Occupant Energy Index: Understanding How Occupant Behavior Impacts Energy Use

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ABSTRACT

Standard procedures for estimating energy consumption of a building rely upon simulation and utilize the building's architectural details, its energy efficiency features, normalized weather data, and standard operating assumptions. Operating assumptions, such as thermostat setpoints, daily water consumption, appliance purchases, and interior shading schedules, are standardized for the purpose of producing consistent ratings. However, in practice, occupants can behave very differently, resulting in consumption that varies significantly from the simulation. The Occupant Energy Index is a scale that assesses the impact of variations in occupant behavior. This paper illustrates how such a scale can be defined and used by policy makers and program designers.

Introduction

Consider a home built to the requirements of the weakest energy code in the country. Now, remove all of the occupants from the house, turn off all of the HVAC systems, flip off the lights and unplug all the appliances. Is the result a zero energy home?

Most would think not, because once the occupants return the odds are good that consumption will dramatically increase. This scenario may emphasize the obvious - that occupants play a large role in determining the energy consumption of a home. However, consider a home at the other end of the spectrum – one that not only exceeds every energy code in the country, but also produces power onsite. How much might energy consumption increase when occupants return to this home?

Past research has demonstrated that occupant behavior can have dramatic impacts on energy consumption. Maintained interior temperatures of similar homes located in the same geographic location have been found to vary by 10 degrees Fahrenheit, resulting in cooling energy variations of approximately 5:1 (Parker et. al., 1996).

The purpose of this paper was to assess the impact of occupants on the energy consumption of a home and begin to define a uniform process for quantifying these impacts. The uniform process serves to define the Occupant Energy Index (OEI), which allows occupant behavior to be indexed. An illustration of how this concept has been used to assist program designers is then included.

For the purpose of this paper, occupant impacts were defined as any energy consumption in a building that is primarily attributable to the behavior of a specific occupant. The following were considered to fall under the domain of occupant impacts: schedules for opening and closing windows and shades; thermostat setpoints; water consumption; and lighting and appliance quantity, efficiency, and schedule.

Conversely, energy consumption that is not primarily attributable to a specific occupant, such as consumption driven by equipment efficiency, component insulation levels, and architectural characteristics, did not fall under this definition.

The energy performance of a home, excluding most occupant impacts, can already be evaluated using the Home Energy Rating System (HERS). The Home Energy Rating System is a uniform methodology for assessing the performance of a proposed home relative to a standard reference home design. Its value is not in predicting actual utility bills, but rather in the uniformity of its rating process. It evaluates the impact of equipment efficiencies, component insulation levels, and architectural characteristics and allows the home to be benchmarked on the HERS index. The reference home has an index of 100, by definition. A zero energy home scores zero on the index and a home that consumes more energy than the reference home scores above 100. HERS contains some basic assumptions about occupant behavior and its impact on annual consumption. For example, it modifies daily water consumption based on the quantity of bedrooms, makes limited modifications to thermostat setpoints based on thermostat type, and modifies internal gains based on the use of efficient lighting, ceiling fans, dishwashers, and refrigerators. HERS does not contain adjustments for other occupant behaviors, such as variations in the usage schedule and efficiency of other appliances.

HERS serves as one model for defining the OEI and was used for this paper. However, in this instance, a reference occupant is defined in place of a reference home and the scale exclusively measures impacts from occupant behavior. Therefore, the scale accounts for occupant behavior such as thermostat setpoints; hot water consumption; and the quantity, efficiency, and schedule of all lighting and plug loads, such as TV's, microwaves, and computers. The OEI Reference Occupant has a self-defined index of 100, which comprises a specific occupant profile. An occupant with a more energy-intensive profile would score greater than 100 and an occupant with the least energy-intensive profile would score zero:

- OEI 0 – zero energy using occupant
- OEI 100 – reference energy using occupant
- OEI 200 – double energy using occupant

The following describes an analysis designed to evaluate the parameters that may be used in defining a reference occupant for the OEI.

Methodology

This analysis was conducted using the DOE2.1E energy modeling program along with a proprietary front-end. Homes were modeled using the HERS methodology coupled with customized occupant profiles. This analysis was limited to three cities:

1. A hot and humid climate (Houston, TX),
2. A mixed climate (Baltimore, MD), and,
3. A cold climate (Minneapolis, MN).

This analysis was divided into four steps:

1. Define a baseline housing construction and occupant profile for each city.
2. Define all attributes of a reference occupant for each city. This step more thoroughly defines the occupant parameters that result in the consumption associated with the baseline occupant profile. For example, thermostat setpoints, appliance and lighting quantities and operating schedules, and daily hot water consumption are defined.
3. Identify and analyze individual changes to the baseline occupant profile to estimate its impact on total annual energy consumption.
4. Assess the synergistic impact of multiple changes to the baseline occupant profile in two bundles – all changes to the profile that decrease energy consumption and all changes to the profile that

increase energy consumption. These bundles serve to illustrate how varying occupant profiles would create variation on the OEI.

The methodology and results of each of these steps is discussed in more detail below.

Step 1: Define a Baseline Housing Construction and Occupant Profile

The baseline housing construction for each city was defined using the HERS Reference home, which is similar to the 2006 IECC standard design. The specifications for these homes are listed in Table 1.

Energy consumption associated with an occupant profile was accounted for in two ways. First, annual lighting and appliance consumption was calculated based on the quantity, efficiency, and annual hours of use. Second, for each occupant profile the authors defined a custom daily internal gains distribution curve and peak internal gains value. These were then modeled in conjunction with the housing construction to determine how they impacted the heating, cooling, and water heating consumption. The customized internal gains distribution curve used for the baseline occupant profile is presented in Figure 2.

Table 1. House Characteristics of the Base Cases*

House Characteristic		Base Case
House Characteristics	Area per Floor (ft^2)	2000
	Number of Stories	single
	Foundation Type	slab-on-grade, vented crawlspace, unconditioned bsmt
	Aspect Ratio	2:1
	Window Distribution	25% on each side
Shell	Framing	2x4, 16” O.C.
	Window Area	18%
	Window U-value	[0.75, 0.40, 0.35]*
	Window SHGC	[0.40, 0.55, 0.55]*
	Attic Insulation	[R-30, R-38, R-49]*
	Wall Insulation	[R-13, R-13, R-19]*
	Wall Sheathing	[None]*
	Slab Insulation	[R-0, N/A,N/A]*
	Roof Absorptivity	0.75
	Air Infiltration	[0.00048 SLA]*
HVAC + DHW	Air Conditioner	[13 SEER]*
	Gas Furnace	[78 AFUE]*
	Heat Pump	[7.7 HSPF]*
	Duct Leakage	[80 DSE]*
	Duct Insulation	
	Hot Water	[0.59 EF gas]*
Arch	Exterior Shading	[None]*

* Specifications within brackets are base home characteristics for hot, moderate and cold climates, respectively, as required by the 2006 IECC Residential Energy Efficiency Code.

	Building Orientation:	North
Lighting & Appliances	Lighting	Standard
	Appliances	Standard
Behavior Modification	Thermostat	Manual Heating 68/ Cooling 78
	Hot Water Utilization	Standard Hot Water Use

The baseline energy use, including heating, cooling, water heating, lighting, appliances and plug loads end-uses are presented in Figures 3-5 for each of the three cities analyzed in this study. These pie charts illustrate the relative magnitude of each of the end-uses for the baseline scenario in each location.

It is important to note that these values are not intended to represent the energy consumption of an average home. Instead, they reflect the energy consumption of a baseline home configured to meet the specifications of the HERS reference home.

Figure 1. Baseline Internal Gains Distribution

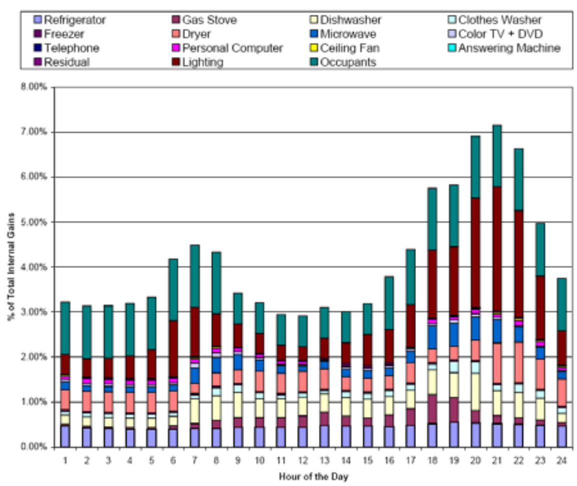
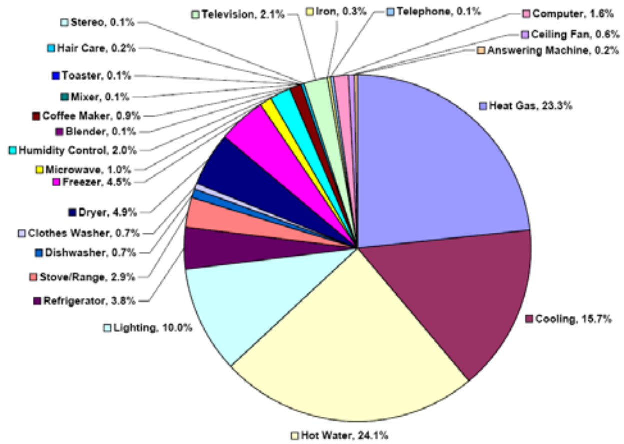
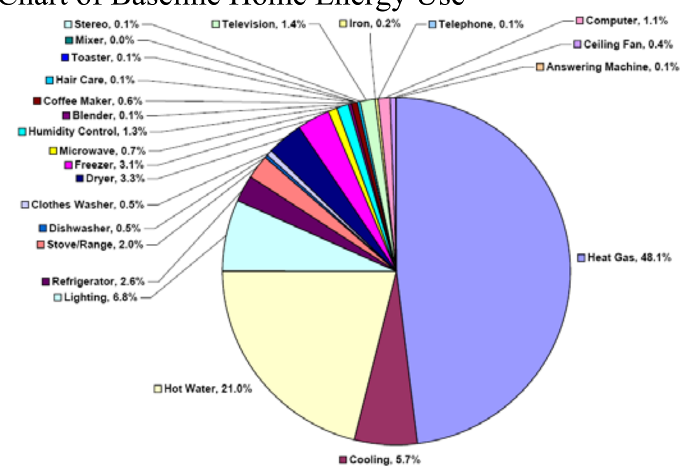


Figure 2. Houston Pie Chart of Baseline Home Energy Use



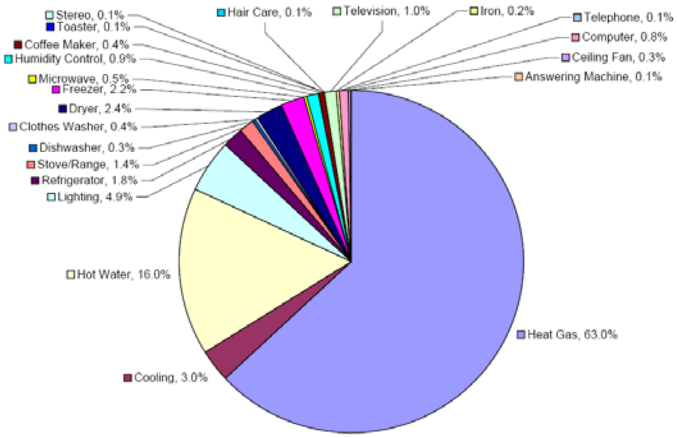
For Houston, a hot and humid climate, energy use for heating, cooling and hot water accounts for 63% of the annual energy use of the home. Prior to the development of the 2006 HERS Guidelines, the remaining 37% of the home's energy use was not capable of being addressed through the HERS methodology. In addition, all end-uses presented in the table can be influenced by occupant behavior and decisions.

Figure 3. Baltimore Pie Chart of Baseline Home Energy Use



For Baltimore, a mixed climate, the energy use for heating, cooling and hot water accounts for approximately 75% of the annual energy use of the home. In comparison to Houston, these end-uses comprise over 10% more of total energy use, suggesting that the same occupant behavior in different climates can produce variable impacts.

Figure 4. Minneapolis Pie Chart of Baseline Home Energy Use



For Minneapolis, a cold climate, the energy use for heating, cooling and hot water accounts for approximately 82% of the annual energy use of the home. With 63% of total energy consumption accounted for by space heating, one might infer that an occupant profile will impact end-uses in Minneapolis significantly different than end-uses in Houston.

Step 2: Define All Attributes of a Reference Occupant

The reference occupant is defined by how the home occupants use their thermostats, hot water, lighting and all of the miscellaneous appliances and plug loads, such as TV's, microwave, blender, computer, hair dryer, electric shaver, etc. Miscellaneous appliances and plug loads use a tremendous amount of energy in a typical home. It is these miscellaneous appliance and plug loads that vary the most between each house, since each occupant has different items and different use of those items. Each of these occupant based energy uses are discussed in more detail in the following subsections.

Appliances

The basis for consumption ratings for each of the appliances is as defined by the Department of Energy and was used to calculate the annual appliance electricity consumption, as shown in Table 2. The appliance schedule helps to determine a baseline electric energy bill for each month, the relative magnitude that each appliance plays on the overall energy bill, and the amount of heat gain from the appliances that provides internal heat gain to the building. These values can be refined to vary based on the number of occupants or type of occupants as desired.

Table 2. Appliance Schedule and Annual Electricity Consumption (kWh)

	Appliance Schedule	Appliance Units	Annual Appliance Electricity Consumption (kWh)
Refrigerator	-	-	526
Dishwasher	5	loads/week used	874
Clothes Washer	4	loads/week used	182
Clothes Dryer	4	loads/week used	1820
Standard TV	7	hrs/day	289
DVD Player	4	hrs/wk	5
VCR Player	2	hrs/wk	3
Cable Box	7	hrs/day	64
CD Player	2	hrs/day	146
Computer CPU	5	hrs/day	219

C. Monitor	5	hrs/day	274
Coffee Maker	1	hrs/day	438
Microwave	10	min/day	67
Toaster	3	min/day	20
Upright Vacuum	1	hrs/wk	75
Clock	2	Number	175
Hair Dryer	7	min/day	80
Iron	3	hrs/wk	281
Stove	1	hrs/day	976
Total	-	-	**6512**

Lighting

The average lighting for the typical occupant was determined from various sources (DOE, 2002; Heschong Mahone, 1999; LRC, 1996), as shown in Table 3, categorized by each room and summarized to include energy consumption and hours of lighting usage. Similar to the appliance schedule, the lighting schedule was used to predict actual energy usage for lighting and heat gain into the space. While it was not possible to have one set of values that represented all occupants, these values were intended to represent the lighting usage of an average or typical occupant.

Table 3. Lighting Schedule and Electricity Consumption Categorized by Room Type (kWh)

	Lighting Electricity (kWh)	**Daily Light Used (hours)**
Kitchen	172	3.7
Dining Room	74	3.2
Living Room	186	2.7
Family Room	48	2.1
Master Bedroom	60	1.3
Hall	45	2.0
Bedroom(s)	81	1.2
Bathroom(s)	129	1.9
Closet(s)	64	1.4
Utility	57	2.5
Garage/carport	49	2.2
Outdoor Lighting	71	3.1
Other/storage	0	1.4
Total	**1037**	**-**

Thermostat and Temperatures

Table 4 shows the thermostat setpoint temperatures that were used for the reference occupant, which were set to 68 degrees for heating and 76 degrees for cooling. The thermostat utilized a 5 degree cooling setup between 9 AM and 3 PM and a 5 degree heating setback between 11 PM and 6 AM.

Table 4. Thermostat Settings

	Energy Bill Simulation			
	Weekday		Weekend	
Hour	**Heating**	**Cooling**	**Heating**	**Cooling**
12:00 AM	63	76	68	76
1:00 AM	63	76	68	76
2:00 AM	63	76	68	76
3:00 AM	63	76	68	76
4:00 AM	63	76	68	76
5:00 AM	63	76	68	76
6:00 AM	68	76	68	76
7:00 AM	68	76	68	76
8:00 AM	68	76	68	76
9:00 AM	68	81	68	76
10:00 AM	68	81	68	76
11:00 AM	68	81	68	76
12:00 PM	68	81	68	76
1:00 PM	68	81	68	76
2:00 PM	68	81	68	76
3:00 PM	68	76	68	76
4:00 PM	68	76	68	76
5:00 PM	68	76	68	76
6:00 PM	68	76	68	76
7:00 PM	68	76	68	76
8:00 PM	68	76	68	76
9:00 PM	68	76	68	76
10:00 PM	68	76	68	76
11:00 PM	63	76	68	76

Hot Water

The Domestic Hot Water (DHW) heater consumption was calculated based on the number of bedrooms, occupant data, and seasonal variations (NYSERDA,1994). Seasonal variation is not typically accounted for in energy analysis, but provides a significantly better understanding of how variations in occupant behavior impact water and energy consumption. During the colder months of the year, heat loss from pipes will increase and occupants will typically extend the duration of their showers and increase other hot water uses. The following exhibit shows the seasonal weighting factors both as a monthly percent of the annual hot water usage and as a monthly percent of the hot water used in the average month.

Table 5. Hot Water Seasonal Weighting Factors

Month	Seasonal Weighting Factors	
	Percent of Annual Hot Water Usage	Percent of Average Month Hot Water Usage
January	9.0%	108%
February	9.0%	108%
March	9.0%	108%
April	9.0%	108%
May	9.0%	108%
June	7.3%	87%
July	7.3%	87%
August	7.3%	87%
September	8.0%	96%
October	8.0%	96%
November	8.0%	96%
December	9.0%	108%

Step 3: Identify and Analyze Individual Changes to the Baseline Occupant Profile

A series of mini-studies were conducted to determine the impact of individual changes to the baseline occupant profile. The impact was measured as a change in each of the home's end use categories - heating, including fans; cooling, including fans; water heating; lighting; and plug loads/appliances.

Occupant Impacts via Thermostat

To assess thermostats, the heating and cooling setpoints of the baseline occupant profile were modified. Changes to thermostat setpoints are presented first because they were found to have the largest impact on the overall energy use of the home among all individual changes to the baseline occupant profile.

In this analysis the "Base Case" had temperature settings consistent with the HERS reference home – 68 degrees F for the heating setpoint and 78 degrees F for the cooling setopint. To approximate an energy-intensive occupant attempting to maintain consistent mean radiant temperature year-round, the heating setpoint was increased to 74 degrees F and the cooling setpoint was reduced to 72 degrees. To approximate an energy-conservative occupant attempting to minimize utility costs, the heating setpoint was reduced to 62 degrees F and the cooling setpoint was increased to 84 degrees F.

Table 6. Houston Thermostat Energy Use Scenarios

Case	HERS Index	Site Energy % Savings	Purchased Energy % Savings	Heat Gas (MBTU)	Cooling Elec (MBTU)	DHW Gas (MBTU)	Lighting Elec (MBTU)	Appliance Elec (MBTU)
Base Case	100	0.0 %	0.0 %	16.3	11.0	16.8	7.0	18.8
Thermostat (74,72)	141	-30.0 %	-26.9 %	29.9	18.4	16.8	7.0	18.8
Thermostat (62,84)	71	20.9 %	18.9 %	7.0	5.6	16.8	7.0	18.8

In Houston, the revised thermostat setpoints impacted the purchased energy use by as much as 46% between the least and most energy intensive occupant, actual site energy by more than 50%, and as much as 70 points on the HERS Index between the energy-intensive and energy-conservative occupant.

Table 7. Baltimore Thermostat Energy Use Scenarios

Case	HERS Index	Site Energy % Savings	Purchased Energy % Savings	Heat Gas (MBTU)	Cooling Elec (MBTU)	DHW Gas (MBTU)	Lighting Elec (MBTU)	Appliance Elec (MBTU)
Base Case	100	0.0 %	0.0 %	49.5	5.9	21.6	7.0	18.8
Thermostat (74,72)	134	-25.7 %	-23.5 %	71.0	10.8	21.6	7.0	18.8
Thermostat (62,84)	77	20.2 %	17.7 %	31.5	3.1	21.6	7.0	18.8

In Baltimore, the revised thermostat setpoints impacted the purchased energy use of the baseline home by as much as 41% between the energy-intensive and energy-conservative occupant.

Table 8. Minneapolis Thermostat Energy Use Scenarios

Case	HERS Index	Site Energy % Savings	Purchased Energy % Savings	Heat Gas (MBTU)	Cooling Elec (MBTU)	DHW Gas (MBTU)	Lighting Elec (MBTU)	Appliance Elec (MBTU)
Base Case	100	0.0 %	0.0 %	90.6	4.3	23.1	7.0	18.8
Thermostat (74,72)	139	-23.0 %	-22.8 %	117.4	10.6	23.1	7.0	18.8
Thermostat (62,84)	79	17.6 %	16.4 %	68.4	1.3	23.1	7.0	18.8

In Minneapolis, the revised thermostat setpoints impacted the purchased energy use of the baseline home by as much as 39% between the energy-intensive and energy-conservative occupant.

Occupant Impacts via Lighting

To assess lighting, the quantity of fixtures and the percentage of fluorescent lighting was modified. In this analysis the "Base Case" had a lighting intensity consistent with the HERS reference home, which assumes 10% fluorescent lighting. To approximate an energy intensive occupant, the lighting intensity was doubled. To approximate an energy-conservative occupant, the lighting intensity was decreased and the percentage of fluorescent lighting was increased. These modifications impacted the heating, cooling and lighting energy consumption of the baseline home.

Table 9. Houston Lighting Energy Use Scenarios

Case	HERS Index	Site Energy % Savings	Purchased Energy % Savings	Heat Gas (MBTU)	Cooling Elec (MBTU)	DHW Gas (MBTU)	Lighting Elec (MBTU)	Appliance Elec (MBTU)
Base Case	100	0.0 %	0.0 %	16.3	11.0	16.8	7.0	18.8
100% Flourescent	96	3.5 %	5.1 %	16.9	10.6	16.8	4.3	18.8
No Lights On	88	9.1 %	13.1 %	17.9	10.0	16.8	0.0	18.8
Double Lights On	112	-9.1 %	-13.1 %	14.6	12.0	16.8	14.0	18.8

In Houston, the revised lighting intensity and percentage of fluorescent lighting had a significant impact on the energy use of the home. As lighting intensity increased, so did the cooling load. As will be seen, this impact diminishes as in colder climates.

Table 10. Baltimore Lighting Energy Use Scenarios

Case	HERS Index	Site Energy % Savings	Purchased Energy % Savings	Heat Gas (MBTU)	Cooling Elec (MBTU)	DHW Gas (MBTU)	Lighting Elec (MBTU)	Appliance Elec (MBTU)
Base Case	100	0.0 %	0.0 %	49.5	5.9	21.6	7.0	18.8
100% Flourescent	97	1.4 %	3.1 %	51.0	5.6	21.6	4.3	18.8
No Lights On	92	3.8 %	8.1 %	53.3	5.3	21.6	0.0	18.8

Double Lights On	108	-4.0 %	-8.3 %	46.0	6.5	21.6	14.0	18.8

Table 11. Minneapolis Lighting Energy Use Scenarios

Case	HERS Index	Site Energy % Savings	Purchased Energy % Savings	Heat Gas (MBTU)	Cooling Elec (MBTU)	DHW Gas (MBTU)	Lighting Elec (MBTU)	Appliance Elec (MBTU)
Base Case	100	0.0 %	0.0 %	90.6	4.3	23.1	7.0	18.8
100% Flourescent	99	0.4 %	1.9 %	93.0	4.0	23.1	4.3	18.8
No Lights On	97	1.0 %	4.7 %	96.8	3.8	23.1	0.0	18.8
Double Lights On	107	-1.2 %	-4.9 %	84.9	4.8	23.1	14.0	18.8

Occupant Impacts via Refrigerators

To assess refrigerators, equipment efficiency and quantity were modified. The "Base Case" scenario assumed an equipment efficiency consistent with the HERS Reference Home. To approximate an energy-intensive occupant, two refrigerators were modeled. To approximate energy-conservative occupants, an ENERGY STAR refrigerator and a best-available efficiency refrigerator were modeled, as well as no refrigerator at all.

These modifications impacted the appliances, heating and cooling energy consumption of the baseline home. The minimum and maximum energy use studied, "No Refrigerator" and "Two Refrigerators" vary by as much as 4.9% less energy use to as much as 4.8% increase in energy use from the baseline. Refrigerators have a larger impact on energy savings in the hottest climates.

Table 12. Houston Refrigerator Energy Use Scenarios

Case	HERS Index	Site Energy % Savings	Purchased Energy % Savings	Heat Gas (MBTU)	Cooling Elec (MBTU)	DHW Gas (MBTU)	Lighting Elec (MBTU)	Appliance Elec (MBTU)
Base Case	100	0.0 %	0.0 %	16.3	11.0	16.8	7.0	18.8
ENERGY STAR	99	0.8 %	1.0 %	16.3	10.9	16.8	7.0	18.4
Highest Efficiency	99	1.3 %	1.7 %	16.4	10.9	16.8	7.0	17.9
No Refrigerator	99	3.4 %	4.9 %	16.9	10.6	16.8	7.0	16.2
Two Refrigerators	105	-3.2 %	-4.8 %	15.5	11.4	16.8	7.0	21.5

Table 13. Baltimore Refrigerator Energy Use Scenarios

Case	HERS Index	Site Energy % Savings	Purchased Energy % Savings	Heat Gas (MBTU)	Cooling Elec (MBTU)	DHW Gas (MBTU)	Lighting Elec (MBTU)	Appliance Elec (MBTU)
Base Case	100	0.0 %	0.0 %	49.5	5.9	21.6	7.0	18.8
ENERGY STAR	100	0.2 %	0.4 %	49.8	5.9	21.6	7.0	18.4
Highest Efficiency	99	0.5 %	1.1 %	50.0	5.8	21.6	7.0	17.9
No Refrigerator	97	1.2 %	2.9 %	51.1	5.6	21.6	7.0	16.2
Two Refrigerators	103	-1.4 %	-3.0 %	48.0	6.1	21.6	7.0	21.5

Table 14. Minneapolis Refrigerator Energy Use Scenarios

Case	HERS Index	Site Energy % Savings	Purchased Energy % Savings	Heat Gas (MBTU)	Cooling Elec (MBTU)	DHW Gas (MBTU)	Lighting Elec (MBTU)	Appliance Elec (MBTU)
Base Case	100	0.0 %	0.0 %	90.6	4.3	23.1	7.0	18.8
ENERGY STAR	99	0.1 %	0.4 %	91.0	4.1	23.1	7.0	18.4
Highest Efficiency	99	0.1 %	0.6 %	91.5	4.1	23.1	7.0	17.9
No Refrigerator	98	0.3 %	1.7 %	93.1	4.0	23.1	7.0	16.2
Two Refrigerators	102	-0.3 %	-1.7 %	88.3	4.4	23.1	7.0	21.5

Among the individual modifications analyzed, the top three occupant impacts were due to thermostat setpoints, lighting intensity, and refrigerator efficiency and quantity. The next seven most significant impacts are shown below for Houston. Additional data were generated for the other locations, but not included here due to space limitations.

Occupant Impacts via Cooking Range

To assess cooking ranges, the efficiency of the burners (through the pilot and variability of low to high flame) and annual hours of use were modified.

In hot and humid climates, where cooling is a primary concern, the amount of cooking and location of cooking can have a significant impact on the heating and cooling load of the home. Often indoor/outdoor kitchens can provide significant energy savings year-round in hot climates, where kitchens are enclosed during the heating season and open during the cooling season. An occupant that often entertains by cooking for other people will be a high energy user.

Table 15. Houston Cooking Range Energy Use Scenarios

Case	HERS Index	Site Energy % Savings	Purchased Energy % Savings	Heat Gas (MBTU)	Cooling Elec (MBTU)	DHW Gas (MBTU)	Lighting Elec (MBTU)	Appliance Elec (MBTU)
Base Case	100	0.0 %	0.0 %	16.3	11.0	16.8	7.0	18.8
Efficient Range	99	0.8 %	1.0 %	16.3	10.9	16.8	7.0	18.4
Highest Efficiency	99	1.1 %	1.5 %	16.4	10.9	16.8	7.0	18.1
No Cooking	97	2.8 %	4.0 %	16.8	10.6	16.8	7.0	16.8
Double Cooking	104	-2.4 %	-3.6 %	15.6	11.3	16.8	7.0	20.9

Occupant Impacts via Dishwasher

To assess dishwashers, the equipment efficiency and annual wash cycles were modified. These modifications primarily impacted the appliance and hot water energy consumption of the baseline home. Similar to cooking, an occupant that entertains guests will tend to have an increased number of annual wash cycles.

Table 16. Houston Dishwasher Energy Use Scenarios

Case	HERS Index	Site Energy % Savings	Purchased Energy % Savings	Heat Gas (MBTU)	Cooling Elec (MBTU)	DHW Gas (MBTU)	Lighting Elec (MBTU)	Appliance Elec (MBTU)
Base Case	100	0.0 %	0.0 %	16.3	11.0	16.8	7.0	18.8
ENERGY STAR	100	0.7 %	0.6 %	16.3	11.0	16.4	7.0	18.7
Highest Efficiency	100	1.0 %	0.8 %	16.3	11.0	16.3	7.0	18.7
No Dishwashing	98	4.7 %	3.7 %	16.4	10.9	14.0	7.0	18.3
Double Dishwashing	103	-4.5 %	-3.5 %	16.1	11.0	19.6	7.0	19.3

Occupant Impacts via Clothes Washer

To assess clothes washers, the equipment efficiency and annual wash cycles were modified. Similar to the dishwasher, the clothes washer primarily impacted the appliance and hot water energy consumption of the baseline home. An occupant that has a profession which requires significant cleaning of often soiled clothes will be a high energy user.

Table 17. Houston Clothes Washer Energy Use Scenarios

Case	HERS Index	Site Energy % Savings	Purchased Energy % Savings	Heat Gas (MBTU)	Cooling Elec (MBTU)	DHW Gas (MBTU)	Lighting Elec (MBTU)	Appliance Elec (MBTU)
Base Case	100	0.0 %	0.0 %	16.3	11.0	16.8	7.0	18.8
ENERGY STAR	100	0.8 %	0.7 %	16.3	11.0	16.4	7.0	18.7
Highest Efficiency	100	1.1 %	0.9 %	16.3	11.0	16.2	7.0	18.6
No Heated Washing	98	2.8 %	2.5 %	16.4	10.9	15.4	7.0	18.3
Double Washing	102	-2.6 %	-2.2 %	16.1	11.0	18.3	7.0	19.3

Occupant Impacts via Freezer

To assess freezers, equipment efficiency and quantity were modified. Often a home will not have a separate stand-alone freezer, which in itself is the primary decision that impacts the amount of energy use. A high energy user will tend to be an occupant that buys food in bulk.

Table 18. Houston Freezer Energy Use Scenarios

Case	HERS Index	Site Energy % Savings	Purchased Energy % Savings	Heat Gas (MBTU)	Cooling Elec (MBTU)	DHW Gas (MBTU)	Lighting Elec (MBTU)	Appliance Elec (MBTU)
Base Case	100	0.0 %	0.0 %	16.3	11.0	16.8	7.0	18.8
ENERGY STAR	99	0.7 %	0.9 %	16.3	10.9	16.8	7.0	18.4
Highest Efficiency	99	1.0 %	1.4 %	16.4	10.9	16.8	7.0	18.1
No Freezers	95	4.2 %	6.0 %	17.0	10.5	16.8	7.0	15.6
Two Freezers	106	-4.0 %	-5.9 %	15.4	11.5	16.8	7.0	22.0

Occupant Impacts via Microwave

To assess microwaves, the capacity and quantity of microwaves were modified. The microwave has a large electric demand, but does not have long term use like other appliances. As a result, promoting increased adoption can decrease energy consumption relative to a range, while deterring increased adoption can reduce demand. In this study the authors have focused on its impact on energy consumption.

Table 19. Houston Microwave Energy Use Scenarios

Case	HERS Index	Site Energy % Savings	Purchased Energy % Savings	Heat Gas (MBTU)	Cooling Elec (MBTU)	DHW Gas (MBTU)	Lighting Elec (MBTU)	Appliance Elec (MBTU)
Base Case	100	0.0 %	0.0 %	16.3	11.0	16.8	7.0	18.8
ENERGY STAR	100	0.2 %	0.3 %	16.3	11.0	16.8	7.0	18.7
Highest Efficiency	100	0.5 %	0.7 %	16.3	10.9	16.8	7.0	18.6
No Microwave Use	99	1.0 %	1.4 %	16.4	10.9	16.8	7.0	18.1
Double Microwave	102	-0.8 %	-1.2 %	16.0	11.1	16.8	7.0	19.5

Occupant Impacts via TV/DVD

To assess televisions and DVD players, equipment efficiency and annual hours of use were modified. A home's entertainment center, starting with the TV and DVD player, has become a more prominent energy using segment of a home, with larger TVs, increased TV use and increased video gaming. Both the increase in number of TV's and the increase in number of hours of TV use increases the energy use of the appliances and heat gain in the home. In Houston, with a baseline of only 2.1% of the home energy use coming from TV's, increasing the usage of television will increased the purchased energy by2.8%.

Table 20. Houston TV/DVD Energy Use Scenarios

Case	HERS Index	Site Energy % Savings	Purchased Energy % Savings	Heat Gas (MBTU)	Cooling Elec (MBTU)	DHW Gas (MBTU)	Lighting Elec (MBTU)	Appliance Elec (MBTU)
Base Case	100	0.0 %	0.0 %	16.3	11.0	16.8	7.0	18.8
ENERGY STAR	100	0.2 %	0.3 %	16.3	11.0	16.8	7.0	18.7
Highest Efficiency	99	0.6 %	0.8 %	16.3	10.9	16.8	7.0	18.5
No TV or DVD Use	98	1.9 %	2.8 %	16.6	10.8	16.8	7.0	17.3
Double TV/DVD Use	103	-1.9 %	-2.8 %	15.9	11.3	16.8	7.0	20.3

Occupant Impacts via Computers

To assess computers, the equipment efficiency and hours of annual hours of use were modified. Similar to televisions, computers have become more prominent. Additionally, there is a large variance in both the number of computers in a home and the amount of time when computers in use.

Table 21. Houston Computers Energy Use Scenarios

Case	HERS Index	Site Energy % Savings	Purchased Energy % Savings	Heat Gas (MBTU)	Cooling Elec (MBTU)	DHW Gas (MBTU)	Lighting Elec (MBTU)	Appliance Elec (MBTU)
Base Case	100	0.0 %	0.0 %	16.3	11.0	16.8	7.0	18.8
ENERGY STAR	100	0.2 %	0.2 %	16.3	11.0	16.8	7.0	18.7
Highest Efficiency	100	0.5 %	0.6 %	16.3	10.9	16.8	7.0	18.6
No Computer	98	1.6 %	2.2 %	16.5	10.8	16.8	7.0	17.7
Double Computer Use	102	-1.2 %	-1.9 %	15.9	11.1	16.8	7.0	19.9

Occupant Impacts via Ceiling Fans

To assess ceiling fans, equipment efficiency and quantity were modified. Ceiling fans offer an interesting situation for occupant energy use. On one hand, ceiling fans use energy, create heat gain that needs to be cooled, but they also increase comfort in higher space temperatures. In the analysis that was conducted for this mini-study, the authors looked at only the impact of fan usage without regard to potential thermostat savings from increased comfort.

Table 22. Houston Ceiling Fan Energy Use Scenarios

Case	HERS Index	Site Energy % Savings	Purchased Energy % Savings	Heat Gas (MBTU)	Cooling Elec (MBTU)	DHW Gas (MBTU)	Lighting Elec (MBTU)	Appliance Elec (MBTU)
Base Case	100	0.0 %	0.0 %	16.3	11.0	16.8	7.0	18.8
ENERGY STAR	100	0.1 %	0.1 %	16.3	11.0	16.8	7.0	18.8
Highest Efficiency	100	0.1 %	0.2 %	16.3	11.0	16.8	7.0	18.7
No Ceiling Fans	99	0.8 %	1.0 %	16.3	10.9	16.8	7.0	18.4
Double Ceiling Fan Use	101	-0.4 %	-0.7 %	16.1	11.0	16.8	7.0	19.2

Step 4: Define a Low & High Energy Using Occupant

In combining each of the lowest and highest energy using occupant behaviors, this study was able to determine the maximum energy savings impact from the variations in occupant decisions and behavior that were analyzed in the mini-studies.

Four scenarios are summarized below for each of the three analyzed cities: the base case scenario using the HERS reference home; a scenario with zero lighting and appliance usage; a scenario with all high-efficiency appliances and lighting; and a scenario with double the quantity of reference home appliances and increased lighting energy use.

Houston

Table 23. Houston Energy Use Scenarios

Case	HERS Index	Site Energy % Savings	Purchased Energy % Savings	Heat Gas (MBTU)	Cooling Elec (MBTU)	DHW Gas (MBTU)	Lighting Elec (MBTU)	Appliance Elec (MBTU)
Base Case	100	0.0 %	0.0 %	16.3	11.0	16.8	7.0	18.8
Zero Lighting / Appliances	27	62.5 %	71.6 %	10.5	3.1	12.6	0.0	0.0
All Efficient Lighting / Appliances	82	14.7 %	20.2 %	18.9	9.5	15.7	2.9	12.6
Double Lighting / Appliances Usage	135	-25.4 %	-36.6 %	11.6	14.1	16.8	14.0	37.6

With purchased energy savings of 71.6% in the zero lighting and appliances scenario, an occupant that was able to live in that minimalist situation would achieve an Occupant Energy Index of 28.4 (100 – 71.6). Another occupant, who simply lived the same as the reference occupant, but made the decision to purchase the highest efficiency appliances would achieve a 79.2 OEI without compromising comfort or convenience.

Baltimore

Table 24. Baltimore Energy Use Scenarios

Case	HERS Index	Site Energy % Savings	Purchased Energy % Savings	Heat Gas (MBTU)	Cooling Elec (MBTU)	DHW Gas (MBTU)	Lighting Elec (MBTU)	Appliance Elec (MBTU)
Base Case	100	0.0 %	0.0 %	49.5	5.9	21.6	7.0	18.8
Zero Lighting / Appliances	45	39.9 %	51.1 %	44.0	2.3	15.6	0.0	0.0
All Efficient Lighting / Appliances	87	6.7 %	12.8 %	55.4	5.0	20.0	2.9	12.6
Double Lighting / Appliances Usage	123	-10.6 %	-22.5 %	39.3	7.8	21.6	14.0	37.6

Minneapolis

Table 25. Minneapolis Energy Use Scenarios

Case	HERS Index	Site Energy % Savings	Purchased Energy % Savings	Heat Gas (MBTU)	Cooling Elec (MBTU)	DHW Gas (MBTU)	Lighting Elec (MBTU)	Appliance Elec (MBTU)
Base Case	100	0.0 %	0.0 %	90.6	4.3	23.1	7.0	18.8
Zero Lighting / Appliances	60	24.1 %	34.6 %	90.3	2.4	16.5	0.0	0.0
All Efficient Lighting / Appliances	93	2.2 %	7.6 %	100.3	3.5	21.3	2.9	12.6
Double Lighting / Appliances Usage	115	-2.8 %	-13.1 %	73.8	5.9	23.1	14.0	37.6

Conclusions

While there are opportunities to analyze the efficiency of homes through the Home Energy Rating System, industry has not made progress on the ability to predict, rate and educate home owners about their own impact on the energy use of their home. The Occupant Energy Index can be utilized by the home industry to help consumers understand the impact of their decision and behavior on the overall energy use of the home.

While there multiple concepts that can be used to define the Occupant Energy Index this paper uses an approach that is similar to Home Energy Rating System. This paper illustrates that there is the potential for significant energy savings or increased energy usage based on occupant decisions and behavior. With a static home, occupants can shift the energy use of the home by 50% or more, with selecting more or less efficient appliances and by using the appliances more or less than a typical occupant.

This energy use that is currently not capable of being analyzed or tracked can have a significant impact on the actual performance of a utility or government energy efficiency program. The use of the Occupant Energy Index will allow for professionals in the home building industry to educate consumers, provide bill guarantees to builders, and determine actual potential for energy and demand savings for utility and government energy efficiency programs.

References

Alabama Cooperative Extension System, 2003, http://www.aces.edu/dept/extcomm/newspaper/april11b03.html

American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. 2001 ASHRAE Handbook: Fundamentals. Atlanta, GA. 2001.

Department of Energy (DOE): US Lighting Market Characterization Volume I, p.83 2002.

Heschong Mahone CA Baseline, p.4 1999.

International Conference of Building Officials. 2006 International Energy Conservation Code. 2006.
Otter Tail Power Company, 2006, http://www.otpco.com/SaveEnergyMoney/applianceEnergyUsage.asp

Rensselaer Polytechnic Institute, Lighting Research Center (LRC), Lighting Pattern Book for Homes, p.100, 1996.

Natural Resources Canada, 2006, http://oee.nrcan.gc.ca/equipment/english/page162.cfm?PrintView=N&Text=N

Natural Resources Canada, 2006, http://oee.nrcan.gc.ca/equipment/english/page162.cfm?PrintView=N&Text=N

NYSERDA, Report, 94-19, Energy Use and Domestic Hot Water Consumption, November 1994.

Parker, D., Mazzara, M., Sherwin, J., 1996. "Monitored Energy Use Patterns In Low-Income Housing In A Hot And Humid Climate," Tenth Symposium on Improving Building Systems in Hot Humid Climates, Ft. Worth, TX, p. 316

Tampa, Florida, 2006, http://www.tampagov.net/dept_water/conservation_education/Customers/Water_use_calculator.asp

US DOE, EIA, 2006, http://www.eia.doe.gov/emeu/recs/

US EPA, ENERGY STAR, 2006,
http://www.energystar.gov/ia/partners/manuf_res/salestraining_res/Dishwasher_Sales_Training.ppt

US EPA, ENERGY STAR, 2006,
http://www.energystar.gov/index.cfm?c=clotheswash.pr_clothes_washers