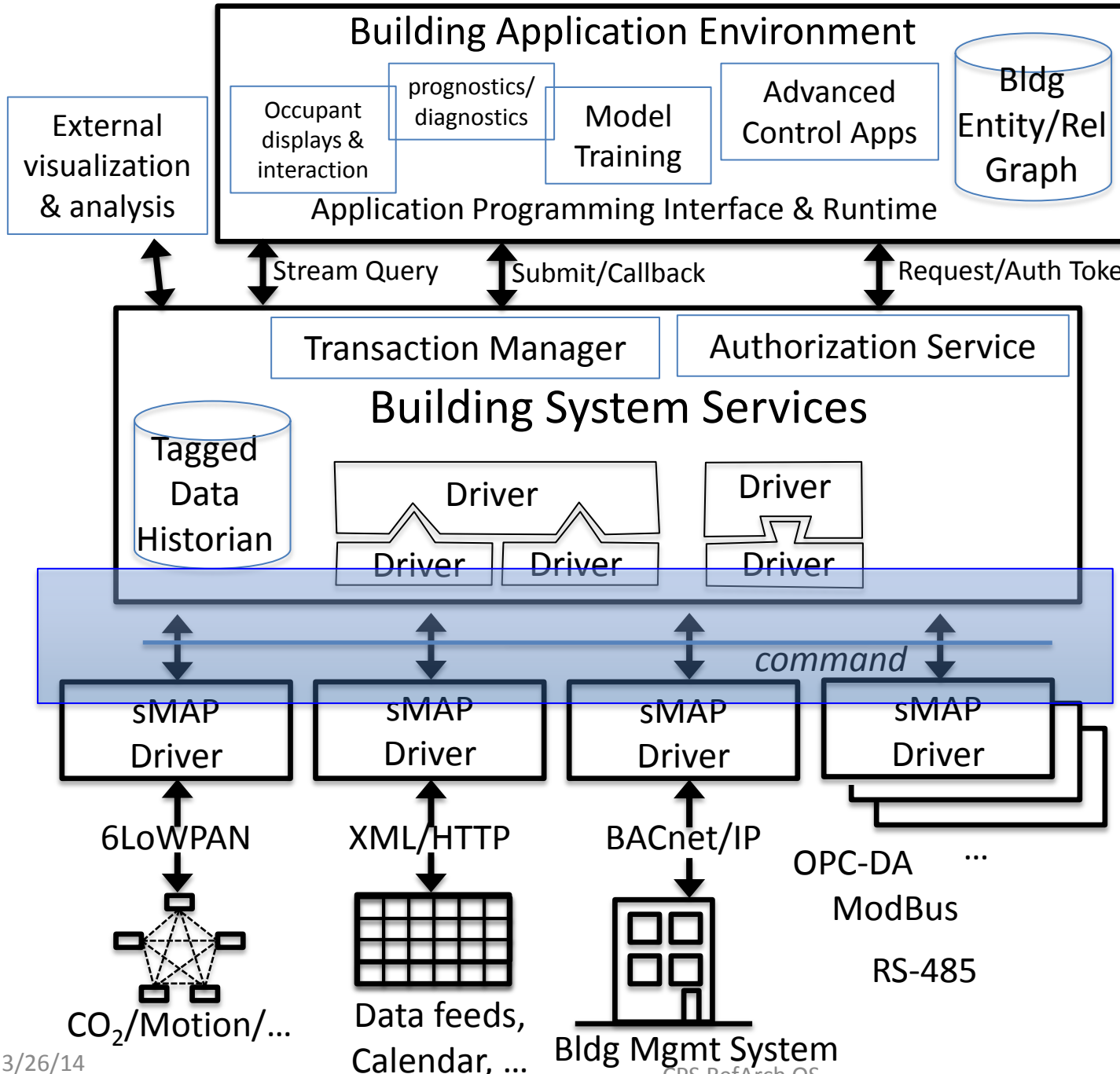
BOSSwave Illustration

- WAVE URI : <nvk>/<path>/<op>

A $\xrightarrow[t,p]{}$ B_x D.o.T :

A grants B permission p to t, unforgeably





Portability

Reliability
Fault-Tolerance
Security
Data Archiving
Hardware Independence

Hardware Presentation Layer
- JSON data stream + attribute metadata as resource-oriented web services

Physical Systems

Key Challenges

- Scale
  - ~110 M buildings in US
  - Automate all aspects of the process
    - after insertion of basic capability
- Heterogeneity
  - in Design, Implementation, Use, …
  - Automated metadata acquisition & context
  - Learning throughout lifecycle
- Uncertainty
  - In time, space, use, behavior, …
- Empowerment and Balance
  - Privacy, security, autonomy, control, opportunity

Thoughts

- Architecture <= experience + aspiration
- Great system design takes serious application, iteration, exploration, and shake out.
- New infrastructure emerges as an overlay on the established one
- The CPS community provides the basis for an interesting early overlay
  - Architecture is a *process* more than a *problem*

https://github.com/SoftwareDefinedBuildings

Where to go for more

- Stephen Dawson-Haggerty, Andrew Krioukov, Jay Taneja, and David Culler. **BOSS: Building Operating System Services.** ***to appear in Proceedings of the 10th USENIX Symposium on Networked Systems Design and Implementation (NSDI '13), April 2013.***
- **Building Application Stack (BAS) , Andrew Krioukov, Gabe Fierro, Nikita Kitaev, David Culler.** ***4th ACM Workshop On Embedded Sensing Systems For Energy-Efficiency In Buildings, Toronto, Canada, Nov 2012.***
- **A Living Laboratory Study in Personalized Automated Lighting Controls, Andrew Krioukov, Stephen Dawson-Haggerty, Linda Lee, Omar Rehmane, David Culler.** ***3rd ACM Workshop On Embedded Sensing Systems For Energy-Efficiency In Buildings, Seattle, WA, Nov 2011.***
- @scale: Insights from a Large, Long-Lived Appliance Energy WSN." Stephen Dawson-Haggerty, Steven Lanzisera, Jay Taneja, Richard Brown, and David Culler. In Proceedings of the 11th ACM/IEEE Conference on Information Processing in Sensor Networks, SPOTS Track (IPSN/SPOTS '12), April 2012
- **A Living Laboratory Study in Personalized Automated Lighting Controls, Andrew Krioukov, Stephen Dawson-Haggerty, Linda Lee, Omar Rehmane, David Culler.** ***3rd ACM Workshop On Embedded Sensing Systems For Energy-Efficiency In Buildings, Seattle, WA, Nov 2011.***
- Stephen Dawson-Haggerty, Xiaofan Jiang, Gilman Tolle, Jorge Ortiz, and David Culler. **sMAP — a Simple Measurement and Actuation Profile for Physical Information.** ***in Proceedings of the Eighth ACM Conference on Embedded Networked Sensor Systems (SenSys '10), November 2010.***
- http://code.google.com/p/smap-data/
- http:// SDB.cs.berkeley.edu
- https://github.com/SoftwareDefinedBuildings