Building Envelope Performance Testing

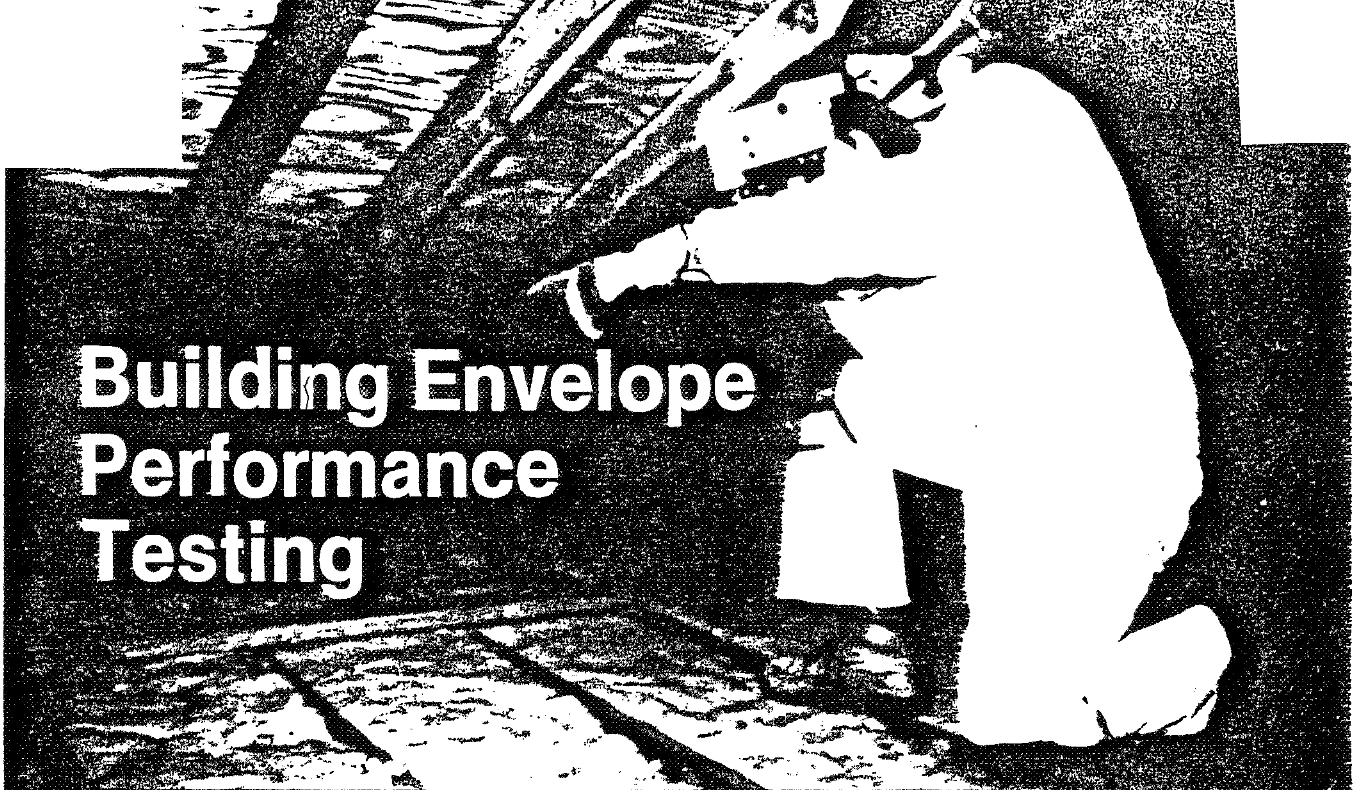

Fig. 1: The "house doctor" using portable infrared scanning techniques and internal building pressure to uncover elusive leakage paths beneath a sea of insulation (Photo credit to New Jersey Natural Gas—one of five gas utility house doctor teams).

Improved methods of testing for both air leakage sites and the thermal integrity of the building envelope are described. To meet current and proposed standards of performance in new and existing buildings requires that careful attention is paid to proper installation, as well as proper choice of envelope materials. How these materials work as a wall system is often quite complex. Appropriate inspection techniques become an important ingredient if the necessary performance goals are to be achieved. An instrumented energy audit is described which adds certain critical information to help evaluate building envelope performance.

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IN this era of energy shortages and environmental concerns, the role of the building envelope has taken on ever-increasing importance. Not only must the building envelope achieve high standards of thermal insulation, but the envelope must also deal effectively with critical aspects of the ventilation requirements. For example, today, more than ever before, one must examine the reliance upon air infiltration for the fresh air supply in residential buildings. Tight construction standards used in some houses have meant that forced air systems, some incorporating heat recovery, are now being used in the most advanced home ventilation designs.[1] In this respect, residential design appears to be moving toward increased sophistication, that which we have come to expect in modern, larger buildings.

Unfortunately, we cannot afford to replace our older buildings with appropriate new designs. Each year we add less than 2% to our existing building stock. The best choice for the other 98% often lies in a properly chosen retrofit package so that the building may remain economically viable as energy prices rise. To achieve this goal, the important question of how to provide the proper upgrading of the building envelope should be given adequate attention.

The use of an instrumented audit, in contrast with a walk-through audit, has been investigated as a means of supplying the data necessary to make the proper choice of building envelope retrofit.[2] This article describes one version of an instrumented audit and what often missing information it can supply so that a comprehensive analysis can be made prior to retrofit choice.

REQUIRED INFORMATION

Two items that are often poorly documented in the evaluation of building envelope performance are the envelope air infiltration sites, including leakage rates, and the thermal insulation values of walls, ceilings, and floors. The infiltration sites must be pinpointed so that effective measures may be taken to seal the envelope. The infiltration rate is necessary if accurate calculations are to be made with regard to this important component of building energy loss. The thermal characteristics of the envelope are often quite complex. Dynamic effects at times may prove to be dominant.[3] However, a careful evaluation performed at the right time of the day can yield useful data on the thermal performance of the envelope for accurate analysis.

MEASUREMENT STRATEGY

In the pursuit of air infiltration leakage sites, cataloging can prove time consuming. To speed up the process, a pressure differential may be applied across the building envelope. Under this condition, air leakage is enhanced; furthermore, all the leakage is in one direction. For example, if we intend to investigate all the possible locations where outside air could penetrate the building envelope, we are aided by depressurizing the building interior and then seeking out the leakage sites. The air leakage can be detected by a number of methods including smoke tracers. The method we prefer for the audit procedure, where time is extremely important, is to use infrared scanning.[2,4-7] In this way, broad surface areas may be quickly assessed. This eliminates the lack of precision associated with visual leak site assessment. A crack along a

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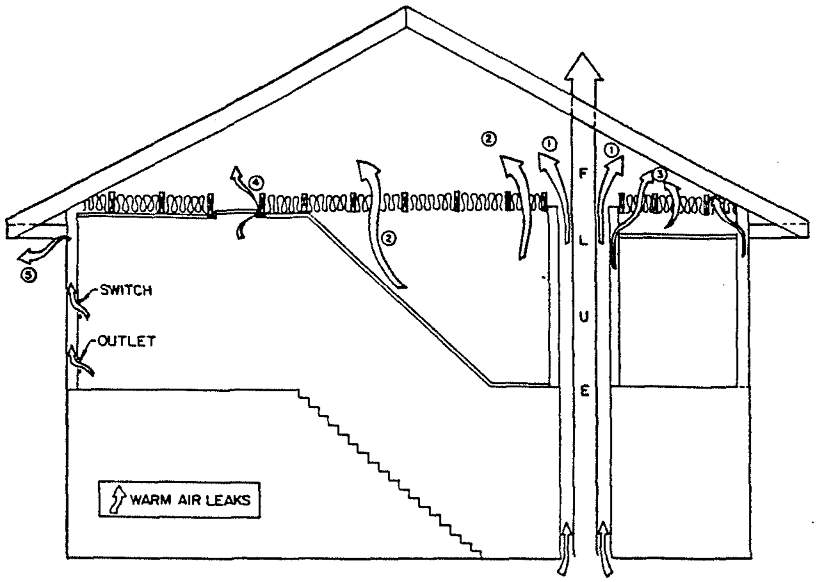

Fig. 2. Typical leak sites, "bypasses", in the upper building envelope. The bypasses include, (1) opening around the flue, (2) leakage above the stairwell ceiling, (3) dropped ceilings, (4) attic access points, (5) switches, outlets and eaves.

Table 1 Air Infiltration Rates from Duct and Bottle Sampling

Time Interval	Duct Samples	Bottle Samples Floor 7	Floor 3	Floor A	20-min. Avg.
18:20–18:40	1.25	1.36	1.57	1.07	1.33
18:40–19:00	1.09	1.30	1.18	.91	1.13
19:00–19:20	1.03	1.14	1.75	1.04	1.31
19:20–19:40	1.43	1.51	.80	1.65	1.32
	1.20 Avg. A.I. Duct	1.33	1.33 Avg. A.I. per Floor	1.17	1.27 Avg. A.I. All Floors

molding doesn't necessarily mean a connection to the outside. With lower outside temperatures, any leakage results in cold air impinging on interior surfaces at definite locations along the molding. This is monitored by the infrared equipment and confirms that leakage indeed is present and exactly where.[2,4-7] How much leakage is taking place will be discussed later.

Once there has been a commitment to infrared scanning, that same instrumentation is available for analyzing the thermal performance irregularities in the envelope. Surveying the internal surfaces of the building exterior is usually three times as sensitive a measurement as an outside survey.[4] This is because the surface temperature of the wall, as it relates to the thermal characteristics of the wall, is amplified by the thermal resistance of the air layer. Since the thermal resistance of the inside air layer is usually three or more times that of the outside air layer (where wind effects are present) the surface temperature variations inside are that much more distinct. Some of the latest infrared equipment allows these surface temperatures to be quantified; however, the use of a rapid acting, accurate surface temperature probe has also proven very useful[2] (accuracies to ± 0.1C and <10 second response are desirable).

EQUIPMENT AND TECHNIQUE

Pressurization or depressurization of the building may be accomplished in a number of ways. If the building has a powerful enough ventilation system, it may be used by appropriately altering supply or exhaust. Where this is not the case, a powerful fan needs to be separately deployed. In the residential sector, this air flow can be most easily achieved using a blower door, a calibrated fan of variable speed mounted so that it is adjustable to fit a wide variety of doorways.[6] Use of this technique can provide an overall rating of envelope leakiness by noting the air flow necessary to achieve a given pressure difference or through a series of pressure-flow measurements establishing a pressure profile (to pressures of 75 Pa, 0.3 inch of water).[8,9,10]

The infrared equipment also changes character depending on the application. The large building calls for IR units that can record the information: e.g., the data from the IR scanning may be preserved on video tape. This may consist of a unit that is wheeled from room-to-room on a cart, rapidly documenting the surface temperature patterns of the building interior surface. At the other extreme, in the residence, the paramount requirement is portability. Access to attic, crawl space, and basement areas becomes critical. Hence, small portable scanners become attractive in the home energy audit.[2]

Although leakage estimates using pressurization techniques may yield overall or local information, natural air exchange rates may also prove necessary in evaluating the energy appetite of the building.[8] The tracer gas technique can be applied as a spot check as part of the audit procedure. Table 1 illustrates these kinds of data obtained from a less than two hour test of a seven-story building. Samples of the decaying tracer gas concentration were obtained directly from the duct system and from bottle samples for individual floors.[2] This later technique uses pint-sized (500 cc) polyethylene bottles fitted with natural rubber septums in the caps (this allows hypodermic air sampling from the bottle). The technique involves seeding the building with the tracer gas, sulfur hexafluoride (SF_6), waiting for complete mixing (order of one half hour) and then sampling in the duct system or at individual locations. With the bottle method, empty bottles are squeezed ten times or so to completely fill each bottle with the ambient air. The bottles are then returned to the lab for analysis on gas chromatograph— election capture type equipment sensitive to SF_6 concentrations to less than one part per billion. Even the largest building can be quickly checked for air exchange rate and air infiltration levels using small quantities of this nontoxic gas. Automated systems are also available to record these data.[10,11,12]

RESIDENTIAL EXAMPLE

The DOE-sponsored research at Princeton University has been focused on housing, primarily single family and townhouses in the residential sector.

An example of an instrumented audit, popularized as the "house doctor approach," will be taken from that experience.[2,7] However, many of the building conditions encountered as well as the methodology that has evolved can be directly applied to the full range of building sizes.

The technique followed in Princeton's house doctor approach incorporates more than just the evaluation of the building envelope, *i.e.*, heating/cooling equipment performance, terrain factors, etc. are among other features of the energy audit.[2,13] The building envelope evaluation, however, certainly plays a key role.

Using a blower door to pressurize the house to 25 Pa (0.1 inch of water) warm air is forced into the attic and out through the walls and floors. Infrared scanning in the attic (as shown in Fig. 1) transforms the sea of insulation into a series of revelations.[4,6] Construction defects are all too evident as warm air moves freely through the porous insulation. Sources of the leakage include interior walls, access doors, fan louvers, plumbing, electrical, and lighting related openings.[4,14] Features such as dropped ceilings can account for major leakage losses and require corrective action. One solution is to place a polyethylene vapor barrier under the insulation and then replace the insulation. The house doctor approach encourages such immediate retrofits so that the repair can be evaluated by the change in leakage rate (lower flow to achieve the same pressure differential as recorded by the blower door).

After the attic, the basement is similarly scanned. Exterior infrared scanning for leaks is also enhanced by the pressurization. However, the best infrared external scanning takes place past midnight when solar effects have dissipated, hence the IR emphasis in the house doctor audit has normally been confined to internal scanning.

Depressurizing the house allows the interior surfaces to be checked for leakage sites. It isn't just the inside surfaces of the external envelope that require scanning. The internal walls can also provide leakage paths to the attic or basement.[4,6] Piping and ducting run through the walls and also open avenues to floors above or below. Such building features are made readily apparent as cold outside air is drawn into these cavities under depressurization (under normal house operation the openings would allow warm air to escape into the attic).

The inner surfaces of the external walls, ceilings, and floors reveal how well the insulation is doing its job. Depressurizing the interior tends to enhance any insulation irregularities. The thermal bridges are evident in the scanning procedure. Areas where moisture has penetrated the envelope are immediately evident as cold spots. Leakage sites provide different temperature patterns from the insulation variations, thus one can scan for both at the same time. Any leakage around windows is spotted as a cold flair-shaped area. The window itself may require local smoke tracer checkout because of the variety of emissivities in the window components. Molding, electrical switches, and outlets, fireplaces, etc., characteristically leak at various levels.[4,6,15] Again, the cure can be applied immediately via special gaskets, interior caulking, weatherstripping, etc.

CONCLUSIONS

The combination of pressurization/depressurization and infrared scanning has been demonstrated to provide a means for rapid energy auditing of the building envelope. Evaluation of the envelope in the normal size home is a process that takes less than an hour. In that period of time, important infiltration and building envelope performance factors are evaluated. With these data and information on air infiltration rates the *energy audit moves from a qualitative to a quantitative energy analysis.* The same statements can be made with regard to our largest buildings, where much needs to be learned as to how the building envelope is actually functioning and how floor-to-floor variations are involved. Complex interaction between the ventilating system and the building envelope can be assessed by such auditing procedures and these techniques, when properly used, can provide the data necessary for retrofitting decisions.

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