BOSS: Building Operating System Services

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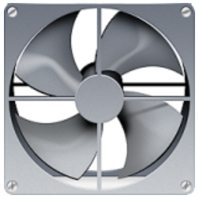
Sutardja-Dai Hall
UC Berkeley
93,000 sq. ft.
with Digital Controls

73% of US electricity is consumed in buildings
U.S. Energy Information Administration, 2009

2/3 of building occupants are uncomfortable
UC Berkeley CBE Study of 30,000 occupants

>70% of large buildings have digital controls

12 Variable Speed Fans



138 Air Dampers

312 Light Relays

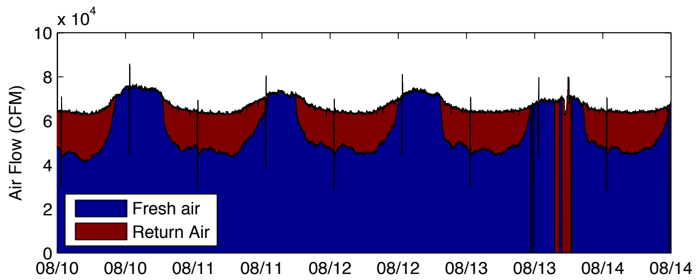
50 Electrical Sub-meters

151 Temperature Sensors

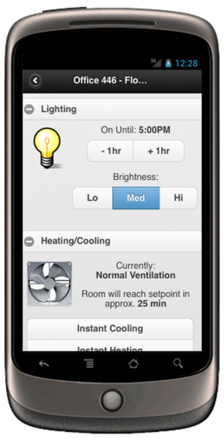
> 6,000 Sense and Control Points


60
70
80
50
60
70
80
50

Applications



Ventilation Optimization:
17% energy savings



Occupant Lighting Controls
50-60% savings

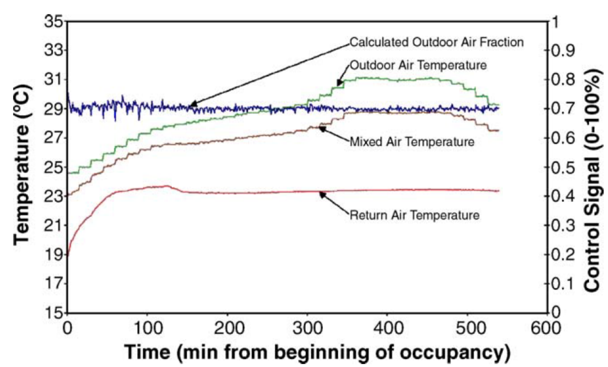
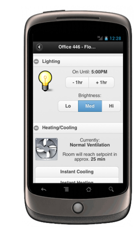


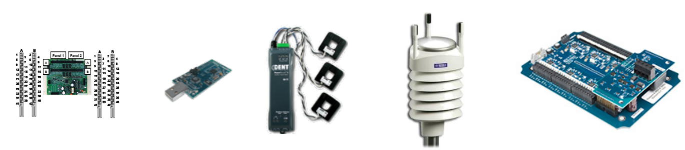
Fig. 4. Emulation study AHU recirculation damper stuck closed.

Automated Fault Detection:
10 - 40% energy savings

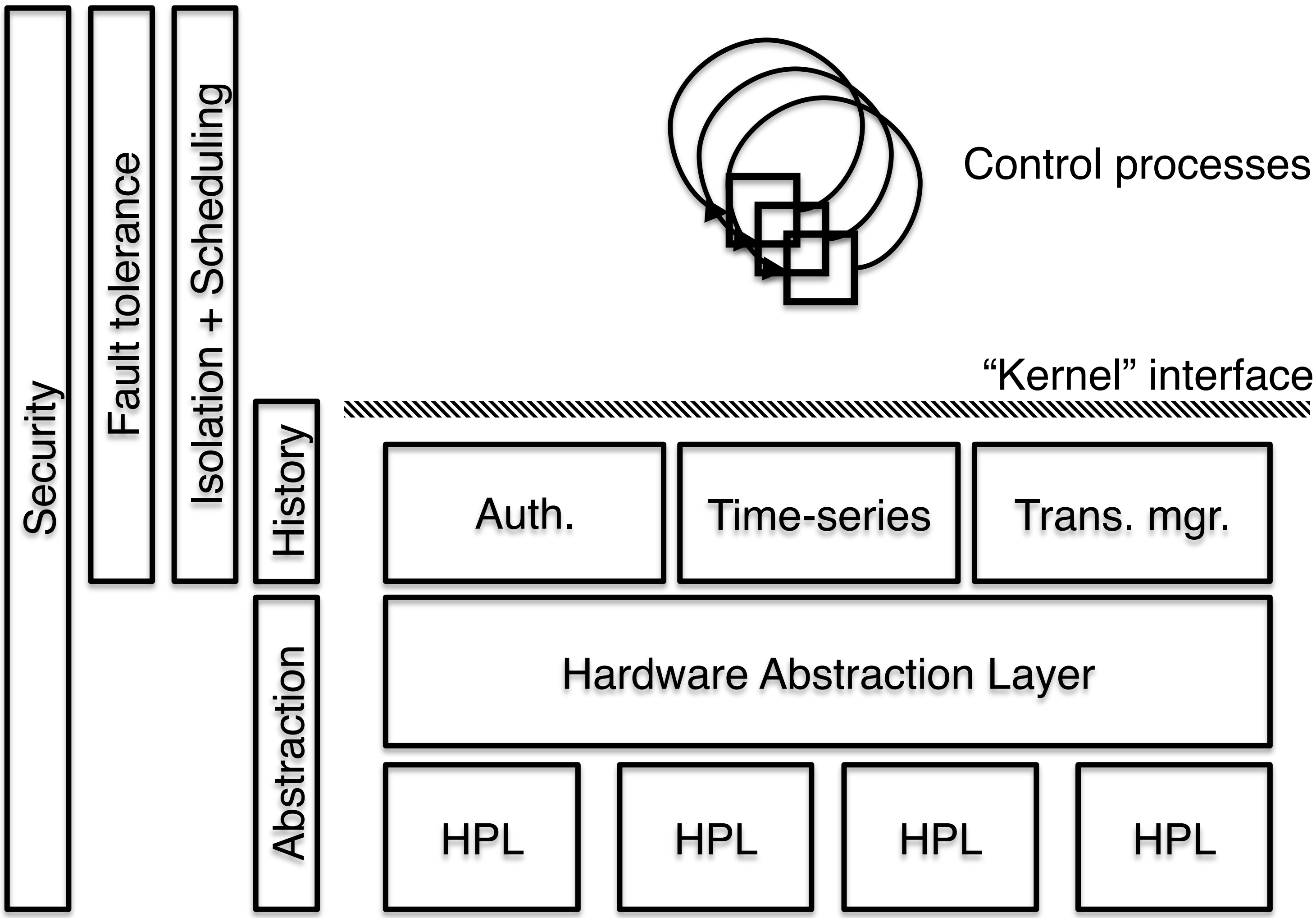
Goals and Challenges

- Portability
  - Write once, run anywhere for buildings?
  - *Current practice*: hand-coded logic
- Fault tolerance
  - Partial failures of controllers
  - Network partitions
  - *Current practice*: really tough hardware
- Multiple processes
  - Concurrent applications and users
  - *Current practice*: none
- Federation
  - Multiple heterogeneous systems
  - *Current practice*: lots of stovepipes
- Scale
- Security & privacy



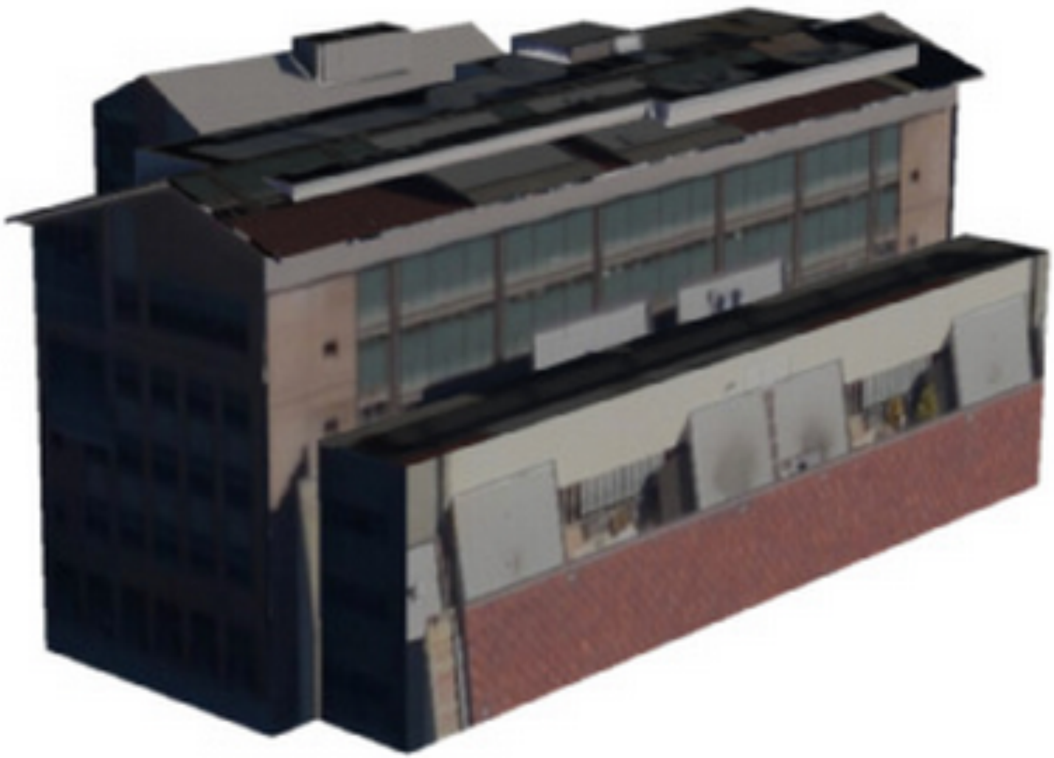


BOSS: Building Operating System Services



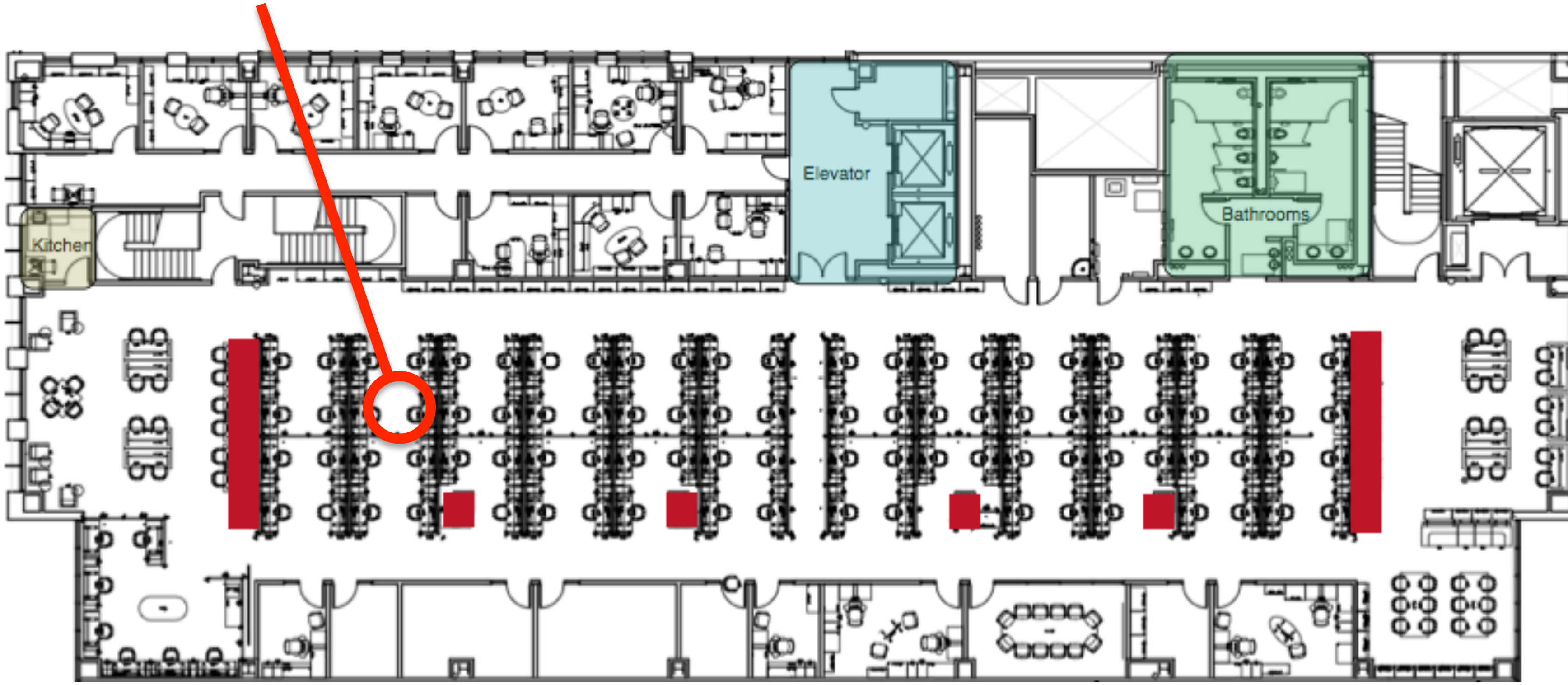
Challenge: Portability

Buildings are custom designed



LoCal

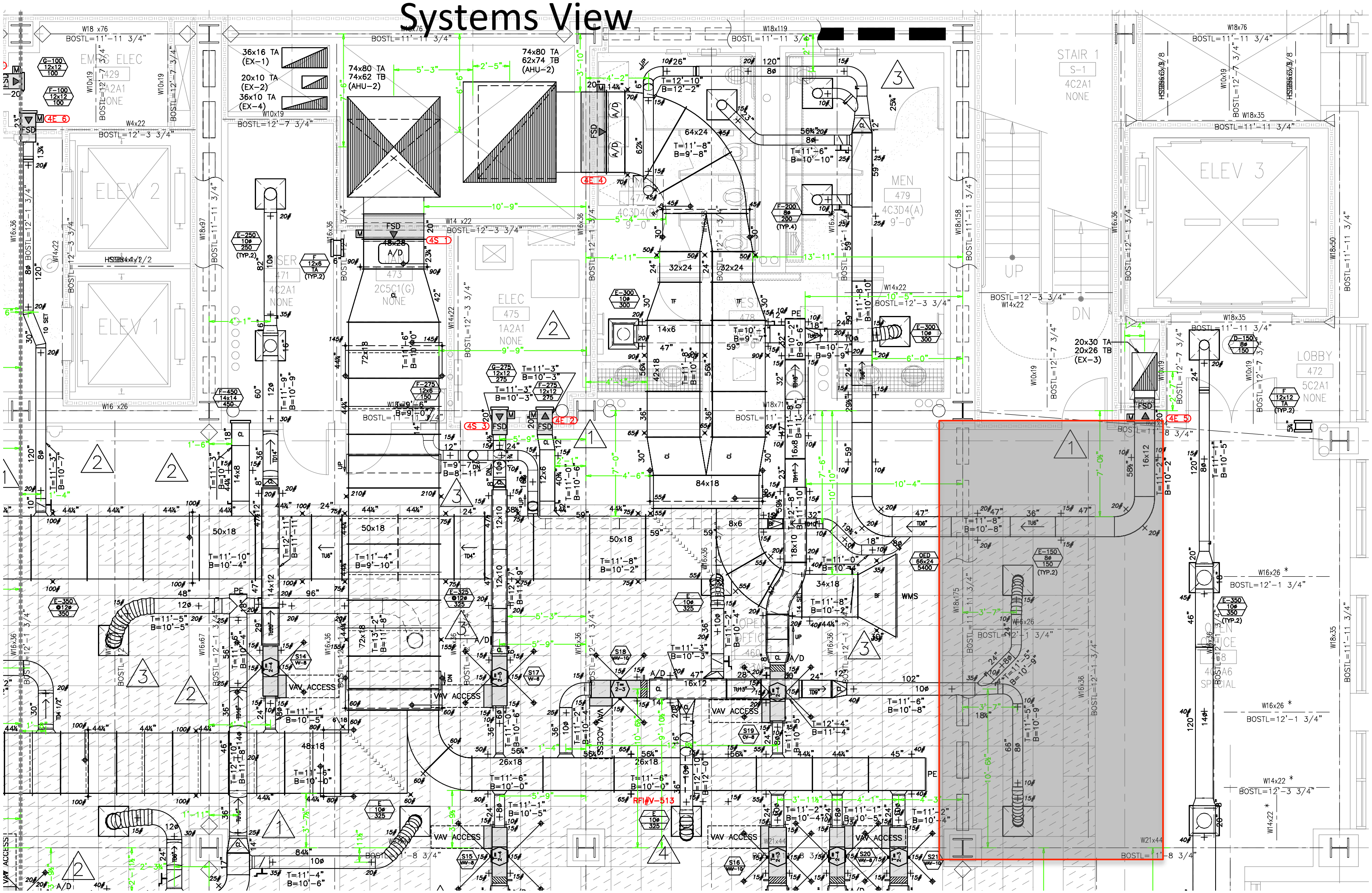
Hardware Abstraction
Physical view



Open area 450

Hardware Abstraction

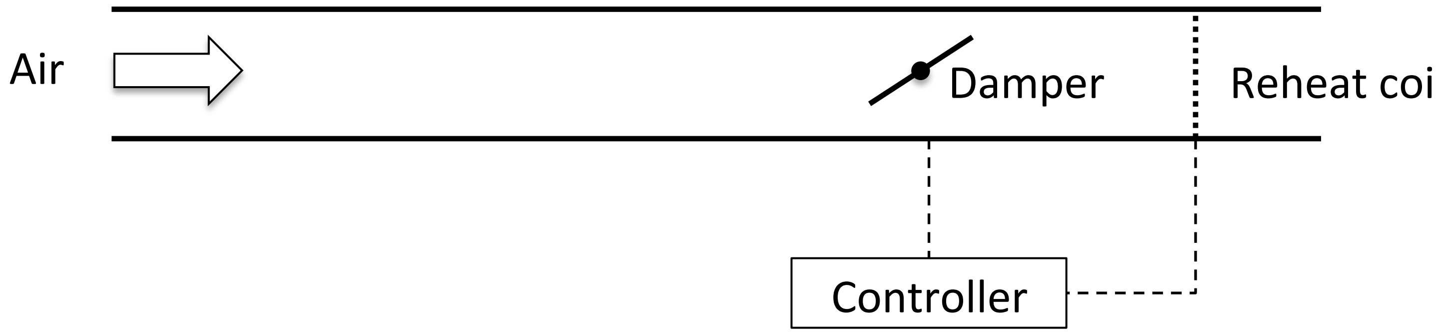
Systems View



VAV S4-21

Hardware Abstraction

Controls view



SDH.MEC-08.S4-21:DMPR COMD
device: 220018 instance: 101

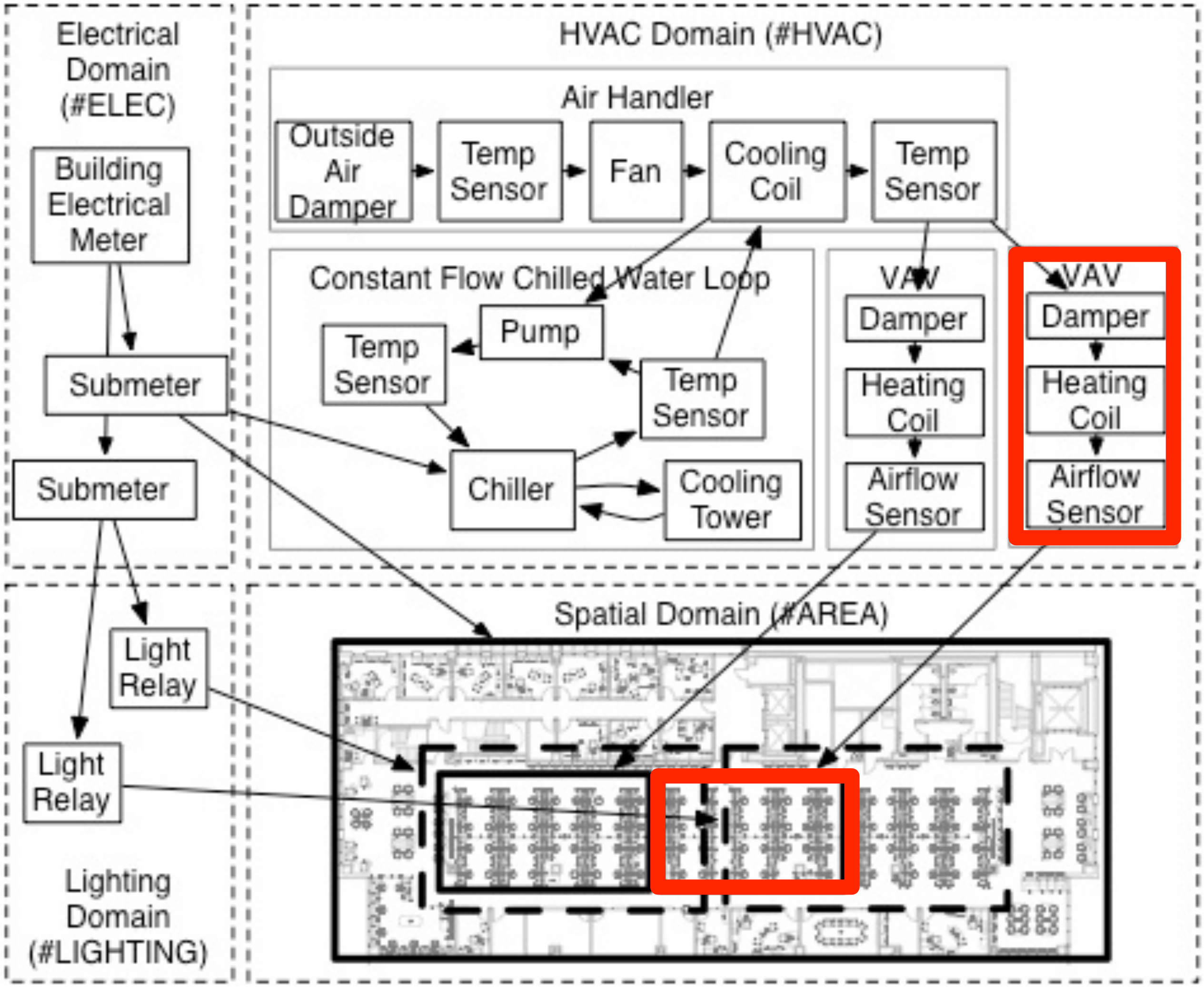
SDH.MEC-08.S4-21:VLV COMD
device: 220018 instance: 102

BACnet

legacy solution: overload point names

Hardware Abstraction Layer

#VAV > $(120, 20)



Summary: Hardware Abstraction Layer

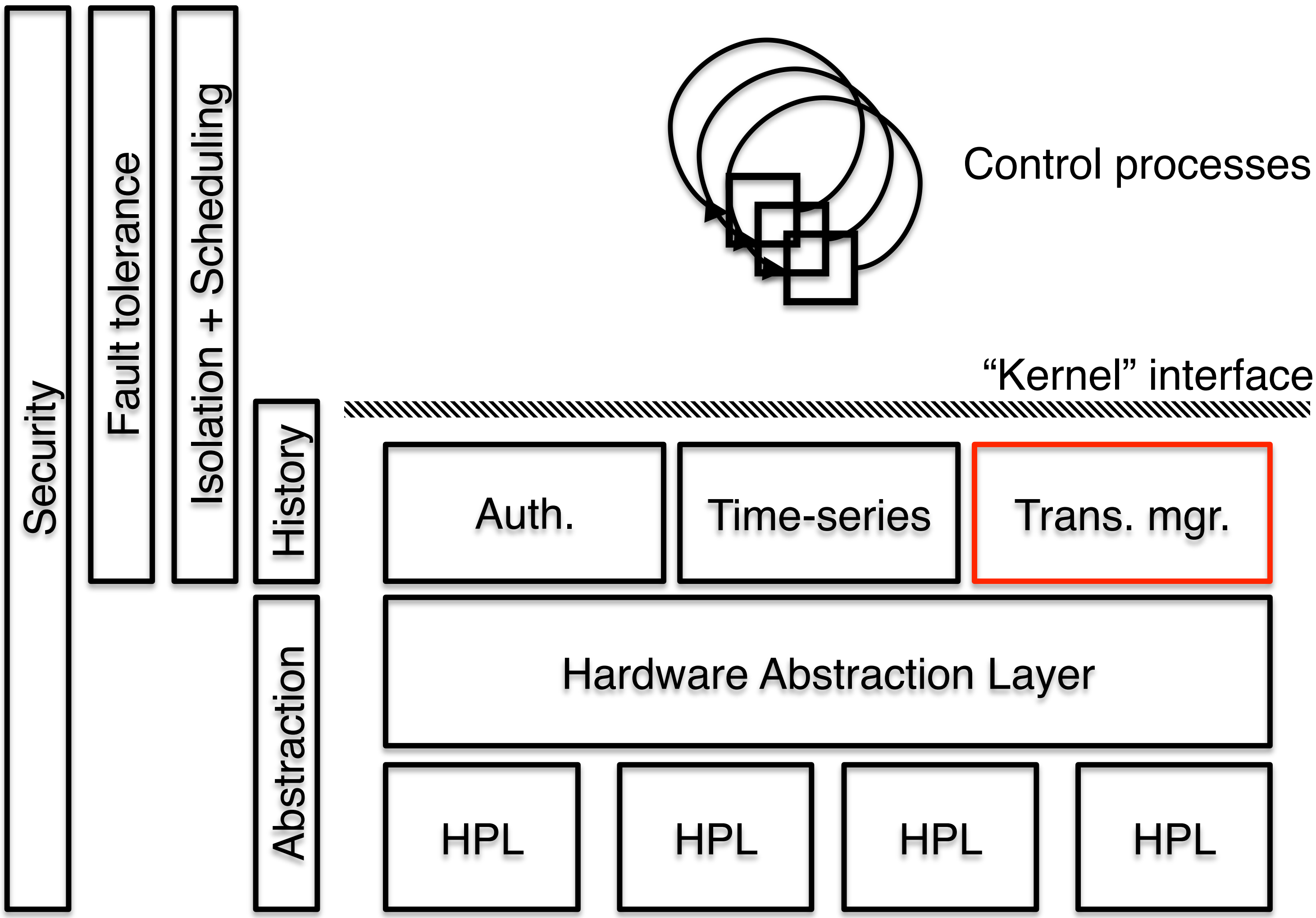
Program applications in terms of *relationships between system components*

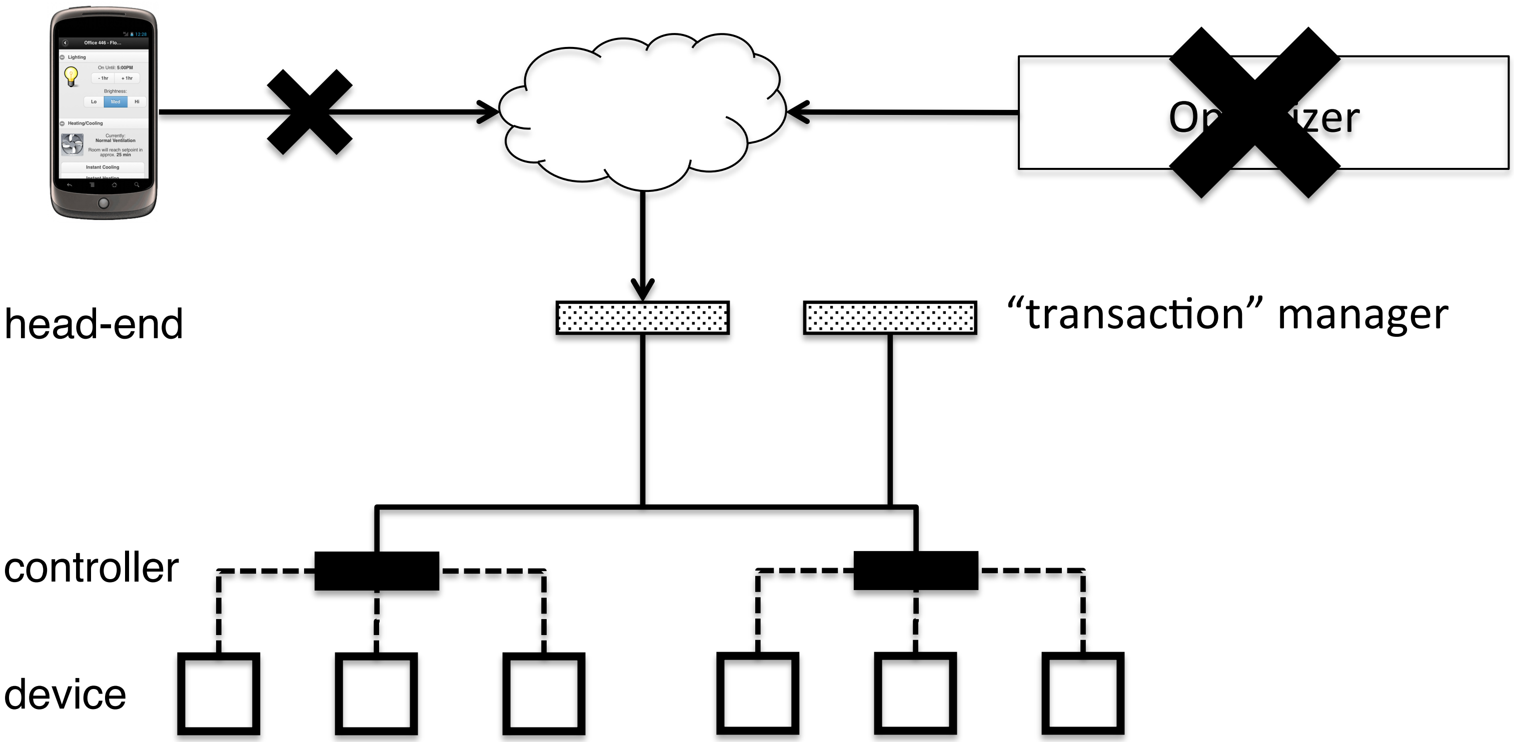
- Computer systems tend to hide the physicality
  - memory hierarchies, network topology
- Unavoidable in buildings
  - "it gets too hot on the sunny side"

Allow for scale by avoiding hard-coding

- "Run this in every room, except those on the north side"

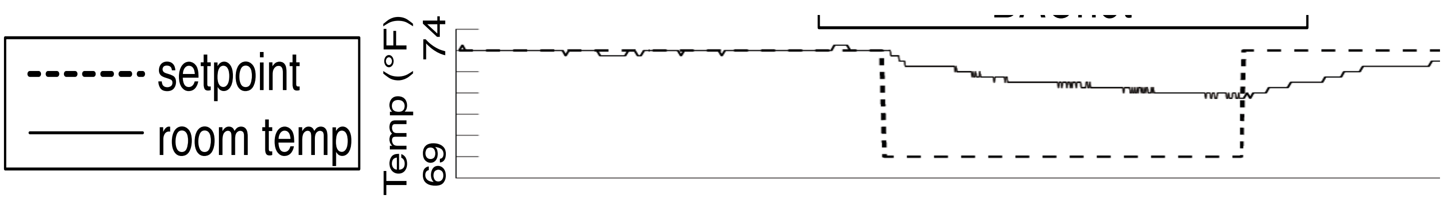
BOSS: Building Operating System Services




head-end
"transaction" manager
controller
device

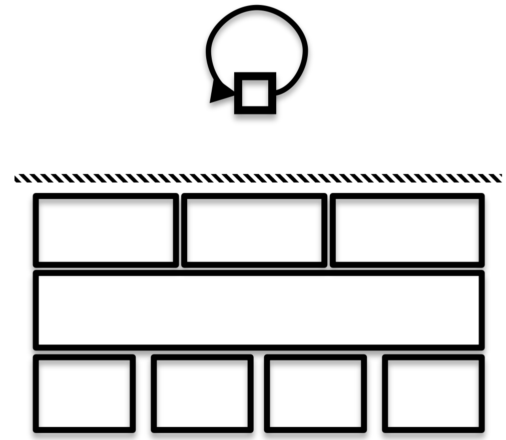
BOSS solution: "transactions": write access to the building

- Writes to distributed resources
- Which interact in physical space
- Which are subject to failure
- Extend writes with
  - Priorities
  - Leases
  - Notifications
  - Reversion sequences



More BOSS

- sMAP Hardware Presentation Layer
  - 30 Drivers, 30k data streams
- Archiver data storage service
  - 500 writes/sec
  - Stream cleaning and processing
- Family of apps
  - Personal ventilation and lighting control
  - Electric grid-aware consumption



Name	Sensor Type	Access Method	Channels
ISO Data	CAISO, NYISO, PJM, MISO, ERCOT	Web scrape	1211
ACme devices	Plug-load electric meter	Wireless 6lowpan mesh	344
EECS submetering project	Dent Instruments PowerScout 18 electric meters	Modbus	4644
EECS steam and condensate	Cadillac condensate; Central Station steam meter	Modbus/TCP	13
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


Wellman
Mulford
C. V. Starr East Asian Library
Evans
Hearst Mining Circle
Stanley Hall
Memorial Pool
Memorial Glade
University Drive
East Gate
Hearst Greek Theatre
Pimentel
North Fork of Strawberry Creek
Moffitt Undergraduate Library
David Gardner Stacks (underground)
Campbell
Tan
Latimer
Lewis
Springer Gateway
West Circle
Doe Memorial Library
Bancroft Library
LeConte
Gilman
Giauque
Hildebrand
Gayley Rd.
Eucalyptus Grove
Life Sciences Addition
Valley Life Sciences
Chan Shun Auditorium
California
Campanile Esplanade
Sather Tower
Birge
Grinnell Natural Area
Sather Rd.
South Hall Rd.
Annex
Women's Faculty Club
Girton
Andersen Auditorium
Durant
Wheeler
Faculty Club
Senior Hall
Schlessinger Way
South
Stephens
Cheit
Haas School of Business
South Fork of Strawberry Creek
Dwinelle
Faculty Glade
Minor Addition
Minor Hall
Hellman Tennis Center
Hazardous Materials Facility
Central Heating Plant
Sather Gate
Moses
Hertz
Dwinelle Annex
Old Art Gallery
Anthony
Morrison
Eye Center
Calvin Laboratory
Wurster
Alumni House
A & E
North Field
Hargrove Music Library
2241
2243
Evans Diamond
Haas Pavilion
César Chávez Student Center
Barrows
Edwards Stadium/ Goldman Field
Zellerbach Playhouse
Sproul Plaza
Sproul Hall
Kleeberger Field House
Bleachers
Hearst Field Annex
2251
Zellerbach
Lower Sproul
Martin Luther
Hearst Gym
Bancroft
Kroeber
Recreational
Spieker
Boalt Hall

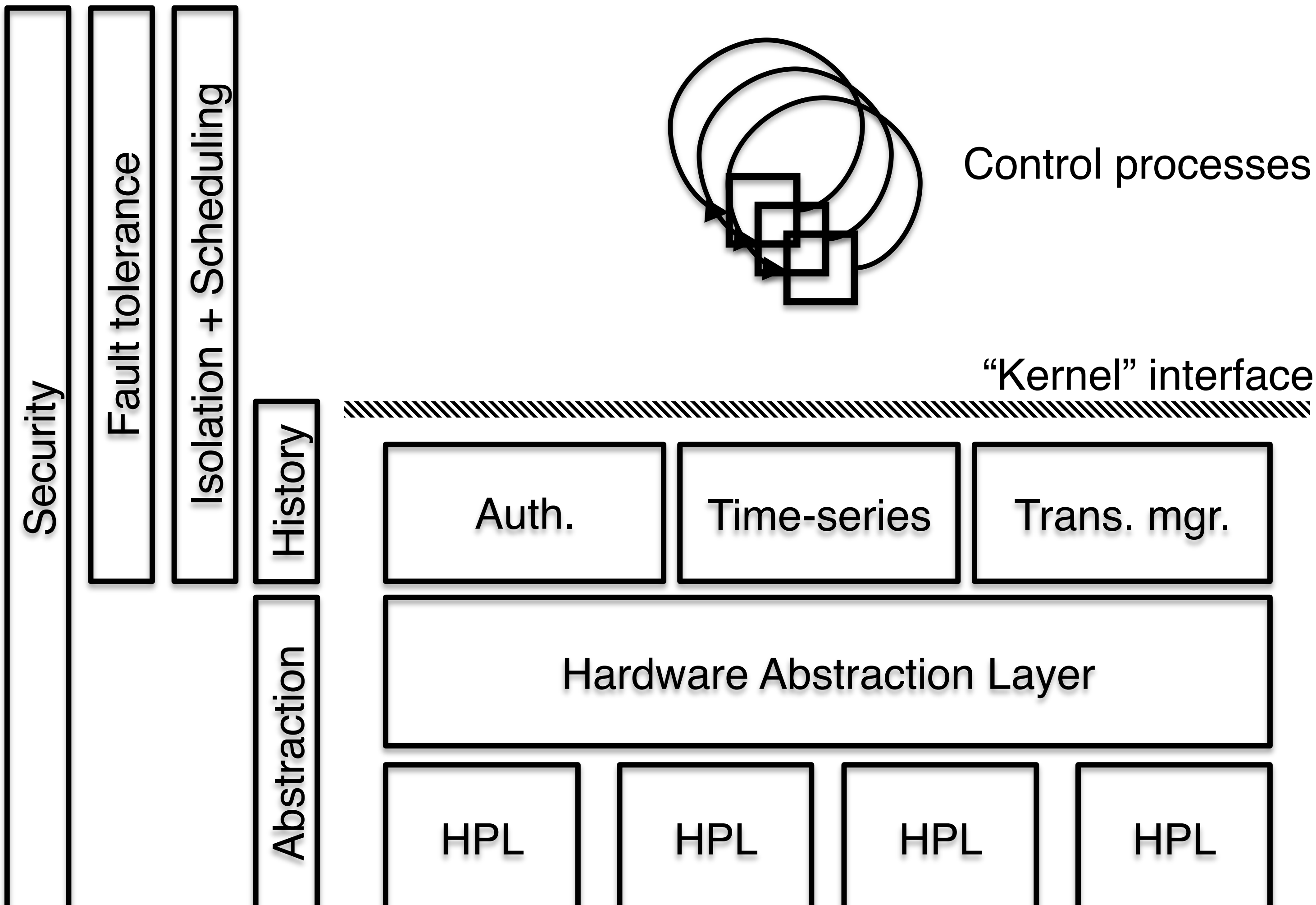


The New York Times

Takeaways

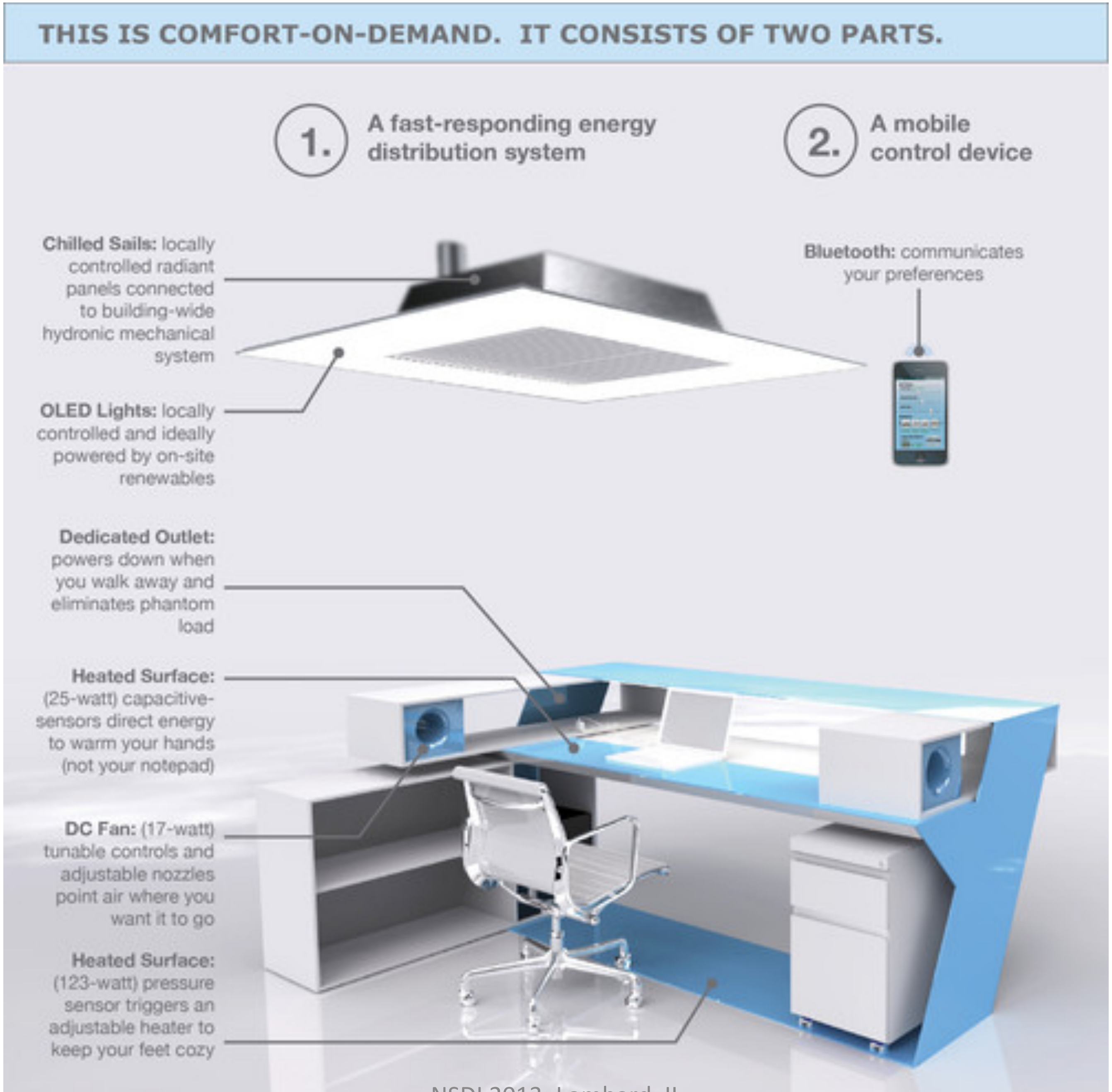
- Applying computer systems design to buildings: lots of pieces, potential
  - Control systems
  - Mechanical systems
  - Occupants
- 30% electricity + steam savings, 60% lighting savings in test apps
- Many pieces at http://smap.cs.berkeley.edu
- Control systems + CS future work
  - Making use of the torrent of data?
  - Compile/enforce constraints into the network?
  - How to verify applications are behaving?

Thank you


Security
Fault tolerance
Isolation + Scheduling
History
Abstraction
Control processes
"Kernel" interface
Auth.
Time-series
Trans. mgr.
Hardware Abstraction Layer
HPL
HPL
HPL
HPL

```
proc = BossProcess(timeout=15min, auth_token=ABC)
while True:
  for dmp in hal.find(’#OUT_AIR_DMP > #AH’):
    for vav in hal.find(’#VAV < $%s’ % dmp.name):
      occ = model.estimate_occupancy(vav)
      vav.set_min_airflow((vav.min_fresh_air() /
            dmp.get_percent_open()) * occ)
  time.sleep(15*60)
```

Write applications in terms of relationship between hardware elements


THIS IS COMFORT-ON-DEMAND. IT CONSISTS OF TWO PARTS.
1. A fast-responding energy distribution system
2. A mobile control device
Chilled Sails: locally controlled radiant panels connected to building-wide hydronic mechanical system
OLED Lights: locally controlled and ideally powered by on-site renewables
Bluetooth: communicates your preferences
Dedicated Outlet: powers down when you walk away and eliminates phantom load
Heated Surface: (25-watt) capacitive-sensors direct energy to warm your hands (not your notepad)
DC Fan: (17-watt) tunable controls and adjustable nozzles point air where you want it to go
Heated Surface: (123-watt) pressure sensor triggers an adjustable heater to keep your feet cozy

legacy solution: encode everything in point name

SDH.MEC-08.S5-01.AIR_VOLUME

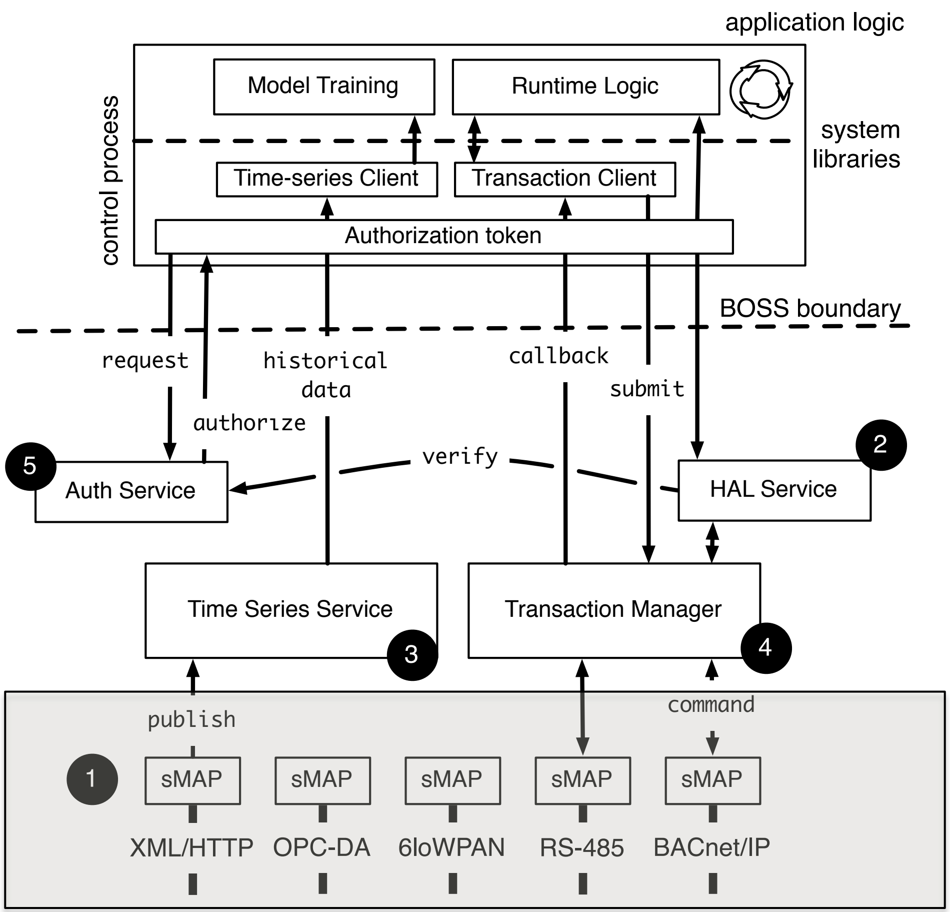
building name

MEC: Modular Equipment Controller #8

S: VAV, 5: 5^{th} floor, 01: the 1^{st} one

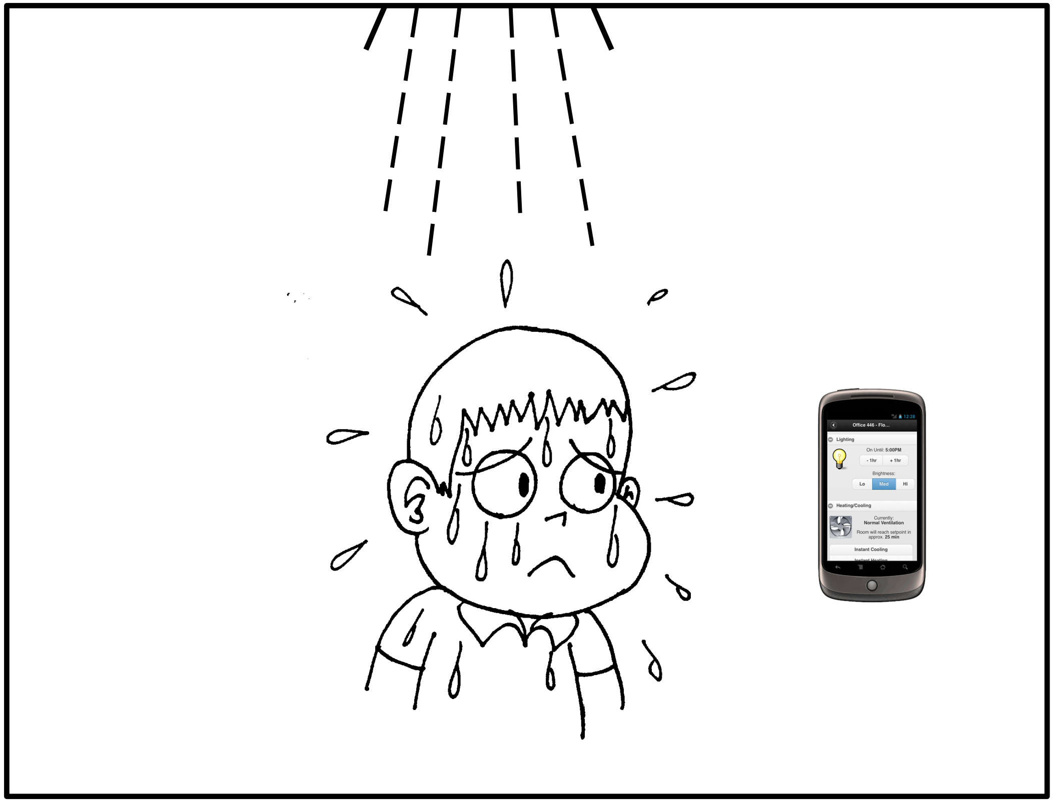
quantity being measured

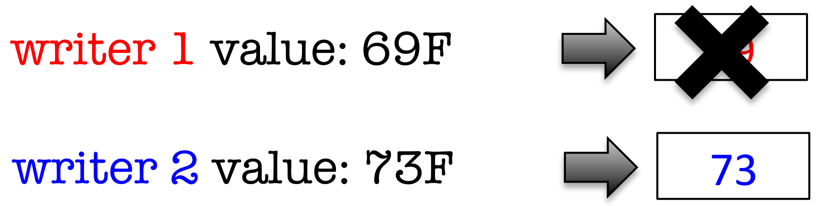
BOSS



a collection of services enabling *portable, robust* **applications** for the physical environment

1. Hardware presentation layer: sMAP
2. Hardware abstraction layer: device-specific logic
3. Time-series service: the archiver
4. Reliable control inputs: the transaction manager
5. Security: the authorization service





- No arbitration between applications
- Orphaned writes

Command Sequence

1. Set damper to 100% open
2. Set valve to 0% open
3. … wait 10 minutes
4. Reset to "whatever was happening before"

What if…

1. #1 or #2 fail?
2. Client fails/becomes partitioned during #3?
3. Another application tries to do something?

BOSS solution: “transactions”

Extend writes with

- Priorities
- Leases
- Notifications
- Reversion sequences

overridden!

writer 1 value: 69F priority: 3 lease: 3600s

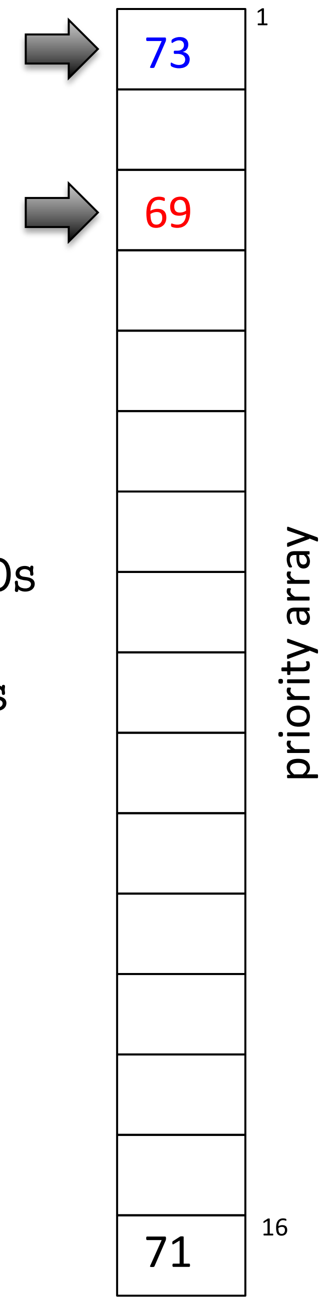
writer 2 value: 73F priority: 1 lease: 300s

<time passes>

writer 2 clear

writer 1 crashes

… writer 1 revert sequence runs



present value: 73cfm