To be published as a Chapter in "IEA Report on Air Infiltration," IEA.

Energy and Environment Division

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May 23, 1978

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Prepared for the U.S. Department of Energy under Contract No. W-7405-ENG-48

LBL-7830

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This work was supported by the U. S. Department of Energy

Case Studies in Air Infiltration

I. Background

All references to case studies in air infiltration research must ultimately go back to the group of four publications of J. B. Dick and his associates between 1949 and 1951 (Dick, 1949; Dick, 1950a; Dick, 1950b; Dick and Thomas, 1951). Dick's identification and exploration of key problems reads like a catalog of issues in air infiltration -- many of which are still unresolved. This remarkable set of papers should be read carefully by all who are seriously interested in examining air infiltration in buildings.

In the first paper of the group (Dick, 1949) the author reports detailed air change measurements in four of a group of twenty similar houses in Abbots Langley. The homes were unoccupied but operated in a manner which simulated occupation by a family of four. Different heating systems existed in the homes. The influence of the type of heating system on the infiltration rate was examined. Hydrogen was used as the tracer gas in the measurements; its concentration was monitored using a katharometer to detect changes in the thermal conductivity of the hydrogen-air mixture as the hydrogen concentration changed.

In reporting the results of this research, Dick is careful to separate the air change rates of rooms from the air change rate of entire houses. In doing this he models and experimentally measures concentrations of tracer gas due to air flow between rooms. He is therefore able to distinguish between air change in a room due to infiltration of outdoor air and air change in a room due to air movement from adjacent rooms. (We note that when central air distribution systems are used to mix the tracer gas with the air and distribute it throughout the house, this distinction ceases to be important.)

sheltered terrain than the Abbots Langley homes; further, the Bucknalls sites all had heating and ventilation systems which were alike.

As in the earlier study at Abbots Langley the authors show that the air infiltration rate in these houses can be represented by a function of the form $INF = A + Bv$.

The effect of occupancy is to increase the total leakage area of the shell as windows and vents are opened. Measurements of air exchange rates, wind speed and number of vents open show that the effects of vent openings on infiltration rates can be represented by an expression of the form

$$INF = A + Bv + Cn + Dnv$$

where A, B, C and D are constants while n is the number of open vents.

Window and vent openings were correlated with weather conditions. Seventy per cent of the observed variance in the number of vents and windows opened could be associated with the external temperature. As the temperature fell the number of window and vent openings decreased rapidly. Since the infiltration rate increases rapidly with numbers of openings this observed relation between temperature and window openings lead to the curious but understandable result that the infiltration rate decreases in these homes as the external temperature decreases. The effect is large enough to lead to the conclusion that the heat loss due to infiltration is independent of the external air temperature! Both of these results, which are clearly not to be expected in unoccupied buildings, are evidence of the importance of understanding occupancy effects in modeling air infiltration.

The Bucknalls site, since it was more sheltered, showed examples of both temperature and wind driven infiltration. Dick and Thomas analyzed their results by separating infiltration measurements into two regimes: those for which wind driven effects predominate and those for which the stack effect, i.e. air density differences caused by different indoor and outdoor temperatures, to explore other building types. This work is only beginning. Current activities in these fields are reviewed in section II, below.

II. Current Activities

We shall divide current activities by building type and subdivide each of these according to the presence or absence of central forced air heating. The reason for this division is two-fold. The blower in the central forced air system can be used to mix the tracer gas and distribute it uniformly to the structure. This simplifies mixing and multi-chamber problems; however we find that complications can also occur using this procedure since the air ducts in the distribution system often leak significant amounts of air.

A. Single Family Detached Structures

1. Central Forced Air Distribution

The largest recent study reported is that of Sepsy, et. al. of Ohio State University (Sepsy, Jones, McBride, Blancett, 1978). This study will be published soon as a report of the Electric Power Research Institute (EPRI). Nine homes were monitored in the study; seven of these had central forced air heating systems. A large amount of data was obtained which related infiltration rates and weather variables; a thorough statistical analysis of these data was performed. The authors found that their results could be represented best by

$$INF = \beta_0 C_T (4\Delta P_T + \sqrt{2} \ \Delta P_v)^{1/2}$$

where

$$\Delta P_T = A \ P \ h \ (\frac{1}{T_o} - \frac{1}{T_i})$$

and

$$\Delta P_v = \frac{B}{T_o} v^2$$

In this expression β_0 is a statistical regression coefficient (which essentially describes the construction quality of the house), A and B are large group of townhouses in New Jersey has recently been published in the journal Energy and Buildings. Air infiltration measurements in two of the centrally heated townhouses is the subject considered by Malik (1978) in his paper in this issue. Malik's work shows the effect on air infiltration of wind speed and direction, indoor-outdoor temperature difference and rate of furnace firing. One of his more interesting results is statistical evidence for a non-linear wind-temperature interaction when the wind speeds were larger than 5 $^{m}/s$. The effects had opposite signs in the two test houses. In one, the air exchange rate was enhanced when high wind speeds were coupled with large values of indoor-outdoor temperature difference, in the other the opposite was true. Sinden (1978) has argued persuasively that both effects are physically reasonable. It is inviting to speculate about the nature of the destructive interference which reduces air infiltration as the temperature decreases when one has high wind speeds. Such information could be useful for design applications.

2. Non-Central Air

Several studies are underway or are planned for this building type. The National Bureau of Standards in the U.S. is engaged in a study of air infiltration rates and air leakage rates using fan pressurization in three low-rise apartment houses in Chicago. This topic is discussed further in section III, below.

De Gids and coworkers, in the Netherlands have made a careful study of air infiltration in a third story flat located in a block of flats close to the North Sea. In this study particular attention was paid to surface pressure differences between the inside of the flat and the outside walls. The study was attempting to relate calculated air flows based upon supply and exhaust fans and of ventilation due to infiltration through structural cracks and cracks around doors and windows. A controlled flow tracer gas system using CO_2 is used for the measurements; measurements of changes of concentration of the tracer as a function of time allow calculation of air flows.

Kelnhofer, ~~Hemt~~ Hunt and Didion (1976) have reported measurements of ventilation rates in a nine-story office building using SF_6 tracer gas technique. They investigated a building in which all floors were sealed except the ground floor and the mechanical equipment room at the top of the building. A central air distribution system allowed whole building injection via the air supply system and whole-building sampling using the return air ducts. Results obtained using tracer gas correlations were compared with those obtained by measuring exhaust rates for the building. Agreement was very good. Again the existence of a central air distribution system, as in the case of measurements in single-family detached houses, permits effective use of tracer gas techniques.

A study of the air leakage properties of the central administration building of National Bureau of Standards will soon be underway. Again in this case, a central air-handling system is present in the building which will facilitate use of a tracer gas in the building.

The chart below summarizes projects completed or in progress in the areas given above.

III. Problems and Needs

This section has two major thrusts: (A) Case studies must be expanded to survey building types which have not been adequately investigated. The types are shown on the chart above and include everything except single-family detached houses. (B) A major investigation, viz. the correlation of air leakage measurements using fan pressurization and air infiltration remains to be completed in single family detached homes.

Consider (A) first. The need to expand measurement of infiltration and ventilation to include larger and more complicated building styles is clear. However, many instrumentation problems must be solved before such measurements will be meaningful. The problems are not new. For example they were discussed by Dick and his co-workers in the papers referred to above. However, as measurements are extended to larger and larger buildings the problems become more severe and may require the development of entirely new instrumentation techniques.

The two most serious problems are those of adequate mixing of the tracer gas in the space under test and multi-chamber effects caused by tracer gas movement between rooms.

Mixing is assumed to be perfect when the simplest kind of concentration decay measurements are described. When a large blower is present in a closed ventilation system or heating system, mixing can be quite good. When other forms of heating systems are used, auxiliary mixing with fans or blowers is generally advisable. How should this be done? One technique is to inject the tracer gas into test space, mix it with a fan or blower, then turn off the fan to avoid disturbing the natural pressure distribution driving the infiltration. (We note that this technique can only be employed when using concentration decay, not when controlled flow injection techniques are used.) Two assumptions are implicit here. The first is the belief that once the tracer gas is mixed

These problems help explain the current lack of results -- they can and should be eliminated in order to allow progress in this new area.

The other major problem is one currently associated with single family detached houses but, if solved, could have important applications to other building styles as well. Many groups currently are examining the possibility of correlating the results of air leakage measurements using fan pressurization with tracer gas infiltration measurements. If this is successful, the results will be important both for those who are interested in computer modeling of energy use in a building and also for those who are interested in establishing construction quality standards for air leakage in buildings.

The motivation for seeking the correlation arises because of the wide range of results obtained by those who attempt to relate infiltration rates to weather parameters. While the functional forms of these relationships are quite similar for measurements on different single family residence, the constants which enter the equation differ widely from house to house. The major source of this variation may be the differences in construction quality between houses which determine the leakage detail of the structure. If this hypothesis is valid an independent measurement of construction quality should reduce the variation between coefficients and allow adequate modeling of air infiltration rates to be done for a "typical" house.

How can construction quality be measured? Again one must speculate but current thinking suggests that fan pressurization measurements of air leakage may provide the best measurements for purposes of air infiltration modeling. This measurement is made by sealing a fan into the building shell and adjusting the fan speed to obtain an overpressure within the structure. Mass flow continuity then predicts that the air flow rate through the fan is equal to the air leakage rate of the structure of the working pressure difference. Fan pressurization measurements of air leakage are not analogs of air leakage due to

IV. Recommended R & D Projects and Project Areas.

A. IEA Sponsorship

Participants in the 1978 Paris seminar adopted, as one of the projects appropriate for IEA sponsorship, the following: the IEA should "Examine the Possibility of a Correlation of Pressurization Air Leakage Measurements and Tracer Gas Infiltration Measurements in Single Family Residences."

This statement was later refined and written into an Annex to be considered by the IEA Executive Committee on Building and Community Systems. If approved by the Executive Committee, and if an operating agent can be found, a project lasting approximately twenty-six months would be begun. It would be oriented toward standards; the objectives put forth in the Annex are:

1. To determine if pressurization tests can be used to predict natural air leakage rates.

2. To establish a construction quality standard for air leakage.

The project shall be task shared and coordinated by the operating agent. The IEA, then, will help standardize procedures used to examine the possible correlation, aid the communication of information among the research groups examining the problem, provide a forum to allow researchers to discuss their results and aid in drafting possible standards.

Construction quality standards for new buildings have the disadvantage of only slowly affecting energy consumption. There is a need for more case studies of performance of a building before and after efforts are made to make the building shell tighter. Those who have investiments in existing housing should be able to learn how to reduce their energy consumption without having to purchase new energy-efficient housing. The experience gained in studies designed to reduce air infiltration and therefore energy consumption in existing housing, in particular the techniques used to accomplish the reduction, should become part of a catalog of construction techniques available to all

V. Bibliography

Dick, J. B. (1949)
Experimental Studies in Natural Ventilation of Houses, J. Inst. Heat. Vent. Eng. 1949; 17: 420-466.

Dick, J. B. (1950a)
Measurements of Ventilation Using Tracer Gas Technique, Heat. Piping Air Cond. 1950; 22: 131-137.

Dick, J. B. (1950b)
Fundamentals of Natural Ventilation in Houses, J. Inst. Heat. Vent. Eng. 1950; 18: 123-134.

Dick, J. B.; Thomas, D. A. (1951)
Ventilation Research in Occupied Houses, J. Inst. Heat. Vent. Eng. 1951; 19: 306-326.

de Gids, W. F.; Ton, J. A.; van Schijudel, L. L. M. (1977)
Investigation of the Relationship between the Natural Ventilation of a Flat and the Meteorological Conditions, Publication 620 of the Research Institute for Environmental Hygiene TNO (1977).

Honma, Hiroshi (1975)
Ventilation of Dwellings and its Disturbances, Stockholme, Faibo Grafiska, 1975.

Kelnhofer, W. J.; Hunt, C. M.; Didion, D. A. (1976)
Determination of Combined Air Exfiltration and Ventilation Rates in a Nine Story Office Building, Proceedings of Conference on Improving Efficiency and Performance of HVAC Equipment and Systems for Commercial and Industrial Buildings. Purdue University, April 12-14 (1976): 322-328.

Malik, Nicholas (1978)
Field Studies of the Dependence of Air Infiltration on Outside Temperature and Wind, Energy and Buildings 1978; 1: 281-292.

Sepsy, C. F.; Jones, C. D.; McBride, M.; Blancett, R. (1978)
OSU/EPRI Final Report, Environmental Control Group, Department of Mechanical Engineering, Ohio State University (1978).

Shaw, C. Y.; Tamura, G. T. (1977)
The Calculation of Air Infiltration Rates Caused by Wind and Stack Action for Tall Buildings, ASHRAE Trans. 1977; 83-II:

Sinden, F. W. (1978a)
Theoretical Basis for Tracer Gas Measurements of Air Infiltration, Building and Environment 1978; 12:

Sinden, F. W. (1978b)
Wind Temperature and Natural Ventilation - Theoretical Considerations, Energy and Buildings 1978; 1: 275-280.