Adding GPS-Control to Traditional Thermostats: An Exploration of Potential Energy Savings and Design Challenges

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Photos are taken from the individual homepages of the researchers.

Outline

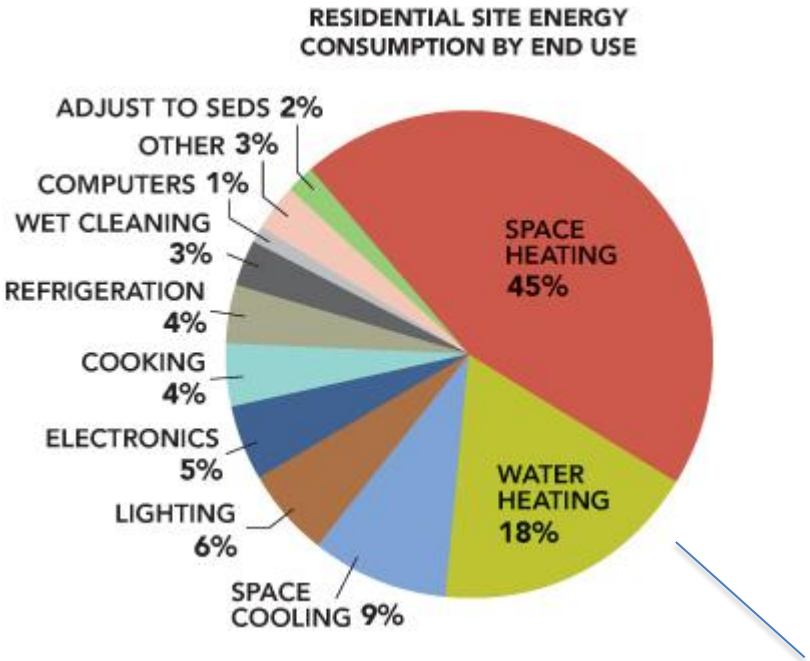
- A GPS-Controlled Thermostat
- Real-Time Implementation
- Exploratory Simulations

Introduction

(4 slides)

Motivation

- With only 5% of the world‘s population, the U.S. uses 25% of the world‘s energy[2]
- 9% of the total U.S. energy consumption for heating and cooling[1]



http://buildingsdatabook.eren.doe.gov/ChapterIntro2.aspx (2008)

Glossary

- Setback: Reduce the temperature when away or during night
  - 49% of homes are unoccupied during the day in the U.S.
- Comfort level: The temperature people feel comfortable in their homes. Typically somewhere between 19 and 22° Celsius
- HVAC: Heating, Ventilation, Air Conditioning

Thermostats

- M-Therms (manual thermostats):
  - Simple control of the heating and cooling system
  - Adjusting the temperature up or down as desired
  - Most energy efficient option if setbacks used correctly
  - Significant discomfort upon return to home

- P-Therms (programmable thermostats):
  - A series of programmed settings
  - Take effect at different times of the day
  - Reprogramming often tricky with current UI‘s

M-Therms: http://www.todaysconcept.com/honeywell-110b-digital-manual-thermostat.html
P-Therms: http://en.wikipedia.org/wiki/Programmable_thermostat

Thermostats(2)

Table 1. Thermostat usage statistics in the U.S

(In millions)	Total homes in the U.S.	Estimated no. of homes using setback when away	Estimated no. of homes not using setback when away
Manual Thermostat	62.16	21.7	40.46
Programmable Thermostat	33.3	18.7	14.60
Total	95.46	40.4	55.06

65%

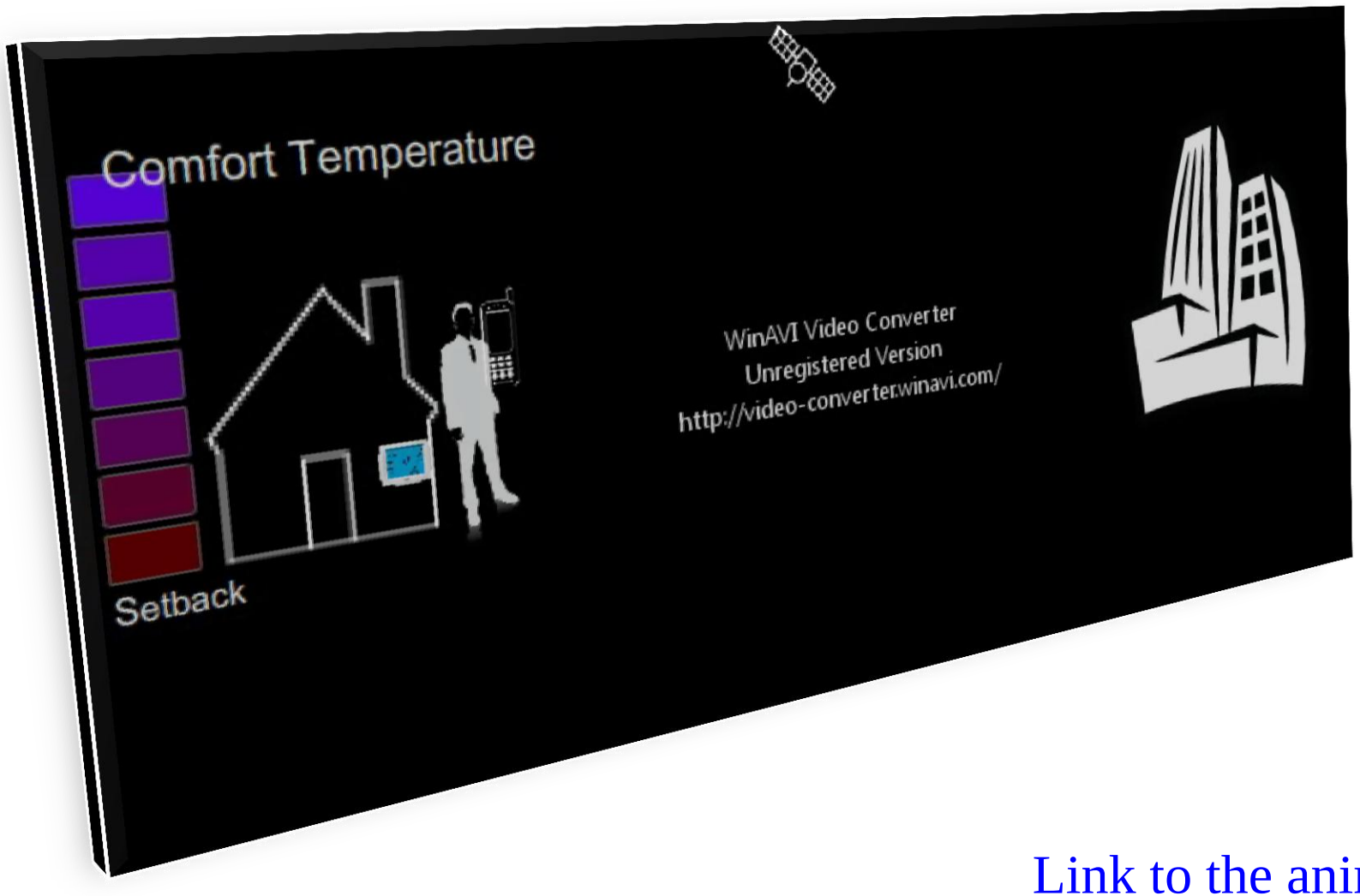
44%

58%

A GPS-Controlled Thermostat

(5 pages)

The general idea



Link to the animation.

Goals

- Highly adaptable just-in-time heating and cooling mode
- Easy to install and use by augmenting current thermostats
- Save energy
- Adapts to irregular schedules
- Home is always comfortable on return
- Use travel-to-home time / distance via location aware phones
- Motivate users for additional savings
  using context-sensitive promting

freedigitalphotos.net

Services used

- MapQuest WebService:
  - Wikipedia: MapQuest is an American free online web mapping service owned by AOL. MapQuest provides some extent of street-level detail and/or driving directions for a variety of countries.

mapquest developer network
http://developer.mapquest.com/

- Yahoo Weather WebService:
  - For http://weather.yahooapis.com/forecastrss?p=02139 you get:

YAHOO!

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   ▶<item>...</item>
  </channel>
</rss>
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Heating and Cooling Tables for the Houses

- Created with T profile data collected over 3 days
- Heating table: time it takes for the house to heat up by 1°F (0.55°C) from each starting T given outdoor T and HVAC running at full capacity
- Cooling table: Same but for heat loss
- Values not directly observed were estimated from the 3 days of data collection

Algorithm In- and Output

- Inputs:
  - Indoor / Outdoor T
  - Latitude/Longitude coordinate for each occupant‘s phone
  - Heating/cooling tables of the home
  - Additional information (min allowed T, occupant schedules, ...)

- Output (each minute):
  - Target T based on travel-to-home time
  - Simulated indoor T and the HVAC cyle state / duration (on/off)
  - Simulates operation of M-Therm and P-Therm

Real-Time Implementation

(5 slides)

Set-up

- 14 days, 1 house (~280m^2), 1 participant
- M-therm / RCS TR40 computer-controlled thermostat
- Server: Laptop (MapQuest, Yahoo weather)
- Client: GPS-enabled mobile phone (Motorola 9Qh Global)
- Two interfaces on laptop and phone (prompts)

http://www.resconsys.com/products/stats/serial.htm

http://pdadb.net/imageview.php?file=motorola_q9_global.jpg

How it works

1. Server receives GPS cordinates from Client (once per min)
2. Server contacts MapQuest for travel time and distance
3. Server contacts Yahoo weather service for outdoor T
4. Algorithm calculates target T
5. Server sends target T to thermostat, gets current T in return
6. Server sends travel time, distance, current T and possible other information to Client
7. Client may prompt user for feedback

Laptop Interface

- A: Current home T
- B & C: Current state of system
- D: Why this is the state
- E: What the user can do to change it
- F: Energy and Monetary saving since installed
- K: Rewards for energy saving decision
- I & J: How the system is going to react to change
- H: Cool button to manually control (override GPS)
- L: Manually change settings

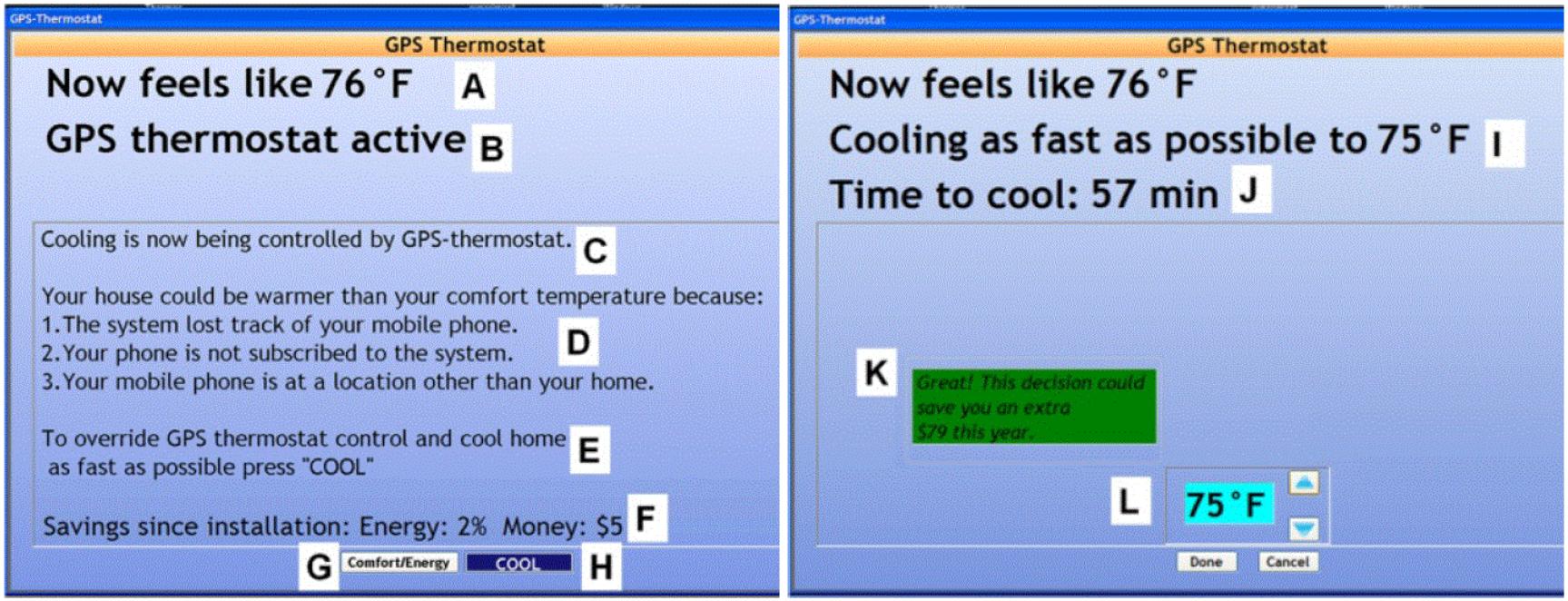

Figure 5. Screenshots of the laptop thermostat interface (simulating a wall thermostat LCD).

Mobile Phone Interface

- Minimalistic
- When detects user >2 min away from home after being home
  - beeps
  - asks user if willing to return to a warmer house
  - asks user for a return time
- Provides user with information on additional savings
- Provides time to cool down if return to a warmer house

Evaluation

- 8 of 24 prompts answered, each led to energy savings
- Each answer the user gave saved an average of 0.32% or $0.25 in energy
- Expected savings estimated by users travel patterns and home T response characteristics:

Table 7. Expected savings across similar homes and commute patterns for two weeks.

Thermostat	Expected Savings (%)	Expected Savings 2 wks ($)
Manual	1.05	0.84
Manual augmented with GPS	3.3	2.60
Programmable	5.84	4.64
Programmable augmented with GPS	7.3	5.80

Exploratory Simulations

(6 slides)

Set-up

- Recruited 8 people living in 4 different homes near Boston
- TrackStick Pro GPS logger in cars for 3 months
- In- / outdoor T and humidity logger
- Current logger between thermostat and HVAC
- 3 days of measurement
- Heating / cooling tables for the houses
- Control house

http://www.trackstick.com/products/trackstickpro/

Four Scenarios

- Baseline: The thermostat is set to the comfort T at all times
- Manual setback: T manually lowered upon leaving the house and manually raised upon returning
- Programmable setback: Schedules were programmed for lowering and raising the setpoint each day based on standard work patterns. (System starts heating 30 min before the return, setback T: 15.5°C)
- GPS-thermostat: Target T is set as a function of travel-to-home time

A Typical Day (Control House)

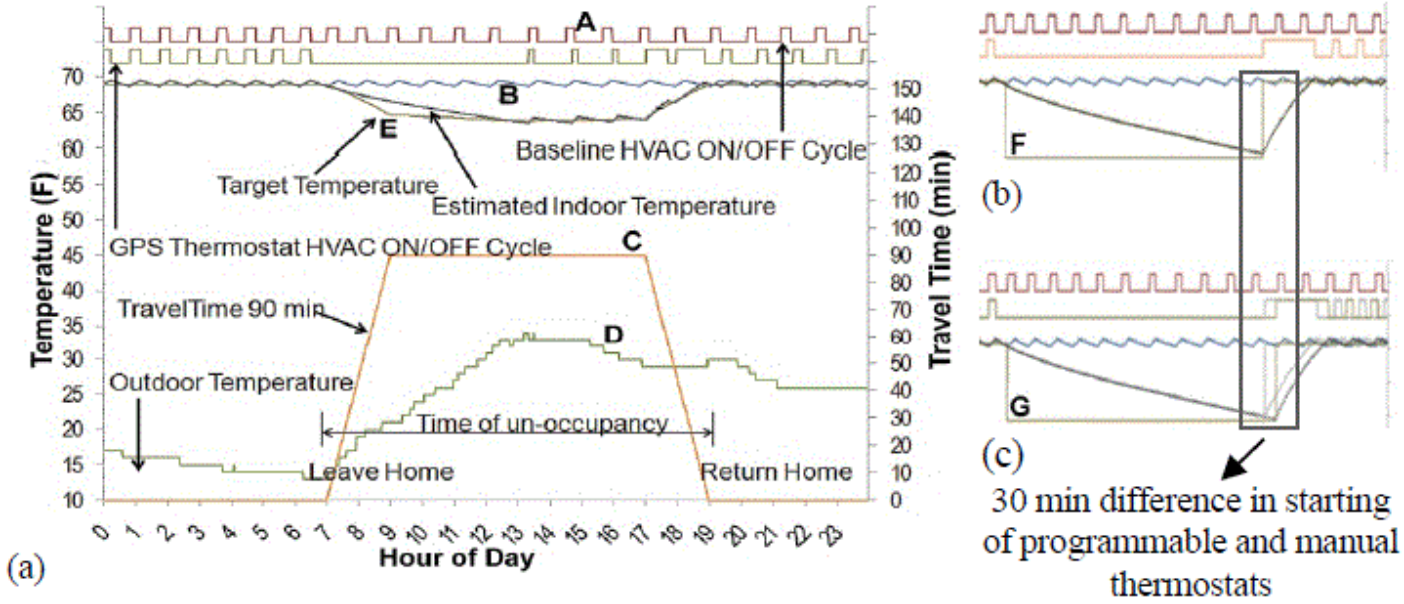

Figure 1. A typical day with 90 min simulated travel time and simulated results with different thermostat types, as explained in the text.

- A: Estimated heater cycle
- B: The baseline
- C: Travel time (90 min)
- D: Outdoor T fluctuation
- E: Target T based on travel distance
- F: Target T for P-Therm
- G: Target T for M-Therm

Results with Common Travel Patterns (Control House)

- P-Therms and M-Therms are independent of travel time
- GPS-Therms savings increase as the travel time increases
- If someone works near home only low savings are possible
- GPS-Therm only useful when M-/P-Therms are not used correctly

Type (travel time)	Savings each workday (%)	Savings each workday ($)	Expected compliance (%)	Expected savings (%)	Expected savings ($)
Manual thermostat	24.7	2.16	35	8.65	0.756
Prog. thermostat	21.74	1.9	56.2	12.22	1.068
GPS therm (15 min)	5	0.38	90	4.5	0.342
GPS therm (26 min)	7.6	0.57	90	6.84	0.513
GPS therm (45 min)	11.75	0.88	90	10.57	0.792
GPS therm (60 min)	13.82	1.04	90	12.44	0.936
GPS therm (90 min)	17.05	1.28	90	15.35	1.152

Results Using Real Travel Time Data

- Simulator always used min travel-to-home time for each house
- Travel time increased with traffic congestion index
- Baseline for calculating savings is cost of using no setback
- Setback set to 15.5° C, P-Therms also set on weekends
- House 2 had 12 days vacations in the 3 months of simulation

	Savings for study duration % ($)			
Thermostat	**House#1 - 75 days CT = 67, LT = 65**	**House#2 - 75 days CT = 69, LT = 67**	**House#3 - 60 days CT = 69, LT = 67**	**House#4 - 60 days CT = 69, LT = 67**
Programmable	19.4% ($168)	14.1% ($102.80)	17.1% ($387.50)	13.5% ($244.30)
Manual	18.0% ($165.90)	13.7% ($97.30)	14.6% ($332.90)	12.6% ($225.70)
GPS	2.9% ($25.50)	7.1% ($49.70)	0.3% ($7.50)	0.8% ($15.50)
	Expected savings for study duration % ($)			
Manual defaults to GPS	8.2% ($74.60)	9.4% ($66.30)	5.3% ($121.40)	4.9% ($89.10)
Programmable defaults to GPS	12.2% ($105.60)	11.0% ($79.60)	9.7% ($221.10)	7.9% ($144.10)

Simulation Using Just-in-Time Questions

- Return at lower T: Lower target T
- Specify a time to return home: Ignore GPS data
- Combine both: maximum savings

Table 6. Simulated savings for a work week for prompting scenarios with a travel time of 26 min.

	Num prompts answered/wk	Expected savings(%)	Expected savings($)
Manual augmented with GPS	0	13.59	1.13
Manual augmented with GPS + Return time	2	16.91	1.37
Manual augmented with GPS + Return time	3	18.62	1.50
Manual augmented with GPS + Lower T	2	14.54	1.20
Manual augmented with GPS + Lower T	3	15.03	1.23
Manual augmented with GPS + Return time + Lower T	2	17.21	1.41
Manual augmented with GPS + Return time + Lower T	3	18.89	1.53
Programmable augmented with GPS	0	15.55	1.32
Programmable augmented with GPS + Return time	2	17.79	1.49
Programmable augmented with GPS + Return time	3	18.92	1.57
Programmable augmented with GPS + Lower T	2	16.19	1.37
Programmable augmented with GPS + Lower T	3	16.52	1.40
Programmable augmented with GPS + Return time + Lower T	2	17.95	1.51
Programmable augmented with GPS + Return time + Lower T	3	19.21	1.61

Summary

(3 slides)

Issues

- Aesthetic concerns: Close to thermostat are often no electrical or Internet outlets
- Cost: Payback time 12-36mo. (phone, thermostat, laptop...)
- Time away: work close to home -> promting, react to typical behaviour
- Temperature vs comfort: User wants more info on T on phone, rather think in terms of comfort (humidity, clothes,...)
- Phone limitations: GPS lock time, battery life, GPRS coverage
- Improve algorithm: outside T forecast, detect driving, dynamically update lookup tables for T profile of homes, modify question promting, control hot water heating, night setbacks

Summary

- Client-Server model using mobile phone and a laptop
- Send GPS coordinates every minute
- Use web services to obtain travel to home time / distance and outside temperature
- Use promting on mobile phones to get additional information

- Save up to 7% on HVAC energy use in some households
- M-Therms and P-Therms still perform better when used correctly
- To evaluate potential savings due to the user feedback on prompts more work is needed

Personal Opinion

- If you build a user interface (UI) for mobile phones, why not let the users manually control the entire system, if they like
- If it does not save more energy than existing solutions, why not try to make those better? (Especially P-Therms)
- Just supports standalone houses. No ideas about apartment buildings or similar environments presented

- Potential future work:
  - Is more feedback by a better implementation of the UI on modern Smartphones possible? Combination with a game, a high-score etc.
  - Does a web-based UI further improve user feedback? (security?)
  - Will giving user more control in an „expert“ UI besides a „normal“ UI improve savings and user feedback?

Questions?

http://www-01.ibm.com/software/ch/de/academic-initiative/images/question_markSml50x50.jpg

Referenzes

- [1] M. Gupta, S. S. Intille, and K. Larson, "Adding GPS-control to traditional thermostats: An exploration of potential energy savings and design challenges," *Proceedings of the Seventh International Conference on Pervasive Computing*, pp. 95-114, 2009.

- [2] CIA, The World Fact Book: https://www.cia.gov/library/publications/the-world-factbook