THE PREDICTION OF AIR INFILTRATION

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Introduction

Infiltration, the naturally-induced air flow through the building envelope, typically accounts for one-third of the energy load of residential buildings while at the same time acting as the primary mechanism for removing internally-generated pollutants and thus assuring adequate indoor air quality. To minimize energy use one may wish to minimize infiltration, but to insure adequate indoor air quality one may wish to increase infiltration. This apparent contradiction implies that the prediction of infiltration for a new or existing structure can be one of the more critical calculations an engineer or architect can make.

Fan Pressurization Test Methods

Typically, the fan pressurization method is used to measure the air flow rate at one pressure difference, commonly at 50 Pascal (Pa). The fan pressurization method described in this report is used for determining the effective leakage area of a building. The effective leakage area is a quantity conceptually equivalent to the sum of the areas of all the cracks and holes in the building envelope through which air is able to pass. This quantity is the scale parameter for estimating natural infiltration in the simplified model described below.

Natural infiltration is typically driven by pressure differences across the building envelope in the range of 0 to 10 Pa. Fan pressurization uses a blower door, a door-mounted, variable speed fan capable of moving large volumes (up to 7000 m^3/hr) of air into or out of a structure and a differential pressure gauge such as an incline manometer. By supplying a constant air flow with the fan, a pressure difference across the building envelope can be maintained. When the differential pressure is held constant, all air flowing through the fan must also be flowing through the building envelope. The influences of wind and temperature difference on the flow and pressure measurements are diminished by making the measurements at pressure differences greater than 10 Pa.

To make the fan pressurization measurement, the blower door is sealed into an exterior doorway, and the pressure gauge is set up with one pressure tap placed outside in a location protected from the wind. The inside pressure tap should be placed out of the direct flow path of the fan. All exterior doors and windows should be closed, and if a fireplace and/or a wood-burning stove are present, make sure that their dampers are closed to prevent soot from entering the building. All interior doors, except closet doors, should be open. The blower door is then used to blow air into (pressurize) and to suck air out of (depressurize) the building at a series of fixed pressure differentials (e.g., from 10 to 70 Pa at 10 Pa intervals). The air flow (or some quantity directly related to it) and the pressure difference are measured at each point. The resulting pressure versus air flow curves for both pressurization and depressurization are used to find the effective leakage area of the building (1).

Data Analysis

Air flow through the building envelope is a combination of viscous flow and turbulent flow. The former is proportional to ΔP while the latter is proportional to the sqare root of ΔP. Air flow through the envelope can be characterized by the equation:

$$Q = K\,(\Delta P)^n \qquad (1)$$

The coefficients K and n are obtained using a log-linearized curve-fitting technique. The curves generated by fan pressurization are extrapolated to a reference pressure of 4 Pa (assumed to be representative of natural infiltration) by solving for Q at 4 Pa in Equation 1.

The effective leakage area is defined assuming that in the pressure range characteristic of natural infiltration (-10 to +10 Pa), the flow versus pressure behavior of a building more closely resembles square-root (turbulent) than viscous flow and can be described by:

$$L = \frac{Q_4}{[(2/\rho)\,\Delta P_4]^{0.5}} \qquad (2)$$

The total leakage area of the envelope, L_o, is defined as the average of the effective leakage areas from pressurization and depressurization.

Calculation of Infiltration Using the LBL Model

The LBL infiltration model is based on physical simplifications of the many effects that enter into the process of air infiltration. The considerations behind these simplifications have been examined in great detail in previous works (2,3), and will be summarized in the sections to follow.

Superposition

Although the effective leakage area determines the flow through the envelope as a function of pressure, it is not a simple matter to calculate the point pressures on the surface of the building. For weather driven infiltration there are two independent driving forces: wind and temperature difference (stack effect). To simplify the point pressure problem, we can calculate the wind-induced and stack-induced infiltration independently; but, we cannot simply add them to find the total infiltration. We can, however, use our simplified leakage expression to combine the two; because flow is proportional to the square-root of the pressure, we add them in quadrature. (See equation 3.)

Stack Induced Infiltration

The stack effect is caused by a difference in temperature between the air inside and the air outside the building. This temperature difference causes a density difference and this buoyancy creates a pressure gradient along any vertical boundary.

The leaks in a building are distributed over the entire envelope, thus a detailed summation would be required to determine the flow at each point on the envelope. To avoid this level of detail, we have grouped the envelope leakage into three categories: floor, wall, and ceiling leakage area. Within each area we assume that the leaks are evenly distributed. Thus, we have three parameters that describe the leaks: L_o, the total leakage area; R, the fraction of the total leakage area in the floor and ceiling; and X, the difference between the floor and ceiling leakage areas divided by the total leakage area. (See equations 4 and 5 for the stack induced infiltration.)

Wind Induced Infiltration

When wind flows around a building it induces pressure differences across the external faces of the envelope. These pressure differences are proportional to the local wind speed and the degree of shielding of the building. We have calculated the generalized shielding coefficient, C, for five degrees of obstruction around the building; the values are summarized in Table 1.

Most wind data is taken from a weather tower not necessarily at the height of the building. The measured wind speed must be converted from a weather station into a local wind speed for our model. We use a method that uses two terrain parameters to describe the wind profile. (See equations 6 and 7 for the wind induced infiltration and Table 2. for the terrain parameters.)

Summary of Equations

Superposition:

$$Q_{weather} = \sqrt{Q_w^2 + Q_s^2} \qquad (3)$$

Stack Induced Infiltration:

$$Q_s = L_o\, f_s \sqrt{g\, H_s \,\left|\frac{\Delta T}{T}\right|} \qquad (4)$$

$$f_s = \frac{(1 + R/2)}{3}\left(1 - \frac{X^2}{(2-R)^2}\right)^{3/2} \qquad (5)$$

Wind Induced Infiltration:

$$Q_w = L_o\, v\, f_w \qquad (6)$$

$$f_w = C\,(1 - R)^{1/3}\,\frac{\alpha_w \left[\frac{H_w}{10}\right]^{\gamma_w}}{\alpha_t \left[\frac{H_t}{10}\right]^{\gamma_t}} \quad (7)$$

Table 1. Generalized shielding coefficients

Shielding Class	C	Description
I	0.324	No obstructions or local shielding whatsoever.
II	0.285	Light local shielding with few obstructions.
III	0.240	Moderate local shielding, some obstructions within two house heights.
IV	0.185	Heavy shielding, obstructions around most of perimeter.
V	0.102	Very heavy shielding, large obstruction around perimeter within ten meters.

Table 2. Terrain parameters for standard terrain classes

Class	γ	α	Description
I	0.10	1.30	Ocean or other body of water with at least 5 km of unrestricted expanse.
II	0.15	1.00	Flat terrain with some isolated obstacles.
III	0.20	0.85	Rural areas with low buildings, trees, or other scattered obstacles.
IV	0.25	0.67	Urban, industrial or forest areas or other built-up area.
V	0.35	0.47	Center of large city or other heavily built-up area.

Conclusion

The fan pressurization technique is a simple method that is used to measure the air tightness of a building. The air tightness of a building can be expressed by the effective leakage area at 4 Pa. or by the air exchange rate at 50 Pa. The effective leakage area and local weather data can be used as inputs to the LBL infiltration model that predicts natural infiltration rates. Both the fan pressurization technique and LBL infiltration model can be used in a variety of ways: energy estimates, air quality calculations, consensus standards, and code requirements.

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References

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(2) Sherman, M.H. Air Infiltration in Buildings. Ph.D Thesis, University of California, Berkeley, CA, 1980.

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Nomenclature

C	generalized shielding coefficient. (See Table 1)
H	height. [m]
H_s	stack height of building. (highest-lowest leak) [m]
H_t	height of weather tower. [m] (wind measurement)
H_w	wind height of building. (ceiling height above grade) [m]
K	leakage coefficient.
L	effective leakage area. [m^2]
L_o	total leakage area of envelope. [m^2]
Q	air flow (infiltration, ventilation). [m^3/s]
Q_4	air flow at 4 Pa. [m^3/s]
Q_s	stack induced infiltration. [m^3/s]
Q_w	wind induced infiltration. [m^3/s]
$Q_{weather}$	natural infiltration. [m^3/s]
R	fraction of total leakage area in the floor and ceiling.
T	absolute (inside) temperature. [295 K]
X	difference in ceiling/floor fractional leakage area.
α	terrain coefficient. (See Table 2)
f_s	stack factor.
f_w	wind factor.
g	the acceleration of gravity. [9.8 m/s^2]
γ	terrain exponent of tower (t) and building (w). (See Table 2)
n	leakage exponent.
ρ	the density of (outside) air. [1.2 kg/m^3]
v	measured wind speed. [m/s]
ΔP	outside-inside pressure difference. [Pa]
ΔP_4	leakage reference pressure. [4 Pa]
ΔT	inside-outside temperature difference. [K]

SUMMARY

M.H. Sherman and J.B. Dickinson: The Prediction of Air Infiltration. Air infiltration is responsible for about one-third of the space conditioning loads in residential buildings; it is also the primary method for maintaining adequate indoor air quality (by diluting internally generated pollutants). Recent recognition of this dichotomy has increased the desire for a simple and reasonably accurate method for estimating air infiltration. This paper describes such a method in a manner so that engineers or auditors who are not specially trained in infiltration research can estimate air infiltration. This method requires two steps: field measurement of the building properties, and calculation of the infiltration from weather data and the measured properties. In this paper we will describe fan pressurization techniques and how to use them to measure the air tightness of the building envelope, and we will describe the procedures required to make infiltration predictions with the Lawrence Berkeley Laboratory infiltration model.

RESUME

M.H. Sherman et J.B. Dickinson: L'estimation de l'infiltration de l'air. L'infiltration de l'air correspond a peu pres au tiers des charges du conditionnement de l'air dans les batiments residentiels. C'est aussi la principale methode pour le maintien d'une qualite suffisante de l'air interieur. La reconnaissance recente de cette dichotomie a augmente le desir de trouver une methode facile et raisonablement precise pour estimer l'infiltration de l'air. Ce papier decrit une telle methode d'une facon pratique pour que les ingenieurs ou "auditeurs" puissent estimer l'infiltration de l'air. Cette methode pour la prediction de l'infiltration de l'air necessite deux etapes: le mesurement sur le terrain des proprietes du batiment, et le calcul de l'infiltration, a partir des donnees meteorologiques et des "proprietes" mesurees. Dans ce papier nous decrirons des techniques de pressurisation par ventilation. Puis, nous decrirons les procedures necessaires pour faire des predictions quant a l'infiltration grace au modele mathematique du "Lawrence Berkeley Laboratory."

KURZFASSUNG

M.H. Sherman and J.B. Dickinson: Die Vorhersage von Luft-Infiltration von Wohngebaeuden. Die Luftdurchstroemung von Gebaeuden ist fuer etwa ein drittel der Waermeverluste von Wohngebaeuden verantwortlich. Weiterhin ist die Infiltration, infolge der Verduennung der Schadstoffen, die hauptsaechliche Quelle zur Aufrechterhaltung der Raumluftqualitaet. Aus diesen Gruenden entstand der Bedarf nach einem zuverlaessigen, einfach zu handhabenden Rechenmodell zur Vorhersage der Luft-Infiltration. Es wird eine Methode beschrieben, die selbst den nicht speziell fuer Lueftungswaermeverluste ausgebildeten Energieberater in die Lage versetzt, eine Vorhersage ueber den Infiltrationsaustausch zu treffen. Das vorgestellte Modell arbeitet in zwei Schritten; der Messung der Durchlaessigkeit der Aussenhuelle mittels einer Blowerdoor vor Ort und der anschliessenden Berechnung der Infiltration mit Hilfe von Wetterdaten und den Messdaten der Blowerdoormessungen. Durchlaessigkeitsmessungen sowie ihre Aussagekraft fuer die Bestimmung der Infiltration werden beschrieben.