
A Cathedralized Attic in a Hot, Humid Climate—Is it Worth Conditioning?

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ABSTRACT

Cathedralized attics in energy efficient homes in hot, humid climates provide a hospitable, performance-enhancing environment for air handlers and ductwork. This is because a well-insulated, airtight building enclosure is constructed at the roof line and indoor temperature and humidity levels are not near outside levels. Although cathedralized attics with space conditioning systems located within them are not typically provided with dedicated supply and return air, it is not clear if more energy would be saved if the space, and the air distribution system in it, were directly conditioned, thereby turning the space into a conditioned mechanical room. Or, would the energy cost of directly conditioning the space negate the possible air distribution system performance benefits that result from the system being in a directly conditioned space?

Research is ongoing at a Building America house built in 2005 in Orlando, Florida that has a cathedralized attic. The attic contains dedicated supply and return air ductwork that can be activated remotely and is alternatively directly and indirectly conditioned for several weeks at a time. Temperature and humidity monitoring sensors within the attic space and the living space below provide comparative information on the conditions within both spaces.

Results of measurements taken during cooling conditions and the analysis of the energy performance of the air distribution system during directly conditioned and indirectly conditioned cases indicate that marginally more energy is used when the cathedralized attic is directly conditioned. When the attic was directly conditioned during cooling, over-cooling occurred periodically in one of the living spaces. Similar circumstances occurred when the attic was directly conditioned during heating.

INTRODUCTION

As part of the annual International Builders' Show®, a house is built to showcase the latest products, technologies, and design ideas. This house, called The New American Home® (TNAH), is sponsored by the National Council of the Housing Industry (NCHI), a committee of the National Association of Home Builders (NAHB). TNAH 2006 was built in the hot humid climate of Orlando, Florida. The U.S. Department of Energy's Building America program, through IBACOS Inc., was an integral part of the design team and spearheaded the design and implementation of energy efficiency measures in the house. As a result, the house achieved 39% whole house energy savings relative to the Building

America Benchmark (Hendron 2004) and an HERS score of 91 (according to HERS 1999 methodology).

Construction of TNAH 2006, with 6,506 square feet (604.4m) of floor area and a volume of 103,587ft (2,933m) including attic space, started in January 2005 and was completed in January 2006. The house has a slab-on-grade foundation, is predominately two stories in height and contains five bedrooms and four full bathrooms. The main energy efficiency features of the house include:

- The creation of cathedralized attics using low density, open cell spray foam insulation, with R-20 (RSI 3.5) thermal performance, installed at the underside of roof decking (including gable ends) to create an air and thermal barrier for the reduction of air movement and heat

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transfer between the attic space and the outside. Attic venting was eliminated to prevent the entry of unwanted outdoor air.

- Air handlers and ductwork located in cathedralized attic space. Electric air-source heat pumps were used for space conditioning and sized according to ACCA Manual J 8th Edition. Average system performance is SEER = 15.4 and HSPF = 7.9.
- Two passive air inlet systems connected to the return air plenum of their respective blower coil (air handler) unit provide mechanical ventilation for the house.
- An airtight building enclosure. Airtightness testing determined a value of 2.6 air changes per hour at 50 Pa test pressure, equivalent to an average 0.23 natural air changes per hour.
- Windows with a low solar heat gain coefficient (SHGC) to reduce cooling loads, SHGC = 0.26, U = 0.33.
- Exterior concrete block walls with R-5 using extruded polystyrene insulation placed directly on the inside wall face without gaps between joints.
- All joints and connections within the air distribution system were sealed with approved water-based mastic for airtightness. Each air distribution system was engineered for optimum performance according to ACCA Manual D. Dedicated, fully ducted return air ductwork is part of each air distribution system. Registers are located in room ceilings.

Research Study Objectives

A research study was initiated in TNAH 2006 to examine whether a house in a hot, humid climate would have better energy performance if a cathedralized attic was directly conditioned rather than indirectly conditioned. The master bathroom attic would serve as the study location because it was easily accessible, isolated from the rest of the house and is similar in size to attics of smaller houses. Questions to be answered in the study include:

- Would energy be saved if the attic space, and the air distribution system in it, were directly conditioned, thereby turning the attic space into a conditioned mechanical room?
- How similar or different are temperature and humidity conditions sensors within the attic space and the living space during directly conditioned and indirectly conditioned situations?

MASTER BEDROOM SUITE

The master bedroom suite, with a total of 1,190 ft² (110.6 m²) of floor area, is located on the west side of the house. As a single story, the suite differs from the balance of the house which is two stories high. As shown, the layout in Figure 1, the master bedroom area is separate from the rest of the suite due to its location at the north end of the suite. The bedroom's attic is essentially separate from other spaces with mechanical and electrical

services only being able to reach it. Supply ductwork reaches the bedroom in high sidewall locations on its south side.

The balance of the master suite includes a sitting room and the master bathroom area which contains a laundry area and two walk-in closets (master bathroom). This part of the master suite has its own attic area (master bathroom attic), measuring 41' (12.5m) at its longest point and 21'3" (6.5m) at its widest point for a total (horizontal) area of 790 ft² (73.4m²). The master bathroom attic is about 5' (1.5m) high at the roof peak. The office/sitting area east of the master suite is a separate, two-story space. Figure 2 shows the master bedroom suite under construction with the master bedroom on the left and the office/sitting area in the background. Cathedralizing of the master bathroom attic using low density spray foam insulation installed at the underside of roof decking and at gable ends occurred prior to the installation of the concrete roof shingles.

The master bathroom drywall ceiling did not receive airtightness measures, which allowed air movement to occur through ceiling penetrations between the living space and attic. Ceiling penetrations include an attic hatch, plumbing penetrations and light and exhaust fan housings/fixtures. Since air movement is possible between the two spaces, when the attic is not being conditioned it is indirectly conditioned from

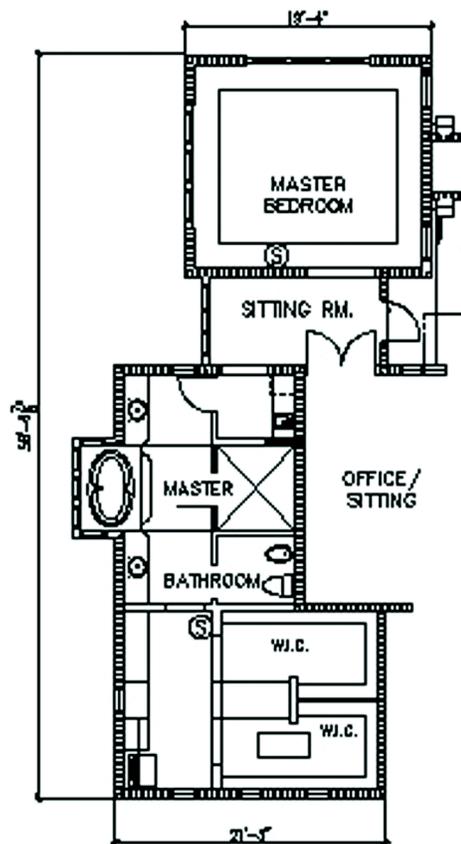


Figure 1 Architectural layout of The New American Home® 2006 master bedroom suite.



Figure 2 Master bedroom suite is under construction (view from west) with master bathroom attic under framing at right. The master bedroom is at the left and now contains north-facing windows. The west-facing was framed for an architectural wall detail that contains windows in its top third.

the living space below and incidental losses from the air distribution system in the attic due to conductive losses and distribution system air leakage.

The master suite, including the master bathroom, are conditioned by a heat pump system comprised of a blower coil (air handler) unit with 4-tons nominal cooling capacity and a heat pump outdoor unit with 3-tons nominal cooling capacity, the most popular combination of units according to the manufacturer. The heat pump system also has one duct run serving the lower level of the office/sitting area. Cooling and heating load calculations determined that a blower coil unit with 3-ton nominal cooling capacity would provide sufficient airflow and cooling capacity, but the builder’s HVAC subcontractor chose to install the more readily available and popular 4-ton unit. The installed system has a rated total cooling capacity of 36,600 Btu/h (10.7 kW) and cooling efficiency rating of 18.6 SEER. Referring to the summary of key HVAC design information displayed in Table 1, the heat pump system ended up being oversized by 55% for total cooling and by 73% for heating compared to ACCA Manual J calculations. The master suite’s ductwork consists of R-4 insulated flexible ducts with insulated fiberglass ductboard used for rectangular plenum and duct transition components. Duct airtightness pressurization testing (at 25 Pa) of the master suite’s air distribution system found 85 cfm (40 L/s) of air leakage, equivalent to 6% of total system airflow (1425 cfm, 596 L/s). This level of duct air leakage was less than the Building America project target of 10%. Since the mechanical ventilation systems used in other areas of the house met its ventilation needs, a ventilation system was not provided for the master suite area.

Table 1. Summary of Key Design Information for Master Suite’s Heat Pump System

Summer Design Conditions	
Outside dry-bulb temperature	95°F (35.0°C)
Inside dry-bulb temperature	73°F (22.8°C)*
Winter Design Conditions	
Outside dry-bulb temperature	38°F (3.3°C)
Inside dry-bulb temperature	70°F (21.1°C)*
Load Calculations	
Required sensible cooling output	20,698 Btu/h (6.1 kW)
Required total cooling output	23,655 Btu/h (6.9 kW)
Required heating output	28,576 Btu/h (8.4 kW)
Installed Equipment Specifications	
Sensible cooling output (BTUH)	31,110 Btu/h (9.1 kW)
Total cooling output (BTUH)	36,600 Btu/h (10.7 kW)
Total heating output (BTUH)	49,455 Btu/h (14.5 kW)

* Values used per recommendation by HVAC Subcontractor

DATA COLLECTION

Monitoring Study Set-up and Procedure

To simulate and remotely control the conditioning of the master bathroom attic for the study, additional ductwork, mechanical dampers and controls were added to the master suite air distribution system as shown in Figure 3. Eight-inch (190 mm) diameter R-4 insulated supply and return ductwork was used to serve the master bathroom attic from the master suite air distribution system located in the attic. The ductwork was sized (according to ACCA Manual J) to supply and return 100 cfm (47 L/s) of air through diffusers and grilles, mounted vertically in the attic. Airflow measurements determined that the supply diffuser delivered about 104 cfm of air. A mechanical damper, normally set to remain open, was installed on each dedicated attic duct run. A relay driver allowed for remote control operation of the mechanical dampers through the data logging system. The dampers could be either closed or opened, thereby simulating an indirectly conditioned attic or directly conditioned attic respectively when the blower coil unit delivered air. Power for damper operation came from the blower coil unit. The damper position was changed every 21 days, thereby allowing a different conditioning case in the attic every three weeks.

Electric current in the blower coil unit was measured using 50 Amp CT (current transducers) with a 0-5VDC output. A Watthour transducer with two CTs measured the electrical consumption of the heat pump outdoor unit. Indoor temperature and relative humidity levels within living spaces were recorded by sensors, noted in Figure 1 by the circled “s” symbol, in the master bedroom and in the master bathroom

Table 2. Summary of Analysis Periods

Analysis Period	Measurements Analyzed	Timeline
Cooling, attic directly conditioned (CD)	Energy use, temperature, moisture*	September 6–18, 2006
Cooling, attic indirectly conditioned (CI)	Energy use, temperature, moisture	September 18–30, 2006
Nonconditioned (NC)	Temperature, moisture	November 1–December 10, 2006
Heating, attic directly conditioned (HD)	Temperature, moisture	February 8–27, 2007

* Moisture load was not analyzed for the master bedroom attic

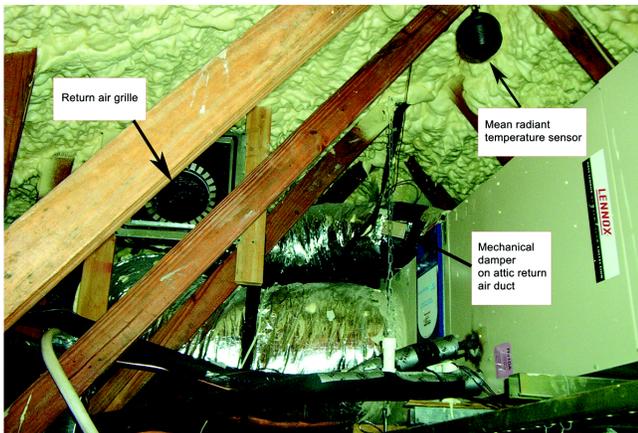


Figure 3 Dedicated return air duct with mechanical damper in the master bedroom attic. Several components added for the study are highlighted.

approximately 67" (1.70m) above floor level. The mean radiant temperature and relative humidity in the master bathroom attic were measured, the latter using a portable data logger. The attic mean radiant temperature sensor was located near the peak of the roof and is offset about 5 feet horizontally away from the master laundry temperature sensor below.

Outdoor temperatures and humidity levels were also measured. A preliminary examination of measurement data revealed that the outdoor temperature values peaked to extreme levels during the late afternoon. An examination of the outdoor sensors revealed that they were inadequately shaded from the late afternoon sun, and inaccurate measurements resulted for five hours each day. During data analysis, these inaccurate measurement values were replaced with temperature and humidity values obtained from the Orlando Executive Airport (Weather Underground 2006). The replacement values displayed reasonable conformance with the temperature and humidity trends exhibited by the measurement values before and after the inaccurate readings.

All sensors were connected to a data logger system. Readings were collected from sensors every 10 seconds. Data collection began at the end of August 2006 and the house was unoccupied. To facilitate easier comparison of measurement data, all data was compiled into an hourly format.

Measurement Results

The data was reviewed to determine whether continuous data sets were available for directly and indirectly conditioned attic cases under similar outdoor temperature conditions, thereby allowing for relevant comparison. One complete continuous data set, under cooling conditions, was observed in September 2006. For each conditioning case, 286 hours (11.91 days) of continuous data was found to be available for analysis.

In November and December 2006, the builder chose to disengage the thermostat since the house was unoccupied and outdoor temperatures were mild. For the purpose of analysis, this non-conditioning period where neither heating nor cooling occurred in the master suite spaces offered informative temperature and moisture load conditions for a cathedralized attic.

The three week period in 2007 when heating was required in the master suite was a shorter duration than expected. Due to the short heating season, the only useful data was obtained when the attic was directly conditioned. As a result, no comparable energy usage analysis was possible. Temperature and moisture load conditions in this period would be available for analysis. The house was unoccupied throughout each analysis period summarized in Table 2.

Cooling Period Measurements

During the analysis period for cooling, the thermostat serving the suite, which is located in the master bedroom, was set at a constant 76° F (24.4°C) temperature setpoint. The system fan was set on automatic so that it would run when called for. Cooling was the only space conditioning function to occur during the analysis period.

In Figures 4 and 5, the energy use or temperature values to the left of the black vertical line occurred when the master bathroom attic was directly conditioned. Values to the right of the line occurred when the master bathroom attic was indirectly conditioned. Figure 4 displays the energy use measured at the heat pump outdoor unit during the analysis period. In both conditioning cases there were periods, usually overnight and early morning, where the heat pump outdoor unit was not running, up to 14 consecutive hours in the directly conditioned case and 19 consecutive hours in the indirectly conditioned case. The longest consecutive span that the heat pump outdoor unit was running was 19 hours in the directly conditioned case and 16 hours in the indirectly conditioned case. The highest

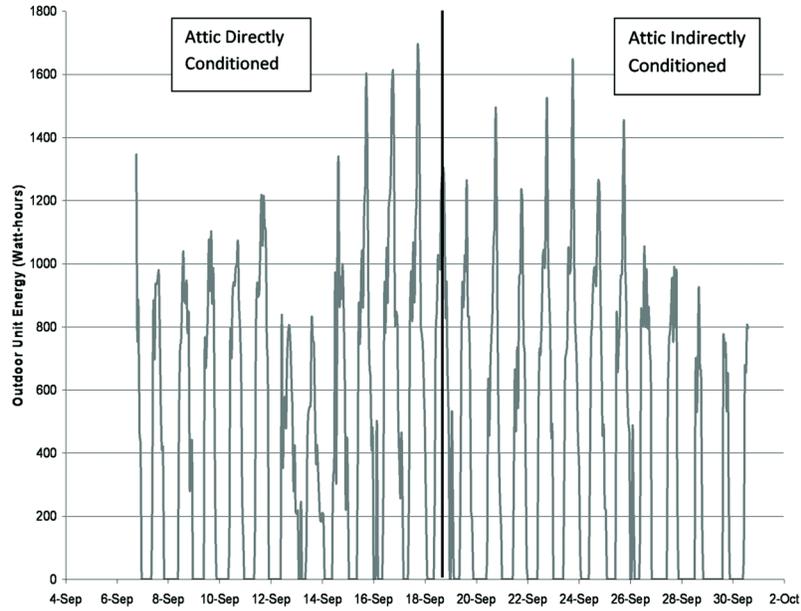


Figure 4 Energy use measured at master suite heat pump outdoor unit during analysis.

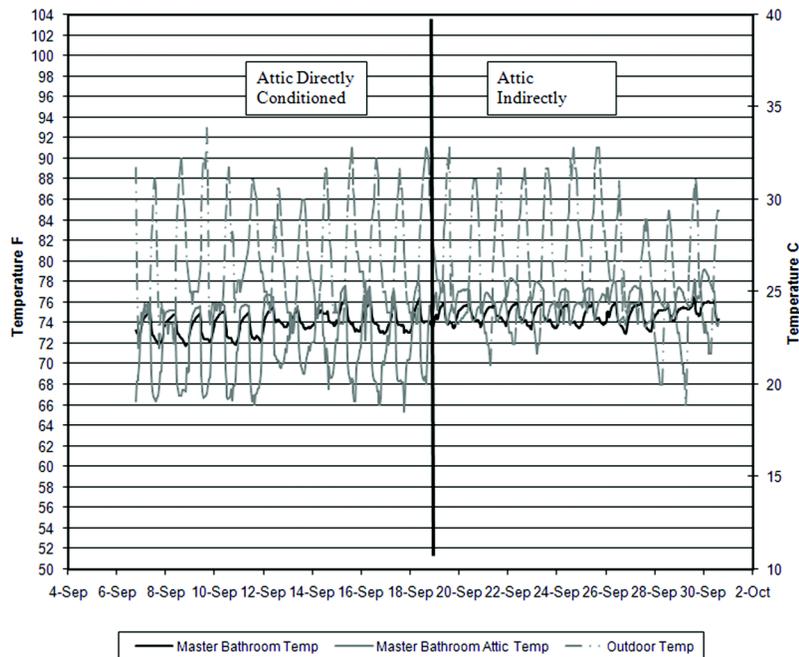


Figure 5 Key temperatures measured during cooling analysis period.

hourly energy use for the heat pump outdoor was 1688 watt-hours when the attic was directly conditioned.

For each attic conditioning case, there is a base level of electrical use in the blower coil unit. In each instance, this level represents the energy used by the mechanical damper control system while the unit was not running. For the indirectly conditioned case, a greater amount of energy was used by the

damper control system to keep it closed, averaging 193 watt-hours every hour during the analysis period, amounting to an average of 87 watt-hours more than when the damper was open (attic directly conditioned).

Figure 5 shows three key temperature measurements for each conditioning case: outdoor, master bathroom, and master bathroom attic mean radiant temperature. Outdoor tempera-

tures (dotted gray line) peaked at 93°F (33.9°C), a level 2°F (1.1°C) less than the summer outdoor design temperature used to conduct cooling load calculations. The temperatures in the attic (solid gray line) vary more when it is directly conditioned than when it is indirectly conditioned. When the attic is directly conditioned, it is being cooled to temperatures below those found in the master bathroom and below the thermostat setpoint temperature, 76°F (24.4°C), to temperatures as low as 66°F (18.9°C). The master bathroom temperature (black line) reached 72°F (22.2°C) frequently during the CD period. During the CI period, temperatures in the attic and master bathroom each have a narrower range and remain closer to the setpoint temperature.

A summary of measurements taken during the analysis period is shown in Table 3. The average outdoor, master bedroom, master bathroom and master bathroom attic mean radiant temperature during each conditioning case is noted. The space conditioning system did a good job of maintaining the setpoint temperature, 76° F (24.4°C), in the master bedroom during the entire analysis period. Average dew point temperatures in the master bedroom and master bathroom were similar for the analysis period. In the indirectly conditioned attic case, the average dew point temperature in the master bathroom attic was 3.7°F (2°C) higher than the similar value for the living space below. Master suite attic measurements were obtained via a portable data logger, but due to data retrieval problems this information was not available during the directly conditioned case. Total (gross) electrical energy use for the space conditioning system is also noted for each conditioning case.

Non-Conditioning Period Measurements

During the non-conditioning analysis period, outdoor temperatures ranged from a minimum of 43°F (6.1°C) to 85°F (29.4°C). In Figure 6, three key temperature measurements are shown: master bathroom and master bathroom attic mean radiant temperature, and master bathroom attic dew point temperature during the non-conditioning period. Temperatures in the master bathroom attic (gray line) and master bathroom (black line) follow the same pattern throughout the period with the former averaging 1.3°F (0.7°C) hotter. Master bathroom attic dew point temperatures (dotted gray line) peaked at 58.9°F (15.0°C) and were a minimum of 19°F (10.6°C) less than the attic temperature. Master bathroom attic dew point temperatures averaged 48.4°F (8.9°C) and were 2.4°F (1.3°C) lower in the NC period than the CI period.

Heating Period Measurements

During the analysis period for heating, only the attic was directly conditioned. The setpoint temperature on the thermostat was 71°F (21.7°C). In Figure 7, three key temperature measurements are shown: master bathroom, master bathroom attic mean radiant temperature, and outdoor temperature. The average temperature in the master bedroom (thermostat) was 72.7°F (22.6°C). The master bathroom’s average temperature was 75.7°F (24.3°C), or 3°F (1.7°C) higher than the average thermostat temperature and was often 5°F (2.8°C) warmer than it. The master bathroom attic mean radiant temperature averaged 79.7°F (26.5°C), was 7°F (3.9°C) hotter on average than the average thermostat temperature, and reached a peak

Table 3. Summary of Measurements taken During Cooling Analysis Period

		Directly Conditioned Attic Case	Indirectly Conditioned Attic Case
Average temperatures	Outdoor	80.0°F (26.7°C)	79.3°F (26.3°C)
	Master Bedroom (Thermostat)	76.5°F (24.7°C)	76.4°F (24.7°C)
	Master Bathroom	73.9°F (23.3°C)	74.8°F (23.8°C)
	Master Bathroom Attic Mean Radiant	71.8°F (22.1°C)	76.2°F (24.6°C)
Average dew-point temperature	Outdoor	70.3°F (21.3°C)	66.6°F (19.2°C)
	Master Bedroom (Thermostat)	48.9°F (9.4°C)	48.7°F (9.3°C)
	Master Bathroom	46.6°F (8.1°C)	47.1°F (8.4°C)
	Master Bathroom Attic	N/A	50.8°F (10.4°C)
Maximum dew-point temperature	Master Bathroom Attic	N/A	54.4°F (12.4°C)
Space conditioning total electrical energy use from measurements (kWh)	Heat Pump Outdoor Unit	130.1	110.4
	Blower Coil Unit	40.9	64.2
	Total System	171.0	174.6

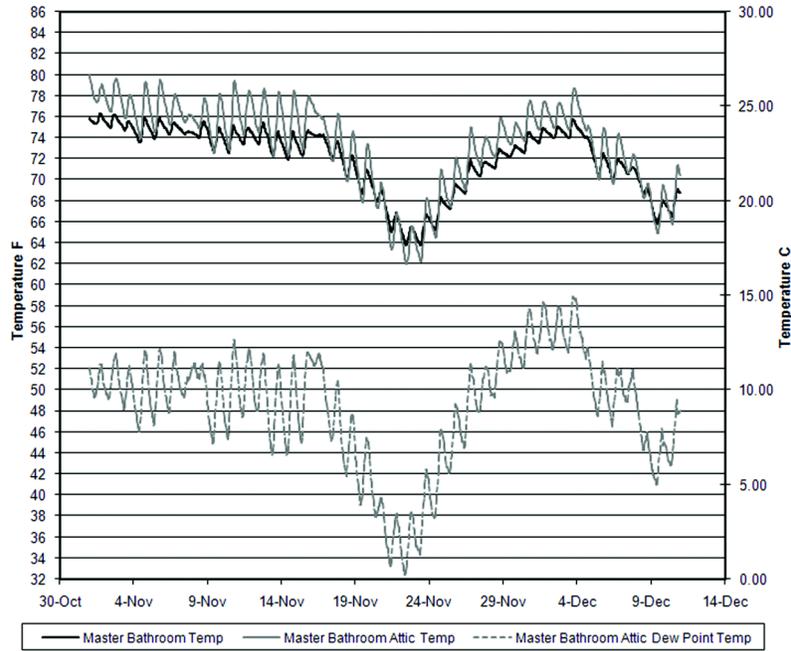


Figure 6 Key temperatures measured during nonconditioning analysis period.

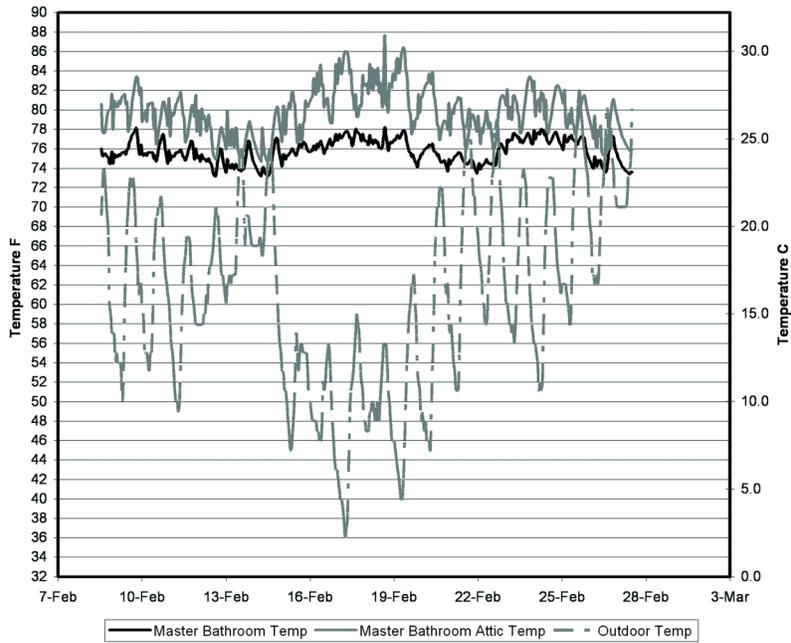


Figure 7 Key temperatures measured during heating analysis period.

of 87.6°F (30.9°C) during one hour. Dew point temperature measurements in the living spaces averaged 45.7°F (7.6°C), indicating that the moisture load in these areas is not a cause for concern. Master bathroom attic dew point temperature information was not available.

ANALYSIS

To facilitate accurate comparison of measurements between conditioning cases in the cooling analysis period, a comparison of actual cooling degree days (65°F base) was undertaken based on outdoor temperature measurements

Table 4. Adjusted Electrical Energy Results for Master Suite Space Conditioning System

		Directly Conditioned Attic Case	Indirectly Conditioned Attic Case
Cooling degree days		182	169
Normalized electrical energy use (kWh)	Heat pump outdoor unit	121.0	110.4
	Blower coil unit	38.1	39.3
	Total system	159.1	149.8

during each analysis period. The number of cooling degree days determined for each conditioning cases is noted in Table 4 with the directly conditioned attic period experiencing a greater need for cooling (by 6.9%). As a result, the energy use in the directly conditioned case was normalized/reduced by 6.9% to facilitate a fair comparison between energy use values in both cases. To account for the greater amount of energy used by the mechanical damper control system in the indirectly conditioned attic case, blower coil unit energy use for the case was normalized/reduced by 86.8 watts per hour (24.8 kWh for the cooling analysis period). In the directly conditioned attic case, the average hourly runtime for the blower coil unit was determined to be 25%. Due to the power draw of the mechanical damper when closed, which made the attic indirectly conditioned, the runtime of the blower coil unit could not be accurately determined for this case.

OBSERVATIONS

Cooling Period Energy Use

As shown in Table 4, after normalization of data to equalize climatic and mechanical damper energy use between attic conditioning cases, total space conditioning system electrical energy use during the cooling analysis period was lower in the indirectly conditioned case. The difference in energy use between the conditioning cases is 9.3 kWh (per 169 cooling degree days) or 5.8%. If the difference in energy use between conditioning cases was extrapolated for the 3508 cooling degree days experienced in Orlando in 2006 (CPC 2007), the total difference in energy use would be 193.8 kWh for the entire cooling season. Based on the local utility rate for the Orlando area of 8.9¢ per hour for the measurement period (FPSC 2006), the additional energy cost of directly conditioning the attic, instead of leaving it indirectly conditioned, would be \$17.25 per cooling season.

During the cooling analysis period, the air distribution system did not run continuously during any 24 hour period. In the directly conditioned attic case, the average hourly runtime for the blower coil unit was determined to be 25%. Based on the energy consumption of the blower coil unit when the attic is indirectly conditioned (since runtime data is not available) its average hourly runtime should be less than 25%. A 25% blower coil unit runtime value is not uncommon for an energy efficient house although this value would be higher on a day when the summer outdoor design temperature is reached. The system had enough cooling capacity to

condition the master bedroom suite to the setpoint temperature level on a consistent basis.

Because the house is unoccupied, the effects of internal heat gains and moisture loading were not a factor in energy use calculations although they were accounted for in the air distribution system design. The house is currently for sale. Once sold and occupied, the effects of internal heat gains and moisture loading can be studied.

Temperature Conditions During Cooling Period

During the cooling analysis period, average temperature values were found to be acceptable in all living spaces except in the master bathroom when the attic was directly conditioned. As shown in Figure 5, master bathroom temperatures dipped to 72 °F (22.2°C) or 4°F (2.2°C) below the setpoint temperature, several times during the analysis period, indicating that over-cooling was occurring. Homeowners could experience thermal discomfort in such temperature conditions. As shown in Table 3, average temperatures in the master bedroom during both conditioning cases were virtually identical. The average temperature measurements in all spaces during the CI period are consistent, which indicates that the airtight and well insulated building enclosure is performing as expected.

The average mean radiant temperature in the master bathroom attic during the CD period was 2.1°F (1.2°C) lower than the master bathroom average temperature, 4.7°F (2.6°C) cooler than the room with the thermostat, and it often reached a chilly 66°F (18.9°C). Very cool attic temperatures increase the possibility of condensation occurring on surfaces in the attic. For a non-living space area, the attic, to be cooler than a living space, in a hot, humid climate-located house, is not commonplace. It can be argued that having an unlivable space as the coolest place in the house during the cooling season is not beneficial to homeowner comfort and not the best energy cost value for an energy efficient house (or any house for that matter).

With over-cooling occurring frequently in the master bathroom and the master bathroom attic only during the directly conditioned period, the air distribution system design does not appear to be appropriate for these areas during that case.

Temperature Conditions During Nonconditioned and Heating Periods

During the non-conditioned period, the difference between average master bathroom attic and master bathroom

temperatures was a minimal 1.3°F (0.7°C) and indicated the effect of air stratification. During the HD period, the master bathroom average temperature was 75.7°F (24.3°C), and it was warmer than the thermostat by an average of 3°F (1.7°C). In addition, the attic was found to average 7°F (3.9°C) warmer than the room with thermostat and 4°F (2.2°C) higher than the average temperature in the master bathroom. With no temperature measurements from the indirectly conditioned attic case for the heating period with which to make a comparison, it is unknown the extent to which over-heating in the attic during the HD period may be due to air stratification (from living areas). Many homeowners would find an average heating season temperature of 75.7°F (24.3°C) uncomfortable for a living space. With attic temperatures averaging 79.7°F (26.5°C), the attic has turned into the warmest area of the master suite during the HD period and this is not the best energy cost value for an energy efficient house. Due to the over-heating condition in the master bathroom and attic, the air distribution system design to directly condition the attic for these areas may not be appropriate for the HD period.

Moisture Conditions

In the CI and NC periods, the maximum dew point temperature in all spaces is low enough to suggest that the moisture load in them is not a concern. In addition, it is likely that the moisture load in the attic during the CD period was less (in the absence of measurements), than in the CI period, because it received cooled air. The moisture load in the attic during cooling and non-conditioning periods does not appear to be high enough to warrant dehumidification measures specifically for that space at least in the house's unoccupied state.

CONCLUSIONS

Information has been obtained on space conditioning system energy use, and the temperature and moisture conditions, associated with a cathedralized attic with 790 ft (73.4m) of horizontal area located in Orlando, Florida. The attic is alternately conditioned either directly or indirectly to allow for performance comparisons. During the cooling analysis period, the effort taken to directly condition the master bathroom attic resulted in a marginal additional amount of energy use (9.3 kWh) by the space conditioning system (for cooling). It is estimated that \$17.25 more in energy costs, per cooling

season, would be spent by the homeowner if the attic was directly conditioned instead of indirectly conditioned.

When the attic was directly conditioned during cooling, the living space directly below it experienced several occasions when temperatures dropped up to 4°F (2.2°C) below the setpoint temperature indicating that over-cooling was happening and homeowner discomfort could result. In addition, temperatures in the conditioned attic reached 10°F (5.5°C) below the thermostat setpoint temperature. During the limited heating season, the master bathroom average temperature was 75.7°F (24.3°C). The attic was being over-heated as well. The air distribution system design does not appear to be appropriate for the master bathroom and its attic in directly conditioned attic situations during both cooling and heating. The moisture load in the attic during cooling and non-conditioning periods does not appear to be high enough to warrant dehumidification measures specifically for that space, at least in the house's unoccupied state.

The analysis of energy performance and environmental conditions information found no advantage to directly conditioning a cathedralized attic located in a hot humid climate over having it indirectly conditioned.

ACKNOWLEDGMENTS

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