Performance of Building America Initiative Houses with Unvented Attics and Tile Roofs Constructed by Pulte Homes, Las Vegas Division

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Armin Rudd

Abstract:

A residential attic model, contained in the finite element computer program FSEC 3.0, was empirically aligned with measured attic data from three roof research facilities in Florida and Illinois. This model was then used to simulate hourly space conditioning energy use, and roof and attic temperatures, for peak cooling days and annual weather, for Orlando, Florida and Las Vegas, Nevada. Results showed that, when compared to typically vented attics with the air distribution ducts present, sealed cathedralized attics (i.e. unvented attic with the air barrier and insulation at the sloped roof plane) can be constructed without an associated energy penalty in hot climates.

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HISTORICAL PERSPECTIVE

Detailed Simulations

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Table 1 Summary Of Annual Simulation Results For Las Vegas: Space conditioning

Las Vegas, Nevada **Simulation Description**	**Annual Cooling Load % Difference**	**Annual Heating Load % Difference**	**Annual Total Load [1] % Difference**	**Annual Total Cost [2] % Difference**
Reference case (1:150 vented attic, R-28 flat insulation, ducts in attic, black shingles)				
Sealed attic, R-40 sloped insulation	-5.0	-11.4	-8.9	-7.6
Sealed attic, R-28 sloped insulation, white	-11.1	-0.7	-4.7	-7.0
Ducts in conditioned space	-4.5	-4.0	-4.2	-4.3
Sealed attic, R-28 sloped insulation	0.3	-6.1	-3.6	-2.2
White tile	-9.0	2.6	-1.9	-4.4
1:300 Attic vent area	0.8	-0.8	-0.2	0.2
Sealed attic, R-40 flat insulation	4.9	-2.7	0.2	1.9
Sealed attic, R-28 flat insulation	9.7	2.9	5.5	6.9
Duct leakage 10% return 5% supply	8.3	10.2	9.5	9.1
Duct leakage 15% return 10% supply	14.3	17.6	16.4	15.6

[1] Load based on: 10 SEER cooling, electric heat
[2] Cost based on: 10 SEER cooling and $.07/kW-h, gas heat (combo water heater system 60% efficiency) and $.02/kW-h

Angel Park Subdivision

Following the favorable indications from simulation results, code variance was obtained and two test houses were constructed in Angel Park with sealed cathedralized (unvented) attics. These houses were tested and monitored to evaluate their cooling energy performance compared to a conventional vented attic house.

Short-term monitoring

Results from short-term testing in the late summer of 1996 showed that the unvented attic houses had cooling energy use savings over the conventional 1:150 vented attic house (an average of 19 percent). This was mostly due to sealing the attic and getting the air distribution ducts inside the air and thermal boundary of the building.

Tile top temperatures were hardly effected by the sealed attic. The 3 F maximum tile top temperature difference agreed well with the simulated prediction. The maximum measured plywood roof sheathing temperature increase of 17 F for the sealed attics is less than the temperature variation experienced by changing from tile to asphalt shingles of any available color. During the test period, the maximum measured roof sheathing temperature of 126 F for the sealed attics is well within an acceptable temperature performance range of wood-based roof sheathing (< 180 F).

These results set into motion plans to build an entire subdivision (Cypress Pointe) according to the Building Science Consortium (BSC) Building America Initiative (BAI) specifications.

Long-term monitoring

One of the two unvented attic houses (Angel Park Lot 24) and the conventional vented attic house (Angel Park Lot 22) were monitored between July 1997 and March 1998. Analysis of the cooling season data showed an average of 5% savings for the unvented attic house. This is illustrated in Figure 1. The data was somewhat challenging to analyze due to a number of factors including: 1) different occupant habits impacting cooling system efficiency and internal heat generation; and 2) the addition of a pool at the BAI house which necessitated the removal and reinstallation of the outside compressor-condenser unit. These challenges increased the level of uncertainty in the result. The expected result was at least 15% savings for the BAI house.

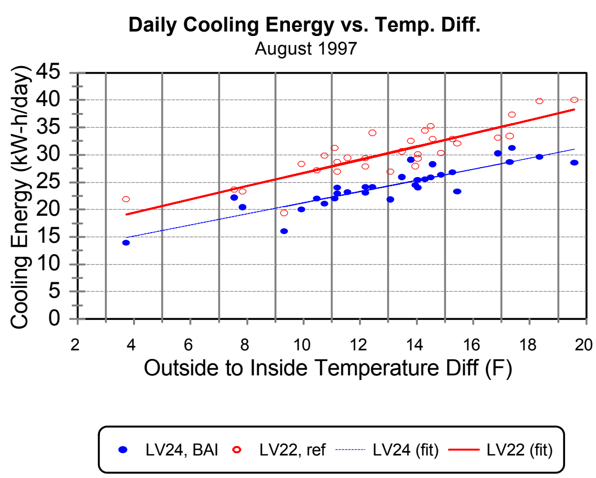

Figure 1 Regression of cooling energy consumption verus inside to outside temperature difference for the vented attic (LV22) and unvented attic houses

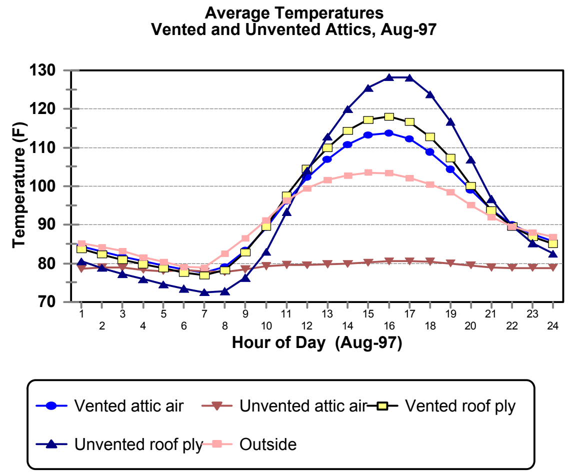

Figure 2 Average hourly temperatures for the month of August showing the large difference in environment where the air distribution system ducts reside

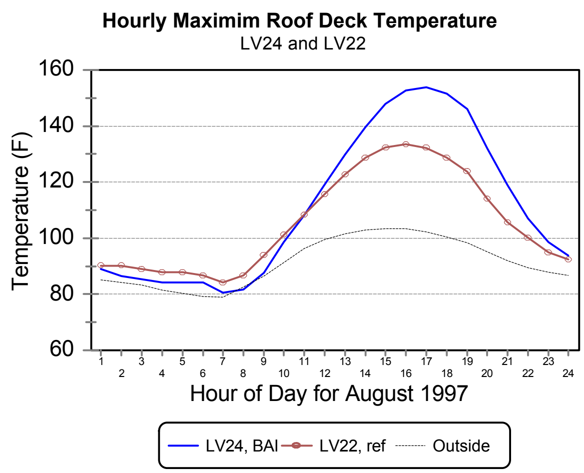

Figure 3 Hourly maximum bottom of roof sheathing temperatures for the vented (LV22) and unvented attic houses, peaking at about 20 F differential

Analysis of the heating season data showed heating energy consumption savings of over 50% for the BAI unvented attic house. This information is shown in Table 2 and Figures 4 and 5. In addition to the benefits of the sealed cathedralized attic, part of these savings were also due to the higher performing low-e windows, however, the exact effect of the windows is unknown since the use of window coverings varied with the occupants. We have found that most window coverings in the Las Vegas climate are kept closed during the summer, somewhat limiting the benefit of high performance windows, but use varies in the winter.

Table 2 Summary of measured heating data for unvented and vented attic houses in Las Vegas 7-28 February 1998

	Avg Outside Temp. (F)	Avg Inside Temp. (F)	Avg Temp. Diff. (F)	Cooling On-time (h)	Heating On-time (h)	Heating Delivered (kW-h)	Heating Delivered (kW-h/day)	Normalized Heating Delivered (kW-h/day-F)	% Diff.
Vented Attic	50.0	70.9	-20.9	0	84.8	1618	76	3.55	
Unvented Attic	50.0	76.9	-26.8	0	63.6	951	45	1.63	-54%

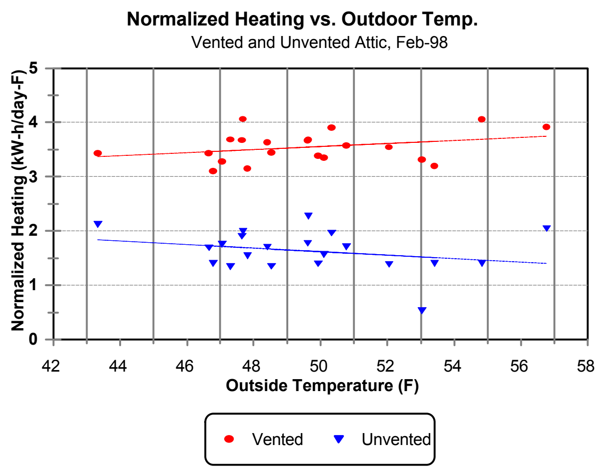

Figure 4 Regression of heating energy delivered, normalized for inside to outside temperature difference, versus outdoor temperature

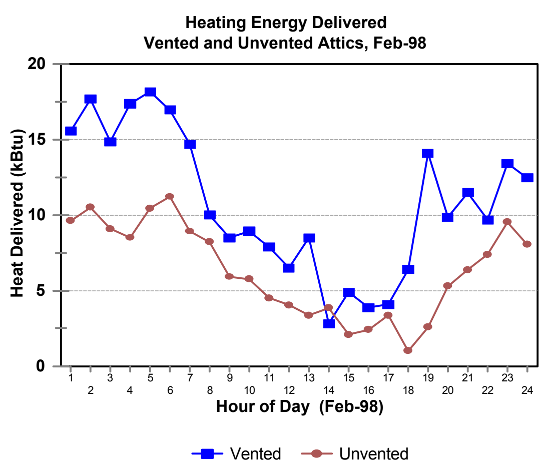

Figure 5 Hourly average heating energy delivered, measured at the air handler unit, for the month of February

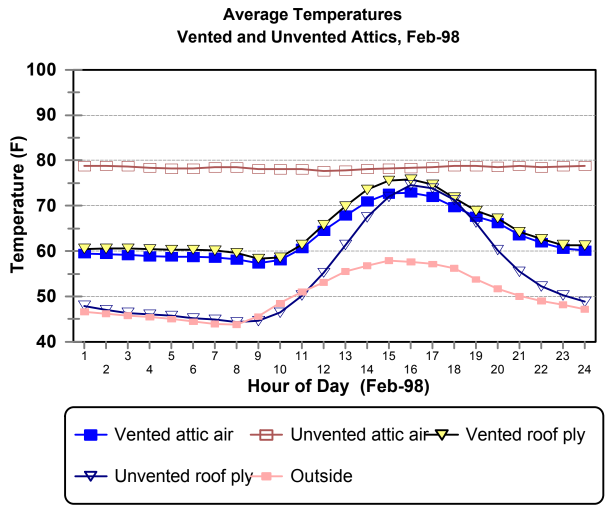

Figure 6 Hourly average temperatures for the vented and unvented attics for the month of February, showing the large difference between the environments where the air distribution ducts reside

Figure 7 is a high/low/mean plot of the temperature of the bottom of the roof sheathing of the unvented attic. At night, the sheathing temperature briefly approaches the indoor air dewpoint temperature of about 45 F, then sharply rises during the day. Moisture measurements were made of the roof sheathing during the winter and all readings were below 6% moisture content.

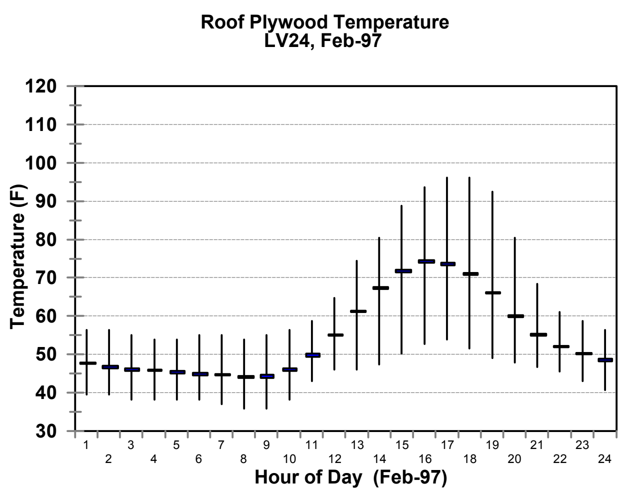

Figure 7 High/low/mean plot of the temperature at the bottom of roof sheathing temperature for the unvented attic for the month of February, the sheathing had low moisture content

Cypress Pointe and Crown Ridge Subdivisions

The entire Cypress Pointe subdivision was constructed using the Building America specifications. Five of these houses were tested and instrumented for long-term monitoring. The data has been collected and is being analyzed. The Crown Ridge subdivision is still under construction and all of the houses are using the Building America specifications.

CURRENT ACTIVITY

Right-sizing the cooling systems

Typically cooling systems are oversized. Much of this is based on rule-of-thumb and tradition. Generally, a major disadvantage of oversizing cooling systems is the lack of humidity control in humid climates. While humidity control is not a problem in dry climates, less frequent and shorter air circulation periods will increase temperature variations and decrease comfort.

The BSC Building America Program seeks to extract first cost out of oversized cooling systems to pay for building improvements that will reduce total energy consumption and increase comfort. In the Southwestern U.S. market, these improvements generally include: 1) unvented attic; 2) high performance glazing with spectrally selective low-e coating; 3) superior building airtightness and thermal insulation; and 4) mechanical ventilation system. In some cases, these improvements can also allow further economies with the heating system, like combination space and domestic hot water heating systems.

Up to now, Pulte Homes has not realized the full potential of extracted first cost from oversized cooling systems. Until recently all the Building America houses have had cooling systems that were traditionally sized for the inside air handler/evaporator coil units and somewhat smaller than traditional size for the outside condenser-compressor units. In addition to higher first cost, the high airflow indoor units have an electrical energy consumption penalty. In some cases, the high air flow has created challenges for the central-fan-integrated supply ventilation system.

<u>80% houses at Arbor View</u>

In the summer of 1999, two houses were constructed at Arbor View with cooling systems that were significantly reduced in size compared to the traditional sizing method. For each house, the cooling system was sized using ACCA Manual J procedures, then cut further by approximately 80%. The indoor and outdoor units were correctly matched. These houses were instrumented to determine whether the smaller cooling systems were meeting the load and maintaining comfort. Several different analyses showed that one house (Arbor View Lot 6 Plan 2260, 2260 ft^2) was working well, while the other (Arbor View Lot 7 Plan 1787, 1787 ft^2) was probably sized too small. As it turned out, at Las Vegas outdoor conditions, the actual installed systems were sized at 84% and 70% of the Manual J total cooling load for Lot 6 and 7, respectively. We are not recommending sizing below 80% of the Manual J calculated total load.

Figures 8a and 8b are histograms showing the frequency of cooling system on-time over one half hour periods. All of the measured on-time fractions for Lot 6 were below 0.8, meaning that the system was never running all the time to meet the thermostat setpoint. For Lot 7, 94% of the on-time fractions were below 0.8, and 4% were between 0.9 and 1.0.

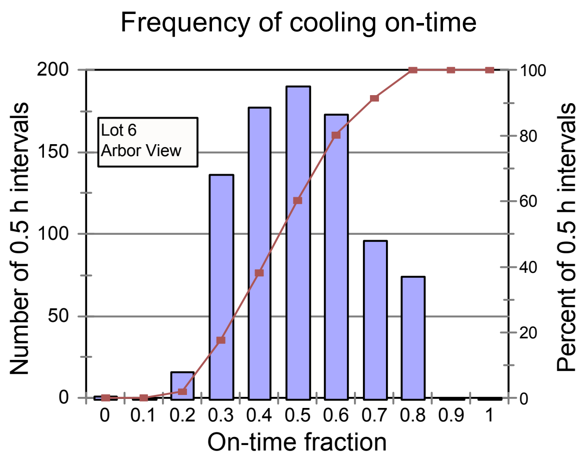

Figure 8a Frequency of cooling on-time fraction over one-half hour intervals for Lot 6

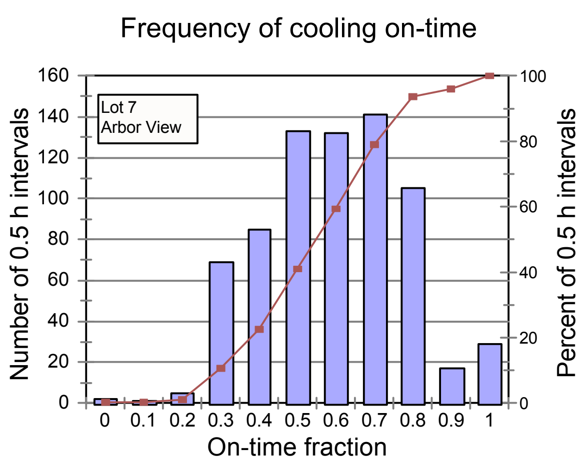

Figure 8b Frequency of cooling on-time fraction over one-half hour intervals for Lot 7

Figures 9a and 9b show a scatter and regression plot of cooling on-time fraction versus outside to inside temperature differential. At a 30 F temperature difference, the cooling on-time fraction was about 0.7 and 0.9 for Lot 6 and Lot 7, respectively.

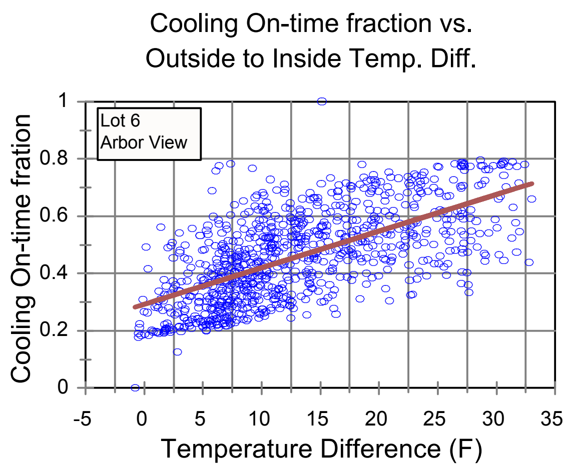

Figure 9a Regression of cooling on-time fraction versus inside to outside temperature difference for Lot 6

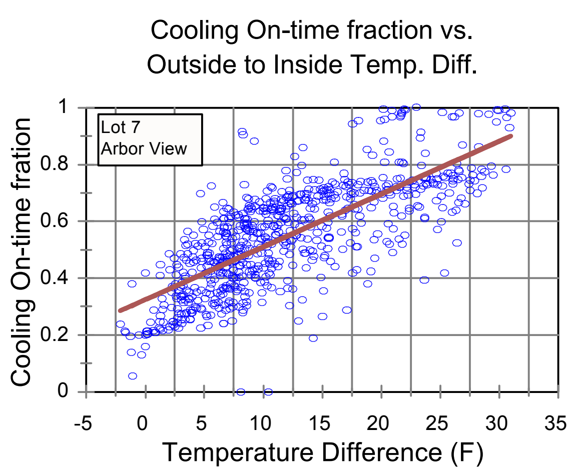

Figure 9b Regression of cooling on-time fraction versus inside to outside temperature difference for Lot 7

Paralleling the analysis presented by Proctor 1998, Figures 10a and 10b show a scatter plot of the relative sensible load (RSL) versus the mean outside temperature. The RSL is the ratio of the measured delivered sensible capacity to the estimated design load (EDL). In Figures 10a and 10b, the EDL is equal to the sensible capacity from manufactures data for the specified and installed equipment. The manufacturers data was selected at indoor conditions of 80 F drybulb and 67 F wetbulb temperature, and at 95 F outdoor drybulb temperature. For Lot 6, the RSL exceeded 67% of the EDL 19% of the time. That occurred 35% of the time for Lot 7. There were 10 one-half hour periods where the outside air temperature exceeded the design temperature of 106 F.

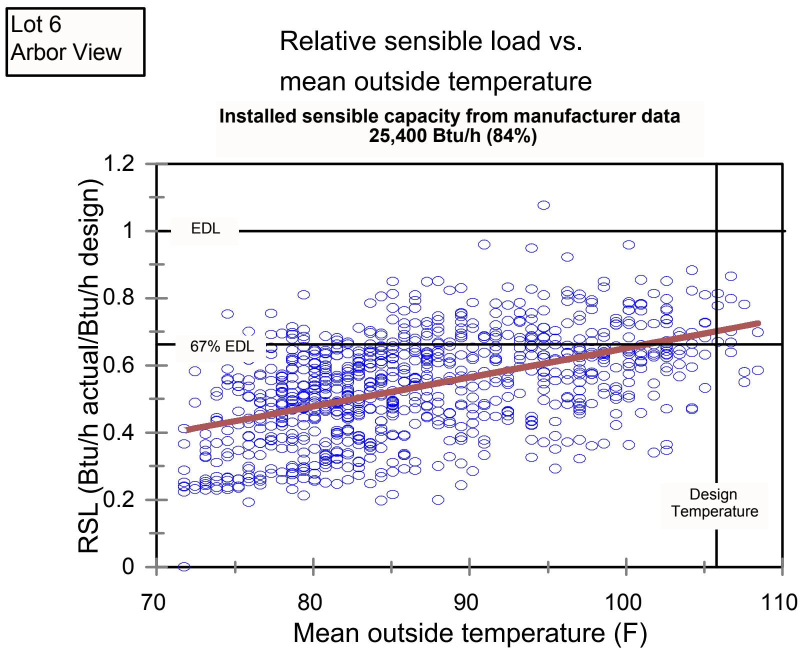

Figure 10a Relative sensible load (RSL) versus mean outside air temperature for installed equipment at Lot 6

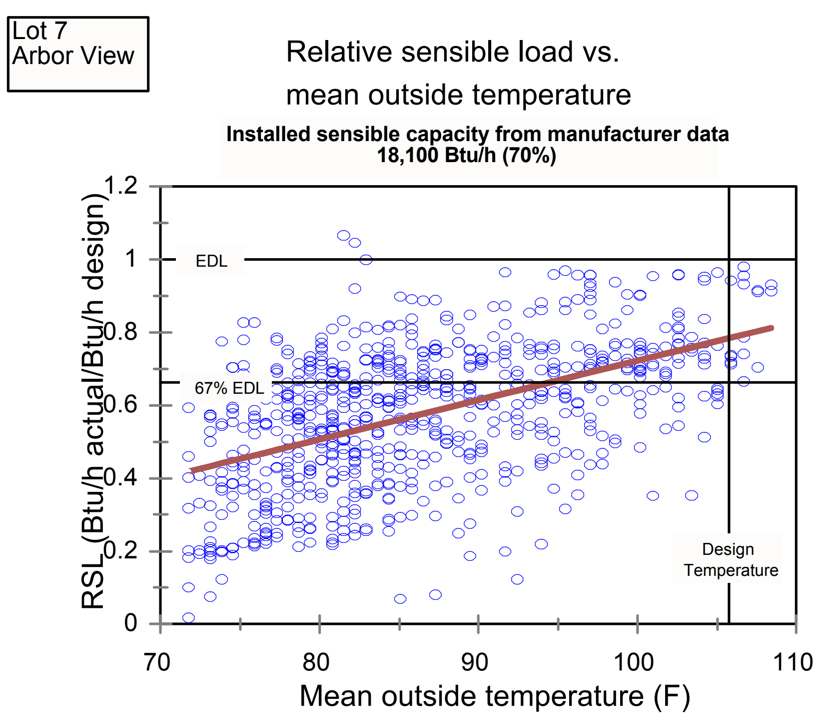

Figure 10b Relative sensible load (RSL) versus mean outside air temperature for installed equipment at Lot 7

To determine whether the smaller cooling systems could maintain comfortable room temperatures throughout the house, seven thermocouples were distributed in each house. Figures 11a and 11b illustrate the temperature variation between rooms. For the house at Lot 6, the average local variation ranged from -0.7 to +1.4 degrees from the house average. The Great Room was consistently warmer than the other locations. During testing, a supply register with low airflow was identified in this area.

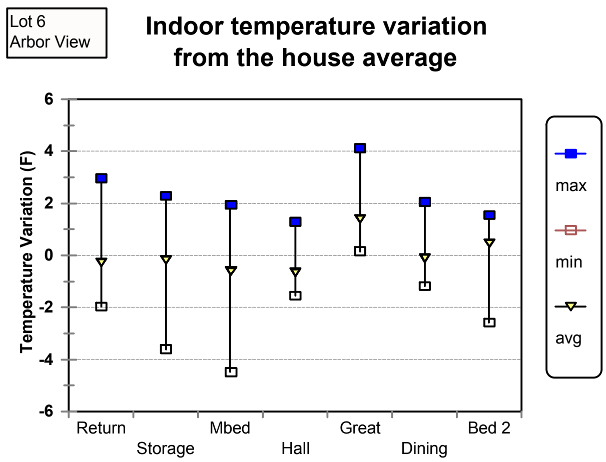

Figure 11a High/low/mean plot showing temperature variation from the house average for six rooms and the central return for Lot 6

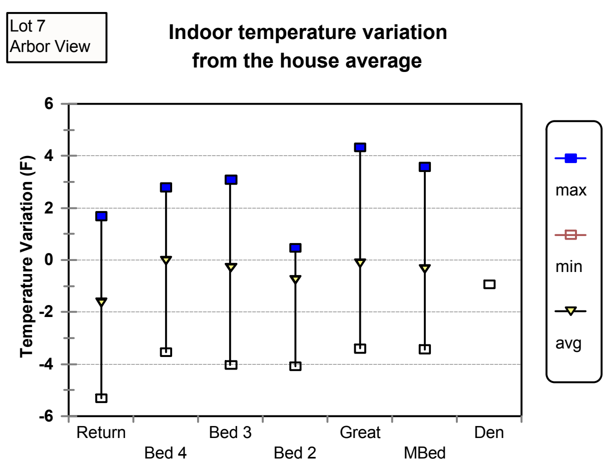

Figure 11b High/low/mean plot showing temperature variation from the house average for six rooms and the central return for Lot 7

For the house at Lot 7, except for the optional Den, the average local temperature variation ranged from -1.6 to 0.0 degrees from the house average. The minimum temperature variation in the Den was -0.9 degrees from the house average. The temperature measurement in the Den was greatly affected by solar radiation from the skylights, hence, the average (+3.2 F) and maximum temperature variations in that location were not valid.

Recovery from thermostat setup

Some discussion, and testing, has centered around the issue of recovery time from a thermostat setup. Upon leaving the house, some homeowners are accustomed to setting up the thermostat cooling setpoint, or even turning the cooling system off, and setting it back or turning it on when they return. For conventional homes in dry climates, with oversized cooling systems, and without much duct leakage to outside, this strategy has probably worked to provide acceptable comfort while reducing cooling bills. Assuming the oversized capacity is not lost due to duct leakage and duct heat gain, the excess capacity has been available to bring the house back to setpoint usually within one-half hour. Once the desired setpoint is attained, the oversized system will cycle less efficiently, and for shorter time periods allowing greater temperature variation throughout the house. For cooling systems that are “right-sized,” the recovery time can be somewhat longer than one-half hour, however, once the desired setpoint is attained the system will cycle on for longer time periods, increasing efficiency and comfort.

More significant, the BSC Building America team believes that recovery time may not be an important metric. It is believed that superior comfort control can be achieved for the same or less operating cost by taking the excess first cost out of oversized cooling systems, and applying that resource to building improvements, and leaving the cooling setpoint continuously at a comfortable setting. A controlled experiment should be designed and implemented to validate this strategy.

About this Report

This report was produced in cooperation with the Building America Program and Builder Partner Pulte Homes.

About the Author

Armin Rudd is a principal engineer at Building Science Corporation in Westford, Massachusetts. More information about Armin Rudd can be found at www.buildingscienceconsulting.com.

Direct all correspondence to: Building Science Corporation, 30 Forest Street, Somerville, MA 02143.

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