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Analysis of Air Change Rates in Swedish Residential Buildings

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ABSTRACT: Measurements of the rate of air exchange in residential buildings have been carried out by the Swedish Institute for Building Research since 1970. The results of an analysis of these measurements are presented in this paper for about 500 buildings not having mechanical ventilation.

The studied buildings include one- and two-story, detached, single-family houses, row houses, and multifamily residential buildings built between 1900 and 1982 and of various design. In some cases, the buildings have been retrofitted by improving the insulation of the attic or the exterior walls. The building sites vary from freely exposed to a sheltered urban environment.

Tracer gas measurements using the decay technique have been used for the determination of the rate of air exchange. In about 300 cases, the measurement of air change rates has been complemented by measurements using pressurization techniques. Data on 50 other parameters also have been collected. These parameters describe the building geometry, the building design, and the meteorological conditions at the time of measurement. The measurements have been performed with the outdoor temperature varying from −15 to −25°C and for wind speeds from 0 to 10 m/s.

The calculation model used for the analysis includes two dimensionless variables and two parameters. The dependent variable is given by the measured air change rate and the geometric properties of the building, while the other variable is defined as the ratio of the aeromotive force to the buoyancy force. The two parameters of the model represent the degree of wind shelter and the leakage area of the building, respectively.

For the analysis, the buildings have been divided into classes according to the building environment, the year of construction, and the type of building.

KEY WORDS: air change rate, infiltration model, leakage area, pressure coefficient, pressurization, tracer gas

In this paper we report results from an analysis of data on the rate of air change and volume flow rate in pressurization of residential buildings. The

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data have been collected by the Swedish Institute for Building Research (SIB) from 1974 to 1982. These data have been collected for various research projects having different purposes, like determination of the energy status of buildings, assessment of the indoor air quality in buildings, investigation of buildings with radon content in the air, diagnosis of building damages caused by moisture, etc. Data from measurements in about 1200 buildings are now being transferred to a data file.

The results given in this report are based on data from 500 buildings not having mechanical ventilation, representing one- and two-story detached homes, two story row houses, and three-story apartment buildings situated in different parts of Sweden. Measured rates of air change that include buildings with mechanical ventilation have been reported elsewhere [*1*]. Measurements have been carried out in buildings of various designs, but the data analyzed in this paper emanate mainly from buildings of a light structure. During the measurements, climate variables such as indoor and outdoor air temperature, the wind speed and direction at the building site, etc. have been recorded.

The rate of air change has been determined by measurement of the decay of tracer gas [nitrous oxide (N_2O)] concentration in the air [*2*] from an initial concentration of 30 to 100 ppm. Fans have been placed in every room of the house or apartment to ensure mixing of the air.

The pressurization measurements have been performed according to the Swedish standard for measurements of this kind (The National Swedish Authority for Testing, Inspection and Metrology: Standard Method Description SP 1977:1). The buildings have been subjected to an over- and underpressure in steps until a pressure difference of at least 50 Pa has been attained. The flow rate of the supplied or extracted air volume has been recorded.

To make a comparison between measurements performed under different climatic conditions, it is necessary to use some model to reduce as far as possible the influence of the temperature difference, the wind, and the building shape on the results. The results from the measurements have been analyzed using a simple model of the mechanisms producing the airflow through the building envelope. The use of a similar, but simpler, model has been reported elsewhere [*3*]. The model used here has the following characteristics:

1. The air leaks are assumed to be uniformly distributed over the exposed parts of the building's exterior walls and ceiling.
2. The airflow across the building envelope is produced by buoyancy forces and aeromotive forces.
3. Exterior walls are exposed to buoyancy as well as aeromotive forces, while the ceiling is exposed only to buoyancy forces (Fig. 1).
4. In the model, exterior walls are divided into two surfaces having the same area, the windward and the leeward surfaces, both associated with a uniformly distributed pressure difference that is caused by aeromotive forces

relative to the building interior and that is of equal magnitude but of different sign.

5. The model contains two parameters. One parameter, the relative leakage area, is defined as the ratio of the total area of the air leaks, as determined from the model, to the area of the building envelope. The other parameter, the pressure difference coefficient across the building envelope, describes the wind-driven difference in pressure just mentioned. The value of the former parameter is to be determined.

6. The value of the pressure difference coefficient is fixed in the model if the wind exposure of the building site and the geometry of the building are known. In practice, we make a distinction only between exposed and sheltered building sites and between buildings having an approximately square

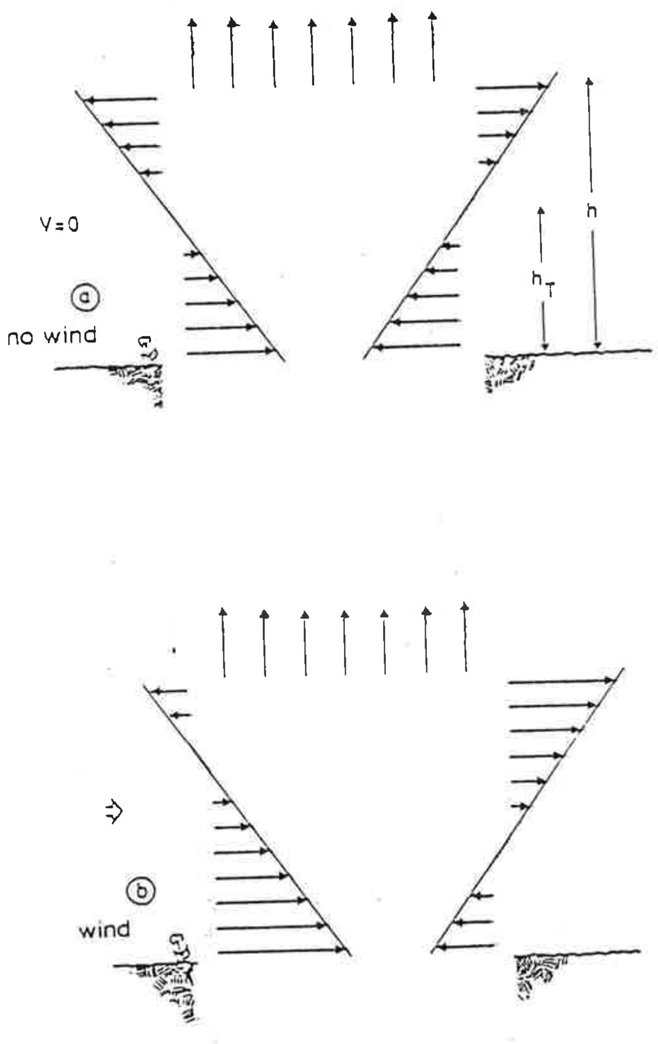


FIG. 1—*The pressure across the building envelope assumed in the model. The height* h *is the height of the building interior above the ground, and* h_T *is the height at which the buoyancy force is equal to zero. (a) No wind present; (b) wind present.*

main floor (for example, detached homes) and those having a rectangular floor (for example, row houses or rectangular apartment buildings). For these building categories, the numeric value of the pressure difference coefficient has been determined by use of information from wind-tunnel studies of the pressure distribution over the building for buildings of different shape and wind exposure [*4*].

7. The required input data to the model consist of geometrical properties of the building, such as the volume, the height of the building interior above the ground, the ceiling area, and the area of the building facades, and of measured variables, such as the rate of air exchange (for tracer gas measurements), the volume flow rate for a given over- or underpressure (for pressurization measurements), the wind speed at a height equal to that of the top of the building, the wind direction, and the internal and external air temperature.

This model has been applied to determine the relative leakage area of a building using data from a tracer gas measurement or from a pressurization measurement.

Results and Discussion

To determine the relative leakage area of buildings, we have mainly used data from tracer gas measurements. Buildings have been divided into various categories described by variables such as single-family dwellings (SFD) versus multifamily dwellings (MFD); age of the building; features of the building exterior, such as buildings with an envelope consisting mainly of wood, concrete, light concrete, or bricks, in addition to the insulating material; the foundation of the building, such as buildings with a basement versus buildings erected on a slab; prefabricated buildings versus buildings erected on site; and buildings with a fireplace versus buildings without one, etc.

It has been found that the most important factor determining the relative leakage area of a building is whether the building is prefabricated or built on site. Another important factor is the presence or absence of a fire place, but the importance of this factor is greatly reduced if the slide valve is closed. The age of the building also should be an important factor, but its effect is reduced because many of the old buildings where measurements have been performed already have been retrofitted or weather-stripped. The influence of the other factors just listed cannot be seen because of experimental errors, errors stemming from the method of analysis, and the actual differences between nominally identical buildings.

Regarding the classification of buildings according to their age, this is a rather straightforward procedure for Swedish buildings if one assumes that they have been built according to the prescriptions of the building code in force when the building was designed. One building code has been valid from 1940 to 1960, another from 1960 to 1975, and the present one from 1975.

TABLE 1—*Relative leakage area for some building categories calculated using data from tracer gas measurements and the average recorded air change rate, ACH, wind speed, v, and temperature difference, ΔT.*

Building Category	Period	Sample Size	Relative Leakage Area, cm^2/m^2	Average ACH, h^{-1}	Average Wind Speed, v, m/s	Average Temperature Difference, ΔT, K
3-story MFD with fireplace	1940 to 1960	30	7.2 ± 3.1	0.78	2.4	16
3-story MFD, no fireplace	1940 to 1960	35	3.9 ± 1.1	0.49	1.7	25
3-story MFD	1960 to 1975	85	3.0 ± 0.9	0.35	2.3	22
Detached SFD	1940 to 1960					
Nonretrofitted		15	2.5 ± 1.0	0.35	2.0	21
Retrofitted		35	2.7 ± 2.0	0.42	2.0	22
Detached SFD and row houses	1960 to 1975					
Sheltered site		190	3.0 ± 1.4	0.31	2.4	16
Exposed site		40	3.2 ± 1.3	0.33	2.9	19
Detached SFD on slab prefabricated	1970 to 1975	20	1.2 ± 0.5	0.17	1.4	18
Detached SFD and row houses	1975 and later	16	1.4 ± 0.6	0.20	2.1	20

Results for which statistically significant data are available are presented in Table 1. The spread within each category is typically on the order of 40%. The experimental error can be estimated to be 10 to 15%, and the error caused by the simplifications made in the construction of the model is estimated to be of the same magnitude. The resulting error in the calculated relative leakage area then can be expected to be between 15 and 20%. The model error should not be important when the model is applied to a group of nominally identical buildings constructed by the same company and erected by the same workers. However, under these circumstances, the variation in relative leakage area for such a group of buildings has been found to be between 20 and 40%.

If data from tracer gas measurements and pressurization measurements are to be used to calculate the relative leakage area, it is important to verify that both methods lead to the same result. To do this, the relative leakage area has been calculated for those detached homes where tracer gas measurements, as well as pressurization measurements down to a pressure difference of about 5 Pa, have been carried out.

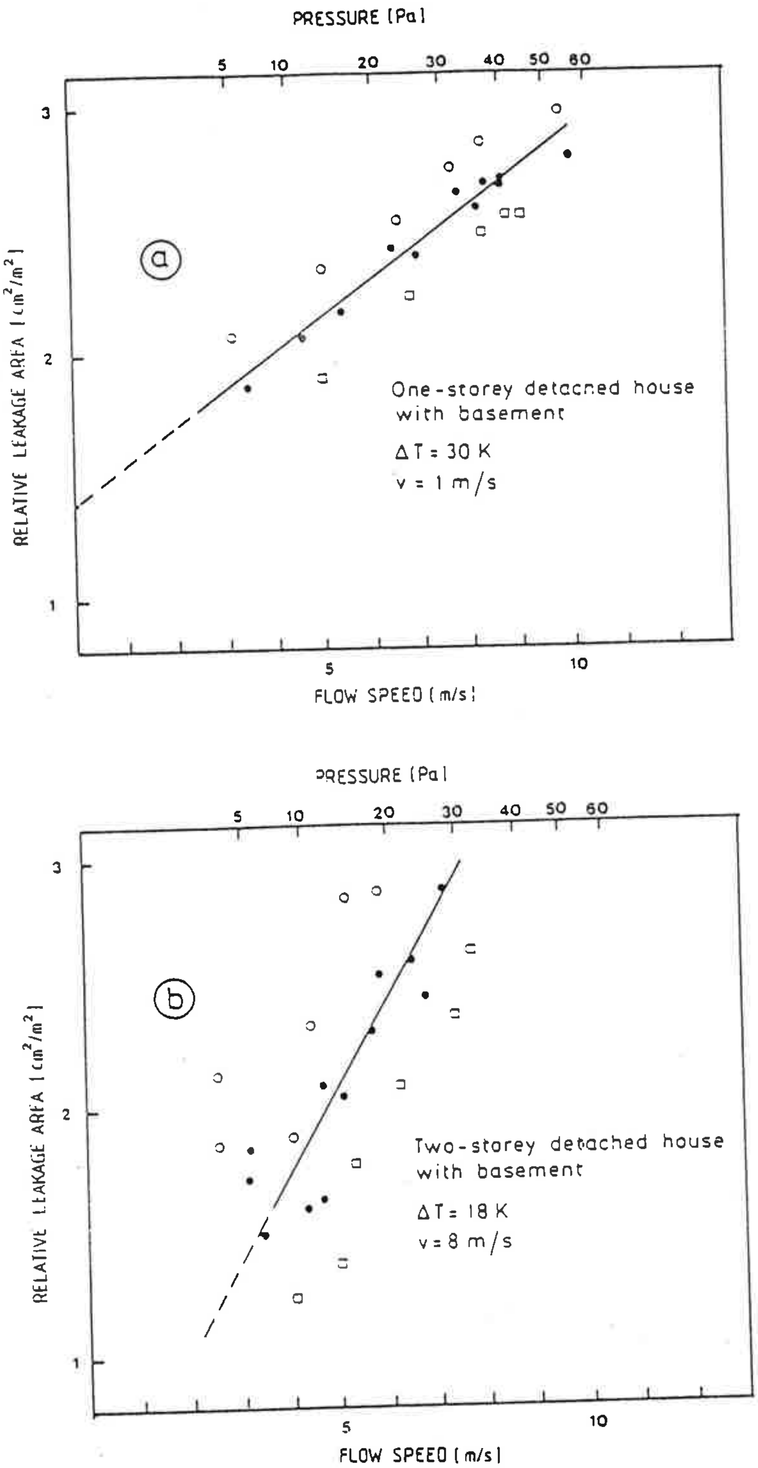
The procedure followed for this calculation is as follows. First, the data for the under- and the overpressure have been corrected to take away the influence from the pressure differences caused by buoyancy and aeromotive forces on the resulting volume air flow, so that the data points from the under- and the overpressurization fall approximately on the same curve. Examples of the result of such a correction are presented in Fig. 2. After this step, the resulting relative leakage area has been determined, using a linear extrapolation, for the average pressure difference across the building envelope at hand when the tracer gas measurement was performed.

The results of the just-mentioned calculation are presented in Fig. 3. There is a rather good agreement between the relative leakage area calculated using data from tracer gas measurements and data from pressurization measurements for the case when no openings have been sealed. The actual error is of the same magnitude as the expected experimental error; that is, there seems to be strong evidence that the two methods yield the same result. However, the number of studied buildings is too small for any definite conclusions to be drawn. This question will be studied in more detail in the near future.

Conclusions

The relative leakage area of buildings has been calculated for some building categories using data from tracer gas measurements. The results show that the most important factor determining the relative leakage area of a building is whether the building has been prefabricated or erected on site. Otherwise, buildings of the same age have about the same relative leakage area, independent of the design, provided there is no fireplace.

A method has been employed to study the correlation between the calcu-



o over pressure, □ under pressure, • corrected value

FIG. 2—*Examples of the correction of over- and underpressurization data. The relative leakage area, obtained from pressurization measurements, is plotted verus the average air flow velocity.*

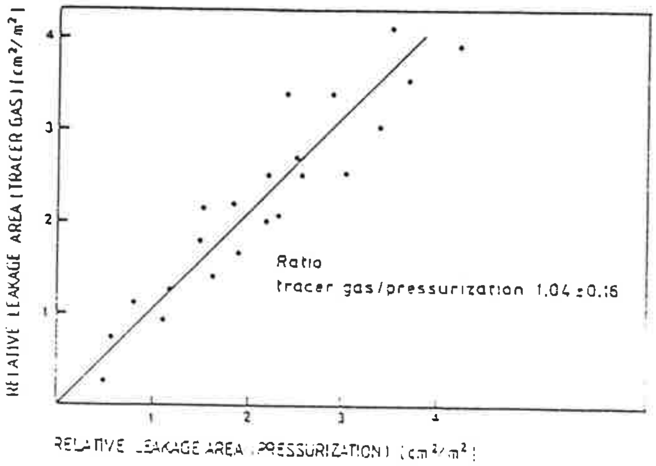


FIG. 3—*The value of the relative leakage area obtained from tracer gas measurements versus the value obtained from pressurization.*

lated relative leakage area, using data from tracer gas measurements, and data from pressurization measurements. There is evidence that both experimental methods lead to the same result.

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DISCUSSION

R. Grot (written discussion)[1]—What is the accuracy of the leakage area measurement? You quote an error of +15% for tracer gas.

C. A. Boman and M. D. Lyberg (authors' closure)—Assuming an error of 10 to 15% for a tracer gas or pressurization measurement and, in addition, an error of 15% because a rather simple model is used, the resulting error for the determination of the leakage area should be about 20%.

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