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Significance of Air Infiltration on Building Energy Conservation Design, Standards, and Codes

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ABSTRACT: Air infiltration in residences accounts for 30 to 75 percent of the heating load, and present design procedures in commercial buildings result in excessive amounts of controlled fresh air introduction to offset air exfiltration losses. Simulation studies on retrofit potential of residences reveal that, while portions of the building heating and cooling loads can be reduced substantially using cost-effective techniques, air infiltration remains a dominant factor in the loads.

With the advent of a priority status for energy conservation, many new standards have been developed. These standards have been of three primary natures: prescriptive, component performance, and performance. Because new residential designs are making buildings tighter, with less air infiltration, three new standards are necessary to follow the trend in design. These standards are: (1) the use of pressurization-evacuation test methods to set a construction quality performance standard, (2) the use of ducted outside air with heat recovery for fresh air introduction to super-tight residences, and (3) the use of ducted outside air to fossil-fuel burning units for combustion purposes.

KEY WORDS: air infiltration, building standards, building codes, performance standards, prescriptive standards, energy conservation, fresh air requirements, combustion, air leakage, construction quality, measurements

Recently, energy conservation has reached a high national priority, resulting in the rapid development of numerous new building standards and the adoption of new building codes for the sole purpose of saving energy. Historically, standards and codes have been related to health and safety, and the nearly equal priority given to energy-related standards has

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caused inconsistencies between accepted standards and conflict among building code officials who are tempted to adopt and codify these standards.

This paper discusses the significance of air infiltration on building energy conservation and the need for new standards related to air infiltration.

Discussion

The building energy-related standards that have been recently and continue to be developed are taking on three primary forms: (1) prescriptive standards, which are the specification of nominal building materials and designs (50.8 by 101.6 mm for example, (2 by 4 in.) wood studs on 406.4 mm (16 in.) centers); (2) component performance standards, which increase design flexibility, by specifying minimum performance levels of individual components of a building design (for example, the U-value of a wall must be 1.2 $W/M^2 \cdot K$ maximum for a 6000 deg day (18°C base) climate; the minimum energy efficient residence (EER) rating for a water chiller must be 4.0); and (3) performance standards, which generally specify a minimum performance for the building as a whole, allowing the greatest flexibility in the building design (for example, the office building must be designed to consume 55 000 $Btu/ft^2/year$ maximum of end-use energy).[2] These three generic types of standards allow progressively increased flexibility in design and respectively aggravate the problems in codifying and enforcing for compliance. Even energy-related prescriptive standards that have been codified have been difficult to enforce properly, due to their newness and inadequately trained local enforcement officials (for instance, portions of the California Residential Standards), who inspect the construction of buildings in the field. Component performance standards are difficult to develop, even those regarding only the design stage. The primary source of the difficulty is the dynamic interaction of various design components. (This is particularly illustrated in the design of window area and orientation because of the daylighting, natural ventilation, heat transfer, and life-safety implications). After design compliance, the field inspection for compliance in construction becomes more tedious and requires greater technical expertise of the local enforcement official (for example, how does one measure the R-value of a window assembly?). The scenario for building performance standards is even more complicated. Enforcement may require the tedious review of design methodologies, which are often unorthodox, frequently entailing nonstandard procedures that have not yet been widely accepted. In this area, in particular, it appears extremely difficult to enforce uniform compliance of actual energy use in buildings due to the variability of user activities that heavily impacts the energy performance

[2] An additional type standard to the one mentioned and the health and safety standard is the method of testing a standard, such as those tests used for insulation.

of a building. This phenomenon is perhaps best illustrated by the effects of air infiltration on building energy consumption.

Air infiltration (and exfiltration) is defined as the natural, uncontrolled leakage of air through cracks and unsealed joints in the building structure; around windows and doors; and through porous floors, walls, and ceilings. It is a function of a large number of time-varying parameters. Generally, poor resistance to air leakage by the building structure is determined by the design, construction workmanship, maintenance, and the occupants' use of the building.

The fresh air that is provided the structure through the process of air infiltration serves useful purposes as a general means of control of moisture levels, indoor air quality, and combustion air for fossil-fuel burning heating sources. However, its impact or significance on energy conservation is large, as documented in numerous recent case studies. The literature reveals a range of 30 to 75 percent of the total heating load in small residences [*1*].[3] Recent studies have shown the magnitude of makeup air heating losses through ceiling exfiltration may be greater than the heat transmission loss associated with a noninsulated attic [*2*]. There are little data available for large residential or commercial buildings, due to the great expense and technical difficulty in measuring air infiltration rates. However, commercial buildings with central air handlers are designed and maintained to operate at a positive pressure throughout the building to overcome the occupant discomfort associated with drafts caused by uncontrolled infiltration. Tamura and Shaw have recently shown that the use of positive pressure may effect three times the ventilation load compared to the natural air infiltration loading [*3*]. The energy required to satisfy the ventilation load ranges from 5 to 30 percent of the total energy consumption of many commercial buildings (the low value is typical of offices, the high value for hospitals).

Due to the magnitude of the effects of air infiltration, a large amount of recent attention has been directed toward understanding the phenomenon and reducing its impact on energy conservation. Two independent simulation analysis of energy retrofit potential in small residences have concluded that the significance of air infiltration on energy consumption increases after retrofit [*4,5*].[4] That is, the retrofit techniques available to reduce conduction and radiation heat transfer are more effective than those retrofit methods available to reduce convective and mass transport heat transfer caused by air infiltration. To reduce the effects of air infiltration, Federal and private sector research is being conducted on new materials and applications in the area of caulking, weatherstripping, and insulation.

[3] The italic numbers in brackets refer to the list of references appended to this paper.
[4] This however, may be a function of the modeling procedure.

These new materials may require new health and safety standards, as well as energy-related prescriptive and performance standards.

In new residential building design and construction, a high priority has been given to the reduction of the magnitude of air infiltration. A variety of distinctive approaches have been taken. These include the following examples:

1. A design philosophy has been established to avoid breaking the living space envelope in order to reduce the air flow pathways in the residence. Hallway lights normally located in the ceiling have been mounted on sidewalls. Electrical outlets have been located in floor members as opposed to the wall. A sealed combustion fireplace is installed with separate outside air ducting. Nonoperable windows have been installed and extreme care has been given to the application of the vapor barrier. Vapor barrier material selection has switched recently to a continuous 4-mil polyethylene. Also, some contractors are installing a mylar film to reduce radiative effects, as well as air and moisture transport; for example, National Association of Home Builders' (NAHB) Energy Efficient Residence [*6*].

2. Some California dwellings have also attempted to reduce air leakage through the building envelope by careful application of vapor barriers to both inner and outer surfaces of the wall cavity (this is not recommended for most climates). In addition, sealed combustion heating units have been installed to avoid the use of conditioned air for combustion air. Kitchen and bathroom air, normally exhausted, are filtered through a charcoal bed, and then recirculated to the room space. A third, unusual design feature is the installation of an air economizer cycle and controls, which allows the controlled use of outside air for cooling purposes during appropriate climate conditions (for example, minimum energy dwelling; Mission Viejo, Calif. [*7*]).

3. In Japan, Canada, Sweden, and Norway, air-to-air heat exchangers have been designed for use in extremely tight residences such as those previously described. Air is exhausted from the building in a controlled manner after heat is transferred to an incoming fresh air stream. Air change rates are on the order of 0.5 air changes per hour, approximately twice that of the tight houses described previously. The exhaust air stream may be made up of the combination of kitchen and bathroom exhaust air as well as normally recirculated air [*8–10*]. Some similar ideas on ventilation systems for low energy dwellings are described next. The cost-effectiveness of these ideas is undetermined.

(*a*) Natural ventilation controller exhaust ducts from kitchen, bath, water closets, and laundry provide a conduit for the natural exhausting of house air. A valve, sensing outside air temperature and wind velocity, adjusts the air flow openings in these exhaust ducts to maintain 0.5 air changes per hour (ACH). Whenever a light comes on in bath, water closet, or laundry, fans are turned on to switch to mechanical ventilation. These fans are an integral part of a heat exchanger (HX) located in the attic space. Air is exhausted through the forementioned exhaust ducts through the HX. The fan supply rating is at 0.8 ACH, but with heat recovery represents an effective 0.5 ACH. (Note that under natural venting conditions, no heat recovery occurs.)

(*b*) Under-roof flow path for supply air kitchen and bath fans exhaust air from the house. Supply air is brought in via an air channel located under the roof. The air is preheated to 12 to 14°C by this design.

(*c*) Twostage heat recovery. Air/air, then an air/earth heat wheel is used to recover 90 percent (effective) of the energy being lost through exhaust fans. The incoming fresh air is passed through the heat wheel, and discharged into a hollow basement concrete wall. By passing through the cavity of the basement wall, heat is exchanged with the earth prior to being supplied to the house.

(*d*) Heat exchange with solar hot water storage tank. Fresh air is passed around the base of a storage tank. The base of the tank is finned to improve heat exchange. A secondary benefit is that the water being discharged from the base of the tank to the collectors will be of lower temperature, thus raising solar system efficiency.

(*e*) Exhaust air to crawl space supply and exhaust fans are employed as in most ventilation systems. However they are remote from each other, providing a higher confidence in removal of living space air without "short-circuiting." Air is exhausted into the crawl space of the dwelling, thus keeping the crawl space at a higher temperature than normal construction. This means of ventilation then allows less insulation to be required in the crawl space, provides a positive means of preventing soil offgassing into the living space, and may promote warmer floor temperature providing greater comfort conditions for the occupants. The economics of this idea have not been compared against normal heat recovery ventilation schemes.

4. A patented system employed in Sweden, and being investigated in the United States, employs the use of a controlled fresh air stream fed by a fan into the wall cavity between the insulation and the sheathing, forced through the fibrous insulation to the interior of the residence. The inventors claim that the heat gain from solar radiation is utilized similar to solar collectors, and that conductive heat loss through the structure can be minimized. The basis of the design required a very air-tight outer wall and ceiling surface, as well as certain climatological conditions to be successful [*11*].

As occurs in many new design and construction practices directed as the resolution of a single problem (energy consumption), problems other than those which are energy-related have surfaced. In the NAHB home with very low air infiltration rates (Design Philosophy 1), excessive winter humidity levels were observed, disrupting occupant comfort; eventually a dehumidifier relieved the problem. Furthermore, suspicions about indoor air quality and flash fire considerations have been raised [*12*]. Mechanical and construction problems have also been observed: in the residential application of outside air ducting, cases of severe air leakage from the ducts has occurred, resulting in increased air infiltration rates above standard designs.

It is important to note the trend in the four residential designs, since the development of any new air infiltration-leakage energy-related standards depends on these developments. In the first residential design, extreme care was taken in the construction quality of the architectural features of the residence. In the second case, mechanical system modifications reduce the dependency on infiltration for the fresh air to the combustion units. In the third case, further mechanical system modifications were made to provide greater quantities of fresh air and to increase the utilization of fresh air. In the fourth case, the attempt has been made for architectural and mechanical system integration to satisfy health, safety, and energy requirements.

In following this scenario, new air infiltration standards need to be developed in three areas of interest: (1) architectural and construction quality, (2) forced ventilation system integrity, and (3) further health and safety integrity. Specific standards for new residences which address these areas of interest are discussed below:

1. Construction Quality Standard for Air Leakage—A method is currently available for determining air leakage rates at an arbitrary pressure difference. The proposed test methodology is the pressurization-evacuation techniques, currently being standardized by ASTM Subcommittee E06.41 on Infiltration Performances. While it should be noted that the test procedure is repeatable (over time) for a wide variety of building types and climates, the results obtained from the tests may be time dependent in some buildings. Air leakage paths change due to movement of insulation (settling) and windows (dislodging), and moisture levels (swelling or contracting crack size). The test methodology can be extended to establish a minimum performance standard for the whole building. The ideal justification for using this method to get a performance standard would be the existence of a strong correlation between the results of pressurization-evacuation tests with natural air infiltration rates. However, this correlation has not been readily evident [*13*]. However, this ideal correlation may not be necessary for the development of the performance standard. Once the standard is developed, it may be one of the few performance standards

that has the potential for reasonable codification and use by local enforcement officials. For example, the Swedish Building Code already has incorporated this type of approach, selecting 50 Pa as the arbitrary pressure difference, and the design unit of cubic meter per hour of air leakage [*14*]. For code use in the United States, the methodology requires (*a*) agreement by local code enforcement officials to utilize the necessary equipment; (*b*) understanding of the test equipment and procedure, probably requiring further training of the officials; and (*c*) an inspection crew as opposed to a single inspector.

2. Sealed Combustion Standards—Approximately 25 liters per second of air are needed for combustion of most gas or oil residential heating systems. In most houses, this air is provided from conditioned space. In very air-tight residences, there is concern that carbon monoxide generation or flameout may occur due to a lack of sufficient combustion air. As noted previously, the resolution of this problem is technically available (and being employed with greater frequency) through the use of fresh air ducting directly to the combustion units. To ensure proper ducting and control of the amount of incoming air as well as health and safety, a prescriptive type standard may be needed, describing acceptable duct leakage, damper configuration, controls, and the relationship to other heating system modifications (flue dampers, derating, etc.). Due to the prescriptive nature of the standard, codification should be relatively simple. However, it may require the development of field test procedures and training of inspectors in order to assure reasonable enforcement.

3. Mechanical Fresh Air Ventilation Standard—Due to the problems associated with maintaining occupant health and comfort and structural integrity, it may be necessary in very air-tight residences, to provide mechanical fresh air ventilation. It is estimated that very air-tight residences can be designed economically for an average air change rate of 0.2 air changes per hour. The mechanical fresh air standard will probably specify a minimum of about 0.5 air changes per hour (on the average), and specify the use of heat recovery from exhaust air. Technical and economical problems associated with controls, acceptable damper leakage, heat recovery design, and the relationship to the sealed combustion standard must be addressed. Codification of the standard does not appear to be difficult; however, enforcement by local enforcement officials will require training, and possibly new test procedures.

Tables 1, 2, and 3 list various parameters that will need to be addressed for each standard.

General Conclusions

Air infiltration has a significant impact on the energy required by

TABLE 1—*Parameters significantly affecting construction quality standard for air leakage.* [a]

Development of test methodology
Correlation of pressurization-evacuation results
Fan calibration
Appropriate units for reporting results
Normalization of results (from house to house)
Time dependence of testing
Correlation of pressurization-evacuation with natural air infiltration rates[a]
External shielding effects relationship
Applicability for nonsingle-family detached residences[a]
Relationship to passive solar (natural ventilation designs)
Weather dependency
Institutional barriers related to codification and enforcement[a]

[a] Does not require specification in a standard, but is a prerequisite to the development of a standard.

TABLE 2—*Parameters significantly affecting sealed combustion standard.*

Duct leakage
Duct insulation
Damper leakage
Controls
Pressure relationship to other heating system modifications
Flue dampers
Heat recovery
Derating
Corrosion of heat exchanger[a]
Test procedure for field evaluation[a]
Off-time effects of air leakage through system[a]
Location of vent
Oil atomization with cold combustion air

[a] Does not require specification in a standard, but is a prerequisite for the development of a standard.

TABLE 3—*Mechanical fresh air ventilation standard.*

Duct leakage
Duct insulation
Damper leakage
Control selection (economizer, enthalpy, CO_2, or other)
Relationship to indoor air quality[a]
Relationship to comfort (relative humidity, odors)[a]
Freeze and moisture control
Off-time effects[a]
Heat recovery from exhaust air sources
Location of vents
Location of exhaust air ducts
Air stream mixing (stratification control)[a]
Test procedure in the field
Institutional barriers related to codification and enforcement[a]

[a] Does not require specification in the standard, but is a prerequisite to the development of a standard.

buildings. Many new and innovative designs are being employed to reduce air infiltration rates in residential construction. Concurrent with the development of these new designs, the development of energy-related standards for air infiltration are required, and in most cases, are technically feasible today.

References

[*1*] Mattingly, G. E. and Peters, E. F., "Wind and Trees—Air Infiltrations in Housing," Report No. 20, Princeton University Center for Environmental Studies, Princeton, N.J., 1975.

[*2*] Beyea, J. and Dutt, G., Testimony before the Federal Trade Commission on Insulation Labelling, Hearings held 1 March 1978.

[*3*] Tamura, G. and Shaw, C., *Transactions*, American Society for Heating, Refrigerating, and Air-Conditioning Engineers, Vol. 82, 1976, pp. 122–134.

[*4*] Hittman Associates, Inc., "Development of Residential Buildings Energy Conservation Research, Development, and Demonstration Strategies," HIT-681, submitted to Department of Energy Aug. 1977.

[*5*] Rosenfeld, Art, "The Two Zone Computer Program," (available through Lawrence Berkeley Laboratory, Berkeley, Calif. 94720).

[*6*] The National Association of Home Builders: Energy Efficient Residence, NAHB Research Foundation, 627 Southlawn Lane, Rockville, Md. 20850.

[*7*] "Minimum Energy Dwellings Workbook," Department of Energy, Washington, D.C., 1978.

[*8*] Besant, R. W., Brooks, E. E., Schoenau, G. J., and Dumont, R. S., "Design of Low Cost Ventilation Air Heat Exchangers," University of Saskatchewan, Saskatchewan, Canada.

[*9*] Besant, R. W., Dumont, R. S., and Van Ee, D., "An Air to Air Heat Exchange for Residences," University of Saskatchewan, Saskatchewan, Canada.

[*10*] Pederson, Otto, "The Norlett Heat Recuperation Unit," Norlett Corp., 1801 Askin, Norway.

[*11*] Vanderwerf, Jan, "The TT System," Wausau Homes, P.O. Box 1204, Wausau, Wis. 54401.

[*12*] Hollowell, Craig, "Effect of Energy Conservation on Indoor Air Quality," American Society for Heating, Refrigerating, and Air-Conditioning Engineers' Symposium, Jan. 1979.

[*13*] Grimsrud, D. and Harrje, D., "Preliminary Test Specifications: Infiltration—Pressurization Correlations," International Energy Agency Buildings and Community Systems Committee, Anex IV, 1978.

[*14*] Swedish Building Code, 1977.