U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES PROGRAM

Field Test Protocol: Standard Internal Load Generation for Unoccupied Test Homes

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June 2011

Building America
U.S. Department of Energy

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Prepared for:

Building America

Building Technologies Program

Office of Energy Efficiency and Renewable Energy

U.S. Department of Energy

Prepared by:

Advanced Residential Buildings Group

Electricity, Resources & Building System Integration

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June 2011

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Definitions

BA	Building America
DC	Direct Current
HSP	House Simulation Protocol
NC	Normally Closed

Introduction

In Building America prototypical homes, it is common to conduct heavily instrumented short-term tests (which are akin to a research-level commissioning exercise) prior to occupancy. These tests are used primarily to ensure each home is built to specification, and that the systems are operating as the manufacturers intended. Once a home is occupied, lower level instrumentation is typically used for long-term monitoring of its systems to gauge whether the home and systems achieve the expected energy performance in a real-world setting. Instrumentation is reduced during occupied, long-term monitoring because:

- Heavy instrumentation may inconvenience occupants.
- Monitoring complex real-time occupant behaviors is difficult because they do not lend themselves to consistent prediction or modeling.
- Occupant behaviors represent only the study household, and are unlikely to be average or standard. Many times we want to observe occupancy stressing a home by operating it in unexpected ways, but capturing that and translating it back to simulation are extremely difficult. This often makes it difficult to demonstrate energy savings in a statistically relevant way.

One way to investigate a subset of occupant-incurred impacts is to use unoccupied homes and create heat and moisture loads to represent “standard” occupants. This forces building systems to operate with realistic but known loads, and eliminates the complexity and uncertainty created by occupant behaviors during long-term monitoring. When the loads generated during the field test align with loads used to simulate the building, determining that the building was constructed as specified and that equipment is operating as designed becomes much more straightforward.

A few researchers have tried to generate representative loads, but those efforts were generally not consistent with the Building America House Simulation Protocol (HSP) (Hendron and Engebrecht 2010). The most recent effort was by Oak Ridge National Laboratory with real-time automated control of lights and appliances as well as human load simulation in heavily instrumented field laboratory houses (Christian et al. 2010). The load generation complies with HSP, but the heavy instrumentation was expensive and required intensive custom engineering effort.

This report describes a simple and general way to generate HSP-consistent internal sensible and latent loads in unoccupied homes. It is newly updated and provides instructions about how to calculate and set up the operational profiles in unoccupied homes. The document is split into two sections: how to determine the internal loads’ magnitudes and schedules, and which tools and methods should be used to generate those internal loads to achieve research goals.

Load Calculation

Compliance With HSP

HSP prescribes the annual energy or usage consumption calculation methods for lighting, appliances, miscellaneous electric and gas loads, and domestic hot water, with individual normalized hourly profiles for each. HSP also prescribes occupancy profiles with average sensible and latent hourly loads. To determine internal loads complying with HSP, a researcher should use Building America (BA) analysis spreadsheets on "New Construction" or "Existing Home" (Building America 2011). These provide annual hourly operational profiles for each end use. End uses that the researcher plans to study and control individually (for example, lighting and lighting controls) should be drawn from the appropriate analysis spreadsheet. All other end use loads, when summed together, become the whole-house sensible and latent load hourly profiles, which can be generated using this protocol.

Different Loads in Different Spaces

Generating a central artificial latent and sensible load to match the HSP profile usually suffices for a whole-house simulation need. In field test settings the load generators may need to be distributed to effectively replicate loads that would occur in individual spaces of interest. And if the central location is in a confined space, the researcher may not achieve the expected load. How to best distribute the load generators, and what level of load divisions are required, depend heavily on the research questions being addressed in that test home. For example, if the air handler is of primary interest to the study and local condensation is not a concern, a point source for the whole house or one for each floor may very well suffice. On the other hand, if air distribution and thermal comfort in upstairs bedrooms are of particular concern, distributed loads may be appropriate. But for the latter scenario, logistical concerns such as frequency of refilling humidifiers and spillage possibility for hard-plumbed humidifiers will need to be addressed carefully.

Table 1 is an example of a weekday profile of occupant-generated space loads, based on the 2010 HSP profiles, for a 3,300-ft2, 4-bedroom, 2.5-bath, 2-story home with a finished basement. Sensible and latent loads are divided into downstairs and upstairs portions. Basement load is grouped into the downstairs (first floor) portion. Appliances such as the clothes washer, clothes dryer, dishwasher, refrigerator, cooking range, and oven are grouped with downstairs loads. Lighting, miscellaneous electric loads, and sink uses are split into downstairs and upstairs portions. Shower and bath loads are put into the upstairs portion. Downstairs (living space) and upstairs (bedroom space) occupancy profiles are used based on HSP. Volume of moisture is calculated based on latent heat of vaporization (h_{fg}) for water at room temperature 70°F (21.1°C), i.e. h_{fg} = 1075 Btu/lbm (2500 J/g). For water density, 62.32 lbm/ft^3 (1 g/mL) is assumed. Note that if the test home has a refrigerator, it should be unplugged during the test period so that sensible load is not duplicated.

> **Example:** *Generating the whole-house latent load in a bathroom shower stall without distributed air circulation will impose too heavy a local moisture load and cause local air saturation and condensation on surfaces. This will shift the latent-to-sensible load ratio and delay the release of latent load of interest (change in schedule). Further, the moisture may be absorbed into building materials or run down the drain instead of being removed by mechanical equipment.*

Table 1. Sample Internal Sensible and Latent Load Profile

	Downstairs/Living			Upstairs/Bedrooms		
Hour	**Sensible (Wh)**	**Latent (Wh)**	**Moisture (mL)**	**Sensible (Wh)**	**Latent (Wh)**	**Moisture (mL)**
1	168	15	21	314	147	217
2	158	13	19	304	143	211
3	150	10	15	301	142	209
4	148	10	15	301	143	211
5	171	12	17	327	147	217
6	227	15	23	402	169	248
7	382	117	173	370	140	206
8	408	132	195	337	119	176
9	338	114	169	198	62	91
10	295	91	134	161	50	73
11	294	89	131	153	42	61
12	297	92	136	143	35	51
13	297	94	139	133	28	41
14	289	88	130	131	25	37
15	287	86	127	133	23	34
16	316	92	136	156	24	36
17	417	120	176	226	28	42
18	570	192	283	291	36	53
19	686	241	355	354	39	58
20	688	215	317	395	39	58
21	675	202	298	402	39	57
22	625	219	323	329	38	55
23	415	120	177	338	95	141
24	221	21	31	365	155	228
Total	**8519**	**2402**	**3539**	**6565**	**1908**	**2811**

If room thermal comfort and air distribution are of particular research concern to a researcher, such as in bedrooms and bathrooms, load generation can be further split for each bedroom and bathroom.

Table 2 is an example of subdividing the loads into master bedroom, master bathroom, and two of the three guest bedrooms. Shower, bath, and sink are all grouped into the master bathroom. Lighting, miscellaneous, and occupancy loads are evenly divided into each simulated bedroom.

Table 2. Sample Internal Sensible and Latent Profiles for Individual Bedrooms

	Downstairs/Living			Each Bedroom (3 total)			Master Bathroom		
Hour	Sensible (Wh)	Latent (Wh)	Moisture (mL)	Sensible (Wh)	Latent (Wh)	Moisture (mL)	Sensible (Wh)	Latent (Wh)	Moisture (mL)
1	168	15	21	93	44	65	35	15	22
2	158	13	19	92	44	65	29	11	16
3	150	10	15	91	44	65	27	10	14
4	148	10	15	91	44	65	28	11	15
5	171	12	17	96	44	65	39	15	22
6	227	15	23	109	44	65	76	36	53
7	382	117	173	82	22	33	126	73	108
8	408	132	195	70	15	22	128	74	110
9	338	114	169	32	0	0	103	62	91
10	295	91	134	26	0	0	84	50	73
11	294	89	131	26	0	0	73	42	61
12	297	92	136	26	0	0	64	35	51
13	297	94	139	26	0	0	55	28	41
14	289	88	130	26	0	0	52	25	37
15	287	86	127	28	0	0	50	23	34
16	316	92	136	33	0	0	57	24	36
17	417	120	176	49	0	0	78	28	42
18	570	192	283	64	0	0	100	36	53
19	686	241	355	77	0	0	122	39	58
20	688	215	317	87	0	0	135	39	58
21	675	202	298	89	0	0	135	39	57
22	625	219	323	72	0	0	113	38	55
23	415	120	177	85	22	33	83	29	43
24	221	21	31	103	44	65	57	23	33
Total	**8519**	**2402**	**3539**	**1572**	**368**	**542**	**1850**	**803**	**1184**

Load Generation

Load-Generating Equipment

Two loads are being generated: sensible and latent.

Sensible Load Generation

Electric convective heaters should be used to generate sensible load. These heaters contain a resistance heating element and a fan. This equipment was chosen because of the added benefit of circulating the load for more realistic temperature distribution. The heater must be oriented so that fan-forced convection does not affect other systems. For example, if the heater blows directly at a large sliding glass door, the home envelope heat transfer will be undesirably altered. Proximity of the heater to sensors also needs to be considered.

Each heater should have its power cord metered; electrical energy consumed is equal to sensible load generated. Heaters and humidifiers shall be cycled on at the start of every 15-minute timestep, for sufficient duration to generate the desired hourly profile. Once 25% of the hourly load is reached from power metering feedbacks (in kilowatt-hours), the heater should be cycled off for that timestep. It is desirable to have long runtimes, so the heater should be sized as closely as possible to the highest hourly load.

Latent Load Generation

An ultrasonic humidifier, which uses a metal diaphragm vibrating at an ultrasonic frequency to create very fine water droplets that silently exit the humidifier as cool fog, should be used to generate latent load. Unlike a steam humidifier, it can release moisture at room temperature almost instantly without a warmup period, and does not heat the room air with hot steam from a heated water basin. And unlike an evaporative humidifier, its moisture release rate is steady regardless of ambient relative humidity. Therefore, using an ultrasonic humidifier is a more effective way of dividing sensible and latent into separately controllable loads. Demineralization cartridges and regular cleaning are required to prevent mineral buildup. The humidifier should face toward the center of the room to allow water droplets to fully evaporate. The humidifier may need to be elevated so the atomized water can evaporate before it lands on a solid surface such as a floor or cabinet.

The humidifier’s water reservoir will not hold sufficient water for long-term monitoring. The water level can be maintained manually or automatically. For a manual refill operation, the researcher will need to calculate the moisture release rate, humidifier container volume, daily loads, and number of days between refills to determine the number of humidifiers needed. A schematic for automatic reservoir filling is provided in Figure 1. Table 3 shows a list of heaters and humidifiers needed to generate the load profiles in Table 1.

Table 4 provides a list of instrumentation that enables automated load generation. This list is for reference only, but is representative of a test home’s requirements.

Table 3. List of Heaters and Humidifiers

Equipment	Location	Manufacturer/Model	Capacity	Electrical	Accessories	Comment
Electric heater	Center of family room	Sunbeam SFH1000	1,200 W	120 V, 1200 W	None	A
Humidifier	Kitchen counter, next to sink	Sharper Image HE100283	5.72 mL/min (lab tested)	120 V, 45 W	AOS 7531 demineralization cartridge	B
Electric heater	Upstairs hallway	Sunbeam SFH1000	1,200 W	120 V, 1200 W	None	A

Comments:
A Heat/fan only setting.
B Provide water mineral filter at sink faucet to reduce mineralization. PUR, GE, or equivalent filters are acceptable.

Table 4. List of Instrumentation

Monitored / Controlled Parameter	Sensor Description	Sensor Manufacturer	Sensor Part Number	Sensor Accuracy	Qty.	Comment
		For Humidifier				
Make-up water flow rate	Plastic flow sensor: low to medium water flow rate	Omega	FTB601B	± 1% of reading	1	
Control valve	2-way N.C. solenoid valve for potable water	ASCO	8256 NSF 61-1/4”	NA	1	A
Level switch	Ultrasonic solid-state liquid level switch	Omega	LVU-A701	NA	1	B
AC/DC relay controller with manual override	Humidifier power disconnect and make-up water control valve relay	Campbell	SDM-CD16AC	NA	1	C
Humidifier power disconnect	Solid-state relay	Grainger	1EGJ5	NA	1	
Humidifier make-up water control valve relay	Solid-state relay	Grainger	1EGJ5	NA	1	
Humidifier current	Current transducer with 0–5-V DC output	LEM	AT 10 B5	± 1.5%	1	D
		For Electric Heater				
AC/DC relay controller with manual override	Heater power disconnect	Campbell	SDM-CD16AC	NA	1	C
Solid-state relay	Power disconnect	Grainger	1EGJ5	NA	1	
Electric heater	Watt node power meter	Continental Control Systems	WNB-3Y-208-P3 100HZ output	± 0.5%	1	
	Solid core current transformer	Continental Control Systems	CTS-0750-015	± 1%	1	

General Note: use 3/8-in. copper pipe, braided flex stainless steel metal piping or 1/4-in. PVC piping rated at 100 psig minimum, with compression fittings to plumb supply water to the flow meter, solenoid valves, and humidifier.

Comments:
A N. C. Normally closed, power open. Solenoid valve will close on losing power.
B Normally open level switch by default. When the high water level is reached or the level switch loses power, the level switch will disconnect power to the solenoid valve.
C Only a control point is needed on the relay controller.
D When two or three manual refill humidifiers are bundled together in parallel operations, one current transducer can be used to meter the total lumped power.

Figure 1 shows a photo of the plumbed humidifier with flow meter and solenoid valve under the kitchen faucet in a pilot test home. The humidifier has two water basins. The top tanks were removed to enable auto feed application. Two acrylic plates with precut holes were glued to the rim of the water basins. The plates cover the water surface with holes for make-up water line and level switch. An electrical bushing (a hollow insulating liner) was used to support the level switch. A push-in fitting was used to support the make-up water tubing. The level switch and the make-up water inlet were purposely placed on different sides of the humidifier. This gave some room for water self leveling in the basins during every water feed and prevented unstable operation of the level switch. A demineralization cartridge needs to be placed in the same basin with the make-up water line to prevent unstable operation of the level switch. Figure 2 is a schematic of piping diagram with controls layout.

NREL/PIX 19201
Credit: Xia Fang

NREL/PIX 19202
Credit: Xia Fang

NREL/PIX 19203
Credit: Xia Fang

Figure 1. Kitchen humidifier in a laboratory home

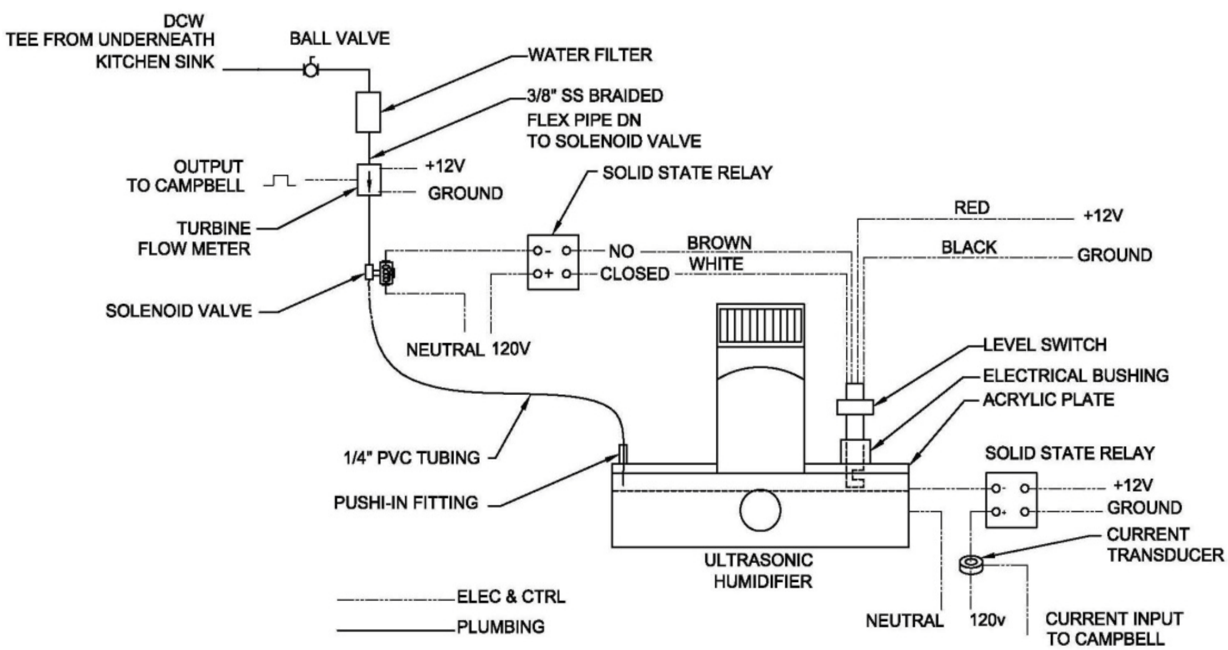

Figure 2. Humidifier piping diagram and controls

At the beginning of each timestep, the solenoid valve for make-up water shall open for water feed to the humidifier until the level switch high level line is reached. The flow meter provides a reading and gives feedback for the make-up water provided.

Alternately, for generating separate small room loads, small convective heaters and manual feed humidifiers can be used. Table 5 shows the recommended small humidifiers and heaters for that situation.

Table 5. Room Heaters and Humidifiers

Equipment	Location	Manufacturer/Model	Capacity	Electrical	Accessories	Comments
Electric heater	Bedroom	Burton 150/300W ceramic heater and fan	150 W	120 V	12-V converter	
Humidifier	Bedroom	Sharper Image HE100280	4.75 mL/min (Lab tested)	120 V, 25 W	Demineralization cartridge	One-gallon tank. Humidifier shall have manual water feed once a week.

Ultrasonic humidification is almost load-neutral to the room air. While evaporation of water droplets creates a positive latent load, this results in a negative sensible (cooling) load. Power consumption of the humidifier only partly offsets the negative sensible load to the room air, so heater runtimes must be increased to compensate. Table 6 shows the necessary sensible load adjustment compared with Table 1, and represents the final control strategy for load generation.

Table 6. Sample Load Profiles With Sensible Load Adjusted

	Downstairs / Living			Each Bedroom (3 total)			Master Bathroom		
Hour	Latent (Wh)	Moisture (mL)	Adjusted Sensible (Wh)	Latent (Wh)	Moisture (mL)	Adjusted Sensible (Wh)	Latent (Wh)	Moisture (mL)	Adjusted Sensible (Wh)
1	15	21	179	44	65	129	15	22	47
2	13	19	168	44	65	127	11	16	38
3	10	15	158	44	65	127	10	14	35
4	10	15	156	44	65	127	11	15	37
5	12	17	180	44	65	132	15	22	51
6	15	23	240	44	65	144	36	53	105
7	117	173	477	22	33	99	73	108	185
8	132	195	515	15	22	82	74	110	188
9	114	169	430	0	0	32	62	91	152
10	91	134	368	0	0	26	50	73	124
11	89	131	366	0	0	26	42	61	107
12	92	136	372	0	0	26	35	51	92
13	94	139	373	0	0	26	28	41	78
14	88	130	360	0	0	26	25	37	72
15	86	127	356	0	0	28	23	34	69
16	92	136	390	0	0	33	24	36	76
17	120	176	513	0	0	49	28	42	101
18	192	283	725	0	0	64	36	53	129
19	241	355	880	0	0	77	39	58	154
20	215	317	862	0	0	87	39	58	167
21	202	298	838	0	0	89	39	57	167
22	219	323	802	0	0	72	38	55	143
23	120	177	511	22	33	103	29	43	107
24	21	31	238	44	65	138	23	33	75
Total	**2402**	**3539**	**10457**	**368**	**542**	**1869**	**803**	**1184**	**2498**

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DOE/GO-102011-3321 ▪ June 2011

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