The Smart Thermostat: Using Occupancy Sensors to Save Energy in Homes

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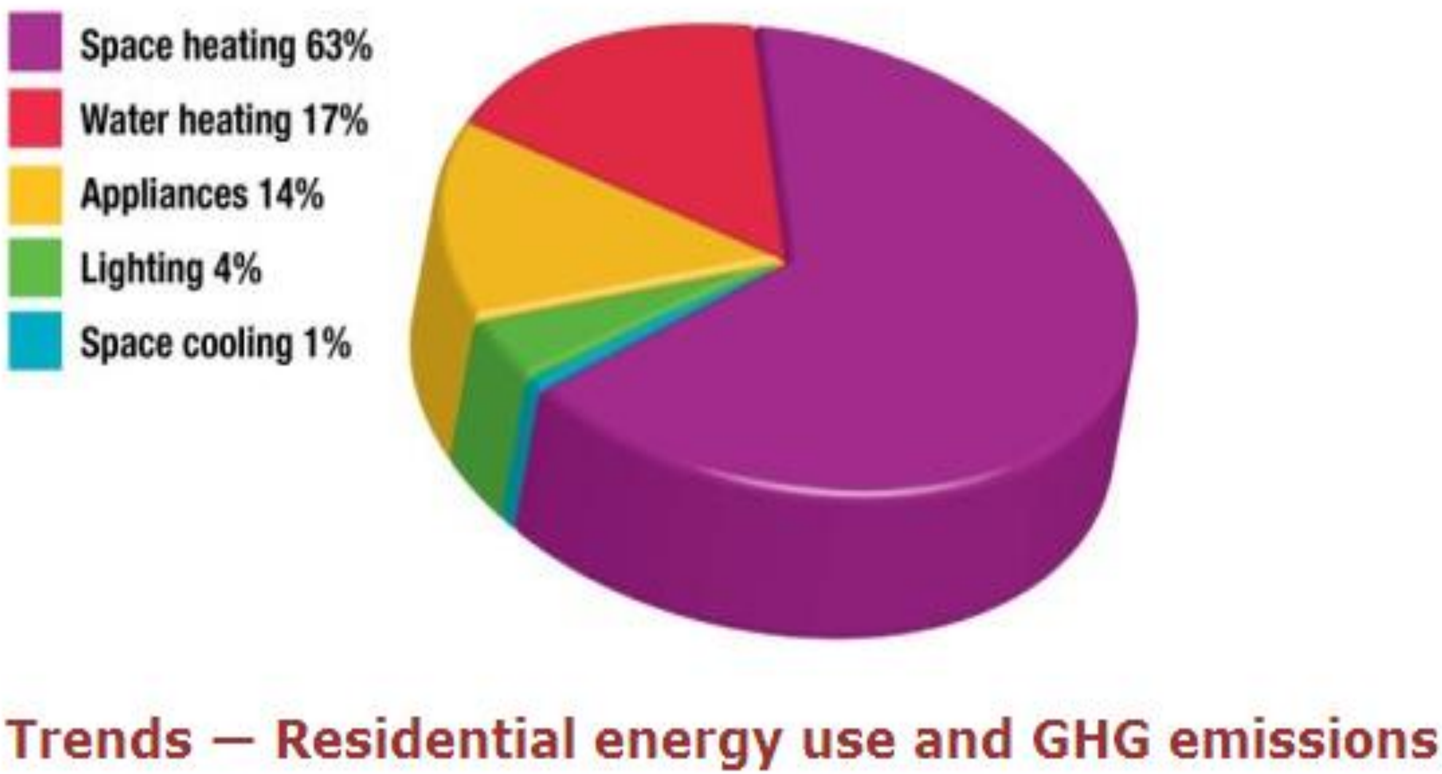
ECE 720 – Cyber Physical Systems

Outline

- Introduction
- Related Work
- Proposed Solution
- Challenges
- The Smart Thermostat
- Experimental Setup/Evaluation
- Limitations and Future Work
- Conclusion

Introduction

HVAC – Heating, Ventilation and Cooling



Office of Energy Efficiency, Canada - 2009

Introduction (Problem Definition)

20 – 30% of this energy could be saved by turning off the HVAC system when residents are away or sleep.

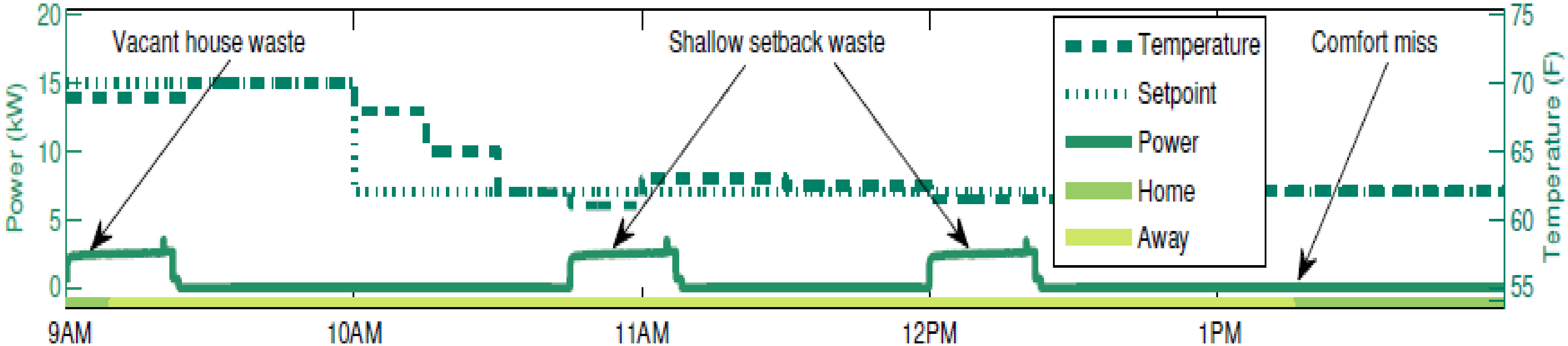
QUESTION: What's the justification; All this hassle for optimizing will only save me about $15/month. So is it worth it?

ANSWER: National Impact. "Tragedy of the commons"

- Saves 100billion kWh which is $15billion annually.
- Prevents approx 1.12billion tons of pollutants emission

Related Work (Programmable Thermostats)

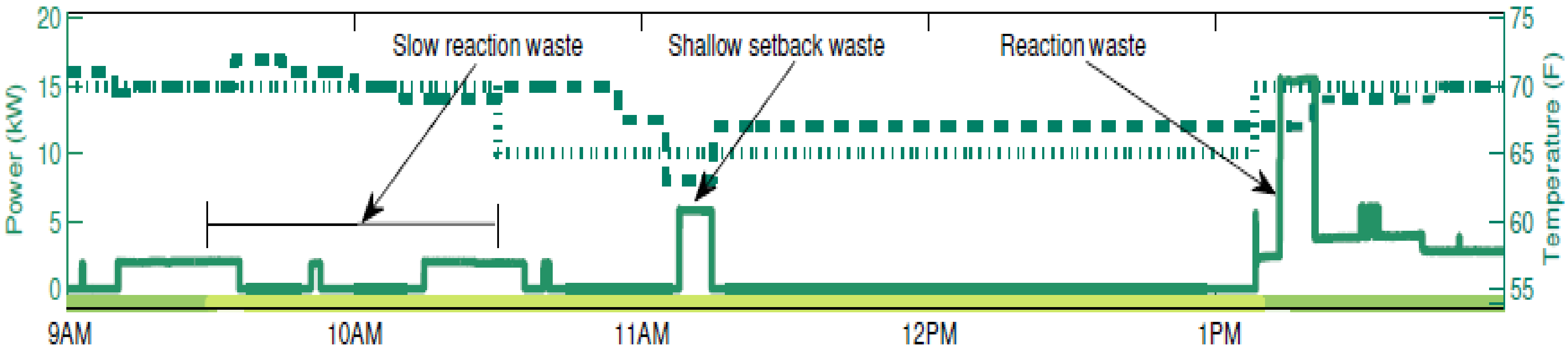
- Uses Setback Schedule



Not Efficient!

Related Work (Reactive Thermostats)

Uses motion sensors, door sensors or card key access systems to turn the HVAC on or off based on occupancy.



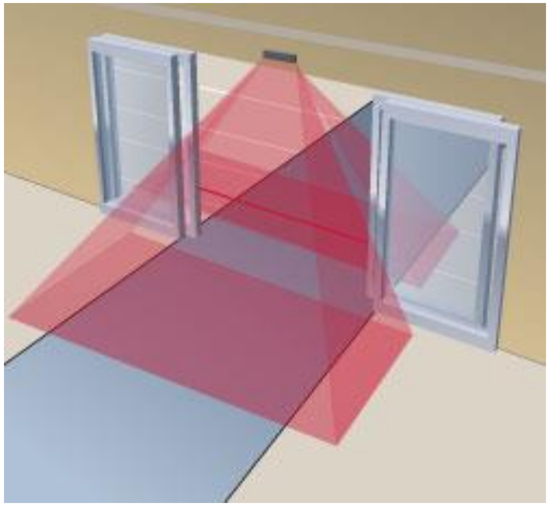
Saves less energy than Programmable!

Not Efficient!

Proposed Solution (The Smart Thermostat)

Uses occupancy sensors to automatically turn off the HVAC system when the occupant are sleeping or away.

<Approach> Wireless motion sensors and door sensors



<Aim> Turn the HVAC system off as much as possible to **SAVE ENERGY** without sacrificing **OCCUPANT COMFORT**.

Challenges

1. Motion sensors are poor!

Solution: A novel algorithm that analyzes patterns in the sensor data.

2. When to turn the HVAC back on!

(Too early or too late will waste energy)

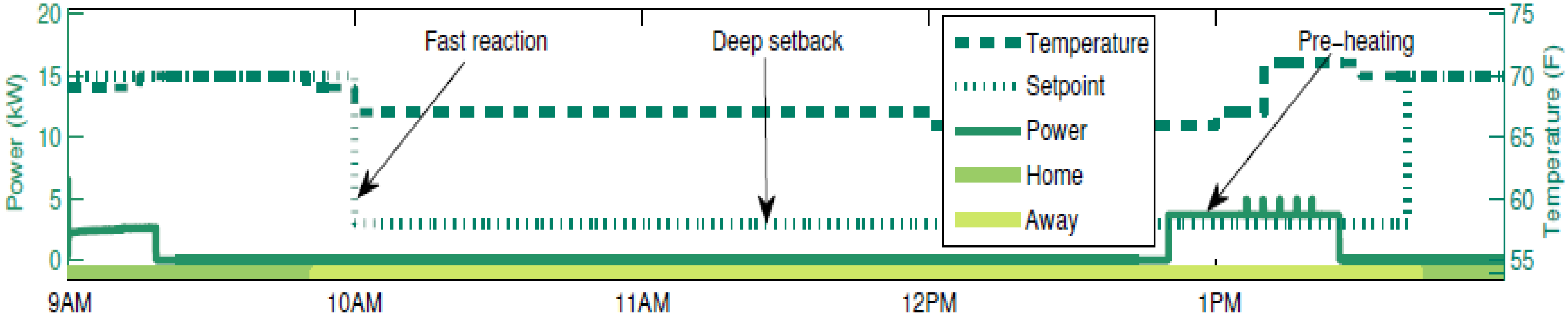
Solution:

- Calculation of best possible preheat time, t
- Use of higher efficiency equipment to slowly preheat – Heat pumps.
- Use of lower efficiency equipment to respond to quick heating – Electric Coils, Gas furnace

Smart Thermostats

3 Energy Saving Technique

1. A probabilistic Model to process sensor data and estimate state.
2. Combine historical occupancy patterns with online sensor
3. Deep Setback

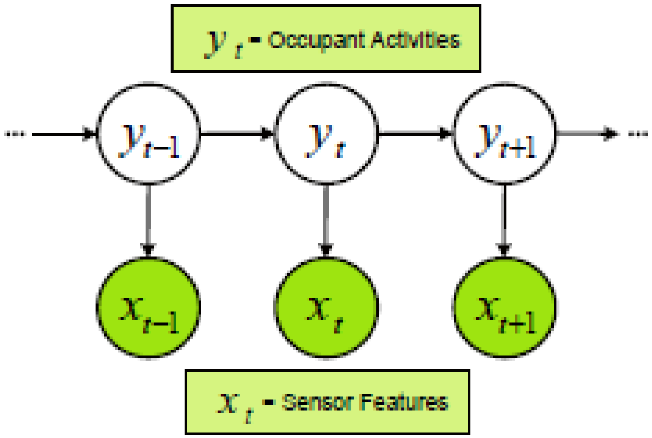


Smart Thermostat: 28% Energy Savings

Reactive Thermostat: 6.8% Energy Savings

Turning the HVAC System Off

Hidden Markov Model (HMM) to estimate the probability of the home in 3 states (Away, Active or Sleep)



(yt) – distribution over the home state; Away, Active, Sleep
xt – vector of 3 features of the sensor data
i. time of the day at 4-hour granularity.
ii. Total number of sensor firing in the time interval dT
iii. Binary to indicate presence of front door, etc. sensor firing in the time dT.

(These features are calculated every five minutes)

Turning the HVAC System On

Challenge: whether and when to preheat the house.

Preheating too early or too late, not good!

Solution:

- Get an optimal preheating time, T that minimizes the long-term energy usage.
- Then slow preheating with high efficiency equipment to time, T. (a > T)
- If early return, (before T) switch to high capacity but low efficiency equipment for quick heating. (a < T)

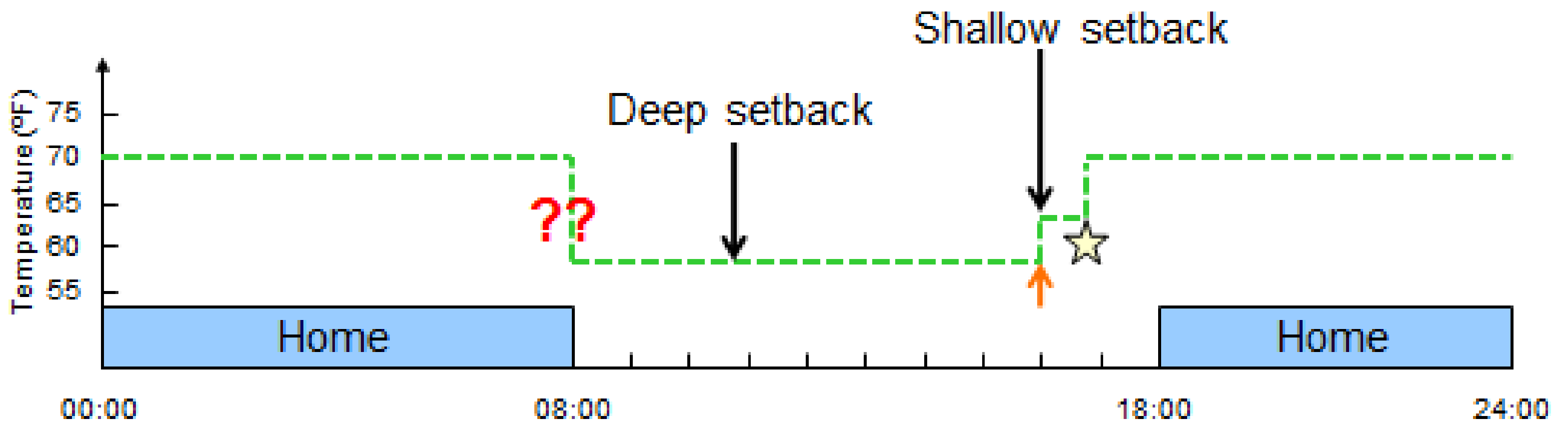
To get T, 2 important steps:

- Know the capacity and efficiency for each stage of the HVAC System.
- Analyze historical occupancy pattern of the home.

Note: [a – arrival time]

Using Deep Setbacks

Example: As low as 10°C for heating and high as 40°C for cooling.

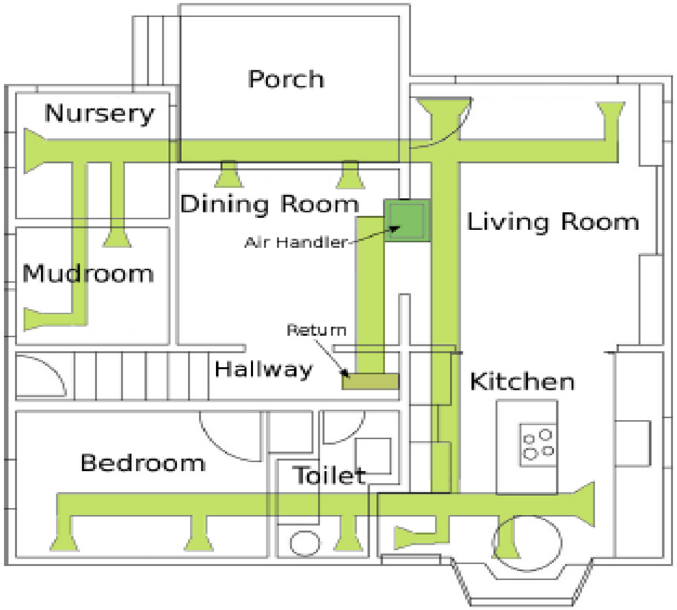


Experimental Setup

- Empirical data traces from 8 instrumental homes
- Occupant survey of 41 homes
- 2 public smart home datasets (collected by manually labelling leave, return, sleep etc. time)

Model the home in the figure using **EnergyPlus Simulator** to general energy predictions and compare with empirical energy measurements

(Various conditions such as different climates considered)



Experimental Setup

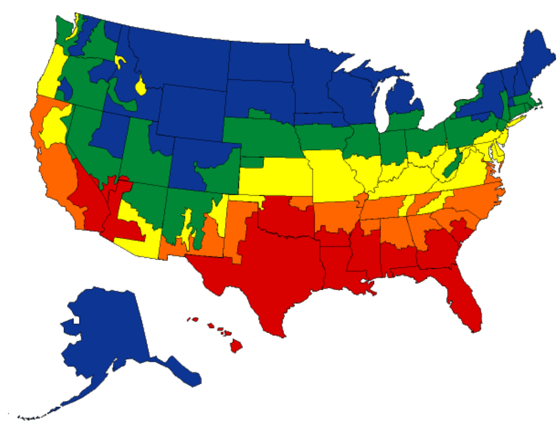
- Person Types




- House Types



- Climate Zones

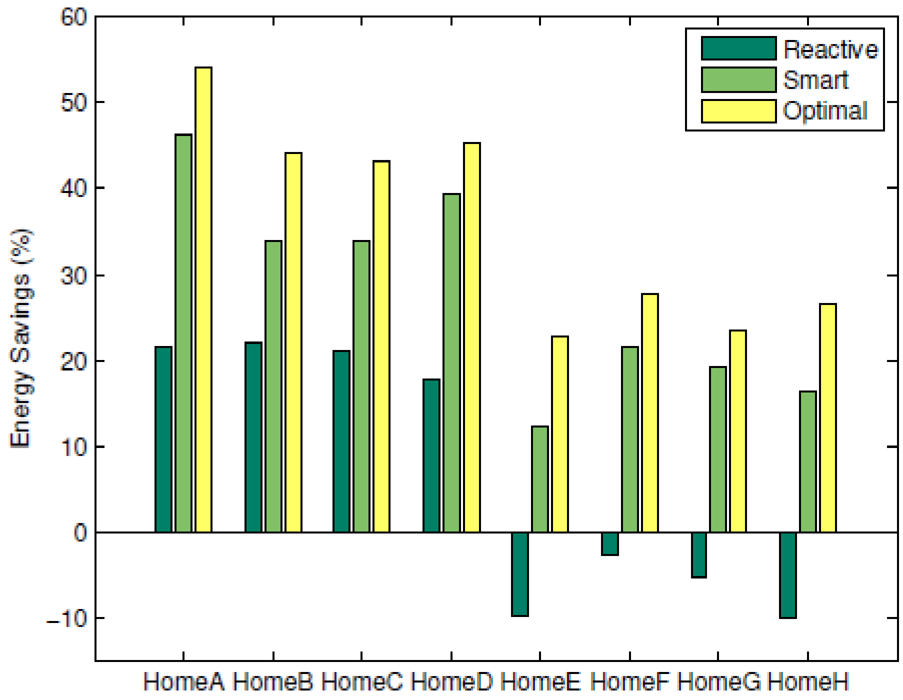


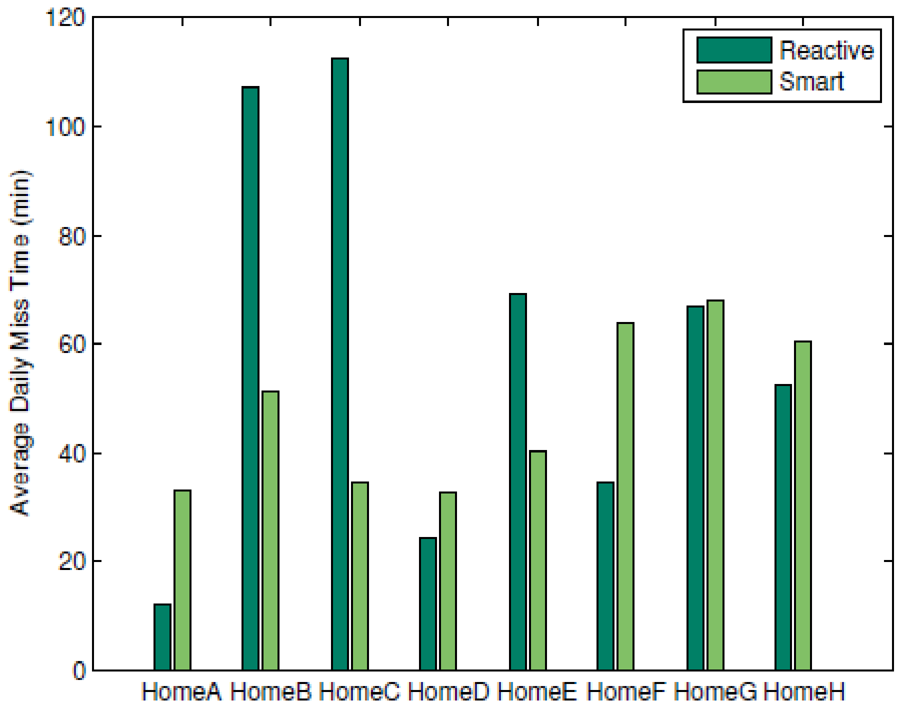
Zone 1	Minneapolis, MN
Zone 2	Pittsburg, PA
Zone 3	Washington, D.C.
Zone 4	San Francisco, CA
Zone 5	Houston, TX

Evaluation

Energy Efficiency + User Comfort

(energy savings) (miss time)



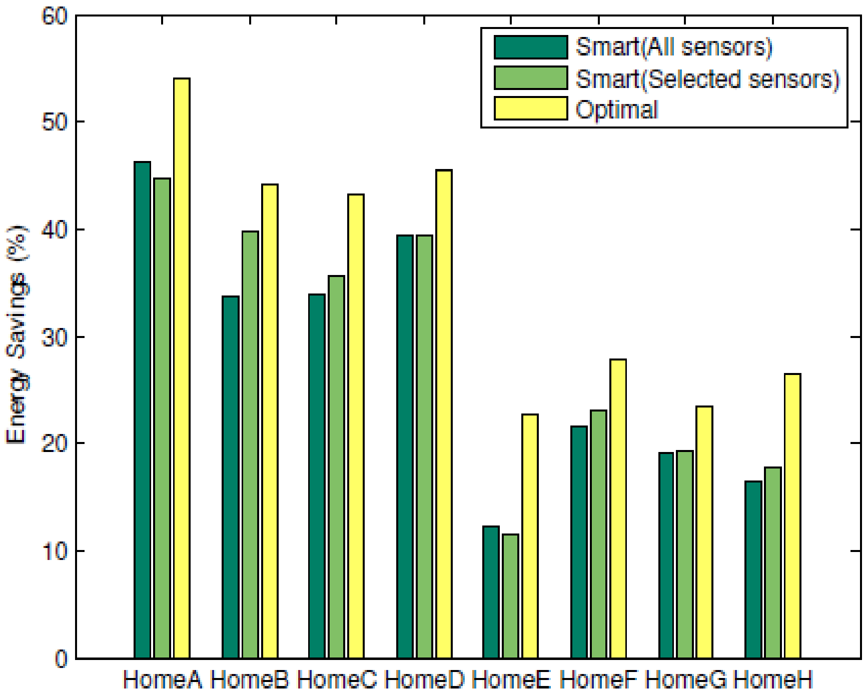


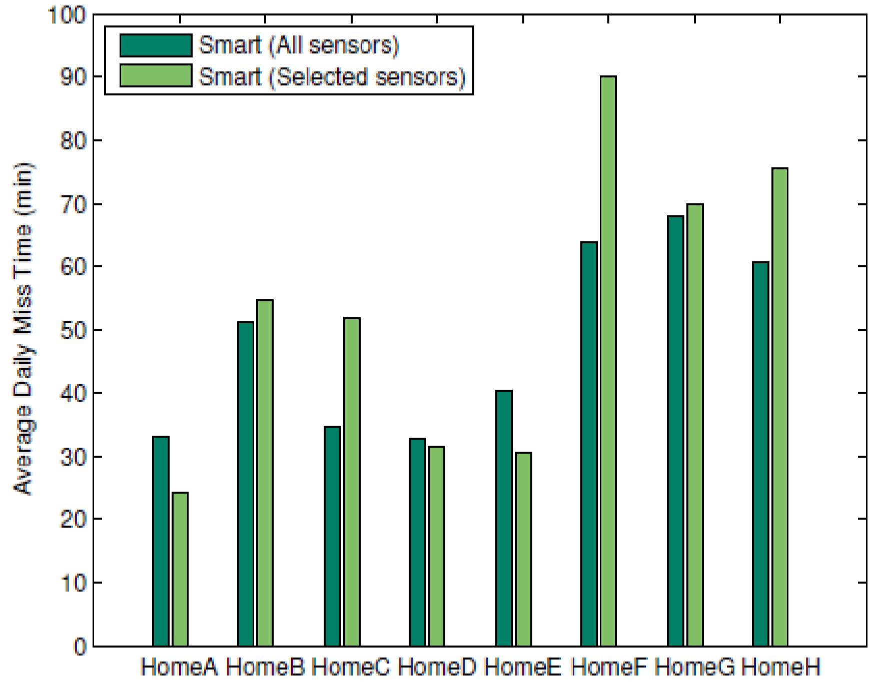
Reactive: saves 2.9kWh (6.8%), misses 60 minutes on average!
Smart: saves 11.8kWh (27.9%), misses 48 minutes on average!

Evaluation (Sensitivity to Number of Sensors)

Set A: 12 – 20 sensors

Set B: 3 – 5 sensors





Result: The smart thermostat for both sensors sets provide similar energy savings and miss time.

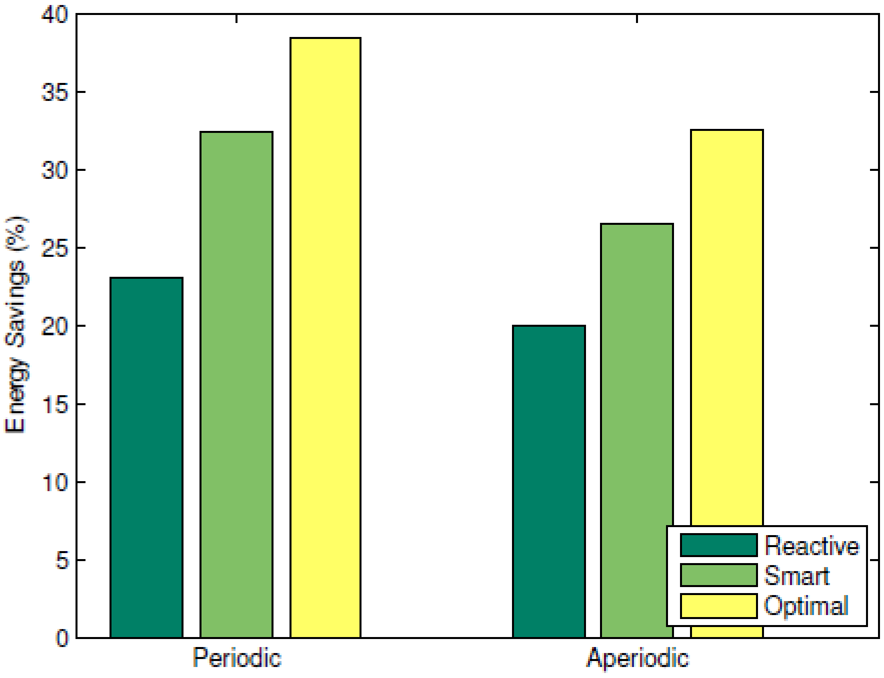
Set A: 23.6% savings, 48 minutes miss time

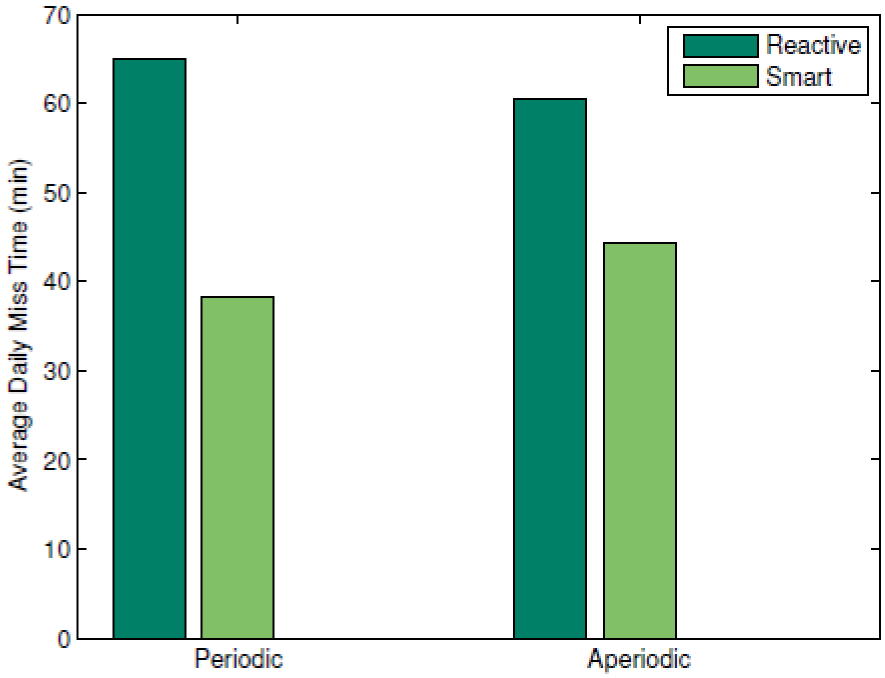
Set B: 28.9% savings, 54 minutes miss time

Evaluation (Sensitivity to Occupancy Patterns)

Set A: Periodic occupants

Set B: Aperiodic occupants





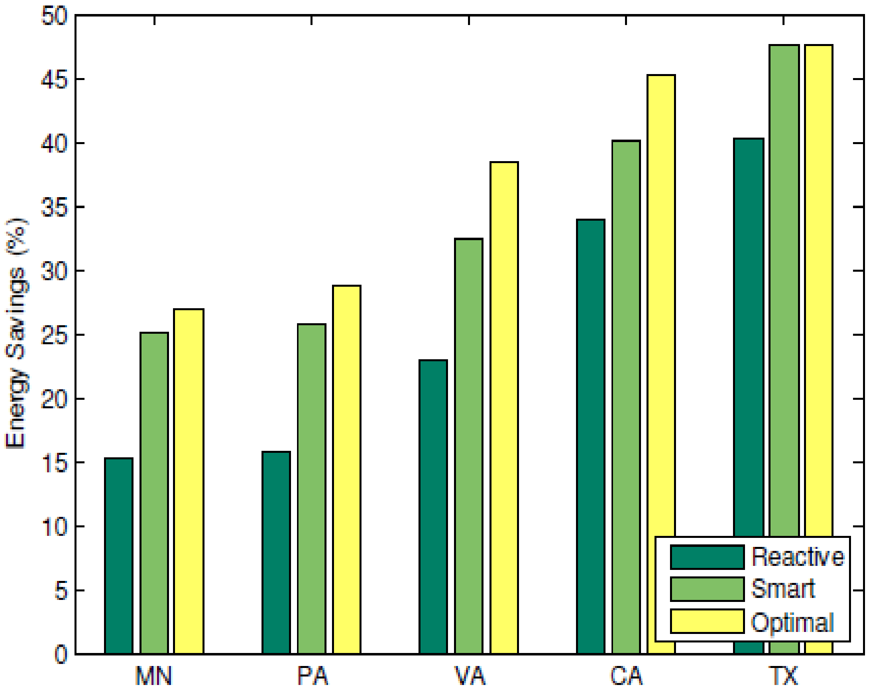
Result: The smart thermostat benefits periodic people more than aperiodic people.

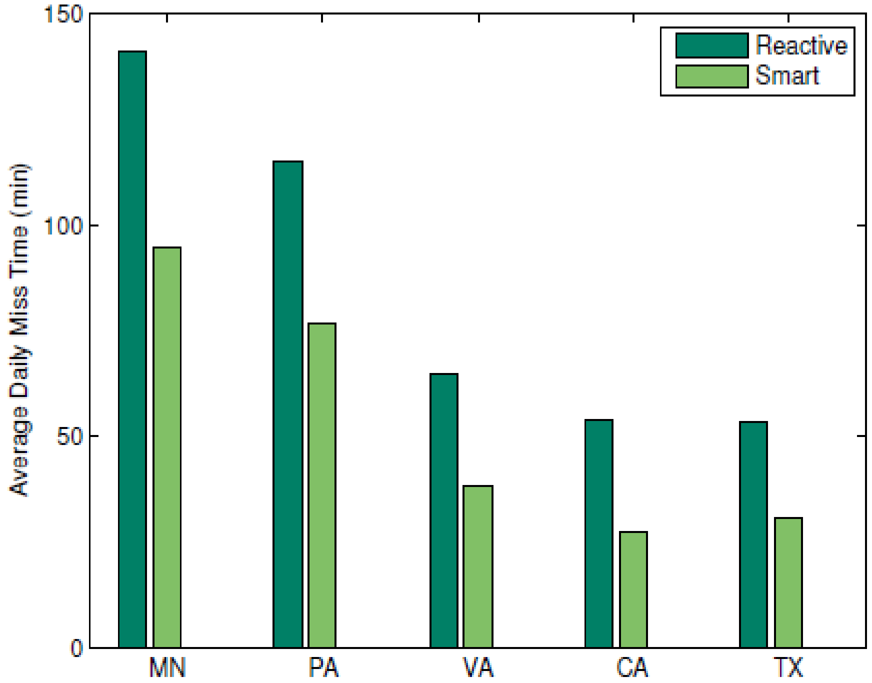
Set A: 32.4% savings, 38 minutes miss time

Set B: 26.4% savings, 44 minutes miss time

Evaluation (Sensitivity to Climate Zones)

Colder Climates to Warmer Climates – From January to July (Minneapolis, Pennsylvania, Virginia, California, Texas)





Observation: As the climate becomes warmer from MN to TX, the smart thermostat approaches optimal schemes in terms of percent energy savings.

Limitations and Future Work

- Assumption: No pets and plants in homes
- Evaluation for only a single type of equipment
- Zoning: To stabilize temperature in different parts of the house.

Conclusion

A combination of long term occupancy and sleep patterns with real time sensor data to control HVAC system.

- Low cost: less than $25 per home for sensors
- Savings: 28% of residential energy consumption saved on average.
- Low Hassle: Automatic temperature control
- Saves 113.9billion kWh nationwide per year
- Prevents 1.12billion tons of air pollutants released.

Q&A

Thank you!