Inside A Smart Thermostat: What Really Influences Savings

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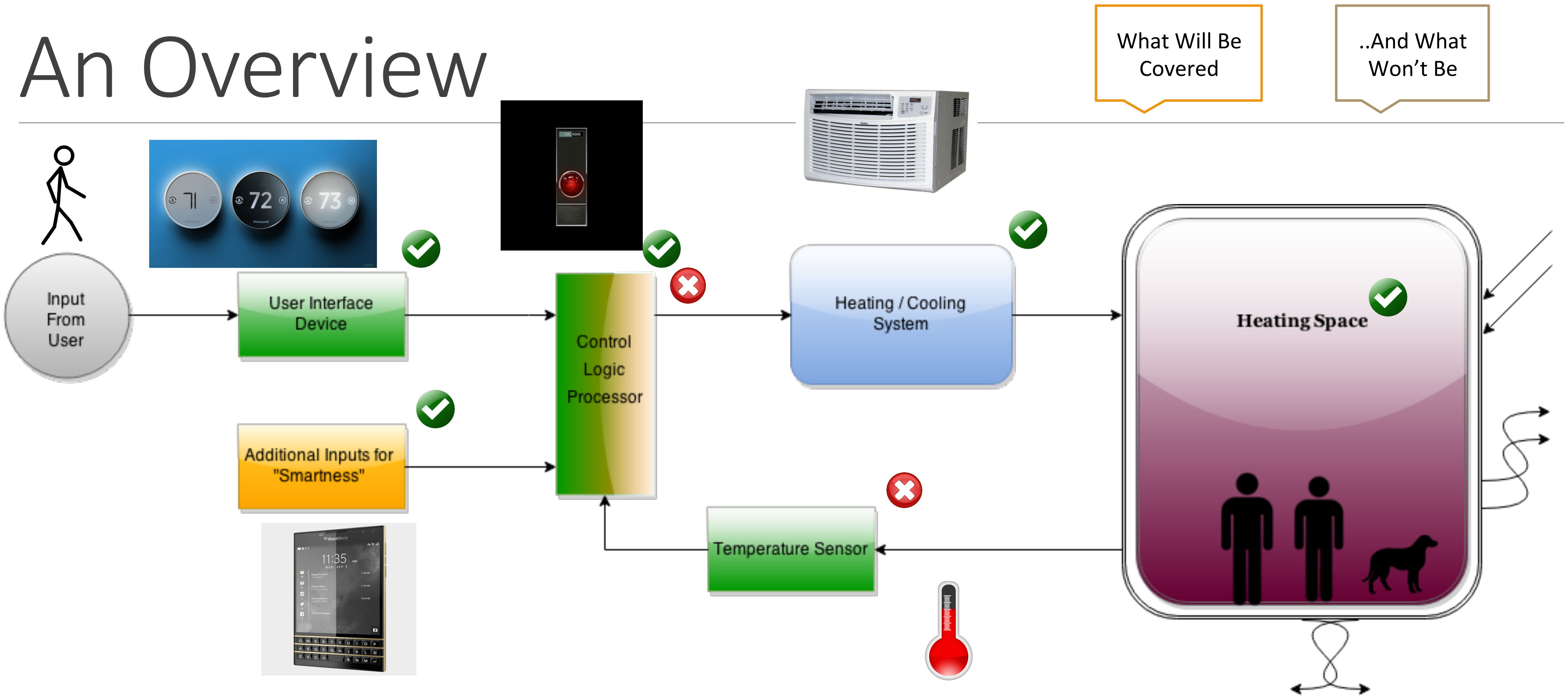
An Overview



The "Universe" that the thermostat operates in heavily influences the savings (or lack thereof).

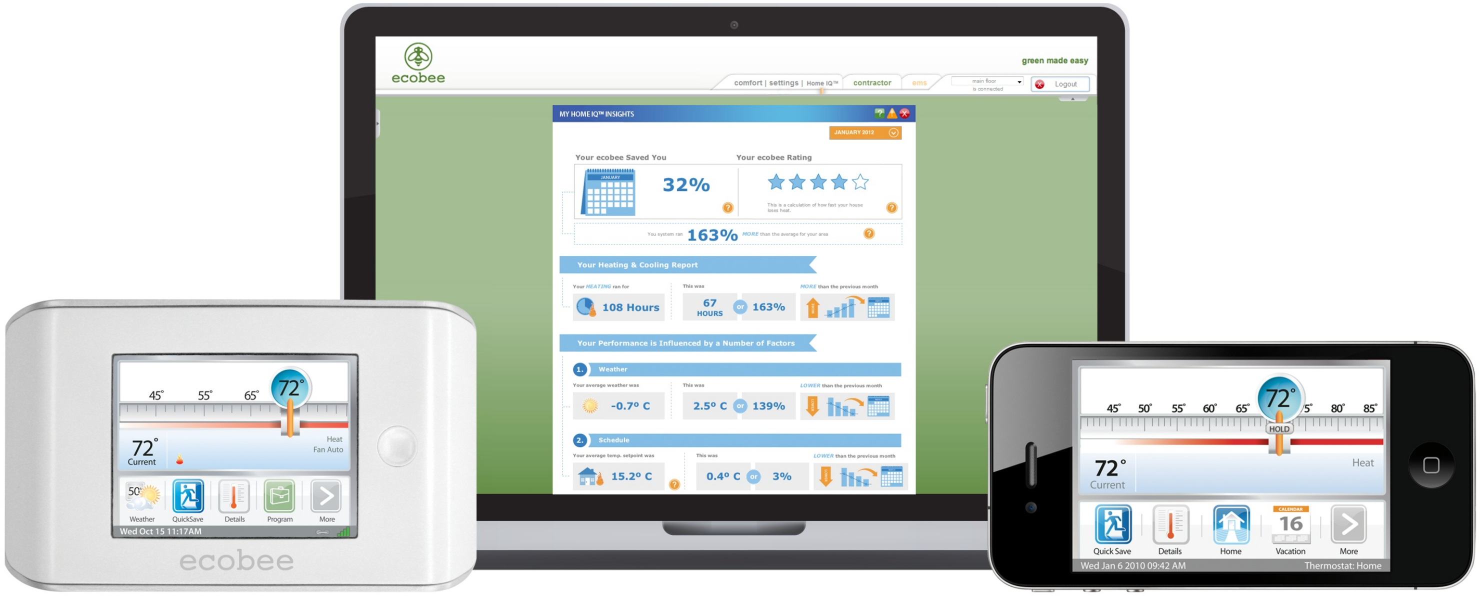
List of Topics

The topics that will be covered, in order, are:

1. Input and Display Types
2. Heating and Cooling Systems
3. Insulation Types and Materials
4. The “Smart” Thermostat
    - Sensing
    - Prediction
5. Miscellaneous Factors
6. Arguments

Input and Display Types

- What information should be displayed? When?
- Does the user feel a “loss of control”?
- How many steps does it take to perform common tasks?
- Is it change for the sake of change?



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Information may be:

- Real-time or Delayed
- Cumulative or Transitory
- Predictive or non-predictive

“It has been found, in empirical studies, that individualized energy use information in the form of better bills, periodic feedback, and continuous feedback, can lead to reductions in energy Use.”
- **“The Effects of Household Characteristics and Energy Use Consciousness on the Effectiveness of Real-Time Energy Use Feedback: A Pilot Study”, D. Allen and K. Janda**

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The capacity to use a system depends heavily on:

- Age and accessibility issues
- Motivation to monitor and/or adapt to the system
- Level of tech-savviness

*"I'm not really happy with it anymore. The problem is, it is **too controlling**… It makes assumptions, and I don't like the **assumptions**, and I can't train it to make different assumptions. I feel like **I've lost control** over it."*

*"He walked past the Nest **once every hour for the next six hours** even though he had turned off Auto-Away – he wanted to make sure the Nest knew he was there"*

*"Nest is **incapable to understand** the **intent** behind sensed behavior and **users have difficulty in understanding** how the Nest works."*

"Learning from a Learning Thermostat: Lessons for Intelligent Systems for the Home"(2013) by R. Yang, M. Newman

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Gestures? Voice commands?

As systems become more complex and include more functionalities, they tend to become increasingly tedious to operate.

May be alleviated by the use of better, more intuitive input devices

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What value does an additional functionality to the end user?

How many users will use the ‘on a holiday’ feature? How many will be confused?

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Literature Review

What Does The Literature Say?

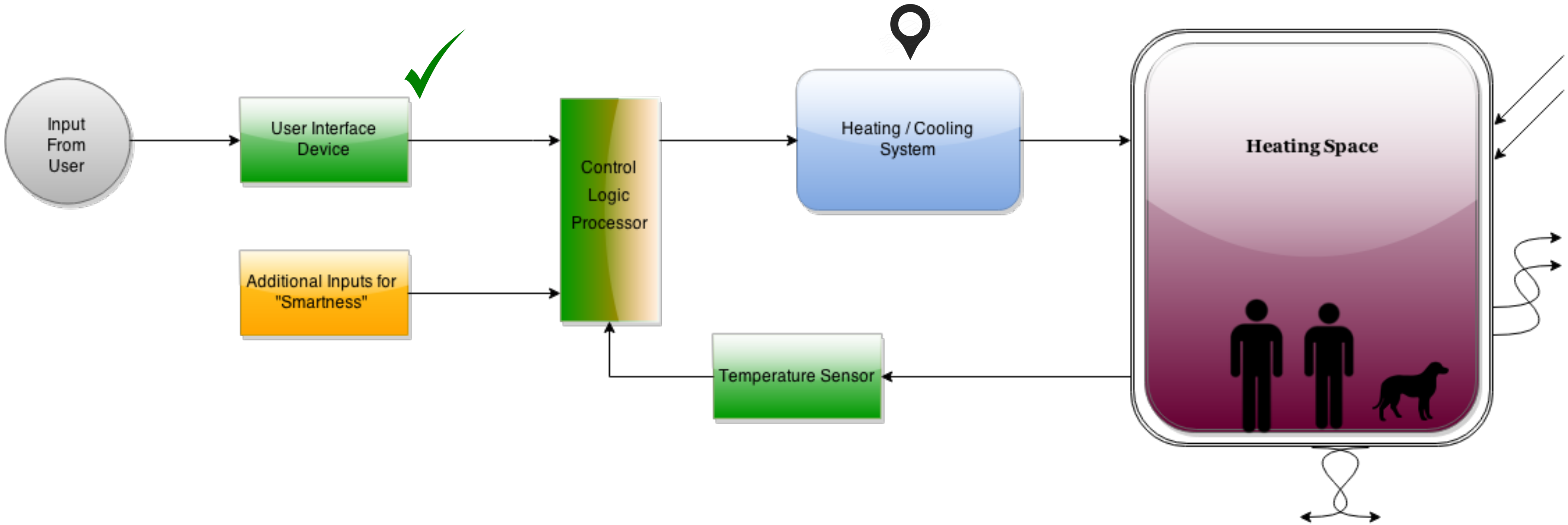
"*Programmable* thermostats have not seen great market penetration; only about half are actually programmed to adjust temperatures at night or unoccupied times, and thus they do not necessarily save energy. The EPA review and other studies indicate that people find programmable thermostats **difficult to understand**, and **lack the confidence and motivation to overcome difficulties** in programming."[1]

Why?

- Lack of understanding of how the HVAC system works
- Cost vs usefulness- heightened expectations of what the system can do
- "It just looks complicated, I don't want to touch it."
- "Setback uses more energy because the house needs to use more energy to heat up again."

[1] How People Use Thermostats in Homes: A Review (2011) ; T. Peffer, et. al. Emphasis added.

Overview


Input
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User
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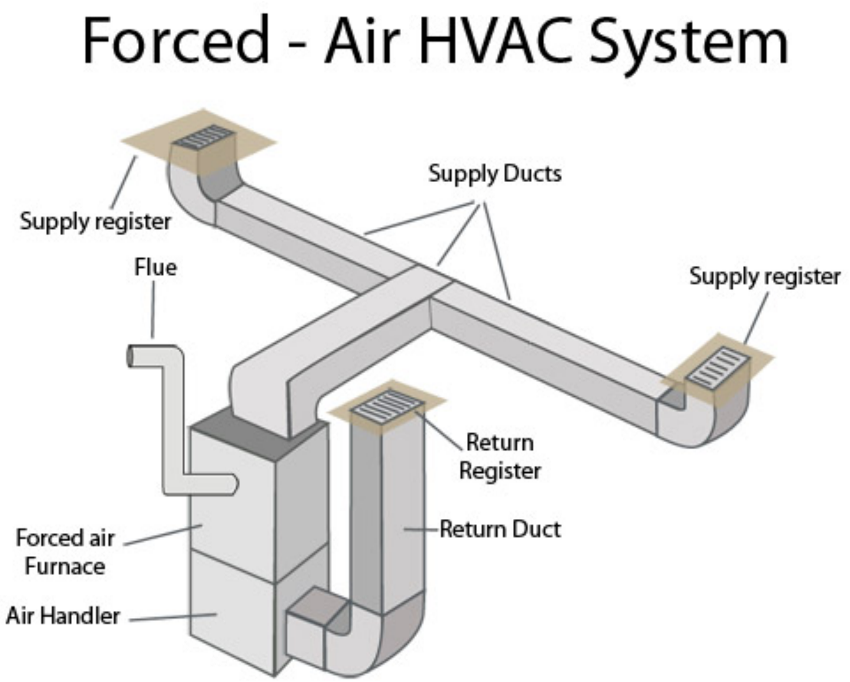
Heating Space

Heating Systems

Primarily Two Main Types:

1. Radiant Heat/Radiators
2. Forced Air



Cooling Systems

Basically Two Types:

1. Simple Mechanical Fans
2. Air Conditioners

“Low Energy Actuators”

Present an interesting opportunity for saving energy

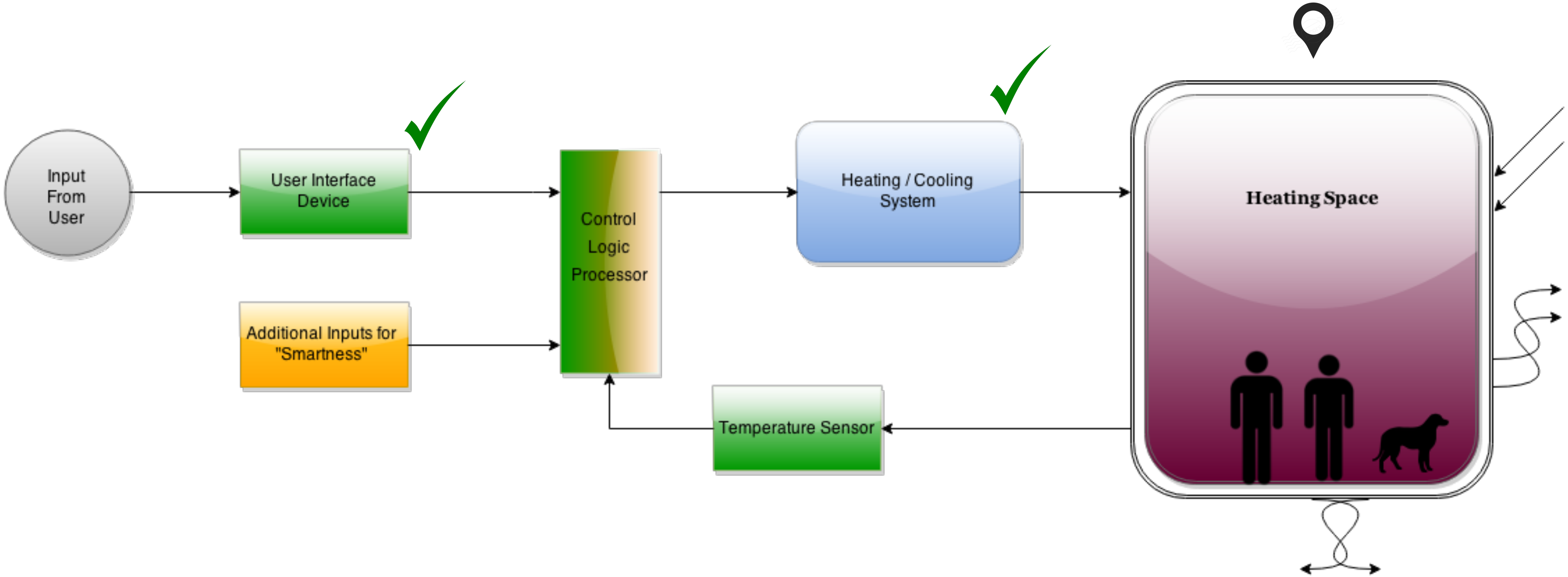
Examples:

- Blinds Operation for heating
- Evaporative Cooling

A Portable Evaporative Cooler

Automated Blinds – Look to the left ☺

Overview



Input From User
User Interface Device
Additional Inputs for "Smartness"
Control Logic Processor
Heating / Cooling System
Heating Space
Temperature Sensor

Insulation Types and Materials

What do the R- and U-values mean?

The U-value is simply the reciprocal of the R-value.

Typically measured in $m^2 . K/W$ (SI Units) or $ft^2 . °F . h/BTU$ (US)

Provides a relative measure for comparing the effectiveness of insulators.

What about costs?

Material type	R-value	Cost per square foot	Cost per square foot per R-value
Fiberglass batt (3.5 - 12 inches thick)	13	$0.20 to $0.40	$0.02
	30	$0.60 to $1.00	$0.03
Loose fill such as fiberglass, cellulose, and mineral wool (8 - 23 inches thick)	30	$0.45 to $1.35	$0.03
	50	$0.75 to $2.25	
Open cell polyurethane spray foam (3.5 inches thick)	12.6	$1.70 to $2.50	$0.17
Closed cell polyurethane spray foam (1 inch thick)	6.5	$1.30 to $2.00	$0.25
Expanded polystyrene foam board (1 inch thick)	3.8 – 4.4	$0.20 to $0.35	$0.07
Extruded polystyrene foam board (1 inch thick)	5	$0.40 to $0.55	$0.10
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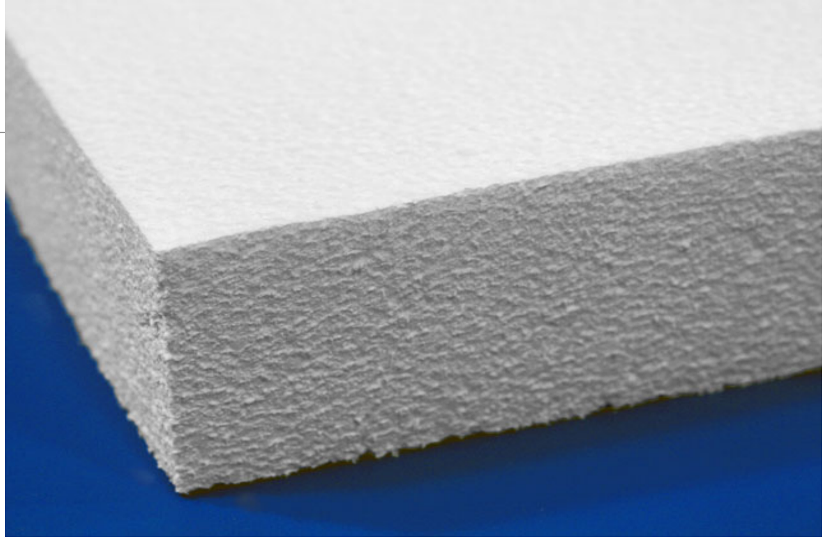

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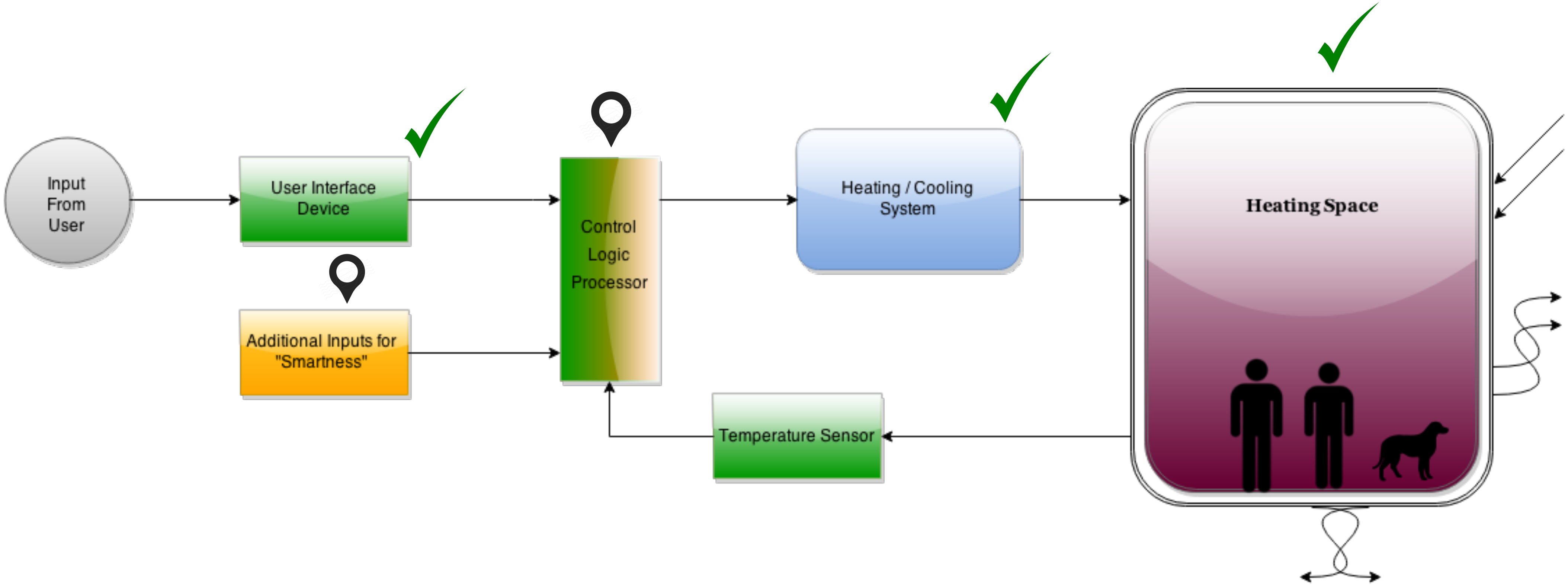
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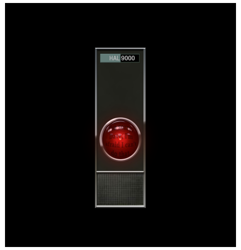


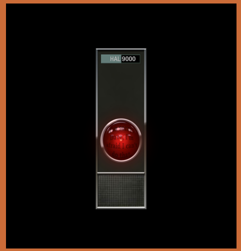
The “Smart” Thermostat

Can be classified under two basic categories:

1. Schedule Based
2. Context-aware

Schedule Based thermostats learn the occupancy patterns of the residents and make predictions based on this learning

Context-aware thermostats have some sensors and/or access to databases that give them additional contextual cues to better estimate the probability of occupancy.

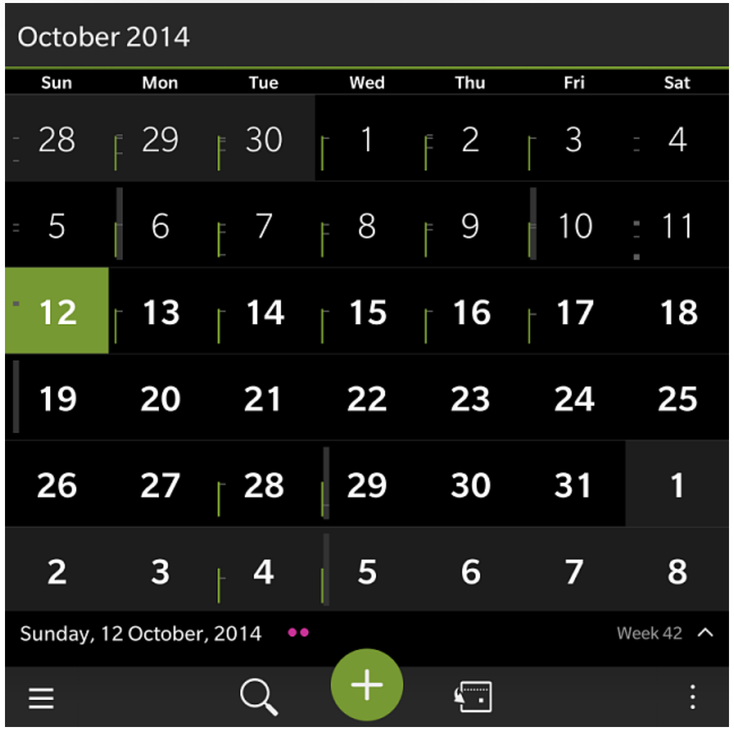


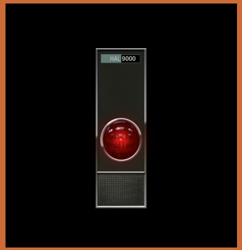
The “Smart” Thermostat - Sensing

A variety of sensors have been used both commercially and in the academia.

Some of the prominent ones are:

- Infrared/Heat sensors
- Ultrasound/Microwave Detectors
- Calendar Appointments
- GPS Beacons
- WiFi Information





The "Smart" Thermostat: Prediction

Primary examples for non-contextual prediction algorithms:

- Neurothermostat
- PreHeat
- Presence Probabilities
- Commercial products – Nest, EcoBee

Algorithms for context-aware systems vary depending on the sensors/inputs used.

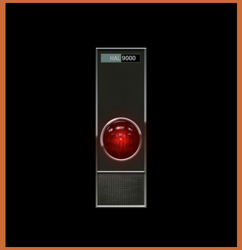
ISO 13790 average efficiency gain for all experiments with **low U-values (good insulation)**. ☼ and ☁ denote *clear* and *cloudy* scenarios respectively. The rightmost column shows the average total daily energy consumption when no occupancy prediction and setback algorithm is applied.

	Efficiency gain (%)														$\sum$**kWh**	
Weather	OPT ☼	OPT ☁	MAT ☼	MAT ☁	MDMAT ☼	MDMAT ☁	PP ☼	PP ☁	PPS ☼	PPS ☁	PH ☼	PH ☁	REA ☼	REA ☁	NO SETB. ☼	NO SETB. ☁
F-U$_{low}$ (well insulated flat)																
Very low	5	4	4	2	4	2	4	2	4	2	4	3	13	14	51	55
Freezing	8	6	6	5	6	5	6	5	6	5	6	5	10	12	38	44
Low	10	9	8	8	8	8	8	8	8	8	8	8	10	12	27	32
Moderate	11	12	10	11	10	11	10	11	10	11	10	11	11	13	17	20
H-U$_{low}$ (well insulated house)																
Very low	4	3	3	1	3	1	3	1	3	1	3	2	15	16	155	166
Freezing	6	5	4	4	4	3	5	3	4	3	5	4	10	12	119	134
Low	8	7	6	6	6	6	6	6	6	6	7	6	9	10	84	99
Moderate	9	10	8	8	8	8	8	8	8	8	8	8	9	10	53	65

Same as above, but for flats and houses with **poor insulation**

	Efficiency gain (%)														$\sum$**kWh**	
Weather	OPT ☼	OPT ☁	MAT ☼	MAT ☁	MDMAT ☼	MDMAT ☁	PP ☼	PP ☁	PPS ☼	PPS ☁	PH ☼	PH ☁	REA ☼	REA ☁	NO SETB. ☼	NO SETB. ☁
F-U$_{high}$ (poorly insulated flat)																
Very low	10	9	9	9	9	9	9	9	9	9	9	9	11	11	123	124
Freezing	14	13	14	13	14	13	14	13	14	13	14	13	14	14	95	100
Low	16	17	16	17	16	17	16	17	16	17	16	17	16	17	69	74
Moderate	18	19	18	19	18	19	18	19	18	19	18	19	18	19	45	48
I-U$_{high}$ (poorly insulated house)																
Very low	7	6	6	6	6	5	6	5	6	5	6	5	12	12	328	332
Freezing	11	10	10	9	10	9	10	9	10	9	10	9	13	13	255	269
Low	14	14	13	13	13	13	13	13	13	13	13	13	14	14	186	200
Moderate	15	15	14	15	14	15	14	15	14	15	14	15	15	15	122	133

Source: "Predicting household occupancy for smart heating control: A comparative performance analysis of state-of-the-art approaches", W. Kleiminger, F. Mattern, S. Santini



Context Aware Systems

We consider the example of a GPS enabled system

GPS controlled system proposed in "Adding GPS-control to traditional thermostats: An exploration of potential energy savings and design challenges,“ M. Sharma et al.

Expected savings across similar homes and commute patterns for two weeks

Thermostat	Expected Savings (%)	Expected Savings ($)
Manual	1.05	0.84
Programmable	5.84	4.64
Programmable augmented with GPS System	7.3	5.80

Similar systems can be designed using geo-location derived from WiFi networks logged in by the mobile phone.

Miscellaneous Factors

Other factors which were not discussed but which are also important considerations.

1. Weather prediction – Accuracy and effects on savings
2. Social acceptance issues
3. Ease and cost of installation
4. Rebound effect for energy savings

Rebound Effect

We should not make things more energy efficient at all!

… Or maybe we should?

"This survey indicates that we have reason to be sceptical of the ability of below-cost energy efficiency to drive real and lasting reductions in total energy consumption and thus, the ability of efficiency measures to significantly contribute to climate and energy security objectives directly."[2]

"(We should) therefore focus primarily on shifting the means of energy *production* (rather than end use), relying on zero-carbon and renewable energy sources to diversify and decarbonize the global energy supply system"[2]

"Macroeconomic models estimate total combined rebound effects to be in the range of 20–60% ... In sum, rebound effects are small and are therefore no excuse for inaction."[3]

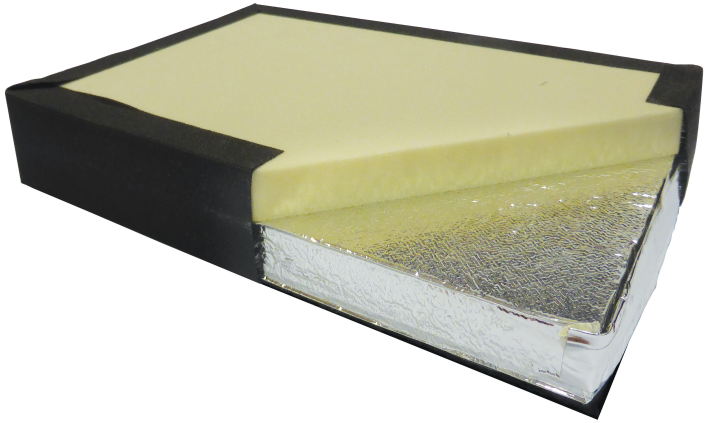
"Energy-efficiency measures should be on the policy menu to curb energy use and to address global warming."[3]

[2] "Energy Emergence: Rebound and Backfire as Emergent Phenomena"(2011), Breakthrough Institute

[3] "The Rebound Effect is Overplayed", Nature(2013); K. Gillingham et al

Arguments

Where is it logical to use a smart thermostat?



Gradients of Insulation and heating capacities

- Forced Air Systems- ramp up less than 30 minutes
- Wall mounted radiant heaters- between 5-12 hours
- Underfloor heating systems- up to a day or two

Where does the ‘middle ground’ lie? Is it too much of a niche?

Arguments - Against

Smart thermostat vs Insulation

1. Economics:

“Insulating the 50 sq.m. (540 sq.ft.) attic space of a typical house costs around €400 and could save approximately € 130 a year (up to 20% of your fuel bill) so it would pay for itself in about three years.”
- ”A Detailed Guide to Insulating Your Home”, Sustainable Energy Authority of Ireland

Contrast this with 7-15% savings for the OPT system for poorly insulated houses and just 4-10% savings for well insulate homes.

2. “Guaranteed” Savings vs. Case – Dependant

3. No Behavioural Changes Required

4. Assured Thermal Comfort – No Dependence on Predictions

Arguments - Against

What about Cooling?

Prediction unnecessary for cooling because of two factors:

- Very quick cool down time
- Practically no ramp up time required

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What about Cooling?

Forced Air Systems

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Follow the same arguments as Air Conditioners, severely negating the ‘selling point’ of Smart thermostats i.e., energy savings.

Arguments - Against

What about Cooling?

Forced Air Systems

"Ideal" case

Prediction unnecessary for cooling because of two factors:

- Very quick cool down time
- Practically no ramp up time required

Follow the same arguments as Air Conditioners, severely negating the 'selling point' of Smart thermostats i.e., energy savings.

Wouldn't the ideal case be one of the following?

1. A well insulated home (using VIPs) using a low power, highly efficient, heating system
2. Otherwise, in poorly insulated homes, a perfectly reactive system coupled with a forced air heating system.

What about thermal comfort in the second case?

A ‘First-World Problem’?

Can the thermostat really be called “Smart” when the smartest thing to do would be to keep your jacket on for 15 minutes longer?

“Nest is just the first step!” - Willi

Arguments – For

Why limit ourselves to present technologies?

Instead of focussing on just savings, why not shift the focus to thermal comfort?

But can we measure thermal comfort?

Perhaps a thermostat could detect these fluctuations and automatically set the optimally comfortable temperature!

E.g. A Smartwatch could sense the heartbeat and alert the smart thermostat to change the temperature.

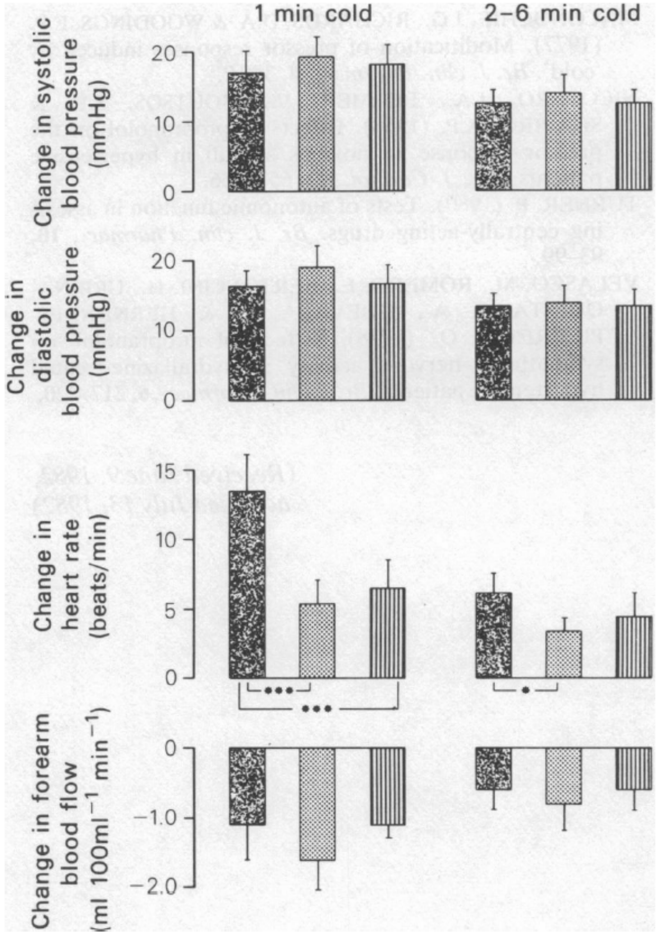

Figure 1 Changes from basal values in blood pressure, heart rate and forearm blood flow during cold exposure in 17 volunteers in control experiments and after propranolol and metoprolol. Mean values ± s.e. mean are given, ■ control, ⊠ propranolol, ◫ metoprolol, **P* < 0.05; ****P* < 0.001.

Image Source: “Effects of cold exposure on blood pressure, heart rate and forearm blood flow in normotensives during selective and non-selective i3-adrenoceptor blockade”(1982), H. Houbon et al.

Arguments – For

Savings can still be increased

In IoT vision of things, the smart thermostat will not make many mistakes. Why?

Privacy Issues?

- The thermostat could have access to the owner's work schedule
- GPS coordinates and other inputs(schedules, Facebook updates, etc.) could tell the thermostat when the owner is on a holiday
- Multi-zone occupancy detection: Turn down heating for rarely used rooms
- The vehicle/mobile maps app could tell the precise ETA of the owner
- …..

Arguments – For

Savings can still be increased

What about Ventilation?

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- …..

The so-called ideal case of a VIP building especially needs good ventilation!

Other factors such as humidity, wind speed, direct sunlight exposure, presence of drafts, etc. also affect our thermal perception.

An *ideal* thermostat could arrange the surroundings to set all these factor to the optimum settings.

References

Thank you for your attention!

[1] How People Use Thermostats in Homes: A Review (2011) ; T. Peffer, et. al.

[2] “Energy Emergence: Rebound and Backfire as Emergent Phenomena”(2011), Breakthrough Institute

[3] “The Rebound Effect is Overplayed”, Nature(2013); K. Gillingham et al

[4] "Adding GPS-control to traditional thermostats: An exploration of potential energy savings and design challenges,“ M. Sharma et al.

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[6] “Learning from a Learning Thermostat: Lessons for Intelligent Systems for the Home”, R. Yang & M. Newman

[7] “A detailed guide to insulating your home”(2006), Sustainable Energy Authority of Ireland

[8] “Guide to Home Installation”; U.S. Department of Energy

[9] “Predicting household occupancy for smart heating control: A comparative performance analysis of state-of-the-art approaches”, W. Kleiminger, F. Mattern, S. Santini

[10] “Why Occupancy-Responsive Adaptive Thermostats Do Not Always Save - and the Limits for When They Should”(2014), J. Woolley et al.

[11] “Thermostats Can’t Fix This: Case Studies on Advanced Thermostat Field Tests”(2014), S. Outcault et al.

[12] “The Effects of Household Characteristics and Energy Use Consciousness on the Effectiveness of Real-Time Energy Use Feedback: A Pilot Study”(2006), D. Allen & K. Janda

[13] “The History of Ventilation and Temperature Control”(1999), ASHRAE Journal, J. Janssen.