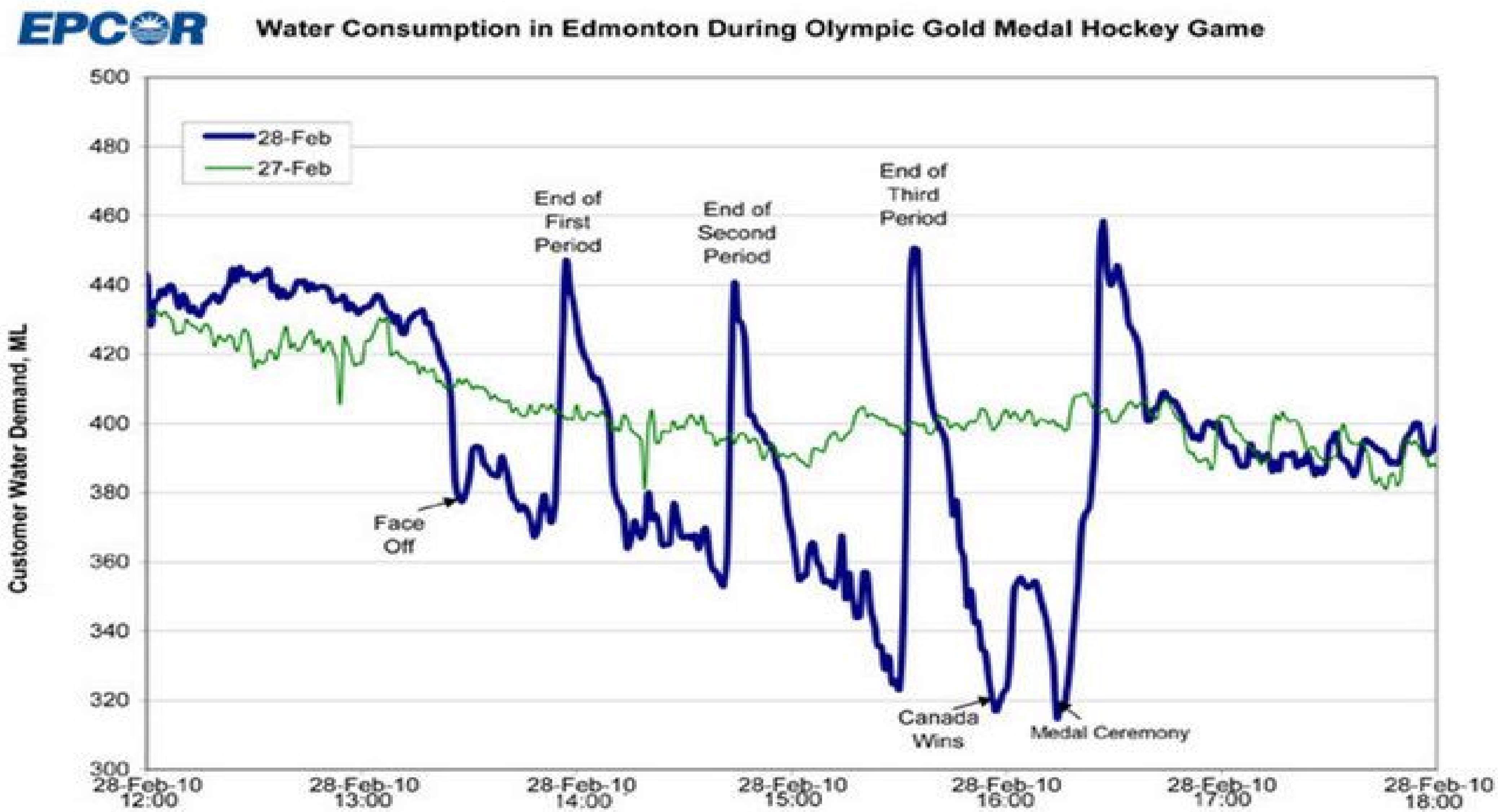
Computational Intelligence and Energy

A 'Bridging the Gap' workshop
Sponsored by EPSRC
14/04/2010



EPCOR
Water Consumption in Edmonton During Olympic Gold Medal Hockey Game
28-Feb
27-Feb
Customer Water Demand, ML
500
480
460
440
420
400
380
360
340
320
300
End of First Period
End of Second Period
End of Third Period
Face Off
Canada Wins
Medal Ceremony
28-Feb-10 12:00
28-Feb-10 13:00
28-Feb-10 14:00
28-Feb-10 15:00
28-Feb-10 16:00
28-Feb-10 17:00
28-Feb-10 18:00

Big Areas

- Data Analysis
- Modelling, Simulation
- Optimization
- Autonomous Agents (devices, users)

Program

9.30- 9.50 **Introduction to the Workshop** Dr. Thorsten Schnier, Computer Science, University of Birmingham

9.50-10.25 **Understanding Household Consumption: Approaches to automatic load disaggregation** Dr. Chris Bowers, School of Computer Science, UoB

10.25-11.00 **Data Driven Thermal Modelling of Buildings** Dr. Thorsten Schnier, Computer Science, UoB

11.00-11.30 *Coffee Break*

11.30-12.05 **Multi-objective Evolutionary Building Design** Prof. Jonathan Wright, Civil and Building Engineering, Loughborough University

12.05-12.40 **Intelligent Optimisation Algorithms - Aplication Examples in Power Systems** Dr Jihong Wang, School of Electrical Engineering, University of Birmingham

12.40-13.40 *Lunch*

13.40-14.15 **What Distributed Agent-Based Modelling can do for Energy Networks** Dr. Bart Craenen, School of Computer Science, University of Birmingham

14.15-14.50 **Smart Grids: From Theory to Practice Dr. Xiao-Ping Zhang**, School of Electrical Engineering, UoB

14.50-15.10 *Coffee break*

15.10-15.45 **An Agent Based Approach to Analysing Electricity Markets** Andrew Fielder, Computer Science, UoB

15.45-16.15 **Workshop Summary** Prof. Xin Yao, Computer Science, University of Birmingham

Natural Computation and Energy Data

Making sense of Smart Metering

Thorsten Schnier, Cercia

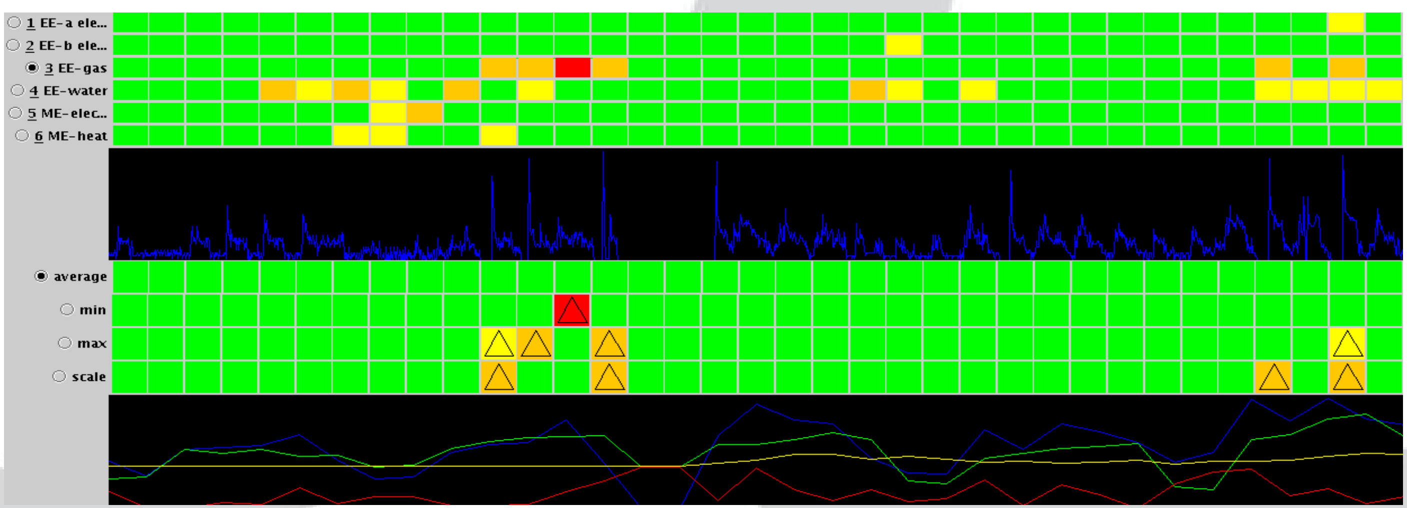
Chris Bowers, Xiaoli Li, Xin Yao

Everyone is on about energy...

- Ambitious reduction targets
- Fairly little action...
- Cuts needed in all areas
- Smart metering to be rolled out to domestic properties
- Do we understand our energy consumption?

Did something just happen?

- Smart metering in larger sites
  - e.g. UoB campus
- Large amounts of data, one person responsible
- Can we help this one person?



Detecting 'unusual' events

- Works by...
  - Identifying correlations
  - Comparing predicted/measured values
  - Classifying likelihood and scale of 'surprise'
  - Constantly updates model
- Drawbacks
  - Won't catch slow drift
  - Does not provide analysis

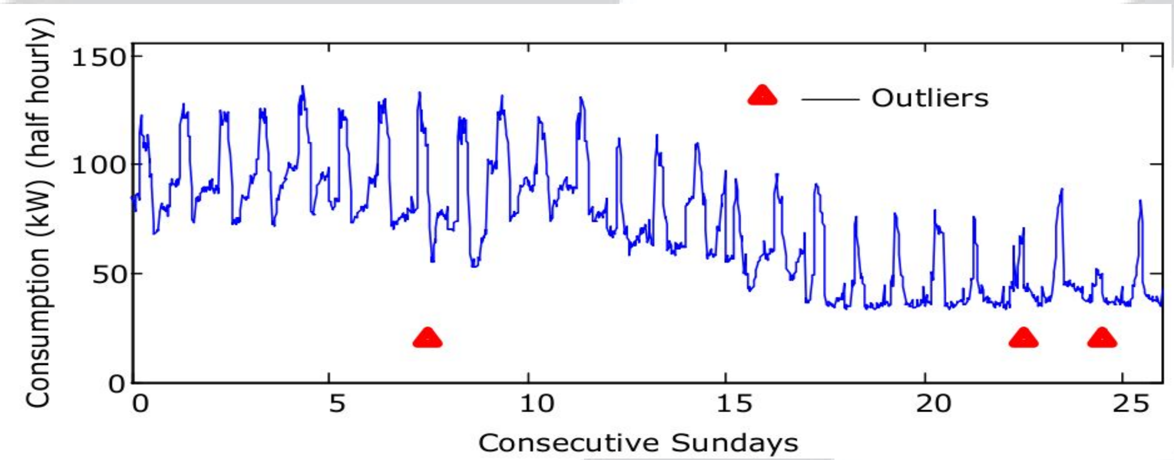
Is it Sunday yet?

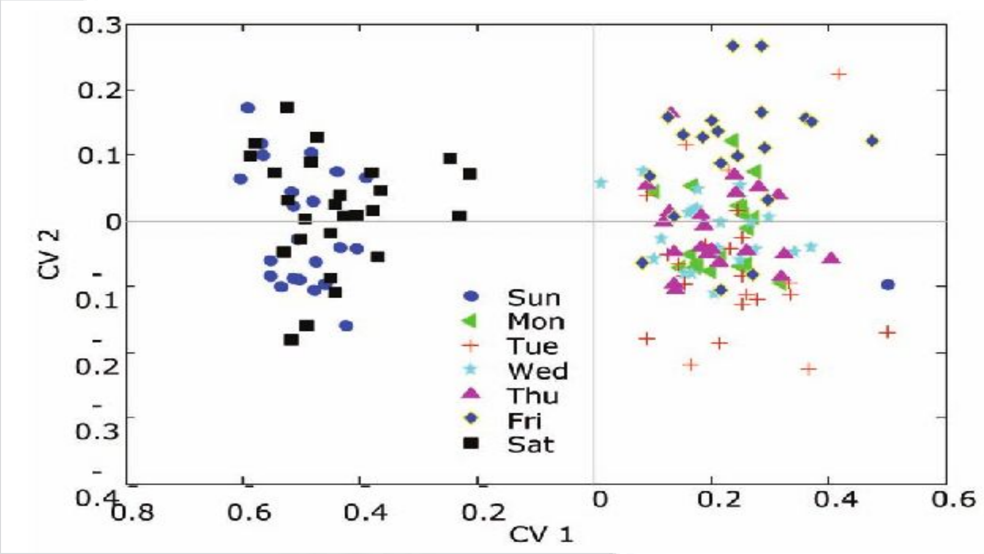
- Classification of time series data
  - Weekday/weekend
  - Working patterns (incl. daylight saving time)
  - Public holidays
  - 'Unusual' events
- Extremely useful for later analysis

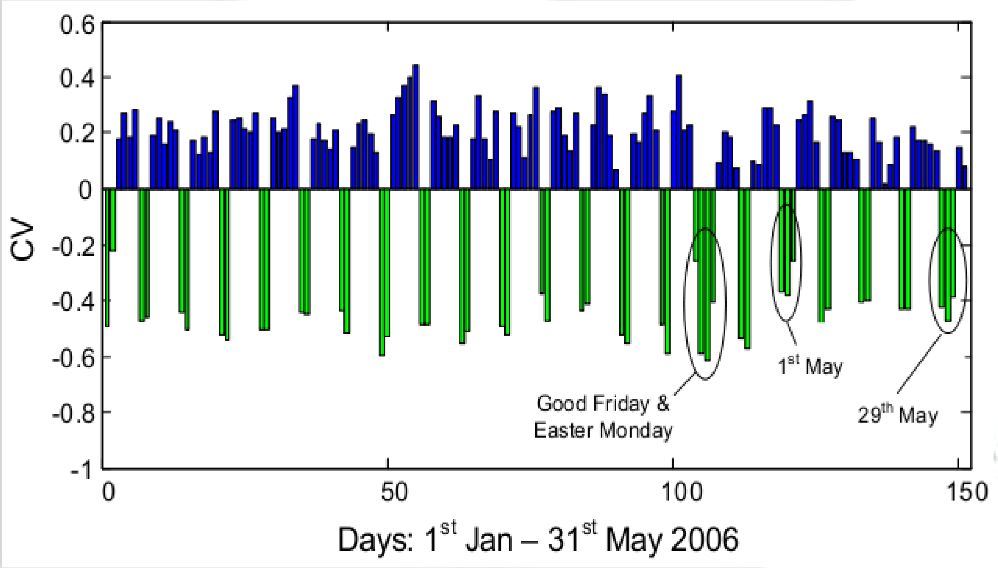
Is it Sunday yet?

1. Feature extraction: Mean, Peak, 2nd order auto-regression over the day (a1, a2)
2. Outlier detection: Q-test on a per-feature base
3. Canonical variates analysis (CVA), Linear discriminate analysis (LDA)

Classification and Outlier Detection



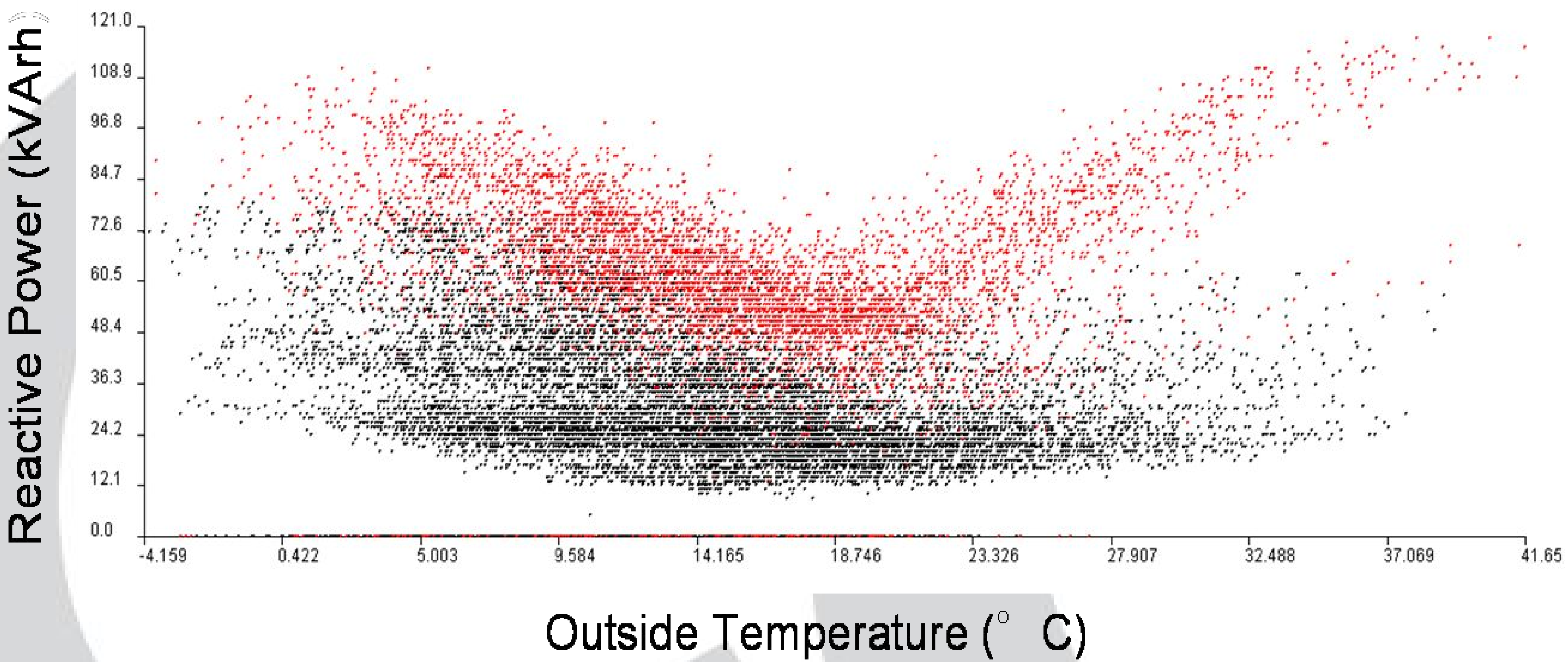




Is it just me or is it very warm today?

- Modelling of building thermal dynamics
  - Heating, cooling, losses, gains, ...
  - Structural changes
- Just based on meter point data
  - Plus local weather info

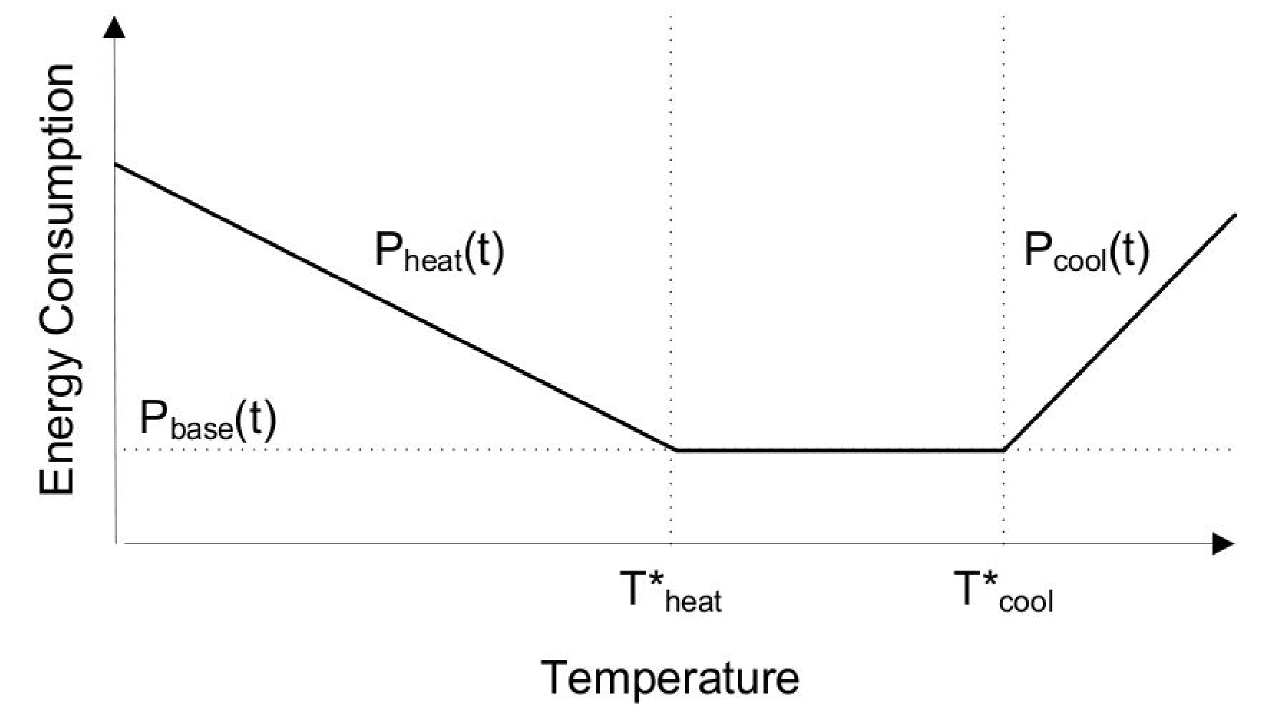
Clear temperature correlation



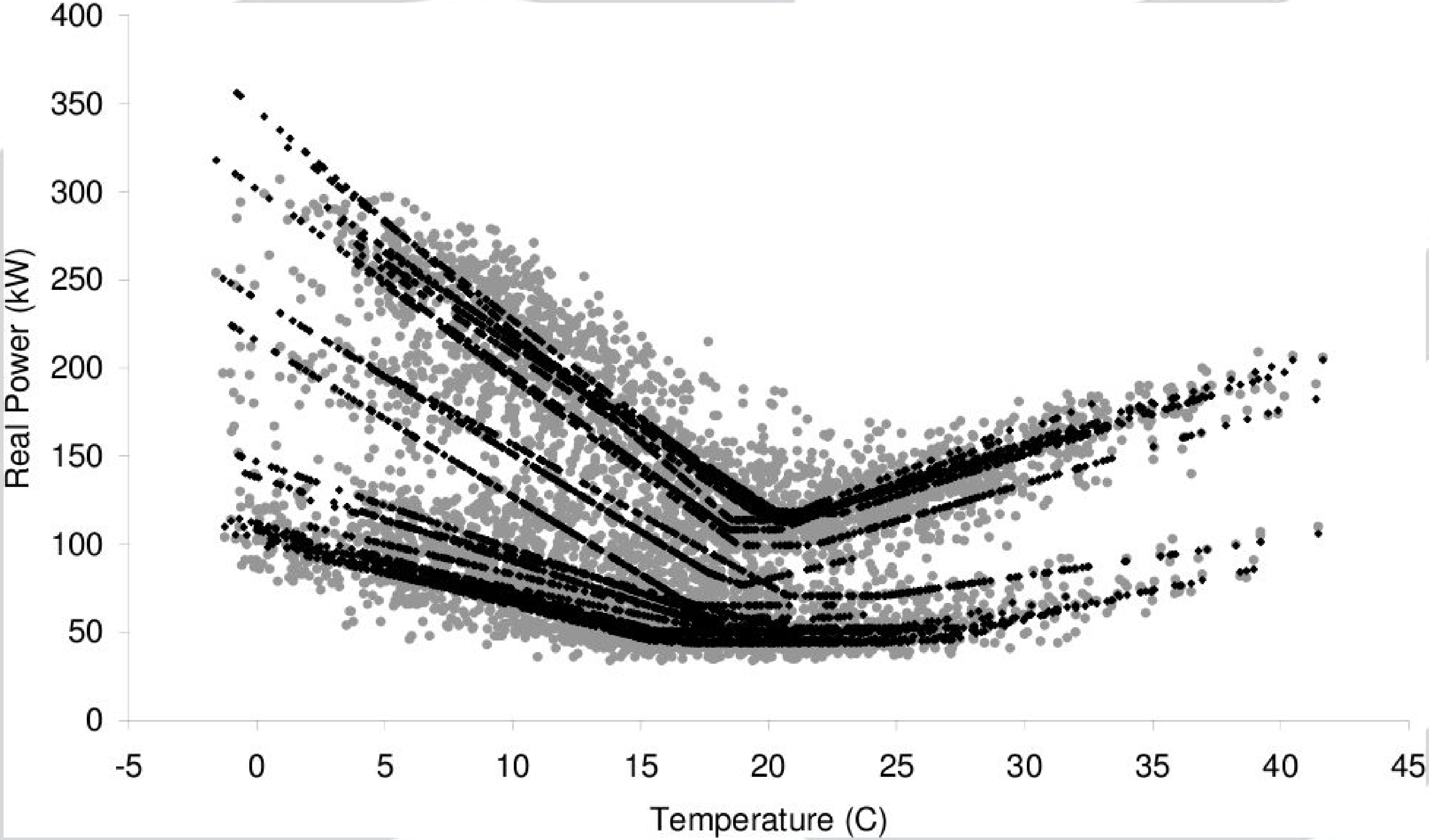
Simple static model

7 * 24 independent models with 5 variables

(840 variables, or 1010 with reactive data)

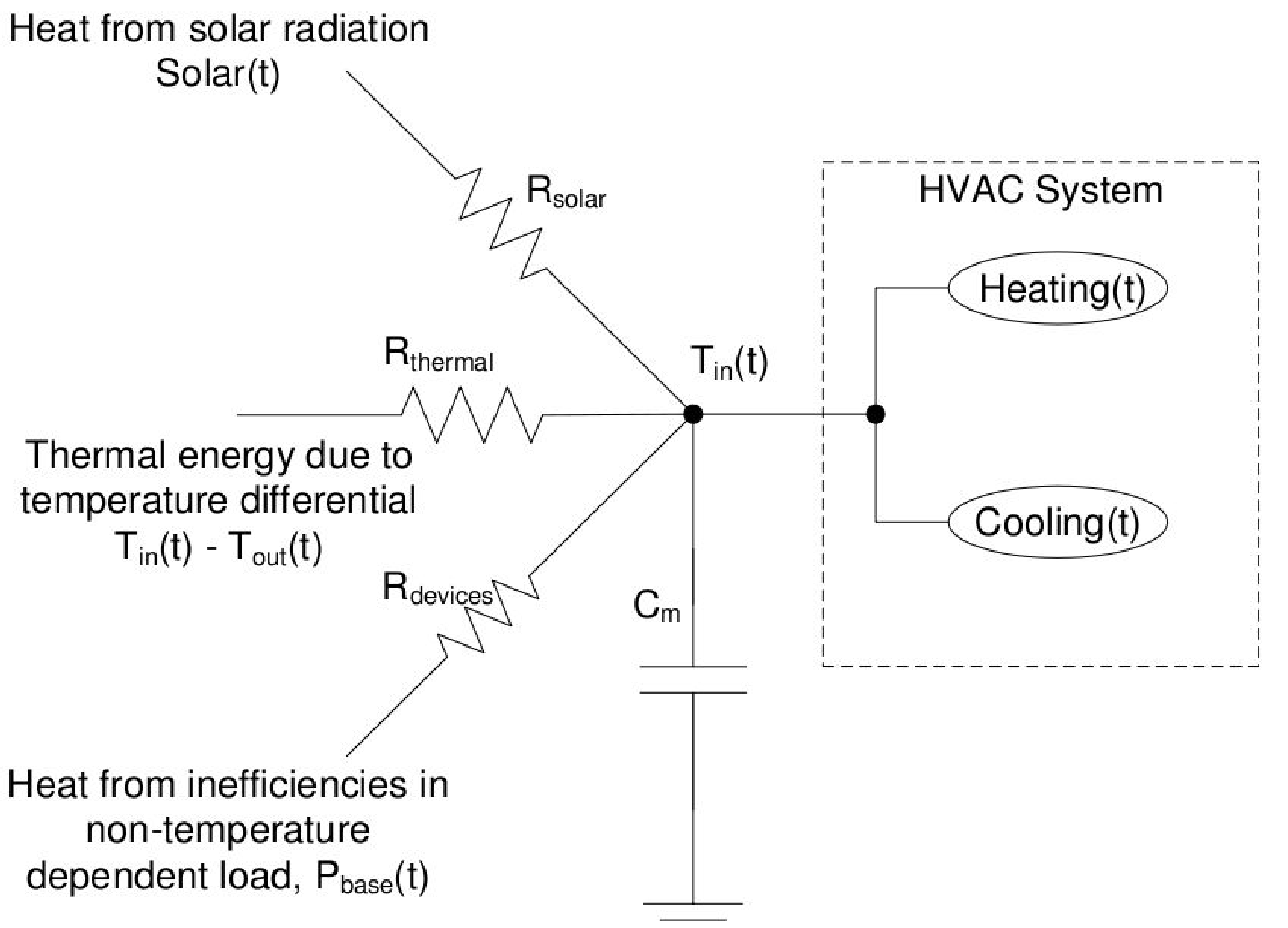


Even better if broken down by hour



Simple dynamic model

- Simple dynamic model



Hourly model updates

$$Q_{thermal}(t) = \frac{T_{out}(t) - T_{in}(t)}{R_{thermal}} \quad Q_{solar}(t) = \mu_{solar} \cdot Solar(t) \quad Q_{devices}(t) = \epsilon_{devices} \cdot P_{base}(t)$$

$$T_{passive}(t) = T_{in}(t-1) + \frac{1}{C_m}\left(Q_{thermal}(t) + Q_{solar}(t) + Q_{devices}(t)\right)$$

$$Q_{heat}(t) = \min\left(C_m \cdot \lambda_{heat} \cdot \max\left(T^*_{heat}(t) - T_{passive}(t), 0\right), Q_{Hmax}\right)$$

$$Q_{cool}(t) = min\left(C_m \cdot \lambda_{cool} \cdot \max\left(T_{passive}(t) - T^*_{cool}(t), 0\right), Q_{Cmax}\right)$$

$$T_{in}(t) = T_{passive}(t) + \frac{Q_{heat}(t)}{C_m} - \frac{Q_{cool}(t)}{C_m}$$

$$P_{real}(t) = P_{base}(t) + \eta_{heat} \cdot Q_{heat}(t) + \eta_{cool} \cdot Q_{cool}(t)$$

$$P_{reactive}(t) = P_{ibase}(t) + \rho_{heat} \cdot Q_{heat}(t) + \rho_{cool} \cdot Q_{cool}(t)$$

Surprisingly hard to evolve

- Evolutionary 'tricks'
  - Self-adaptive evolutionary programming
  - Special mutation operators for time series
  - Initialization with 'sensible' values
  - Inherently stable building controllers
- Fitness: Mean Absolute Error
- 10 + 3 * 24 * 7 (= 514) parameters
  - (+ 2 + 24*7 parameters with reactive data)
- Also work on differential evolution

Test sites

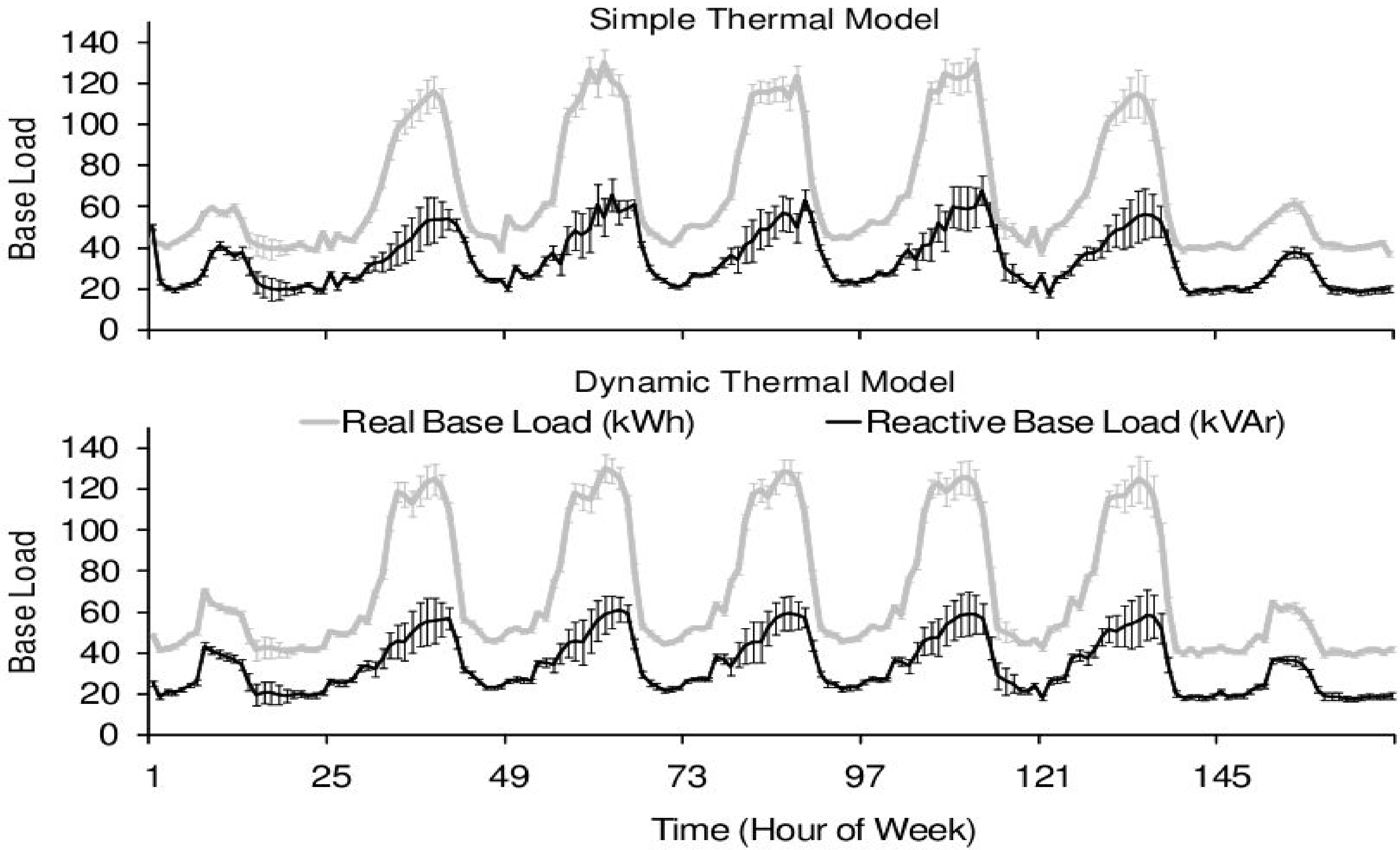
Real-world building

- Industrial site, 1 year data, only meter point data (hourly), weather data from University
- Mixed building structure, large cooling/heating loads, no gas,

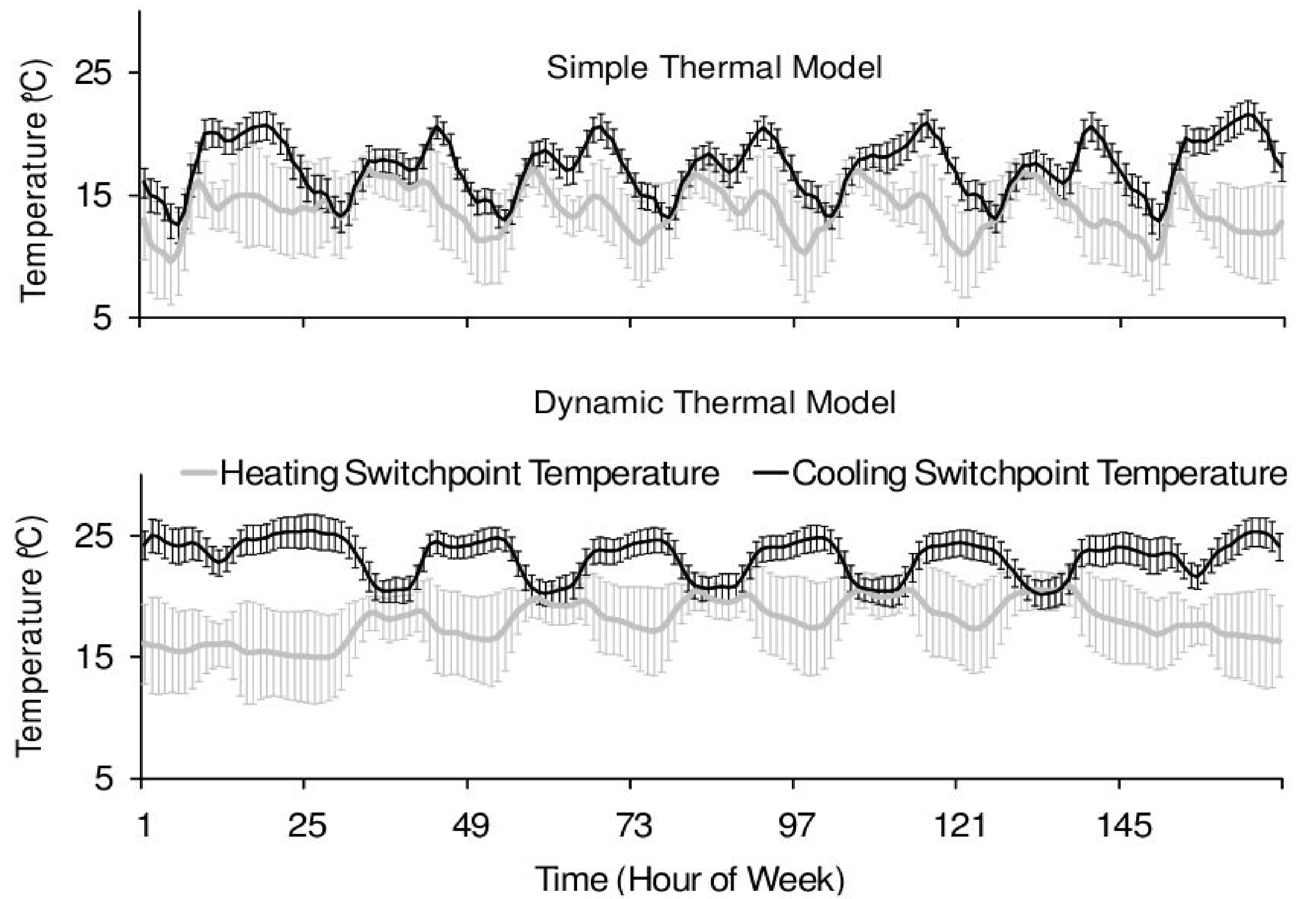
Simulation validation

- EnergyPlus simulation, standard retail building
- Full sub-metering, Chicago weather data

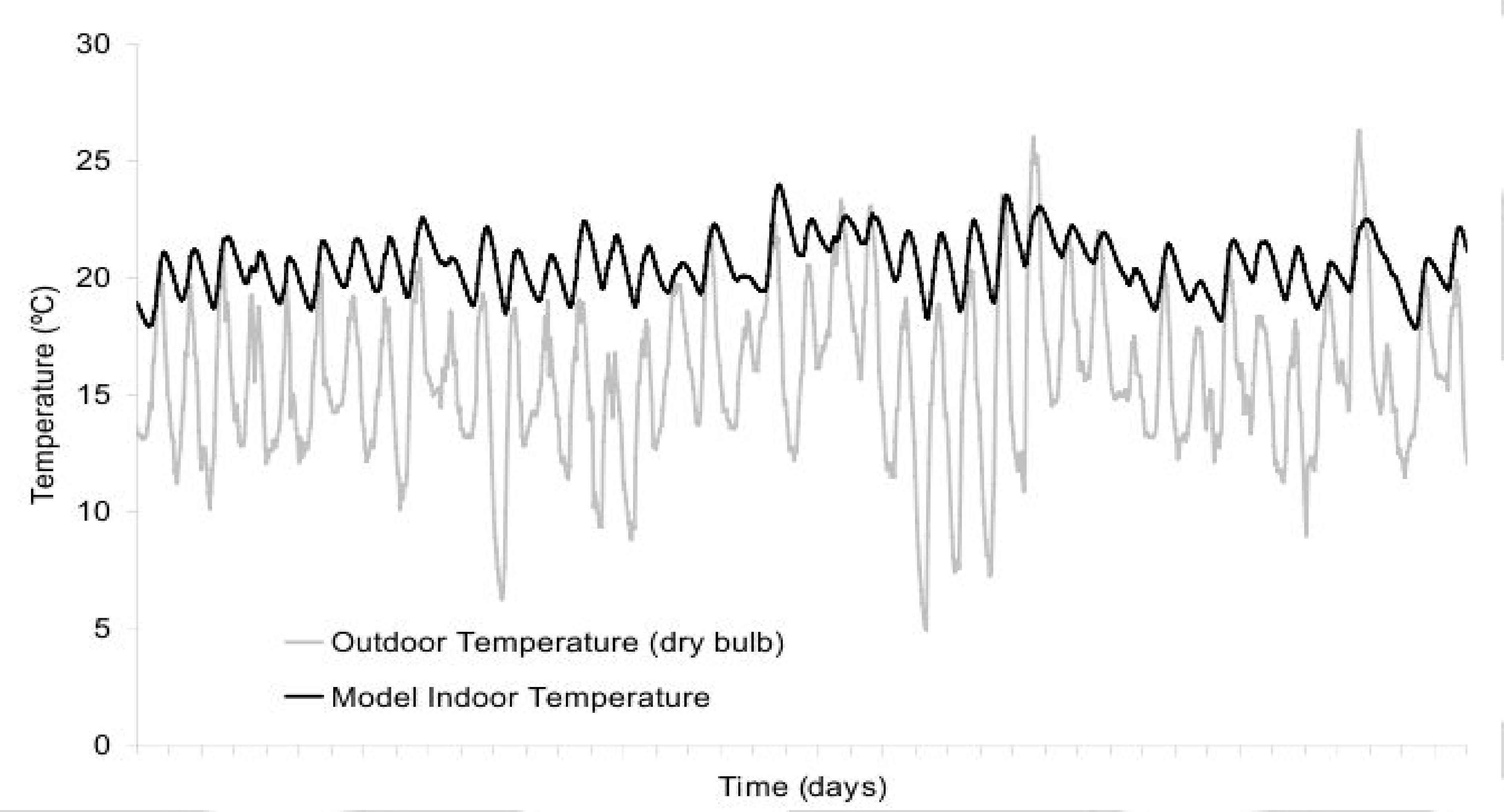
Base loads


Simple Thermal Model
140
120
100
80
60
40
20
0
Base Load
Dynamic Thermal Model
Real Base Load (kWh)
Reactive Base Load (kVAr)
140
120
100
80
60
40
20
0
Base Load
1
25
49
73
97
121
145
Time (Hour of Week)

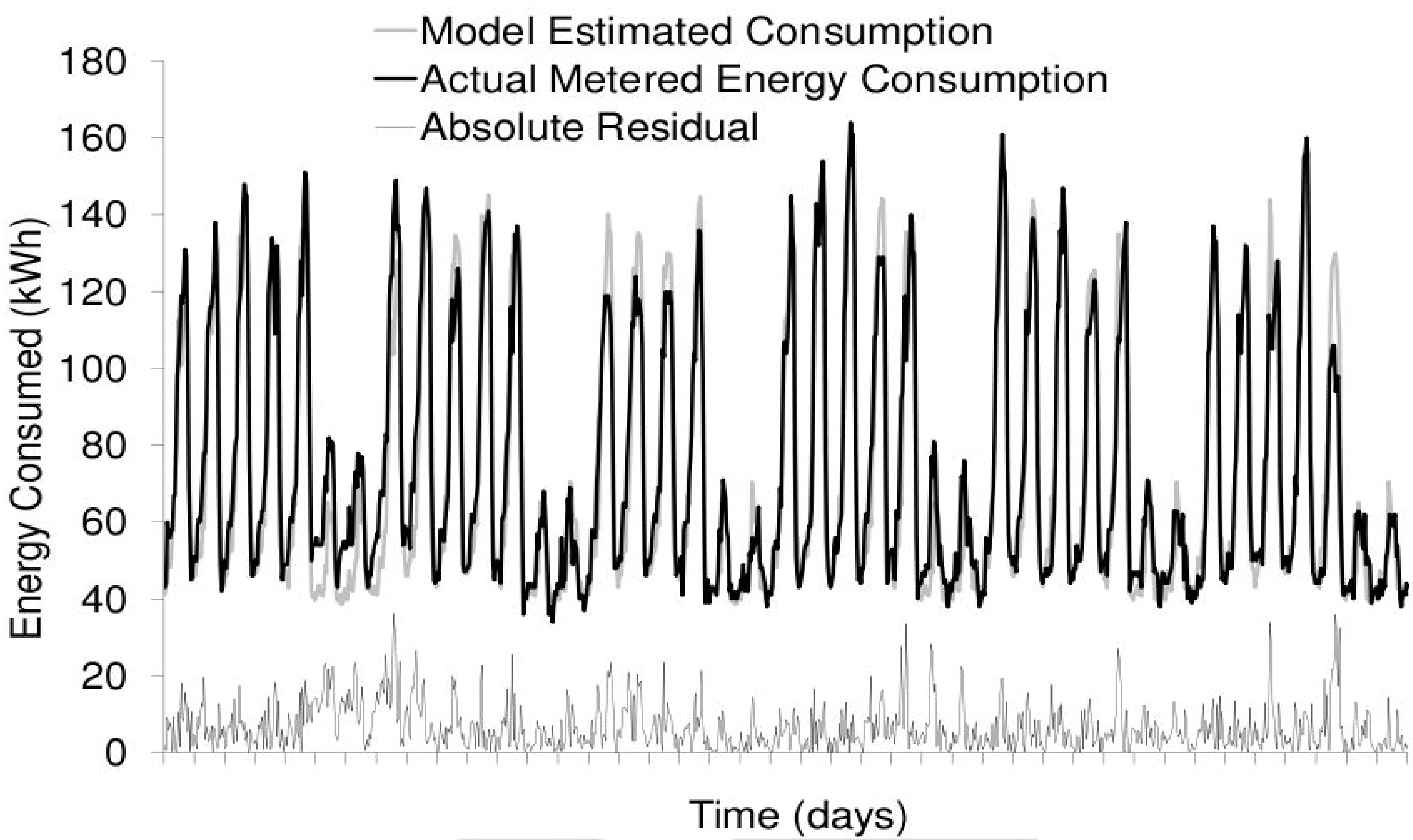
Temperature Goals



Model Temperatures



Consumption Estimates



Model results

	Steady State Model		Dynamic Model		Simulation
	best	average	best	average	
total MAE (kWh)	16.02	16.67(±0.77)	11.75	12.35(±0.46)	
heat MAE (kWh)	14.75	15.30(±0.65)	10.24	10.72(±0.41)	
cool MAE (kWh)	1.63	1.86(±0.21)	1.60	1.93(±0.45)	
annual heat (kWh)	245484	240069(±4414)	264435	256588(±9009)	273197
annual cool (kWh)	24272	22338(±1668)	26416	21361(±6256)	30693
annual load (kWh)	561865	557803(±5049)	577285	571152(±6925)	589469

What can we tell?

- Heating/Cooling/Other Energy use breakdown - *very high*
- Heat flow breakdowns - *medium (*)*
- Temperature Dependency - *high*
- Solar Dependency - *medium*
- Usage patterns - *very high*
- As Predictive Model - *high - very high*
- *What-if* scenarios, intervention analysis: *medium (*)*

(*) given certain assumptions

What about the parameters?

- Building Mass, Thermal Coefficient, Solar Coefficient, ... ?
- Not orthogonal - some interdependency
- Range of answers - no clear fitness correlation
- Enough data ? More knowledge?

Model Issues

- Heating and Cooling at the same time?
- Single building mass - only one state variable
- But - enough data/systematic error ?

Summary

- Very promising:
  - Entirely data-driven
  - Valuable results
- Room for improvement
  - More domain knowledge
  - Calibration
  - Information from extreme events
  - Better model