# Testing And Analysis Of The Comparative Performance Of Cellulose Vs. Fiberglass Insulation

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## INTRODUCTION

This report summarizes the findings of comparative field tests and analysis sponsored by the Govenor's Office of Energy Conservation in Colorado on production housing models using both fiberglass and cellulose insulation materials. The participating company was McStain Enterprises, a mid-size (250 homes/year) production builder based in Boulder Colorado. Field test coordination and energy analysis were conducted by SOCTECH (State of Colorado Technical Energy Consultants for Homebuilders).

## REASON FOR STUDY

Fiberglass insulation, in the form of faced or unfaced batts, is by far the most common material used for filling stud wall cavities and cathedral ceilings in residential construction. However, SOCTECH infrared camera scans of numerous homes by large and small production builders have indicated air leakage pathways through and around the fiberglass material in many standard installations. Meanwhile, cellulose insulation manufacturers, installers, and several building scientists have claimed that the natural structure of overlapping fibers make the cellulose material inherently more resistant to air movement and therefore more effective at reducing air infiltration when installed as insulation within building cavities. Since air infiltration is considered to be the largest single source of heat loss in a typical new home, any significant reductions would lead to commensurate heating bill savings by the homeowners.

Although cellulose insulation, made from recycled paper and/or cardboard, and treated with a fire retardant, has been available for many years, its use has been largely restricted to attic installations where it can be blown in as an overall blanket coverage. Over the past several years, techniques for installing cellulose in wall cavities have been improved. Some involve spray applications using water or latex glue binders which allow the material to adhere to vertical frame wall cavities. A newer system, known as "dry pack" utilizes a reinforced plastic membrane which is stapled to the face of wall studs and holds the dry cellulose insulation in place.

This study was initiated, at McStain's request, by the SOCTECH consultants for two reasons. It provided the opportunity to explore and document some qualitative differences between cellulose and fiberglass materials and confirm or dispel claims of reduced infiltration. It also served McStains' interests by investigating ways to improve the quality and energy efficiency of their homes, as well as increasing the recycled content of building materials.

## TESTING PROCEDURES

The procedures were set up to provide a direct comparison of air leakage rates based on "side-by-side" fiberglass vs. cellulose installations. Six representative home models were chosen for testing, all located in the Meadow View development in Longmont Colorado. The homes varied in size from 1555 to 2350 square feet of finished floor area, and all had unfinished basements.

Standard features included 2 x 6 frame walls with R19 unfaced fiberglass batt insulation, R38 blown fiberglass attics (R30 batts in vaulted areas), R11 vinyl faced fiberglass blankets on basement walls, an 80% efficient gas forced air furnace, vinyl windows, and a foam seal package around windows, doors, electrical and plumbing penetrations,.

In order to provide consistency for the purposes of this study, all the homes received foam sealing packages performed by the same company and installer. The only variation in air sealing was the application of foam to the connection of frame partitions to the attic. This was intended to be done for all homes, but scheduling problems prevented 5 homes, both cellulose and fiberglass, from receiving the "attic seal." See Test Results section and Appendix A for more information.

Two or three homes of each model type were selected. At least one home of each model was insulated with conventional fiberglass batts; the other(s) was (were) insulated with one of two cellulose insulating systems. Two homes received a "spray applied" cellulose, while five received a "dry pack" cellulose. These twelve houses were then tested using a "blower door" whole house pressurization tool to measure and quantify air leakage rates. Standard openings, such as combustion air intake ducts and bath fans, were left open for all tests to most accurately simulate actual operating conditions. In addition, an infrared (heat sensing) camera was used during some tests to identify air leakage pathways and other qualitative differences between the two types of insulation.

The results of these tests were then input into a computer energy analysis program known as Colorado HERS (Home Energy Rating System) to estimate the approximate annual energy and fuel bill savings resulting from reduced infiltration.

## TEST RESULTS

There are several comparative numbers that were either produced by the blower door or that were calculated from blower door outputs. They can be used separately for specific analysis between individual buildings or averaged together to indicate overall performance differences. These numbers are described below along with the overall averages for the fiberglass and cellulose house tests.

One output from the blower door is known as the ELA or Equivalent Leakage Area, which is a measurement that represents the total area of holes and cracks in a building shell as one number measured in square inches. The ELA averaged 183 sq. in. in the cellulose homes, while the fiberglass homes ELA averaged 226 sq. in. (a 25% increase). Since these tests were conducted using side-by-side comparisons of identical models, the direct comparison of ELA's should be quite accurate for indicating relative performance.

However, when comparing these findings to any other homes, or between model types, the ELA must be adjusted to reflect the variable shape and surface area of different models. For this purpose a Leakage Ratio is used, which is calculated by dividing the ELA by 100 square feet of exterior building shell surface area. The resulting LR number can be used, much like an automobile miles-per-gallon rating, to compare houses of different size and configuration to each other. The average LR for the cellulose homes was 2.87, while the fiberglass homes averaged 3.75 square inches of leakage area per 100 square feet of building shell.

The final number that is used most often for calculating comparative heating costs and is often referenced by code officials and heating subcontractors is known as the Natural Air Changes Per Hour or ACH. This number is not a direct output from a blower door test, but a mathematical derivation that attempts to convert a one-time leakage test into an annual average infiltration rate based on numerous factors including:

The monetary impact of fuel savings were calculated using the Colorado Home Energy Rating System (HERS) computer software. A whole house energy analysis was performed on each model for which side-by-side tests had been conducted (Goldenrod model excluded). This included detailed information on building component surface areas and insulation values. Only two variables were changed for the comparative analysis of insulation systems. One was the natural air change rates that had been obtained from blower door testing data in the field. The other was a slightly higher rated R Value for cellulose wall insulation (R21 for 5-1/2" cavity vs. R19). The resulting difference in the annual heating bills between cellulose and fiberglass averaged $65.20 in favor of the cellulose insulation. The results are summarized below. See Appendix B for HERS analysis summaries.

| PREDICTED ANNUAL SPACE HEATING COSTS | | | |
|---|---|---|---|
| MODEL TYPE | FIBERGLASS | CELLULOSE | SAVINGS |
| SUNFLOWER | $584.73 | $541.19 | $43.54 |
| SAGEWOOD | $476.22 | $415.39 | $60.82 |
| BLUEBELL | $533.58 | $467.23 | $66.35 |
| COLUMBINE | $449.14 | $361.57 | $87.57 |
| CORNFLOWER | $572.29 | $504.55 | $67.73 |
| | | AVERAGE TOTAL | $65.20 |

It should also be emphasized that the fuel savings predictions above could be significantly affected by other factors such as: number of occupants and lifestyle variations; solar orientation of the building; thermostat setback points; etc.

## FIELD OBSERVATIONS INSULATION COMPARISONS

The test results support the conclusion that cellulose insulation can effectively reduce air infiltration. Field observations confirm this conclusion based on two significant differences between cellulose and fiberglass.

First, the nature of the materials are different. Fiberglass wall insulation consists of long fibers of glass that are spun together into a mat of material. The fibers generally run in one direction and the overall density of the material is fairly low (R11@ 0.5, R13@ 0.7, R15@ 1.2 pounds per cubic foot). Cellulose, on the other hand, consists of short fibers that lay in all directions and has an overall density two to three times that of fiberglass (2.2 to over 3 pounds per cubic foot depending on installation). The natural characteristics of interwoven short fibers and higher density make cellulose inherently better suited to reducing air movement.

Second, the nature of application differs between fiberglass and cellulose. Fiberglass batts, whether faced or unfaced, are manufactured in dimensions based on standard stud spacing. In a conventional tract home there are numerous wall cavities that do not conform to the standard batt widths, and therefore require field cutting. These locations in particular are susceptible to a poor fit, which compromises the materials' performance. In addition, the numerous obstacles within stud cavities, such as electrical wiring, plumbing pipes or heating ducts, can interfere with proper placement of fiberglass batts. Cellulose, with its small fibers and blown in application method is much more likely to completely fill all cavity sizes and around encroachments.

Field observations can easily identify air movements in wall cavities by using the combination of the blower door and an infrared "heat sensing" camera. On a cold day, when the differential between the inside and outside temperatures is fairly high, the blower door can be used to depressurize the house. This creates a negative pressure that pulls cold air through holes in the building shell into the interior of the home. The infrared camera can detect these leakage pathways as dark (cold) spots and streaks against the light (warm) interior surfaces.

Generally, the most common air leakage pathways observed in fiberglass insulated wall systems were through electrical wiring holes and outlets, and around poorly fit batts, either in non-standard cavities or in standard cavities where the batts had gaps at the top and/or bottom. It should be noted that the walls with thicker batts (2 x 6 with R19) used in this subdivision generally showed fewer flaws than did standard walls (2 x 4 even with R 15) that had been previously observed in other homes by the same builder. Leaks into the attic area were most evident at connections between interior partitions and the attic, as well as at the exterior wall to truss or rafter connection where material blown from a central attic location had not provided complete coverage. Additional ceiling leaks were observed around recessed can lights, in "upducts" installed as part of an evaporative cooling system option, at poorly installed batts in vaulted ceilings and at "pony wall" transitions between flat and vaulted ceilings. Floor systems often leaked at rim joists and cantilever projections.

Most of the above mentioned air leakage pathways were reduced by the cellulose insulation. Wall cavities had minimal leakage. Spray applied cellulose minimized leaks at floor rim joists. Leaks to the attic from interior partitions were also minimal, although this may have been the affect of the foam "attic seal." Full attic coverage, can light coverage, pony wall application and rim joist insulation all varied with individual installation quality.

There were several significant differences between the two cellulose application techniques as well. Because of the "learning curve" involved in the new dry pack system, difficulties resulted from overfilling or underfilling cavity spaces. Overfilling can cause pillowing of the plastic membrane and make drywall installation difficult. Underfilling can allow settling at the top of the wall cavity. An additional limitation of the dry pack system was the inability to insulate rim joists or cantilevers, which were therefore filled with fiberglass batts. This "learning curve seemed to be reflected in the test results, as the first dry pack house (1005 Chestnut) had the highest ACH of all the cellulose houses.

## NON-INSULATION RELATED AIR LEAKAGE

Although not directly related to the comparison of fiberglass and cellulose insulation systems, there were several other notable areas of air leakage that were identified and that affected the overall results. They also serve as examples of commonly overlooked infiltration problems in production building. See photos. These include:

- Whole house fan apertures or evaporative cooling ducts that were not sealed seasonally. These large connections to the attic or outside can have an enormous impact on infiltration. One house tested had its overall air leakage reduced by 1/3 simply by sealing off the evaporative cooler (a 5-minute task).
- Fireplace models that claim to be "sealed combustion." Of the two standard models used by the builder, the "direct vent" model was relatively airtight, while the sealed combustion unit which required a separate 4inch outside air duct leaked badly through the firebox.
- Oversized combustion air to furnaces. In addition to the standard two 6 or 8 inch combustion air ducts to the basement furnace location, all homes had a 4 inch outside air duct connected directly to the return air plenum. This introduces a substantial volume of cold outside air directly into the home and will contribute to over-pressurizing the building, thereby increasing the loss of heated air to the exterior. An additional health concern was observed where these air intakes were mounted directly above the foundation radon vent.
- High efficiency furnaces, supplied as an option, maintained the same combustion air ducting as a conventional furnace even though it's needs were met by the small PVC intake and exhaust pipes.
- Basement sump pits tied directly to the perimeter foundation drain system and not properly sealed with a tight fitting lid. These are also a potential radon source.

annual temperature averages; wind speed and shielding from adjacent buildings or landscape; building height (two story buildings create a stronger "stack effect" than do one story buildings); etc. It should be noted that Natural ACH is a scientific guesstimate and not the most accurate number for comparison. Different blower door companies may use slightly different assumptions or calculations to arrive at "natural" ACH. These tests used calculations from the Minneapolis Blower Door Company. Although not as accurate for direct comparison as the LR, calculated natural ACH is a required input for fuel saving predictions, including the Colorado HERS computer program, and was used for that purpose in this analysis.

The cellulose houses calculated natural air change per hour (ACH) averaged .31, significantly lower then the fiberglass houses ACH which averaged .42 (35% higher). See Appendix A for a complete list of test results sorted in ascending order of ACH.

One additional important note when analyzing blower door test results is that not all the numbers are consistent. For instance, there is no direct correlation between the LR and the natural ACH since variations in building volume and surface area can skew the results. Individual comparisons can be seen in Appendix A.

By combining the various test results and calculations as delineated above for the houses tested, it is apparent that the cellulose houses averaged significantly lower levels of air infiltration than did the fiberglass houses. These tests indicate that the installation of cellulose insulation in walls and ceilings does create a tighter building envelope and reduces air infiltration relative to standard fiberglass batt insulation. However, it must be emphasized that no insulation product provides a complete "air barrier" or eliminates the need for sealing penetrations with foam and taking other steps to reduce air leakage in homes. See the Evaluation of Results and Field Observation sections for additional information.

## EVALUATION OF RESULTS

The number of homes tested in this study provides a reasonable statistical sample to indicate the superiority of cellulose over fiberglass for the purpose of achieving a tighter building envelope. The average performance of all homes tested showed that fiberglass had a 25% to 35% higher level of infiltration when compared to cellulose. When cellulose was used the average impact to utility bills was a projected 12% to 14% reduction in space heating costs. However, it should be noted that there were significant variations in the quality of installation and resulting performance between individual homes.

The individual variation in quality control is a large factor that can either accentuate the differences between insulation products or virtually eliminate them. One example shows up obviously in the differences between the two Columbine models. Despite being the smallest of all models tested, the differences between the two homes were extreme. The high quality spray cellulose application proved to be the best performer of all homes tested (LR = 2.43, ACH = .27) while the fiberglass unit, with poor attention to detail, proved to be one of the worst in terms of absolute performance (LR = 3.70, ACH = .49). On the other hand, it should be noted that one fiberglass installation (Bluebell at 954 Alder) had a lower Leakage Ratio (3.29) than three of the cellulose installations. See Appendix A.

This emphasizes the fact that individual quality control measures can have a dramatic impact on each homes' performance. See the Field Observations section for examples.

The impact of the "attic seal" was inconclusive and requires further study. It appears that the foam application where partition walls intersect the attic did reduce air leakage. Within the fiberglass homes, the two lowest LR results came from the homes with the attic seal. However, Infrared scans were not performed to assess, compare or verify the qualitative differences between sealed and non-sealed homes. The fact that all the cellulose homes received the attic seal may have enhanced their performance. But, given the nature of cellulose itself to reduce air movement, it is assumed that the attic seal would have less of an impact on performance than it would in the fiberglass attics.

## SUMMARY

Two significant conclusions should be emphasized from this study.

First, regardless of the insulation material used, the quality of installation and attention to detail is the most important factor in achieving successful performance. While the average performance of all homes tested favored cellulose, it should be noted that one fiberglass installation had a lower Leakage Ratio than three of the cellulose installations.

The overall energy efficiency of residential construction relies on a comprehensive approach to the many systems and components within a building. Although air infiltration usually makes up the largest single portion of building heat loss, air leaks come from many different locations. No single product or strategy can solve the problem.

Second, by conducting a controlled side-by-side test of fiberglass and cellulose insulation systems, this study indicates that the use of a properly installed cellulose insulation system can significantly contribute to the reduction of air leakage in wall cavities and attics, thereby reducing building heat loss and utility bills. It appears that the short fibers of the cellulose material, and the blown-in application, allow it to fill voids more effectively, while the higher density minimizes air movement. The average performance of all homes tested showed cellulose with a 25% to 35% reduction in infiltration when compared to fiberglass. The average impact to utility bills was a projected 12% to 14% reduction in space heating costs.

## ACKNOWLEDGMENT

The Govenor's Office of Energy Conservation and its consultants would like to thank McStain enterprises for their participation in this study. McStain's ongoing interest in improving energy efficiency and quality, while reducing the environmental impact of their homes, continues to make them a socially responsible leader in the building field.

Although it is not the focus of this report, the SOCTECH consultants would like to acknowledge the many things that were done well to increase the energy efficiency within the construction of all of the McStain models that were tested. From the 2 x 6 wall framing and good quality windows which comprised a well insulated building envelope, to the attention to air sealing details and well designed attic access panels, McStain was obviously working to improve both large systems and small details. We commend their efforts and hope that this report will help contribute to additional refinements in their already exemplary homes.

## DISCLAIMER

The comparison of cellulose and fiberglass materials as insulation products includes many issues that are not addressed in this report. Concerns over health effects on installers and homeowners, fire retardancy comparisons and other safety issues are not addressed. Neither the author nor the Colorado Office of Energy Conservation endorse the use of either product over the other. These test results and analysis should be considered within the larger context of issues. Additional information is available in the form of separate Appendices as a resource for further investigations but is not intended as a comprehensive or definitive compilation.