Small Homes, Excellent Enclosures, Almost No Heating System: Fact or Fiction?

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ABSTRACT

This paper presents two projects in cold climates and examines the relationship between very energy efficient single family residential thermal enclosures, comfort conditions, and simplified space conditioning systems. A project in Massachusetts allowed for the comparison of room-to-room temperatures between a single point-source, gas fired heater and a traditional, ducted, forced air, gas fired furnace in very similar houses, all built to the same construction standard. The other project, in Illinois, allowed for evaluation of room temperatures in a house with individually controlled electric resistance heaters placed in each room in conjunction with a fully ducted energy recovery ventilator. Six-minute average temperatures were recorded in the Massachusetts project, and two-minute average temperatures were recorded in the Illinois project. Temperature readings were taken in bedrooms and main living spaces in each house. The Massachusetts houses had a single thermostat located in the main living space, and the Illinois project used individual thermostats in each room. The data collected suggests that dramatically simplified heating systems can provide equivalent or better temperature uniformity and occupant comfort than a traditional forced air system in a low load house.

INTRODUCTION

An ongoing U.S. government-funded research project is focused on identifying strategies and solutions to move the US residential housing industry towards new single-family housing with very low annual energy use. As part of this effort, the authors have been performing energy analysis, design, construction, and monitoring of houses with highly insulated thermal enclosures and significantly simplified space conditioning systems. These projects include a 28-unit co-housing project in western Massachusetts and several houses in central Illinois. These houses are all currently occupied, with continuing research to be conducted for new projects in the planning stages in other parts of the Northeast and Midwest. The basic premise of these projects is to aggressively improve the energy efficiency of houses through thermal enclosure design, and thereby eliminate the need and expense of a traditional ducted forced air system by replacing it with a much simpler system. The aim is to enable the savings from the reduced cost of the space conditioning system to offset the increases in costs associated with the thermal enclosure.

Project Descriptions and Design Approaches

The first project in Massachusetts is a 28-unit clustered co-housing community. House sizes vary from 684 square feet (64 m^2) to 3768 square feet (350 m^2). The design approach was to create standardized modules that would accommodate smaller affordable units and larger market rate units. The houses in this study are two-bedroom, two-story houses. An illustration of two representative houses and the heating systems used in this study is shown in Figure 1. All houses are designed with glazing favoring the southern exposure for passive solar gain in the winter, and they are clustered to minimize heat gain in summer. Roofs are oriented and designed to accommodate installation of solar thermal or solar electric systems. In addition, the steep pitch roofs (10/12 or 12/12)

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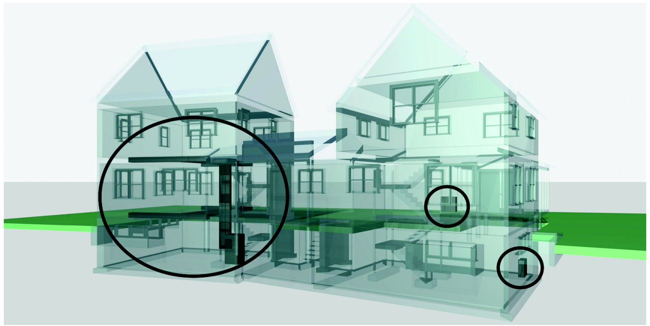

Figure 1 *Massachusetts houses showing heating system strategies (in black, circled for emphasis).*

Figure 2 *South elevation of Illinois house.*

allow for additional living space in the attic for those residents who desire it.

The basic approach is to optimize floor area and volume with a minimal amount of exterior thermal enclosure area, a strategy employed in concept by many production builders.

The houses in central Illinois are built using the "Passivehaus" principle. Houses are again oriented to the south to allow for passive solar gain; however, less consideration has been made in the roof pitch to allow for optimal output if solar panels were installed in the future. These houses are being built by a non-profit developer, who targets the affordable market. The house in this study uses a very simplified "shoebox" architectural shape and seeks to minimize exterior surface area while maximizing enclosed floor area and volume, as seen in Figure 2.

House Characteristics

Both of these projects go well beyond code minimums with respect to the thermal enclosure elements and system strategies. Table 1 gives main thermal enclosure elements for each house. It should be noted that the enclosure strategy for the house in Illinois is significantly more aggressive than the Massachusetts project.

Heating and Ventilation Systems. The Massachusetts houses in this study use two different heating systems. Two of the Massachusetts houses (MA1 & MA2) use a single, modulating, gas-fired, direct-vent unit heater (8,400 Btuh to 30,700 Btuh, 2 461W to 8 997 W, calculated efficiency from manufacturer's data approximately 0.81) with a modulating fan (121 W peak electrical draw at high speed, 203 cfm to 360 cfm, 96 L/s to 170 L/s) located on the first floor within the main living space. In MA2, an identical space heating unit is located in the basement, with the basement walls insulated and no insulation in the floor over the basement. The basements in all of the MA houses have a full set of stairs to the first floor, with a standard interior door at the top of the stairs on the first floor level. No specific air sealing measures isolate the first floor from the basement. The occupants typically keep the door closed in both houses. With an incoming air temperature of 66°F (19°C), these units produce supply air temperatures in the 90°F to 154°F (32°C to 66°C) range. In MA1, the occupants maintained a constant temperature with the controls built into the point source heater. In MA2, the occupants would need to manually set up and set back temperatures. The system in the third Massachusetts house (MA3) is a natural gas-fired, single stage, 93 percent AFUE, sealed combustion, 42,000 Btuh (12,309 W) output furnace with a 1/2 hp (approximately 500 W peak electrical draw) blower and insulated metal and flexible ductwork located in the unconditioned basement. Each room in the house had at least one fully ducted supply and return, with the exception of the bathrooms where only a ducted supply was provided. The estimated output temperature of this unit, using the total airflow measured at the registers, is approximately 132ºF (55ºC). During field retrieval of data, the setback thermostat programming for the house was recorded. The setback schedule is as follows:

6:00 A.M. to 8:00 A.M. = 66ºF (19 ºC)
8:00 A.M. to 6:00 P.M. = 59ºF (15 ºC)
6:00 P.M. to 11:00 P.M. = 66ºF (19 ºC)
11:00 P.M. to 6:00 A.M. = 58ºF (14 ºC)

Each Massachusetts house uses a ventilation system comprised of a single bath exhaust fan on a controller designed for a low-level continuous ventilation rate, with the ability to boost the fan for point source exhaust.

The Illinois house (IL1) uses single electric resistance baseboard heaters in each room. One 500 W (1706 Btuh) heater was installed in each of the three bedrooms, and two 750 W (2560 Btuh each) heaters were installed on the first floor in the living area and the dining area. Each heater is individually controlled by a separate, non-setback thermostat. The house has a ducted energy recovery ventilation (ERV) system that supplies fresh air to the occupied rooms and exhausts air from the kitchen and bathrooms. It is a variable speed system, designed for lower levels of background ventilation with boost capacity for point source exhaust.

Table 1. Thermal Enclosure Characteristics

Building assembly	Massachusetts Houses – 1175 to 1488 sf (138 m^2) not including basement, 2 Bedroom	Illinois House - 1450 sf (135 m^2) 3 Bedroom
Foundation	Full basement	Slab on Grade
Slab	1 in. (25 mm) XPS under slab R-5 (U_o=0.2)	2-3/4 in. (70 mm) XPS perimeter insulation R- 14 (U=0.07), 16 in. EPS under Slab R-64 (U=0.02)
Basement walls	Not insulated in MA1, MA2 built with R-5 XPS and R-13 fiberglass batts (U_o=0.07)	NA
Floor over basement	R-19 fiberglass batt (U_o=0.047) (MA1 only)	NA
Walls	2x6 in.(nominal) @16 in. OC (38mm x140mm @0.4 m OC) with 2x3 in (nominal) horizontal strapping @16 in. OC (38mm x 64mm @0.4 m OC) with OSB sheathing; cellulose insulation, R-24 (U_o=0.054)	14 in. (356 mm) engineered I joist @ 24 in. (0.6 m) OC, with R-1.5 fiberboard sheathing; blown in fiberglass R-57 (U_o=0.034)
Windows	Double glazed low-e clad wood framed, U- 0.35, SHGC 0.39	Triple glazed, insulated fiberglass frame, U-0.20, SHGC 0.23
Roof	2x12 in. (nominal)@16 in. OC (38mm x 292 mm @0.4 m OC); cellulose insulation R-38 (U_o=0.025)	16 in. (0.4 m) engineered I joists @ 24 in.(0.6m) OC; blown in fiberglass R-64 (U_o=0.017)
Airtightness*	776 to 860 cfm @ 50 PA (~0.20 ACH nat.)	58 cfm @ 50 PA (~0.01 ACH nat.)

* ACH nat. is calculated per ASHRAE Standard 136-1993, based on blower door test performed on each house

Table 2. Design Conditions and Peak Loads for Above-Grade Conditioned Floor Area

	Indoor Design Temp.	Outdoor Design Temp.	MA1 & MA3 1175 sf (109 m^2) Peak Loads	MA2 1488 sf (138 m^2) Peak Loads	IL1 1450 sf (135 m^2) Peak Loads
Western Massachusetts					
Heating	71ºF (22 ºC)	-2ºF (-19 ºC)	21,672 Btuh (6351 W)	25,997 Btuh (7618 W)	NA
Cooling	76ºF (24 ºC)	85ºF (24 ºC)	12,336 Btuh (3615 W)	13,810 Btuh 4047 W)	NA
Central Illinois					
Heating	71ºF (22 ºC)	-6ºF (-21 ºC)	NA	NA	10,996 Btuh (3221W)
Cooling	77ºF (25 ºC)	91ºF (33 ºC)	NA	NA	14,866 Btuh (3568 W)

In mid February, after several freeze up events during peak low temperatures, a 250 W (732 Btu) section of electric resistance heat tape was installed in the incoming air stream to prevent freeze-up of the ERV core. This operated from February 9, 2007 to February 22, 2007.

Peak heating and cooling loads for the MA1, MA2, MA3, and IL1 houses are shown in Table 2.

MONITORING OBJECTIVES

The objective of the study in the Massachusetts houses was to evaluate the room-to-room temperature uniformity throughout the houses, during winter conditions, and the room-by-room deviation from the main space where the thermostat was located. These houses are very similar in size and were all built with the same thermal enclosure characteristics. The houses were monitored to understand the relative floor to floor and room by room temperature differences between a single point source system and a ducted forced air system. IL1 was monitored to evaluate supply air temperature of a dedicated ERV system and whether there was a discernable impact on room temperatures.

Monitoring System

The houses in this study were already constructed when the monitoring systems were installed. This limited the precision and quantity of data that could be collected. Highly detailed analysis relative to the performance of these houses is not possible, but the data does give a reasonable representation of temperatures in the houses. Occupants were surveyed in the Massachusetts houses on their behavior relative to door operation. All stated that they rarely closed bedroom doors at any time during the study period. As single point heating and the relative temperature distribution was not a focus of the Illinois house study, no surveys were undertaken on occupant door closure behavior or how occupants of the IL1 house adjust the temperature settings on a room-by-room basis. This initial set of data was gathered to provide some basic feedback to the project team to identify potentially successful strategies at a system level, how operation of the systems might impact relative temperatures within the houses, and possible system issues and unintended interactions that might cause customer objections, which would need to be addressed in future projects. More detailed monitoring of similar houses is being planned and is discussed in the conclusions section.

The monitoring strategy used for all of the houses consisted of miniature temperature data loggers installed on each floor, in each bedroom, and outdoors. At the Massachusetts houses, a single data logger was placed in each of the following locations: the basement, the first floor, each of the two second floor bedrooms, and the hall at the top of the stairwell on the second floor.

In IL1, temperature measurements were taken on the first floor in the living and dining area and the bedroom, and on the second floor in the two bedrooms and the gallery, a walkway adjacent to a double height space above the dining area. Temperatures were also measured at the incoming and outgoing airstreams on both sides of the heat exchanger at the ERV (four temperatures total).

Test Periods

Temperatures in houses MA1 and MA3 were measured in March 2006, and MA2 and MA3 had temperature measurements taken from January through February 2007. The MA3 data logger at the hall at the top of the stairs failed to record data for the 2007 period; however, data is available from the 2006 period, which showed very close tracking with bedroom temperatures. Room air temperatures were measured at IL1 from December to March 2007, with ERV air temperatures recorded from February to March 2007.

ANALYSIS METHODOLOGY

The general approach for the study of the Massachusetts houses is to evaluate temperature differentials between each floor of the house based on heating system types and temperature differentials within each house from room to room. While Rittelmann (2006) has found conflicting standards related to evaluating whole house comfort, ACCA (2004) states that residential forced-air systems should be designed to maintain room-to-room temperatures within 2.0°F (1.1°C) with a maximum of 4.0°F (2.2°C). Air temperature is only one factor in measuring overall thermal comfort (ASHRAE 2004), but in well-insulated houses with Low-E windows, Rittelmann (2006) has found that air temperature and mean radiant temperature track fairly closely, except when the windows are experiencing direct solar gain.

Air velocity and stratification from floor to ceiling are not evaluated in this study; however, floor-to-floor temperature differences are. Supply and return airflow readings were taken in each room in MA3 and room-by-room peak heating load calculations, using ACCA Manual J methodology, were performed. Results indicated that, if perfectly balanced, the first floor would require approximately 60 percent of the total system airflow, with the remaining 40 percent going to the second floor. Air flow measurements at each supply and return register using a low-flow balometer showed that the supply airflow was approximately equal on the first and second floor. The first floor return air was approximately 55 percent of the total return airflow. Total measured supply airflow was 565 cfm (267 L/s) and total measured return airflow was 544 cfm (258 L/s).

The analysis in IL1 evaluates the incoming air temperature from the ERV and whether temperature impacted the individually controlled rooms, especially during periods of extremely cold weather.

Temperature Data for Houses MA1, MA2, and MA3

Figures 3 through 8 present temperature data collected in MA1, MA2, and MA3, showing both absolute temperatures and differences between first-floor and bedroom temperatures. The absolute temperatures are shown for the study period. The temperature differences are shown for the coldest days during the study period, when the greatest stack pressures occur. This data, therefore, is expected to reflect the greatest level of stratification and natural infiltration— driving maximum temperature differences.

Temperature Data for House IL1

Figure 9 shows the average of indoor temperatures, heating power, and the ventilation supply air stream temperature in IL1 for the coldest days of the study period, when ERV supply air temperatures were available and the resistance heat tape was not operating in the ERV system. Early in February, the ERV unit periodically froze up, and on February 9, 2007, the builder installed a small amount of electric resistance heat into the incoming air stream to eliminate freeze up at the unit. This is an option the manufacturer of the unit provides; however, the builder chose not to purchase this option at the time of installation and had to perform the retrofit after the problems occurred. The data is presented reflects when the heat tape was not operational in order to eliminate the temperature bias introduced by heating the incoming air stream.

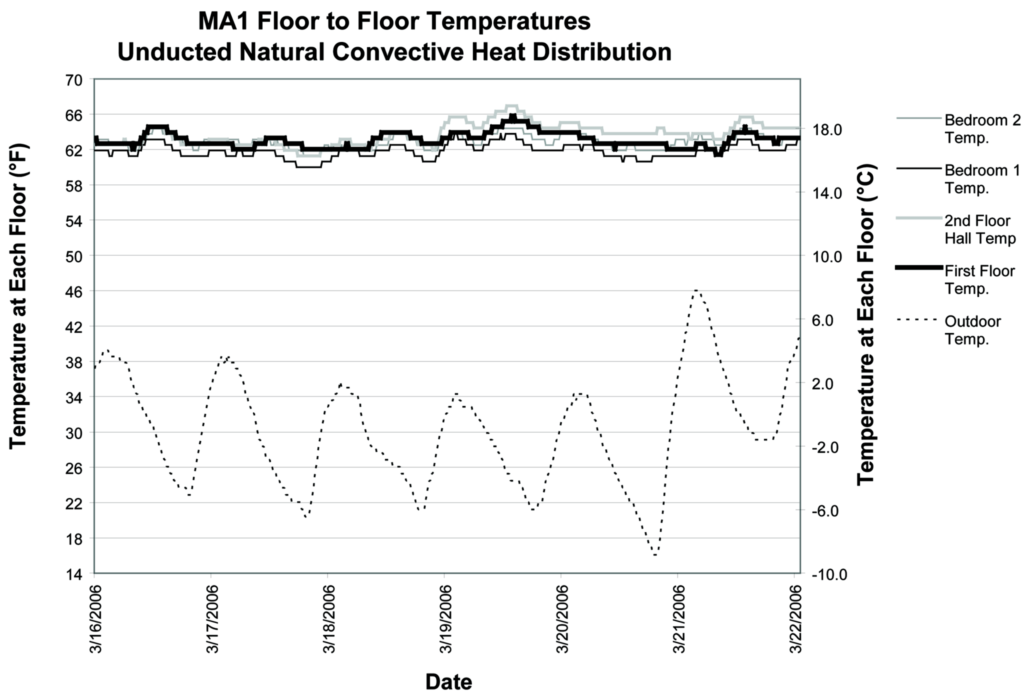

Figure 3 *Room temperature readings in house MA1, March 2006.*

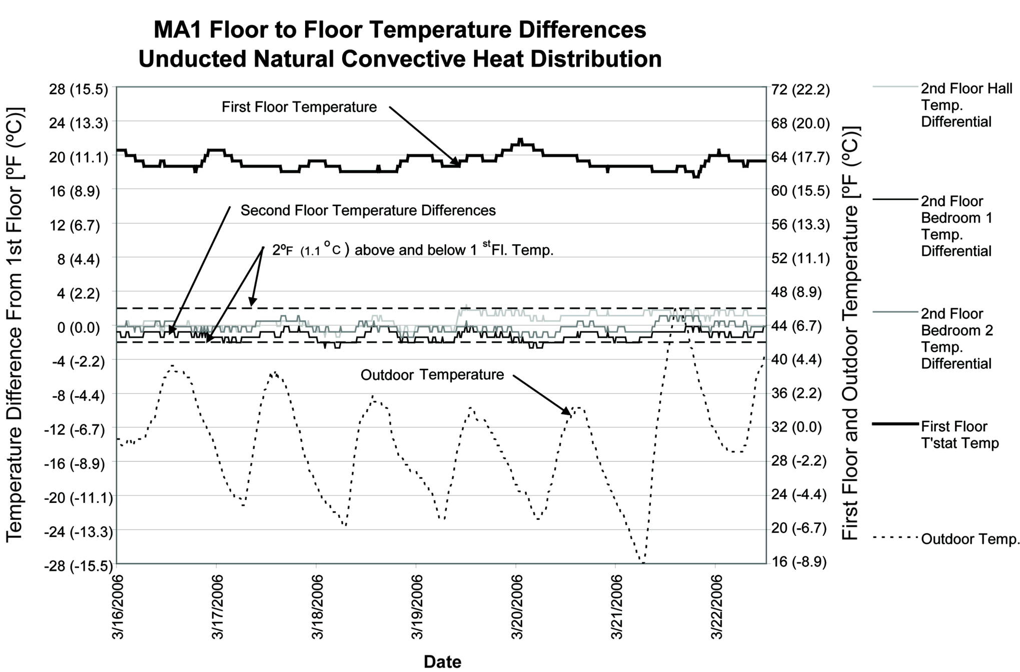

Figure 4 *Temperature differences from first floor to second floor in house MA1, March 2006.*

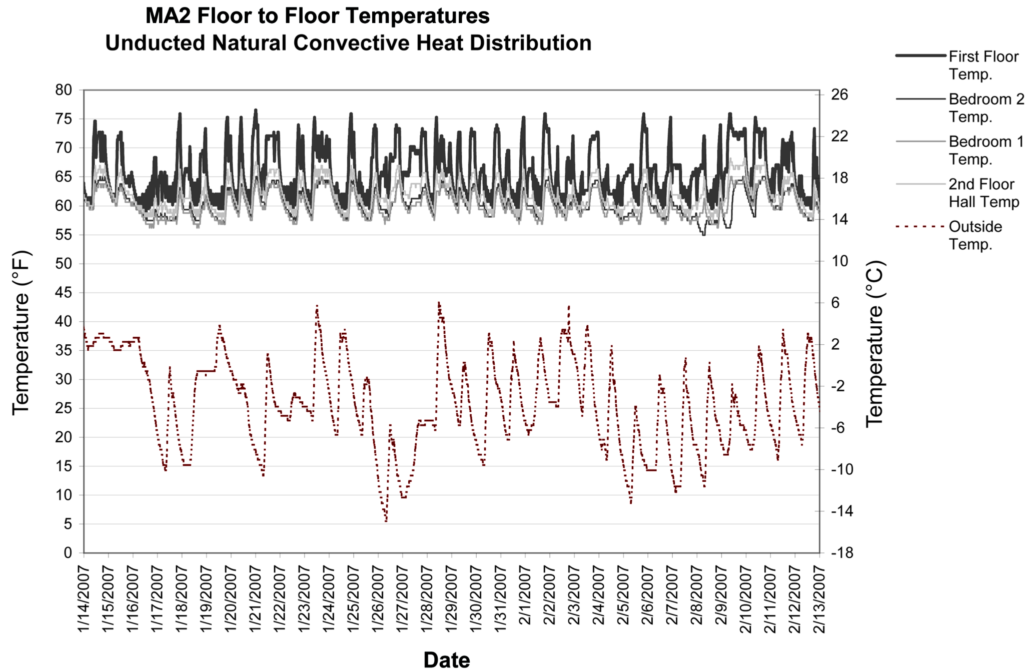

Figure 5 *Room temperature readings in house MA2, January to February 2007.*

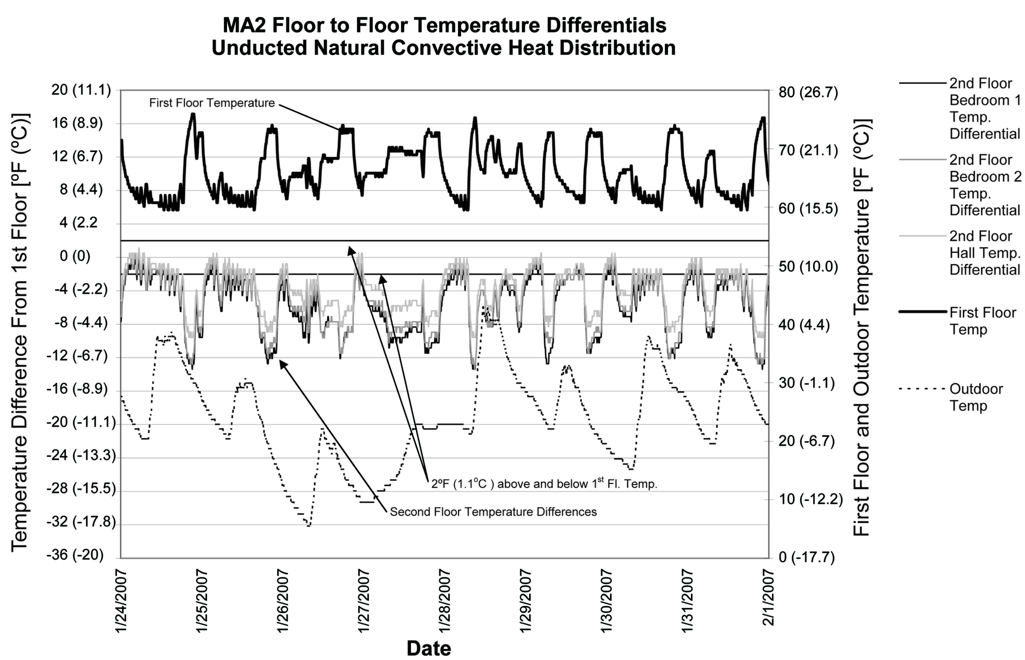

Figure 6 *Temperature differences from first floor to second floor in house MA2, January 2007.*

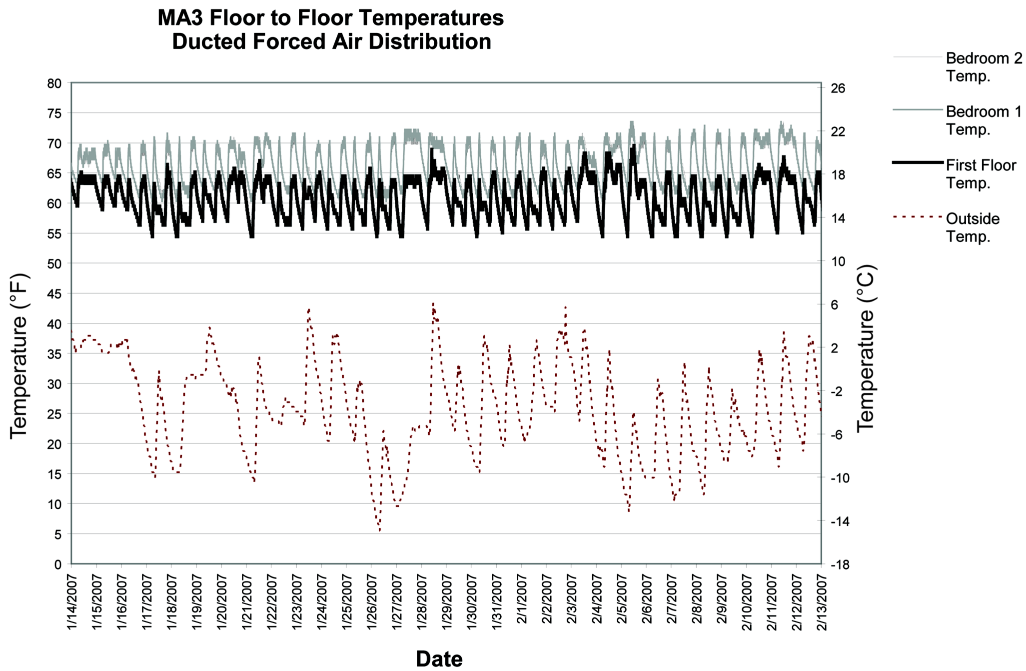

Figure 7 *Room temperature readings in house MA3, January to February 2007.*

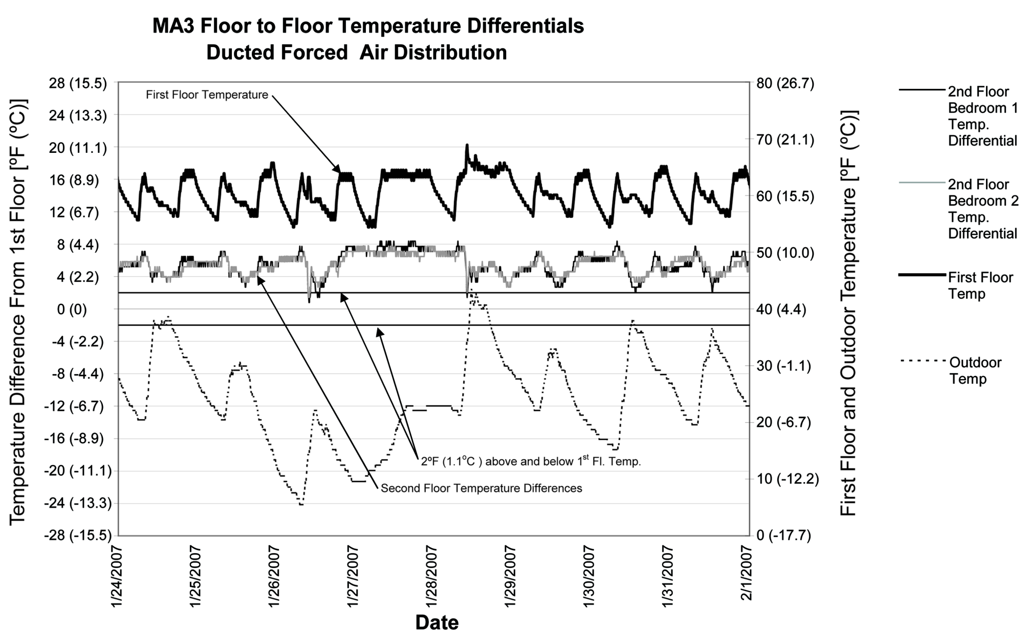

Figure 8 *Temperature differences from first floor to second floor in house MA3, January 2007.*

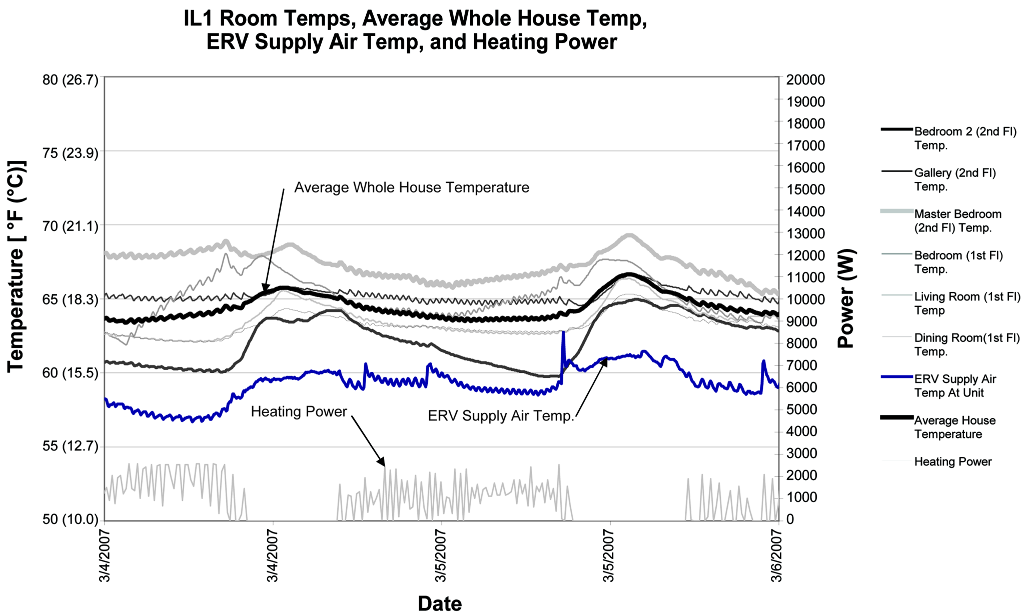

Figure 9 *Room Temperatures, ERV supply air temperature and power for IL1.*

DISCUSSION

MA1, MA2, and MA3

From this data, there is a significant disparity between MA1 and MA2 in terms of ability to maintain uniform temperatures throughout the conditioned space of the house. As these houses were very similar in size, it appears that the setback control had a significant impact on the floor-to-floor temperature differences. MA1, using a control strategy that maintained a fairly stable first floor temperature, had second floor bedroom temperatures well within the +/-2.0ºF (1.1°C) range for the entire study period in 2006. It should be noted that the lowest outdoor temperature experienced during this study period was 16ºF (-8.9°C). The floor-to-floor temperature differences in MA2 ranged from 2.0ºF to 12ºF (1.1°C to 6.7 ° C). In evaluating temperature uniformity on the second floor, the temperature difference from bedroom to bedroom was well within the +/-2.0ºF (1.1°C) range for the entire study period – and it exceeded this range for only six brief periods. Temperature differences in the hall at the top of the stairs were slightly larger, ranging from 2.0 ºF to 4.0 ºF (1.1°C to 2.2°C) for the study period.

Temperature differences from floor to floor in the MA3 house were consistently higher than in the MA1 house and more consistent than the comparable setback control in MA2. The second floor temperatures in MA3 were 4.0ºF to 8.0ºF (2.2°C to 4.4ºC) higher than the first floor for most of the study period, with only five brief periods when the temperature was as low as 2.0ºF (1.1°C) higher than the first floor temperatures. While this can be attributed in part to the measured airflows on the second floor of MA being approximately 9% higher for supply and 5% lower for return than would be required to meet the calculated peak loads, the temperature differences did not tend to converge when the system was presumed to be off during setback. Temperatures did converge in MA2 whenever the occupants lowered the thermostat setting. Even if perfectly balanced, it is doubtful that the temperature differences in MA3 would be in the +/-2.0ºF (1.1°C) range seen in MA1.

MA1 shows that floor-to-floor temperatures generally are within the 2.0°F (1.1°C) temperature range; however, the system is also being operated at a more constant temperature with fewer aggressive setups and setbacks. Given that the relative location of air leaks in the house is unknown and the upstairs temperatures are generally lower than the first floor, stack effect appears to be a less dominant form of heat transfer to the second floor bedrooms than conduction through the floor. This can be seen in Figure 3, where the hall temperature, which is at the top of an open stairwell, is frequently warmer than the first floor, whereas the bedrooms are consistently slightly cooler than the first floor, even with the bedroom doors open virtually all of the time, as reported by the occupants. The higher hall temperatures are expected due to stratification. The period of greatest temperature uniformity from floor to floor is when the first floor is running at a fairly uniform temperature, which is presumably when the unit heater is running very frequently.

IL1

With individually controlled room heaters and a centrally ducted ERV, the data shows that supply air temperature to each room is approximately 5.0°F (3.3°C) lower than the average room air temperature. The data in Figure 9 does not show any correlation to ERV supply air temperature and individual room temperatures. Outside temperatures during the time period in Figure 9 ranged from lows of approximately 15.0ºF (-9.4°C) to a high of 40.0ºF (4.4°C). Similar patterns were observed at very low temperatures (0.0ºF, -17.7°C). The supply air temperature does track the average inside temperature fairly well, as would be expected. The data suggests that the low volume of ERV supply air to each room is easily mixed and tempered by the heating units in each room. All supply air outlets are either in the ceiling or on high sidewalls, where the highest temperature in each room would be expected due to stratification. While room-to-room temperatures varied by up to 10.0°F (5.5°C), this can be attributed to individual occupant choices as to their personal comfort levels, particularly in the bedrooms. The living/dining area temperatures were kept fairly constant at approximately 64.0°F (17.7°C), but were periodically set to approximately 68.0°F (20.0°C). The thermostatic controls on the electric heaters limited the individual room space temperature variance to less than 1.0°F (0.5°C). The temperature difference between the living/dining area and the gallery on the second floor, which communicates directly to the first floor through a large double height space, was between 0.0ºF and 3.0°F (0.0°C to 1.1°C), indicating very little floor-to-floor stratification. In an interview, the occupants said that they are able to keep thermostat set points lower in the house and maintain comfort primarily, in their view, due to the extreme air tightness of the building. The effect of the passive solar gain is evident in Figure 9, which compares electric power and inside temperatures. Temperatures in the living room on sunny days increased by approximately 2.0°F (1.1°C), with no power being used in the house for heating energy.

House Size, Advanced Thermal Enclosure, and Appropriate Space Conditioning Responses

Both the Massachusetts and Illinois projects used a design strategy to invest more in the enclosure technology and dramatically simplify the heating system, attempting to achieve significant energy savings without increasing overall construction costs. Monitoring systems were also installed to evaluate whether traditional ducted space conditioning systems can provide adequate comfort in low load houses. As houses are becoming more and more energy efficient, peak heating and cooling loads are significantly lower. While the forced air system in MA3 used the lowest output furnace available, it was still more than 50 percent larger than needed. Even if a modulating furnace was used in this house and designed for peak load using the part load capacity of the furnace, the authors' experience has been that it is very difficult to design a distribution system that will provide the velocities needed at the supply outlets to mix room air, and the strategy is not adequately addressed in residential space conditioning design manuals such as ACCA Manual D (1995). Additionally, supply registers or outlets that can assure desired throw and mixing are difficult – if not impossible – to source from register manufacturers.

By U.S. standards, these houses are smaller than average, and the thermal enclosures have higher insulation values, better windows, and, to a varying degree, greater air tightness than typical code construction. From the data collected, it appears that point source system will work in smaller, highly efficient houses, if the indoor temperature is kept relatively constant and doors in second floor rooms are kept open. The larger question is how to scale this up to houses that represent the more typical 1,800 square foot to 2,800 square foot (167 m2 to 260 m2) housing in the United States. The authors have investigated comfort complaints in houses built to Energy Star Homes® levels of performance with traditional ducted forced air systems, and they have concluded that a combination of factors lead to wider swings in room-to-room temperature differences. Comfort complaints are frequently made about rooms served by the longest duct run, and thermostats are located significantly closer to the shortest runs in the system. The authors have also measured 10°F to 15°F (5.5°C to 7.8°C) temperature differences at the supply outlets of the longer runs compared to the supply air temperature at the shortest run in the house. The energy difference in part is due to duct leakage, but also to the energy transfer between the air and the mass of the ductwork. Unless the system is running for a long period of time, the air temperature at the end of long duct runs will never actually reach the necessary temperature to maintain the temperature at the thermostat. This issue is compounded because the thermostat is frequently near the shortest run in the house, and standard design practice is to assume the same outlet temperature for each run when designing a duct system. As loads are reduced in higher efficiency housing, new strategies, such as efficient single point source systems or room-by-room systems with individual control, may be the new paradigm.

While MA1 demonstrated good temperature uniformity by maintaining a relatively stable temperature in the space where the heater was located and keeping bedroom doors open, this is not necessarily a viable option for houses where occupants will be closing doors to bedrooms. One possible solution to this is a low volume air circulation system utilizing a low energy, quiet multi-port exhaust fan that draws air from the main space with the heater and distributes it to the bedrooms. The data suggests that due to the very low loads in these houses, the volume of air needed should be minimal given the heat transfer that will occur through uninsulated floors and wall assemblies between interior spaces. Pressure relief devices (like jump ducts and transfer grilles) should be installed to assure that rooms receiving air are not pressurized, causing possible air leakage into insulated assemblies. This may also be a viable option for houses with very low cooling loads by utilizing a single, high-efficiency, through-the-wall unit air conditioner. The authors plan to undertake more detailed engineering analysis to evaluate this strategy in future projects, especially with respect to floor to ceiling stratification.

Ventilation Efficacy and Point Source Heating

In MA1, MA2, and MA3, the ventilation strategy is an exhaust fan on a control system designed for a low level continuous ventilation rate, with the ability to boost the fan for point source exhaust. Because of the moderate level of air tightness in these houses, it is assumed that adequate ventilation will be provided due to the negative pressure induced by the exhaust fan and general natural air exchange. MA2, with a forced air system, will likely have a more uniform distribution and mixing of ventilation air due to the operation of the furnace. It should be noted, however, that there are significant time periods when the furnace is in setback mode and presumably not operating. The point source system has no general mixing strategy, and it is unclear if each room is getting an appropriate amount of fresh air due to natural air exchange and induced ventilation from the exhaust fan. Measurements should be taken in these houses during winter, shoulder seasons, and summer to understand the ventilation efficacy of this strategy. Because leaks in buildings are somewhat random, certain rooms (particularly bedrooms) may not receive adequate ventilation. The low volume air distribution system described above could also help to assure reasonable distribution of fresh air with an exhaust only ventilation strategy. Tracer gas testing conducted by the authors in conjunction with the National Renewable Energy Laboratory in a four bedroom house in Fort Wayne, Indiana in late April 2007 showed very good mixing of 70 cfm (33 L/s) of supply-only fresh air using a whole house ducted forced air distribution system running at 350 cfm (165 L/s). The authors are planning additional studies on ventilation efficacy in several new projects that are scheduled to begin construction between 2007 and 2008. Further research in this area is needed.

Comfort, Distributed Heating Devices, and Energy Recovery Ventilation

While the ideal scenario for comfort is room-by-room control, there are very few options for its energy efficient implementation. Electric resistance heat was chosen in IL1 primarily for first cost reasons; however, the source energy efficiency of electric resistance heat is approximately 33 percent compared to the approximate 81 percent efficiency of the point source space heater used in the Massachusetts project. The trade-off in the Illinois project was to take the financial savings from the low cost space heating system (due to the aggressive thermal enclosure investment) and invest in a more sophisticated ERV system. What is unknown is how effective an ERV can be at providing well-mixed ventilation air at ASHARAE 62.2 rates. In IL1, ASHRAE 62.2 ventilation rates would require approximately 60 cfm (28 L/s) continuous ventilation; however, when distributed to three bedrooms and the main living space, this translates to only about 10 cfm (5 L/s) per bedroom and 30 cfm (14 L/s) for the main living space. The challenge with such low flow rates is to ensure that the air being delivered will mix properly within the space that it is delivered to. If higher volumes of air are needed to properly mix ventilation air in very low load houses, new ERV designs may be needed to introduce low levels of outside air while providing higher volumes of re-circulated inside air. Alternately, new terminal devices may be needed that can operate at low air volumes but provide the throw and velocity necessary to provide for some level of mixing in the room, without creating air speeds in the occupied zone that would negatively impact comfort conditions.

CONCLUSIONS

As thermal enclosures of houses in cold climates of the United States become more energy efficient, the use of traditional ducted forced air systems may not be the most appropriate choice from a comfort standpoint. The very low loads associated with these houses translate into a significant mismatch with conventional furnace sizes. When fixed output furnaces are used, they will short cycle even at peak conditions, and, due to variables such as poor duct design and improper balancing, significant temperature variations can exist within the house. Greater temperature uniformity and improved comfort are achievable through the use of point source or distributed low output heating strategies that do not rely on a whole house air distribution system. However, some form of simplified air mixing system may be required to assure temperature uniformity throughout the house, due to occupant operation of the heater and opening and closing of doors to rooms. Ventilation efficacy must be considered when choosing systems for low load houses, and further research is needed to evaluate different strategies that may be appropriate.

While very limited in scope, the data collected from these houses indicates that with reasonable improvements to the thermal enclosure of the house, dramatically different space conditioning solutions can be considered and provide equivalent or superior comfort to the occupant compared to a traditional forced air system.

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