Methods for Network-Enabled Embedded Monitoring and Control for High-Performance Buildings

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NSF CPS PI meeting, Arlington, August 11, 2010

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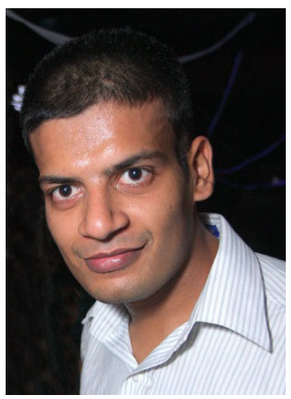

Chenda Liao

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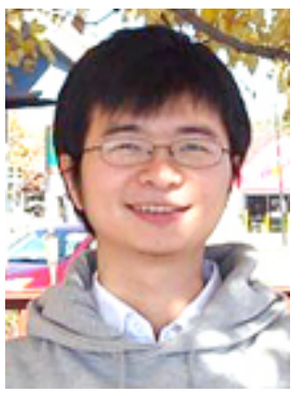

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Feb 5, 2010

Kick-off meeting, East Hartford

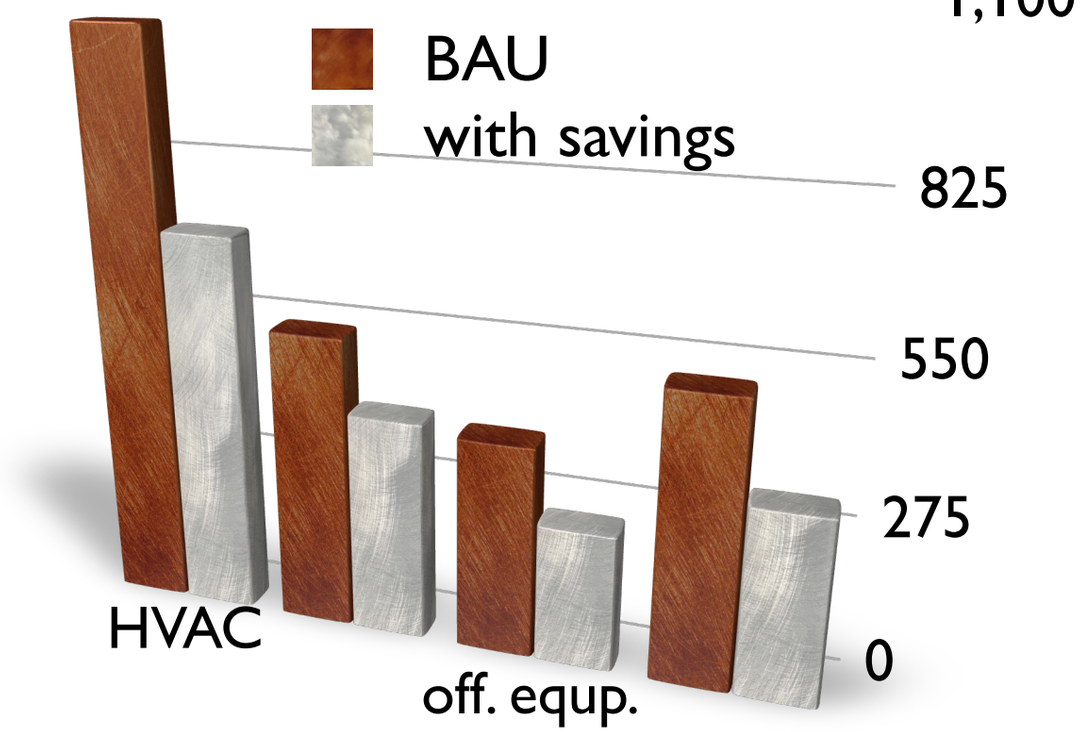
March 23, 2010

project awarded

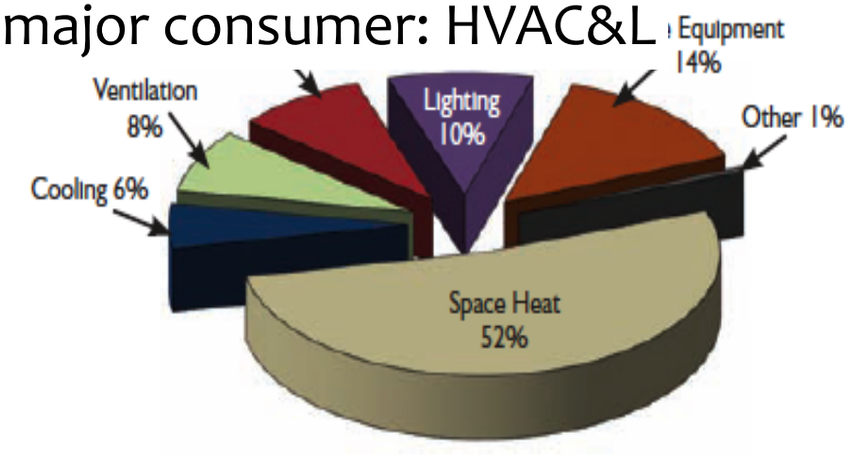
Buildings and Energy (U.S.)

> 71% of electricity*, 39% of total energy use*, 38% of CO2 emissions*
> commercial / residential ~ 1, but growing

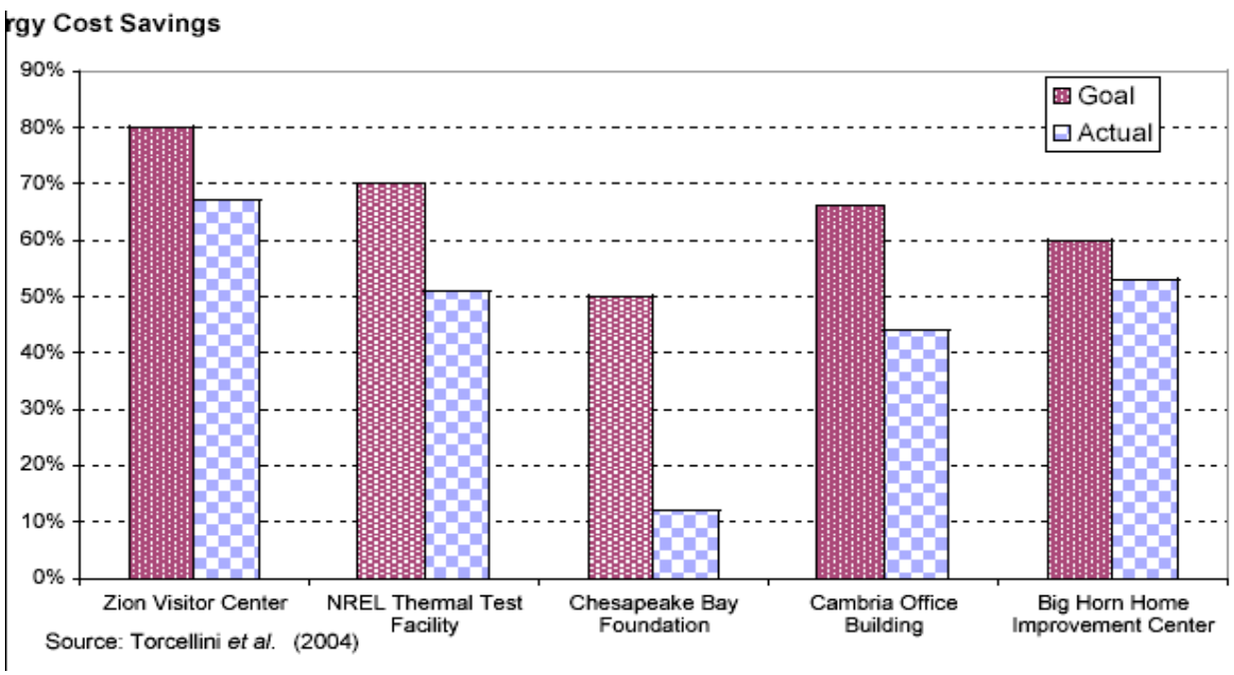
2050 U.S. building sector energy use prediction **



major consumer: HVAC&L



Gaps between design and actual performance

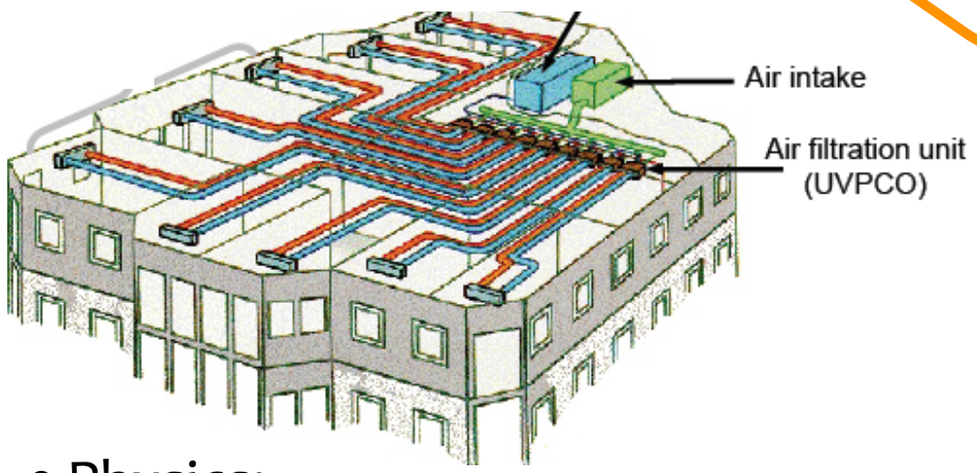


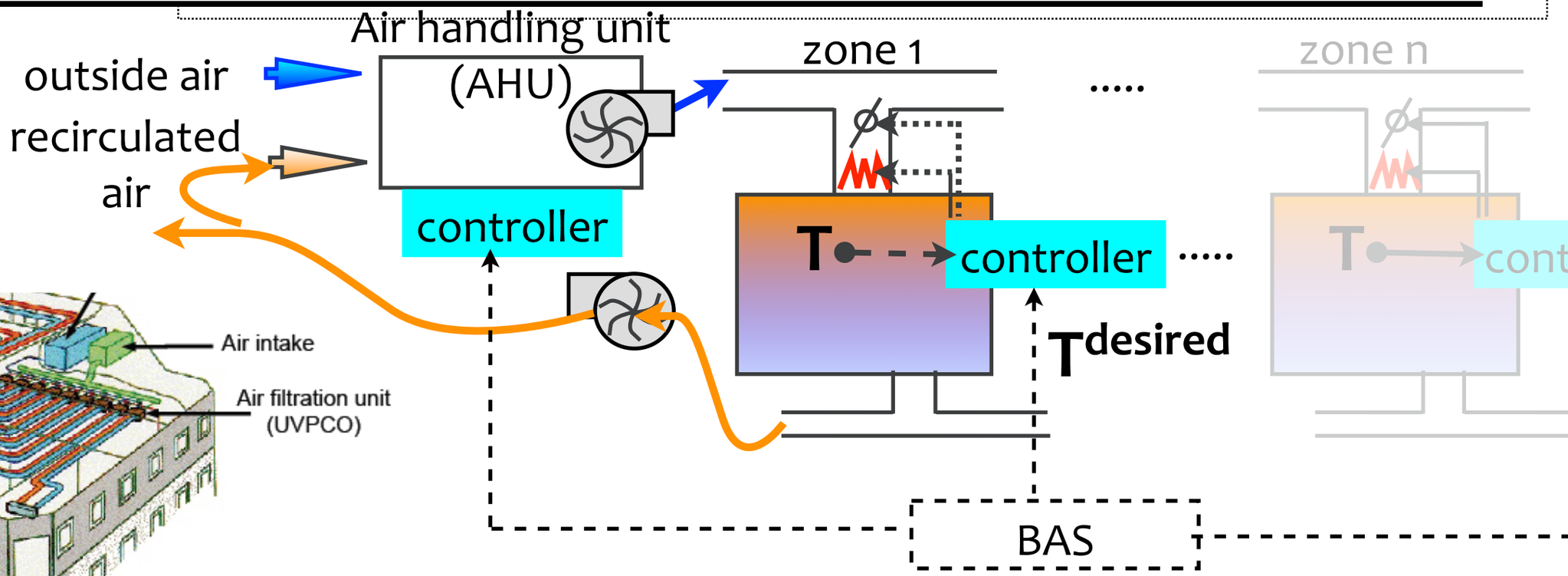
** based on an assumed 55% reduction in HVAC energy use through improved HVAC equipment and controls [source: "U.S. Building-Sector Energy Efficiency Potential", LBNL-1096E, Brown et. al. 2008]

Inefficiency in building HVAC

Sources of inefficiency:

- controls (open-loop schedule + local feedback)
- HVAC system design (worst case "load")





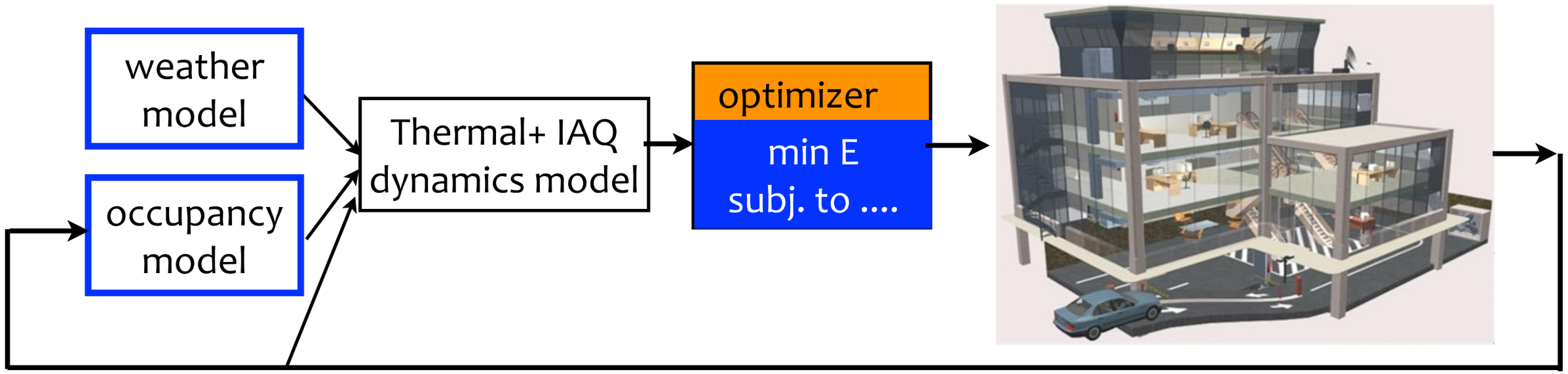
- Physics:
  - thermal, contaminant transport, occupants,
- Cyber:
  - thousands of sensors (temp, flow rate, status, CO_2, video...)
  - control logics at several scales (zone-level, building-level)

attributes:

- time-varying, building-specific
- complex interconnection

Optimal control?

"minimize energy use while maintaining comfort and IAQ"

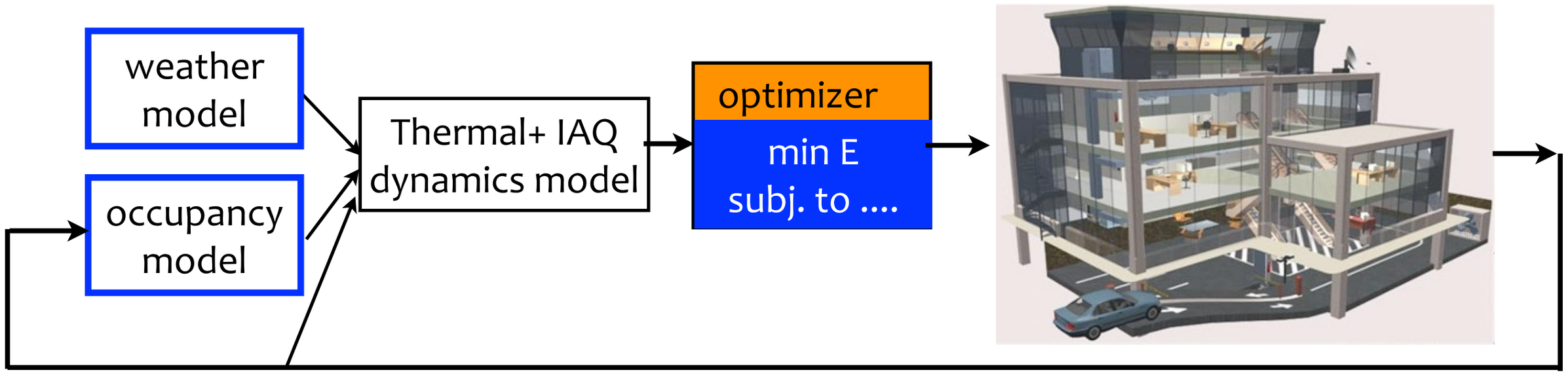


issues

- complex physics
- building-specific and time-varying: need for adaptation
- large design space for the cyber system

Design and Implementation

"minimize energy use while maintaining comfort and IAQ"



Design and Implementation

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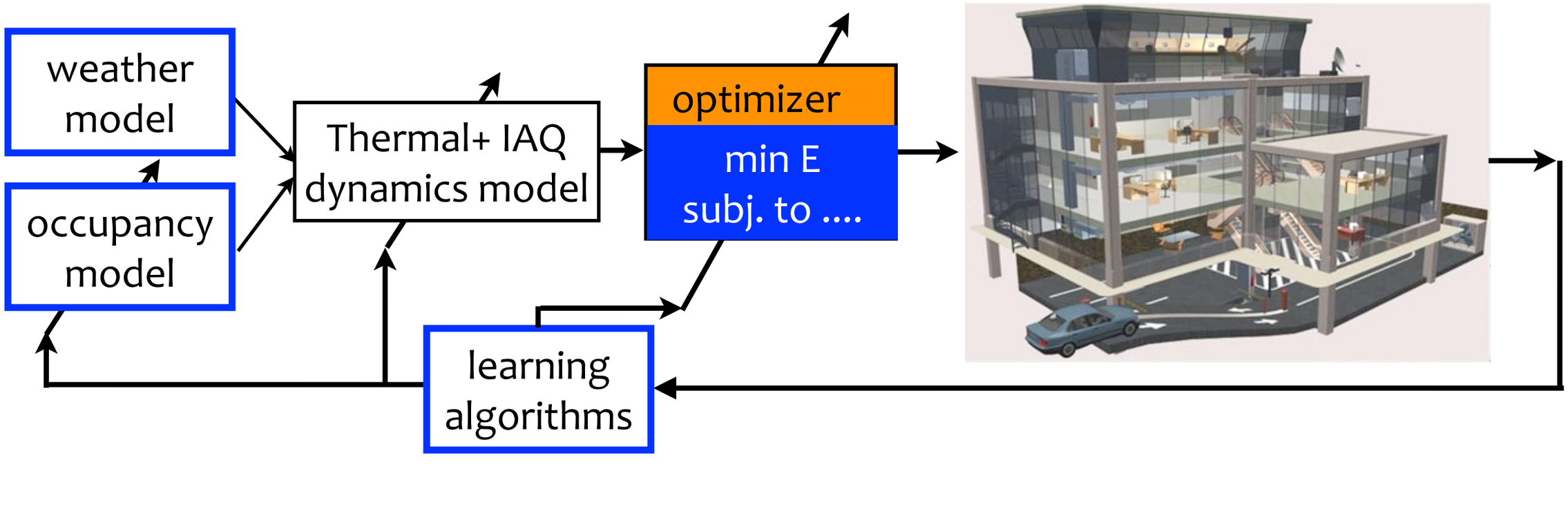
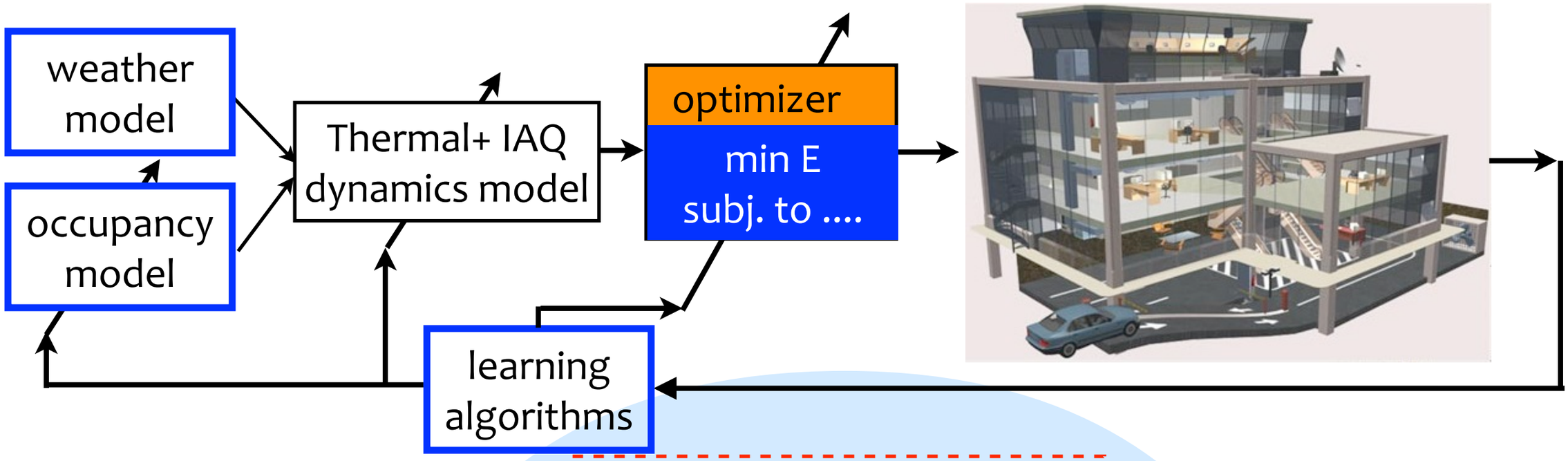
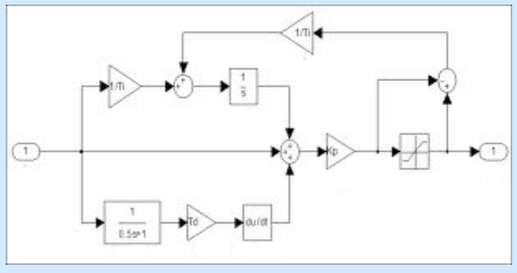


Design and Implementation

"minimize energy use while maintaining comfort and IAQ"



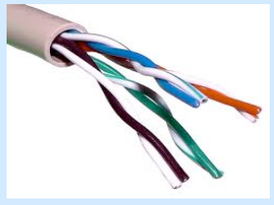
control and estimation computations

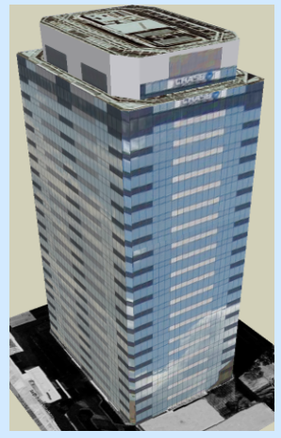


stream processing

Processing Elements

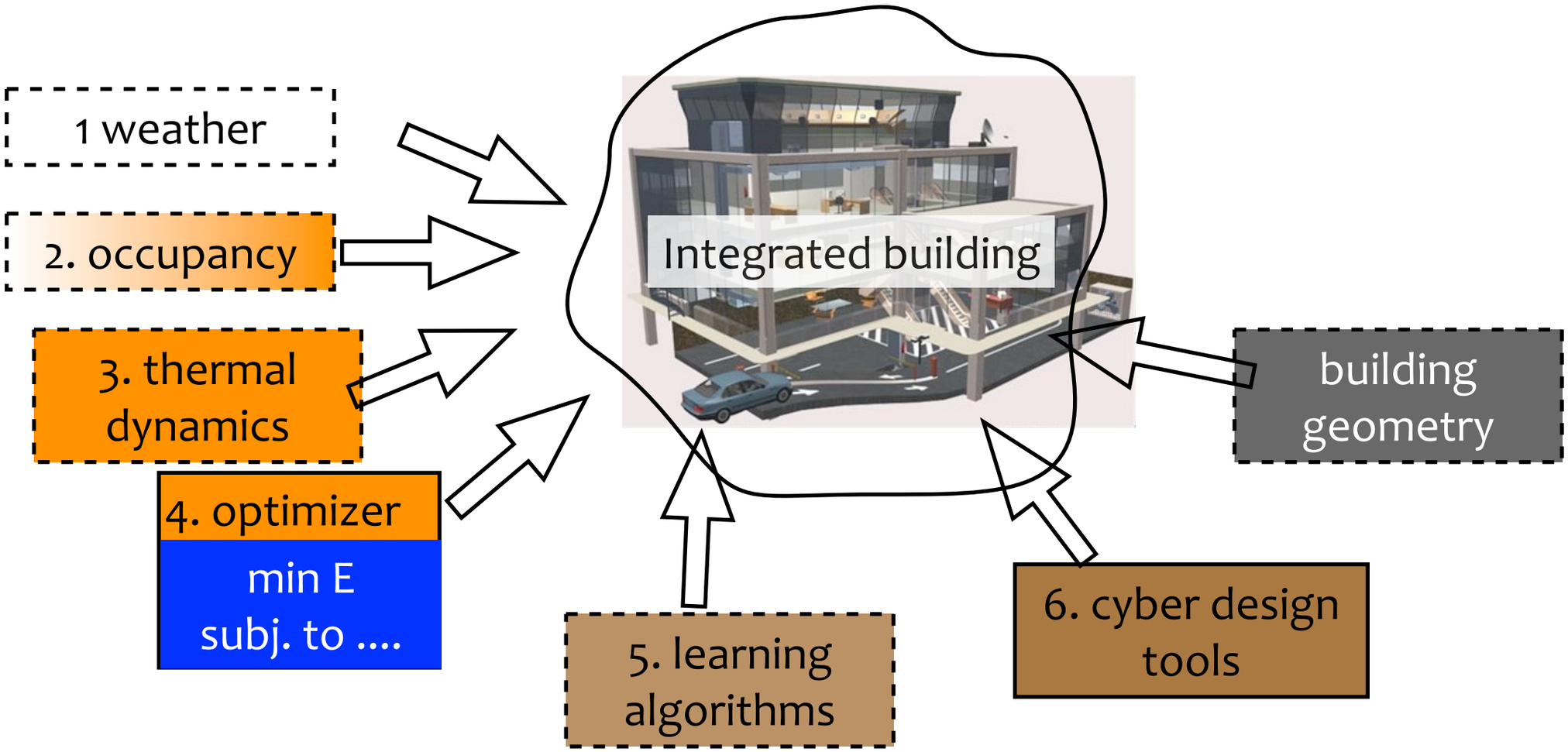
Communication Elements





Building physical constraints

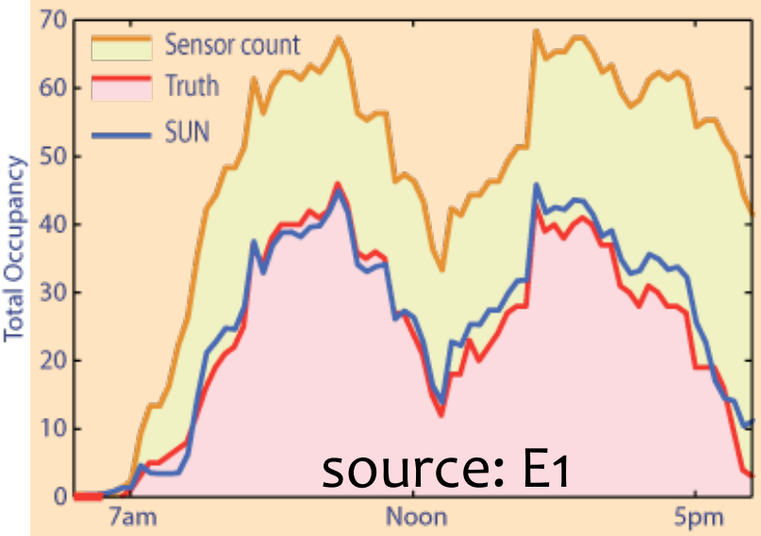
Integrated buildings : networked CPS



2. Occupancy (modeling,estimation,..)

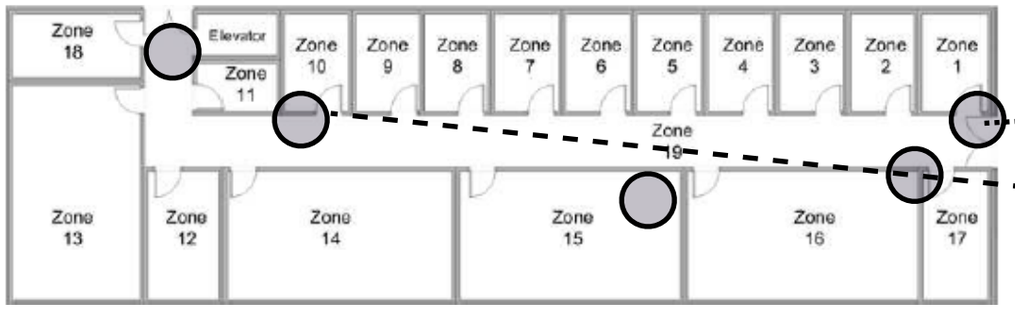
measurements + model of dynamics + (computation) => estimation and prediction

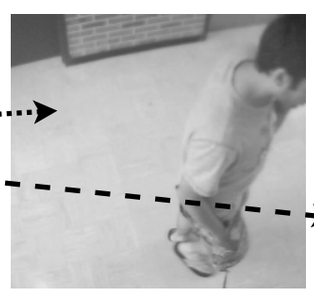
"flow rate" measurements lead to cumulative error!

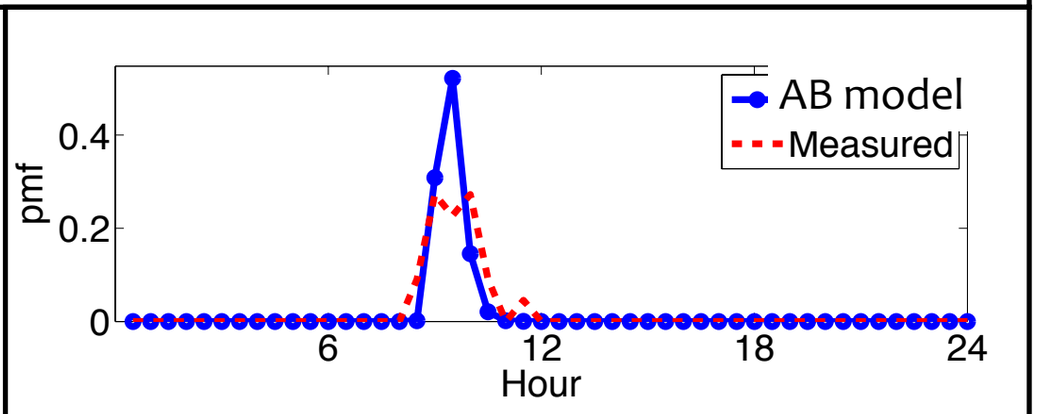


E1. Meyn, Surana, Lin, Oggianu, Narayanan and Frewen, IEEE Conference on Decision and Control, 2009

agent-based models
> captures building-level phenomenon from individual-level behavior
> extract reduced order (graphical) models for estimation/prediction







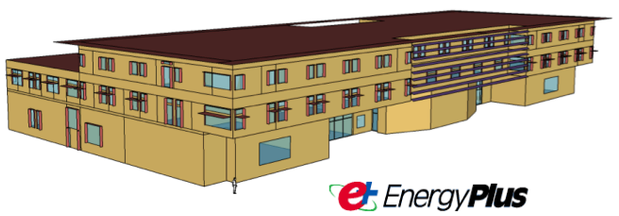
Publications:
1. C. Liao and P. Barooah, American Control Conference, July 2010
2. C. Liao and P. Barooah, Journal of Building Performance Simulation (in review)

3. Thermal and IAQ dynamics

$$\dot{X} = AX + BT_o + f(X, U, W)$$

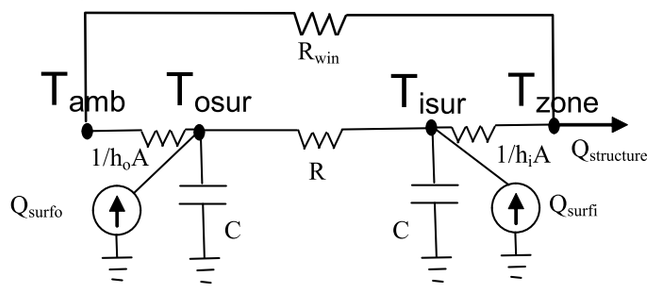
BMS data

Building geometry and materials



Recast

Dynamic Model (lumped RC network)



- standard practice, well validated
- lumped model, but ...

1 zone - 8 states
4 zones - 42 states
66 zones - 880 states
.....

Need further reduction of model order for real-time application

Structure preserving model reduction methods
> aggregation into a smaller RC-network through a Markov chain
> (on-line adaption of aggregate R,C values)
> extension into bilinear form

Publication
K. Deng, P. Barooah, P. G. Mehta, and S. P. Meyn. *Building Thermal Model Reduction via Aggregation of States*. American Control Conf., July 2010

6. Integrated CPS design environment

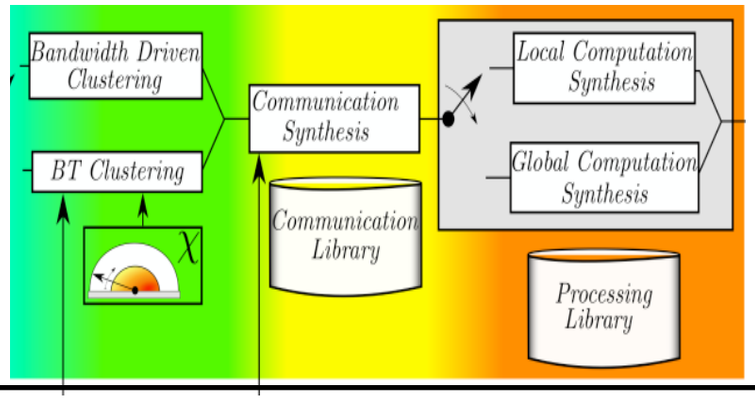
Bridging the gap from specification to implementation : Synthesis-based Design Methodology

Input

- Application Task Specification
- Physical Constraints
- Libraries of processing and communication elements

Design steps

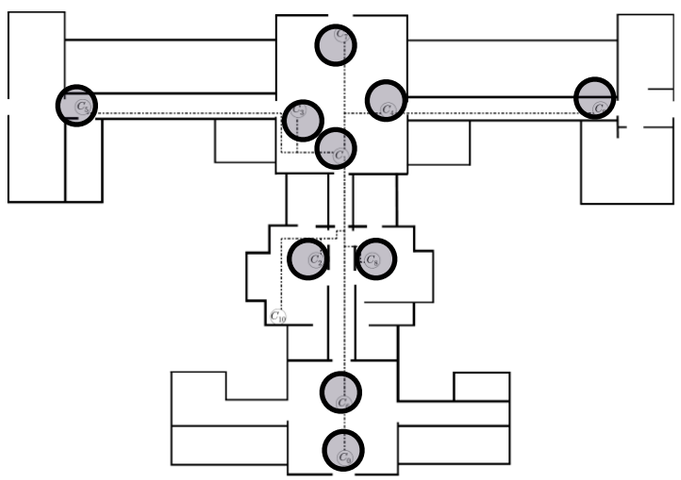
- Task Clustering
- Communication Synthesis
- Computation Synthesis



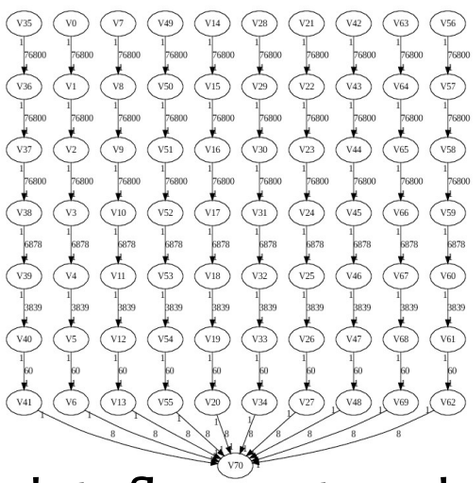
Output

- Choice of processing elements
- Mapping of actors to processing elements
- Implementation of the interconnection network

Case study: camera network design for occupancy estimation



building layout and camera locations



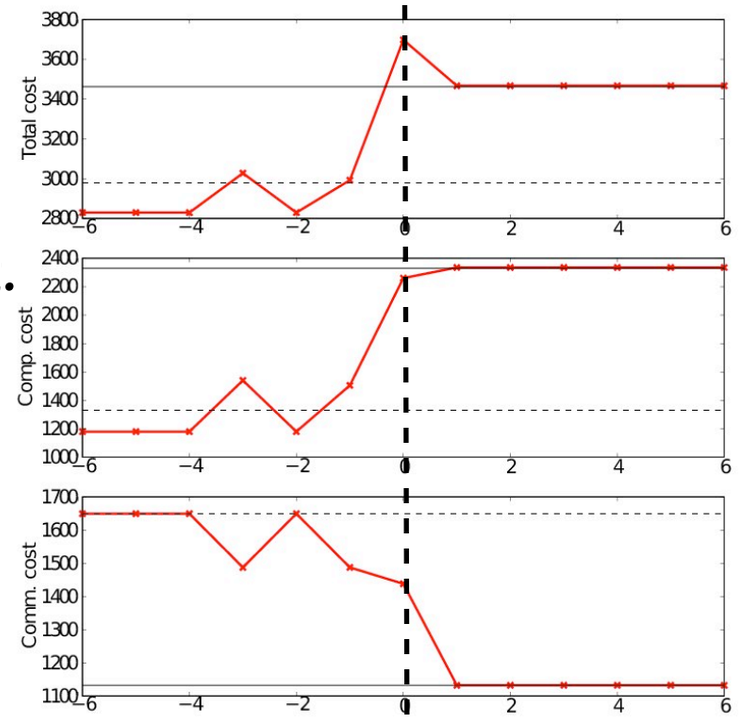
dataflow network

Centralized | Distributed

Total cost

Comput. cost

Comm. cost



Summary

- Buildings are the largest consumers of energy
- Buildings are complex cyber physical systems
- Computation, communication and control
- Adaptation to time-variations is crucial
- Large (un-utilized) data streams

Pugh Hall (UF campus)

- 53,000 sq. ft., LEED Silver
- 3 AHUs, 66 VAV boxes,
- > 1000 “points”

- Value of information: what to measure, what to model?
- Appropriate CPS performance metrics?
- Information management and longevity?