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

BUILDING TECHNOLOGIES PROGRAM

Final Expert Meeting Report: Simplified Space Conditioning Strategies for Energy Efficient Houses

Dave Stecher
IBACOS, Inc.

July 2011

Building America
U.S. Department of Energy

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

Final Expert Meeting Report: Simplified Space Conditioning Strategies for Energy Efficient Houses

Prepared for:

Building America

Building Technologies Program

Office of Energy Efficiency and Renewable Energy

U.S. Department of Energy

Prepared by:

IBACOS, Inc.

2214 Liberty Avenue

Pittsburgh, Pennsylvania 15222

NREL Technical Monitor: Michael Gestwick

Task Order KNDJ-0-40341-02

Deliverable 1.3.4

July 2011

[This page left blank]

Contents

List of Figures

Unless otherwise noted, all figures were created by IBACOS.

List of Tables

Unless otherwise noted, all tables were created by IBACOS

Definitions

ACCA	Air Conditioning Contractors of America
ACH	air changes per hour
AHU	air handling unit
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers
Bth	British thermal unit
CFD	computational fluid dynamics
cfm	cubic feet per minute
CFM50/SF	cubic feet per minute air leakage per square foot of enclosure area at 50Pa depressurization
COP	coefficient of performance
DHU	ductless air handler unit
DWH	domestic water heating
EF	energy factor
EER	energy efficiency ratio
ERV	energy recovery ventilator
GSHP	ground source heat pump
HP	heat pump
HPWH	heat pump water heater
HRV	heat recovery ventilator
HSPF	heating seasonal performance factor
kWh	kilowatt-hours
Low-E	low emissivity
MBH	thousand Btu/h

MMBtu	million British thermal units
Pa	pascals
PV	photovoltaic system
RF	recovery factor
RH	relative humidity
R-x	resistance value
SEER	seasonal energy efficiency ratio
SF	square foot or square footage
SHGC	solar heat gain coefficient
SIPS	structural insulated panel system
U-x	overall heat transfer coefficient
VT	visible transmittance
ZEH	zero energy home

Executive Summary

A Building America Expert Meeting was held on March 11, 2011, at the Seaport Hotel in Boston, Massachusetts on the topic of simplified space conditioning systems in low load homes. This meeting provided a forum for presentations and discussions on the interrelationship between advanced thermal enclosures, space conditioning systems, and comfort; and an outside peer review of IBACOS' research plan for the topic. This report presents background on the topic, meeting objectives, logistics, invitees, and presentations.

Seven presentations were given describing current implementation efforts in addition to field research documenting the thermal comfort and energy characteristics of installed simplified space conditioning systems in both new and retrofit applications. IBACOS' 2011 research plans in the area were also presented and evaluated. The meeting was attended by 15 people with experience in the areas of design, construction, instrumentation, and analysis of houses with simplified space conditioning systems. The first major outcome of the meeting was a realization that although space conditioning with reduced size and complexity have been successfully implemented in many cases, more research is needed to characterize the means of interaction between defined airspaces in the house to enable simple systems to be designed to meet the demands of a mass market audience. The second major outcome of the meeting was a thorough critique of, and many improvements to, IBACOS' research plans to define these characteristics.

Background on Simplified Space Conditioning Systems and Heat Flow Characteristics within Houses and Justification of Need

IBACOS anticipates that houses achieving 50% whole house source energy savings with respect to the Building America House Simulation Protocol (HSP) (Hendron 2010) will be "low load." Low load is defined by IBACOS as a house with a thermal enclosure that yields a maximum space heating and cooling load of less than 10 BTU/hr-ft2. IBACOS hypothesizes that heating and cooling energy in low load houses will be distributed sufficiently throughout the house via convective currents through open doors or transfer grilles, buoyancy, and conduction through interior partition walls. This hypothesis is based on research performed by Fiest (2005) where computational fluid dynamics (CFD) models of dwellings meeting the Passivhaus energy standard indicate that, at 1.8°F delta T, it is possible to have conductive transfer of 0.3 to 0.6 BTU/hr-ft2 of wall area and convective transfer of 300 to 600 BTU/hr per open interior door. Field test data obtained by IBACOS (2008, 2010a, 2010b) from a Passivhaus in Climate Zone 5 also supports this hypothesis. This data indicates that sufficient thermal comfort for the occupant (according to ASHRAE 55-2010, ACCA, and other metrics based on air temperature, relative humidity, air speed, and mean radiant temperature) can be obtained in all parts of the house from cooling air supplied to a single point. There has also been work in the area of displacing resistance electric space conditioning with heat pump technology in existing homes in New England (Swift 2010) and the Pacific Northwest (Baylon 2010). While neither of these studies specifically focused on documenting occupant comfort, they did show 35% to 44% electric savings for heating.

There are alternatives to conventional central ducted space conditioning systems system, such as distributed fan coils with minimized ducts, terminal fan coil units, or point source units with buoyant force or ventilation driven distribution. A recent Building America (BA) Meeting identifying gaps and barriers established "distributed space conditioning strategy" as a key research need in the space conditioning area.

One proven, general strategy for significant energy savings is to bring all of the ducts of a forced air system inside the conditioned space. During a retrofit of a conventional system, it is generally impractical to bring the ducts inside the conditioned space unless the attic roof deck is insulated, which can be costly. Advances in space conditioning equipment, such as multi-splits (heat pumps which combine a single outdoor unit with multiple indoor ducted or ductless air handler units), may provide distributed space conditioning solutions that would allow for abandoning duct systems in unconditioned spaces.

More research is needed to evaluate the level of energy efficiency and the conditions where simplified space conditioning systems will work in new and retrofitted houses. Guidance is needed on the design and installation of these systems to support a wider adoption throughout the new construction and retrofit market.

The purpose of this expert meeting was to recap the current state of knowledge in this area and to provide a peer review of IBACOS's research plan for new and existing unoccupied test houses with minimized space conditioning systems.

Meeting Logistics

IBACOS held this session on Friday, March 11, 2011 at the Seaport Hotel in Boston, Massachusetts. Since the meeting was held immediately following the Northeast Sustainable Energy Association's (NESEA) Building Energy 11 conference, many of the expert meeting participants were already in the area for the conference. Furthermore, webinar technology was used to enable one speaker from the West Coast to present without the need for two days of travel, round trip, to physically attend.

Topic

Simplified Space Conditioning Strategies for Energy Efficient Houses

Location and Time

Seaport Hotel
200 Seaport Blvd, Boston, Massachusetts 02210-2031
March 11, 2011

Attendees

The meeting included 15 contributions from 15 industry representatives plus two IBACOS team members. Additionally, 18 individuals participated in some or all of the meeting via the webinar in listen-only mode. All meeting attendees are listed in Table 1.

Table 1. Expert Meeting Contributors/Listen-only Participants (*)

Name	Organization
Linda Wigington*	Affordable Comfort Inc.
Patrick O'Malley*	Building Knowledge
Kohta Uenoϒ	Building Science Corp.
Honorata Wytrykowska	Building Science Corp.
Daniel Bergey	Building Science Corp.
Dan Dempsey	Carrier Corporation
Hugh Henderson*	CDH Energy/ARIES
Tom Hartman	Coldham & Hartman Architects
Andrew Webster	Coldham & Hartman Architects
Joe Swift	Connecticut Light and Power

Jane Bugbee	Connecticut Light and Power
David Springer*	Davis Energy Group
David Baylonϒ	Ecotope
El Hassan Ridouane	Fireside Hearth & Home
Patrick Gillis	Florida Solar Energy Center
Peter Thibeault	Fraunhofer CSE
Larry Brand	Gas Technology Institute
Dave Robinsonϒ	GreenEarthEquities
Thom Phillips*	Habitat for Humanity of Michigan
Dave Stecher	IBACOS, Inc.
Duncan Prahlϒ	IBACOS, Inc.
Anthony Grisolia*	IBACOS, Inc.
Glenn Cottrell*	IBACOS, Inc.
Amber Wood*	NAHB Research Center
Michael Gestwick	National Renewable Energy Laboratory (NREL)
Jon Winkler	NREL
Lieko Earleϒ	NREL
Dane Christensen*	NREL
Eric Wilson*	NREL
Hassan Ridouane*	NREL
Xia Fang*	NREL
Marc Rosenbaum	South Mountain Company
Robb Aldrichϒ	Steven Winter Associates Inc.
Srikanth Puttagunta*	Steven Winter Associates Inc.

Jordan Dentz*	The Levy Partnership/ARIES
R. Carter Scottϒ	Transformations, Inc.

ϒ Speaker

Figure 1. Photo taken during Expert Meeting

Meeting Objectives and Agenda

This meeting provided a forum for presentations and discussions on the interrelationship between advanced thermal enclosures, space conditioning systems, and comfort. The meeting consisted of presentations and discussion related to energy and comfort measurement and metrics for low load space conditioning strategies; and evaluation of IBACOS' research plan on these systems. Ventilation strategies, while important, were not a primary focus of this session. IBACOS feels that this could be a future session as this research area progresses.

IBACOS' Research Questions

IBACOS has defined the following research questions relative to this area of study:

- Provided that the DOE's long-term research is successful in other thermal enclosure areas (new and existing houses), what are the alternative strategies to conventional central ducted space conditioning systems that will provide thermal comfort for the occupant according to ASHRAE 55-2010, ACCA, and others (air temperature, relative humidity, air speed, and mean radiant temperature)?
- What are the terminal conditions and parameters needed for simplified space conditioning systems (e.g. face velocity, Btu/cfm, duration of run cycle) to provide thermal comfort in new and existing homes in different U.S. climate regions?

- What is the ventilation distribution efficacy of simplified space conditioning strategies? What kinds of ventilation distribution strategies are needed?
- What technology gaps exist where new product development is needed to enable simplified space conditioning strategies to succeed in providing good thermal comfort, humidity control, and ventilation air distribution? What are the characteristics of the new products?
- How do low load new houses and significantly retrofitted houses respond to externally induced peak load situations (e.g. when the outside temperature and RH are at or above design conditions) or internally induced peak loads (e.g., large gatherings of people in one space, significant home electronics waste heat)? What is the impact on simplified space conditioning strategies and operation?

Meeting Specific Objectives

The major objectives of this meeting were to:

- Review the results of existing field data and participant experiences with respect to energy savings and occupant comfort in houses with minimized space conditioning systems.
- Receive feedback on IBACOS' simplified space conditioning research objectives and test plan.
- Identify relevant and useful outputs for stakeholders using the results of this research.
- Identify the current gaps between the existing market-based space conditioning products and future needs.

Agenda

The meeting closely followed the agenda found in Table 2.

Table 2. Expert Meeting Agenda

8:00 am – 8:15 am	Introductions and Project Overview; IBACOS
8:15 am – 8:45 am	Carter Scott – Strategies attempted and lessons learned from installing simplified space conditioning systems in houses with good thermal enclosures
8:45 am – 9:15 am	Kohta Ueno – Monitoring results from a house built by Carter Scott, heated and cooled from two points (one per floor), including measurement of individual room temperatures, door state (open or closed), and system runtime
9:15 am – 9:45 am	Duncan Prahl – One year of monitoring results from a house in Central Illinois with cooling provided from one point. Winter results from four houses in Massachusetts using a mini-split in the main living space, with electric resistance in other rooms.
9:45 am – 10:00 am	Break

10:00 am– 10:30 am	Robb Aldrich – Design tool used to provide a reasonability check when considering single point space conditioning in a house. Application of tool in a duplex in Massachusetts. Monitoring Results and lessons learned.
10:30 am – 10:45 am	Lieko Earle – Initial monitoring results from NAHBRC/NREL study of twelve 1930s era townhomes in Maryland with electric baseboard heat.
10:45 am – 11:15 am	Dave Robinson – Strategy for and lessons learned from using concealed unit mini-splits with all ducts inside the envelope in retrofit homes in Fresno, California. Also a model whereby Energy Wise investors can do deep energy retrofits even Near Zero with little or no program assistance.
11:15 am – 11:45 pm	Presentation of IBACOS' Simplified Space Conditioning Research Plan
11:45 pm- 12:45 pm	Lunch
12:45 pm – 1:15 pm	David Baylon – Pertinent results from multi-year, multi home study in the Pacific Northwest where, in each house, a mini-split heat pump was installed to supplant electric resistance heat.
1:15 pm – 2:15 pm	Roundtable Discussion: Discussion of Research Strategy, Industry and Technology Gaps, and Opportunities; IBACOS
2:15 pm – 2:30 pm	Break
2:30 pm – 3:15 pm	Roundtable Discussion: Discussion of Research Strategy, Industry and Technology Gaps, and Opportunities (Continued); IBACOS
3:15 pm – 3:30 pm	Summary and Next Steps
3:30 pm	Meeting Conclusion

Presentations

Seven presentations were given describing current research efforts related to simplified space conditioning systems in both new and retrofit applications. Additionally, IBACOS' 2011 research plans were presented. The presentations are summarized below.

Experiences in Implementing Mini-Split Heat pumps – Carter Scott

Transformations, Inc. is a builder in New England specializing in highly efficient houses. During his presentation, Carter Scott discussed several houses and the various attempts to install small mini-split heat pumps. Seven houses were discussed with installed system capacity from 12 MBH for the Solar Ranch to 36 MBH for the Greek Revival and the Colonial, listed below:

- Needham (one 9 MBH upstairs, one 12 MBH downstairs),
- Farmhouse (two 9MBH upstairs, one 12MBH downstairs),
- Greek Revival (2 x 9MBH upstairs, 2 x 9 MBH downstairs),
- Colonial (originally 18 MBH down, 15MBH up, upgraded to 36 MBH with third zone),
- Solar Ranch (one 12 MBH DHU)
- Farmhouse II (2 x 12 MBH units)

Wall-mounted, ductless air handler units (DHU) were used in most houses with at least one DHU per above grade floor. The upstairs DHU typically was mounted in the hallway and the main floor DHU mounted in the living room. In houses with multiple DHUs per floor, DHUs were placed in rooms with the greatest expected occupancy, while others were passively conditioned. Two houses used ducted-concealed air handler units (AHUs). Although the duct runs were generally short, the installation cost of the ducted AHUs was higher than the DHUs. Since the DHUs were installed prior to drywall with no additional work after, the entire space conditioning system was installed during a single visit to the house by the mechanical contractor.

Despite a design peak load of 17 MBH, the 33 MBH system in the Colonial house needed to be increased in capacity after the first winter, due to the heat pump derating during very cold weather. The change in total capacity was small, 33 MBH to 36 MBH, and a third zone was added in the basement to remedy one unintended consequence of removing the heating system and ductwork, and their associated "accidental" heat gains from the basement: cold floors on the first floor.

Any of these strategies might be considered risky by a traditional HVAC contractor, but in all cases (apart from the initially undersized Colonial house) no occupant comfort complaints were noted.

Massachusetts Two Point Heating: Monitoring Results – Kohta Ueno

Monitoring results were presented by Building Science Corporation for the winter of 2011 from a house built by Transformations, Inc. The house was heated and cooled by two DHUs (one per floor). Measurements included individual room temperatures, door state (open or closed), and system runtime.

Thermal enclosure specifications of this 1,835 square feet, two-story house include R-45 walls, R-60 attic, R-28 Slab, U 0.2 (R-5) / 0.26 SHGC windows. One issue that was discussed was the apparent poor performance of one of the mini-split systems based on what appeared to be long runtime with low system output. However, as many of the participants noted, these mini-splits are not simply on or off, they vary system capacity and operational energy based on the what the system perceives the need of the house to be. System operation was measured using a state logger, which could only tell when the system was not completely off. So although the system appeared to be on, it may have just been operating at very minimal capacity. Other graphs Kohta presented indicating no correlation between exterior temperature and runtime supported this hypothesis. Additional concerns included potential snow blockage of airflow through the outdoor unit which had been experienced by many people using this system in the northeast due to the abnormally large amount of snow received by the region in the winter of 2011. It was noted that many traditional heat pump units account for this issue by using an upflow design instead of a side flow design. The exact physics of how this works were not discussed.

The occupants used deep setbacks on the second floor, and a noticeable spike occurred in the hallway (where the mini-split was located) upon recovery. Data indicated that the master bedroom lagged behind other rooms. However, this was determined to be a sensor that fell off its original mounting location.

The most notable result of this research is the impact of interior partition door state on room conditions, which until this point, had not been well documented. Door state results showed a much better correlation between rooms and the hallway when there was a high frequency of the door being open. Two bedrooms had door open frequency of 92%. While the third bedroom, which was used as storage, had a door open frequency of 44%. Generally the rooms were within 7°F of the temperature in the hallway. However the third bedroom did experience a greater number of occurrences with a temperature differences larger than 7°F. The magnitude of these temperature differences was also greater than the other two upstairs bedrooms.

The results of this study showed that single point heating is effective at maintaining rooms close to set point, however leaving doors closed and deep setbacks can result in large temperature differences.

Single Point Cooling and Heating: Temperature and Energy Monitoring Results from Six houses – Duncan Prahl

Key summer and winter data from one year of monitoring results from a house in Central Illinois with cooling provided from one point was presented and discussed.

Specifications of the central Illinois 1,200 square feet (net), two-story house include R-60 walls, R-80 attic, R-20 or 50 underslab (depending on location), U 0.16 (R-6.25) / 0.61 SHGC windows (south orientation only, others low SHGC). The heating and cooling system consists of one inverter-driven mini-split heat pump with DHU located in the stairwell and electric resistance baseboard heaters in all rooms which are controlled by a central thermostat with individual unit restriction control.

Electric consumption monitoring results showed that heating energy was on par with energy required for plug loads, and cooling energy was slightly less than the ERV fan energy.

Temperature data showed that during cooling, all rooms were generally within 2°F of the temperature at the thermostat. Data also showed that during several of the hottest days of the season, the system was able to cool the house below the set point of the electric resistance heat, causing a brief period of simultaneous heating and cooling. The mini-split was able to maintain temperature despite full operation of the electric resistance heat.

Although it is impressive that the cooling system maintained temperature, it brings to light an important issue of the need for controls integration for mini-split heat pumps when used in conjunction with other heating systems. During the winter time, lack of controls integration was a factor in the lack of operation of the heat pump. Due to the relatively confined space the stairwell where the DHU is located, it would heat up the stairwell quickly and turn itself off, as the temperature sensor is located in the DHU. The location of the DHU also prevented sufficient heating energy from reaching the downstairs living space, leaving the thermostat for the baseboard heat dissatisfied, and resulting in the operation of the electric resistance heat. Due to this issue, the occupant chose to not operate the heat pump during the winter. Room temperatures remained uniform within 2°F of the temperature at the thermostat location.

Winter results from four houses in Massachusetts using a mini-split in the main living space, with electric resistance radiant panel heaters in other rooms were then presented and discussed. Specifications of the Massachusetts two-story houses include R-31walls, R-49 attic, R-20 foundation and under slab, U 0.19 (R-5.25) windows. One inverter driven mini-split is used with DHU located in the main living space, and electric radiant panels are installed in bedrooms, which were controlled by individual thermostats in each room.

Monthly energy consumption of the heat pump and electric resistance heat were each sub-metered. Temperature was measured in each of the three bedrooms and compared with the measured temperature in the main living area by categorizing the hourly sampled temperature differences into 4°F temperature bins for each month. The results showed that the two houses with greater operation of electric resistance heat had more consistent temperatures throughout the house, without substantially more total electricity consumption. In these two houses, between 50% and 60% of the time all rooms were within +/- 2°F of the temperature in the conditioned zone, with remaining samples evenly distributed into bins immediately adjacent to the +/- 2°F bin. For the two houses that had greater heat pump operation, temperatures of all rooms were within +/- 2°F only 25% to 40% of the time. Outlying bins were consistently grouped in the range of temperature below -2°F of the thermostat. What was unknown from this study was the impact of door state (open/closed).

ASHRAE standards indicate that none of these houses would be comfortable to the typical occupant. However, in all of these houses, occupants had individual thermostat control and chose to operate the house in the manner indicated by the results.

Finally, test data from a two-week test from February 16th to 28th, 2011 at IBACOS' cold climate new construction unoccupied test house was presented. During outdoor temperatures averaging approximately 40°F, when all second floor bedroom doors were closed and conditioned air was provided only to the hallway, the bedrooms were on average 7°F cooler. Within 3 hours of opening the doors, temperatures stabilized to about +/- 1°F.

Simpler HVAC: Design Methods and Monitoring Results – Robb Aldrich

Robb presented results from work performed on four houses in Massachusetts including the design tool used to determine the amount of fan forced airflow necessary in non-directly conditioned rooms along with monitoring results and lessons learned from the built houses.

Specifications of these four, two-story, two-bedroom houses in western Massachusetts built by RDI include R-40+ walls, R-50 attic, with triple pane windows. A two-stage (10.2 MBH low stage, 16 MBH high stage) gas fired unit heater is located in the main living space. To facilitate circulation from the main living space to the upstairs bedrooms, an exhaust fan was installed that pulled air from the ceiling of the living room and supplied it to the upstairs bedrooms.

Robb demonstrated the Excel-based spreadsheet tool that was used during the design process to estimate the contribution steady state heat transfer to the rooms through interior partition structures and to determine the amount of fan airflow necessary to maintain uniform relative age of air in each room and to help equalize temperatures in these houses. This type of calculation is appropriate when designing buildings with any habitable rooms that will not be actively conditioned.

After the houses were completed, the modeling results were validated when tracer gas tests conducted by NREL indicated that the operation of the fan provided sufficient circulation to the rooms with doors closed, equivalent to having the doors open. This study also showed that when the doors were closed with the fan off, room air circulation was greatly reduced.

Temperature data collected through the winter of 2011 indicated that for three houses, all spaces in the home were within 4°F at least 80% of the winter. The fourth house had cooler bedrooms, most likely due to an oversized heater being specified and the use of an aggressive thermostat setback strategy by the occupants.

Also presented were monitoring results from a two-story house using a mini-split heat pump with one wall mounted AHU on the main floor and one in one of the two bedrooms in the finished walkout basement. The occupants disliked the aesthetics of the wall-mounted AHUs, reported that there were thermal and acoustic comfort issues with the ERV unit and supply air locations. The occupants also disliked not having warm floors as in a radiant floor system, but did have desirably low energy bills.

Preliminary Temperature Data from GHI Townhomes – Lieko Earle

Lieko presented initial monitoring results from a study by NAHBRC/NREL of twelve 1930s era townhomes in Maryland with electric baseboard heat.
Greenbelt Homes is a cooperative housing community consisting of 1,571 homes constructed by the federal government between 1936 and 1941. It consists of two-story townhomes with three different construction types: concrete masonry unit (CMU), wood framed with brick façade or wood framed with vinyl siding. Initially constructed with essentially no insulation, in the 1980s, insulation was installed where possible (e.g. attics, framed wall cavities, and crawlspaces).

Heating is provided by baseboard heaters with individual thermostats located in each room. Cooling is via window or through wall air conditioners where installed.

Greenbelt Homes has planned several upgrades for 2015 including: windows, doors, and baseboard heaters. Twenty-eight units are planned to be upgraded via a phased implementation with monitoring occurring before upgrade and between each phase. Occupant concerns range from economy-oriented desire to control the temperature in each space, to comfort-oriented desire for in-floor heating and whole house cooling.

Data from three units was presented for the period between November 28th and December 22nd. Each unit had a distinctly different operation with average heating electrical energy of 5, 50, and 100 kWh per day for the three units. The units had correspondingly different operational temperatures: 55 to 65°F, 65 to 70°F, and 70 to 75°F respectively. The range of electricity consumption that was broader than the range of temperatures for the three units was likely due to conduction through party walls between units. It appears that the 5kWh/day house was being heated by its neighbors, and the 100kWh/day house was heating its neighbor's house. In many cases the temperature readings indicate that occupants are using the thermostat knob as a throttle instead of leaving it at a fixed set point.

Retrofit Strategies Incorporating Mini-Split Heat Pumps– Dave Robinson

This presentation was on strategies and lessons learned by Green Earth Equities from installing mini-split heat pumps with wall-mounted DHUs and concealed ducted AHUs with all ducts inside the envelope in retrofit homes in Fresno, California. A model whereby energy wise investors can do deep energy retrofits up to near zero energy homes with little or no program assistance was discussed.

Energy efficiency upgrades, combined with interior and exterior cosmetic makeovers have been executed successfully on 12 foreclosed houses (3 bedroom, 2 bath) in Fresno, California and sold at a profit. Specifications for the 1,200 square feet, one-story one house presented include R-16 walls, R-55 attic, U 0.30 (R-3.33) windows. The HVAC system has been retrofitted by eliminating all ductwork from the unconditioned attic and replacing the traditional ducted forced air heat pump with an ACCA properly-sized inverter driven mini-split connected to a DHU located in the main living space and an AHU concealed in the hallway ceiling and ducted to the bedrooms via short straight sheet metal ducts located within the thermal enclosure. House air sealing performed with blower door verification and an ERV provides balanced and continuous ventilation by delivering fresh air directly into the main living space near the hallway return for the ducted AHU. Utility bill data collected through the first summer of occupancy shows summertime electric consumption for cooling of between 100 and 200 kWh per month.

Based on Dave's experience, the successful retrofit business is a balance between remodeling, real estate and building performance. The basic strategy includes choosing the right house, designing it properly, building it well, marketing it effectively and selling it for a profit. Energy package hard costs generally constitute 25% of the total upgrade cost while the remainder is spent for key components necessary for the market viability of the retrofit house including: granite counters, new tile and wood floors, carpeting, new roof, outdoor plantings and other cosmetic details. Ideal houses for this strategy are 30 to 50 year old tract houses with three or four bedrooms and two baths. These have the best opportunity for both cosmetic and energy upgrades with the least potential for more difficult repair problems.

One notable benefit for contractors working for a foreclosure retrofitter is that since the houses are unoccupied and they have repeatable business, they end up doing more projects with less marketing costs and inconveniences than would occur performing retrofits with individual clients in occupied houses.

IBACOS Simplified Space Conditioning Research Plan – Dave Stecher

IBACOS presented research plans for three unoccupied test houses. Test Plans (KNDJ-0-40341-02 Deliverables 2.1.1, 7.1 and 7.3) have been submitted to NREL for each of these houses. The executive summary appears below.

"The purpose of the three houses is to create research facilities to determine the level of reduction of fan forced distribution that is possible while maintaining satisfactory occupant comfort in a well insulated, airtight house by comparing the seasonal performance of three different distribution systems. This test plan includes questions addressing the specific thermal energy output performance aspects of the equipment, but moreover, the relationship between the distribution method, the house and the occupants. Primarily:

- To what magnitude does the interior temperature and relative humidity vary in different rooms under various weather conditions?
- How does the system respond to extreme load conditions?
- How does the system respond to erratic thermostat behavior?"

Research Findings from Electric Resistance Heat Displacement Program – David Baylon

David presented pertinent results from multi-year, multi-home study conducted by Ecotope in the Pacific Northwest where a mini-split heat pump was installed to displace the use of electric resistance heat throughout much of the year to provide energy savings. The total house electricity consumption before and after retrofit was analyzed for 84 homes, in addition to measurement of the electricity consumption of the mini-split heat pump installed in each house. The goal is to determine to what degree the mini-split heat pump reduced house heating electricity consumption.

The results showed a wide range of mini-split heat pump operation. Some houses had almost no-heat pump operation, with almost all heating continuing to be done by electric resistance heat. In other cases, no electric resistance heat was used by the occupants after the installation of the ductless heat pump. Although no individual room temperature measurements were taken, this indicates that at least for some houses, the single point mini-split heat pump was able to satisfy the occupants comfort requirements.

Preliminary results indicate electricity savings from measured houses in climate zone 4 was between 41% and 51%. Houses in climate zone 5 and 6 ranged from 16% to 27% savings. However, the absolute savings were similar across all climates. The percentage savings appeared to be greater in milder climates primarily because the amount of heating required in these cold periods is much higher in zones 5 and 6 than in zone 4 and the mini split was not sized for the total heating needs of the house. COP reduction was secondary, in most cases less than 30%, occurring only as temperatures fell below 20 °F.

Discussion

The primary purpose of the discussion portion of the meeting was to critique IBACOS' unoccupied test house Test Plans. The key questions, critical issues, gaps and barriers, and future research discussed by the meeting participants are summarized below.

Answers to Key Questions

Several questions were discussed regarding research goals and test equipment setup in the houses:

- What should the range of supply air temperatures be for short term airflow tests?

  The range of temperatures to be tested during short term airflow testing was discussed and it was agreed that for heating the range should be from 90°F to 140°F. Temperatures outside of this range were considered to be unreasonable for any production heating system to produce.

- What room-to-room temperature differences are considered "acceptable"?

  As the temperature difference between the indirectly conditioned rooms and the directly conditioned spaces changes, the amount of heat transfer increases, however if the rooms are occupied, a strict +/- 2°F temperature range is applicable (although thoroughly debated by members of the meeting). If the room is unoccupied, larger temperature variations may be acceptable.

- Where should the thermostat be located?

  In all test cases the thermostat will be located in the main living space which is actively conditioned in all distribution test cases.

- How should heating and cooling be generated in the house?

  The option of using a single air handler unit containing a hydronic coil with heated and cooled water was well received by those in attendance as a good system to use to facilitate easy measurement of the amount of thermal energy entering the room. Some questions arose around whether or not the system should be operated as a modulating system. The challenges are that there was little understanding of exactly how modulating systems work (e.g. controls programming for appropriate response). There was consensus among the group that modulating systems would provide inherently better comfort than non-modulating systems. So it was decided that operating the houses as a non-modulating system would represent the worst case scenario for occupant comfort characteristics of the three distribution systems.

- What "load" will the test respond to?

  The load of the house and system size will be according to ACCA calculations. The true load of the house will be determined via field measurements of the thermal output of the air handler unit. One suggestion from the attendees was to modify "tonnage" to evaluate remote room comfort. The example was given that in a house with two 12MBH mini-split heat pumps, it would be possible to just operate one heat pump, cutting the total system capacity in half, and measure the response of the house to this undersizing to determine if dramatic temperature fluctuations occur during peak conditions. This example strategy will not be implemented initially, but depending on the results of the first year of operation, IBACOS will consider evaluating the house in an undersized condition.

- How many temperature measurements are necessary?

  Another question that was raised was how many temperature measurements would be needed per room on a long-term basis. It was the opinion of some of the experts there that as few as one air temperature measurement per room could be sufficient to characterize the performance of the different distribution systems.

- What additional house characteristics do designers need to know to implement simplified space conditioning systems?

  A goal that developed through this meeting is to develop a target thermal enclosure area weighted thermal conductivity value (UA value) and load (Btu/h) for each climate that are thresholds, that if achieved will allow each particular distribution system to work. Furthermore, in a given room, the relationship between the heat transfer through the thermal enclosure and the heat transfer through the interior partitions or openings must be balanced if active distribution is to be avoided for that room.

Critical Issues

Although there are many critical issues related to space conditioning outlined in the IBACOS unoccupied test house Test Plans, during this meeting the following issues were brought to light by the experts as key issues that were not overtly addressed in the plan and should be addressed in some way by IBACOS or other researchers:

- Comfort expectations in retrofit houses
  - In existing houses, comfort levels may already be well below ASHRAE levels. But in retrofits, how much of an improvement is necessary to satisfy occupants that the house is more comfortable? Are strategies improving energy efficiency by reducing the total usable area of the house by segmenting and retrofitting only a few viable rooms?
  - How quickly can the house recover from a deep temperature setback (e.g grid failure, vacation)?
- The impact of basements
  - Basements add an additional level of complexity when trying to reduce the amount of active distribution in a house. Many issues were discussed regarding what the possible influences of an insulated but unfinished basement might be on the comfort levels in the habitable portions of the house. This includes: what temperature should a designer expect or require the basement to be conditioned to, and if there are ASHRAE or GRI requirements or existing research in the area. Depending on the level of active conditioning in the basement, does it present a parasitic load on the rooms above it or is it actively heating those spaces? It was determined that this was out of the project scope of the two slab on grade hot-dry unoccupied test houses that IBACOS is proposing, however, pending a suitable

house in the cold or mixed humid climate with basement, some of these issues could be explored.

- Air tightness requirements in new and retrofit houses
    - The level of air tightness in houses can have a substantial impact on occupant comfort; in new construction houses it was accepted by the group that air leakage rates of 1 to 1.5 ACH50 are reasonable to achieve. However, in existing construction houses, the situation is much more variable. Those with experience in retrofit of existing houses indicated that air leakage rates of 3.5 to 5 ACH50 would be readily achievable without extensive changes to the house, provided that combustion safety is addressed when decreasing the air infiltration rate of an existing house.
- Measuring and documenting air leakage
    - Another question that arose was the way in which air leakage is documented. The ACH50 metric allows houses with good volume to surface area ratios to score better, which generally favors large houses while punishing small houses. Some in attendance prefer the metric of air leakage flow rate (cfm) at 50 Pascals (Pa) depressurization divided by the total building thermal enclosure surface area (all six sides, also known as CFM50/SF shell). Using this type of metric is also important in the design of houses capable of incorporating minimized space conditioning strategies, as individual room loads can be influenced by the amount of exterior surface area.
    - It was agreed that .1 CFM50/SF shell was an appropriate goal for new construction houses or deep energy retrofits. Green Earth Equities has been able to achieve 0.2 CFM50/SF shell on several houses, albeit these houses are slab on grade with stucco finish, which inherently lends itself to an airtight structure. This number is less than what Building Science Corporation uses (0.25 CFM50/SF shell) as their new construction air tightness standard for houses built on a large scale production basis. However more research should be done on a national basis to determine what levels of airtightness are reasonable to achieve during moderate retrofits based on regional house construction typology.
    - After some discussion it became clear that just applying the per unit area air leakage rate would be insufficient for calculating room loads, and that the position of the room in the house must also be considered. There are two primary means by which air leakage leads to occupant comfort: cold jets of air hitting the occupant directly (commonly referred to as drafts), and whole house stratification due to the stack effect enabled by leakage points near the base and top of the house. Although the unit area air leakage rate may help in identifying the impact of the latter, it does not help with the former. Cold jets of air that may hit occupants will create local areas of occupant discomfort, and should be identified during the air leakage test and fixed. The impact of air leakage on natural convective air movement inside the house should be identified and documented in test houses.

Technology and Research Gaps

The following technology and Research Gaps were identified during the meeting:

- When a mini-split heat pumps is oversized for heating, does its ability to vary capacity produce adequate cooling and dehumidification to maintain comfort?
- Measuring equipment power draw/stage for variable capacity systems and, in general, understanding of the operation of variable capacity systems is challenging.
    - On – Using simple electrical measurements, it is difficult to determine what the amount of conditioning energy that a variable capacity mini-split is outputting into a house because there are hundreds of thermal output possibilities as opposed to the more than two or three distinct output stages of a typical forced air system. It is not clear what factors the manufacturers use in their control algorithms to have the system operate at a particular capacity, and for how long before modifying that capacity.
    - Off – When the system is not providing any heating or cooling, does it periodically or continually run a circulation fan through the unit? What are the standby functions that require energy when the unit is "off"?
- Snow buildup around outdoor unit impacts performance.
    - Issue for mini-splits, however, according to an attendee, up flow standard (non-mini-split) heat pumps designed for the American market are less susceptible to this issue.
- There is a need to standardize reporting and measurement methodologies.
- What are the energy and comfort implications of setbacks in houses with minimized space conditioning systems?
- Control systems and strategies are needed that can integrate the use of products that were not originally designed to be used together such as mini-split heat pumps and electric baseboard heat, but also consider heat pump water heaters, and whole house ventilation strategies.

Future Research

Several possible interesting research areas came up during the course of discussion. While these will not be performed by IBACOS in 2011, they are worth noting and may be included in future research plans:

- What is the human response expectation to satisfy comfort? Research presented through this meeting has shown that occupant comfort is variable based on the personal desires of the occupants. Have these expectations changed since the last time ASHRAE comfort guidelines were developed?
- Once basic concepts are proven, it would be useful to determine what ASHRAE/ACCA Guidelines are impacted, such as space conditioning loads, airflow, and sizing strategies, and modify those guidelines appropriately to accommodate space conditioning systems with minimal or no active distribution.

- There is a large opportunity to reduce wintertime heating energy consumption of buildings with electric resistance heat. One way presented in the meeting was via the installation of air source mini-split heat pumps. Are there other viable systems that can be implemented?
- After the physical requirements are known, determine the size of market for simplified space conditioning systems.

Conclusions and Next Steps

IBACOS has incorporated the results of this meeting into its Test Plans for three unoccupied test houses to be constructed in 2011 and operated through 2012.

References

Baylon, David, et al. Performance of Ductless Heat Pumps in the Pacific Northwest: Proceedings of the 2010 ACEEE Summer Study on Energy Efficiency in Buildings. ACEEE, Pacific Grove, California, August 15-20, 2010.

Feist, W., et al., 2005. Re-inventing Air Heating: Convenient and Comfortable within the Frame of the Passive House Concept,. Energy and Buildings 37, 1186-1203.

Hendron, Robert and Engebrecht, Cheryn. Building America House Simulation Protocols. Golden, CO: National Renewable Energy Laboratory. October 2010

IBACOS. DE-FC26-08NT02231. Building America Program Annual Report Budget Period 1. Pittsburgh: IBACOS. December, 2008.

IBACOS. DE-FC26-08NT02231. Building America Program Annual Report Budget Period 2. Pittsburgh: IBACOS. February 2010a.

IBACOS. DE-FC26-08NT02231. Building America Final Technical Report. Pittsburgh: IBACOS. December 2010b.

Swift, Joseph, and Rebecca Meyer, Ductless Heat Pumps for Residential Customers in Connecticut. Proceedings of the 2010 ACEEE Summer Study on Energy Efficiency in Buildings. ACEEE, Pacific Grove, California, August 15–20, 2010.

EERE Information Center
1-877-EERE-INFO (1-877-337-3463)
www.eere.energy.gov/informationcenter

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

DOE/GO-102011-3344 ▪ July 2011

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 10% post-consumer waste.